NEC

Preliminary User's Manual

LAKI

Communication Controller

µPD98503

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Date Published May 2001

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NOTES FOR CMOS DEVICES

① PRECAUTION AGAINST ESD FOR SEMICONDUCTORS

Note:

Strong electric field, when exposed to a MOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop generation of static electricity as much as possible, and quickly dissipate it once, when it has occurred. Environmental control must be adequate. When it is dry, humidifier should be used. It is recommended to avoid using insulators that easily build static electricity. Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work bench and floor should be grounded. The operator should be grounded using wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions need to be taken for PW boards with semiconductor devices on it.

② HANDLING OF UNUSED INPUT PINS FOR CMOS

Note:

No connection for CMOS device inputs can be cause of malfunction. If no connection is provided to the input pins, it is possible that an internal input level may be generated due to noise, etc., hence causing malfunction. CMOS devices behave differently than Bipolar or NMOS devices. Input levels of CMOS devices must be fixed high or low by using a pull-up or pull-down circuitry. Each unused pin should be connected to V_{DD} or GND with a resistor, if it is considered to have a possibility of being an output pin. All handling related to the unused pins must be judged device by device and related specifications governing the devices.

③ STATUS BEFORE INITIALIZATION OF MOS DEVICES

Note:

Power-on does not necessarily define initial status of MOS device. Production process of MOS does not define the initial operation status of the device. Immediately after the power source is turned ON, the devices with reset function have not yet been initialized. Hence, power-on does not guarantee out-pin levels, I/O settings or contents of registers. Device is not initialized until the reset signal is received. Reset operation must be executed immediately after power-on for devices having reset function.

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PREFACE

Readers

This manual is intended for engineers who need to be familiar with the capability of *LAKI* in order to develop application systems based on it.

Purpose

The purpose of this manual is to help users understand the hardware capabilities (listed below) of the *LAKI*.

Configuration

This manual consists of the following chapters:

- Introduction
- VR4120A™ CPU
- System controller
- Ethernet™ controller
- USB controller
- UART
- Timer
- Micro Wire™
- General Purpose Input/Output

Guidance

Readers of this manual should already have a general knowledge of electronics, logic circuits, and microcomputers.
To gain an overall understanding of the function of the *LAKI*:
→ Read through all the chapters, in sequence.

To check the electrical characteristics of the *LAKI*:
→ Refer to the separate data sheet.

Any remaining reference to the µPD98501 (KORVA) device in this manual should be interpreted as "LAKI", which is functional equivalent in these cases.

Notation

This manual uses the following conventions:

Data bit significance:	High-order bits on the left side; low-order bits on the right side
Active low:	XXXX_B (Pin and signal names are suffixed with _B.)
Note:	Explanation of an indicated part of text
Caution:	Information requiring the user's special attention
Remark:	Supplementary information
Numerical value:	Binary ... xxxx or xxxxB Decimal ... xxxx Hexadecimal ... xxxxH

Related Document

Use this manual in combination with the following document.
The related documents indicated in this publication may include preliminary versions. However, preliminary versions are not marked as such.

- *LAKI* Data Sheet: To be prepared

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CHAPTER 1 INTRODUCTION

LAKI is a high performance controller which includes high performance MIPS™ based 64bit RISC processor VR4120A CPU core, Ethernet Controller, USB controller Block and SDRAM interface.

1.1 Features

- Includes high performance MIPS based 64-bit RISC processor VR4120A
- Can perform RTOS and network middleware (M/W) on the chip
- Includes interface for PROM and flash ROM used for storing boot program
- Includes single 10/100Mbps Ethernet controller compliant to IEEE802.3,IEEE 802.3u and IEEE802.3x
- Can directly connect external Ethernet PHY device through 3.3V MII interface
- Includes USB full speed function controller compliant to USB specification 1.1
- Supports operation conforming to the USB Communication Device Class Specification
- Can directly connect 64Mbit and 128Mbit SDRAM as external memory
- Includes boundary scan function(JTAG) compliant to IEEE 1149.1
- Includes Micro Wire interface
- Includes 2ch general purpose timers
- Using advanced CMOS technology
- Supply Voltage 2.5V (required 3.3V supply for 3.3V interface)
- Package T-BGA-256

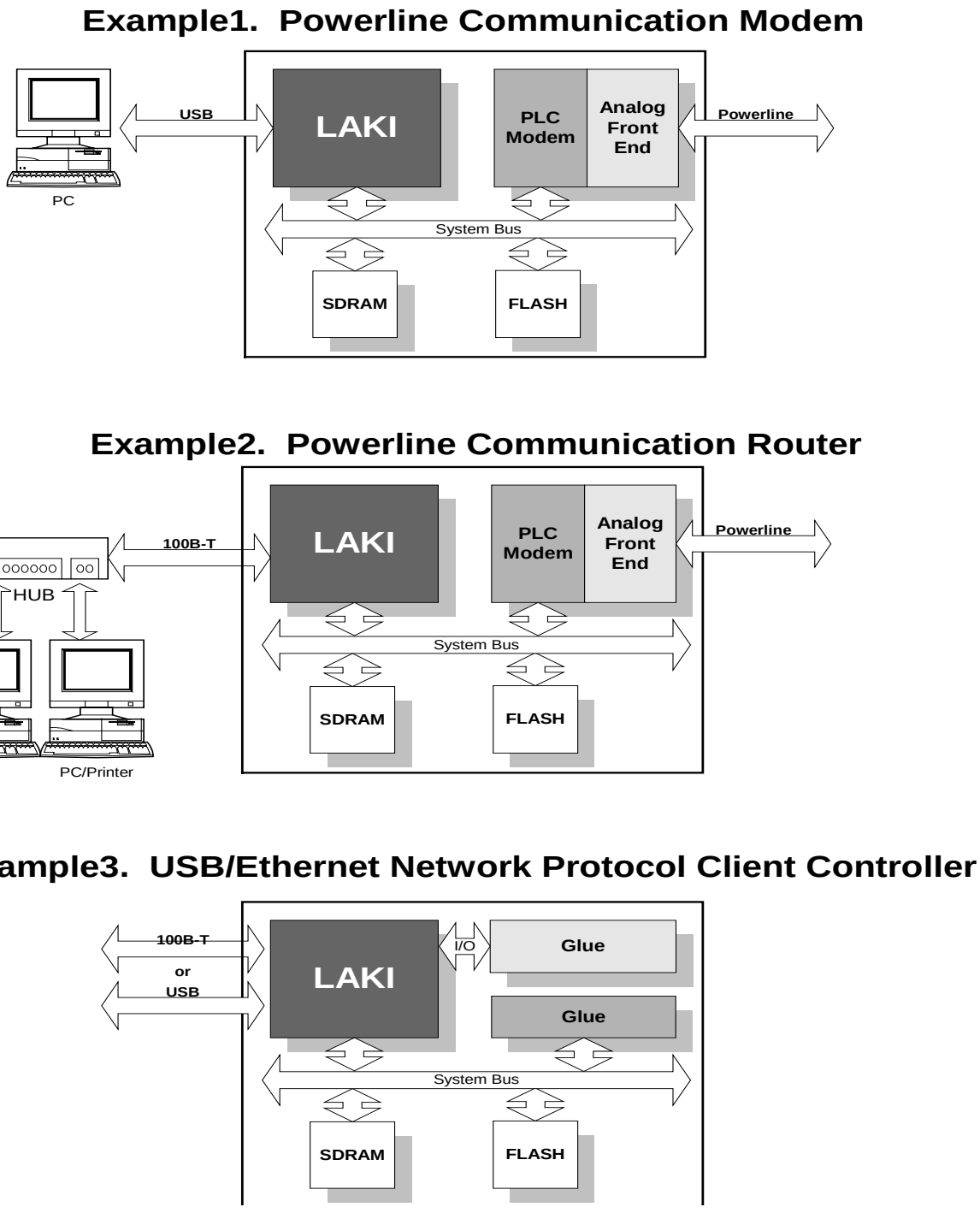
1.2 Ordering Information

Part Number	Package
μPD98503N7-B6	256 pin TBGA

1.3 System Configuration

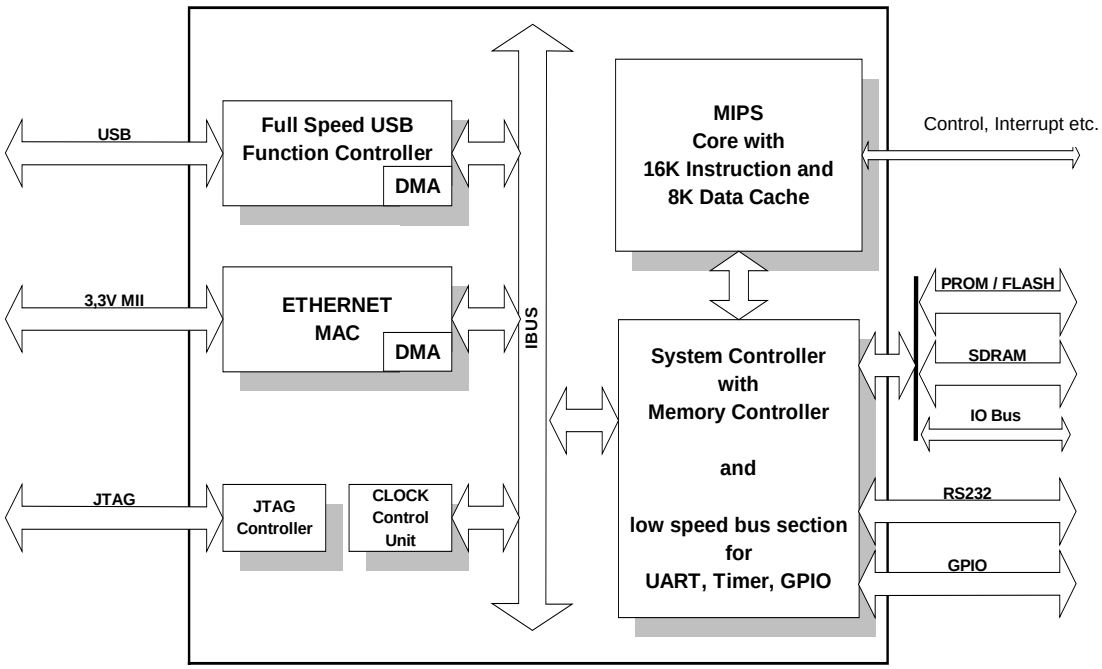
LAKI can perform as a network controller for arbitrary applications, requiring a high performance CPU to run network protocol stacks, an Ethernet or USB Communication Class interface and a powerful bus interface which allows the connection of external devices and memories. USB and Ethernet functions will exclusively operate each other.

Figure 1-1. Examples of a LAKI System Configuration



1.4 Block Diagram (Summary)

Figure 1-2. Block Diagram of LAKI



1.5 Block Diagram (Detail)

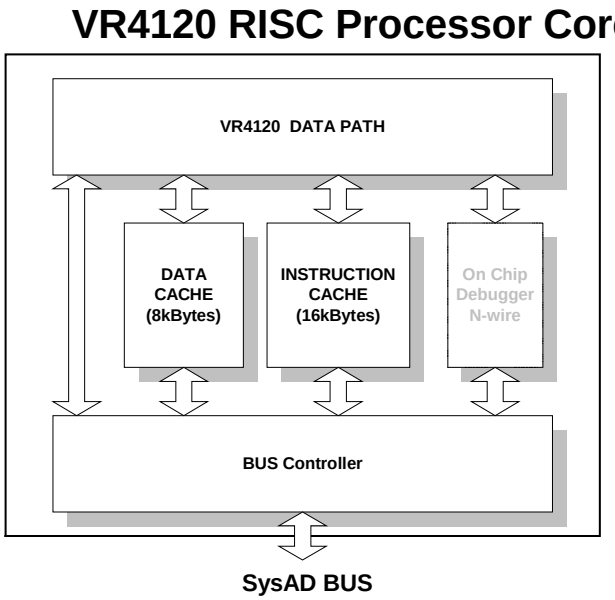
1.5.1 VR4120A RISC processor core

NEC will support real-time OS running on the high performance VR4120A RISC processor core. The core can perform network protocols (TCP/IP, PPP, SNMP, HTTP etc) to realize the targeted network control function. Middlewares including RTOS will be loaded to SDRAM from external PROM and Flash ROM and by setting write protected area for such a area, high speed processing will be realized together with large size instruction cache.

Features of VR4120A RISC Processor Core are as follows;

- MIPS/I/II/III instruction set will be supported (FPU, LL, LLD, SC, SCD instruction will be excluded)
- Realize high speed processing of application by supporting high speed multiply and accumulate function
- Includes Large size cache memory (Instruction:16kbytes, Data:8kbytes)
- Supports up to 1T byte virtual address space by using full associative TLB
- Implements switching function between Big-Endian and Little-Endian

Figure 1-3. Block Diagram of VR4120A RISC Processor



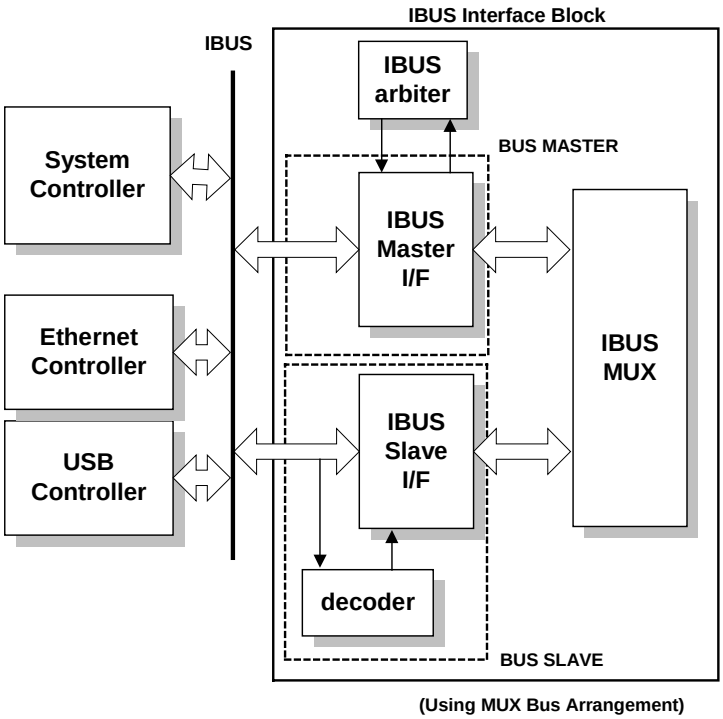
1.5.2 IBUS

The IBUS is a 32-bit, 66-MHz high-speed on-chip bus which enables interconnection between itself and IBUS(64-bit bus).

The IBUS supports the following bus protocols;

- Single read/write transfer
- Burst read/write transfer
- Slave lock
- Retry and disconnect
- Bus parking

Figure 1-4. Block Diagram of IBUS



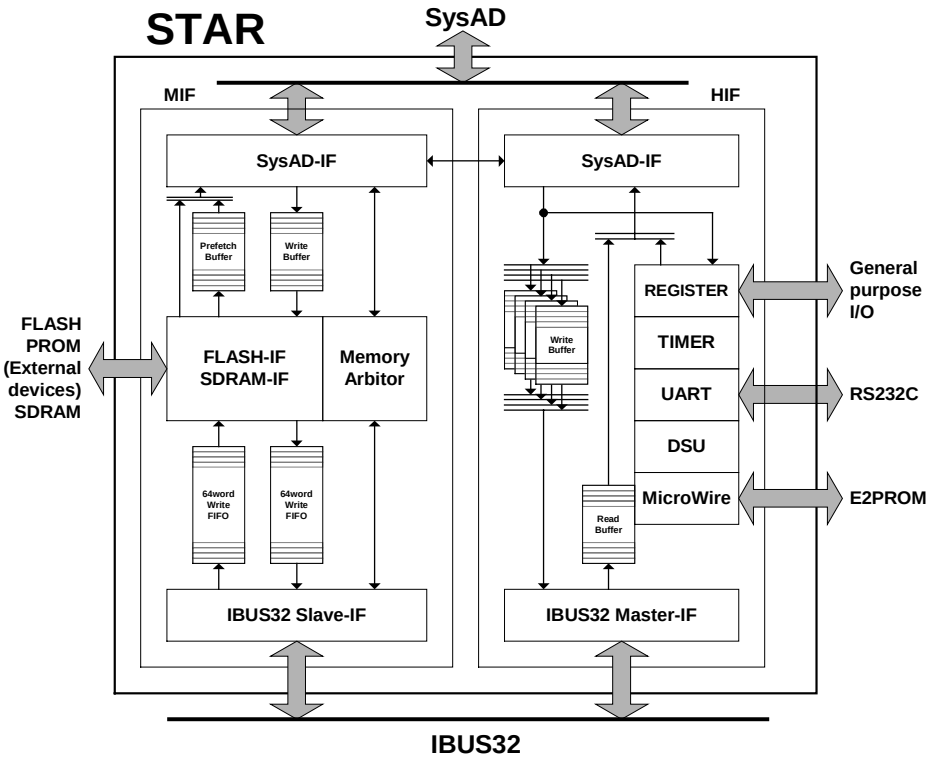
1.5.3 System controller

System controller is LAKI's internal system controller. It provides bridging function among the VR4120A System Bus "SysAD", NEC original high speed on-chip bus "IBUS" and the system bus for SDRAM/PROM/FLASH and external expansions.

Features of System controller are as follows;

- Implements 4word prefetch FIFO buffer between SysAD and Memory
- Implements 32bit×64word FIFO buffer for each TX and RX between IBUS and Memory.
- Implements 32bit× 4word command buffer to IBUS from VR4120A
- Provides bus bridging function among SysAD bus and IBUS(internal bus) and MEMORY
- Supports Endian Converting function on SysAD bus
- Can directly connect 64Mbit/128Mbit SDRAM(MAX.32MBytes) and PROM/FLASH(MAX.8MBytes) memory
- Supports all VR4120A bus cycles at 66MHz or 100MHz
- PROM/FLASH data signals multiplexed on SDRAM data signals
- Supports 266 MB/sec (32bit @66MHz) bursts on IBUS
- Generates NMI and INT
- Supports Universal Asynchronous Receiver/Transmitter(UART)
- Supports separated 2ch Timer
- Supports Deadmans Switch Unit(Watch Dog Timer)
- Supports general purpose input/output pins
- Supports Micro Wire interface

Figure 1-5. Block Diagram of System Controller



1.5.4 <empty>

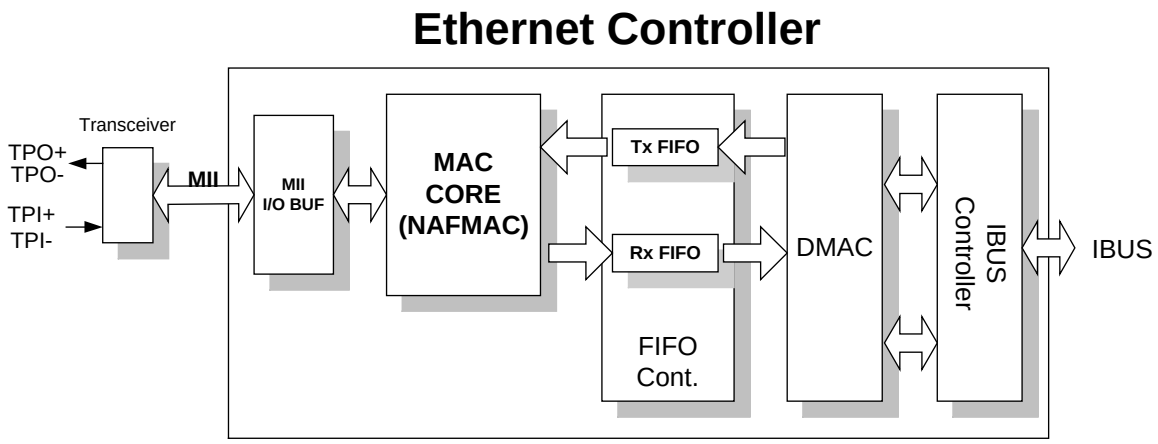
1.5.5 Ethernet controller

Ethernet Controller supports single channel 10Mbps/100Mbps Ethernet MAC (Media Access Control) function and MII (Media Independent Interface) function

Features of Ethernet Controller are as follows;

- Supports 10M/100M Ethernet MAC function compliant to IEEE802.3 and IEEE802.3u
- Supports 3.3V MII compliant to IEEE802.3u
- Supports full duplex operation for both 100Mbps and 10Mbps
- Supports flow control function compliant to IEEE802.3x/D3.2
- Implements 256Byte FIFO buffer for each TX and RX
- Implements address filtering functions for unicast/multicast/broadcast
- Implements MIB counters for network management (MIB II, Ether-like MIB,IEEE802.3LME are supported)
- Supports loopback function within MII interface
- Implements local DMA controller with individual DMA channels for each TX and RX

Figure 1-7. Block Diagram of Ethernet Controller

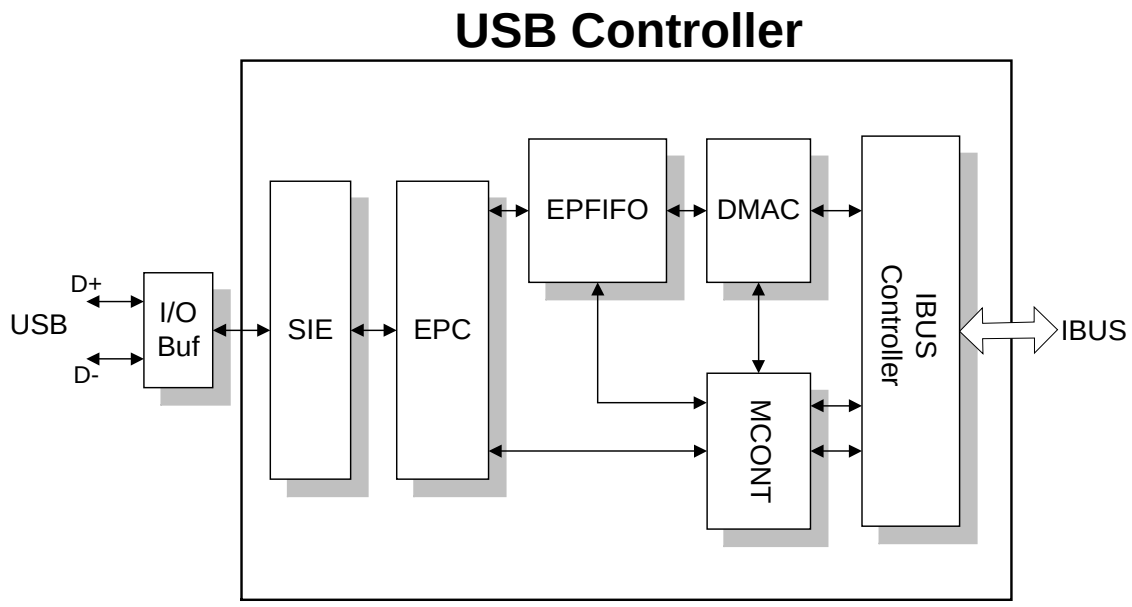


1.5.6 USB controller

USB Controller provides Full Speed Function device function defined in Universal Serial Bus.
Features of USB Controller are as follows;

- Compliant to Universal Serial Bus Specification Rev1.1
- Supports xDSL Sub Class function compliant to Communication Class Definition
- Supports Device class function by software running on VR4120A core
- Performs 12Mbps Full Speed USB function device (Hub function will be not supported)
- Can handle Suspend, Resume and Wake-up management signaling
- Supports Remote Wake-up.
- Implements 7 kinds of endpoints (Control, Interrupt IN/OUT, Isochronous IN/OUT, Bulk IN/OUT)
- Implements 64Bytes FIFO buffer used for Control transfer for TX
- Implements 128Bytes FIFO buffer used for Isochronous transfer for TX
- Implements 128Bytes FIFO buffer used for Bulk transfer for TX
- Implements 64Bytes FIFO buffer used for Interrupt transfer for TX
- Implements 128Bytes shared FIFO buffer used for Control/Isochronous/Bulk/Interrupt transfer for RX
- Implements local DMAC(DMA controller) block
- Can directly connect USB connector through USB dedicated I/O buffer

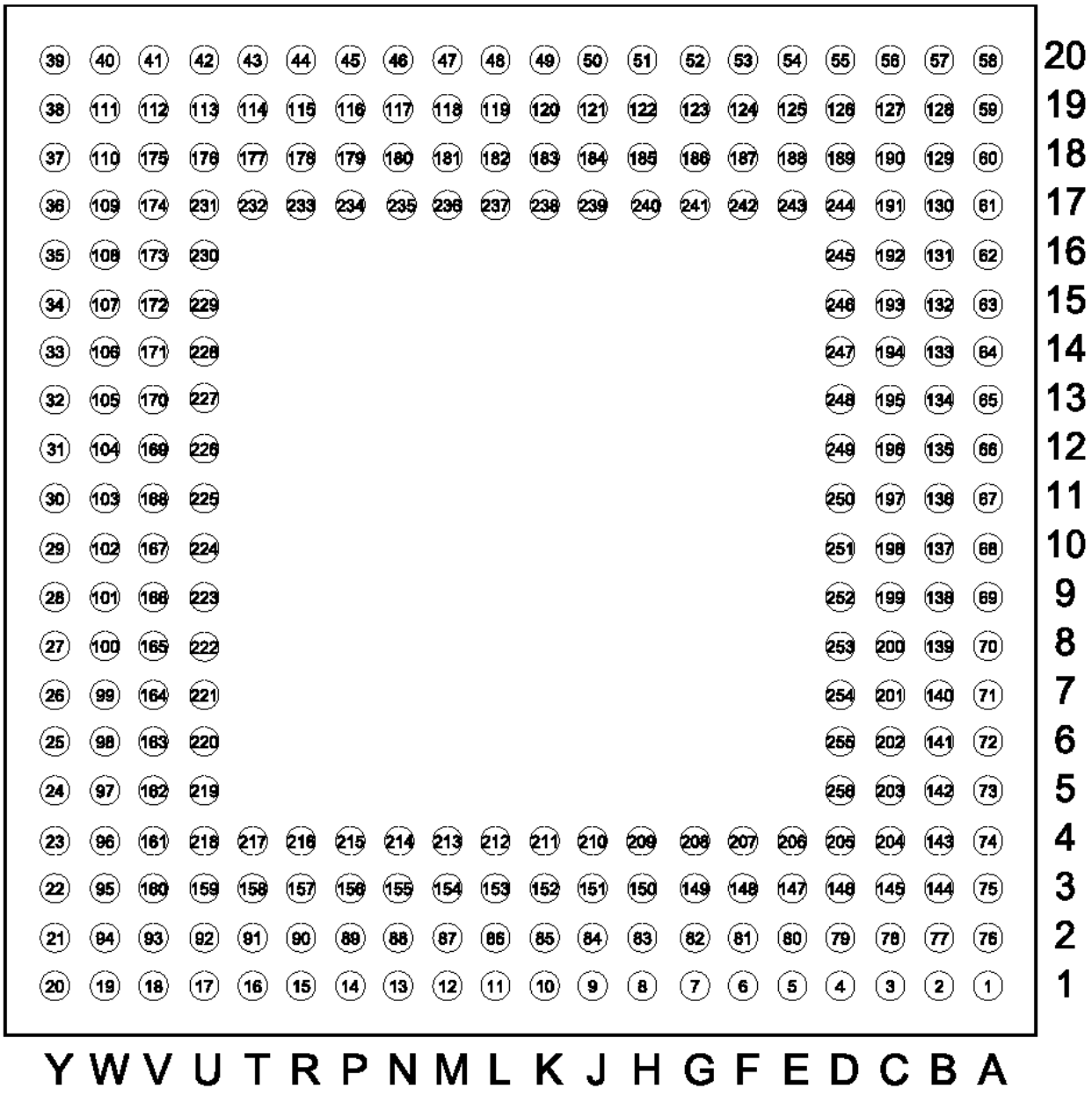
Figure 1-8. Block Diagram of USB Controller



1.6 Pin Configuration (Bottom View)

- 256-pin Tape BGA (27mm x 27mm)
  product code: µPD98503N7-B6

(BOTTOM VIEW)



Pin Name

Pin No.	Pin Name	Pin No.	Pin Name	Pin No.	Pin Name	Pin No.	Pin Name	Pin No.	Pin Name
A01	IC-PDn	C13	URDSR	H01	GND	P17	GND	V13	VDD2
A02	IC-Open	C14	VDD2	H02	VDD2	P18	VDD2	V14	VDD2
A03	ENDCEN	C15	URSDI	H03	GND	P19	SMD7	V15	SMD31
A04	RMSL0	C16	SMA4	H04	VDD3	P20	SMD6	V16	SMD27
A05	GPIO0	C17	SMA6	H17	VDD3	R01	MIRD3	V17	SMD24
A06	GPIO4	C18	VDD2	H18	GND	R02	MIRER	V18	VDD2
A07	GPIO6	C19	SMA12	H19	SEXCS2	R03	MIRDV	V19	SMD18
A08	GPIO8	C20	SMA14	H20	SDCS	R04	MITD0	V20	SMD16
A09	EXNMI	D01	GND	J01	IC-PDn	R17	SMD11	W01	MITER
A10	GPIO13	D02	IC-Open	J02	IC-PDn	R18	SMD10	W02	MITE
A11	GPIO14	D03	IC-Open	J03	IC-Open	R19	SMD9	W03	GND
A12	MWDI	D04	GND	J04	IC-Open	R29	SMD8	W04	JDI
A13	MWDO	D05	VDD3	J17	SDCKE1	T01	MITD1	W05	RSTB
A14	URDCD	D06	GPIO1	J18	SDRAS	T02	MITD2	W06	CLKSL
A15	URDTR	D07	GND	J19	SDCKE0	T03	MICRS	W07	SCLK
A16	SMA1	D08	VDD3	J20	SDCLK0	T04	GND	W08	PSAGND
A17	SMA3	D09	GPIO9	K01	IC-PDn	T17	VDD3	W09	PUAVD
A18	SMA5	D10	GND	K02	IC-PDn	T18	SMD14	W10	PUSTBY
A19	SMA8	D11	VDD3	K03	GND	T19	SMD12	W11	IC-PDn
A20	SMA9	D12	MWSK	K04	VDD2	T20	GND	W12	USBDP
B01	IC-PUp	D13	URRTS	K17	GND	U01	MITD3	W13	IC-Open
B02	IC-PDn	D14	GND	K18	VDD2	U02	MIRCLK	W14	IC-PDn
B03	IC-PDn	D15	SMA0	K19	SDCLK1	U03	IC-PDn	W15	IC-PDn
B04	IC-PDn	D16	VDD3	K20	GND	U04	GND	W16	GND
B05	RMSL1	D17	GND	L01	IC-PUp	U05	JDO	W17	SMD26
B06	GPIO3	D18	SMA13	L02	IC-PDn	U06	IC-PUp	W18	SMD23
B07	GPIO5	D19	SMA15	L03	VDD2	U07	GND	W19	SMD21
B08	GPIO7	D20	SMA16	L04	GND	U08	IC-Open	W20	SMD19
B09	GPIO11	E01	GND	L17	SDWE	U09	PSDVD	Y01	MIMCLK
B10	GPIO12	E02	VDD2	L18	IC-PDn	U10	PUDGND	Y02	IC-Open
B11	GPIO15	E03	IC-Open	L19	VDD3	U11	GND	Y03	JMS
B12	MWCS	E04	IC-Open	L20	SDCAS	U12	VDD3	Y04	JRSTB
B13	URCTS	E17	VDD3	M01	IC-PDn	U13	GND	Y05	IC-PUp
B14	URCLK	E18	GND	M02	IC-PDn	U14	GND	Y06	IC-PDn
B15	URSDO	E19	SMA17	M03	VDD2	U15	SMD30	Y07	PSTBY
B16	SMA2	E20	SMA18	M04	GND	U16	VDD3	Y08	PSAVD
B17	GND	F01	IC-PDn	M17	GND	U17	GND	Y09	PUAGND
B18	SMA7	F02	IC-PDn	M18	SMD2	U18	SMD17	Y10	IC-Open
B19	SMA10	F03	IC-PDn	M19	SMD1	U19	SMD15	Y11	USBCLK
B20	SMA11	F04	IC-Open	M20	SMD0	U20	SMD13	Y12	VDD3
C01	IC-Open	F17	SMA19	N01	GND	V01	MITCLK	Y13	IC-Open
C02	IC-PDnR	F18	SMA20	N02	MIMD	V02	MICOL	Y14	IC-Open
C03	VDD2	F19	SRMOE	N03	MIRD0	V03	VDD2	Y15	IC-PDn
C04	GND	F20	SRMCS	N04	VDD3	V04	JCK	Y16	SMD29
C05	BIG	G01	IC-PDn	N17	VDD3	V05	VDD3	Y17	SMD28
C06	GPIO2	G02	IC-PDn	N18	SMD5	V06	IC-PUp	Y18	SMD25
C07	VDD2	G03	VDD2	N19	SMD4	V07	VDD2	Y19	SMD22
C08	GND	G04	GND	N20	SMD3	V08	PSDGND	Y20	SMD20
C09	GPIO10	G17	GND	P01	MIRD1	V09	PUDVD		
C10	VDD2	G18	VDD2	P02	MIRD2	V10	IC-PDn		
C11	EXINT	G19	SEXCS0	P03	VDD2	V11	VDD2		
C12	GND	G20	SEXCS1	P04	GND	V12	USBDM		

Special pin name description:

IC-PDn: Pull Down

IC-PDnR: Pull Down with Resistor

IC-PUp: Pull Up

IC-PUpR: Pull Up with Resistor

IC-Open: Test output shall be left open

1.7 Pin Function

Symbol of I/O column indicates following status in this section.

I :Input
O :Output
I/O :Bidirection
I/OZ :Bidirection (Include Hi-Z state)
I/OD :Bidirection (Open drain output)
OZ :Output (Include Hi-Z state)
OD :Output (Open drain)

1.7.1 System PLL power supply

Pin Name	Pin No.	I/O	Active Level	Function
PSAGND	100			Analog ground
PSAVD	27			Analog power supply
PSDGND	165			Digital ground
PSDVD	223			Digital power supply

1.7.2 USB PLL power supply

Pin Name	Pin No.	I/O	Active Level	Function
PUAGND	28			Analog ground
PUAVD	101			Analog power supply
PUDGND	224			Digital ground
PUDVD	166			Digital power supply

1.7.3 System control interface

Pin Name	Pin No.	I/O	Active Level	Function
SCLK	99	I		System clock (33MHz)
CLKSL	98	I		Clock select (100MHz/66MHz)
PSTBY	26	I	H	System PLL standby mode control input
PUSTBY	102	I	H	USB PLL Standby mode control
BIG	203	I	H	VR4120A Bigendian mode
ENDCEN	75	I		Big Endian mode enable
EXINT_B	197	I	L	External interrupt
EXNMI_B	69	I	L	External non-maskable interrupt
RST_B	97	I	L	System reset
ROMSEL0	74	I		ROM access bus width
ROMSEL1	142	I		(ROMSEL1/0=L/L;32bit, L/H;16bit, H/L;8bit)

1.7.4 System bus interface

(1/2)

Pin Name	Pin No.	I/O	Active Level	Function
SDCLK0	50	O		SDRAM Clock
SDCLK1	120	O		SDRAM Clock
SDCKE0	121	O	H	SDRAM Clock Enable
SDCKE1	239	O	H	SDRAM Clock Enable
SDCS_B	51	O	L	SDRAM Chip select
SDRAS_B	184	O	L	SDRAM Row address strobe
SDCAS_B	48	O	L	SDRAM Column address strobe
SDWE_B	237	O	L	SDRAM/PROM/FLASH write enable
SRMCS_B	53	O	L	PROM/FLASH chip select
SRMOE_B	124	O	L	PROM/FLASH output enable
SEXCS0_B	123	O	L	Extended Chip Select 0
SEXCS1_B	52	O	L	Extended Chip Select 1
SEXCS2_B	122	O	L	Extended Chip Select 2
SMA0	246	O		System Bus Address
SMA1	62	O		System Bus Address
SMA2	131	O		System Bus Address
SMA3	61	O		System Bus Address
SMA4	192	O		System Bus Address
SMA5	60	O		System Bus Address
SMA6	191	O		System Bus Address
SMA7	129	O		System Bus Address
SMA8	59	O		System Bus Address
SMA9	58	O		System Bus Address
SMA10	128	O		System Bus Address
SMA11	57	O		System Bus Address
SMA12	127	O		System Bus Address
SMA13	189	O		System Bus Address
SMA14	56	O		System Bus Address
SMA15	126	O		System Bus Address
SMA16	55	O		System Bus Address
SMA17	125	O		System Bus Address
SMA18	54	O		System Bus Address
SMA19	242	O		System Bus Address
SMA20	187	O		System Bus Address

(2/2)

Pin Name	Pin No.	I/O	Active Level	Function
SMD0	47	I/O		System Bus data
SMD1	118	I/O		System Bus data
SMD2	181	I/O		System Bus data
SMD3	46	I/O		System Bus data
SMD4	117	I/O		System Bus data
SMD5	180	I/O		System Bus data
SMD6	45	I/O		System Bus data
SMD7	116	I/O		System Bus data
SMD8	44	I/O		System Bus data
SMD9	115	I/O		System Bus data
SMD10	178	I/O		System Bus data
SMD11	233	I/O		System Bus data
SMD12	114	I/O		System Bus data
SMD13	42	I/O		System Bus data
SMD14	177	I/O		System Bus data
SMD15	113	I/O		System Bus data
SMD16	41	I/O		System Bus data
SMD17	176	I/O		System Bus data
SMD18	112	I/O		System Bus data
SMD19	40	I/O		System Bus data
SMD20	39	I/O		System Bus data
SMD21	111	I/O		System Bus data
SMD22	38	I/O		System Bus data
SMD23	110	I/O		System Bus data
SMD24	174	I/O		System Bus data
SMD25	37	I/O		System Bus data
SMD26	109	I/O		System Bus data
SMD27	173	I/O		System Bus data
SMD28	36	I/O		System Bus data
SMD29	35	I/O		System Bus data
SMD30	229	I/O		System Bus data
SMD31	172	I/O		System Bus data

1.7.5 USB Interface

Pin Name	Pin No.	I/O	Active Level	Function
USBCLK	30	I		External USB clock
USBDM	169	I/O		USB data (-)
USBDP	104	I/O		USB data (+)

1.7.6 Ethernet interface

Pin Name	Pin No.	I/O	Active Level	Function
MIRCLK	92	I		MII - Receive clock (25MHz)
MIMCLK	20	O		MII - management clock
MIMD	88	I/O		MII - management
MICOL	93	I		MII - Collision
MICRS	158	I		MII - carrier Sense
MIRDV	157	I		MII - Receive data valid
MIRER	90	I		MII - Receive error
MIRD0	155	I		MII - Receive data
MIRD1	14	I		MII - Receive data
MIRD2	89	I		MII - Receive data
MIRD3	15	I		MII - Receive data
MITCLK	18	I		MII - Transmit clock (25MHz)
MITE	94	O		MII - Transmit enable
MITER	19	O		MII - Transmit error
MITD0	216	O		MII - Transmit data
MITD1	16	O		MII - Transmit data
MITD2	91	O		MII - Transmit data
MITD3	17	O		MII - Transmit data

1.7.7 UART and Micro Wire interface

Pin Name	Pin No.	I/O	Active Level	Function
URCLK	133	I		UART external Clock
URSDO	132	O		UART serial data output
URSDI	193	I		UART serial data input
URDTR_B	63	O	L	UART data terminal ready
URRTS_B	248	O	L	UART data request to send
URCTS_B	134	I	L	UART clear to send
URDCD_B	64	I	L	UART data carrier detect
URDSR_B	195	I	L	UART data set ready
MWDI	66	I		Micro Wire data in
MWSK	249	O		Micro Wire SK
MWCS	135	O		Micro Wire chip select
MWDO	65	O		Micro Wire data out

1.7.8 Parallel port interface

Pin Name	Pin No.	I/O	Active Level	Function
GPIO0	73	I/O		General Purpose Input/Output
GPIO1	255	I/O		General Purpose Input/Output
GPIO2	202	I/O		General Purpose Input/Output
GPIO3	141	I/O		General Purpose Input/Output
GPIO4	72	I/O		General Purpose Input/Output
GPIO5	140	I/O		General Purpose Input/Output
GPIO6	71	I/O		General Purpose Input/Output
GPIO7	139	I/O		General Purpose Input/Output
GPIO8	70	I/O		General Purpose Input/Output
GPIO9	252	I/O		General Purpose Input/Output
GPIO10	199	I/O		General Purpose Input/Output
GPIO11	138	I/O		General Purpose Input/Output
GPIO12	137	I/O		General Purpose Input/Output
GPIO13	68	I/O		General Purpose Input/Output
GPIO14	67	I/O		General Purpose Input/Output
GPIO15	136	I/O		General Purpose Input/Output

1.7.9 Boundary scan interface

Pin Name	Pin No.	I/O	Active Level	Function
JCK	161	I		B-SCAN clock
JDI	96	I		B-SCAN input-data
JDO	219	OZ		B-SCAN output-data
JMS	22	I		B-SCAN mode select
JRSTB_B	23	I	L	B-SCAN reset

1.8 I/O Register Map

Core	OFFSET	Register Length (Byte)	Name	Access by VR4120A	Description
Ether	00H	4	En_MACC1	R/W	MAC configuration register 1
Ether	04H	4	En_MACC2	R/W	MAC configuration register 2
Ether	08H	4	En_IPGT	R/W	Back-to-Back IPG register
Ether	0CH	4	En_IPGR	R/W	Non Back-to-Back IPG register
Ether	10H	4	En_CLRT	R/W	Collision register
Ether	14H	4	En_LMAX	R/W	Max packet length register
Ether	18H-1CH	-	N/A	-	Reserved for future use
Ether	20H	4	En_RETX	R/W	Retry count register
Ether	24H-50H	-	N/A	-	Reserved for future use
Ether	54H	4	En_LSA2	R/W	Station Address register 2
Ether	58H	4	En_LSA1	R/W	Station Address register 1
Ether	5CH	4	En_PTVR	R	Pause timer value read register
Ether	60H	-	N/A	-	Reserved for future use
Ether	64H	4	En_VLTP	R/W	VLAN type register
Ether	80H	4	En_MIIC	R/W	MII configuration register
Ether	84H-90H	-	N/A	-	Reserved for future use
Ether	94H	4	En_MCMD	W	MII command register
Ether	98H	4	En_MADR	R/W	MII address register
Ether	9CH	4	En_MWTD	R/W	MII write data register
Ether	A0H	4	En_MRDD	R	MII read data register
Ether	A4H	4	En_MIND	R	MII indicator register
Ether	A8H-C4H	-	N/A	-	Reserved for future use
Ether	CCH	4	En_HT1	R/W	Hash table register 1
Ether	D0H	4	En_HT2	R/W	Hash table register 2
Ether	D4H-D8H	-	N/A	-	Reserved for future use
Ether	DCH	4	En_CAR1	R/W	Carry register 1
Ether	E0H	4	En_CAR2	R/W	Carry register 2
Ether	E4H-12CH	-	N/A	-	Reserved for future use
Ether	130H	4	En_CAM1	R/W	Carry mask register 1
Ether	134H	4	En_CAM2	R/W	Carry mask register 2
Ether	138H-13CH	-	N/A	-	Reserved for future use
Ether	140H	4	En_RBYT	R/W	Receive Byte Counter
Ether	144H	4	En_RPKT	R/W	Receive Packet Counter
Ether	148H	4	En_RFCS	R/W	Receive FCS Error Counter
Ether	14CH	4	En_RMCA	R/W	Receive Multicast Packet Counter
Ether	150H	4	En_RBCA	R/W	Receive Broadcast Packet Counter
Ether	154H	4	En_RXCF	R/W	Receive Control Frame Packet Counter
Ether	158H	4	En_RXPF	R/W	Receive PAUSE Frame Packet Counter
Ether	15CH	4	En_RXUO	R/W	Receive Unknown OP code Counter
Ether	160H	4	En_RALN	R/W	Receive Alignment Error Counter
Ether	164H	4	En_RFLR	R/W	Receive Frame Length Out of Range Counter
Ether	168H	4	En_RCDE	R/W	Receive Code Error Counter
Ether	16CH	4	En_RFCR	R/W	Receive False Carrier Counter
Ether	170H	4	En_RUND	R/W	Receive Undersize Packet Counter
Ether	174H	4	En_ROVR	R/W	Receive Oversize Packet Counter
Ether	178H	4	En_RFRG	R/W	Receive Error Undersize Packet Counter
Ether	17CH	4	En_RJBR	R/W	Receive Error Oversize Packet Counter
Ether	180H	4	En_R64	R/W	Receive 64 Byte Frame Counter
Ether	184H	4	En_R127	R/W	Receive 65 to 127 Byte Frame Counter
Ether	188H	4	En_R255	R/W	Receive 128 to 255 Byte Frame Counter
Ether	18CH	4	En_R511	R/W	Receive 256 to 511 Byte Frame Counter
Ether	190H	4	En_R1K	R/W	Receive 512 to 1023 Byte Frame Counter
Ether	194H	4	En_RMAX	R/W	Receive Over 1023 Byte Frame Counter
Ether	198H	4	En_RVBT	R/W	Receive Valid Byte Counter
Ether	1C0H	4	En_TBYT	R/W	Transmit Byte Counter
Ether	1C4H	4	En_TPCT	R/W	Transmit Packet Counter
Ether	1C8H	4	En_TFCS	R/W	Transmit CRC Error Packet Counter
Ether	1CCH	4	En_TMCA	R/W	Transmit Multicast Packet Counter
Ether	1D0H	4	En_TBCA	R/W	Transmit Broadcast Packet Counter
Ether	1D4H	4	En_TUCA	R/W	Transmit Unicast Packet Counter
Ether	1D8H	4	En_TXPF	R/W	Transmit PAUSE control Frame Counter
Ether	1DCH	4	En_TDFR	R/W	Transmit Single Deferral Packet Counter
Ether	1E0H	4	En_TXDF	R/W	Transmit Excessive Deferral Packet Counter
Ether	1E4H	4	En_TSCL	R/W	Transmit Single Collision Packet Counter
Ether	1E8H	4	En_TMCL	R/W	Transmit Multiple collision Packet Counter
Ether	1ECH	4	En_TLCL	R/W	Transmit Late Collision Packet Counter
Ether	1F0H	4	En_TXCL	R/W	Transmit Excessive Collision Packet Counter

Core	OFFSET	Register Length (Byte)	Name	Access by VR4120A	Description
Ether	1F4H	4	En_TNCL	R/W	Transmit Total Collision Counter
Ether	1F8H	4	En_TCSE	R/W	Transmit Carrier Sense Error Counter
Ether	1FCH	4	En_TIME	R/W	Transmit Internal MAC Error Counter
Ether	200H	4	En_TXCR	R/W	Transmit Configuration Register
Ether	204H	4	En_TXFCR	R/W	Transmit FIFO Control Register
Ether	208H	4	En_TXDTR	W	Transmit Data Register
Ether	20CH	4	En_TXSR	R	Transmit Status Register
Ether	210H	4	N/A	-	Reserved for future use
Ether	214H	4	En_TXDPR	R/W	Transmit Descriptor Register
Ether	218H	4	En_RXCR	R/W	Receive Configuration Register
Ether	21CH	4	En_RXFCR	R/W	Receive FIFO Control Register
Ether	220H	4	En_RXDTR	R	Receive Data Register
Ether	224H	4	En_RXSR	R	Receive Status Register
Ether	228H	4	N/A	-	Reserved for future use
Ether	22CH	4	En_RXDPR	R/W	Receive Descriptor Register
Ether	230H	4	En_RXPDR	R/W	Receive Pool Descriptor Register
SYSCNT	00H	4	S_GMR	R/W	General Mode Register
SYSCNT	04H	4	S_GSR	R	General Status Register
SYSCNT	08H	4	S_ISR	RC	Interrupt Status Register
SYSCNT	0CH	4	S_IMR	W	Interrupt Mask Register
SYSCNT	10H	4	S_NSR	R	NMI Status Register
SYSCNT	14H	4	S_NMR	R/W	NMI Enable Register
SYSCNT	18H	4	S_VER	R	Version Register
SYSCNT	1CH	4	reserved	R/W	Reserved (see chapter 3.2.2.8)
SYSCNT	20H	4	S_GIOER	R/W	GPIO Output Enable Register
SYSCNT	24H	4	S_GOPR	R/W	GPIO Output (Write) Register
SYSCNT	28H	4	S_GIPR	R	GPIO Input (Read) Register
SYSCNT	2CH-2FH	-	N/A	-	Reserved
SYSCNT	30H	4	S_WRCR	W	Warm Reset Control Register
SYSCNT	34H	4	S_WRSR	R	Warm Reset Status Register
SYSCNT	38H	4	S_PWCR	W	Power Control Register
SYSCNT	3CH	4	S_PWSR	R	Power Control Status Register
SYSCNT	40H-48H	-	N/A	-	Reserved
SYSCNT	4CH	4	S_ITCNTR	R/W	IBUS Timeout Timer Control Register
SYSCNT	50H	4	S_ITSETR	R/W	IBUS Timeout Timer Set Register
SYSCNT	54H-7FH	-	N/A	-	Reserved
SYSCNT	80H	4	UARTDLL	R/W	UART, Divisor Latch LSB Register [DLAB=1]
SYSCNT	80H	4	UARTRBR	R	UART, Receiver Buffer Register [DLAB=0,READ]
SYSCNT	80H	4	UARTTHR	W	UART, Transmitter Holding Register [DLAB=0,WRITE]
SYSCNT	84H	4	UARTDLM	R/W	UART, Divisor Latch MSB Register [DLAB=1]
SYSCNT	84H	4	UARTIER	R/W	UART, Interrupt Enable Register [DLAB=0]
SYSCNT	88H	4	UARTFCR	W	UART, FIFO control Register [WRITE]
SYSCNT	88H	4	UARTIIR	R	UART, Interrupt ID Register [READ]
SYSCNT	8CH	4	UARTLCR	R/W	UART, Line control Register
SYSCNT	90H	4	UARTMCR	R/W	UART, Modem Control Register
SYSCNT	94H	4	UARTLSR	R/W	UART, Line status Register
SYSCNT	98H	4	UARTMSR	R/W	UART, Modem Status Register
SYSCNT	9CH	4	UARTSCR	R/W	UART, Scratch Register
SYSCNT	A0H	4	DSUCNTR	R/W	DSU Control Register
SYSCNT	A4H	4	DSUSETR	R/W	DSU Dead Time Set Register
SYSCNT	A8H	4	DSUCLRR	W	DSU Clear Register
SYSCNT	ACH	4	DSUTIMR	R/W	DSU Elapsed Time Register
SYSCNT	B0H	4	TMMR	R/W	Timer Mode Register
SYSCNT	B4H	4	TM0CSR	R/W	Timer CH0 Count Set Register
SYSCNT	B8H	4	TM1CSR	R/W	Timer CH1 Count Set Register
SYSCNT	BCH	4	TM0CCR	R	Timer CH0 Current Count Register
SYSCNT	C0H	4	TM1CCR	R	Timer CH1 Current Count Register
SYSCNT	C4H-CFH	-	N/A	-	Reserved
SYSCNT	D0H	4	ECCR	W	EEPROM™ Command Control Register
SYSCNT	D4H	4	ERDR	R	EEPROM Read Data Register
SYSCNT	D8H	4	MACAR1	R	MAC Address Register 1
SYSCNT	DCH	4	MACAR2	R	MAC Address Register 2
SYSCNT	E0H	4	MACAR3	R	MAC Address Register 3
SYSCNT	E4H-FFH	-	N/A	-	Reserved
SYSCNT	100H	4	RMMDR	R/W	Boot ROM Mode Register
SYSCNT	104H	4	RMATR	R/W	Boot ROM Access Timing Register
SYSCNT	108H	4	SDMDR	R/W	SDRAM Mode Register
SYSCNT	10CH	4	SDTSR	R/W	SDRAM Type Selection Register
SYSCNT	110H	4	SDPTR	R/W	SDRAM Precharge Timing Register
SYSCNT	114H	4	SDRMR	R/W	SDRAM Precharge Mode Register
SYSCNT	118H	4	SDRCR	R	SDRAM Precharge Timer Count Register
SYSCNT	11CH	4	SDRMR	R/W	SDRAM Refresh Mode Register
SYSCNT	120H	4	SDRCR	R	SDRAM Refresh Timer Count Register
SYSCNT	124H	4	MBCR	R/W	Memory Bus Control Register

Core	OFFSET	Register Length (Byte)	Name	Access by VR4120A	Description
SYSCNT	128H-FFFH	-	N/A	-	Reserved
USB	00H	4	U_GMR	R/W	USB General Mode Register
USB	04H	4	U_VER	R	USB Frame number/Version Register
USB	08H	-	N/A	R/W	Reserved for future use
USB	0CH	-	N/A	R	Reserved for future use
USB	10H	4	U_GSR1	R	USB General Status Register 1
USB	14H	4	U_IMR1	R/W	USB Interrupt Mask Register 1
USB	18H	4	U_GSR2	R	USB General Status Resister 2
USB	1CH	4	U_IMR2	R/W	USB Interrupt Mask Register 2
USB	20H	4	U_EP0CR	R/W	USB EP0 Control Register
USB	24H	4	U_EP1CR	R/W	USB EP1 Control Register
USB	28H	4	U_EP2CR	R/W	USB EP2 Control Register
USB	2CH	4	U_EP3CR	R/W	USB EP3 Control Register
USB	30H	4	U_EP4CR	R/W	USB EP4 Control Register
USB	34H	4	U_EP5CR	R/W	USB EP5 Control Register
USB	38H	4	U_EP6CR	R/W	USB EP6 Control Register
USB	3CH	-	N/A	-	Reserved for future use
USB	40H	4	U_CMR	R/W	USB Command Register
USB	44H	4	U_CA	R/W	USB Command Address Register
USB	48H	4	U_TEPSR	R/W	USB Tx EndPoint Status Register
USB	4CH	-	N/A	-	Reserved for future use
USB	50H	4	U_RP0IR	R/W	USB Rx Pool0 Information Register
USB	54H	4	U_RP0AR	R	USB Rx Pool0 Address Register
USB	58H	4	U_RP1IR	R/W	USB Rx Pool1 Information Register
USB	5CH	4	U_RP1AR	R	USB Rx Pool1 Address Register
USB	60H	4	U_RP2IR	R/W	USB Rx Pool2 Information Register
USB	64H	4	U_RP2AR	R	USB Rx Pool2 Address Register
USB	68H	-	N/A	-	Reserved for future use
USB	6CH	-	N/A	-	Reserved for future use
USB	70H	4	U_TMSA	R/W	USB Tx MailBox Start Address Register
USB	74H	4	U_TMBA	R/W	USB Tx MailBox Bottom Address Register
USB	78H	4	U_TMRA	R/W	USB Tx MailBox Read Address Register
USB	7CH	4	U_TMWA	R	USB Tx MailBox Write Address Register
USB	80H	4	U_RMSA	R/W	USB Rx MailBox Start Address Register
USB	84H	4	U_RMBA	R/W	USB Rx MailBox Bottom Address Register
USB	88H	4	U_RMRA	R/W	USB Rx MailBox Read Address Register
USB	8CH	4	U_RMWA	R	USB Rx MailBox Write Address Register
USB	90H-FFH	-	N/A	-	Reserved for future use
USB	100H	4	U_TDN	R	USB EP0 Tx Data Phase NAK Counter
USB	104H	4	U_TDS	R	USB EP0 Tx Data Phase STALL Counter
USB	108H	-	N/A	-	Reserved for future use
USB	10CH	-	N/A	-	Reserved for future use
USB	110H	4	U_THT	R	USB EP0 Tx Handshake Phase Timeout Counter
USB	114H	-	N/A	-	Reserved for future use
USB	118H	-	N/A	-	Reserved for future use
USB	11CH	-	N/A	-	Reserved for future use
USB	120H	4	U_RDT	R	USB EP0 Rx Data Phase Timeout Counter
USB	124H	4	U_RDCER	R	USB EP0 Rx Data Phase CRC Error Counter
USB	128H	4	U_RDBER	R	USB EP0 Rx Data Phase Bitstuff Error Counter
USB	12CH	4	U_RDTER	R	USB EP0 Rx Data Phase Data Toggle Error Counter
USB	130H	4	U_RHT	R	USB EP0 Rx Handshake Phase Timeout Counter
USB	134H	4	U_RHN	R	USB EP0 Rx Handshake Phase NAK Counter
USB	138H	4	U_RHS	R	USB EP0 Rx Handshake Phase STALL Counter
USB	13CH	-	N/A	R	Reserved for future use
USB	140H-15FH	-	N/A	-	Reserved for future use
USB	160H	4	U_DT2	R	USB EP2 Data Phase Timeout Counter
USB	164H	4	U_DCER2	R	USB EP2 Data Phase CRC Error Counter
USB	168H	4	U_DBER2	R	USB EP2 Data Phase Bitstuff Error Counter
USB	16CH	-	N/A	-	Reserved for future use
USB	170H-17FH	-	N/A	-	Reserved for future use
USB	180H	4	U_DN3	R	USB EP3 Data Phase NAK Counter
USB	184H	4	U_DS3	R	USB EP3 Data Phase STALL Counter
USB	188H	-	N/A	-	Reserved for future use
USB	18CH	-	N/A	-	Reserved for future use
USB	190H	4	U_HT3	R	USB EP3 Handshake Phase Timeout Counter
USB	194H	-	N/A	-	Reserved for future use
USB	198H	-	N/A	-	Reserved for future use
USB	19CH	-	N/A	-	Reserved for future use
USB	1A0H	4	U_DT4	R	USB EP4 Data Phase Timeout Counter
USB	1A4H	4	U_DCER4	R	USB EP4 Data Phase CRC Error Counter
USB	1A8H	4	U_DBER4	R	USB EP4 Data Phase Bitstuff Error Counter
USB	1ACH	4	U_DTER4	R	USB EP4 Data Phase Data Toggle Error Counter
USB	1B0H	4	U_HT4	R	USB EP4 Handshake Phase Timeout Counter
USB	1B4H	4	U_HN4	R	USB EP4 Handshake Phase NAK Counter

Core	OFFSET	Register Length (Byte)	Name	Access by VR4120A	Description
USB	1B8H	4	U_HS4	R	USB EP4 Handshake Phase STALL Counter
USB	1BCH	-	N/A	-	Reserved for future use
USB	1C0H	4	U_DN5	R	USB EP5 Data Phase NAK Counter
USB	1C4H	4	U_DS5	R	USB EP5 Data Phase STALL Counter
USB	1C8H	-	N/A	-	Reserved for future use
USB	1CCH	-	N/A	-	Reserved for future use
USB	1D0H	4	U_HT5	R	USB EP5 Handshake Phase Timeout Counter
USB	1D4H	-	N/A	-	Reserved for future use
USB	1D8H	-	N/A	-	Reserved for future use
USB	1DCH	-	N/A	-	Reserved for future use
USB	1E0H	4	U_DT6	R	USB EP6 Data Phase Timeout Counter
USB	1E4H	4	U_DCER6	R	USB EP6 Data Phase CRC Error Counter
USB	1E8H	4	U_DBER6	R	USB EP6 Data Phase Bitstuff Error Counter
USB	1ECH	4	U_DTER6	R	USB EP6 Data Phase Data Toggle Error Counter
USB	1F0H	4	U_HT6	R	USB EP6 Handshake Phase Timeout Counter
USB	1F4H	4	U_HN6	R	USB EP6 Handshake Phase NAK Counter
USB	1F8H	4	U_HS6	R	USB EP6 Handshake Phase STALL Counter
USB	1FCH	-	N/A	-	Reserved for future use

Base address

Ethernet Controller (Ether) (n = 1) - 1000_2000H

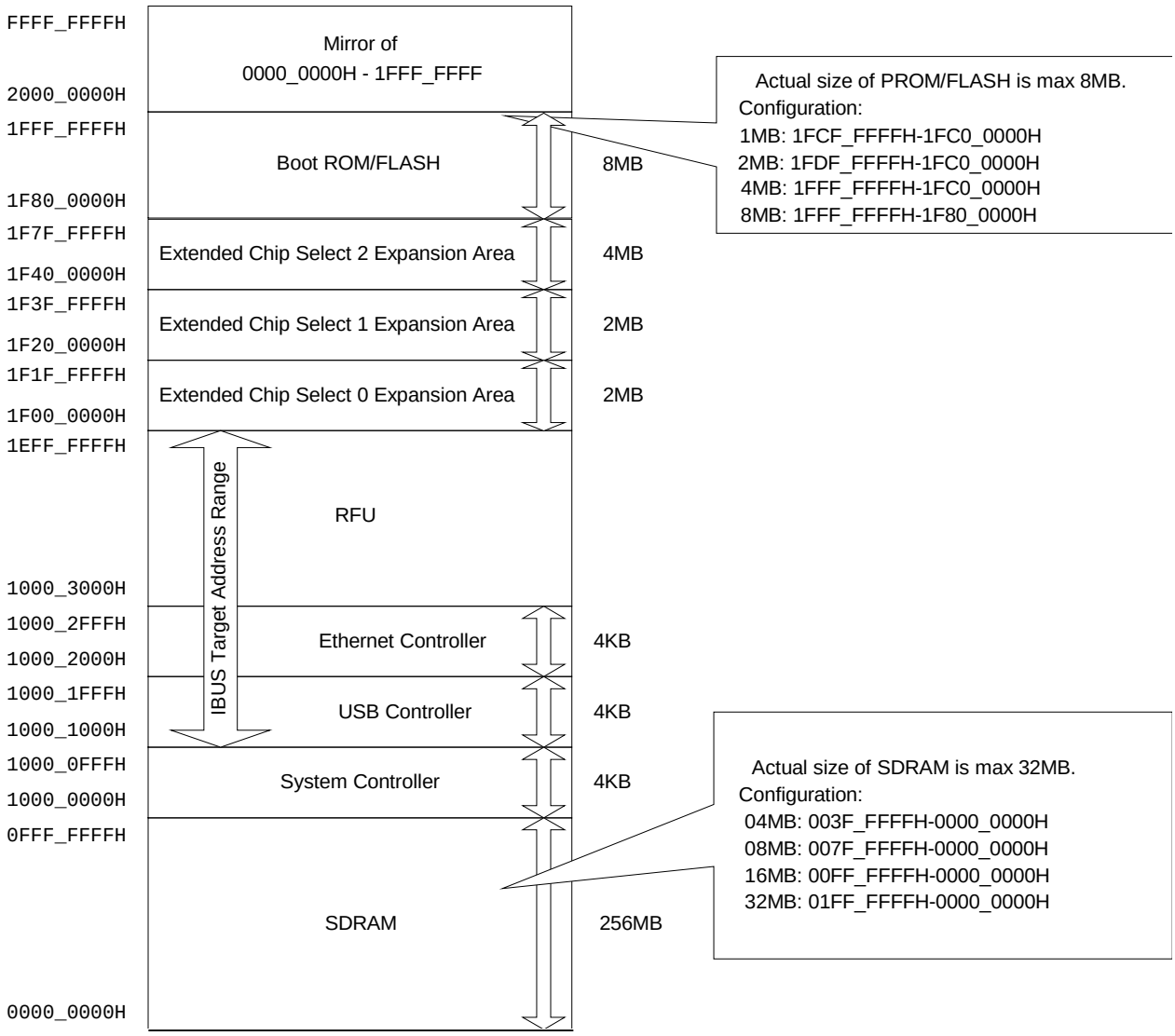
USB Controller (USB) - 1000_1000H

System Controller (SYSCNT) - 1000_0000H

1.9 Memory Map

Using a 32-bit address, the processor physical address space encompasses 4Gbytes. VR4120A uses this 4Gbyte physical address space as shown in the following figure.

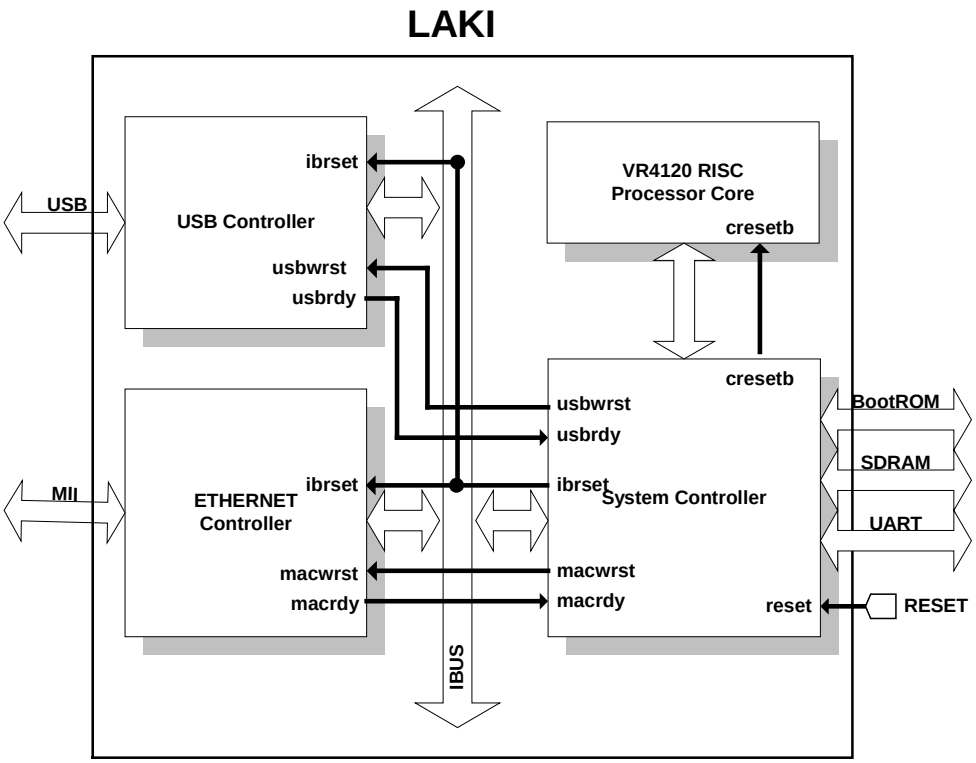
Figure 1-9. Memory Map



1.10 Reset Configuration

The rising edge of external system reset (RESET) serves as LAKI's reset. The System Controller generates the internal reset signal for the global reset of LAKI. After 4 IBUS clock, the System Controller deassert the internal reset signal synchronously with IBUS clock (66MHz). And also the System Controller generates the internal Cold Reset signal and Hot Reset signal for performing the cold reset of VR4120A. Once power to LAKI is established, the System Controller asserts both Cold Reset signal and Hot Reset signal. After approximately 16ms Cold Reset signal assertion, the System Controller deasserts the Cold Reset signal synchronously with MOUT. And after 16 MOUT clock cycles at deassertion of the Cold Reset, the System Controller deasserts the Hot Reset signal synchronously with MOUT.

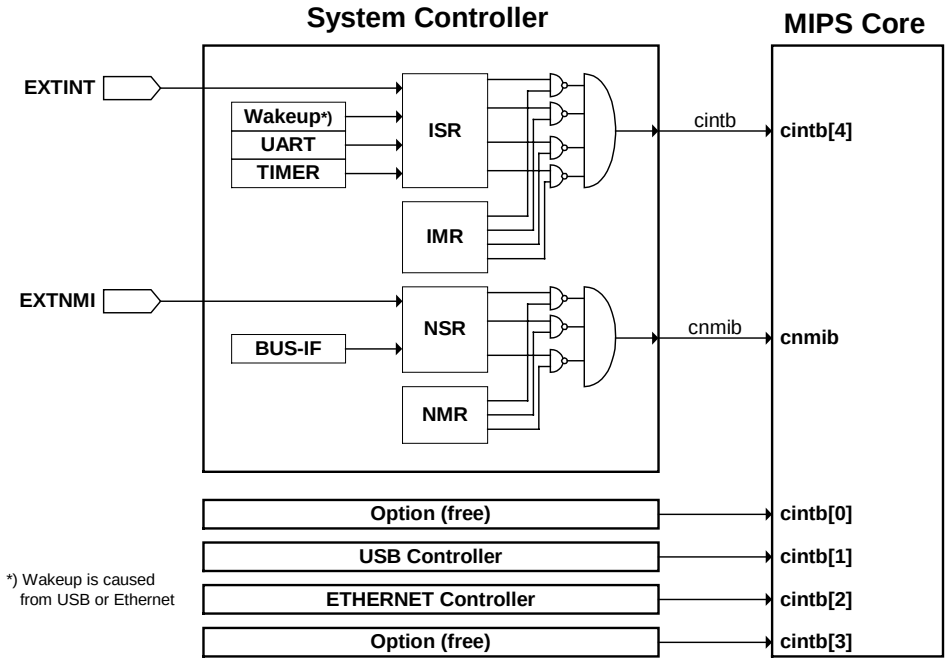
Figure 1-10. Reset Configuration



1.11 Interrupts

The controller supports maskable interrupts and Non-Maskable to the CPU.

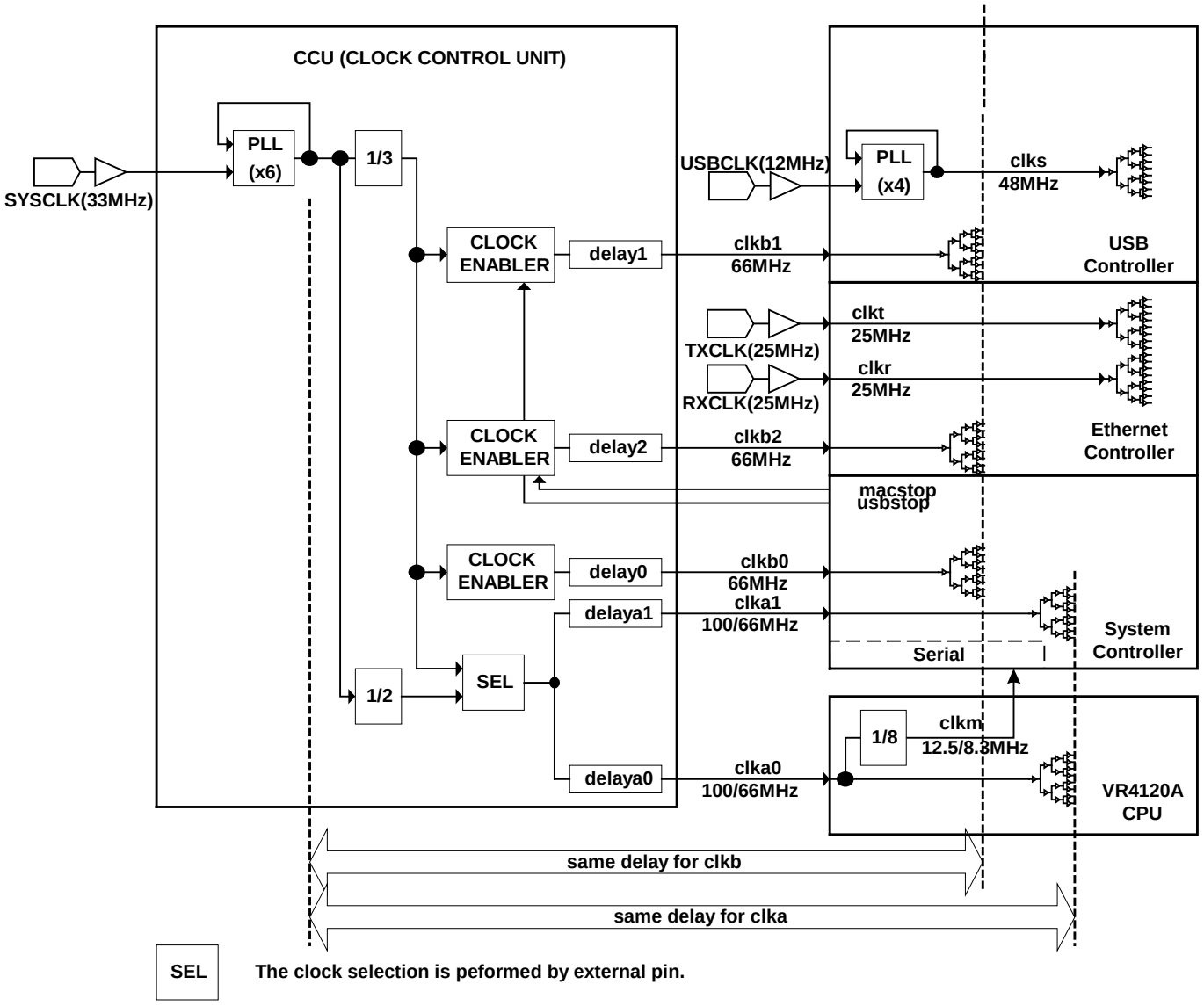
Figure 1-11. Interrupt Signal Connection



1.12 Clock Control Unit

This section describes LAKI's internal clock supplied by Clock Control Unit (CCU) with following figure.

Figure 1-12. Block Diagram of Clock Control Unit



[MEMO]

CHAPTER 2 VR4120A

Caution LAKI doesn't support MIPS16 instructions.

In order to secure compatibility with future NEC network controller devices, it is recommended not to take advantage of the MIPSIII instruction set, which might not be supported in future devices.

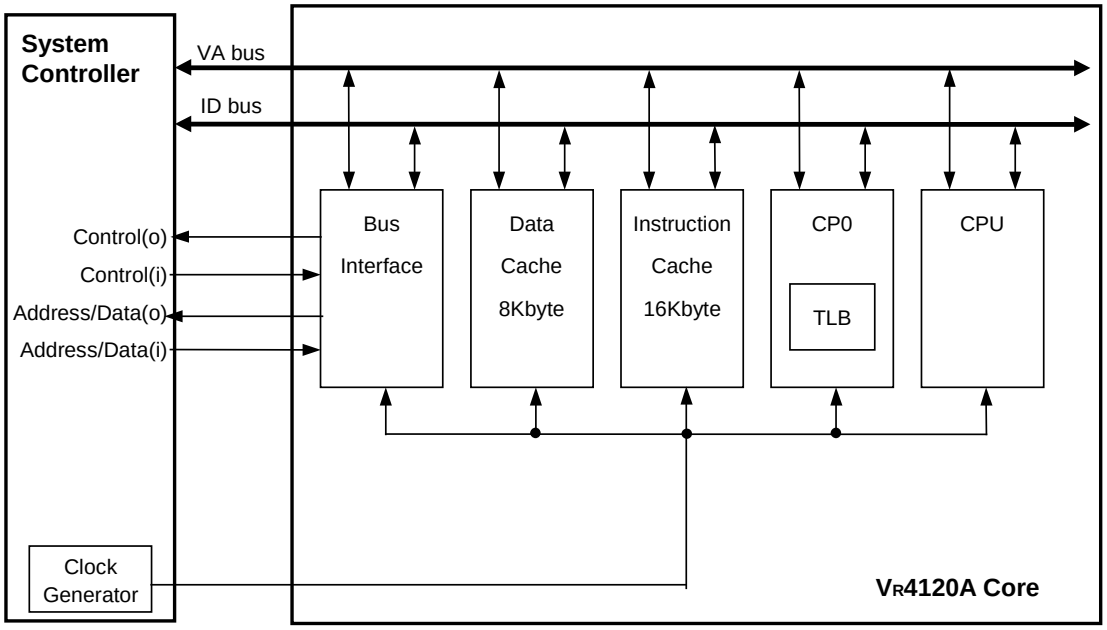
This chapter describes an VR4120A RISC Processor Core operation (MIPS instruction, Pipeline, etc.). Following in this Document, it is call for VR4120A RISC Processor Core with "VR4120A" or "VR4120A Core" simply.

2.1 Overview for VR4120A

Figure 2-1 shows the internal block diagram of the VR4120A core.

In addition to the conventional high-performance integer operation units, this CPU core has the full-associative format translation look aside buffer (TLB), which has 32 entries that provide mapping to 2- page pairs (odd and even) for one entry. Moreover, it also has instruction caches, data caches, and bus interface.

Figure 2-1. VR4120A Core Internal Block Diagram



2.1.1 Internal block configuration

2.1.1.1 CPU

CPU has hardware resources to process an integer instruction. They are the 64-bit register file, 64-bit integer data bus, and multiply-and-accumulate operation unit.

2.1.1.2 Coprocessor 0 (CP0)

CP0 incorporates a memory management unit (MMU) and exception handling function. MMU checks whether there is an access between different memory segments (user, supervisor, and kernel) by executing address conversion. The translation lookaside buffer (TLB) converts virtual addresses to physical addresses.

2.1.1.3 Instruction cache

The instruction cache employs direct mapping, virtual index, and physical tag. Its capacity is 16 Kbytes.

2.1.1.4 Data cache

The data cache employs direct mapping, virtual index, physical tag, and write back. Its capacity is 8 Kbytes.

2.1.1.5 CPU bus interface

The CPU bus interface controls data transmission/reception between the VR4120A and the BCU, which is one of peripheral units. The VR4120A interface consists of two 32-bit multiplexed address/data buses (one is for input, and another is for output), clock signals, and control signals such as interrupts.

2.1.2 VR4120A registers

The VR4120A has the following registers.

- ✧ general-purpose register (GPR): 64 bits × 32

In addition, the processor provides the following special registers:

- ✧ 64-bit Program Counter (PC)
- ✧ 64-bit HI register, containing the integer multiply and divide upper doubleword result
- ✧ 64-bit LO register, containing the integer multiply and divide lower doubleword result

Two of the general-purpose registers have assigned the following functions:

- ✧ r0 is hardwired to a value of zero, and can be used as the target register for any instruction whose result is to be discarded. r0 can also be used as a source when a zero value is needed.
- ✧ r31 is the link register used by link instruction, such as JAL (Jump and Link) instructions. This register can be used for other instructions. However, be careful that use of the register by a link instruction will not coincide with use of the register for other operations.

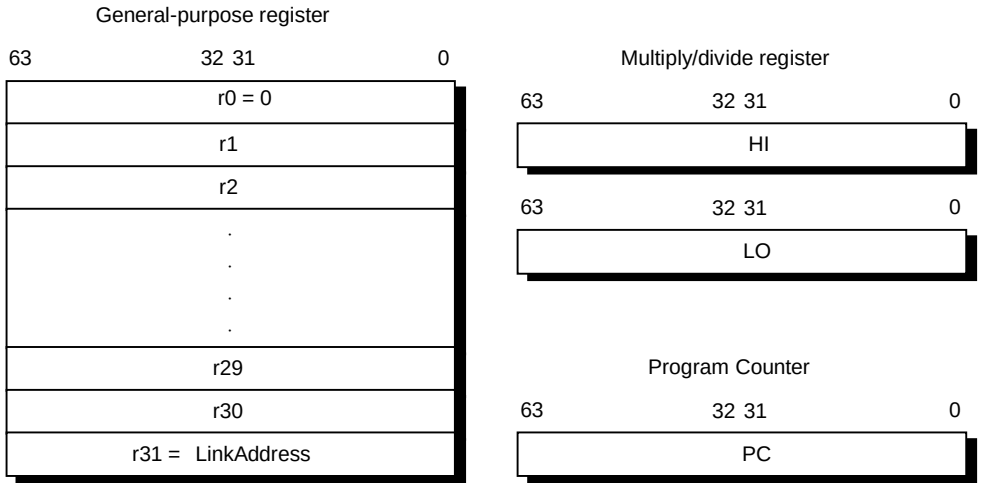
The register group is provided within the CP0 (system control coprocessor), to process exceptions and to manage addresses.

CPU registers can operate as either 32-bit or 64-bit registers, depending on the VR4120A processor operation mode.

The operation of the CPU register differs depending on what instructions are executed: 32-bit instructions or MIPS16 instructions. Anyhow: LAKI does not support MIPS16 mode !

Figure 2-2 shows the CPU registers.

Figure 2-2. VR4120A Registers



The VR4120A has no Program Status Word (PSW) register as such; this is covered by the Status and Cause registers incorporated within the System Control Coprocessor (CP0).

The CP0 registers are used for exception handling or address management. The overview of these registers is described in **2.1.5 Coprocessors (CP0)**.

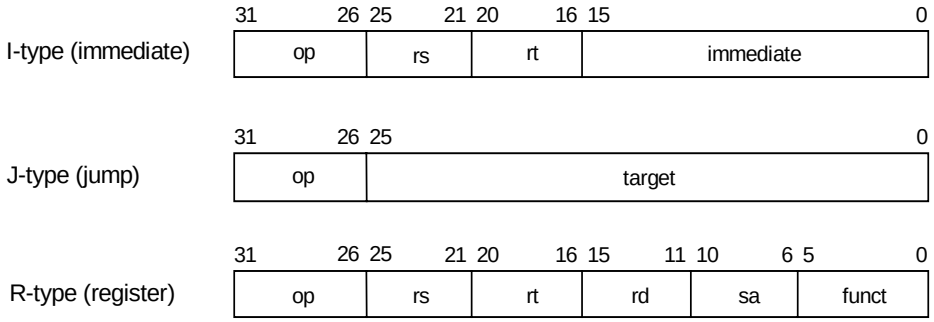
2.1.3 VR4120A instruction set overview

For CPU instructions, there are two types of instructions – 32-bit length instruction (MIPS III) and 16-bit length instruction (MIPS16). MIPS16 is not supported by LAKI.

2.1.3.1 MIPS III instruction

All the CPU instructions are 32-bit length when executing MIPS III instructions, and they are classified into three instruction formats as shown in Figure 2-3: immediate (I-type), jump (J-type), and register (R-type). The field of each instruction format is described in **Section 2.2 MIPS III Instruction Set Summary**.

Figure 2-3. CPU Instruction Formats (32-bit Length Instruction)



The instruction set can be further divided into the following five groupings:

(a) Load and store instructions move data between memory and general-purpose registers. They are all immediate (I-type) instructions, since the only addressing mode supported is base register plus 16-bit, signed immediate offset.

(b) Computational instructions perform arithmetic, logical, shift, and multiply and divide operations on values in registers. They include R-type (in which both the operands and the result are stored in registers) and I-type (in which one operand is a 16-bit signed immediate value) formats.

(c) Jump and branch instructions change the control flow of a program. Jumps are always made to an absolute address formed by combining a 26-bit target address with the high-order bits of the Program Counter (J-type format) or register address (R-type format). The format of the branch instructions is I type. Branches have 16-bit offsets relative to the Program Counter. JAL instructions save their return address in register 31.

(d) Coprocessor 0 (System Control Coprocessor, CP0) instructions perform operations on CP0 registers to control the memory-management and exception-handling facilities of the processor.

(e) Special instructions perform system calls and breakpoint operations, or cause a branch to the general exception-handling vector based upon the result of a comparison. These instructions occur in both R-type and I-type formats.

For the operation of each instruction, refer to **Section 2.2 MIPS III Instruction Set Summary** and **APPENDIX A MIPS III INSTRUCTION SET DETAILS**.

2.1.3.2 <empty>

2.1.4 Data formats and addressing

The VR4120A uses following four data formats:

- ✧ Doubleword (64 bits)

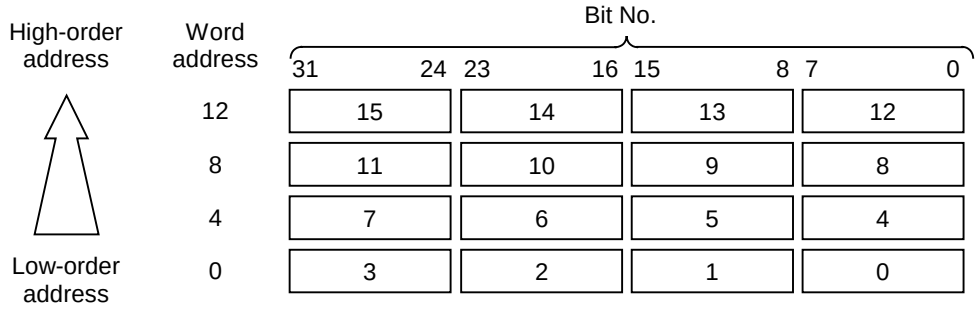
- ✧ Word (32 bits)
- ✧ Halfword (16 bits)
- ✧ Byte (8 bits)

For LAKI, byte ordering within all of the larger data formats - halfword, word, doubleword - can be configured in either big-endian or little-endian order.

Endianness refers to the location of byte 0 within the multi-byte data structure.

When configured as a little-endian system, byte 0 is always the least-significant (rightmost) byte, which is compatible with iAPX™ and DEC VAX™ conventions. Figures 2-5 and 2-6 show this configuration.

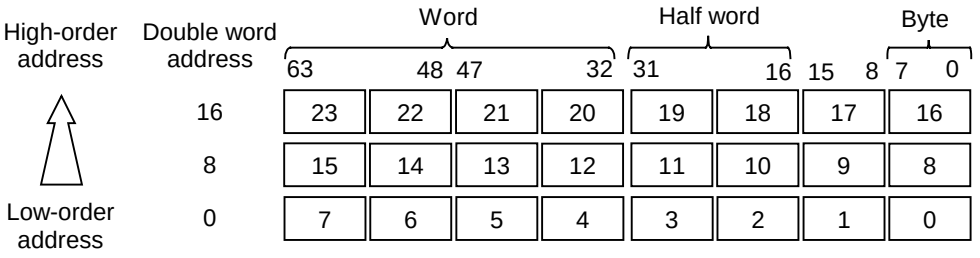
Figure 2-5. Little-Endian Byte Ordering in Word Data



Remarks 1. The lowest byte is the lowest address.

2. The address of word data is specified by the lowest byte's address.

Figure 2-6. Little-Endian Byte Ordering in Double Word Data



Remarks 1. The lowest byte is the lowest address.

2. The address of word data is specified by the lowest byte's address.

The CPU core uses the following byte boundaries for halfword, word, and doubleword accesses:

- ✧ Halfword: An even byte boundary (0, 2, 4...)
- ✧ Word: A byte boundary divisible by four (0, 4, 8...)
- ✧ Doubleword: A byte boundary divisible by eight (0, 8, 16...)

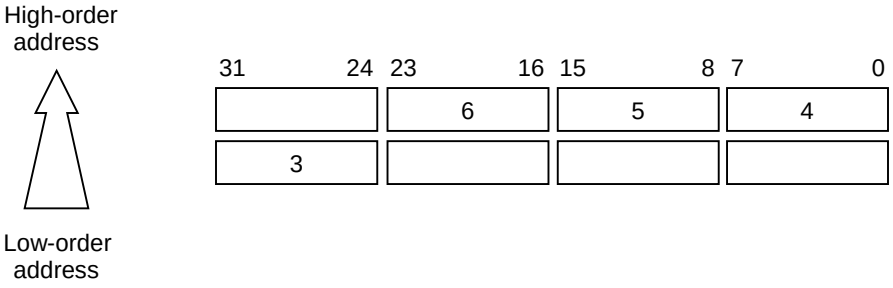
The following special instructions to load and store data that are not aligned on 4-byte (word) or 8-byte (doubleword) boundaries:

LWL	LWR	SWL	SWR
LDL	LDR	SDL	SDR

These instructions are used in pairs to provide an access to misaligned data. Accessing misaligned data incurs one additional instruction cycle over that required for accessing aligned data.

Figure 2-7 shows the access of a misaligned word that has byte address 3 for the little-endian conventions.

Figure 2-7. Misaligned Word Accessing (Little-Endian)



2.1.5 Coprocessors (CP0)

MIPS ISA defines 4 types of coprocessors (CP0 to CP3).

- CP0 translates virtual addresses to physical addresses, switches the operating mode (kernel, supervisor, or user mode), and manages exceptions. It also controls the cache subsystem to analyze a cause and to return from the error state.
- CP1 is reserved for floating-point instructions.
- CP2 is reserved for future definition by MIPS.
- CP3 is no longer defined. CP3 instructions are reserved for future extensions.

Figure 2-8 shows the definitions of the CP0 register, and Table 2-1 shows simple descriptions of each register. For the detailed descriptions of the registers related to the virtual system memory, refer to **Section 2.4 Memory Management System**. For the detailed descriptions of the registers related to exception handling, refer to **Section 2.5 Exception Processing**.

Figure 2-8. CP0 Registers

Register No.	Register name	Register No.	Register name
0	Index[Note 1]	16	Config[Note 1]
1	Random[Note 1]	17	LLAddr[Note 1]
2	EntryLo0[Note 1]	18	WatchLo[Note 2]
3	EntryLo1[Note 1]	19	WatchHi[Note 2]
4	Context[Note 2]	20	XContext[Note 2]
5	PageMask[Note 1]	21	RFU
6	Wired[Note 1]	22	RFU
7	RFU	23	RFU
8	BadVAddr[Note 1]	24	RFU
9	Count[Note 2]	25	RFU
10	EntryHi[Note 1]	26	PErr[Note 2]
11	Compare[Note 2]	27	CacheErr[Note 2]
12	Status[Note 2]	28	TagLo[Note 1]
13	Cause[Note 2]	29	TagHi[Note 1]
14	EPC[Note 2]	30	ErrorEPC[Note 2]
15	PRId[Note 1]	31	RFU

Notes 1. for Memory management
2. for Exception handling

Remark RFU: Reserved for future use

Table 2-1. System Control Coprocessor (CP0) Register Definitions

Register Number	Register Name	Description
0	Index	Programmable pointer to TLB array
1	Random	Pseudo-random pointer to TLB array (read only)
2	EntryLo0	Low half of TLB entry for even VPN
3	EntryLo1	Low half of TLB entry for odd VPN
4	Context	Pointer to kernel virtual PTE in 32-bit mode
5	PageMask	TLB page mask
6	Wired	Number of wired TLB entries
7	—	Reserved for future use
8	BadVAddr	Virtual address where the most recent error occurred
9	Count	Timer count
10	EntryHi	High half of TLB entry (including ASID)
11	Compare	Timer compare
12	Status	Status register
13	Cause	Cause of last exception
14	EPC	Exception Program Counter
15	PRId	Processor revision identifier
16	Config	Configuration register (specifying memory mode system)
17	LLAddr	Reserved for future use
18	WatchLo	Memory reference trap address low bits
19	WatchHi	Memory reference trap address high bits
20	XContext	Pointer to kernel virtual PTE in 64-bit mode
21 to 25	—	Reserved for future use
26	PErr Note	Cache parity bits
27	CacheErr Note	Index and status of cache error
28	TagLo	Cache Tag register (low)
29	TagHi	Cache Tag register (high)
30	ErrorEPC	Error Exception Program Counter
31	—	Reserved for future use

Note This register is defined to maintain compatibility with the VR4100™. This register is not used in the LAKI hardware.

2.1.6 Floating-point unit (FPU)

The VR4120A does not support the floating-point unit (FPU). Coprocessor Unusable exception will occur if any FPU instructions are executed. If necessary, FPU instructions should be emulated by software in an exception handler.

2.1.7 CPU core memory management system (MMU)

The VR4120A has a 32-bit physical addressing range of 4 Gbytes. However, since it is rare for systems to implement a physical memory space as large as that memory space, the CPU provides a logical expansion of memory space by translating addresses composed in the large virtual address space into available physical memory addresses. The VR4120A supports the following two addressing modes:

- 32-bit mode, in which the virtual address space is divided into 2 Gbytes for user process and 2 Gbytes for the kernel.
- 64-bit mode, in which the virtual address is expanded to1 Tbyte (2^{40} bytes) of user virtual address space.

A detailed description of these address spaces is given in **Section 2.5 Memory Management System**.

2.1.8 Translation lookaside buffer (TLB)

Virtual memory mapping is performed using the translation lookaside buffer (TLB). The TLB converts virtual addresses to physical addresses. It runs by a full-associative method. It has 32 entries, each mapping a pair of pages having a variable size (1 KB to 256 KB).

2.1.8.1 Joint TLB (JTLB)

JTLB holds both an instruction address and data address.

For fast virtual-to-physical address decoding, the VR4120A uses a large, fully associative TLB (joint TLB) that translates 64 virtual pages to their corresponding physical addresses. The TLB is organized as 32 pairs of even-odd entries, and maps a virtual address and address space identifier (ASID) into the 4-Gbyte physical address space.

The page size can be configured, on a per-entry basis, to map a page size of 1 KB to 256 KB. A CP0 register stores the size of the page to be mapped, and that size is entered into the TLB when a new entry is written. Thus, operating systems can provide special purpose maps; for example, a typical frame buffer can be memory-mapped using only one TLB entry.

Translating a virtual address to a physical address begins by comparing the virtual address from the processor with the physical addresses in the TLB; there is a match when the virtual page number (VPN) of the address is the same as the VPN field of the entry, and either the Global (G) bit of the TLB entry is set, or the ASID field of the virtual address is the same as the ASID field of the TLB entry.

This match is referred to as a TLB hit. If there is no match, a TLB Miss exception is taken by the processor and software is allowed to refill the TLB from a page table of virtual/physical addresses in memory.

2.1.9 Operating modes

The VR4120A has three operating modes:

- ✧ User mode
- ✧ Supervisor mode
- ✧ Kernel mode

The manner in which memory addresses are translated or mapped depends on these operating modes. Refer to **Section 2.4 Memory Management System** for details.

2.1.10 Cache

The VR4120A chip incorporates instruction and data caches, which are independent of each other. This configuration enables high-performance pipeline operations. Both caches have a 64-bit data bus, enabling a one-clock access. These buses can be accessed in parallel. The instruction cache of the VR4120A has a storage capacity of 16 KB, while the data cache has a capacity of 8 KB.

A detailed description of caches is given in **Section 2.8 Cache Memory**.

2.1.11 Instruction Pipeline

The VR4120A has a 6-stage instruction pipeline. Under normal circumstances, one instruction is issued each cycle.

A detailed description of pipeline is provided in **Section 2.4 Pipeline**.

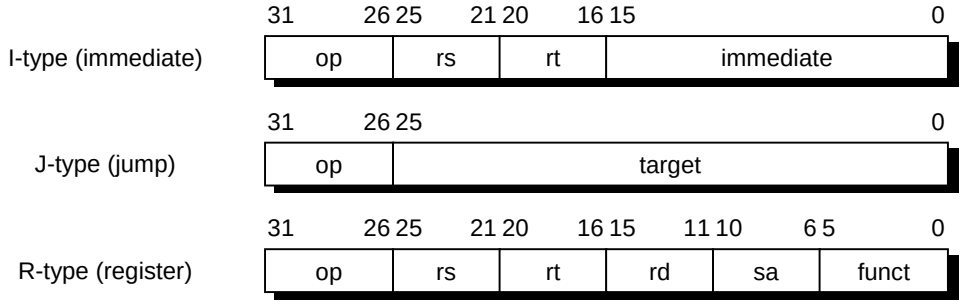
2.2 MIPS III Instruction Set Summary

This section is an overview of the MIPS III ISA central processing unit (CPU) instruction set; refer to **APPENDIX A MIPS III INSTRUCTION SET DETAILS** for detailed descriptions of individual CPU instructions.

2.2.1 MIPS III ISA instruction formats

Each MIPS III ISA CPU instruction consists of a single 32-bit word, aligned on a word boundary. There are three instruction formats - immediate (I-type), jump (J-type), and register (R-type) - as shown in Figure 2-9. The use of a small number of instruction formats simplifies instruction decoding, allowing the compiler to synthesize more complicated and less frequently used instruction and addressing modes from these three formats as needed.

Figure 2-9. MIPS III ISA CPU Instruction Formats



op:	6-bit operation code
rs:	5-bit source register specifier
rt:	5-bit target (source/destination) register specifier or branch condition
immediate:	16-bit immediate value, branch displacement, or address displacement
target:	26-bit unconditional branch target address
rd:	5-bit destination register specifier
sa:	5-bit shift amount
funct:	6-bit function field

2.2.1.1 Support of the MIPS ISA

The VR4120A CORE does not support a multiprocessor operating environment. Thus the synchronization support instructions defined in the MIPS II and MIPS III ISA - the load linked and store conditional instructions - cause reserved instruction exception. The load/link (LL) bit is eliminated.

Caution That the SYNC instruction is handled as a NOP instruction since all load/store instructions in this processor are executed in program order.

2.2.2 Instruction classes

The CPU instructions are classified into five classes.

2.2.2.1 Load and store instructions

Load and store are immediate (I-type) instructions that move data between memory and general registers. The only addressing mode that load and store instructions directly support is base register plus 16-bit signed immediate offset.

(1) Scheduling a load delay slot

A load instruction that does not allow its result to be used by the instruction immediately following is called a delayed load instruction. The instruction slot immediately following this delayed load instruction is referred to as the load delay slot.

In the VR4000 Series, a load instruction can be followed directly by an instruction that accesses a register that is loaded by the load instruction. In this case, however, an interlock occurs for a necessary number of cycles. Any instruction can follow a load instruction, but the load delay slot should be scheduled appropriately for both performance and compatibility with the VR Series™ microprocessors. For detail, see **Section 2.4 Pipeline**.

(2) Store delay slot

When a store instruction is writing data to a cache, the data cache is kept busy at the DC and WB stages. If an instruction (such as load) that follows directly the store instruction accesses the data cache in the DC stage, a hardware-driven interlock occurs. To overcome this problem, the store delay slot should be scheduled.

Table 2-2. Number of Delay Slot Cycles Necessary for Load and Store Instructions

Instruction	Necessary Number of PCycles
Load	1
Store	1

(3) Defining access types

Access type indicates the size of a VR4120A data item to be loaded or stored, set by the load or store instruction opcode. Access types and accessed byte are shown in Table 2-3.

Regardless of access type or byte ordering (endianness), the address given specifies the low-order byte in the addressed field. For a little-endian configuration, the low-order byte is the least-significant byte.

The access type, together with the low-order three bits of the address, define the bytes accessed within the addressed doubleword (shown in Table 2-3). Only the combinations shown in Table 2-3 are permissible; other combinations cause address error exceptions.

Tables 2-4 and 2-5 list the ISA-defined load/store instructions and extended-ISA instructions, respectively.

Table 2-3. Byte Specification Related to Load and Store Instructions

Access Type (Value)	Low-Order Address Bit			Accessed Byte							
				Little Endian							
	2	1	0	63							0
Doubleword (7)	0	0	0	7	6	5	4	3	2	1	0
7-byte (6)	0	0	0		6	5	4	3	2	1	0
	0	0	1	7	6	5	4	3	2	1	
6-byte (5)	0	0	0			5	4	3	2	1	0
	0	1	0	7	6	5	4	3	2		
5-byte (4)	0	0	0				4	3	2	1	0
	0	1	1	7	6	5	4	3			
Word (3)	0	0	0					3	2	1	0
	1	0	0	7	6	5	4				
Triple byte (2)	0	0	0						2	1	0
	0	0	1					3	2	1	
	1	0	0		6	5	4				
	1	0	1	7	6	5					
Halfword (1)	0	0	0							1	0
	0	1	0					3	2		
	1	0	0			5	4				
	1	1	0	7	6						
Byte (0)	0	0	0								0
	0	0	1							1	
	0	1	0						2		
	0	1	1					3			
	1	0	0				4				
	1	0	1			5					
	1	1	0		6						
	1	1	1	7							

Table 2-4. Load/Store Instruction

Instruction	Format and Description	op	base	rt	offset
Load Byte	LB rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. The bytes of the memory location specified by the address are sign extended and loaded into register rt.				
Load Byte Unsigned	LBU rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. The bytes of the memory location specified by the address are zero extended and loaded into register rt.				
Load Halfword	LH rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. The halfword of the memory location specified by the address is sign extended and loaded to register rt.				
Load Halfword Unsigned	LHU rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. The halfword of the memory location specified by the address is zero extended and loaded to register rt.				
Load Word	LW rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. The word of the memory location specified by the address is sign extended and loaded to register rt. In the 64-bit mode, it is further sign extended to 64 bits.				
Load Word Left	LWL rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. Shifts to the left the word whose address is specified so that the address-specified byte is at the left-most position of the word. The result of the shift operation is merged with the contents of register rt and loaded to register rt. In the 64-bit mode, it is further sign extended to 64 bits.				
Load Word Right	LWR rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. Shifts to the right the word whose address is specified so that the address-specified byte is at the right-most position of the word. The result of the shift operation is merged with the contents of register rt and loaded to register rt. In the 64-bit mode, it is further sign extended to 64 bits.				
Store Byte	SB rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. The least significant byte of register rt is stored to the memory location specified by the address.				
Store Halfword	SH rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. The least significant halfword of register rt is stored to the memory location specified by the address.				
Store Word	SW rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. The lower word of register rt is stored to the memory location specified by the address.				

Table 2-5. Load/Store Instruction (Extended ISA)

Instruction	Format and Description	op	base	rt	offset
Store Word Left	SWL rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. Shifts to the right the contents of register rt so that the left-most byte of the word is in the position of the address-specified byte. The result is stored to the lower word in memory.				
Store Word Right	SWR rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. Shifts to the left the contents of register rt so that the right-most byte of the word is in the position of the address-specified byte. The result is stored to the upper word in memory.				
Load Doubleword	LD rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. The doubleword of the memory location specified by the address are loaded into register rt.				
Load Doubleword Left	LDL rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. Shifts to the left the double word whose address is specified so that the address-specified byte is at the left-most position of the double word. The result of the shift operation is merged with the contents of register rt and loaded to register rt.				
Load Doubleword Right	LDR rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. Shifts to the right the double word whose address is specified so that the address-specified byte is at the right-most position of the double word. The result of the shift operation is merged with the contents of register rt and loaded to register rt.				
Load Word Unsigned	LWU rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. The word of the memory location specified by the address are zero extended and loaded into register rt.				
Store Doubleword	SD rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. The contents of register rt are stored to the memory location specified by the address.				
Store Doubleword Left	SDL rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. Shifts to the right the contents of register rt so that the left-most byte of the double word is in the position of the address-specified byte. The result is stored to the lower doubleword in memory.				
Store Doubleword Right	SDR rt, offset (base) The offset is sign extended and then added to the contents of the register base to form the virtual address. Shifts to the left the contents of register rt so that the right-most byte of the double word is in the position of the address-specified byte. The result is stored to the upper doubleword in memory.				

2.2.2.2 Computational instructions

Computational instructions perform arithmetic, logical, and shift operations on values in registers. Computational instructions can be either in register (R-type) format, in which both operands are registers, or in immediate (I-type) format, in which one operand is a 16-bit immediate.

Computational instructions are classified as:

(1) ALU immediate instructions

(2) Three-operand type instructions

(3) Shift instructions

(4) Multiply/divide instructions

To maintain data compatibility between the 64- and 32-bit modes, it is necessary to sign-extend 32-bit operands correctly. If the sign extension is not correct, the 32-bit operation result is meaningless.

Table 2-6. ALU Immediate Instruction

Instruction	Format and Description: op | rs | rt | immediate
Add Immediate	ADDI rt, rs, immediate The 16-bit immediate is sign extended and then added to the contents of register rs to form a 32-bit result. The result is stored into register rt. In the 64-bit mode, the operand must be sign extended. An exception occurs on the generation of 2's complement overflow.
Add Immediate Unsigned	ADDIU rt, rs, immediate The 16-bit immediate is sign extended and then added to the contents of register rs to form a 32-bit result. The result is stored into register rt. In the 64-bit mode, the operand must be sign extended. No exception occurs on the generation of integer overflow.
Set On Less Than Immediate	SLTI rt, rs, immediate The 16-bit immediate is sign extended and then compared to the contents of register rt treating both operands as signed integers. If rs is less than the immediate, the result is set to 1; otherwise, the result is set to 0. The result is stored to register rt.
Set On Less Than Immediate Unsigned	SLTIU rt, rs, immediate The 16-bit immediate is sign extended and then compared to the contents of register rt treating both operands as unsigned integers. If rs is less than the immediate, the result is set to 1; otherwise, the result is set to 0. The result is stored to register rt.
And Immediate	ANDI rt, rs, immediate The 16-bit immediate is zero extended and then ANDed with the contents of the register. The result is stored into register rt.
Or Immediate	ORI rt, rs, immediate The 16-bit immediate is zero extended and then ORed with the contents of the register. The result is stored into register rt.
Exclusive Or Immediate	XORI rt, rs, immediate The 16-bit immediate is zero extended and then Ex-ORed with the contents of the register. The result is stored into register rt.
Load Upper Immediate	LUI rt, immediate The 16-bit immediate is shifted left by 16 bits to set the lower 16 bits of word to 0. The result is stored into register rt. In the 64-bit mode, the operand must be sign extended.

Table 2-7. ALU Immediate Instruction (Extended ISA)

Instruction	Format and Description: op | rs | rt | immediate
Doubleword Add Immediate	DADDI rt, rs, immediate The 16-bit immediate is sign extended to 64 bits and then added to the contents of register rs to form a 64-bit result. The result is stored into register rt. An exception occurs on the generation of integer overflow.
Doubleword Add Immediate Unsigned	DADDIU rt, rs, immediate The 16-bit immediate is sign extended to 64 bits and then added to the contents of register rs to form a 64-bit result. The result is stored into register rt. No exception occurs on the generation of overflow.

Table 2-8. Three-Operand Type Instruction

Instruction	Format and Description: op | rs | rt | rd | sa | funct
Add	ADD rd, rs, rt The contents of registers rs and rt are added together to form a 32-bit result. The result is stored into register rd. In the 64-bit mode, the operand must be sign extended. An exception occurs on the generation of integer overflow.
Add Unsigned	ADDU rd, rs, rt The contents of registers rs and rt are added together to form a 32-bit result. The result is stored into register rd. In the 64-bit mode, the operand must be sign extended. No exception occurs on the generation of integer overflow.
Subtract	SUB rd, rs, rt The contents of register rt are subtracted from the contents of register rs. The 32-bit result is stored into register rd. In the 64-bit mode, the operand must be sign extended. An exception occurs on the generation of integer overflow.
Subtract Unsigned	SUBU rd, rs, rt The contents of register rt are subtracted from the contents of register rs. The 32-bit result is stored into register rd. In the 64-bit mode, the operand must be sign extended. No exception occurs on the generation of integer overflow.
Set On Less Than	SLT rd, rs, rt The contents of registers rs and rt are compared, treating both operands as signed integers. If the contents of register rs is less than that of register rt, the result is set to 1; otherwise, the result is set to 0. The result is stored to register rd.
Set On Less Than Unsigned	SLTU rd, rs, rt The contents of registers rs and rt are compared treating both operands as unsigned integers. If the contents of register rs is less than that of register rt, the result is set to 1; otherwise, the result is set to 0. The result is stored to register rd.
And	AND rd, rt, rs The contents of register rs are logical ANDed with that of general register rt bit-wise. The result is stored to register rd.
Or	OR rd, rt, rs The contents of register rs are logical ORed with that of general register rt bit-wise. The result is stored to register rd.
Exclusive Or	XOR rd, rt, rs The contents of register rs are logical Ex-ORed with that of general register rt bit-wise. The result is stored to register rd.
Nor	NOR rd, rt, rs The contents of register rs are logical NORed with that of general register rt bit-wise. The result is stored to register rd.

Table 2-9. Three-Operand Type Instruction (Extended ISA)

Instruction	Format and Description: op | rs | rt | rd | sa | funct
Doubleword Add	DADD rd, rt, rs The contents of register rs are added to that of register rt. The 64-bit result is stored into register rd. An exception occurs on the generation of integer overflow.
Doubleword Add Unsigned	DADDU rd, rt, rs The contents of register rs are added to that of register rt. The 64-bit result is stored into register rd. No exception occurs on the generation of integer overflow.
Doubleword Subtract	DSUB rd, rt, rs The contents of register rt are subtracted from that of register rs. The 64-bit result is stored into register rd. An exception occurs on the generation of integer overflow.
Doubleword Subtract Unsigned	DSUBU rd, rt, rs The contents of register rt are subtracted from that of register rs. The 64-bit result is stored into register rd. No exception occurs on the generation of integer overflow.

Table 2-10. Shift Instruction

Instruction	Format and Description: op | rs | rt | rd | sa | funct
Shift Left Logical	SLL rd, rs, sa The contents of register rt are shifted left by sa bits and zeros are inserted into the emptied lower bits. The 32-bit result is stored into register rd. In the 64-bit mode, the operand must be sign extended.
Shift Right Logical	SRL rd, rs, sa The contents of register rt are shifted right by sa bits and zeros are inserted into the emptied higher bits. The 32-bit result is stored into register rd. In the 64-bit mode, the operand must be sign extended.
Shift Right Arithmetic	SRA rd, rt, sa The contents of register rt are shifted right by sa bits and the emptied higher bits are sign extended. The 32-bit result is stored into register rd. In the 64-bit mode, the operand must be sign extended.
Shift Left Logical Variable	SLLV rd, rt, rs The contents of register rt are shifted left and zeros are inserted into the emptied lower bits. The lower five bits of register rs specify the shift count. The 32-bit result is stored into register rd. In the 64-bit mode, the operand must be sign extended.
Shift Right Logical Variable	SRLV rd, rt, rs The contents of register rt are shifted right and zeros are inserted into the emptied higher bits. The lower five bits of register rs specify the shift count. The 32-bit result is stored into register rd. In the 64-bit mode, the operand must be sign extended.
Shift Right Arithmetic Variable	SRAV rd, rt, rs The contents of register rt are shifted right and the emptied higher bits are sign extended. The lower five bits of register rs specify the shift count. The 32-bit result is stored into register rd. In the 64-bit mode, the operand must be sign extended.

Table 2-11. Shift Instruction (Extended ISA)

Instruction	Format and Description	op	rs	rt	rd	sa	funct
Doubleword Shift Left Logical	DSLL rd, rt, sa The contents of register rt are shifted left by sa bits and zeros are inserted into the emptied lower bits. The 64-bit result is stored into register rd.						
Doubleword Shift Right Logical	DSRL rd, rt, sa The contents of register rt are shifted right by sa bits and zeros are inserted into the emptied higher bits. The 64-bit result is stored into register rd.						
Doubleword Shift Right Arithmetic	DSRA rd, rt, sa The contents of register rt are shifted right by sa bits and the emptied higher bits are sign extended. The 64-bit result is stored into register rd.						
Doubleword Shift Left Logical Variable	DSLLV rd, rt, rs The contents of register rt are shifted left and zeros are inserted into the emptied lower bits. The lower six bits of register rs specify the shift count. The 64-bit result is stored into register rd.						
Doubleword Shift Right Logical Variable	DSRLV rd, rt, rs The contents of register rt are shifted right and zeros are inserted into the emptied higher bits. The lower six bits of register rs specify the shift count. The 64-bit result is stored into register rd.						
Doubleword Shift Right Arithmetic Variable	DSRAV rd, rt, rs The contents of register rt are shifted right and the emptied higher bits are sign extended. The lower six bits of register rs specify the shift count. The 64-bit result is stored into register rd.						
Doubleword Shift Left Logical + 32	DSLL32 rd, rt, sa The contents of register rt are shifted left by 32 + sa bits and zeros are inserted into the emptied lower bits. The 64-bit result is stored into register rd.						
Doubleword Shift Right Logical + 32	DSRL32 rd, rt, sa The contents of register rt are shifted right by 32 + sa bits and zeros are inserted into the emptied higher bits. The 64-bit result is stored into register rd.						
Doubleword Shift Right Arithmetic + 32	DSRA32 rd, rt, sa The contents of register rt are shifted right by 32 + sa bits and the emptied higher bits are sign extended. The 64-bit result is stored into register rd.						

Table 2-12. Multiply/Divide Instructions

Instruction	Format and Description	op	rs	rt	rd	sa	funct
Multiply	MULT rs, rt The contents of registers rt and rs are multiplied, treating both operands as 32-bit signed integers. The 64-bit result is stored into special registers HI and LO. In the 64-bit mode, the operand must be sign extended.						
Multiply Unsigned	MULTU rs, rt The contents of registers rt and rs are multiplied, treating both operands as 32-bit unsigned integers. The 64-bit result is stored into special registers HI and LO. In the 64-bit mode, the operand must be sign extended.						
Divide	DIV rs, rt The contents of register rs are divided by that of register rt, treating both operands as 32-bit signed integers. The 32-bit quotient is stored into special register LO, and the 32-bit remainder is stored into special register HI. In the 64-bit mode, the operand must be sign extended.						
Divide Unsigned	DIVU rs, rt The contents of register rs are divided by that of register rt, treating both operands as 32-bit unsigned integers. The 32-bit quotient is stored into special register LO, and the 32-bit remainder is stored into special register HI. In the 64-bit mode, the operand must be sign extended.						
Move From HI	MFHI rd The contents of special register HI are loaded into register rd.						
Move From LO	MFLO rd The contents of special register LO are loaded into register rd.						
Move To HI	MTHI rs The contents of register rs are loaded into special register HI.						
Move To LO	MTLO rs The contents of register rs are loaded into special register LO.						

Table 2-13. Multiply/Divide Instructions (Extended ISA)

Instruction	Format and Description	op	rs	rt	rd	sa	funct
Doubleword Multiply	DMULT rs, rt The contents of registers rt and rs are multiplied, treating both operands as signed integers. The 128-bit result is stored into special registers HI and LO.						
Doubleword Multiply Unsigned	DMULTU rs, rt The contents of registers rt and rs are multiplied, treating both operands as unsigned integers. The 128-bit result is stored into special registers HI and LO.						
Doubleword Divide	DDIV rs, rt The contents of register rs are divided by that of register rt, treating both operands as signed integers. The 64-bit quotient is stored into special register LO, and the 64-bit remainder is stored into special register HI.						
Doubleword Divide Unsigned	DDIVU rs, rt The contents of register rs are divided by that of register rt, treating both operands as unsigned integers. The 64-bit quotient is stored into special register LO, and the 64-bit remainder is stored into special register HI.						
Multiply and Add Accumulate	MACC{h}{u}{s} rd, rs, rt The contents of registers rt and rs are multiplied, treating both operands as 32-bit signed integers. The result is added to the combined value of special registers HI and LO. The 64-bit result is stored into special registers HI and LO. If h=0, the same data as that stored in register LO is also stored in register rd; if h=1, the same data as that stored in register HI is also stored in register rd. If u is specified, the operand is treated as unsigned data. If s is specified, registers rs and rd are treated as a 16-bit value (32 bits sign- or zero-extended), and the value obtained by combining registers HI and LO is treated as a 32-bit value (64 bits sign- or zero-extended). Moreover, saturation processing is performed for the operation result in the format specified with u.						
Doubleword Multiply and Add Accumulate	DMACC{h}{u}{s} rd, rs, rt The contents of registers rt and rs are multiplied, treating both operands as 32-bit signed integers. The result is added to value of special register LO. The 64-bit result is stored into special register LO. If h=0, the same data as that stored in register LO is also stored in register rd; if h=1, undefined data is stored in register rd. If u is specified, the operand is treated as unsigned data. If s is specified, registers rs and rd are treated as a 16-bit value (32 bits sign- or zero-extended), and register LO is treated as a 32-bit value (64 bits sign- or zero-extended). Moreover, saturation processing is performed for the operation result in the format specified with u.						

MFHI and MFLO instructions after a multiply or divide instruction generate interlocks to delay execution of the next instruction, inhibiting the result from being read until the multiply or divide instruction completes.

Table 2-14 gives the number of processor cycles (PCycles) required to resolve interlock or stall between various multiply or divide instructions and a subsequent MFHI or MFLO instruction.

Table 2-14. Number of Stall Cycles in Multiply and Divide Instructions

Instruction	Number of Instruction Cycles
MULT	1
MULTU	1
DIV	36
DIVU	36
DMULT	3
DMULTU	3
DDIV	68
DDIVU	68
MACC	0
DMACC	0

2.2.2.3 Jump and branch instructions

Jump and branch instructions change the control flow of a program. All jump and branch instructions occur with a delay of one instruction: that is, the instruction immediately following the jump or branch instruction (this is known as the instruction in the delay slot) always executes while the target instruction is being fetched from memory.

For instructions involving a link (such as JAL and BLTZAL), the return address is saved in register r31.

Table 2-15. Number of Delay Slot Cycles in Jump and Branch Instructions

Instruction	Necessary Number of Cycles
Branch instruction	1
Jump instruction	1

(1) Overview of jump instructions

Subroutine calls in high-level languages are usually implemented with J or JAL instructions, both of which are J-type instructions. In J-type format, the 26-bit target address shifts left 2 bits and combines with the high-order 4 bits of the current program counter to form a 32-bit or 64-bit absolute address.

Returns, dispatches, and cross-page jumps are usually implemented with the JR or JALR instructions. Both are R-type instructions that take the 32-bit or 64-bit byte address contained in one of the general registers.

For more information, refer to **APPENDIX A MIPS III INSTRUCTION SET DETAILS**.

(2) Overview of branch instructions

A branch instruction has a PC-related signed 16-bit offset.

Tables 2-16 through 2-18 show the lists of Jump, Branch, and Expanded ISA instructions, respectively.

Table 2-16. Jump Instruction

Instruction	Format and Description	op	target
Jump	JAL target The contents of 26-bit target address is shifted left by two bits and combined with the high-order four bits of the PC. The program jumps to this calculated address with a delay of one instruction.		
Jump And Link	J target The contents of 26-bit target address is shifted left by two bits and combined with the high-order four bits of the PC. The program jumps to this calculated address with a delay of one instruction. The address of the instruction following the delay slot is stored into r31 (link register).		

Instruction	Format and Description	op	target
Jump And Link Exchange	JALX target The contents of 26-bit target address is shifted left by two bits and combined with the high-order four bits of the PC. The program jumps to this calculated address with a delay of one instruction, and then the ISA mode bit is reversed. The address of the instruction following the delay slot is stored into r31 (link register).		

Instruction	Format and Description	op	rs	rt	rd	sa	funct
Jump Register	JR rs The program jumps to the address specified in register rs with a delay of one instruction.						
Jump And Link Register	JALR rs, rd The program jumps to the address specified in register rs with a delay of one instruction. The address of the instruction following the delay slot is stored into rd.						

There are the following common restrictions for Tables 2-17 and 2-18.

(3) Branch address

All branch instruction target addresses are computed by adding the address of the instruction in the delay slot to the 16-bit offset (shifted left by 2 bits and sign-extended to 64 bits). All branches occur with a delay of one instruction.

(4) Operation when unbranched (Table 2-18)

If the branch condition does not meet in executing a likely instruction, the instruction in its delay slot is nullified. For all other branch instructions, the instruction in its delay slot is unconditionally executed.

Remark The target instruction of the branch is fetched at the EX stage of the branch instruction. Comparison of the operands of the branch instruction and calculation of the target address is performed at phase 2 of the RF stage and phase 1 of the EX stage of the instruction. Branch instructions require one cycle of the branch delay slot defined by the architecture. Jump instructions also require one cycle of delay slot. If the branch condition is not satisfied in a branch likely instruction, the instruction in its delay slot is nullified.

There are special symbols used in the instruction formats of Tables 2-17 through 2-21.

REGIMM	: Opcode
Sub	: Sub-operation code
CO	: Sub-operation identifier
BC	: BC sub-operation code
br	: Branch condition identifier
op	: Operation code

Table 2-17. Branch Instructions

Instruction	Format and Description: op | rs | rt | offset
Branch On Equal	BEQ rs, rt, offset If the contents of register rs are equal to that of register rt, the program branches to the target address.
Branch On Not Equal	BNE rs, rt, offset If the contents of register rs are not equal to that of register rt, the program branches to the target address.
Branch On Less Than Or Equal To Zero	BLEZ rs, offset If the contents of register rs are less than or equal to zero, the program branches to the target address.
Branch On Greater Than Zero	BGTZ rs, offset If the contents of register rs are greater than zero, the program branches to the target address.

Instruction	Format and Description: REGIMM | rs | sub | offset
Branch On Less Than Zero	BLTZ rs, offset If the contents of register rs are less than zero, the program branches to the target address.
Branch On Greater Than Or Equal To Zero	BGEZ rs, offset If the contents of register rs are greater than or equal to zero, the program branches to the target address.
Branch On Less Than Zero And Link	BLTZAL rs, offset The address of the instruction that follows delay slot is stored to register r31 (link register). If the contents of register rs are less than zero, the program branches to the target address.
Branch On Greater Than Or Equal To Zero And Link	BGEZAL rs, offset The address of the instruction that follows delay slot is stored to register r31 (link register). If the contents of register rs are greater than or equal to zero, the program branches to the target address.

Instruction	Format and Description: COP0 | BC | br | offset
Branch On Coprocessor 0 True	BC0T offset Adds the 16-bit offset (shifted left by two bits and sign extended to 32 bits) to the address of the instruction in the delay slot to calculate the branch target address. If the conditional signal of the coprocessor 0 is true, the program branches to the target address with one-instruction delay.
Branch On Coprocessor 0 False	BC0F offset Adds the 16-bit offset (shifted left by two bits and sign extended to 32 bits) to the address of the instruction in the delay slot to calculate the branch target address. If the conditional signal of the coprocessor 0 is false, the program branches to the target address with one-instruction delay.

Table 2-18. Branch Instructions (Extended ISA)

Instruction	Format and Description: op | rs | rt | offset
Branch On Equal Likely	BEQL rs, rt, offset If the contents of register rs are equal to that of register rt, the program branches to the target address. If the branch condition is not met, the instruction in the delay slot is discarded.
Branch On Not Equal Likely	BNEL rs, rt, offset If the contents of register rs are not equal to that of register rt, the program branches to the target address. If the branch condition is not met, the instruction in the delay slot is discarded.
Branch On Less Than Or Equal To Zero Likely	BLEZL rs, offset If the contents of register rs are less than or equal to zero, the program branches to the target address. If the branch condition is not met, the instruction in the delay slot is discarded.
Branch On Greater Than Zero Likely	BGTZL rs, offset If the contents of register rs are greater than zero, the program branches to the target address. If the branch condition is not met, the instruction in the delay slot is discarded.

Instruction	Format and Description: REGIMM | rs | sub | offset
Branch On Less Than Zero Likely	BLTZL rs, offset If the contents of register rs are less than zero, the program branches to the target address. If the branch condition is not met, the instruction in the delay slot is discarded.
Branch On Greater Than Or Equal To Zero Likely	BGEZL rs, offset If the contents of register rs are greater than or equal to zero, the program branches to the target address. If the branch condition is not met, the instruction in the delay slot is discarded.
Branch On Less Than Zero And Link Likely	BLTZALL rs, offset The address of the instruction that follows delay slot is stored to register r31 (link register). If the contents of register rs are less than zero, the program branches to the target address. If the branch condition is not met, the instruction in the delay slot is discarded.
Branch On Greater Than Or Equal To Zero And Link Likely	BGEZALL rs, offset The address of the instruction that follows delay slot is stored to register r31 (link register). If the contents of register rs are greater than or equal to zero, the program branches to the target address. If the branch condition is not met, the instruction in the delay slot is discarded.

Instruction	Format and Description: COP0 | BC | br | offset
Branch On Coprocessor 0 True Likely	BC0TL offset Adds the 16-bit offset (shifted left by two bits and sign extended to 32 bits) to the address of the instruction in the delay slot to calculate the branch target address. If the conditional signal of the coprocessor 0 is true, the program branches to the target address with one-instruction delay. If the branch condition is not met, the instruction in the delay slot is discarded.
Branch On Coprocessor 0 False Likely	BC0FL offset Adds the 16-bit offset (shifted left by two bits and sign extended to 32 bits) to the address of the instruction in the delay slot to calculate the branch target address. If the conditional signal of the coprocessor 0 is false, the program branches to the target address with one-instruction delay. If the branch condition is not met, the instruction in the delay slot is discarded.

2.2.2.4 Special instructions

Special instructions generate software exceptions. Their formats are R-type (Syscall, Break). The Trap instruction is available only for the VR4000 Series. All the other instructions are available for all VR Series.

Table 2-19. Special Instructions

Instruction	Format and Description: SPECIAL | rs | rt | rd | sa | funct
Synchronize	SYNC Completes the load/store instruction executing in the current pipeline before the next load/store instruction starts execution.
System Call	SYSCALL Generates a system call exception, and then transits control to the exception handling program.
Breakpoint	BREAK Generates a break point exception, and then transits control to the exception handling program.

Table 2-20. Special Instructions (Expanded ISA) (1/2)

Instruction	Format and Description: SPECIAL | rs | rt | rd | sa | funct
Trap If Greater Than Or Equal	TGE rs, rt The contents of register rs are compared with that of register rt, treating both operands as signed integers. If the contents of register rs are greater than or equal to that of register rt, an exception occurs.
Trap If Greater Than Or Equal Unsigned	TGEU rs, rt The contents of register rs are compared with that of register rt, treating both operands as unsigned integers. If the contents of register rs are greater than or equal to that of register rt, an exception occurs.
Trap If Less Than	TLT rs, rt The contents of register rs are compared with that of register rt, treating both operands as signed integers. If the contents of register rs are less than that of register rt, an exception occurs.
Trap If Less Than Unsigned	TLTU rs, rt The contents of register rs are compared with that of register rt, treating both operands as unsigned integers. If the contents of register rs are less than that of register rt, an exception occurs.
Trap If Equal	TEQ rs, rt If the contents of registers rs and rt are equal, an exception occurs.
Trap If Not Equal	TNE rs, rt If the contents of registers rs and rt are not equal, an exception occurs.

Table 2-20. Special Instructions (Expanded ISA) (2/2)

Instruction	Format and Description: REGIMM | rs | sub | immediate
Trap If Greater Than Or Equal Immediate	TGEI rs, immediate The contents of register rs are compared with 16-bit sign-extended immediate data, treating both operands as signed integers. If the contents of register rs are greater than or equal to 16-bit sign-extended immediate data, an exception occurs.
Trap If Greater Than Or Equal Immediate Unsigned	TGEIU rs, immediate The contents of register rs are compared with 16-bit zero-extended immediate data, treating both operands as unsigned integers. If the contents of register rs are greater than or equal to 16-bit sign-extended immediate data, an exception occurs.
Trap If Less Than Immediate	TLTI rs, immediate The contents of register rs are compared with 16-bit sign-extended immediate data, treating both operands as signed integers. If the contents of register rs are less than 16-bit sign-extended immediate data, an exception occurs.
Trap If Less Than Immediate Unsigned	TLTIU rs, immediate The contents of register rs are compared with 16-bit zero-extended immediate data, treating both operands as unsigned integers. If the contents of register rs are less than 16-bit sign-extended immediate data, an exception occurs.
Trap If Equal Immediate	TEQI rs, immediate If the contents of register rs and immediate data are equal, an exception occurs.
Trap If Not Equal Immediate	TNEI rs, immediate If the contents of register rs and immediate data are not equal, an exception occurs.

2.2.2.5 System control coprocessor (CP0) instructions

System control coprocessor (CP0) instructions perform operations specifically on the CP0 registers to manipulate the memory management and exception handling facilities of the processor.

Table 2-21. System Control Coprocessor (CP0) Instructions (1/2)

Instruction	Format and Description: COP0 | sub | rt | rd | 0
Move To System Control Coprocessor	MTC0 rt, rd The word data of general register rt in the CPU are loaded into general register rd in the CP0.
Move From System Control Coprocessor	MFC0 rt, rd The word data of general register rd in the CP0 are loaded into general register rt in the CPU.
Doubleword Move To System Control Coprocessor 0	DMTC0 rt, rd The doubleword data of general register rt in the CPU are loaded into general register rd in the CP0.
Doubleword Move From System Control Coprocessor 0	DMFC0 rt, rd The doubleword data of general register rd in the CP0 are loaded into general register rt in the CPU.

Table 2-21. System Control Coprocessor (CP0) Instructions (2/2)

Instruction	Format and Description	COP0	CO	funct
Read Indexed TLB Entry	TLBR The TLB entry indexed by the index register is loaded into the entryHi, entryLo0, entryLo1, or page mask register.			
Write Indexed TLB Entry	TLBWI The contents of the entryHi, entryLo0, entryLo1, or page mask register are loaded into the TLB entry indexed by the index register.			
Write Random TLB Entry	TLBWR The contents of the entryHi, entryLo0, entryLo1, or page mask register are loaded into the TLB entry indexed by the random register.			
Probe TLB For Matching Entry	TLBP The address of the TLB entry that matches with the contents of entryHi register is loaded into the index register.			
Return From Exception	ERET The program returns from exception, interrupt, or error trap.			

Instruction	Format and Description	COP0	CO	funct
STANDBY	STANDBY The processor's operating mode is transited from fullspeed mode to standby mode.			
SUSPEND	SUSPEND The processor's operating mode is transited from fullspeed mode to suspend mode.			
HIBERNATE	HIBERNATE The processor's operating mode is transited from fullspeed mode to hibernate mode.			

Instruction	Format and Description	CACHE	base	op	offset
Cache Operation	Cache op, offset (base) The 16-bit offset is sign extended to 32 bits and added to the contents of the register case, to form virtual address. This virtual address is translated to physical address with TLB. For this physical address, cache operation that is indicated by 5-bit sub-opcode is performed.				

2.3 Pipeline

This section describes the basic operation of the VR4120A Core pipeline, which includes descriptions of the delay slots (instructions that follow a branch or load instruction in the pipeline), interrupts to the pipeline flow caused by interlocks and exceptions, and CP0 hazards.

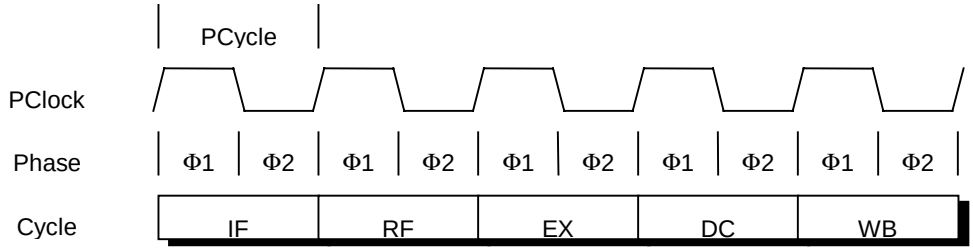
2.3.1 Pipeline stages

The pipeline is controlled by ACLK (one cycle of ACLK which runs at 8-times frequency of MasterClock) and one cycle of this ACLK is called PCycle. Each pipeline stage takes one PCycle.

2.3.1.1 Pipeline in MIPS III instruction mode

The VR4120A has a five-stage instruction pipeline; each stage takes one PCycle, and each PCycle has two phases: Φ1 and Φ2, as shown in Figure 2-10. Thus, the execution of each instruction takes at least 5 PCycles. An instruction can take longer - for example, if the required data is not in the cache, the data must be retrieved from main memory.

Figure 2-10. Pipeline Stages (MIPS III Instruction Mode)

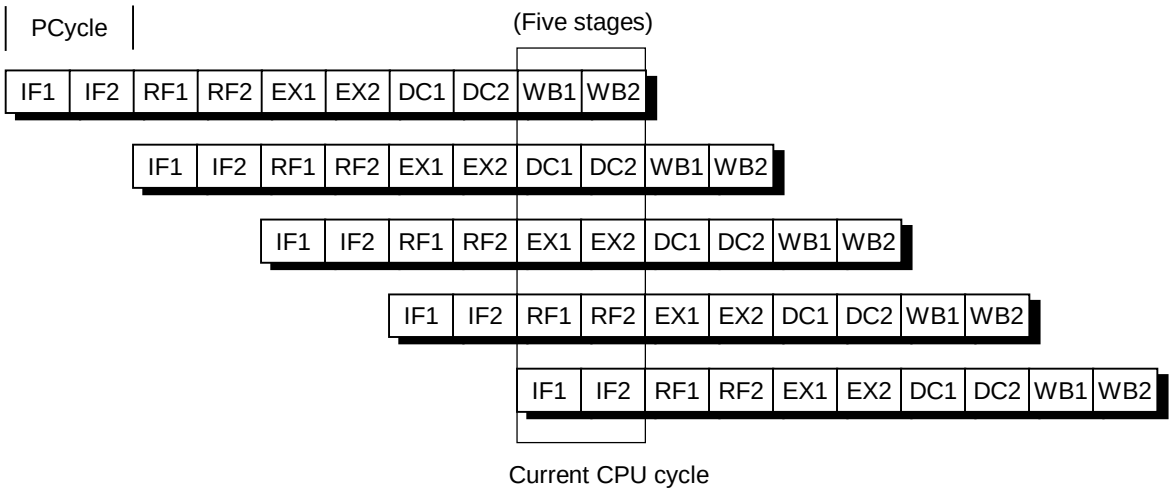


The five pipeline stages are:

- ✧ IF - Instruction cache fetch
- ✧ RF - Register fetch
- ✧ EX - Execution
- ✧ DC - Data cache fetch
- ✧ WB - Write back

Figure 2-11 shows the five stages of the instruction pipeline. In this figure, a row indicates the execution process of each instruction, and a column indicates the processes executed simultaneously.

Figure 2-11. Instruction Execution in the Pipeline



2.3.1.2 Pipeline in MIPS16 (16-bit length) instruction mode

The VR4120A, which has internal stages for converting MIPS16 instructions into 32-bit instructions, uses a 6-stagepipeline in the MIPS16 mode. As a result, the execution of each instruction requires at least 6 PCycles. Anyhow, this mode is not available in LAKI.

2.3.1.3 Pipeline activities

MIPS III instruction

Figure 2-14 shows the activities that can occur during each pipeline stage in MIPS III Instruction mode. Table 2-42 describes these pipeline activities.

Figure 2-14. Pipeline Activities (MIPS III)

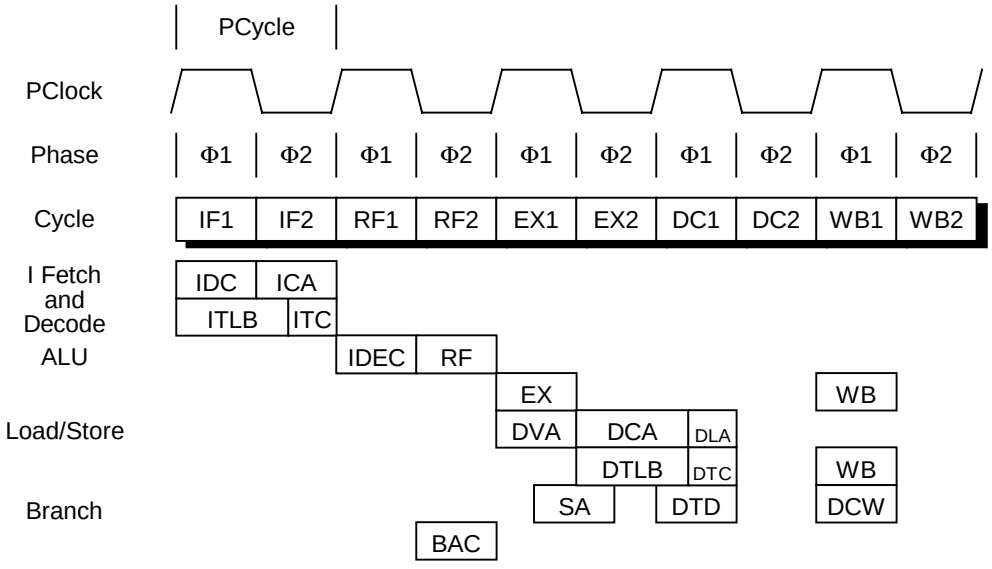


Table 2-42. Operation in Each Stage of Pipeline (MIPS III)

Cycle	Phase	Mnemonic	Description
IF	Φ1	IDC	Instruction cache address decode
		ITLB	Instruction address translation
	Φ2	ICA	Instruction cache array access
		ITC	Instruction tag check
RF	Φ1	IDEC	Instruction decode
	Φ2	RF	Register operand fetch
		BAC	Branch address calculation
EX	Φ1	EX	Execution stage
		DVA	Data virtual address calculation
		SA	Store align
	Φ2	DCA	Data cache address decode/array access
		DTLB	Data address translation
DC	Φ1	DLA	Data cache load align
		DTC	Data tag check
		DTD	Data transfer to data cache
WB	Φ1	DCW	Data cache write
		WB	Write back to register file

2.3.2 Branch delay

During a VR4120A's pipeline operation, a one-cycle branch delay occurs when:

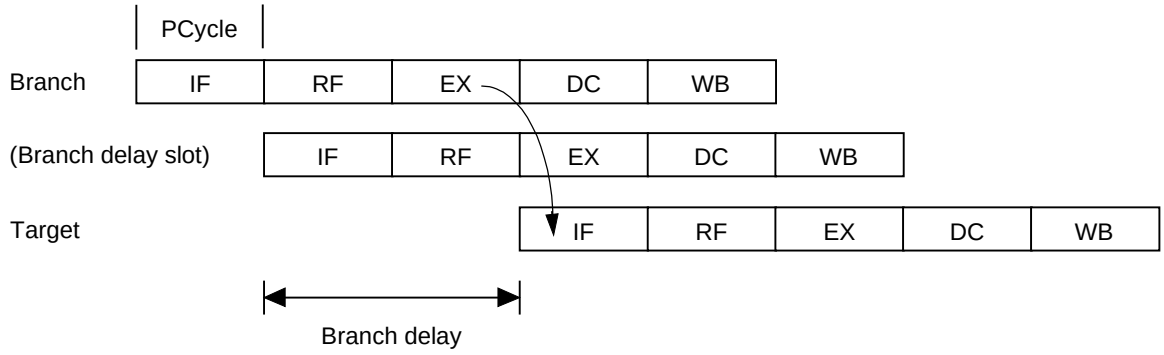
- Target address is calculated by a Jump instruction
- Branch condition of branch instruction is met and then logical operation starts for branch-destination comparison

The instruction location following the Jump/Branch instruction is called a branch delay slot.

The instruction address generated at the EX stage in the Jump/Branch instruction are available in the IF stage, two instructions later. In MIPS III instruction mode, branch delay is two cycles. One instruction in the branch delay slot is executed, except for likely instruction.

Figure 2-16 illustrates the branch delay and the location of the branch delay slot during MIPS III instruction mode.

Figure 2-16. Branch Delay (In MIPS III Instruction Mode)



2.3.3 Load delay

In the case of a load instruction, 2 cycles are required for the DC stage, for reading from the data cache and performing data alignment. In this case, the hardware automatically generates on interlock.

A load instruction that does not allow its result to be used by the instruction immediately following is called a delayed load instruction. The instruction immediately following this delayed load instruction is referred to as the load delay slot.

In the VR4120A, the instruction immediately following a load instruction can use the contents of the loaded register, however in such cases hardware interlocks insert additional delay cycles. Consequently, scheduling load delay slots can be desirable, both for performance and VR-Series processor compatibility.

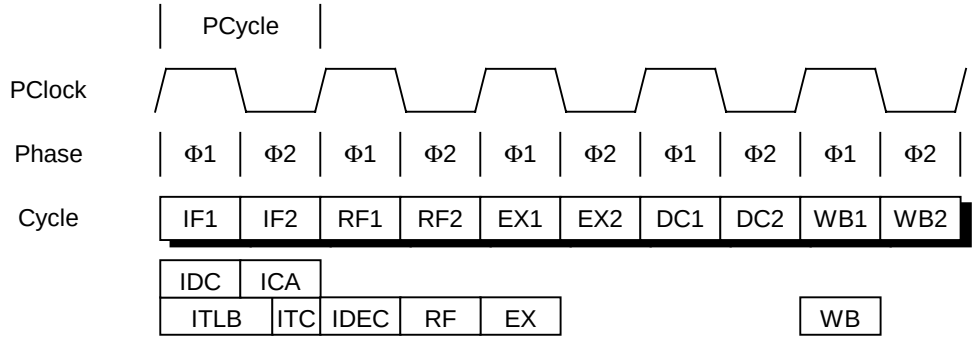
2.3.4 Pipeline operation

The operation of the pipeline is illustrated by the following examples that describe how typical instructions are executed. The instructions described are six: ADD, JALR, BEQ, TLT, LW, and SW. Each instruction is taken through the pipeline and the operations that occur in each relevant stage are described.

2.3.4.1 Add instruction (ADD rd, rs, rt)

IF stage	In Φ1 of the IF stage, the eleven least-significant bits of the virtual access are used to access the instruction cache. In Φ2 of the IF stage, the cache index is compared with the page frame number and the cache data is read out. The virtual PC is incremented by 4 so that the next instruction can be fetched.
IT stage	The MIPS16 instruction is translated into a 32-bit length instruction (during MIPS16 instruction mode only).
RF stage	During Φ2, the 2-port register file is addressed with the rs and rt fields and the register data is valid at the register file output. At the same time, bypass multiplexers select inputs from either the EX- or DC-stage output in addition to the register file output, depending on the need for an operand bypass.
EX stage	The ALU controls are set to do an A + B operation. The operands flow into the ALU inputs, and the ALU operation is started. The result of the ALU operation is latched into the ALU output latch during Φ1.
DC stage	This stage is a NOP for this instruction. The data from the output of the EX stage (the ALU) is moved into the output latch of the DC.
WB stage	During Φ1, the WB latch feeds the data to the inputs of the register file, which is addressed by the rd field. The file write strobe is enabled. By the end of Φ1, the data is written into the file.

Figure 2-18. ADD Instruction Pipeline Activities (In MIPS III Instruction Mode)



2.3.4.2 Jump and link register instruction (JALR rd, rs)

IF stage — Same as the IF stage for the ADD instruction.

IT stage — Same as the IT stage for the ADD instruction.

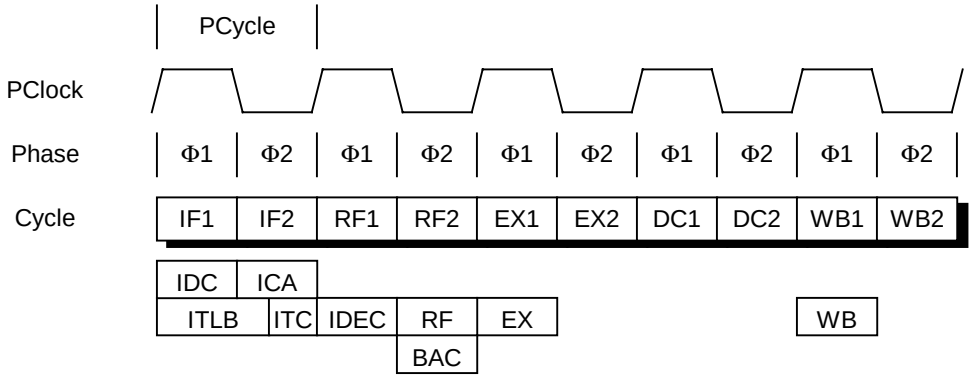
RF stage — A register specified in the rs field is read from the file during Φ2 at the RF stage, and the value read from the rs register is input to the virtual PC latch synchronously. This value is used to fetch an instruction at the jump destination. The value of the virtual PC incremented during the IF stage is incremented again to produce the link address PC + 8 (PC + 4 in the case of MIPS16 ISA) where PC is the address of the JALR instruction. The resulting value is the PC to which the program will eventually return. This value is placed in the Link output latch of the Instruction Address unit.

EX stage — The PC + 8 value (PC + 4 value in the case of MIPS16 ISA) is moved from the Link output latch to the output latch of the EX stage.

DC stage — The PC + 8 value (PC + 4 value in the case of MIPS16 ISA) is moved from the output latch of the EX stage to the output latch of the DC stage.

WB stage — Refer to the ADD instruction. Note that if no value is explicitly provided for rd then register 31 is used as the default. If rd is explicitly specified, it cannot be the same register addressed by rs; if it is, the result of executing such an instruction is undefined.

Figure 2-20. JALR Instruction Pipeline Activities (In MIPS III Instruction Mode)



2.3.4.3 Branch on equal instruction (BEQ rs, rt, offset)

IF stage — Same as the IF stage for the ADD instruction.

IT stage — Same as the IT stage for the ADD instruction.

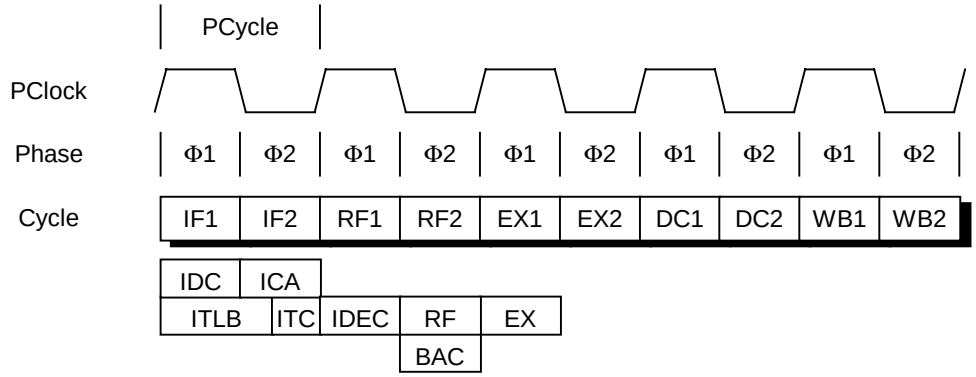
RF stage — During Φ2, the register file is addressed with the rs and rt fields. A check is performed to determine if each corresponding bit position of these two operands has equal values. If they are equal, the PC is set to PC + target, where target is the sign-extended offset field. If they are not equal, the PC is set to PC + 4.

EX stage — The next PC resulting from the branch comparison is valid at the beginning of Φ2 for instruction fetch.

DC stage — This stage is a NOP for this instruction.

WB stage — This stage is a NOP for this instruction.

Figure 2-22. BEQ Instruction Pipeline Activities (In MIPS III Instruction Mode)



2.3.4.4 Trap if less than instruction (TLT rs, rt)

IF stage — Same as the IF stage for the ADD instruction.

IT stage — MIPS16 instruction set does not have TLT instruction, therefore this stage does not occur.

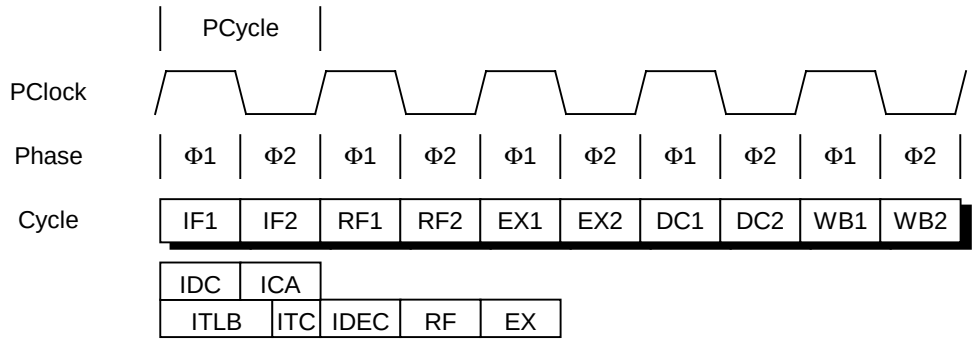
RF stage — Same as the RF stage for the ADD instruction.

EX stage — ALU controls are set to do an A - B operation. The operands flow into the ALU inputs, and the ALU operation is started. The result of the ALU operation is latched into the ALU output latch during Φ1. The sign bits of operands and of the ALU output latch are checked to determine if a less than condition is true. If this condition is true, a Trap exception occurs. The value in the PC register is used as an exception vector value, and from now on any instruction will be invalid.

DC stage — No operation

WB stage — The value of the PC is loaded to EPC register if the less than condition was met in the EX stage. The Cause register ExCode field and BD bit are updated appropriately, as is the EXL bit of the Status register. If the less than condition was not met in the EX stage, no activity occurs in the WB stage.

Figure 2-24. TLT Instruction Pipeline Activities



2.3.4.5 Load word instruction (LW rt, offset (base))

IF stage — Same as the IF stage for the ADD instruction.

IT stage — Same as the IT stage for the ADD instruction.

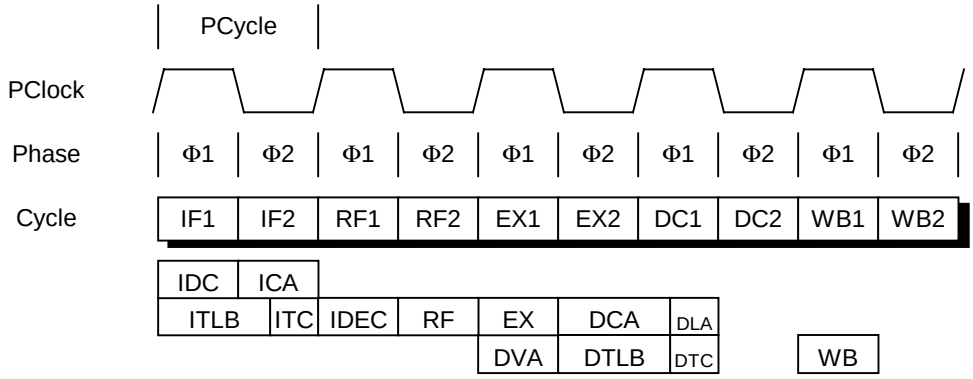
RF stage — Same as the RF stage for the ADD instruction. Note that the base field is in the same position as the rs field.

EX stage — Refer to the EX stage for the ADD instruction. For LW, the inputs to the ALU come from GPR[base] through the bypass multiplexer and from the sign-extended offset field. The result of the ALU operation that is latched into the ALU output latch in Φ1 represents the effective virtual address of the operand (DVA).

DC stage — The cache tag field is compared with the Page Frame Number (PFN) field of the TLB entry. After passing through the load aligner, aligned data is placed in the DC output latch during Φ2.

WB stage — During Φ1, the cache read data is written into the register file addressed by the rt field.

Figure 2-25. LW Instruction Pipeline Activities (In MIPS III Instruction Mode)



2.3.4.6 Store word instruction (SW rt, offset (base))

IF stage — Same as the IF stage for the ADD instruction.

IT stage — Same as the IT stage for the ADD instruction.

RF stage — Same as the RF stage for the LW instruction.

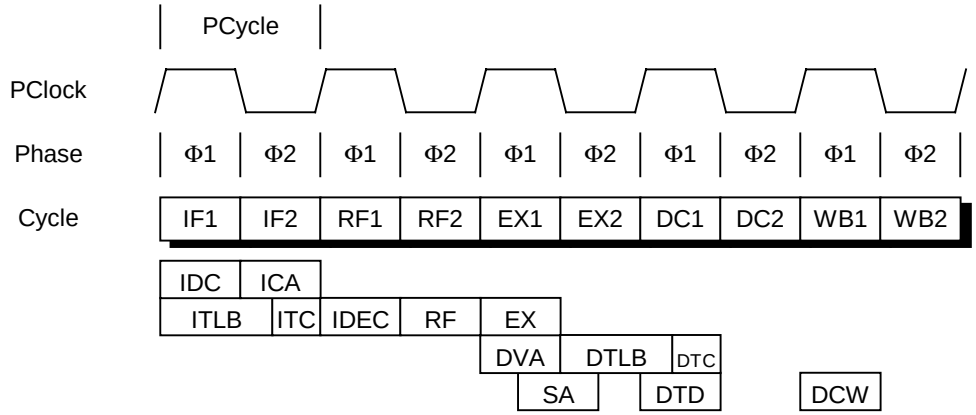
EX stage — Refer to the LW instruction for a calculation of the effective address. From the RF output latch, the GPR[rt] is sent through the bypass multiplexer and into the main shifter, where the shifter performs the byte-alignment operation for the operand. The results of the ALU are latched in the output latches during Φ1. The shift operations are latched in the output latches during Φ2.

DC stage — Refer to the LW instruction for a description of the cache access.

WB stage — If there was a cache hit, the content of the store data output latch is written into the data cache at the appropriate word location.

Note that all store instructions use the data cache for two consecutive PCycles. If the following instruction requires use of the data cache, the pipeline is slipped for one PCycle to complete the writing of an aligned store data.

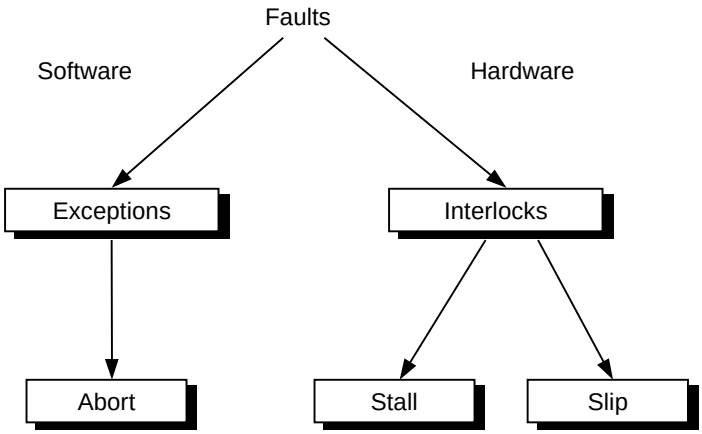
Figure 2-27. SW Instruction Pipeline Activities (In MIPS III Instruction Mode)



2.3.5 Interlock and exception handling

Smooth pipeline flow is interrupted when cache misses or exceptions occur, or when data dependencies are detected. Interruptions handled using hardware, such as cache misses, are referred to as interlocks, while those that are handled using software are called exceptions. As shown in Figure 2-29, all interlock and exception conditions are collectively referred to as faults.

Figure 2-29. Relationship among Interlocks, Exceptions, and Faults



At each cycle, exception and interlock conditions are checked for all active instructions.

Because each exception or interlock condition corresponds to a particular pipeline stage, a condition can be traced back to the particular instruction in the exception/interlock stage, as shown in Table 2-44. For instance, an LDI Interlock is raised in the Register Fetch (RF) stage.

Tables 2-45 and 2-46 describe the pipeline interlocks and exceptions listed in Table 2-44.

Table 2-44. Correspondence of Pipeline Stage to Interlock and Exception Conditions

Stage / Status	IF	RF (IT)	EX	DC	WB

Interlock	Stall	–	ITM ICM	–	DTM DCM DCB	–
	Slip	–	LDI MDI SLI CP0	–	–	–
Exception		IAErr	NMI ITLB INTr IBE SYSC BP CUn RSVD	Trap OVF DAErr	Reset DTLB TMod WAT DBE	–

Remark In the above table, exception conditions are listed up in higher priority order.

Table 2-45. Pipeline Interlock

Interlock	Description
ITM	Instruction TLB Miss
ICM	Instruction Cache Miss
LDI	Load Data Interlock
MDI	MD Busy Interlock
SLI	Store-Load Interlock
CP0	Coprocessor 0 Interlock
DTM	Data TLB Miss
DCM	Data Cache Miss
DCB	Data Cache Busy

Table 2-46. Description of Pipeline Exception

Exception	Description
IAErr	Instruction Address Error exception
NMI	Non-maskable Interrupt exception
ITLB	ITLB exception
IPErr	Instruction Parity Error exception
INTr	Interrupt exception
IBE	Instruction Bus Error exception
SYSC	System Call exception
BP	Breakpoint exception
CUn	Coprocessor Unusable exception
RSVD	Reserved Instruction exception
Trap	Trap exception

OVF	Integer overflow exception
DAErr	Data Address Error exception
Reset	Reset exception
DTLB	DTLB exception
DTMod	DTLB Modified exception
DPErr	Data Parity Error exception
WAT	Watch exception
DBE	Data Bus Error exception

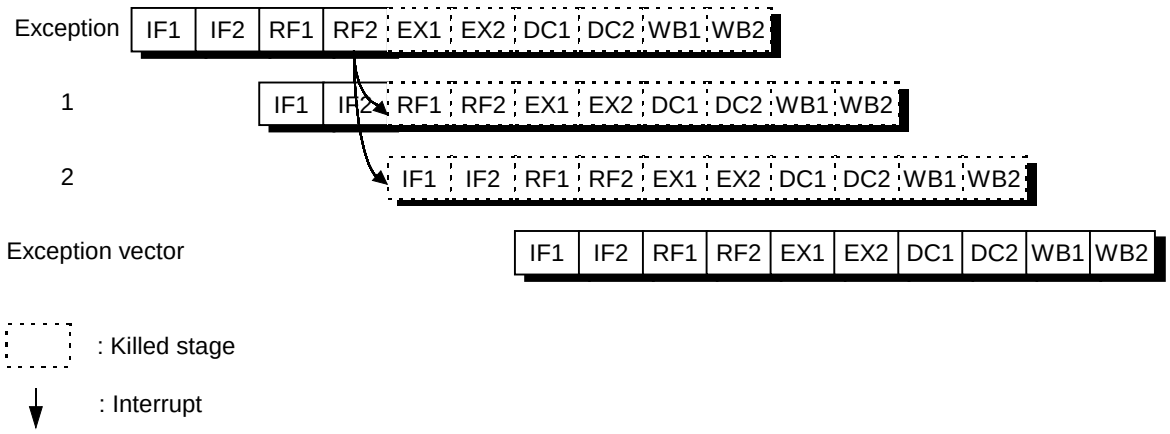
2.3.5.1 Exception conditions

When an exception condition occurs, the relevant instruction and all those that follow it in the pipeline are cancelled. Accordingly, any stall conditions and any later exception conditions that may have referenced this instruction are inhibited; there is no benefit in servicing stalls for a cancelled instruction.

When an exceptional conditions is detected for an instruction, the VR4120A will discard it and all following instructions. When this instruction reaches the WB stage, the exception flag and various information items are written to CP0 registers. The current PC is changed to the appropriate exception vector address and the exception bits of earlier pipeline stages are cleared.

This implementation allows all preceding instructions to complete execution and prevents all subsequent instructions from completing. Thus the value in the EPC is sufficient to restart execution. It also ensures that exceptions are taken in the order of execution; an instruction taking an exception may itself be killed by an instruction further down the pipeline that takes an exception in a later cycle.

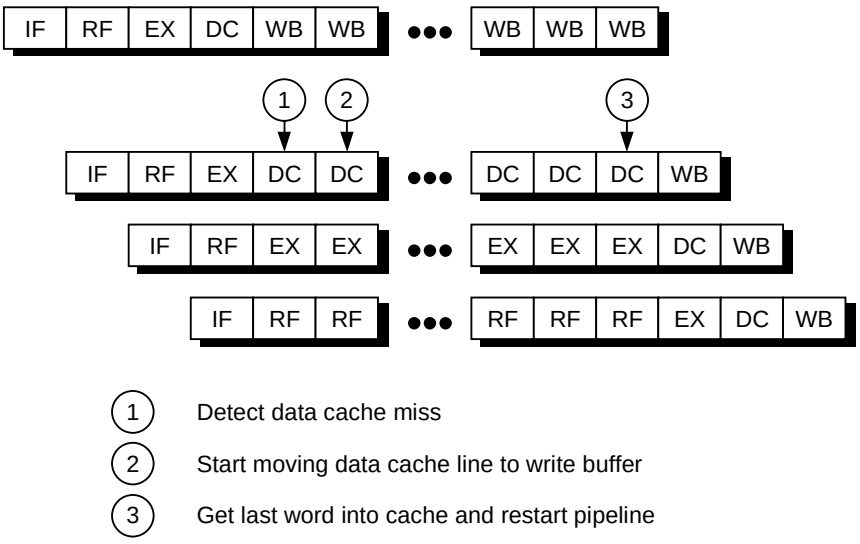
Figure 2-30. Exception Detection



2.3.5.2 Stall conditions

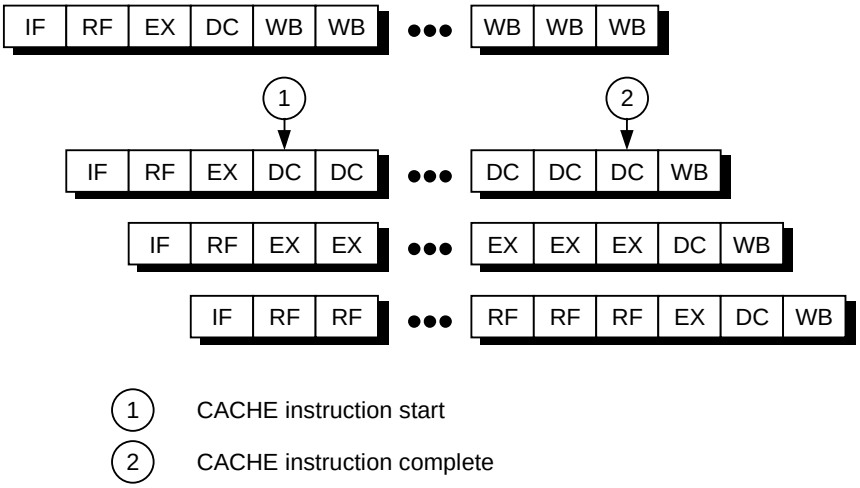
Stalls are used to stop the pipeline for conditions detected after the RF stage. When a stall occurs, the processor will resolve the condition and then the pipeline will continue. Figure 2-31 shows a data cache miss stall, and Figure 2-32 shows a CACHE instruction stall.

Figure 2-31. Data Cache Miss Stall



If the cache line to be replaced is dirty — the W bit is set — the data is moved to the internal write buffer in the next cycle. The write-back data is returned to memory. The last word in the data is returned to the cache at 3, and pipelining restarts.

Figure 2-32. CACHE Instruction Stall

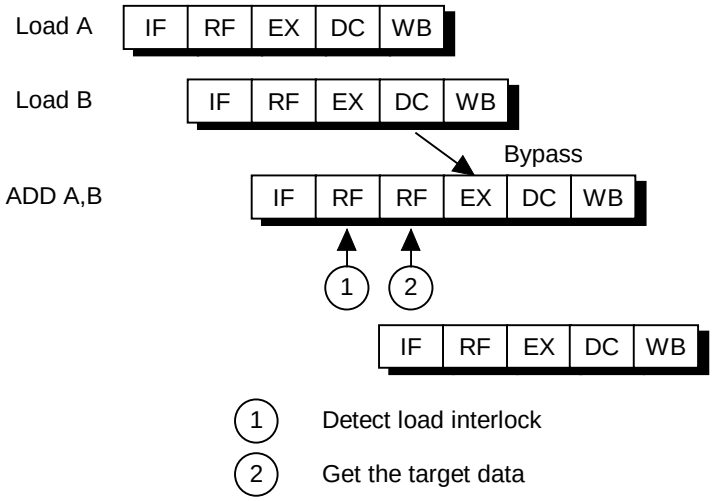


When the CACHE instruction enters the DC stage, the pipeline stalls while the CACHE instruction is executed. The pipeline begins running again when the CACHE instruction is completed, allowing the instruction fetch to proceed.

2.3.5.3 Slip conditions

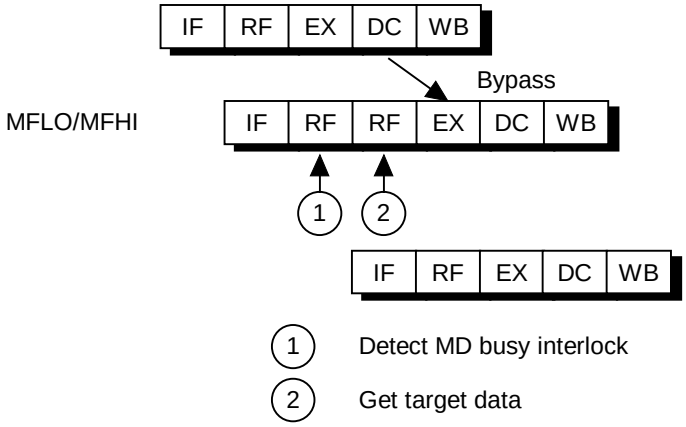
During Φ2 of the RF stage and Φ1 of the EX stage, internal logic will determine whether it is possible to start the current instruction in this cycle. If all of the source operands are available (either from the register file or via the internal bypass logic) and all the hardware resources necessary to complete the instruction will be available whenever required, then the instruction "run"; otherwise, the instruction will "slip". Slipped instructions are retired on subsequent cycles until they issue. The backend of the pipeline (stages DC and WB) will advance normally during slips in an attempt to resolve the conflict. NOPs will be inserted into the bubble in the pipeline. Instructions killed by branch likely instructions, ERET or exceptions will not cause slips.

Figure 2-33. Load Data Interlock



Load Data Interlock is detected in the RF stage shown in as Figure 2-33 and also the pipeline slips in the stage. Load Data Interlock occurs when data fetched by a load instruction and data moved from HI, LO or CP0 registers is required by the next immediate instruction. The pipeline begins running again when the clock after the target of the load is read from the data cache, HI, LO and CP0 registers. The data returned at the end of the DC stage is input into the end of the RF stage, using the bypass multiplexers.

Figure 2-34. MD Busy Interlock



MD Busy Interlock is detected in the RF stage as shown in Figure 2-34 and also the pipeline slips in the stage. MD Busy Interlock occurs when HI/LO register is required by MFHI/MFLO instruction before finishing Mult/Div execution.

The pipeline begins running again the clock after finishing Mult/Div execution. The data returned from the HI/LO register at the end of the DC stage is input into the end of the RF stage, using the bypass multiplexers.

Store-Load Interlock is detected in the EX stage and the pipeline slips in the RF stage. Store-Load Interlock occurs when store instruction followed by load instruction is detected. The pipeline begins running again one clock after.

Coprocessor 0 Interlock is detected in the EX stage and the pipeline slips in the RF stage. A coprocessor interlock occurs when an MTC0 instruction for the Configuration or Status register is detected.

The pipeline begins running again one clock after.

2.3.5.4 Bypassing

In some cases, data and conditions produced in the EX, DC and WB stages of the pipeline are made available to the EX stage (only) through the bypass data path.

Operand bypass allows an instruction in the EX stage to continue without having to wait for data or conditions to be written to the register file at the end of the WB stage. Instead, the Bypass Control Unit is responsible for ensuring data and conditions from later pipeline stages are available at the appropriate time for instructions earlier in the pipeline.

The Bypass Control Unit is also responsible for controlling the source and destination register addresses supplied to the register file.

2.3.6 Program compatibility

The VR4120A core is designed taking into consideration program compatibility with other VR-Series processors. However, because the VR4120A differs from other processors in its architecture, it may not be able to run some programs that run on other processors. Likewise, programs that run on the VR4120A will not necessarily run on other processors. Matters which should be paid attention to when porting programs between the VR4120A core and other VR-Series processors are listed below.

- The VR4120A core does not support floating-point instructions since it has no Floating-Point Unit (FPU).
- Multiply-add instructions (DMACC, MACC) are added in the VR4120A.
- Instructions for power modes (HIBERNATE, STANDBY, SUSPEND) are added in the VR4120A to support power modes.
- The VR4120A does not have the LL bit to perform synchronization of multiprocessing. Therefore, the CPU core does not support instructions which manipulate the LL bit (LL, LLD, SC, SCD).
- A 16-bit length MIPS16 instruction set is added in the VR4120A, but not available in LAKI
- The CP0 hazards of the VR4120A are equally or less stringent than those of other processors (for details, see **APPENDIX C VR4120A COPROCESSOR 0 HAZARDS**).
- An instruction for debug has been added for the VR4120A. However, this instruction cannot be used for the VR4120A.

For more information, refer to **APPENDIX A MIPS III INSTRUCTION SET DETAILS**, the VR4100, VR4111 User's Manual, or the VR4300™ User's Manual.

The list of instructions supported by VR-Series products is shown below.

Table 2-47. VR Series Supported Instructions

Instruction \ Product	VR4100 VR4102™	VR4111™	VR4120A Core	VR4300 VR4305™ VR4310™	VR5000™ VR10000™
MIPS I instruction set	O	O	O	O	O
MIPS II instruction set	O	O	O	O	O
MIPS III instruction set	O	O	O	O	O
LL bit operation	×	×	×	O	O
MIPS IV instruction set	×	×	×	×	O
MIPS16 instruction set	×	O	(O)	×	×
16-bit multiply-add operation	O	O	O (Use of 32-bit multiply-add operation	×	×
32-bit multiply-add operation	×	×	O	×	×
Floating-point operation	×	×	×	O	O
Power mode transfer	O	O	O	×	×

2.4 Memory Management System

The VR4120A Core provides a memory management unit (MMU) which uses a translation lookaside buffer (TLB) to translate virtual addresses into physical addresses. This chapter describes the virtual and physical address spaces, the virtual-to-physical address translation, the operation of the TLB in making these translations, and the CP0 registers that provide the software interface to the TLB.

2.4.1 Translation lookaside buffer (TLB)

Virtual addresses are translated into physical addresses using an on-chip TLB[Note]. The on-chip TLB is a fully-associative memory that holds 32 entries, which provide mapping to odd/even page in pairs for one entry. These pages can have five different sizes, 1 K, 4 K, 16 K, 64 K, and 256 K, and can be specified in each entry. If it is supplied with a virtual address, each of the TLB entries is checked simultaneously to see whether they match the virtual addresses that are provided with the ASID field and saved in the EntryHi register.

If there is a virtual address match, or “hit,” in the TLB, the physical page number is extracted from the TLB and concatenated with the offset to form the physical address.

If no match occurs (TLB “miss”), an exception is taken and software refills the TLB from the page table resident in memory. The software writes to an entry selected using the Index register or a random entry indicated in the Random register.

If more than one entry in the TLB matches the virtual address being translated, the operation is undefined and the TLB may be disabled. In this case, the TLB-Shutdown (TS) bit of the status register is set to 1, and the TLB becomes unusable (an attempt to access the TLB results in a TLB Mismatch exception regardless of whether there is an entry that hits). The TS bit can be cleared only by a reset.

Note Depending on the address space, virtual addresses may be converted to physical addresses without using a TLB. For example, address translation for the kseg0 or kseg1 address space does not use mapping. The physical addresses of these address spaces are determined by subtracting the base address of the address space from the virtual addresses.

2.4.2 Virtual address space

This section describes the virtual/physical address space and the manner in which virtual addresses are converted or “translated” into physical addresses in the TLB. The VR4120A virtual address can be either 32 or 64 bits wide, depending on whether the processor is operating in 32-bit or 64-bit mode.

In 32-bit mode, addresses are 32 bits wide. The maximum user process size is 2 Gbytes (2^{31}).
In 64-bit mode, addresses are 64 bits wide. The maximum user process size is 1 Tbyte (2^{40}).

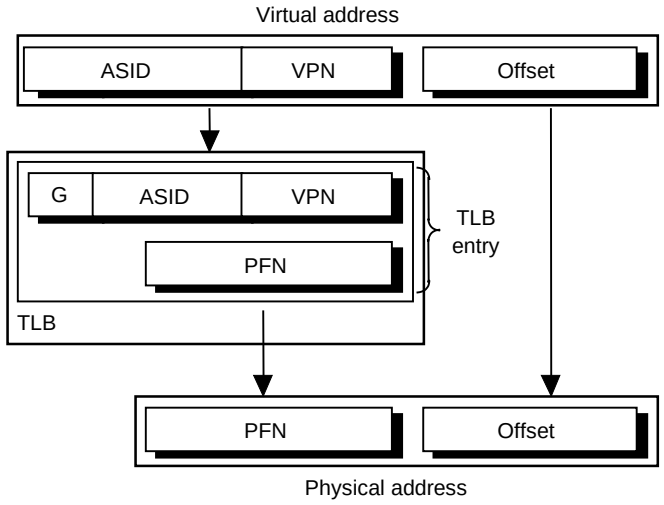
As shown in Figure 2-35, the virtual address is extended with an address space identifier (ASID), which reduces the frequency of TLB flushing when switching contexts. This 8-bit ASID is in the CP0 EntryHi register, described later in this chapter. The Global (G) bit is in the EntryLo0 and EntryLo1 registers, described later in this section.

Figure 2-35. Virtual-to-Physical Address Translation

1 The virtual page number (VPN) in the virtual address (VA) is compared with the VPN in the TLB.

2 If there is a match, the page frame number (PFN) representing the high-order bits of the physical address is output from the TLB.

3 The offset is then added to the PFN passing through the TLB.



2.4.2.1 Virtual-to-physical address translation

Converting a virtual address to a physical address begins by comparing the virtual address from the processor with the virtual addresses in the TLB; there is a match when the virtual page number (VPN) of the address is the same as the VPN field of the entry, and either:

- ✧ the Global (G) bit of the TLB entry is set to 1
- ✧ the ASID field of the virtual address is the same as the ASID field of the TLB entry.

This match is referred to as a TLB hit. If there is no match, a TLB Mismatch exception is taken by the processor and software is allowed to refill the TLB from a page table of virtual/physical addresses in memory.

If there is a virtual address match in the TLB, the physical address is output from the TLB and concatenated with the offset, which represents an address within the page frame space. The offset does not pass through the TLB. Instead, the low-order bits of the virtual address are output without being translated. For details about the physical address, see **Section 2.5.5.11 Virtual-to-physical address translation**.

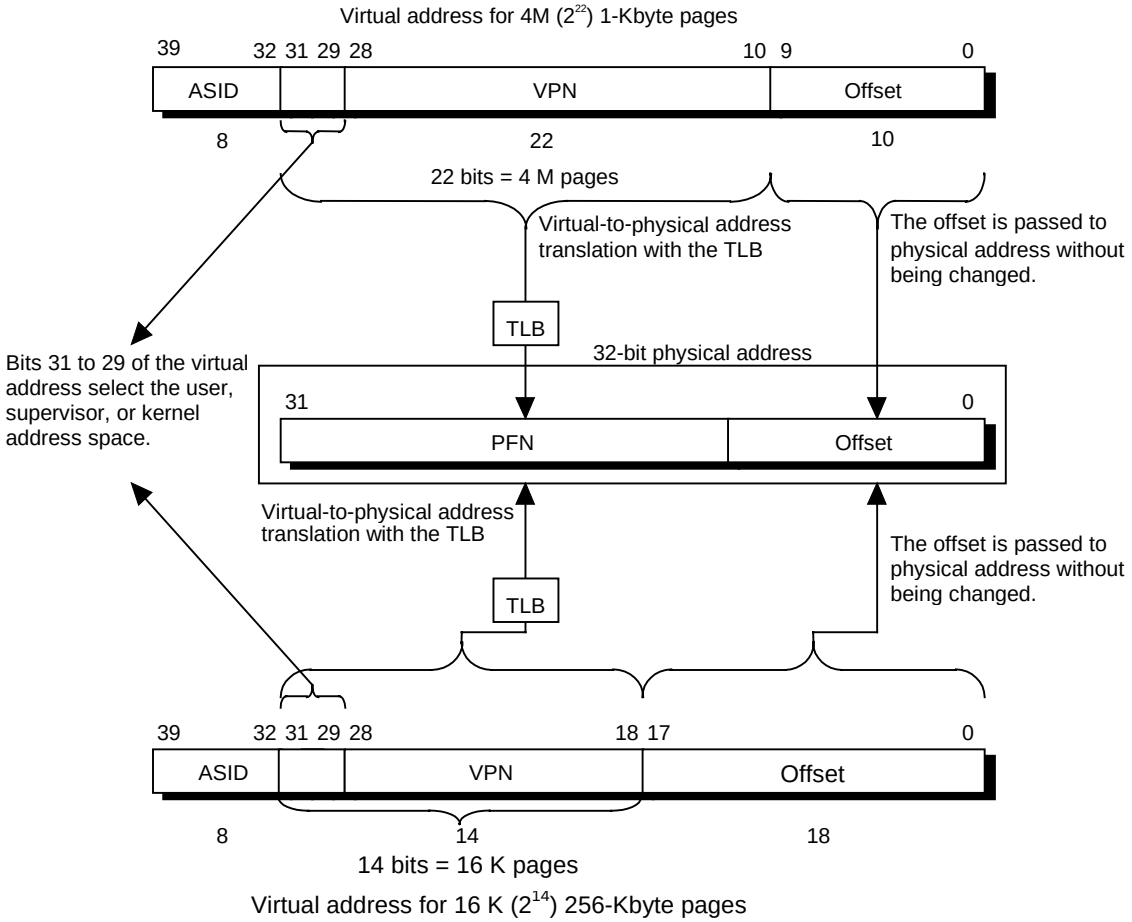
The next two sections describe the 32-bit and 64-bit mode address translations.

2.4.2.2 32-bit mode address translation

Figure 2-36 shows the virtual-to-physical-address translation of a 32-bit mode address. The pages can have five different sizes between 1 Kbyte (10 bits) and 256 Kbytes (18 bits), each being 4 times as large as the preceding one in ascending order, that is 1 K, 4 K, 16 K, 64 K, and 256 K.

- ✧ Shown at the top of Figure 2-36 is the virtual address space in which the page size is 1 Kbyte and the offset is 10 bits. The 22 bits excluding the ASID field represents the virtual page number (VPN), enabling selecting a page table of 4 M entries.
- ✧ Shown at the bottom of Figure 2-36 is the virtual address space in which the page size is 256 Kbytes and the offset is 18 bits. The 14 bits excluding the ASID field represents the VPN, enabling selecting a page table of 16 K entries.

Figure 2-36. 32-bit Mode Virtual Address Translation



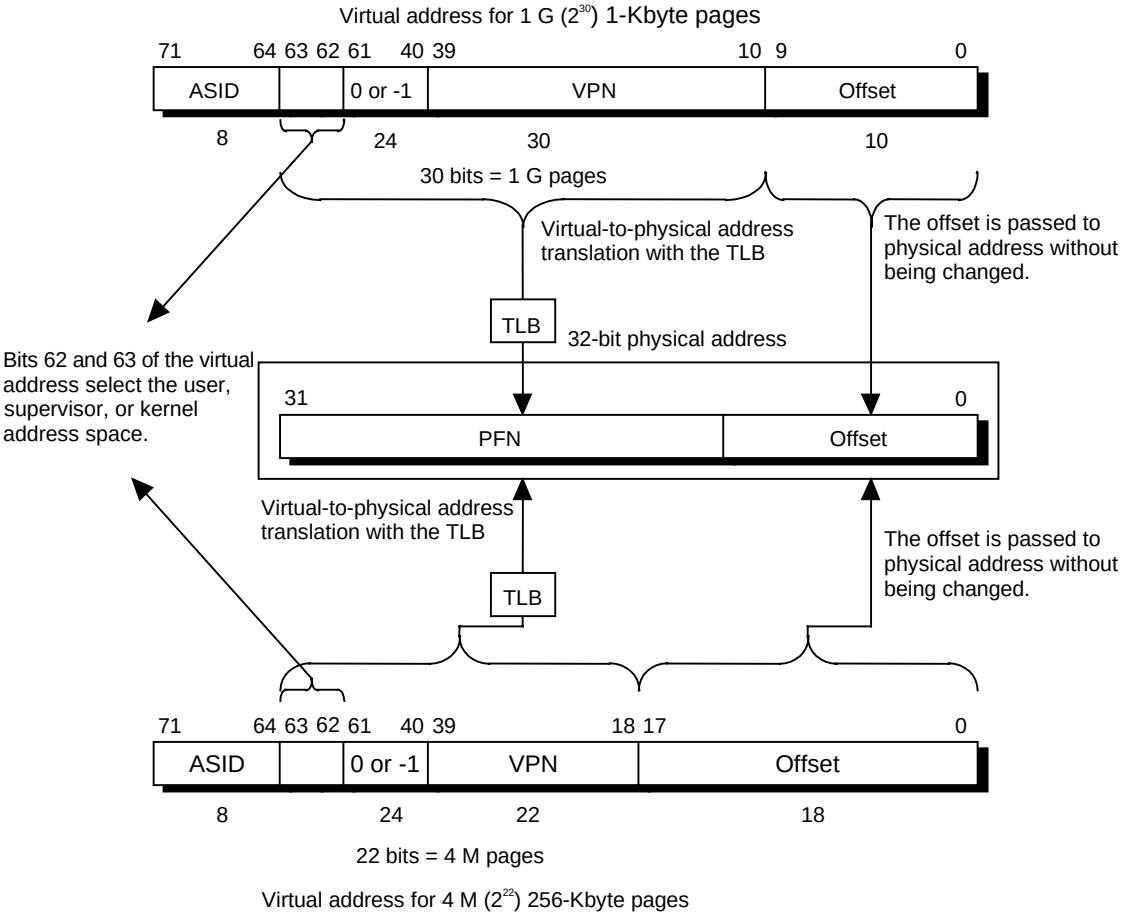
2.4.2.3 64-bit mode address translation

Figure 2-37 shows the virtual-to-physical-address translation of a 64-bit mode address. This figure illustrates the two possible page size; a 1-Kbyte page (10 bits) and a 256-Kbyte page (18 bits).

- ✧ Shown at the top of Figure 2-37 is the virtual address space in which the page size is 1 Kbyte and the offset is 10 bits. The 30 bits excluding the ASID field represents the virtual page number (VPN), enabling selecting a page table of 1 G entry.

✧ Shown at the bottom of Figure 2-37 is the virtual address space in which the page size is 256 Kbytes and the offset is 18 bits. The 22 bits excluding the ASID field represents the VPN, enabling selecting a page table of 4 M entries.

Figure 2-37. 64-bit Mode Virtual Address Translation



2.4.2.4 Operating modes

The processor has three operating modes that function in both 32- and 64-bit operations:

✧ User mode
✧ Supervisor mode
✧ Kernel mode

User and Kernel modes are common to all VR-Series processors. Generally, Kernel mode is used to execute the operating system, while User mode is used to run application programs. The VR4000 series processors have a third mode, which is called Supervisor mode and categorized in between User and Kernel modes. This mode is used to configure a high-security system.

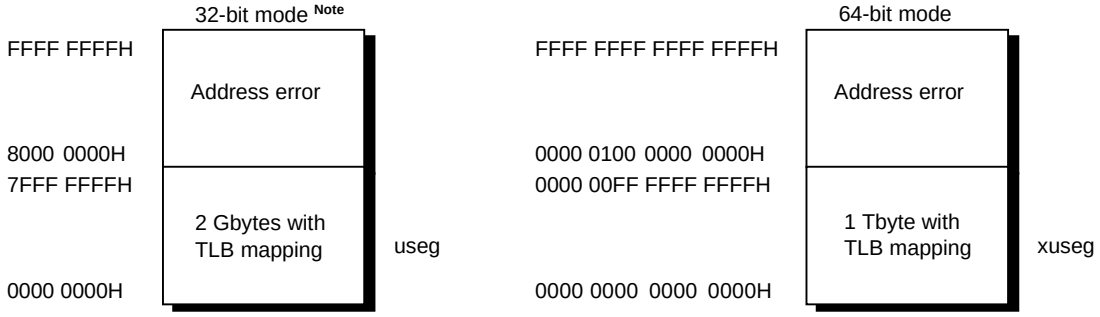
When an exception occurs, the CPU enters Kernel mode, and remains in this mode until an exception return instruction (ERET) is executed. The ERET instruction brings back the processor to the mode in which it was just before the exception occurs.

2.4.2.5 User mode virtual addressing

In user mode, a single virtual address space labeled User segment is available ; its size is

- ✧ 2-Gbyte (2^{31} bytes) in 32-bit mode (useg)
- ✧ 1-Tbyte (2^{40} bytes) in 64-bit mode (xuseg)

Figure 2-38. User Mode Address Space



Note The VR4120A uses 64-bit addresses within it. When the processor is running in Kernel mode, it saves the contents of each register or restores their previous contents to initialize them before switching the context. For 32-bit mode addressing, bit 31 is sign-extended to bits 32 to 63, and the resulting 32 bits are used for addressing. Usually, it is impossible for 32-bit mode programs to generate invalid addresses. If context switching occurs and the processor enters Kernel mode, however, an attempt may be made to save an address other than the sign-extended 32-bit address mentioned above to a 64-bit register. In this case, user-mode programs are likely to generate an invalid address.

The User segment starts at address 0 and the current active user process resides in either useg (in 32-bit mode) or xuseg (in 64-bit mode). The TLB identically maps all references to useg/xuseg from all modes, and controls cache accessibility.

The processor operates in User mode when the Status register contains the following bit-values:

- ✧ KSU = 10
- ✧ EXL = 0
- ✧ ERL = 0

In conjunction with these bits, the UX bit in the Status register selects addressing mode as follows:

- ✧ When UX = 0, 32-bit useg space is selected.
- ✧ When UX = 1, 64-bit xuseg space is selected.

Table 2-48 lists the characteristics of each user segment (useg and xuseg).

Table 2-48. Comparison of useg and xuseg

Address Bit Value	Status Register Bit Value				Segment Name	Address Range	Size
	KSU	EXL	ERL	UX			
32-bit A31 = 0	10	0	0	0	useg	0000 0000H to 7FFF FFFFH	2 Gbytes (2^{31} bytes)
64-bit A(63:40) = 0	10	0	0	1	xuseg	0000 0000 0000 0000H to 0000 00FF FFFF FFFFH	1 Tbyte (2^{40} bytes)

(1) useg (32-bit mode)

In User mode, when UX = 0 in the Status register and the most significant bit of the virtual address is 0, this virtual address space is labeled useg.

Any attempt to reference an address with the most-significant bit set while in User mode causes an Address Error exception (see **Section 2.6 Exception Processing**).

The TLB Mismatch exception vector is used for TLB misses.

(2) xuseg (64-bit mode)

In User mode, when UX = 1 in the Status register and bits 63 to 40 of the virtual address are all 0, this virtual address space is labeled xuseg.

Any attempt to reference an address with bits 63 to 40 equal to 1 causes an Address Error exception (see **Section 2.6 Exception Processing**).

The XTLB Mismatch exception vector is used for TLB misses.

2.4.2.6 Supervisor-mode virtual addressing

Supervisor mode shown in Figure 2-39 is designed for layered operating systems in which a true kernel runs in Kernel mode, and the rest of the operating system runs in Supervisor mode.

The processor operates in Supervisor mode when the Status register contains the following bit-values:

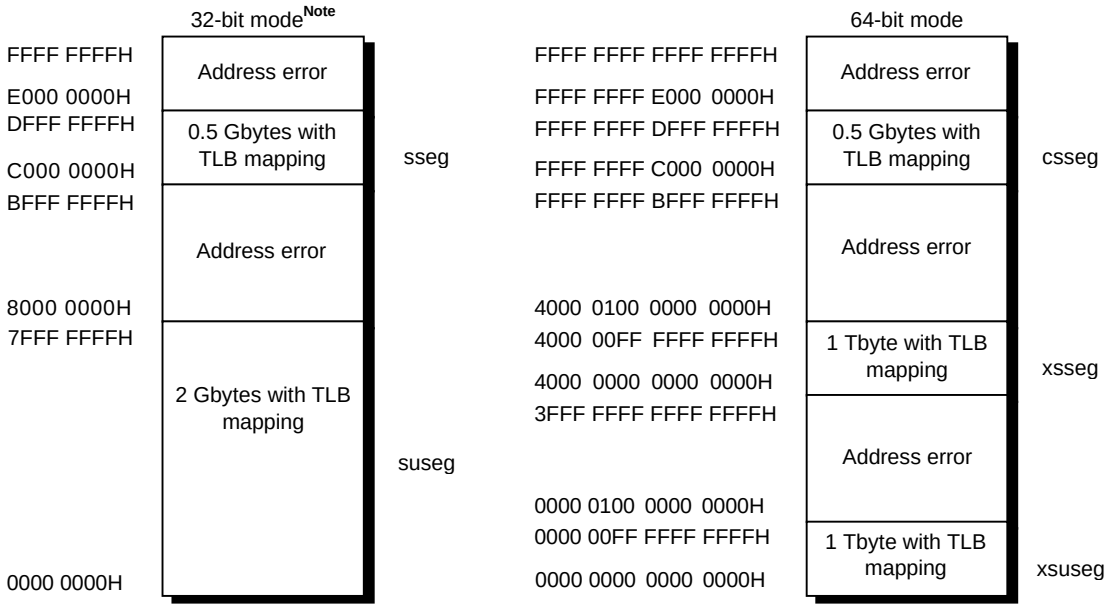
- ✧ KSU = 01
- ✧ EXL = 0
- ✧ ERL = 0

In conjunction with these bits, the SX bit in the Status register selects Supervisor mode addressing:

- ✧ When SX = 0: 32-bit supervisor space is selected.
- ✧ When SX = 1: 64-bit supervisor space is selected.

Figure 2-39 shows the supervisor mode address mapping, and Table 2-49 lists the characteristics of the Supervisor mode segments.

Figure 2-39. Supervisor Mode Address Space



Note The VR4120A uses 64-bit addresses within it. For 32-bit mode addressing, bit 31 is sign-extended to bits 32 to 63, and the resulting 32 bits are used for addressing. Usually, it is impossible for 32-bit mode programs to generate invalid addresses. In an operation of base register + offset for addressing, however, a two's complement overflow may occur, causing an invalid address. Note that the result becomes undefined. Two factors that can cause a two's complement follow:

- ✧ When offset bit 15 is 0, base register bit 31 is 0, and bit 31 of the operation "base register + offset" is 1
- ✧ When offset bit 15 is 1, base register bit 31 is 1, and bit 31 of the operation "base register + offset" is 0

Table 2-49. 32-bit and 64-bit Supervisor Mode Segments

Address Bit Value	Status Register Bit Value				Segment Name	Address Range	Size
	KSU	EXL	ERL	SX			
32-bit A31 = 0	01	0	0	0	suseg	0000 0000H to 7FFF FFFFH	2 Gbytes (2^{31} bytes)
32-bit A(31:29) = 110	01	0	0	0	sseg	C000 0000H to DFFF FFFFH	512 Mbytes (2^{29} bytes)
64-bit A(63:62) = 00	01	0	0	1	xsuseg	0000 0000 0000 0000H to 0000 00FF FFFF FFFFH	1 Tbyte (2^{40} bytes)
64-bit A(63:62) = 01	01	0	0	1	xsseg	4000 0000 0000 0000H to 4000 00FF FFFF FFFFH	1 Tbyte (2^{40} bytes)
64-bit A(63:62) = 11	01	0	0	1	csseg	FFFF FFFF C000 0000H to FFFF FFFF DFFF FFFFH	512 Mbytes (2^{29} bytes)

(1) suseg (32-bit supervisor mode, user space)

When SX = 0 in the Status register and the most-significant bit of the virtual address space is set to 0, the suseg virtual address space is selected; it covers 2 Gbytes (2^{31} bytes) of the current user address space. The virtual address is extended with the contents of the 8-bit ASID field to form a unique virtual address. This mapped space starts at virtual address 0000 0000H and runs through 7FFF FFFFH.

(2) sseg (32-bit supervisor mode, supervisor space)

When SX = 0 in the Status register and the most-significant three bits of the virtual address space are 110, the sseg virtual address space is selected; it covers 512 Mbytes (2^{29} bytes) of the current supervisor virtual address space. The virtual address is extended with the contents of the 8-bit ASID field to form a unique virtual address. This mapped space begins at virtual address C000 0000H and runs through DFFF FFFFH.

(3) xsuseg (64-bit supervisor mode, user space)

When SX = 1 in the Status register and bits 63 and 62 of the virtual address space are set to 00, the xsuseg virtual address space is selected; it covers 1 Tbyte (2^{40} bytes) of the current user address space. The virtual address is extended with the contents of the 8-bit ASID field to form a unique virtual address. This mapped space starts at virtual address 0000 0000 0000 0000H and runs through 0000 00FF FFFF FFFFH.

(4) xsseg (64-bit supervisor mode, current supervisor space)

When SX = 1 in the Status register and bits 63 and 62 of the virtual address space are set to 01, the xsseg virtual address space is selected; it covers 1 Tbyte (2^{40} bytes) of the current supervisor virtual address space. The virtual address is extended with the contents of the 8-bit ASID field to form a unique virtual address. This mapped space begins at virtual address 4000 0000 0000 0000H and runs through 4000 00FF FFFF FFFFH.

(5) csseg (64-bit supervisor mode, separate supervisor space)

When SX = 1 in the Status register and bits 63 and 62 of the virtual address space are set to 11, the csseg virtual address space is selected; it covers 512 Mbytes (2^{29} bytes) of the separate supervisor virtual address space. The virtual address is extended with the contents of the 8-bit ASID field to form a unique virtual address. This mapped space begins at virtual address FFFF FFFFH C000 0000 and runs through FFFF FFFF DFFF FFFFH.

2.4.2.7 Kernel-mode virtual addressing

If the Status register satisfies any of the following conditions, the processor runs in Kernel mode.

- ✧ KSU = 00
- ✧ EXL = 1
- ✧ ERL = 1

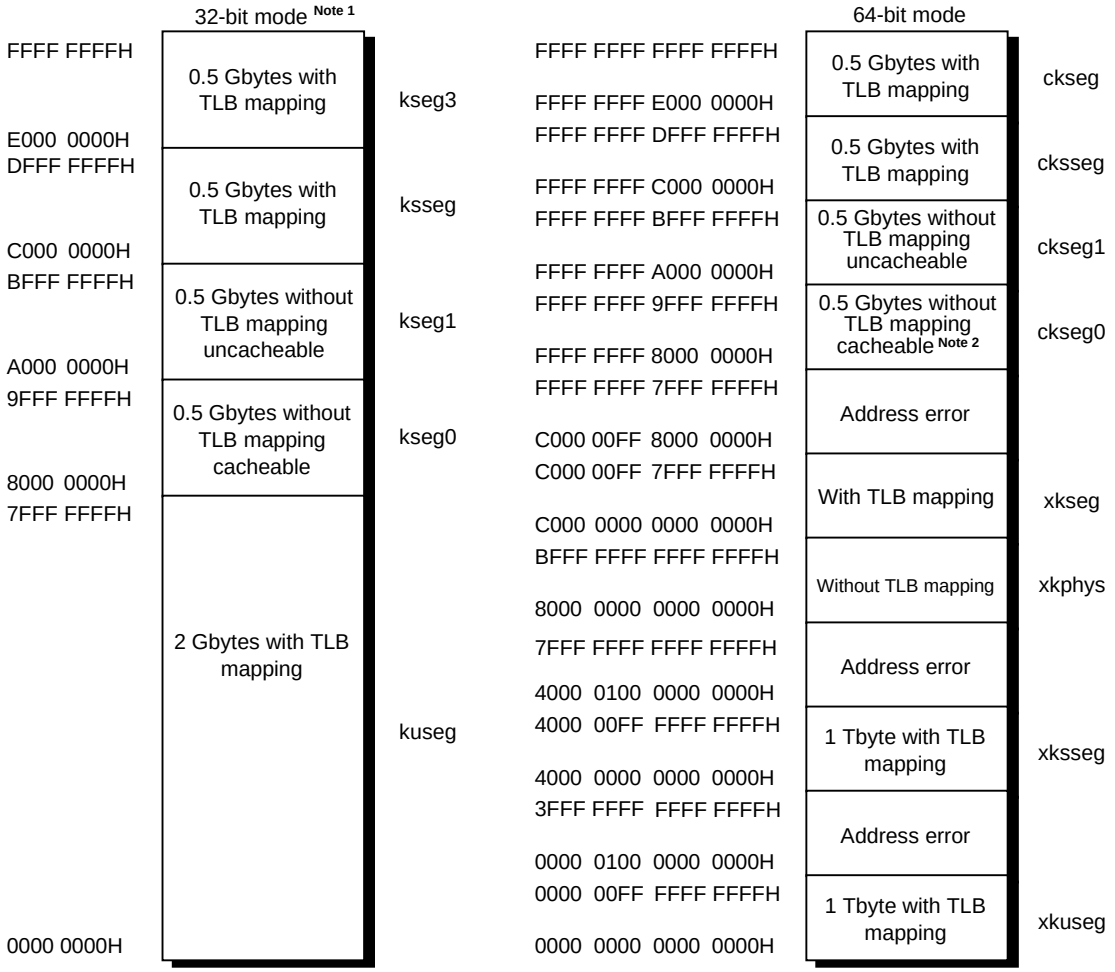
The addressing width in Kernel mode varies according to the state of the KX bit of the Status register, as follows:

- ✧ When KX = 0: 32-bit kernel space is selected.
- ✧ When KX = 1: 64-bit kernel space is selected.

The processor enters Kernel mode whenever an exception is detected and it remains in Kernel mode until an exception return (ERET) instruction is executed and results in ERL and/or EXL = 0. The ERET instruction restores the processor to the mode existing prior to the exception.

Kernel mode virtual address space is divided into regions differentiated by the high-order bits of the virtual address, as shown in Figure 2-40. Table 2-50 lists the characteristics of the 32-bit Kernel mode segments, and Table 2-51 lists the characteristics of the 64-bit Kernel mode segments.

Figure 2-40. Kernel Mode Address Space



Notes 1. The VR4120A uses 64-bit addresses within it. For 32-bit mode addressing, bit 31 is sign-extended to bits 32 to 63, and the resulting 32 bits are used for addressing. Usually, a 64-bit instruction is used for the program in 32-bit mode.

2. The K0 field of the Config register controls cacheability of kseg0 and ckseg0.

Table 2-50. 32-bit Kernel Mode Segments

Address Bit Value	Status Register Bit Value				Segment Name	Virtual Address	Physical Address	Size
	KSU	EXL	ERL	KX				
A31 = 0	KSU = 00 or EXL = 1 or ERL = 1			0	kuseg	0000 0000H to 7FFF FFFFH	TLB map	2 Gbytes (2^{31} bytes)
A(31:29) = 100				0	kseg0	8000 0000H to 9FFF FFFFH	0000 0000H to 1FFF FFFFH	512 Mbytes (2^{29} bytes)
A(31:29) = 101				0	kseg1	A000 0000H to BFFF FFFFH	0000 0000H to 1FFF FFFFH	512 Mbytes (2^{29} bytes)
A(31:29) = 110				0	ksseg	C000 0000H to DFFF FFFFH	TLB map	512 Mbytes (2^{29} bytes)
A(31:29) = 111				0	kseg3	E000 0000H to FFFF FFFFH	TLB map	512 Mbytes (2^{29} bytes)

(1) kuseg (32-bit kernel mode, user space)

When KX = 0 in the Status register, and the most-significant bit of the virtual address space is 0, the kuseg virtual address space is selected; it is the current 2-Gbyte (2^{31}-byte) user address space.

The virtual address is extended with the contents of the 8-bit ASID field to form a unique virtual address.

If the ERL bit of the Status register is 1, the user address space is assigned 2 Gbytes (2^{31} bytes) without TLB mapping and becomes unmapped (with virtual addresses being used as physical addresses) and uncached so that the cache error handler can use it. This allows the Cache Error exception code to operate uncached using r0 as a base register.

(2) kseg0 (32-bit kernel mode, kernel space 0)

When KX = 0 in the Status register and the most-significant three bits of the virtual address space are 100, the kseg0 virtual address space is selected; it is the current 512-Mbyte (2^{29}-byte) physical space.

References to kseg0 are not mapped through TLB; the physical address selected is defined by subtracting 8000 0000H from the virtual address.

The K0 field of the Config register controls cacheability (see **Section 2.6 Exception Processing**).

(3) kseg1 (32-bit kernel mode, kernel space 1)

When KX = 0 in the Status register and the most-significant three bits of the virtual address space are 101, the kseg1 virtual address space is selected; it is the current 512-Mbyte (2^{29}-byte) physical space.

References to kseg1 are not mapped through TLB; the physical address selected is defined by subtracting A000 0000H from the virtual address.

Caches are disabled for accesses to these addresses, and main memory (or memory-mapped I/O device registers) is accessed directly.

(4) ksseg (32-bit kernel mode, supervisor space)

When KX = 0 in the Status register and the most-significant three bits of the virtual address space are 110, the ksseg virtual address space is selected; it is the current 512-Mbyte (2^{29}-byte) virtual address space. The virtual address is extended with the contents of the 8-bit ASID field to form a unique virtual address.

(5) kseg3 (32-bit kernel mode, kernel space 3)

When KX = 0 in the Status register and the most-significant three bits of the virtual address space are 111, the kseg3 virtual address space is selected; it is the current 512-Mbyte (2^{29}-byte) kernel virtual space. The virtual address is extended with the contents of the 8-bit ASID field to form a unique virtual address.

Table 2-51. 64-bit Kernel Mode Segments

Address Bit Value	Status Register Bit Value				Segment Name	Virtual Address	Physical Address	Size
	KSU	EXL	ERL	KX				
A(63:62) = 00	KSU = 00 or EXL = 1 or ERL = 1			1	xkuseg	0000 0000 0000 0000H to 0000 00FF FFFF FFFFH	TLB map	1 Tbyte (2^{40} bytes)
A(63:62) = 01				1	xksseg	4000 0000 0000 0000H to 4000 00FF FFFF FFFFH	TLB map	1 Tbyte (2^{40} bytes)
A(63:62) = 10				1	xkphys	8000 0000 0000 0000H to BFFF FFFF FFFF FFFFH	0000 0000H to FFFF FFFFH	4 Gbytes (2^{32} bytes)
A(63:62) = 11				1	xkseg	C000 0000 0000 0000H to C000 00FF 7FFF FFFFH	TLB map	2^{40} to 2^{31} bytes
A(63:62) = 11 A(63:31) = -1				1	ckseg0	FFFF FFFF 8000 0000H to FFFF FFFF 9FFF FFFFH	0000 0000H to 1FFF FFFFH	512 Mbytes (2^{29} bytes)
A(63:62) = 11 A(63:31) = -1				1	ckseg1	FFFF FFFF A000 0000H to FFFF FFFF BFFF FFFFH	0000 0000H to 1FFF FFFFH	512 Mbytes (2^{29} bytes)
A(63:62) = 11 A(63:31) = -1				1	cksseg	FFFF FFFF C000 0000H to FFFF FFFF DFFF FFFFH	TLB map	512 Mbytes (2^{29} bytes)
A(63:62) = 11 A(63:31) = -1				1	ckseg3	FFFF FFFF E000 0000H to FFFF FFFF FFFF FFFFH	TLB map	512 Mbytes (2^{29} bytes)

(6) xkuseg (64-bit kernel mode, user space)

When KX = 1 in the Status register and bits 63 and 62 of the virtual address space are 00, the xkuseg virtual address space is selected; it is the 1-Tbyte (2^{40} bytes) current user address space. The virtual address is extended with the contents of the 8-bit ASID field to form a unique virtual address.

If the ERL bit of the Status register is 1, the user address space is assigned 2 Gbytes (2^{31} bytes) without TLB mapping and becomes unmapped (with virtual addresses being used as physical addresses) and uncached so that the cache error handler can use it. This allows the Cache Error exception code to operate uncached using r0 as a base register.

(7) xksseg (64-bit kernel mode, current supervisor space)

When KX = 1 in the Status register and bits 63 and 62 of the virtual address space are 01, the xksseg address space is selected; it is the 1-Tbyte (2^{40} bytes)current supervisor address space. The virtual address is extended with the contents of the 8-bit ASID field to form a unique virtual address.

(8) xkphys (64-bit kernel mode, physical spaces)

When the KX = 1 in the Status register and bits 63 and 62 of the virtual address space are 10, the virtual address space is called xkphys and selected as either cached or uncached. If any of bits 58 to 32 of the address is 1, an attempt to access that address results in an address error.

Table 2-52. Cacheability and xkphys Address Space

Bits 61-59	Cacheability	Start Address
0	Cached	8000 0000 0000 0000H to 8000 0000 FFFF FFFFH
1	Cached	8800 0000 0000 0000H to 8800 0000 FFFF FFFFH
2	Uncached	9000 0000 0000 0000H to 9000 0000 FFFF FFFFH
3	Cached	9800 0000 0000 0000H to 9800 0000 FFFF FFFFH
4	Cached	A000 0000 0000 0000H to A000 0000 FFFF FFFFH
5	Cached	A800 0000 0000 0000H to A800 0000 FFFF FFFFH
6	Cached	B000 0000 0000 0000H to B000 0000 FFFF FFFFH
7	Cached	B800 0000 0000 0000H to B800 0000 FFFF FFFFH

(9) xkseg (64-bit kernel mode, physical spaces)

When the KX = 1 in the Status register and bits 63 and 62 of the virtual address space are 11, the virtual address space is called xkseg and selected as either of the following:

- Kernel virtual space xkseg, the current kernel virtual space; the virtual address is extended with the contents of the 8-bit ASID field to form a unique virtual address
  This space is referenced via TLB. Whether cache can be used or not is determined by bit C of each page's TLB entry.
- One of the four 32-bit kernel compatibility spaces, as described in the next section.

(10) 64-bit kernel mode compatible spaces (ckseg0, ckseg1, cksseg, and ckseg3)

If the conditions listed below are satisfied in Kernel mode, ckseg0, ckseg1, cksseg, or ckseg3 (each having 512 Mbytes) is selected as a compatible space according to the state of the bits 30 and 29 (two low-order bits) of the address.

✧ The KX bit of the Status register is 1.
✧ Bits 63 and 62 of the 64-bit virtual address are 11.
✧ Bits 61 to 31 of the virtual address are all 1.

(a) ckseg0

This space is an unmapped region, compatible with the 32-bit mode kseg0 space. The K0 field of the Config register controls cacheability and coherency.

(b) ckseg1

This space is an unmapped and uncached region, compatible with the 32-bit mode kseg1 space.

(c) cksseg

This space is the current supervisor virtual space, compatible with the 32-bit mode ksseg space.
References to cksseg are mapped through TLB. Whether cache can be used or not is determined by bit C of each page's TLB entry.

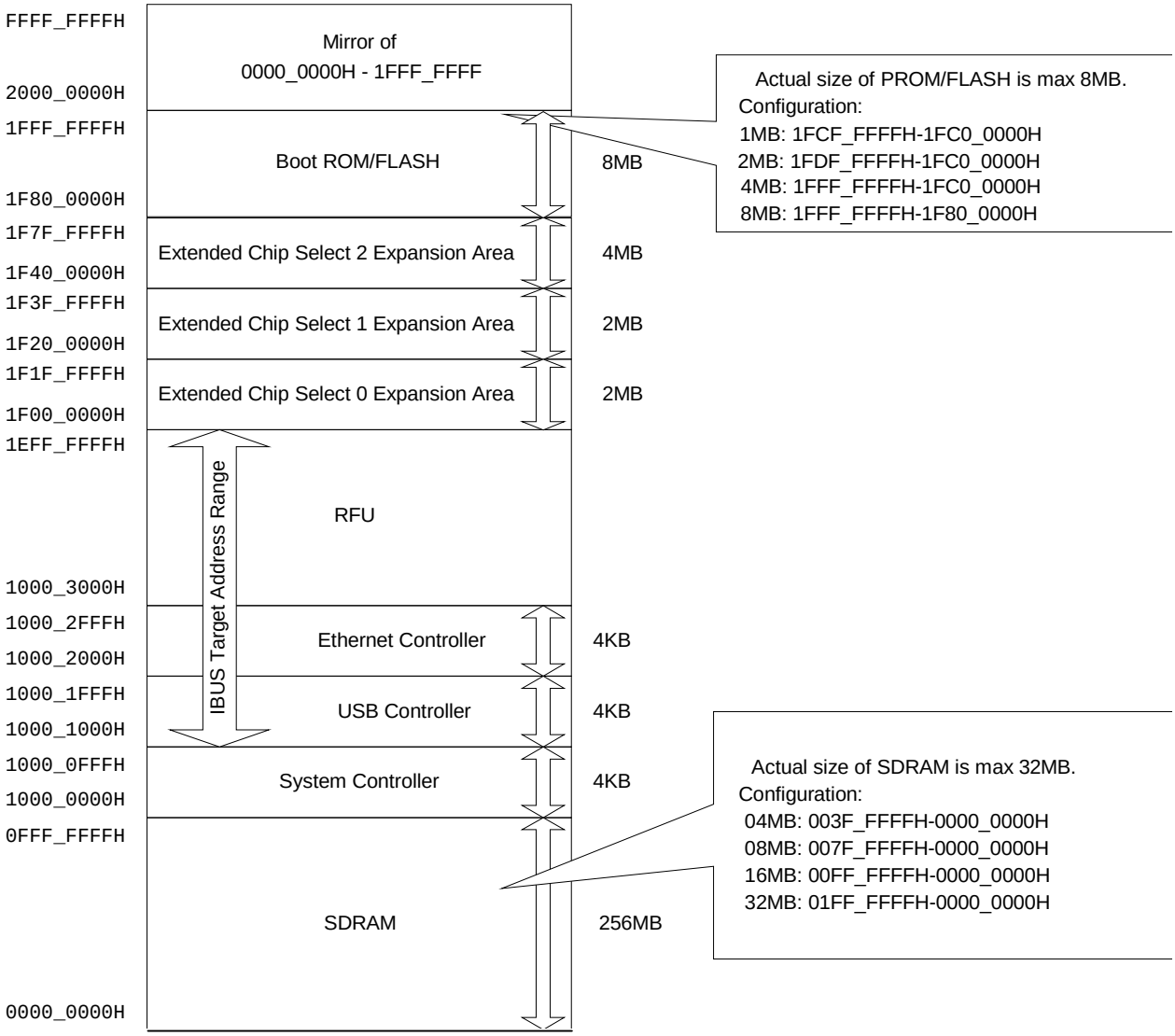
(d) ckseg3

This space is the current supervisor virtual space, compatible with the 32-bit mode kseg3 space.
References to ckseg3 are mapped through TLB. Whether cache can be used or not is determined by bit C of each page's TLB entry.

2.4.3 Physical address space

So VR4120A core uses a 32-bit address, that the processor physical address space encompasses 4 Gbytes. The VR4120A uses this 4-Gbyte physical address space as shown in Figure 2-41.

Figure 2-41 LAKI Physical Address Space



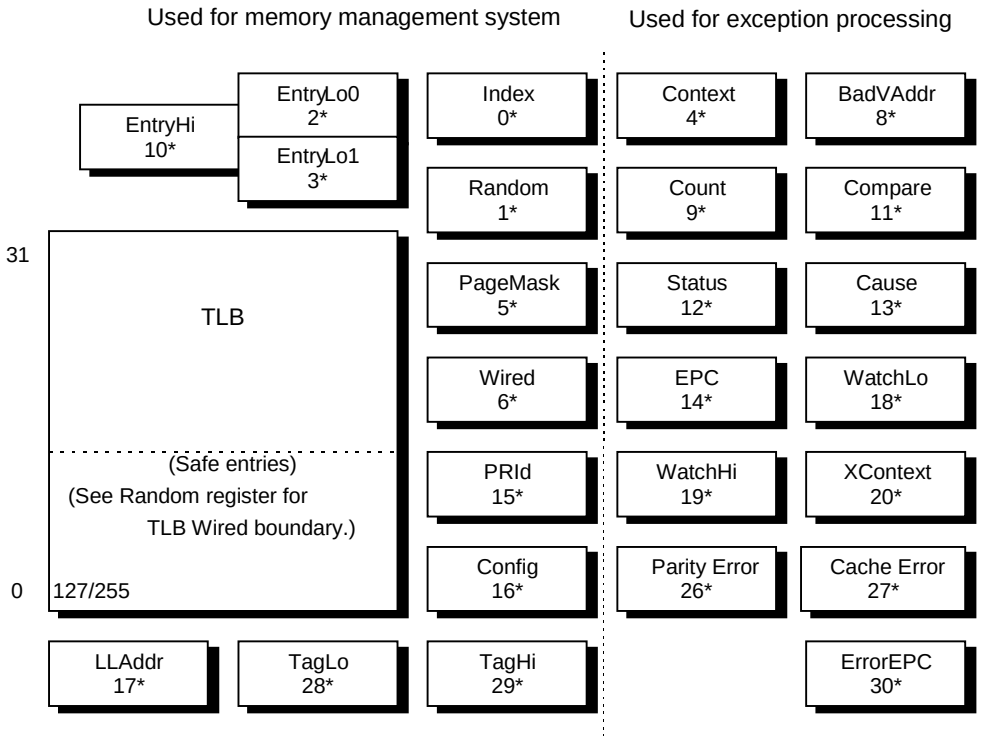
2.4.3.1 <empty>

2.4.4 System control coprocessor

The System Control Coprocessor (CP0) is implemented as an integral part of the CPU, and supports memory management, address translation, exception processing, and other privileged operations. The CP0 contains the registers and a 32-entry TLB shown in Figure 2-42. The sections that follow describe how the processor uses each of the memory management-related registers.

Remark Each CP0 register has a unique number that identifies it; this number is referred to as the register number.

Figure 2-42. CP0 Registers and TLB

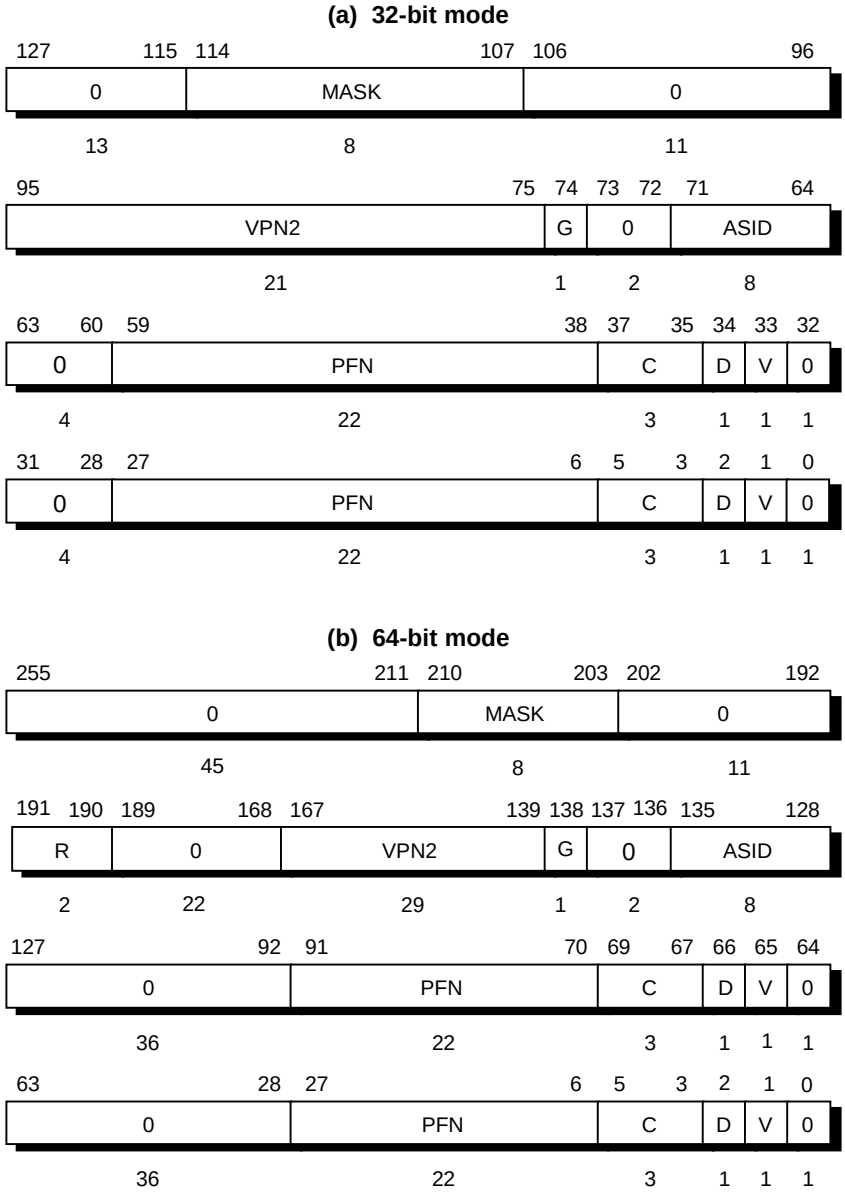


Remark *: Register number

2.4.4.1 Format of a TLB entry

Figure 2-43 shows the TLB entry formats for both 32- and 64-bit modes. Each field of an entry has a corresponding field in the EntryHi, EntryLo0, EntryLo1, or PageMask registers.

Figure 2-43. Format of a TLB Entry



The format of the EntryHi, EntryLo0, EntryLo1, and PageMask registers are nearly the same as the TLB entry. However, it is unknown what bit of the EntryHi register corresponds to the TLB G bit.

2.4.5 CP0 registers

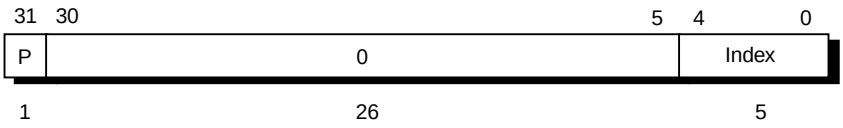
The CP0 registers explained below are accessed by the memory management system and software. The parenthesized number that follows each register name is the register number.

2.4.5.1 Index register (0)

The Index register is a 32-bit, read/write register containing five low-order bits to index an entry in the TLB. The most-significant bit of the register shows the success or failure of a TLB probe (TLBP) instruction.

The Index register also specifies the TLB entry affected by TLB read (TLBR) or TLB write index (TLBWI) instructions.

Figure 2-44. Index Register



P : Indicates whether probing is successful or not. It is set to 1 if the latest TLBP instruction fails. It is cleared to 0 when the TLBP instruction is successful.

Index : Specifies an index to a TLB entry that is a target of the TLBR or TLBWI instruction.

0 : RFU. Write 0 in a write operation. When this field is read, 0 is read.

2.4.5.2 Random register (1)

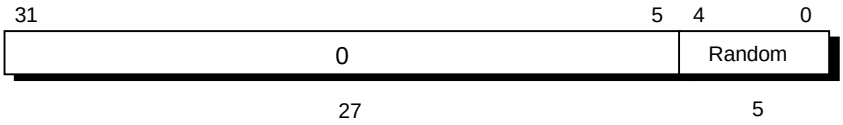
The Random register is a read-only register. The low-order 5 bits are used in referencing a TLB entry. This register is decremented each time an instruction is executed. The values that can be set in the register are as follows:

- ✧ The lower bound is the content of the Wired register.
- ✧ The upper bound is 31.

The Random register specifies the entry in the TLB that is affected by the TLBWR instruction. The register is readable to verify proper operation of the processor.

The Random register is set to the value of the upper bound upon Cold Reset. This register is also set to the upper bound when the Wired register is written. Figure 2-45 shows the format of the Random register.

Figure 2-45. Random Register



Random : TLB random index

0 : RFU. Write 0 in a write operation. When this field is read, 0 is read.

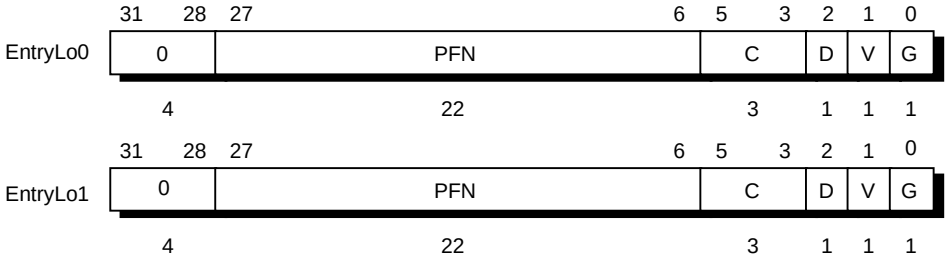
2.4.5.3 EntryLo0 (2) and EntryLo1 (3) registers

The EntryLo register consists of two registers that have identical formats: EntryLo0, used for even virtual pages and EntryLo1, used for odd virtual pages. The EntryLo0 and EntryLo1 registers are both read-/write-accessible. They are used to access the on-chip TLB. When a TLB read/write operation is carried out, the EntryLo0 and EntryLo1 registers hold the contents of the low-order 32 bits of TLB entries at even and odd addresses, respectively.

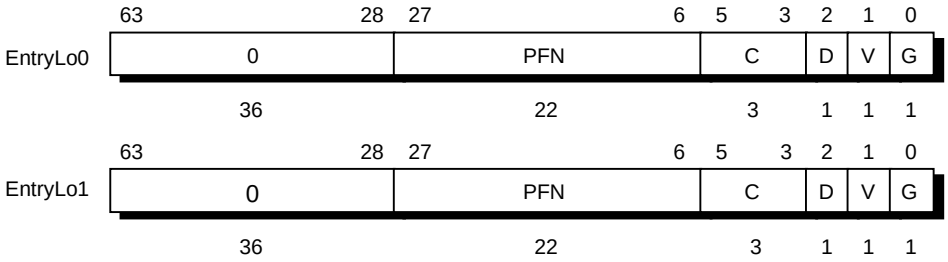
Since the contents of these registers after reset is undefined, initialize these registers via software.

Figure 2-46. EntryLo0 and EntryLo1 Registers

(a) 32-bit mode



(b) 64-bit mode



PFN : Page frame number; high-order bits of the physical address.

C : Specifies the TLB page attribute (see Table 2-54).

D : Dirty. If this bit is set to 1, the page is marked as dirty and, therefore, writable. This bit is actually a write-protect bit that software can use to prevent alteration of data.

V : Valid. If this bit is set to 1, it indicates that the TLB entry is valid; otherwise, a TLB Invalid exception (TLBL or TLBS) occurs.

G : Global. If this bit is set in both EntryLo0 and EntryLo1, then the processor ignores the ASID during TLB lookup.

0 : RFU. Write 0 in a write operation. When this field is read, 0 is read.

The coherency attribute (C) bits are used to specify whether to use the cache in referencing a page. When the cache is used, whether the page attribute is “cached” or “uncached” is selected by algorithm.

Table 2-54 lists the page attributes selected according to the value in the C bits.

Table 2-54. Cache Algorithm

C Bit Value	Cache Algorithm
0	Cached
1	Cached
2	Uncached
3	Cached
4	Cached
5	Cached
6	Cached
7	Cached

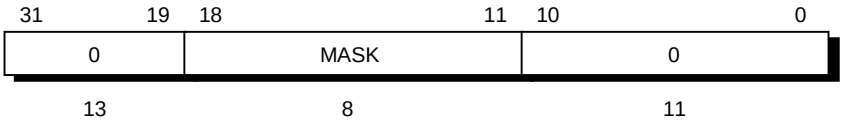
2.4.5.4 PageMask register (5)

The PageMask register is a read/write register used for reading from or writing to the TLB; it holds a comparison mask that sets the page size for each TLB entry, as shown in Table 2-55. Page sizes must be from 1 Kbyte to 256 Kbytes.

TLB read and write instructions use this register as either a source or a destination; Bits 18 to 11 that are targets of comparison are masked during address translation.

Since the contents of the PageMask register after reset is undefined, initialize this register via software.

Figure 2-47. Page Mask Register



MASK : Page comparison mask, which determines the virtual page size for the corresponding entry.

0 : RFU. Write 0 in a write operation. When this field is read, 0 is read.

Table 2-55 lists the mask pattern for each page size. If the mask pattern is one not listed below, the TLB behaves unexpectedly.

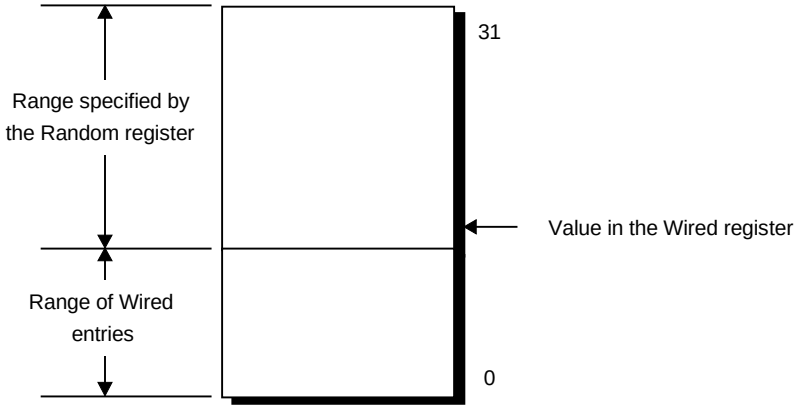
Table 2-55. Mask Values and Page Sizes

Page Size	Bit							
	18	17	16	15	14	13	12	11
1 Kbyte	0	0	0	0	0	0	0	0
4 Kbytes	0	0	0	0	0	0	1	1
16 Kbytes	0	0	0	0	1	1	1	1
64 Kbytes	0	0	1	1	1	1	1	1
256 Kbytes	1	1	1	1	1	1	1	1

2.4.5.5 Wired register (6)

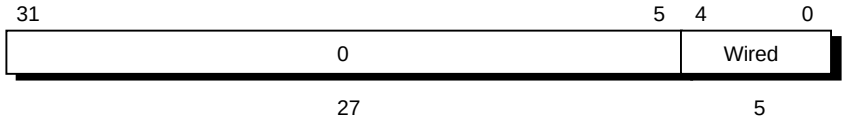
The Wired register is a read/write register that specifies the lower boundary of the random entry of the TLB as shown in Figure 2-48. Wired entries cannot be overwritten by a TLBWR instruction. They can, however, be overwritten by a TLBWI instruction. Random entries can be overwritten by both instructions.

Figure 2-48. Positions Indicated by Wired Register



The Wired register is set to 0 upon Cold Reset. Writing this register also sets the Random register to the value of its upper bound (see **Section 2.5.5.2 Random register (1)**). Figure 2-49 shows the format of the Wired register.

Figure 2-49. Wired Register



Wired : TLB wired boundary

0 : RFU. Write 0 in a write operation. When this field is read, 0 is read.

2.4.5.6 EntryHi register (10)

The EntryHi register is write-accessible. It is used to access the on-chip TLB. The EntryHi register holds the high-order bits of a TLB entry for TLB read and write operations. If a TLB Mismatch, TLB Invalid, or TLB Modified exception occurs, the EntryHi register holds the high-order bit of the TLB entry. The EntryHi register is also set with the virtual page number (VPN2) for a virtual address where an exception occurred and the ASID. See **Section 2.6 Exception Processing** for details of the TLB exception.

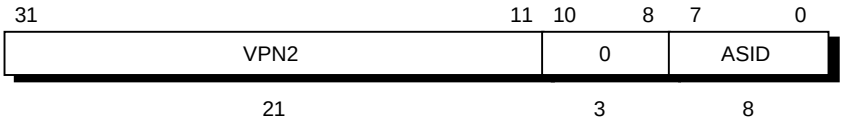
The ASID is used to read from or write to the ASID field of the TLB entry. It is also checked with the ASID of the TLB entry as the ASID of the virtual address during address translation.

The EntryHi register is accessed by the TLBP, TLBWR, TLBWI, and TLBR instructions.

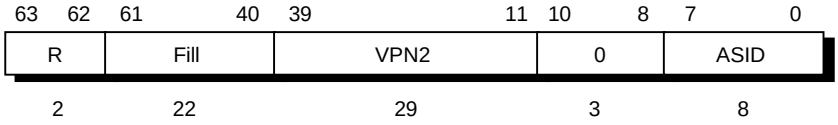
Since the contents of the EntryHi register after reset is undefined, initialize this register via software.

Figure 2-50. EntryHi Register

(a) 32-bit mode



(b) 64-bit mode



VPN2: Virtual page number divided by two (mapping to two pages)

ASID : Address space ID. An 8-bit ASID field that lets multiple processes share the TLB; each process has a distinct mapping of otherwise identical virtual page numbers.

R : Space type (00 → user, 01 → supervisor, 11 → kernel). Matches bits 63 and 62 of the virtual address.

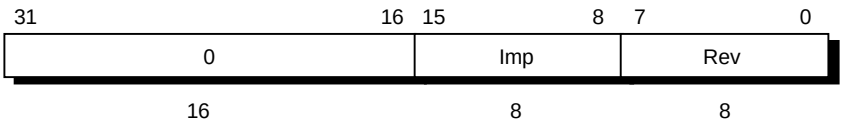
Fill : RFU. Ignored on write. When read, returns zero.

0 : RFU. Write 0 in a write operation. When this field is read, 0 is read.

2.4.5.7 Processor revision identifier (PRId) register (15)

The 32-bit, read-only Processor Revision Identifier (PRId) register contains information identifying the implementation and revision level of the CPU and CP0. Figure 2-51 shows the format of the PRId register.

Figure 2-51. PRId Register



Imp : CPU core processor ID number (0CH for the VR4120A)

Rev : CPU core processor revision number

0 : RFU. Write 0 in a write operation. When this field is read, 0 is read.

The processor revision number is stored as a value in the form y.x, where y is a major revision number in bits 7 to 4 and x is a minor revision number in bits 3 to 0.

The processor revision number can distinguish some CPU core revisions, however there is no guarantee that changes to the CPU core will necessarily be reflected in the PRId register, or that changes to the revision number necessarily reflect real CPU core changes. Therefore, create a program that does not depend on the processor revision number area.

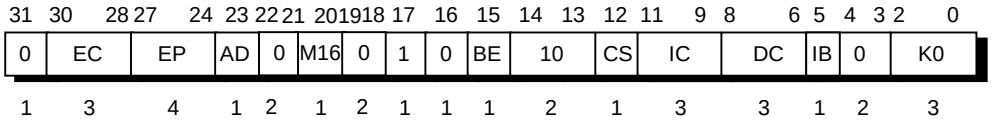
2.4.5.8 Config register (16)

The Config register specifies various configuration options selected on VR4120A processors.

Some configuration options, as defined by the EC and BE fields, are set by the hardware during Cold Reset and are included in the Config register as read-only status bits for the software to access. Other configuration options are read/write (AD, EP, and K0 fields) and controlled by software; on Cold Reset these fields are undefined. Since only a subset of the VR4000 Series options are available in the VR4120A, some bits are set to constants (e.g., bits 14:13) that were variable in the VR4000 Series. The Config register should be initialized by software before caches are used. Figure 2-52 shows the format of the Config register.

Since the contents of the Config register after reset is undefined, initialize this register via software.

Figure 2-52. Config Register Format



EC : Frequency ratio of system interface clock (VTCLK) (read only)
- 0 to 6 → RFU
- 7 → Pipeline clock (ACLK) frequency /1

EP : Transfer data pattern (cache write-back pattern) setting
- 0 → DDDD
- Others → RFU

AD : Accelerate data mode
- 0 → VR4000 Series compatible mode
- 1 → RFU

M16: MIPS16 ISA mode enable/disable indication (read only)
- 0 → MIPS16 instruction cannot be executed
- 1 → MIPS16 instruction can be executed.

BE : BigEndianMem. Endian mode of memory and a kernel.
- 0 → Little endian
- 1 → Big endian

CS : Cache size mode indication (fixed to 1 in the VR4120A)
- 0 → IC = $2^{(n+12)}$ Bytes, DC = $2^{(n+12)}$ Bytes
- 1 → IC = $2^{(n+10)}$ Bytes, DC = $2^{(n+10)}$ Bytes

IC : Instruction cache size indication. In the VR4120A, $2^{(IC+10)}$ bytes.
- 4 → 16 Kbytes
- Others → RFU

DC : Data cache size indication. In the VR4120A, $2^{(DC+10)}$ bytes.
- 3 → 8 Kbytes
- Others → RFU

IB : Select refill size (note: IB must be set to ’0’; 8 words refill size is not supported!)
- 0 → 4 words (16 bytes)
- 1 → 8 words (32 bytes)

K0 : kseg0 cache coherency algorithm
- 010 → Uncached
- Others → Cached

1 : 1 is returned when read.

0 : 0 is returned when read.

Caution Be sure to set the EP field, the AD bit and the IB bit to 0. If they are set with any other values, the processor may behave unexpectedly.

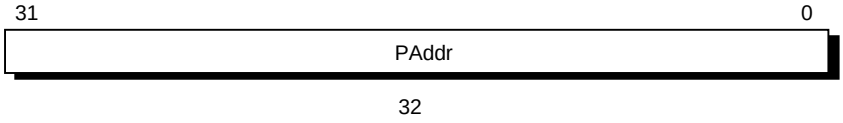
2.4.5.9 Load linked address (LLAddr) register (17)

The read/write Load Linked Address (LLAddr) register is not used with the VR4120A processor except for diagnostic purpose, and serves no function during normal operation.

LLAddr register is implemented just for compatibility between the VR4120A and VR4000/VR4400™.

The contents of the LLAddr register after reset is undefined.

Figure 2-53. LLAddr Register



PAddr: 32-bit physical address

2.4.5.10 Cache tag registers (TagLo (28) and TagHi (29))

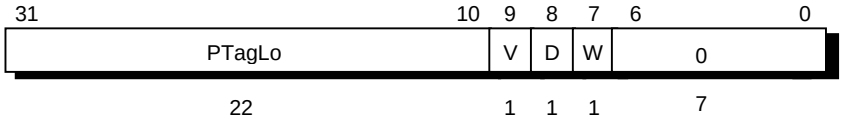
The TagLo and TagHi registers are 32-bit read/write registers that hold the primary cache tag during cache initialization, cache diagnostics, or cache error processing. The Tag registers are written by the CACHE and MTC0 instructions.

Figures 2-54 and 2-55 show the format of these registers.

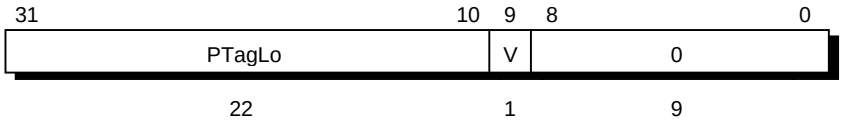
The contents of these registers after reset is undefined.

Figure 2-54. TagLo Register

(a) When used with data cache



(b) When used with instruction cache



PTagLo: Specifies physical address bits 31 to 10.

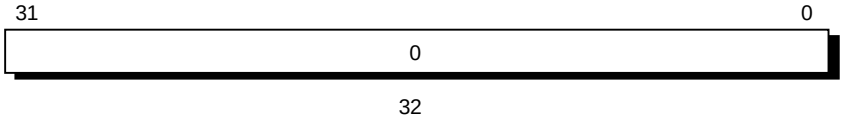
V : Valid bit

D : Dirty bit. However, this bit is defined only for the compatibility with the VR4000 Series processors, and does not indicate the status of cache memory in spite of its readability and writability. This bit cannot change the status of cache memory.

W : Write-back bit (set if cache line has been updated)

0 : RFU. Write 0 in a write operation. When this field is read, 0 is read.

Figure 2-55. TagHi Register



0: RFU. Write 0 in a write operation. When this field is read, 0 is read.

2.4.5.11 Virtual-to-physical address translation

During virtual-to-physical address translation, the CPU compares the 8-bit ASID (when the Global bit, G, is not set to 1) of the virtual address to the ASID of the TLB entry to see if there is a match. One of the following comparisons are also made:

- ✧ In 32-bit mode, the high-order bits[Note] of the 32-bit virtual address are compared to the contents of the VPN2 (virtual page number divided by two) of each TLB entry.
- ✧ In 64-bit mode, the high-order bits[Note] of the 64-bit virtual address are compared to the contents of the VPN2 (virtual page number divided by two) of each TLB entry.

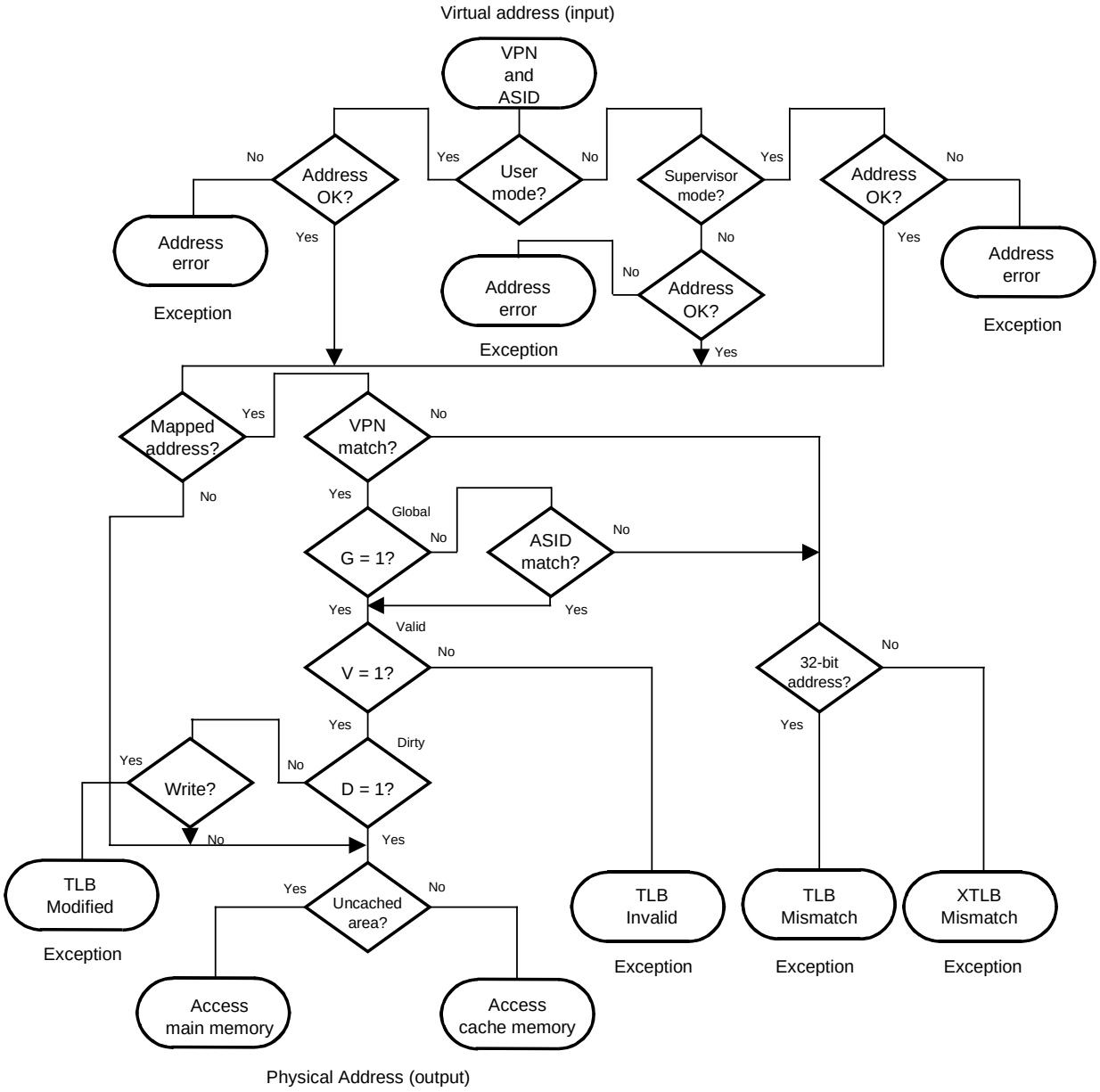
If a TLB entry matches, the physical address and access control bits (C, D, and V) are retrieved from the matching TLB entry. While the V bit of the entry must be set to 1 for a valid address translation to take place, it is not involved in the determination of a matching TLB entry.

Figure 2-56 illustrates the TLB address translation flow.

Notes 1. Up to bit 28. Number of bits depends on the TBL page size

2. Up to bit 29. Number of bits depends on the TBL page size

Figure 2-56. TLB Address Translation



2.4.5.12 TLB misses

If there is no TLB entry that matches the virtual address, a TLB Refill (miss) exception occurs[Note]. If the access control bits (D and V) indicate that the access is not valid, a TLB Modified or TLB Invalid exception occurs. If the C bit is 010, the retrieved physical address directly accesses main memory, bypassing the cache.

Note See **Section 2.6 Exception Processing** for details of the TLB Miss exception.

2.4.5.13 TLB instructions

The instructions used for TLB control are described below.

(1) Translation lookaside buffer probe (TLBP)

The translation lookaside buffer probe (TLBP) instruction loads the Index register with a TLB number that matches the content of the EntryHi register. If there is no TLB number that matches the TLB entry, the highest-order bit of the Index register is set.

(2) Translation lookaside buffer read (TLBR)

The translation lookaside buffer read (TLBR) instruction loads the EntryHi, EntryLo0, EntryLo1, and PageMask registers with the content of the TLB entry indicated by the content of the Index register.

(3) Translation lookaside buffer write index (TLBWI)

The translation lookaside buffer write index (TLBWI) instruction writes the contents of the EntryHi, EntryLo0, EntryLo1, and PageMask registers to the TLB entry indicated by the content of the Index register.

(4) Translation lookaside buffer write random (TLBWR)

The translation lookaside buffer write random (TLBWR) instruction writes the contents of the EntryHi, EntryLo0, EntryLo1, and PageMask registers to the TLB entry indicated by the content of the Random register.

2.5 Exception Processing

This chapter describes VR4120A CPU exception processing, including an explanation of hardware that processes exceptions.

2.5.1 Exception processing operation

The processor receives exceptions from a number of sources, including translation lookaside buffer (TLB) misses, arithmetic overflows, I/O interrupts, and system calls. When the CPU detects an exception, the normal sequence of instruction execution is suspended and the processor enters Kernel mode (see **Section 2.5 Memory Management System** for a description of system operating modes). If an exception occurs while executing a MIPS16 instruction, the processor stops the MIPS16 instruction execution, and shifts to the 32-bit instruction execution mode.

The processor then disables interrupts and transfers control for execution to the exception handler (located at a specific address as an exception handling routine implemented by software). The exception handler saves the context of the processor, including the contents of the program counter, the current operating mode (User or Supervisor), statuses, and interrupt enabling. This context is saved so it can be restored when the exception has been serviced.

When an exception occurs, the CPU loads the Exception Program Counter (EPC) register with a location where execution can restart after the exception has been serviced. The restart location in the EPC register is the address of the instruction that caused the exception or, if the instruction was executing in a branch delay slot, the address of the branch instruction immediately preceding the delay slot. Note that no branch delay slot generated by executing a branch instruction exists when the processor operates in the MIPS16 mode.

When MIPS16 instructions are enabled to be executed, bit 0 of the EPC register indicates the operating mode in which an exception occurred. It indicates 1 when in the MIPS16 instruction mode, and indicates 0 when in the MIPS III instruction mode.

The VR4120A processor supports a Supervisor mode and high-speed TLB refill for all address spaces. The VR4120A CPU also provides the following functions:

- ✧ Interrupt enable (IE) bit
- ✧ Operating mode (User, Supervisor, or Kernel)
- ✧ Exception level (normal or exception is indicated by the EXL bit in the Status register)
- ✧ Error level (normal or error is indicated by the ERL bit in the Status register).

Interrupts are enabled when the following conditions are satisfied:

2.5.1.1 Interrupt enable

An interrupt is enabled when the following conditions are satisfied.

- Interrupt enable bit (IE) = 1
- EXL bit = 0, ERL bit = 0
- Corresponding IM field bits in the Status register = 1

2.5.1.2 Operating mode

The operating mode is specified by KSU bit in the Status register when both the exception level and error level are normal (0). The operation enters Kernel mode when either EXL bit or ERL bit in the Status register is set to 1.

2.5.1.3 Exception/error levels

Returning from an exception resets the exception level to normal (0) (for details, see **APPENDIX A MIPS III INSTRUCTION SET DETAILS**).

The registers that retain address, cause, and status information during exception processing are described in **Section 2.6.3 Exception processing registers**. For a description of the exception process, see **Section 2.6.4 Details of exceptions**.

2.5.2 Precision of exceptions

VR4120A CPU exceptions are logically precise; the instruction that causes an exception and all those that follow it are aborted and can be re-executed after servicing the exception. When succeeding instructions are discarded, exceptions associated with those instructions are also discarded. Exceptions are not taken in the order detected, but in instruction fetch order.

The exception handler can determine the cause of an exception and the address. The program can be restarted by rewriting the destination register - not automatically, however, as in the case of all the other precise exceptions where no status change occurs.

2.5.3 Exception processing registers

This section describes the CP0 registers that are used in exception processing. Table 2-56 lists these registers, along with their number-each register has a unique identification number that is referred to as its register number. The CP0 registers not listed in the table are used in memory management (for details, see **Section 2.5 Memory Management System**).

The exception handler examines the CP0 registers during exception processing to determine the cause of the exception and the state of the CPU at the time the exception occurred.

The registers in Table 2-56 are used in exception processing, and are described in the sections that follow.

Table 2-56. CP0 Exception Processing Registers

Register Name	Register Number
Context register	4
BadVAddr register	8
Count register	9
Compare register	11
Status register	12
Cause register	13
EPC register	14
WatchLo register	18
WatchHi register	19
XContext register	20
Parity Error register[Note]	26
Cache Error register[Note]	27
Error EPC register	30

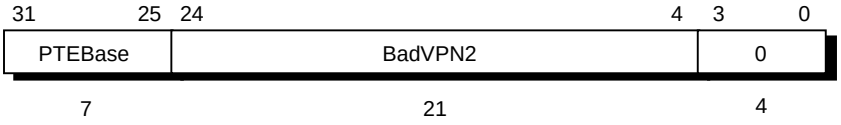
Note This register is prepared to maintain compatibility with the VR4100. This register is not used in LAKI hardware.

2.5.3.1 Context register (4)

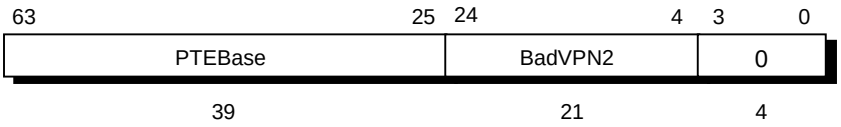
The Context register is a read/write register containing the pointer to an entry in the page table entry (PTE) array on the memory; this array is a table that stores virtual-to-physical address translations. When there is a TLB miss, the operating system loads the unsuccessfully translated entry from the PTE array to the TLB. The Context register is used by the TLB Refill exception handler for loading TLB entries. The Context register duplicates some of the information provided in the BadVAddr register, but the information is arranged in a form that is more useful for a software TLB exception handler. Figure 2-57 shows the format of the Context register.

Figure 2-57. Context Register Format

(a) 32-bit mode



(b) 64-bit mode



PTEBase : The PTEBase field is a base address of the PTE entry table.

BadVPN2 : This field holds the value (VPN2) obtained by halving the virtual page number of the most recent virtual address for which translation failed.

0 : RFU. Write 0 in a write operation. When this field is read, 0 is read.

The PTEBase field is used by software as the pointer to the base address of the PTE table in the current user address space.

The 21-bit BadVPN2 field contains bits 31 to 11 of the virtual address that caused the TLB miss; bit 10 is excluded because a single TLB entry maps to an even-odd page pair. For a 1-Kbyte page size, this format can directly address the pair-table of 8-byte PTEs. When the page size is 4 Kbytes or more, shifting or masking this value produces the correct PTE reference address.

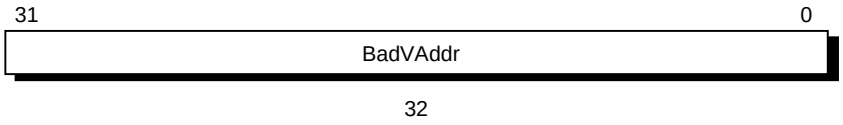
2.5.3.2 BadVAddr register (8)

The Bad Virtual Address (BadVAddr) register is a read-only register that saves the most recent virtual address that failed to have a valid translation, or that had an addressing error. Figure 2-58 shows the format of the BadVAddr register.

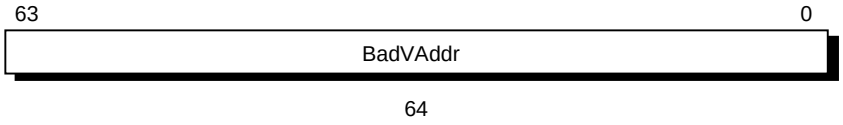
Caution This register saves no information after a bus error exception, because it is not an address error exception.

Figure 2-58. BadVAddr Register Format

(a) 32-bit mode



(b) 64-bit mode



BadVAddr: Most recent virtual address for which an addressing error occurred, or for which address translation failed.

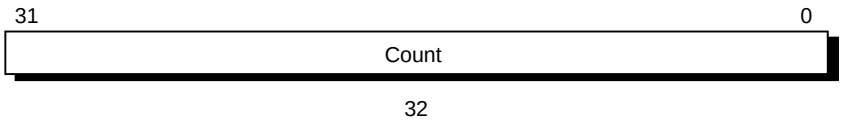
2.5.3.3 Count register (9)

The read/write Count register acts as a timer. It is incremented in synchronization with the frequencies of MasterOut clock, regardless of whether instructions are being executed, retired, or any forward progress is actually made through the pipeline.

This register is a free-running type. When the register reaches all ones, it rolls over to zero and continues counting. This register is used for self-diagnostic test, system initialization, or the establishment of inter-process synchronization.

Figure 2-59 shows the format of the Count register.

Figure 2-59. Count Register Format



Count: 32-bit up-date count value that is compared with the value of the Compare register.

2.5.3.4 Compare register (11)

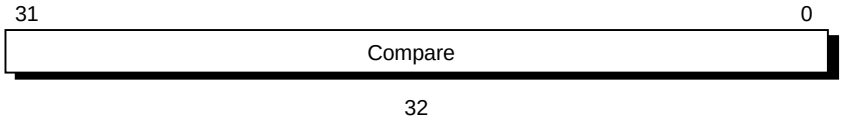
The Compare register causes a timer interrupt; it maintains a stable value that does not change on its own.

When the value of the Count register (see **Section 2.6.3.3 Count register (9)**) equals the value of the Compare register, the IP7 bit in the Cause register is set. This causes an interrupt as soon as the interrupt is enabled.

Writing a value to the Compare register, as a side effect, clears the timer interrupt request.

For diagnostic purposes, the Compare register is a read/write register. Normally, this register should be only used for a write. Figure 2-60 shows the format of the Compare register.

Figure 2-60. Compare Register Format

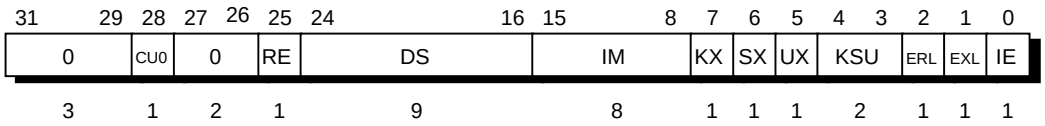


Compare: Value that is compared with the count value of the Count register.

2.5.3.5 Status register (12)

The Status register is a read/write register that contains the operating mode, interrupt enabling, and the diagnostic states of the processor. Figure 2-61 shows the format of the Status register.

Figure 2-61. Status Register Format



CU0 : Enables/disables the use of the coprocessor (1 → Enabled, 0 → Disabled).
CP0 can be used by the kernel at all times.

RE : Enables/disables reversing of the endian setting in User mode. Be sure to set to 0 since the VR4120A core can operate with either the little endian or big endian setting but cannot reverse the endian setting.
0 … Disabled
1 … Setting prohibited

DS : Diagnostic Status field (see Figure 2-62).

IM : Interrupt Mask field used to enable/disable external/internal and software interrupts (0 → Disabled, 1 → Enabled). This field consists of 8 bits that are used to control eight interrupts. The bits are assigned to interrupts as follows:
IM7 : Masks a timer interrupt.
IM(6:2) :Mask ordinary interrupts (Int(4:0)[Note]).
IM(1:0) : Software interrupts.

Note Int(4:0) are internal signals of the CPU core. For details about connection refer to the on-chip peripheral units and to chapter 1.11

KX : Enables 64-bit addressing in Kernel mode (0 → 32-bit, 1 → 64-bit). If this bit is set, an XTLB Refill exception occurs if a TLB miss occurs in the Kernel mode address space.
In addition, 64-bit operations are always valid in kernel mode.

SX : Enables 64-bit addressing and operation in Supervisor mode (0 → 32-bit, 1 → 64-bit). If this bit is set, an XTLB Refill exception occurs if a TLB miss occurs in the Supervisor mode address space.

UX: : Enables 64-bit addressing and operation in User mode (0 → 32-bit, 1 → 64-bit). If this bit is set, an XTLB Refill exception occurs if a TLB miss occurs in the User mode address space.

KSU : Sets and indicates the operating mode (10 → User, 01 → Supervisor, 00 → Kernel).

ERL : Sets and indicates the error level (0 → Normal, 1 → Error).

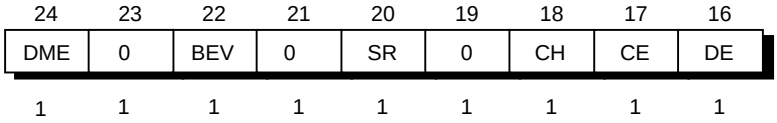
EXL : Sets and indicates the exception level (0 → Normal, 1 → Exception).

IE : Sets and indicates interrupt enabling/disabling (0 → Disabled, 1 → Enabled).

0 : RFU. Write 0 in a write operation. When this bit is read, 0 is read.

Figure 2-62 shows the details of the Diagnostic Status (DS) field. All DS field bits other than the TS bit are writable.

Figure 2-62. Status Register Diagnostic Status Field



DME : Sets and indicates the debug mode. (0 … Disabled ;1 … Enabled)

BEV : Specifies the base address of a TLB Refill exception vector and common exception vector (0 → Normal, 1 → Bootstrap).

SR : Occurs a Soft Reset or NMI exception (0 → Not occurred, 1 → Occurred).

CH : CP0 condition bit (0 → False, 1 → True). This bit can be read and written by software only; it cannot be accessed by hardware.

CE, DE: These are prepared to maintain compatibility with the VR4100, and are not used in the VR4120A Core hardware.

0 : RFU. Write 0 in a write operation. When this field is read, 0 is read.

The status register has the following fields where the modes and access status are set.

(1) Interrupt enable

Interrupts are enabled when all of the following conditions are true:

- ✧ IE is set to 1.
- ✧ EXL is cleared to 0.
- ✧ ERL is cleared to 0.
- ✧ The appropriate bit of the IM is set to 1.

(2) Operating modes

The following Status register bit settings are required for User, Kernel, and Supervisor modes.

- ✧ The processor is in User mode when KSU = 10, EXL = 0, and ERL = 0.
- ✧ The processor is in Supervisor mode when KSU = 01, EXL = 0, and ERL = 0.
- ✧ The processor is in Kernel mode when KSU = 00, EXL = 1, or ERL = 1.

(3) 32- and 64-bit modes

The following Status register bit settings select 32- or 64-bit operation for User, Kernel, and Supervisor operating modes. Enabling 64-bit operation permits the execution of 64-bit opcodes and translation of 64-bit addresses. 64-bit operation for User, Kernel and Supervisor modes can be set independently.

- ✧ 64-bit addressing for Kernel mode is enabled when KX bit = 1. 64-bit operations are always valid in Kernel mode.
- ✧ 64-bit addressing and operations are enabled for Supervisor mode when SX bit = 1.
- ✧ 64-bit addressing and operations are enabled for User mode when UX bit = 1.

(4) Kernel address space accesses

Access to the kernel address space is allowed when the processor is in Kernel mode.

(5) Supervisor address space accesses

Access to the supervisor address space is allowed when the processor is in Supervisor or Kernel mode.

(6) User address space accesses

Access to the user address space is allowed in any of the three operating modes.

(7) Status after reset

The contents of the Status register are undefined after Cold resets, except for the following bits in the diagnostic status field.

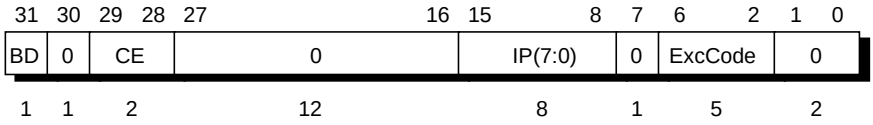
- TS and SR are cleared to 0.
- ERL and BEV are set to 1.
- SR is 0 after Cold reset, and is 1 after Soft reset or NMI interrupt.

Remark Cold reset and Soft reset are CPU core reset (see **Section 2.7 Initialization Interface**).

2.5.3.6 Cause register (13)

The 32-bit read/write Cause register holds the cause of the most recent exception. A 5-bit exception code indicates one of the causes (see Table 2-57). Other bits hold the detailed information of the specific exception. All bits in the Cause register, with the exception of the IP1 and IP0 bits, are read-only; IP1 and IP0 are used for software interrupts. Figure 2-63 shows the fields of this register; Table 2-57 describes the Cause register codes.

Figure 2-63. Cause Register Format



BD : Indicates whether the most recent exception occurred in the branch delay slot (1 → In delay slot, 0 → Normal).

CE : Indicates the coprocessor number in which a Coprocessor Unusable exception occurred. This field will remain undefined for as long as no exception occurs.

IP : Indicates whether an interrupt is pending (1 → Interrupt pending, 0 → No interrupt pending).

- IP7 : A timer interrupt.
- IP(6:2) : Ordinary interrupts (Int(4:0)[Note]).
- IP(1:0) : Software interrupts. Only these bits cause an interrupt exception, when they are set to 1 by means of software.

Note Int(4:0) are internal signals of the CPU core. For details about connection refer to the on-chip peripheral units and to chapter 1.11

ExcCode: Exception code field (refer to Table 2-57 for details).

0 : RFU. Write 0 in a write operation. When this field is read, 0 is read.

Table 2-57. Cause Register Exception Code Field

Exception Code	Mnemonic	Description
0	Int	Interrupt exception
1	Mod	TLB Modified exception
2	TLBL	TLB Refill exception (load or fetch)
3	TLBS	TLB Refill exception (store)
4	AdEL	Address Error exception (load or fetch)
5	AdES	Address Error exception (store)
6	IBE	Bus Error exception (instruction fetch)
7	DBE	Bus Error exception (data load or store)
8	Sys	System Call exception
9	Bp	Breakpoint exception
10	RI	Reserved Instruction exception
11	CpU	Coprocessor Unusable exception
12	Ov	Integer Overflow exception
13	Tr	Trap exception
14 to 22	—	RFU
23	WATCH	Watch exception
24 to 31	—	RFU

The VR4120A CPU has eight interrupt request sources, IP7 to IP0. For the detailed description of interrupts, refer to **Section 2.8 CPU Core Interrupts**.

(1) IP7

This bit indicates whether there is a timer interrupt request.

It is set when the values of Count register and Compare register match.

(2) IP6 to IP2

IP6 to IP2 reflect the state of the interrupt request signal of the CPU core.

(3) IP1 and IP0

These bits are used to set/clear a software interrupt request.

2.5.3.7 Exception program counter (EPC) register (14)

The Exception Program Counter (EPC) is a read/write register that contains the address at which processing resumes after an exception has been serviced. The contents of this register change depending on whether execution of MIPS16 instructions is enabled or disabled. Setting the MIPS16EN pin after RTC reset specifies whether execution of the MIPS16 instructions is enabled or disabled.

When the MIPS16 instruction execution is disabled, the EPC register contains either:

- Virtual address of the instruction that caused the exception.
- Virtual address of the immediately preceding branch or jump instruction (when the instruction associated with the exception is in a branch delay slot, and the BD bit in the Cause register is set to 1).

When the MIPS16 instruction execution is enabled, the EPC register contains either:

- Virtual address of the instruction that caused the exception and ISA mode at which an exception occurs.
- Virtual address of the immediately preceding branch or jump instruction and ISA mode at which an exception occurs (when the instruction associated with the exception is in a branch delay slot of the jump instruction, and the BD bit in the Cause register is set to 1).

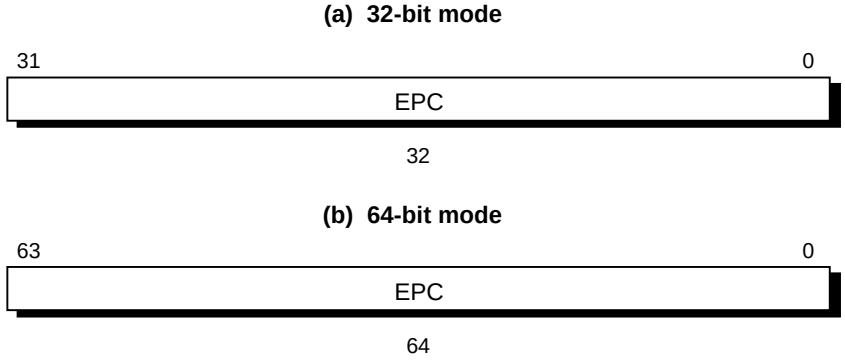
When the 16-bit instruction is executed, the EPC register contains either:

- Virtual address of the instruction that caused the exception and ISA mode at which an exception occurs.
- Virtual address of the immediately preceding Extend or jump instruction and ISA mode at which an exception occurs (when the instruction associated with the exception is in a branch delay slot of the jump instruction or in the instruction following the Extend instruction, and the BD bit in the Cause register is set to 1).

The EXL bit in the Status register is set to 1 to keep the processor from overwriting the address of the exception-causing instruction contained in the EPC register in the event of another exception.

Figure 2-64 shows the EPC register format when MIPS16 ISA is disabled, and Figure 2-65 shows the EPC register format when MIPS16 ISA is enabled.

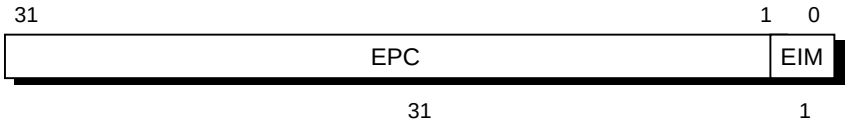
Figure 2-64. EPC Register Format (When MIPS16 ISA Is Disabled)



EPC: Restart address after exception processing.

Figure 2-65. EPC Register Format (When MIPS16 ISA Is Enabled)

(a) 32-bit mode

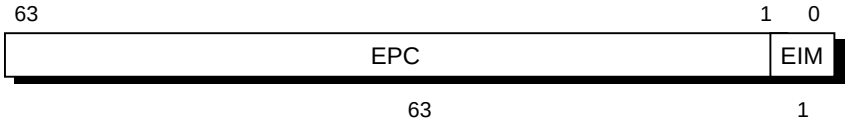


EPC: Virtual address that caused the exception (31:1).

EIM: ISA mode at which an exception occurs.

(1: when MIPS16 SIA instruction is executed, 0: when MIPS III ISA instruction is executed.)

(b) 64-bit mode



EPC: Virtual address that caused the exception (63:1).

EIM: ISA mode at which an exception occurs.

(1: when MIPS16 ISA instruction is executed, 0: when MIPS III ISA instruction is executed.)

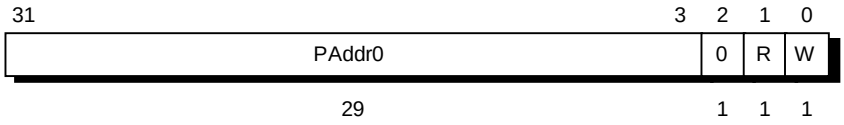
2.5.3.8 WatchLo (18) and WatchHi (19) registers

The VR4120A processor provides a debugging feature to detect references to a selected physical address; load and store instructions to the location specified by the WatchLo and WatchHi registers cause a Watch exception.

Figures 2-66 and 2-67 show the format of the WatchLo and WatchHi registers.

Figure 2-66. WatchLo Register Format

WatchLo Register



PAddr0 : Specifies physical address bits 31 to 3.

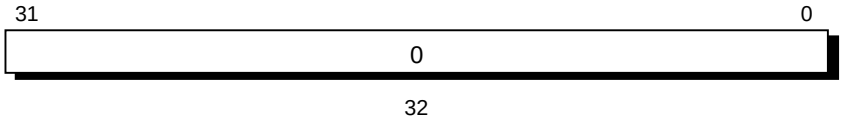
R : If this bit is set to 1, an exception will occur when a load instruction is executed.

W : If this bit is set to 1, an exception will occur when a store instruction is executed.

0 : RFU. Write 0 in a write operation. When this field is read, 0 is read.

Figure 2-67. WatchHi Register Format

WatchHi Register



0 : RFU. Write 0 in a write operation. When this field is read, 0 is read.

2.5.3.9 XContext register (20)

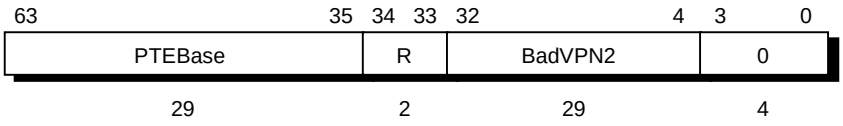
The read/write XContext register contains a pointer to an entry in the page table entry (PTE) array, an operating system data structure that stores virtual-to-physical address translations. If a TLB miss occurs, the operating system loads the untranslated data from the PTE into the TLB to handle the software error.

The XContext register is used by the XTLB Refill exception handler to load TLB entries in 64-bit addressing mode.

The XContext register duplicates some of the information provided in the BadVAddr register, and puts it in a form useful for the XTLB exception handler.

This register is included solely for operating system use. The operating system sets the PTEBase field in the register, as needed. Figure 2-68 shows the format of the XContext register.

Figure 2-68. XContext Register Format



PTEBase : The PTEBase field is a base address of the PTE entry table.

R : Space type (00 → User, 01→ Supervisor, 11 → Kernel). The setting of this field matches virtual address bits 63 and 62.

BadVPN2 : This field holds the value (VPN2) obtained by halving the virtual page number of the most recent virtual address for which translation failed.

0 : RFU. Write 0 in a write operation. When this field is read, 0 is read.

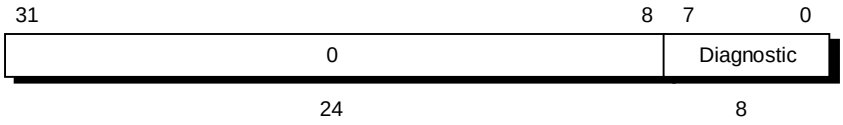
The 29-bit BadVPN2 field has bits 39 to 11 of the virtual address that caused the TLB miss; bit 10 is excluded because a single TLB entry maps to an even-odd page pair. For a 1-Kbyte page size, this format may be used directly to address the pair-table of 8-byte PTEs. For 4-Kbyte or more page and PTE sizes, shifting or masking this value produces the appropriate address.

2.5.3.10 Parity error register (26)

The Parity Error (PErr) register is a readable/writable register. This register is defined to maintain software-compatibility with the VR4100, and is not used in hardware because the VR4120A CPU has no parity.

Figure 2-69 shows the format of the PErr register.

Figure 2-69. Parity Error Register Format



Diagnostic : 8-bit self diagnostic field.

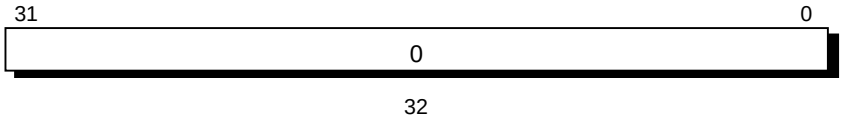
0 : RFU. Write 0 in a write operation. When this field is read, 0 is read.

2.5.3.11 Cache error register (27)

The Cache Error register is a readable/writable register. This register is defined to maintain software-compatibility with the VR4100, and is not used in hardware because the VR4120A CPU has no parity.

Figure 2-70 shows the format of the Cache Error register.

Figure 2-70. Cache Error Register Format



0 : RFU. Write 0 in a write operation. When this field is read, 0 is read.

2.5.3.12 ErrorEPC register (30)

The Error Exception Program Counter (ErrorEPC) register is similar to the EPC register. It is used to store the Program Counter value at which the Cache Error, Cold Reset, Soft Reset, or NMI exception has been serviced.

The read/write ErrorEPC register contains the virtual address at which instruction processing can resume after servicing an error. The contents of this register change depending on whether execution of MIPS16 instructions is enabled or disabled. Setting the MIPS16EN pin after RTC reset specifies whether the execution of MIPS16 instructions is enabled or disabled.

When the MIPS16 instruction execution is disabled, this address can be:

- Virtual address of the instruction that caused the exception.
- Virtual address of the immediately preceding branch or jump instruction, when the instruction associated with the error exception is in a branch delay slot.

When the MIPS16 instruction execution is enabled during a 32-bit instruction execution, this address can be:

- Virtual address of the instruction that caused the exception and ISA mode at which an exception occurs.
- Virtual address of the immediately preceding branch or jump instruction and ISA mode at which an exception occurs when the instruction associated with the exception is in a branch delay slot.

When the MIPS16 instruction execution is enabled during a 16-bit instruction execution, this address can be:

- Virtual address of the instruction that caused the exception and ISA mode at which an exception occurs.
- Virtual address of the immediately preceding jump instruction or Extend instruction and ISA mode at which an exception occurs when the instruction associated with the exception is in a branch delay slot of the jump instruction or is the instruction following the Extend instruction.

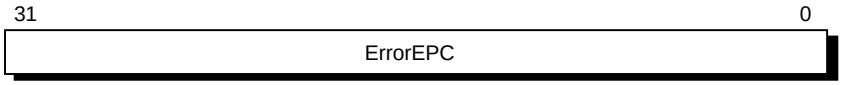
The contents of the ErrorEPC register do not change when the ERL bit of the Status register is set to 1. This prevents the processor when other exceptions occur from overwriting the address of the instruction in this register which causes an error exception.

There is no branch delay slot indication for the ErrorEPC register.

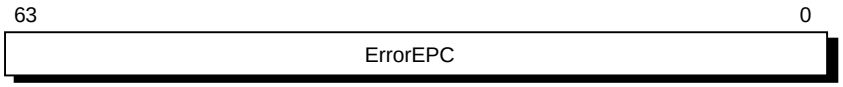
Figure 2-71 shows the format of the ErrorEPC register when the MIPS16 ISA is disabled. Figure 2-72 shows the format of the ErrorEPC register when the MIPS16 ISA is enabled.

Figure 2-71. ErrorEPC Register Format (When MIPS16 ISA Is Disabled)

(a) 32-bit mode



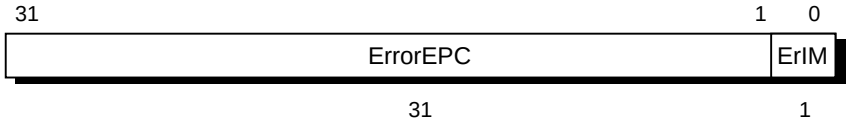
(b) 64-bit mode



ErrorEPC: Program counter that indicates the restart address after Cold reset, Soft reset, or NMI exception.

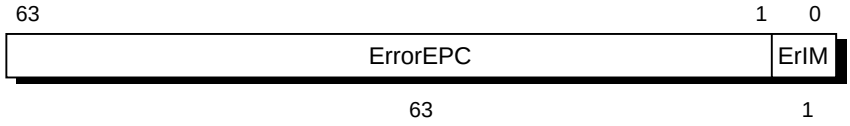
Figure 2-72. ErrorEPC Register Format (When MIPS16 ISA Is Enabled)

(a) 32-bit mode



ErrorEPC: Virtual restart address (31:1) after Cold reset, Soft reset, or NMI exception.
ErIM: ISA mode at which an error exception occurs (1: MIPS16 ISA, 0: MIPS III ISA).

(b) 64-bit mode



ErrorEPC: Virtual restart address (63:1) after Cold reset, Soft reset, or NMI exception.
ErIM: ISA mode at which an error exception occurs (1: MIPS16 ISA, 0: MIPS III ISA).

2.5.4 Details of exceptions

This section describes causes, processes, and services of the VR4120A's exceptions.

2.5.4.1 Exception types

This section gives sample exception handler operations for the following exception types:

- ✧ Cold Reset
- ✧ Soft Reset
- ✧ NMI
- ✧ Remaining processor exceptions

When the EXL and ERL bits in the Status register are 0, either User, Supervisor, or Kernel operating mode is specified by the KSU bits in the Status register. When either the EXL or ERL bit is set to 1, the processor is in Kernel mode.

When the processor takes an exception, the EXL bit is set to 1, meaning the system is in Kernel mode. After saving the appropriate state, the exception handler typically resets the EXL bit back to 0. The exception handler sets the EXL bit to 1 so that the saved state is not lost upon the occurrence of another exception while the saved state is being restored.

Returning from an exception also resets the EXL bit to 0. For details, see **APPENDIX A MIPS III INSTRUCTION SET DETAILS**.

2.5.4.2 Exception vector address

The Cold Reset, Soft Reset, and NMI exceptions are always branched to the following reset exception vector address. This address is in an uncached, unmapped space.

- ✧ BFC0 0000H in 32-bit mode (virtual address)
- ✧ FFFF FFFF BFC0 0000H in 64-bit mode (virtual address)

Vector addresses for the remaining exceptions are a combination of a vector offset and a base address.

64-/32-bit mode exception vectors and their offsets are shown below.

Table 2-58. 64-Bit Mode Exception Vector Base Addresses

	Vector Base Address (Virtual)	Vector Offset
Cold Reset Soft Reset NMI	FFFF FFFF BFC0 0000H (BEV bit is automatically set to 1)	0000H
TLB Refill (EXL = 0)	FFFF FFFF 8000 0000H (BEV = 0) FFFF FFFF BFC0 0200H (BEV = 1)	0000H
XTLB Refill (EXL = 0)		0080H
Other exceptions		0180H

Table 2-59. 32-Bit Mode Exception Vector Base Addresses

	Vector Base Address (Virtual)	Vector Offset
Cold Reset Soft Reset NMI	BFC0 0000H (BEV bit is automatically set to 1)	0000H
TLB Refill (EXL = 0)	8000 0000H (BEV = 0) BFC0 0200H (BEV = 1)	0000H
XTLB Refill (EXL = 0)		0080H
Other exceptions		0180H

(1) TLB refill exception vector

When BEV bit = 0, the vector base address (virtual) for the TLB Refill exception is in kseg0 (unmapped) space.

- ✧ 8000 0000H in 32-bit mode
- ✧ FFFF FFFF 8000 0000H in 64-bit mode

When BEV bit = 1, the vector base address (virtual) for the TLB Refill exception is in kseg1 (uncached, unmapped) space.

- ✧ BFC0 0200H in 32-bit mode
- ✧ FFFF FFFF BFC0 0200H in 64-bit mode

This is an uncached, non-TLB-mapped space, allowing the exception handler to bypass the cache and TLB.

2.5.4.3 Priority of exceptions

While more than one exception can occur for a single instruction, only the exception with the highest priority is reported. Table 2-60 lists the priorities.

Table 2-60. Exception Priority Order

High	Cold Reset
↑	Soft Reset
|	Debug (pin)
|	Debug (instruction address break)
|	NMI
|	Address Error (instruction fetch)
|	TLB/XTLB Refill (instruction fetch)
|	TLB Invalid (instruction fetch)
|	Interrupt (other than NMI)
|	Bus Error (instruction fetch)
|	Debug (Dbrek instruction)
|	System Call
|	Breakpoint
|	Coprocessor Unusable
|	Reserved Instruction
|	Trap
|	Integer Overflow
|	Debug (data address break)
|	Address Error (data access)
|	TLB/XTLB Refill (data access)
|	TLB Invalid (data access)
|	TLB Modified (data write)
|	Watch
↓	Bus Error (data access)
Low	Debug (data-data break) NOTE

Note: Including when both the address and data conditions match at data access.

Hereafter, handling exceptions by hardware is referred to as "process", and handling exception by software is referred to as "service".

2.5.4.4 Cold reset exception

(1) Cause

The Cold Reset exception occurs when the ColdReset_B signal (internal) is asserted and then deasserted. This exception is not maskable. The Reset_B signal (internal) must be asserted along with the ColdReset_B signal (for details, see **Section 2.7 Initialization Interface**).

(2) Processing

The CPU provides a special interrupt vector for this exception:

- ✧ BFC0 0000H (virtual address) in 32-bit mode
- ✧ FFFF FFFF BFC0 0000H (virtual address) in 64-bit mode

The Cold Reset vector resides in unmapped and uncached CPU address space, so the hardware need not initialize the TLB or the cache to process this exception. It also means the processor can fetch and execute instructions while the caches and virtual memory are in an undefined state.

The contents of all registers in the CPU are undefined when this exception occurs, except for the following register fields:

- When the MIPS16 instruction execution is disabled while the ERL of Status register is 0, the PC value at which an exception occurs is set to the ErrorEPC register.
  When the MIPS16 instruction execution is enabled while the ERL of Status register is 0, the PC value at which an exception occurs is set to the ErrorEPC register and the ISA mode in which an exception occurs is set to the least significant bit of the ErrorEPC register.
- TS and SR bits of the Status register are cleared to 0.
- ERL and BEV bits of the Status register are set to 1.
- The Random register is initialized to the value of its upper bound (31).
- The Wired register is initialized to 0.
- Bits 31 to 28 and bits 22 to 3 of the Config register are set to fixed values.
- All other bits are undefined.

(3) Servicing

The Cold Reset exception is serviced by:

- Initializing all processor registers, coprocessor registers, TLB, caches, and the memory system
- Performing diagnostic tests
- Bootstrapping the operating system

2.5.4.5 Soft reset exception

(1) Cause

A Soft Reset (sometimes called Warm Reset) occurs when the ColdReset_B signal (internal) remains deasserted while the Reset_B signal (internal) goes from assertion to deassertion (for details, see **Section 2.7 Initialization Interface**).

A Soft Reset immediately resets all state machines, and sets the SR bit of the Status register. Execution begins at the reset vector when the reset is deasserted.

This exception is not maskable.

Caution In LAKI, a soft reset never occurs.

(2) Processing

The CPU provides a special interrupt vector for this exception (same location as Cold Reset):

- ✧ BFC0 0000H (virtual) in 32-bit mode
- ✧ FFFF FFFF BFC0 0000H (virtual) in 64-bit mode

This vector is located within unmapped and uncached address space, so that the cache and TLB need not be initialized to process this exception. The SR bit of the Status register is set to 1 to distinguish this exception from a Cold Reset exception.

When this exception occurs, the contents of all registers are preserved except for the following registers:

- When the MIPS16 instruction execution is disabled, the PC value at which an exception occurs is set to the ErrorEPC register.
  When the MIPS16 instruction execution is enabled, the PC value at which an exception occurs is set to the ErrorEPC register and the ISA mode in which an exception occurs is set to the least significant bit of the ErrorEPC register.

- ERL, SR, and BEV bits of the Status register are set to 1.

During a soft reset, access to the operating cache or system interface may be aborted. This means that the contents of the cache and memory will be undefined if a Soft Reset occurs.

(3) Servicing

The Soft Reset exception is serviced by:

- Preserving the current processor states for diagnostic tests
- Reinitializing the system in the same way as for a Cold Reset exception

2.5.4.6 NMI exception

(1) Cause

The Nonmaskable Interrupt (NMI) exception occurs when the NMI signal (internal) becomes active. This interrupt is not maskable; it occurs regardless of the settings of the EXL, ERL, and IE bits in the Status register (for details, see **Section 2.9 CPU Core Interrupts**).

(2) Processing

The CPU provides a special interrupt vector for this exception:

- ✧ BFC0 0000H (virtual) in 32-bit mode
- ✧ FFFF FFFF BFC0 0000H (virtual) in 64-bit mode

This vector is located within unmapped and uncached address space so that the cache and TLB need not be initialized to process an NMI exception. The SR bit of the Status register is set to 1 to distinguish this exception from a Cold Reset exception.

Unlike Cold Reset and Soft Reset, but like other exceptions, NMI is taken only at instruction boundaries. The states of the caches and memory system are preserved by this exception.

When this exception occurs, the contents of all registers are preserved except for the following registers:

- When the MIPS16 instruction execution is disabled, the PC value at which an exception occurs is set to the ErrorEPC register.

  When the MIPS16 instruction execution is enabled, the PC value at which an exception occurs is set to the ErrorEPC register and the ISA mode in which an exception occurs is set to the least significant bit of the ErrorEPC register.

- The ERL, SR, and BEV bits of the Status register are set to 1.

(3) Servicing

The NMI exception is serviced by:

- Preserving the current processor states for diagnostic tests
- Reinitializing the system in the same way as for a Cold Reset exception

2.5.4.7 Address error exception

(1) Cause

The Address Error exception occurs when an attempt is made to execute one of the following. This exception is not maskable.

- Execution of the LW, LWU, SW, or CACHE instruction for word data that is not located on a word boundary
- Execution of the LH, LHU, or SH instruction for half-word data that is not located on a half-word boundary
- Execution of the LD or SD instruction for double-word data that is not located on a double-word boundary
- Referencing the kernel address space in User or Supervisor mode
- Referencing the supervisor space in User mode
- Referencing an address that does not exist in the kernel, user, or supervisor address space in 64-bit Kernel, User, or Supervisor mode
- Branching to an address that was not located on a word boundary when the MIPS16 instruction is disabled
- Branching to address whose least-significant 2 bits are 10 when the MIPS16 instruction is enabled

(2) Processing

The common exception vector is used for this exception. The AdEL or AdES code in the Cause register is set. If this exception has been caused by an instruction reference or load operation, AdEL is set. If it has been caused by a store operation, AdES is set.

When this exception occurs, the BadVAddr register stores the virtual address that was not properly aligned or was referenced in protected address space. The contents of the VPN field of the Context and EntryHi registers are undefined, as are the contents of the EntryLo register.

When the MIPS16 instruction is disabled, the EPC register contains the address of the instruction that caused the exception. However, if this instruction is in a branch delay slot, the EPC register contains the address of the preceding jump or branch instruction, and the BD bit of the Cause register is set to 1.

When the MIPS16 instruction is enabled, the EPC register contains the address of the instruction that caused the exception, and the least significant bit stores the ISA mode in which an exception occurs. However, if this instruction is in a branch delay slot or is the instruction following the Extend instruction, the EPC register contains the address of the preceding jump or Extend instruction, and the BD bit of the Cause register is set to 1.

(3) Servicing

The kernel reports the UNIX® SIGSEGV (segmentation violation) signal to the current process, and this exception is usually fatal.

2.5.4.8 TLB exceptions

Three types of TLB exceptions can occur:

- TLB Refill exception occurs when there is no TLB entry that matches a referenced address.
- A TLB Invalid exception occurs when a TLB entry that matches a referenced virtual address is marked as being invalid (with the V bit set to 0).
- The TLB Modified exception occurs when a TLB entry that matches a virtual address referenced by the store instruction is marked as being valid (with the V bit set to 1).

The following three sections describe these TLB exceptions.

(1) TLB refill exception (32-bit space mode)/XTLB refill exception (64-bit space mode)

(a) Cause

The TLB Refill exception occurs when there is no TLB entry to match a reference to a mapped address space. This exception is not maskable.

(b) Processing

There are two special exception vectors for this exception; one for references to 32-bit address spaces, and one for references to 64-bit address spaces. The UX, SX, and KX bits of the Status register determine whether the user, supervisor or kernel address spaces referenced are 32-bit or 64-bit spaces. When the EXL bit of the Status register is set to 0, either of these two special vectors is referenced. When the EXL bit is set to 1, the common exception vector is referenced.

This exception sets the TLBL or TLBS code in the ExcCode field of the Cause register. If this exception has been caused by an instruction reference or load operation, TLBL is set. If it has been caused by a store operation, TLBS is set.

When this exception occurs, the BadVAddr, Context, XContext and EntryHi registers hold the virtual address that failed address translation. The EntryHi register also contains the ASID from which the translation fault occurred. The Random register normally contains a valid location in which to place the replacement TLB entry. The contents of the EntryLo register are undefined.

When the MIPS16 instruction is disabled, the EPC register contains the address of the instruction that caused the exception. However, if this instruction is in a branch delay slot, the EPC register contains the address of the preceding jump or branch instruction, and the BD bit of the Cause register is set to 1.

When the MIPS16 instruction is enabled, the EPC register contains the address of the instruction that caused the exception, and the least significant bit stores the ISA mode in which an exception occurs. However, if this instruction is in a branch delay slot or is the instruction following the Extend instruction, the EPC register contains the address of the preceding jump or Extend instruction, and the BD bit of the Cause register is set to 1.

(c) Servicing

To service this exception, the contents of the Context or XContext register are used as a virtual address to fetch memory words containing the physical page frame and access control bits for a pair of TLB entries. The memory word is written into the TLB entry by using the EntryLo0, EntryLo1, or EntryHi register.

It is possible that the physical page frame and access control bits are placed in a page where the virtual address is not resident in the TLB. This condition is processed by allowing a TLB Refill exception in the TLB Refill exception handler. In this case, the common exception vector is used because the EXL bit of the Status register is set to 1.

(2) TLB invalid exception

(a) Cause

The TLB Invalid exception occurs when the TLB entry that matches with the virtual address to be referenced is invalid (the V bit is set to 0). This exception is not maskable.

(b) Processing

The common exception vector is used for this exception. The TLBL or TLBS code in the ExcCode field of the Cause register is set. If this exception has been caused by an instruction reference or load operation, TLBL is set. If it has been caused by a store operation, TLBS is set.

When this exception occurs, the BadVAddr, Context, Xcontext, and EntryHi registers contain the virtual address that failed address translation. The EntryHi register also contains the ASID from which the translation fault occurred. The Random register normally stores a valid location in which to place the replacement TLB entry. The contents of the EntryLo register are undefined.

When the MIPS16 instruction is disabled, the EPC register contains the address of the instruction that caused the exception. However, if this instruction is in a branch delay slot, the EPC register contains the address of the preceding jump or branch instruction, and the BD bit of the Cause register is set to 1.

When the MIPS16 instruction is enabled, the EPC register contains the address of the instruction that caused the exception, and the least significant bit stores the ISA mode in which an exception occurs. However, if this instruction is in a branch delay slot or is the instruction following the Extend instruction, the EPC register contains the address of the preceding jump or Extend instruction, and the BD bit of the Cause register is set to 1.

(c) Servicing

Usually, the V bit of a TLB entry is cleared in the following cases:

- ✧ When a virtual address does not exist
- ✧ When the virtual address exists, but is not in main memory (a page fault)
- ✧ When a trap is required on any reference to the page (for example, to maintain a reference bit)

After servicing the cause of a TLB Invalid exception, the TLB entry is located with a TLBP (TLB Probe) instruction, and replaced by an entry with its V bit set to 1.

(3) TLB modified exception

(a) Cause

The TLB Modified exception occurs when the TLB entry that matches with the virtual address referenced by the store instruction is valid (V bit is 1) but is not writable (D bit is 0). This exception is not maskable.

(b) Processing

The common exception vector is used for this exception, and the Mod code in the ExcCode field of the Cause register is set.

When this exception occurs, the BadVAddr, Context, Xcontext, and EntryHi registers contain the virtual address that failed address translation. The EntryHi register also contains the ASID from which the translation fault occurred. The contents of the EntryLo register are undefined.

When the MIPS16 instruction is disabled, the EPC register contains the address of the instruction that caused the exception. However, if this instruction is in a branch delay slot, the EPC register contains the address of the preceding jump or branch instruction, and the BD bit of the Cause register is set to 1.

When the MIPS16 instruction is enabled, the EPC register contains the address of the instruction that caused the exception, and the least significant bit stores the ISA mode in which an exception occurs. However, if this instruction is in a branch delay slot or is the instruction following the Extend instruction, the EPC register contains the address of the preceding jump or Extend instruction, and the BD bit of the Cause register is set to 1.

(c) Servicing

The kernel uses the failed virtual address or virtual page number to identify the corresponding access control bits. The page identified may or may not permit write accesses; if writes are not permitted, a write protection violation occurs.

If write accesses are permitted, the page frame is marked dirty (/writable) by the kernel in its own data structures.

The TLBP instruction places the index of the TLB entry that must be altered into the Index register. The word data containing the physical page frame and access control bits (with the D bit set to 1) is loaded to the EntryLo register, and the contents of the EntryHi and EntryLo registers are written into the TLB.

2.5.4.9 Bus error exception

(1) Cause

A Bus Error exception is raised by board-level circuitry for events such as bus time-out, local bus parity errors, and invalid physical memory addresses or access types. This exception is not maskable.

A Bus Error exception occurs only when a cache miss refill, uncached reference, or unbuffered write occurs simultaneously. In other words, it occurs when an illegal access is detected during BCU read.

For details of illegal accesses.

(2) Processing

The common interrupt vector is used for a Bus Error exception. The IBE or DBE code in the ExcCode field of the Cause register is set, signifying whether the instruction caused the exception by an instruction reference, load operation, or store operation.

When the MIPS16 instruction is disabled, the EPC register contains the address of the instruction that caused the exception. However, if this instruction is in a branch delay slot, the EPC register contains the address of the preceding jump or branch instruction, and the BD bit of the Cause register is set to 1.

When the MIPS16 instruction is enabled, the EPC register contains the address of the instruction that caused the exception, and the least significant bit stores the ISA mode in which an exception occurs. However, if this instruction is in a branch delay slot or is the instruction following the Extend instruction, the EPC register contains the address of the preceding jump or Extend instruction, and the BD bit of the Cause register is set to 1.

(3) Servicing

The physical address at which the fault occurred can be computed from information available in the System Control Coprocessor (CP0) registers.

- If the IBE code in the Cause register is set (indicating an instruction fetch), the virtual address is contained in the EPC register.
- If the DBE code is set (indicating a load or store), the virtual address of the instruction that caused the exception is saved to the EPC register.

The virtual address of the load and store instruction can then be obtained by interpreting the instruction. The physical address can be obtained by using the TLBP instruction and reading the EntryLo register to compute the physical page number.

At the time of this exception, the kernel reports the UNIX SIGBUS (bus error) signal to the current process, but the exception is usually fatal.

2.5.4.10 System call exception

(1) Cause

A System Call exception occurs during an attempt to execute the SYSCALL instruction. This exception is not maskable.

(2) Processing

The common exception vector is used for this exception, and the Sys code in the ExcCode field of the Cause register is set.

The EPC register contains the address of the SYSCALL instruction unless it is in a branch delay slot, in which case the EPC register contains the address of the preceding branch instruction.

If the SYSCALL instruction is in a branch delay slot, the BD bit of the Status register is set to 1; otherwise this bit is cleared.

(3) Servicing

When this exception occurs, control is transferred to the applicable system routine.

To resume execution, the EPC register must be altered so that the SYSCALL instruction does not re-execute; this is accomplished by adding a value of 4 to the EPC register before returning.

If a SYSCALL instruction is in a branch delay slot, interpretation (decoding) of the branch instruction is required to resume execution.

2.5.4.11 Breakpoint exception

(1) Cause

A Breakpoint exception occurs when an attempt is made to execute the BREAK instruction. This exception is not maskable.

(2) Processing

The common exception vector is used for this exception, and the Bp code in the ExcCode field of the Cause register is set.

When the MIPS16 instruction is disabled, the EPC register contains the address of the instruction that caused the exception. However, if this instruction is in a branch delay slot, the EPC register contains the address of the preceding jump or branch instruction, and the BD bit of the Cause register is set to 1.

When the MIPS16 instruction is enabled, the EPC register contains the address of the instruction that caused the exception, and the least significant bit stores the ISA mode in which an exception occurs. However, if this instruction is in a branch delay slot or is the instruction following the Extend instruction, the EPC register contains the address of the preceding jump or Extend instruction, and the BD bit of the Cause register is set to 1; otherwise this bit is cleared.

(3) Servicing

When the Breakpoint exception occurs, control is transferred to the applicable system routine. Additional distinctions can be made by analyzing the unused bits of the BREAK instruction (bits 25 to 6), and loading the contents of the instruction whose address the EPC register contains.

To resume execution, the EPC register must be altered so that the BREAK instruction does not re-execute; this is accomplished by adding a value of 4 to the EPC register before returning.

When a Breakpoint exception occurs while executing the MIPS16 instruction, a value of 2 should be added to the EPC register before returning.

If a BREAK instruction is in a branch delay slot, interpretation (decoding) of the branch instruction is required to resume execution.

2.5.4.12 Coprocessor unusable exception

(1) Cause

The Coprocessor Unusable exception occurs when an attempt is made to execute a coprocessor instruction for either:

- ✧ a corresponding coprocessor unit that has not been marked usable (Status register bit, CU0 = 0), or
- ✧ CP0 instructions, when the unit has not been marked usable (Status register bit, CU0 = 0) and the process executes in User or Supervisor mode.

This exception is not maskable.

(2) Processing

The common exception vector is used for this exception, and the CPU code in the ExcCode field of the Cause register is set. The CE bit of the Cause register indicates which of the four coprocessors was referenced.

When the MIPS16 instruction is disabled, the EPC register contains the address of the instruction that caused the exception. However, if this instruction is in a branch delay slot, the EPC register contains the address of the preceding jump or branch instruction, and the BD bit of the Cause register is set to 1.

When the MIPS16 instruction is enabled, the EPC register contains the address of the instruction that caused the exception, and the least significant bit stores the ISA mode in which an exception occurs. However, if this instruction is in a branch delay slot or is the instruction following the Extend instruction, the EPC register contains the address of the preceding jump or Extend instruction, and the BD bit of the Cause register is set to 1.

(3) Servicing

The coprocessor unit to which an attempted reference was made is identified by the CE bit of the Cause register. One of the following processing is performed by the handler:

- ✧ If the process is entitled access to the coprocessor, the coprocessor is marked usable and the corresponding state is restored to the coprocessor.
- ✧ If the process is entitled access to the coprocessor, but the coprocessor does not exist or has failed, interpretation of the coprocessor instruction is possible.
- ✧ If the BD bit in the Cause register is set to 1, the branch instruction must be interpreted; then the coprocessor instruction can be emulated and execution resumed with the EPC register advanced past the coprocessor instruction.
- ✧ If the process is not entitled access to the coprocessor, the kernel reports UNIX SIGILL/ILL_PRIVIN_FAULT (illegal instruction/privileged instruction fault) signal to the current process, and this exception is fatal.

2.5.4.13 Reserved instruction exception

(1) Cause

The Reserved Instruction exception occurs when an attempt is made to execute one of the following instructions:

- Instruction with an undefined major opcode (bits 31 to 26)
- SPECIAL instruction with an undefined minor opcode (bits 5 to 0)
- REGIMM instruction with an undefined minor opcode (bits 20 to 16)
- 64-bit instructions in 32-bit User or Supervisor mode
- RR instruction with an undefined minor op code (bits 4 to 0) when executing the MIPS16 instruction
- I8 instruction with an undefined minor op code (bits 10 to 8) when executing the MIPS16 instruction

64-bit operations are always valid in Kernel mode regardless of the value of the KX bit in the Status register. This exception is not maskable.

(2) Processing

The common exception vector is used for this exception, and the RI code in the ExcCode field of the Cause register is set.

When the MIPS16 instruction is disabled, the EPC register contains the address of the instruction that caused the exception. However, if this instruction is in a branch delay slot, the EPC register contains the address of the preceding jump or branch instruction, and the BD bit of the Cause register is set to 1.

When the MIPS16 instruction is enabled, the EPC register contains the address of the instruction that caused the exception, and the least significant bit stores the ISA mode in which an exception occurs. However, if this instruction is in a branch delay slot or is the instruction following the Extend instruction, the EPC register contains the address of the preceding jump or Extend instruction, and the BD bit of the Cause register is set to 1.

(3) Servicing

All currently defined MIPS ISA instructions can be executed. The process executing at the time of this exception is handled by a UNIX SIGILL/ILL_RESOP_FAULT (illegal instruction/reserved operand fault) signal. This error is usually fatal.

2.5.4.14 Trap exception

(1) Cause

The Trap exception occurs when a TGE, TGEU, TLT, TLTU, TEQ, TNE, TGEI, TGEUI, TLTI, TLTUI, TEQI, or TNEI instruction results in a TRUE condition. This exception is not maskable.

(2) Processing

The common exception vector is used for this exception, and the Tr code in the ExcCode field of the Cause register is set.

The EPC register contains the address of the trap instruction causing the exception unless the instruction is in a branch delay slot, in which case the EPC register contains the address of the preceding branch instruction and the BD bit of the Cause register is set to 1.

(3) Servicing

At the time of a Trap exception, the kernel reports the UNIX SIGFPE/FPE_INTOVF_TRAP (floating-point exception/integer overflow) signal to the current process, but the exception is usually fatal.

2.5.4.15 Integer overflow exception

(1) Cause

An Integer Overflow exception occurs when an ADD, ADDI, SUB, DADD, DADDI, or DSUB instruction results in a 2's complement overflow. This exception is not maskable.

(2) Processing

The common exception vector is used for this exception, and the Ov code in the ExcCode field of the Cause register is set.

The EPC register contains the address of the instruction that caused the exception unless the instruction is in a branch delay slot, in which case the EPC register contains the address of the preceding branch instruction and the BD bit of the Cause register is set to 1.

(3) Servicing

At the time of the exception, the kernel reports the UNIX SIGFPE/FPE_INTOVF_TRAP (floating-point exception/integer overflow) signal to the current process, and this exception is usually fatal.

2.5.4.16 Watch exception

(1) Cause

A Watch exception occurs when a load or store instruction references the physical address specified by the WatchLo/WatchHi registers. The WatchLo/WatchHi registers specify whether a load or store or both could have initiated this exception.

- When the R bit of the WatchLo register is set to 1: Load instruction
- When the W bit of the WatchLo register is set to 1: Store instruction
- When both the R bit and W bit of the WatchLo register are set to 1: Load instruction or store instruction

The CACHE instruction never causes a Watch exception.

The Watch exception is postponed while the EXL bit in the Status register is set to 1, and Watch exception is only maskable by setting the EXL bit in the Status register to 1.

(2) Processing

The common exception vector is used for this exception, and the Watch code in the ExcCode field of the Cause register is set.

When the MIPS16 instruction is disabled, the EPC register contains the address of the instruction that caused the exception. However, if this instruction is in a branch delay slot, the EPC register contains the address of the preceding jump or branch instruction, and the BD bit of the Cause register is set to 1.

When the MIPS16 instruction is enabled, the EPC register contains the address of the instruction that caused the exception, and the least significant bit stores the ISA mode in which an exception occurs. However, if this instruction is in a branch delay slot or is the instruction following the Extend instruction, the EPC register contains the address of the preceding jump or Extend instruction, and the BD bit of the Cause register is set to 1.

(3) Servicing

The Watch exception is a debugging aid; typically the exception handler transfers control to a debugger, allowing the user to examine the situation. To continue, once the Watch exception must be disabled to execute the faulting instruction. The Watch exception must then be reenabled. The faulting instruction can be executed either by the debugger or by setting breakpoints.

2.5.4.17 Interrupt exception

(1) Cause

The Interrupt exception occurs when one of the eight interrupt conditions[Note] is asserted. Each of the eight interrupts can be masked by clearing the corresponding bit in the IM field of the Status register, and all of the eight interrupts can be masked at once by clearing the IE bit of the Status register or setting the EXL/ERL bit.

Note They are 1 timer interrupt, 5 ordinary interrupts, and 2 software interrupts.

(2) Processing

The common exception vector is used for this exception, and the Int code in the ExcCode field of the Cause register is set.

The IP field of the Cause register indicates current interrupt requests. It is possible that more than one of the bits can be simultaneously set (or cleared) if the interrupt request signal is asserted and then deasserted before this register is read.

When the MIPS16 instruction is disabled, the EPC register contains the address of the instruction that caused the exception. However, if this instruction is in a branch delay slot, the EPC register contains the address of the preceding jump or branch instruction, and the BD bit of the Cause register is set to 1.

When the MIPS16 instruction is enabled, the EPC register contains the address of the instruction that caused the exception, and the least significant bit stores the ISA mode in which an exception occurs. However, if this instruction is in a branch delay slot or is the instruction following the Extend instruction, the EPC register contains the address of the preceding jump or Extend instruction, and the BD bit of the Cause register is set to 1.

(3) Servicing

If the interrupt is caused by one of the two software-generated exceptions (SW0 or SW1), the interrupt condition is cleared by setting the corresponding Cause register bit to 0.

If the interrupt is caused by hardware, the interrupt condition is cleared by deactivating the corresponding interrupt request signal.

2.5.5 Exception processing and servicing flowcharts

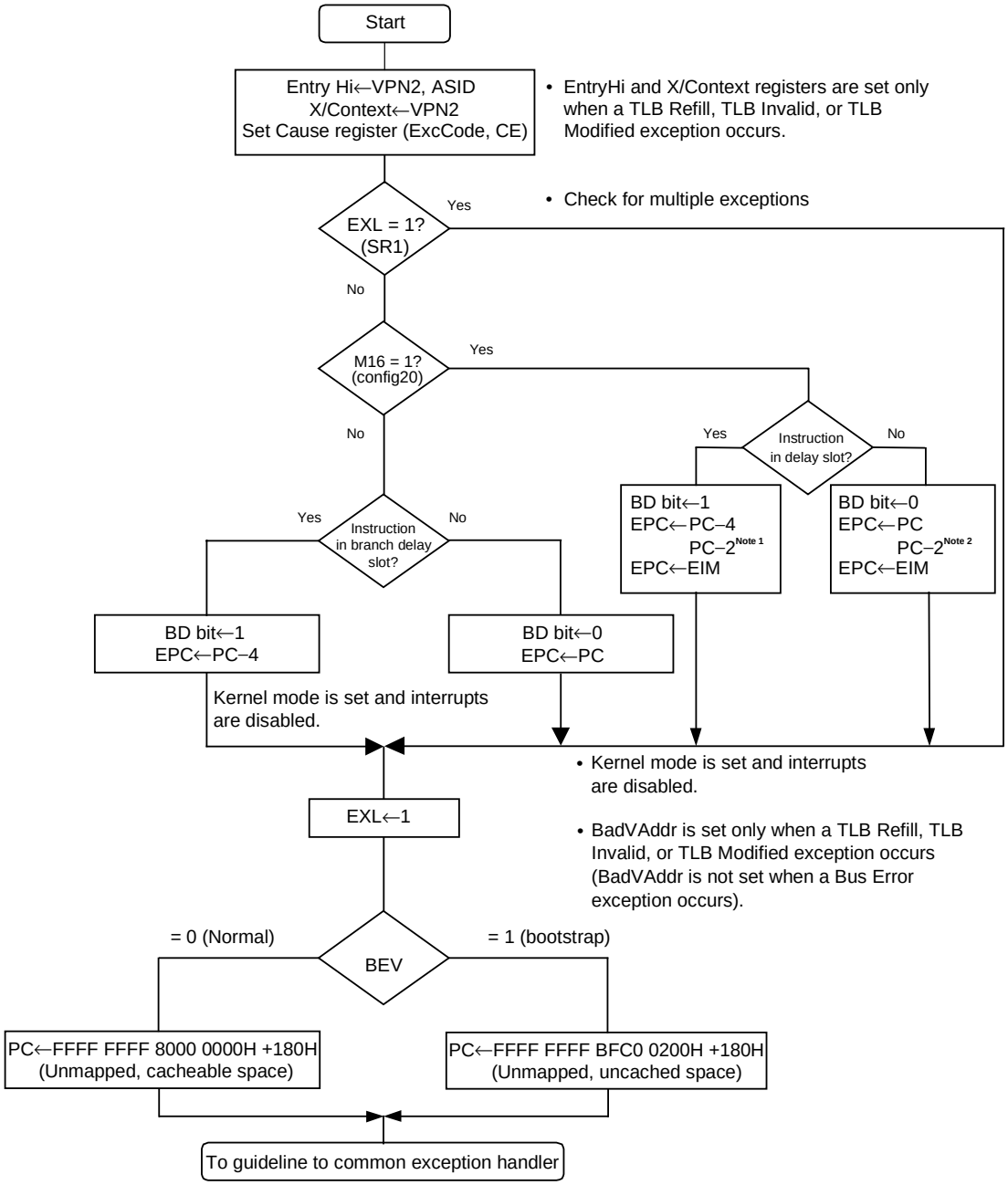
The remainder of this chapter contains flowcharts for the following exceptions and guidelines for their handlers:

- ✧ Common exceptions and a guideline to their exception handler
- ✧ TLB/XTLB Refill exception and a guideline to their exception handler
- ✧ Cold Reset, Soft Reset and NMI exceptions, and a guideline to their handler.

Generally speaking, the exceptions are "processed" by hardware (HW); the exceptions are then "serviced" by software (SW).

Figure 2-73. Common Exception Handling (1/2)

(a) Handling Exceptions other than Cold Reset, Soft Reset, NMI, and TLB/XTLB Refill (Hardware)



Notes 1. When the JR or JALR instruction of MIPS16 instructions

2. When the Extend instruction of MIPS16 instructions

Remark The interrupts can be masked by setting the IE or IM bit.
The Watch exception can be set to pending state by setting the EXL bit to 1.

Figure 2-73. Common Exception Handling (2/2)

(b) Servicing Common Exceptions (Software)

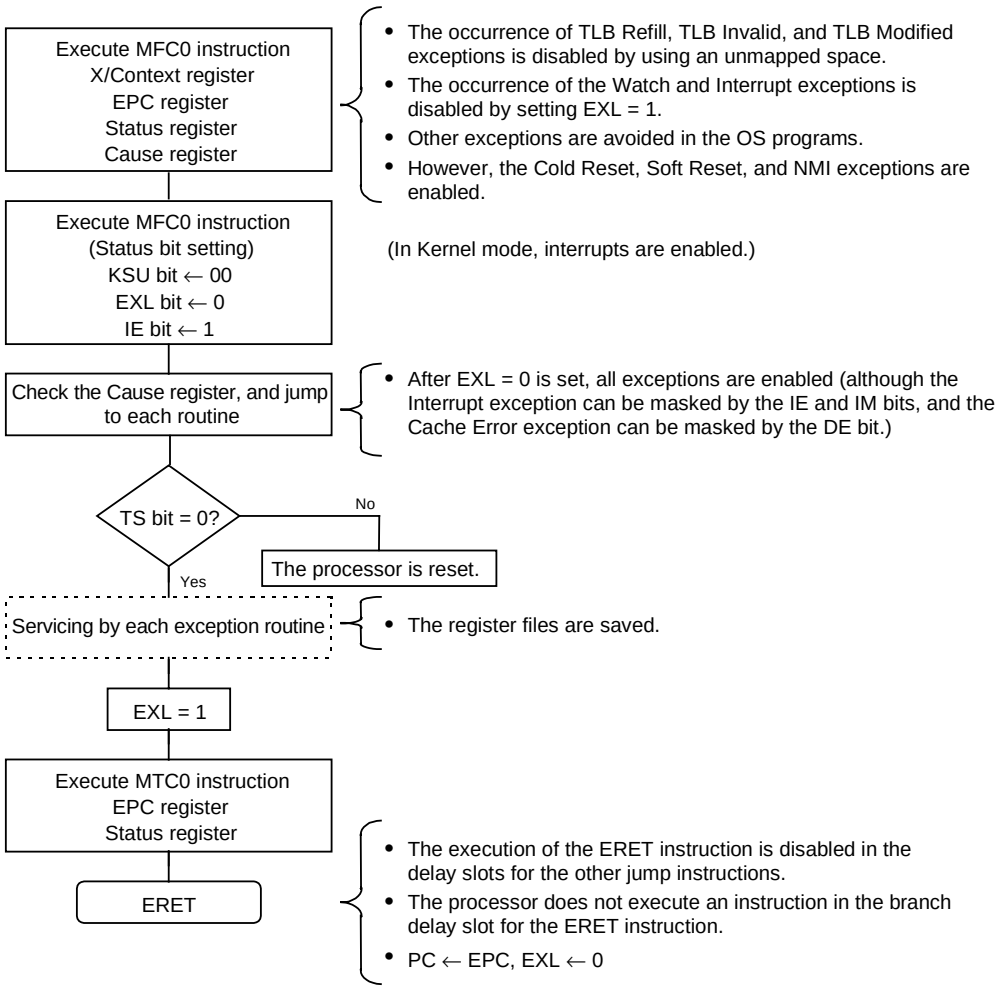
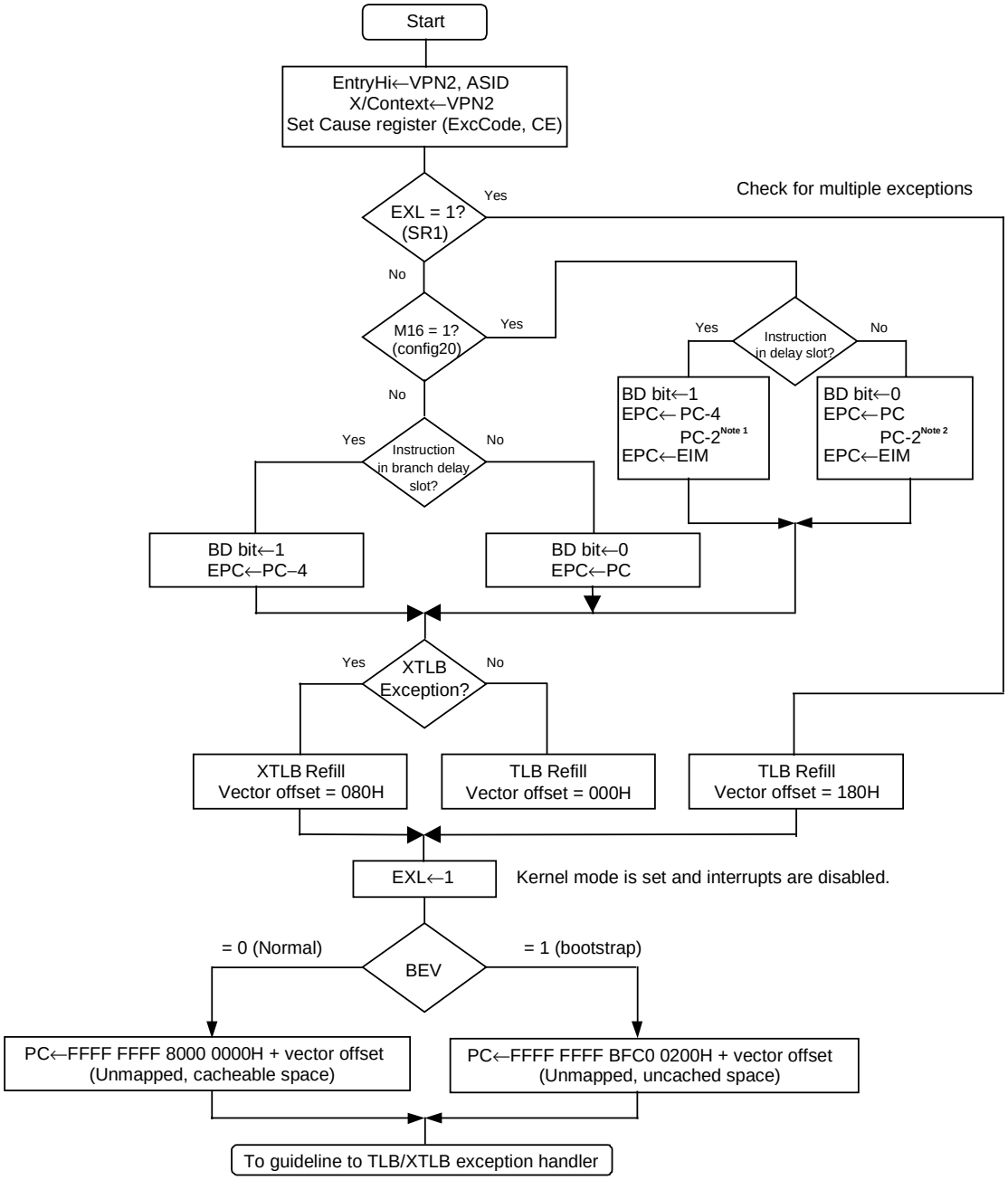


Figure 2-74. TLB/XTLB Refill Exception Handling (1/2)

(a) Handling TLB/XTLB Refill Exceptions (Hardware)



Notes 1. When the JR or JALR instruction of MIPS16 instructions

2. When the Extend instruction of MIPS16 instructions

Figure 2-74. TLB/XTLB Refill Exception Handling (2/2)

(b) Servicing TLB/XTLB Refill Exceptions (Software)

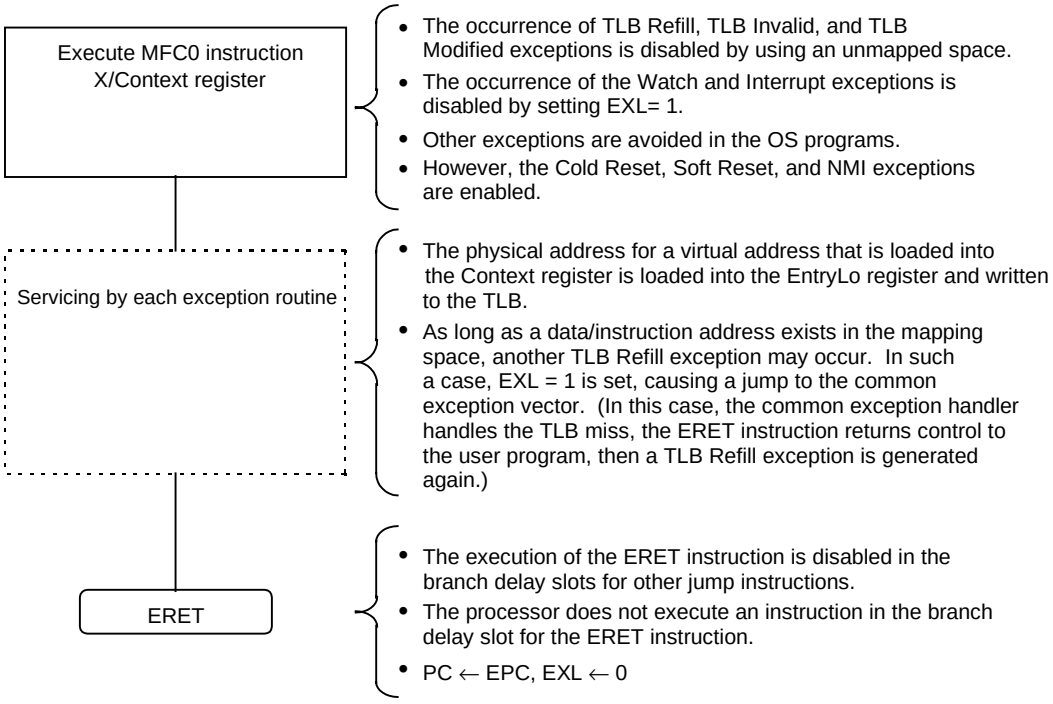
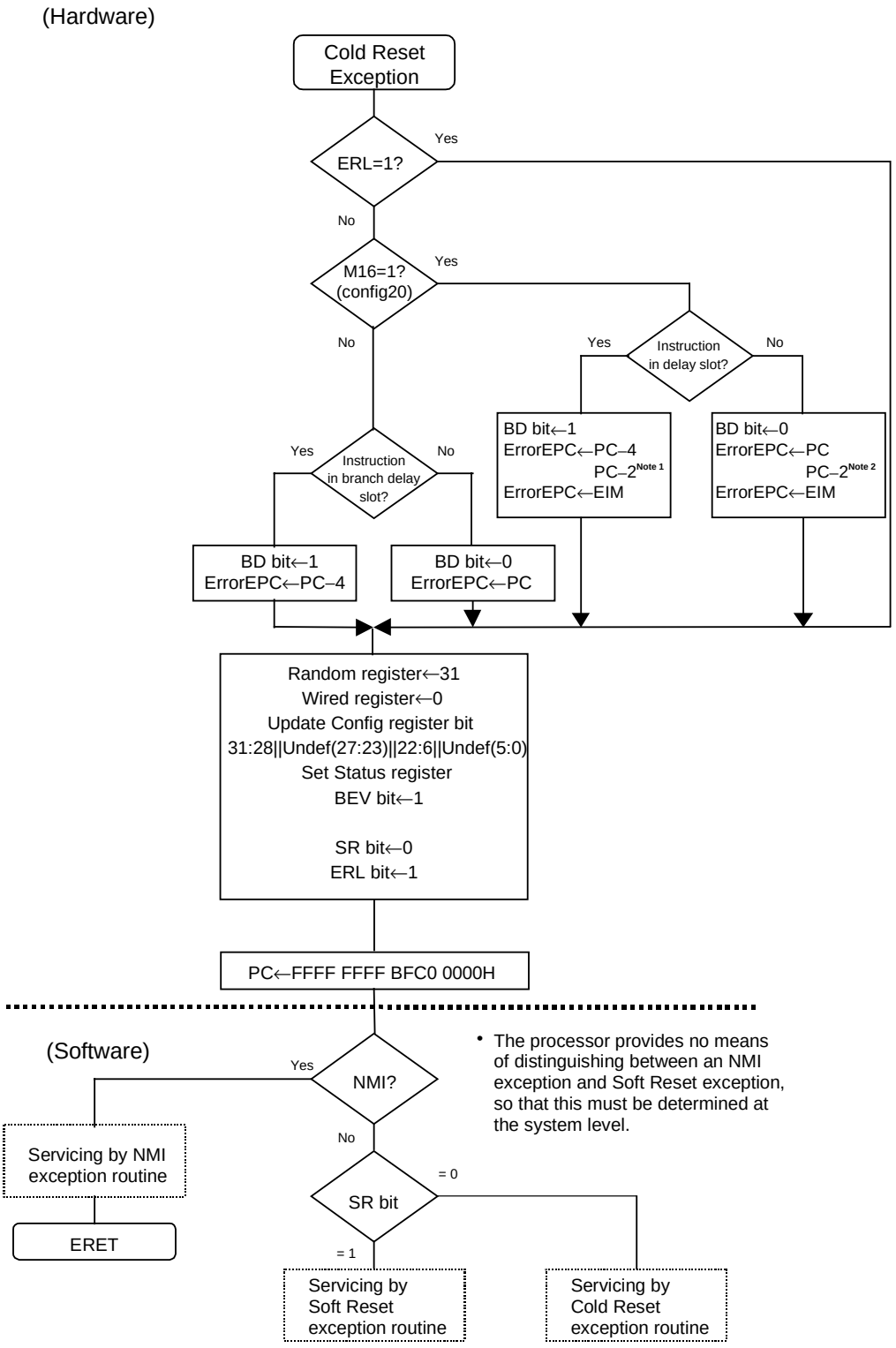


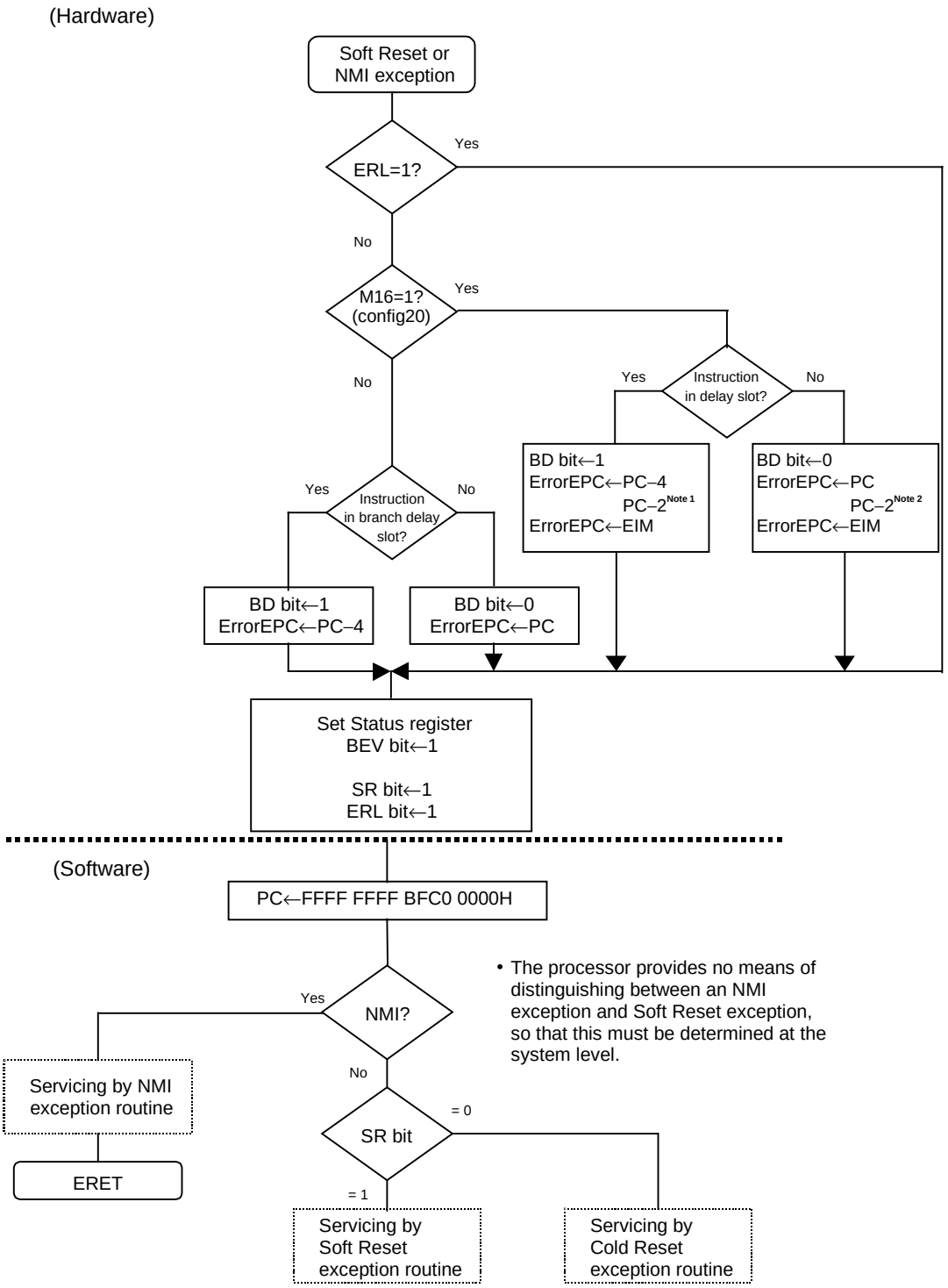
Figure 2-75. Cold Reset Exception Handling



Notes 1. When the JR or JALR instruction of MIPS16 instructions

2. When the Extend instruction of MIPS16 instructions

Figure 2-76. Soft Reset and NMI Exception Handling



Notes 1. When the JR or JALR instruction of MIPS16 instructions

2. When the Extend instruction of MIPS16 instructions

2.6 Initialization Interface

This section describes the reset sequence of the VR4120A Core. For details about factors of reset or reset of the whole VR4120A Core.

2.6.1 Cold reset

In the VR4120A Core, a cold reset sequence is executed in the CPU core in the following cases:

- Hardware reset
- Deadman's SW shutdown
- Software shutdown
- HAL Timer shutdown

A Cold Reset completely initializes the CPU core, except for the following register bits.

- The SR bit of the Status register is cleared to 0.
- The ERL and BEV bits of the Status register are set to 1.
- The upper limit value (31) is set in the Random register.
- The Wired register is initialized to 0.
- In the Config register, bits 31 to 28 are set to 7, bit 20 is set to the same setting as the MIPS16EN pin, bit 15 is set to the same setting as the BIG pin, bits 11 to 9 are set to 4, bits 8 to 6 are set to 3, and bit 5 is set to 0. All other bits in the Config register are undefined.
- The values of the other registers are undefined.

2.6.2 Soft reset

A Soft Reset initializes the CPU core without affecting the clocks; in other words, a Soft Reset is a logic reset. In a Soft Reset, the CPU core retains as much state information as possible; all state information except for the following is retained:

- The SR, ERL and BEV bits of the Status register are set to 1.
- The Count register is initialized to 0.
- The IP7 bit of the Cause register is cleared to 0.
- Any Interrupts generated on the SysAD bus are cleared.
- NMI is cleared.
- In the Config register, bits 31 to 28 are set to 7, bit 20 is set to the same setting as the MIPS16EN pin, bit 15 is set to the same setting as the BIG pin, bits 11 to 9 are set to 4, bits 8 to 6 are set to 3, and bit 5 is set to 0. All other bits in the Config register are undefined.

2.6.3 VR4120A processor modes

The VR4120A supports various modes, which can be selected by the user. The CPU core mode is set each time a write occurs in the Status register and Config register. The on-chip peripheral unit mode is set by writing to the I/O register.

This section describes the CPU core's operation modes. For operation modes of on-chip peripheral units, see the chapters describing the various units.

2.6.3.1 Power modes

The VR4120A supports four power modes: Fullspeed mode, Standby mode, Suspend mode, and Hibernate mode.

(1) Fullspeed mode

This is the normal operation mode.

The VR4120A core's default operation status is Fullspeed mode. After a reset, the VR4120A core returns to Fullspeed mode.

(2) Standby mode

The effect of the Standby Mode is the same as for the Suspend Mode.

(3) Suspend mode

When a SUSPEND instruction is executed, the VR4120A core can be set to Suspend mode. In Suspend mode, all of the internal clocks in the VR4120A core except for the timer and interrupt control clocks are held at high level.

When a SUSPEND instruction has completed the WB stage, the VR4120A core waits until the CPU interface (SysAD Bus) enters the idle state. After confirming this idle state, the VR4120A internal clock signals are fixed at high level by the on-chip clock generator. Operation of the interrupt clock (MOUT) continues.

The VR4120A core in Suspend mode is returned to Fullspeed mode if any interrupt occurs, including a timer interrupt that occurs internally.

(4) Hibernate mode

When a HIBERNATE instruction is executed, the VR4120A core can be set to Hibernate mode. In Hibernate mode, all of the internal clocks in the VR4120A core are held at high level, including the interrupt clock (MOUT).

Note that during Hibernate mode the on-chip clock generator still operates with the CPU clock (100MHz/66MHz). The VR4120A core is returned to Fullspeed mode from Hibernate mode via a Cold Reset.

If the power continues to be supplied during Hibernate mode, there is no need to initialize the clock generator on a Cold Reset.

2.6.3.2 Privilege mode

The VR4120A supports three system modes: kernel expanded addressing mode, supervisor expanded addressing mode, and user expanded addressing mode. These three modes are described below.

(1) Kernel expanded addressing mode

When the Status register's KX bit has been set, an expanded TLB miss exception vector is used when a TLB miss occurs for the kernel address. While in kernel mode, the MIPS III operation code can always be used, regardless of the KX bit.

(2) Supervisor expanded addressing mode

When the Status register's SX bit has been set, the MIPS III operation code can be used when in supervisor mode and an expanded TLB miss exception vector is used when a TLB miss occurs for the supervisor address.

(3) User expanded addressing mode

When the Status register's UX bit has been set, the MIPS III operation code can be used when in user mode, and an expanded TLB miss exception vector is used when a TLB miss occurs for the user address. When this bit is cleared, the MIPS I and II operation codes can be used, as can 32-bit virtual addresses.

2.6.3.3 <empty>

2.6.3.4 Bootstrap exception vector (BEV)

The BEV bit is used to generate an exception during operation testing (diagnostic testing) of the cache and main memory system. This bit is automatically set to 1 after reset or NMI exception.

When the Status register's BEV bit has been set, the address of the TLB miss exception vector is changed to the virtual address FFFF FFFF BFC0 0200H and the ordinary execution vector is changed to address FFFF FFFF BFC0 0380H.

When the BEV bit is cleared, the TLB miss exception vector's address is changed to FFFF FFFF 8000 0000H and the ordinary execution vector is changed to address FFFF FFFF 8000 0180H.

2.6.3.5 Cache error check

The Status register's CE bit has no meaning because the VR4120A does not support cash parity.

2.6.3.6 Parity error prohibit

When the Status register's DE bit has been set, the processor does not issue any cache parity error exceptions.

2.6.3.7 Interrupt enable (IE)

When the Status register's IE bit has been cleared, no interrupts can be received except for reset interrupts and nonmaskable interrupts.

2.7 Cache Memory

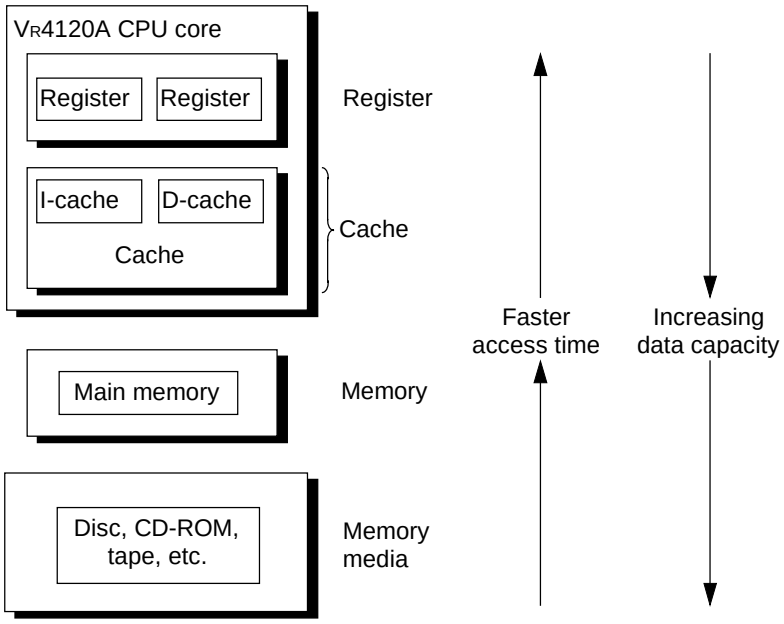
This section describes in detail the cache memory: its place in the VR4120A Core memory organization, and individual organization of the caches.

2.7.1 Memory organization

Figure 2-77 shows the VR4120A Core system memory hierarchy. In the logical memory hierarchy, the caches lie between the CPU and main memory. They are designed to make the speedup of memory accesses transparent to the user.

Each functional block in Figure 2-77 has the capacity to hold more data than the block above it. For instance, main memory (physical memory) has a larger capacity than the caches. At the same time, each functional block takes longer to access than any block above it. For instance, it takes longer to access data in main memory than in the CPU on-chip registers.

Figure 2-77. Logical Hierarchy of Memory



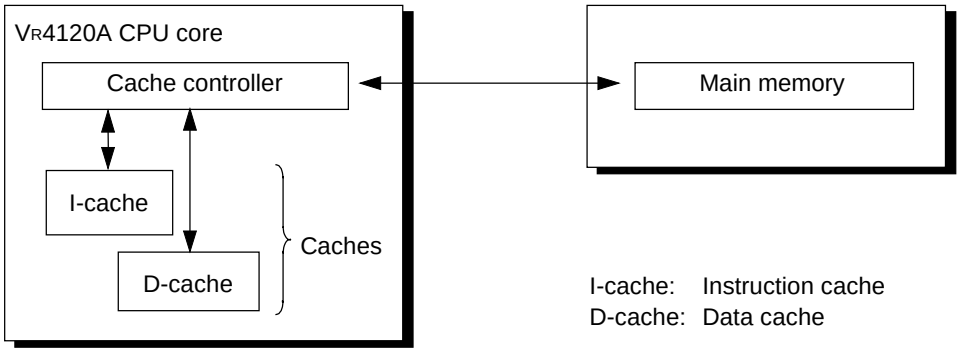
The VR4120A has two on-chip caches: one holds instructions (the instruction cache), the other holds data (the data cache). The instruction and data caches can be read in one PCycle.

2 PCycles are needed to write data. However, data writes are pipelined and can complete at a rate of one per Pcycle. In the first stage of the cycle, the store address is translated and the tag is checked; in the second stage, the data is written into the data RAM.

2.7.2 Cache organization

This section describes the organization of the on-chip data and instruction caches. Figure 2-78 provides a block diagram of the VR4120A Core cache and memory model.

Figure 2-78. Cache Support



(1) Cache line lengths

A cache line is the smallest unit of information that can be fetched from main memory for the cache, and that is represented by a single tag.

The line size for the instruction/data cache is 4 words (16 bytes).

For the cache tag, see **2.8.2.1 Organization of the instruction cache (I-cache)** and **2.8.2.2 Organization of the data cache (D-cache)**.

(2) Cache sizes

The instruction cache in the VR4120A Core is 16 Kbytes; the data cache is 8 Kbytes.

2.7.2.1 Organization of the instruction cache (I-cache)

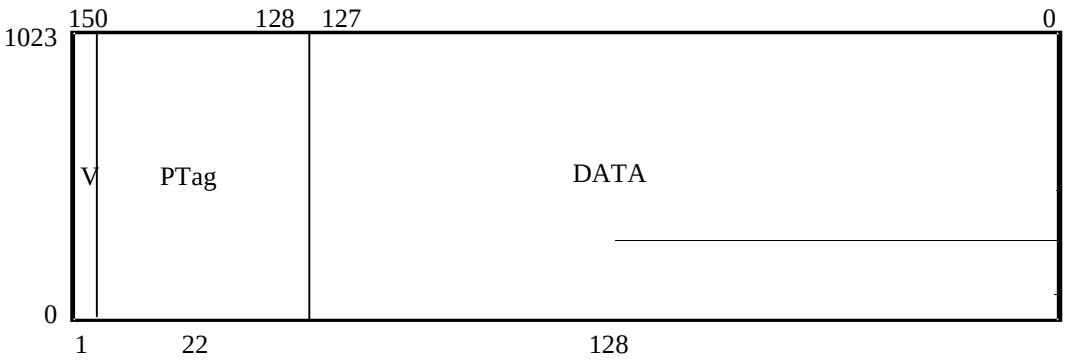
Each line of I-cache data (although it is actually an instruction, it is referred to as data to distinguish it from its tag) has an associated 23-bit tag that contains a 22-bit physical address, and a single valid bit.

The VR4120A Core I-cache has the following characteristics:

- ✧ direct-mapped
- ✧ indexed with a virtual address
- ✧ checked with a physical tag
- ✧ organized with a 4-word (16-byte) cache line

Figure 2-79 shows the organization of the instruction cache and the cache line format when the line size is 4 words (16 bytes).

Figure 2-79. Instruction Cache Organization and Line Format



PTag : Physical tag (bits 31 to 10 of physical address)
V : Valid bit
Data : Cache data

2.7.2.2 Organization of the data cache (D-cache)

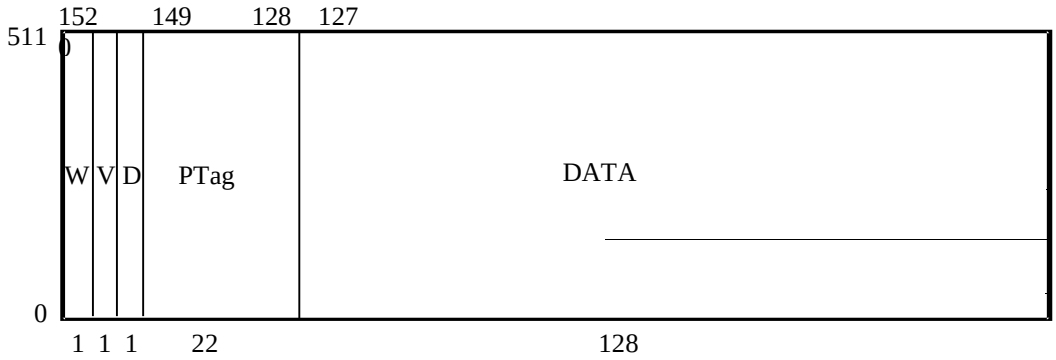
Each line of D-cache data has an associated 25-bit tag that contains a 22-bit physical address, a Valid bit, a Dirty bit, and a Write-back bit.

The VR4120A Core D-cache has the following characteristics :

- ✧ write-back
- ✧ direct-mapped
- ✧ indexed with a virtual address
- ✧ checked with a physical tag
- ✧ organized with a 4-word (16-byte) cache line.

Figure 2-80 shows the format and organization of a 4-word (16-byte) based D-cache .

Figure 2-80. Data Cache Organization and Line Format



W : Write-back bit (set if cache line has been written)
D : Dirty bit
V : Valid bit
PTag : Physical tag (bits 31 to 10 of physical address)
Data : D-cache data

2.7.2.3 Accessing the caches

Figure 2-81 shows the virtual address (VA) index into the caches. The number of virtual address bits used to index the instruction and data caches depends on the cache size.

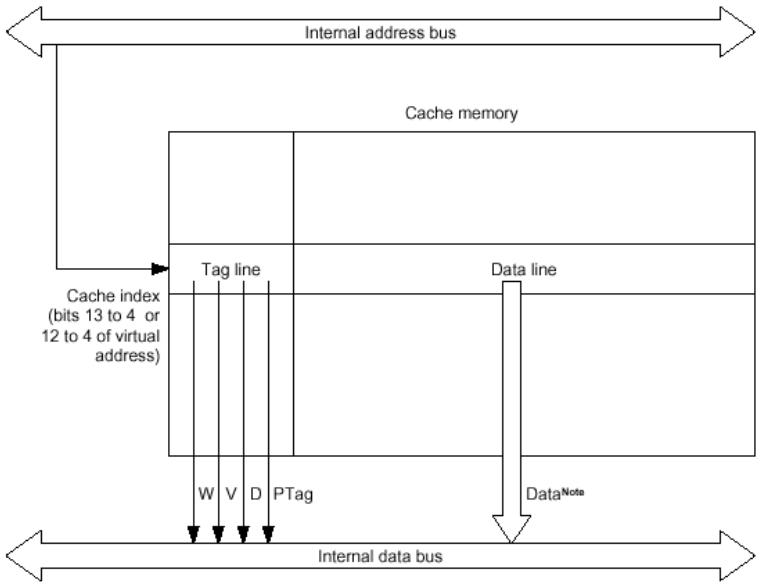
(1) Data cache addressing

Using VA (12:4). The most-significant bit is VA12 because the cache size is 8 Kbytes.
The least-significant bit is VA4 because the line size is 4 words (16 bytes).

(2) Instruction cache addressing

Using VA (13:4). The most-significant bit is VA13 because the cache size is 16 Kbytes.
The least-significant bit is VA4 because the line size is 4 words (16 bytes).

Figure 2-81. Cache Data and Tag Organization



2.7.3 Cache operations

As described earlier, caches provide temporary data storage, and they make the speedup of memory accesses transparent to the user. In general, the CPU core accesses cache-resident instructions or data through the following procedure:

1. The CPU core, through the on-chip cache controller, attempts to access the next instruction or data in the appropriate cache.
2. The cache controller checks to see if this instruction or data is present in the cache.
   - ✧ If the instruction/data is present, the CPU core retrieves it. This is called a cache hit.
   - ✧ If the instruction/data is not present in the cache, the cache controller must retrieve it from memory. This is called a cache miss.
3. The CPU core retrieves the instruction/data from the cache and operation continues.

It is possible for the same data to be in two places simultaneously: main memory and cache. This data is kept consistent through the use of a write-back methodology; that is, modified data is not written back to memory until the cache line is to be replaced.

Instruction and data cache line replacement operations are described in the following sections.

2.7.3.1 Cache write policy

The VR4120A Core manages its data cache by using a write-back policy; that is, it stores write data into the cache, instead of writing it directly to memory[Note]. Some time later this data is independently written into memory. In the VR4120A implementation, a modified cache line is not written back to memory until the cache line is to be replaced either in the course of satisfying a cache miss, or during the execution of a write-back CACHE instruction.

When the CPU core writes a cache line back to memory, it does not ordinarily retain a copy of the cache line, and the state of the cache line is changed to invalid.

Note Contrary to the write-back, the write-through cache policy stores write data into the memory and cache simultaneously.

2.7.4 Cache states

(1) Cache line

The three terms below are used to describe the state of a cache line:

- ✧ Dirty: a cache line containing data that has changed since it was loaded from memory.
- ✧ Clean: a cache line that contains data that has not changed since it was loaded from memory.
- ✧ Invalid: a cache line that does not contain valid information must be marked invalid, and cannot be used. For example, after a Soft Reset, software sets all cache lines to invalid. A cache line in any other state than invalid is assumed to contain valid information. Neither Cold reset nor Soft reset makes the cache state invalid. Software makes the cache state invalid.

(2) Data cache

The data cache supports three cache states:

- ✧ Invalid
- ✧ Valid clean
- ✧ Valid dirty

(3) Instruction cache

The instruction cache supports two cache states:

- ✧ Invalid
- ✧ Valid

The state of a valid cache line may be modified when the processor executes a CACHE operation. CACHE operations are described in **APPENDIX A MIPS III INSTRUCTION SET DETAILS**.

2.7.5 Cache state transition diagrams

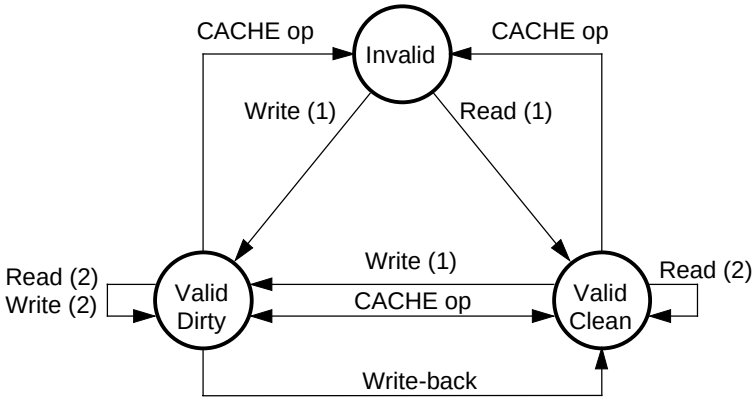
The following section describes the cache state diagrams for the data and instruction cache lines. These state diagrams do not cover the initial state of the system, since the initial state is system-dependent.

2.7.5.1 Data cache state transition

The following diagram illustrates the data cache state transition sequence. A load or store operation may include one or more of the atomic read and write operations shown in the state diagram below, which may cause cache state transitions.

- ✧ Read (1) indicates a read operation from main memory to cache, inducing a cache state transition.
- ✧ Read (2) indicates a read operation from cache to the CPU core, which induces no cache state transition.
- ✧ Write (1) indicates a write operation from CPU core to cache, inducing a cache state transition.
- ✧ Write (2) indicates a write operation from CPU core to cache, which induces no cache state transition.

Figure 2-82. Data Cache State Diagram

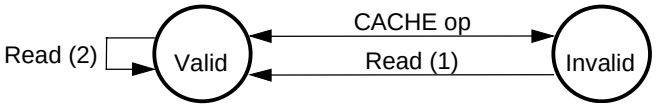


2.7.5.2 Instruction cache state transition

The following diagram illustrates the instruction cache state transition sequence.

Read (1) indicates a read operation from main memory to cache, inducing a cache state transition.
Read (2) indicates a read operation from cache to the CPU core, which induces no cache state transition.

Figure 2-83. Instruction Cache State Diagram



2.7.6 Cache data integrity

Figures 2-84 to 2-98 shows checking operations for various cache accesses.

Figure 2-84. Data Check Flow on Instruction Fetch

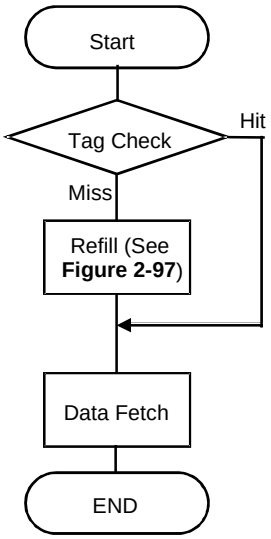


Figure 2-85. Data Check Flow on Load Operations

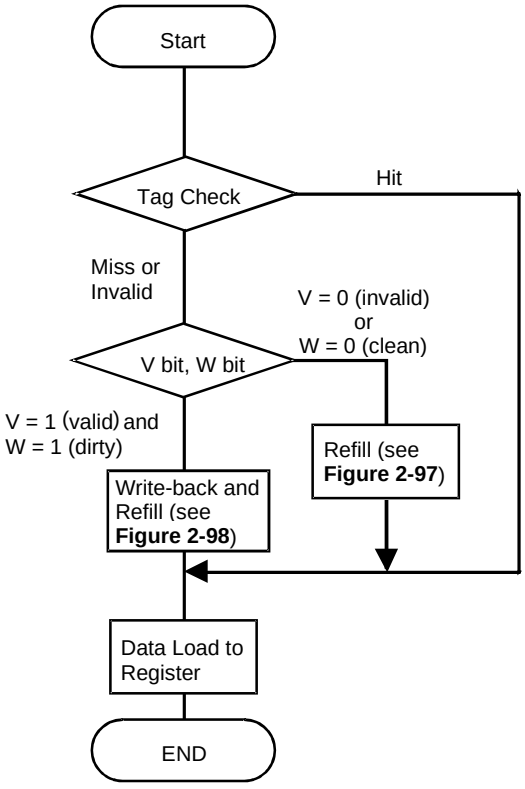


Figure 2-86. Data Check Flow on Store Operations

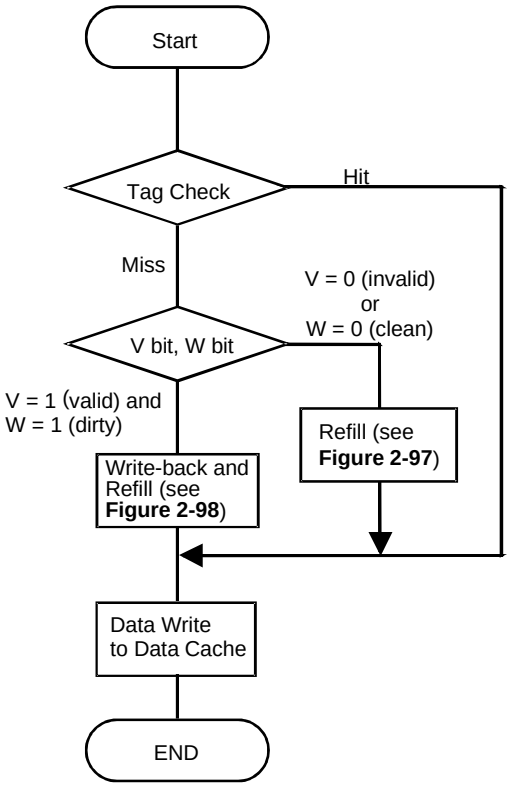


Figure 2-87. Data Check Flow on Index_Invalidate Operations

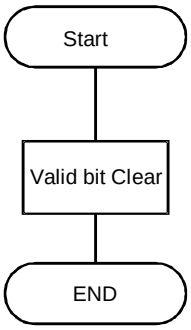


Figure 2-88. Data Check Flow on Index_Writeback_Invalidate Operations

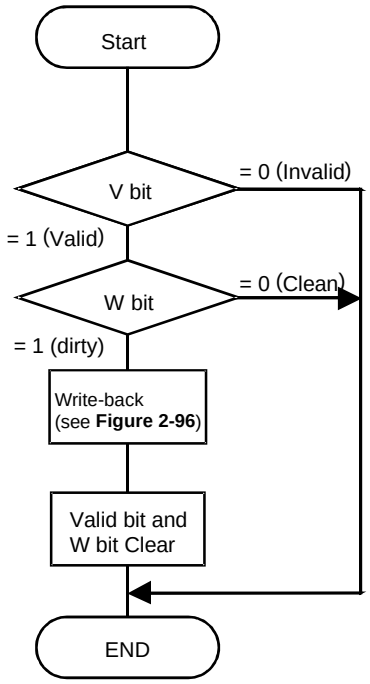


Figure 2-89. Data Check Flow on Index_Load_Tag Operations

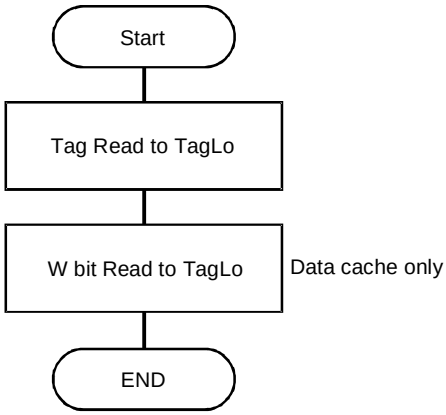


Figure 2-90. Data Check Flow on Index_Store_Tag Operations

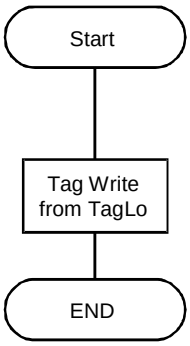


Figure 2-91. Data Check Flow on Create_Dirty Operations

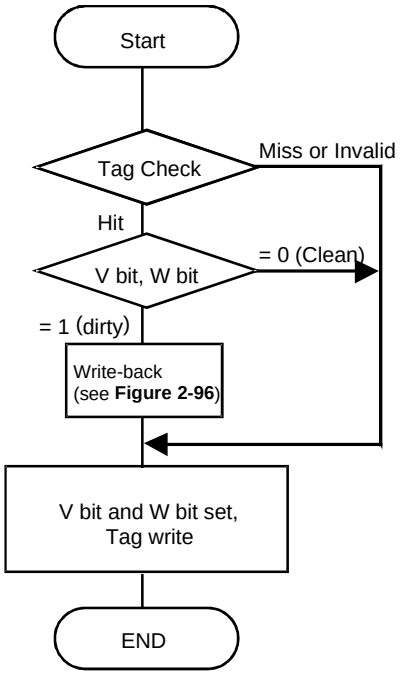


Figure 2-92. Data Check Flow on Hit_Invalidate Operations

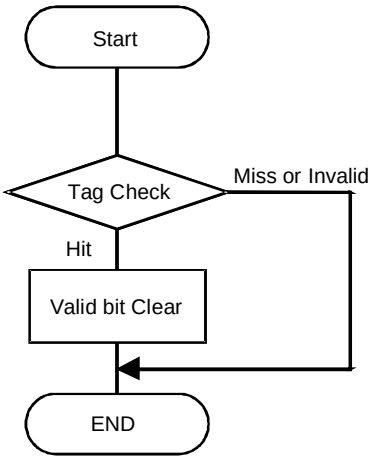


Figure 2-93. Data Check Flow on Hit_Writeback_Invalidate Operations

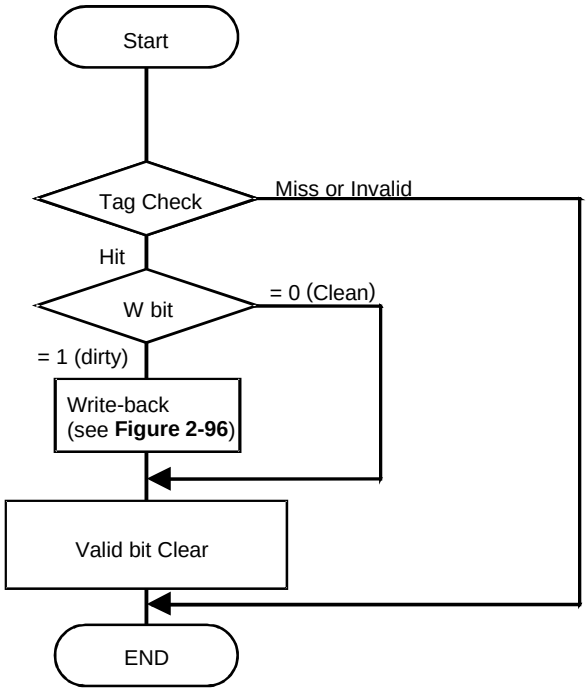


Figure 2-94. Data Check Flow on Fill Operations

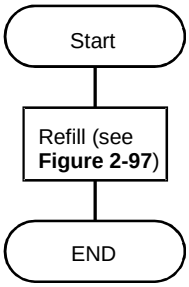


Figure 2-95. Data Check Flow on Hit_Writeback Operations

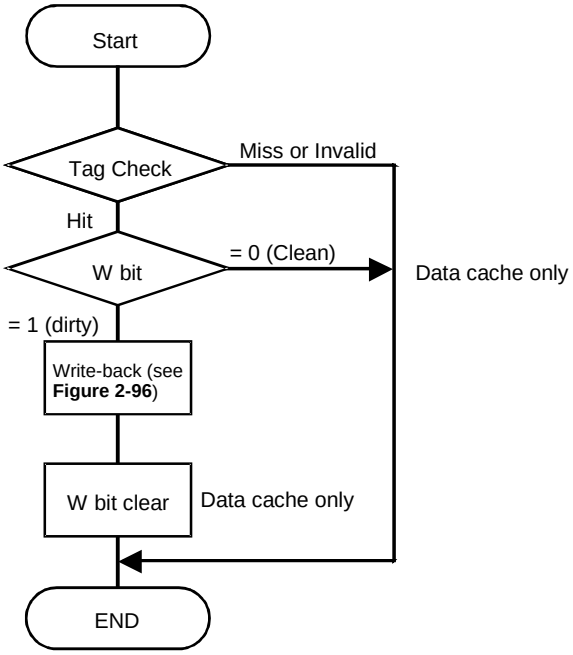


Figure 2-96. Writeback Flow

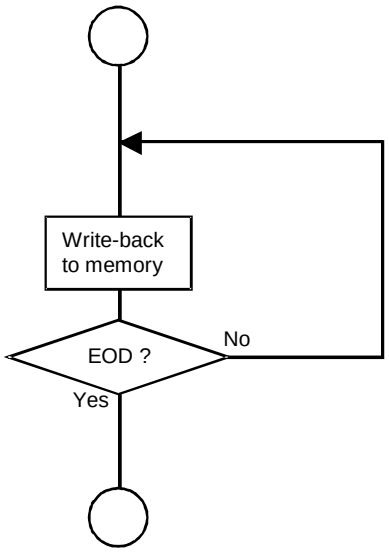


Figure 2-97. Refill Flow

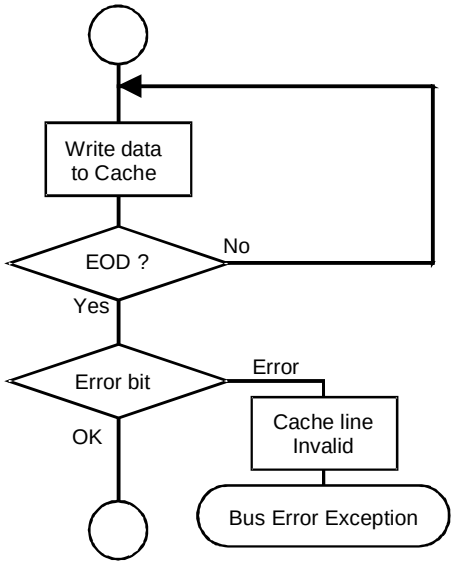
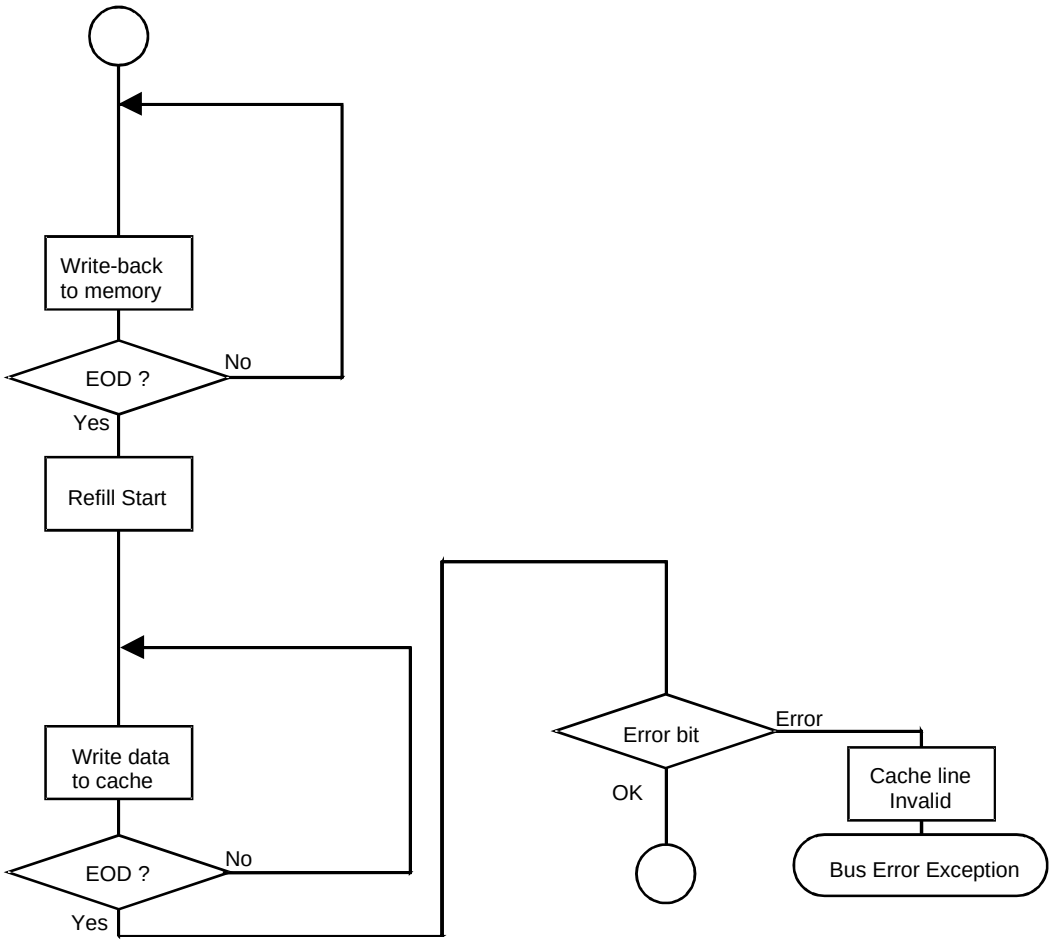


Figure 2-98. Writeback & Refill Flow



Remark Write-back Procedure:

On a store miss write-back, data tag is checked and data is transferred to the write buffer. If an error is detected in the data field, the write back is not terminated; the erroneous data is still written out to main memory. If an error is detected in the tag field, the write-back bus cycle is not issued.

The cache data may not be checked during CACHE operation.

2.7.7 Manipulation of the caches by an external agent

The VR4120A does not provide any mechanisms for an external agent to examine and manipulate the state and contents of the caches.

2.8 CPU Core Interrupts

Four types of interrupt are available on the CPU core. These are:

- ✧ one non-maskable interrupt, NMI
- ✧ five ordinary interrupts
- ✧ two software interrupts
- ✧ one timer interrupt

For the interrupt request input to the CPU core.

2.8.1 Non-maskable interrupt (NMI)

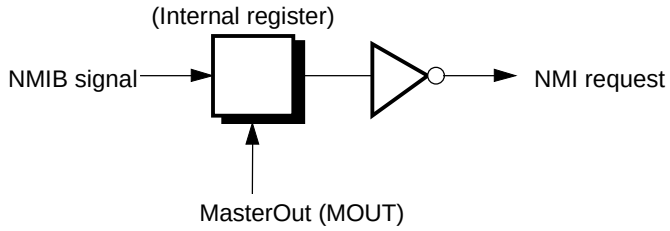
The non-maskable interrupt is acknowledged by asserting the NMIB signal (internal), forcing the processor to branch to the Reset Exception vector. This signal is latched into an internal register at the rising edge of MasterOut (MOUT) signal (internal), as shown in Figure 2-99.

NMI only takes effect when the processor pipeline is running.

This interrupt cannot be masked.

Figure 2-99 shows the internal service of the NMIB signal. The NMIB signal is latched into an internal register by the rising edge of MasterOut (MOUT). The latched signal is inverted to be transferred to inside the device as an NMI request.

Figure 2-99. Non-maskable Interrupt Signal



2.8.2 Ordinary interrupts

Ordinary interrupts are acknowledged by asserting the Int(4:0) signals (internal).

The Int(4:0) signals are level-triggered. Maintain a low level until an ordinary interrupt exception occurs.

After the occurrence of an ordinary interrupt exception, the Int(4:0) signals must be made high level before returning to the ordinary routine or before multiple interrupts are enabled.

This interrupt request can be masked with the IM (6:2), IE, and EXL fields of the Status register.

2.8.3 Software interrupts generated in CPU core

Software interrupts generated in the CPU core use bits 1 and 0 of the IP (interrupt pending) field in the Cause register. These may be written by software, but there is no hardware mechanism to set or clear these bits.

After the processing of a software interrupt exception, corresponding bit of the IP field in the Cause register must be cleared before returning to ordinary routine or enabling multiple interrupts until the operation returns to normal routine.

This interrupt request is maskable through the IM (1:0), IE, and EXL fields of the Status register.

2.8.4 Timer interrupt

The timer interrupt uses bit 7 of the IP (interrupt pending) field of the Cause register. This bit is set automatically whenever the value of the Count register equals the value of the Compare register, and an interrupt request is acknowledged.

This interrupt is maskable through IM7 of the IM field of the Status register.

2.8.5 Asserting interrupts

2.8.5.1 Detecting hardware interrupts

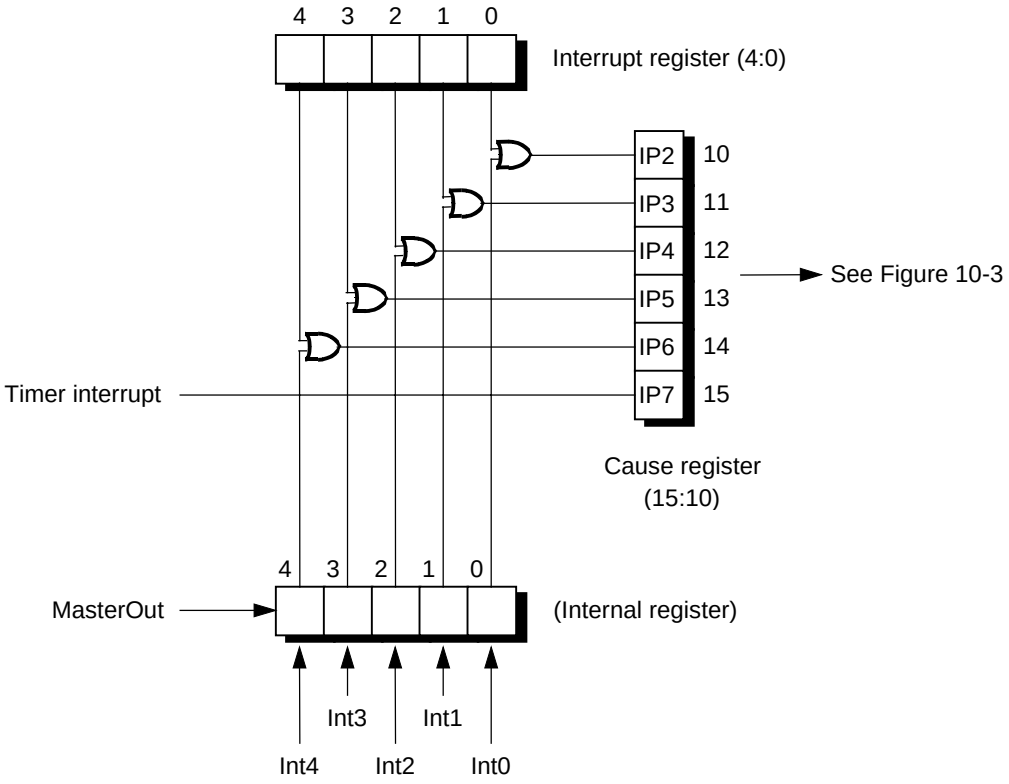
Figure 2-100 shows how the hardware interrupts are readable through the Cause register.

The timer interrupt signal, IP7, is directly readable as bit 15 of the Cause register.

Bits 4 to 0 of the Interrupt register are bit-wise ORed with the current value of the Int4 to 0 signals and the result is directly readable as bits 14 to 10 of the Cause register.

IP1 and IP0 of the Cause register, which are described in **Section 2.6 Exception Processing**, are software interrupts. There is no hardware mechanism for setting or clearing the software interrupts.

Figure 2-100. Hardware Interrupt Signals

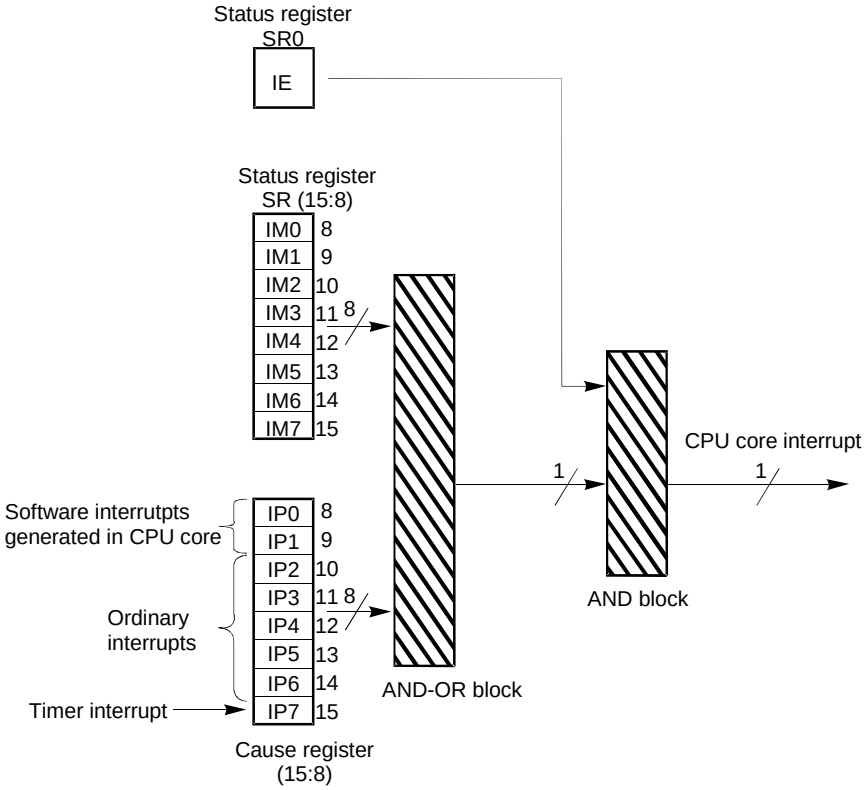


2.8.5.2 Masking interrupt signals

Figure 2-101 shows the masking of the CPU core interrupt signals.

- ✧ Cause register bits 15 to 8 (IP7 to IP0) are AND-ORed with Status register interrupt mask bits 15 to 8 (IM7 to IM0) to mask individual interrupts.
- ✧ Status register bit 0 is a global Interrupt Enable (IE). It is ANDed with the output of the AND-OR logic shown in Figure 2-101 to produce the CPU core interrupt signal. The EXL bit in the Status register also enables these interrupts.

Figure 2-101. Masking of Interrupt Request Signals



Bit	Function	Setting
IE	Whole interrupts enable	1 : Enable 0 : Disable
IM(7:0)	Interrupt mask	Each bit 1 : Enable 0 : Disable
IP(7:0)	Interrupt request	Each bit 1 : Pending 0 : Not pending

[MEMO]

CHAPTER 3 SYSTEM CONTROLLER

3.1 Overview

This block is an internal system controller for LAKI. System Controller provides bridging function among the CPU system bus “SysAD”, NEC original high speed on-chip bus “IBUS” and system bus for SDRAM/PROM/FLASH and functional expansions.

Features of System Controller are as follows.

- Provides bus bridging function among SysAD bus, IBUS and external system bus (MEMORY etc.)
- Supports Endian Converting function on SysAD bus
- Can directly connect 16M/64/128Mbit-SDRAM and PROM/FLASH
- Supports Deadman’s SW Timer and separated 2ch Timers
- Supports general purpose input output pins
- Supports single UART and Microwire™ interface

3.1.1 CPU interface

- Connects directly to the VR4120A CPU bus “SysAD bus”.
- Supports all VR4120A bus cycles at 66MHz or 100MHz.
- Supports only data rate D.
- Supports only sequential ordering.
- 4word (16byte) x 4entry write command buffer.
- Little-Endian or Big-Endian byte order.

3.1.2 Memory interface

- 66MHz or 100MHz memory bus.
- Up to 32MB Base memory range supports SDRAM.
- Up to 8MB write-protectable Boot memory range supports PROM/FLASH.
- On-chip programmable SDRAM refresh controller.
- 4word (16byte) Write data buffer.
- 4word (16byte) Prefetch data buffer (memory-to-CPU).
- PROM/FLASH data signals multiplexed on SDRAM data signals.
- Variable Flash memory data bus. (8, 16, 32bit)
- Programmable memory bus arbitration priority.
- Programmable address ranges for the memory.
- Programmable RAS-CAS Delay (2,3,4 clock).
- Programmable CAS Latency (2,3 clock).

3.1.3 IBUS interface

- Master and target capability.
- 64word (256byte) IBUS Slave TxFIFO (IBUS read data from MEMORY).
- 64word (256byte) IBUS Slave RxFIFO (IBUS writes data to MEMORY).
- 4word (16byte) IBUS Master TxFIFO (VR4120A read data from IBUS).
- 4word (16byte) IBUS Master RxFIFO (VR4120A writes data to IBUS).
- Supports the bus timer to detect IBUS stall.

- 66MHz IBUS clock rate.
- Supports 266 MB/sec (32bit @66MHz) bursts on IBUS.

3.1.4 UART

- Universal Asynchronous Receiver/Transmitter
- Modem control functions
- Even, odd or no parity bit generation
- Fully prioritized interrupt control

3.1.5 Microwire

- For storing Ethernet MAC addresses in a serial EEPROM, LAKI features a simple serial interface which connects to Microwire™ compliant EEPROMs

3.1.6 Timer

- Two 32bit loadable general purpose timers generating Interrupt to CPU

3.1.7 Interrupt controller

- Generates NMI and INT
- All interrupt causing events maskable

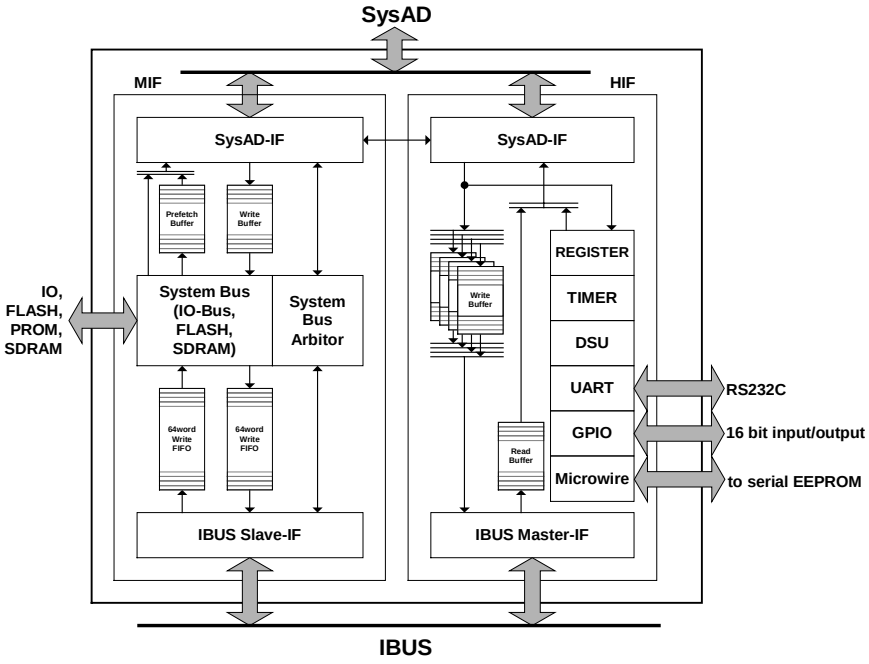
3.1.8 DSU (Deadman's SW UNIT)

- Deadman's SW UNIT generates cold reset to CPU

3.1.9 General Purpose Input/Output Pins

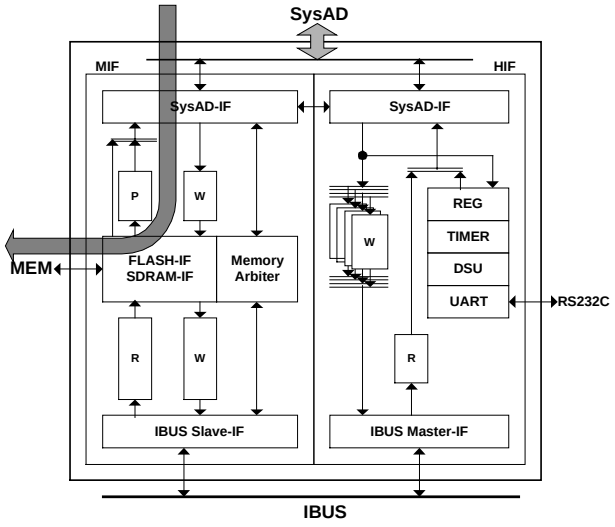
- 16 input/output pins

3.1.10 System block diagram

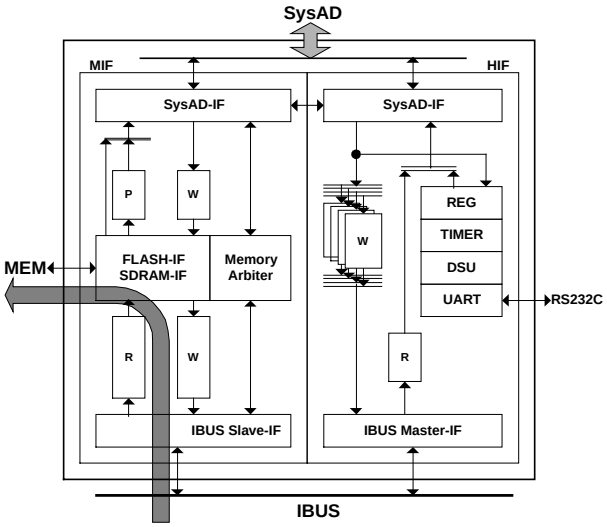


3.1.11 Data flow diagram

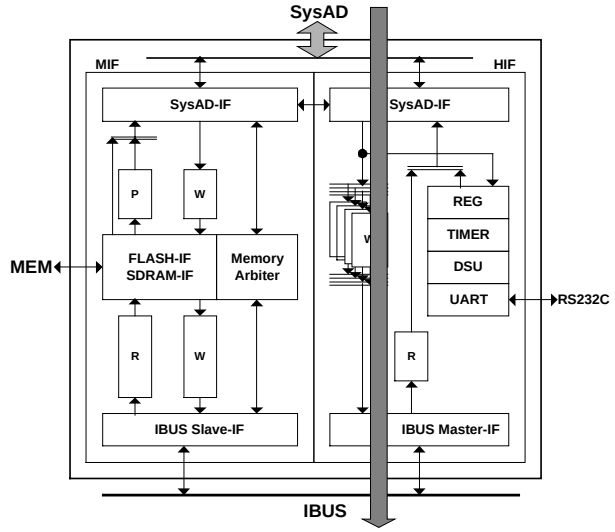
VR4120A Core to SDRAM



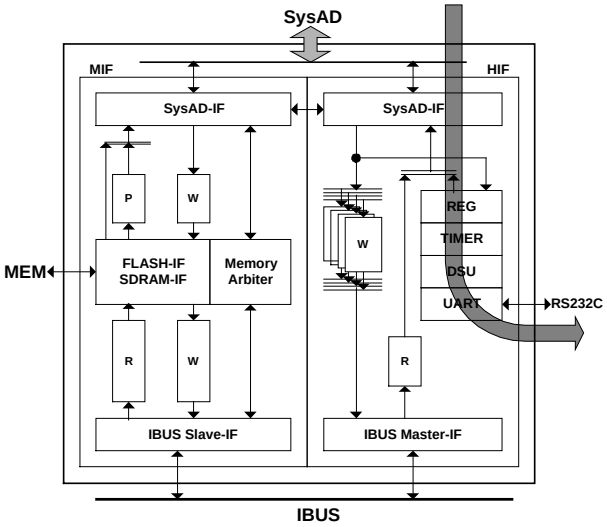
IBUS to SDRAM



VR4120A Core to IBUS



VR4120A Core to UART



3.2 Registers

3.2.1 Register summary

Following Table summarizes the controller's register set. The base address for the set is 1000_0000H in the physical address space.

Offset	Name	R/W	Access	Description	Default
00H	S_GMR	R/W	W/H/B	General Mode Register	00000000H
04H	S_GSR	R	W/H/B	General Status Register	unknown
08H	S_ISR	RC	W/H/B	Interrupt Status Register	00000000H
0CH	S_IMR	R/W	W/H/B	Interrupt Mask Register	00000000H
10H	S_NSR	RC	W/H/B	NMI Status Register	00000000H
14H	S_NMR	R/W	W/H/B	NMI Mask Register	00000000H
18H	S_VER	R	W/H/B	Version Register	00000301H
1CH	reserved	R/W	W/H/B	reserved	00000000H
20H	S_GIOER	R/W	W/H/B	GPIO Output Enable Register	00000000H
24H.	S_GOPR	R/W	W/H/B	GPIO Output (Write) Register	00000000H
28H.	S_GIPR	R	W/H/B	GPIO Input (Read) Register	00000000H
2CH: 2FH	N/A	----	----	Reserved	unknown
30H	S_WRCR	W	W/H/B	Warm Reset Control Register	00000000H
34H	S_WRSR	R	W/H/B	Warm Reset Status Register	00000000H
38H	S_PWCR	R/W	W/H/B	Power Control Register	00000000H
3CH	S_PWSR	R	W/H/B	Power Control Status Register	00000000H
40H: 4BH	N/A	----	----	Reserved	unknown
4CH	ITCNTR	R/W	W/H/B	IBUS Timeout Timer Control Register	00000000H
50H	ITSETR	R/W	W/H/B	IBUS Timeout Timer Set Register	80000000H
54H: 7FH	N/A	----	----	Reserved	unknown
80H	UARTRBR	R	W/H/B	UART, Receiver Buffer Register [DLAB=0,READ]	unknown
80H	UARTTHR	W	W/H/B	UART, Transmitter Holding Register [DLAB=0,WRITE]	unknown
80H	UARTDLL	R/W	W/H/B	UART, Divisor Latch LSB Register [DLAB=1]	unknown
84H	UARTIER	R/W	W/H/B	UART, Interrupt Enable Register [DLAB=0]	unknown
84H	UARTDLM	R/W	W/H/B	UART, Divisor Latch MSB Register [DLAB=1]	unknown
88H	UARTIIR	R	W/H/B	UART, Interrupt ID Register [READ]	unknown
88H	UARTFCR	W	W/H/B	UART, FIFO control Register [WRITE]	unknown
8CH	UARTLCR	R/W	W/H/B	UART, Line control Register	unknown
90H	UARTMCR	R/W	W/H/B	UART, Modem Control Register	unknown
94H	UARTLSR	R/W	W/H/B	UART, Line status Register	unknown
98H	UARTMSR	R/W	W/H/B	UART, Modem Status Register	unknown
9CH	UARTSCR	R/W	W/H/B	UART, Scratch Register	unknown
A0H	DSUCNTR	R/W	W/H/B	DSU Control Register	00000000H
A4H	DSUSETR	R/W	W/H/B	DSU Dead Time Set Register	80000000H
A8H	DSUCLRR	W	W/H/B	DSU Clear Register	00000000H
ACH	DSUTIMR	R	W/H/B	DSU Elapsed Time Register	00000000H
B0H	TMMR	R/W	W/H/B	Timer Mode Register	00000000H
B4H	TM0CSR	R/W	W/H/B	Timer CH0 Count Set Register	00000000H
B8H	TM1CSR	R/W	W/H/B	Timer CH1 Count Set Register	00000000H
BCH	TM0CCR	R	W/H/B	Timer CH0 Current Count Register	FFFFFFFFH

Offset	Name	R/W	Access	Description	Default
C0H	TM1CCR	R	W/H/B	Timer CH1 Current Count Register	FFFFFFFFH
C4H: CFH	N/A	----	----	Reserved	unknown
D0H	ECCR	W	W/H/B	EEPROM Command Control Register	00000000H
D4H	ERDR	R	W/H/B	EEPROM Read Data Register	80000000H
D8H	MACAR1	R	W/H/B	MAC Address Register 1	00000000H
DCH	MACAR2	R	W/H/B	MAC Address Register 2	00000000H
E0H	MACAR3	R	W/H/B	MAC Address Register 3	00000000H
E4H: FFH	N/A	----	----	Reserved	unknown
100H	RMMDR	R/W	W	Boot ROM Mode Register	00000000H
104H	RMATR	R/W	W	Boot ROM Access Timing Register	00000000H
108H	SDMDR	R/W	W	SDRAM Mode Register	00000330H
10CH	SDTSR	R/W	W	SDRAM Type Selection Register	00000000H
110H	SDPTR	R/W	W	SDRAM Precharge Timing Register	00000142H
114: 11BH	N/A	----	----	Reserved	unknown
11CH	SDRMR	R/W	W	SDRAM Refresh Mode Register	00000200H
120H	SDRCR	R	W	SDRAM Refresh Timer Count Register	00000200H
124H	MBCR	R/W	W	Memory Bus Control Register	00000000H
128H	MESR	RC	W	Memory Error Status Register	00000000H
12CH	MEAR	RC	W	Memory Error Address Register	00000000H
130H: FFFH	N/A	----	----	Reserved	unknown

Remarks 1. In the “R/W” field,
“W” means “writeable”
“R” means “readable”
“RC” means “read-cleared”
“----“ means “not accessible”

2. All internal registers are 32bit word aligned register.

3. The burst access to the internal register is prohibited.
If such burst access has been occurred, IRERR bit in NSR is set and NMI will assert to CPU.

4. Read access to the reserved area will set the CBERR bit in the NSR register, and the dummy read response data with the data-error bit set on SysCMD[0] is returned.

5. Write access to the reserved area will set the CBERR bit in the NSR register, and the write data is lost.

6. In the “Access” filed,
“W” means that Word access is valid.
“H” means that Half word access is valid.
“B” means that Byte access is valid.

7. Write access to the read-only register cause no error, but the write data is lost.

8. The CPU can access all internal register, but IBUS Master device cannot access them.

3.2.2 General registers

3.2.2.1 General Mode Register (S_GMR)

The General Mode Register "S_GMR" is read-write and word aligned 32bit register. After initializing, VR4120A set the IAEN bit to enable the IBUS arbiter. S_GMR is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
0	CRST	Cold Reset: 0 = do nothing 1 = perform cold reset (same as hardware system reset)
1	IAEN	IBUS Arbiter Enable: 0 = disable (IBUS Arbiter does not allow the grant except System Controller) 1 = enable.
2	MPFD	Memory-to-CPU Prefetch FIFO disable: 0 = enable 1 = disable
3	UCSEL	UART Source Clock Selection: 0 = use 1/2 of CPU clock 1 = use external clock (18.432MHz)
7:4	Reserved	Hardwired to 0.
8	HSWP	HIF Block Data swap function enable: 1= enable 0 = disable
9	MSWP	MIF Block Data swap function enable: 1 = enable 0 = disable
31:10	Reserved	Hardwired to 0.

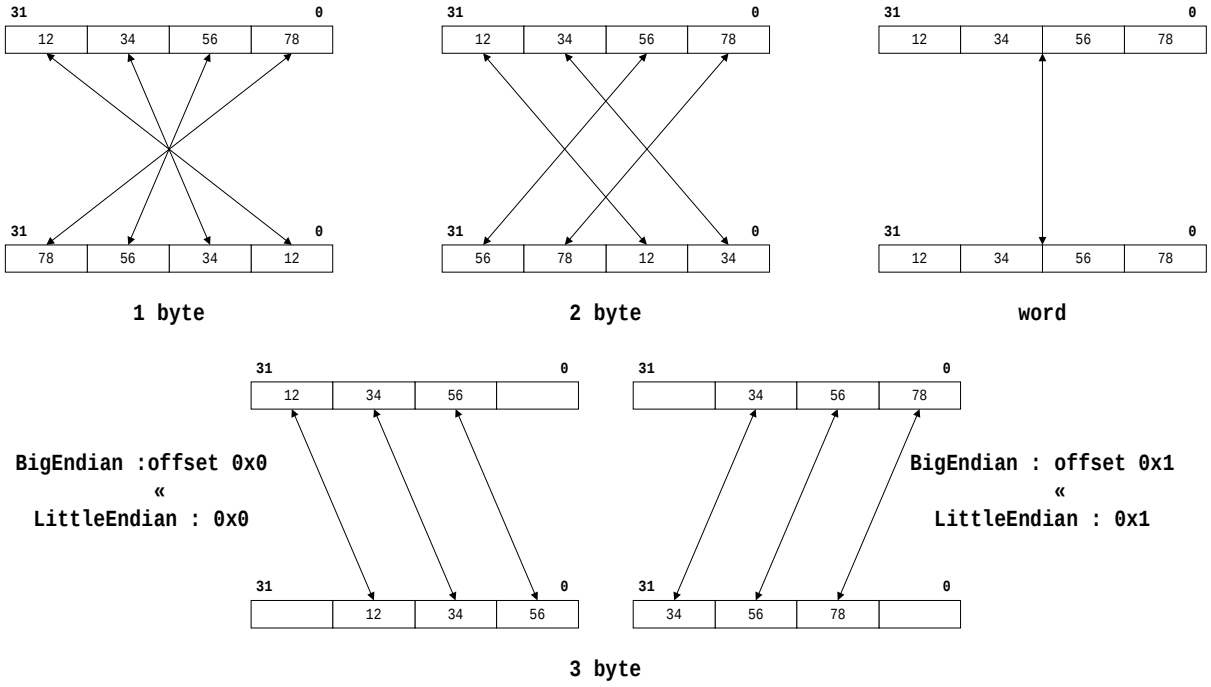
The "HSWP" bit on General mode register is enabler for the endian converter that is located between sysad interface and IBUS master interface, so this works only in IBUS target area. This converter is effective at the case of address swap mode only. This converter performs following data operations.

Endian Translation Table for the data swap mode

HSWP on GMR	Data Size	offset address [1:0]*	Before Translation input data[31:0] in Data Phase	After Translation output data[31:0] in Data Phase	Note
0	any	any	[31:0]	[31:0]	i.e. now
1	Over 1 word	0			
	1 byte	0,1,2,3	[31:24][23:16][15:8][7:0]	[7:0][15:8][23:16][31:24]	-
	2 byte	0,2	[31:16][15:0]	[15:0] [31:16]	-
	3 byte	0	[31:8][7:0]	[31:24][23:0]	-
		1	[31:24][23:0]	[31:8][7:0]	-

* : This offset address[1:0] is expression on bigendian mode.

In the following Figure, Upper side is 4 octet data of SysAD BUS. And Lower side is 4 octet data of IBUS master I/F.

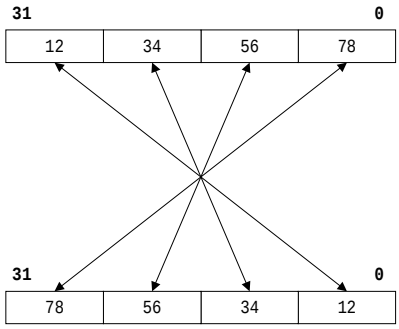


The “MSWP” bit in General mode register is enabler for the endian converter that is located between memory interface and IBUS slave interface, so this works only for memory access via IBUS slave I/F. This converter is effective at the case of address swap mode only. This converter performs following data operations.

Endian Translation Table for the data swap mode

MSWP on GMR	Before Translation input data[31:0] in Data Phase	After Translation output data[31:0] in Data Phase	Note
0	[31:0]	[31:0]	i.e. now
1	[31:24][23:16][15:8][7:0]	[7:0][15:8][23:16][31:24]	-

In the following Figure, Upper side is 4 octet data of memory I/F, and Lower side is 4 octet data of IBUS slave I/F.



3.2.2.2 General Status Register (S_GSR)

The General Status Register “S_GSR” is read-only and word aligned 32bit register. S_GSR shows the status of external pin of LAKI. S_GSR contains the following fields:

Bits	Field	Description
0	ENDCEN	This field reflects the status of external pin “ENDCEN” after reset. 0 = connected to GND, It means that Endian Converter is disabled. 1 = connected to VCC, It means that Endian Converter is enabled.
1	CCLKSEL	This field reflects the status of external pin “CCLKSEL” after reset. 0 = connected to GND, It means that CPU is operated at 100MHz. 1 = connected to VCC, It means that CPU is operated at 66MHz.
31:2	Reserved	Hardwired to 0.

3.2.2.3 Interrupt Status Register (S_ISR)

The Interrupt Status Register “S_ISR” is read-clear and word aligned 32bit register. “S_ISR” shows the interruption status from SysAD / IBUS interfaces, TIMER, UART and so on. If corresponding bit in S_IMR(Interrupt Mask Register) is reset and the interrupt is not masked, System Controller interrupt to VR4120A using interrupt signal. The bit in S_ISR is reset after being read by the VR4120A. When the same type of incidents occurs before the bit has been read, the bit will be set again. S_ISR is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
0	TM0IS	TIMER CH0 interrupt. 1 = TIMER CH0 interrupt pending 0 = No TIMER CH0 interrupt pending
1	TM1IS	TIMER CH1 interrupt. 1 = TIMER CH1 interrupt pending 0 = No TIMER CH1 interrupt pending
2	UARTIS	UART interrupt. 1 = UART interrupt pending. 0 = No UART interrupt pending. UART interruption are one of the following interruption: 1. UART Receive data Buffer Full Interrupt 2. UART Transmitter Buffer empty Interrupt 3. UART Line status Interrupts 4. UART Modem status Interrupts
3	EXTIS	External Interrupt. 1 = External Interrupt pending. 0 = No External interrupt pending.
4	WUIS	Wakeup Interrupt. 1 = Any wakeup requests pending. 0 = No wakeup requests pending.
31:5	Reserved	Hardwired to 0.

Remark To clear this register, the CPU must read the byte contained the TMS0IS field.

The Wakeup Interrupt WUIS in S_ISR[4] is generated based on a logical OR function from the USB and ETHERNET MAC wakeup requests in register S_PWSR[8] and S_PWSR[9]. The WUIS interrupt can be masked with the S_IMR[4] register bit WUIM. The causes S_PWSR[8] and S_PWSR[9] cannot be masked individually.

The Wakeup Interrupt WUIS is seen from the CPU in the exception cause register (CPU register 13) as IP[6]. There this interrupt can be masked with the IM[6] bit in the VR4120A status register (CPU register 12).

3.2.2.4 Interrupt Mask Register (S_IMR)

The Interrupt Mask Register “S_IMR” is read-write and word aligned 32bit register. S_IMR masks interruption for each corresponding incident. A Mask bit, which locates in the same bit location to a corresponding bit in S_ISR, controls interruption triggered by the incident. If a bit of this register is reset to zero, the corresponding bit of the S_ISR is masked. If it is set to 1, the corresponding bit is unmasked. When the mask bit is reset and the bit in S_ISR is set, System Controller assert interruption signal to interrupt VR4120A. It is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
0	TM0IM	TIMER CH0 interrupt mask. 1 = unmask. 0 = mask.
1	TM1IM	TIMER CH1 interrupt mask. 1 = unmask. 0 = mask.
2	UARTIM	UART interrupt mask. 1 = unmask. 0 = mask.
3	EXTIM	External interrupt mask 1 = unmask. 0 = mask.
4	WUIM	Wakeup interrupt mask 1 = unmask. 0 = mask.
31:5	Reserved	Hardwired to 0.

3.2.2.5 NMI Status Register (S_NSR)

The Interrupt Status Register “S_NSR” is read-clear and word aligned 32bit register. “S_NSR” shows the non-maskable interruption “NMI” status from SysAD / IBUS interfaces, External NMI, Memory Interface and so on. If corresponding bit in S_NMR (NMI Mask Register) is reset and the NIM is disabled, System Controller interrupt to VR4120A using non-maskable interrupt signal. The bit in S_NSR is reset after being read by the VR4120A. When the same type of incidents occurs before the bit has been read, the bit will be set again. S_NSR is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
0	CBERR	CPU Bus Error. CPU Bus error includes the illegal bus command, illegal data align, illegal bust size, and illegal access to the RFU area in register space. 1 = CPU bus error. 0 = No such error.
1	IBERR	IBUS Bus Error. IBUS Bus error is occurred when CPU access to the RFU area in the IBUS Target Address Space (see MEMORY MAP section). 1 = A bus error occurred during the IBUS master access. 0 = No such error.
2	ITERR	IBUS Timeout Error. IBUS Timeout error is occurred when the IBUS is stalled. 1 = IBUS timeout error. 0 = No such error.
3	MAERR	Memory Address Error. Memory Address error includes the memory access to the illegal memory space (RFU space and out range of the SDRAM/ROM space) and the illegal memory access (byte or half-word ROM access or burst write access to the ROM). 1 = An address range error occurred during the memory access. 0 = No such error.
4	EXTNMI	External NMI. 1 = External NMI is asserted 0 = External NMI is not asserted.
5	IRERR	Illegal Internal Register Access Error. 1 = illegal internal Register access, ex burst access, has been performed. 0 = No such access
31:6	Reserved	Hardwired to 0.

Remark To clear this register, the CPU must read the byte contained the CBERR field.

3.2.2.6 NMI Mask Register (S_NMR)

The NMI Mask Register “S_NMR” is read-write and word aligned 32bit register. S_NMR enables NMI for each corresponding incident. A Enable bit, which locates in the same bit location to a corresponding bit in S_NSR, controls interruption triggered by the incident. If a bit of this register is reset to zero, the corresponding bit of the S_NSR is disabled. If it is set to 1, the corresponding bit is enabled. When the enable bit is reset and the bit in S_NSR is set, System Controller assert interruption signal to interrupt VR4120A. S_NMR is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
0	CBERRE	CPU Bus Error enable. 1 = enable. 0 = disable.
1	IBERRE	IBUS Bus Error. 1 = enable. 0 = disable.
2	ITERRE	IBUS Timeout Error. 1 = enable 0 = disable
3	MAERRE	Memory Address Error. 1 = enable 0 = disable
4	EXTNMIE	External NMI. 1 = enable 0 = disable
5	IRERRE	Illegal Internal Register Access Error. 1 = enable 0 = disable
31:6	Reserved	Hardwired to 0.

3.2.2.7 Version register (S_VER)

The Version Register “S_VER” is read-only and word aligned 32bit register. Version Register shows version number of the System Control Unit in LAKI. S_VER is initialized to 0x0301 at reset and contains the following fields:

Bits	Field	Description
7:0	MINOR	Minor revision. Hardwired to 01H
15:8	MAJOR	Major revision. Hardwired to 03H
31:16	Reserved	Hardwired to 0.

3.2.2.8 S_IOR Register

Remark: the output only port register of earlier NEC communication processor devices has been replaced with the following general purpose input/output registers.

3.2.2.9 General Purpose I/O Output Enable Register (S_GIOER)

The GIOER register is read-write and word aligned 32bit register. It is used to control the direction (input or output mode) of the GPIO pins. Writing '1' into a register bit enables the output mode of the corresponding pin. The GIOER register is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
0	GPIOOE0	GPIO[0] output mode enable; 0 = disable output mode 1 = enable output mode
1	GPIOOE1	GPIO[1] output mode enable; 0 = disable output mode 1 = enable output mode
2	GPIOOE2	GPIO[2] output mode enable; 0 = disable output mode 1 = enable output mode
3	GPIOOE3	GPIO[3] output mode enable; 0 = disable output mode 1 = enable output mode
4	GPIOOE4	GPIO[4] output mode enable; 0 = disable output mode 1 = enable output mode
5	GPIOOE5	GPIO[5] output mode enable; 0 = disable output mode 1 = enable output mode
6	GPIOOE6	GPIO[6] output mode enable; 0 = disable output mode 1 = enable output mode
7	GPIOOE7	GPIO[7] output mode enable; 0 = disable output mode 1 = enable output mode
8	GPIOOE8	GPIO[8] output mode enable; 0 = disable output mode 1 = enable output mode
9	GPIOOE9	GPIO[9] output mode enable; 0 = disable output mode 1 = enable output mode
10	GPIOOE10	GPIO[10] output mode enable; 0 = disable output mode 1 = enable output mode
11	GPIOOE11	GPIO[11] output mode enable; 0 = disable output mode 1 = enable output mode
12	GPIOOE12	GPIO[12] output mode enable; 0 = disable output mode 1 = enable output mode
13	GPIOOE13	GPIO[13] output mode enable; 0 = disable output mode 1 = enable output mode
14	GPIOOE14	GPIO[14] output mode enable; 0 = disable output mode 1 = enable output mode
15	GPIOOE15	GPIO[15] output mode enable; 0 = disable output mode 1 = enable output mode
16:31	Reserved	reserved

3.2.2.10 General Purpose I/O Output (Write) Register (S_GOPR)

The GOPR register is read-write and word aligned 32bit register. It is used to set the data of GPIO pins, which are switched to output mode. Writing '1' into a register bit switches the corresponding pin to high level. The GOPR register is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
0	GPIOO0	GPIO[0] output register; 0 = output low level 1 = output high level
1	GPIOO1	GPIO[1] output register; 0 = output low level 1 = output high level
2	GPIOO2	GPIO[2] output register; 0 = output low level 1 = output high level
3	GPIOO3	GPIO[3] output register; 0 = output low level 1 = output high level
4	GPIOO4	GPIO[4] output register; 0 = output low level 1 = output high level
5	GPIOO5	GPIO[5] output register; 0 = output low level 1 = output high level
6	GPIOO6	GPIO[6] output register; 0 = output low level 1 = output high level
7	GPIOO7	GPIO[7] output register; 0 = output low level 1 = output high level

Bits	Field	Description
8	GPIOO8	GPIO[8] output register; 0 = output low level 1 = output high level
9	GPIOO9	GPIO[9] output register; 0 = output low level 1 = output high level
10	GPIOO10	GPIO[10] output register; 0 = output low level 1 = output high level
11	GPIOO11	GPIO[11] output register; 0 = output low level 1 = output high level
12	GPIOO12	GPIO[12] output register; 0 = output low level 1 = output high level
13	GPIOO13	GPIO[13] output register; 0 = output low level 1 = output high level
14	GPIOO14	GPIO[14] output register; 0 = output low level 1 = output high level
15	GPIOO15	GPIO[15] output register; 0 = output low level 1 = output high level
16:31	Reserved	Reserved

3.2.2.11 General Purpose I/O Input (Read) Register (S_GIPR)

The GIPR register is read-only and word aligned 32bit register. It is used to read the data of GPIO pins, which are switched to input mode. Reading '1' corresponds to high level. The GIPR register is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
0	GPIOI0	GPIO[0] input register; 0 = input low level 1 = input high level
1	GPIOI1	GPIO[1] input register; 0 = input low level 1 = input high level
2	GPIOI2	GPIO[2] input register; 0 = input low level 1 = input high level
3	GPIOI3	GPIO[3] input register; 0 = input low level 1 = input high level
4	GPIOI4	GPIO[4] input register; 0 = input low level 1 = input high level
5	GPIOI5	GPIO[5] input register; 0 = input low level 1 = input high level
6	GPIOI6	GPIO[6] input register; 0 = input low level 1 = input high level
7	GPIOI7	GPIO[7] input register; 0 = input low level 1 = input high level
8	GPIOI8	GPIO[8] input register; 0 = input low level 1 = input high level
9	GPIOI9	GPIO[9] input register; 0 = input low level 1 = input high level
10	GPIOI10	GPIO[10] input register; 0 = input low level 1 = input high level
11	GPIOI11	GPIO[11] input register; 0 = input low level 1 = input high level
12	GPIOI12	GPIO[12] input register; 0 = input low level 1 = input high level
13	GPIOI13	GPIO[13] input register; 0 = input low level 1 = input high level
14	GPIOI14	GPIO[14] input register; 0 = input low level 1 = input high level
15	GPIOI15	GPIO[15] input register; 0 = input low level 1 = input high level
16:31	Reserved	reserved

3.2.2.12 Warm Reset Control Register (S_WRCR)

The Warm Reset Control Register “S_WRCR” is read-write and word aligned 32bit register. S_WRCR generates warm-reset request to USB Controller and Ethernet Controller independently. S_WRCR is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
0	USBWR	Warm Reset request for USB Controller: 0 = do nothing. 1 = perform warm reset.
1	MACWR	Warm Reset request for Ethernet Controller : 0 = do nothing. 1 = perform warm reset.
2	reserved	reserved
3	reserved	reserved
4	UARTWR	Warm Reset request for UART: 0 = do nothing. 1 = perform warm reset.
31:5	Reserved	Hardwired to 0.

Remark All field in this register will read back as zero

3.2.2.13 Warm Reset Status Register (S_WRSR)

The Warm Reset Status Register “S_WRSR” is read-only and word aligned 32bit register. S_WRSR indicates the response from USB Controller and Ethernet Controller independently. S_WRCR is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
0	USBWRST	shows Warm Reset Status from USB Controller: 0 = USB Controller is busy to perform the warm reset.. 1 = warm reset has been done. USB Controller is ready. .
1	MACWRST	shows Warm Reset Status from Ethernet Controller : 0 = Ethernet Controller #1 is busy to perform the warm reset.. 1 = warm reset has been done. MAC Ethernet Controller is ready.
2	reserved	reserved
3	reserved	reserved
4	UARTWRST	shows Warm Reset Status from UART: 0 = UART is busy to perform the warm reset. 1 = warm reset has been done. UART is ready.
31:5	Reserved	Hardwired to 0.

3.2.2.14 Power Control Register (S_PWCR)

The Power Control Register “S_PWCR” is read-write and word aligned 32bit register. S_PWCR requests to keep the IDLE State for USB Controller and Ethernet Controller. CPU must request these interface block to keep the IDLE State and check their acknowledgement using read the Power Status Register “S_PWSR” prior to perform SUSPEND by setting following xxxSTOP field. S_WRCR is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
0	USBIDRQ	IDLE request for USB Controller: 0 = do nothing. 1 = request to keep the IDLE State.
1	MACIDRQ	IDLE request for Ethernet Controller : 0 = do nothing. 1 = request to keep the IDLE State.
2	reserved	reserved
3	reserved	Reserved
15:4	Reserved	Hardwired to 0.
16	USBSTOP	SUSPEND request for USB Controller: 0 = enable system clock for USB Controller. 1 = disable system clock for USB Controller.
17	MACSTOP	SUSPEND request for Ethernet Controller : 0 = enable system clock for Ethernet Controller . 1 = disable system clock for Ethernet Controller .
18	reserved	reserved
19	reserved	reserved
31:20	Reserved	Hardwired to 0.

Remark Before accesses to this register, the CPU must flush the internal write command buffer by reading the IBUS target

3.2.2.15 Power Status Register (S_PWSR)

The Power Status Register “S_PWSR” is read-only and word aligned 32bit register. The IDLE filed in S_PWSR indicates the status that it is ready to SUSPEND. The WKUP filed in S_PWSR indicates the wakeup request. When IDLE field becomes one, VR4120A RISC Processor can disable the system clock for the corresponding device by setting the STOP field in S_PWCR. When WKUP field in S_PWSR becomes one, VR4120A must enable the system clock for the corresponding device by resetting the STOP field in S_PWCR. The S_WRCR is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
0	USBIDLE	This field indicate the IDLE status in USB Controller 0 = Not in IDLE state. It means USB Controller is NOT ready to SUSPEND. 1 = in IDLE state. It means USB Controller is ready to SUSPEND.
1	MACIDLE	This field indicate the IDLE status in Ethernet Controller 0 = Not in IDLE state. It means Ethernet Controller is NOT ready to SUSPEND. 1 = in IDLE state. It means Ethernet Controller is ready to SUSPEND.
2	reserved	reserved
3	reserved	reserved
7:4	Reserved	Hardwired to 0.
8	USBWKUP	This field indicate the wakeup request from USB Controller 0 = No wakeup request is pending. 1 = wakeup request is pending.
9	MACWKUP	This field indicate the wakeup request form Ethernet Controller 0 = No wakeup request is pending. 1 = wakeup request is pending.
10	reserved	reserved
11	reserved	reserved
31:12	Reserved	Hardwired to 0.

3.3 CPU Interface

The System Controller provides the direct interface for the VR4120A using the 32bit SysAD Bus operated at 100MHz or 66MHz.

3.3.1 Overview

- Connects directly to the VR4120A CPU bus “SysAD bus”.
- Supports all VR4120A bus cycles at 66MHz or 100MHz.
- Supports only data rate D.
- Supports only sequential ordering.
- 4word (16byte) x 4entry Write command buffer.
- Little-Endian or Big-Endian byte order.

3.3.2 Data rate control

The CPU-to-System Controller data rate is programmable in the EP field (bits 27:24) of the CPU’s Configuration Register. The controller supports only data rate D.

3.3.3 Address decoding

The controller latches the address on the SysAD bus. It then decodes the address and SysCmd signals to determine the transaction type. Ten address ranges can be decoded:

- One range for External Boot PROM or FLASH.
- One range for External SDRAM.
- One range for System Controller’s internal configuration registers.

Boot PROM/FLASH is mapped according to its size. System Controller’s internal registers are fixed at base address 1000_0000H, to allow the VR4120A to access them during boot, before they have been configured. All other decode ranges are programmable.

3.3.4 Endian conversion

The BE bit in the CPU’s Configuration Register specifies the CPU’s byte ordering at reset. BE=0 configures little-endian order, BE=1 configures big-endian order. CPU interface of the system controller supports either big- or little-endian byte ordering on the SysAd bus by using Endian Converter. All of the other interfaces in the System Controller operate only in little-endian mode.

When the CPU is operated in the big-endian mode(external BIG-pin is HIGH), the System Controller provides the two endian conversion method controlled by external ENDCEN-pin. If ENDCEN-pin is LOW, the System Controller performs the data swap on the SysAD Bus (see Endian Translation Table for data swap mode). If ENDCEN-pin is HIGH, The System Controller performs the address swap on the SysAD Bus(the detail is described in the Endian Transfer Table for the address swap mode).

Table 3-1. Endian Configuration Table

BIG-pin	ENDCEN-pin	Status Reg RE field in CPU	Endian in CPU	Endian in System Controller	Endian Converter Operation
0	0	0	LITTLE	LITTLE	Transparent
0	1	0	LITTLE	LITTLE	Transparent
1	0	0	BIG	LITTLE	Data swap mode
1	1	0	BIG	LITTLE	Address swap mode

Remark VR4120A CORE does NOT support reverse endian mode.

Table 3-2. Endian Translation Table in Endian Converter

CPU Access Type		BIG	ENDCEN	Before Translation SysAD[1:0] in Address Phase	After Translation SysAD[1:0] in Address Phase	NOTE
Block	2word 4word	1	1	00	00	valid
				01	01	invalid
				10	10	invalid
				11	11	invalid
Single	1byte	1	1	00	11	valid
				01	10	valid
				10	01	valid
				11	00	valid
Single	2byte	1	1	00	10	valid
				01	11	invalid
				10	00	valid
				11	01	invalid
Single	3byte	1	1	00	01	valid
				01	00	valid
				10	11	invalid
				11	10	invalid
Single	4byte	1	1	00	00	valid
				01	01	invalid
				10	10	invalid
				11	11	invalid

CPU Access Type	BIG	ENDCEN	Before Translation SysAD[1:0] in Dataphase	After Translation SysAD[1:0] in Dataphase	NOTE
Any	1	0	[31:24][23:16][15:8][7:0]	[7:0][15:8][23:16][31:24]	Byte swap

3.3.5 I/O performance

The following table shows the I/O performance accessing from the VR4120A via Host Interface.

W/R	Target Area	Burst Length	Access Latency [CPU clocks]
R	IBUS Target	1	24
R	IBUS Target	2	24-1
R	IBUS Target	4	27-1-1-1
R	Internal Register (except UART)	1	7
R	Internal Register (except UART)	2	INVALID
R	Internal Register (except UART)	4	INVALID
R	Internal UART Register	1	14 (depend UART source clock)
R	Internal UART Register	2	INVALID
R	Internal UART Register	4	INVALID
W	IBUS Target	1	23
W	IBUS Target	2	23
W	IBUS Target	4	23-2-1-2
W	Internal Write Command FIFO	1	6-1(WAIT)
W	Internal Write Command FIFO	2	6-1
W	Internal Write Command FIFO	4	6-1-1-1
W	Internal Register (except UART)	1	7
W	Internal Register (except UART)	2	INVALID
W	Internal Register (except UART)	4	INVALID
W	Internal UART Register	1	15 (depend UART source clock)
W	Internal UART Register	2	INVALID
W	Internal UART Register	4	INVALID

Remarks 1. BUS frequency : SysAD=100MHz , IBUS=66MHz

2. The latency value accessing to the IBUS Target does NOT include IBUS bus arbitration cycle (about 6 CPU clocks)

3.4 Memory Interface

The CPU accesses memory attached to the controller in the normal way, by addressing the memory space.

3.4.1 Overview

- 66MHz or 100MHz memory bus.
- Up to 32MB Base memory range supports SDRAM.
- Up to 8MB write-protectable Boot memory range supports PROM/FLASH.
- On-chip programmable SDRAM refresh controller.
- 4word (16byte) Prefetch data buffer (Memory-to-CPU).
- PROM/FLASH data signals multiplexed on SDRAM data signals.
- Programmable memory bus arbitration priority.
- Programmable address ranges for the memory.
- Programmable RAS-CAS delay (2,3,4 clock).
- Programmable CAS latency (2,3 clock).

3.4.2 Memory regions and devices

The controller connects directly to memory and manages the addresses, data and control signals for the following address ranges:

- One Boot PROM/FLASH range (programmable)
  - Three extended chip select ranges (4x 1M, 2x2M) for functional system bus expansion
    These are located in the lower 8M address range of the 16M PROM/FLASH address range, so that in total 8M PROM/FLASH and 8M expansion area is supported (see also memory map in chapter 1)
    Please note, that the bus timing is the same for functional system bus expansion and PROM/FLASH.
- One System Memory range (programmable)

The following types of memory modules as an example but not limited to, can be used:

- FLASH can be used in the Boot ROM.
- PROM can be used in the Boot ROM.
- 16Mbit/64Mbit/128Mbit SDRAM can be used in the system memory.

Boot ROM can be populated with PROM or 85-ns FLASH chips. Prior to accessing PROM/FLASH, software must configure this address range. The system memory can be populated with 16Mbit/64Mbit/128Mbit SDRAM chips. The system memory is used for the RTOS, M/W and F/W. Prior to accessing SDRAM, software must configure this address range.

Recommended SDRAM Devices are listed following:

- 16Mbit SDRAM (NEC part numbers μPD4516161).
- 64Mbit SDRAM (NEC part numbers μPD4564323, μPD4564163).
- 128Mbit SDRAM (NEC part numbers μPD45128163).

Recommended FLASH Devices are listed following:

- 4Mbit FLASH (NEC part numbers μPD29F800AL).
- 16Mbit FLASH (NEC part numbers μPD29F1600AL).

3.4.3 Memory signal connections

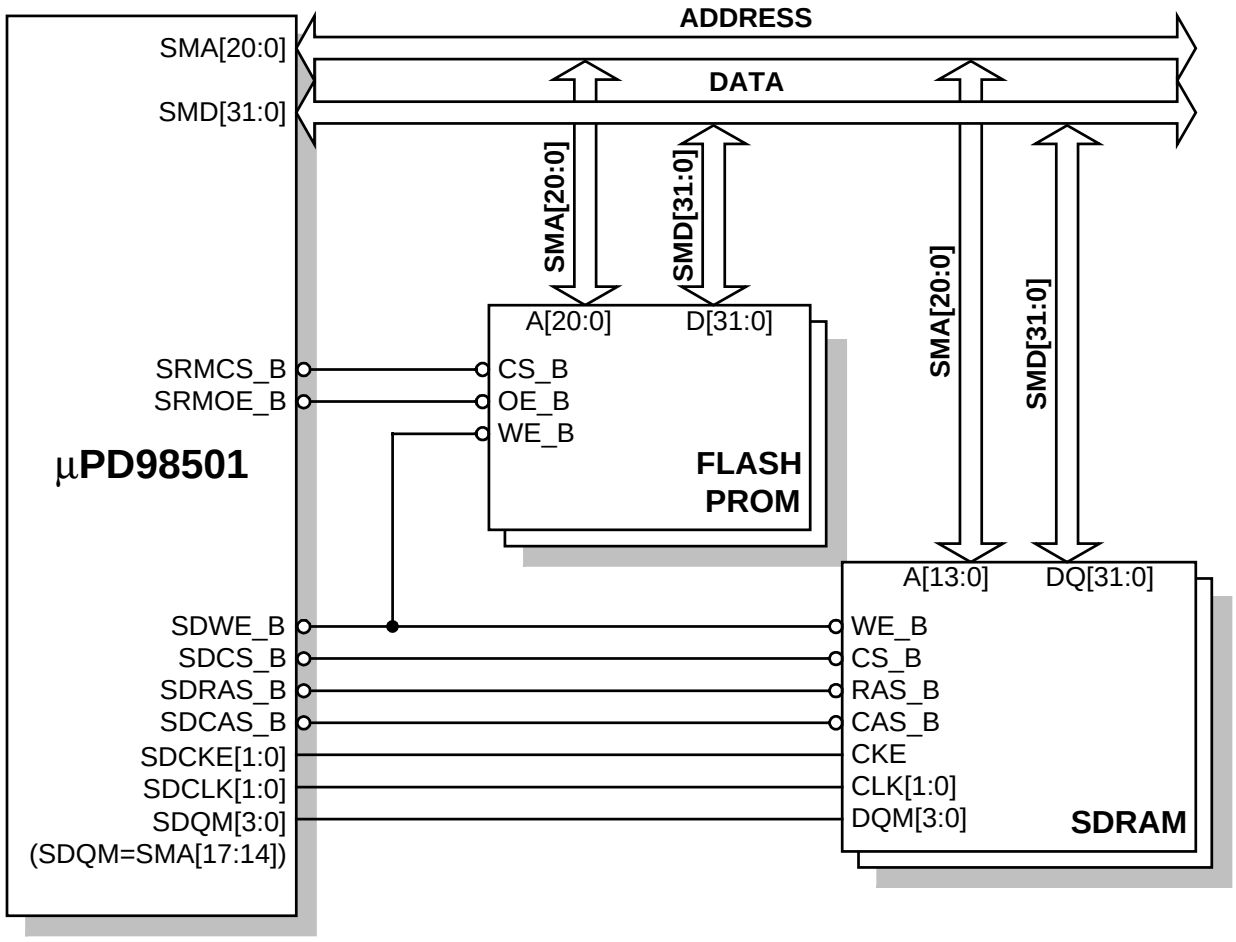


Table 3-3. External Pin Mapping

External Pin		Access to ROM	Access to SDRAM
Name	Bits		
SMA	[13:0]	A[13:0]	A[13:0]
	[17:14]	A[17:14]	SDQM[3:0]
	[20:18]	A[20:18]	
SMD	[31:0]	D[31:0]	DQ[31:0]
SDCS_B		---	SDCS_B
SDRAS_B		---	SDRAS_B
SDCAS_B		---	SDCAS_B
SDWE_B		SDWE_B	SDWE_B
SDCKE	[1:0]	---	SDCKE[1:0]
SDCLK	[1:0]	---	SDCLK[1:0]
SRMCS_B		SRMCS_B	---
SRMOE_B		SRMOE_B	---

3.4.4 Memory performance

The latency of memory accesses is determined by memory type, speed and prefetch scheme. Following lists some examples of the number of 66MHz or 100MHz memory-bus clocks required for each transfer of an 4-word (16-byte) CPU instruction-cache line fill. The first number in the “SysAD CPU Clocks” column is for the first word; the remaining numbers for the subsequent words. Only the most common combinations are shown.

Table 3-4. Examples of Memory Performance (4word-burst access from CPU)

Memory Type	Bank-Interleaved	Page Hit	R/W	Prefetch Hit	Access Latency view from CPU [SysAD clocks]
SDRAM,10ns	No	Yes	R	Yes	6-1-1-1
SDRAM,10ns	No	Yes	R	No	14-1-1-1
SDRAM,10ns	No	Yes	W	N/A	9-1-1-1
Flash, 85ns	No	No	R	N/A	19-12-12-12
Flash, 85ns	No	No	W	N/A	18 (Single Access Only))
PROM	No	No	R	N/A	19-12-12-12

Remarks 1. SDRAM Configuration : RCD=3, CL=2, SDCLK=100MHz, FAT=10

2. BUS frequency : SysAD=100MHz , IBUS=66MHz

3. Read performance is calculated by counting the rising edge for CPU clock where the read command is issued by the CPU. Because the CPU issues write data with no wait-states once the write command is issued, the numbers in the table represent the rate at which data is written to memory. The sum of the numbers represents the number of cycles between when the write operation was issued and when the next CPU memory operation can begin.

4. The burst write access to the FLASH/ROM is invalid. The CPU can access to the FLASH / ROM using single access only

Table 3-5. Examples of Memory Performance (4word-burst access from IBUS Master)

Memory Type	Bank-Interleaved	Page Hit	R/W	Prefetch Hit	Access Latency view from IBUS [IBUS clocks]
SDRAM,10ns	No	Yes	R	N/A	18-1-1-1
SDRAM,10ns	No	Yes	W	N/A	12-1-1-1
Flash, 85ns	No	No	R	N/A	45-1-1-1
Flash, 85ns	No	No	W	N/A	INVALID
PROM	No	No	R	N/A	45-1-1-1

Remarks 1. SDRAM Configuration : RCD=3, CL=2, SDCLK=100MHz, FAT=10

2. BUS frequency : SysAD=100MHz , IBUS=66MHz

3. Above access latency doses Not include the IBUS arbitration cycle (4 IBUS clocks)

4. Any write access to the FLASH/ROM is prohibited. If the IBUS master perform the write access to the FLASH/ROM, The IBUS bus error will be occurred.

3.4.5 Memory control registers

3.4.5.1 ROM Mode Register (RMMDR)

The ROM Mode Register “RMMDR” is read-write and word aligned 32bit register. RMMDR is used to setup the PROM/FLASH memory interface. RMMDR is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
1:0	FSM	FLASH/PROM Size Model: 00 = mode1 (4MByte mode) 01 = mode2 (8MByte mode) 10 = mode3 (1Mbyte Mode) 11 = mode4 (2Mbyte Mode)
7:2	Reserved	Hardwired to 0.
8	WM	Write Mask: 0 = Masked. FLASH data is protected from unintentional write. 1 = Not Masked. FLASH data is not protected.
31:9	Reserved	Hardwired to 0.

Remarks 1. DON’T change the value on the FSM field after setting the value 01 into the FSM field

2. DON’T set the reserved value to each field in this register.

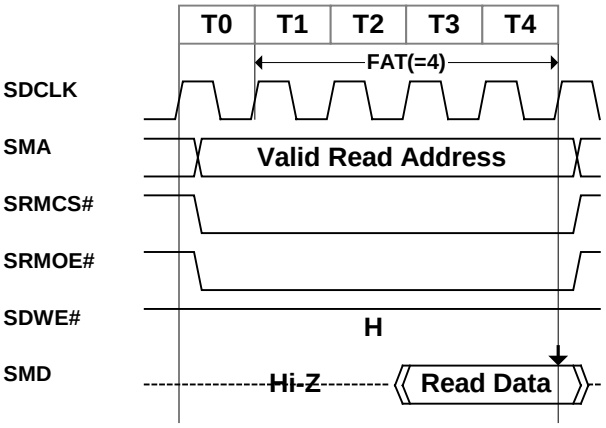
3.4.5.2 ROM Access Timing Register (RMATR)

The ROM Access Timing Register “RMATR” is read-write and word aligned 32bit register. RMATR is used to set the access time in the PROM/FLASH interface. RMATR is initialized to 0 at reset and contains the following fields:

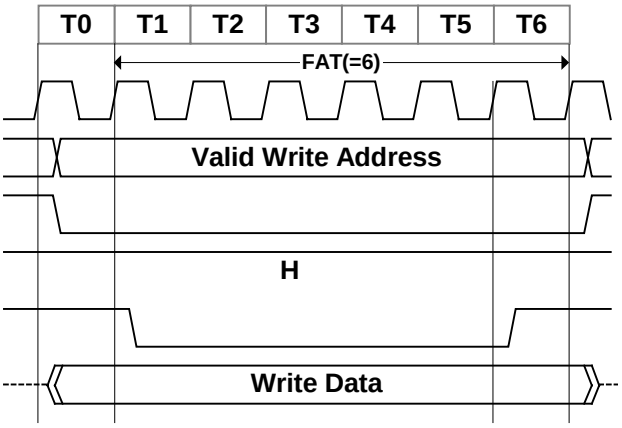
Bits	Field	Description		
2:0	FAT	FLASH/PROM Access Timing for Normal ROM:		
		000 = 18clock	66MHz:272.4ns	100MHz:180ns
		001 = 4clock	66MHz: 60.6ns	100MHz: 40ns
		010 = 6clock	66MHz: 90.9ns	100MHz: 60ns
		011 = 8clock	66MHz:121.2ns	100MHz: 80ns
		100 = 10clock	66MHz:151.5ns	100MHz:100ns
		101 = 12clock	66MHz:181.8ns	100MHz:120ns
		110 = 14clock	66MHz:212.1ns	100MHz:140ns
		111 = 16clock	66MHz:242.4ns	100MHz:160ns
31:3	Reserved	Hardwired to 0.		

Remark ROM Access Timing is depended on the system clock frequency.

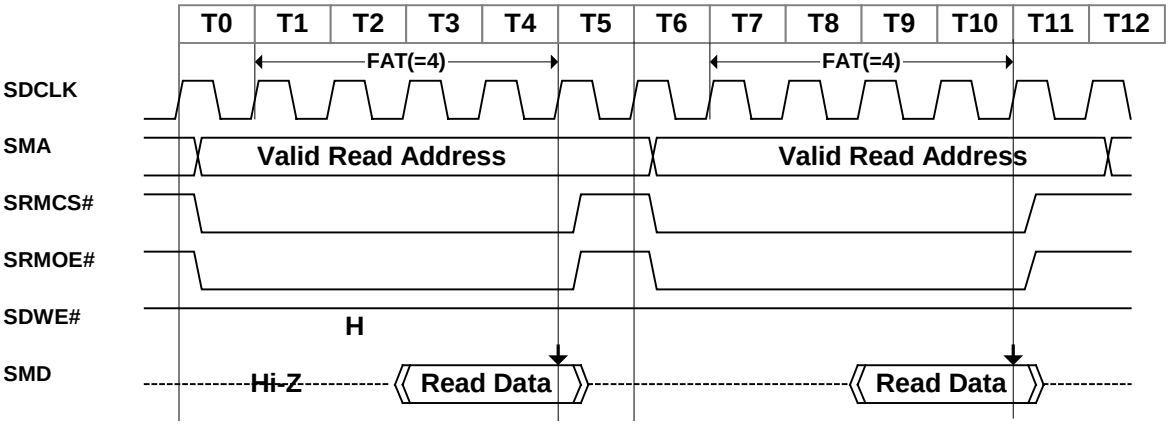
Normal ROM Read Cycle



FLASH Memory Write Cycle



ROM Burst Read Cycle



3.4.5.3 SDRAM Mode Register (SDMDR)

The SDRAM Mode Register “SDMDR” is read-write and word aligned 32bit register. SDMDR is used to setup the SDRAM interface. SDMDR is initialized to 330H at reset and contains the following fields:

Bits	Field	Description		
2:0	BL	SDRAM Burst Length: 000 = 1 (default) 001 = reserved 010 = reserved 011 = reserved 1xx = reserved		
3	Reserved	Hardwired to 0.		
6:4	LTMD	SDRAM CAS Latency: 000 = reserved 001 = reserved 010 = 2 011 = 3 (default) 1xx = reserved		
7	Reserved	Hardwired to 0.		
9:8	RCD	SDRAM RAS-CAS Delay:		
		00 = reserved		
		01 = 2clock	66MHz: 30.3ns	100MHz: 20ns
		10 = 3clock	66MHz: 45.5ns	100MHz: 30ns
		11 = 4clock (default)	66MHz: 60.6ns	100MHz: 40ns
31:10	Reserved	Hardwired to 0.		

Remark RAS-CAS Delay time is depended on the system clock frequency.

3.4.5.4 SDRAM Type Selection Register (SDTSR)

The SDRAM Type Selection Register “SDTSR” is read-write and word aligned 32bit register. SDTSR is used to setup the type of SDRAM. SDTSR is initialized to 0 at reset and contains the following fields:

Bits	Field	Description	
1:0	CAB	Number of column address bits (except bank select pins): 00 = 7bit (default) 01 = 8bit 10 = 9bit 11 = 10bit	
3:2	Reserved	Hardwired to 0.	
6:4	RAB	Total number of SDRAM address bits (RAS+CAS) (except bank select pins): 000 = 17bit (default) 001 = 18bit 010 = 19bit 011 = 20bit 100 = 21bit 101 = 22bit 110 = reserved 111 = reserved	
7	BTM	Number of Bank: 0 = 1 or 2 bank (default) 1 = 3 or 4 bank	
9:8	SDS	Total SDRAM Size:	
		00 = 4MByte (default)	003F_FFFFH – 0000_0000H
		01 = 8MByte	007F_FFFFH – 0000_0000H
		10 = 16MByte	00FF_FFFFH – 0000_0000H
		11 = 32Mbyte	01FF_FFFFH – 0000_0000H
31:10	Reserved	Hardwired to 0.	

EXAMPLE:

SDRAM	Parts No.	Type (bank x word x bit)	column address	row address	CAB	RAB
16Mbit	μPD4516161	2 x 0.5M x 16	8	11	8	19
64Mbit	μPD4564323	4 x 0.5M x 32	8	11	8	19
64Mbit	μPD4564163	4 x 1.0M x 16	8	12	8	20
128Mbit	μPD45128163	4 x 2.0M x 16	9	12	9	21

3.4.5.5 SDRAM Precharge Timing Register (SDPTR)

The SDRAM Precharge Timing Register “SDPTR” is read-write and word aligned 32bit register. SDPTR is used to set the Precharge Timing for the SDRAM Controller. SDPTR is initialized to 142H at reset and contains the following fields:

Bits	Field	Description		
1:0	PAT	Precharge command -> Active command timing (t_{RP}):		
		00 = 2clock	66MHz: 30.3ns	100MHz: 20ns
		01 = 3clock	66MHz: 45.5ns	100MHz: 30ns
		10 = 4clock(default)	66MHz: 60.6ns	100MHz: 40ns
		11 = reserved		
3:2	Reserved	Hardwired to 0.		
6:4	APT	Active command -> Precharge command timing (t_{RAS}):		
		000 = 4clock	66MHz: 60.6ns	100MHz: 40ns
		001 = 5clock	66MHz: 75.7ns	100MHz: 50ns
		010 = 6clock	66MHz: 90.9ns	100MHz: 60ns
		011 = 7clock	66MHz: 106.0ns	100MHz: 70ns
		100 = 8clock(default)	66MHz: 121.2ns	100MHz: 80ns
		101 = reserved		
		110 = reserved		
		111 = reserved		
7	Reserved	Hardwired to 0.		
8	DPL	Input data -> Precharge command timing (t_{DPL}):		
		0 = 1clock	66MHz: 15.2ns	100MHz: 10ns
		1 = 2clock(default)	66MHz: 30.3ns	100MHz: 20ns
31:9	Reserved	Hardwired to 0.		

3.4.5.6 SDRAM Refresh Mode Register (SDRMR)

The SDRAM Refresh Mode Register “SDRMR” is read-write and word aligned 32bit register. SDRMR is used to initialize the SDRAM Refresh Controller. SDRMR is initialized to 0000_0200H at reset and contains the following fields:

Bits	Field	Description
15:0	RCSET	Reload value for SDRAM Refresh Timer Counter. This value, in system clock ticks, is automatically reloaded into the Refresh timer counter after the counter reached zero. The Refresh timer counter counts down from this value. Thus, time of the count cycle corresponds to 1 plus this filed value. The default value (200H = 512) is the refresh rate for an SDRAM chip that requires 4096 refresh cycle every 32ms (ex. one refresh every 7.8125 μs) for system clock running at 66MHz. This is very conservative but it allows for successful boot, after which the reload value can be increased. RCSET[7:0] is hardwired to 0, thus the timer value less than 100H cannot set this field. If such value is set into this field, the default value “200H” is automatically loaded.
31:16	Reserved	Hardwired to 0.

3.4.5.7 SDRAM Refresh Timer Count Register (SDRCR)

The SDRAM Refresh Timer Count Register “SDRCR” is read-only and word aligned 32bit register. SDRCR is 16bit timer that causes an SDRAM refresh when it expires. The SDRAM refresh controller automatically reloads this free-running timer. SDRCR is initialized to 000_0200H at reset and contains the following fields:

Bits	Field	Description
15:0	RCC	This filed shows the current value of SDRAM Refresh Timer.
31:16	Reserved	Hardwired to 0.

3.4.5.8 System Bus (Memory Bus) Control Register (MBCR)

The System Bus (Memory Bus) Control Register “MBCR” is read-write and word aligned 32bit register. MBCR is used to selects priority for ether CPU or IBUS for memory access. The VR4120A can assign higher priority to CPU request for memory than IBUS request or assign equal priority to CPU and IBUS request for memory. MBCR is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
0	BPR	Priority for memory access: 0 : SysAD(CPU) > IBUS = Refresh (default) The memory arbiter allows the CPU to perform one memory transaction when the current word counts of burst access from IBUS reaches each 16words or 32words. 1 : SysAD(CPU) = IBUS = Refresh The memory arbiter doses allows the CPU to perform the memory transaction when the burst memory access form IBUS are
31:1	Reserved	Hardwired to 0.

3.4.5.9 Memory Error Status Register (MESR)

The Memory Error Status Register “MESR” is read-cleared and word aligned 32bit register. MESR indicates the error status in the Memory Controller. MESR can accept the next error after the CPU read both MESR and MEAR Register (see below). MESR is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
0	SBAER	The memory access form SysAD cause an address range error: 0 = No Error 1 = Error is occurred
1	IBAER	The memory access form IBUS cause an address range error: 0 = No Error 1 = Error is occurred
2	RMAE	Indicate the address error in ROM space. 0 = No Error in ROM space. 1 = Error is occurred in ROM space.
3	SDAE	Indicate the address error in SDRAM space. 0 = No Error in SDRAM space. 1 = Error is occurred in SDRAM space.
7:4	Reserved	Hardwired to 0.
8	RMWE	ROM write error: 0 = No Error 1 = Illegal ROM access, byte or half-word or burst write, is occurred.
31:9	Reserved	Hardwired to 0.

3.4.5.10 Memory Error Address Register (MEAR)

The Memory Error Address Register “MEAR” is read-cleared and word aligned 32bit register. MEAR indicates the memory address in the Memory Controller. MEAR can accept the next error address after the CPU read both MESR Register and MEAR. MEAR is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
31:0	BEA	This field maintains a memory address in error.

3.4.6 Boot ROM / Extended Chip Select

The System Controller supports up to 8MB of boot memory. This memory must be populated with either of the following two types of memory devices:

3.4.6.1 Boot ROM configuration and address ranges

Boot ROM can be populated with PROM or 85-ns Flash chips, and it must have an access time of 200ns or less. The System Controller supports 8,16 and 32-bit Boot ROM at locations 1F80_0000H through 1FFF_FFFFH in the physical memory space on VR4120A. The Boot ROM does not support CPU cache operations.

Table 3-6. Boot-ROM Size Configuration at Reset

RMMDR.FSM	Boot ROM Size	Address Range
00	4MB	1FC0_0000H through 1FFF_FFFH
01	8MB	1F80_0000H through 1FFF_FFFH
10	1MB	1FC0_0000H through 1FCF_FFFH
11	2MB	1FC0_0000H through 1FDF_FFFH

ROMSEL[1:0]	11	10	01		00	
	---	8bit	16bit		32bit	
RMMDR.FSM		Byte Mode	Word Mode	Byte Mode	Word Mode	Byte Mode
00	---	---	4MB (2Mx16bit)	2MBx2 (2Mx8bit)	2MBx2 (1Mx16bit)	1MBx4 (1Mx8bit)
01	---	---	---	---	4MBx2 (2Mx16bit)	2MBx4 (2Mx8bit)
10	---	1MB (1Mx8bit)	---	---	---	---
11	---	2MB (2Mx8bit)	2MB (1Mx16bit)	1MBx2 (1Mx8bit)	---	---

The controller asserts the FLASH/ROM chip select (SRMCS_B) in the address range 1F80_0000H through 1FFF_FFFFH. When writes are performed to the ROM/FLASH memory space, the controller asserts SDWE_B in conjunction with SRMCS_B. When reads are performed, the controller asserts SRMOE_B in conjunction with SRMCS_B. If the CPU attempts to access Boot ROM addresses outside the defined size of the FLASH/ROM, the controller returns 0 with the data error bit set on SysCMD[0]. In addition, the NMI Status Register “S_NSR” is updated and NMI is asserted on the signal, if the interrupt is enabled in the NMI Mask Register “S_NMR”.

3.4.6.2 FLASH memory write-protection

The FLASH Memory can be protected in software. Software protection is implemented by programming the WM field in ROM Mode Register “RMMDR”.

3.4.6.3 FLASH memory operations

The FLASH Memory can be programmed using following write cycle sequence by VR4120A. The following commands are example of operations for the NEC μPD29F800L FLASH Memory (in Byte Mode).

Table 3-7. Command Sequence

(a) Program Command Sequence (4 Write Cycles)

1st Write		2nd Write		3rd Write		4th Write		5th Write		6th Write	
A	1FC2AAA8H	A	1FC15554H	A	1FC2AAA8H	A	PA	A		A	
D	AAAAAAAAH	D	55555555H	D	A0A0A0A0H	D	PD	D		D	

(b) Chip Erase Command Sequence (6 Write Cycles)

1st Write		2nd Write		3rd Write		4th Write		5th Write		6th Write	
A	1FC2AAA8H	A	1FC15554H	A	1FC2AAA8H	A	1FC2AAA8H	A	1FC15555H	A	1FC2AAA8H
D	AAAAAAAAH	D	55555555H	D	80808080H	D	AAAAAAAAH	D	55555555H	D	10101010H

(c) Sector Erase Command Sequence (6 Write Cycles)

1st Write		2nd Write		3rd Write		4th Write		5th Write		6th Write	
A	1FC2AAA8H	A	1FC15554H	A	1FC2AAA8H	A	1FC2AAA8H	A	1FC15554H	A	EA
D	AAAAAAAAH	D	55555555H	D	80808080H	D	AAAAAAAAH	D	55555555H	D	30303030H

Remark A = Memory Write Address
D = Memory Write Data
PA = Address of FLASH Location to be programmed.
EA = Data to be programmed at Location PA.
EA = Block Address of FLASH Location to be erased.

Please note the following comments:

1) Read cycle can’t interrupt these write commands.

So, it is impossible for LAKI system to program Flash memory with fetching from Flash memory.

2) These write commands for Flash memory will be change on following system factors.

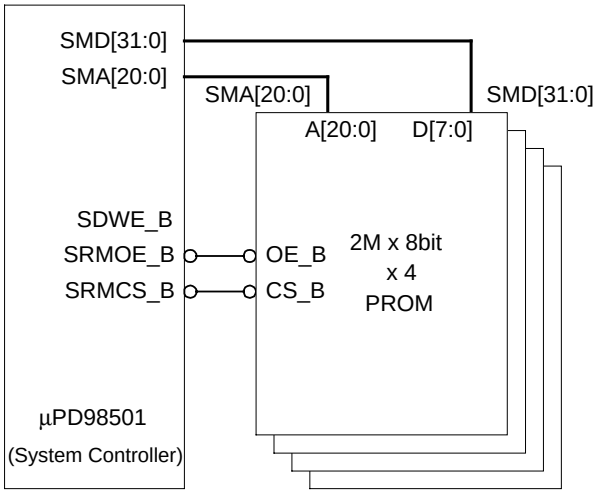
a) Flash manufacturer company:Write sequences is differ among each company.
b) Endian mode (There are 3 system endian mode; Littlendian, Bigendian with data swap mode and Bigendian with address swap mode)
c) Flash data BUS size of Flash memory (ordinary Flash memory has both 8 and 16 bit D-BUS mode)
d) Flash data BUS size of STAR (8, 16, 32 bit)

Please consider these system factors in case of Flash memory programming.

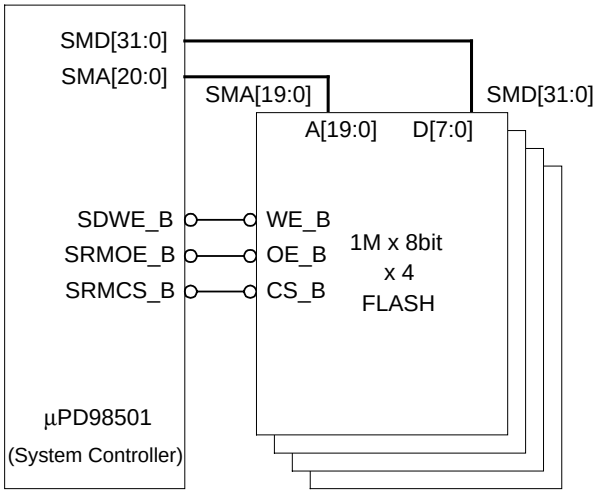
3.4.6.4 Boot ROM signal connections

FLASH/ROM Configuration

Example (8MB PROM)



Example (4MB FLASH)



3.4.6.5 Extended Chip Selects

The controller asserts the FLASH/ROM chip select (SRMCS#) in the address range 1F80_0000H through 1FFF_FFFFH. Also, it asserts SEXCS0# in 1F00_0000H through 1F1F_FFFFH, SEXCS1# in 1F20_0000H through 1F3F_FFFFH and SEXCS2# in 1F40_0000H through 1F7F_FFFFH. Relationships between Memory map address (on SysAD BUS) to external 21bit address bus are the follwing table.

Table 3-8. Relationship between memory map and address bus

Memory Address [31:0]	Output value [20:0]		
	8 bit	16 bit	32 bit
Boot ROM area (use SRMCS# pin for chip select) – 8MB -			
0x1FFF_FFFF	Non-available	0x1F_FFFF	0x1F_FFFF
0x1FF0_0000		0x18_0000	0x1C_0000
0x1FEF_FFFF		0x17_FFFF	0x1B_FFFF
0x1FE0_0000		0x10_0000	0x18_0000
0x1FDF_FFFF	0x1F_FFFF	0x0F_FFFF	0x17_FFFF
0x1FD0_0000	0x10_0000	0x08_0000	0x14_0000
0x1FCF_FFFF	0x0F_FFFF	0x07_FFFF	0x13_FFFF
0x1FC0_0000	0x00_0000	0x00_0000	0x10_0000
0x1FBF_FFFF	Non-available	Non-available	0x0F_FFFF
0x1FB0_0000			0x0C_0000
0x1FAF_FFFF			0x0B_FFFF
0x1FA0_0000			0x08_0000
0x1F9F_FFFF	Non-available		0x07_FFFF
0x1F90_0000			0x04_0000
0x1F8F_FFFF			0x03_FFFF
0x1F80_0000			0x00_0000
External device area 2 (use SEXCS2# pin for chip select) – 4MB -			
0x1F7F_FFFF	Non-available	0x1F_FFFF	0x1F_FFFF
0x1F70_0000		0x18_0000	0x1C_0000
0x1F6F_FFFF		0x17_FFFF	0x1B_FFFF
0x1F60_0000		0x10_0000	0x18_0000
0x1F5F_FFFF	0x1F_FFFF	0x0F_FFFF	0x17_FFFF
0x1F50_0000	0x10_0000	0x08_0000	0x14_0000
0x1F4F_FFFF	0x0F_FFFF	0x07_FFFF	0x13_FFFF
0x1F40_0000	0x00_0000	0x00_0000	0x10_0000
External device area 1 (use SEXCS1# pin for chip select) – 2MB -			
0x1F3F_FFFF	0x1F_FFFF	0x1F_FFFF	0x0F_FFFF
0x1F30_0000	0x10_0000	0x18_0000	0x0C_0000
0x1F2F_FFFF	0x0F_FFFF	0x17_FFFF	0x0B_FFFF
0x1F20_0000	0x00_0000	0x10_0000	0x08_0000
External device area 0 (use SEXCS0# pin for chip select) – 2MB -			
0x1F1F_FFFF	0x1F_FFFF	0x0F_FFFF	0x07_FFFF
0x1F10_0000	0x10_0000	0x08_0000	0x04_0000
0x1F0F_FFFF	0x0F_FFFF	0x07_FFFF	0x03_FFFF
0x1F00_0000	0x00_0000	0x00_0000	0x00_0000
RMSL[1:0]	2’b10	2’b01	2’b00

When writes are performed to the FLASH/ROM memory space, the controller asserts SDWE# in conjunction with SRMCS#, SXCS0#, SXCS1# or SXCS2#. When reads are performed, the controller asserts SRMOE# in conjunction with SRMCS#, SXCS0#, SXCS1# or SXCS2#.

If the CPU attempts to access FLASH/ROM addresses outside the defined size of the FLASH/ROM, the controller returns 0 with the data error bit set on SysCMD[0]. In addition, the NMI Status Register “NSR” is updated and NMI is asserted on the star_nmib_na# signal, if the interrupt is enabled in the NMI Enable Register “NER”.

3.4.7 SDRAM

3.4.7.1 SDRAM address range

System Memory can be populated with SDRAM chips, and it must have an access time of 10ns or less. The System Controller supports 16Mbit or 64Mbit and 128Mbit SDRAM at locations 0000_0000H through 01FF_FFFFH in the physical memory space on VR4120A. The SDRAM supports CPU cache operations,.

Table 3-9. SDRAM Size Configuration at Reset

SDMDR.SDS	SDRAM Size	Address Range
00	4MB	0000_0000H through 003F_FFFH
01	8MB	0000_0000H through 007F_FFFH
10	16MB	0000_0000H through 00FF_FFFH
11	32MB	0000_0000H through 01FF_FFFH

3.4.7.2 SDRAM device configurations

The controller supports the following 16Mbit 64Mbit and 128Mbit. NEC SDRAM parts and configurations in System Memory. Following Table shows some of the SDRAM configurations supported for system memory.

Table 3-10. SDRAM Configurations Supported

Memory Size	SMA Address Bits Required	Organization (bank x word x bit)	Quantity	NEC Part Number
4MB	12:0	2 x 0.5M x 16	2	μPD4516161
8MB	12:0	4 x 0.5M x 32	1	μPD4564323
16MB	13:0	4 x 1.0M x 16	2	μPD4564163
32MB	13:0	4 x 2.0M x 16	2	μPD45128163

3.4.7.3 SDRAM burst-type and banks

The terms interleaved and bank have multiple meanings in the context of memory design using SDRAM chips. The meanings are:

- Banks (applied to memory modules and SDRAM chips in different ways): The banks referenced with respect to memory modules differ from the banks inside an SDRAM chip. For module, This controller does not support what identifies their bank. Following Table shows bank select signals.

Table 3-11. SDRAM Bank Select Signals Mapping

MuxAd Bank Signal	Memory Bank select inputs	NEC Parts Number
SMA [11]	A[11]	μPD4516161
SMA [12:11]	BA[1:0]	μPD4564323
SMA [13:12]	A[13:12]	μPD4564163
SMA [13:12]	A[13:12]	μPD45128163

- Burst Type (applies to SDRAM chips): The burst type of a single SDRAM chip is programmed in the chip's Mode Register to be either interleaved or sequential. This concept relates only to the word-order in which data is read into and written out of the SDRAM chip. The concept does not relate to the number of words transferred in a given clock cycle. The burst type for all SDRAM chips attached to LAKI is configured during the Memory Initialization procedure. The memory controller in the System Controller does NOT support the interleaved burst mode and support only sequential burst mode.

3.4.7.4 SDRAM word ordering

Following Table shows the word-address order for a 4-word instruction-cache line fill from SDRAM. This order is determined by the SDRAM chips' burst type, which is programmed during the Memory Initialization procedure. The memory controller programs the burst type and word order the same for all SDRAM chips connected to it (in the System Memory ranges). The term "sequential" in this table refers to the SDRAM burst type. Burst length depends only on the access type performed by the CPU.

Table 3-12. SDRAM Word Order for Instruction-Cache Line-Fill

Start Column Address A1.A0	SDRAM-Chip Burst Type	
	Sequential	Interleaved
00	0-1-2-3	not supported
01	1-2-3-0	not supported
10	2-3-0-1	not supported
11	3-0-1-2	not supported

Remark The memory controller does not support the interleaved burst type for SDRAMs. It assumes that all SDRAMs are initialized to the sequential burst type, using a burst length of 4 words.

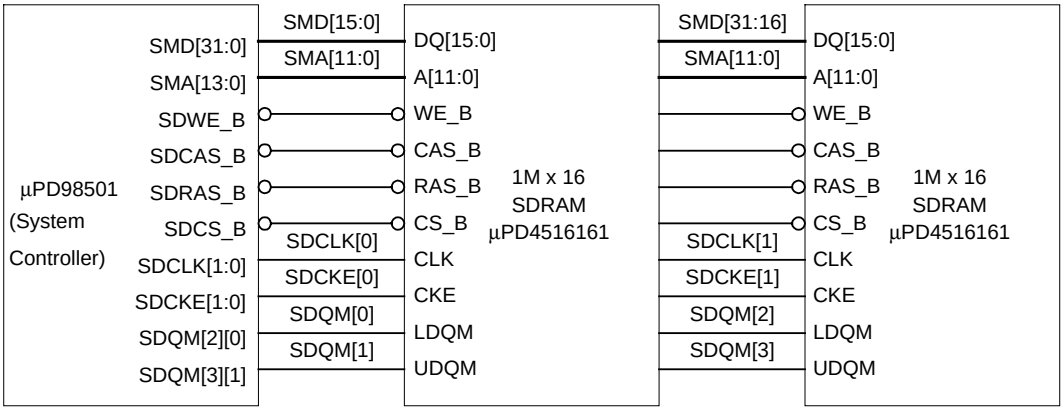
3.4.7.5 SDRAM signal connections

Following Figure shows how the NEC 16Mbit SDRAMs are connected for System Memory. SMA[11] is the bank select signal. In command cycle, SMA[11] low selects Bank A and SMA[11] High selects Bank B. Both banks share the same SDCSB, SDRASB, SDCASB, and SDWEB signals.

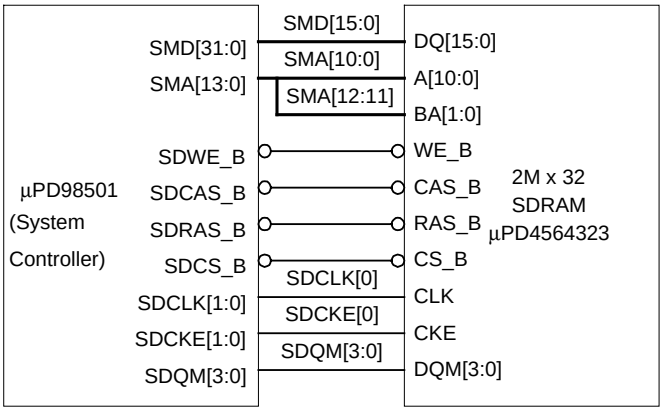
The two banks of System Memory behave as two halves of the address range, with the highest unmasked address bit controlling bank selection.

SDRAM Configuration

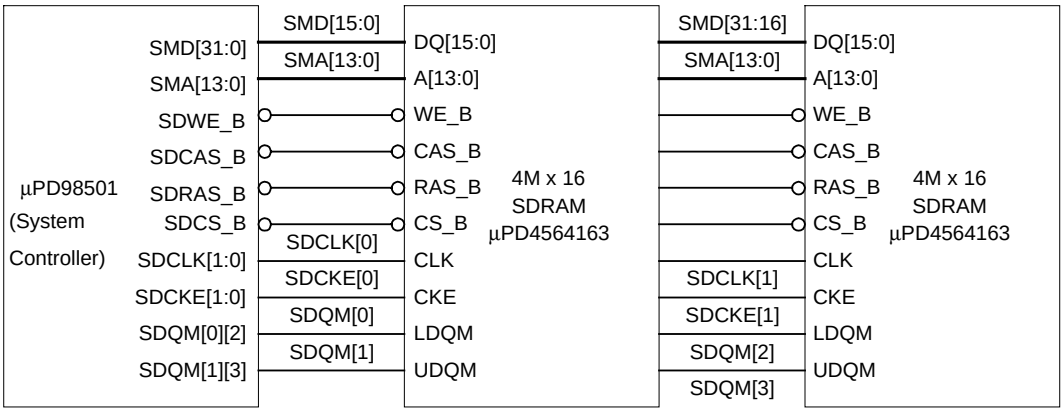
4MB



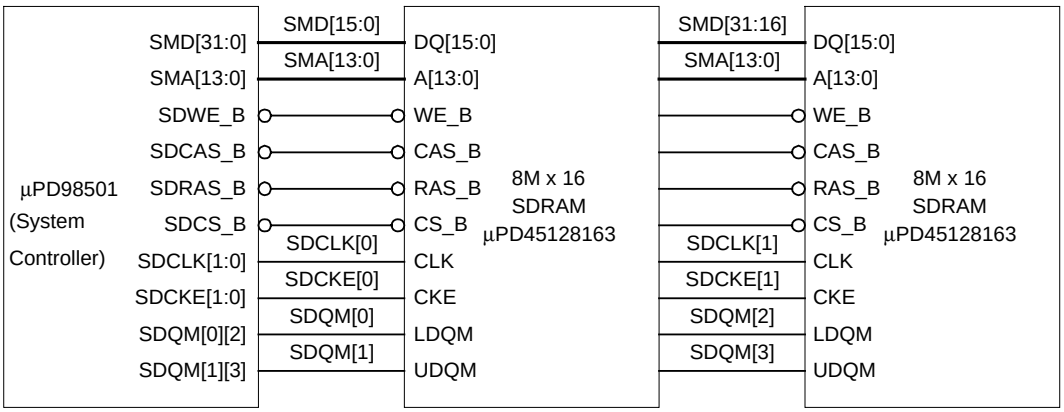
8MB



16MB



32MB



3.4.8 SDRAM refresh

The System Controller supports CAS-Before-RAS (CBR) DRAM refresh to all SDRAM address ranges. The refresh clock is derived from the system clock; its rate is determined by programming the RCR filed in the SDRAM Refresh Mode Register “SDRMR”.

The refresh logic requests access to SDRAM from the internal bus-arbitration logic each time the counter reaches 0. The refresh logic can accumulate up to a maximum of 15 refresh requests while it is waiting for the bus. Once the refresh logic owns the bus, all accumulated refreshes are performed to system memory, and no other accesses (CPU or IBUS) are allowed. Refreshes are staggered by one clock; that is, there will be at least one bus clock between transitions on any pair of SDRASB signals. Refresh automatically clears the system-memory prefetch FIFO.

3.4.9 Memory-to-CPU prefetch FIFO

The memory controller automatically prefetches 4 words from system memory into a 4-words prefetch FIFO. That is, after each burst 4-words read, the memory controller prefetches 4 additional words into its internal prefetch FIFO. If the processor subsequently attempts a read from an address immediately following (sequential to) the address of the last read cycle, the first 4 words will supplied from the prefetch FIFO.

The memory controller compares the current SysAD address with the previous address to determine the sequential nature of the access. Prefetched words are retained in the prefetch FIFO if accesses to resources other than System Memory are performed between System Memory accesses.

3.4.10 CPU-to-memory write FIFO

The memory controller has a 4-word CPU-to-Memory Write FIFO. This FIFO accepts writes at the maximum CPU speed. A single address is held for the buffered write, allowing the buffering of a single write transaction. That transaction may be a word, double-word, 4-word data-cache write-back. When a word is placed in the FIFO by the CPU, the memory controller attempts to write the FIFO’s contents to memory as quickly as possible. If the next CPU read or write is addressed to memory, the controller negates ready signal, thus causing the next CPU transaction (read or write) to stall until the controller empties its FIFO. If the next CPU transaction (read or write) is addressed to a IBUS target, the memory controller asserts ready signal, thus the CPU transaction to complete.

3.4.11 SDRAM memory initialization

The memory controller automatically initializes the SDRAM after the global reset. The following sections describe the configuration sequence used for this initialization.

3.4.11.1 Power-on initialization sequence by memory controller

Follow this sequence to configure memory after reset:

1. Waits for 100 μs after power-on.
2. Performs all bank Precharge.
3. Performs two sequential auto Refresh (CBR).

3.4.11.2 Memory initialization sequence using software

The SDRAM must be initialized by the Software using following sequence after power-on initialization.

1. Program the SDRAM Type Selection Register “SDTSR”
2. Program the SDRAM Mode Register “SDMDR”.
3. Wait for 20 μs.
4. Program the DRAM Refresh Counter Register.

At this point, memory is ready to use. All other configuration registers in the controller should then be programmed before commencing normal operation.

Remark The Software should NOT change the SDTSR and SDMDR after SDRAM initialization sequence

3.5 IBUS Interface Register

3.5.1 ITCNTR (IBUS timeout timer control register)

The IBUS Timeout timer Control Register “ITCNTR” is read-write and word aligned 32bit register. ITCNTR is used to enable use of the IBUS Timeout Timer. ITCNTR is initialized to 0H at reset and contains the following field:

Bits	Field	Description
0	ITWEN	IBUS Timeout Timer enable 1 = Enable 0 = Disable
31:1	Reserved	Hardwired to 0.

3.5.2 ITSETR (IBUS timeout timer set register)

The IBUS Timeout timer Set Register “ITSETR” is read-write and word aligned 32bit register. ITSET is used to detect the stall of the IBUS using the bus timer. The IBUS Timeout Timer counts the rising edge of the CPU clock while the IBUS Frame Signal (ibframe) is asserting. If the bus timer reaches the following ITTIME value, IBUS timer assert the NMI to CPU when of NER Register is set. The IBUS Timeout value can be set in 1-clock increments in a range from 1 to 2^{32}-1 CPU clock. However, the CPU operation is undefined when 0 has been set to ITTIME field. ITSETR is initialized to 8000_0000H at reset and contains the following fields:

Bits	Field	Description
31:0	ITTIME	IBUS Timeout value setting Timeout = ITTIME value system clock period (100MHz:10ns, 66MHz:15ns) example: ITTIME = 05F5E100H (100MHz) or 03F940AAH (66MHz) -> Timeout = 1sec ITTIME = 0BEBC200H (100MHz) or 07F28154H (66MHz) -> Timeout = 2sec ITTIME = 11E1A300H (100MHz) or 0BEBC200H (66MHz) -> Timeout = 3sec : : :

3.6 DSU (Deadman's SW Unit)

3.6.1 Overview

The DSU detects when the CPU is in runaway (endless loop) state and resets the CPU to minimize runaway time. The use of the DSU to minimize runaway time effectively minimizes data loss that can occur due to software-related runaway states.

3.6.2 Registers

3.6.2.1 DSUCNTR

This register is used to enable use of the Deadman's Switch functions.

DSUCNTR is 32bit word-aligned register. Default is 00000000H.

Bits	Field	Description
0	DSWEN	Deadman's Switch function enable 1 = Enable 0 = Disable
31:1	Reserved	Hardwired to 0.

3.6.2.2 DSUSETR

This register sets the cycle for Deadman's Switch functions. The Deadman's Switch cycle can be set in 1-clock increments in a range from 1 to 2^{32}-1 clock. The DSUCLRR's DSWCLR bit must be set by means of software within the specified cycle time. DSUSETR is 32bit word-aligned register. Default is 80000000H.

Bits	Field	Description
31:0	DEDTIM	Deadman's Switch cycle setting DSU cycle = DEDTIME value system clock period (100MHz:10ns, 66MHz:15ns) example: DEDTIM = 05F5E100H (100MHz) or 03F940AAH (66MHz) -> DSU cycle = 1sec DEDTIM = 0BEBC200H (100MHz) or 07F28154H (66MHz) -> DSU cycle = 2sec DEDTIM = 11E1A300H (100MHz) or 0BEBC200H (66MHz) -> DUS cycle = 3sec : : :

3.6.2.3 DSUCLRR

This register clears the Deadman's Switch counter by setting the DSWCLR bit in this register to 1. The CPU automatically shuts down if 1 is not written to this register within the period specified in DSUSETR. DSUCLR is 32bit word-aligned register. Default is 00000000H.

Bits	Field	Description
0	DSWCLR	Deadman's Switch counter clear. Cleared to 0 when 1 is written. 1 = Clear 0 = Don't clear
31:1	Reserved	Hardwired to 0.

3.6.2.4 DSUTIMR

This register indicates the elapsed time for the current Deadman's Switch timer.

DSUTIMR is 32bit word-aligned and read-only register. Default is 00000000H.

Bits	Field	Description
31:0	CRTTIM	Current Deadman's Switch timer value (Elapsed time) example: CRTTIM = 05F5E100H (100MHz) or 03F940AAH (66MHz) ->1sec CRTTIM = 0BEBC200H (100MHz) or 07F28154H (66MHz) -> 2sec CRTTIM = 11E1A300H (100MHz) or 0BEBC200H (66MHz) -> 3sec : : :

3.6.3 DSU register setting flow

The DSU register setting flow is described below.

1. Set the DSU's count-up value (From 1 to 2^{31}-1).
   The CPU will be reset if it does not clear (1 is not written to DSUCLRR) the timer within this time period.
2. Enable the DSU
3. Clear the timer within the time period specified in step 1 above.
   For normal use, repeat step 3. To obtain the current elapsed time:
4. Disable the DSU for shutdown.

3.7 Endian Mode Software Issues

3.7.1 Overview

The native endian mode for MIPS processors, like Motorola and IBM 370 processors, is big endian. However, the native mode for Intel (which developed the PCI standard) and VAX processors is little endian. For PCI-compatibility reasons, most PCI peripheral chips operate natively in little-endian mode. While LAKI is natively little-endian, it supports either big- or little-endian mode on the SysAD bus. The state of the ENDIAN signal at reset determines this endian mode. However, there are important considerations when using the controller in a mixed-endian design. The most important aspect of the endian issue is which byte lanes of the SysAD bus are activated for a particular address. If the big-endian mode is implemented for the CPU interface, the controller swaps bytes within words and halfwords that are coming in and going out on the SysAD bus. All of the System Controller's other interfaces operate in little-endian mode.

The sections below view the endian issue from a programmer's perspective. They describe how to implement mixed-endian designs and how to make code endian-independent.

Data in memory is always ordered in little-endian mode, even with a big-endian CPU.

Data in all internal registers and FIFOs is considered little-endian regardless of CPU endianness.

Data addresses are not swapped inside the device for accesses from a little-endian CPU to all local registers when "ENDCEN" bit in the General Status Register "S_GSR" is reset.

Data addresses are swapped inside the device for accesses from a big-endian CPU to all local registers when "ENDCEN" bit in the General Status Register "S_GSR" is set.

Data addresses are swapped inside the device for accesses from a big-endian CPU to memory when "ENDCEN" bit in the General Status Register "S_GSR" is set.

3.7.2 Endian modes

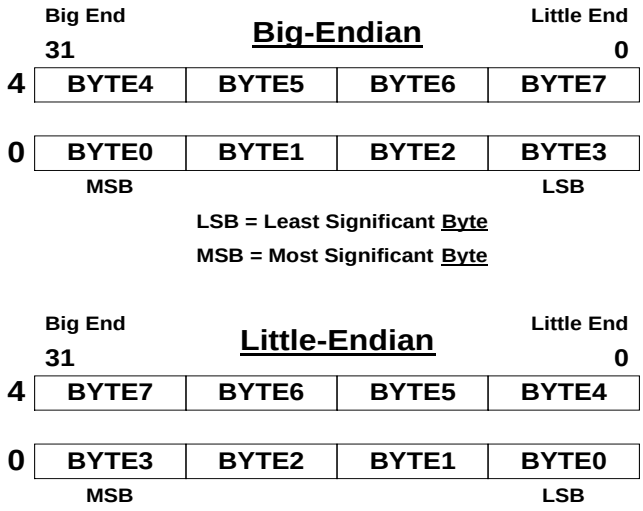
The endian mode of a device refers to its word-addressing method and byte order:

Big-endian devices address data items at the big end (most significant bit number). The most-significant byte (MSB) in an addressed data item is at the lowest address.

Little-endian devices address data items at the little end (least significant bit number). The most significant byte (MSB) in an addressed data item is at the highest address.

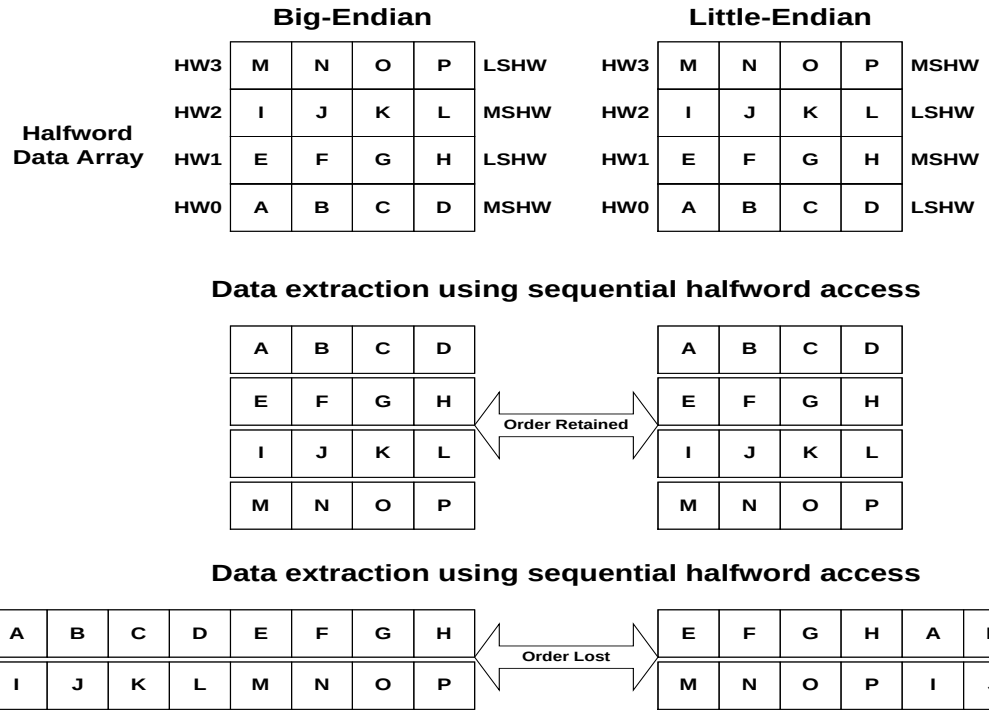
The following figures shows the bit and byte order of the two endian modes, as it applies to bytes within word-sized data items. The bit order within bytes is the same for both modes. The big (most-significant) bit is on the left side, and the little (least significant) bit is on the right side. Only the bit order of sub-items is reversed within a larger addressable data item (halfword, word, doubleword) when crossing between the two endian modes. The sub-items' order of significance within the larger data item remains the same. For example, the least significant half word (LSHW) in a word is always to the right and the most-significant halfword (MSHW) is to the left.

Figure 3-1. Bit and Byte Order of Endian Modes



If the access type matches the data item type, no swapping of data sub-items is necessary. Thus, when making half-word accesses into a data array consisting of halfword data, no byte-swapping takes place. In this case, data item bit order is retained between the two endian modes. The code that sequentially accesses the half-word data array would be identical, regardless of the endianness of its CPU. The code would be endian-independent.

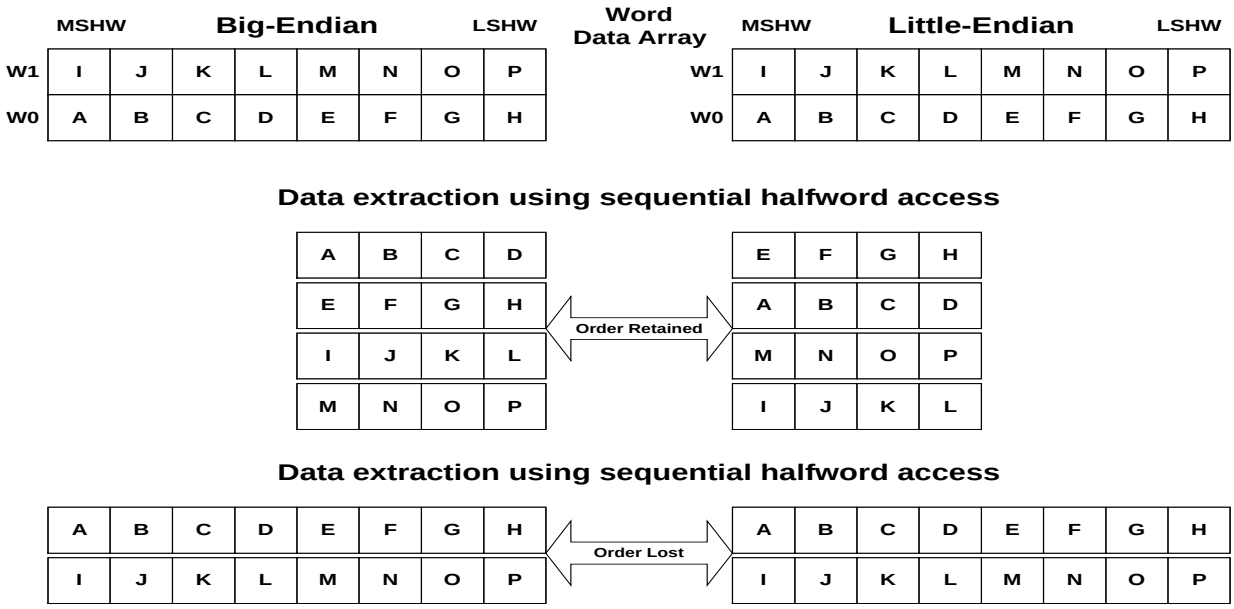
Figure 3-2. Halfword Data-Array Example



However, when making half-word accesses into a data array consisting of word data, access to the more-significant halfword requires the address corresponding to the less significant half word (and vice versa). Such code is not endian-independent. A supergroup access (for example, accessing two half words simultaneously as a word from

a half-word data array) causes the same problem. Such problems also arise when a halfword access is made into a 32-bit register, whereas a word access into a 32-bit register creates no problem.

Figure 3-3. Word Data-Array Example



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CHAPTER 4 <empty>

[MEMO]

CHAPTER 5 ETHERNET CONTROLLER

5.1 Overview

This section describe Ethernet communication block. This Ethernet Controller block comprises of a 10/100Mbps Ethernet MAC (Media Access Control), data transmit/receive FIFOs, DMA and NEC original high speed bus interface.

LAKI implements a single-channel Ethernet Controller.

5.1.1 Features

- IEEE802.3/802.3u/802.3x Compliant:
  - 10/100Mbps Ethernet MAC
  - Media Independent Interface (MII)
  - Flow Control
- Full duplex operation for 10Mbps and 100Mbps
- Address Filtering:
  - unicast
  - multicast
  - broadcast
- Statistics counters for management information
  - RMON
  - SNMP MIB
- Large independent receive and transmit FIFOs
- Direct Memory Access (DMA) with programmable burst size providing for low CPU utilization
- Internal Bus interface (IBUS): 32bit @66MHz

5.1.2 Block diagram of Ethernet controller block

The following list describes this block hardware components, and Figure 5-1 shows a block diagram of this block:

IBUS Interface - Data transfer is done via this IBUS interface between CPU and Ethernet Controller or memory and Ethernet Controller. This performance is approximately 2Gbps (32 bit x 66MHz). Also in this block, IBUS protocol operation is done [retry, disconnect and so on].

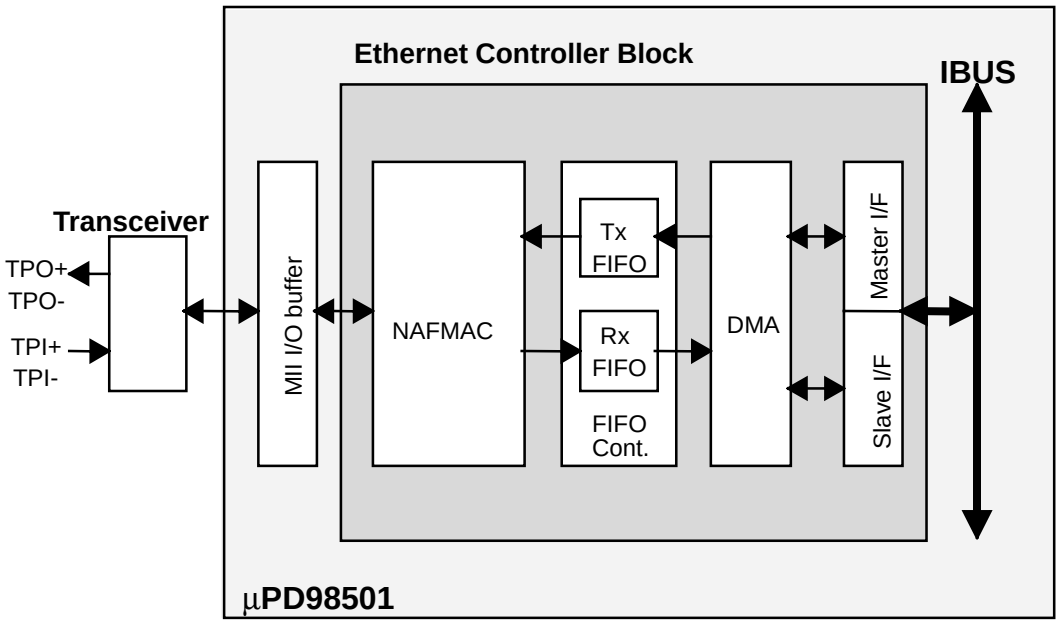
DMA Controller - DMA controller contains dual reception and transmission controller, which handle data transfers between memory and FIFOs. This DMA controller supports a byte alignment.

FIFO Controller - FIFO controller contains two independent FIFOs for reception and transmission. This controller supports automatic packet deletion on receive (after a collision or address filtering) and packet retransmission after a collision on transmit.

MAC - MAC is fully compliant with IEEE802.3, IEEE802.3u and IEEE802.3x.

MII I/O Buffer - MII I/O buffers are compliant IEEE802.3u and are connect to standard PHY device.

Figure 5-1. Block Diagram of Ethernet Controller



5.2 Register

Register of this block has following four category. Please show in Table 5-1.
VR4120A RISC Core controls following Register sets via System Controller and IBUS.
LAKI has a single-channel Ethernet Controller (#1). The controller's base address is 1000_2000H.
References to Ethernet Channel #2 are reserved and not implemented in LAKI.

Table 5-1. Ethernet Controller's Register Map

Offset Address	Descriptions
00H – 13FH	MAC Control Registers
140H – 1FFH	Statistics Counter Registers
200H – 233H	DMA and FIFO Management Registers
234H – 23FH	Interrupt and Configuration Registers

MAC Control Registers map is shown in Table 5-2.

Table 5-2. MAC Control Register Map

Address	Register	Description	R/W	Default
00H	En_MACC1	MAC configuration register 1	R/W	0000_0000H
04H	En_MACC2	MAC configuration register 2	R/W	0000_0000H
08H	En_IPGT	Back-to-Back IPG register	R/W	0000_0013H
0CH	En_IPGR	Non Back-to-Back IPG register	R/W	0000_0E13H
10H	En_CLRT	Collision register	R/W	0000_370FH
14H	En_LMAX	Max packet length register	R/W	0000_0600H
18H-1CH	N/A	Reserved for future use	-	-
20H	En_RETX	Retry count register	R/W	0000_0000H
24H-50H	N/A	Reserved for future use	-	-
54H	En_LSA2	Station Address register 2	R/W	0000_0000H
58H	En_LSA1	Station Address register 1	R/W	0000_0000H
5CH	En_PTVR	Pause timer value read register	R	0000_0000H
60H	N/A	Reserved for future use	-	-
64H	En_VLTP	VLAN type register	R/W	0000_0000H
80H	En_MIIC	MII configuration register	R/W	0000_0000H
84H-90H	N/A	Reserved for future use	-	-
94H	En_MCMD	MII command register	W	0000_0000H
98H	En_MADR	MII address register	R/W	0000_0000H
9CH	En_MWTD	MII write data register	R/W	0000_0000H
A0H	En_MRDD	MII read data register	R	0000_0000H
A4H	En_MIND	MII indicator register	R	0000_0000H
A8H-C4H	N/A	Reserved for future use	-	-
C8H	En_AFR	Address Filtering register	R/W	0000_0000H
CCH	En_HT1	Hash table register 1	R/W	0000_0000H
D0H	En_HT2	Hash table register 2	R/W	0000_0000H
D4H-D8H	N/A	Reserved for future use	-	-
DCH	En_CAR1	Carry register 1	R/W	0000_0000H
E0H	En_CAR2	Carry register 2	R/W	0000_0000H
E4H-12CH	N/A	Reserved for future use	-	-
130H	En_CAM1	Carry mask register 1	R/W	0000_0000H
134H	En_CAM2	Carry mask register 2	R/W	0000_0000H
138H-13CH	N/A	Reserved for future use	-	-

Remarks 1. These reserve registers must not be accessed.

2. n =1 (Ethernet Controller #1)

5.2.1 Statistics counter registers

MAC gathers statistical information about the receive and transmit operations from the statistics counters.

Each counter consists of 32 bits counter. When a counter overflow condition occurs, the corresponding bit of the En_CAR1 register or En_CAR2 register is set to 1, and it can generate an interrupt. The interrupt can be masked by setting the bits of En_CAM1 register or En_CAM2 register.

Some time is required to complete the updating of all statistics counters after the change of the status vector (TSV or RSV) because of the count operation.

Table 5-3. Statistics Counter Register Map

(1/2)

Address	Register	Description	R/W
140H	En_RBYT	Receive Byte Counter	R/W
144H	En_RPKT	Receive Packet Counter	R/W
148H	En_RFCS	Receive FCS Error Counter	R/W
14CH	En_RMCA	Receive Multicast Packet Counter	R/W
150H	En_RBCA	Receive Broadcast Packet Counter	R/W
154H	En_RXCF	Receive Control Frame Packet Counter	R/W
158H	En_RXPF	Receive PAUSE Frame Packet Counter	R/W
15CH	En_RXUO	Receive Unknown OP code Counter	R/W
160H	En_RALN	Receive Alignment Error Counter	R/W
164H	En_RFLR	Receive Frame Length Out of Range Counter	R/W
168H	En_RCDE	Receive Code Error Counter	R/W
16CH	En_RFCR	Receive False Carrier Counter	R/W
170H	En_RUND	Receive Undersize Packet Counter This counter is incremented each time a frame is received which is less than 64 bytes in length and contains a valid FCS.	R/W
174H	En_ROVR	Receive Oversize Packet Counter This counter is incremented each time a frame is received which exceeds 1518 bytes length and contains a valid FCS.	R/W
178H	En_RFRG	Receive Error Undersize Packet Counter This counter is incremented each time a frame is received which is less than 64 bytes in length and contains a invalid FCS, includes alignment error.	R/W
17CH	En_RJBR	Receive Error Oversize Packet Counter This counter is incremented each time a frame is received which exceeds 1518 bytes length and contains an invalid FCS or includes an alignment error.	R/W
180H	En_R64	Receive 64 Byte Frame Counter This counter is incremented for each good or bad frame received which is 64 bytes in length.	R/W
184H	En_R127	Receive 65 to 127 Byte Frame Counter This counter is incremented for each good or bad frame received which is 65 to 127 bytes in length.	R/W

Remark n =1 (Ethernet Controller #1)

(2/2)

Address	Register	Description	R/W
188H	En_R255	Receive 128 to 255 Byte Frame Counter This counter is incremented for each good or bad frame received which is 128 to 255 bytes in length.	R/W
18CH	En_R511	Receive 256 to 511 Byte Frame Counter This counter is incremented for each good or bad frame received which is 256 to 511 bytes in length.	R/W
190H	En_R1K	Receive 512 to 1023 Byte Frame Counter This counter is incremented for each good or bad frame received which is 512 to 1023 bytes in length.	R/W
194H	En_RMAX	Receive Over 1023 Byte Frame Counter This counter is incremented for each good or bad frame received which is over 1023 bytes in length.	R/W
198H	En_RVBT	Receive Valid Byte Counter This counter is incremented by the byte count of each valid packet received.	R/W
1C0H	En_TBYT	Transmit Byte Counter	R/W
1C4H	En_TPCT	Transmit Packet Counter	R/W
1C8H	En_TFCS	Transmit CRC Error Packet Counter	R/W
1CCH	En_TMCA	Transmit Multicast Packet Counter	R/W
1D0H	En_TBCA	Transmit Broadcast Packet Counter	R/W
1D4H	En_TUCA	Transmit Unicast Packet Counter	R/W
1D8H	En_TXPF	Transmit PAUSE control Frame Counter	R/W
1DCH	En_TDFR	Transmit Single Deferral Packet Counter	R/W
1E0H	En_TXDF	Transmit Excessive Deferral Packet Counter	R/W
1E4H	En_TSCL	Transmit Single Collision Packet Counter	R/W
1E8H	En_TMCL	Transmit Multiple collision Packet Counter	R/W
1ECH	En_TLCL	Transmit Late Collision Packet Counter	R/W
1F0H	En_TXCL	Transmit Excessive Collision Packet Counter	R/W
1F4H	En_TNCL	Transmit Total Collision Counter	R/W
1F8H	En_TCSE	Transmit Carrier Sense Error Counter This counter is incremented for each frame transmitted which carrier sense error occurs during transmission.	R/W
1FCH	En_TIME	Transmit Internal MAC Error Counter This counter is incremented for each frame transmitted in which an internal MAC error occurs during transmission.	R/W

Remark n =1 (Ethernet Controller #1)

5.2.2 DMA and FIFO management registers

These registers control to transfer receive and transmit data by internal DMAC of this block.

Table 5-4. DMA and FIFO Management Registers Map

Address	Register	Description	R/W	Default
200H	En_TXCR	Transmit Configuration Register	R/W	0000_0000H
204H	En_TXFCR	Transmit FIFO Control Register	R/W	FFFF_40C0H
208H	En_TXDTR	Transmit Data Register	W	0000_0000H
20CH	En_TXSR	Transmit Status Register	R	0000_0000H
210H	N/A	Reserved for future use	-	-
214H	En_TXDPR	Transmit Descriptor Register	R/W	0000_0000H
218H	En_RXCR	Receive Configuration Register	R/W	0000_0000H
21CH	En_RXFCR	Receive FIFO Control Register	R/W	C040_0040H
220H	En_RXDTR	Receive Data Register	R	0000_0000H
224H	En_RXSR	Receive Status Register	R	0000_0000H
228H	N/A	Reserved for future use	-	-
22CH	En_RXDPR	Receive Descriptor Register	R/W	0000_0000H
230H	En_RXPDR	Receive Pool Descriptor Register	R/W	0000_0000H

Remark n =1 (Ethernet Controller #1)

5.2.3 Interrupt and configuration registers

These register control interrupt occur and configuration for this block.

Table 5-5. Interrupt and Configuration Registers Map

Address	Register	Description	R/W	Default
234H	En_CCR	Configuration Register	R/W	0000_0000H
238H	En_ISR	Interrupt Service Register	R	0000_0000H
23CH	En_MSR	Mask Serves Register	R/W	0000_0000H

Remark n =1 (Ethernet Controller #1)

5.2.4 Detail of MAC control registers

5.2.4.1 En_MACC1-MAC Configuration Register 1 (00H R/W)

Bit	Field	Functions	Default
31:15	-	Reserved for future use. Write as 0	-
14	MACLB	MAC loopback: Setting this bit to 1 switches into loopback mode which routes from Transmit Function Block to Receive Function Block.	0
13:12	-	Reserved for future use. Write as 0	-
11	TXFC	Transmit flow control enable: Setting this bit to 1 enables to transmit the pause control frame.	0
10	RXFC	Receive flow control enable: Setting this bit to 0 enables MAC to execute PAUSE operation for the pause time on the setting of the pause timer. The setting of the pause timer must be updated every time a valid PAUSE control frame is received regardless of the setting of this bit.	0
9	SRXEN	Receive enable: Setting this bit to 1 enables the function of the MAC Address field filtering.	0
8	PARF	Control packet pass: Setting this bit to 1 allows MAC to check for all received packets including control frames. When this bit is set to 0, MAC does not check the reception of a control frame.	0
7	PUREP	Pure preamble: Setting this bit to 1 allows the recognition of start of a new packet only when a pure preamble (“0101” only) is seen.	0
6	FLCHT	Length field check: When this bit is set to 1, MAC compares the length field value in the packet to the actual packet length, and indicates the result in the status vector. When this bit is set 0, MAC does not check the Frame length field.	0
5	NOBO	No Back Off: When this bit is set to 1, MAC always transmits the packet with no backoff operation.	0
4	-	Reserved for future use. Write as 0	-
3	CRCEN	CRC append enable: Setting this bit to 1 enables MAC to append calculated CRC code to the end of transmitted packet automatically.	0
2	PADEN	PAD append enable: Setting this bit to 1 enables MAC to append PAD when the transmitted packet length is less than 64 octets because the input data (TPD) length is less than 60 bytes before appending the CRC.	0
1	FULLD	Full duplex enable: Setting this bit to 1 enables the full duplex operation.	0
0	HUGEN	Large packet enable: Setting this bit to 1 enable MAC to transmit and receive a packet of which length is over the value of En_LMAX register.	0

5.2.4.2 En_MACC2-MAC Configuration Register 2 (04H R/W)

Bit	Field	Functions	Default
31:11	-	Reserved for future use. Write as 0	-
10	MCRST	MAC Control Block software reset: Setting this bit to 1 forces MAC Control Block to a software reset operation. In order to complete the software reset state, this bit needs to be cleared.	0
9	RFRST	Receive Function Block software reset: Setting this bit to 1 forces the Receive Function Block to a software reset operation. In order to complete the software reset state, this bit needs to be cleared.	0
8	TFRST	Transmit Function Block software reset: Setting this bit to 1 forces Transmit Function Block to a software reset operation. In order to complete the software reset state, this bit needs to be cleared.	0
7	-	Reserved for future use. Write as 0.	-
6	BPNB	Back Pressure No Back Off: When this bit is set to 1, MAC transmits the packet with no backoff operation after the back pressure operation only.	0
5	APD	Auto VLAN PAD: When this bit is set to 1, if the ETPID field in the current transmit packet matches the value in the En_VLTP register , MAC pads the current packet as a VLAN packet when the current packet should be padded .	0
4	VPD	VLAN PAD mode: When this bit is set to 1, MAC always pads the current packet as a VLAN packet when the current packet should be padded.	0
3:2	-	Reserved for future use. Write as 0.	-

5.2.4.3 En_IPGT-Back to Back IPG Register (08H R/W)

Bit	Field	Functions	Default
31:7	-	Reserved for future use. Write as 0	-
6:0	IPGT	Back-To-Back IPG : This field sets IPG when transmit operation is executed with Back-to-back mode. The formula for the Back-to-Back IPG is: IPG = (5 + IPGT) × 4 bits time	13H

5.2.4.4 En_IPGR-Non Back to Back IPG Register (0CH R/W)

Bit	Field	Functions	Default
31:15	-	Reserved for future use. Write as 0	-
14:8	IPGR1	Carrier sense time: This field sets the carrier sense time when the transmit operation is executed in non Back-to-Back mode. The formula for the carrier sense time is: Carrier sense time = (2 + IPGR1) × 4 bits time The carrier sense time defined in this field is included in the non Back-to-Back IPG defined in the IPGR2 field.	0EH
7	-	Reserved for future use. Write as 0	-
6:0	IPGR2	Non Back-To-Back IPG: This field sets IPG when transmit operation is executed with non Back-to-Back mode. The formula for the non Back-to-Back IPG is: IPG = (5 + IPGR2) × 4 bits time	13H

5.2.4.5 En_CLRT-Collision Register (10H R/W)

Bit	Field	Functions	Default
31:14	-	Reserved for future use. Write as 0	-
13:8	LCOL	Late collision window: This fields sets collision window size. The formula for the collision window size is: collision window size = (LCOL + 8) × 8 bits time	38H
7:4	-	Reserved for future use. Write as 0	-
3:0	RETRY	Maximum number of retry: This field sets the maximum number of retries during the transmission. If a retry occurs beyond this value, the current transmission is aborted.	0FH

5.2.4.6 En_LMAX-Maximum Packet Length Register (14H R/W)

Bit	Field	Functions	Default
31:16	-	Reserved for future use. Write as 0	-
15:0	MAXF	Maximum packet length: This field sets the maximum the length of transmit and receive packet by the octet when En_MACC1 register: HUGEN bit is set to 1. Receive: If the current receive packet length is greater than the value of MAXF, MAC terminates the reception. Transmit: If the current transmit packet length is greater than the value of MAXF, MAC aborts the transmission.	600H

5.2.4.7 En_RETX-Retry Counter Register (20H R/W)

Bit	Field	Functions	Default
31:4	-	Reserved for future use. Write as 0	-
3:0	RETX	Retry counter: This field indicates the number of the retries during the current transmission.	0

5.2.4.8 En_LSA2-Station Address Register (54H R/W)

Bit	Field	Functions	Default
31:16	-	Reserved for future use. Write as 0	-
15:0	LSA2	Station address SA (47:32)	0

5.2.4.9 En_LSA1-Station Address Register (58H R/W)

Bit	Field	Functions	Default
31:0	LSA1	Station address SA(31:0): This field sets the station address. The station address: SA(47:0) is used by the MAC Control Block as the source address in the PAUSE control frame, and used for the comparison with the destination address of the receive packet.	0

5.2.4.10 En_PTVR-Pause Timer read Register (5CH R)

Bit	Field	Functions	Default
31:16	-	Reserved for future use.	-
15:0	PTCT	Pause timer counter: This field indicates the current pause timer value.	0

5.2.4.11 En_VLTP-VLAN Type Register (64H R/W)

Bit	Field	Functions	Default
31:16	-	Reserved for future use. Write as 0	-
15:0	VLTP	VLAN type: This field sets ETPID value. Receive : Detects a VLAN frame by comparing this field with the ETPID field in the received packet. Transmit : If En_MACC2 register: APD bit is set to 1 and the ETPID field in the current transmit packet matches this field, MAC pads as a VLAN packet when the current packet should be padded	0

5.2.4.12 En_MIIC-MII Configuration Register (80H R/W)

Bit	Field	Functions	Default
31:16	-	Reserved for future use. Write as 0	-
15	MIRST	MII Management Interface Block software reset: Setting this bit to 1 forces the MII Management Interface Block to a software reset operation. In order to complete the software reset state, this bit needs to be cleared.	0
14:4	-	Reserved for future use. Write as 0	-
3:2	CLKS	Select frequency range: This field sets the frequency range of HCLK input. MDC is generated by dividing down the HCLK and the clock division is set by this bits. The settings of this bits are: 00: HCLK is equal to 25 MHz 01: HCLK is less than or equal to 33 MHz 10: HCLK is less than or equal to 50 MHz 11: HCLK is less than or equal to 66 MHz MDC is set less than or equal to 2.5MHz. by the setting of this bits.	0
1:0	-	Reserved for future use. Write as 0	-

5.2.4.13 En_MCMD-MII Command Register (94H W)

Bit	Field	Functions	Default
31:2	-	Reserved for future use. Write as 0	-
1	SCANC	SCAN command: When this bit is set to 1, MAC executes the SCAN command.	0
0	RSTAT	MII management read: When this bit is set to 1, MAC executes the read access through MII management interface.	0

5.2.4.14 En_MADR-MII Address Register (98H R/W)

Bit	Field	Functions	Default
31:13	-	Reserved for future use. Write as 0	-
12:8	FIAD	MII PHY address: This field sets PHY address to be selected during this operation.	0
7:5	-	Reserved for future use. Write as 0	-
4:0	RGAD	MII register address: This field sets register address to be accessed during this operation.	0

5.2.4.15 En_MWTD-MII Write Data Register (9CH R/W)

Bit	Field	Functions	Default
31:16	-	Reserved for future use. Write as 0	-
15:0	CTLD	MII write data: This field sets the MII management write data for write access through the MII management interface.	0

5.2.4.16 En_MRDD-MII Read Data Register (A0H R)

Bit	Field	Functions	Default
31:16	-	Reserved for future use.	-
15:0	CTLD	MII write data: This field sets the MII management write data for write access through the MII management interface.	0

5.2.4.17 En_MIND-MII Indicate Register (A4H R)

Bit	Field	Functions	Default
31:3	-	Reserved for future use.	-
2	NVALID	SCAN command start status: This bit is set to 1 when En_MCMD register: SCANC bit is set to 1. When the first read access using the SCAN command is completed, this bit is cleared.	0
1	SCANA	SCAN command active: This bit is set to 1 while En_MCMD register: SCANC bit is set to 1.	0
0	BUSY	BUSY: This bit indicates that the MAC is executing a management access to the external PHY device through the MII management interface. This bit is set to 1 during the management access.	0

5.2.4.18 En_AFR-Address Filtering Register (C8H R/W)

Bit	Field	Functions	Default
31:4	-	Reserved for future use. Write as 0	-
3	PRO	Promiscuous mode: When this bit is set to 1, all receive packets are accepted.	0
2	PRM	Accept Multicast: When this bit is set to 1, all multicast packets are accepted.	0
1	AMC	Accept Multicast (qualified): When this bit is set to 1, multicast packets that match the conditions using hash table are accepted.	0
0	ABC	Accept Broadcast: When this bit is set to 1, all broadcast packets are accepted.	0

PRO	PRM	AMC	ABC	Unicast	Multicast	Broadcast
0	0	0	0	Yes (SA)	No	No
0	0	0	1	Yes (SA)	No	Pass
0	X	1	1	Yes (SA)	Pass	Pass
0	1	0	1	Yes (SA)	Yes (Hash)	Pass
0	X	1	0	Yes (SA)	Pass	No
0	1	0	0	Yes (SA)	Yes (Hash)	No
1	X	X	X	Pass	Pass	Pass
SRXEN = 0				Disable	Disable	Disable

5.2.4.19 En_HT1-Hash Table Register 1 (CCH R/W)

Bit	Field	Functions	Default
31:0	HT1	Hash table 1: This register is used with the HT2 register as the hash table for detection of qualified multicast packets. This register sets the upper 32bits of the hash table. HT(63:32)	0

5.2.4.20 En_HT2-Hash Table Register 2 (D0H R/W)

Bit	Field	Functions	Default
31:0	HT2	Hash table 2: This register is used with the HT1 register as the hash table for detection of qualified multicast packets. This register sets the lower 32bits of the hash table. HT(31:0)	0

5.2.4.21 En_CAR1-Carry Register 1 (DCH R/W)

The bits of this register indicate that an overflow event has occurred in a statistics counter. Each bit corresponds to a counter, and the bit is set to 1 when the corresponding statistics counter overflow event occurs.

Bit	Field	Functions	Default
31:16	-	Reserved for future use. Write as 0	-
15	C1VT	En_RVBT counter carry bit	0
14	C1UT	En_TUCA counter carry bit	0
13	C1BT	En_TBCA counter carry bit	0
12	C1MT	En_TMCA counter carry bit	0
11	C1PT	En_TPCT counter carry bit	0
10	C1TB	En_TBYT counter carry bit	0
9	C1MX	En_RMAX counter carry bit	0
8	C11K	En_R1K counter carry bit	0
7	C1FE	En_R511 counter carry bit	0
6	C1TF	En_R255 counter carry bit	0
5	C1OT	En_R127 counter carry bit	0
4	C1SF	En_R64 counter carry bit	0
3	C1BR	En_RBCA counter carry bit	0
2	C1MR	En_RMCA counter carry bit	0
1	C1PR	En_RPKT counter carry bit	0
0	C1RB	En_RBYT counter carry bit	0

5.2.4.22 En_CAR2-CARRY Register 2 (E0H R/W)

The bits of this register indicate that an overflow event has occurred in a statistics counter. Each bit corresponds to a counter, and the bit is set to 1 when the corresponding statistics counter overflow event occurs.

Bit	Field	Functions	Default
31	C2XD	Status vector overrun bit	0
30:23	-	Reserved for future use. Write as 0	-
22	C2IM	En_TIME counter carry bit	0
21	C2CS	En_TCSE counter carry bit	0
20	C2BC	En_TNCL counter carry bit	0
19	C2XC	En_TXCL counter carry bit	0
18	C2LC	En_TLCL counter carry bit	0
17	C2MC	En_TMCL counter carry bit	0
16	C2SC	En_TSCL counter carry bit	0
15	C2XD	En_TXDF counter carry bit	0
14	C2DF	En_TDFR counter carry bit	0
13	C2XF	En_TXPF counter carry bit	0
12	C2TE	En_TFCS counter carry bit	0
11	C2JB	En_RJBR counter carry bit	0
10	C2FG	En_RFRG counter carry bit	0
9	C2OV	En_ROVR counter carry bit	0
8	C2UN	En_RUND counter carry bit	0
7	C2FC	En_RFCR counter carry bit	0
6	C2CD	En_RCDE counter carry bit	0
5	C2FO	En_RFLR counter carry bit	0
4	C2AL	En_RALN counter carry bit	0
3	C2UO	En_RXUO counter carry bit	0
2	C2PF	En_RXPF counter carry bit	0
1	C2CF	En_RXCF counter carry bit	0
0	C2RE	En_RFCS counter carry bit	0

5.2.4.23 En_CAM1-CARRY Register 1 Mask Register (130H R/W)

This register masks Interrupt that is generated from the setting of the bits in the En_CAR1 register. Each mask bit can be enabled independently.

Bit	Field	Functions	Default
31:16	-	Reserved for future use. Write as 0	-
15	M1VT	En_RVBT counter carry mask bit	0
14	M1UT	En_TUCA counter carry mask bit	0
13	M1BT	En_TBCA counter carry mask bit	0
12	M1MT	En_TMCA counter carry mask bit	0
11	M1PT	En_TPCT counter carry mask bit	0
10	M1TB	En_TBYT counter carry mask bit	0
9	M1MX	En_RMAX counter carry mask bit	0
8	M11K	En_R1K counter carry mask bit	0
7	M1FE	En_R511 counter carry mask bit	0
6	M1TF	En_R255 counter carry mask bit	0
5	M1OT	En_R127 counter carry mask bit	0
4	M1SF	En_R64 counter carry mask bit	0
3	M1BR	En_RBCA counter carry mask bit	0
2	M1MR	En_RMCA counter carry mask bit	0
1	M1PR	En_RPKT counter carry mask bit	0
0	M1RB	En_RBYT counter carry mask bit	0

5.2.4.24 En_CAM2-CARRY Register 2 Mask Register (134H R/W)

This register masks the Interrupt that is generated from the setting of the bits in the En_CAR2 register. Each mask bit can be enabled independently.

Bit	Field	Functions	Default
31	M2XD	Status vector overrun mask bit	0
30:23	-	Reserved for future use. Write as 0	-
22	M2IM	En_TIME counter carry mask bit	0
21	M2CS	En_TCSE counter carry mask bit	0
20	M2BC	En_TNCL counter carry mask bit	0
19	M2XC	En_TXCL counter carry mask bit	0
18	M2LC	En_TLCL counter carry mask bit	0
17	M2MC	En_TMCL counter carry mask bit	0
16	M2SC	En_TSCL counter carry mask bit	0
15	M2XD	En_TXDF counter carry mask bit	0
14	M2DF	En_TDFR counter carry mask bit	0
13	M2XF	En_TXPF counter carry mask bit	0
12	M2TE	En_TFCS counter carry mask bit	0
11	M2JB	En_RJBR counter carry mask bit	0
10	M2FG	En_RFRG counter carry mask bit	0
9	M2OV	En_ROVR counter carry mask bit	0
8	M2UN	En_RUND counter carry mask bit	0
7	M2FC	En_RFCR counter carry mask bit	0
6	M2CD	En_RCDE counter carry mask bit	0
5	M2FO	En_RFLR counter carry mask bit	0
4	M2AL	En_RALN counter carry mask bit	0
3	M2UO	En_RXUO counter carry mask bit	0
2	M2PF	En_RXPF counter carry mask bit	0
1	M2CF	En_RXCF counter carry mask bit	0
0	M2RE	En_RFCS counter carry mask bit	0

5.2.5 Detail of DMA and FIFO management registers

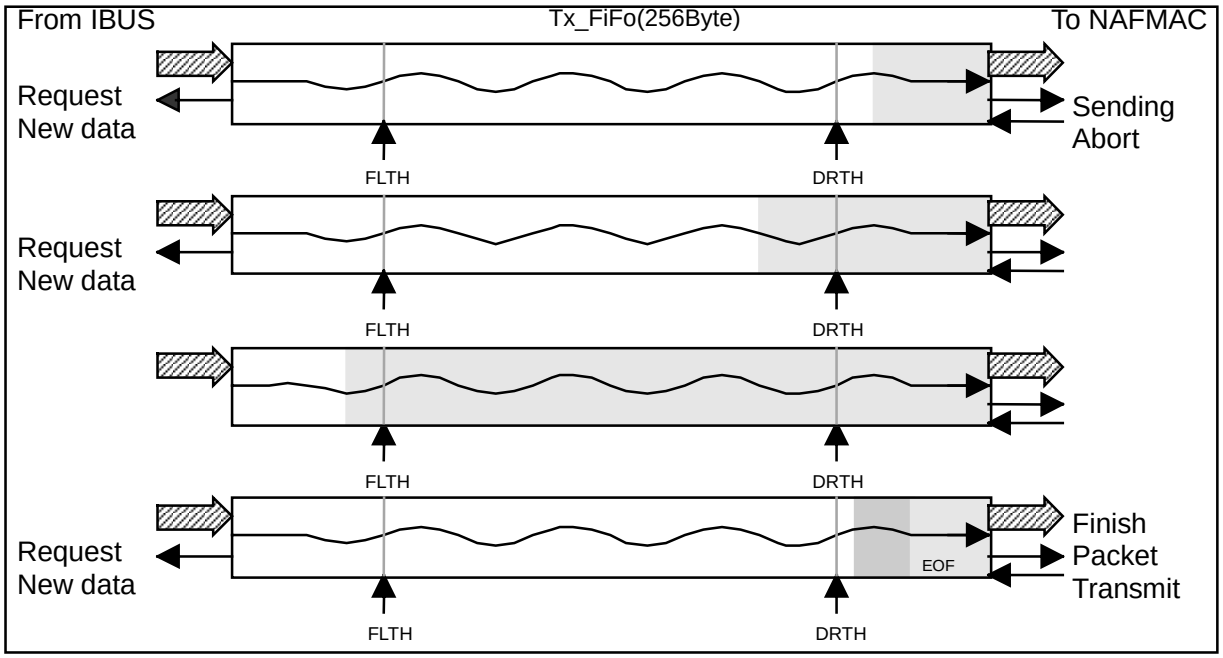
5.2.5.1 En_TXCR-Transmit Configuration Register (200H R/W)

Bit	Field	Functions	Default
31	TXE	Transmit Enable: 0: Disable 1: Enable	0
30:19	-	Reserved for future use. Write as 0	-
18:16	DTBS [2:0]	DMA Transmit Burst Size: 000: 1 Word (4 bytes) 001: 2 Word (8 bytes) 010: 4 Word (16 bytes) 011: 8 Word (32 bytes) 100: 16 Word (64 bytes) 101: 32 Word (128 bytes) 110: 64 Word (256 bytes) 111: Reserved for future use	0
15:1	-	Reserved for future use. Write as 0	-
0	AFCE	Auto Flow Control Enable: 0: Disable 1: Enable	0

5.2.5.2 En_TXFCR-Transmit FIFO Control Register (204H R/W)

Bit	Field	Functions	Default
31:16	TPTV	Transmit Pause Timer Value:	FFFFH
15:10	TX_DRTH	Transmit Drain Threshold Level: This threshold is enable to the transmit data to the MAC form the FIFO. If the transfer data is not finish by DMAC and the buffer empty pointer exceed this pointer, this Ethernet sends Abort Packet. Please see the Figure 5-2. This is a word pointer.	10H
9:8	-	Reserved for future use. Write as 0	-
7:2	TX_FRTH	Transmit Fill Threshold Level: This threshold is enable to transmit data to the FIFO from IBUS via internal DMAC of this block. Please see the Figure 5-2. This is a word pointer.	03H
1:0	-	Reserved for future use. Write as 0	-

Figure 5-2. Tx FIFO Control Mechanism



5.2.5.3 En_TXDTR-Transmit Data Register (208H W)

Bit	Field	Functions	Default
32:0	XMT_D [31:0]	Transmit Data	0

5.2.5.4 En_TXSR-Transmit Status Register (20CH R)

Bit	Field	Functions	Default
31	CSE	Carrier lost was detected during the transmission	0
30	TBP	Back pressure occurred when the packet was received	0
29	TPP	A packet request during the PAUSE operation was transmitted Note1	0
28	TPCF	A PAUSE control frame was transmitted	0
27	TCFR	A control frame was transmitted	0
26	TUDR	The TPUR pin was set high and aborted. Note 2	0
25	TGNT	A packet greater than the value of the En_LMAX register in length was transmitted and aborted. Note 3	0
24	LCOL	Collision occurred out of the collision window and the transmission was aborted.	0
23	ECOL	The number of collisions was greater than the value of the En_RETX register and the transmission was aborted.	0
22	TEDFR	The transmission was deferred beyond 24888 bits time and aborted.	0
21	TDFR	Transmission deferral occurred at least one time but less than an excessive deferral.	0
20	TBRO	A broadcast packet was transmitted.	0
19	TMUL	A multicast packet was transmitted.	0
18	TDONE	The transmission was completed.	0
17	TFLOR	The value of the length field in the transmitted packet was over 1518 bytes.Note4	0
16	TFLER	The value of the length field in the transmitted packet didn't match the actual data byte length. Note 4, 5	0
15	TCRCE	The attached CRC in the data byte stream didn't match the internal generated CRC when the En_MACC1 register: CRCEN bit was cleared to 0.	0
14:11	TCBC	The number of collisions for the previous transmission only.	0
10:0	TBYT	The number of the transmitted bytes not including collided bytes.Note6	0

Notes 1. This status is not reported if the packet requested during the PAUSE operation was a control frame requested by TPCF pin.

2. This status is reported only when no collision events occurred.

3. This status is reported only when the En_MACC1 register: HUGEN bit is cleared.

4. This status is not reported if En_MACC1 register: FLCHT bit is cleared.

5. When the value of the length field was over 1518 bytes, it is reported only as TFLOR status, not as TFLER status.

6. When the transmission was aborted, this value is not correct.

5.2.5.5 En_TXDPR-Transmit Descriptor Pointer(214H R/W)

Bit	Field	Functions	Default
31:2	XMTDP	Transmit Descriptor Please see the Section 5.3.2.1.	0H
1:0	-	Reserved for future use. Write as 0	-

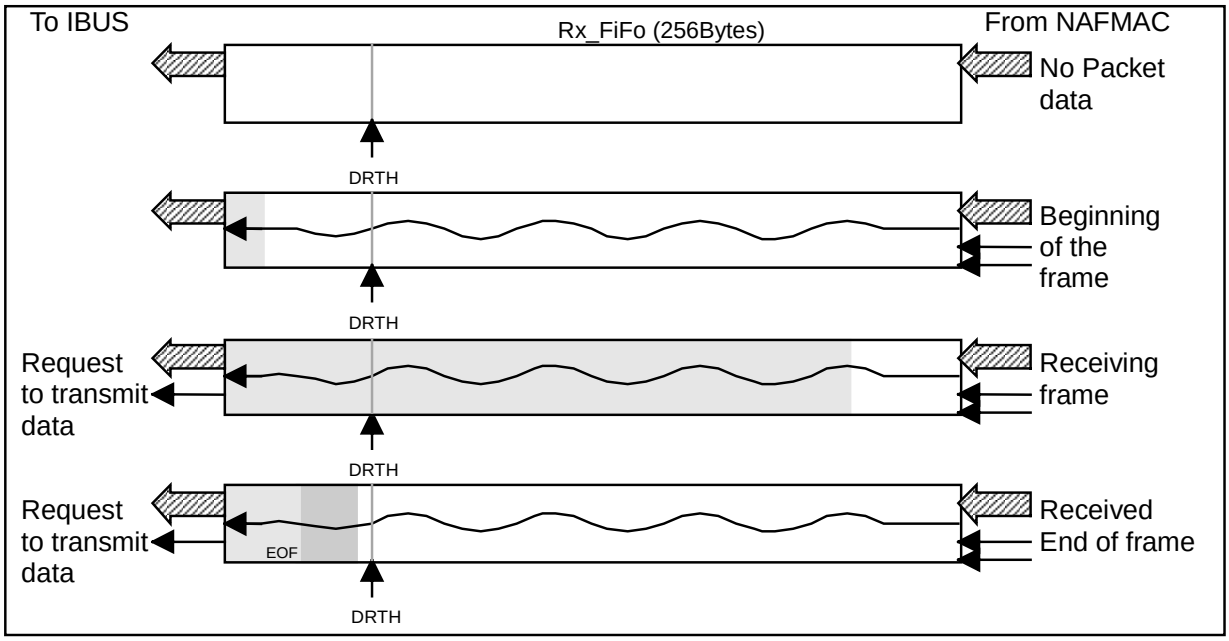
5.2.5.6 En_RXCR-Receive Configuration Register (218H R/W)

Bit	Field	Functions	Default
31	RXE	Receive Enable: 0: Disable 1: Enable	0
30:19	-	Reserved for future use. Write as 0	-
18:16	DRBS [2:0]	DMA Transmit Burst Size: 000: 1 Word (4 bytes) 001: 2 Word (8 bytes) 010: 4 Word (16 bytes) 011: 8 Word (32 bytes) 100: 16 Word (64 bytes) 101: 32 Word (128 bytes) 110: 64 Word (256 bytes) 111: Reserved for future use	0
15:0	-	Reserved for future use. Write as 0	-

5.2.5.7 En_RXFCR-Receive FIFO Control Register (21CH R/W)

Bit	Field	Functions	Default
31:26	UWM [7:2]	Upper Water Mark: This pointer is used with Auto Flow Control Enable in En_TXCR. When the receiving data fill level exceeds this pointer, the transmit module generates a flow control frame automatically.	30H
25:24	-	Reserved for future use. Write as 0	-
23:18	LWN [7:2]	Lower Water Mark:	10H
17:8	-	Reserved for future use. Write as 0	-
7:2	RX_DRTH	Receive Drain Threshold Level This threshold is enable to the transmit data to the IBUS via internal DMAC form the FIFO. Please see the Figure 5-3. This pointer is a word pointer.	10H
1:0	-	Reserved for future use. Write as 0	-

Figure 5-3. Rx FIFO Control Mechanism



5.2.5.8 En_RXDTR-Receive Data Register (220H R)

Bit	Field	Functions	Default
32:0	RCV_D [31:0]	Receive Data	0

5.2.5.9 En_RXSR-Receive Status Register (224H R)

Bit	Field	Functions	Default
31	RLENE	A packet which was less than 64 octets or larger than 1518 octets was received.(If a VLAN packet, the packet was less than 68 bytes or larger than 1522 bytes)	0
30	VLAN	A packet in which the Ethernet-encoded TPID field matched the value of the En_VLTP register was received.Note1	0
29	USOP	A control frame containing an unknown OP code was received. Note 2	0
28	PRCF	A control frame containing the PAUSE OP code was received. Note 2	0
27	RCFR	A frame containing a valid type field designating it as a control frame was received. Note 2	0
26	DBNB	An alignment error occurred.	0
25	RBRO	A broadcast packet was received.	0
24	RMUL	A multicast packet was received.	0
23	RXOK	A packet which had a valid CRC and no RXER was received. Note 1	0
22	RLOR	The value of the length field in the received packet was over 1518 bytes. Note 3	0
21	RLER	The value of the length field in the received packet didn't match the actual data byte length. Note 3, Note 4	0
20	RCRCE	A CRC error occurred.	0
19	RCV	RXER was detected.	0
18	CEPS	A False Carrier was detected.	0
17	REPS	A packet which had a preamble and SFD only or one data nibble only was received.	0
16	PAIG	The previous packet with the following status was received and • The carrier length was 6072 nibble (3036 octets) • Short IPG • When En_MACC1 register: PUREP bit was set to 1, an invalid preamble or invalid SFD was detected.	0
15:0	RBYT	The received byte count	0

Note 1. This status is not reported when a CRC error or RXER occurs.
2. This status is not reported when a CRC error occurs.
3. This status is not reported if En_MACC1 register: FLCHT bit is cleared.
4. When the value of the length field is over 1518 bytes, it is reported only as RLOR status, not as RLER status.

5.2.5.10 En_RXDPR-Receive Descriptor Pointer (22CH R/W)

Bit	Field	Functions	Default
31:2	RCVDP	Receive Descriptor Pointer: Please see the Section 5.3.2.1.	0H
1:0	-	Reserved for future use. Write as 0	-

5.2.5.11 En_RXPDR-Receive Pool Descriptor Pointer (230H R/W)

Bit	Field	Functions	Default
31	-	Reserved for future use. Write as 0	-
30:28	AL[2:0]	Alert Level	0H
27:16	-	Reserved for future use. Write as 0	-
15:0	RNOD [15:0]	Remaining Number of Descriptor	0H

5.2.6 Detail of interrupt and configuration registers

5.2.6.1 En_CCR-Configuration Register (240H R/W)

Bit	Field	Functions	Default
31:1	-	Reserved for future use. Write as 0	-
0	SRT	Software Reset	0H

Note: SRT bit is automatically cleared. So read value of this register is always '0'

5.2.6.2 En_ISR-Interrupt Serves Register (244H R with clear)

Bit	Field	Functions	Default
31:16	-	Reserved for future use. Write as 0	-
15	XMTDN	Transmit Done	0
14	TBDR	Transmit Buffer Descriptor Request at Null	0
13	TFLE	Transmit Frame Length Exceed	0
12	UR	Underrun	0
11	TABR	Transmit Aborted	0
9:8	-	Reserved for future use. Write as 0	-
10	TCFRI	Control Frame Transmit	0
7	RCVDN	Receive Done	0
6	RBDRS	Receive Buffer Descriptor Request at alert level	0
5	RBDRU	Receive Buffer Descriptor Request at zero	0
4	OF	Overflow	0
3	LFAL	Link Failed	0
2:1	-	Reserved for future use. Write as 0	-
0	CARRY	Carry Flag: CARRY indicates an overflow of the statistics counters	0

5.2.6.3 En_MSR-Mask Serves Register (23CH R/W)

Each interrupt source is maskable. En_MSR register shows which interrupts are enable.

Default value is all “0” which means all interrupt sources are disable.

Bit	Field	Functions	Default
31:16	-	Reserved for future use. Write as 0	-
15	XMTDN	Transmit Done	0
14	TBDR	Transmit Buffer Descriptor Request at Null	0
13	TFLE	Transmit Frame Length Exceed	0
12	UR	Underrun	0
11	TABR	Transmit Aborted	0
9:8	-	Reserved for future use. Write as 0	-
10	TCFRI	Control Frame Transmit	0
7	RCVDN	Receive Done	0
6	RBDRS	Receive Buffer Descriptor Request at alert level	0
5	RBDRU	Receive Buffer Descriptor Request at zero	0
4	OF	Overflow	0
3	LFAL	Link Failed	0
2:1	-	Reserved for future use. Write as 0	-
0	CARRY	Carry Flag: CARRY indicates an overflow of the statistics counters	0

5.3 Operation

5.3.1 Initialization

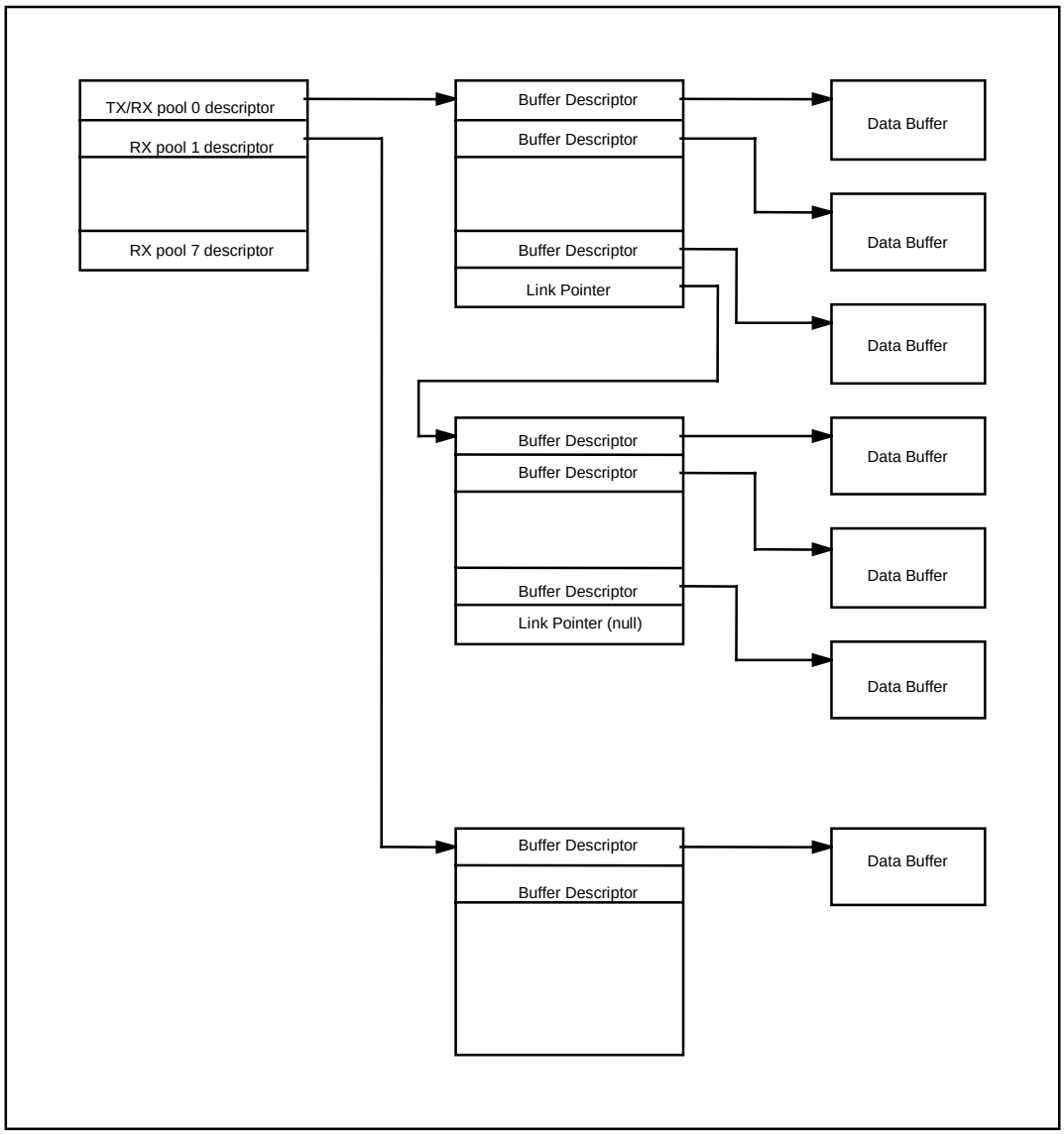
After a power on or a software reset , VR4120A RISC Core has to set the following registers:

i) Interrupt Mask Registers
ii) Configuration Registers
iii) MII Management Registers
iv) Pool / Buffer Descriptor Registers

5.3.2 Buffer structure for Ethernet block

The data buffer structure for Ethernet Controller is shown in Figure 5-4.

Figure 5-4. Buffer Structure for Ethernet Block



5.3.3 Buffer descriptor format

The Transmit Descriptor format is shown in Figure 5-5 and the description is shown in Table 5-6.

Figure 5-5. Transmit Descriptor Format

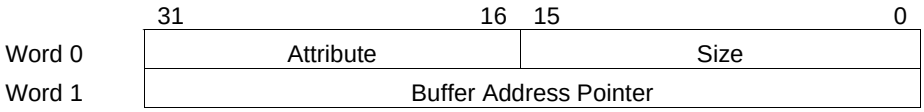


Table 5-6. Attribute for Transmit Descriptor

Attribute	Bit Name	Status
31	L	Last Descriptor
30	D/L	Data Buffer / Link Pointer
29	OWN	Owner 1:Ethernet Controller 0: VR4120A
28	DBRE	Data Buffer Read Error
27	TUDR	Transmit Underrun Error
26	CSE	Carrier Sense Lost Error
25	LCOL	Late Collision
24	ECOL	Excessive Collision
23	EDFR	Excessive Deferral
22:19	-	Reserved for future use. Write as 0.
18	TGNT	Transmit Giant Frame
17	HBF	Heart Beat Fail for ENDEC mode
16	TOK	Transmit OK
15:0	SIZE	Transmit Byte Count

The Receive Descriptor format is shown in Figure 5-6 and the description is shown in Table 5-7.

Figure 5-6. Receive Descriptor Format

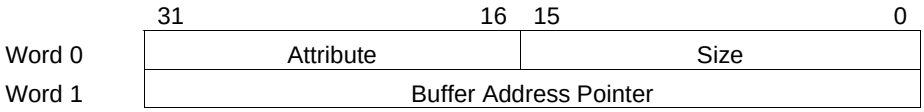


Table 5-7. Attribute for Receive Descriptor

Attribute	Bit Name	Status
31	L	Last Frame
30	D/L	Data Buffer / Link Pointer
29	OWN	Owner bit 1:Ethernet Controller 0: VR4120A
28	DBWE	Data Buffer Write Error
27:25	FTYP	Frame Type[2:0]: 000 Broadcast Frame 001 Multicast Frame 010 Unicast Frame 011 VLAN Frame 100 PAUSE control frame 101 Control Frame (except pause) 11x Reserved for future use
24	OVRN	Overrun Error
23	RUNT	Runt packet
22	FRGE	Fragment Error
21	RCV	Detects RXER
20	FC	False Carrier
19	CRCE	CRC Error
18	FAE	Frame Alignment Error
17	RFLE	Receive Frame Length Error
16	RXOK	Receive OK
15:0	SIZE	Receive Byte Count

Remark RUNT packet: less than 64 bytes packet with a good FCS
FRAGMENT packet: less than 64 bytes packet with either a bad FCS or a bad FCS with an alignment error

5.3.4 Frame transmission

The transmitter is designed to work with almost no intervention from the host processor. Once the driver enables the transmitter by setting the Transmit Descriptor Register (XMTDP) and the Transmit Enable (TXE), Ethernet Controller fetches the first Transmit Data Buffer from Buffer Descriptor.

When the drain threshold level of the transmit FIFO was over, the MAC transmit logic will assert TX_EN and start transmitting the preamble sequence, the start frame delimiter, and then the frame information. However, the controller defers the transmission if the line is busy (carrier sense is active). Before transmitting, the controller has to wait for carrier sense to become inactive. Once carrier sense is inactive, the controller determines if carrier sense stays inactive for IPGR1 bit time in En_IPGR register. If so, then the transmission begins after waiting an additional IPGR2 – IPGR1 bit times (i.e., IPG is generally 96 bit times).

If a collision occurs during the transmit frame, Ethernet Controller follows the specified back-off procedures and attempts to re-transmit the frame until the retry limit threshold is reached (RETRY in En_CLRT register). Ethernet Controller holds the first 64 bytes of the transmit frame in the transmit FIFO, so that Ethernet Controller does not have to be retrieved from system memory in case of a collision. This improves bus utilization and latency.

When Ethernet Controller reads the Transmit Data Buffer, and it shows the end of data buffer “L bit is active”, Ethernet Controller adds the FCS after the end of data if CRCEN in En_MACC1 register is enable.

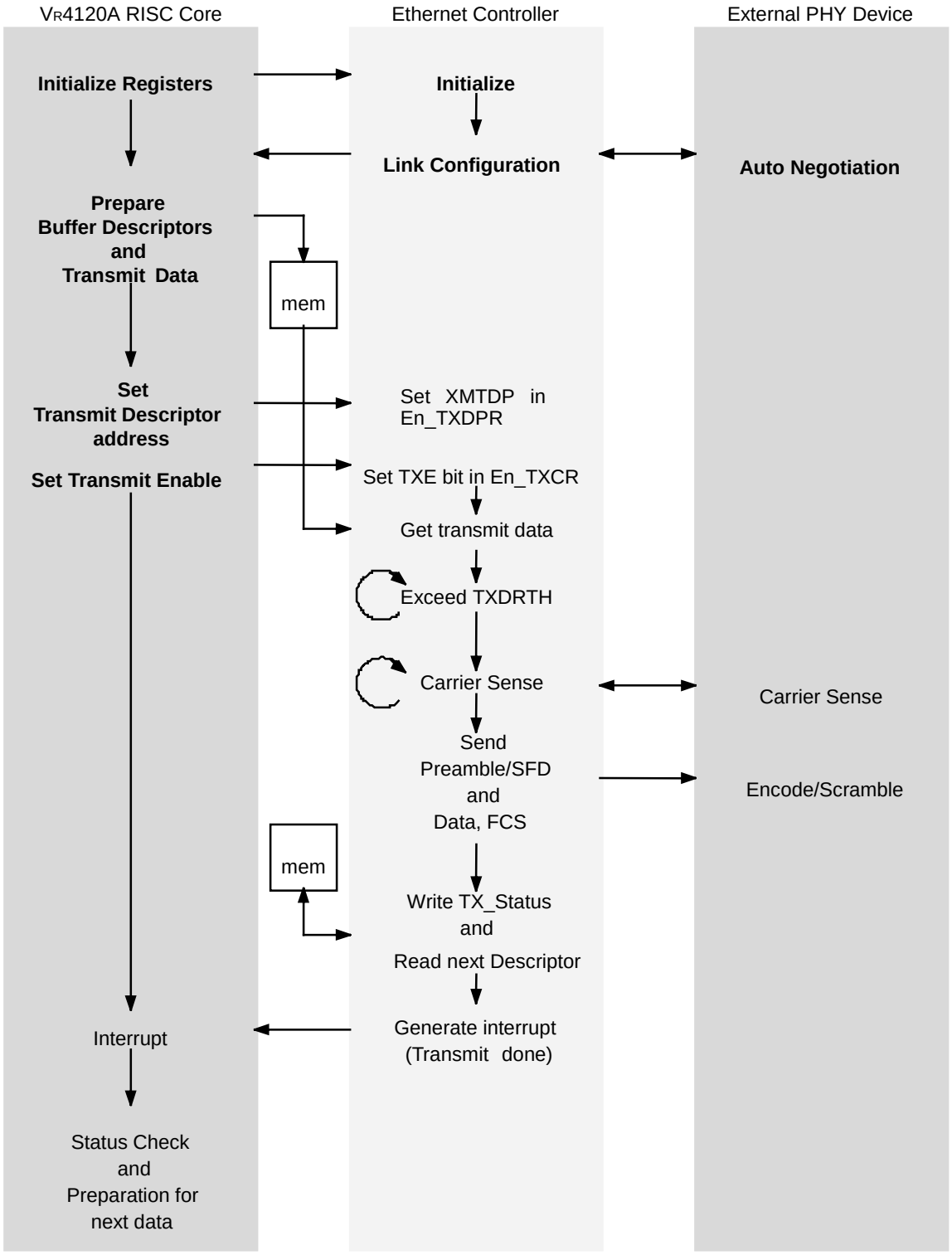
Short frames are automatically padded by the transmit logic if PADEN bit in En_MACC1 register is set. If the transmit frame length exceeds 1518 bytes, Ethernet Controller will assert an interrupt. However, the entire frame will be transmitted (no truncation).

If the current descriptor does not contain the end of frame, Ethernet Controller reads next buffer descriptor, and then reads the continuous data from the data buffer. After Ethernet Controller sent out the whole packet,. Ethernet Controller writes the transmission status into the last descriptor (L=1), and generates an interrupt to indicates the end of transmission.

When Ethernet Controller received the pause control frame and if it is active, Ethernet Controller transmitter stops immediately if no transmission is in progress or continues transmission until the current frame either finishes or terminates with a collision. When the pause timer was expired or Ethernet Controller received a zero value of pause control frame, Ethernet Controller resumes transmission with the next frame.

Transmit procedure is as follows: (Figure 5-7)

Figure 5-7. Transmit Procedure



Operation flow for transmit packet

i) Prepares transmit data in data buffer
ii) Initializes registers (En_TXDPR, En_TXCR)
iii) Reads buffer descriptor for transmission from SDRAM
iv) Reads transmit data from data buffer by using master DMA burst operation
v) Waits for exceeding of transmit drain threshold (TXDRTH)
   Senses carrier
   Transmits data (Preamble. SFD, data)
vi) Reads continuous data?
   If the current buffer descriptor does not show a last packet (L=0), it reads continuous data.
   Increments current Transmit Descriptor Pointer
vii) Reads next buffer descriptor
viii) Reads continuous data from data buffer again
ix) Stores the transmit status in the buffer descriptor
x) Generates an interrupt
xi) Reads next buffer descriptor and data, if available

5.3.5 Frame reception

The receiver is designed to work with almost no intervention from the host processor and can perform address recognition, CRC checking and maximum frame length checking.

When the driver enables the receiver by setting Receive Descriptor Pointer Register (En_RXDPR) and Receive Enable (RXE), it will immediately start processing receive frames. The receiver will first check for a valid preamble (PA) / start frame delimiter (SFD) header at the beginning packet. If the PA/SFD is valid, it will be stripped and the frame will be processed by the receiver. If a valid PA/SFD is not found the frame will be ignored.

Once a collision window (64 bytes) of data has been received and if address recognition has not rejected the frame, Ethernet Controller starts transferring the incoming frame to the receive data buffer. If the frame is a runt (due to collision) or is rejected by address recognition, no receive buffers are filled. Thus, no collision frames are presented to the user except late collisions, which indicate serious LAN problems.

It has no matter since after the reception it writes the receive status into the descriptor even if the received data were gone out to SDRAM.

If the incoming frame exceeds the length of the data buffer, Ethernet Controller fetches the next Receive Descriptor Buffer in the table and, if it is empty, continues transferring the rest of the frame to this data buffer.
If the remaining number of descriptors is under four times of the alert level, Ethernet Controller generates an interrupt to request new additional descriptors.

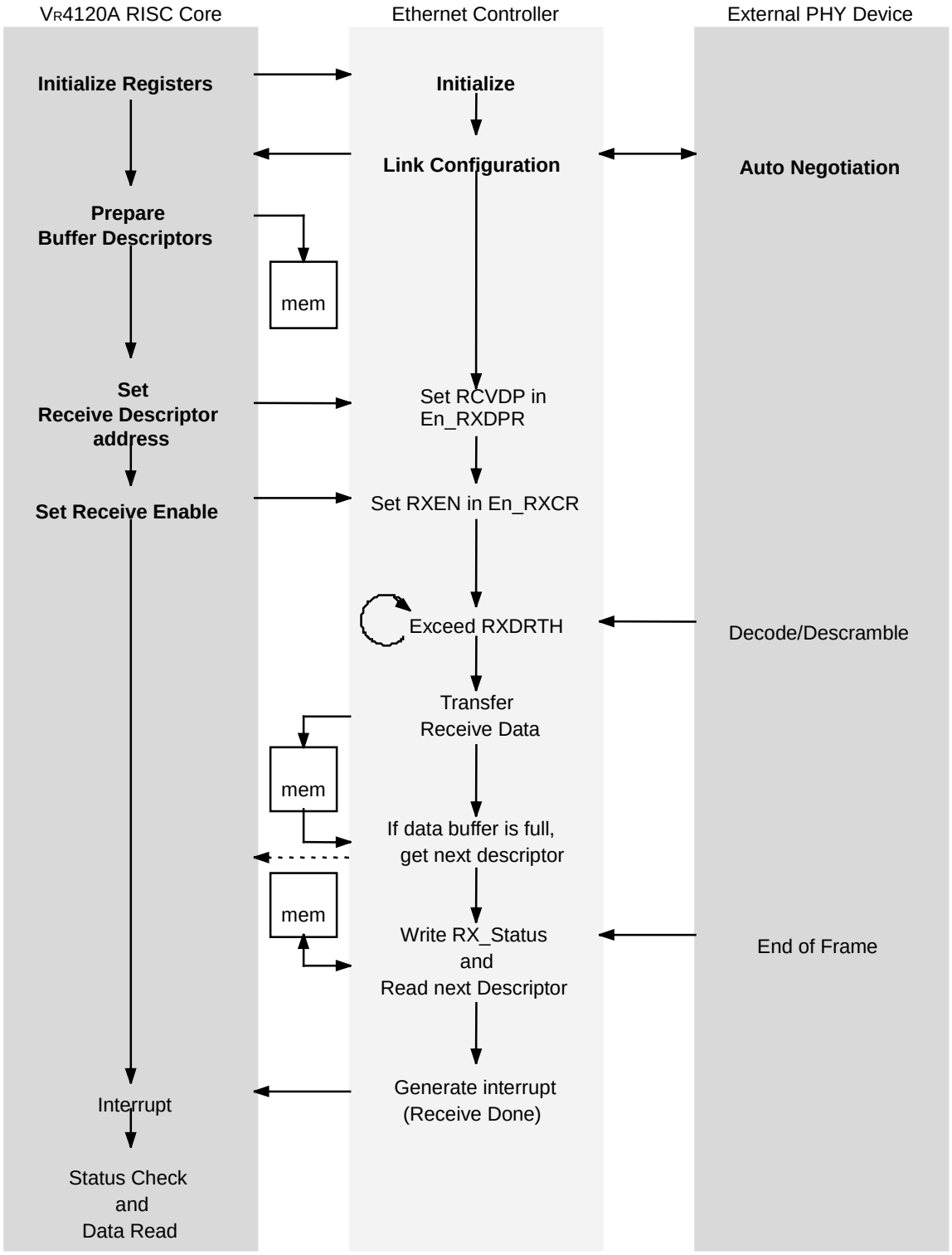
During reception, Ethernet Controller checks for a frame that is either too short or too long. When the frame ends (carrier sense is negated), the receive CRC field is checked out and written to the data buffer. The data length written to the last data Buffer in the Ethernet frame is the length of the entire frame. Frames that are less then 64 bytes in length are not DMA'd (transferred) and, are rejected in hardware with no impact on system bus utilization if the data is in the Rx FIFO.

Caution Recommend a high (over 16 words) drain threshold.

When the receive frame is complete, Ethernet Controller sets the L-bit in the Receive Descriptor, writes the frame status bits into the Receive Descriptor, and sets the OWN-bit. Ethernet Controller generates a maskable interrupt, indicating that a frame has been received and is in memory. Ethernet Controller then waits for a new frame.

Receive procedure is as follows:(Figure 5-8)

Figure 5-8. Receive Procedure



Operation flow for receive packet

i) Prepares the receive buffer descriptors
ii) Initializes registers (En_RXDPR, En_RXCR, En_MSR)
iii) Reads the receive buffer descriptor
iv) Waits for exceeding of receive drain threshold (RXDRTH)
v) Writes receive data to data buffer by using master DMA burst operation
vi) Increments the Receive Descriptor Pointer if the current data buffer is full
vii) Check out the RNOD
If the remaining number of descriptors is less than four times of the alert level, generates an interrupt to request an adding descriptor.
viii) Reads the next buffer descriptor
ix) Stores the received data
x) Stores the receive status in Receive Descriptor
xi) Generates an interrupt for the end of reception
xii) Reads next Receive Descriptor if available

How to add the receive buffer descriptors

i) Prepares the receive buffer descriptors
ii) Sets the number of buffer descriptors in En_RXPDR as well as the alert level
iii) Generates an interrupt by this Ethernet Controller
iv) Adds the receive buffer descriptors in the memory
v) Sets the number of buffer descriptors in En_RXPDR as well as the alert level

[MEMO]

CHAPTER 6 USB CONTROLLER

6.1 Overview

This block is built into the LAKI Access Network Controller and, in cooperation with the USB, performs the processing required for transferring data. The following lists the features of USB Controller.

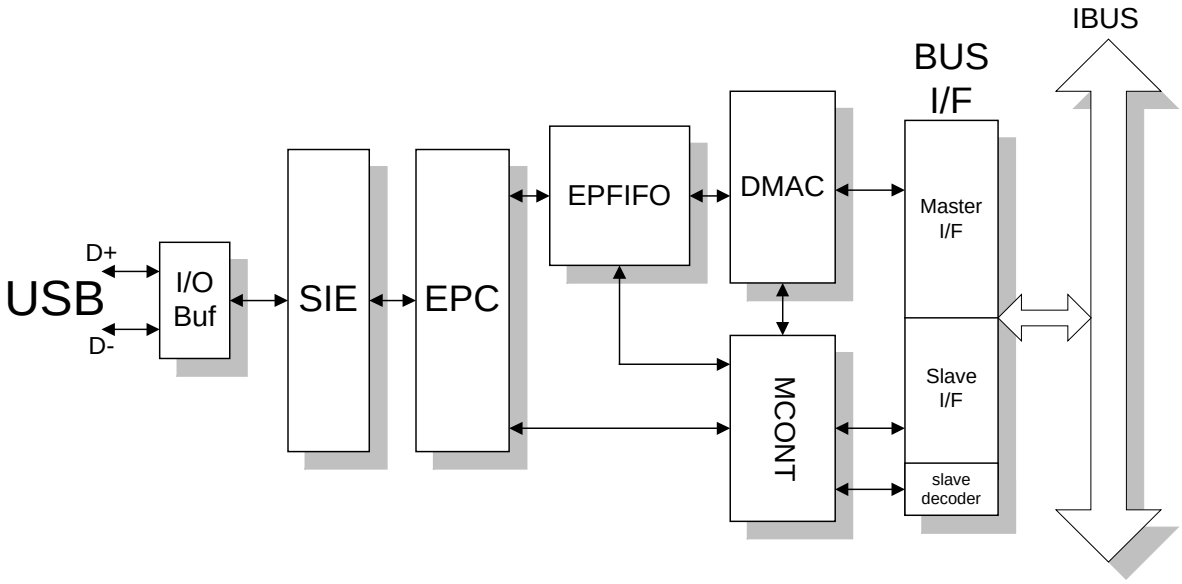
6.1.1 Features

- Conforms to Universal Serial Bus Specification Rev 1.1
- Supports operation conforming to the USB Communication Device Class Specification
- Supports data transfer at full speed (12 Mbps)
- In addition to the control Endpoint, a further six Endpoints are built in (Interrupt in/out, Isochronous in/out and Bulk in/out)
- For Control transfer, a built-in 64-byte FIFO is provided for send
- For Isochronous transfer, a built-in 128-byte FIFO is provided for send
- For Bulk transfer, a built-in 128-byte FIFO is provided for send
- For Interrupt transfer, a built-in 64-byte FIFO is provided for send
- For Control/Isochronous/Bulk/Interrupt transfer, a built-in 128-byte shared FIFO is provided for receive
- A DMA function for transferring send/receive data is built in
- A Control/Status registers are built in
- Compatible with the Suspend and Resume signaling issued from the Host PC (Processing by the VR4120A RISC Processor is required)
- Remote Wake-up is supported (Processing by the VR4120A RISC Processor is required)
- Directly connect to Internal BUS (IBUS) Master and Slave Interface block
- All the counters required to indicate the USB status are built in

6.1.2 Internal block diagram

USB Controller internal block diagram is as shown below.

Figure 6-1. USB Controller Internal Configuration



USB Controller's configuration features the following blocks.

SIE (Serial Interface Engine)	:	Performs Serial/Parallel conversion, NRZI encode/decode, CRC calculation, etc.
EPC (EndPoints Controller)	:	Performs data send/receive for each Endpoint.
EPFIFO (RX FIFO)	:	FIFO for Send and Receive
MCONT (Main Controller)	:	Block for controlling sending and receiving.
DMAC (DMA Controller)	:	Block for controlling DMA transfer.
Master_if (Master Interface)	:	Master section of the Internal BUS interface.
Slave_if (Slave Interface)	:	Slave section of the Internal BUS interface.
I/O Buf (I/O Buffer)	:	I/O buffer that satisfies the electrical specifications of the USB.
Internal BUS	:	The internal bus of LAKI.

6.2 Register Set

This section explains the mapping of those registers that can be accessed from IBUS.

6.2.1 Register map

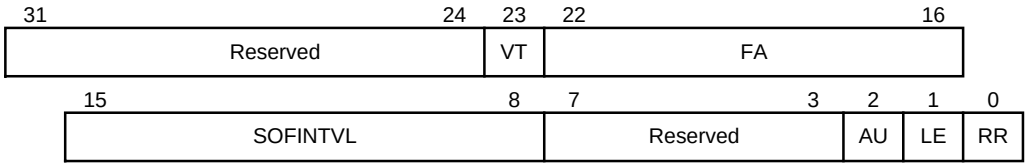
Offset Address	Register	Description	R/W	Default Value
00H	U_GMR	USB General Mode Register	R/W	00001800H
04H	U_VER	USB Frame number/Version Register	R	02010000H
08H	N/A	Reserved for future use	R/W	00000000H
0CH	N/A	Reserved for future use	R	00000000H
10H	U_GSR1	USB General Status Register 1	R	00000000H
14H	U_IMR1	USB Interrupt Mask Register 1	R/W	00000000H
18H	U_GSR2	USB General Status Resister 2	R	00000000H
1CH	U_IMR2	USB Interrupt Mask Register 2	R/W	00000000H
20H	U_EP0CR	USB EP0 Control Register	R/W	00000000H
24H	U_EP1CR	USB EP1 Control Register	R/W	00000000H
28H	U_EP2CR	USB EP2 Control Register	R/W	00000000H
2CH	U_EP3CR	USB EP3 Control Register	R/W	00000000H
30H	U_EP4CR	USB EP4 Control Register	R/W	00000000H
34H	U_EP5CR	USB EP5 Control Register	R/W	00000000H
38H	U_EP6CR	USB EP6 Control Register	R/W	00000000H
3CH	N/A	Reserved for future use	-	-
40H	U_CMR	USB Command Register	R/W	00000000H
44H	U_CA	USB Command Address Register	R/W	00000000H
48H	U_TEPSR	USB Tx EndPoint Status Register	R/W	00000000H
4CH	N/A	Reserved for future use	-	-
50H	U_RP0IR	USB Rx Pool0 Information Register	R/W	00000000H
54H	U_RP0AR	USB Rx Pool0 Address Register	R	00000000H
58H	U_RP1IR	USB Rx Pool1 Information Register	R/W	00000000H
5CH	U_RP1AR	USB Rx Pool1 Address Register	R	00000000H
60H	U_RP2IR	USB Rx Pool2 Information Register	R/W	00000000H
64H	U_RP2AR	USB Rx Pool2 Address Register	R	00000000H
68H	N/A	Reserved for future use	-	-
6CH	N/A	Reserved for future use	-	-
70H	U_TMSA	USB Tx MailBox Start Address Register	R/W	00000000H
74H	U_TMBA	USB Tx MailBox Bottom Address Register	R/W	00000000H
78H	U_TMRA	USB Tx MailBox Read Address Register	R/W	00000000H
7CH	U_TMWA	USB Tx MailBox Write Address Register	R	00000000H
80H	U_RMSA	USB Rx MailBox Start Address Register	R/W	00000000H
84H	U_RMBA	USB Rx MailBox Bottom Address Register	R/W	00000000H
88H	U_RMRA	USB Rx MailBox Read Address Register	R/W	00000000H
8CH	U_RMWA	USB Rx MailBox Write Address Register	R	00000000H
90-1FFH	N/A	Reserved for future use	-	-

Remark USB base address: 1000_1000H

6.2.2 Explanation of registers

This section explains each bit field of the address-mapped registers.

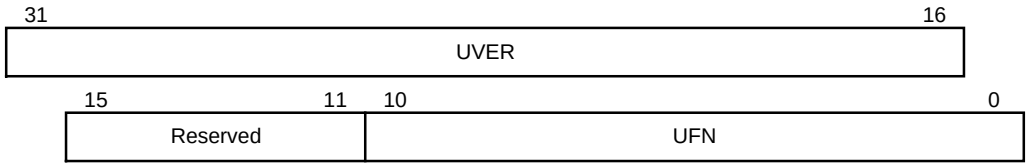
6.2.2.1 USB General Mode Register (U_GMR): 00H



This register is used for setting the operation of USB Controller. The low-order eight bits can be written to once only when the device is being initialized. If the values of these bits are changed while sending or receiving is being performed, the operation of USB Controller may become unpredictable.

Bit	Field	Description	R/W
31-24	Reserved	Reserved for future use	R
23	VT (Function Address Valid Timing)	If this bit is 1, FA become valid immediately. If this bit is 0, FA will become valid after USB Controller receives subsequent ACK packet on EndPoint0.	R/W
22-16	FA (Function Address)	Register that stores the USB Function Address. This is allocated by the Host PC as part of the USB configuration process. The VR4120A RISC Processor sets the allocated address in this register.	R/W
15-8	SOFINTVL (SOF Interval)	This value is used to define the allowable skew for SOF packet. The default value should be 18H.	R/W
7-3	Reserved	Reserved for future use	R
2	AU (Auto Update)	Frame Number auto update enable. If this bit is set, Frame Number Register will be updated though SOF packet is corrupted.	R/W
1	LE (Loopback Enable)	Bit for enabling internal loopback mode. When this bit is set to 1, USB Controller operates in loopback mode. Setting loopback mode enables the testing of the internal DMA controller that is built into USB Controller. When loopback mode is set, USB packets are not output. Also, USB packets are not received. For a detailed explanation of loopback mode, see Section 6.8.	R/W
0	RR (Remote Resume)	When Remote Resume is to be performed, the VR4120A RISC Processor sets this bit. Once this bit has been set, USB Controller issues Resume Signaling to the USB for a period of 5 ms. Upon the completion of Resume Signaling, this bit is automatically reset to 0.	R/W

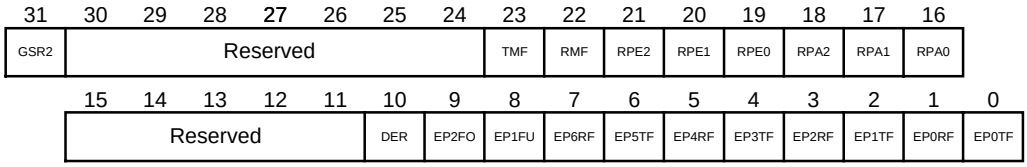
6.2.2.2 USB Frame Number/Version Register (U_VER): 04H



Register that stores the current Frame Number of the USB and version of the USB Controller block. Revision code for LAKI is 0x0201.

Bit	Field	Description	R/W
31-16	UVER (USB Version)	The Revision Number of the USB Controller block is stored into this register.	R
15-11	Reserved	Reserved for future use	R
10-0	UFNR (USB Frame Number)	Register that stores the Frame Number of the USB. The current USB Frame Number can be viewed from the VR4120A RISC Processor.	R

6.2.2.3 USB General Status Register 1 (U_GSR1): 10H



This register indicates the current status of USB Controller.

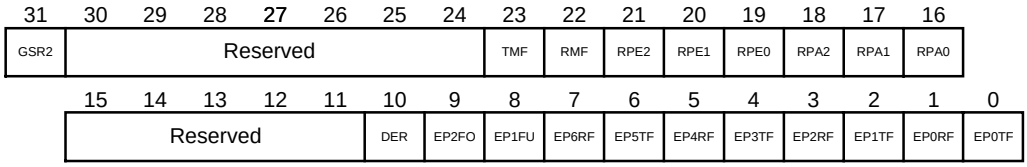
(1/2)

Bit	Field	Description	R/W
31	GSR2	If some bit of General Status Register2 is set to 1 and the corresponding bit of Interrupt Mask Register2 is set to 1, this GSR2 bit will be active.	R
30-24	Reserved	Reserved for future use	R
23	TMF (Tx MailBox Full)	Bit that indicates that the send mailbox area is full. This bit is set to 1 when the USB Tx MailBox Read Address and the USB Tx MailBox Write Address match. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
22	RMF (Rx MailBox Full)	Bit that indicates that the receive mailbox area is full. This bit is set to 1 when the USB Rx MailBox Read Address and the USB Rx MailBox Write Address match. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
21	RPE2 (Rx Pool2 Empty)	Bit that indicates that receive Pool2 is empty. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
20	RPE1 (Rx Pool1 Empty)	Bit that indicates that receive Pool1 is empty. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
19	RPE0 (Rx Pool0 Empty)	Bit that indicates that receive Pool0 is empty. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
18	RPA1 (Rx Pool2 Alert)	This bit is set to 1 when the number of Buffer Directories remaining in receive Pool2 matches the value set with the Rx Pool2 Information Register.	R/Clear
17	RPA1 (Rx Pool1 Alert)	This bit is set to 1 when the number of Buffer Directories remaining in receive Pool1 matches the value set with the Rx Pool1 Information Register.	R/Clear
16	RPA0 (Rx Pool0 Alert)	This bit is set to 1 when the number of Buffer Directories remaining in receive Pool0 matches the value set with the Rx Pool0 Information Register. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
15-11	Reserved	Reserved for future use	R
10	DER (DMA Error)	Bit that indicates that an error occurred while DMA transfer was being performed. This bit is set to 1 if an error occurs on the Internal BUS during DMA transfer. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
9	EP2FO (EP2 FIFO Error)	Bit that indicates that an overrun has occurred for the FIFO of EndPoint2 (Isochronous OUT). If the FIFO becomes full while EndPoint2 is performing a transaction, USB Controller can no longer receive data, such that all subsequent data is discarded. Should this occur, this bit is set to 1. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear

(2/2)

Bit	Field	Description	R/W
8	EP1FU (EP1 FIFO Error)	Bit that indicates that an underrun has occurred for the FIFO of EndPoint1 (Isochronous IN). If the FIFO empties while EndPoint1 is performing a transaction, This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
7	EP6RF (EP6 Rx Finished)	Bit that indicates that EndPoint6 (Interrupt OUT) has completed the receiving of a data segment. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
6	EP5TF (EP5 Tx Finished)	Bit that indicates that EndPoint5 (Interrupt IN) has completed the sending of a data segment. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
5	EP4RF (EP4 Rx Finished)	Bit that indicates that EndPoint4 (Bulk OUT) has completed the receiving of a data segment. The timing when this bit will be set varies with Rx Mode. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
4	EP3TF (EP3 Tx Finished)	Bit that indicates that EndPoint3 (Bulk IN) has completed the sending of a data segment. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
3	EP2RF (EP2 Rx Finished)	Bit that indicates that EndPoint2 (Isochronous OUT) has completed the receiving of a data segment. The timing when this bit will be set varies with Rx Mode. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
2	EP1TF (EP1 Tx Finished)	Bit that indicates that EndPoint1 (Isochronous IN) has completed the sending of a data segment. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
1	EP0RF (EP0 Rx Finished)	Bit that indicates that EndPoint0 (Control) has completed the receiving of a data segment. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
0	EP0TF (EP0 Tx Finished)	Bit that indicates that EndPoint0 (Control) has completed the sending of a data segment. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear

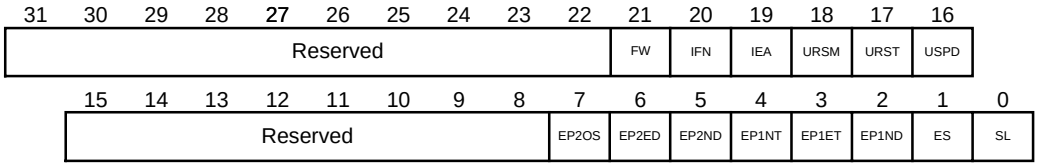
6.2.2.4 USB Interrupt Mask Register 1 (U_IMR1): 14H



This register is used to mask interrupts.

When a bit is set to 1, if the bit corresponding to the USB General Status Register1 (Address: 10H) is set to 1, an interrupt is issued.

6.2.2.5 USB General Status Register 2 (U_GSR2): 18H



This register indicates the current status of USB Controller.

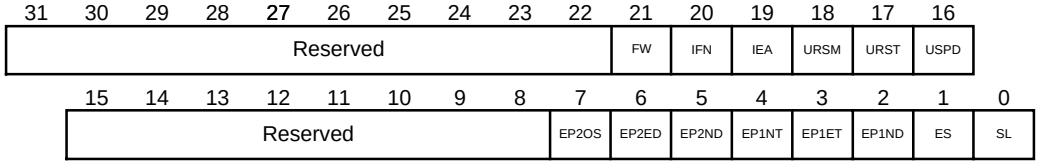
(1/2)

Bit	Field	Description	R/W
31-21	Reserved	Reserved for future use	R
21	FW (Frame Number Written)	This bit is set to 1 when Frame Number is written to “FrameNumber/Version Register”(04H).	
20	IFN (Incorrect Frame Number)	This bit is set to 1 when received Frame Number is Incorrect.	R/Clear
19	IEA (Incorrect EndPoint Access)	This bit is set to 1 when USB Controller received IN or OUT Token with incorrect EndPoint Number. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
18	URSM (USB Resume)	Bit that indicates that USB Controller has received a Resume Signaling from the Host PC. When USB Controller detects Resume Signaling, it sets this bit to 1. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
17	URST (USB Reset)	Bit that indicates that USB Controller has received a Reset Signaling from the Host PC. When USB Controller detects Resume Signaling, it sets this bit to 1. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
16	USPD (USB Suspend)	Bit that indicates that the USB has entered the Suspend status. When USB Controller detects the arrival of Suspend Signaling from the USB, this bit is set to 1. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
15-8	Reserved	Reserved for future use	R

(2/2)

Bit	Field	Description	R/W
7	EP2OS (Over Size)	This bit is set to 1 when the received data size is over 1023Byte on EndPoint2.	R/Clear
6	EP2ED (Extra Data on EndPoint2)	This bit is set to 1 when extra data packet is detected on Isochronous EndPoint (EndPoint2).	R/Clear
5	EP2ND (Isochronous Data Corrupted)	Bit that indicates that Isochronous data is corrupted on EndPoint2. This bit is reset to 0 when the VR4120A RISC Processor performs a read.	R/Clear
4	EP1NT (No Token on EP1)	This bit is set to 1 when IN Token packet does not come on EndPoint1 between two SOFs.	R/Clear
3	EP1ET (Extra Token on EP1)	This bit is set to 1 when IN Token packet comes twice on EndPoint1 between two SOFs.	R/Clear
2	EP1ND (No Data on EP1)	This bit is set to 1 when IN Token packet comes but data is not ready on EndPoint1.	R/Clear
1	ES (Extra SOF)	This bit is set to 1 when extra SOF packet is detected.	R/Clear
0	SL (SOF Loss)	This bit is set to 1 when USB Controller doesn't receive SOF packet.	R/Clear

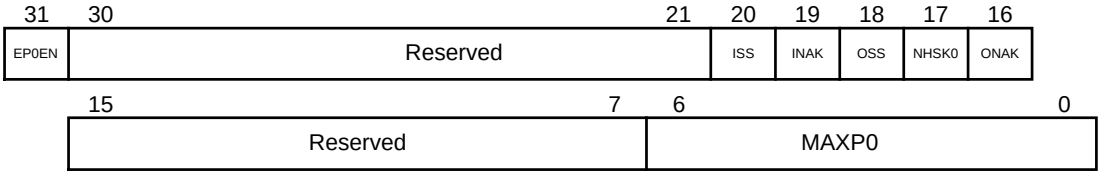
6.2.2.6 USB Interrupt Mask Register 2 (U_IMR2): 1CH



This register is used to mask interrupts.

When a bit is set to 1, if the bit corresponding to the USB General Status Register2 (Address: 18H) is set to 1, an interrupt is issued.

6.2.2.7 USB EP0 Control Register (U_EP0CR): 20H



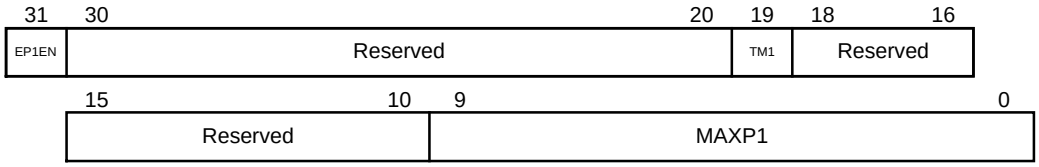
Register that is used for setting the operation of EndPoint0.

If the value in the MAXP field is rewritten during a send or receive operation, the operation of USB Controller may become unpredictable. Therefore the MAXP can be written to once only, when initial setting is being performed.

Bit	Field	Description	R/W
31	EP0EN (EndPoint Enable)	If the VR4120A RISC Processor sets this bit to 1, EndPoint0 is enabled for transmitting and receiving data from and to USB.	R/W
30-19	Reserved	Reserved for future use	R
20	ISS (IN Send Stall)	If the VR4120A RISC Processor sets this bit to 1, STALL packet is sent at the Data Phase. If SETUP packet is received when this bit is active, USB Controller clears this bit to 0.	R/W
19	INAK (IN NAK)	If the VR4120A RISC Processor sets this bit to 1, NAK packet is sent at the Data Phase.	R/W
18	OSS (OUT Send Stall)	If the VR4120A RISC Processor sets this bit to 1, STALL handshake is performed at the Handshake Phase. If SETUP packet is received when this bit is active, USB Controller clears this bit to 0.	R/W
17	NHSK0 (No Handshake)	If the VR4120A RISC Processor sets this bit to 1, No Handshake is performed at the Handshake Phase.	R/W
16	ONAK (OUT NAK)	If the VR4120A RISC Processor sets this bit to 1, NAK Handshake is performed at the Handshake Phase.	R/W
15-7	Reserved	Reserved for future use	R
6-0	MAXP0 (MAX Packet size)	Register that stores the Max Packet Size for EndPoint0. Prior to the start of a USB transaction, the VR4120A RISC Controller must write an appropriate value into this register. When this field contains 0, no transaction is performed at EndPoint0.	R/W

Remark When a STALL handshake is sent by a control endpoint in either the Data or Status stage of a control transfer, a STALL handshake must be returned on all succeeding access to that endpoint until a SETUP PID is received. The endpoint is not required to return a STALL handshake after it receives a subsequent SETUP PID. (referred from USB1.1 Specification)

6.2.2.8 USB EP1 Control Register (U_EP1CR): 24H

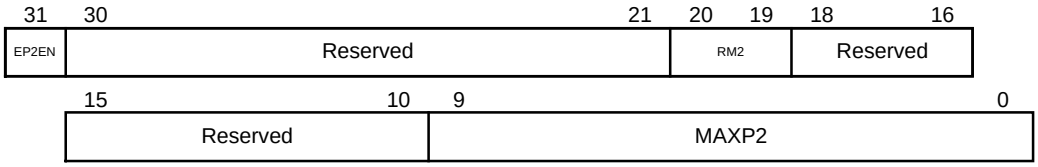


Register for setting the operation of EndPoint1.

If the value in the MAXP field is rewritten during a send or receive operation, the operation of USB Controller may become unpredictable. Therefore the MAXP can be written to once only, when initial setting is being performed.

Bit	Field	Description	R/W
31	EP1EN (EndPoint Enable)	If the VR4120A RISC Processor sets this bit to 1, EndPoint1 is enabled for transmitting and receiving data from and to USB.	R/W
30-20	Reserved	Reserved for future use	R
19	TM1 (Tx Mode)	Bit for setting the send mode. When this bit is set to 0, sending is performed in SZLP Mode. When this bit is set to 1, sending is performed in NZLP Mode. For a detailed explanation of the send modes, see Section 6.5.3.	R/W
18-10	Reserved	Reserved for future use	R
9-0	MAXP1 (MAX Packet size)	Register that stores the Max Packet Size of EndPoint1. Prior to the start of a USB transaction, the VR4120A RISC Processor must write an appropriate value into this register. When this field contains 0, no transaction is performed at EndPoint1.	R/W

6.2.2.9 USB EP2 Control Register (U_EP2CR): 28H

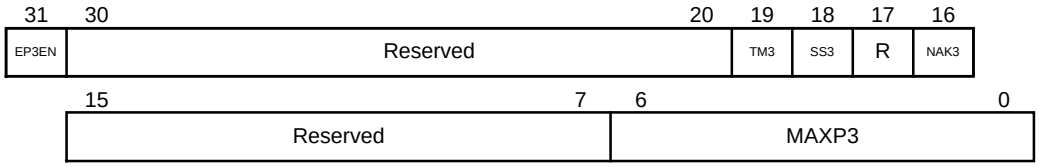


Register for setting the operation of EndPoint2.

If the value in the MAXP field is rewritten during a send or receive operation, the operation of USB Controller may become unpredictable. Therefore the MAXP can be written to once only, when initial setting is being performed.

Bit	Field	Description	R/W
31	EP2EN (EndPoint Enable)	If the VR4120A RISC Processor sets this bit to 1, EndPoint2 is enabled for transmitting and receiving data from and to USB.	R/W
30-20	Reserved	Reserved for future use	R
20-19	RM2 (Rx Mode)	Bit for setting the receive mode. When this bit is set to 00 or 01, receiving is performed in Normal Mode. When this bit is set to 10, receiving is performed in Assemble Mode. When this bit is set to 11, receiving is performed in Separate Mode. For a detailed explanation of the receive modes, see Section 6.6.4.	R/W
18-10	Reserved	Reserved for future use	R
9-0	MAXP2 (MAX Packet size)	Register that stores the Max Packet Size of EndPoint2. Prior to the start of a USB transaction, the VR4120A RISC Processor must write an appropriate value into this register. When this field contains 0, no transaction is performed at EndPoint2.	R/W

6.2.2.10 USB EP3 Control Register (U_EP3CR): 2CH

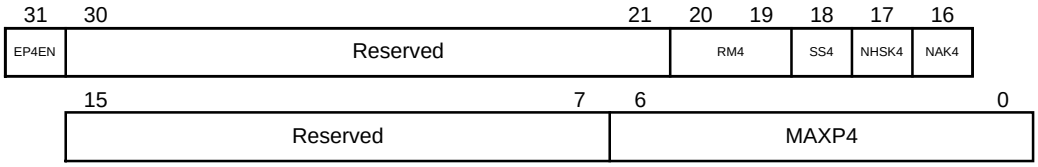


Register for setting the operation of EndPoint3.

If the value in the MAXP field is rewritten during a send or receive operation, the operation of USB Controller may become unpredictable. Therefore the MAXP can be written to once only, when initial setting is being performed.

Bit	Field	Description	R/W
31	EP3EN (EndPoint Enable)	If the VR4120A RISC Processor sets this bit to 1, EndPoint3 is enabled for transmitting and receiving data from and to USB.	R/W
30-20	Reserved	Reserved for future use	R
19	TM3 (Tx Mode)	Bit for setting the send mode. When this bit is set to 0, sending is performed in SZLP Mode. When this bit is set to 1, sending is performed in NZLP Mode. For a detailed explanation of the send modes, see Section 6.5.3.	R/W
18	SS3 (Send Stall)	If the VR4120A RISC Processor sets this bit to 1, STALL packet is sent by EndPoint3.	R/W
17	Reserved	Reserved for future use	R
16	NAK3	If the VR4120A RISC Processor sets this bit to 1, NAK packet is sent by EndPoint3.	R/W
15-7	Reserved	Reserved for future use	R
6-0	MAXP3 (MAX Packet size)	Register that stores the Max Packet Size for EndPoint3. Prior to the start of a USB transaction, the VR4120A RISC Processor must write an appropriate value into this register. When this field contains 0, no transaction is performed at EndPoint3.	R/W

6.2.2.11 USB EP4 Control Register (U_EP4CR): 30H

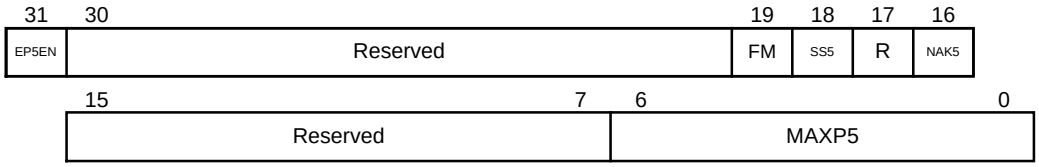


Register for setting the operation of and EndPoint4.

If the value in the MAXP field is rewritten during a send or receive operation, the operation of USB Controller may become unpredictable. Therefore the MAXP can be written to once only, when initial setting is being performed.

Bit	Field	Description	R/W
31	EP4EN (EndPoint Enable)	If the VR4120A RISC processor sets this bit to 1, EndPoint4 is enabled for transmitting and receiving data from and to USB.	R/W
30-21	Reserved	Reserved for future use	R
20-19	RM4 (Rx Mode)	Bit for setting the send mode. When this bit is set to 0, sending is performed in SZLP Mode. When this bit is set to 1, sending is performed in NZLP Mode. For a detailed explanation of the send modes, see Section 6.5.3.	R/W
18	SS4 (Send Stall)	If the VR4120A RISC Processor sets this bit to 1, STALL handshake is performed at EndPoint4.	R/W
17	NHSK4 (No Handshake)	If the VR4120A RISC Processor sets this bit to 1, No Handshake is performed at EndPoint4.	R/W
16	NAK4	If the VR4120A RISC Processor sets this bit to 1, NAK Handshake is performed at EndPoint4.	R/W
15-7	Reserved	Reserved for future use	R
6-0	MAXP4 (MAX Packet size)	Register that stores the Max Packet Size for EndPoint4. Prior to the start of a USB transaction, the VR4120A RISC Processor must write an appropriate value into this register. When this field contains 0, no transaction is performed at EndPoint4.	R/W

6.2.2.12 USB EP5 Control Register (U_EP5CR): 34H

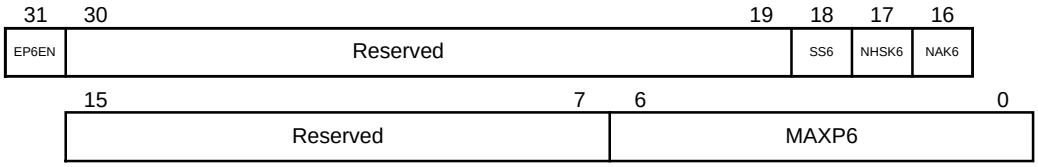


Register for setting the operation of EndPoint5.

If the value in the MAXP field is rewritten during a send or receive operation, the operation of USB Controller may become unpredictable. Therefore the MAXP can be written to once only, when initial setting is being performed.

Bit	Field	Description	R/W
31	EP5EN (EndPoint Enable)	If the VR4120A RISC processor sets this bit to 1, EndPoint5 is enabled for transmitting and receiving data from and to USB.	R/W
30-20	Reserved	Reserved for future use	R
19	FM (Feedback Mode)	If the VR4120A RISC Processor sets this bit to 1, EndPoint5 performs in feedback mode. (For further information about Feedback mode, please refer to USB Specification 1.1)	R/W
18	SS5 (Send Stall)	If the VR4120A RISC Processor sets this bit to 1, STALL handshake is performed at EndPoint5.	R/W
17	Reserved	Reserved for future use	R
16	NAK5	If the VR4120A RISC processor sets this bit to 1, NAK Handshake is performed at EndPoint5.	R/W
15-7	Reserved	Reserved for future use	R
6-0	MAXP5 (MAX Packet size)	Register that stores the Max Packet Size for EndPoint5. Prior to the start of a USB transaction, the VR4120A RISC Processor must write an appropriate value into this register. When this field contains 0, no transaction is performed at EndPoint5.	R/W

6.2.2.13 USB EP6 Control Register (U_EP6CR): 38H

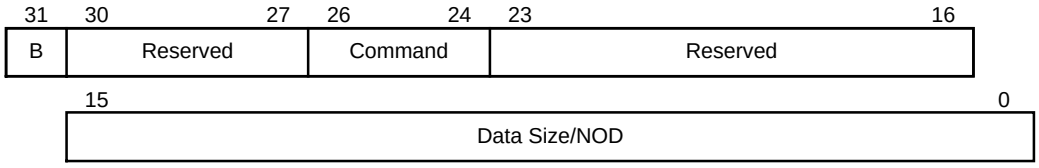


Register for setting the operation of EndPoint6.

If the value in the MAXP field is rewritten during a send or receive operation, the operation of USB Controller may become unpredictable. Therefore the MAXP can be written to once only, when initial setting is being performed.

Bit	Field	Description	R/W
31	EP6EN (EndPoint Enable)	If the VR4120A RISC Processor sets this bit to 1, EndPoint6 is enabled for transmitting and receiving data from and to USB.	R/W
30-19	Reserved	Reserved for future use	R
18	SS6 (Send Stall)	If the VR4120A RISC Processor sets this bit to 1, STALL handshake is performed at EndPoint6.	R/W
17	NHSK6 (No Handshake)	If the VR4120A RISC Processor sets this bit to 1, No Handshake is performed at EndPoint6.	R/W
16	NAK6	If the VR4120A RISC Processor sets this bit to 1, NAK Handshake is performed at EndPoint6.	R/W
15-7	Reserved	Reserved for future use	R
6-0	MAXP6 (MAX Packet size)	Register that stores the Max Packet Size for EndPoint6. Prior to the start of a USB transaction, the VR4120A RISC Processor must write an appropriate value into this register. When this field contains 0, no transaction is performed at EndPoint6.	R/W

6.2.2.14 USB Command Register (U_CMR): 40H



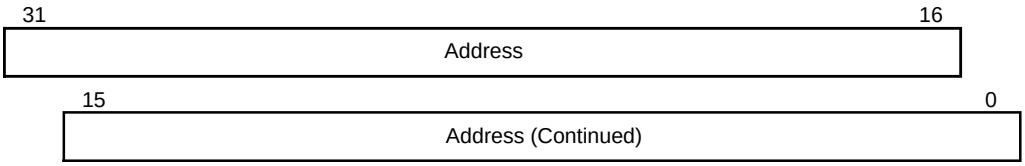
Register for adding data segment send or receive Buffer Directories.

The VR4120A RISC Processor writes commands into this register.

Whenever B bit (Bit 31) is set, even if VR4120A RISC Processor writes commands into this register, the value will not change.

Bit	Field	Description	R/W
31	B (Busy)	Bit that indicates whether the interpretation of an issued command has terminated. When the execution of the command has not yet terminated, this bit will be set to 1. When the execution of a command has terminated, this bit will be set to 0. When the VR4120A RISC Processor issues one command immediately after another, it is necessary to confirm that this bit is set to 0.	R
30-27	Reserved	Reserved for future use	R/W
26-24	Command	Field for specifying the type of a command. USB Controller's internal processing varies depending on the value written into this field. 000: Data sending at EndPoint0 001: Data sending at EndPoint1 010: Data sending at EndPoint3 011: Data sending at EndPoint5 100: Addition of Buffer Directories to Pool0 101: Addition of Buffer Directories to Pool1 110: Addition of Buffer Directories to Pool2 111: Reserved (Don't Use)	R/W
23-16	Reserved	Reserved for future use	R
15-0	Data Size/NOD (Data Size / Number Of Buffer Directory)	The meaning of this field depends on the value written into the EPN field. EPN=0xx: This field has no meaning. EPN=100,101,110: Indicates the number of Buffer Directories added to a pool. EPN=111: This field has no meaning.	R/W

6.2.2.15 USB Command Address Register (U_CA): 44H

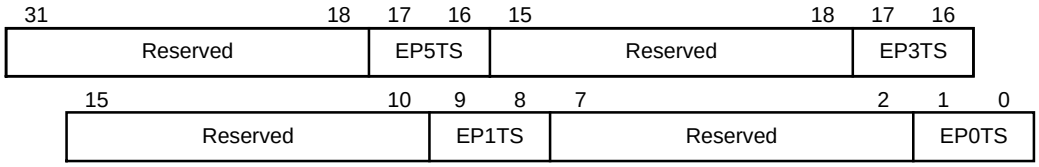


Register for adding data segment for send or receive Buffer Directories.

The VR4120A RISC Processor writes the head address of either the send data or the receive Buffer Directory into this register.

Bit	Field	Description	R/W
31-0	Address	The meaning of this field varies depending on the value written into the EPN field of the USB Tx Rx Command Register. EPN=0xx: Head address of the send packet EPN=100,101,110: Head address of the Buffer Directory to be added to the receive pool EPN=111: This register has no meaning.	R/W

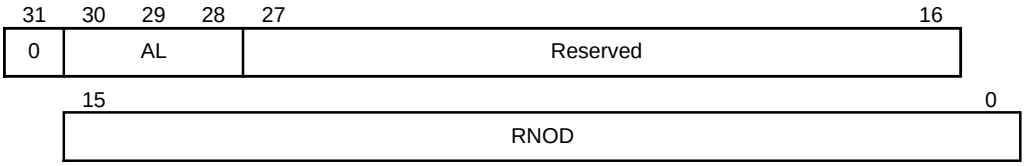
6.2.2.16 USB Tx EndPoint Status Register (U_TEPSR): 48H



Register that indicates the status of the EndPoint being used for data sending.

Bit	Field	Description	R/W
31-26	Reserved	Reserved for future use	R
25-24	EP5TS (EP5 Tx Status)	Register that indicates the send status of EndPoint5 This register is not cleared, even if read. 00: There is no data scheduled to be sent (Idle) 01: There is one data item scheduled to be sent 10: There are two data items that are scheduled to be sent (Busy)	R
23-18	Reserved	Reserved for future use	R
17-16	EP3TS (EP3 Tx Status)	Register that indicates the send status of EndPoint3 This register is not cleared, even if read. 00: There is no data scheduled to be sent (Idle) 01: There is one data item scheduled to be sent 10: There are two data items that are scheduled to be sent (Busy)	R
15-10	Reserved	Reserved for future use	R
9-8	EP1TS (EP1 Tx Status)	Register that indicates the send status of EndPoint1 This register is not cleared, even if read. 00: There is no data scheduled to be sent (Idle) 01: There is one data item scheduled to be sent 10: There are two data items that are scheduled to be sent (Busy)	R
7-2	Reserved	Reserved for future use	R
1-0	EP0TS (EP1 Tx Status)	Register that indicates the send status of EndPoint0 This register is not cleared, even if read. 00: There is no data scheduled to be sent (Idle) 01: There is one data item scheduled to be sent 10: There are two data items that are scheduled to be sent (Busy)	R

6.2.2.17 USB Rx Pool0 Information Register (U_RP0IR): 50H

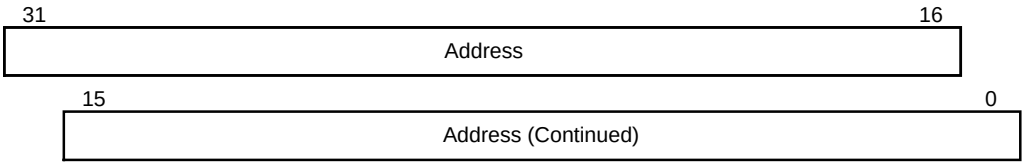


Register that indicates the information of Receive Pool0.

The VR4120A RISC Processor write to this register once only when the device is being initialized.

Bit	Field	Description	R/W
31	Reserved	Reserved for future use Write 0 to this bit.	R
30-28	AL (Alert Level)	Sets the warning level for Pool0. If the number of Buffer Directories remaining in this pool equals the value set in this field, USB Controller sets the RPA0 bit of the USB General Status Register1 to 1. Writing n into this field is equivalent to specifying n x 4 (remaining number of Buffer Directories = 4, 8, 12, ..., 28). When 000 is written into this field, this function is disabled and no notification is posted to the VR4120A RISC Processor.	R/W
27-16	Reserved	Reserved for future use	R
15-0	RNOD (Remaining Number of Buffer Directory)	Indicates the number of Buffer Directories remaining in Pool0. The VR4120A RISC Processor can only read this field. Unlike the μPD98401A and the μPD98405, there is no need to write a value into this field during initialization. Buffer Directory addition is performed entirely using the USB Tx Rx Command Register.	R

6.2.2.18 USB Rx Pool0 Address Register (U_RP0AR): 54H

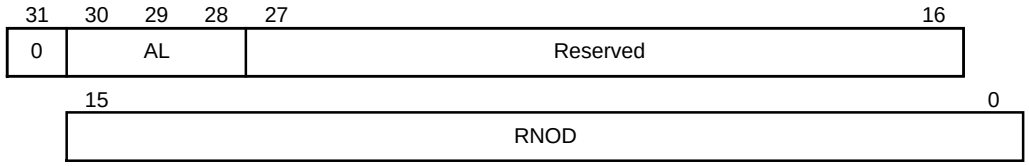


This register indicates the head address of Buffer Directory which is currently used.

The way to set up Rx Pool is described at Section 6.6.3.

Bit	Field	Description	R/W
31-0	Buffer Directory Address	Register that indicates the head address of the first Buffer Directory in Pool0. The VR4120A RISC Processor can only read this register. Unlike the μPD98401A and the μPD98405, there is no need to write a value into this register during initialization. Buffer Directory addition is performed entirely using the USB Tx Rx Command Register.	R

6.2.2.19 USB Rx Pool1 Information Register (U_RP1IR): 58H

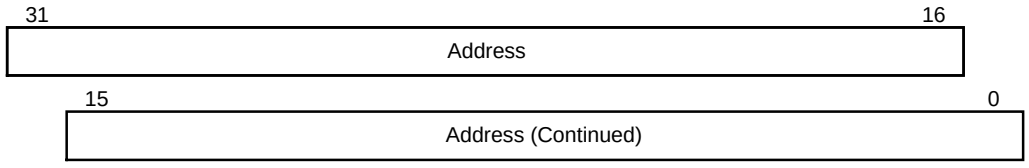


Register that indicates the data in Receive Pool1.

The VR4120A RISC Processor write to this register once only when the device is being initialized.

Bit	Field	Description	R/W
31	Reserved	Reserved for future use Write 0 to this bit.	R
30-28	AL (Alert Level)	Sets the warning level for Pool1. If the number of Buffer Directories remaining in this pool equals the value set in this field, USB Controller sets the RPA1 bit of the USB General Status Register1 to 1. Writing n into this field is equivalent to specifying n x 4 (remaining number of Buffer Directories = 4, 8, 12, ..., 28). When 000 is written into this field, this function is disabled and no notification is posted to the VR4120A RISC Processor.	R/W
27-16	Reserved	Reserved for future use	R
15-0	RNOD (Remaining Number of Buffer Directory)	Indicates the number of Buffer Directories remaining in Pool1. The VR4120A RISC Processor can only read this field. Unlike the μPD98401A and the μPD98405, there is no need to write a value into this field during initialization. Buffer Directory addition is performed entirely using the USB Tx Rx Command Register.	R

6.2.2.20 USB Rx Pool1 Address Register (U_RP1AR): 5CH

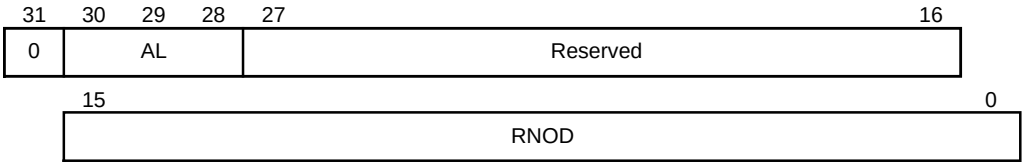


This register indicates the head address of Buffer Directory which is currently used.

The way to set up Rx Pool is described at Section 6.6.3.

Bit	Field	Description	R/W
31-0	Buffer Directory Address	Register that indicates the head address of the first Buffer Directory in Pool1. The VR4120A RISC Processor can only read this register. Unlike the μPD98401A and the μPD98405, there is no need to write a value into this register during initialization. Buffer Directory addition is performed entirely using the USB Tx Rx Command Register.	R

6.2.2.21 USB Rx Pool2 Information Register (U_RP2IR): 60H

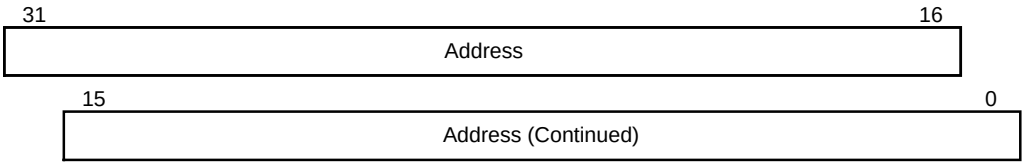


Register that indicates the data in Receive Pool2.

The VR4120A RISC Processor write to this register once only when the device is being initialized.

Bit	Field	Description	R/W
31	Reserved	Reserved for future use Write 0 to this bit.	R
30-28	AL (Alert Level)	Sets the warning level for Pool2. If the number of Buffer Directories remaining in this pool equals the value set in this field, USB Controller sets the RPA2 bit of the USB General Status Register1 to 1. Writing n into this field is equivalent to specifying n x 4 (remaining number of Buffer Directories = 4, 8, 12, ..., 28). When 000 is written into this field, this function is disabled and no notification is posted to the VR4120A RISC Processor.	R/W
27-16	Reserved	Reserved for future use	R
15-0	RNOD (Remaining Number of Buffer Directory)	Indicates the number of Buffer Directories remaining in Pool2. The VR4120A RISC Processor can only read this field. Unlike the μPD98401A and the μPD98405, there is no need to write a value into this field during initialization. Buffer Directory addition is performed entirely using the USB Tx Rx Command Register.	R

6.2.2.22 USB Rx Pool2 Address Register (U_RP2AR): 64H

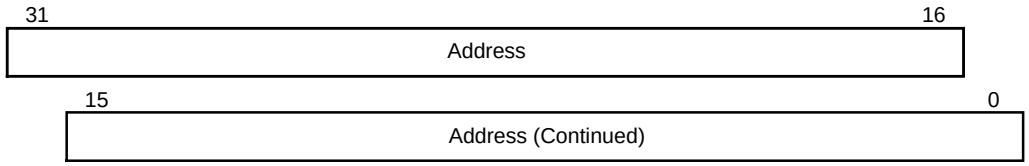


This register indicates the head address of Buffer Directory which is currently used.

The way to set up Rx Pool is described at Section 6.6.3.

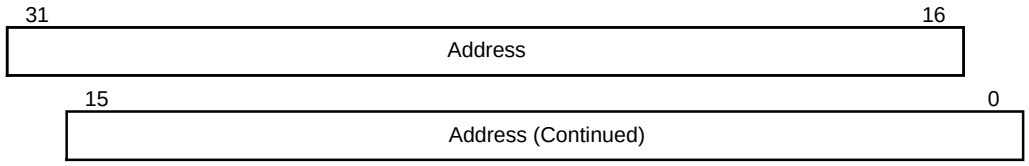
Bit	Field	Description	R/W
31-0	Buffer Directory Address	Register that indicates the head address of the first Buffer Directory in Pool2. The VR4120A RISC Processor can only read this register. Unlike the μPD98401A and the μPD98405, there is no need to write a value into this register during initialization. Buffer Directory addition is performed entirely using the USB Tx Rx Command Register.	R

6.2.2.23 USB Tx MailBox Start Address Register (U_TMSA): 70H



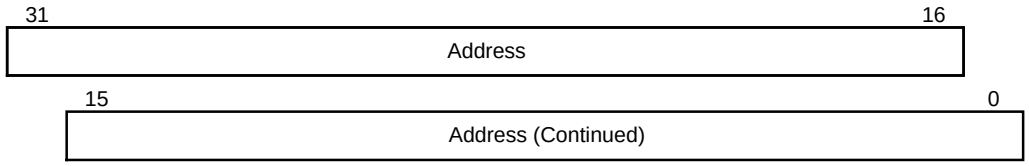
Bit	Field	Description	R/W
31-0	Address	Register that indicates the head address of the send MailBox area. The VR4120A RISC Processor need set a value in this field once only, at initialization.	R/W

6.2.2.24 USB Tx MailBox Bottom Address Register (U_TMBA): 74H



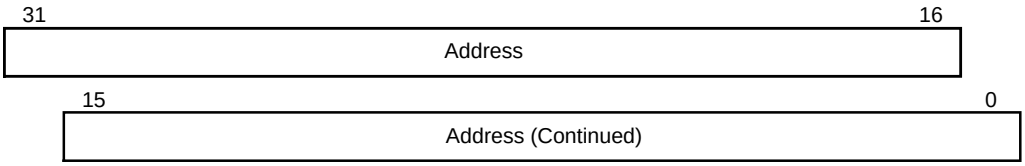
Bit	Field	Description	R/W
31-0	Address	Register that indicates the end address of the send MailBox area. The VR4120A RISC Processor need set a value in this field once only, at initialization.	R/W

6.2.2.25 USB Tx MailBox Read Address Register (U_TMRA): 78H



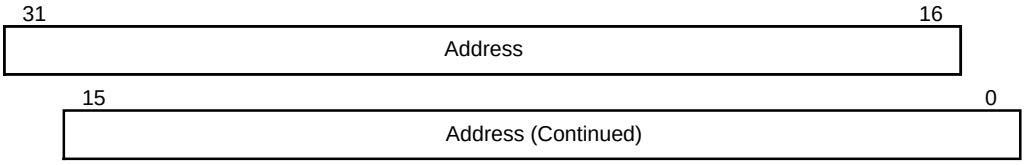
Bit	Field	Description	R/W
31-0	Address	Register that indicates the address of the area that will be read next by the VR4120A RISC processor. After the VR4120A RISC Processor reads the contents of a MailBox, the value set in this register must be changed by VR4120A RISC Processor.	R/W

6.2.2.26 USB Tx MailBox Write Address Register (U_TMWA): 7CH



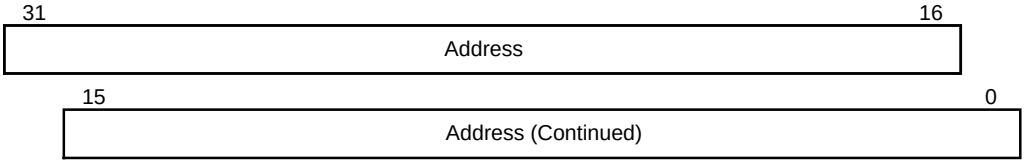
Bit	Field	Description	R/W
31-0	Address	Register that indicates the address in the send mailbox area to which USB Controller will next write.	R

6.2.2.27 USB Rx MailBox Start Address Register (U_RMSA): 80H



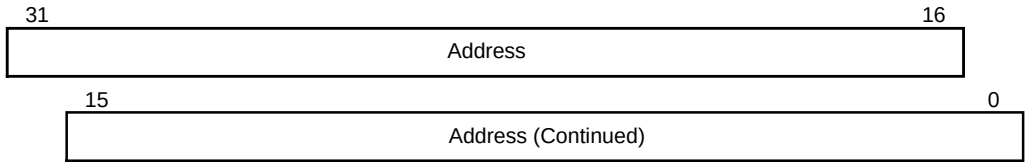
Bit	Field	Description	R/W
31-0	Address	Register that indicates the head address of the receive mailbox area. The VR4120A RISC Processor need set a value in this field once only, at initialization.	R/W

6.2.2.28 USB Rx MailBox Bottom Address Register (U_RMBA): 84H



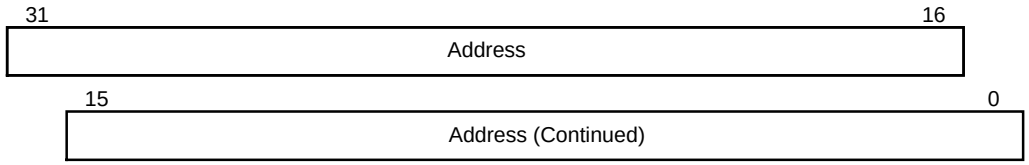
Bit	Field	Description	R/W
31-0	Address	Register that indicates the end address of the receive mailbox area. The VR4120A RISC Processor need set a value in this field once only, at initialization.	R/W

6.2.2.29 USB Rx MailBox Read Address Register (U_RMRA): 88H



Bit	Field	Description	R/W
31-0	Address	Register that indicates the address of the area that will be read next by the VR4120A RISC Processor. After the VR4120A RISC Processor reads the contents of a mailbox, the value set in this register must be changed by VR4120A RISC Processor.	R/W

6.2.2.30 USB Rx MailBox Write Address Register (U_RMWA): 8CH

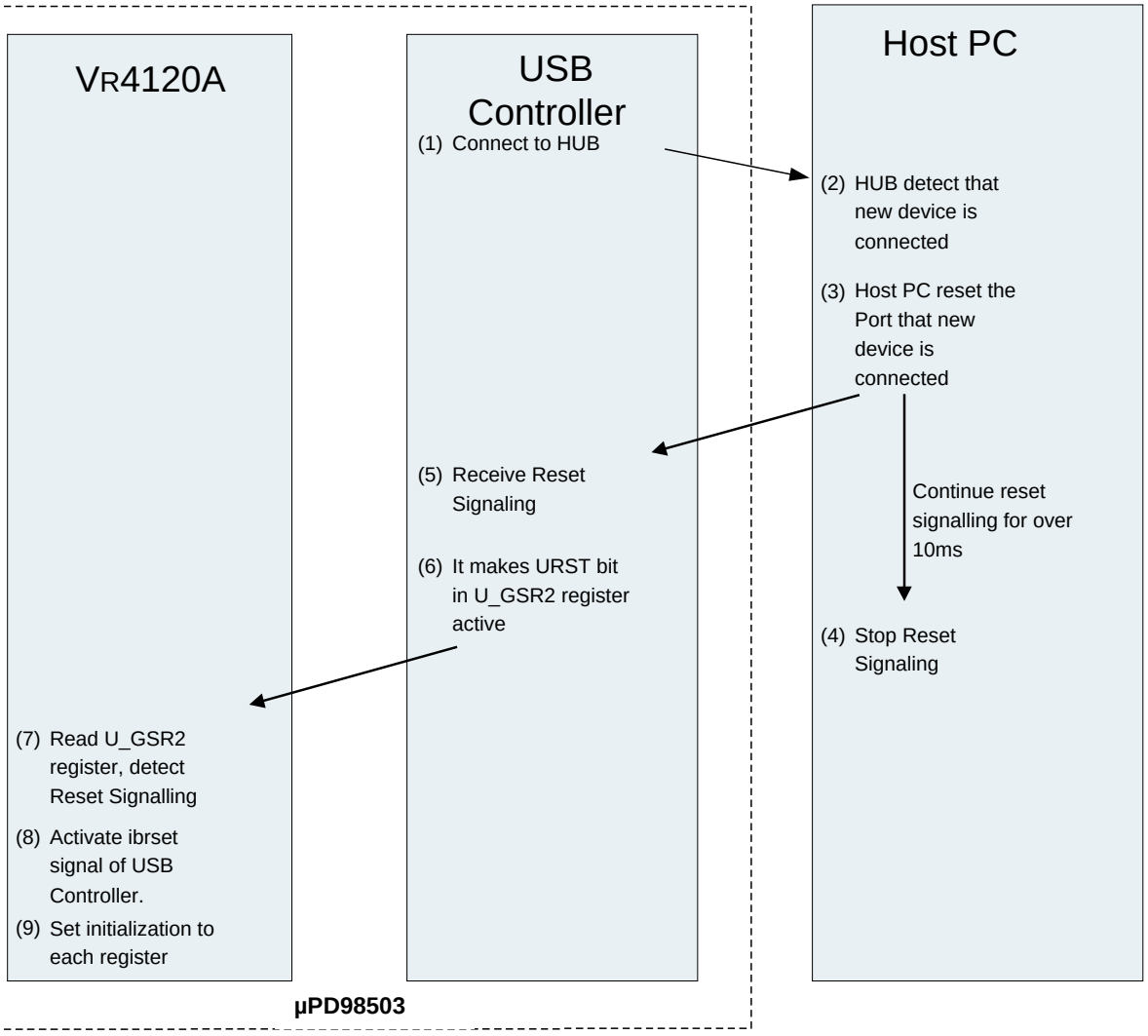


Bit	Field	Description	R/W
31-0	Address	Register that indicates the address in the receive mailbox area to which USB Controller will next write.	R

6.3 USB Attachment Sequence

This section describes the sequence that is followed when USB Interface (LAKI) is attached to a USB hub.

Figure 6-2. USB Attachment Sequence



(1) USB port of LAKI is attached to the HUB.
(2) Notification that a new device (LAKI) has been connected to the HUB is posted to the Host PC.
(3) The Host PC issues Reset Signaling to Reset the port to which the device has been connected.
(4) Once 10 ms have elapsed, the Host PC halts the issue of the Reset Signaling.
(5) Notification of the Reset Signaling performed by the Host PC is posted to USB Controller.
(6) To post notification of the Reset by the Host PC to the VR4120A RISC Processor, the URST bit of the U_GSR2 register is made active.
(7) The VR4120A RISC Processor reads the USB Controller U_GSR2 register and, upon finding that the URST bit is active, determines that Reset Signaling has been issued.
(8) To initialize USB Controller, the VR4120A RISC Processor activate reset signal of USB Controller.
(9) Upon the completion of the reset, USB Controller performs initialization by writing a value into each of USB Controller's internal registers.

6.4 Initialization

After USB Controller has been reset, the VR4120A RISC Processor must set several USB Controller registers. The setting that must be performed by the VR4120A RISC Processor is listed below.

(1) A desired mode is written into the USB General Mode Register.

(2) The receive pool area is secured in system memory, and the information it contains is set in the following registers:

- USB Rx Pool0 Information Register: (Address: 50H)
- USB Rx Pool0 Address Register: (Address: 54H)
- USB Rx Pool1 Information Register: (Address: 58H)
- USB Rx Pool1 Address Register: (Address: 5CH)
- USB Rx Pool2 Information Register: (Address: 60H)
- USB Rx Pool2 Address Register: (Address: 64H)

(3) The send/receive mailbox area is secured in system memory, and the information it contains is set in the following registers:

- USB Tx MailBox Start Address Register (Address: 70H)
- USB Tx MailBox Bottom Address Register (Address: 74H)
- USB Tx MailBox Read Address Register (Address: 78H)
- USB Tx MailBox Write Address Register (Address: 7CH)
- USB Rx MailBox Start Address Register (Address: 80H)
- USB Rx MailBox Bottom Address Register (Address: 84H)
- USB Rx MailBox Read Address Register (Address: 88H)
- USB Rx MailBox Write Address Register (Address: 8CH)

(4) A value is written into the MAXP field of the USB EP0 Control Register, the EP1-2 Control Register, the EP3-4 Control Register, and the EP5-6 Control Register. Then, each EndPoint is enabled.

The settings made up to this point enable the start of data sending/receiving, as well as the ability to respond to Device Configuration from the Host PC.

(5) Device Configuration is started via EndPoint0. Therefore a response must be returned to EndPoint0. At this stage, the USB Function Address is allocated. The VR4120A RISC Processor must write that value into the Function Address field in USB General Mode Register (Address: 00H).

The initialization procedure is completed.

In addition to the above, it may be necessary to write a value into the USB Interrupt Mask Register (Address: 14H or 1CH) and enable the interrupt.

6.4.1 Receive pool setting

For details of the receive pool setting, see Section 6.6.3.

6.4.2 Send/receive mailbox setting

After USB Controller sends a data segment, it indicates the status by writing a send indication into system memory. The area into which an indication is written is called a "mailbox," and exists within the system memory. As part of initialization, the VR4120A RISC Processor must set the mailboxes. USB Controller uses the mailboxes as a buffer having a ring configuration in system memory. This buffer is set using four registers for each of sending and receiving.

Registers for setting a send mailbox

- TMSA (USB Tx MailBox Start Address Register: 70H)
- TMBA (USB Tx MailBox Bottom Address Register: 74H)
- TMRA (USB Tx MailBox Read Address Register: 78H)
- TMWA (USB Tx MailBox Write Address Register: 7CH)

Registers for setting a receive mailbox

- RMSA (USB Rx MailBox Start Address Register: 80H)
- RMBA (USB Rx MailBox Bottom Address Register: 84H)
- RMRA (USB Rx MailBox Read Address Register: 88H)
- RMWA (USB Rx MailBox Write Address Register: 8CH)

Remarks 1. At initialization, TMRA must be set to the same value as TMSA. Similarly, RMRA must be set to the same value as RMSA.

2. When VR4120A RISC Processor writes the value to TMSA firstly after reset, USB Controller automatically copies the value to TMWA internally. Similarly, when VR4120A RISC Processor writes the value to RMSA firstly after reset, USB Controller automatically copies the value to RMWA internally.

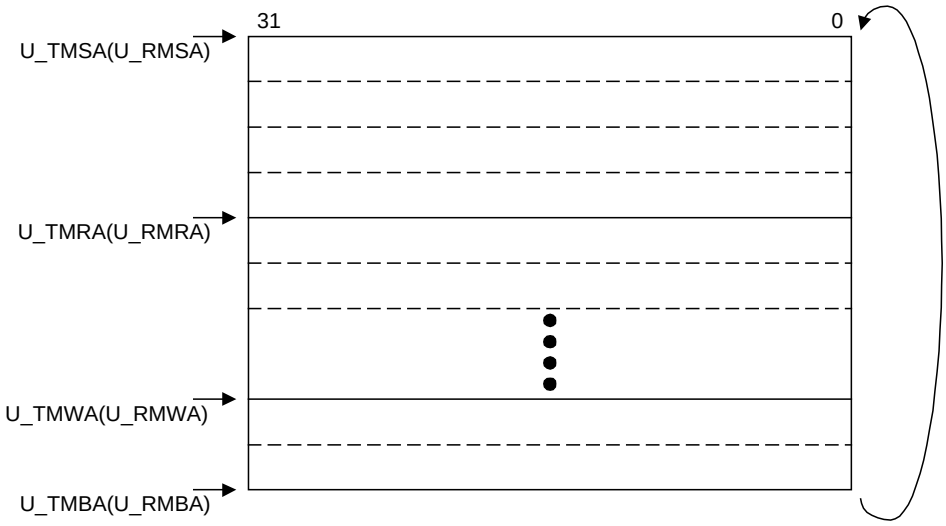
3. Do not set the same values for TMSA and TMBA.

4. Among those registers used to set the mailboxes, the VR4120A RISC Processor updates only TMRA and RMRA. The other registers are written to only as part of initialization. They are not to be written to at any other time.

5. Each receive indication has a two-word configuration. Therefore, the size of the receive mailbox must be an integer multiple of two words.

The configuration of the mailboxes in system memory is as shown in the following figure 6-3.

Figure 6-3. Mailbox Configuration



When USB Controller writes an indication, the write pointer (TMWA or RMWA) is incremented. Every time that USB Controller writes an indication, it also sets the send/receive end bit of the corresponding EndPoint and, provided it is not masked, issues an interrupt.

When USB Controller revises the value of the write pointer (TMWA or RMWA), the write pointer is forced to jump to the start address (TMSA or RMSA) when it reaches the bottom address (TMBA or RMBA). USB Controller uses the read pointer (TMRA or RMRA) to prevent the overwriting of those indications that the VR4120A RISC Processor has not yet read out. The read pointer (TMRA or RMRA) is managed and updated by the VR4120A RISC Processor. Each time the VR4120A RISC Processor reads an indication from a mailbox, it writes the address subsequent to the most recently read indication into the read pointer register (TMRA or RMRA). The read pointer register (TMRA or RMRA) is updated by the VR4120A RISC Processor, but only read by USB Controller.
When both the write pointer (TMWA or RMWA) and read pointer (TMRA and RMRA) point to the same address, USB Controller sets the TMF bit (send mailbox full) or RMF bit (receive mailbox full) of the USB General Status Register1 to indicate the mailbox full state and, provided it is not masked, issues an interrupt.

In the mailbox full status, USB Controller will not issue the next indication. The VR4120A RISC Processor must read an indication from the full mailbox and update the read pointer (TMRA or RMRA).

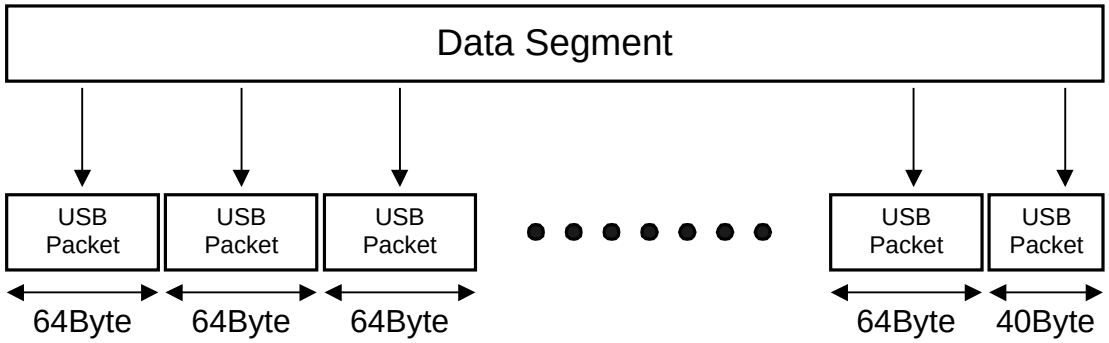
6.5 Data Send Function

This section explains USB Controller's data send function.

6.5.1 Overview of send processing

USB Controller takes the data segments in system memory, divides them into USB packets, then sends them to the Host PC. The VR4120A RISC Processor sets the size of USB packet in the MAXP field of the EP0 Control Register, the EP1-2 Control Register, the EP3-4 Control Register, and the EP5-6 Control Register (in the example shown below, a value of 64 bytes has been set).

Figure 6-4. Division of Data into USB Packets



When the data segments are divided by a value other than that set in the MAXP field, the last item of the divided data will be smaller than the value set in the MAXP field (40 bytes in the example shown above). As a result, the Host PC can identify the boundary between data segments. If a data segment is divided by the value set in the MAXP field, a zero-length USB packet will be sent after the last item of the divided data. (Only in send SZLP Mode. In send NZLP Mode, a zero-length USB packet is not sent. For an explanation of the send modes, see Section 6.5.3.)

After all the data segments have been transferred, USB Controller writes the "send indication" which have send status information into the mailbox in system memory.

For an explanation of the send indication, see Section 6.5.6.

With USB Controller, the sending of two data segments can be scheduled for a given EndPoint. Each scheduled send is performed upon the issue of a send command. The current send status can be determined by reading the contents of the USB Tx EndPoint Status Register (Address: 48H).

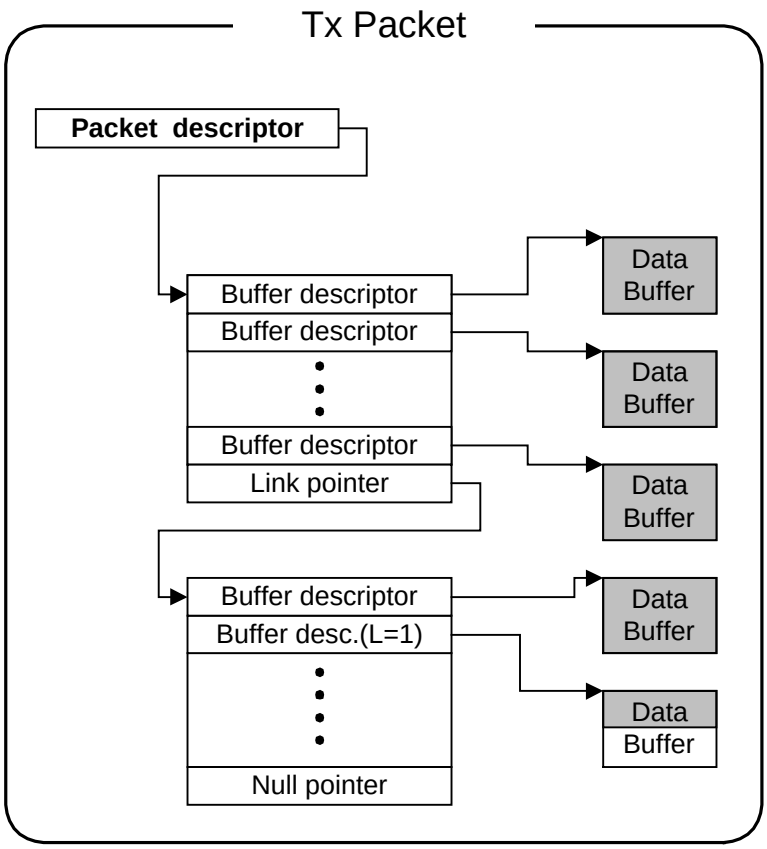
For an explanation of how to issue the send command, see Section 6.5.4.

6.5.2 Send buffer configuration

Upon sending data to the Host PC, the VR4120A RISC Processor creates a send buffer in system memory, then informs USB Controller.

The configuration of the send buffer is as shown below.

Figure 6-5. Send Buffer Configuration

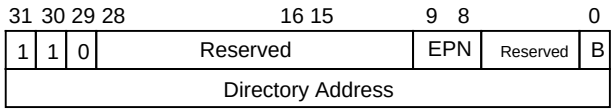


A send packet is configured by breaking up multiple data buffers in system memory. These data buffers are bundled together in the "packet directory." The "ADDRESS" field of the Packet descriptor contains the start address of the packet directory.

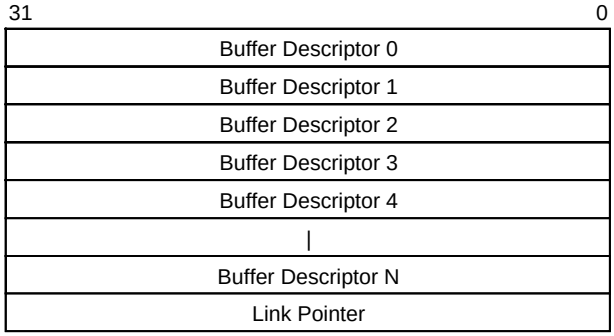
The formats of the Packet descriptor, Packet directory, Buffer descriptor, and Link Pointer in the send buffer of the USB Controller block are as shown below.

Figure 6-6. Configuration of Send Packet Descriptors

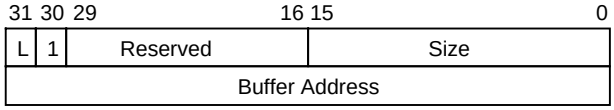
-Tx Packet Descriptor



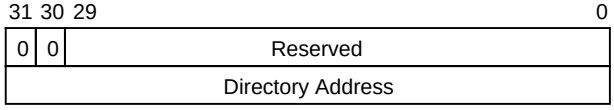
-Tx Packet Directory



-Tx Buffer Descriptor



-Tx Link Pointer



Tx Packet Descriptor: Maintains the data in the Tx Packet.
Bit 31 to bit 29 are set to 110.
EPN indicates the number of the EndPoint that is to send a packet.
Bit0 indicates whether it is possible to write the next command..
The "Directory Address" field indicates the start address of the send packet directory.

Tx Packet Directory: This is the send packet directory. It is configured by bundling together the buffer descriptor and the link pointer. A single send Buffer Directory can accommodate up to 255 buffer descriptors.

Tx Buffer Descriptor: This is the send buffer descriptor. It maintains the data in the receive buffer.
When Bit31 (Last bit) is active, the Buffer Descriptor indicates the last buffer in a packet.
Bit30 is used to discriminate between the Buffer Descriptor and Link Pointer. When set to 1, this bit indicates the Buffer Descriptor.
The "Size" field indicates the buffer size. As the buffer size, a value between 1 and 64K bytes can be set. The "Buffer Address" field indicates the head address of the buffer.

Tx Link Pointer: This is the link pointer. It points to the next packet directory.
Bit31 is usually set to 0.

Bit30 is used to discriminate between the Buffer Descriptor and Link Pointer. When set to 0, this bit indicates the Link Pointer.

The "Directory Address" field indicates the head address of the next Buffer Directory.

6.5.3 Data send modes

USB Controller supports two send modes. These modes differ only in whether a zero-length USB packet is sent after the data segment. In all other aspects they are identical. The send mode is switched using the TM bit (Bit 19) of the USB EP1 EndPoint Control Register (Address: 24H) and USB EP3 EndPoint Control Register (Address: 2CH).

Cautions 1. The setting made with the TM bit applies only to EndPoint1 and EndPoint3.

2. When EndPoint0 and EndPoint5 are used to send data, NZLP mode is usually used.

(1) SZLP (Send Zero Length Packet) mode

In this mode, when the data segment is divided by the value set in the MAXP field, a zero-length packet is sent after the completion of data segment sending.

When the data segment has not been divided by the value set in the MAXP field, a USB Short Packet is sent.

(2) NZLP (Non Zero Length Packet) mode

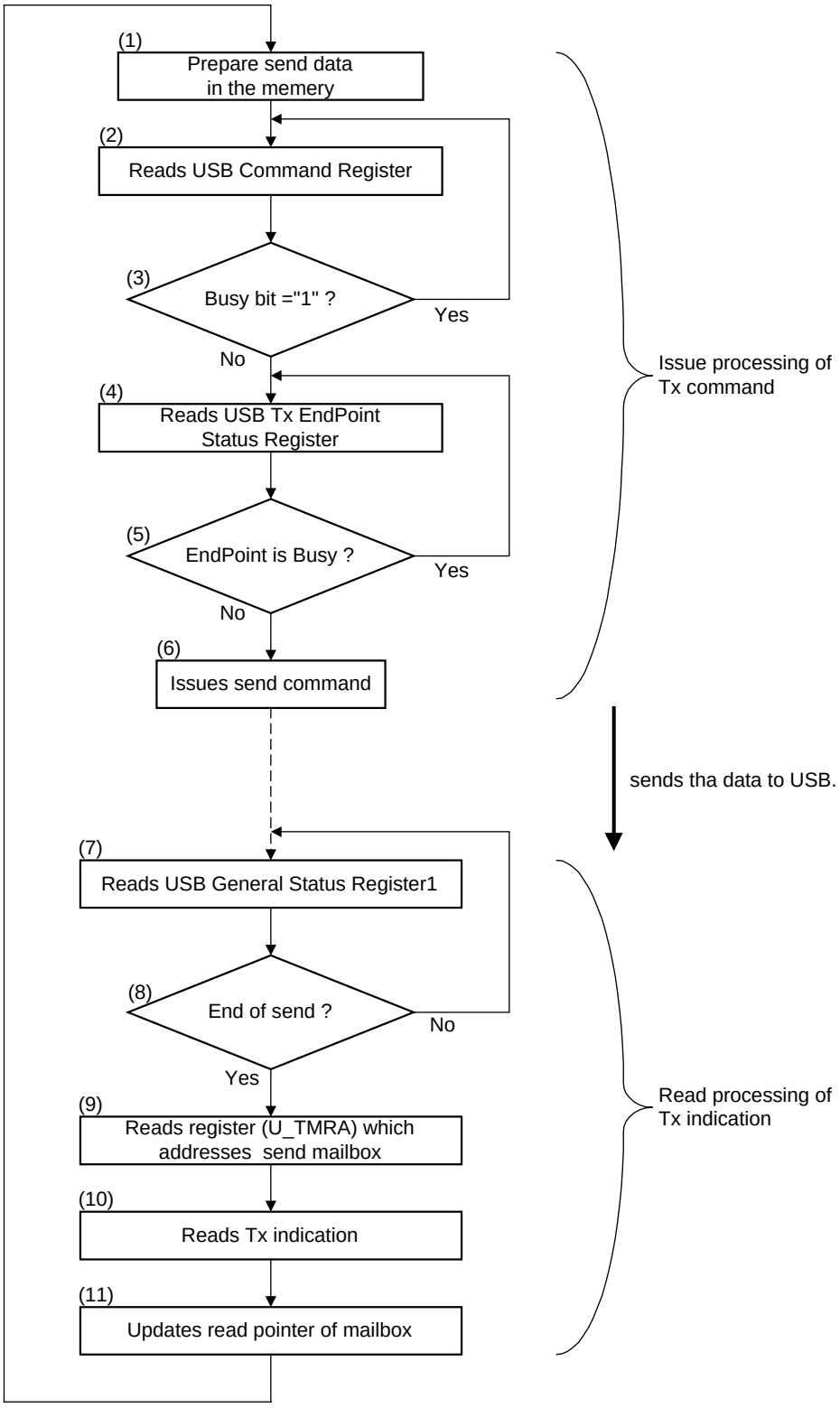
In this mode, even when the data segment is divided by the value set in the MAXP field, a zero-length packet is not sent after the completion of data segment sending.

When the data segment has not been divided by the value set in the MAXP field, a USB Short Packet is sent in the same way as in SZLP Mode.

6.5.4 VR4120A RISC processor processing at data sending

This section explains the processing performed by the VR4120A RISC Processor when sending data.

Figure 6-7. VR4120A RISC Processor Processing at Data Sending



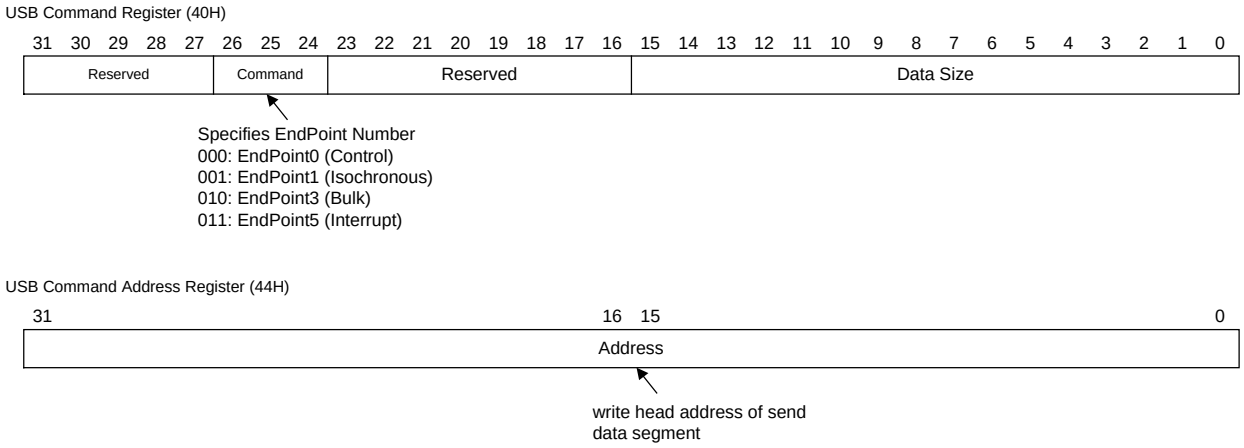
(1) First, the VR4120A RISC Processor prepares the send data in system memory. The data must be of a format that corresponds to the configuration of the send buffer.
(2) The VR4120A RISC Processor reads the USB Command Register.
(3) The VR4120A RISC Processor checks whether the Busy bit of the USB Command Register has been set. If the Busy bit is set, it indicates that USB Controller is still executing the previous command. Thus the VR4120A RISC Processor can not issue a new command.
(4) The VR4120A RISC Processor reads the USB Tx EndPoint Status Register.
(5) The VR4120A RISC Processor checks whether the EndPoint that is to perform send next is in the Busy status. If the EndPoint is Busy, the VR4120A RISC Processor repeats the processing from the reading of the USB Tx EndPoint Status Register.
(6) The VR4120A RISC Processor issues the Tx command.
(7) The VR4120A RISC Processor reads the USB General Status Registers 1.
(8) The VR4120A RISC Processor checks whether sending has terminated.
(9) The VR4120A RISC Processor reads the contents of the USB Tx Mailbox Read Address Register (Address: 78H).
(10) The VR4120A RISC Processor reads the send indication.
(11) The VR4120A RISC Processor updates the contents of the USB Tx MailBox Read Address Register.

By issuing a send command, the sending of a data segment can be scheduled.

A send command is issued by writing a value into the registers listed below. When writing, it is necessary to write first to the USB Command Address Register, then the USB Command Register.

If data size field of USB Command Register is “0”, USB Controller sends Zero-Length Packet.

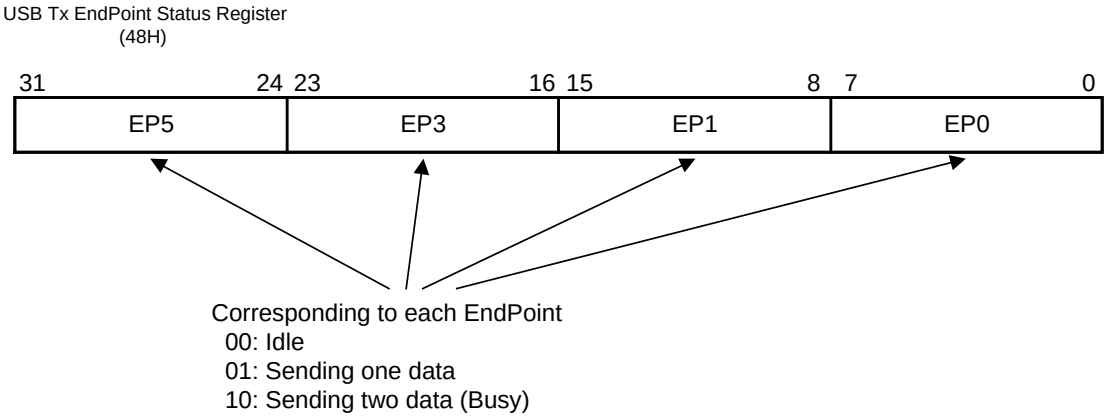
Figure 6-8. Send Command Issue



For a given EndPoint, it is possible to schedule the sending of up to two data items. Once two data items have been sent, even if the VR4120A RISC Processor writes a send command into the USB Command Register to send a third data item, that command is ignored.

The number of data items that are scheduled to be sent can be determined by reading the USB Tx EndPoint Status Register.

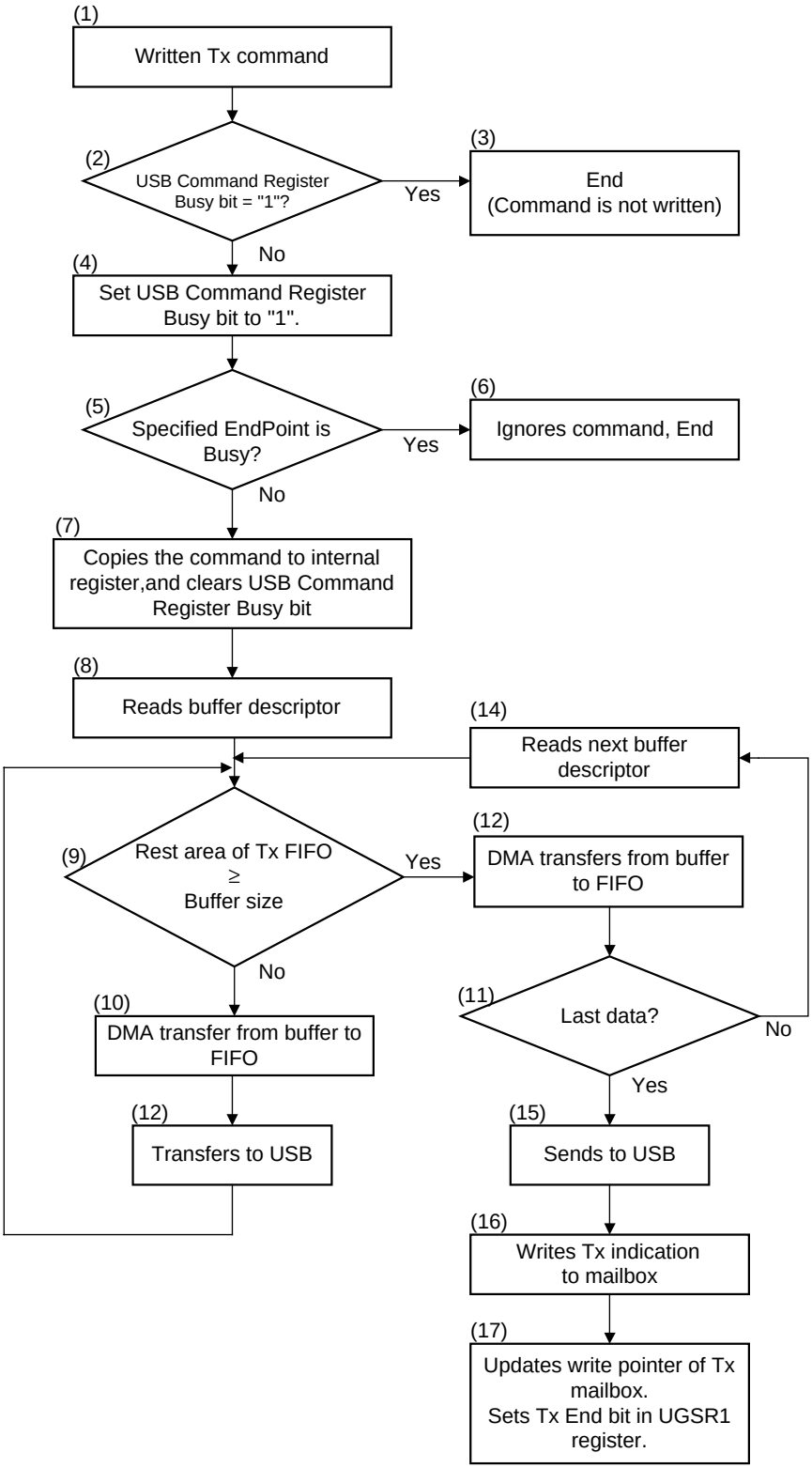
Figure 6-9. Send Status Register



6.5.5 USB controller processing at data sending

This section presents all of the processing performed by USB Controller at data sending. For an explanation of the operation of each block at data sending, see Section 6.9.

Figure 6-10. USB Controller Send Operation Flow Chart



Numbers (1) to (15) do not indicate the order in which USB Controller must perform processing. Instead, these numbers correspond to those in the following explanation.

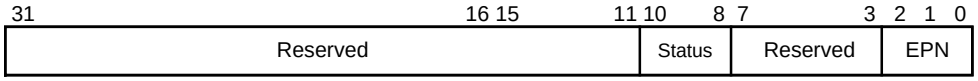
(1) USB Controller starts send processing upon receiving a send command from the VR4120A RISC Processor.
(2) At the instant that the command is written, USB Controller checks whether the Busy bit (Bit 31) of the USB Command Register is set.
(3) Set Busy Bit of USB Command Register to “1”.
(4) If the Busy bit (Bit 31) of the USB Command Register is set, the command written in (1) is ignored.
(5) USB Controller checks whether the EndPoint specified with the send command is currently in the Busy status (two items of data are scheduled to be sent).
(6) If the EndPoint specified with the send command is found to be in the Busy status, the command written in (1) is ignored.
(7) The command written into the USB Command Register and USB Command Address Register in (1) is copied to an internal register and the Busy bit of the USB Command Register is returned to 0.
(8) USB Controller reads the buffer descriptor that contains the value that is written into the USB Command Address Register at the same time as the send command.
(9) USB Controller compares the size of the area remaining in the send FIFO with the buffer size of the buffer descriptor read in the previous step.
(10) If step (8) reveals that the area remaining in the send FIFO is smaller, USB Controller DMA- transfers the data from the buffer until the send FIFO is full.
(11) Once the send FIFO is full, USB Controller transfers the data to the USB.
(12) If step (8) reveals that the area remaining in the send FIFO is larger, USB Controller DMA-transfers all the data in the buffer to the send FIFO.
(13) USB Controller checks whether the DMA-transferred data is the last data of the data segments to be sent to a Host.
(14) If the DMA-transferred data is not the last to be sent, it indicates that the buffer is empty. Therefore, USB Controller reads the next buffer descriptor.
(15) If the DMA-transferred data is the last to be sent, USB Controller writes a Tx indication in the mailbox.
(16) USB Controller updates the mailbox write pointer (USB Tx MailBox Write Address Register). It also sets the send completion bit of the USB General Status Register1 and, provided it is not masked, issues an interrupt to the VR4120A RISC Processor.

6.5.6 Tx indication

For every data segment that it sends, USB Controller writes a send indication into the send mailbox. After writing a send indication, USB Controller sets the send completion bit of USB General Status Register1 to 1 and, provided it is not masked, issues an interrupt to the VR4120A RISC Processor.

The format of the send indication is as shown below.

Figure 6-11. Send Indication Format



Status: Field that indicates the status upon data sending.

Bit10: When set to 0, indicates that an IBUS error has not occurred.
When set to 1, indicates that processing terminated abnormally due to the occurrence of an IBUS error.

Bit9: When set to 0, indicates that a buffer underrun did not occur during data sending.
When set to 1, indicates that a buffer underrun occurred.
This bit is set only when sending data to EndPoint1.

Bit8: When set to 0, data sending is performed in SZLP mode.
When set to 1, data sending is performed in NZLP mode.
For EndPoint0 and EndPoint5, this bit is usually set to 1.

EPN: Field that indicates the EndPoint number.

000: EndPoint0
010: EndPoint1
100: EndPoint3
110: EndPoint5

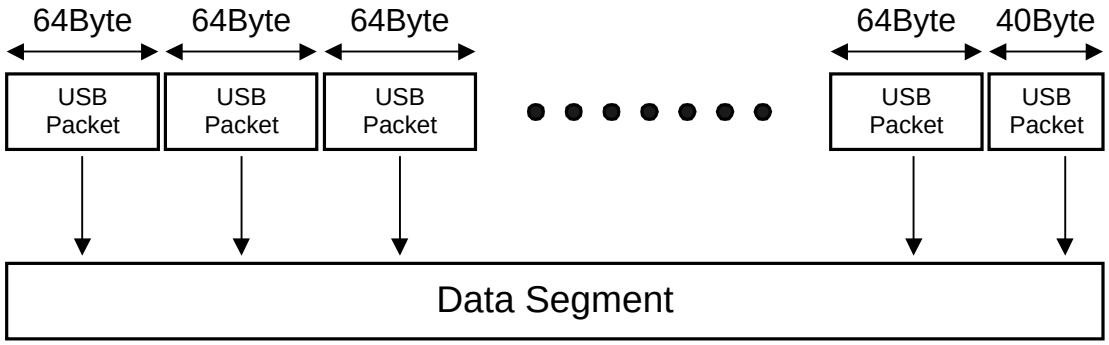
6.6 Data Receive Function

This section explains USB Controller's data receive function.

6.6.1 Overview of receive processing

USB Controller takes the USB packets that it receives from the USB, stores them into system memory in order, then creates a single data segment. The VR4120A RISC Processor sets the size of a single USB packet in the MAXP field of the EP0 Control Register, EP1-2 Control Register, EP3-4 Control Register, and EP5-6 Control Register. (The figure shown below is an example when the packet size is set to 64 bytes.)

Figure 6-12. Division of Data into USB Packets



When the data segments are divided by a value other than that set in the MAXP field, the last item of the divided data will be smaller than the value set in the MAXP field (40 bytes in the example shown above). As a result, USB Controller can identify the boundary between data segments. If a data segment is divided by the value set in the MAXP field, a zero-length USB packet will be sent from the Host PC to USB Controller after the last item of the divided data.

When sending data received from the USB to system memory, an area for the send data is required in system memory. This area is referred to as the receive buffer. It must be secured by the VR4120A RISC Processor. For an explanation of the receive buffer, see Section 6.6.2.

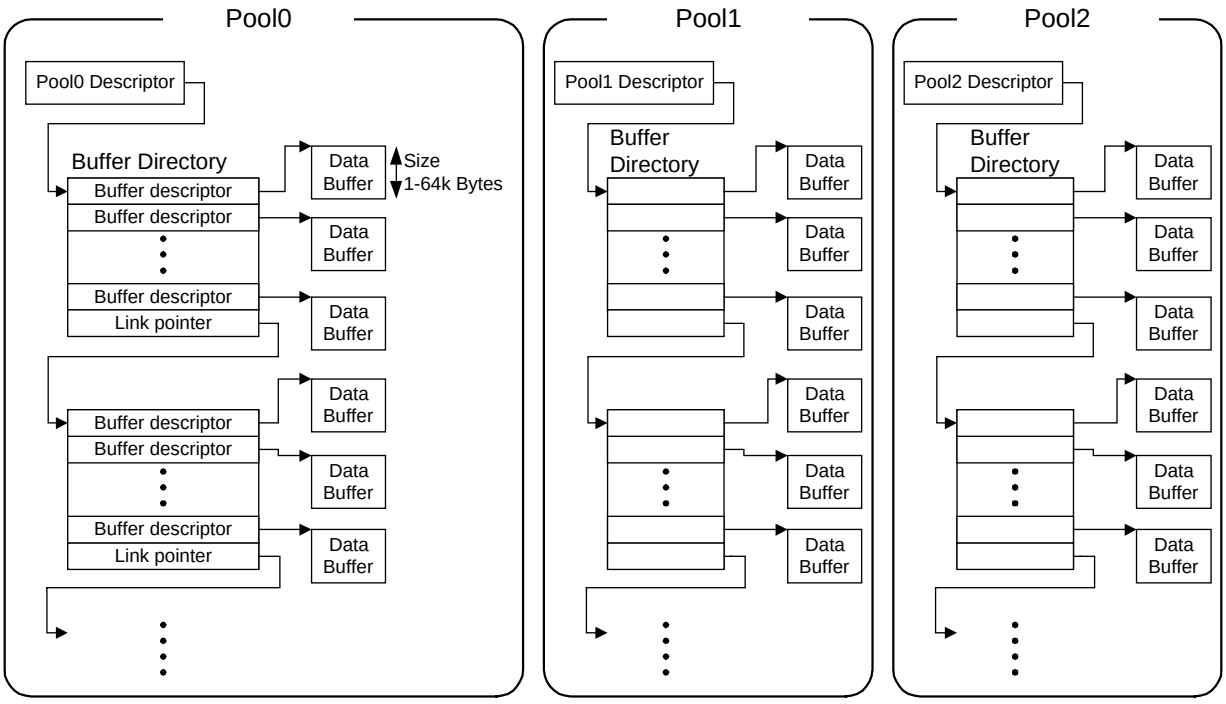
Upon the completion of data segment transfer, USB Controller writes the "Rx indication" into a mailbox in system memory. For an explanation of the Rx modes, see Section 6.6.7.

6.6.2 Receive buffer configuration

Data received from the USB is stored into a receive pool in system memory.

USB Controller uses three receive pools. The configuration of the receive pools is shown below.

Figure 6-13. Receive Pool Configuration

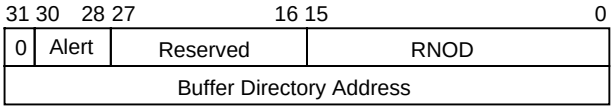


The receive pool is configured of the buffer directory, that bundles together the buffers, as well as the buffers themselves. The receive pool is prepared in system memory by the VR4120A RISC Processor.

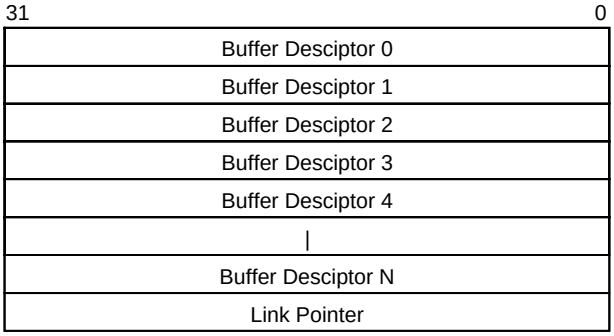
The formats of the Pool Descriptor, Buffer Directory, Buffer descriptor, and Link Pointer are each described below.

Figure 6-14. Receive Descriptor Configuration

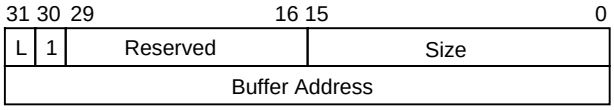
-Rx Pool Descriptor



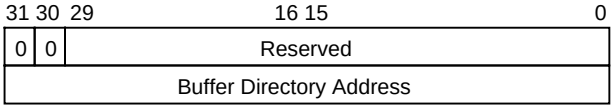
-Rx Buffer Directory



-Rx Buffer Descriptor



-Rx Link Pointer



Rx Pool Descriptor: Contains the receive pool data.
The "Buffer Directory Number" field indicates the remaining Buffer Directory number. When USB Controller uses a new Buffer Directory upon receiving data, USB Controller decrements this field by one.
After decrementing the value in RNOD field, if decremented value becomes equal to the value 4 times of Alert filed USB Controller sets Bit16 (Pool0) or Bit17 (Pool1) or Bit18 (Pool2) in USB General Status Register1 to one. If not masked, USB Controller generates interrupt to VR4120A RISC Processor.
Once decrementing causes this field to reach 0, USB Controller makes Bit19 (Pool0) or Bit20 (Pool1) or Bit21 (Pool2) of the General Status Register1 active provided it is not masked, issues an interrupt to the VR4120A RISC Processor. The "Buffer Directory Address" field indicates the start address of the receive Buffer Directory.

Rx Buffer Directory: A receive Buffer Directory. This is configured of a buffer descriptor and a link pointer. A single receive Buffer Directory can contain up to 255 buffer descriptors.

Rx Buffer Descriptor: Contains the receive buffer data.
When Bit31 (Last bit) is active, that Buffer Descriptor indicates the last buffer in the pool.

Bit30 is used to discriminate between the Buffer Descriptor and Link Pointer. When set to 1, this bit indicates the Buffer Descriptor.

The "Size" field indicates the buffer size. As the buffer size, a value between 1 and 64K bytes can be set. The "Buffer Address" field indicates the head address of the buffer.

Rx Link Pointer: This is the link pointer. It indicates the last Buffer Directory.

Bit31 is usually set to 0.

Bit30 is used to discriminate between the Buffer Descriptor and Link Pointer. When set to 0, this bit indicates the Link Pointer.

The "Buffer Directory Address" field indicates the head address of the next Buffer Directory.

6.6.3 Receive pool settings

USB Controller uses two receive pools.

Pool0	**For EndPoint0 (Control) and EndPoint6 (Interrupt)**
Pool1	**For EndPoint2 (Isochronous)**
Pool2	**For EndPoint4 (Bulk)**

The data in each of these two pools is written into the corresponding registers.

Pool0	**USB Rx Pool0 Information Register**	**(Address: 50H)**
	USB Rx Pool0 Address Register	**(Address: 54H)**
Pool1	**USB Rx Pool1 Information Register**	**(Address: 58H)**
	USB Rx Pool1 Address Register	**(Address: 5CH)**
Pool2	**USB Rx Pool2 Information Register**	**(Address: 60H)**
	USB Rx Pool2 Address Register	**(Address: 64H)**

The VR4120A RISC Processor can know the current status of each pool by reading these registers.

Upon initialization, after the VR4120A RISC Processor secures a receive pool area in the system memory area, it makes the settings for the pool by setting the head address of the pool, plus the number of Buffer Directories that the pool contains. The VR4120A RISC Processor can write values only into the Alert filed of four registers above. Other filed must be set using USB Command Register and USB Command Address Register.

The VR4120A RISC Processor adds Buffer Directories to each pool by using the USB Command Register (Address: 40H) and the USB Command Address Register (Address: 44H).

To add Buffer Directories to a receive pool, the VR4120A RISC Processor performs the following processing.

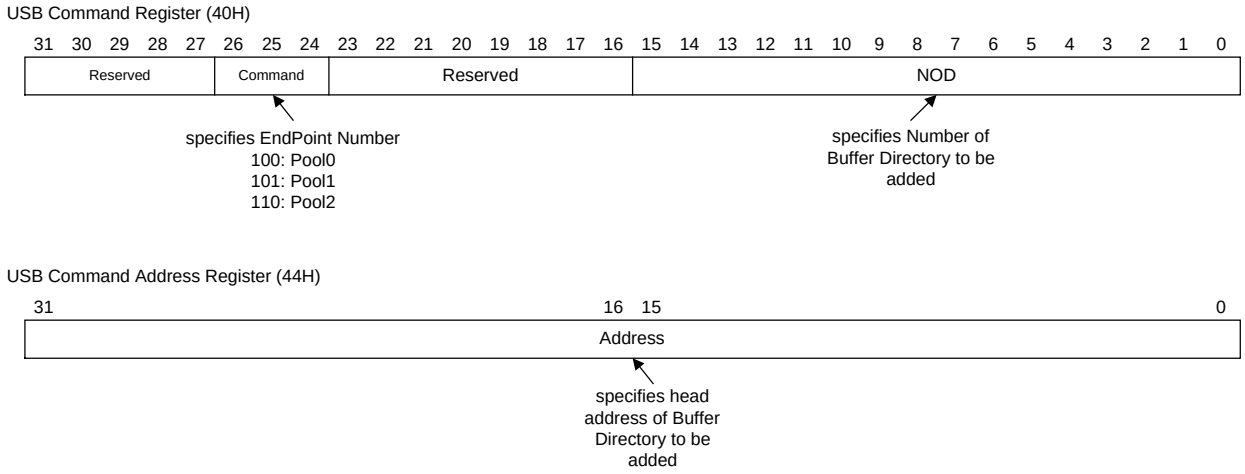
(1) The VR4120A RISC Processor secures the Buffer Directory to be added to the pool, and the buffer, in system memory. When multiple Buffer Directories are to be added, they are linked in advance.

(2) The VR4120A RISC Processor writes the head address of the Buffer Directory to be added into the link pointer to the last Buffer Directory in the list of dependent Buffer Directories in the pool.

(3) The VR4120A RISC Processor writes the head address of the Buffer Directory to be added into the USB Command Address Register (Address: 44H).

(4) The VR4120A RISC Processor writes the pool number and size of the Buffer Directory to be added into the USB Command Register (Address: 40H).

Figure 6-15. Buffer Directory Addition Command



The operation of USB Controller varies with whether any unused Buffer Directories remain in the corresponding pool when the Buffer Directory addition command is written into the USB Command Register.

(a) If any unused Buffer Directories remain in the pool (when the RNOD field in the Pool Information Register is set to other than 0), USB Controller adds the number in the NOD field of the command to the RNOD field of the Pool Information Register.

(b) When the pool is empty (when the RNOD field in the Pool Information Register is 0), USB Controller loads the value set in the NOD field of the command into the RNOD field of the Pool Information Register. Furthermore, it loads the value written in the USB Command Address Register into the Pool Address Register.

6.6.4 Data receive mode

USB Controller has different receive processing every EndPoint and receive mode.

The receive mode was determined by RM field (Bit20-19) in USB EP2 Control Register (Address 28H) and USB EP4 Control Register (Address 30H). There are four kinds of receive processing.

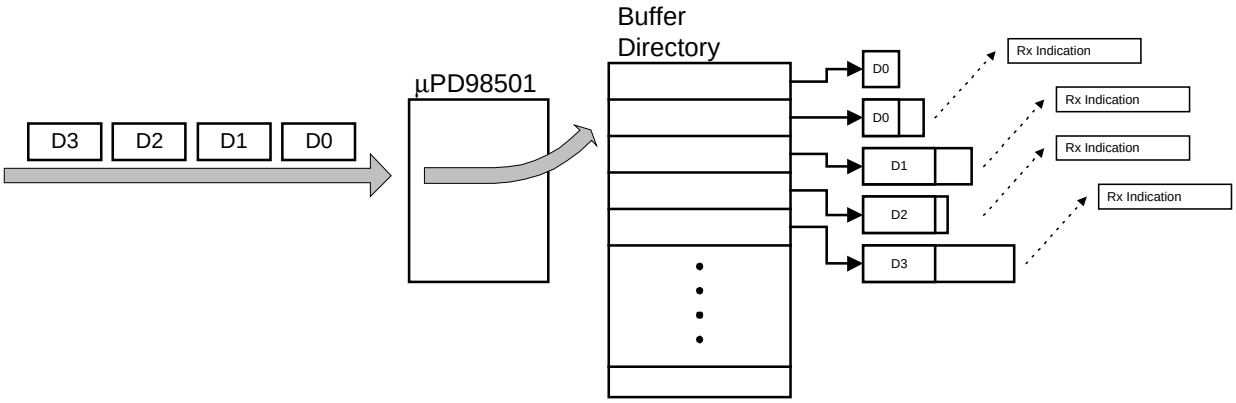
(1) EndPoint0, EndPoint6
(2) EndPoint2, EndPoint4 Normal Mode
(3) EndPoint2, EndPoint4 Assemble Mode
(4) EndPoint2, EndPoint4 Separate Mode

Each processing explains below.

(1) Reception in EndPoint0, EndPoint6

Same processing is executed without relations in receive mode in EndPoint0, EndPoint6 every time.

Figure 6-16. Data Receiving in EndPoint0, EndPoint6

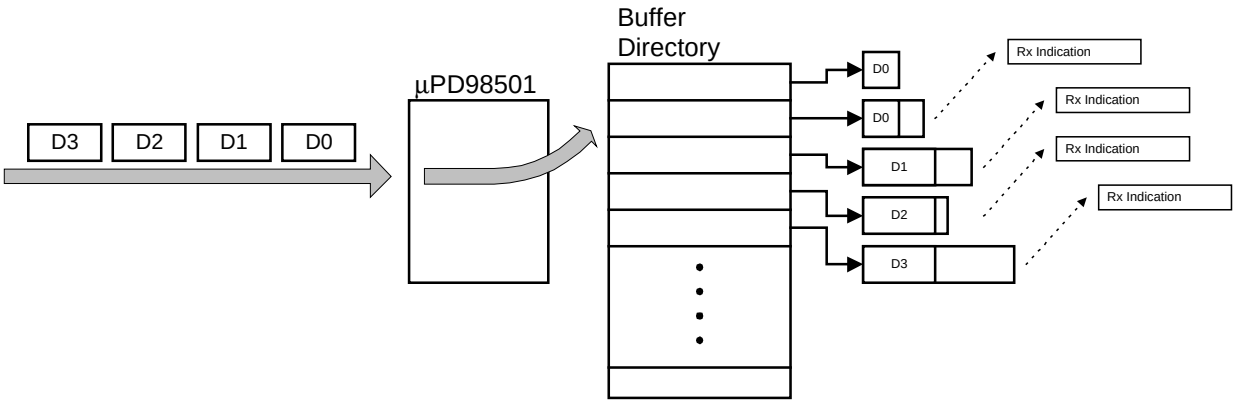


When USB Controller receives one USB packet, stores it in Data Buffer and write Rx indication to the Mailbox. USB Controller renews the size field and Last field in Buffer Descriptor every USB packet before writing Rx Indication.

(2) EndPoint2, EndPoint4, normal mode

The processing in EndPoint2, EndPoint4 receive Normal mode is explained below.

Figure 6-17. EndPoint2, EndPoint4 Receive Normal Mode

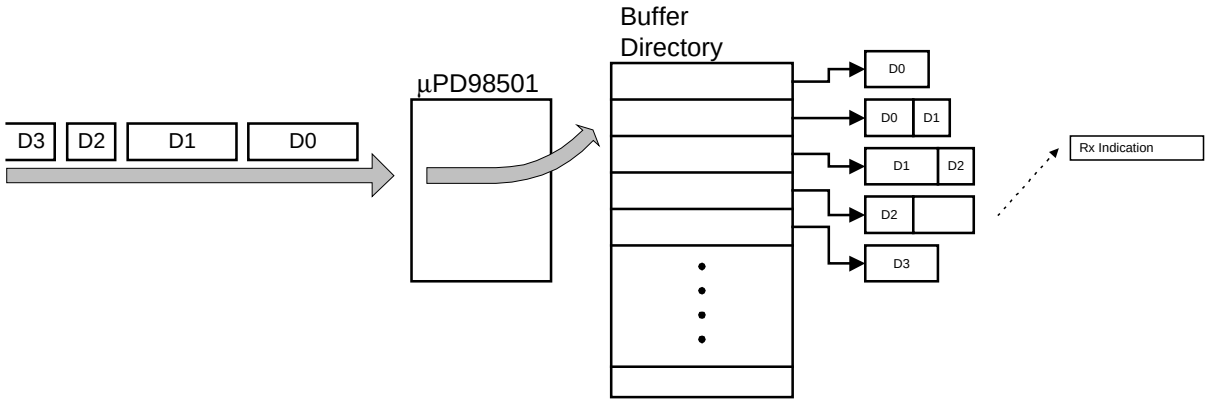


When USB Controller receives one USB packet, stores it in Data Buffer and write Rx indication to the Mailbox. USB Controller renews the size field and Last field in Buffer Descriptor every USB packet before writing Rx Indication.

(3) EndPoint2, EndPoint4, assemble mode

The processing in EndPoint2, EndPoint4 receive Assemble mode is explained below.

Figure 6-18. EndPoint2, EndPoint4 Receive Assemble Mode



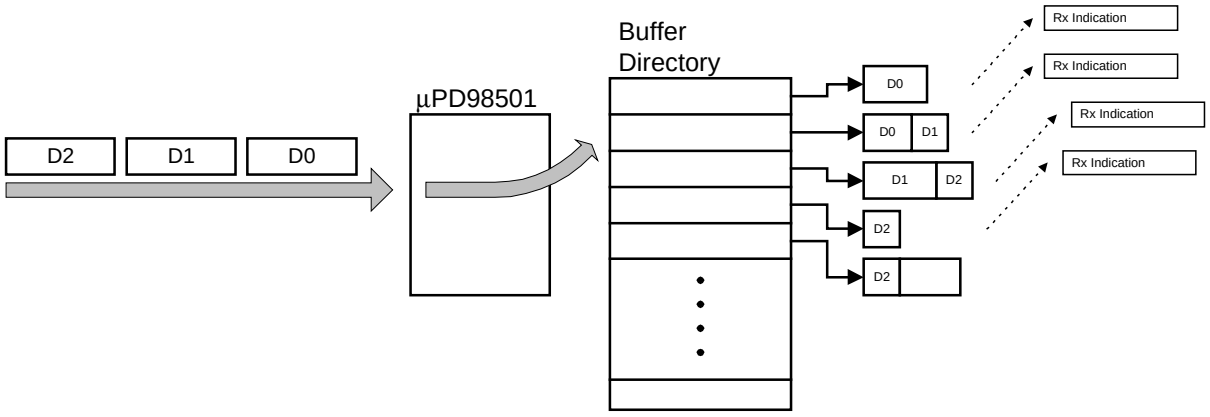
In this mode USB Controller issues Rx indication after receiving one data segment.

In other word, after USB Controller writes the Short packet or Zero-Length Packet received from USB to buffer in system memory, USB Controller renewing Size field, Last bit in last Buffer Descriptor and issues Rx indication.

(4) EndPoint2, EndPoint4, separate mode

The processing in EndPoint2, EndPoint4 receive separate mode is explained below.

Figure 6-19. EndPoint2, EndPoint4 Receive Separate Mode



In this mode, after USB Controller receives USB packet and stores the data in receive buffer, it issues Rx indication when buffer was full. If buffer was full in the middle of USB packets, in that time it issues indication. After that, processing of storing the USB packet to next buffer continues.

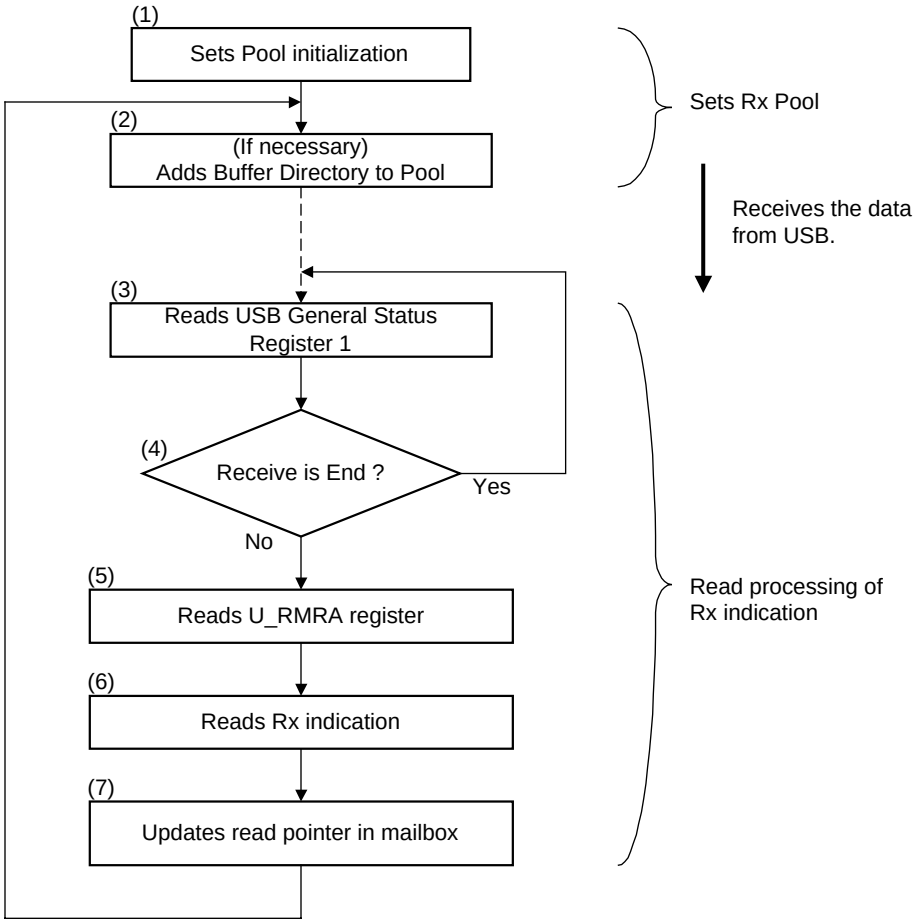
It does not execute to renew Size field, Last bit in Buffer Descriptor.

Caution If you want to guarantee the behavior of Isochronous EndPoint as well as possible, Rx Normal Mode and software processing is recommended. Rx Assemble mode and Separate Mode is not fit to Isochronous EndPoint.

6.6.5 VR4120A RISC processor receive processing

This section explains the processing that the VR4120A RISC Processor must perform when data is being sent.

Figure 6-20. VR4120A RISC Processor Receive Processing



Numbers (1) to (7) do not indicate the order in which the VR4120A RISC Processor must perform processing. Instead, these numbers correspond to those in the following explanation.

(1) First, as part of initialization, the VR4120A RISC Processor must make the necessary Pool settings.
(2) For receiving, the VR4120A RISC Processor must add Buffer Directories to the Pool, if necessary.
(3) The VR4120A RISC Processor reads the USB General Status Register 1.
(4) The VR4120A RISC Processor checks whether receiving has ended.
(5) If receiving has ended, the VR4120A RISC Processor reads the receive mailbox setting register (USB Rx MailBox Read Address Register Address: 88H) to determine the address of Mailbox VR4120A RISC Processor must read in the next time.
(6) Then, the VR4120A RISC Processor reads the Rx indication from the indicated mailbox.
(7) The VR4120A RISC Processor updates the receive mailbox read address (USB Rx MailBox Read Address Register).

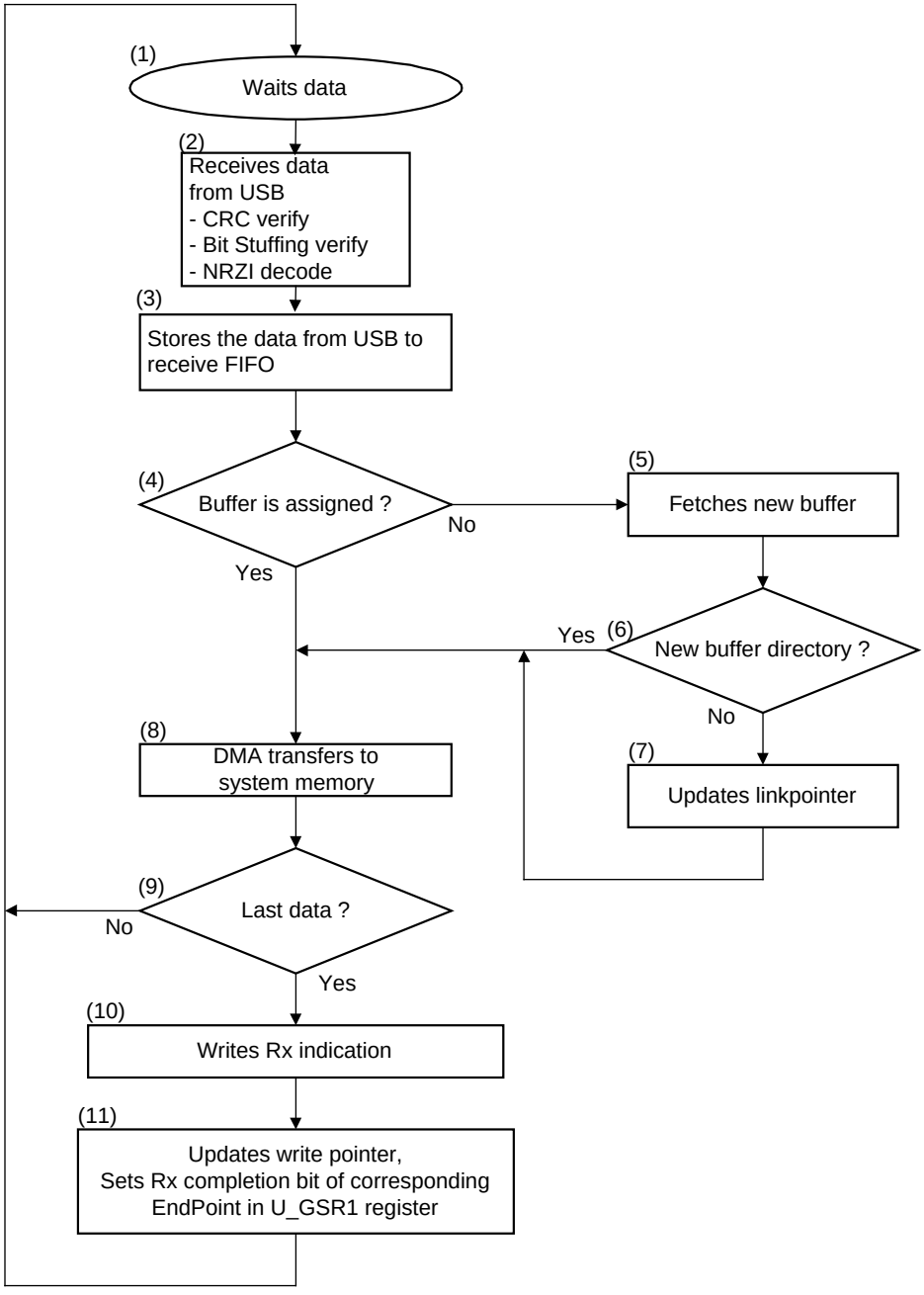
6.6.6 USB controller receive processing

This section presents all of the processing performed by USB RISC Processor at data receiving. For an explanation of the operation of each block at data receiving, see Section 6.9.

6.6.6.1 Assemble mode

The following figure illustrates the receive operations performed by USB Controller in Assemble Mode.

Figure 6-21. USB Controller Receive Operations (Assemble Mode)



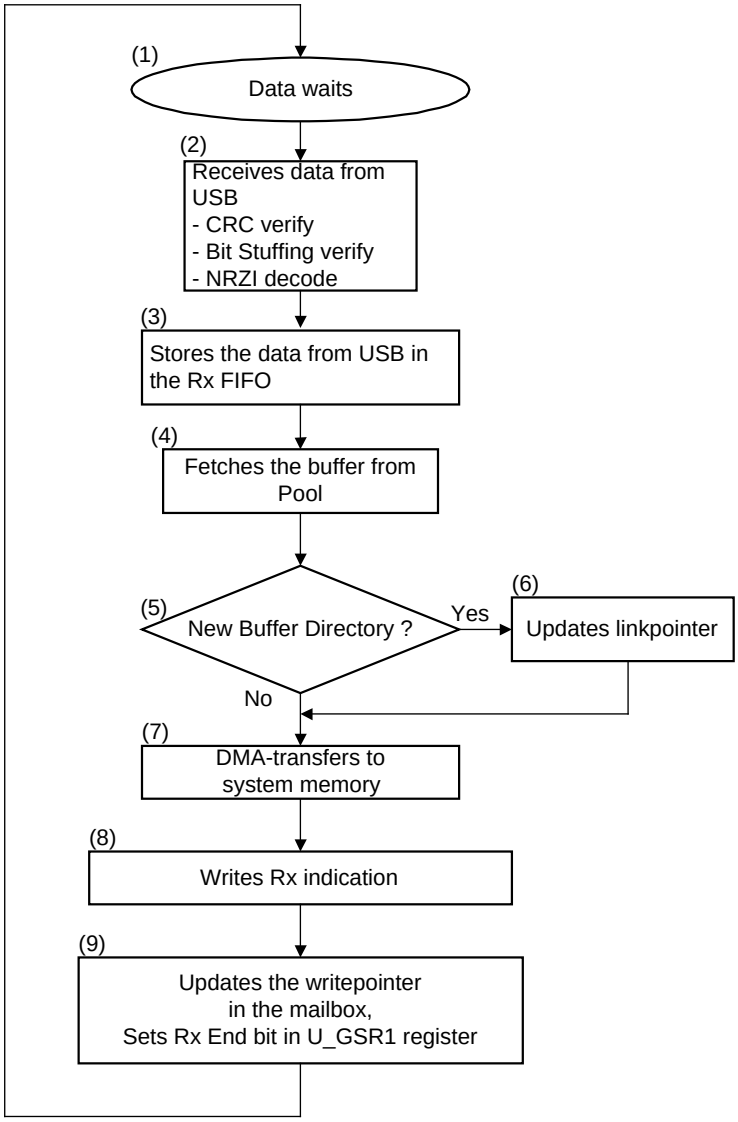
Numbers (1) to (11) do not indicate the order in which USB Controller must perform processing. Instead, these numbers correspond to those in the following explanation.

(1) USB Controller is in the status where it waits to receive data (USB Packets) from the USB.
(2) USB Controller receives data (USB Packets) from the USB. As it is receiving the data, USB Controller performs NRZI decoding, CRC check, and Bit Stuffing Error check.
(3) USB Controller stores the received data into the FIFO.
(4) USB Controller checks whether a buffer for storing receive data has been allocated in system memory.
(5) If USB Controller finds that a buffer has not been allocated, it prepares a new buffer.
(6) USB Controller checks whether the buffer prepared in (5) is in a new Buffer Directory.
(7) If USB Controller finds that the buffer is in a new Buffer Directory, USB Controller updates the link pointer for the Buffer Directory that has been used up to that point. It also updates the Buffer Directory address of the pool descriptor.
(8) USB Controller then DMA-transfers data from the FIFO to system memory.
(9) USB Controller checks whether the DMA-transferred data is the last data.
(10) If USB Controller finds that the transferred data is in fact the last data, renews the Size field and Last bit of Buffer Descriptor and writes the Rx indication into the prepared Mailbox.
(11) USB Controller updates the write pointer of the mailbox (Rx MailBox Write Address Register Address: 8CH). Also, it sets the receive completion bit of the USB General Status Register1 and, provided it is not masked, issues an interrupt to the VR4120A RISC Processor.

6.6.6.2 Separate mode

The following figure illustrates the receive operations performed by USB Controller in Separate Mode.

Figure 6-22. USB Controller Receive Operation Sequence (Separate Mode)



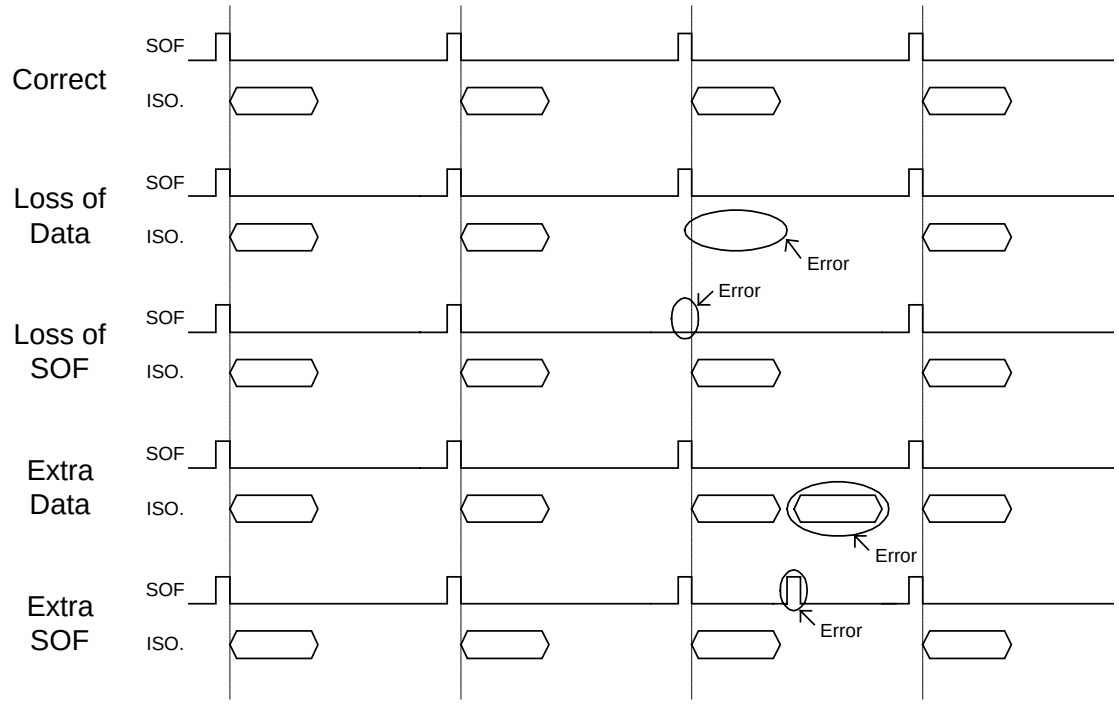
The difference from Assemble mode is the timing at which USB Controller writes the Rx Indication.

6.6.7 Detection of errors on USB

USB Controller has some functions which detect some errors on the USB.

Errors shown in figure below are related to Isochronous EndPoint and SOF packet.

Figure 6-23. USB Timing Errors



(1) If “Loss of Data” error has occurred, EP2ND bit (Bit 5) in USB General Status Register2 will be set. The other action of USB Controller for this error is explained in next section (Section 6.6.8).

(2) If “Loss of SOF” error has occurred, SL bit (Bit 0) in USB General Status Register2 will be set.
In this case, USB Controller only reflect the error to USB General Status Register.

(3) If “Extra Data” error has occurred, EP2ED bit (Bit 6) in USB General Status Register2 will be set.
In this case, USB Controller only reflect the error to USB General Status Register.

(4) If “Extra SOF” error has occurred, ES bit (Bit 1) in USB General Status Register2 will be set.
In this case, USB Controller only reflect the error to USB General Status Register.

USB Controller can detect the other Error listed below.

- Isochronous data oversize error: If received data packet size is over MaxPacketSize of EndPoint2, USB Controller will set EP2OS bit (Bit 7) in USB General Status Register2.

- Incorrect EndPoint Number: If received IN/OUT TOKEN packet includes the EndPoint Number which is not enabled by VR4120A RISC Processor or which is over 7, USB Controller will set IEA bit (Bit 19) in USB General Status Register2.

- No data in EndPoint1 Tx FIFO: If IN TOKEN packet for EndPoint2 comes when Tx FIFO for EndPoint2 is not ready, USB Controller will not send any data

to USB and will set EP1ND bit (2 Bit) in USB General Status Register2.

- Extra Token on EndPoint1: If IN TOKEN packet for EndPoint2 comes which between two SOFs, USB Controller will set EP1ET bit (Bit 3) in USB General Status Register2. In this case, USB Controller will send data only once.

- No Token on EndPoint1: If IN TOKEN packet for EndPoint2 does not come between two SOFs, USB Controller will set EP1NT bit (Bit4) in USB General Status Register2.

6.6.8 Rx data corruption on isochronous EndPoint

On Isochronous Rx EndPoint (EP2), one data packet comes per one frame.

If any Isochronous data packet doesn't come between two SOF packet, it is assumed that Isochronous data is corrupted.

In the case of corruption, action of USB Controller varies according to Rx Mode.

(a) Rx normal mode

USB Controller sets EP2ND (EndPoint2 No Data) bit (Bit 6) in USB General Status Register2.

USB Controller doesn't write any Rx Indications.

USB Controller doesn't write any data to Data Buffer on System Memory.

(b) Rx assemble mode

USB Controller sets EP2ND (EndPoint2 No Data) bit (Bit 6) in USB General Status Register2.

USB Controller writes dummy data to Data Buffer. (In fact, USB Controller only increment pointer which addresses Data Buffer by MaxPacketSize. No DMA transfer occurs.)

USB Controller writes Rx Indications which indicates that received data was corrupted on Isochronous EndPoint.

(c) Rx separate mode

USB Controller sets EP2ND (EndPoint2 No Data) bit (Bit 6) in USB General Status Register2.

USB Controller writes dummy data to Data Buffer (In fact, USB Controller only increment pointer which addresses Data Buffer by MaxPacketSieze. No DMA transfer occurs.)

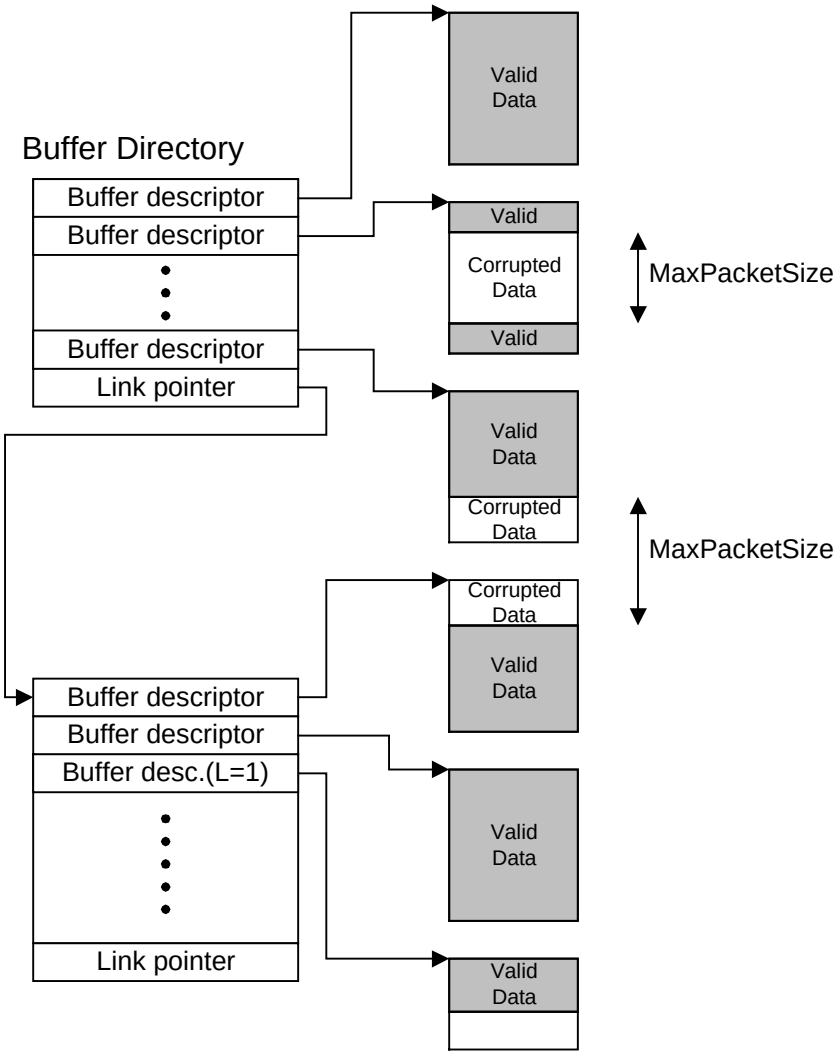
USB Controller writes Rx Indications which indicates that received data was corrupted on Isochronous EndPoint.

Example

When USB Controller performs receiving in Rx Assemble Mode or Rx Separate Mode, if data corruption occurs on Isochronous Rx EndPoint (EndPoint4), Data Buffers becomes as figure 6-24.

Shaded area in following figure is filled by valid data. If USB Controller detects that data is corrupted, next data must be stored in Data Buffer which keeps area for corrupted data. Corrupted data area is equal to MaxPacketSize of Isochronous Rx EndPoint (EndPoint2).

Figure 6-24. Example of Buffers Including Corrupted Data



6.6.9 Rx FIFO overrun

On Isochronous Rx EndPoint (EP2), if data supplement to FIFO is delayed by some problem, Rx FIFO Overrun will occur.

In the case of corruption, action of USB Controller varies according to Rx Mode.

(a) Rx normal mode

USB Controller sets EP2FO (EndPoint2 No Data) bit (Bit 9) in USB General Status Register2.

USB Controller writes the Rx Indications which indicates that EP2 FIFO Overrun has occurred.

USB Controller doesn't write any dummy data to Data Buffer on System Memory.

(b) Rx assemble mode

USB Controller sets EP2FO (EndPoint2 No Data) bit (Bit 9) in USB General Status Register2.

USB Controller writes dummy data to Data Buffer (In fact, USB Controller only increment pointer which addresses Data Buffer by MaxPacketSize. No DMA transfer occurs.) so that the sum of received data and dummy data becomes equal to MaxPacketSize.

After USB Controller receives “USB short packet”, USB Controller writes Rx Indications which indicates that EP2 FIFO Overrun has occurred.

(c) Rx separate mode

USB Controller sets EP2FO (EndPoint2 No Data) bit (Bit 9) in USB General Status Register2.

USB Controller writes dummy data to Data Buffer (In fact, USB Controller only increment pointer which addresses Data Buffer by MaxPacketSieze. No DMA transfer occurs.) so that the sum of received data and dummy data becomes equal to MaxPacketSize.

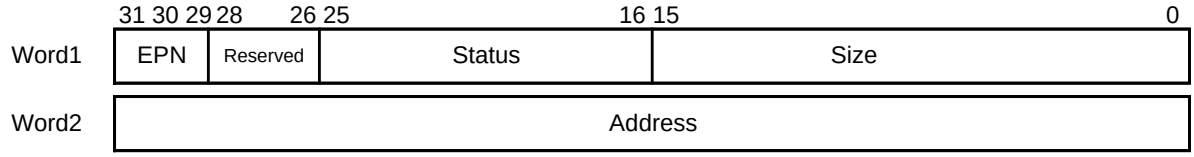
USB Controller writes Rx Indications which indicates that EP2 FIFO Overrun has occurred.

6.6.10 Rx indication

For every data segment that it receives, USB Controller writes a receive indication into the receive mailbox. After writing a receive indication, USB Controller sets the receive completion bit of the USB General Status Register to 1 and, provided it is not masked, issues an interrupt.

The format of the receive indication is as shown below.

Figure 6-25. Receive Indication Format



Remark Bit29 to Bit25 are reserved.

EPN: Field that indicates the EndPoint number.

001: EndPoint0
011: EndPoint2
101: EndPoint4
111: EndPoint6

Status: Field that indicates the status upon data receiving.

Bit25: When set to 0, indicates that an data corruption didn’t occur on EndPoint2.
When set to 1, indicates that an data corruption occurred on EndPoint2.

Bit24: When set to 0, indicates that an IBUS error has not occurred.
When set to 1, indicates that processing terminated abnormally due to the occurrence of an IBUS error.
When this bit is set to 1, the Address field has no meaning.

Bit23: When set to 0, indicates that the received data is other than a USB Setup packet.
When set to 1, indicates that the received data is a USB Setup packet.

This bit is set only when receiving the data from the Control EndPoint (EndPoint0). If data is received from any other EndPoint, this bit is not set.

Bit22: When set to 0, indicates that a buffer overrun did not occur.
When set to 1, indicates that a buffer overrun occurred.
This bit is set only when receiving the data from the EndPoint1.

Bit21: When set to 0, indicates that a Data toggle Error has not occurred.
When set to 1, indicates that a Data toggle Error has occurred.
When this bit is set to 1 when receiving data from the Isochronous EndPoint (EndPoint2), it indicates that part of the data stored in system memory may have been lost.
For any other EndPoint, even if this bit is set to 1, data is not lost.

Bit20: When set to 0, indicates that a CRC error has not occurred.
When set to 1, indicates that a CRC error has occurred.
When this bit is set to 1 when receiving data from the Isochronous EndPoint (EndPoint2), it indicates that the data stored in system memory includes a CRC error.
For any other EndPoint, even if a CRC error occurs, the packet will be resent such that the data stored into main memory will not include an error.

Bit19: When set to 0, indicates that a Bit Stuffing Error has not occurred.
When set to 1, indicates that a Bit Stuffing Error has occurred.
When this bit is set to 1 when receiving data from the Isochronous EndPoint (EndPoint2), it indicates that the data stored in system memory contains a Bit Stuffing Error.
For any other EndPoint, even if a Bit Stuffing Error occurs, the packet will be resent such that the data stored into main memory does not contain an error.

Bit18: When set to 0, indicates that the size of the received data is up to 65535 bytes.
When set to 1, indicates that the size of the received data is greater than 65535 bytes.

Bit17-16: When set to 00 or 01, indicates that data is received in Normal Mode.
When set to 10, indicates that data is received in Assemble Mode.
When set to 11, indicates that data is received in Separate Mode.
When using EndPoint0 and EndPoint6, this field should be set to 00.

Size: Indicates the size of the received data.
When the size of the received data exceeds 65535 (FFFFH) bytes, Bit18 is set to 1, and this field will contain 65535 (FFFFH).

Address: Indicates the head address of the buffer into which the received data is stored.

6.7 Power Management

USB Controller has a built in feature that allows it to use interrupts to inform the VR4120A RISC Processor of its having received Suspend or Resume signaling from the Host PC. When the VR4120A Processor receives a Suspend or Receive interrupt, it must perform the appropriate processing.

Also, for those instances when the port to which LAKI is connected is in the Suspend status (LAKI is in the Suspend status), USB Controller has a function for issuing Remote Wake Up signaling to switch the Suspend status to Resume.

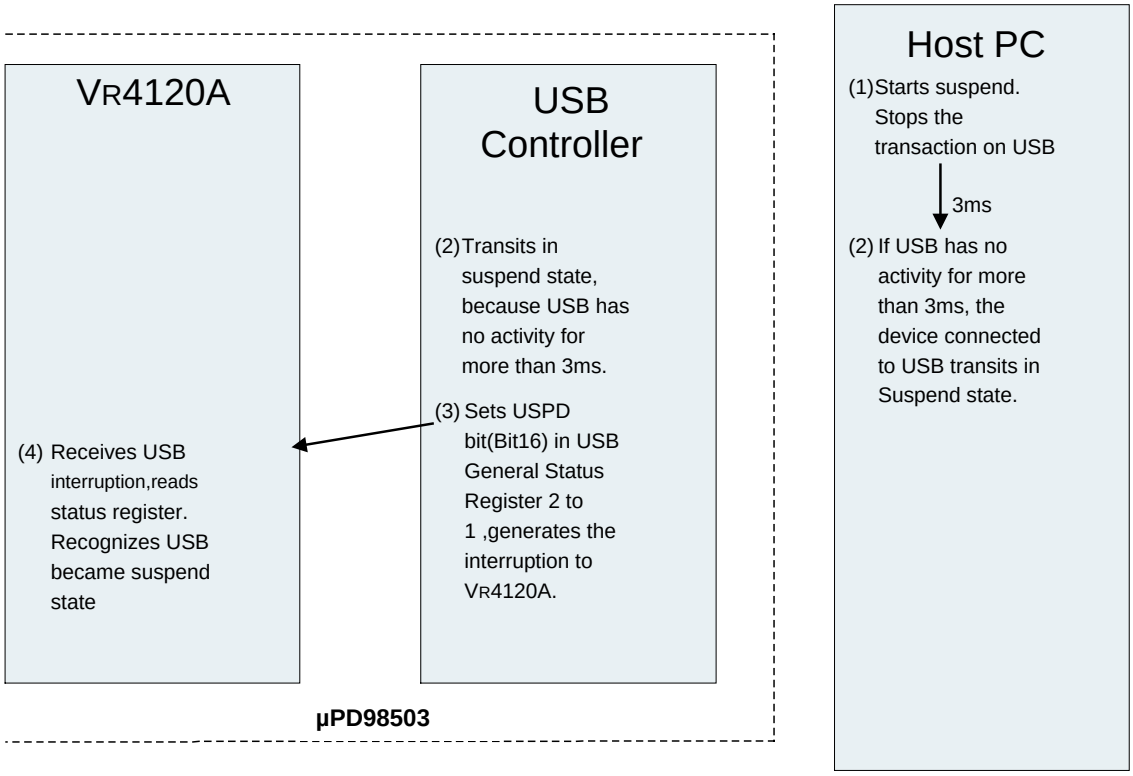
As a result, even if LAKI is in the Suspend status, data that shall be send to the USB is not discarded but is instead can be passed to the Host PC.

The following sections explain each of the sequences.

6.7.1 Suspend

The Suspend sequence is as shown below.

Figure 6-26. Suspend Sequence



(1) The host places the USB in the Suspend status. Traffic stops flowing through the USB.

(2) After 3 ms there is no traffic through the USB. Therefore, all of the devices connected to the USB shift to the Suspend status. In the same way, USB Controller also enters the Suspend status. If DMA transfer is being performed, however, USB Controller does not enter the Suspend status until after the completion of DMA transfer.

(3) USB Controller makes the USPD bit (Bit16) of the USB General Status Register2 (Address: 18H) active, then issues an interrupt to the VR4120A RISC Processor if interrupt is not masked.

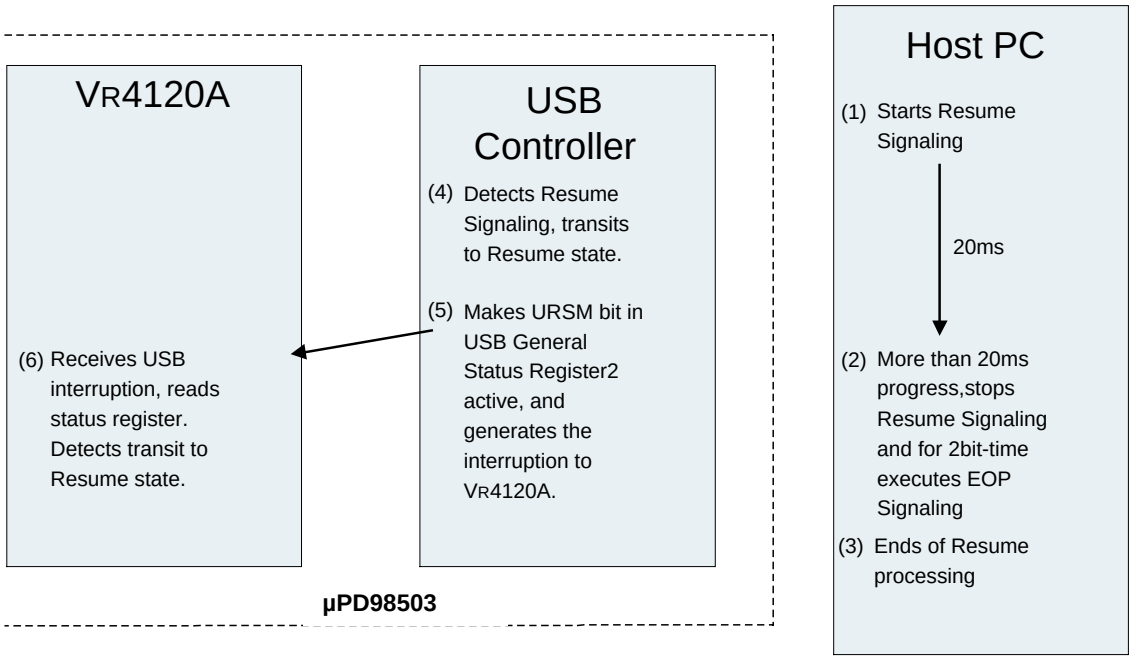
(4) The VR4120A RISC Processor receives the interrupt from USB Controller, reads the USB General Status Register2 and, as a result, determines that the USB is in the Suspend status.

The VR4120A RISC Processor is not permitted to write to other than USB Controller's USB General Mode Register and USB Interrupt Mask Register2 while USB Controller is in the Suspend status. Otherwise, after USB Controller enters the Resume status, its operation will be unpredictable.

6.7.2 Resume

The Resume sequence is shown below.

Figure 6-27. Resume Sequence



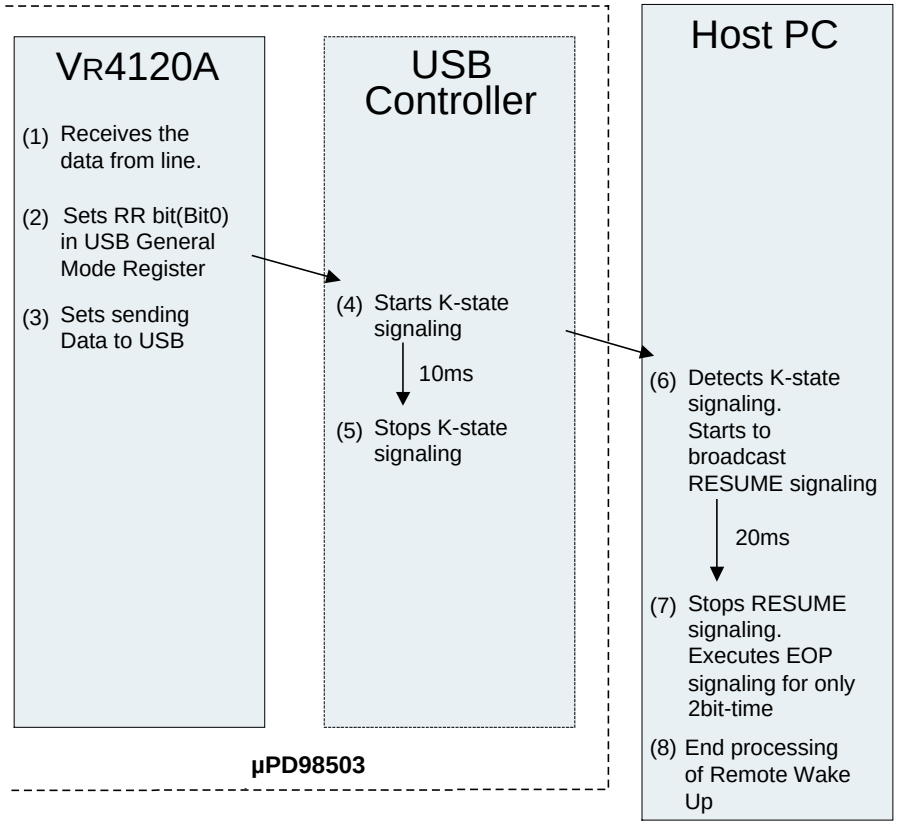
(1) The Host PC starts Resume Signaling. The Resume Signaling is passed to every device connected to the USB.
(2) After at least 20 ms have elapsed, the Host PC stops the Resume Signaling then performs EOP Signaling for a 2bit-time duration.
(3) This causes the Host PC to terminate its Resume processing.
(4) USB Controller receives the Resume Signaling.
(5) USB Controller makes the URSM bit (Bit18) of the USB General Status Register2 (Address: 18H) active, then issues an interrupt to the VR4120A RISC Processor. If clock supplement is stopped, VR4120A RISC Processor has to check "usbwakeup_p" signal instead of "URSM" bit.
(6) The VR4120A RISC Processor receives the interrupt from USB Controller and, as a result, determines that the USB has entered the Resume status.

After USB Controller enters the Resume status, it continues with the send/receive processing it was performing immediately before it entered the Suspend status.

6.7.3 Remote wake up

The Remote Wake Up sequence is shown below.

Figure 6-28. Remote Wake Up Sequence



(1) Here, it is assumed that the USB is in the Suspend status. Data received from another communication line.

(2) The VR4120A RISC Processor sets the RR bit (Bit 0) of the USB General Mode Register in order to switch the USB in the Suspend status to the Resume status.

(3) Once the RR bit of the USB General Mode Register has been set, USB Controller starts K-state Signaling for the USB.

(4) The VR4120A RISC Processor can continue to set send data for the USB. Specifically, the VR4120A RISC Processor prepares send data in system memory, then writes data into the USB Command Register (Address: 40H) and the USB Command Address Register (Address: 44H).

(5) USB Controller continues K-state Signaling for 5 ms, then terminates the signaling.

(6) The Host PC, upon receiving the K-state Signaling, broadcasts RESUME signaling. This RESUME signaling continues for a minimum of 20 ms.

(7) Once at least 20 ms have elapsed, the Host PC terminates RESUME Signaling, then issues EOP Signaling for a 2bit-time duration.

(8) As a result of this sequence, Remote Wake Up is terminated, and the transaction being performed by the USB is restarted.

6.8 Loopback Mode

USB Controller features a built-in loopback function for test purposes.

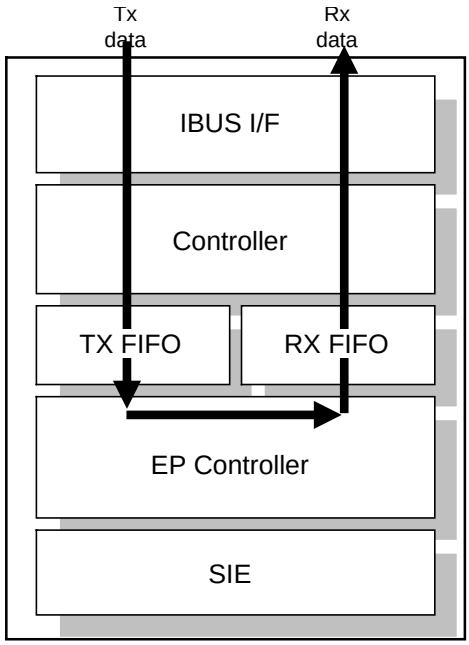
To enable the loopback function, set the LE bit (Bit 1) of the USB General Mode Register to 1.

Once the loopback function has been activated, USB Controller writes the data read from system memory into the send FIFO. The data is returned by the EndPoint Controller. The returned data is written into the receive FIFO, after which it is returned to system memory.

Sending and receiving should be performed using the normal settings. The send and receive indications are issued as normal.

The internal data flow is as shown below.

Figure 6-29. Data Flow in Loopback Mode



As shown in the figure, in loopback mode data reception from the USB and data sending to the USB are not performed. All data is returned by the EndPoint Controller.

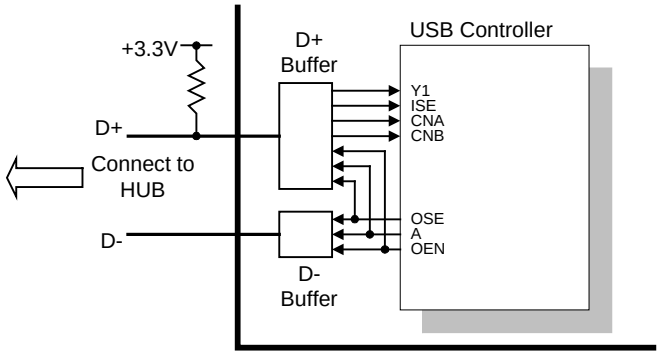
Following table indicates the Endpoint which is used to send data and the Endpoint at which the data will be received.

Tx EndPoint	Rx EndPoint
EndPoint0 (Control)	EndPoint0 (Control)
EndPoint1 (Isochronous)	EndPoint2 (Isochronous)
EndPoint3 (Bulk)	EndPoint4 (Bulk)
EndPoint5 (Interrupt)	EndPoint6 (Interrupt)

6.9 Example of Connection

USB Controller is connected to LAKI's internal USB I/O buffer and the internal bus (IBUS) as shown in the following figure 6-30.

Figure 6-30. Example of Connection



When designing a PCB, it is necessary to connect a 1.5 k ohm pull-up resistor between the D+ pin and the 3.3 V power supply to indicate the presence of a full-speed device. In addition, the impedance between the USB connector and each of the D+ and D- pins must be adjusted to 27 ohm.

The circuit must be designed such that the LAKI power supply is turned on and off together with the external 3.3 V power supply. If the LAKI power supply is off, but the external 3.3 V power supply is on, the USB HUB connected to LAKI will assume that a new device has been connected but, because the LAKI power is off, no response can be returned.

For details of the electrical specifications of the USB, refer to USB Specification 1.1.

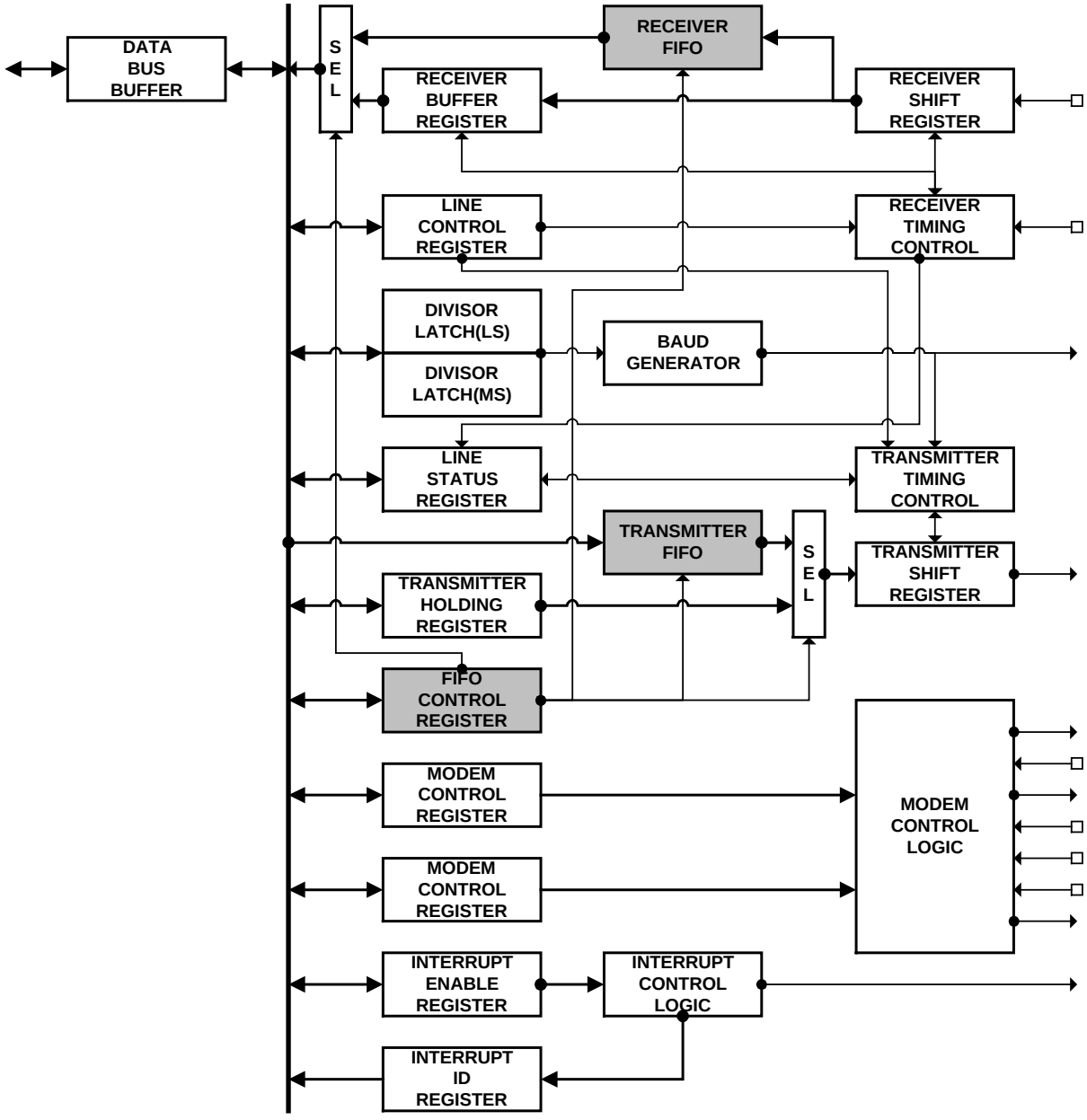
[MEMO]

CHAPTER 7 UART

7.1 Overview

UART is a serial interface that conforms to the RS-232-C communication standard and is equipped with two one-channel interfaces, one for transmission and one for reception. This unit is functionally compatible with the NS16550D, but does not support the FIFO mode.

7.2 UART Block Diagram



Caution The FIFO control blocks are implemented in the UART, but not supported in LAKI

7.3 UART Registers

This controller uses the NEC NA16550L Mega-Function as its internal UART. This UART is functionally identical to the National Semiconductor NS16550D. Refer to the NEC “User’s Manual. Mega FunctionNA16550L” for more information and programming details.

7.3.1 UART Receiver data Buffer Register (UARTRBR) (80H, DLAB = 0, R)

This register holds receive data. It is only accessed when the Divisor Latch Access bit(DLAB) is cleared in the UARTLCR.

Bits	Field	Description
7:0	UDATA	UART data (read only) when DLAB = 0.
31:8	Reserved	Hardwired to 0.

7.3.2 UART Interrupt Enable Register (UARTIER) (84H, DLAB = 1, R/W)

This register is used to enable UART interrupts. It is only accessed when the Divisor Latch Access bit (DLAB) is set in the UARTLCR. The UARTIM bit2 in Interrupt Mask Register “IMR” is a global enable for interrupt sources enabled by this register.

Bits	Field	Description
0	ERBFI	UART Receive data Buffer Full Interrupt 1 = Enable receive-data-available interrupt 0 = Disable such interrupts Receive data-Buffer-Full state reported to UARTLSR
1	ERBEI	UART Transmitter Buffer empty Interrupt 1 = Enable Transmitter Buffer empty interrupt 0 = Disable such interrupts Transmitter Buffer empty state reported to UARTLSR
2	ERBLI	UART Line status Interrupts 1 = Enable Line status error interrupt 0 = Disable such interrupts Line status error interrupt state reported to UARTLSR
3	ERBMI	UART Modem status Interrupts 1 = Enable Modem status change interrupt 0 = Disable such interrupts Modem status changes are reported to UARTMSR
31:4	Reserved	Hardwired to 0.

7.3.3 UART Divisor Latch LSB Register (UARTDLL) (80H, DLAB = 1, R/W)

This register is used to set the divisor (division rate) for the baud rate generator. The data in this register and the upper 8-bit data in UARTDLM register are together handled as 16-bit data.

Bits	Field	Description
7:0	DIVLSB	UART divisor latch (least significant byte) Only accessed when DLAB = 1 in UARTLCR
31:8	Reserved	Hardwired to 0.

7.3.4 UART Divisor Latch MSB Register (UARTDLM) (84H, DLAB = 1, R/W)

This register is used to set the divisor (division rate) for the baud rate generator. The data in this register and the lower 8-bit data in UARTDLL register are together handled as 16-bit data.

Bits	Field	Description
7:0	DIVLSB	UART divisor latch (least significant byte) Only accessed when DLAB = 1 in UARTLCR
31:8	Reserved	Hardwired to 0.

Table 7-1. Correspondence between Baud Rates and Divisors

Baud Rate	UART Source Clock Frequency					
	18.432MHz (Use External Clock)		33.000MHz (CPU Clock = 66MHz)		50.000MHz (CPU Clock = 100MHz)	
	Divisor	Error	Divisor	Error	Divisor	Error
50	23040	0	41250	>1%	62500	0
75	15360	0	27500	>1%	41667	>1%
110	10473	0	18750	>1%	28409	>1%
134.5	8565	0	15335	>1%	23234	>1%
150	7680	0	13750	>1%	20833	>1%
300	3840	0	6875	>1%	10417	>1%
600	1920	0	3438	>1%	5208	>1%
1200	920	0	1719	>1%	2604	>1%
1800	640	0	1146	>1%	1736	>1%
2000	573	0	1031	>1%	1562	>1%
2400	480	0	859	>1%	1302	>1%
3600	320	0	573	>1%	868	>1%
4800	240	0	430	>1%	651	>1%
7200	160	0	286	>1%	434	>1%
9600	120	0	215	>1%	326	>1%
19200	60	0	107	>1%	163	>1%
38400	30	0	54	>1%	81	>1%
56000	21	2.04%	37	>1%	56	>1%
128000	9	0	16	>1%	24	1.69%
144000	8	0	14	2.25%	22	1.38%
192000	6	0	11	2.41%	16	1.69%
230400	5	0	9	>1%	14	3.22%
288000	4	0	7	2.25%	11	1.38%
384000	3	0	5	6.90%	8	1.69%
576000	2	0	4	11.7%	5	7.83%
1152000	1	0	2	11.7%	3	10.6%

Remark If UCSEL bit in the S_GMR Register is set, The external UART clock “URCLK” is used as UART source clock.

If UCSEL bit is reset, 1/2 of CPU clock is used as UART source clock.

7.3.5 UART Interrupt ID Register (UARTIIR) (88H, R)

This register indicates priority levels for interrupts and existence of pending interrupt. From highest to lowest priority, these interrupts are receive line status, receive data ready, character timeout, transmit holding register empty, and modem status. The contents of UARTIIR[3] bit is valid only in FIFO mode, and it is always 0 in 16550 mode. UARTIIR[2] bit becomes 1 when UARTIIR[3] bit is set to 1.

Bits	Field	Description		
0	INTPENDL	Pending interrupts 0 = UART Interrupt pending(read only) 1 = No UART interrupt pending		
3:1	UIID	Indicates the priority level of pending interrupt.		
		UIID[2:0]	Priority	Source of interrupt
		3	Highest	Receiver Line status: Overrun Error, Parity, Framing Error, or Break interrupt
		2	2nd Highest	Received data available: Receiver Data Available or Trigger Level Reached
		6	3rd Highest	Character timeout indication: No change in receiver FIFO during the last four character times and FIFO is not empty.
		1	4th Highest	Transmitter holding Register Empty
		0	5th Highest	Modem Status: CTS_L, DSR_L or DCD_L.
5:4	Reserved	Hardwired to 0.		
7:6	UFIFOEN	UART FIFO is enable (read only) Both bits set to 1 when the transmit/receive FIFO is enabled in the UFIFOEN0 bit is set in the UARTFCR.		
31:8	Reserved	Hardwired to 0.		

Remark LAKI does NOT support the FIFO mode, thus the UFIFOEN field will show zero.

7.3.6 UART FIFO Control Register (UARTFCR) (88H, W)

This register is used to control the FIFOs: enable FIFO, clear FIFO, and set the receive FIFO trigger level. (This UARTFCR register is not available, this is because that it is not possible to use FIFO mode.)

Bits	Field	Description
0	UFIFOEN0	UART Receiver FIFO Enable. (write-only) 1 = enable receive and transmit FIFOs. 0 = disable and clear receive and transmit FIFOs.
1	URFRST	UART Receiver FIFO Reset. (write-only) 1 = clear receive FIFO and reset counter. 0 = no clear.
2	UTFRST	UART Transmitter FIFO Reset. (write-only) 1 = clear transmit FIFO and reset counter. 0 = no clear.
3	FIFOMD	Switch between 16550 mode and FIFO mode 1= From 16550 mode to FIFO mode (INVALID) 0= From FIFO mode to 16550 mode
5:4	Reserved	Hardwired to 0.
7:6	URFTR	UART Receive FIFO Trigger level. When the trigger level is reached, a Receive-buffer-Full interrupt is generated, if enable by the ERBFI bit in the UARTIER. Number of bytes in Receiver FIFO is following. 0 = 1byte 1 = 4byte 2 = 8byte 3 = 14bytes
31:8	Reserved	Hardwired to 0.

7.3.7 UART Line Control Register (UARTLCR) (8CH, R/W)

This register is used to specify the format for asynchronous communication and exchange and to set the divisor latch access bit. Bit 6 is used to send the break status to the receive side's UART. When bit 6 = 1, the serial output (URSDO) is forcibly set to the spacing (0) state. The setting of bit 5 becomes valid according to settings in bits 4 and 3.

Bits	Field	Description
1:0	WLS	Word length select. 11 = 8 bits 10 = 7 bits 01 = 6 bits 00 = 5 bits
2	STB	Number of stop bits. 1 = 2 bits, except 1.5 stop bits for 5 words 0 = 1 bit
3	PEN	Parity enable. 1 = generate parity on writes, check it on reads. 0 = no parity generation or checking. For the UART, even or odd parity can be generated or checked, as specified in Bit 4 (EPS).
4	EPS	Parity select. 1 = even parity 0 = odd parity
5	USP	Stick parity. Please set 0.
6	REV	Reserved for future use. Please set 0 when V_R4120A access.
7	DLAB	Divisor Latch access bit. 1 = access baud-rate divisor at offset 84H 0 = access URSDO/URSDI and IE at offset 84H When this bit is set, UART accesses the UART Divisor Latch LSB Register (UARTDLM) at offset 84H. When cleared, the UART accesses the Receiver Data Buffer Register (UARTRBR) on reads at offset 80H, the UARTTHR on writes at offset 80H, and UARTIER on any accesses at offset 84H.
31:8	Reserved	Hardwired to 0.

7.3.8 UART Modem Control Register (UARTMCR) (90H, R/W)

This register controls the state of external URDTR_B and URRTS_B modem-control signals and of the loop-back test.

Bits	Field	Description
0	DTR	Data Terminal Ready. 1 = negate URDTR_B signal. 0 = assert URDTR_B signal.
1	RTS	Request To Send. 1 = negate URRTS_B signal. 0 = assert URRTS_B signal.
2	OUT1	Out 1 (internal). 1 = OUT1_B (internal) state active. 0 = OUT1_B (internal) state inactive (reset value). This is a user-defined bit that has no associated external signal. Software can write to the bit, but this has no effect.
3	OUT2	Out 2 (internal). 1 = OUT2_B (internal) state active. 0 = OUT2_B (internal) state inactive (reset value). This is a user-defined bit that has no associated external signal. Software can write to the bit, but this has no effect.
4	LOOP	Loop-Back Test. 1 = loop-back. 0 = normal operation. This is an NEC internal test function.
31:5	Reserved	Hardwired to 0.

7.3.9 UART Line Status Register (UARTLSR) (94H, R/W)

This register reports the current state of the transmitter and receiver logic.

Bits	Field	Description
0	DR	Receive-Data Ready. 1 = receive data buffer full. 0 = receive data buffer not full. Receive data is stored in the UART Receiver Data Buffer Register (UARTRBR).
1	OE	Receive-Data Overrun Error. 1 = overrun error on receive data. 0 = no such error.
2	PE	Receive-Data Parity Error. 1 = parity error on receive data. 0 = no such error.
3	FE	Receive-Data Framing Error. 1 = framing error on receive data. 0 = no such error.
4	BI	Break Interrupt. 1 = break received on URSDI signal. 0 = no break.
5	THRE	Transmitter Holding Register Empty. 1 = transmitter holding register empty. 0 = transmitter holding register not empty. Transmit data is stored in the UART Transmitter Data Holding Register (UARTTHR)
6	TEMT	Transmitter Empty. 1 = transmitter holding and shift registers empty. 0 = transmitter holding or shift register not empty.
7	RFERR	Receiver FIFO Error. 1 = parity, framing, or break error in receiver buffer. 0 = no such error.
31:8	Reserved	Hardwired to 0.

Remark RFERR will not become to 1, because LAKI does NOT support FIFO mode.

7.3.10 UART Modem Status Register (UARTMSR) (98H, R/W)

This register reports the current state of and changes in various control signals.

Bits	Field	Description
0	DCTS	Delta Clear To Send. 1 = URCTS_B state changed since this register was last read. 0 = no such change.
1	DDSR	Delta Data Set Ready. 1 = URDSR_B input signal changed since this register was last read. 0 = no such change.
2	TERI	Trailing Edge Ring Indicator. 1 = RI_B state changed since this register last read. 0 = no such change. RI_B is not implemented as an external signal, so this bit is never set by the controller.
3	DDCD	Delta Data Carrier Detect. 1 = URDCD_B state changed since this register was last read. 0 = no such change.
4	CTS	Clear To Send. 1 =URCTS_B state active. 0 = URCTS_B state inactive. This bit is the complement of the URCTS_B input signal. If the LOOP bit in the UART Modem Control Register (UARTMCR), is set to 1, the CTS bit is equivalent to the RTS bit in the UARTMCR.
5	DSR	Data Set Ready. 1 = URDSR_B state active. 0 = URDSR_B state inactive. This bit is the complement of the URDSR_B input signal. If the LOOP bit in the UART Modem Control Register (UARTMCR), is set to 1, the DSR bit is equivalent to the DTR bit in the UARTMCR.
6	RI	Ring Indicator. 1 = not valid. 0 = always reads 0. This bit has no associated external signal.
7	DCD	Data Carrier Detect. 1 =URDCD_B state active. 0 = URDCD_B state inactive. This bit is the complement of the URDCD_B input signal. If the LOOP bit in the UART Modem Control Register (UARTMCR), is set to 1, the DCD bit is equivalent to the OUT2 bit in the UARTMCR.
31:8	Reserved	Hardwired to 0.

7.3.11 UART Scratch Register (UARTSCR) (9CH, R/W)

This register contains a UART reset bit plus 8 bits of space for any software use.

Bits	Field	Description
7:0	USCR	UART Scratch Register. Available to software for any purpose.
31:8	Reserved	Hardwired to 0.

[MEMO]

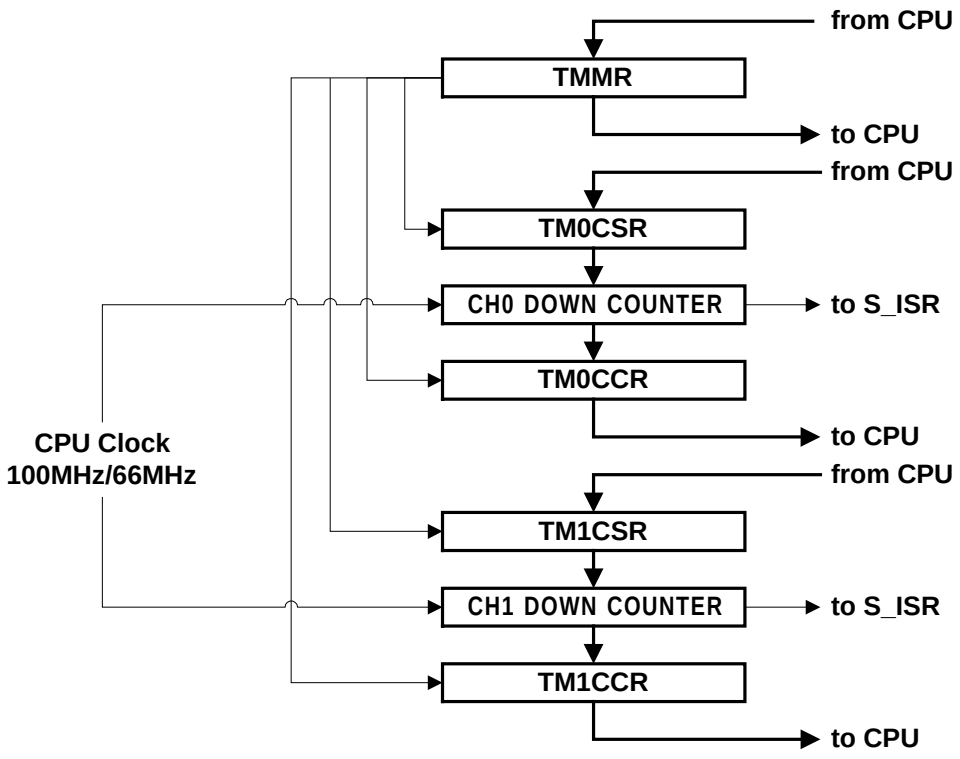
CHAPTER 8 TIMER

8.1 Overview

There are two Timers. The timers are clocked at the system clock rate. All two timers are read/writable by the CPU. Timers can be read by the CPU while they are counting. They can be automatically reloaded with the previously loaded value and restarted or can be stopped while in progress. Two timers issues interrupt to the CPU upon reaching their maximum value, the interrupts can be enabled/disabled.

The TM0IS and TM1IS fields in the Interrupt Status Register “S_ISR” indicate the end of timer count, when set indicate there is a timer event that completed. All timers count up. The read-write registers “TM0CSR” or “TM1CSR” have different offset from the read register so write registers are not affected while a value is read from the read registers “TM0CCR” / ”TM1CCR” which indicate a running count of the timer/counter at a given time. Once a value is loaded in the TM0CSR/TM1CSR, it stays there until Timer’s interrupts are cleared in the Interrupt Status Register “S_ISR”. The original value can be reloaded in the counter to restart it from that count if Timer CH0 / CH1 reload enable bit is set in the Timer Mode Register “TMMR”. Interrupts are automatically cleared upon CPU reading the Interrupt Status Register of System Controller “S_ISR”.

8.2 Block Diagram



8.3 Timer Registers

8.3.1 Timer Mode Register (TMMR) (B0H, R/W)

The Timer Mode Register “TMMR” is read-write and word aligned 32bit register. TMMR is used to control the timer. TMMR is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
0	TM0EN	Timer CH0 enable: 1 = Enable, starts the timer (Automatically reloads the original timer value and starts if timer had expired) 0 = Disable, stops the timer
7:1	Reserved	Hardwired to 0.
8	TM1EN	Timer CH1 enable: 1 = Enable, starts the timer (Automatically reloads the original timer value and starts if timer had expired) 0 = Disable, stops the timer
31:9	Reserved	Hardwired to 0.

8.3.2 Timer CH0 Count Set Register (TM0CSR) (B4H, R/W)

The Timer CH0 Count Set Register “TM0CSR” is read-write and word aligned 32bit register. CPU (VR4120A) loads a value in it and the counter starts counting down from the (TM0CSR –1) value, when it reaches 0000_0000H, it generates an interrupt to the CPU via Interrupt Status Register “ISR” if the TM0IS in ISR is not masked by TM0IM in IMR. TM0CSR is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
31:0	TM0SET	Initial and Reload Value for Timer CH0

8.3.3 Timer CH1 Count Set Register (TM1CSR) (B8H, R/W)

The Timer CH1 Count Set Register “TM1CSR” is read-write and word aligned 32bit register. CPU (VR4120A) loads a value in it and the counter starts counting down from the (TM1CSR –1) value, when it reaches 0000_0000H, it generates an interrupt to the CPU via Interrupt Status Register “ISR” if the TM1IS in ISR is not masked by TM1IM in IMR. TM1CSR is initialized to 0 at reset and contains the following fields:

Bits	Field	Description
31:0	TM1SET	Initial and Reload Value for Timer CH1

8.3.4 Timer CH0 Current Count Register (TM0CCR) (BCH, R)

The Timer CH0 Current Count Register “TM0CCR” is read-only and word aligned 32bit register. CPU (VR4120A) can read its value to get timer CH0 current count. TM0CSR is initialized to FFFF_FFFFH at reset and contains the following fields:

Bits	Field	Description
31:0	TM0CNT	Timer CH0 Current Count Value

8.3.5 Timer CH1 Current Count Register (TM1CCR) (C0H, R)

The Timer CH1 Current Count Register “TM1CCR” is read-only and word aligned 32bit register. CPU (VR4120A) can read its value to get timer CH1 current count. TM1CCR is initialized to FFFF_FFFFH at reset and contains the following fields:

Bits	Field	Description
31:0	TM0CNT	Timer CH0 Current Count Value

[MEMO]

CHAPTER 9 MICRO WIRE

9.1 Overview

This E2PROM interface is compatible with the MICROWIRE serial interface based EEPROMs. Connection to the “NM93C46” serial E2PROM, manufactured by National Semiconductor, is recommended.

Serial E2PROM memory area is accessed in-directly through micro wire macro registers, that is ECCR and ERDR registers. To access the E2PROM, VR4120 writes a command into the ECCR register of the micro wire macro. When micro wire macro accepts the command, it executes the command via the E2PROM interface. To read E2PROM data, VR4120 sets an address and READ command into the ECCR register. When the micro wire macro is reading data, the MSB bit of the ERDR register is set to 1. Once the micro wire macro finishes reading the data, it sets the MSB bit to 0 and stores the data in the EDAT field. After issuing the command, VR4120 checks that the MSB bit of the ERDR register is set to 0, then obtains the data. To write data into or erase data from the E2PROM, VR4120 must enable write and erase operations using the EWEN command in advance. When no E2PROM is connected, accessing these registers is meaningless.

This micro wire interface has also auto-load function. By this function, USER can read 12 byte data of E2PROM (0x1 to 0x6 of half-word unit) throughout MACAR1-3 registers without ECCR register’s control. This auto-load function works one-time after system boot. And it is necessary for auto-loading to obey initial data format for E2PROM.(refer to table below)

During both auto-loading or loading by ECCR register, MSB bit of ERDR register is asserted to ‘1’ for flag of busy state. At the end of E2PROM loading, MSB bit of ERDR register is de-asserted to ‘0’, and then USER can read MACAR1-3 register or [15:0] field of ERDR register.

9.2 Micro Wire Connection

In contrast to KORVA (µPD98501), the Microwire signals are not shared with the UART modem pins, and there is no SSEL select pins to activate the Microwire required. So the Microwire interface features only four dedicated pins

- MWSK : Clock output line
- MWCS : Chip select line
- MWDO : Serial data output line
- MWDI : Serial data input line

9.3 Operations

9.3.1 Data read at the power up load

After reset release, power up load processes starts .

In case of the value from EEPROM address 00h is :

1. A5A5h
   System Controller sets the EEPROM data (address:01h-06h) in the internal registers (MACAR1, MACAR2, MACAR3).
2. NOT A5A5h
   System Controller sets the fix data “0000_0000h” in the internal registers (MACAR1, MACAR2, MACAR3).

Table 9-1. EEPROM Initial Data

EEPROM Address	Data	Stored Register
00h	5A5A h	-
01h	MAC1 Address data[15: 0]	MACAR1[15: 0]
02h	MAC1 Address data[31:16]	MACAR1[31:16]
03h	MAC1 Address data[47:32]	MACAR2[15: 0]
04h	2nd MAC Address data[15: 0]	MACAR2[31:16]
05h	2nd MAC Address data[31:16]	MACAR3[15:0]
06h	2nd MAC Address data[47:32]	MACAR4[31:16]

Note: 2nd MAC address support is available for compatibility reasons to other NEC network controller devices and may be used to support external 2nd Ethernet port

9.3.2 Accessing to EEPROM

Access to EEPROM starts by writing to the ECCR (EEPROM Command Control Register).

Write command (3bit) and address (6bit) of EEPROM into lower 9bit of ECCR.

There is a difference between write command and read command.

1. Write command
   Write data into upper 16bit of ECCR.
2. Read command
   Data is loaded into lower 16bit of ERDR (EEPROM Read Data Register).

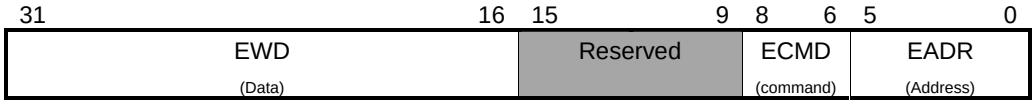
Table 9-2. EEPROM Command List

Command	bit8-6	bit5-0	Operation
READ	110	A5-A0	Read data from EEPROM assigned by address A5-A0.
EWEN	100	11xxxx	Enable Erase/Write command. This command must be executed before other operating.
ERASE	111	A5-A0	Erase data of EEPROM assigned by address A5-A0.
WRITE	101	A5-A0	Write data to EEPROM assigned by address A5-A0.
ERAL	100	10xxxx	Erase all data of EEPROM.
WRAL	100	01xxxx	Write all data to EEPROM.
EWDS	100	00xxxx	Disable Erase/Write command.

9.4 Registers

9.4.1 ECCR (EEPROM Command Control Register) Address 1000_00D0H [Write Only]

The E2PROM Command Control Register “ECCR” is write-only and word aligned 32bit register. ECCR is used to control the R/W operation. ECCR contains the following fields:

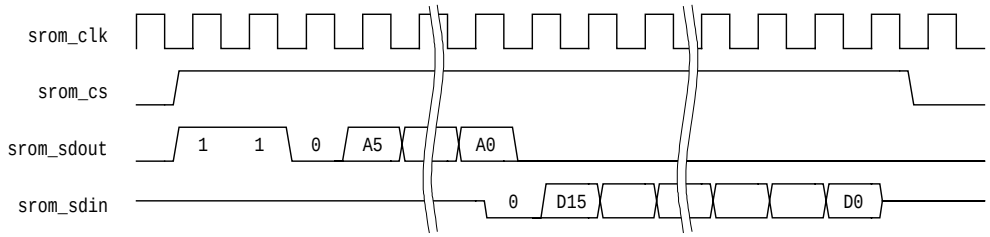


bit 31-16 : EWD - Write data to Serial EEPROM. No meaning in case of data read.

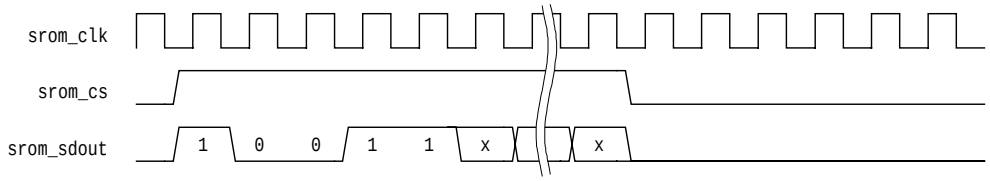
bit 15- 9 : Reserved
bit 8- 6 : ECMD - Serial EEPROM command.
bit 5- 0 : EADR - Serial EEPROM address.

The following graphics show the signal behavior for the different commands:

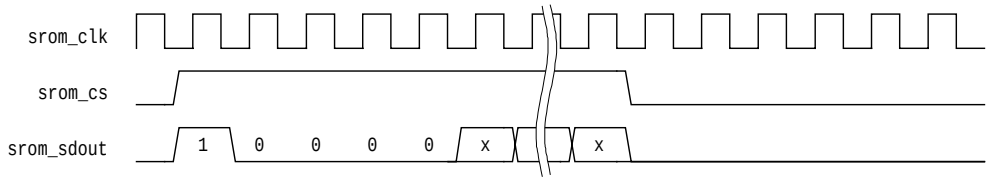
READ:



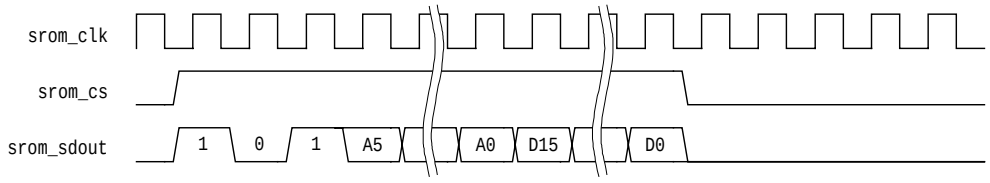
EWEN:



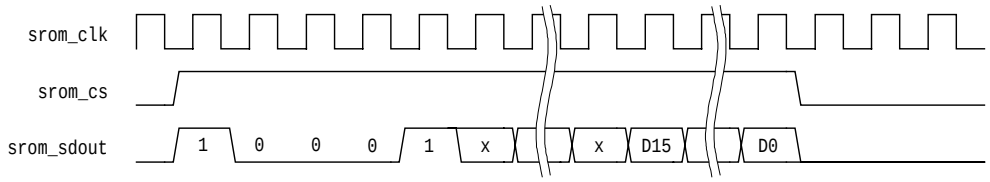
EWDS:



WRITE:

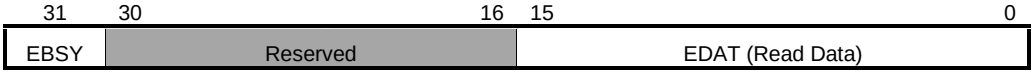


WRAL:



9.4.2 ERDR (EEPROM Read Data Register) Address 1000_00D4H [Read Only]

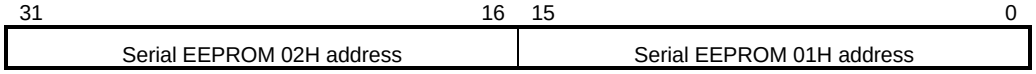
The E2PROM Read Data Register “ERDR” is read-only and word aligned 32bit register. ERDR is used to read E2PROM data. ERDR contains the following fields:



bit 31 : EBSY - Operation status of MICROWIRE block.
1 : busy
0 : idle
bit 30-16 : Reserved
bit 15- 0 : EDAT - Read data from Serial EEPROM.

9.4.3 MACAR1 (MAC Address Register 1) Address 1000_00D8H [Read Only]

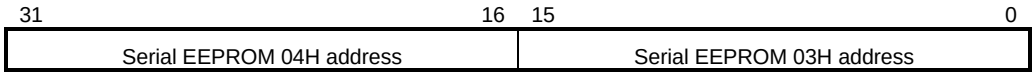
The MAC Address Register “MACAR1” is read-only and word aligned 32bit register. MACAR1 is generally used to be a part of MAC address. It is loaded after system boot, if 0x0 address’s value of E2PROM was 0xA5A5. MACAR1 contains the following fields:



bit 31-0 : Stored Serial EEPROM data of address 01H, 02H.

9.4.4 MACAR2 (MAC Address Register 2) Address 1000_00DCH [Read Only]

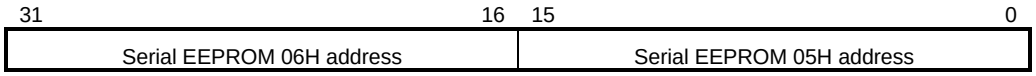
The MAC Address Register “MACAR2” is read-only and word aligned 32bit register. MACAR2 is generally used to be a part of MAC address. It is loaded after system boot, if 0x0 address’s value of E2PROM was 0xA5A5. MACAR2 contains the following fields:



bit 31-0 : Stored Serial EEPROM data of address 03H, 04H.

9.4.5 MACAR3 (MAC Address Register 3) Address 1000_00E0H [Read Only]

The MAC Address Register “MACAR3” is read-only and word aligned 32bit register. MACAR3 is generally used to be a part of MAC address. It is loaded after system boot, if 0x0 address’s value of E2PROM was 0xA5A5. MACAR3 contains the following fields:



bit 31-0 : Stored Serial EEPROM data of address 05H, 06H.

[MEMO]

APPENDIX A MIPS III INSTRUCTION SET DETAILS

This chapter provides a detailed description of the operation of each instruction in both 32- and 64-bit modes. The instructions are listed in alphabetical order.
Please note, that future NEC Network Controller devices might not support the MIPSIII instruction set.

A.1 Instruction Notation Conventions

In this chapter, all variable subfields in an instruction format (such as *rs*, *rt*, *immediate*, etc.) are shown in lowercase names.

For the sake of clarity, we sometimes use an alias for a variable subfield in the formats of specific instructions. For example, we use *base* instead of *rs* in the format for load and store instructions. Such an alias is always lower case, since it refers to a variable subfield.

Figures with the actual bit encoding for all the mnemonics are located at the end of this chapter (**A.6 CPU Instruction Opcode Bit Encoding**), and the bit encoding also accompanies each instruction.

In the instruction descriptions that follow, the operation section describes the operation performed by each instruction using a high-level language notation. The VR4120A CPU can operate as either a 32- or 64-bit microprocessor and the operation for both modes is included with the instruction description.

Special symbols used in the notation are described in Table A-1.

Table A-1. CPU Instruction Operation Notations

Symbol	Meaning
←	Assignment
||	Bit string concatenation
x^y	Replication of bit value *x* into a *y*-bit string. *x* is always a single-bit value
xy:z	Selection of bits *y* through *z* of bit string *x*. Little-endian bit notation is always used. If *y* is less than *z*, this expression is an empty (zero length) bit string
+	2's complement or floating-point addition
-	2's complement or floating-point subtraction
*	2's complement or floating-point multiplication
div	2's complement integer division
mod	2's complement modulo
/	Floating-point division
<	2's complement less than comparison
and	Bit-wise logical AND
or	Bit-wise logical OR
xor	Bit-wise logical XOR
nor	Bit-wise logical NOR
GPR [*x*]	General-Register *x*. The content of GPR [0] is always zero. Attempts to alter the content of GPR [0] have no effect.
CPR [*z, x*]	Coprocessor unit *z*, general register *x*.
CCR [*z, x*]	Coprocessor unit *z*, control register *x*.
COC [*z*]	Coprocessor unit *z* condition signal.
BigEndianMem	Big-endian mode as configured at reset (0 → Little, 1 → Big). Specifies the endianness of the memory interface (see LoadMemory and StoreMemory), and the endianness of Kernel and Supervisor mode execution. However, this value is always 0 since the VR4120A CPU supports the little endian order only.
ReverseEndian	Signal to reverse the endianness of load and store instructions. This feature is available in User mode only, and is effected by setting the RE bit of the Status register. Thus, ReverseEndian may be computed as (SR25 and User mode).However, this value is always 0 since the VR4120A CPU supports the little endian order only.
BigEndianCPU	The endianness for load and store instructions (0 → Little, 1 → Big). In User mode, this endianness may be reversed by setting RE bit. Thus, BigEndianCPU may be computed as BigEndianMem XOR ReverseEndian.However, this value is always 0 since the VR4120A CPU supports the little endian order only.
T + *i*:	Indicates the time steps between operations. Each of the statements within a time step are defined to be executed in sequential order (as modified by conditional and loop constructs). Operations which are marked T + *i*: are executed at instruction cycle *i* relative to the start of execution of the instruction. Thus, an instruction which starts at time *j* executes operations marked T + *i*: at time *i + j*. The interpretation of the order of execution between two instructions or two operations that execute at the same time should be pessimistic; the order is not defined.

(1) Instruction notation examples

The following examples illustrate the application of some of the instruction notation conventions:

Example 1:

$$GPR\ [rt] \leftarrow immediate\ ||\ 0^{16}$$

Sixteen zero bits are concatenated with an immediate value (typically 16 bits), and the 32-bit string is assigned to general register *rt*.

Example 2:

$$(immediate15)^{16}\ ||\ immediate15...0$$

Bit 15 (the sign bit) of an immediate value is extended for 16-bit positions, and the result is concatenated with bits 15 through 0 of the immediate value to form a 32-bit sign extended value.

A.2 Load and Store Instructions

In the VR4120A CPU implementation, the instruction immediately following a load may use the loaded contents of the register. In such cases, the hardware interlocks, requiring additional real cycles, so scheduling load delay slots is still desirable, although not required for functional code.

In the load and store descriptions, the functions listed in Table A-2 are used to summarize the handling of virtual addresses and physical memory.

Table A-2. Load and Store Common Functions

Function	Meaning
AddressTranslation	Uses the TLB to find the physical address given the virtual address. The function fails and an exception is taken if the required translation is not present in the TLB.
LoadMemory	Uses the cache and main memory to find the contents of the word containing the specified physical address. The low-order three bits of the address and the Access Type field indicate which of each of the four bytes within the data word need to be returned. If the cache is enabled for this access, the entire word is returned and loaded into the cache. If the specified data is short of word length, the data position to which the contents of the specified data is stored is determined considering the endian mode and reverse endian mode.
StoreMemory	Uses the cache, write buffer, and main memory to store the word or part of word specified as data in the word containing the specified physical address. The low-order three bits of the address and the Access Type field indicate which of each of the four bytes within the data word should be stored. If the specified data is short of word length, the data position to which the contents of the specified data is stored is determined considering the endian mode and reverse endian mode.

As shown in Table A-3, the Access Type field indicates the size of the data item to be loaded or stored. Regardless of access type or byte-numbering order (endian), the address specifies the byte that has the smallest byte address in the addressed field. This is the rightmost byte in the VR4120A CPU since it supports the little-endian order only.

Table A-3. Access Type Specifications for Loads/Stores

Access Type	Meaning
DOUBLEWORD	8 bytes (64 bits)
SEPTIBYTE	7 bytes (56 bits)
SEXTIBYTE	6 bytes (48 bits)
QUINTIBYTE	5 bytes (40 bits)
WORD	4 bytes (32 bits)
TRIPLEBYTE	3 bytes (24 bits)
HALFWORD	2 bytes (16 bits)
BYTE	1 byte (8 bits)

The bytes within the addressed doubleword that are used can be determined directly from the access type and the three low-order bits of the address.

A.3 Jump and Branch Instructions

All jump and branch instructions have an architectural delay of exactly one instruction. That is, the instruction immediately following a jump or branch (that is, occupying the delay slot) is always executed while the target instruction is being fetched from storage. A delay slot may not itself be occupied by a jump or branch instruction; however, this error is not detected and the results of such an operation are undefined.

If an exception or interrupt prevents the completion of a legal instruction during a delay slot, the hardware sets the EPC register to point at the jump or branch instruction that precedes it. When the code is restarted, both the jump or branch instructions and the instruction in the delay slot are reexecuted.

Because jump and branch instructions may be restarted after exceptions or interrupts, they must be restartable. Therefore, when a jump or branch instruction stores a return link value, register *r31* (the register in which the link is stored) may not be used as a source register.

Since instructions must be word-aligned, a Jump Register or Jump and Link Register instruction must use a register which contains an address whose two low-order bits (low-order one bit in the 16-bit mode) are zero. If these low-order bits are not zero, an address exception will occur when the jump target instruction is subsequently fetched.

A.4 System Control Coprocessor (CP0) Instructions

There are some special limitations imposed on operations involving CP0 that is incorporated within the CPU. Although load and store instructions to transfer data to/from coprocessors and to move control to/from coprocessor instructions are generally permitted by the MIPS architecture, CP0 is given a somewhat protected status since it has responsibility for exception handling and memory management. Therefore, the move to/from coprocessor instructions are the only valid mechanism for writing to and reading from the CP0 registers.

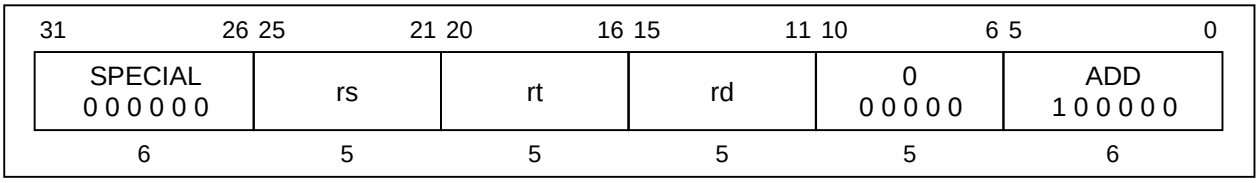
Several CP0 instructions are defined to directly read, write, and probe TLB entries and to modify the operating modes in preparation for returning to User mode or interrupt-enabled states.

A.5 CPU Instruction

This section describes the functions of CPU instructions in detail for both 32-bit address mode and 64-bit address mode.

The exception that may occur by executing each instruction is shown in the last of each instruction's description. For details of exceptions and their processes, see **Section 2.6 Exception Processing**.

ADD — Add — ADD



Format:

ADD rd, rs, rt

Description:

The contents of general register *rs* and the contents of general register *rt* are added to form the result. The result is placed into general register *rd*. In 64-bit mode, the operands must be valid sign-extended, 32-bit values.

An overflow exception occurs if the carries out of bits 30 and 31 differ (2's complement overflow). The destination register *rd* is not modified when an integer overflow exception occurs.

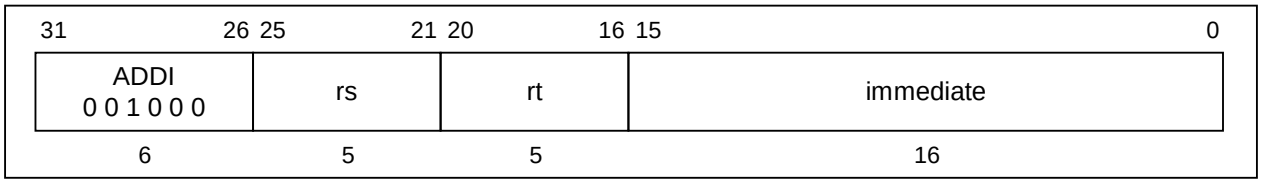
Operation:

```
32   T:   GPR [rd] ← GPR [rs] + GPR [rt]

64   T:   temp ← GPR [rs] + GPR [rt]
          GPR [rd] ← (temp31)^32 || temp31...0
```

Exceptions:

Integer overflow exception

ADDI — Add Immediate — ADDI



Format:

ADDI rt, rs, immediate

Description:

The 16-bit *immediate* is sign-extended and added to the contents of general register *rs* to form the result. The result is placed into general register *rt.* In 64-bit mode, the operand must be valid sign-extended, 32-bit values.

An overflow exception occurs if carries out of bits 30 and 31 differ (2's complement overflow). The destination register *rt* is not modified when an integer overflow exception occurs.

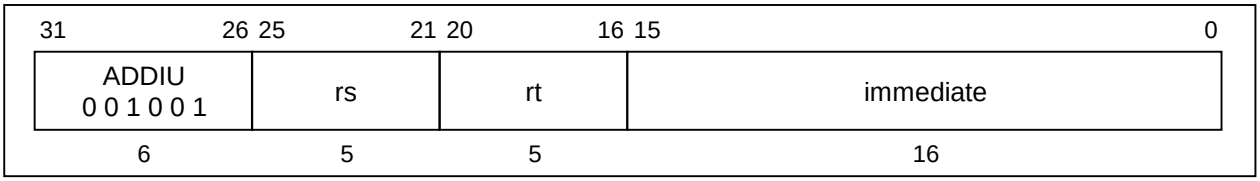
Operation:

```
32    T:    GPR [rt] ← GPR [rs] + (immediate15)^16 || immediate15...0

64    T:    temp ← GPR [rs] + (immediate15)^48 || immediate15...0
            GPR [rt] ← (temp31)^32 || temp31...0
```

Exceptions:

Integer overflow exception

ADDIU Add Immediate Unsigned ADDIU



Format:

ADDIU rt, rs, immediate

Description:

The 16-bit *immediate* is sign-extended and added to the contents of general register *rs* to form the result. The result is placed into general register *rt.* No integer overflow exception occurs under any circumstances. In 64-bit mode, the operand must be valid sign-extended, 32-bit values.

The only difference between this instruction and the ADDI instruction is that ADDIU never causes an integer overflow exception.

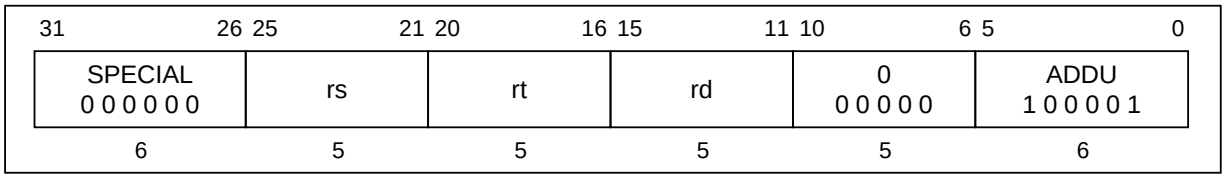
Operation:

```
32   T:   GPR [rt] ← GPR [rs] + (immediate 15)^16 || immediate 15...0

64   T:   temp ←GPR [ rs] + (immediate 15)^48 || immediate 15...0
          GPR [rt] ← (temp 31)^32 || temp 31...0
```

Exceptions:

None

ADDU Add Unsigned ADDU



Format:

ADDU rd, rs, rt

Description:

The contents of general register *rs* and the contents of general register *rt* are added to form the result. The result is placed into general register *rd*. No integer overflow exception occurs under any circumstances. In 64-bit mode, the operands must be valid sign-extended, 32-bit values.

The only difference between this instruction and the ADD instruction is that ADDU never causes an integer overflow exception.

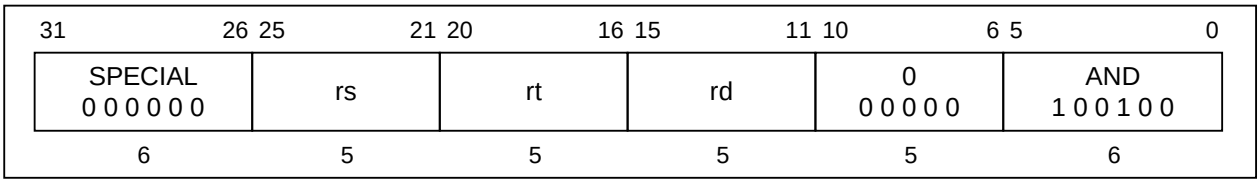
Operation:

```
32    T:    GPR [rd] ← GPR [rs] + GPR [rt]

64    T:    temp ← GPR [rs] + GPR [rt]
            GPR [rd] ← (temp31)^32 || temp31...0
```

Exceptions:

None

AND And AND



Format:

AND rd, rs, rt

Description:

The contents of general register *rs* are combined with the contents of general register *rt* in a bit-wise logical AND operation. The result is placed into general register *rd*.

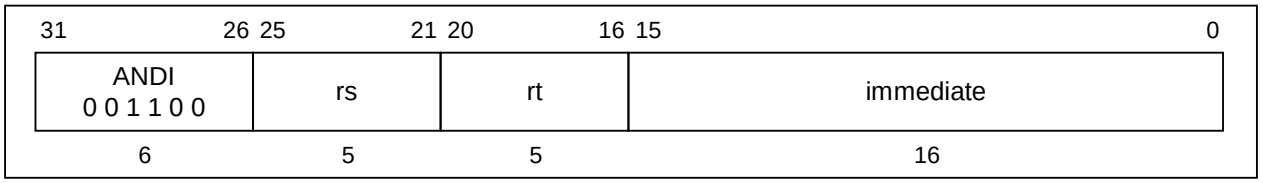
Operation:

```
32   T:   GPR [rd] ←GPR [rs] and GPR [rt]

64   T:   GPR [rd] ← GPR [rs] and GPR [rt]
```

Exceptions:

None

ANDI And Immediate ANDI



Format:

ANDI rt, rs, immediate

Description:

The 16-bit *immediate* is zero-extended and combined with the contents of general register *rs* in a bit-wise logical AND operation. The result is placed into general register *rt*.

Operation:

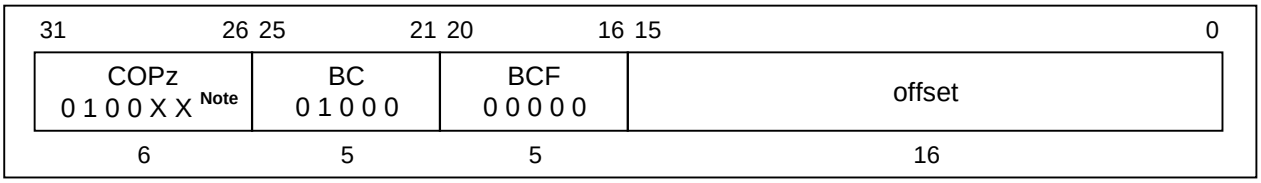
32 T: GPR [rt] $\leftarrow 0^{16}$ || (immediate and GPR [rs]$_{15...0}$)

64 T: GPR [rt] $\leftarrow 0^{48}$ || (immediate and GPR [rs]$_{15...0}$)

Exceptions:

None

BC0F Branch On Coprocessor 0 False BC0F



Format:

BC0F offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset*, shifted left two bits and sign-extended. If contents of CP0's condition signal (CpCond), as sampled during the previous instruction, is false, then the program branches to the target address with a delay of one instruction. Because the condition line is sampled during the previous instruction, there must be at least one instruction between this instruction and a coprocessor instruction that changes the condition line.

Operation:

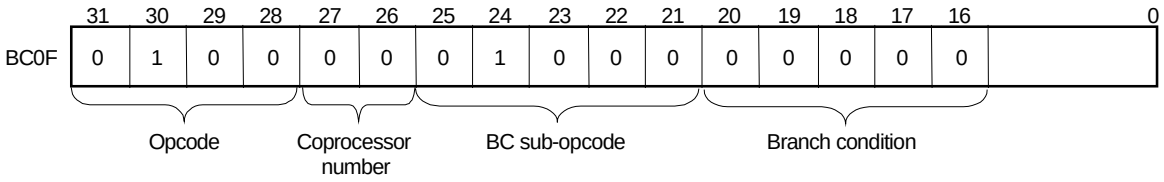
```
32   T-1:  condition ← not SR18
      T:   target ← (offset15)^14 || offset || 0^2
      T+1: if condition then
                PC ←  PC + target
           endif

64   T-1:  condition ← not SR18
      T:   target ← (offset15)^46 || offset || 0^2
      T+1: if condition then
                PC ← PC + target
           endif
```

Exceptions:

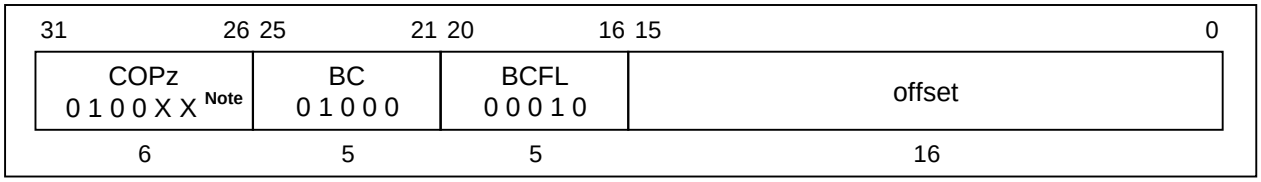
Coprocessor unusable exception

Note See the opcode table below, or **A.6 CPU Instruction Opcode Bit Encoding**.

Opcode Table:



BC0FL Branch On Coprocessor 0 False Likely (1/2) BC0FL



Format:

BC0FL offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset*, shifted left two bits and sign-extended. If the contents of CP0's condition (CpCond) line, as sampled during the previous instruction, is false, the target address is branched to with a delay of one instruction.

If the conditional branch is not taken, the instruction in the branch delay slot is nullified.

Because the condition line is sampled during the previous instruction, there must be at least one instruction between this instruction and a coprocessor instruction that changes the condition line.

Operation:

```
32    T-1:  condition ← not SR18
      T:    target ← (offset15)^14 || offset || 0^2
      T+1:  if condition then
                  PC ← PC + target
            else
                  NullifyCurrentInstruction
            endif

64    T-1:  condition ← not SR
      T:    target ← (offset15)^46 || offset || 0^2
      T+1:  if condition then
                  PC ← PC + target
            else
                  NullifyCurrentInstruction
            endif
```

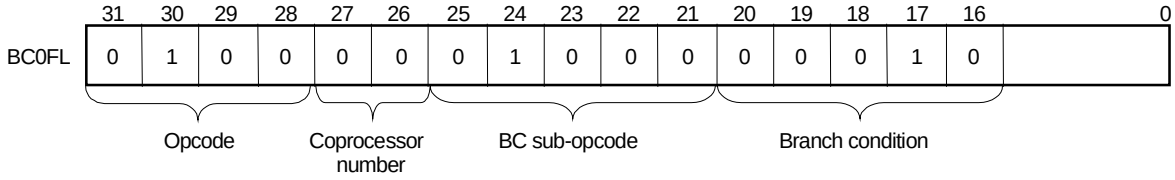
Exceptions:

Coprocessor unusable exception

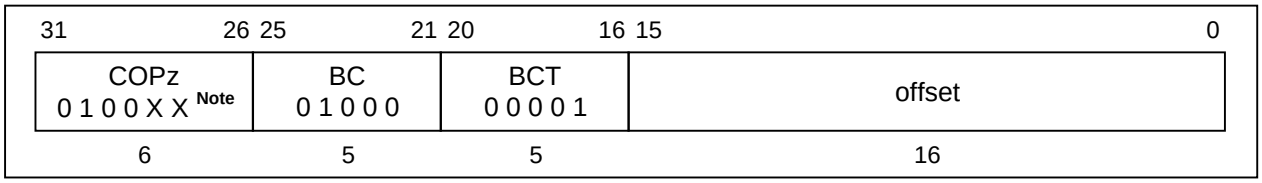
Note See the opcode table below, or **A.6 CPU Instruction Opcode Bit Encoding**.

BC0FL Branch On Coprocessor 0 False Likely (2/2) BC0FL

Opcode Table:



BC0T Branch On Coprocessor 0 True BC0T



Format:

BC0T offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset*, shifted left two bits and sign-extended. If the contents of CP0's condition signal (CpCond) is true, then the program branches to the target address, with a delay of one instruction.

Because the condition line is sampled during the previous instruction, there must be at least one instruction between this instruction and a coprocessor instruction that changes the condition line.

Operation:

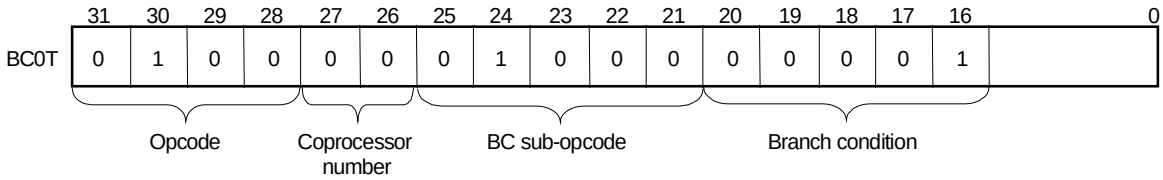
```
32  T-1:  condition ← SR18
      T:  target ← (offset15)^14 || offset || 0^2
    T+1:  if condition then
              PC ← PC + target
          endif

64  T-1:  condition ← SR18
      T:  target ← (offset15)^46 || offset || 0^2
    T+1:  if condition then
              PC ← PC + target
          endif
```

Exceptions:

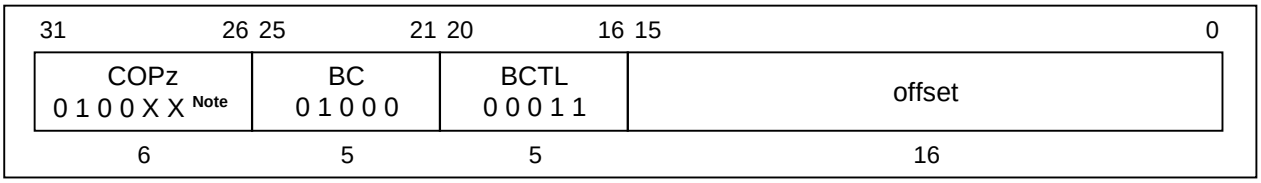
Coprocessor unusable exception

Note See the opcode table below, or **A.6 CPU Instruction Opcode Bit Encoding**.

Opcode Table:



BC0TL Branch On Coprocessor 0 True Likely (1/2) BC0TL



Format:

BC0TL offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset*, shifted left two bits and sign-extended. If the contents of CP0's condition (CpCond) line, as sampled during the previous instruction, is true, the target address is branched to with a delay of one instruction.

If the conditional branch is not taken, the instruction in the branch delay slot is nullified.

Because the condition line is sampled during the previous instruction, there must be at least one instruction between this instruction and a coprocessor instruction that changes the condition line.

Operation:

```
32   T-1:  condition ← SR18
      T:   target ← (offset15)^14 || offset || 0^2
      T+1: if condition then
                PC ← PC + target
           else
                NullifyCurrentInstruction
           endif

64   T-1:  condition ← SR18
      T:   target ← (offset15)^46 || offset || 0^2
      T+1: if condition then
                PC ← PC + target
           else
                NullifyCurrentInstruction
           endif
```

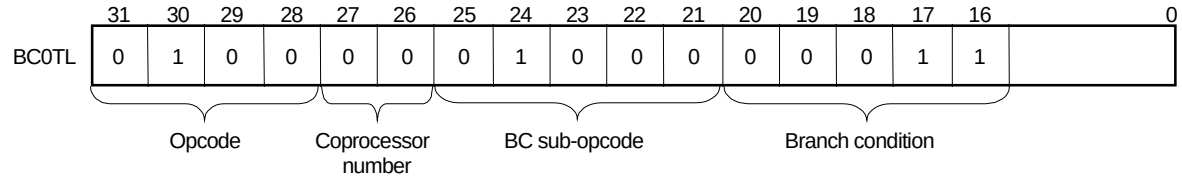
Exceptions:

Coprocessor unusable exception

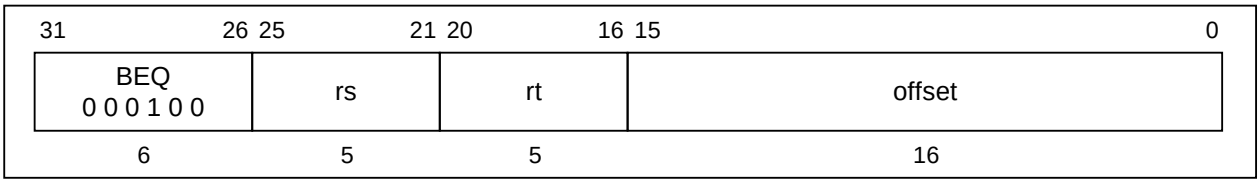
Note See the opcode table below, or **A.6 CPU Instruction Opcode Bit Encoding**.

BC0TL Branch On Coprocessor 0 True Likely (2/2) BC0TL

Opcode Table:



BEQ — Branch On Equal — BEQ



Format:

BEQ rs, rt, offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset*, shifted left two bits and sign-extended. The contents of general register *rs* and the contents of general register *rt* are compared. If the two registers are equal, then the program branches to the target address, with a delay of one instruction.

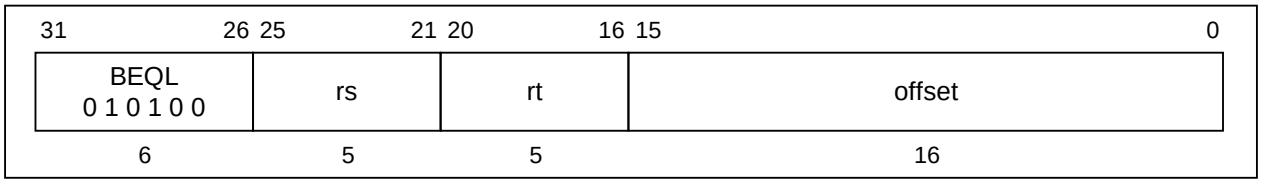
Operation:

```
32   T:    target ← (offset15)^14 || offset || 0^2
           condition ← (GPR [rs] = GPR [rt])
      T+1: if condition then
                PC ← PC + target
           endif

64   T:    target ← (offset15)^46 || offset || 0^2
           condition ← (GPR [rs] = GPR [rt])
      T+1: if condition then
                PC ← PC + target
           endif
```

Exceptions:

None

BEQL Branch On Equal Likely BEQL



Format:

BEQL rs, rt, offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit offset, shifted left two bits and sign-extended. The contents of general register *rs* and the contents of general register *rt* are compared. If the two registers are equal, the target address is branched to, with a delay of one instruction. If the conditional branch is not taken, the instruction in the branch delay slot is nullified.

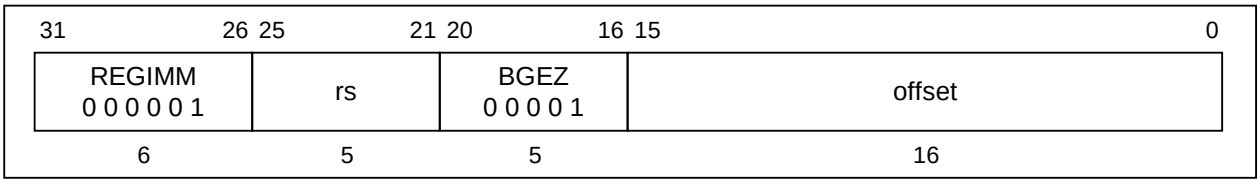
Operation:

```
32    T:    target ← (offset15)^14 || offset || 0^2
            condition ← (GPR [rs] = GPR [rt])
      T+1:  if condition then
                  PC ← PC + target
            else
                  NullifyCurrentInstruction
            endif

64    T:    target ← (offset15)^46 || offset || 0^2
            condition ← (GPR [rs] = GPR [rt])
      T+1:  if condition then
                  PC ← PC + target
            else
                  NullifyCurrentInstruction
            endif
```

Exceptions:

None

BGEZ Branch On Greater Than Or Equal To Zero BGEZ



Format:

BGEZ rs, offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset*, shifted left two bits and sign-extended. If the contents of general register *rs* are zero or greater when compared to zero, then the program branches to the target address, with a delay of one instruction.

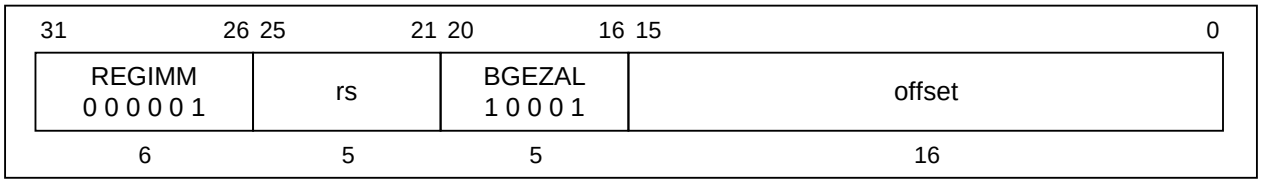
Operation:

```
32   T:   target ← (offset15)^14 || offset || 0^2
          condition ← (GPR [rs]31 = 0)
     T+1: if condition then
               PC ← PC + target
          endif

64   T:   target ← (offset15)^46 || offset || 0^2
          condition ← (GPR [rs]63 = 0)
     T+1: if condition then
               PC ← PC + target
          endif
```

Exceptions:

None

BGEZAL Branch On Greater Than Or Equal To Zero And Link BGEZAL



Format:

BGEZAL rs, offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset,* shifted left two bits and sign-extended. Unconditionally, the address of the instruction after the delay slot is placed in the link register, *r31*. If the contents of general register *rs* are zero or greater when compared to zero, then the program branches to the target address, with a delay of one instruction.

General register *rs* may not be general register *r31*, because such an instruction is not restartable. An attempt to execute this instruction is not trapped, however.

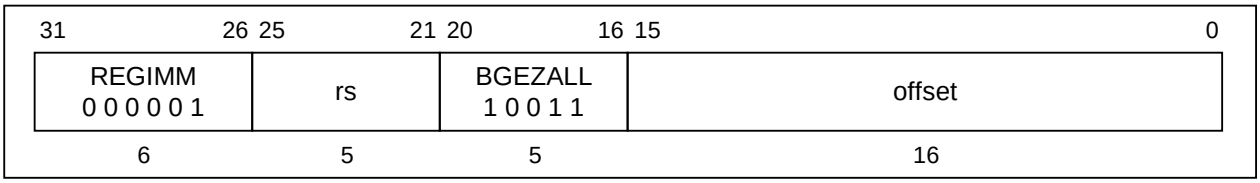
Operation:

```
32    T:    target ← (offset15)^14 || offset || 0^2
            condition ← (GPR [rs]31 = 0)
            GPR [31] ← PC + 8
      T+1:  if condition then
                  PC ← PC + target
            endif

64    T:    target ← (offset15)^46 || offset || 0^2
            condition ← (GPR [rs]63 = 0)
            GPR [31] ← PC + 8
      T+1:  if condition then
                  PC ← PC + target
            endif
```

Exceptions:

None

BGEZALL Branch On Greater Than Or Equal To Zero And Link Likely BGEZALL



Format:

BGEZALL rs, offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset,* shifted left two bits and sign-extended. Unconditionally, the address of the instruction after the delay slot is placed in the link register, *r31*. If the contents of general register *rs* are zero or greater when compared to zero, then the program branches to the target address, with a delay of one instruction. General register *r31* should not be specified as general register *rs*. If register *r31* is specified, restarting may be impossible due to the destruction of *rs* contents caused by storing a link address. Even such instructions are executed, an exception does not result.

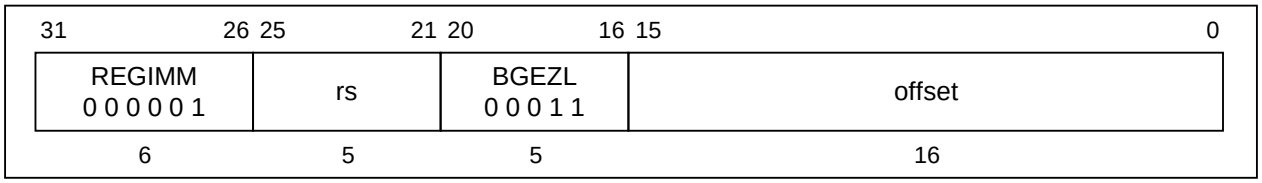
Operation:

```
32    T:    target ← (offset15)^14 || offset || 0^2
            condition ← (GPR [rs]31 = 0)
            GPR [31] ← PC + 8
      T+1:  if condition then
                  PC ← PC + target
            else
                  NullifyCurrentInstruction
            endif

64    T:    target ← (offset15)^46 || offset || 0^2
            condition ← (GPR [rs]63 = 0)
            GPR [31] ← PC + 8
      T+1:  if condition then
                  PC ← PC + target
            else
                  NullifyCurrentInstruction
            endif
```

Exceptions:

None

BGEZL Branch On Greater Than Or Equal To Zero Likely BGEZL



Format:

BGEZL rs, offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset*, shifted left two bits and sign-extended. If the contents of general register *rs* are zero or greater when compared to zero, then the program branches to the target address, with a delay of one instruction. If the conditional branch is not taken, the instruction in the branch delay slot is nullified.

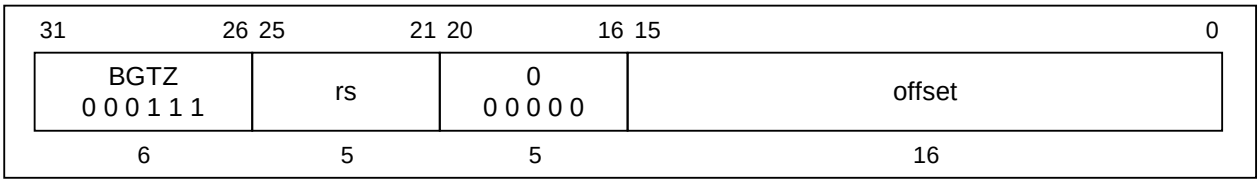
Operation:

```
32    T:    target ← (offset15)^14 || offset || 0^2
            condition ← (GPR [rs]31 = 0)
      T+1:  if condition then
                  PC ← PC + target
            else
                  NullifyCurrentInstruction
            endif

64    T:    target ← (offset15)^46 || offset || 0^2
            condition ← (GPR [rs]63 = 0)
      T+1:  if condition then
                  PC ← PC + target
            else
                  NullifyCurrentInstruction
            endif
```

Exceptions:

None

BGTZ Branch On Greater Than Zero BGTZ



Format:

BGTZ rs, offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset*, shifted left two bits and sign-extended. If the contents of general register *rs* are zero or greater when compared to zero, then the program branches to the target address, with a delay of one instruction.

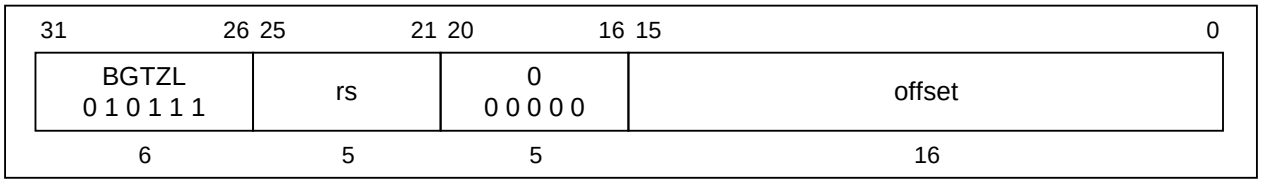
Operation:

```
32   T:    target ← (offset15)^14 || offset || 0^2
           condition ← (GPR [rs] 31 = 0) and (GPR [rs] ≠ 0^32)
      T+1: if condition then
                PC ← PC + target
           endif

64   T:    target ← (offset15)^46 || offset || 0^2
           condition ← (GPR [rs]63 = 0) and (GPR [rs] ≠ 0^64)
      T+1: if condition then
                PC ← PC + target
           endif
```

Exceptions:

None

BGTZL Branch On Greater Than Zero Likely BGTZL



Format:

BGTZL rs, offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset*, shifted left two bits and sign-extended. The contents of general register *rs* are compared to zero. If the contents of general register *rs* are greater than zero, then the program branches to the target address, with a delay of one instruction. If the conditional branch is not taken, the instruction in the branch delay slot is nullified.

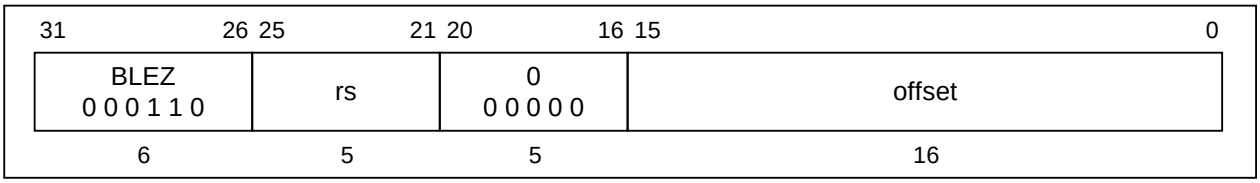
Operation:

```
32    T:    target ← (offset15)^14 || offset || 0^2
            condition ← (GPR [rs]31 = 0) and (GPR [rs] ≠ 0^32)
      T+1:  if condition then
                  PC ← PC + target
            else
                  NullifyCurrentInstruction
            endif

64    T:    target ← (offset15)^46 || offset || 0^2
            condition ← (GPR [rs]63 = 0) and (GPR [rs] ≠ 0^64)
      T+1:  if condition then
                  PC ← PC + target
            else
                  NullifyCurrentInstruction
            endif
```

Exceptions:

None

BLEZ Branch On Less Than Or Equal To Zero BLEZ



Format:

BLEZ rs, offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset*, shifted left two bits and sign-extended. The contents of general register *rs* are compared to zero. If the contents of general register *rs* are zero or smaller than zero, then the program branches to the target address, with a delay of one instruction.

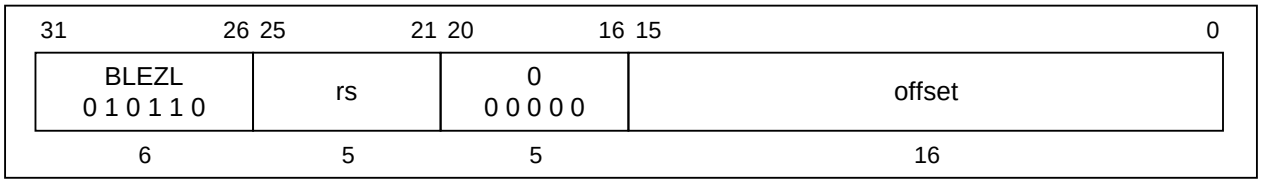
Operation:

```
32   T:    target ← (offset15)^14 || offset || 0^2
           condition ← (GPR [rs]31 = 1) or (GPR [rs] = 0^32)
      T+1: if condition then
                PC ← PC + target
           endif

64   T:    target ← (offset15)^46 || offset || 0^2
           condition ← (GPR [rs]63 = 1) or (GPR [rs] = 0^64)
      T+1: if condition then
                PC ← PC + target
           endif
```

Exceptions:

None

BLEZL Branch On Less Than Or Equal To Zero Likely BLEZL



Format:

BLEZL rs, offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset*, shifted left two bits and sign-extended. The contents of general register *rs* is compared to zero. If the contents of general register *rs* are zero or smaller than zero, then the program branches to the target address, with a delay of one instruction.

If the conditional branch is not taken, the instruction in the branch delay slot is nullified.

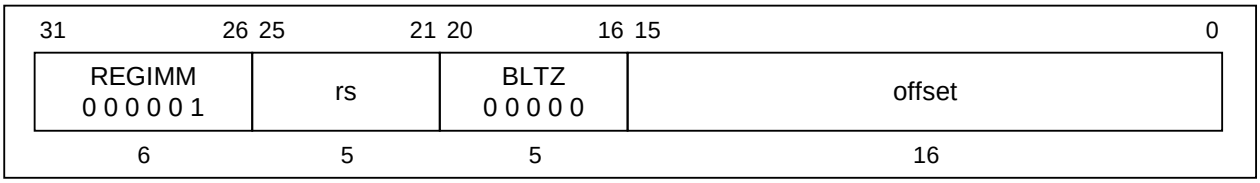
Operation:

```
32   T:    target ← (offset15)^14 || offset || 0^2
           condition ← (GPR [rs]31 = 1) or (GPR [rs] = 0^32)
      T+1: if condition then
                PC ← PC + target
           else
                NullifyCurrentInstruction
           endif

64   T:    target ← (offset15)^46 || offset || 0^2
           condition ← (GPR [rs]63 = 1) or (GPR [rs] = 0^64)
      T+1: if condition then
                PC ← PC + target
           else
                NullifyCurrentInstruction
           endif
```

Exceptions:

None

BLTZ Branch On Less Than Zero BLTZ



Format:

BLTZ rs, offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset*, shifted left two bits and sign-extended. If the contents of general register *rs* are smaller than zero, then the program branches to the target address, with a delay of one instruction.

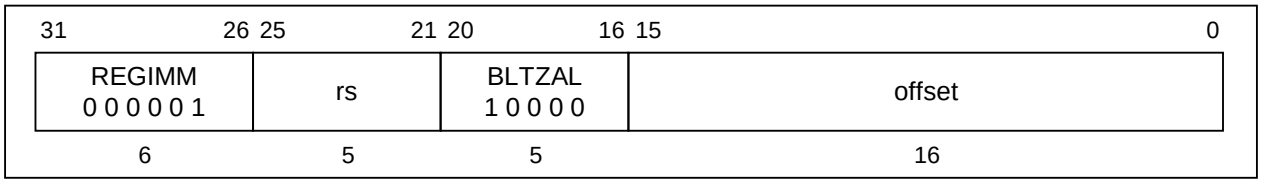
Operation:

```
32   T:    target ← (offset15)^14 || offset || 0^2
           condition ← (GPR [rs]31 = 1)
      T+1: if condition then
                PC ← PC + target
           endif

64   T:    target ← (offset15)^46 || offset || 0^2
           condition ← (GPR [rs]63 = 1)
      T+1: if condition then
                PC ← PC + target
           endif
```

Exceptions:

None

BLTZAL Branch On Less Than Zero And Link BLTZAL



Format:

BLTZAL rs, offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset,* shifted left two bits and sign-extended. Unconditionally, the address of the instruction after the delay slot is placed in the link register, *r31*. If the contents of general register *rs* are smaller than zero when compared to zero, then the program branches to the target address, with a delay of one instruction.

General register *r31* should not be specified as general register *rs*. If register *r31* is specified, restarting may be impossible due to the destruction of *rs* contents caused by storing a link address. Even such instructions are executed, an exception does not result.

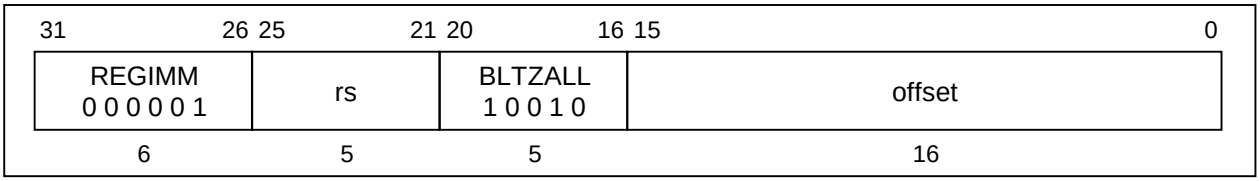
Operation:

```
32   T:   target ← (offset15)^14 || offset || 0^2
          condition ← (GPR [rs]31 = 1)
          GPR [31] ← PC + 8
     T+1: if condition then
               PC ← PC + target
          endif

64   T:   target ← (offset15)^46 || offset || 0^2
          condition ← (GPR [rs]63 = 1)
          GPR [31] ← PC + 8
     T+1: if condition then
               PC ← PC + target
          endif
```

Exceptions:

None

BLTZALL Branch On Less Than Zero And Link Likely BLTZALL



Format:

BLTZALL rs, offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset,* shifted left two bits and sign-extended. Unconditionally, the address of the instruction after the delay slot is placed in the link register, *r31*. If the contents of general register *rs* are smaller than zero when compared to zero, then the program branches to the target address, with a delay of one instruction.

General register *r31* should not be specified as general register *rs*. If register *r31* is specified, restarting may be impossible due to the destruction of *rs* contents caused by storing a link address. Even such instructions are executed, an exception does not result.

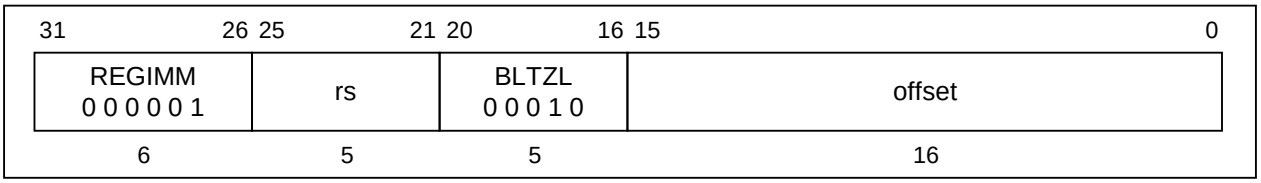
Operation:

```
32    T:    target ← (offset15)^14 || offset || 0^2
            condition ← (GPR [rs]31 = 1)
            GPR [31] ← PC + 8
      T+1:  if condition then
                  PC ← PC + target
            else
                  NullifyCurrentInstruction
            endif

64    T:    target ← (offset15)^46 || offset || 0^2
            condition ← (GPR [rs]63 = 1)
            GPR [31] ← PC + 8
      T+1:  if condition then
                  PC ← PC + target
            else
                  NullifyCurrentInstruction
            endif
```

Exceptions:

None

BLTZL Branch On Less Than Zero Likely BLTZL



Format:

BLTZ rs, offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset*, shifted left two bits and sign-extended. If the contents of general register *rs* are smaller than zero when compared to zero, then the program branches to the target address, with a delay of one instruction. If the conditional branch is not taken, the instruction in the branch delay slot is nullified.

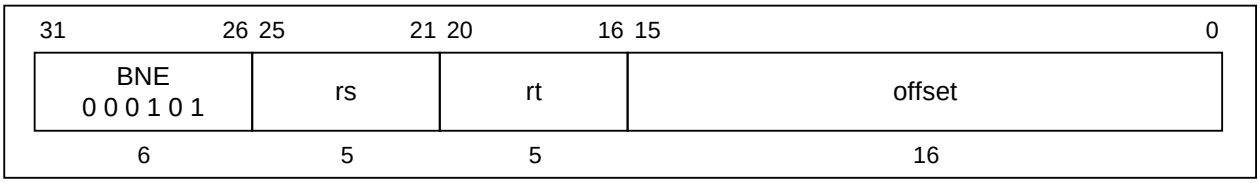
Operation:

```
32    T:    target ← (offset15)^14 || offset || 0^2
            condition ← (GPR [rs]31 = 1)
      T+1:  if condition then
                  PC ← PC + target
            else
                  NullifyCurrentInstruction
            endif

64    T:    target ← (offset15)^46 || offset || 0^2
            condition ← (GPR [rs]63 = 1)
      T+1:  if condition then
                  PC ← PC + target
            else
                  NullifyCurrentInstruction
            endif
```

Exceptions:

None

BNE Branch On Not Equal BNE



Format:

BNE rs, rt, offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset,* shifted left two bits and sign-extended. The contents of general register *rs* and the contents of general register *rt* are compared. If the two registers are not equal, then the program branches to the target address, with a delay of one instruction.

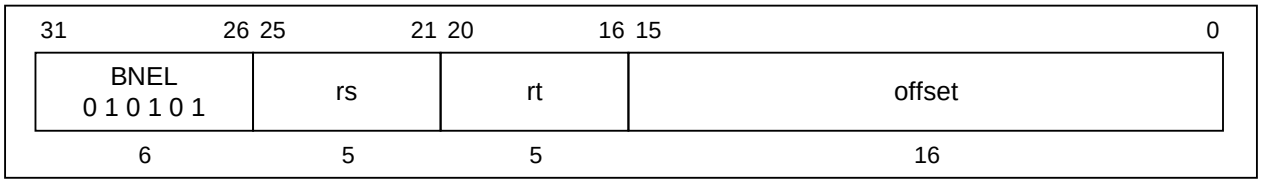
Operation:

```
32   T:    target ← (offset15)^14 || offset || 0^2
           condition ← (GPR [rs] ≠ GPR [rt])
      T+1: if condition then
                PC ← PC + target
           endif

64   T:    target ← (offset15)^46 || offset || 0^2
           condition ← (GPR [rs] ≠ GPR [rt])
      T+1: if condition then
                PC ← PC + target
           endif
```

Exceptions:

None

BNEL Branch On Not Equal Likely BNEL



Format:

BNEL rs, rt, offset

Description:

A branch target address is computed from the sum of the address of the instruction in the delay slot and the 16-bit *offset,* shifted left two bits and sign-extended. The contents of general register *rs* and the contents of general register *rt* are compared. If the two registers are not equal, then the program branches to the target address, with a delay of one instruction.

If the conditional branch is not taken, the instruction in the branch delay slot is nullified.

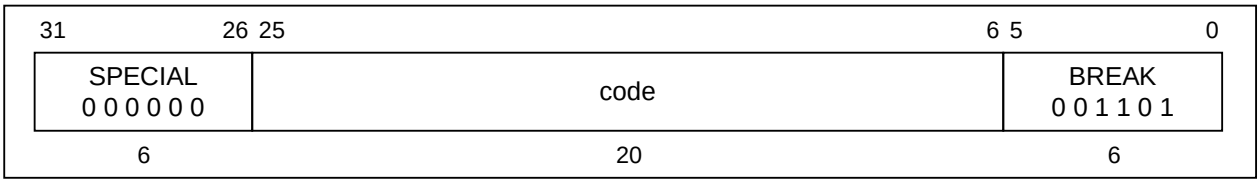
Operation:

```
32    T:    target ← (offset15)^14 || offset || 0^2
            condition ← (GPR [rs] ≠ GPR [rt])
      T+1:  if condition then
                  PC ← PC + target
            else
                  NullifyCurrentInstruction
            endif

64    T:    target ← (offset15)^46 || offset || 0^2
            condition ← (GPR [rs] ≠ GPR [rt])
      T+1:  if condition then
                  PC ← PC + target
            else
                  NullifyCurrentInstruction
            endif
```

Exceptions:

None

BREAK Breakpoint BREAK



Format:

BREAK

Description:

A breakpoint trap occurs, immediately and unconditionally transferring control to the exception handler.

The code field is available for use as software parameters, but is retrieved by the exception handler only by loading the contents of the memory word containing the instruction.

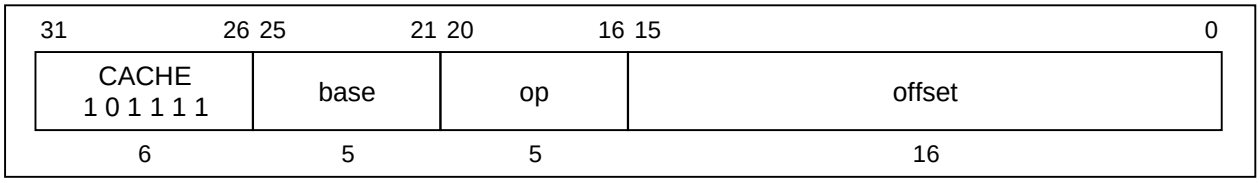
Operation:

```
32, 64 T:    BreakpointException
```

Exceptions:

Breakpoint exception

CACHE — Cache (1/4) — CACHE



Format:

CACHE op, offset (base)

Description:

The 16-bit *offset* is sign-extended and added to the contents of general register *base* to form a virtual address. The virtual address is translated to a physical address using the TLB, and the 5-bit sub-opcode specifies a cache operation for that address.

If CP0 is not usable (User or Supervisor mode) and the CP0 enable bit in the Status register is clear, a coprocessor unusable exception is taken. The operation of this instruction on any operation/cache combination not listed below, or on a secondary cache that is not incorporated in VR4120A CPU, is undefined. The operation of this instruction on uncached addresses is also undefined.

The Index operation uses part of the virtual address to specify a cache block.

For a primary cache of $2^{CACHEBITS}$ bytes with $2^{LINEBITS}$ bytes per tag, vAddrCACHEBITS...LINEBITS specifies the block.

Index_Load_Tag also uses vAddrLINEBITS...3 to select the doubleword for reading parity. When the *CE* bit of the Status register is set, Fill Cache op uses the PErr register to store parity values into the cache.

The Hit operation accesses the specified cache as normal data references, and performs the specified operation if the cache block contains valid data with the specified physical address (a hit). If the cache block is invalid or contains a different address (a miss), no operation is performed.

CACHE Cache (2/4) CACHE

Write back from a cache goes to main memory.
The main memory address to be written is specified by the cache tag and not the physical address translated using TLB.
TLB Refill and TLB Invalid exceptions can occur on any operation. For Index operations[Note] for addresses in the unmapped areas, unmapped addresses may be used to avoid TLB exceptions. Index operations never cause a TLB Modified exception. Bits 17 and 16 of the instruction code specify the cache for which the operation is to be performed as follows.

Code	Name	Cache
0	I	Instruction cache
1	D	Data cache
2	—	Reserved
3	—	Reserved

Note Physical addresses here are used to index the cache, and they do not need to match the cache tag.

Bits 20 to 18 of this instruction specify the contents of cache operaiton. Details are provided from the next page.

CACHE — Cache (3/4) — CACHE

Code	Cache	Name	Operation
0	I	Index_Invalidate	Set the cache state of the cache block to Invalid.
0	D	Index_Write_ Back_Invalidate	Examine the cache state and W bit of the primary data cache block at the index specified by the virtual address. If the state is not Invalid and the W bit is set, then write back the block to memory. The address to write is taken from the primary cache tag. Set cache state of primary cache block to Invalid.
1	I, D	Index_Load_Tag	Read the tag for the cache block at the specified index and place it into the TagLo CP0 registers, ignoring parity errors. Also load the data parity bits into the ECC register.
2	I, D	Index_Store_ Tag	Write the tag for the cache block at the specified index from the TagLo and TagHi CP0 registers.
3	D	Create_Dirty_ Exclusive	This operation is used to avoid loading data needlessly from memory when writing new contents into an entire cache block. If the cache block does not contain the specified address, and the block is dirty, write it back to the memory. In all cases, set the cache state to Dirty.
4	I, D	Hit_Invalidate	If the cache block contains the specified address, mark the cache block invalid.
5	D	Hit_Write_Back Invalidate	If the cache block contains the specified address, write back the data if it is dirty, and mark the cache block invalid.
5	I	Fill	Fill the primary instruction cache block from memory. If the CE bit of the Status register is set, the contents of the ECC register is used instead of the computed parity bits for addressed doubleword when written to the instruction cache.
6	D	Hit_Write_Back	If the cache block contains the specified address, and the W bit is set, write back the data to memory and clear the W bit.
6	I	Hit_Write_Back	If the cache block contains the specified address, write back the data unconditionally.

CACHE — Cache (4/4) — CACHE

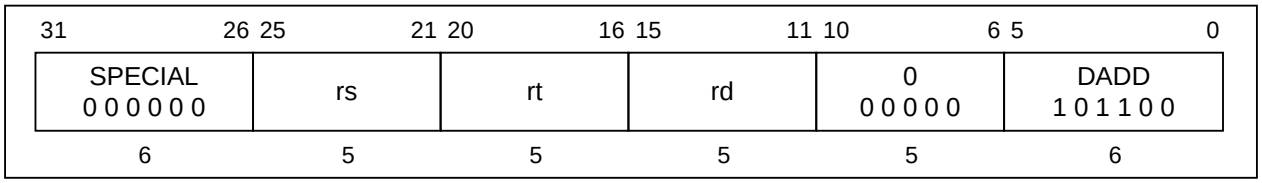
Operation:

```
32, 64 T:   vAddr ← ((offset15)^48 || offset15...0) + GPR [base]
            (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
            CacheOp (op, vAddr, pAddr)
```

Exceptions:

Coprocessor unusable exception
TLB Refill exception
TLB Invalid exception
Bus Error exception
Address Error exception
Cache Error exception

DADD Doubleword Add DADD



Format:

DADD rd, rs, rt

Description:

The contents of general register *rs* and the contents of general register *rt* are added to form the result. The result is placed into general register *rd*.

An overflow exception occurs if the carries out of bits 62 and 63 differ (2's complement overflow). The destination register *rd* is not modified when an integer overflow exception occurs.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

Operation:

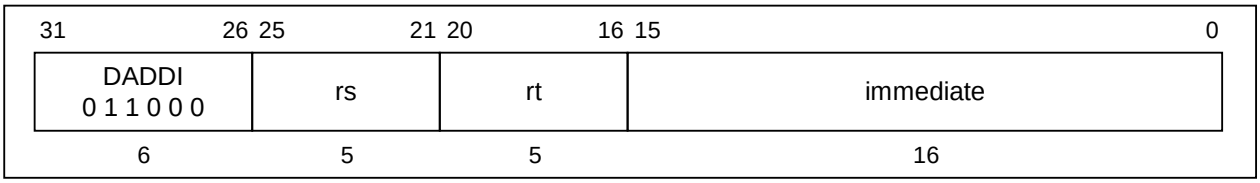
```
64    T:    GPR [rd] ← GPR [rs] + GPR [rt]
```

Exceptions:

Integer overflow exception

Reserved instruction exception (32-bit user mode/supervisor mode)

DADDI Doubleword Add Immediate DADDI



Format:

DADDI rt, rs, immediate

Description:

The 16-bit *immediate* is sign-extended and added to the contents of general register *rs* to form the result. The result is placed into general register *rt.*

An overflow exception occurs if carries out of bits 62 and 63 differ (2's complement overflow). The destination register *rt* is not modified when an integer overflow exception occurs.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

Operation:

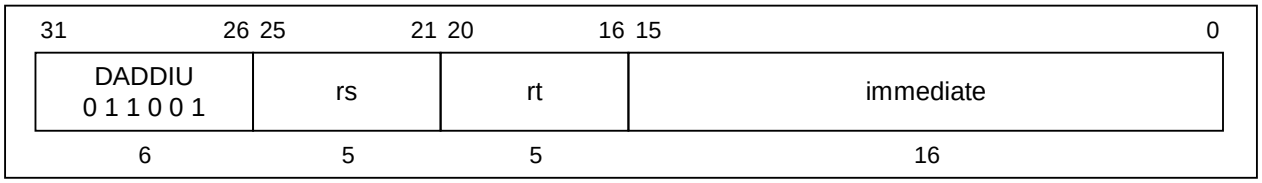
```
64    T:    GPR [rt] ← GPR [rs] + (immediate15)48 || immediate15...0
```

Exceptions:

Integer overflow exception

Reserved instruction exception (32-bit user mode/supervisor mode)

DADDIU Doubleword Add Immediate Unsigned DADDIU



Format:

DADDIU rt, rs, immediate

Description:

The 16-bit *immediate* is sign-extended and added to the contents of general register *rs* to form the result. The result is placed into general register *rt.* No integer overflow exception occurs under any circumstances.

The only difference between this instruction and the DADDI instruction is that DADDIU never causes an overflow exception.

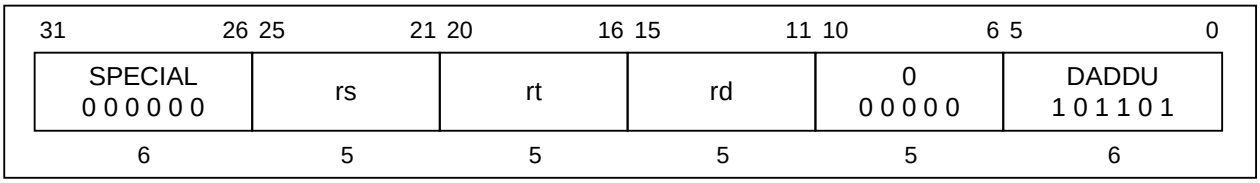
Operation:

64 T: GPR [rt] ← GPR [rs] + $(immediate_{15})^{48}$ || $immediate_{15...0}$

Exceptions:

Reserved instruction exception (32-bit user mode/supervisor mode)

DADDU Doubleword Add Unsigned DADDU



Format:

DADDU rd, rs, rt

Description:

The contents of general register *rs* and the contents of general register *rt* are added to form the result. The result is placed into general register *rd*.

No overflow exception occurs under any circumstances.

The only difference between this instruction and the DADD instruction is that DADDU never causes an overflow exception.

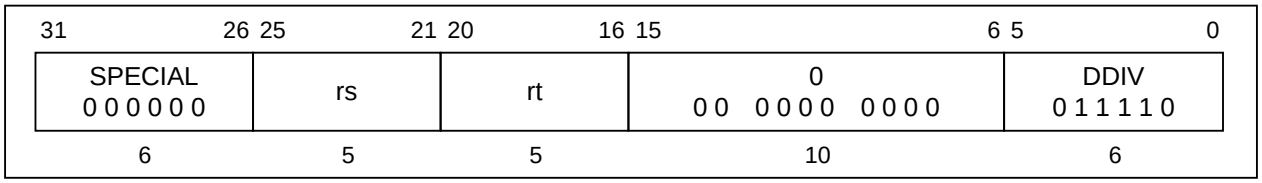
Operation:

```
64    T:    GPR [rd] ← GPR [rs] + GPR [rt]
```

Exceptions:

Reserved instruction exception (32-bit user mode/supervisor mode)

DDIV — Doubleword Divide — DDIV



Format:

DDIV rs, rt

Description:

The contents of general register *rs* are divided by the contents of general register *rt,* treating both operands as 2's complement values. No overflow exception occurs under any circumstances, and the result of this operation is undefined when the divisor is zero.

This instruction is typically followed by additional instructions to check for a zero divisor and for overflow.

When the operation completes, the quotient word of the double result is loaded into special register *LO*, and the remainder word of the double result is loaded into special register *HI*.

If either of the two preceding instructions is MFHI or MFLO, the results of those instructions are undefined. Correct operation requires separating reads of *HI* or *LO* from writes by two or more instructions.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

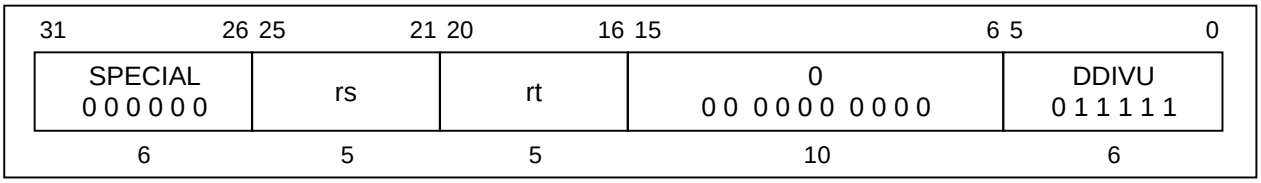
Operation:

```
64    T-2:  LO  ← undefined
            HI  ← undefined
      T-1:  LO  ← undefined
            HI  ← undefined
      T:    LO  ← GPR [rs] div GPR [rt]
            HI  ← GPR [rs] mod GPR [rt]
```

Exceptions:

Reserved instruction exception (32-bit user mode/supervisor mode)

DDIVU Doubleword Divide Unsigned DDIVU



Format:

DDIVU rs, rt

Description:

The contents of general register *rs* are divided by the contents of general register *rt,* treating both operands as unsigned values. No integer overflow exception occurs under any circumstances, and the result of this operation is undefined when the divisor is zero.

This instruction may be followed by additional instructions to check for a zero divisor, inserted by the programmer.

When the operation completes, the quotient word of the double result is loaded into special register *LO*, and the remainder word of the double result is loaded into special register *HI*.

If either of the two preceding instructions is MFHI or MFLO, the results of those instructions are undefined. Correct operation requires separating reads of *HI* or *LO* from writes by two or more instructions.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

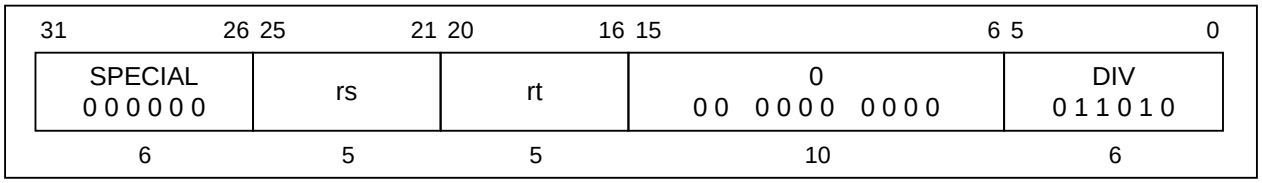
Operation:

```
64    T-2:  LO  ← undefined
            HI  ← undefined
      T-1:  LO  ← undefined
            HI  ← undefined
      T:    LO  ←  (0 || GPR [rs]) div (0 || GPR [rt])
            HI  ← (0 || GPR [rs]) mod (0 || GPR [rt])
```

Exceptions:

Reserved instruction exception (32-bit user mode/supervisor mode)

DIV — Divide — DIV



Format:

DIV rs, rt

Description:

The contents of general register *rs* are divided by the contents of general register *rt,* treating both operands as 2's complement values. No overflow exception occurs under any circumstances, and the result of this operation is undefined when the divisor is zero.

In 64-bit mode, the operands must be valid sign-extended, 32-bit values.

This instruction is typically followed by additional instructions to check for a zero divisor and for overflow.

When the operation completes, the quotient word of the double result is loaded into special register *LO*, and the remainder word of the double result is loaded into special register *HI*.

If either of the two preceding instructions is MFHI or MFLO, the results of those instructions are undefined. Correct operation requires separating reads of *HI* or *LO* from writes by two or more instructions.

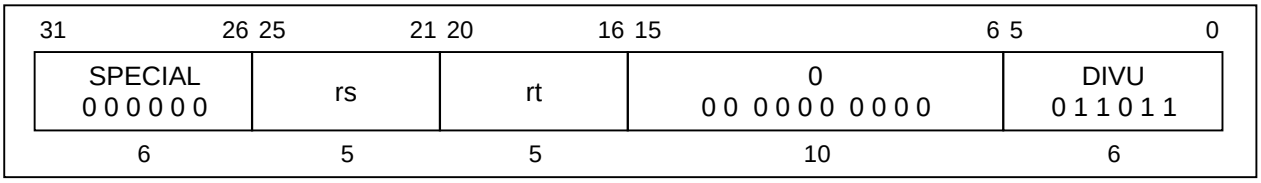
Operation:

```
32    T-2:  LO   ← undefined
            HI   ← undefined
      T-1:  LO   ← undefined
            HI   ← undefined
      T:    LO   ← GPR [rs] div GPR [rt]
            HI   ← GPR [rs] mod GPR [rt]

64    T-2:  LO   ← undefined
            HI   ← undefined
      T-1:  LO   ← undefined
            HI   ← undefined
      T:    q    ← GPR [rs]31..0 div GPR [rt] 31..0
            r    ← GPR [rs]31..0 mod GPR [rt] 31..0
            LO   ← (q31)^32 || q31..0
            HI   ← (r 31)^32|| r31..0
```

Exceptions:

None

DIVU — Divide Unsigned — DIVU



Format:

DIVU rs, rt

Description:

The contents of general register *rs* are divided by the contents of general register *rt,* treating both operands as unsigned values. No integer overflow exception occurs under any circumstances, and the result of this operation is undefined when the divisor is zero.

In 64-bit mode, the operands must be valid sign-extended, 32-bit values.

This instruction is typically followed by additional instructions to check for a zero divisor.

When the operation completes, the quotient word of the double result is loaded into special register *LO*, and the remainder word of the double result is loaded into special register *HI*.

If either of the two preceding instructions is MFHI or MFLO, the results of those instructions are undefined. Correct operation requires separating reads of *HI* or *LO* from writes by two or more instructions.

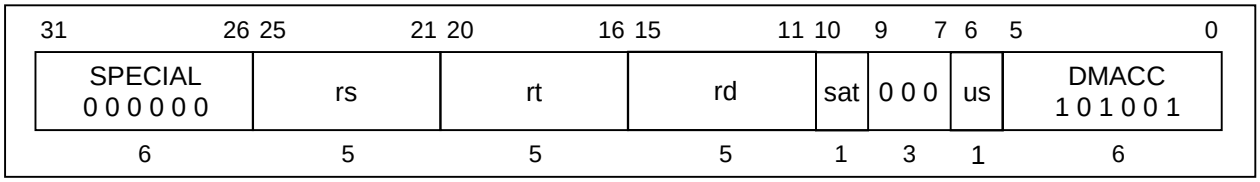
Operation:

```
32   T-2:  LO   ← undefined
           HI   ← undefined
      T-1:  LO   ← undefined
           HI   ← undefined
      T:    LO   ← (0 || GPR [rs]) div (0 || GPR [rt])
           HI   ←  0 || GPR [rs]) mod (0 || GPR [rt])

64   T-2:  LO   ← undefined
           HI   ← undefined
      T-1:  LO   ← undefined
           HI   ← undefined
      T:    q    ← (0 || GPR [rs]31..0) div (0 || GPR [rt]31..0)
           r    ← (0 || GPR [rs]31..0) mod (0 || GPR [rt]31..0)
           LO   ← (q31)32 || q31..0
           HI   ← (r31)32 || r31..0
```

Exceptions:

None

DMACC Doubleword Multiply and Accumulate (1/3) DMACC



Format:

DMACC rd, rs, rt

DMACCU rd, rs, rt

DMACCS rd, rs, rt

DMACCUS rd, rs, rt

Description:

DMACC instruction differs mnemonics by each setting of op codes sat, hi and us as follows.

Mnemonic	sat	us
DMACC	0	0
DMACCU	0	1
DMACCS	1	0
DMACCUS	1	1

The number of significant bits in the operands of the DMACC instruction differ depending on whether saturation processing is executed (sat = 1) or not executed (sat = 0).

- When saturation processing is executed (sat = 1): DMACCS, DMACCUS instructions
  The contents of general register *rs* is multiplied by the contents of general register *rt*. If both operands are set as "us = 1" (DMACCUS instruction), the contents are handled as 16 bit unsigned data. If they are set as "us = 0" (DMACCS instruction), the contents are handled as 16 bit signed integers. Sign/zero expansion by software is required for any bits exceeding 16 bits in the operands.
  The product of this multiply operation is added to the value in the LO special register. If us = 1, this add operation handles the values being added as 32 bit unsigned data. If us = 0, the values are handled as 32 bit signed integers. Sign/zero expansion by software is required for any bits exceeding 32 bits in the LO special register.
  After saturation processing to 32 bits has been performed (see the table below), the sum from this add operation is loaded to the LO special register. When hi = 1, data that is the same as the data loaded to the HI special register is also loaded to the rd general register. When hi = 0, data that is the same as the data loaded to the LO special register is also loaded to the rd general register. Overflow exceptions do not occur.

DMACC Doubleword Multiply and Accumulate (2/3) DMACC

- When saturation processing is not executed (sat = 0): DMACC, DMACCU instructions
  The contents of general register *rs* is multiplied by the contents of general register *rt*. If both operands are set as "us = 1" (DMACCU instruction), the contents are handled as 32 bit unsigned data. If they are set as "us = 0" (DMACC instruction), the contents are handled as 32 bit signed integers. Sign/zero expansion by software is required for any bits exceeding 32 bits in the operands.
  The product of this multiply operation is added to the value in the LO special register. If us = 1, this add operation handles the values being added as 64 bit unsigned data. If us = 0, the values are handled as 64 bit signed integers.
  The sum from this add operation is loaded to the LO special register. When hi = 1, data that is the same as the data loaded to the HI special register is also loaded to the rd general register. When hi = 0, data that is the same as the data loaded to the LO special register is also loaded to the rd general register. Overflow exceptions do not occur.

These operations are defined for 64 bit mode and 32 bit kernel mode. A reserved instruction exception occurs if one of these instructions is executed during 32 bit user/supervisor mode.
The correspondence of us and sat settings and values stored during saturation processing is shown below, along with the hazard cycles required between execution of the instruction for manipulating the HI and LO registers and execution of the DMACC instruction.

Values Stored during Saturation Processing

us	sat	Overflow	Underflow
0	0	Store calculation result as is	Store calculation result as is
1	0	Store calculation result as is	Store calculation result as is
0	1	0000 0000 7FFF FFFFH	FFFF FFFF 8000 0000H
1	1	FFFF FFFF FFFF FFFFH	None

Hazard Cycle Counts

Instruction	Cycle count
MULT, MULTU	1
DMULT, DMULTU	3
DIV, DIVU	36
DDIV, DDIVU	68
MFHI, MFLO	2
MTHI, MTLO	0
MACC	0
DMACC	0

DMACC Doubleword Multiply and Accumulate (3/3) DMACC

Operation:

64, sat=0, us=0 (DMACC instruction)

```
T:    temp1 ← ((GPR[rs]31)32 || GPR [rs]) * ((GPR[rt]31)32 || GPR [rt])
      temp2 ← temp1 + LO
      LO ← temp2
      GPR[rd] ← LO
```

64, sat=0, us=1 (DMACCU instruction)

```
T:    temp1 ← (032 || GPR [rs]) * (032 || GPR [rt])
      temp2 ← temp1 + LO
      LO ← temp2
      GPR[rd] ← LO
```

64, sat=1, us=0 (DMACCS instruction)

```
T:    temp1 ← ((GPR[rs]31)32 || GPR [rs]) * ((GPR[rt]31)32 || GPR [rt])
      temp2 ← saturation(temp1 + LO)
      LO ← temp2
      GPR[rd] ← LO
```

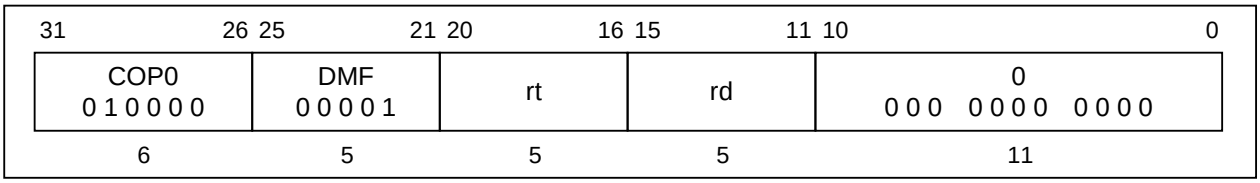
64, sat=1, us=1 (DMACCUS instruction)

```
T:    temp1 ← (032 || GPR [rs]) * (032 || GPR [rt])
      temp2 ← saturation(temp1 + LO)
      LO ← temp2
      GPR[rd] ← LO
```

Exceptions:

Reserved instruction exception (32-bit user mode/supervisor mode)

DMFC0 Doubleword Move From System Control Coprocessor DMFC0



Format:

DMFC0 rt, rd

Description:

The contents of coprocessor register *rd* of the CP0 are loaded into general register *rt.*

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception. All 64-bits of the general register destination are written from the coprocessor register source. The operation of DMFC0 on a 32-bit coprocessor 0 register is undefined.

Operation:

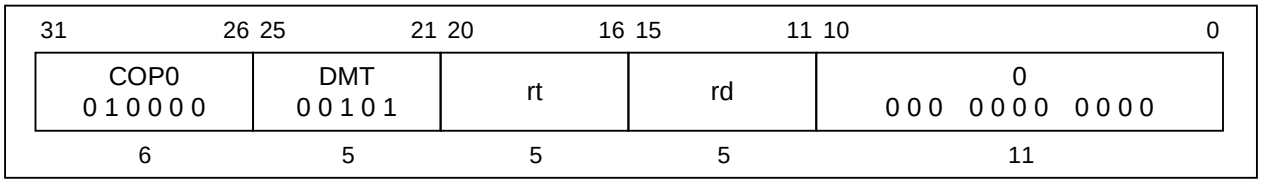
```
64   T:    data ← CPR [0, rd]
     T+1:  GPR [rt] ← data
```

Exceptions:

Coprocessor unusable exception (user mode and supervisor mode if CP0 not enabled)

Reserved instruction exception (32-bit user mode/supervisor mode)

DMTC0 Doubleword Move To System Control Coprocessor DMTC0



Format:

DMTC0 rt, rd

Description:

The contents of general register *rt* are loaded into coprocessor register *rd* of the CP0.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

All 64-bits of the coprocessor 0 register are written from the general register source. The operation of DMTC0 on a 32-bit coprocessor 0 register is undefined.

Because the state of the virtual address translation system may be altered by this instruction, the operation of load instructions, store instructions, and TLB operations immediately prior to and after this instruction are undefined.

Operation:

```
64    T:    data ← GPR [rt]
      T+1:  CPR [0, rd] ← data
```

Exceptions:

Coprocessor unusable exception (In 64-bit/32-bit user and supervisor mode if CP0 not enabled)

Reserved instruction exception (32-bit user mode/supervisor mode)

DMULT Doubleword Multiply DMULT

Format:

DMULT rs, rt

Description:

The contents of general registers *rs* and *rt* are multiplied, treating both operands as 2's complement values. No integer overflow exception occurs under any circumstances.

When the operation completes, the low-order word of the double result is loaded into special register *LO*, and the high-order word of the double result is loaded into special register *HI*.

If either of the two preceding instructions is MFHI or MFLO, the results of these instructions are undefined. Correct operation requires separating reads of *HI* or *LO* from writes by a minimum of two other instructions.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

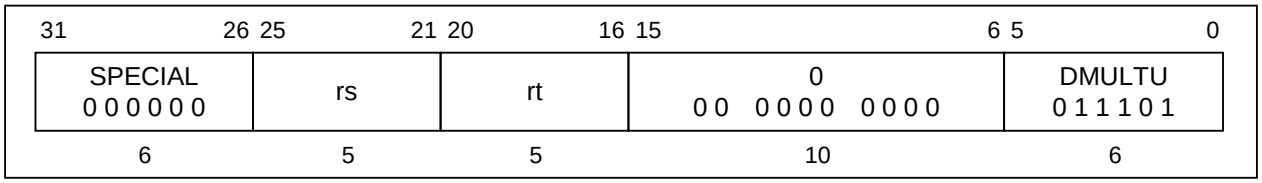
Operation:

```
64   T-2:  LO  ← undefined
           HI  ← undefined
      T-1:  LO  ← undefined
           HI  ← undefined
      T:    t   ← GPR [rs] * GPR [rt]
           LO  ← t63..0
           HI  ← t127..64
```

Exceptions:

Reserved instruction exception (32-bit user mode/supervisor mode)

DMULTU Doubleword Multiply Unsigned DMULTU



Format:

DMULTU rs, rt

Description:

The contents of general register *rs* and the contents of general register *rt* are multiplied, treating both operands as unsigned values. No overflow exception occurs under any circumstances.

When the operation completes, the low-order word of the double result is loaded into special register *LO*, and the high-order word of the double result is loaded into special register *HI*.

If either of the two preceding instructions is MFHI or MFLO, the results of these instructions are undefined. Correct operation requires separating reads of *HI* or *LO* from writes by a minimum of two instructions.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

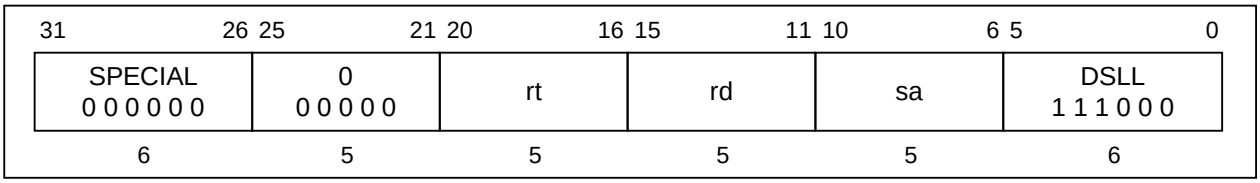
Operation:

```
64   T-2:  LO  ← undefined
           HI  ← undefined
      T-1:  LO  ← undefined
           HI  ← undefined
      T:    t   ← (0 || GPR [rs]) * (0 || GPR [rt])
           LO  ← t63..0
           HI  ← t127..64
```

Exceptions:

Reserved instruction exception (32-bit user mode/supervisor mode)

DSLL Doubleword Shift Left Logical DSLL



Format:

DSLL rd, rt, sa

Description:

The contents of general register *rt* are shifted left by *sa* bits, inserting zeros into the low-order bits. The result is placed in register *rd.*

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

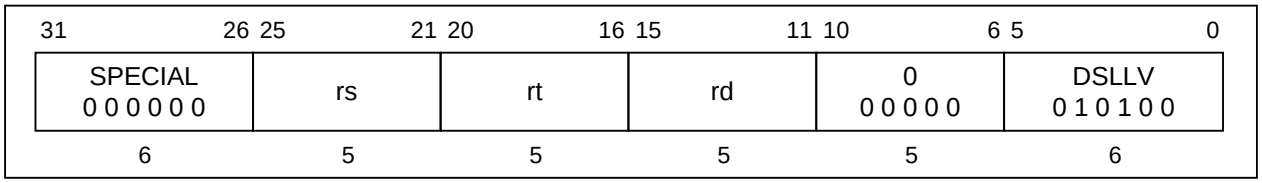
Operation:

```
64    T:    s ← 0 || sa
            GPR [rd] ← GPR [rt] (63 - s)..0 || 0^s
```

Exceptions:

Reserved instruction exception (32-bit user mode/supervisor mode)

DSLLV Doubleword Shift Left Logical Variable DSLLV



Format:

DSLLV rd, rt, rs

Description:

The contents of general register *rt* are shifted left by the number of bits specified by the low-order six bits contained in general register *rs*, inserting zeros into the low-order bits. The result is placed in register *rd*.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

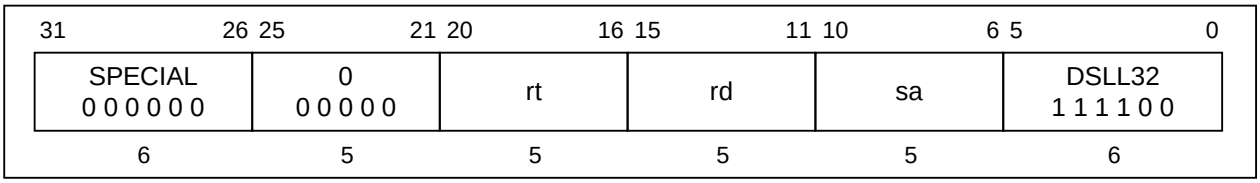
Operation:

```
64    T:    s ← GPR [rs]5..0
            GPR [rd] ← GPR [rt](63 - s)..0 || 0^s
```

Exceptions:

Reserved instruction exception (32-bit user mode/supervisor mode)

DSLL32 Doubleword Shift Left Logical + 32 DSLL32



Format:

DSLL32 rd, rt, sa

Description:

The contents of general register *rt* are shifted left by *32* + *sa* bits, inserting zeros into the low-order bits. The result is placed in register *rd*.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

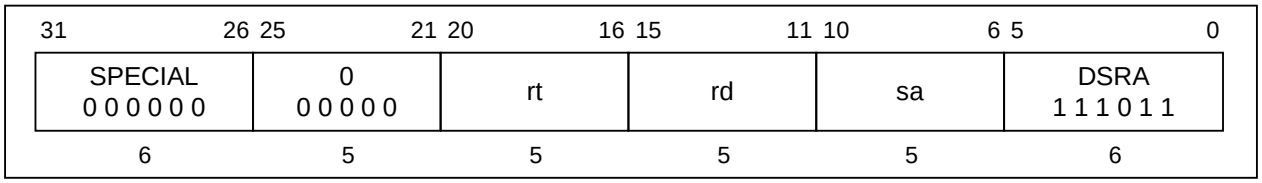
Operation:

```
64    T:    s ← 1 || sa
            GPR [rd] ← GPR [rt] (63 - s)..0 || 0^s
```

Exceptions:

Reserved instruction exception (32-bit user mode/supervisor mode)

DSRA Doubleword Shift Right Arithmetic DSRA



Format:

DSRA rd, rt, sa

Description:

The contents of general register *rt* are shifted right by *sa* bits, sign-extending the high-order bits. The result is placed in register *rd*.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

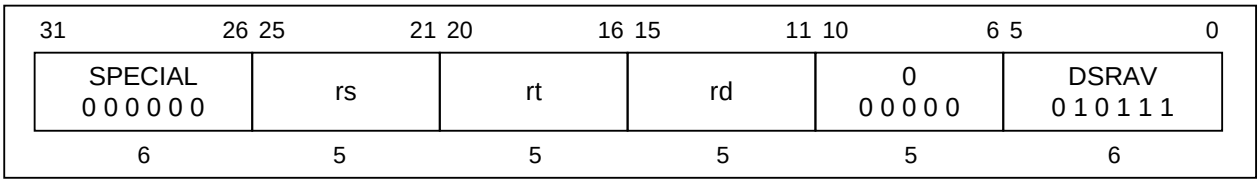
Operation:

```
64    T:    s ← 0 || sa
            GPR [rd] ← (GPR [rt]63)^s || GPR [rt] 63..s
```

Exceptions:

Reserved instruction exception (32-bit user mode/supervisor mode)

DSRAV Doubleword Shift Right Arithmetic Variable DSRAV



Format:

DSRAV rd, rt, rs

Description:

The contents of general register *rt* are shifted right by the number of bits specified by the low-order six bits of general register *rs*, sign-extending the high-order bits. The result is placed in register *rd*.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

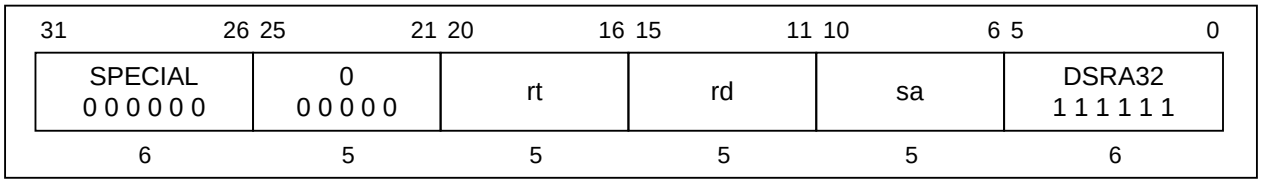
Operation:

```
64   T:   s ← GPR [rs]5..0
          GPR [rd] ← (GPR [rt] 63)^s || GPR [rt] 63..s
```

Exceptions:

Reserved instruction exception (32-bit user mode/supervisor mode)

DSRA32 Doubleword Shift Right Arithmetic + 32 DSRA32



Format:

DSRA32 rd, rt, sa

Description:

The contents of general register *rt* are shifted right by *32* + *sa* bits, sign-extending the high-order bits. The result is placed in register *rd*.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

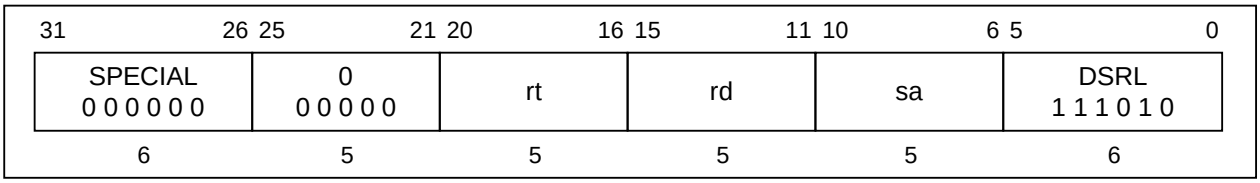
Operation:

```
64    T:    s ← 1 || sa
            GPR [rd] ← (GPR [rt]63)^s || GPR [rt]63..s
```

Exceptions:

Reserved instruction exception (32-bit user mode/supervisor mode)

DSRL Doubleword Shift Right Logical DSRL



Format:

DSRL rd, rt, sa

Description:

The contents of general register *rt* are shifted right by *sa* bits, inserting zeros into the high-order bits. The result is placed in register *rd*.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

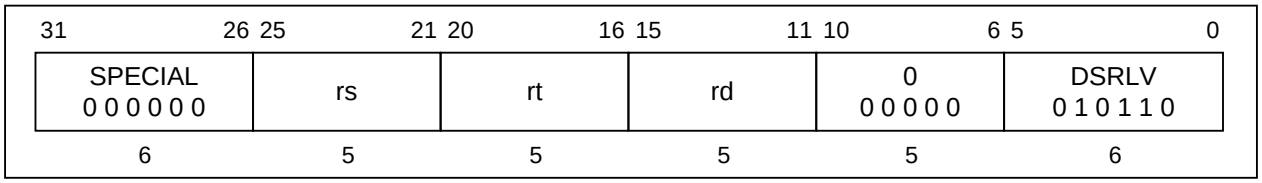
Operation:

```
64    T:    s ← 0 || sa
            GPR [rd] ← 0^s || GPR [rt]63..s
```

Exceptions:

Reserved instruction exception (32-bit user mode/supervisor mode)

DSRLV Doubleword Shift Right Logical Variable DSRLV



Format:

DSRLV rd, rt, rs

Description:

The contents of general register *rt* are shifted right by the number of bits specified by the low-order six bits of general register *rs,* inserting zeros into the high-order bits. The result is placed in register *rd*.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

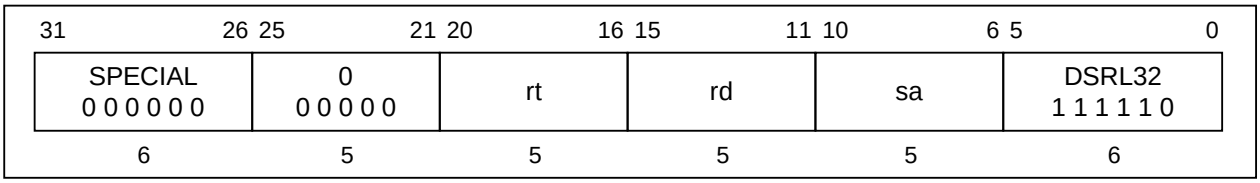
Operation:

```
64    T:    s ← GPR [rs]5..0
            GPR [rd] ← 0^s || GPR [rt]63..s
```

Exceptions:

Reserved instruction exception (32-bit user mode/supervisor mode)

DSRL32 Doubleword Shift Right Logical + 32 DSRL32



Format:

DSRL32 rd, rt, sa

Description:

The contents of general register *rt* are shifted right by *32* + *sa* bits, inserting zeros into the high-order bits. The result is placed in register *rd*.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

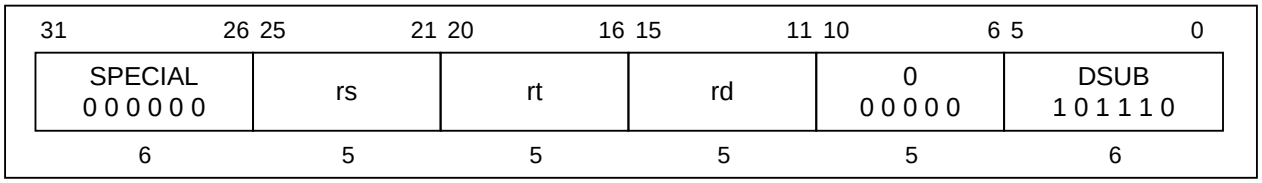
Operation:

```
64    T:    s ← 1 || sa
            GPR [rd] ← 0^s || GPR [rt]63..s
```

Exceptions:

Reserved instruction exception (32-bit user mode/supervisor mode)

DSUB Doubleword Subtract DSUB



Format:

DSUB rd, rs, rt

Description:

The contents of general register *rt* are subtracted from the contents of general register *rs* to form a result. The result is placed into general register *rd.*

An integer overflow exception takes place if the carries out of bits 62 and 63 differ (2's complement overflow). The destination register *rd* is not modified when an integer overflow exception occurs.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

Operation:

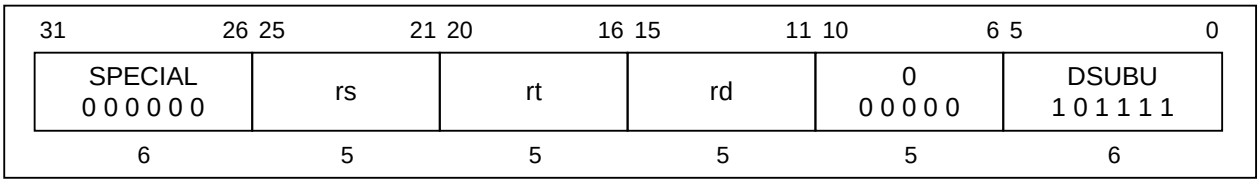
```
64   T:   GPR [rd] ← GPR [rs] – GPR [rt]
```

Exceptions:

Integer overflow exception

Reserved instruction exception (32-bit user mode/supervisor mode)

DSUBU Doubleword Subtract Unsigned DSUBU



Format:

DSUBU rd, rs, rt

Description:

The contents of general register *rt* are subtracted from the contents of general register *rs* to form a result. The result is placed into general register *rd*.

The only difference between this instruction and the DSUB instruction is that DSUBU never traps on overflow. No integer overflow exception occurs under any circumstances.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

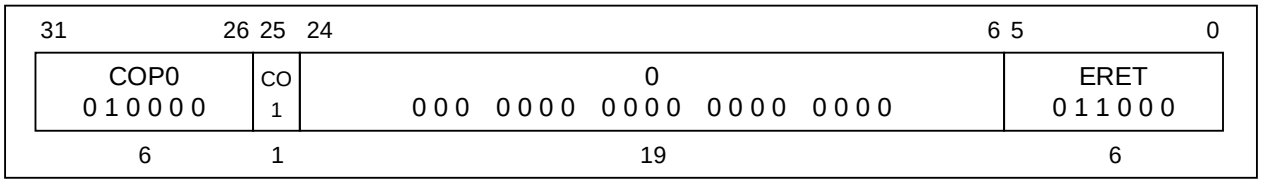
Operation:

```
64    T:    GPR [rd] ← GPR [rs] – GPR [rt]
```

Exceptions:

Reserved instruction exception (32-bit user mode/supervisor mode)

ERET Exception Return ERET



Format:

ERET

Description:

ERET is the instruction for returning from an interrupt, exception, or error trap. Unlike a branch or jump instruction, ERET does not execute the next instruction.

ERET must not itself be placed in a branch delay slot.

If the processor is servicing an error trap (*SR2* = 1), then load the PC from the ErrorEPC register and clear the *ERL* bit of the Status register (*SR2*). Otherwise (*SR2* = 0), load the PC from the EPC register, and clear the *EXL* bit of the Status register (*SR1* = 0).

When a MIPS16 instruction can be executed, the value of clearing the least significant bit of the EPC or error EPC register to 0 is loaded to PC. This means the content of the least significant bit is reflected on the ISA mode bit (internal).

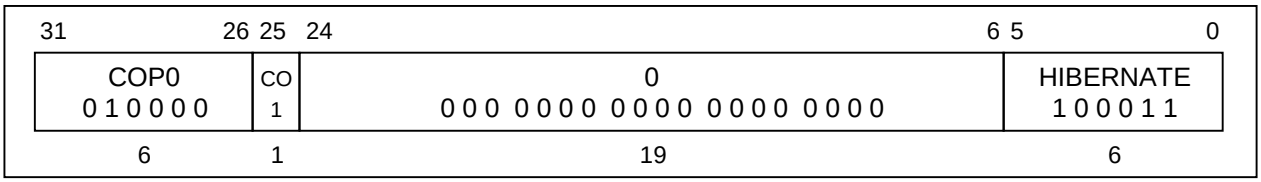
Operation:

```
32, 64   T:   if SR2 = 1 then
                 if MIPS16EN = 1 then
                    PC ← ErrorEPC63..1 || 0
                    ISA MODE ← ErrorEPC0
                 else
                    PC ← ErrorEPC
                 endif
                    SR ← SR31..3 || 0 || SR1..0
              else
                    if MIPS16EN = 1 then
                       PC ← EPC63..1 || 0
                       ISA MODE ← EPC0
                    else
                       PC ← EPC
                    endif
                       SR ← SR31..2 || 0 || SR0
              endif
```

Exceptions:

Coprocessor unusable exception

HIBERNATE Hibernate HIBERNATE



Format:

HIBERNATE

Description:

HIBERNATE instruction starts mode transition from Fullspeed mode to Hibernate mode.

When the HIBERNATE instruction finishes the WB stage, the processor wait by the SysAD bus is idle state, after then the internal clocks and the system interface clocks will shut down, thus freezing the pipeline.

Cold Reset causes the Hibernate mode to the Fullspeed mode transition.

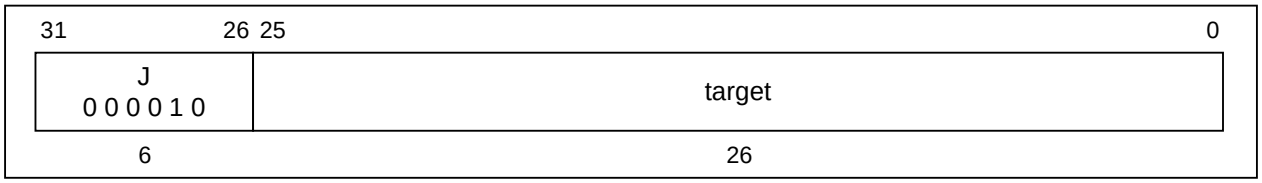
Operation:

```
32, 64 T:
        T+1:  Hibernate operation ()
```

Exceptions:

Coprocessor unusable exception

J — Jump — J



Format:

J target

Description:

The 26-bit target address is shifted left two bits and combined with the high-order four bits of the address of the delay slot. The program unconditionally jumps to this calculated address with a delay of one instruction.

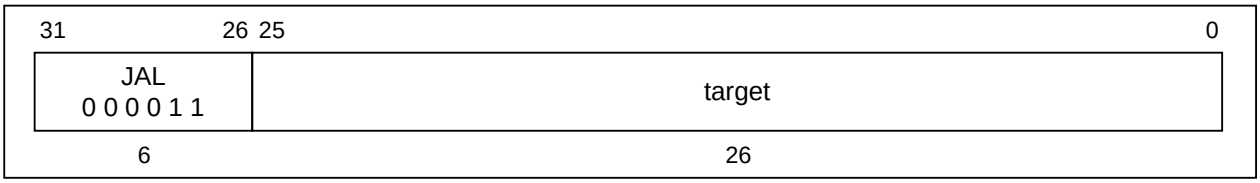
Operation:

```
32    T:     temp ← target
      T+1:   PC ← PC31..28 || temp || 0^2

64    T:     temp ← target
      T+1:   PC ← PC63..28 || temp || 0^2
```

Exceptions:

None

JAL — Jump And Link — JAL



Format:

JAL target

Description:

The 26-bit target address is shifted left two bits and combined with the high-order four bits of the address of the delay slot. The program unconditionally jumps to this calculated address with a delay of one instruction. The address of the instruction after the delay slot is placed in the link register, *r31*. The address of the instruction immediately after a delay slot is placed in the link register (r31). When a MIPS16 instruction can be executed, the value of bit 0 of r31 indicates the ISA mode bit before jump.

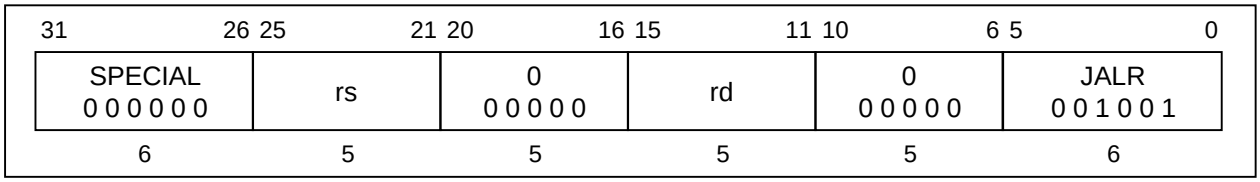
Operation:

```
32   T:    temp ← target
           If MIPS16En = 1 then
               GPR[31] ← (PC+8)31..1 || ISA MODE
           else
               GPR[31] ← PC+8
           endif
      T+1: PC ← PC31..28 || temp || 0^2

64   T:    temp ← target
           If MIPS16EN = 1 then
               GPR[31] ← (PC+8)63..1 || ISA MODE
           else
               GPR[31] ← PC+8
           endif
      T+1: PC ← PC63..28 || temp || 0^2
```

Exceptions:

None

JALR Jump And Link Register JALR



Format:

JALR rs

JALR rd, rs

Description:

The program unconditionally jumps to the address contained in general register *rs*, with a delay of one instruction. When a MIPS16 instruction can be executed, the program unconditionally jumps with a delay of one instruction to the address indicated by the value of clearing the least significant bit of the general-purpose register *rs* to 0. Then, the content of the least significant bit of the general-purpose register *rs* is set to the ISA mode bit (internal). The address of the instruction after the delay slot is placed in general register *rd*. The default value of *rd*, if omitted in the assembly language instruction, is 31. When a MIPS16 instruction can be executed, the value of bit 0 of *rd* indicates the ISA mode bit before jump. Register specifiers *rs* and *rd* may not be equal, because such an instruction does not have the same effect when re-executed. Because storing a link address destroys the contents of *rs* if they are equal. However, an attempt to execute this instruction is *not* trapped, and the result of executing such an instruction is undefined.

Since 32-bit length instructions must be word-aligned, a **JALR** instruction must specify a target register (*rs*) that contains an address whose two low-order bits are zero when a MIPS16 instruction can be executed. If these low-order bits are not zero, an address error exception will occur when the jump target instruction is subsequently fetched.

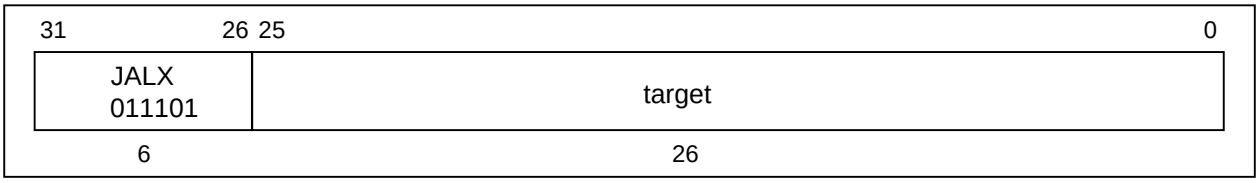
Operation:

```
32, 64   T:     temp ← GPR [rs]
                If MIPS16EN = 1 then
                    GPR [rd] ← (PC + 8)63..1 || ISA MODE
                else
                    GPR [rd] ← PC + 8
                endif
         T+1:   If MIPS16EN = 1 then
                    PC ← temp63..1 || 0
                    ISA MODE ← temp0
                else
                    PC ← temp
                endif
```

Exceptions:

None

JALX Jump And Link Exchange JALX



Format:

JALX target

Description:

When a MIPS16 instruction can be executed, a 26-bit target is shifted to left by 2 bits and then added to higher 4 bits of the delay slot's address to make a target address. The program unconditionally jumps to the target address with a delay of one instruction. The address of the instruction that follows the delay slot is stored to the link register (r31). The ISA mode bit is inverted with a delay of one instruction. The value of bit 0 of the link register (r31) indicates the ISA mode bit before jump.

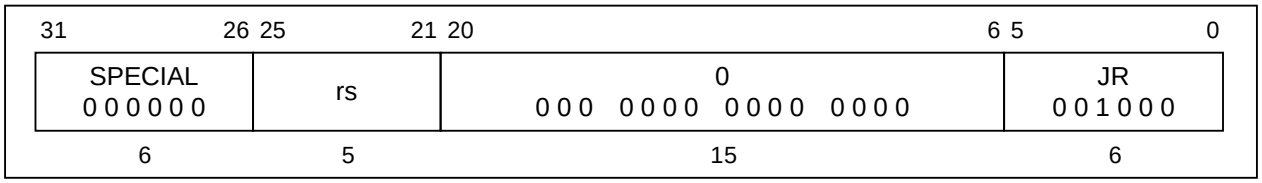
Operation:

```
32   T:    temp ← target
           GPR [31] ← (PC + 8)31..1 || ISA MODE
      T+1: PC ← PC31..28 || temp || 0^2
           ISA MODE toggle

64   T:    temp ← target
           GPR [31] ← (PC + 8)63..1 || ISA MODE
      T+1: PC ← PC63..28 || temp || 0^2
           ISA MODE toggle
```

Exceptions:

Reserved instruction exception (when MIPS16 instruction execution disabled)

JR — Jump Register — JR



Format:

JR rs

Description:

The program unconditionally jumps to the address contained in general register *rs*, with a delay of one instruction.

When a MIPS16 instruction can be executed, the program unconditionally jumps with a delay of one instruction to the address indicated by the value of clearing the least significant bit of the general register *rs* to 0. Then, the content of the least significant bit of the general register *rs* is set to the ISA mode bit (internal).

Since 32-bit length instructions must be word-aligned, a JR instruction must specify a target register (*rs*) that contains an address whose two low-order bits are zero when a MIPS16 instruction can be executed. If these low-order bits are not zero, an address error exception will occur when the jump target instruction is subsequently fetched.

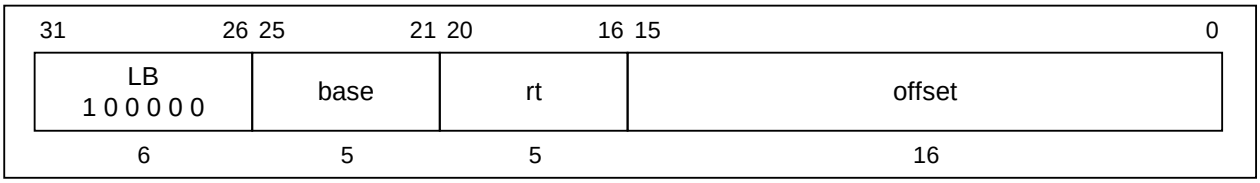
Operation:

```
32, 64   T:      temp ← GPR [rs]
         T+1:    If MIPS16EN = 1 then
                     PC ← temp63..1 || 0
                     ISA MODE ← temp0
                 else
                     PC ← temp
                 endif
```

Exceptions:

None

LB Load Byte LB



Format:

LB rt, offset (base)

Description:

The 16-bit *offset* is sign-extended and added to the contents of general register *base* to form a virtual address. The contents of the byte at the memory location specified by the effective address are sign-extended and loaded into general register *rt*.

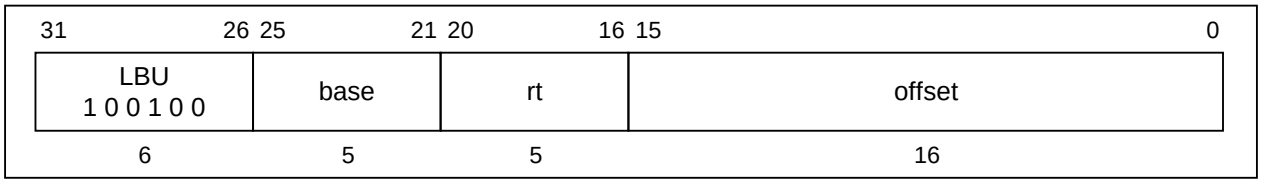
Operation:

```
32   T:   vAddr ← ((offset15)16 || offset15..0) + GPR [base]
          (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
          pAddr ← pAddrPSIZE - 1..3 || (pAddr2..0 xor ReverseEndian3)
          mem ← LoadMemory (uncached, BYTE, pAddr, vAddr, DATA)
          byte ← vAddr2..0 xor BigEndianCPU3
          GPR [rt] ← (mem7 + 8* byte)24 || mem7 + 8* byte..8* byte

64   T:   vAddr ← ((offset15)48 || offset15..0) + GPR [base]
          (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
          pAddr ← pAddrPSIZE - 1..3 || (pAddr2..0 xor ReverseEndian3)
          mem ← LoadMemory (uncached, BYTE, pAddr, vAddr, DATA)
          byte ← vAddr2..0 xor BigEndianCPU3
          GPR [rt] ← (mem7 + 8* byte)56 || mem7 + 8* byte..8* byte
```

Exceptions:

TLB refill exception
TLB invalid exception
Bus error exception
Address error exception

LBU Load Byte Unsigned LBU



Format:

LBU rt, offset (base)

Description:

The 16-bit *offset* is sign-extended and added to the contents of general register *base* to form a virtual address. The contents of the byte at the memory location specified by the effective address are zero-extended and loaded into general register *rt*.

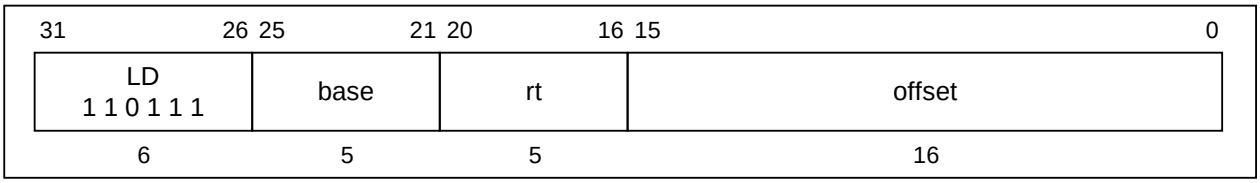
Operation:

```
32    T:   vAddr ← ((offset15)^16 || offset15..0) + GPR [base]
           (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
           pAddr ← pAddrPSIZE - 1..3 || (pAddr2..0 xor ReverseEndian^3)
           mem ← LoadMemory (uncached, BYTE, pAddr, vAddr, DATA)
           byte ← vAddr2..0 xor BigEndianCPU^3
           GPR [rt] ← 0^24 || mem7 + 8* byte..8* byte

64    T:   vAddr ← ((offset15)^48 || offset15..0) + GPR [base]
           (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
           pAddr ← pAddrPSIZE - 1..3 || (pAddr2..0 xor ReverseEndian^3)
           mem ← LoadMemory (uncached, BYTE, pAddr, vAddr, DATA)
           byte ← vAddr2..0 xor BigEndianCPU^3
           GPR [rt] ← 0^56 || mem7 + 8* byte..8* byte
```

Exceptions:

TLB refill exception
TLB invalid exception
Bus error exception
Address error exception

LD Load Doubleword LD



Format:

LD rt, offset (base)

Description:

The 16-bit *offset* is sign-extended and added to the contents of general register *base* to form a virtual address. The contents of the 64-bit doubleword at the memory location specified by the effective address are loaded into general register *rt*.

If any of the three least-significant bits of the effective address are non-zero, an address error exception occurs.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

Operation:

```
64   T:   vAddr ← ((offset15)^48 || offset15..0) + GPR [base]
          (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
          data ← LoadMemory (uncached, DOUBLEWORD, pAddr, vAddr, DATA)
          GPR [rt] ← data
```

Exceptions:

TLB refill exception
TLB invalid exception
Bus error exception
Address error exception
Reserved instruction exception (32-bit user mode/supervisor mode)

LDL Load Doubleword Left (1/3) LDL

Format:

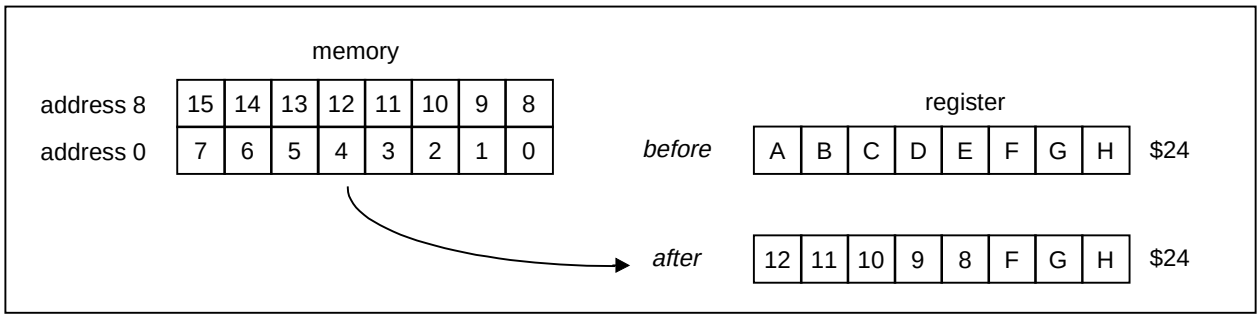
LDL rt, offset (base)

Description:

This instruction can be used in combination with the LDR instruction to load a register with eight consecutive bytes from memory, when the bytes cross a doubleword boundary. LDL loads the left portion of the register with the appropriate part of the high-order doubleword; LDR loads the right portion of the register with the appropriate part of the low-order doubleword.

The LDL instruction adds its sign-extended 16-bit *offset* to the contents of general register *base* to form a virtual address that can specify an arbitrary byte. It reads bytes only from the doubleword in memory that contains the specified starting byte. From one to eight bytes will be loaded, depending on the starting byte specified.

Conceptually, it starts at the specified byte in memory and loads that byte into the high-order (left-most) byte of the register; then it loads bytes from memory into the register until it reaches the low-order byte of the doubleword in memory. The least-significant (right-most) byte(s) of the register will not be changed.



LDL Load Doubleword Left (2/3) LDL

The contents of general register *rt* are internally bypassed within the processor so that no NOP is needed between an immediately preceding load instruction which specifies register *rt* and a following LDL (or LDR) instruction which also specifies register *rt*.

No address error exceptions due to alignment are possible.

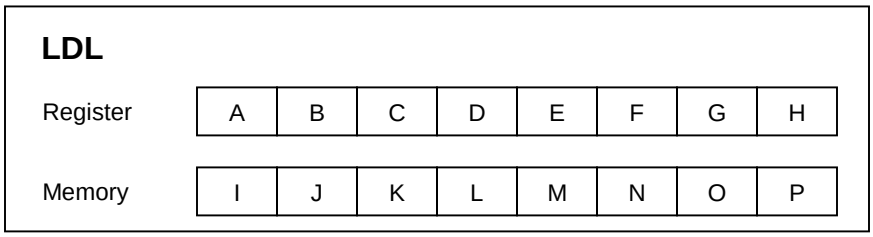
This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

Operation:

```
64    T:    vAddr ← ((offset15)^48 || offset15..0) + GPR [base]
            (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
            pAddr ← pAddrPSIZE - 1..3 || (pAddr2..0 xor ReverseEndian^3)
            if BigEndianMem = 0 then
                  pAddr ← pAddrPSIZE - 1..3 || 0^3
            endif
            byte ← vAddr2..0 xor BigEndianCPU^3
            mem ← LoadMemory (uncached, byte, pAddr, vAddr, DATA)
            GPR [rt] ← mem7 + 8 * byte..0 || GPR [rt]55 – 8 * byte..0
```

LDL Load Doubleword Left (3/3) LDL

Given a doubleword in a register and a doubleword in memory, the operation of LDL is as follows:



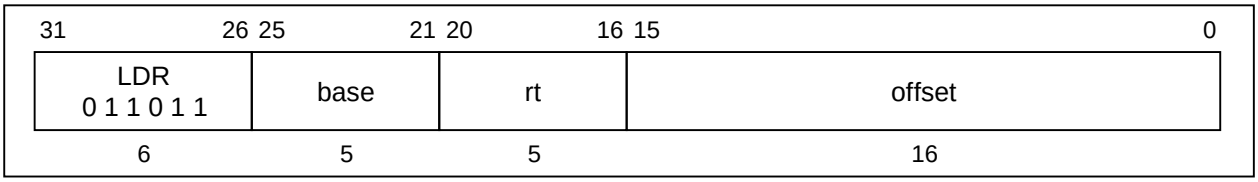
vAddr2..0	Destination	Type	Offset (LEM)
0	P B C D E F G H	0	0
1	O P C D E F G H	1	0
2	N O P D E F G H	2	0
3	M N O P E F G H	3	0
4	L M N O P F G H	4	0
5	K L M N O P G H	5	0
6	J K L M N O P H	6	0
7	I J K L M N O P	7	0

Remark *LEM* Little-endian memory (BigEndianMem = 0)
Type AccessType (see **Table 2-3. Byte Specification Related to Load and Store Instructions**) sent to memory
Offset pAddr2..0 sent to memory

Exceptions:

TLB refill exception
TLB invalid exception
Bus error exception
Address error exception
Reserved instruction exception (32-bit user mode/supervisor mode)

LDR Load Doubleword Right (1/3) LDR



Format:

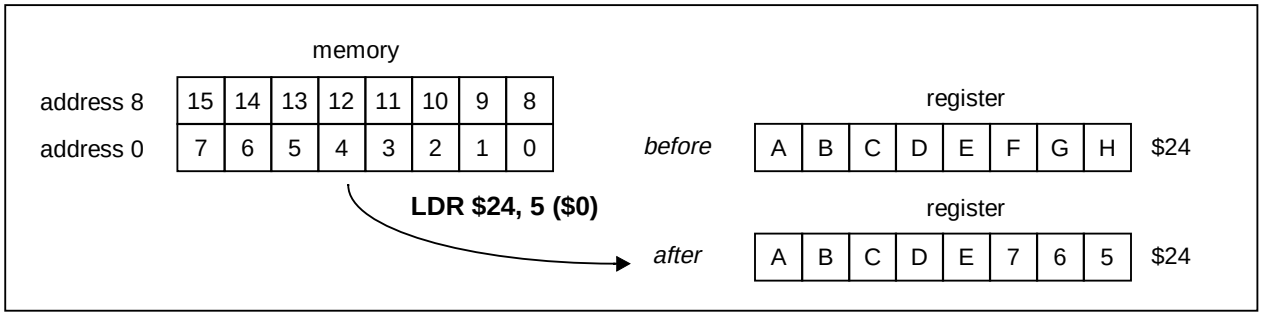
LDR rt, offset (base)

Description:

This instruction can be used in combination with the LDL instruction to load a register with eight consecutive bytes from memory, when the bytes cross a doubleword boundary. LDL instruction loads the high-order portion of data and LDR instruction loads the low-order portion of data.

The LDR instruction adds its sign-extended 16-bit *offset* to the contents of general register *base* to form a virtual address that can specify an arbitrary byte. It reads bytes only from the doubleword in memory that contains the specified starting byte. From one to eight bytes will be loaded, depending on the starting byte specified.

Conceptually, it starts at the specified byte in memory and loads that byte into the low-order (right-most) byte of the register; then it loads bytes from memory into the register until it reaches the high-order byte of the doubleword in memory. The most significant (left-most) byte(s) of the register will not be changed.



LDR Load Doubleword Right (2/3) LDR

The contents of general register *rt* are internally bypassed within the processor so that no NOP is needed between an immediately preceding load instruction which specifies register *rt* and a following LDR (or LDL) instruction which also specifies register *rt*.

No address error exceptions due to alignment are possible.

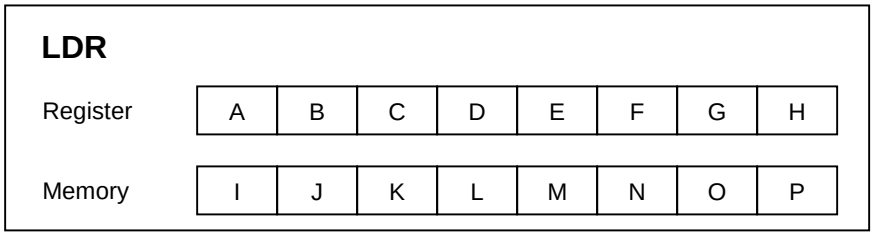
This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

Operation:

```
64    T:    vAddr ← ((offset15)^48 || offset15..0) + GPR [base]
            (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
            pAddr ← pAddrPSIZE - 1..3 || (pAddr2..0 xor ReverseEndian^3)
            if BigEndianMem = 1 then
                  pAddr ← pAddrPSIZE - 1..3 || 0^3
            endif
            byte ← vAddr2..0 xor BigEndianCPU^3
            mem ← LoadMemory (uncached, DOUBLEWORD-byte, pAddr, vAddr, DATA)
            GPR [rt] ← GPR [rt]63..64 – 8 * byte || mem63..8 * byte
```

LDR Load Doubleword Right (3/3) LDR

Given a doubleword in a register and a doubleword in memory, the operation of LDR is as follows:



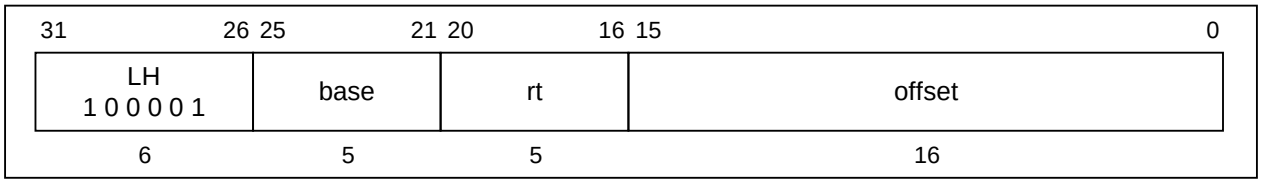
vAddr2..0	Destination	Type	Offset (LEM)
0	I J K L M N O P	7	0
1	A I J K L M N O	6	1
2	A B I J K L M N	5	2
3	A B C I J K L M	4	3
4	A B C D I J K L	3	4
5	A B C D E I J K	2	5
6	A B C D E F I J	1	6
7	A B C D E F G I	0	7

Remark *LEM* Little-endian memory (BigEndianMem = 0)
Type AccessType (see **Table 2-3. Byte Specification Related to Load and Store Instructions**) sent to memory
Offset pAddr2..0 sent to memory

Exceptions:

TLB refill exception
TLB invalid exception
Bus error exception
Address error exception
Reserved instruction exception (32-bit user mode/supervisor mode)

LH Load Halfword LH



Format:

LH rt, offset (base)

Description:

The 16-bit *offset* is sign-extended and added to the contents of general register *base* to form a virtual address. The contents of the halfword at the memory location specified by the effective address are sign-extended and loaded into general register *rt*.

If the least-significant bit of the effective address is non-zero, an address error exception occurs.

Operation:

```
32    T:    vAddr ← ((offset15)^16 || offset15...0) + GPR [base]
            (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
            pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor (ReverseEndian^2 || 0))
            mem ← LoadMemory (uncached, HALFWORD, pAddr, vAddr, DATA)
            byte ← vAddr2...0 xor (BigEndianCPU^2 || 0)
            GPR [rt] ← (mem15 + 8 * byte)^16 || mem15 + 8 * byte...8 * byte

64    T:    vAddr ← ((offset15)^48 || offset15...0) + GPR [base]
            (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
            pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor (ReverseEndian^2 || 0))
            mem ← LoadMemory (uncached, HALFWORD, pAddr, vAddr, DATA)
            byte ← vAddr2...0 xor (BigEndianCPU^2 || 0)
            GPR [rt] ← (mem15 + 8 * byte)^48 || mem15 + 8 * byte...8 * byte
```

Exceptions:

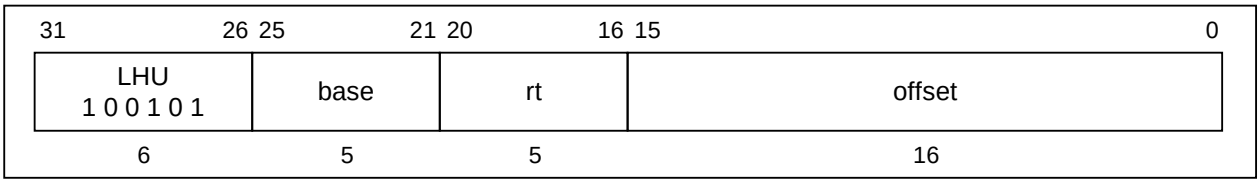
TLB refill exception

TLB invalid exception

Bus error exception

Address error exception

LHU Load Halfword Unsigned LHU



Format:

LHU rt, offset (base)

Description:

The 16-bit *offset* is sign-extended and added to the contents of general register *base* to form a virtual address. The contents of the halfword at the memory location specified by the effective address are zero-extended and loaded into general register *rt*.

If the least-significant bit of the effective address is non-zero, an address error exception occurs.

Operation:

```
32   T:   vAddr ← ((offset15)^16 || offset15...0) + GPR [base]
          (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
          pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor (ReverseEndian^2 || 0))
          mem ← LoadMemory (uncached, HALFWORD, pAddr, vAddr, DATA)
          byte ← vAddr2...0 xor (BigEndianCPU^2 || 0)
          GPR [rt] ← 0^16 || mem15 + 8 * byte...8 * byte

64   T:   vAddr ← ((offset15)^48 || offset15...0) + GPR [base]
          (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
          pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor (ReverseEndian^2 || 0))
          mem ← LoadMemory (uncached, HALFWORD, pAddr, vAddr, DATA)
          byte ← vAddr2...0 xor (BigEndianCPU^2 || 0)
          GPR [rt] ← 0^48 || mem15 + 8 * byte...8 * byte
```

Exceptions:

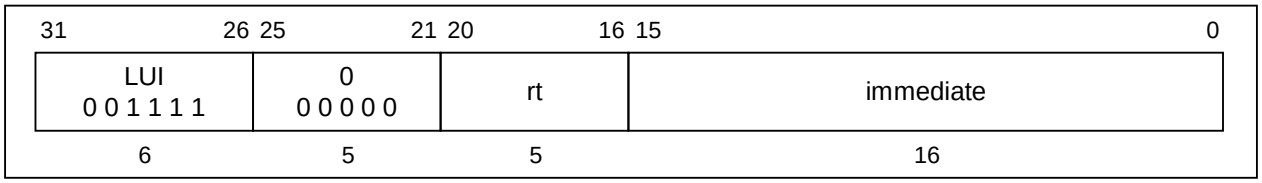
TLB refill exception

TLB invalid exception

Bus Error exception

Address error exception

LUI — Load Upper Immediate — LUI



Format:

LUI rt, immediate

Description:

The 16-bit *immediate* is shifted left 16 bits and concatenated to 16 bits of zeros. The result is placed into general register *rt*. In 64-bit mode, the loaded word is sign-extended.

Operation:

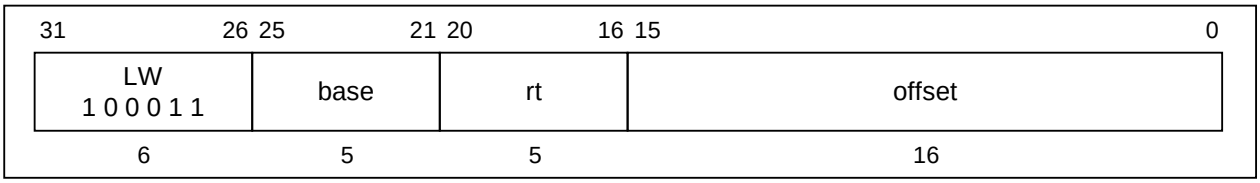
32 T: GPR [rt] ← immediate || 0^{16}

64 T: GPR [rt] ← $(\text{immediate}_{15})^{32}$ || immediate || 0^{16}

Exceptions:

None

LW Load Word LW



Format:

LW rt, offset (base)

Description:

The 16-bit *offset* is sign-extended and added to the contents of general register *base* to form a virtual address. The contents of the word at the memory location specified by the effective address are loaded into general register *rt*. In 64-bit mode, the loaded word is sign-extended.

If either of the two least-significant bits of the effective address is non-zero, an address error exception occurs.

Operation:

```
32    T:   vAddr ← ((offset15)16 || offset15...0) + GPR [base]
           (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
           pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor (ReverseEndian || 02))
           mem ← LoadMemory (uncached, WORD, pAddr, vAddr, DATA)
           byte ← vAddr2...0 xor (BigEndianCPU || 02)
           GPR [rt] ← mem31 + 8 * byte...8 * byte

64    T:   vAddr ← ((offset15)48 || offset15...0) + GPR [base]
           (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
           pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor (ReverseEndian || 02))
           mem ← LoadMemory (uncached, WORD, pAddr, vAddr, DATA)
           byte ← vAddr2...0 xor (BigEndianCPU || 02)
           GPR [rt] ← (mem31 + 8 * byte)32 || mem31 + 8 * byte...8 * byte
```

Exceptions:

TLB refill exception

TLB invalid exception

Bus error exception

Address error exception

LWL Load Word Left (1/3) LWL

Format:

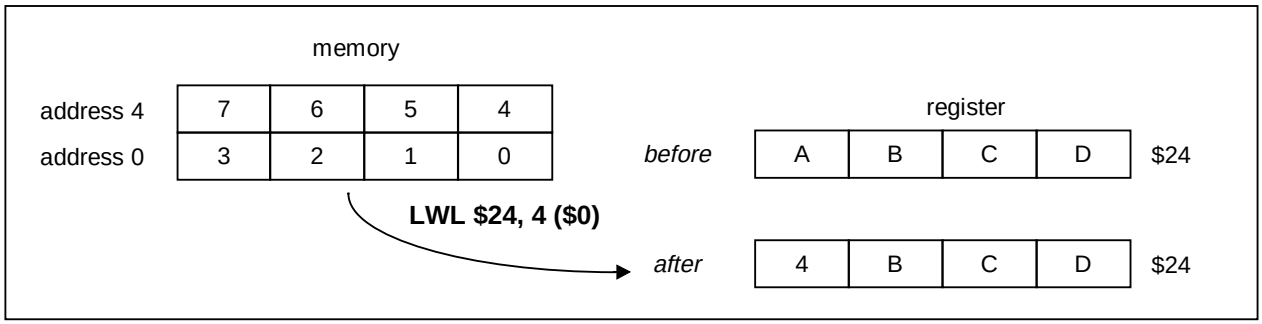
LWL rt, offset (base)

Description:

This instruction can be used in combination with the LWR instruction to load a register with four consecutive bytes from memory, when the bytes cross a word boundary. LWL loads the left portion of the register with the appropriate part of the high-order word; LWR loads the right portion of the register with the appropriate part of the low-order word.

The LWL instruction adds its sign-extended 16-bit *offset* to the contents of general register *base* to form a virtual address that can specify an arbitrary byte. It reads bytes only from the word in memory that contains the specified starting byte. From one to four bytes will be loaded, depending on the starting byte specified. In 64-bit mode, the loaded word is sign-extended.

Conceptually, it starts at the specified byte in memory and loads that byte into the high-order (left-most) byte of the register; then it loads bytes from memory into the register until it reaches the low-order byte of the word in memory. The least-significant (right-most) byte(s) of the register will not be changed.



LWL Load Word Left (2/3) LWL

The contents of general register *rt* are internally bypassed within the processor so that no NOP is needed between an immediately preceding load instruction which specifies register *rt* and a following LWL (or LWR) instruction which also specifies register *rt*.

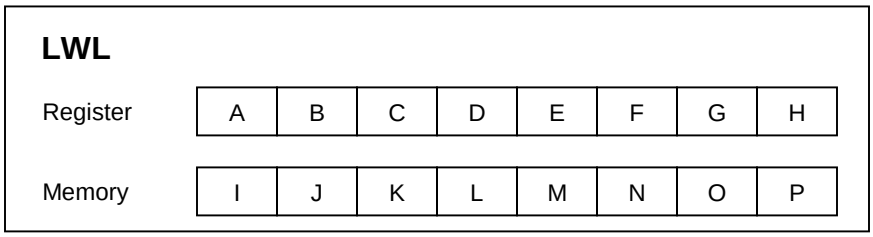
No address error exceptions due to alignment are possible.

Operation:

```
32   T:   vAddr ← ((offset15)^16 || offset15...0) + GPR [base]
          (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
          pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor ReverseEndian^3)
          if BigEndianMem = 0 then
               pAddr ← pAddrPSIZE - 1...2 || 0^2
          endif
          byte ← vAddr1...0 xor BigEndianCPU^2
          word ← vAddr2 xor BigEndianCPU
          mem ← LoadMemory (uncached, byte, pAddr, vAddr, DATA)
          temp ← mem32 * word + 8 * byte + 7...32 * word || GPR [rt]23 – 8 * byte...0
          GPR [rt] ← temp

64   T:   vAddr ← ((offset15)^48 || offset15...0) + GPR [base]
          (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
          pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor ReverseEndian^3)
          if BigEndianMem = 0 then
               pAddr ← pAddrPSIZE - 1...2 || 0^2
          endif
          byte ← vAddr1...0 xor BigEndianCPU^2
          word ← vAddr2 xor BigEndianCPU
          mem ← LoadMemory (uncached, 0 || byte, pAddr, vAddr, DATA)
          temp ← mem32 * word + 8 * byte + 7...32 * word || GPR [rt]23 – 8 * byte...0
          GPR [rt] ← (temp31)^32 || temp
```

LWL Load Word Left (3/3) LWL

Given a doubleword in a register and a doubleword in memory, the operation of LWL is as follows:



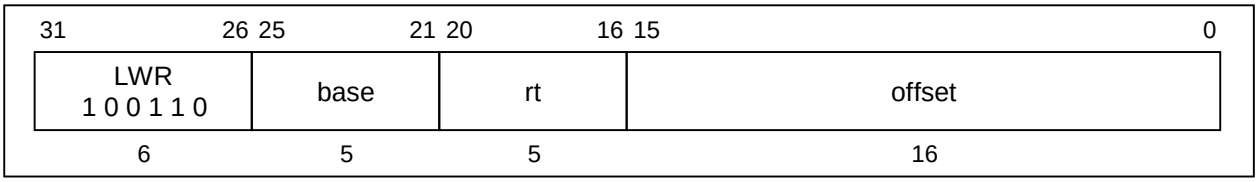
vAddr2..0	Destination	Type	Offset (LEM)
0	S S S S P F G H	0	0
1	S S S S O P G H	1	0
2	S S S S N O P H	2	0
3	S S S S M N O P	3	0
4	S S S S L F G H	0	4
5	S S S S K L G H	1	4
6	S S S S J K L H	2	4
7	S S S S I J K L	3	4

Remark *LEM* Little-endian memory (BigEndianMem = 0)
Type AccessType (see **Table 2-3. Byte Specification Related to Load and Store Instructions**) sent to memory
Offset pAddr2..0 sent to memory
S sign-extend of destination bit 31

Exceptions:

TLB refill exception
TLB invalid exception
Bus error exception
Address error exception

LWR Load Word Right (1/3) LWR



Format:

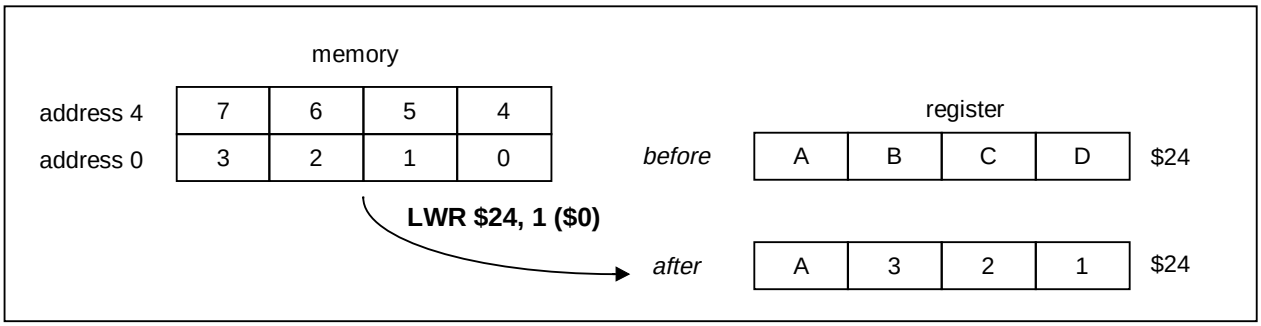
LWR rt, offset (base)

Description:

This instruction can be used in combination with the LWL instruction to load a register with four consecutive bytes from memory, when the bytes cross a word boundary. LWR loads the right portion of the register with the appropriate part of the low-order word; LWL loads the left portion of the register with the appropriate part of the high-order word.

The LWR instruction adds its sign-extended 16-bit *offset* to the contents of general register *base* to form a virtual address that can specify an arbitrary byte. It reads bytes only from the word in memory that contains the specified starting byte. From one to four bytes will be loaded, depending on the starting byte specified. In 64-bit mode, the loaded word is sign-extended.

Conceptually, it starts at the specified byte in memory and loads that byte into the low-order (right-most) byte of the register; then it loads bytes from memory into the register until it reaches the high-order byte of the word in memory. The most significant (left-most) byte(s) of the register will not be changed.



LWR Load Word Right (2/3) LWR

The contents of general register *rt* are internally bypassed within the processor so that no NOP is needed between an immediately preceding load instruction which specifies register *rt* and a following LWR (or LWL) instruction which also specifies register *rt*.

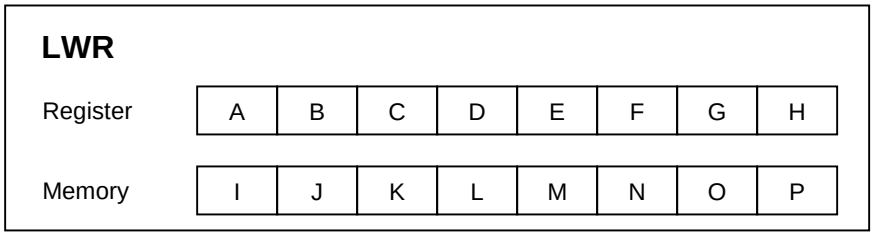
No address error exceptions due to alignment are possible.

Operation:

```
32    T:    vAddr ← ((offset15)^16 || offset15...0) + GPR [base]
            (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
            pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor ReverseEndian^3)
            if BigEndianMem = 1 then
                  pAddr ← pAddrPSIZE - 1...3 || 0^3
            endif
            byte ← vAddr1...0 xor BigEndianCPU^2
            word ← vAddr2 xor BigEndianCPU
            mem ← LoadMemory (uncached, 0 || byte, pAddr, vAddr, DATA)
            temp ← GPR [rt]31...32 – 8 * byte || mem31 + 32 * word...32 * word + 8 * byte
            GPR [rt] ← temp

64    T:    vAddr ← ((offset15)^48 || offset15...0) + GPR [base]
            (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
            pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor ReverseEndian^3)
            if BigEndianMem = 1 then
                  pAddr ← pAddrPSIZE - 1...3 || 0^3
            endif
            byte ← vAddr1...0 xor BigEndianCPU^2
            word ← vAddr2 xor BigEndianCPU
            mem ← LoadMemory (uncached, WORD-byte, pAddr, vAddr, DATA)
            temp ← GPR [rt]31...32 – 8 * byte || mem31 + 32 * word...32 * word + 8 * byte
            GPR [rt] ← (temp31)^32 || temp
```

LWR Load Word Right (3/3) LWR

Given a word in a register and a word in memory, the operation of LWR is as follows:



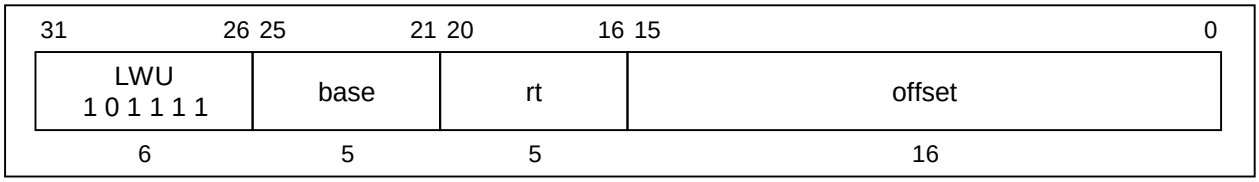
vAddr2..0	Destination	Type	Offset (LEM)
0	S S S S M N O P	3	0
1	S S S S E M N O	2	1
2	S S S S E F M N	1	2
3	S S S S E F G M	0	3
4	S S S S I J K L	3	4
5	S S S S E I J K	2	5
6	S S S S E F I J	1	6
7	S S S S E F G I	0	7

Remark *LEM* Little-endian memory (BigEndianMem = 0)
Type AccessType (see **Table 2-3. Byte Specification Related to Load and Store Instructions**) sent to memory
Offset pAddr2..0 sent to memory
S sign-extend of destination31

Exceptions:

TLB refill exception
TLB invalid exception
Bus error exception
Address error exception

LWU — Load Word Unsigned — LWU



Format:

LWU rt, offset (base)

Description:

The 16-bit *offset* is sign-extended and added to the contents of general register *base* to form a virtual address. The contents of the word at the memory location specified by the effective address are loaded into general register *rt*. The loaded word is zero-extended.

If either of the two least-significant bits of the effective address is non-zero, an address error exception occurs.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

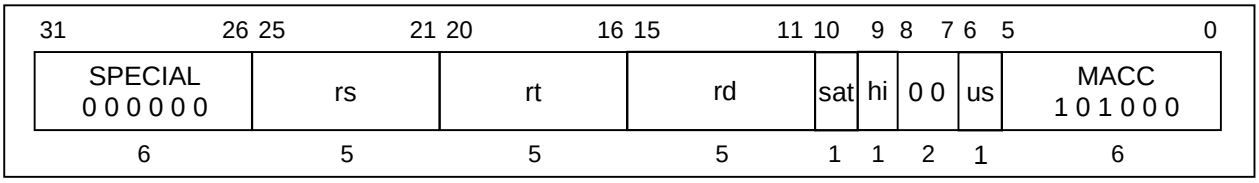
Operation:

```
32    T:    vAddr ← ((offset15)^16 || offset15...0) + GPR [base]
            (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
            pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor (ReverseEndian || 0^2))
            mem ← LoadMemory (uncached, WORD, pAddr, vAddr, DATA)
            byte ← vAddr2...0 xor (BigEndianCPU || 0^2)
            GPR [rt] ← 0^32 || mem31 + 8 * byte...8 * byte

64    T:    vAddr ← ((offset15)^48 || offset15...0) + GPR [base]
            (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
            pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor (ReverseEndian || 0^2))
            mem ← LoadMemory (uncached, WORD, pAddr, vAddr, DATA)
            byte ← vAddr2...0 xor (BigEndianCPU || 0^2)
            GPR [rt] ← 0^32 || mem31 + 8 * byte...8 * byte
```

Exceptions:

TLB refill exception
TLB invalid exception
Bus error exception
Address error exception
Reserved instruction exception (32-bit user mode/supervisor mode)

MACC — Multiply and Accumulate (1/5) — MACC



Format:

MACC rd, rs, rt
MACCU rd, rs, rt
MACCHI rd, rs, rt
MACCHIU rd, rs, rt
MACCS rd, rs, rt
MACCUS rd, rs, rt
MACCHIS rd, rs, rt
MACCHIUS rd, rs, rt

Description:

MACC instruction differs mnemonics by each setting of op codes sat, hi and us as follows.

Mnemonic	sat	hi	us
MACC	0	0	0
MACCU	0	0	1
MACCHI	0	1	0
MACCHIU	0	1	1
MACCS	1	0	0
MACCUS	1	0	1
MACCHIS	1	1	0
MACCHIUS	1	1	1

The number of significant bits in the operands of the MACC instruction differ depending on whether saturation processing is executed (sat = 1) or not executed (sat = 0).

- When saturation processing is executed (sat = 1): MACCS, MACCUS, MACCHIS, MACCHIUS instructions
  The contents of general register *rs* is multiplied by the contents of general register *rt*. If both operands are set as "us = 1" (MACCUS, MACCHIUS instructions), the contents are handled as 16 bit unsigned data. If they are set as "us = 0" (MACCS, MACCHIS instructions), the contents are handled as 16 bit signed integers. Sign/zero expansion by software is required for any bits exceeding 16 bits in the operands. The product of this multiply operation is added to a 64-bit value (of which only the low-order 32 bits are valid) that is linked to the HI and LO special registers. If us = 1, this add operation handles the values being added as 32 bit unsigned data. If us = 0, the values are handled as 32 bit signed integers. Sign/zero expansion by software is required for any bits exceeding 32 bits in the linked HI and LO special registers. After saturation processing to 32 bits has been performed (see the table below), the sum from this add operation is loaded to the HI and LO special register. When hi = 1 (MACCHIS, MACCHIUS instructions), data that is the same as the data loaded to the HI special register is also loaded to the rd general register. When hi = 0 (MACCS, MACCUS instructions), data that is the same as the data loaded to the LO special register is also loaded to the rd general register. Overflow exceptions do not occur.

MACC Multiply and Accumulate (2/5) MACC

- When saturation processing is not executed (sat = 0): MACC, MACCU, MACCHI, MACCHIU instructions
  The contents of general register *rs* is multiplied to the contents of general register *rt*. If both operands are set as "us = 1" (MACCU, MACCHIU instructions), the contents are handled as 32 bit unsigned data. If they are set as "us = 0" (MACC, MACCHI instructions), the contents are handled as 32 bit signed integers. Sign/zero expansion by software is required for any bits exceeding 32 bits in the operands. The product of this multiply operation is added to a 64-bit value that is linked to the HI and LO special registers. If us = 1, this add operation handles the values being added as 64 bit unsigned data. If us = 0, the values are handled as 64 bit signed integers.
  The low-order word from the 64-bit sum from this add operation is loaded to the LO special register and the high-order word is loaded to the HI special register. When hi = 1 (MACCHI, MACCHIU instructions), data that is the same as the data loaded to the HI special register is also loaded to the rd general register. When hi = 0 (MACC, MACCU instructions), data that is the same as the data loaded to the LO special register is also loaded to the rd general register. Overflow exceptions do not occur.

The correspondence of us and sat settings and values stored during saturation processing is shown below, along with the hazard cycles required between execution of the instruction for manipulating the HI and LO registers and execution of the MACC instruction.

Values Stored during Saturation Processing

us	sat	Overflow	Underflow
0	0	Store calculation result as is	Store calculation result as is
1	0	Store calculation result as is	Store calculation result as is
0	1	0000 0000 7FFF FFFFH	FFFF FFFF 8000 0000H
1	1	FFFF FFFF FFFF FFFFH	None

Hazard Cycle Counts

Instruction	Cycle Count
MULT, MULTU	1
DMULT, DMULTU	3
DIV, DIVU	36
DDIV, DDIVU	68
MFHI, MFLO	2
MTHI, MTLO	0
MACC	0
DMACC	0

MACC — Multiply and Accumulate (3/5) — MACC

Operation:

```
32, sat=0, hi=0, us=0 (MACC instruction)
    T:  temp1 ← GPR[rs] * GPR[rt]
        temp2 ← temp1 + (HI || LO)
        LO ← temp2[63..32]
        HI ← temp2[31..0]
        GPR[rd] ← LO
32, sat=0, hi=0, us=1 (MACCU instruction)
    T:  temp1 ← (0 || GPR[rs]) * (0 || GPR[rt])
        temp2 ← temp1 + ((0 || HI) || (0 || LO))
        LO ← temp2[63..32]
        HI ← temp2[31..0]
        GPR[rd] ← LO
32, sat=0, hi=1, us=0 (MACCHI instruction)
    T:  temp1 ← GPR[rs] * GPR[rt]
        temp2 ← temp1 + (HI || LO)
        LO ← temp2[63..32]
        HI ← temp2[31..0]
        GPR[rd] ← HI
32, sat=0, hi=1, us=1 (MACCHIU instruction)
    T:  temp1 ← (0 || GPR[rs]) * (0 || GPR[rt])
        temp2 ← temp1 + ((0 || HI) || (0 || LO))
        LO ← temp2[63..32]
        HI ← temp2[31..0]
        GPR[rd] ← HI
32, sat=1, hi=0, us=0 (MACCS instruction)
    T:  temp1 ← GPR[rs] * GPR[rt]
        temp2 ← saturation(temp1 + (HI || LO))
        LO ← temp2[63..32]
        HI ← temp2[31..0]
        GPR[rd] ← LO
32, sat=1, hi=0, us=1 (MACCUS instruction)
    T:  temp1 ← (0 || GPR[rs]) * (0 || GPR[rt])
        temp2 ← saturation(temp1 + ((0 || HI) || (0 || LO)))
        LO ← temp2[63..32]
        HI ← temp2[31..0]
        GPR[rd] ← LO
```

MACC — Multiply and Accumulate (4/5) — MACC

32, sat=1, hi=1, us=0 (MACCHIS instruction)

T: temp1 ← GPR[rs] * GPR[rt]
temp2 ← saturation(temp1 + (HI || LO))
LO ← $temp2_{63..32}$
HI ← $temp2_{31..0}$
GPR[rd] ← HI

32, sat=1, hi=1, us=1 (MACCHIUS instruction)

T: temp1 ← (0 || GPR[rs]) * (0 || GPR[rt])
temp2 ← saturation(temp1 + ((0 || HI) || (0 || LO)))
LO ← $temp2_{63..32}$
HI ← $temp2_{31..0}$
GPR[rd] ← HI

64, sat=0, hi=0, us=0 (MACC instruction)

T: temp1 ← $((GPR[rs]_{31})^{32}$ || GPR[rs]) * $((GPR[rt]_{31})^{32}$ || GPR[rt])
temp2 ← temp1 + ($HI_{31..0}$ || $LO_{31..0}$)
LO ← $((temp2_{63})^{32}$ || $temp2_{63..32}$)
HI ← $((temp2_{31})^{32}$ || $temp2_{31..0}$)
GPR[rd] ← LO

64, sat=0, hi=0, us=1 (MACCU instruction)

T: temp1 ← $(0^{32}$ || GPR[rs]) * $(0^{32}$ || GPR[rt])
temp2 ← temp1 + ($HI_{31..0}$ || $LO_{31..0}$)
LO ← $((temp2_{63})^{32}$ || $temp2_{63..32}$)
HI ← $((temp2_{31})^{32}$ || $temp2_{31..0}$)
GPR[rd] ← LO

64, sat=0, hi=1, us=0 (MACCHI instruction)

T: temp1 ← $((GPR[rs]_{31})^{32}$ || GPR[rs]) * $((GPR[rt]_{31})^{32}$ || GPR[rt])
temp2 ← temp1 + ($HI_{31..0}$ || $LO_{31..0}$)
LO ← $((temp2_{63})^{32}$ || $temp2_{63..32}$)
HI ← $((temp2_{31})^{32}$ || $temp2_{31..0}$)
GPR[rd] ← HI

64, sat=0, hi=1, us=1 (MACCHIU instruction)

T: temp1 ← $(0^{32}$ || GPR[rs]) * $(0^{32}$ || GPR[rt])
temp2 ← temp1 + ($HI_{31..0}$ || $LO_{31..0}$)
LO ← $((temp2_{63})^{32}$ || $temp2_{63..32}$)
HI ← $((temp2_{31})^{32}$ || $temp2_{31..0}$)
GPR[rd] ← HI

MACC — Multiply and Accumulate (5/5) — MACC

64, sat=1, hi=0, us=0 (MACCS instruction)

T: temp1 ← ((GPR[rs]$_{31}$)^{32} || GPR[rs]) * ((GPR[rt]$_{31}$)^{32} || GPR[rt])
temp2 ← saturation(temp1 + (HI$_{31..0}$ || LO$_{31..0}$))
LO ← ((temp2$_{63}$)^{32} || temp2$_{63..32}$)
HI ← ((temp2$_{31}$)^{32} || temp2$_{31..0}$)
GPR[rd] ← LO

64, sat=1, hi=0, us=1 (MACCUS instruction)

T: temp1 ← (0^{32} || GPR[rs]) * (0^{32} || GPR[rt])
temp2 ← saturation(temp1 + (HI$_{31..0}$ || LO$_{31..0}$))
LO ← ((temp2$_{63}$)^{32} || temp2$_{63..32}$)
HI ← ((temp2$_{31}$)^{32} || temp2$_{31..0}$)
GPR[rd] ← LO

64, sat=1, hi=1, us=0 (MACCHIS instruction)

T: temp1 ← ((GPR[rs]$_{31}$)^{32} || GPR[rs]) * ((GPR[rt]$_{31}$)^{32} || GPR[rt])
temp2 ← saturation(temp1 + (HI$_{31..0}$ || LO$_{31..0}$))
LO ← ((temp2$_{63}$)^{32} || temp2$_{63..32}$)
HI ← ((temp2$_{31}$)^{32} || temp2$_{31..0}$)
GPR[rd] ← HI

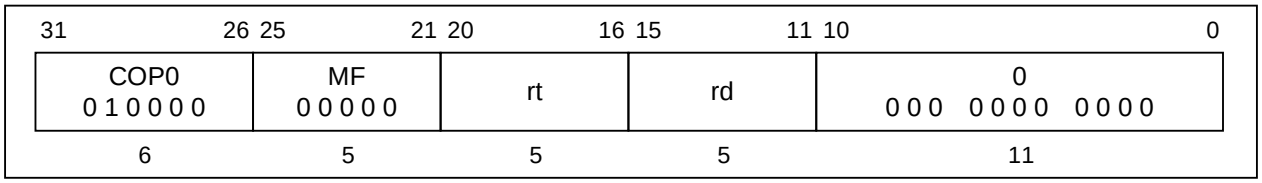
64, sat=1, hi=1, us=1 (MACCHIUS instruction)

T: temp1 ← (0^{32} || GPR[rs]) * (0^{32} || GPR[rt])
temp2 ← saturation(temp1 + (HI$_{31..0}$ || LO$_{31..0}$)
LO ← ((temp2$_{63}$)^{32} || temp2$_{63..32}$)
HI ← ((temp2$_{31}$)^{32} || temp2$_{31..0}$)
GPR[rd] ← HI

Exceptions:

None

MFC0 Move From System Control Coprocessor MFC0



Format:

MFC0 rt, rd

Description:

The contents of coprocessor register *rd* of the CP0 are loaded into general register *rt.*

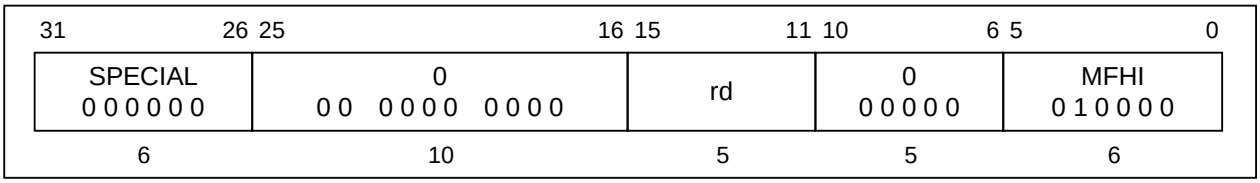
Operation:

```
32    T:     data  ← CPR [0, rd]
      T+1:   GPR [rt] ← data

64    T:     data  ← CPR [0, rd]
      T+1:   GPR [rt] ← (data31)^32 || data31...0
```

Exceptions:

Coprocessor unusable exception (in 64-bit/32-bit user and supervisor mode if CP0 not enabled)

MFHI Move From HI MFHI



Format:

MFHI rd

Description:

The contents of special register *HI* are loaded into general register *rd*.

To ensure proper operation in the event of interruptions, the two instructions which follow a MFHI instruction may not be any of the instructions which modify the *HI* register: MULT, MULTU, DIV, DIVU, MTHI, DMULT, DMULTU, DDIV, DDIVU.

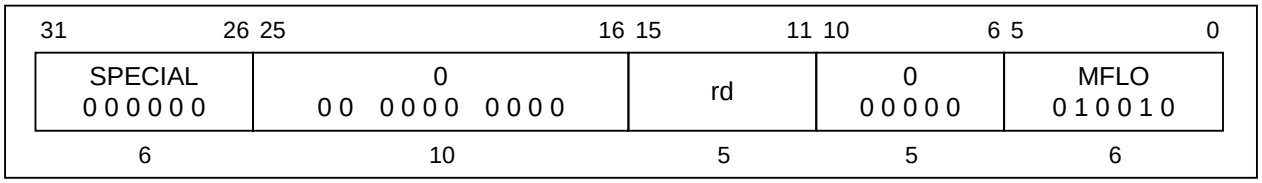
Operation:

```
32, 64 T:    GPR [rd] ← HI
```

Exceptions:

None

MFLO Move From LO MFLO



Format:

MFLO rd

Description:

The contents of special register *LO* are loaded into general register *rd*.

To ensure proper operation in the event of interruptions, the two instructions which follow a MFLO instruction may not be any of the instructions which modify the *LO* register: MULT, MULTU, DIV, DIVU, MTLO, DMULT, DMULTU, DDIV, DDIVU.

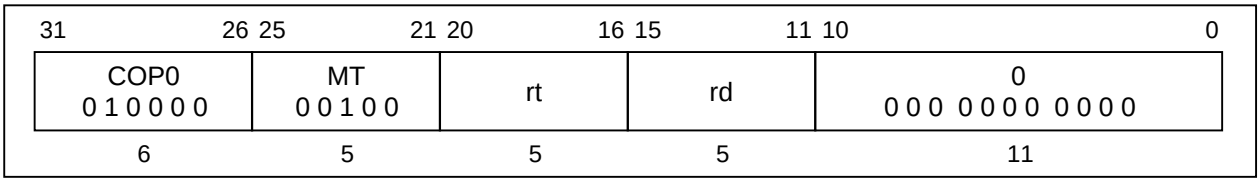
Operation:

```
32, 64 T:    GPR [rd] ← LO
```

Exceptions:

None

MTC0 Move To Coprocessor0 MTC0



Format:

MTC0 rt, rd

Description:

The contents of general register *rt* are loaded into coprocessor register *rd* of coprocessor 0.

Because the state of the virtual address translation system may be altered by this instruction, the operation of load instructions, store instructions, and TLB operations immediately prior to and after this instruction are undefined.

When using a register used by the MTC0 by means of instructions before and after it, refer to **APPENDIX C VR4120A COPROCESSOR 0 HAZARDS** and place the instructions in the appropriate location.

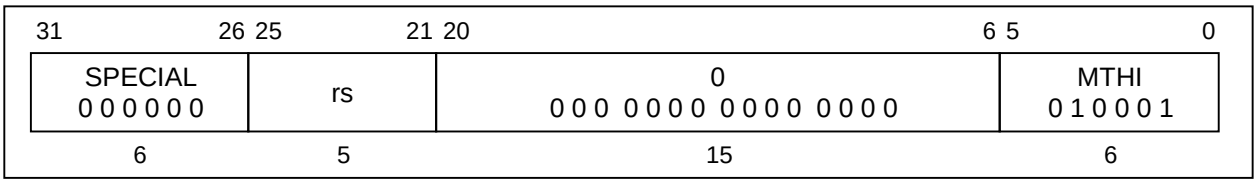
Operation:

```
32, 64  T:    data ← GPR [rt]
        T+1:  CPR [0, rd] ← data
```

Exceptions:

Coprocessor unusable exception (in 64-bit/32-bit user and supervisor mode if CP0 not enabled)

MTHI Move To HI MTHI



Format:

MTHI rs

Description:

The contents of general register *rs* are loaded into special register *HI*.

If a MTHI operation is executed following a MULT, MULTU, DIV, or DIVU instruction, but before any MFLO, MFHI, MTLO, or MTHI instructions, the contents of special register *HI* are undefined.

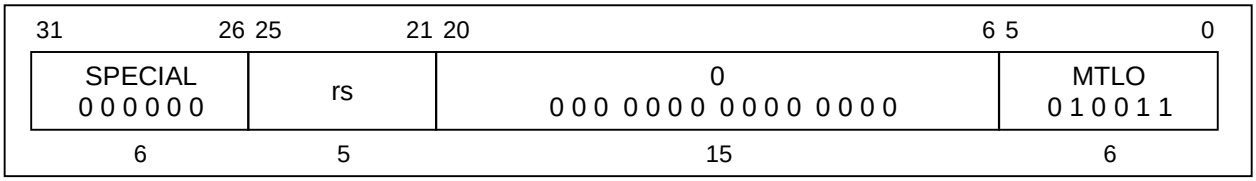
Operation:

```
32, 64 T-2:  HI ← undefined
       T-1:  HI ← undefined
       T:    HI ← GPR [rs]
```

Exceptions:

None

MTLO Move To LO MTLO



Format:

MTLO rs

Description:

The contents of general register *rs* are loaded into special register *LO.*

If an MTLO operation is executed following a MULT, MULTU, DIV, or DIVU instruction, but before any MFLO, MFHI, MTLO, or MTHI instructions, the contents of special register *LO* are undefined.

Operation:

```
32, 64 T-2:  LO ← undefined
       T-1:  LO ← undefined
       T:    LO ← GPR [rs]
```

Exceptions:

None

MULT — Multiply — MULT

Format:

MULT rs, rt

Description:

The contents of general registers *rs* and *rt* are multiplied, treating both operands as signed 32-bit integer. No integer overflow exception occurs under any circumstances.

In 64-bit mode, the operands must be valid 32-bit, sign-extended values.

When the operation completes, the low-order word of the double result is loaded into special register *LO*, and the high-order word of the double result is loaded into special register *HI*.

If either of the two preceding instructions is MFHI or MFLO, the results of these instructions are undefined. Correct operation requires separating reads of *HI* or *LO* from writes by a minimum of two other instructions.

Operation:

```
32    T-2:  LO  ← undefined
            HI  ← undefined
      T-1:  LO  ← undefined
            HI  ← undefined
      T:    t   ← GPR [rs] * GPR [rt]
            LO  ← t31...0
            HI  ← t63...32

64    T-2:  LO  ← undefined
            HI  ← undefined
      T-1:  LO  ← undefined
            HI  ← undefined
      T:    t   ← GPR [rs]31...0 * GPR [rt]31...0
            LO  ← (t31)32 || t31...0
            HI  ← (t63)32 || t63...32
```

Exceptions:

None

MULTU — Multiply Unsigned — MULTU

Format:

MULTU rs, rt

Description:

The contents of general register *rs* and the contents of general register *rt* are multiplied, treating both operands as unsigned values. No overflow exception occurs under any circumstances.

In 64-bit mode, the operands must be valid 32-bit, sign-extended values.

When the operation completes, the low-order word of the double result is loaded into special register *LO*, and the high-order word of the double result is loaded into special register *HI*.

If either of the two preceding instructions is MFHI or MFLO, the results of these instructions are undefined. Correct operation requires separating reads of *HI* or *LO* from writes by a minimum of two instructions.

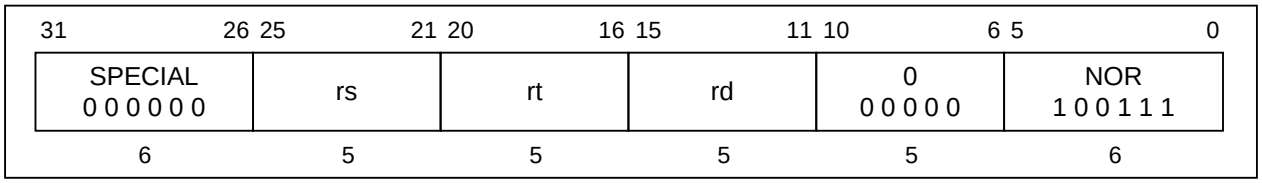
Operation:

```
32   T-2:  LO   ← undefined
           HI   ← undefined
      T-1: LO   ← undefined
           HI   ← undefined
      T:   t    ← (0 || GPR [rs]) * (0 || GPR [rt])
           LO   ← t31...0
           HI   ← t63...32

64   T-2:  LO   ← undefined
           HI   ← undefined
      T-1: LO   ← undefined
           HI   ← undefined
      T:   t    ← (0 || GPR [rs]31...0) * (0 || GPR [rt]31...0)
           LO   ← (t31)32 || t31...0
           HI   ← (t63)32 || t63...32
```

Exceptions:

None

NOR Nor NOR



Format:

NOR rd, rs, rt

Description:

The contents of general register *rs* are combined with the contents of general register *rt* in a bit-wise logical NOR operation. The result is placed into general register *rd*.

Operation:

```
32, 64 T:    GPR [rd] ← GPR [rs] nor GPR [rt]
```

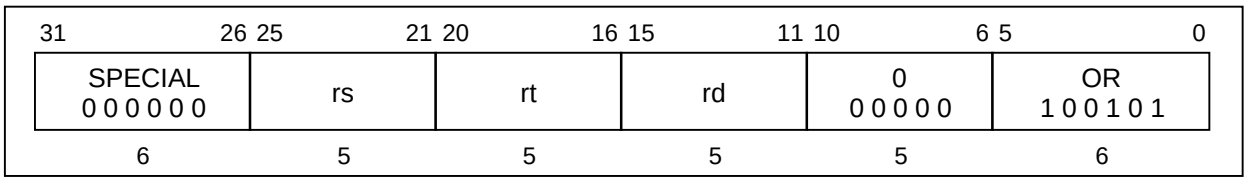
Exceptions:

None

OR

Or

OR



Format:

OR rd, rs, rt

Description:

The contents of general register *rs* are combined with the contents of general register *rt* in a bit-wise logical OR operation. The result is placed into general register *rd*.

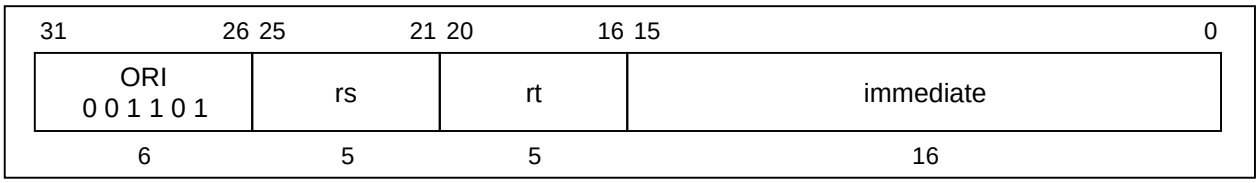
Operation:

```
32, 64 T:   GPR [rd] ← GPR [rs] or GPR [rt]
```

Exceptions:

None

ORI Or Immediate ORI



Format:

ORI rt, rs, immediate

Description:

The 16-bit *immediate* is zero-extended and combined with the contents of general register *rs* in a bit-wise logical OR operation. The result is placed into general register *rt*.

Operation:

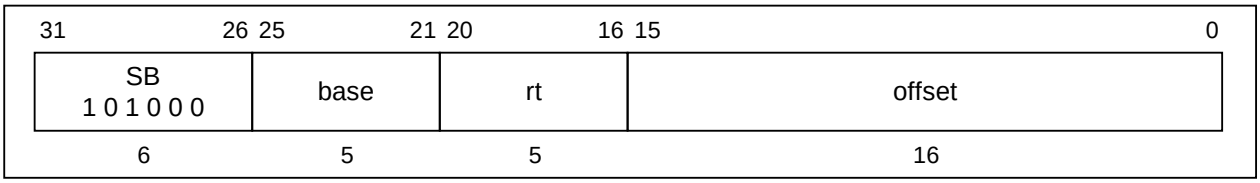
32 T: GPR [rt] ← GPR [rs]$_{31...16}$ || (immediate or GPR [rs]$_{15...0}$)

64 T: GPR [rt] ← GPR [rs]$_{63...16}$ || (immediate or GPR [rs]$_{15...0}$)

Exceptions:

None

SB Store Byte SB



Format:

SB rt, offset (base)

Description:

The 16-bit *offset* is sign-extended and added to the contents of general register *base* to form a virtual address. The least-significant byte of register *rt* is stored at the effective address.

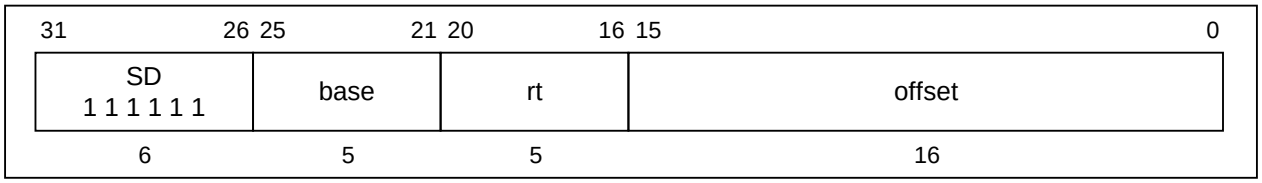
Operation:

```
32   T:   vAddr ← ((offset15)^16 || offset15...0) + GPR [base]
          (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
          pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor (ReverseEndian^3))
          byte ← vAddr2...0 xor BigEndianCPU^3
          data ← GPR [rt]63 – 8 * byte...0 || 0^8 * byte
          StoreMemory (uncached, BYTE, data, pAddr, vAddr, DATA)

64   T:   vAddr ← ((offset15)^48 || offset15...0) + GPR [base]
          (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
          pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor (ReverseEndian^3))
          byte ← vAddr2...0 xor BigEndianCPU^3
          data ← GPR [rt]63 – 8 * byte...0 || 0^8 * byte
          StoreMemory (uncached, BYTE, data, pAddr,  vAddr, DATA)
```

Exceptions:

TLB refill exception
TLB invalid exception
TLB modification exception
Bus error exception
Address error exception

SD Store Doubleword SD



Format:

SD rt, offset (base)

Description:

The 16-bit *offset* is sign-extended and added to the contents of general register *base* to form a virtual address. The contents of general register *rt* are stored at the memory location specified by the effective address.

If either of the three least-significant bits of the effective address are non-zero, an address error exception occurs.

This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

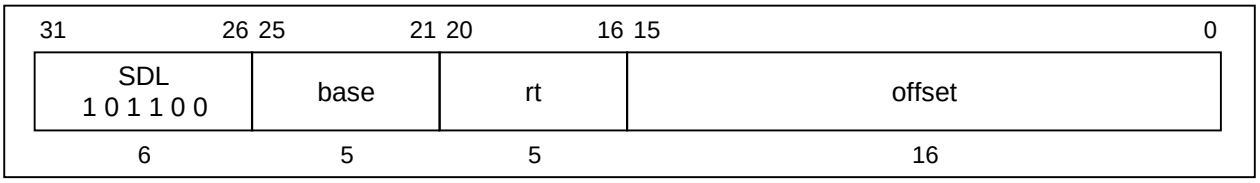
Operation:

```
64    T:    vAddr ← ((offset15)^48 || offset15...0) + GPR [base]
            (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
            data ← GPR [rt]
            StoreMemory (uncached, DOUBLEWORD, data, pAddr, vAddr, DATA)
```

Exceptions:

TLB refill exception
TLB invalid exception
TLB modification exception
Bus error exception
Address error exception
Reserved instruction exception (32-bit user mode/supervisor mode)

SDL Store Doubleword Left (1/3) SDL



Format:

SDL rt, offset (base)

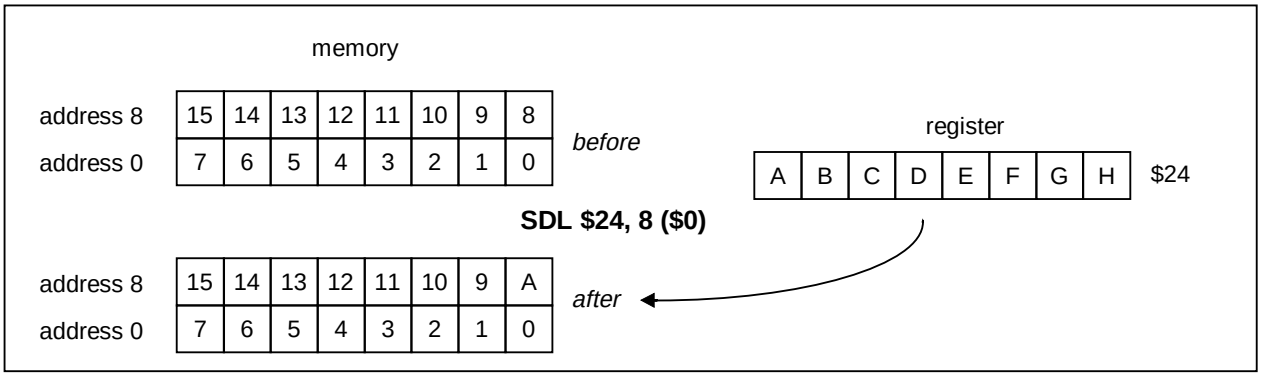
Description:

This instruction can be used with the SDR instruction to store the contents of a register into eight consecutive bytes of memory, when the bytes cross a doubleword boundary. SDL stores the register into the appropriate part of the high-order doubleword of memory; SDR stores the register into the appropriate part of the low-order doubleword.

The SDL instruction adds its sign-extended 16-bit *offset* to the contents of general register *base* to form a virtual address that may specify an arbitrary byte. It alters only the word in memory that contains that byte. From one to four bytes will be stored, depending on the starting byte specified.

Conceptually, it starts at the most-significant byte of the register and copies it to the specified byte in memory; then it copies bytes from register to memory until it reaches the low-order byte of the word in memory.

No address error exceptions due to alignment are possible.



SDL Store Doubleword Left (2/3) SDL

An address error exception is not occurred that specify address is not located in doubleword boundary.

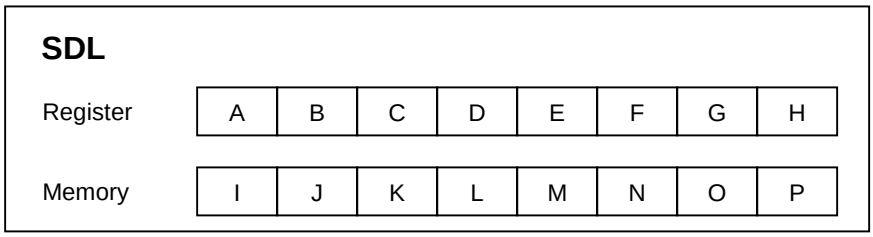
This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

Operation:

```
64    T:    vAddr ← ((offset15)^48 || offset15...0) + GPR [base]
            (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
            pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor ReverseEndian^3)
            if BigEndianMem = 0 then
                  pAddr ← pAddrPSIZE - 1...3 || 0^3
            endif
            byte ← vAddr2...0 xor BigEndianCPU^3
            data ← 0^56 – 8 * byte || GPR [rt]63...56 – 8 * byte
            StoreMemory (uncached, byte, data, pAddr, vAddr, DATA)
```

SDL Store Doubleword Left (3/3) SDL

Given a doubleword in a register and a doubleword in memory, the operation of SDL instruction is as follows:



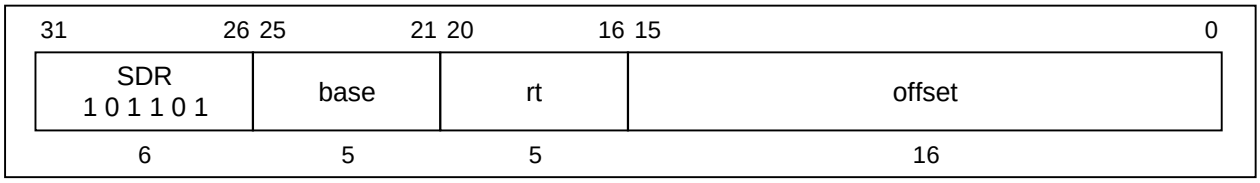
vAddr2..0	Destination	Type	Offset (LEM)
0	I J K L M N O A	0	0
1	I J K L M N A B	1	0
2	I J K L M A B C	2	0
3	I J K L A B C D	3	0
4	I J K A B C D E	4	0
5	I J A B C D E F	5	0
6	I A B C D E F G	6	0
7	A B C D E F G H	7	0

Remark *LEM* Little-endian memory (BigEndianMem = 0)
Type AccessType (see **Table 2-3. Byte Specification Related to Load and Store Instructions**) sent to memory
Offset pAddr2..0 sent to memory

Exceptions:

TLB refill exception
TLB invalid exception
TLB modification exception
Bus error exception
Address error exception
Reserved instruction exception (32-bit user mode/supervisor mode)

SDR Store Doubleword Right (1/3) SDR



Format:

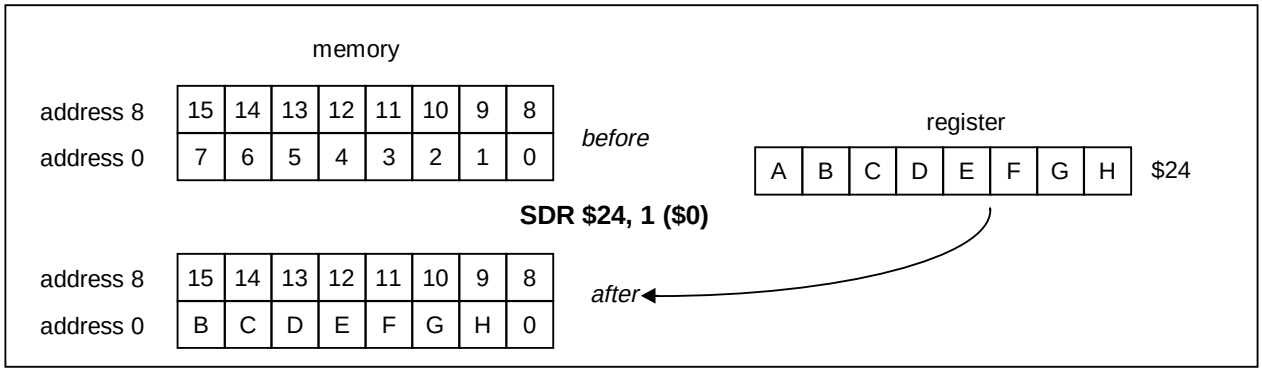
SDR rt, offset (base)

Description:

This instruction can be used with the SDL instruction to store the contents of a register into eight consecutive bytes of memory, when the bytes cross a boundary between two doublewords. SDR stores the register into the appropriate part of the low-order doubleword; SDL stores the register into the appropriate part of the low-order doubleword of memory.

The SDR instruction adds its sign-extended 16-bit *offset* to the contents of general register *base* to form a virtual address that may specify an arbitrary byte. It alters only the word in memory that contains that byte. From one to eight bytes will be stored, depending on the starting byte specified.

Conceptually, it starts at the least-significant byte of the register and copies it to the specified byte in memory; then it copies bytes from register to memory until it reaches the high-order byte of the word in memory. No address error exceptions due to alignment are possible.



SDR Store Doubleword Right (2/3) SDR

An address error exception is not occurred that specify address is not located in doubleword boundary.

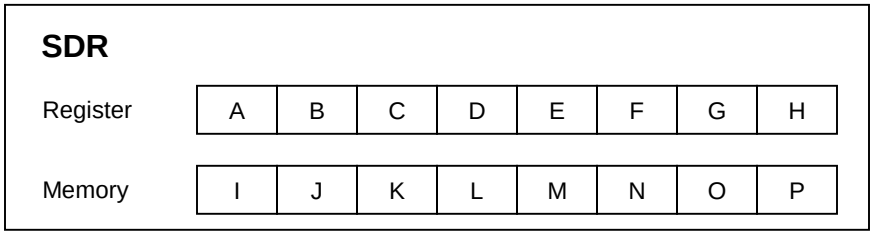
This operation is defined in 64-bit mode or in 32-bit kernel mode. Execution of this instruction in 32-bit user or supervisor mode causes a reserved instruction exception.

Operation:

```
64    T:    vAddr ← ((offset15)^48 || offset15...0) + GPR [base]
            (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
            pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor ReverseEndian^3)
            if BigEndianMem = 0 then
                  pAddr ← pAddrPSIZE - 1...3 || 0^3
            endif
            byte ← vAddr2...0 xor BigEndianCPU^3
            data ← GPR [rt]63 – 8 * byte || 0^8 * byte
            StoreMemory (uncached, DOUBLEWORD-byte, data, pAddr, vAddr, DATA)
```

SDR Store Doubleword Right (3/3) SDR

Given a doubleword in a register and a doubleword in memory, the operation of SDR instruction is as follows:



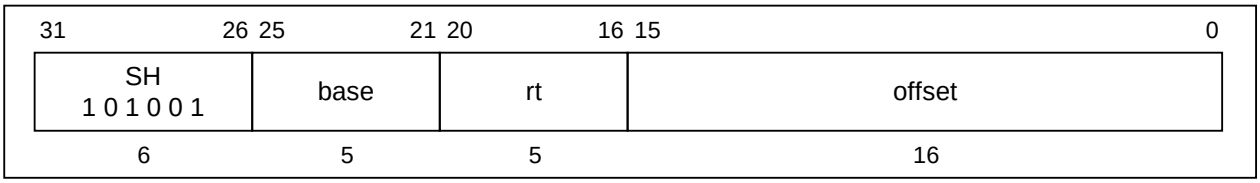
vAddr2..0	Destination	Type	Offset (LEM)
0	A B C D E F G H	7	0
1	B C D E F G H P	6	1
2	C D E F G H O P	5	2
3	D E F G H N O P	4	3
4	E F G H M N O P	3	4
5	F G H L M N O P	2	5
6	G H K L M N O P	1	6
7	H J K L M N O P	0	7

Remark *LEM* Little-endian memory (BigEndianMem = 0)
Type AccessType (see **Table 2-3. Byte Specification Related to Load and Store Instructions**) sent to memory
Offset pAddr2..0 sent to memory

Exceptions:

TLB refill exception
TLB invalid exception
TLB modification exception
Bus error exception
Address error exception
Reserved instruction exception (32-bit user mode/supervisor mode)

SH Store Halfword SH



Format:

SH rt, offset (base)

Description:

The 16-bit *offset* is sign-extended and added to the contents of general register *base* to form an unsigned effective address. The least-significant halfword of register *rt* is stored at the effective address. If the least-significant bit of the effective address is non-zero, an address error exception occurs.

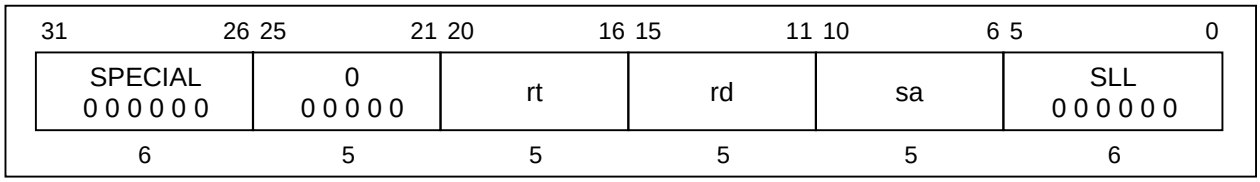
Operation:

```
32    T:   vAddr ← ((offset15)^16 || offset15...0) + GPR [base]
           (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
           pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor (ReverseEndian^2 || 0))
           byte ← vAddr2...0 xor (BigEndianCPU^2 || 0)
           data ← GPR [rt]63 – 8 * byte...0 || 0^8 * byte
           StoreMemory (uncached, HALFWORD, data, pAddr, vAddr, DATA)

64    T:   vAddr ← ((offset15)^48 || offset15...0) + GPR [base]
           (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
           pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor (ReverseEndian^2 || 0))
           byte ← vAddr2...0 xor (BigEndianCPU^2 || 0)
           data ← GPR [rt]63 – 8 * byte...0 || 0^8 * byte
           StoreMemory (uncached, HALFWORD, data, pAddr, vAddr, DATA)
```

Exceptions:

TLB refill exception
TLB invalid exception
TLB modification exception
Bus error exception
Address error exception

SLL — Shift Left Logical — SLL



Format:

SLL rd, rt, sa

Description:

The contents of general register *rt* are shifted left by *sa* bits, inserting zeros into the low-order bits.

The result is placed in register *rd.*

In 64-bit mode, the 32-bit result is sign-extended when placed in the destination register. It is sign extended for all shift amounts, including zero; SLL with zero shift amount truncates a 64-bit value to 32 bits and then sign extends this 32-bit value. SLL, unlike nearly all other word operations, does not require an operand to be a properly sign-extended word value to produce a valid sign-extended word result.

Operation:

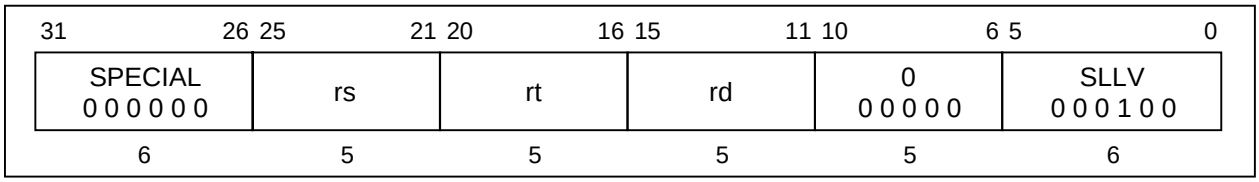
```
32    T:    GPR [rd] ← GPR [rt] 31 - sa...0 || 0^sa

64    T:    s ← 0 || sa
            temp ← GPR [rt] 31 - s...0 || 0^s
            GPR [rd] ← (temp 31)^32 || temp
```

Exceptions:

None

Caution **SLL with a shift amount of zero may be treated as a NOP by some assemblers, at some optimization levels. If using SLL with a purpose of sign-extension, check the assembler specification.**

SLLV — Shift Left Logical Variable — SLLV



Format:

SLLV rd, rt, rs

Description:

The contents of general register *rt* are shifted left the number of bits specified by the low-order five bits contained in general register *rs*, inserting zeros into the low-order bits.

The result is placed in register *rd*.

In 64-bit mode, the 32-bit result is sign-extended when placed in the destination register. It is sign extended for all shift amounts, including zero; SLLV with zero shift amount truncates a 64-bit value to 32 bits and then sign extends this 32-bit value. SLLV, unlike nearly all other word operations, does not require an operand to be a properly sign-extended word value to produce a valid sign-extended word result.

Operation:

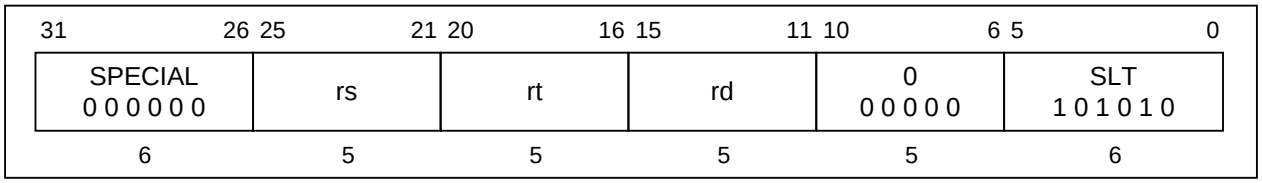
```
32   T:   s ← GPR [rs]4...0
          GPR [rd] ← GPR [rt](31 - s)...0 || 0^s

64   T:   s ← 0 || GPR [rs]4...0
          temp ← GPR [rt](31 - s)...0 || 0^s
          GPR [rd] ← (temp 31)^32 || temp
```

Exceptions:

None

Caution **SLLV with a shift amount of zero may be treated as a NOP by some assemblers, at some optimization levels. If using SLLV with a purpose of sign-extension, check the assembler specification.**

SLT — Set On Less Than — SLT



Format:

SLT rd, rs, rt

Description:

The contents of general register *rt* are subtracted from the contents of general register *rs*. Considering both quantities as signed integers, if the contents of general register *rs* are less than the contents of general register *rt*, the result is set to one; otherwise the result is set to zero.

No integer overflow exception occurs under any circumstances. The comparison is valid even if the subtraction used during the comparison overflows.

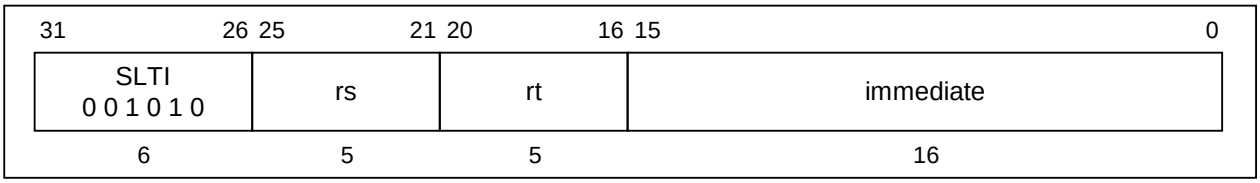
Operation:

```
32    T:    if GPR [rs] < GPR [rt] then
                GPR [rd] ← 0^31 || 1
            else
                GPR [rd] ← 0^32
            endif

64    T:    if GPR [rs] < GPR [rt] then
                GPR [rd] ← 0^63 || 1
            else
                GPR [rd] ← 0^64
            endif
```

Exceptions:

None

SLTI — Set On Less Than Immediate — SLTI



Format:

SLTI rt, rs, immediate

Description:

The 16-bit *immediate* is sign-extended and subtracted from the contents of general register *rs.* Considering both quantities as signed integers, if *rs* is less than the sign-extended *immediate*, the result is set to 1; otherwise the result is set to 0.

No integer overflow exception occurs under any circumstances. The comparison is valid even if the subtraction used during the comparison overflows.

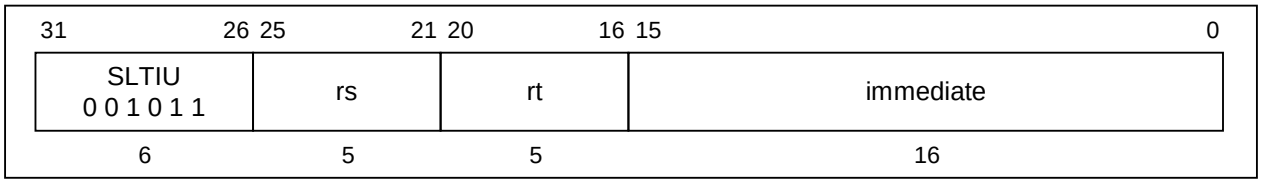
Operation:

```
32    T:   if GPR [rs] < (immediate15) 16 || immediate15...0 then
               GPR [rt] ← 0^31 || 1
           else
               GPR [rt] ← 0^32
           endif

64    T:   if GPR [rs] < (immediate15) 48 || immediate 15...0 then
               GPR [rt] ← 0^63 || 1
           else
               GPR [rt] ← 0^64
           endif
```

Exceptions:

None

SLTIU Set On Less Than Immediate Unsigned SLTIU



Format:

SLTIU rt, rs, immediate

Description:

The 16-bit *immediate* is sign-extended and subtracted from the contents of general register *rs.* Considering both quantities as unsigned integers, if *rs* is less than the sign-extended *immediate*, the result is set to 1; otherwise the result is set to 0.

No integer overflow exception occurs under any circumstances. The comparison is valid even if the subtraction used during the comparison overflows.

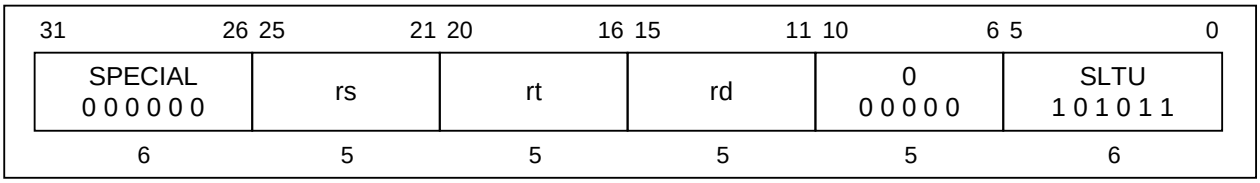
Operation:

```
32    T:    if (0 || GPR [rs]) < (0 || (immediate15) 16 || immediate15...0) then
                  GPR [rt] ← 0^31 || 1
            else
                  GPR [rt] ← 0^32
            endif

64    T:    if (0 || GPR [rs]) < (0 || (immediate15) 48 || immediate15...0) then
                  GPR [rt] ← 0^63 || 1
            else
                  GPR [rt] ← 0^64
            endif
```

Exceptions:

None

SLTU Set On Less Than Unsigned SLTU



Format:

SLTU rd, rs, rt

Description:

The contents of general register *rt* are subtracted from the contents of general register *rs.* Considering both quantities as unsigned integers, if the contents of general register *rs* are less than the contents of general register *rt*, the result is set to 1; otherwise the result is set to 0.

No integer overflow exception occurs under any circumstances. The comparison is valid even if the subtraction used during the comparison overflows.

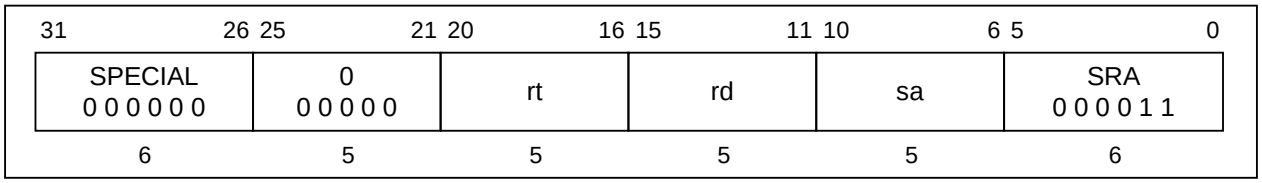
Operation:

```
32    T:    if (0 || GPR [rs]) < 0 || GPR [rt] then
                GPR [rd] ← 0^31 || 1
            else
                GPR [rd] ← 0^32
            endif

64    T:    if (0 || GPR [rs]) < 0 || GPR [rt] then
                GPR [rd] ← 0^63 || 1
            else
                GPR [rd] ← 0^64
            endif
```

Exceptions:

None

SRA — Shift Right Arithmetic — SRA



Format:

SRA rd, rt, sa

Description:

The contents of general register *rt* are shifted right by *sa* bits, sign-extending the high-order bits.

The result is placed in register *rd*.

In 64-bit mode, the operand must be a valid sign-extended, 32-bit value.

Operation:

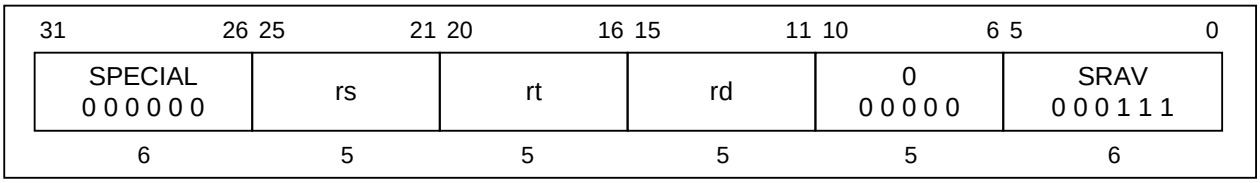
32 T: $GPR[rd] \leftarrow (GPR[rt]_{31})^{sa} \,||\, GPR[rt]_{31...sa}$

64 T:
$s \leftarrow 0 \,||\, sa$
$temp \leftarrow (GPR[rt]_{31})^{s} \,||\, GPR[rt]_{31...s}$
$GPR[rd] \leftarrow (temp_{31})^{32} \,||\, temp$

Exceptions:

None

SRAV Shift Right Arithmetic Variable SRAV



Format:

SRAV rd, rt, rs

Description:

The contents of general register *rt* are shifted right by the number of bits specified by the low-order five bits of general register *rs*, sign-extending the high-order bits.

The result is placed in register *rd*.

In 64-bit mode, the operand must be a valid sign-extended, 32-bit value.

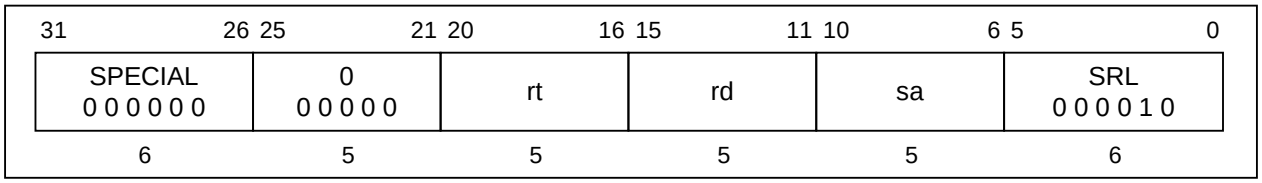
Operation:

```
32   T:   s ← GPR [rs]4...0
          GPR [rd] ← (GPR [rt] 31)^s || GPR [rt]31...s

64   T:   s ← GPR [rs]4...0
          temp ← (GPR [rt]31)^s || GPR [rt]31...s
          GPR [rd] ← (temp31)^32 || temp
```

Exceptions:

None

SRL — Shift Right Logical — SRL



Format:

SRL rd, rt, sa

Description:

The contents of general register *rt* are shifted right by *sa* bits, inserting zeros into the high-order bits.

The result is placed in register *rd*.

In 64-bit mode, the operand must be a valid sign-extended, 32-bit value.

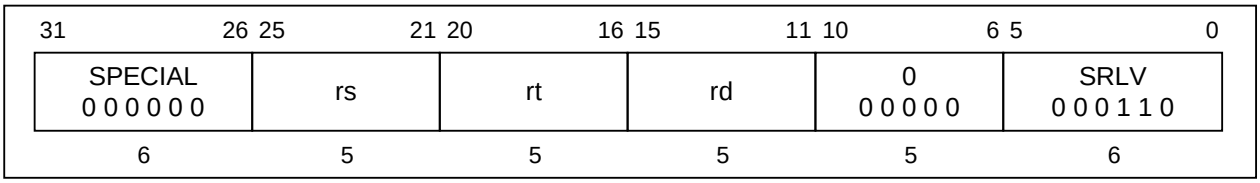
Operation:

```
32    T:    GPR [rd] ← 0^sa || GPR [rt]31...sa

64    T:    s ← 0 || sa
            temp ← 0^s || GPR [rt]31...s
            GPR [rd] ← (temp31)^32 || temp
```

Exceptions:

None

SRLV Shift Right Logical Variable SRLV



Format:

SRLV rd, rt, rs

Description:

The contents of general register *rt* are shifted right by the number of bits specified by the low-order five bits of general register *rs,* inserting zeros into the high-order bits.

The result is placed in register *rd*.

In 64-bit mode, the operand must be a valid sign-extended, 32-bit value.

Operation:

32 T: $s \leftarrow GPR\ [rs]_{4...0}$

$GPR\ [rd] \leftarrow 0^{s} \mid\mid GPR\ [rt]_{31...s}$

64 T: $s \leftarrow GPR\ [rs]_{4...0}$

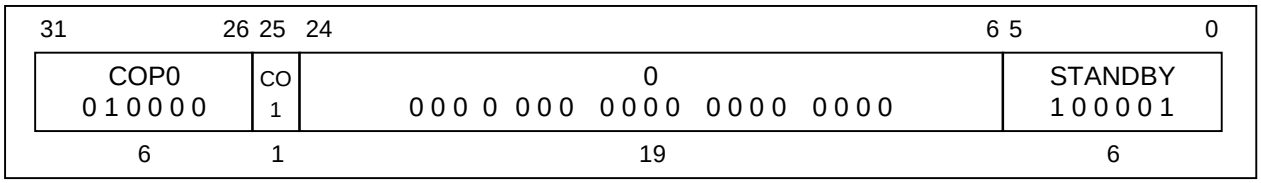
$temp \leftarrow 0^{s} \mid\mid GPR\ [rt]_{31...s}$

$GPR\ [rd] \leftarrow (temp_{31})^{32} \mid\mid temp$

Exceptions:

None

STANDBY Standby STANDBY



Format:

STANDBY

Description:

STANDBY instruction starts mode transition from Fullspeed mode to Standby mode.

When the STANDBY instruction finishes the WB stage, this processor wait by the SysAD bus is idle state, after then the internal clocks will shut down, thus freezing the pipeline. The PLL, Timer/Interrupt clocks and the internal bus clocks (TClock and MasterOut) will continue to run.

Once this processor is in Standby mode, any interrupt, including the internally generated timer interrupt, NMI, Soft Reset, and Cold Reset will cause this processor to exit Standby mode and to enter Fullspeed mode.

Operation:

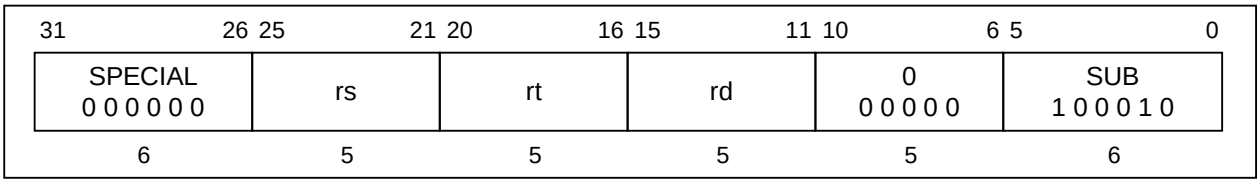
```
32, 64  T:
        T+1:  Standby operation ()
```

Exceptions:

Coprocessor unusable exception

Remark Refer to **Section 2.7.3.1 Power modes** for details about the operation of the peripheral units at mode transition.

SUB Subtract SUB



Format:

SUB rd, rs, rt

Description:

The contents of general register *rt* are subtracted from the contents of general register *rs* to form a result. The result is placed into general register *rd.* In 64-bit mode, the operands must be valid sign-extended, 32-bit values.

The only difference between this instruction and the SUBU instruction is that SUBU never traps on overflow.

An integer overflow exception takes place if the carries out of bits 30 and 31 differ (2's complement overflow). The destination register *rd* is not modified when an integer overflow exception occurs.

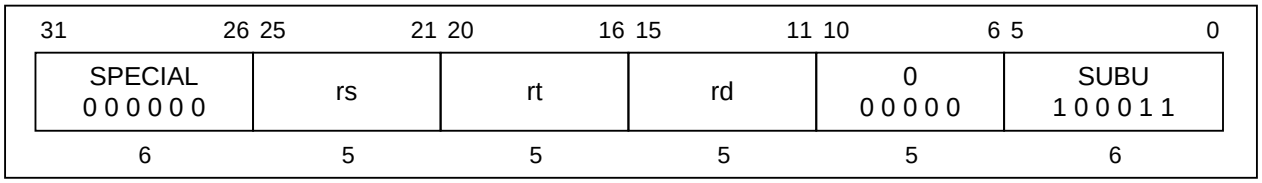
Operation:

```
32   T:   GPR [rd] ← GPR [rs] - GPR [rt]

64   T:   temp ← GPR [rs] - GPR [rt]
          GPR [rd] ← (temp31)^32 || temp31...0
```

Exceptions:

Integer overflow exception

SUBU Subtract Unsigned SUBU



Format:

SUBU rd, rs, rt

Description:

The contents of general register *rt* are subtracted from the contents of general register *rs* to form a result.

The result is placed into general register *rd*.

In 64-bit mode, the operands must be valid sign-extended, 32-bit values.

The only difference between this instruction and the SUB instruction is that SUBU never traps on overflow.

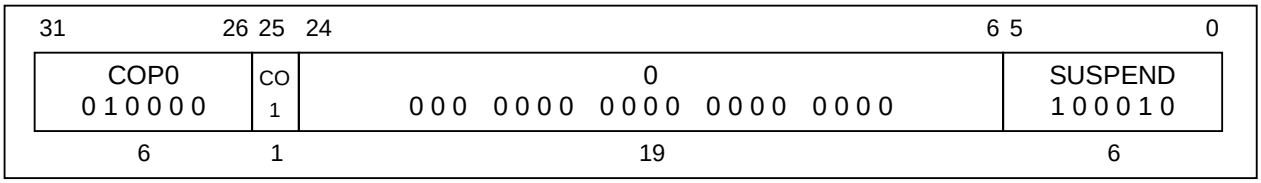
Operation:

```
32    T:    GPR [rd] ← GPR [rs] - GPR [rt]

64    T:    temp ← GPR [rs] - GPR [rt]
            GPR [rd] ← (temp31)^32 || temp31...0
```

Exceptions:

None

SUSPEND Suspend SUSPEND



Format:

SUSPEND

Description:

SUSPEND instruction starts mode transition from Fullspeed mode to Suspend mode.

When the SUSPEND instruction finishes the WB stage, this processor wait by the SysAD bus is idle state, after then the internal clocks including the TClock will shut down, thus freezing the pipeline. The PLL, Timer/Interrupt clocks and MasterOut, will continue to run.

Once this processor is in Suspend mode, any interrupt, including the internally generated timer interrupt, NMI, Soft Reset and Cold Reset will cause this processor to exit Suspend mode and to enter Fullspeed mode.

Operation:

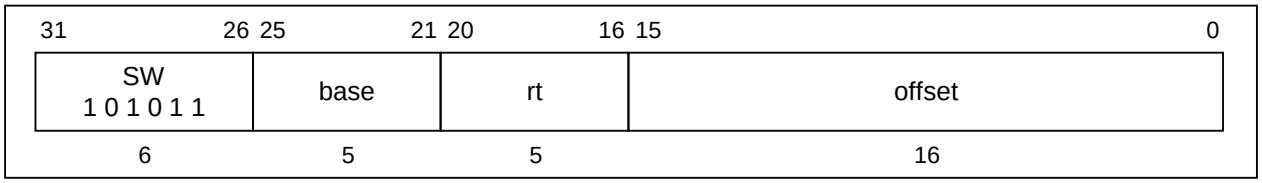
```
32, 64  T:
        T+1:  Suspend Operation ()
```

Exceptions:

Coprocessor unusable exception

Remark Refer to **Section 2.7.3.1 Power modes** for details about the operation of the peripheral units at mode transition.

SW Store Word SW



Format:

SW rt, offset (base)

Description:

The 16-bit *offset* is sign-extended and added to the contents of general register *base* to form a virtual address. The contents of general register *rt* are stored at the memory location specified by the effective address.

If either of the two least-significant bits of the effective address are non-zero, an address error exception occurs.

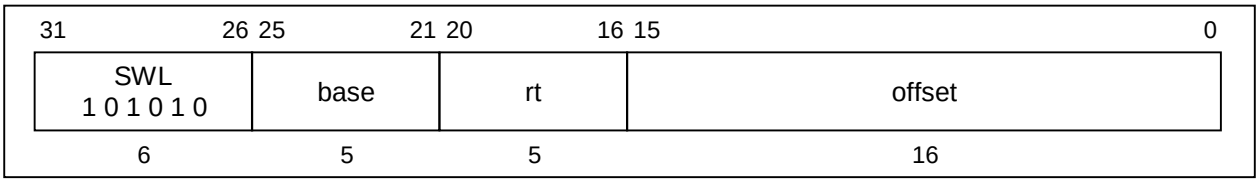
Operation:

```
32    T:    vAddr ← ((offset15)^16 || offset15...0) + GPR [base]
            (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
            pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor (ReverseEndian || 0^2))
            byte ← vAddr2...0 xor (BigEndianCPU || 0^2)
            data ← GPR [rt]63 – 8 * byte || 0^8 * byte
            StoreMemory (uncached, WORD, data, pAddr, vAddr, DATA)

64    T:    vAddr ← ((offset15)^48 || offset15...0) + GPR [base]
            (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
            pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor (ReverseEndian || 0^2))
            byte ← vAddr2...0 xor (BigEndianCPU || 0^2)
            data ← GPR [rt]63 – 8 * byte || 0^8 * byte
            StoreMemory (uncached, WORD, data, pAddr, vAddr, DATA)
```

Exceptions:

TLB refill exception
TLB invalid exception
TLB modification exception
Bus error exception
Address error exception

SWL Store Word Left (1/3) SWL



Format:

SWL rt, offset (base)

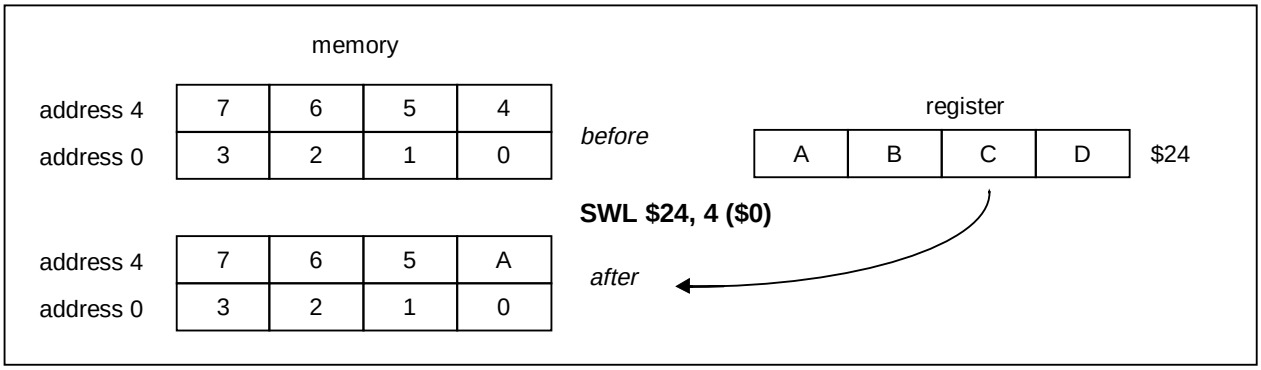
Description:

This instruction can be used with the SWR instruction to store the contents of a register into four consecutive bytes of memory, when the bytes cross a word boundary. SWL stores the register into the appropriate part of the high-order word of memory; SWR stores the register into the appropriate part of the low-order word.

The SWL instruction adds its sign-extended 16-bit *offset* to the contents of general register *base* to form a virtual address that may specify an arbitrary byte. It alters only the word in memory that contains that byte. From one to four bytes will be stored, depending on the starting byte specified.

Conceptually, it starts at the most-significant byte of the register and copies it to the specified byte in memory; then it copies bytes from register to memory until it reaches the low-order byte of the word in memory.

No address error exceptions due to alignment are possible.



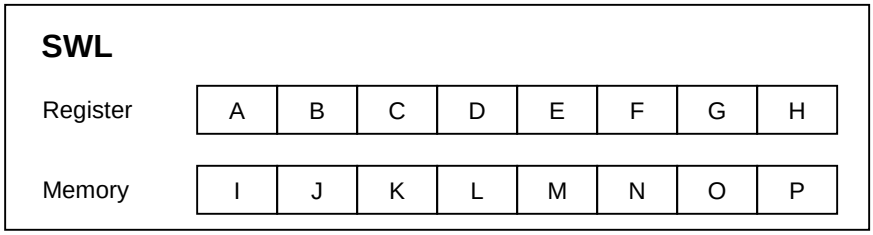
SWL Store Word Left (2/3) SWL

Operation:

```
32    T:    vAddr ← ((offset15)^16 || offset15...0) + GPR [base]
            (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
            pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor ReverseEndian^3)
            if BigEndianMem = 0 then
                  pAddr ← pAddrPSIZE - 1...2 || 0^2
            endif
            byte ← vAddr1...0 xor BigEndianCPU^2
            if (vAddr2 xor BigEndianCPU) = 0 then
                  data ← 0^32 || 0^24 – 8 * byte || GPR [rt]31...24 – 8 * byte
            else
                  data ← 0^24 – 8 * byte || GPR [rt]31...24 – 8 * byte || 0^32
            endif
            StoreMemory (uncached, byte, data, pAddr, vAddr, DATA)

64    T:    vAddr ← ((offset15)^48 || offset15...0) + GPR [base]
            (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
            pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor ReverseEndian^3)
            if BigEndianMem = 0 then
                  pAddr ← pAddrPSIZE - 1...2 || 0^2
            endif
            byte ← vAddr1...0 xor BigEndianCPU^2
            if (vAddr2 xor BigEndianCPU) = 0 then
                  data ← 0^32 || 0^24 – 8 * byte || GPR [rt]31...24 – 8 * byte
            else
                  data ← 0^24 – 8 * byte || GPR [rt]31...24 – 8 * byte || 0^32
            endif
            StoreMemory (uncached, byte, data, pAddr, vAddr, DATA)
```

SWL Store Word Left (3/3) SWL

Given a doubleword in a register and a doubleword in memory, the operation of SWL is as follows:



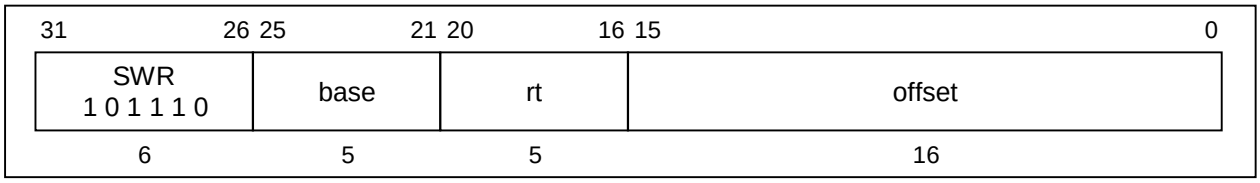
vAddr2..0	Destination	Type	Offset (LEM)
0	I J K L M N O E	0	0
1	I J K L M N E F	1	0
2	I J K L M E F G	2	0
3	I J K L E F G H	3	0
4	I J K E M N O P	0	4
5	I J E F M N O P	1	4
6	I E F G M N O P	2	4
7	E F G H M N O P	3	4

Remark *LEM* Little-endian memory (BigEndianMem = 0)
Type AccessType (see **Table 2-3. Byte Specification Related to Load and Store Instructions**) sent to memory
Offset pAddr2..0 sent to memory

Exceptions:

TLB refill exception
TLB invalid exception
TLB modification exception
Bus error exception
Address error exception

SWR Store Word Right (1/3) SWR



Format:

SWR rt, offset (base)

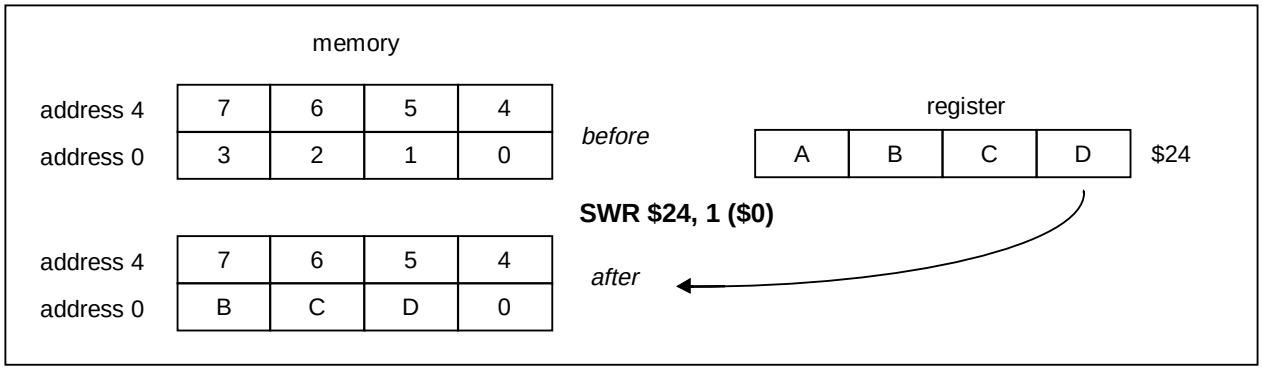
Description:

This instruction can be used with the SWL instruction to store the contents of a register into four consecutive bytes of memory, when the bytes cross a boundary between two words. SWR stores the register into the appropriate part of the low-order word; SWL stores the register into the appropriate part of the low-order word of memory.

The SWR instruction adds its sign-extended 16-bit *offset* to the contents of general register *base* to form a virtual address that may specify an arbitrary byte. It alters only the word in memory that contains that byte. From one to four bytes will be stored, depending on the starting byte specified.

Conceptually, it starts at the least-significant (rightmost) byte of the register and copies it to the specified byte in memory; then copies bytes from register to memory until it reaches the high-order byte of the word in memory.

No address error exceptions due to alignment are possible.



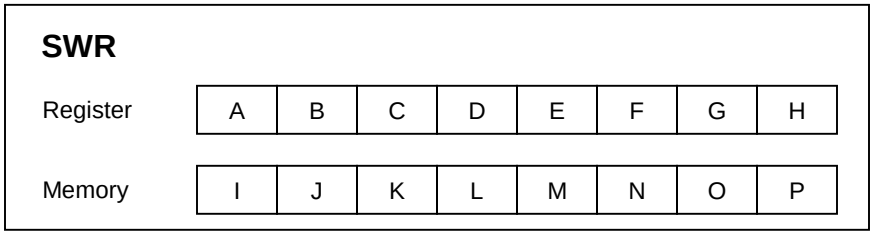
SWR Store Word Right (2/3) SWR

Operation:

```
32    T:    vAddr ← ((offset15)^16 || offset15...0) + GPR [base]
            (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
            pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor ReverseEndian^3)
            if BigEndianMem = 1 then
                  pAddr ← pAddrPSIZE - 1...2 || 0^2
            endif
            byte ← vAddr1...0 xor BigEndianCPU^2
            if (vAddr2 xor BigEndianCPU) = 0 then
                  data ← 0^32 || GPR [rt]31 – 8 * byte...0 || 0^8 * byte
            else
                  data ← GPR [rt]31 – 8 * byte || 0^8 * byte || 0^32
            endif
            StoreMemory (uncached, WORD-byte, data, pAddr, vAddr, DATA)

64    T:    vAddr ← ((offset15)^48 || offset15...0) + GPR [base]
            (pAddr, uncached) ← AddressTranslation (vAddr, DATA)
            pAddr ← pAddrPSIZE - 1...3 || (pAddr2...0 xor ReverseEndian^3)
            if BigEndianMem = 1 then
                  pAddr ← pAddrPSIZE - 1...2 || 0^2
            endif
            byte ← vAddr1...0 xor BigEndianCPU^2
            if (vAddr2 xor BigEndianCPU) = 0 then
                  data ← 0^32 || GPR [rt]31 – 8 * byte...0 || 0^8 * byte
            else
                  data ← GPR [rt]31 – 8 * byte || 0^8 * byte || 0^32
            endif
            StoreMemory (uncached, WORD-byte, data, pAddr, vAddr, DATA)
```

SWR Store Word Right (3/3) SWR

Given a doubleword in a register and a doubleword in memory, the operation of SWR instruction is as follows:



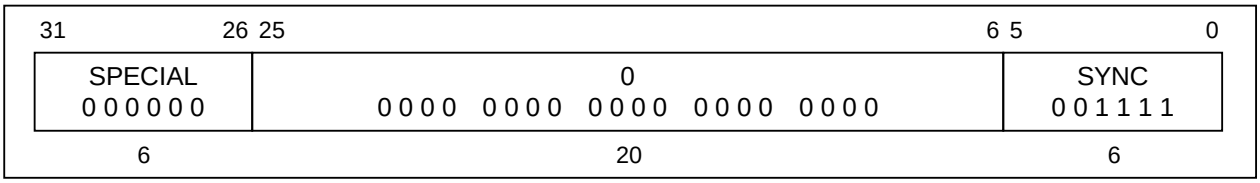
vAddr2..0	Destination	Type	Offset (LEM)
0	I J K L E F G H	3	0
1	I J K L F G H P	2	1
2	I J K L G H O P	1	2
3	I J K L H N O P	0	3
4	E F G H M N O P	3	4
5	F G H L M N O P	2	5
6	G H K L M N O P	1	6
7	H J K L M N O P	0	7

Remark *LEM* Little-endian memory (BigEndianMem = 0)
Type AccessType (see **Table 2-3. Byte Specification Related to Load and Store Instructions**) sent to memory
Offset pAddr2..0 sent to memory

Exceptions:

TLB refill exception
TLB invalid exception
TLB modification exception
Bus error exception
Address error exception

SYNC Synchronize SYNC



Format:

SYNC

Description:

The SYNC instruction is executed as a NOP on the VR4121. This operation maintains compatibility with code compiled for the VR4000.

This instruction is defined to maintain the compatibility with VR4000 and VR4400.

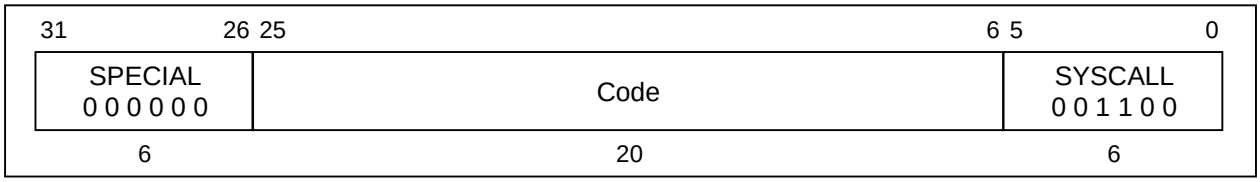
Operation:

```
32, 64 T:    SyncOperation ( )
```

Exceptions:

None

SYSCALL System Call SYSCALL



Format:

SYSCALL

Description:

A system call exception occurs, immediately and unconditionally transferring control to the exception handler. The code field is available for use as software parameters, but is retrieved by the exception handler only by loading the contents of the memory word containing the instruction.

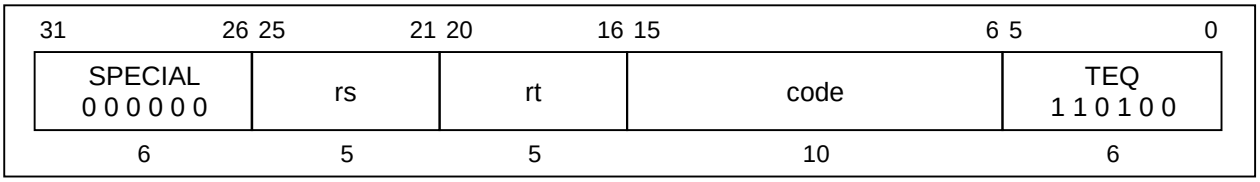
Operation:

```
32, 64 T:    SystemCallException
```

Exceptions:

System Call exception

TEQ — Trap If Equal — TEQ



Format:

TEQ rs, rt

Description:

The contents of general register *rt* are compared to general register *rs*. If the contents of general register *rs* are equal to the contents of general register *rt*, a trap exception occurs.

The code field is available for use as software parameters, but is retrieved by the exception handler only by loading the contents of the memory word containing the instruction.

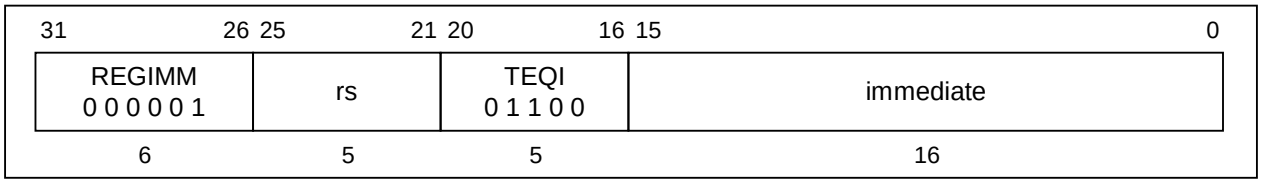
Operation:

```
32, 64  T:      if GPR [rs] = GPR [rt] then
                        TrapException
                endif
```

Exceptions:

Trap exception

TEQI Trap If Equal Immediate TEQI



Format:

TEQI rs, immediate

Description:

The 16-bit *immediate* is sign-extended and compared to the contents of general register *rs*. If the contents of general register *rs* are equal to the sign-extended *immediate*, a trap exception occurs.

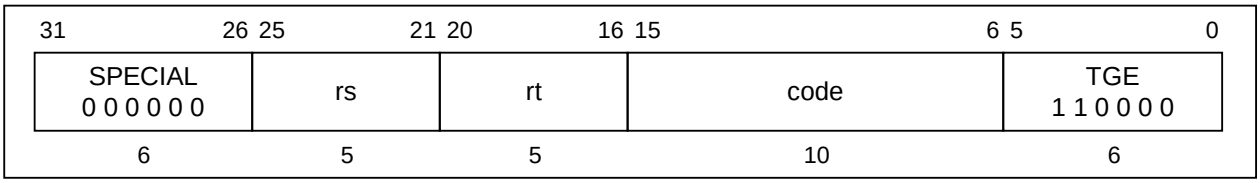
Operation:

```
32    T:    if GPR [rs] = (immediate15)16 || immediate15...0 then
                  TrapException
            endif

64    T:    if GPR [rs] = (immediate15)48 || immediate15...0 then
                  TrapException
            endif
```

Exceptions:

Trap exception

TGE — Trap If Greater Than Or Equal — TGE



Format:

TGE rs, rt

Description:

The contents of general register *rt* are compared to the contents of general register *rs*. Considering both quantities as signed integers, if the contents of general register *rs* are greater than or equal to the contents of general register *rt*, a trap exception occurs.

The code field is available for use as software parameters, but is retrieved by the exception handler only by loading the contents of the memory word containing the instruction.

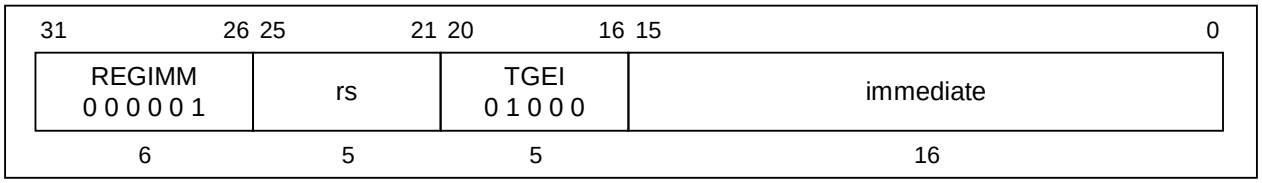
Operation:

```
32, 64  T:    if GPR [rs] ≥ GPR [rt] then
                    TrapException
              endif
```

Exceptions:

Trap exception

TGEI Trap If Greater Than Or Equal Immediate TGEI



Format:

TGEI rs, immediate

Description:

The 16-bit *immediate* is sign-extended and compared to the contents of general register *rs*. Considering both quantities as signed integers, if the contents of general register *rs* are greater than or equal to the sign-extended *immediate*, a trap exception occurs.

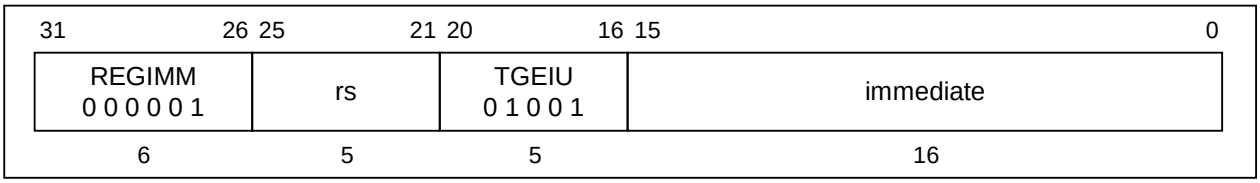
Operation:

```
32    T:    if GPR [rs] ≥ (immediate15)16 || immediate15...0 then
                  TrapException
            endif

64    T:    if GPR [rs] ≥ (immediate15)48 || immediate15...0 then
                  TrapException
            endif
```

Exceptions:

Trap exception

TGEIU Trap If Greater Than Or Equal Immediate Unsigned TGEIU



Format:

TGEIU rs, immediate

Description:

The 16-bit *immediate* is sign-extended and compared to the contents of general register *rs*. Considering both quantities as unsigned integers, if the contents of general register *rs* are greater than or equal to the sign-extended *immediate*, a trap exception occurs.

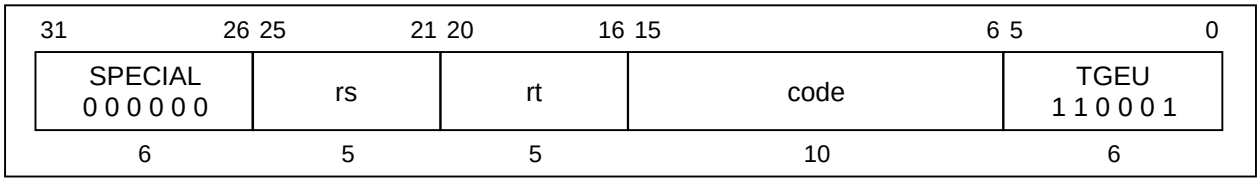
Operation:

```
32    T:    if (0 || GPR [rs]) ≥ (0 || (immediate15)16 || immediate15...0) then
                  TrapException
            endif

64    T:    if (0 || GPR [rs]) ≥ (0 || (immediate15)48 || immediate15...0) then
                  TrapException
            endif
```

Exceptions:

Trap exception

TGEU Trap If Greater Than Or Equal Unsigned TGEU



Format:

TGEU rs, rt

Description:

The contents of general register *rt* are compared to the contents of general register *rs*. Considering both quantities as unsigned integers, if the contents of general register *rs* are greater than or equal to the contents of general register *rt*, a trap exception occurs.

The code field is available for use as software parameters, but is retrieved by the exception handler only by loading the contents of the memory word containing the instruction.

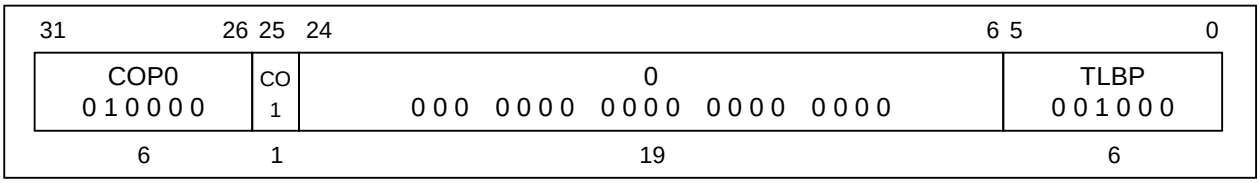
Operation:

```
32, 64  T:    if (0 || GPR [rs]) ≥ (0 || GPR [rt]) then
                    TrapException
              endif
```

Exceptions:

Trap exception

TLBP Probe TLB For Matching Entry TLBP



Format:

TLBP

Description:

The Index register is loaded with the address of the TLB entry whose contents match the contents of the EntryHi register. If no TLB entry matches, the high-order bit of the Index register is set.

The architecture does not specify the operation of memory references associated with the instruction immediately after a TLBP instruction, nor is the operation specified if more than one TLB entry matches.

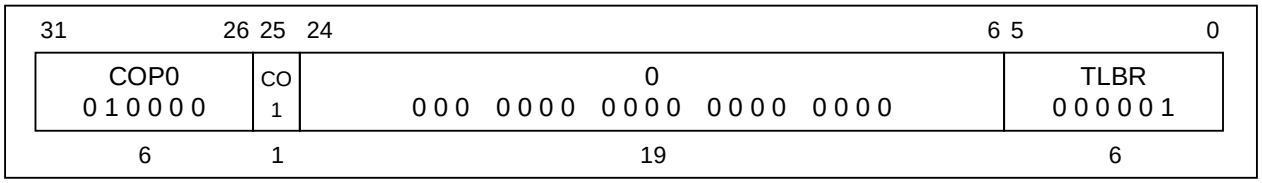
Operation:

```
32    T:    Index ← 1 || 0^25 || Undefined^6
            for i in 0...TLBEntries - 1
                  if (TLB [i]95...77 = EntryHi31...13) and (TLB [i]76 or
                  (TLB [i]71...64 = EntryHi7...0)) then
                        Index ← 0^26 || i5...0
                  endif
            endfor

64    T:    Index ← 1 || 0^25 || Undefined^6
            for i in 0...TLBEntries - 1
                  if (TLB [i]167...141 and not (0^15 || TLB [i]216...205))
                  = (EntryHi39...13) and not (0^15 || TLB [i]216...205)) and
                  (TLB [i]140 or (TLB [i]135...128 = EntryHi7...0)) then
                        Index ← 0^26 || i5...0
                  endif
            endfor
```

Exceptions:

Coprocessor unusable exception

TLBR Read Indexed TLB Entry TLBR



Format:

TLBR

Description:

The EntryHi and EntryLo registers are loaded with the contents of the TLB entry pointed at by the contents of the TLB Index register.

The *G* bit (which controls ASID matching) read from the TLB is written into both of the EntryLo0 and EntryLo1 registers. The operation is invalid (and the results are unspecified) if the contents of the TLB Index register are greater than the number of TLB entries in the processor.

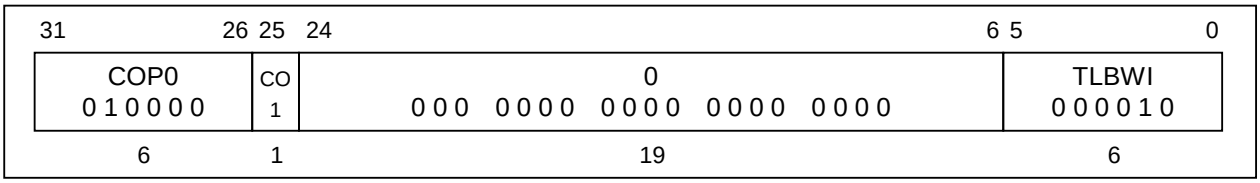
Operation:

```
32    T:   PageMask ← TLB [Index5...0]127...96
           EntryHi ← TLB [Index5...0]95...64 and not TLB [Index5...0]127...96
           EntryLo1 ← TLB [Index5...0]63...33 || TLB [Index5...0]76
           EntryLo0 ← TLB [Index5...0]31...1 || TLB [Index5...0]76

64    T:   PageMask ← TLB [Index5...0]255...192
           EntryHi ← TLB [Index5...0]191...128 and not TLB [Index5...0]255...192
           EntryLo1 ← TLB [Index5...0]127...65 || TLB [Index5...0]140
           EntryLo0 ← TLB [Index5...0]63...1 || TLB [Index5...0]140
```

Exceptions:

Coprocessor unusable exception

TLBWI Write Indexed TLB Entry TLBWI



Format:

TLBWI

Description:

The TLB entry pointed at by the contents of the TLB Index register is loaded with the contents of the EntryHi and EntryLo registers.

The *G* bit of the TLB is written with the logical AND of the *G* bits in the EntryLo0 and EntryLo1 registers.

The operation is invalid (and the results are unspecified) if the contents of the TLB Index register are greater than the number of TLB entries in the processor.

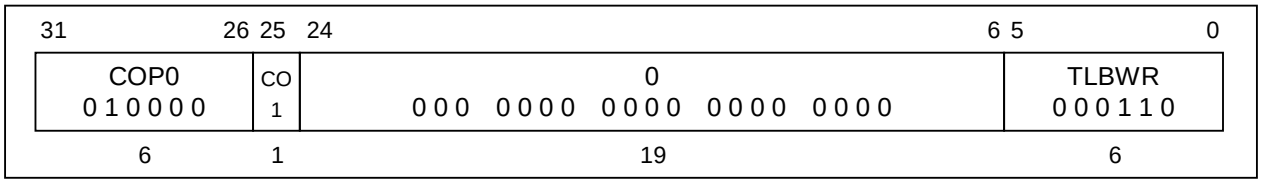
Operation:

```
32, 64 T:    TLB [Index5...0] ←
                    PageMask || (EntryHi and not PageMask) || EntryLo1 || EntryLo0
```

Exceptions:

Coprocessor unusable exception

TLBWR Write Random TLB Entry TLBWR



Format:

TLBWR

Description:

The TLB entry pointed at by the contents of the TLB Random register is loaded with the contents of the EntryHi and EntryLo registers.

The *G* bit of the TLB is written with the logical AND of the *G* bits in the EntryLo0 and EntryLo1 registers.

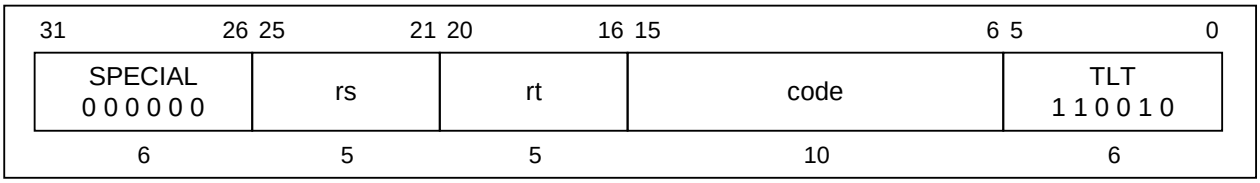
Operation:

```
32, 64 T:    TLB [Random5...0] ←
                    PageMask || (EntryHi and not PageMask) || EntryLo1 || EntryLo0
```

Exceptions:

Coprocessor unusable exception

TLT Trap If Less Than TLT



Format:

TLT rs, rt

Description:

The contents of general register *rt* are compared to general register *rs*. Considering both quantities as signed integers, if the contents of general register *rs* are less than the contents of general register *rt*, a trap exception occurs.

The code field is available for use as software parameters, but is retrieved by the exception handler only by loading the contents of the memory word containing the instruction.

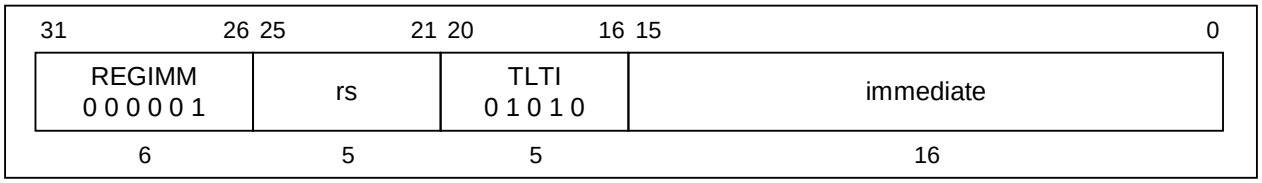
Operation:

```
32, 64  T:    if GPR [rs] < GPR [rt] then
                    TrapException
              endif
```

Exceptions:

Trap exception

TLTI Trap If Less Than Immediate TLTI



Format:

TLTI rs, immediate

Description:

The 16-bit *immediate* is sign-extended and compared to the contents of general register *rs*. Considering both quantities as signed integers, if the contents of general register *rs* are less than the sign-extended *immediate*, a trap exception occurs.

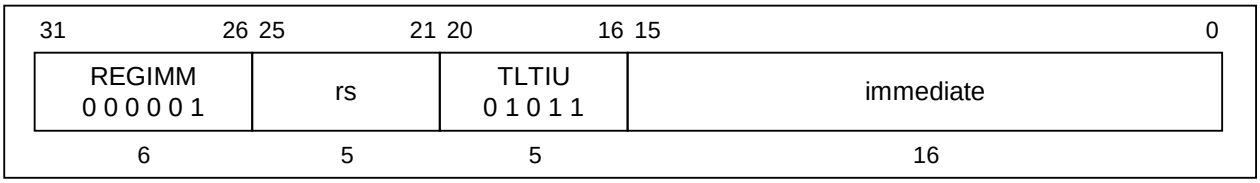
Operation:

```
32    T:    if GPR [rs] < (immediate15)16 || immediate15...0 then
                  TrapException
            endif

64    T:    if GPR [rs] < (immediate15)48 || immediate15...0 then
                  TrapException
            endif
```

Exceptions:

Trap exception

TLTIU Trap If Less Than Immediate Unsigned TLTIU



Format:

TLTIU rs, immediate

Description:

The 16-bit *immediate* is sign-extended and compared to the contents of general register *rs*. Considering both quantities as unsigned integers, if the contents of general register *rs* are less than the sign-extended *immediate*, a trap exception occurs.

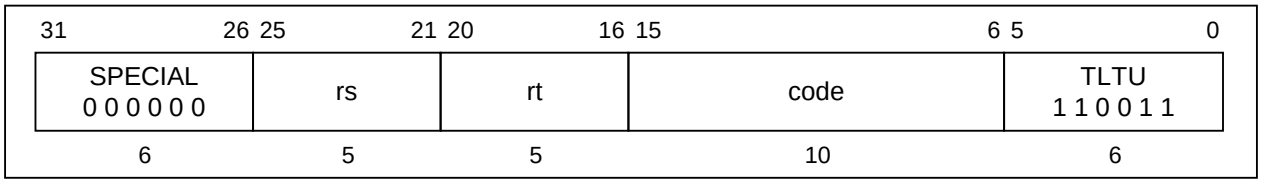
Operation:

```
32    T:    if (0 || GPR [rs]) < (0 || (immediate15)^16 || immediate15...0) then
                  TrapException
            endif

64    T:    if (0 || GPR [rs]) < (0 || (immediate15)^48 || immediate15...0) then
                  TrapException
            endif
```

Exceptions:

Trap exception

TLTU Trap If Less Than Unsigned TLTU



Format:

TLTU rs, rt

Description:

The contents of general register *rt* are compared to general register *rs*. Considering both quantities as unsigned integers, if the contents of general register *rs* are less than the contents of general register *rt*, a trap exception occurs.

The code field is available for use as software parameters, but is retrieved by the exception handler only by loading the contents of the memory word containing the instruction.

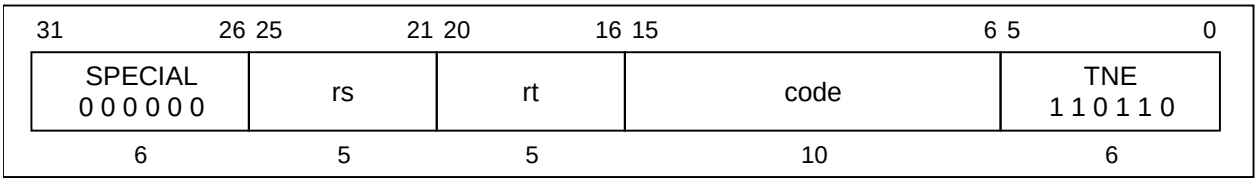
Operation:

```
32, 64  T:    if (0 || GPR [rs]) < (0 || GPR [rt]) then
                    TrapException
              endif
```

Exceptions:

Trap exception

TNE Trap If Not Equal TNE



Format:

TNE rs, rt

Description:

The contents of general register *rt* are compared to general register *rs*. If the contents of general register *rs* are not equal to the contents of general register *rt*, a trap exception occurs.

The code field is available for use as software parameters, but is retrieved by the exception handler only by loading the contents of the memory word containing the instruction.

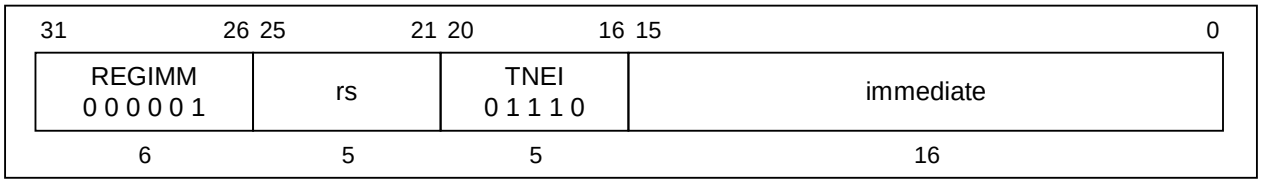
Operation:

```
32, 64  T:    if GPR [rs] ≠ GPR [rt] then
                    TrapException
              endif
```

Exceptions:

Trap exception

TNEI Trap If Not Equal Immediate TNEI



Format:

TNEI rs, immediate

Description:

The 16-bit *immediate* is sign-extended and compared to the contents of general register *rs*. If the contents of general register *rs* are not equal to the sign-extended *immediate*, a trap exception occurs.

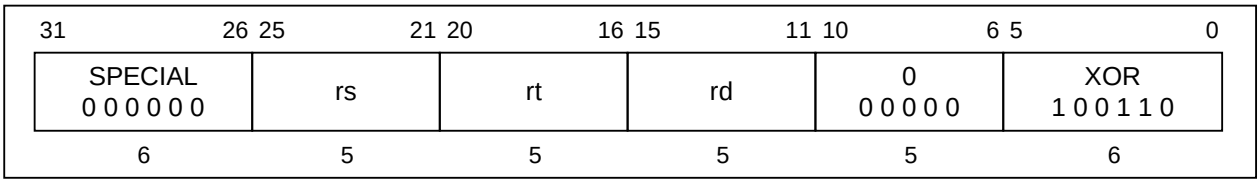
Operation:

```
32    T:    if GPR [rs] ≠ (immediate15)16 || immediate15...0 then
                  TrapException
            endif

64    T:    if GPR [rs] ≠ (immediate15)48 || immediate15...0 then
                  TrapException
            endif
```

Exceptions:

Trap exception

XOR Exclusive Or XOR



Format:

XOR rd, rs, rt

Description:

The contents of general register *rs* are combined with the contents of general register *rt* in a bit-wise logical exclusive OR operation.

The result is placed into general register *rd.*

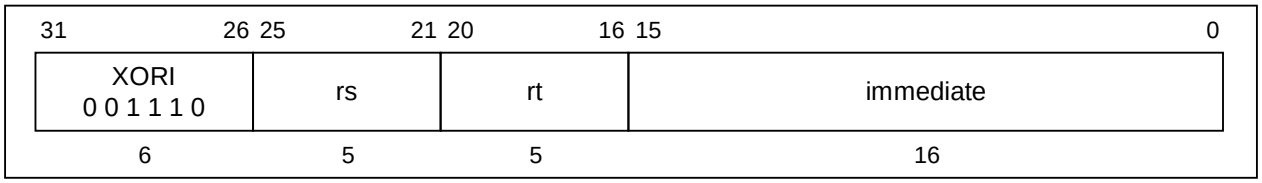
Operation:

```
32, 64 T:    GPR [rd] ← GPR [rs] xor GPR [rt]
```

Exceptions:

None

XORI Exclusive OR Immediate XORI



Format:

XORI rt, rs, immediate

Description:

The 16-bit *immediate* is zero-extended and combined with the contents of general register *rs* in a bit-wise logical exclusive OR operation.

The result is placed into general register *rt.*

Operation:

```
32    T:    GPR [rt] ← GPR [rs] xor (0 16 || immediate)

64    T:    GPR [rt] ← GPR [rs] xor (0 48 || immediate)
```

Exceptions:

None

A.6 CPU Instruction Opcode Bit Encoding

Figure A-1 lists the VR4120A Opcode Bit Encoding.

Figure A-1. VR4120A Opcode Bit Encoding (1/2)

Opcode

31...29 \ 28...26	0	1	2	3	4	5	6	7
0	SPECIAL	REGIMM	J	JAL	BEQ	BNE	BLEZ	BGTZ
1	ADDI	ADDIU	SLTI	SLTIU	ANDI	ORI	XORI	LUI
2	COP0	π	π	*	BEQL	BNEL	BLEZL	BGTZL
3	DADDIε	DADDIUε	LDLε	LDRε	*	JALXθ	*	*
4	LB	LH	LWL	LW	LBU	LHU	LWR	LWUε
5	SB	SH	SWL	SW	SDLε	SDRε	SWR	CACHEδ
6	*	π	π	*	*	π	π	LDε
7	*	π	π	*	*	π	π	SDε

SPECIAL function

5...3 \ 2...0	0	1	2	3	4	5	6	7
0	SLL	*	SRL	SRA	SLLV	*	SRLV	SRAV
1	JR	JALR	*	*	SYSCALL	BREAK	*	SYNC
2	MFHI	MTHI	MFLO	MTLO	DSLLVε	*	DSRLVε	DSRAVε
3	MULT	MULTU	DIV	DIVU	DMULTε	DMULTUε	DDIVε	DDIVUε
4	ADD	ADDU	SUB	SUBU	AND	OR	XOR	NOR
5	MACC	DMACC	SLT	SLTU	DADDε	DADDUε	DSUBε	DSUBUε
6	TGE	TGEU	TLT	TLTU	TEQ	*	TNE	*
7	DSLLε	*	DSRLε	DSRAε	DSLL32ε	*	DSRL32ε	DSRA32ε

REGIMM rt

20...19 \ 18...16	0	1	2	3	4	5	6	7
0	BLTZ	BGEZ	BLTZL	BGEZL	*	*	*	*
1	TGEI	TGEIU	TLTI	TLTIU	TEQI	*	TNEI	*
2	BLTZAL	BGEZAL	BLTZALL	BGEZALL	*	*	*	*
3	*	*	*	*	*	*	*	*

Figure A-1. VR4120AOpcode Bit Encoding (2/2)

COP0 rs (23...21 / 25, 24)

	0	1	2	3	4	5	6	7
0	MF	DMFε	γ	γ	MT	DMTε	γ	γ
1	BC	γ	γ	γ	γ	γ	γ	γ
2	CO							
3								

COP0 rt (18...16 / 20...19)

	0	1	2	3	4	5	6	7
0	BCF	BCT	BCFL	BCTL	γ	γ	γ	γ
1	γ	γ	γ	γ	γ	γ	γ	γ
2	γ	γ	γ	γ	γ	γ	γ	γ
3	γ	γ	γ	γ	γ	γ	γ	γ

CP0 Function (2...0 / 5...3)

	0	1	2	3	4	5	6	7
0	φ	TLBR	TLBWI	φ	φ	φ	TLBWR	φ
1	TLBP	φ	φ	φ	φ	φ	φ	φ
2	ξ	φ	φ	φ	φ	φ	φ	φ
3	ERET χ	φ	φ	φ	φ	φ	φ	φ
4	φ	STANDBY	SUSPEND	HIBERNAT	φ	φ	φ	φ
5	φ	φ	φ	φ	φ	φ	φ	φ
6	φ	φ	φ	φ	φ	φ	φ	φ
7	φ	φ	φ	φ	φ	φ	φ	φ

Key:

* Operation codes marked with an asterisk cause reserved instruction exceptions in all current implementations and are reserved for future versions of the architecture.

γ Operation codes marked with a gamma cause a reserved instruction exception. They are reserved for future versions of the architecture.

δ Operation codes marked with a delta are valid only for VR4400 Series processors with CP0 enabled, and cause a reserved instruction exception on other processors.

φ Operation codes marked with a phi are invalid but do not cause reserved instruction exceptions in VR4121 implementations.

ξ Operation codes marked with a xi cause a reserved instruction exception on VR4121 processor.

χ Operation codes marked with a chi are valid on VR4000 Series only.

ε Operation codes marked with epsilon are valid when the processor operating as a 64-bit processor. These instructions will cause a reserved instruction exception if 64-bit operation is not enabled.

π Operation codes marked with a pi are invalid and cause coprocessor unusable exception.

θ Operation codes marked with a theta are valid when MIPS16 instruction execution is enabled, and cause a reserved instruction exception when MIPS16 instruction execution is disabled.

[MEMO]

APPENDIX B <empty>

APPENDIX C VR4120A COPROCESSOR 0 HAZARDS

The VR4120A core avoids contention of its internal resources by causing a pipeline interlock in such cases as when the contents of the destination register of an instruction are used as a source in the succeeding instruction. Therefore, instructions such as NOP must not be inserted between instructions.

However, interlocks do not occur on the operations related to the CP0 registers and the TLB. Therefore, contention of internal resources should be considered when composing a program that manipulates the CP0 registers or the TLB. The CP0 hazards define the number of NOP instructions that is required to avoid contention of internal resources, or the number of instructions unrelated to contention. This chapter describes the CP0 hazards.

The CP0 hazards of the VR4120A core are as or less stringent than those of the VR4000. Table C-1 lists the Coprocessor 0 hazards of the VR4120A core. Code that complies with these hazards will run without modification on the VR4000.

The contents of the CP0 registers or the bits in the "Source" column of this table can be used as a source after they are fixed.

The contents of the CP0 registers or the bits in the "Destination" column of this table can be available as a destination after they are stored.

Based on this table, the number of NOP instructions required between instructions related to the TLB is computed by the following formula, and so is the number of instructions unrelated to contention:

(Destination Hazard number of A) – [(Source Hazard number of B) + 1]

As an example, to compute the number of instructions required between an MTC0 and a subsequent MFC0 instruction, this is:

(5) – (3 + 1) = 1 instruction

The CP0 hazards do not generate interlocks of pipeline. Therefore, the required number of instruction must be controlled by program.

Table C-1. VR4120A CPU Coprocessor 0 Hazards

Operation	Source		Destination	
	Source Name	No. of Hazards	Destination Name	No. of Hazards
MTC0			CPU General Purpose Register	5
MFC0	CPU General Purpose Register	3		
TLBR	Index, TLB	2	PageMask, EntryHi, EntryLo0, EntryLo1	5
TLBWI TLBWR	Index or Random, PageMask, EntryHi, EntryLo0, EntryLo1	2	TLB	5
TLBP	PageMask, EntryHi	2	Index	6
ERET	EPC or ErrorEPC, TLB	2	Status.EXL, Status.ERL	4
	Status	2		
CACHE Index_Load_Tag			TagLo, TagHi, Parity Error	5
CACHE Index_Store_Tag	TagLo, TagHi, Parity Error	3		
CACHE Hit ops.	Cache line	3	Cache line	5
Coprocessor usable test	Status [CU],[KSU],[EXL,],[ERL]	2		
Instruction fetch	EntryHi [ASID], Status [KSU],[EXL],[ERL],[RE] Config [K0]	2		
	TLB	2		
Instruction fetch exception			EPC, Status	4
			Cause, BadVAddr, Context, XContext	5
Interrupt signals	Cause [IP], Status [IM], [IE],[EXL],[ERL]	2		
Load/Store	EntryHi [ASID], Status [KSU],[EXL],[ERL],[RE] Config [K0], TLB	3		
	Config [AD], [EP]	3		
	WatchHi, WatchLo	3		
Load/Store exception			EPC, Status, Cause, BadVAddr, Context, XContext	5

Cautions 1. If the setting of the K0 bit in the Config register is changed to uncached mode by MTC0, the accessed memory area is switched to the uncached area at the instruction fetch of the third instruction after MTC0.

2. The instruction following MTC0 must not be MFC0.

3. The five instructions following MTC0 to Status register that changes KSU bit and sets EXL and ERL bits may be executed in the new mode, and not kernel mode. This can be avoided by setting EXL bit first, leaving KSU bit set to kernel, and later changing KSU bit.

4. There must be two non-load, non-CACHE instructions between a store and a CACHE instruction using the same cache line as the store destination.

The status during execution of the following instruction for which CP0 hazards must be considered is described below.

(1) MTC0

Destination: The completion of writing to a destination register (CP0) of MTC0.

(2) MFC0

Source: The confirmation of a source register (CP0) of MFC0.

(3) TLBR

Source: The confirmation of the status of TLB and the Index register before the execution of TLBR.

Destination: The completion of writing to a destination register (CP0) of TLBR.

(4) TLBWI, TLBWR

Source: The confirmation of a source register of these instructions and registers used to specify a TLB entry.

Destination: The completion of writing to TLB by these instructions.

(5) TLBP

Source: The confirmation of the PageMask register and the EntryHi register before the execution of TLBP.

Destination: The completion of writing the result of execution of TLBP to the Index register.

(6) ERET

Source: The confirmation of registers containing information necessary for executing ERET.

Destination: The completion of the processor state transition by the execution of ERET.

(7) CACHE Index Load Tag

Destination: The completion of writing the results of execution of this instruction to the related registers.

(8) CACHE Index Store Tag

Source: The confirmation of registers containing information necessary for executing this instruction.

(9) Coprocessor Usable Test

Source: The confirmation of modes set by the bits of the CP0 registers in the "Source" column.

Examples 1. When accessing the CP0 registers in User mode after the contents of the CU0 bit of the Status register are modified, or when executing an instruction such as TLB instructions, CACHE instructions, or branch instructions that use the resource of the CP0.

2. When accessing the CP0 registers in the operating mode set in the Status register after the KSU, EXL, and ERL bits of the Status register are modified.

(10) Instruction Fetch

Source: The confirmation of the operating mode and TLB necessary for instruction fetch.

Examples 1. When changing the operating mode from User to Kernel and fetching instructions after the KSU, EXL, and ERL bits of the Status register are modified.

2. When fetching instructions using the modified TLB entry after TLB modification.

(11) Instruction Fetch Exception

Destination: The completion of writing to registers containing information related to the exception when an exception occurs on instruction fetch.

(12) Interrupts

Source: The confirmation of registers judging the condition of occurrence of interrupt when an interrupt factor is detected.

(13) Loads/Sores

Source: The confirmation of the operating mode related to the address generation of Load/Store instructions, TLB entries, the cache mode set in the K0 bit of the Config register, and the registers setting the condition of occurrence of a Watch exception.

Example When Loads/Stores are executed in the kernel field after changing the mode from User to Kernel.

(14) Load/Store Exception

Destination: The completion of writing to registers containing information related to the exception when an exception occurs on load or store operation.

(15) TLB Shutdown

Destination: The completion of writing to the TS bit of the Status register when a TLB shutdown occurs.

Table C-2 indicates examples of calculation.

Table C-2. Calculation Example of CP0 Hazard and Number of Instructions Inserted

Destination	Source	Contending Internal Resource	Number of Instructions Inserted	Formula
TLBWR/TLBWI	TLBP	TLB Entry	2	5 – (2 + 1)
TLBWR/TLBWI	Load or Store using newly modified TLB	TLB Entry	1	5 – (3 + 1)
TLBWR/TLBWI	Instruction fetch using newly modified TLB	TLB Entry	2	5 – (2 + 1)
MTC0, Status [CU]	Coprocessor instruction that requires the setting of CU	Status [CU]	2	5 – (2 + 1)
TLBR	MFC0 EntryHi	EntryHi	1	5 – (3 + 1)
MTC0 EntryLo0	TLBWR/TLBWI	EntryLo0	2	5 – (2 + 1)
TLBP	MFC0 Index	Index	2	6 – (3 + 1)
MTC0 EntryHi	TLBP	EntryHi	2	5 – (2 + 1)
MTC0 EPC	ERET	EPC	2	5 – (2 + 1)
MTC0 Status	ERET	Status	2	5 – (2 + 1)
MTC0 Status [IE] Note	Instruction that causes an interrupt	Status [IE]	2	5 – (2 + 1)

Note The number of hazards is undefined if the instruction execution sequence is changed by exceptions. In such a case, the minimum number of hazards until the IE bit value is confirmed may be the same as the maximum number of hazards until an interrupt request occurs that is pending and enabled.

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