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April 1<sup>st</sup>, 2010  
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# SH-DSP Software

Application Note

SuperH RISC Engine

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# Preface

The SH-DSP is a CPU core belonging to the SuperH RISC engine family. It is a 32-bit RISC microcontroller based on the SH-2 CPU, optimized for signal processing performance, and incorporating a DSP unit.

These application notes contain example code that makes use of the special features of the SH-DSP as well as explanations of how to utilize the hardware. It is hoped that these application notes will be of use to programmers designing applications that make use of the DSP functions.

***Note that though the operation of the example code contained in these application notes has been verified, it is still necessary to confirm its operation when in an actual implementation.***

For more information on the hardware, please refer to the hardware manual for the appropriate product.

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## SH-DSP Code Samples

These application notes contain example code written to illustrate the special features of the SH-DSP.

Figure 1 shows the format used for listings of source code in the application notes. The main program code is transferred to XRAM and the program is executed in XRAM. This format is compatible with the SH7612. When using other SH-DSP models, the following modifications and cautions apply:

- XRAM starting address setting ..... (1)
- Vector and stack pointer (YRAM ending address + 1 byte) settings ..... (2)
- Usage of commands with other SH-DSP models ..... (3)
- Since space for the data used by the main program is reserved in XRAM or YRAM, changes to XRAM or YRAM address settings to match microcontroller used ..... (4)

```

;*****
;*
;*          Symbol definition
;*
;          [      XRAM address (SH7612)      ]
XRAM_TOP  .EQU  H'1000E000 ----- (2)
;*****
;*          Program transfer routine
;*
          .SECTION VECT, CODE, LOCATE=H'0
;
          .DATA.L   _PRES      ;_PRES ----- (1)
          .DATA.L   H'10020000 ;SP
          .SECTION ROM, CODE, LOCATE=H'1000

_PRES:    MOV.L     #XRAM_TOP, R1
          MOV.L     #MAIN, R10
          MOV.L     #MAIN_E, R11
PRG_MOVE:
          MOV.W     @R10+, R0
          MOV.W     R0, @R1
          ADD       #2, R1
          CMP/GE    R11, R10
          BF        PRG_MOVE
          MOV.L     #XRAM_TOP, R0
          JMP       @R0          ;Branch to program starting address
          NOP          ;at transfer destination

Main program ----- (3)

Data ----- (4)

.END

```

**Figure 1 Source Code Format**



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# Section 1 Example of Calling Functions (DSP Library) from C Source Code

## 1.1 C Source Code Employing Functions (DSP Library)

The example code below, “dsplbr.c,” illustrates calling the “Mean” function in the DSP library (shdsplib.lib) from C source code.

```
/*
  <<SH-DSP Application Notes>>
  -- DSP library usage example --
  "dsplbr.c"
*/
#include "ensigdsp.h" /* Mean value definition */ ----- (1)
#define N 6 /* Input data number */

short dat[6]={45,61,516,3000,-974,10214} /* Input data */

#pragma section X /* XRAM address */ ----- (2)
static short datx[N];
#pragma section Y /* YRAM address */ ----- (3)
static short daty[N];
#pragma section ANS /* Address for storing mean value */
static short answer;
#pragma section

main()
{
  short i,output[1]; /* output for storing variable i
                    and Mean function calculation
                    result */

  int src_x; /* Argument specifying storage area
             for input data */

  for(i=0;i<N;i++)
  {
    datx[i] = dat[i]; /* Copy input data to XRAM */
    daty[i] = dat[i]; /* Copy input data to YRAM */
  }

  /* select XRAM */
*1
  src_x = 1; /* Use XRAM area for Mean ----- (4)
             function calculation */
             /* Pass Mean function arguments and
             calculate mean value */
             /* Store Mean function calculation
             result at answer address */

  while(1); /* Processing complete */
}

```

\*1 Refer to 1.3 Function Execution Process for details.

- (1) The format of the functions in the library shdsplib.lib are defined in the header file ensigndsp.h.
- (2) To ensure efficient X bus data transfer with the DSP unit, it is necessary to place datX[N] in XRAM. Section X needs to be set when linking to addresses in XRAM. (See 1.2 Linking Assignments.)
- (3) To ensure efficient Y bus data transfer with the DSP unit, it is necessary to place datY[N] in YRAM. Section Y needs to be set when linking to addresses in XRAM. (See 1.2 Linking Assignments.)
- (4) If srx\_x = 1, an area in XRAM is used for Mean function calculations. If srx\_x = 0, an area in YRAM is used.

## 1.2 Linking Assignments

When using the DSP library the utmost care must be taken to ensure that the section setting is correct. The example code dsplbr.c shown in section 1.1 has two sections, X and Y. If XRAM and YRAM address are not set for these sections, the functions' internal calculations cannot be performed correctly. These addresses are assigned in the subcommand file.

### 1.2.1 “prglnk1.sub” Subcommand File for Linking

```

INPUT      vect,dsplbr
START      BX(1000ff00),BANS(1000fff0),BY(1001e000) ----- (1)
LIBRARY    shdsplib.lib ----- (2)
PRINT      dsplbr.map
OUTPUT     dsplbr.abs
FORM       A
DEBUG
EXIT

```

- (1) BX(1000ff00) assigns #pragma section X (section X) of dsplbr.c to address H'1000FF00.  
BY(1001e000) assigns #pragma section Y (section Y) of dsplbr.c to address H'1001E000.
- (2) This specifies shdsplib.lib, which includes the Mean function, as the library to be edited.

## 1.2.2 “ini.bat” Batch File for Creating Absolute Files

```
asmsh vect.src -cpu=shdsp -debug -lis
shc dsplbr.c -cpu=sh2 -lis -debug -include=ensigdsp.h
lnk -subcommand=prglnk1.sub
```

## 1.2.3 “vect.src” Vector Table for “dsplbr.c” Program, which Uses DSP Library

```
*****
;*      <<SH-DSP Application Notes>>
;*      -- DSP library usage example --
;*
;*      "vect.src"
*****

        .import          _main

        .section vect,data,locate=h'0
        .data.l          _main
        .data.l          h'10020000
        .end
```

## 1.3 Function Execution Process

Excerpts from the example code `dsplbr.c` shown in section 1.1, and the assembler code resulting from the functions used, as shown below.

<pre>      :       : src_x = 1;  Mean(output,datx,N,src_x;)  answer = output[0]       :       :</pre>	<p>Assembler code resulting from function</p> <table border="1"><thead><tr><th>Address</th><th>Label</th><th>Assembler</th></tr></thead><tbody><tr><td>1001e2fc</td><td>_Mean</td><td>CMP/PZ R7</td></tr><tr><td>1001e2fe</td><td></td><td>BF @1001E322:8</td></tr><tr><td>1001e300</td><td></td><td>MOV #H'01,R1</td></tr><tr><td>1001e302</td><td></td><td>CMP/GT R1,R7</td></tr><tr><td></td><td></td><td>⋮</td></tr><tr><td></td><td></td><td>⋮</td></tr><tr><td>1001e486</td><td></td><td>NEG R2,R2</td></tr><tr><td>1001e488</td><td></td><td>MOV.W R2,@R4</td></tr><tr><td>1001e48a</td><td></td><td>RTS</td></tr></tbody></table>	Address	Label	Assembler	1001e2fc	_Mean	CMP/PZ R7	1001e2fe		BF @1001E322:8	1001e300		MOV #H'01,R1	1001e302		CMP/GT R1,R7			⋮			⋮	1001e486		NEG R2,R2	1001e488		MOV.W R2,@R4	1001e48a		RTS
Address	Label	Assembler																													
1001e2fc	_Mean	CMP/PZ R7																													
1001e2fe		BF @1001E322:8																													
1001e300		MOV #H'01,R1																													
1001e302		CMP/GT R1,R7																													
		⋮																													
		⋮																													
1001e486		NEG R2,R2																													
1001e488		MOV.W R2,@R4																													
1001e48a		RTS																													

In table 1.1, the input data is arranged starting at address H'1000FF00. It is assumed that the data in RAM has been cleared to 0. The data remains the same after the function is executed.

**Table 1.1 Memory Map**

### XRAM Memory

H'1000FF00	002D	003D	0204	0BB8
H'1000FF08	FC32	27E6	0000	0000

**Table 1.2 Function Execution Process**

Excerpt from dsplbr.c Code	Register Contents
Mean(output,datx,N,src_x);	Before execution: R4=H'1001FFFC, R5=H'1000FF00, R6=6, R7=1  After execution: R4=H'1001FFFC, R5=H'1000FF0C, R6=6, R7=H'10000

The function arguments are assigned the declaration sequence R4 to R7, so output=H'1001FFFC, datx=H'1000FF00, N=6, src\_x=1 is passed to the function. The calculation result is held in @R4.

**Table 1.3 C Source Code Execution Process (Process Inside Memory Map)**

Excerpt from dsplbr.c Code	YRAM Memory
answer = output[0];	Before execution: H'1001FF00 0000 0000 0000 0000  After execution: H'1001FF00 0860 0000 0000 0000

The C source code then stores the function calculation result from @R4 in answer (H'1001FF0).

**Table 1.4 Mean Function Calculation Result**

Input Value (decimal)	Input Value (hexadecimal)	Logical Value (decimal)	Logical Value (hexadecimal)	Output Value (hexadecimal)
45	H'2D	2143.666667	H'860	H'860
61	H'3D		(2144 calculated as a decimal value)	
516	H'204			
3000	H'BB8			
-974	H'FC32			
10214	H'27E6			





# Section 2 X/Y Bus Data Access

## 2.1 X Memory Read

### Overview

The data from the XRAM\_ADD address (H'1000FF00) and XRAM\_ADD+2 address (H'1000FF02) is transferred, respectively, to registers X0 and X1.

### Description

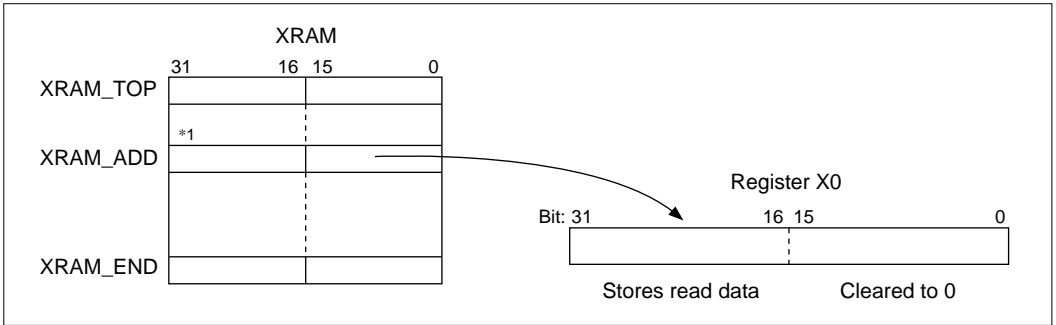
Table 2.1 shows the types of X memory read instructions and the registers that can be used as operands. Data can be read from X memory using the commands listed in table 2.1.

When reading data from X memory the transfer data length is 16 bits, so the data is stored as the upper word of register X0 or X1. When this happens, the lower word of register X0 or X1 is cleared to 0. Processes (1) and (2) in the flowchart are illustrated below.

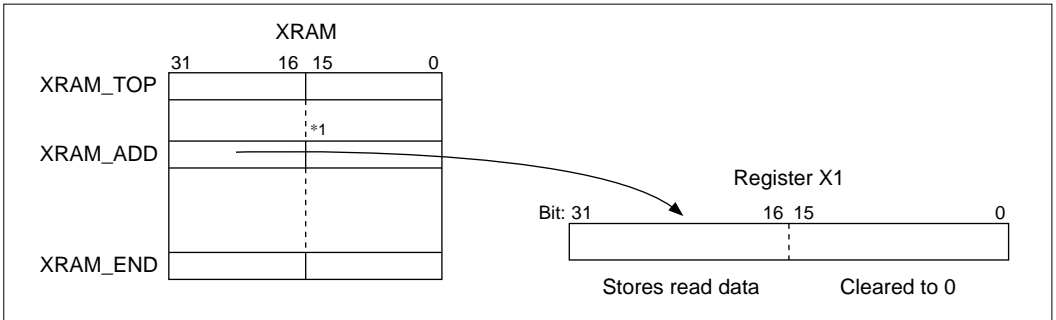
**Table 2.1 X Memory Read Instruction Types**

<b>X Memory Read Instruction</b>	<b>Source Register (Ax)</b>	<b>Destination Register (Dx)</b>	<b>Index Register (Ix)</b>
MOVX.W @Ax,Dx	R4, R5	X0, X1	R8
MOVX.W @Ax+,Dx			
MOVX.W @Ax+Ix,Dx			

## Process (1)

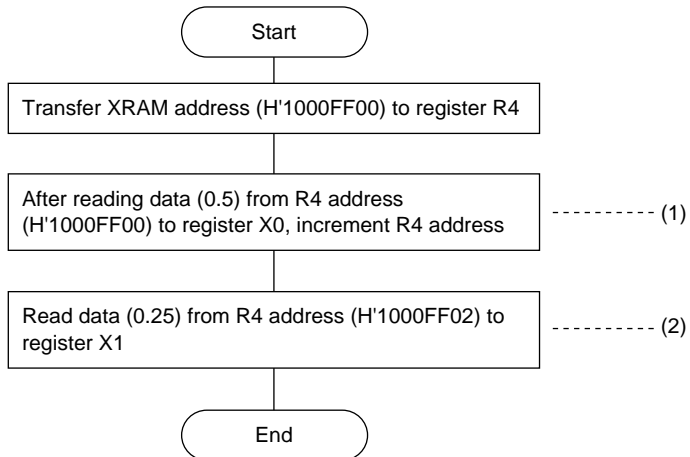


## Process (2)



\*1 : Ignored

## Flowchart



## Main Program

```
*****
;*
;*          X memory read
*****
MAIN:      MOV.L      #XRAM_ADD,R4      ;XRAM_ADD address -> register R4
          MOVX.W     @R4+,X0           ;(H'1000FF00) -> X0
          MOVX.W     @R4,X1           ;(H'1000FF02) -> X1
EXIT:      BRA       EXIT
          NOP
MAIN_E:    NOP
```

## Data

```
*****
;*
;*          Data
*****
          .SECTION XRAM,DATA,LOCATE=H'1000FF00
XRAM_ADD: .XDATA.W      0.5,0.25
```

## 2.2 X Memory Write

### Overview

The data from the XRAM\_ADD1 address (H'1000FF00) and XRAM\_ADD1+2 address (H'1000FF02) is transferred the XRAM\_ADD2 address and XRAM\_ADD2+2 address.

### Description

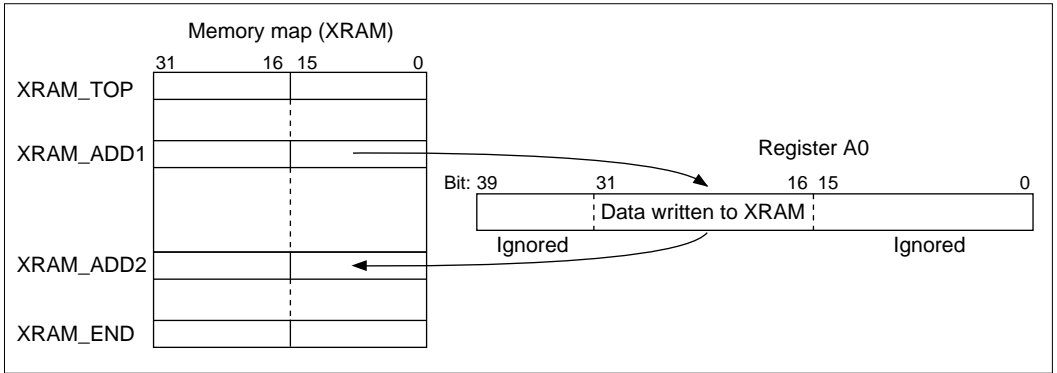
Table 2.2 shows the types of X memory write instructions and the registers that can be used as operands. Data can be written to X memory using the commands listed in table 2.2.

When writing data to X memory the transfer data length is 16 bits, so the upper word data from register A0 or A1, as specified by the instruction, is stored in X memory. When this happens, the guard bit and lower word of register A0 or A1 is ignored. The X memory write instructions can use only registers A0 and A1 as source registers (see Table 2.2 X Memory Write Instruction Types), so when transferring data to register A0 or A1, single data transfers with register A0 or A1 as the destination operand are used. Processes (1) and (2) in the flowchart are illustrated below.

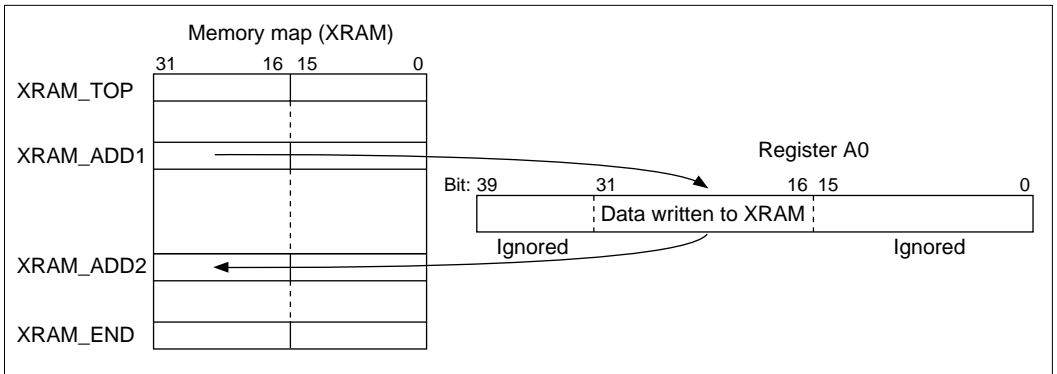
**Table 2.2 X Memory Write Instruction Types**

<b>X Memory Write Instruction</b>	<b>Source Register (Da)</b>	<b>Destination Register (Ax)</b>	<b>Index Register (Ix)</b>
MOVX.W Da,@Ax	A0, A1	R4, R5	R8
MOVX.W Da,@Ax+			
MOVX.W Da,@Ax+Ix			

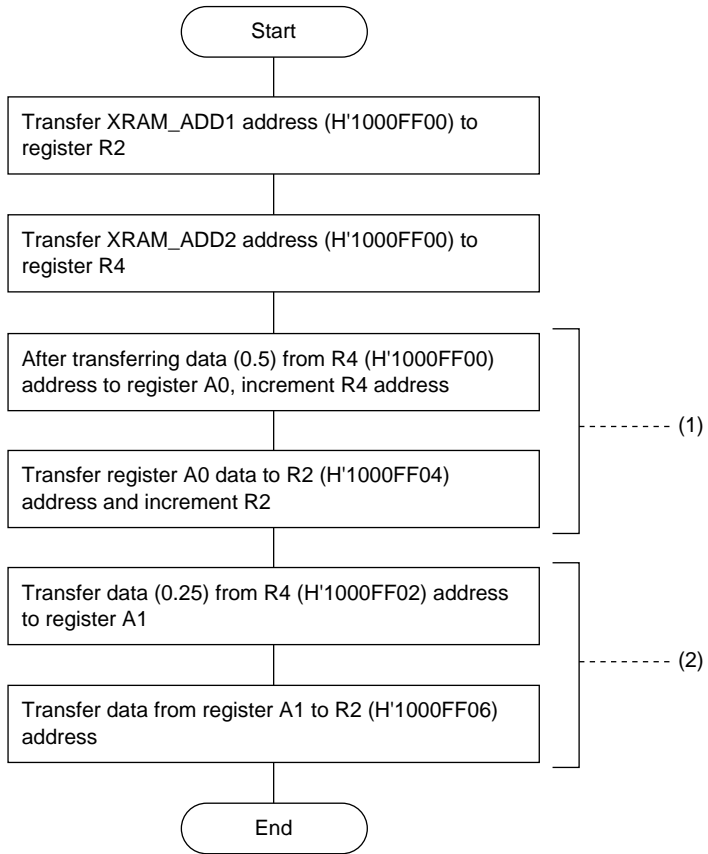
### Process (1)



### Process (2)



# Flowchart



## Main Program

```
*****
;*                               X memory write
;*****
MAIN:   MOV.L   #XRAM_ADD1,R2    ;XRAM_ADD1 -> R2 register
        MOV.L   #XRAM_ADD2,R4    ;XRAM_ADD2 -> R4 register
        MOVS.W  @R2+,A0         ;(H'1000FF00) -> A0 register
        MOVX.W  A0,@R4+         ;A0 register data -> XRAM_ADD2
        MOVS.W  @R2,A1         ;(H'1000FF00) -> A1 register
        MOVX.W  A1,@R4         ;A1 register data -> XRAM_ADD2+2
EXIT:   BRA     EXIT
        NOP
MAIN_E: NOP
```

## Data

```
;*****
;*                               Data
;*****
        .SECTION XRAM,DATA,LOCATE=H'1000FF00
XRAM_ADD1: .XDATA.W    0.5,0.25
XRAM_ADD2: .RES.W      2
```

## 2.3 Y Memory Read

### Overview

The data from the TRAM\_ADD address (H'1001FF00) and YRAM\_ADD+2 address (H'1001FF02) is transferred, respectively, to registers Y0 and Y1.

### Description

Table 2.3 shows the types of Y memory read instructions and the registers that can be used as operands. Data can be read from Y memory using the commands listed in table 2.3.

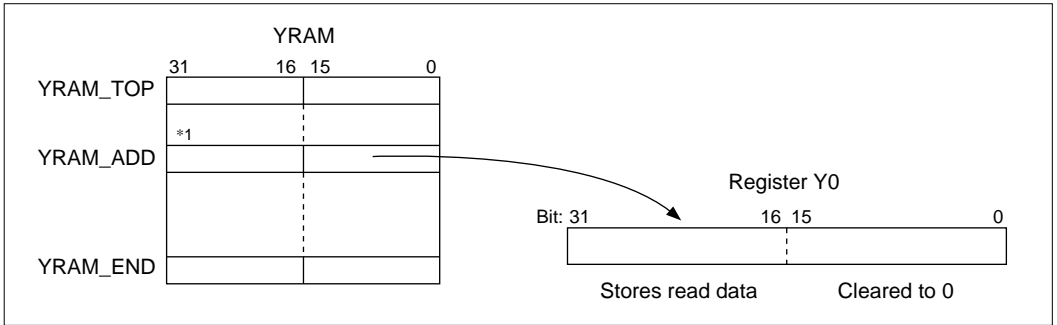
When reading data from Y memory the transfer data length is 16 bits, so the data is stored as the upper word of register Y0 or Y1. When this happens, the lower word of register Y0 or Y1 is cleared to 0. Processes (1) and (2) in the flowchart are illustrated below.

**Table 2.3 Y Memory Read Instruction Types**

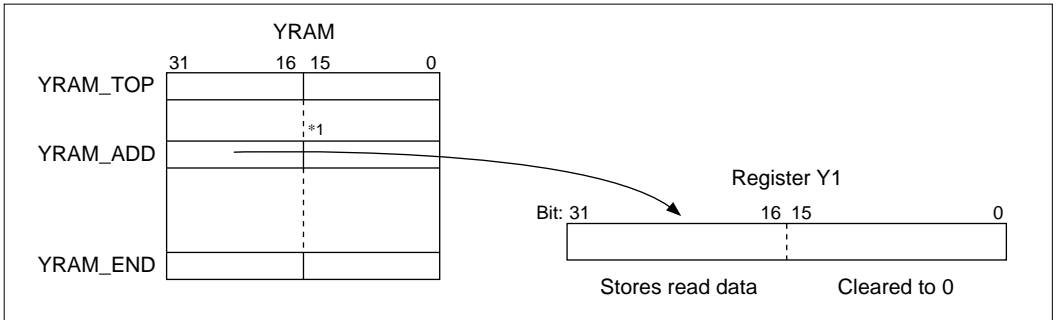
<b>Y Memory Read Instruction</b>	<b>Source Register (Ay)</b>	<b>Destination Register (Dy)</b>	<b>Index Register (ly)</b>
MOVY.W @Ay,Dy	R6, R7	Y0, Y1	R9
MOVY.W @Ay+,Dy			
MOVY.W @Ay+ly,Dy			



## Process (1)

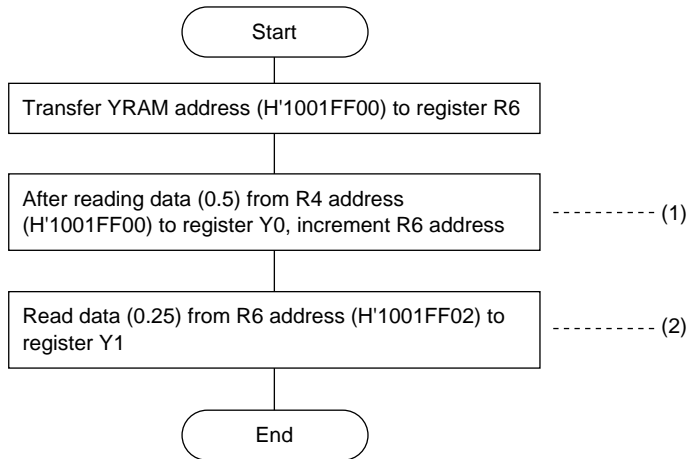


## Process (2)



\*1  : Ignored

## Flowchart



## Main Program

```
;*****  
;*                Y memory read  
;*****  
MAIN:   MOV.L     #YRAM_ADD,R6      ;YRAM_ADD address -> R6 register  
        MOVX.W   @R6+,Y0           ;(H'1001FF00) -> Y0  
        MOVX.W   @R6,Y1            ;(H'1001FF02) -> Y1  
EXIT:   BRA      EXIT  
        NOP  
MAIN_E: NOP
```

## Data

```
;*****  
;*                Data  
;*****  
        .SECTION YRAM,DATA,LOCATE=H'1001FF00  
YRAM_ADD: .XDATA.W      0.5,0.25
```

## 2.4 Y Memory Write

### Overview

The data from the YRAM\_ADD1 address (H'1001FF00) and YRAM\_ADD1+2 address (H'1001FF02) is transferred the YRAM\_ADD2 address and YRAM\_ADD2+2 address.

### Description

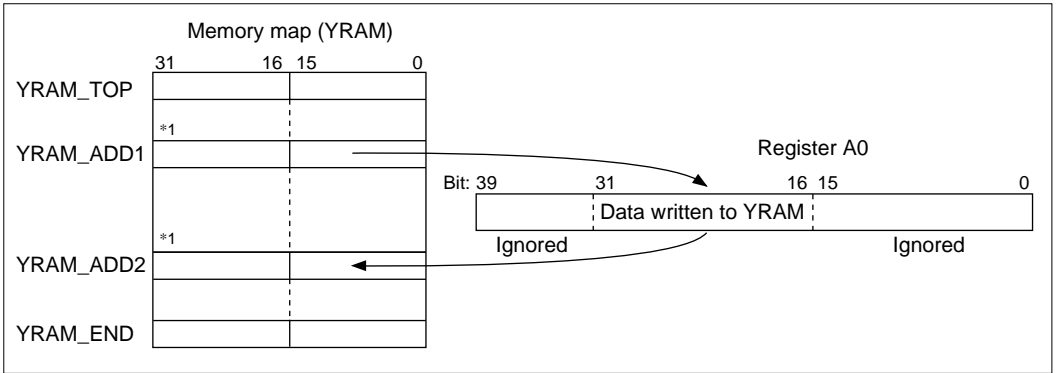
Table 2.4 shows the types of Y memory write instructions and the registers that can be used as operands. Data can be written to Y memory using the commands listed in table 2.4.

When writing data to Y memory the transfer data length is 16 bits, so the upper word data from register A0 or A1, as specified by the instruction, is stored in Y memory. When this happens, the guard bit and lower word of register A0 or A1 is ignored. The Y memory write instructions can use only registers A0 and A1 as source registers (see Table 2.4 Y Memory Write Instruction Types), so when transferring data to register A0 or A1, single data transfers with register A0 or A1 as the destination operand are used. Processes (1) and (2) in the flowchart are illustrated below.

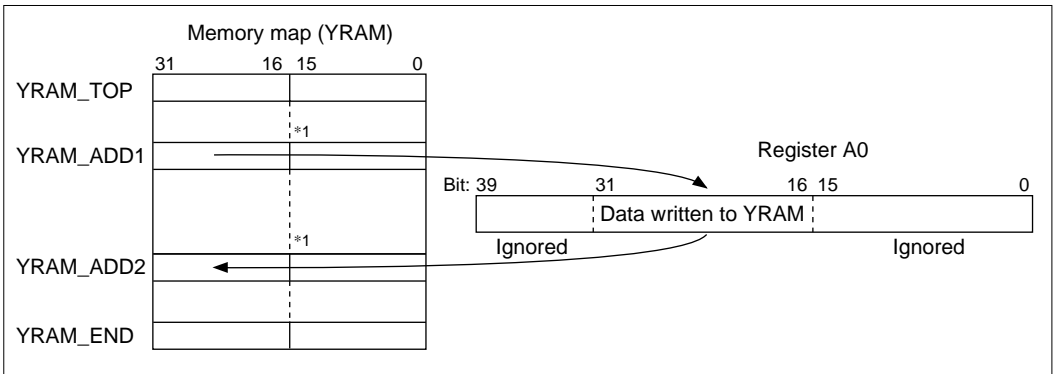
**Table 2.4 Y Memory Write Instruction Types**

<b>Y Memory Write Instruction</b>	<b>Source Register (Da)</b>	<b>Destination Register (Ax)</b>	<b>Index Register (Ix)</b>
MOVY.W Da,@Ax	A0, A1	R6, R7	R9
MOVY.W Da,@Ax+			
MOVY.W Da,@Ax+Ix			

Process (1)

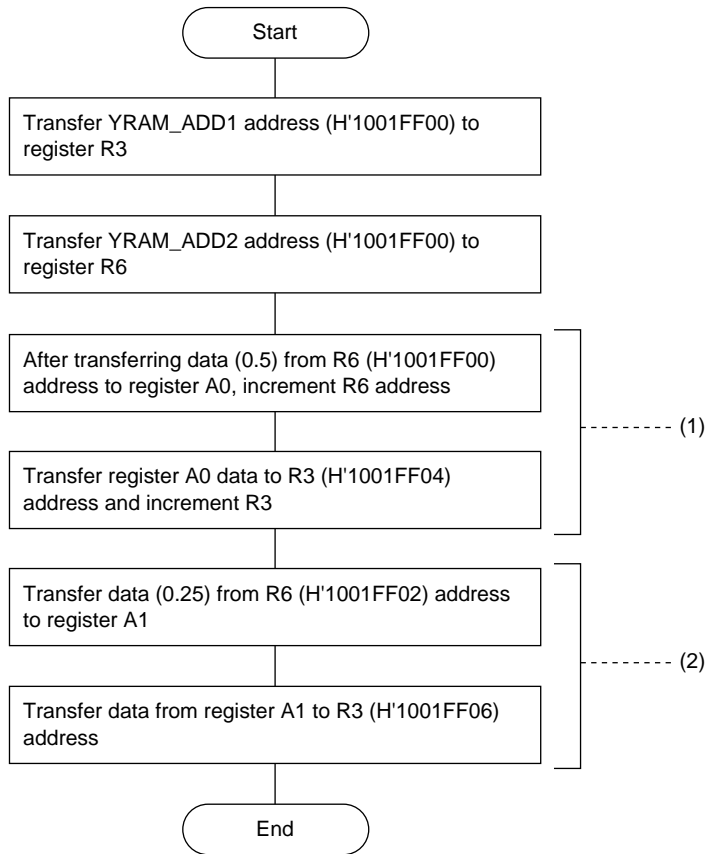


Process (2)



\*1  : Ignored

# Flowchart



## Main Program

```
*****
;*                               Y Memory Write
;*****
MAIN:  MOV.L    #YRAM_ADD1,R3    ;YRAM_ADD1 -> R3 register
      MOV.L    #YRAM_ADD2,R6    ;YRAM_ADD2 -> R6 register
      MOVS.W   @R3+,A0          ;(H'1001FF00) -> A0 register
      MOVX.W   A0,@R6+         ;A0 register data -> YRAM_ADD2
      MOVS.W   @R3,A1          ;(H'1001FF00) -> A1 register
      MOVX.W   A1,@R6         ;A1 register data -> YRAM_ADD2+2
EXIT:  BRA     EXIT
      NOP
MAIN_E: NOP
```

## Data

```
;*****
;*                               Data
;*****
      .SECTION YRAM,DATA,LOCATE=H'1001FF00
YRAM_ADD1:  .XDATA.W    0.5,0.25
YRAM_ADD2:  .RES.W     2
```

# Section 3 16-bit Fixed-point Multiplication

## Overview

Multiplies the 16-bit data at the XRAM-ADD address (H'1000FF000) and the 16-bit data at the YRAM-ADD address (H'1001FF002). The result is stored at the ANS address (H'1001FF002).

## Description

### 1. Data Transfer

Transfer of the data from the XRAM-ADD address (H'1000FF000) and the YRAM-ADD address (H'1001FF002) is performed using X bus data transfer and Y bus data transfer, as described in 2. X/Y Bus Data Access. In process (1) in the flowchart the XRAM and YRAM data is read simultaneously, but no contention occurs because the X bus and Y bus are independent of each other. The format is shown below.

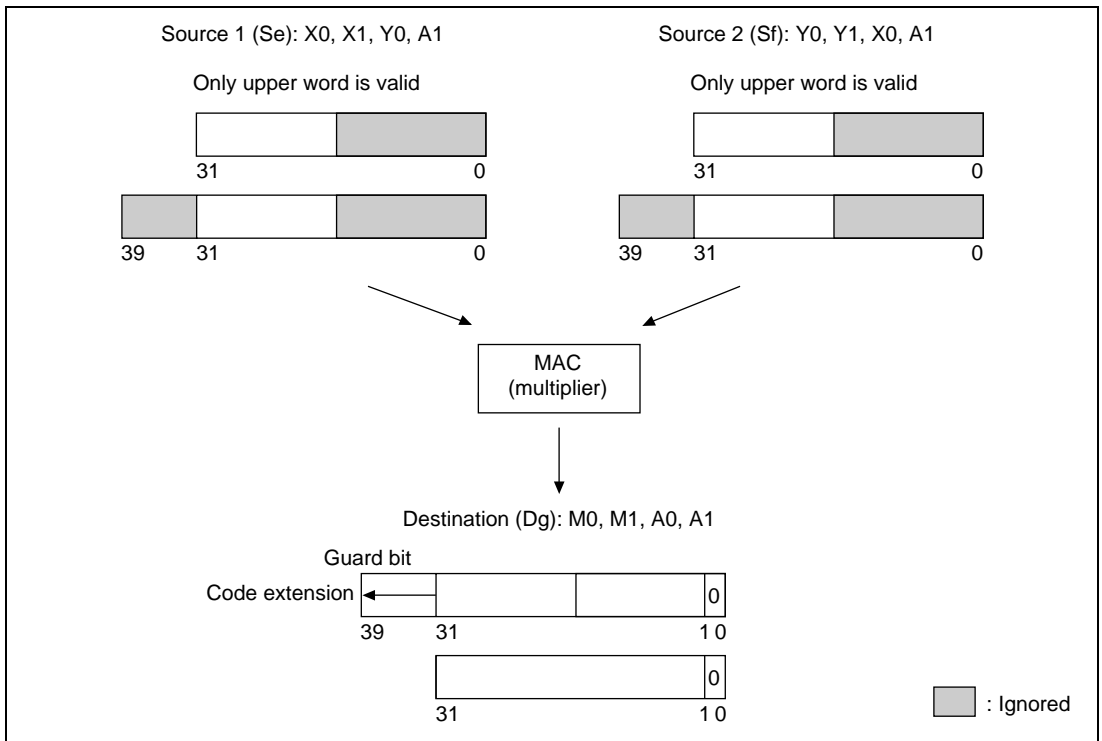
The sequence is [X bus data transfer] then [Y bus data transfer]. If these are described in a single step, the instructions may be combined as either [X memory read] [Y memory write] or [X memory write] [Y memory read].

Format:   MOVX.W @R5,X1   MOVY.W @R7,Y1

## 2. Fixed-point Multiplication

The PMULS instruction is used to perform fixed-point multiplication in process (2) in the flowchart. The format is shown below. The fixed-point multiplication process is shown in figure 3.1. Only the upper word data from source 1 and source 2 is valid. For example, if the longword H'12345678 was read from the source, the portion that would actually be multiplied would be H'1234.

Format: PMULS Se,Sf,Dg



**Figure 3.1 Fixed-point Multiplication Process**



### 3. Overflow

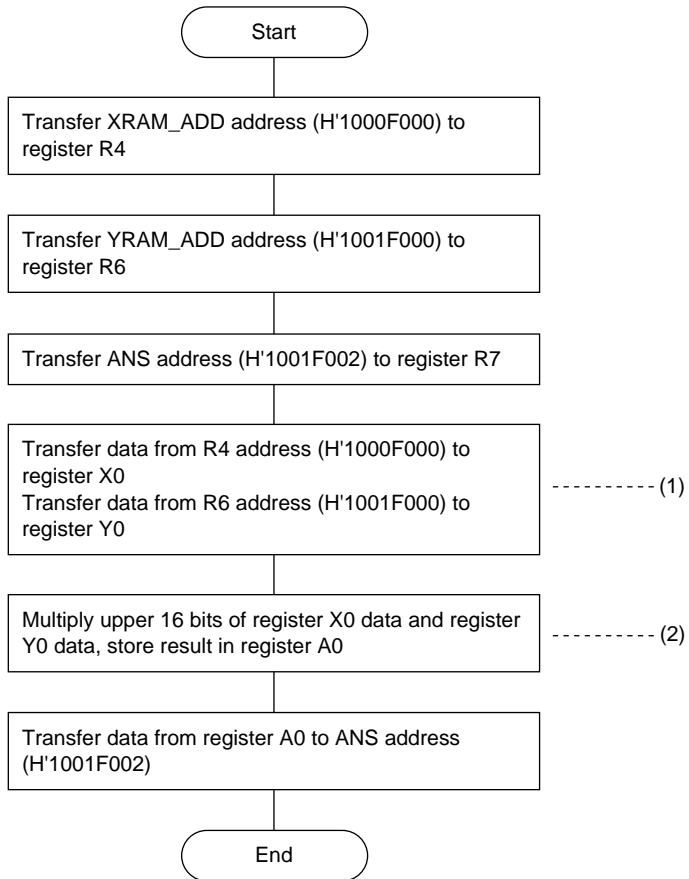
An overflow can occur during fixed-point multiplication only if the operation is H'8000(−1.0) × H'8000(−1.0), in which case the calculation result is H'8000(−1.0). This can happen only when the destination register is a register other than A0 or A1, both of which have guard bits. If the destination register is A0 or A1, the result of the above calculation is the correct value of H'008000000(1.0). Refer to table 3.1 for additional fixed-point multiplication execution examples.

Since the destination register used in the example main program is A0, no overflow problem occurs.

**Table 3.1 Fixed-point Multiplication Execution Examples**

<b>Operation Example</b>	<b>State of Operation Result</b>	<b>Destination Register</b>	<b>Operation Result</b>
H'4000 (0.5) × H'2000 (0.25)	Positive	M0, M1	H'1000 0000 (0.125)
		A0, A1	H'00 1000 0000 (0.125)
H'0800 (0.0625) × H'FC00 (−0.03125)	Negative	M0, M1	H'FFC00 0000 (−1.95×10 <sup>−3</sup> )
		A0, A1	H'FF FFC00 0000 (−1.95×10 <sup>−3</sup> )
H'8000 (−1.0) × H'8000 (−1.0)	Overflow	M0, M1	H'8000 0000 (−0.1)
		A0, A1	H'00 8000 0000 (1.0)

# Flowchart



## Main Program

```
*****
;*          16-bit fixed-point multiplication routine
*****
MAIN:  MOV.L  #0,R4                ;Clear register R4
      MOV.L  #0,R6                ;Clear register R6
      MOV.L  #XRAM_ADD,R4        ;XRAM address -> register R4
      MOV.L  #YRAM_ADD,R6        ;YRAM address -> register R6
      MOV.L  #ANS,R7              ;ANS address -> register R7
      MOVX.W @R4,X0  MOVB.W @R6,Y0 ;XRAM and YRAM address data ->
      PMULS  X0,Y0,A0             ;16-bit fixed-point
      MOVB.W A0,@R7              ;Store multiplication result

EXIT:  BRA   EXIT
      NOP
MAIN_E: NOP
```

## Data

```
*****
;*          Data
*****
      .SECTION XRAM,DATA,LOCATE=H'1000F000
XRAM_ADD: .XDATA.W          0.0625

      .SECTION YRAM,DATA,LOCATE=H'1001F000
YRAM_ADD: .XDATA.W          0.03125
ANS:      .RES.W            1
```



# Section 4 Parallel Execution Instruction

## Overview

Four data values obtained sequentially from the XRAM-ADD address (H'1000FF000) and the YRAM-ADD address (H'1001FF000) are added and multiplied. The addition result is stored at the ANS1 address (H'1000FF004) and the multiplication result at the ANS2 address (H'1001FF004).

## Description

### 1. Structure of Parallel Execution Instruction

The parallel execution instruction is used to transfer data between a DSP register and X memory or Y memory at the same time a DSP operation is being executed. Table 4.1 shows the data transfer and DSP operation structure. The parallel execution instruction comprises a DSP operation portion and a data transfer portion. Table 4.2 lists format examples for the parallel execution instruction. The DSP operation portion is a single instruction like the regular PAND, PINC, and PSHA instructions. However, as shown in table 4.2, its has two-instruction structure the case of the PADD and PMULS instructions, or the PSUB and PMULS instructions. The data transfer portion consists of two instructions, one the data transfer instruction for X memory and the other the data transfer instruction for Y memory. Either one of these data transfer instructions may be used.

**Table 4.1 Data Transfer and DSP Operation Structure**

	Type	Bus Used	Data Transfer Length	Parallel Processing with DSP Operation	Parallel Processing of Data Transfers	Instruction Length
(1)	Double data transfer	X bus Y bus	16 bits	No	No: One or the other data transfer	16 bits
				Yes	Yes: Data transfer with X memory and Y memory at same time	32 bits
(2)	Single data transfer	C bus <sup>*1</sup>	16 bits 32 bits	No	Yes: Data transfer with X memory and Y memory at same time	16 bits

\*1: Note that the name differs depending on the product.

**Table 4.2 Parallel Execution Instruction Format Examples**

DSP Operation Portion		Data Transfer Portion			
PADD	X0,Y0,A0	PMULS	X0,Y0,A1	MOVX.W A0,@R4	MOVY.W A1,@R6
PSUB	X1,Y1,A1	PMULS	X0,Y1,A0	MOVX.W @R5,X1	MOVY.W @R7,Y1
PADD	X0,Y0,A0	PMULS	X0,Y0,A1	MOVX.W A0,@R4	
PINC	X0,Y0,A0			MOVY.W @R6,Y1	
PAND	X0,Y0,A0			MOVX.W A0,@R5	
PSHA	X0,Y0,A0			MOVX.W @R4,X1	MOVY.W A1,@R7

## 2. Parallel Processing of Double Data Transfer and DSP Operation

Process (1) in the flowchart on the following page is double data transfer with no DSP operation instruction parallel processing, which is indicated as **(1)** in table 4.1, and processes (2) and (3) are double data transfer with parallel processing of DSP operation instructions, which is indicated as **(2)** in table 4.1. Processes (2) and (3) consist of four instructions, which is the maximum number that can be declared in a single step. In this case, one execution state is used.

## 3. Effect of DSP Operation Portion Result on Data Transfer Portion

Table 4.3 shows the effect of the DSP operation portion result on the data transfer portion. Instruction 2 (process (3)) uses A0 and A1 as the destination register for the DSP operation portion and also as the source register for the data transfer portion. However, the result of the DSP operation portion is not the data stored in the data transfer portion. In this case the underlined registers are affected, so the calculation result from instruction 1 (process (2)) operation portion is stored in the instruction 2 (process (3)) data transfer portion.

Figure 4.1 shows the instruction 2 pipeline flow. When instructions are executed in parallel, each of the instructions is processed independently, as shown in figure 4.1. The reason the DSP operation portion result does not become the data stored in the data transfer portion in this case is that the WB/DSP stage, in which DSP operations are performed using PADD and PMULS, is later than the MA stage, in which memory access is performed using MOVX.W and MOVY.W.

Note that after the execution of instruction 2 (process (3)), the X1 and Y1 addition and multiplication results are stored in registers A0 and A1.

**Table 4.3 Effect of DSP Operation Portion Result on Data Transfer Portion**

**Excerpts from Main Program**

;Instruction 1

PADD X0,Y0,A0 PMULS X0,Y0,A1 MOVX.W @R4,X1 MOVS.W @R6,Y1

;Instruction 2

PADD X1,Y1,A0 PMULS X1,Y1,A1 MOVX.W A0,@R5+ MOVS.W A1,@R7+

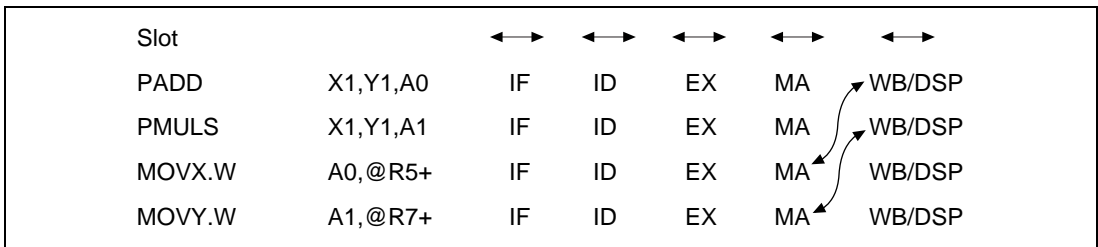
**Content of Registers**

Before execution of instruction 2:

X1=H'1000 0000, Y1=H'0800 0000, A0=H'6000 0000, A1=H'1000 0000

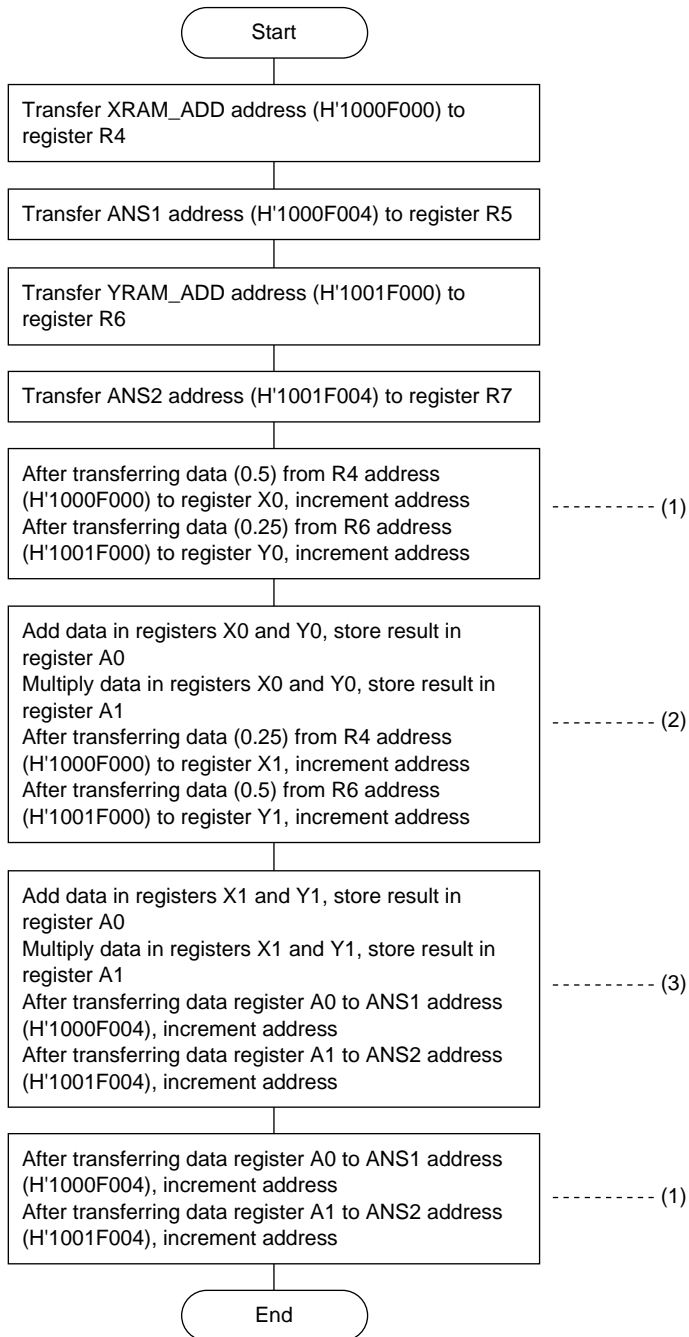
After execution of instruction 2:

X1=H'1000 0000, Y1=H'0800 0000, A0=H'1800 0000, A1=H'0100 0000



**Figure 4.1 Instruction 2 Pipeline Flow**

# Flowchart





## Main Program

```
*****
;*                               Parallel data transfer routine
*****
MAIN:  MOV.L      #XRAM_ADD,R4
        MOV.L      #ANS1,R5
        MOV.L      #YRAM_ADD,R6
        MOV.L      #ANS2,R7

                                MOVX.W @R4+,X0  MOVY.W @R6+,Y0
                                                ;No parallel processing
        PADD  X0,Y0,A0  PMULS X0,Y0,A1  MOVX.W @R4,X1  MOVY.W @R6,Y1
                                                ;Parallel processing
        PADD  X1,Y1,A0  PMULS X1,Y1,A1  MOVX.W A0,@R5+  MOVY.W A1,@R7+
                                                ;Parallel processing
                                                MOVX.W A0,@R5  MOVY.W A1,@R7
                                                ;No parallel processing

EXIT:  BRA        EXIT
        NOP
MAIN_E: NOP
```

## Data

```
*****
;*                               Data (X/YRAM)
*****
        .SECTION XRAM,DATA,LOCATE=H'1000F000
XRAM_ADD:  .XDATA.W      0.5,0.125                ;DSP operation data
ANS1:      .RES.W        2                        ;DSP operation result storage area

        .SECTION YRAM,DATA,LOCATE=H'1001F000
YRAM_ADD:  .XDATA.W      0.25,0.0625             ;DSP operation data
ANS2:      .RES.W        2                        ;DSP operation result storage area
```



# Section 5 Repeat Instruction

## Overview

The average of ten data values stored in XRAM and YRAM is obtained. To accomplish this, the repeat function is used for transferring data from XRAM and YRAM to the DSP unit, and for adding the ten data values.

## Description

### 1. DSP Repeat Control

Three settings are required in order to perform repeat control: I the start address setting for the program to be repeated, II the end address setting for the program to be repeated, III and the setting for the number of repetitions to be performed. After settings I through III have been completed, Process IV is to start the program to be repeated. Note that a minimum of one instruction is required between the processing of III and IV.

The sequence of processes I through IV is shown below.

- I LDRS instruction is used to set the repeat start address in the RS register.
- II LDRE instruction is used to set the repeat end address in the RE register.
- III SETRC instruction is used to set the number of repetitions in the RC register.  
: (Minimum of one instruction inserted.)
- IV Program to be repeated is started.

Process (1) in the flowchart on the next page corresponds to I through III above. After the program to be repeated is started (IV), it is repeated within the scope of process (2). Two main programs are shown in the example, but their function is the same. In (1) repeat control instructions (LDRS, LDRE, and SETRC) are used, and in (2) the extended instruction REPEAT is used. REPEAT automatically generates the CPU instructions (LDRS, LDRE, and SETRC) used to repeat the instructions between the start and end addresses. In the format shown below if the number of repetitions is omitted, the SETRC instruction is not generated.

Format: REPEAT [start address], [end address], [number of repetitions]

In program (1) the repeat start and end addresses are different from the actual addresses, and this is because the address setting change depending on the number of instructions in the program to be repeated. Table 5.1 shows how the RS and RE settings change depending on the number of instructions within the range to be repeated. These are the addresses actually repeated by the program when the repeat start and end addresses are set in RS and RE. Therefore, it is necessary to label the repeat start and end addresses while keeping the offsets listed in Table 5.1 in mind. The setting method for RS and RE in program (1) is described on the next page.

RPT\_S0+N: Address N bytes from the instruction preceding the instruction at the start address of the program to be repeated

RPT\_S: Start address of the program to be repeated

RPT\_E: End address of the program to be repeated

RPT\_E3+4: Address 4 bytes from the instruction three instructions before the instruction at the end address of the program to be repeated

**Table 5.1 RS and RE Setting Values Based on Number of Instructions Within Repeat**

	Number of Instructions in Program to be Repeated			
	1	2	3	4
RS	RPT_S0 + 8	RPT_S0 + 6	RPT_S0 + 4	RPT_S
RE	RPT_S0 + 4	RPT_S0 + 4	RPT_S0 + 4	RPT_E3 + 4

## 2. Repeat Control Using CPU Instructions

Example (a) shows the method for setting addresses in RS and RE. If there are three instructions in the portion to be repeated, RS and RE must be set to the RPT\_S0+4 address, as indicated in Table 5.1. The double data transfer instructions in lines **(1)** and **(2)** of this program have a 16-bit instruction length, so the RPT\_S0+4 address corresponds to the RPT\_E0 address. If RS and RE are set to the address RPT\_E0, the result is program (b).

```
LDRS      RPT_S0+4 address      ;Repeat start address
LDRE      RPT_S0+4 address      ;Repeat end address
SETRC     #5                    ;Repeat counter setting/5 repetitions
RPT_S0:   (1) MOVX.W @R5,X1 MOVY.W @R7,Y1 ;Clear X1, Y1 = 1/10
RPT_S:    (2) MOVX.W @R4+,X0 MOVY.W @R6+,Y0
RPT_E0:   PADD  X0,Y0,M0
RPT_E:    PADD  X1,M0,X1                ;X1/data total
                                                ;A1/average value
PMULS    X1,Y1,A1
```

(a) RS and RE Address Setting Method

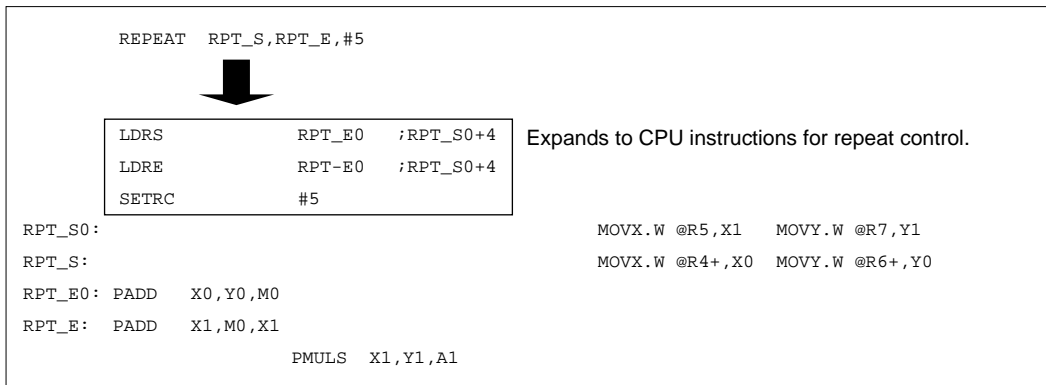


```
LDRS      RPT_E0                ;Repeat start address
LDRE      RPT_E0                ;Repeat end address
SETRC     #5                    ;Repeat counter setting/5 repetitions
RPT_S0:   MOVX.W @R5,X1 MOVY.W @R7,Y1 ;Clear X1, Y1 = 1/10
RPT_S:    MOVX.W @R4+,X0 MOVY.W @R6+,Y0
RPT_E0:   PADD  X0,Y0,M0
RPT_E:    PADD  X1,M0,X1                ;X1/data total
                                                ;A1/average value
PMULS    X1,Y1,A1
```

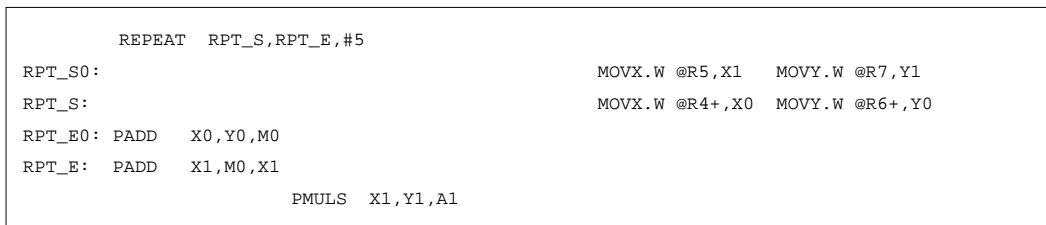
(b) RS and RE Address Setting Method

### 3. Repeat Control Using Extended Instructions

When the extended instruction REPEAT is used there is no need to perform complicated labeling, as is the case when using CPU instructions for repeat control. The following explanation is based on the expanded image of a portion of a repeat program shown as (a) below. With REPEAT one only needs to declare the labels for the start (RPT\_S) and end (RPT\_E) addresses of the program to be repeated, and then the assembler automatically calculates the address values to be used for the RS and RE settings (RPT\_E0 if the code to be repeated contains three instructions), and generates the LDRS, LDRE, and SETRC instructions. When the extended instruction REPEAT is actually used, the result is the repeat program shown in example (b) below.

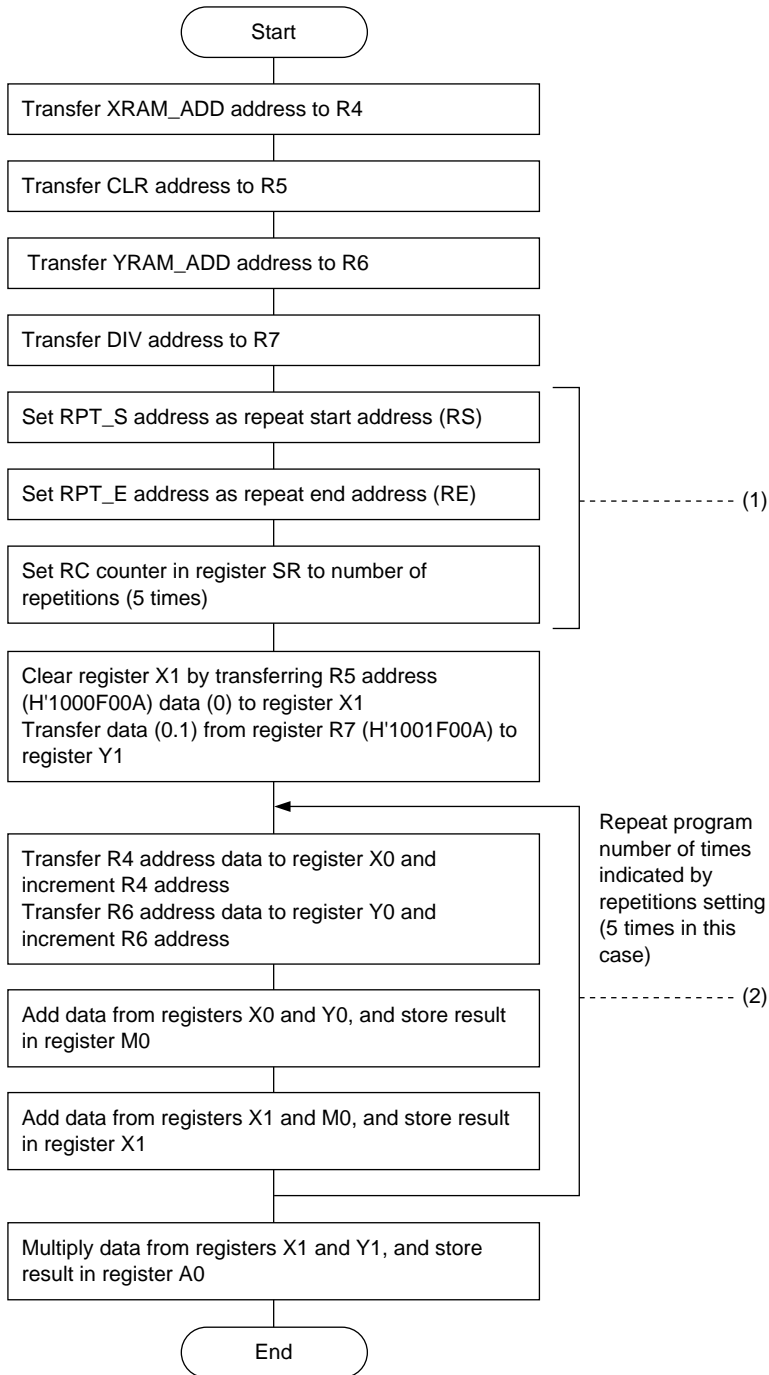


(a) Expanded Image of Repeat Program



(b) Repeat Program Using Extended Instruction REPEAT

# Flowchart



# Main Program

## (1) Repeat Control Using CPU Instructions

```
*****
;*          Repeat routine
*****
MAIN:  MOV.L    #XRAM_ADD,R4
        MOV.L    #CLR,R5
        MOV.L    #YRAM_ADD,R6
        MOV.L    #DIV,R7
        LDRS     RPT_E0                ;Repeat start address
        LDRE     RPT_E0                ;Repeat end address
        SETRC    #5                    ;Repeat counter setting/5
                                         repetitions
                                         MOVX.W @R5,X1  MOVY.W @R7,Y1  ;Clear X1, Y1 = 1/10
RPT_S:                                         MOVX.W @R4+,X0  MOVY.W @R6+,Y0
RPT_E0: PADD    X0,Y0,M0
RPT_E:  PADD    X1,M0,X1                ;X1/data total
                                         PMULS X1,Y1,A1    ;A1/average value
EXIT:   BRA     EXIT
        NOP
MAIN_E: NOP
```

## (2) Repeat Control Using Extended Instruction REPEAT

```
*****
;*          Repeat routine
*****
MAIN:  MOV.L    #XRAM_ADD,R4
        MOV.L    #CLR,R5
        MOV.L    #YRAM_ADD,R6
        MOV.L    #DIV,R7
        MOV.L    #5,R0
        REPEAT  RPT_S,RPT_E,R0        ;CPU instructions for
                                         repeat control generated
                                         automatically
                                         MOVX.W @R5,X1  MOVY.W @R7,Y1  ;Clear X1, Y1 = 1/10
RPT_S:                                         MOVX.W @R4+,X0  MOVY.W @R6+,Y0
        PADD    X0,Y0,M0
RPT_E:  PADD    X1,M0,X1                ;X1/data total
        PMULS X1,Y1,A1                ;A1/average value
EXIT:   BRA     EXIT
        NOP
MAIN_E: NO
```



## Data

\* Same data used by main programs (1) and (2)

```
*****  
;*      Data (X/YRAM)  
*****  
  
      .SECTION XRAM, CODE, LOCATE=H'1000F000  
XRAM_ADD: .XDATA.W    0.0625,0.125,0.0625,0.0625,0.03125 ;DSP operation data  
CLR;      .DATA.W     0                                     ;DSP operation result storage area  
  
      .SECTION YRAM, CODE, LOCATE=H'1001F000  
YRAM_ADD: .XDATA.W    0.0625,0.125,0.03125,0.125,0.0625 ;DSP operation data  
DIV:      .XDATA.W    0.1                                   ;DSP operation result storage area
```



# Section 6 Examples of Arguments Passed Between CPU Instructions and DSP Instructions

## Overview

The two 16-bit fixed-point data values stored at the XRAM\_ADD address (H'1000F000) and YRAM\_ADD address (H'1001F000) are multiplied using DSP instructions and CPU instructions.

## Description

When data is passed between CPU instructions and DSP instructions, R4, R5, R6, and R7 are used as pointers and the data is passed via XRAM and YRAM. The procedure when the result of a calculation performed by the DSP is used by the CPU is described below.

As can be seen in (2-1), (3-1), and (3-2), both the (2) DSP multiplication routine and (3) CPU multiplication routine of the example main program read data stored in XRAM and YRAM.

Example arguments:

PADD X0,Y0,A0 ; Stores result of adding X0 and Y0 in A0  
MOVX.W A0,@R4 ; Transfers A0 data to R4 address  
MOV.W @R4,R0 ; Transfers R4 address data to R0

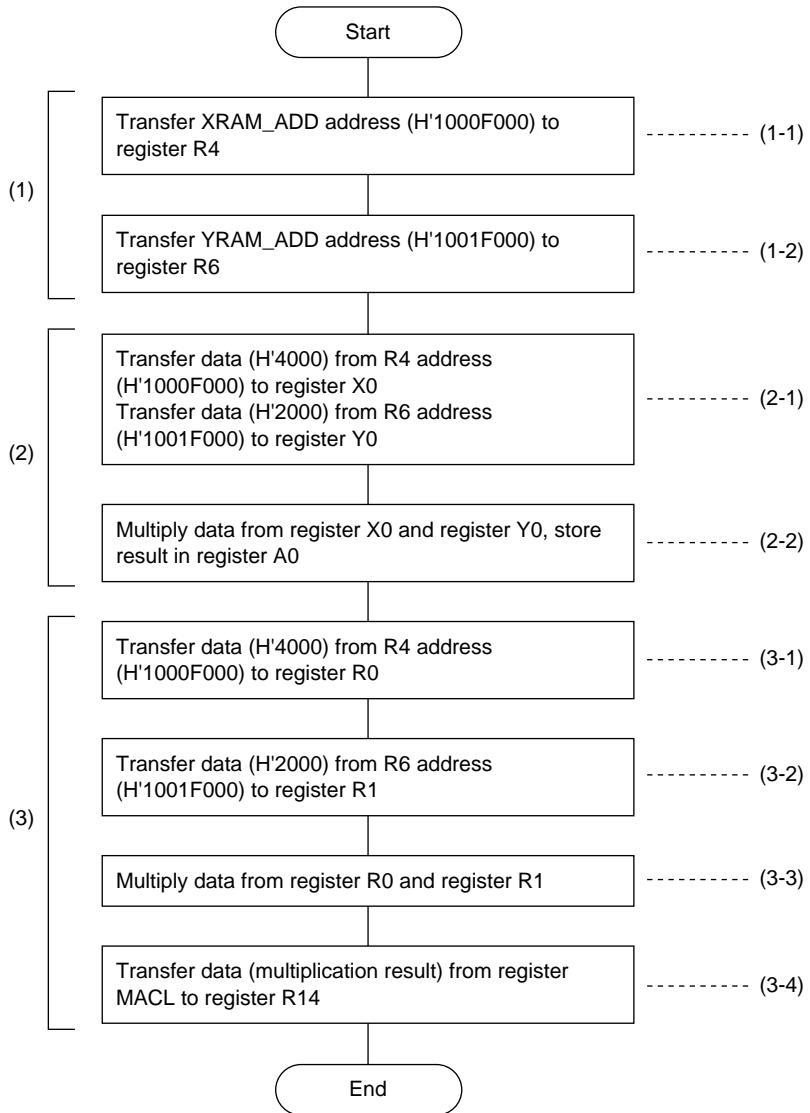
Some points need to be kept in mind when transferring data. Some of the DSP instructions are for handling fixed-point data, and when fixed-point multiplication is performed the result is matched to the MSB. However, when multiplication is performed using CPU instructions, integer multiplication is performed and the is matched to the LSB. This means that the calculation result will differ from that obtained using DSP instructions.

The multiplication process used in (2-1), (3-1), and (3-2) in the (2) DSP multiplication routine and (3) CPU multiplication routine in the flowchart on the following page is shown in table 6.1. This shows that the calculation results after execution differ even if the source operand data is identical. When a DSP instruction (PMULS) is used to multiply integer data, it is necessary to convert the calculation result from fixed-bit data into integer format by performing a bit shift.

**Table 6.1 DSP and CPU Multiplication Process**

	<b>Excerpt from Main Program</b>		<b>Register Contents</b>
(2) DSP multiplication routine	PMULS	X0,Y0,A0	Before execution: X0=H'4000, Y0=2000  After execution: A0=H'1000 0000
(3) CPU multiplication routine	MULS.W STS	R0,R1 MACL,R14	Before execution: R0=H'4000, R1=H'2000  After execution: R14=H'0800 0000

# Flowchart



## Main Program

```
*****
;*                               Initial setting routine
*****
MAIN:  MOV.L    #XRAM_ADD,R4
        MOV.L    #YRAM_ADD,R6

*****
;*                               DSP multiplication routine
*****
                                MOVX.W @R4,X0 MOVY.W @R6,Y0 ;Load 0.5,0.25
        PMULS   X0,Y0,A0                                ;A0 = multiplication result

*****
;*                               CPU multiplication routine
*****
        MOV.L    @R4,R0                                ;H'4000 load
        MOV.L    @R6,R1                                ;H'2000 load
        Muls.W   R0,R1
        STS     MAcl,R14                                ;R14 = multiplication result

EXIT:  BRA     EXIT
        NOP
MAIN_E: NOP
```

## Data

```
*****
;*                               Data
*****
        .SECTION XRAM,DATA,LOCATE=H'1000F000
XRAM_ADD: .XDATA.W 0.5                                ;DSP operation data

        .SECTION YRAM,DATA,LOCATE=H'1001F000
YRAM_ADD: .XDATA.W 0.25                                ;DSP operation data
        .END
```

# Section 7 32-bit Multiplication

## Overview

The 32-bit data value stored at the XRAM\_ADD address (H'1000F000) and the 32-bit data value stored at the YRAM\_ADD address (H'1001F000) are multiplied, and the result (64-bit) is transferred from the ANS address (H'1001F100) to the ANS+7 address (H'1001F107), where it is stored.

## Description

### 1. Overview of Calculation Method

The addresses where the multiplier and multiplicand of a 32-bit multiplication operation are stored, and the address where the result is stored, are shown in figure 7.1. Figure 7.2 shows an overview of the calculation method for 32-bit multiplication. The 32-bit data values (the multiplier and multiplicand) are separated into their upper and lower 16-bit segments (here provisionally called A, B, C, and D), which are then multiplied to produce the 64-bit operation result. The top bit (MSB) of the 16-bit data input to the multiplier is interpreted as the sign bit, and it has a weight of  $-2^0 = -1$ . Therefore, in the example program the first top bit (MSB) is replaced with 0, the product of the various segments is calculated, and a correction items are added using the top bit in order to obtain the 32-bit multiplication result.

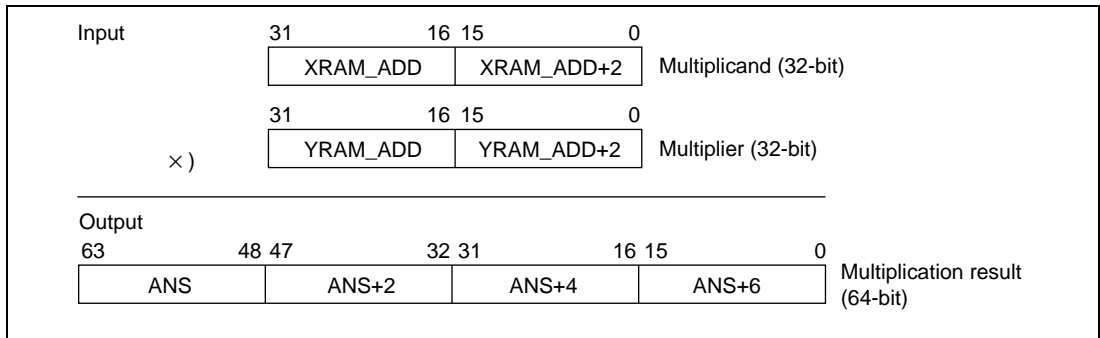
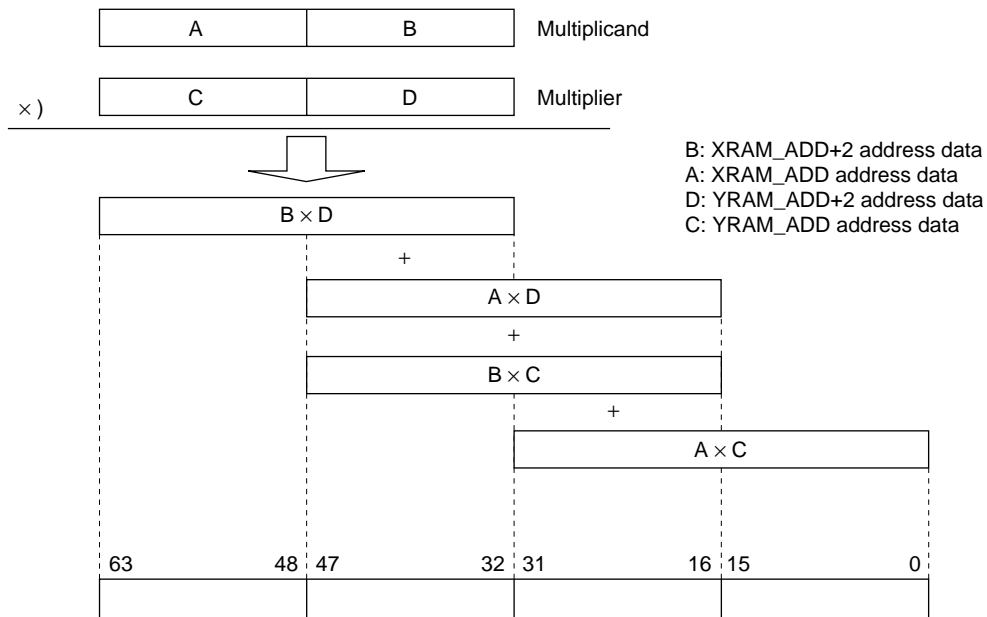


Figure 7.1 32-bit Multiplication

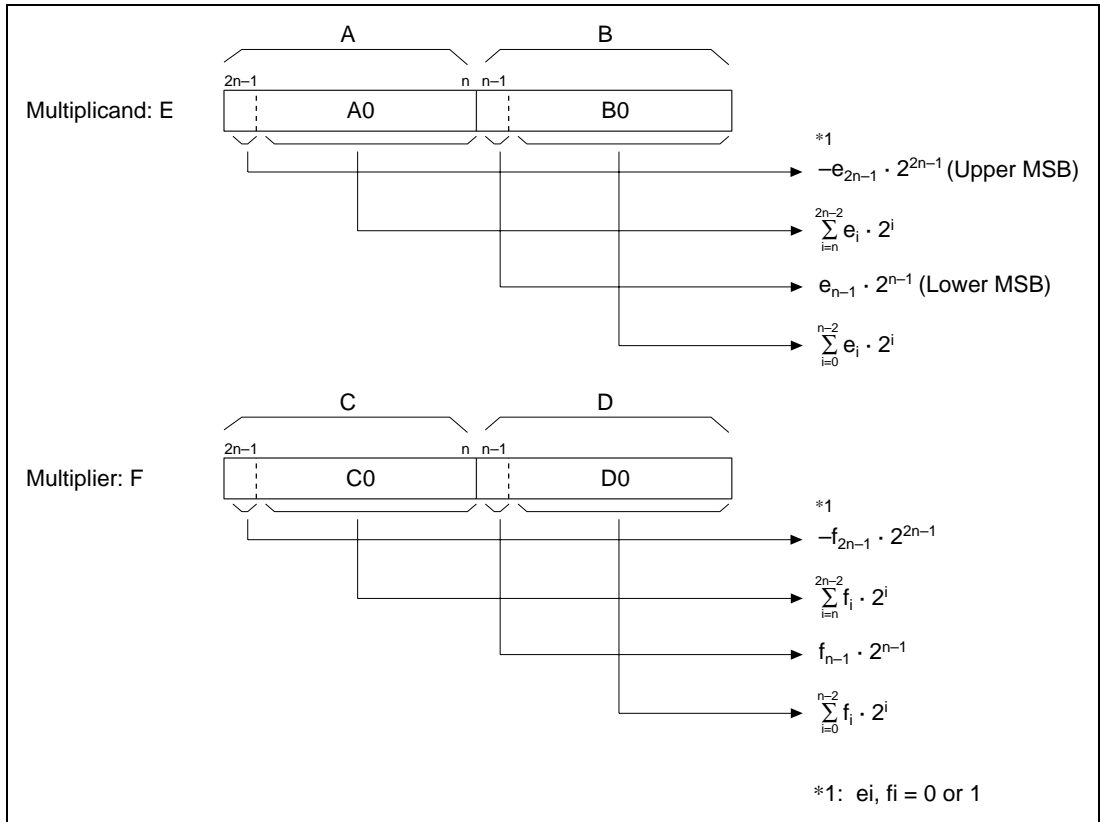


**Figure 7.2 Overview of Calculation Method for 32-bit Multiplication**



## 2. Double-length Calculation Algorithm

If the single-precision number of bits is  $n$ , “double-length” refers to  $2n$  bits. Therefore,  $2n$  bit numbers can be expressed as shown in figure 7.3.



**Figure 7.3 Structure of  $2n$ -bit Numbers**

Here, if  $\Sigma e_i \cdot 2^i = A0$ ,  $\Sigma e_i \cdot 2^i = B0$ ,  $\Sigma e_i \cdot 2^i = C0$ ,  $\Sigma e_i \cdot 2^i = D0$ , performing the double-length multiplication  $E \times F$  is can be expressed as:

$$\begin{aligned}
 E \times F &= (-e_{2n-1} \cdot 2^{2n-1} + A0 + e_{2n-1} \cdot 2^{n-1+} + B0) \times (-f_{2n-1} \cdot 2^{2n-1} + C0 + f_{2n-1} \cdot 2^{n-1+} + D0) \\
 &= e_{2n-1} \cdot f_{2n-1} \cdot 2^{4n-2} \text{ (1)} \\
 &\quad -e_{2n-1} \cdot 2^{2n-1} (C0 + f_{n-1} \cdot 2^{n-1+} + D0) \text{ (2)} \\
 &\quad -f_{2n-1} \cdot 2^{2n-1} (A0 + e_{n-1} \cdot 2^{n-1+} + B0) \text{ (3)} \\
 &\quad +e_{n-1} \cdot 2^{n-1} (C0 + f_{n-1} \cdot 2^{n-1+} + D0) \text{ (4)} \\
 &\quad +f_{n-1} \cdot 2^{n-1} (A0 + B0) \text{ (5)} \\
 &\quad +A0 \cdot C0 + A0 \cdot D0 + B0 \cdot C0 + B0 \cdot D0 \text{ (6)}
 \end{aligned}$$

In the above equation, **(6)** is the product of the segments and **(1)** through **(5)** are correction items.

The correction items involve determining whether the sign bit is “0” or “1” and, if it is “1”, adding it to or deleting it from the product of the segments.

Figure 7.4 shows a 32-bit double-length multiplication algorithm that uses the above equation. The whole can be subdivided into the following six parts:

In part (1), in order to clear the sign bits of A, B, C, and D to 0, the logical product with H'7FFF is obtained, resulting in A0, B0, C0, and D0. In part (2), the product is calculated for the following four segments:  $A0 \cdot C0$ ,  $A0 \cdot D0$ ,  $B0 \cdot C0$ , and  $D0 \cdot C0$ . In parts (3) through (6), the sum is obtained for each digit, and the results are stored at the ANS, ANS+2, ANS+4, and ANS+6 addresses.

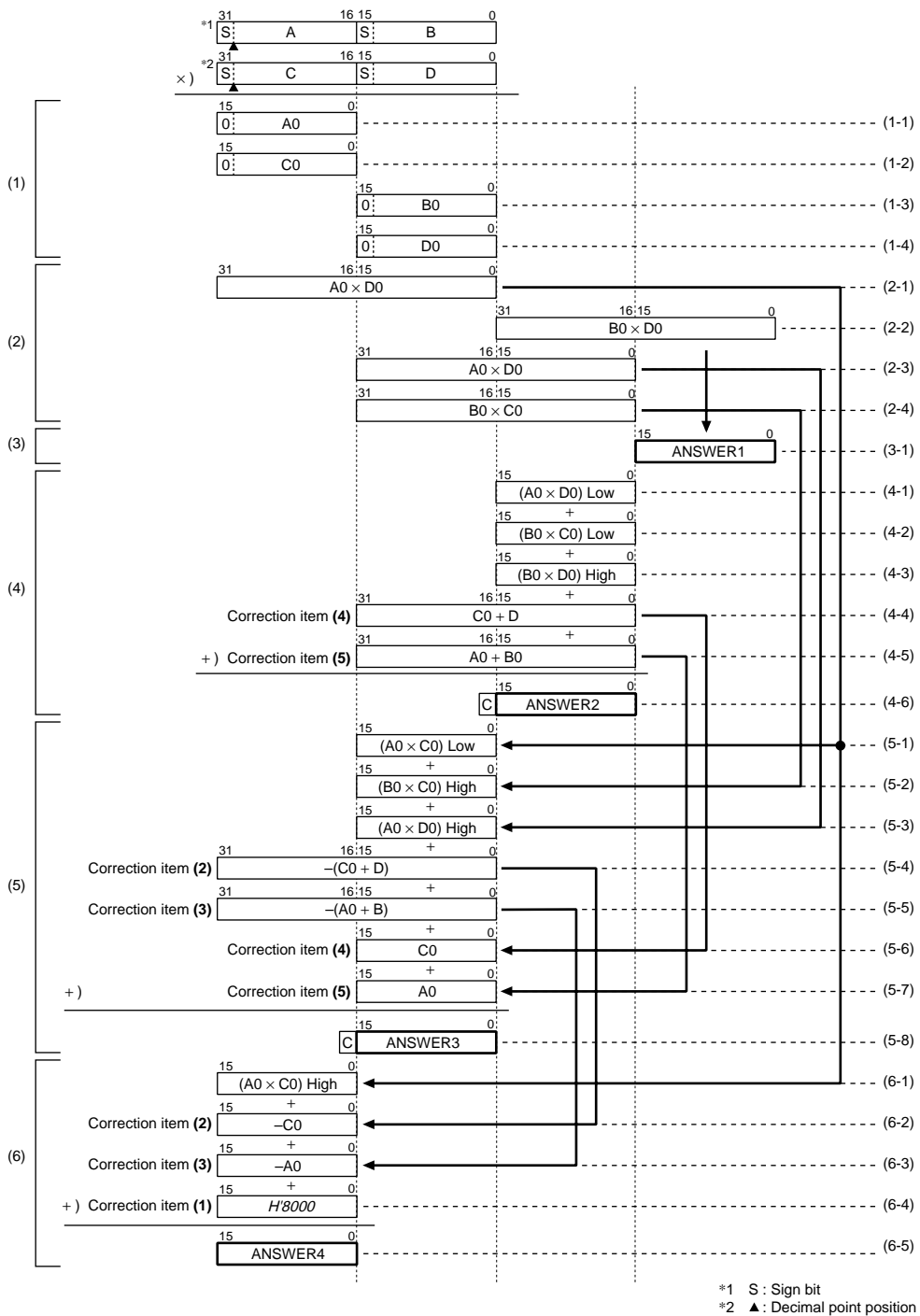
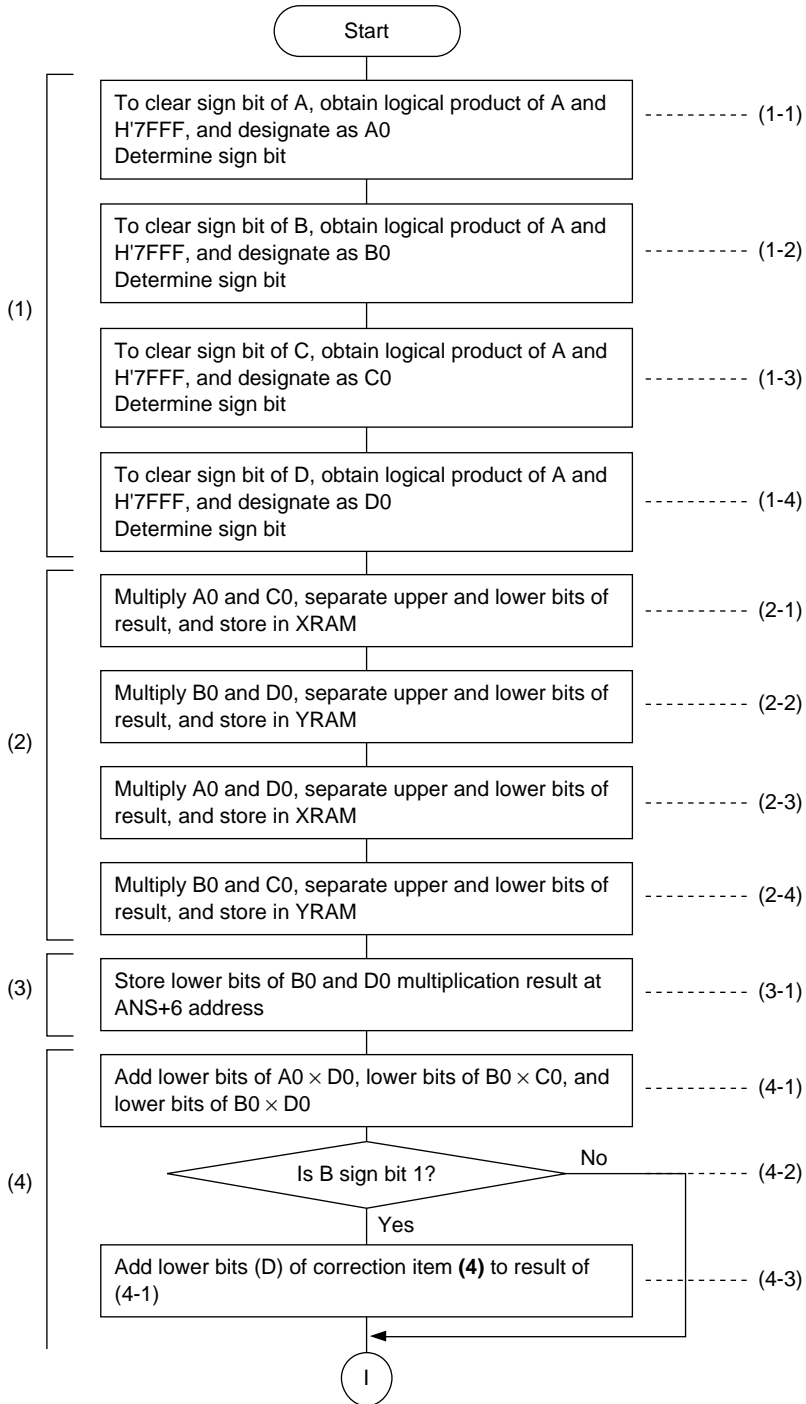
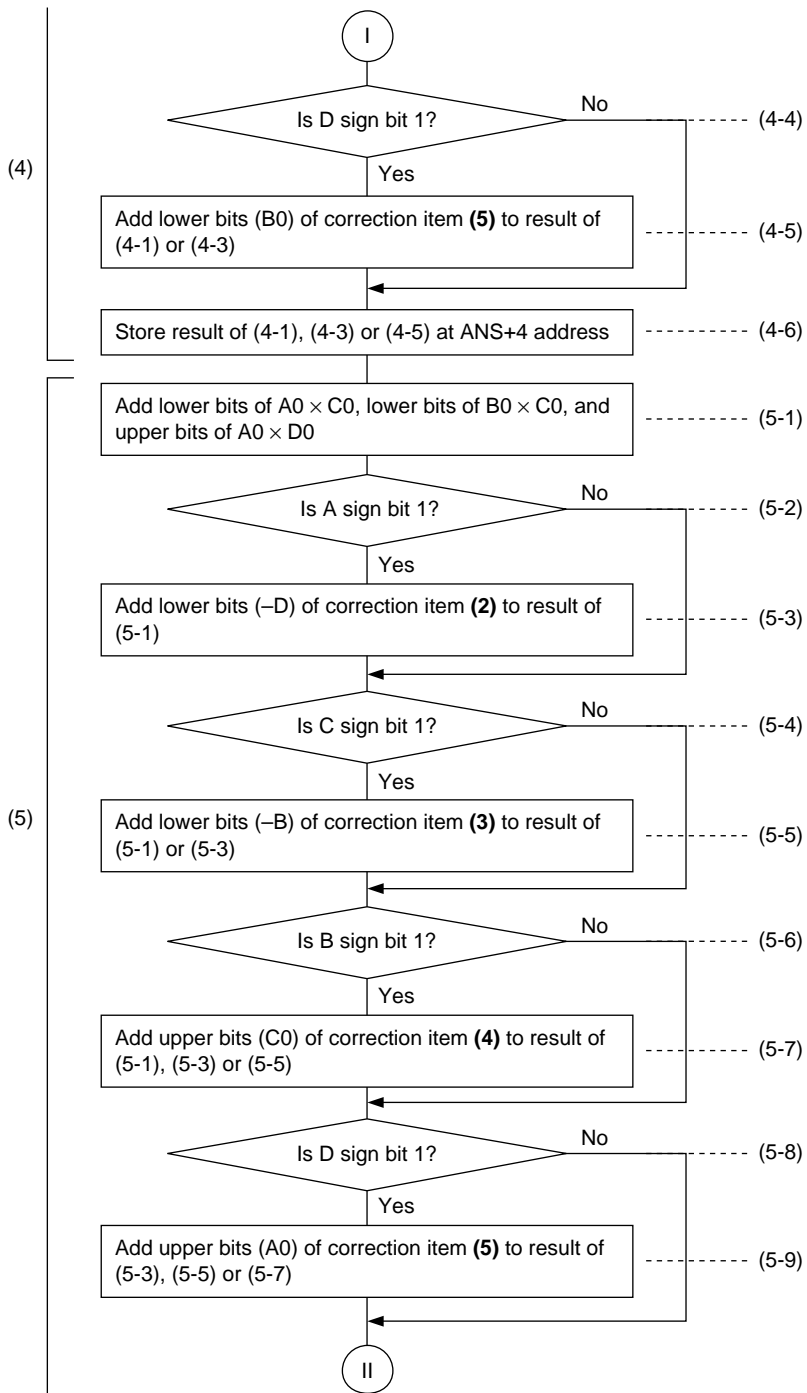
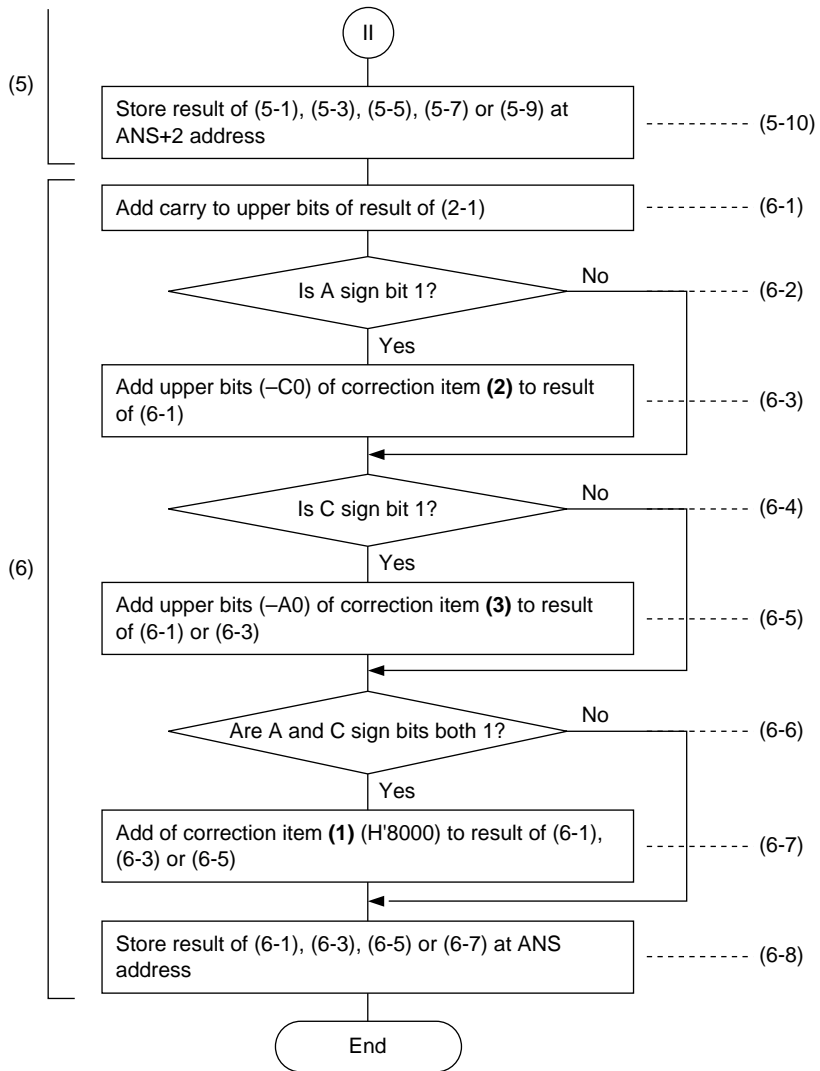


Figure 7.4 32-bit Double-length Multiplication Algorithm

# Flowchart







# Main Program

```
*****
;*          32-bit fixed-point multiplication routine
;*
;*          [A][B] × [C][D]
;*
*****
MAIN: MOV.L  #XRAM_ADD,R4
      MOV.L  #WORKX,R5                      ;XRAM for work
      MOV.L  #YRAM_ADD,R6
      MOV.L  #WORKY,R7                      ;YRAM for work

;Clear sign
      MOV.W  #H'7FFF,R0
      MOV.W  R0,@R7
      PCLR  A1                               MOVX.W @R4+,X0  MOVY.W @R7,Y0 ;A,H'7FFF load
      PAND  X0,Y0,A0                         MOVY.W @R6+,Y1 ;A0,C load
      MOV.W  R0,@R5                           ;H'7FFF -> #WORKX
      PSHA  #1,X0                             MOVX.W @R5,X1   ;A sign check,H'7FFF load
DCT  PINC  A1,A1                             MOVX.W A0,@R5+  ;A0 store
      PAND  X1,Y1,A0                         MOVX.W @R4,X0   ;C0,B load
      MOV.L  R4,@-R15
      MOV.L  #SIGNA,R4
      PCLR  A1                               MOVX.W A1,@R4+
      PSHA  #1,Y1                             MOVY.W A0,@R7+ ;C sign check,C0 store
DCT  PINC  A1,A1                             MOVY.W @R6,Y1  ;B sign check,D load
      PAND  X0,Y0,A0                         MOVX.W A1,@R4+  ;B0
      PCLR  A1
      PSHA  #1,X0                             MOVX.W A0,@R5
DCT  PINC  A1,A1
      PAND  X1,Y1,A0                         MOVX.W A1,@R4+  ;D0,B0 store
      PCLR  A1
      PSHA  #1,Y1
DCT  PINC  A1,A1                             MOVY.W A0,@R7  ;D0 store
      MOVX.W A1,@R4
      MOV.L  @R15+,R4

*****
;*Segment product calculation routine/   B0xD0,A0xC0,B0xC0,A0xD0
*****
      MOV.L  #WORKX,R5
      MOV.L  #WORKY,R7
      MOVX.W @R5+,X0  MOVY.W @R7+,Y0 ;A0,C0
      PMULS  X0,Y0,A1  MOVX.W @R5+,X1  MOVY.W @R7+,Y1 ;A0xC0,B0,D0
      PMULS  X1,Y1,A0  MOVX.W A1,@R5+   ;B0xD0, (A0xC0)H store
      PSHA  #16,A1    MOVY.W A0,@R7+ ;(A0xC0)L, (B0xD0)H store
```

```

PSHA #16,A0 MOVX.W A1,@R5+ ;(B0xD0)L, (A0xC0)L store
PMULS X0,Y1,A1 MOVY.W A0,@R7+;A0xD0, (B0xD0)L store
PSHA #16,A1 MOVX.W A1,@R5+ ;(A0xD0)L, (A0xD0)H store
PMULS X1,Y0,A1 MOVX.W A1,@R5 ;B0xC0, (A0xD0)L store
PSHA #16,A1 MOVY.W A1,@R7+;(B0xC0)L, (B0xC0)H store
MOVY.W A1,@R7 ;(B0xC0)L store

;*****
;*ANSWER1 STORE
;*****

MOV.L R7,@-R15 ;push R7
MOV.L #ANS,R7
ADD #6,R7
MOVY.W A0,@R7+;Store in ANS1
ADD #-2,R7
MOV.L R7,R14 ;R14=#ANS+2
MOV.L @R15+,R7 ;pop R7

*****
;*2-word calculation routine/ R4=#XRAM_ADD+2,R5=#WORKX+10,R6=#YRAM_ADD+2,R7=#WORKY+10
;*****
PCOPY X1,M1
MOV.L #-6,R9
PCLR A1 MOVX.W @R5,X1 MOVY.W @R7+R9,Y1 ;(A0xD0)L load,
;(B0xC0)L load
PADD X1,Y1,A0 MOVY.W @R7+,Y1 ;(A0xD0)L+(B0xC0)L,
;(B0xD0)H load
DCT PINC A1,A1 ;carry check
PADD A0,Y1,A0 ;(A0xD0)L+(B0xC0)
L+(B0xD0)H
DCT PINC A1,A1 ;carry check
MOV.W #'0,R10
MOV.L #SIGND,R0
MOV.W @R0+,R1
CMP/EQ R10,R1 ;Is B negative?
BT HOSEI4_L
MOVY.W @R6,Y1 ;Load D
PADD A0,Y1,A0 ;Add D
DCT PINC A1,A1
HOSEI4_L:
MOV.W @R0,R1
CMP/EQ R10,R1 ;Is D negative?
BT HOSEI5_L
PADD A0,M1,A0 ;Add B0
DCT PINC A1,A1
HOSEI5_L:
MOV.L R4,@-R15 ;push R4

```



```

MOV.L      #CARRY,R4
MOVX.W A1,@R4
;carry store

MOV.L      @R15+,R4
;pop R4

;*****
;*ANSWER2 STORE
;*****

MOV.L      R7,@-R15
;push R7

MOV.L      R14,R7
MOVY.W A0,@R7+
;ANS2 store

ADD        #-2,R7

MOV.L      R7,R14
;R14=#ANS+4

MOV.L      @R15+,R7
;pop R7

;*****
;*3-word calculation routine/
R4=#XRAM_ADD+2,R5=#WORKX+10,R6=#YRAM_ADD+2,R7=#WORKY+6
;*****

MOV.L      #-4,R8
PCOPY X0,A1
MOVX.W @R5+R8,X0
MOVY.W @R7+,Y1
;dummy load

MOVX.W @R5+,X0
MOVY.W @R7+,Y1
;(A0XC0)L load,
(B0XC0)H load

PADD X0,Y1,M1
MOVX.W @R5,X1
;(A0XC0)L+(B0XC0)H,
(A0XD0)H load

DCT PINC M0,M0
;carry check

PADD X1,M1,A0
;(A0XC0)L+(B0XC0)
H+(A0XD0)H

DCT PINC M0,M0
;carry check

;Correction

MOV.W      #H'0,R10
MOV.L      #SIGNA,R0
MOV.W      @R0+,R1
CMP/EQ     R10,R1
;Is A negative?

BT         HOSEI2_L

PSUB A0,Y1,A0
;Subtract D (correction 2)

DCT PDEC M0,M0

HOSEI2_L:

MOV.W      @R0+,R1
CMP/EQ     R10,R1
;Is C negative?

BT         HOSEI3_L

MOVX.W @R4,X1

PCOPY X1,M1
PSUB A0,M1,A0
;Subtract B (correction 3)

DCT PDEC M0,M0

HOSEI3_L:

MOV.W      @R0+,R1
CMP/EQ     R10,R1
;Is B negative?

BT         HOSEI4_H

PADD A0,Y0,A0
;Subtract C0 (correction 4)

```

```

DCT PINC M0,M0
HOSEI4_H:
    MOV.W @R0+,R1
    CMP/EQ R10,R1 ;Is D negative?
    BT HOSEI5_H
    PCOPY A1,M1
    PADD A0,M1,A0 ;Add A0 (correction 5)
DCT PINC M0,M0
HOSEI5_H:
    PCOPY A0,M1
    MOV.L #CARRY,R4
    MOVX.W @R4,X1 ;Load carry
    PADD X1,M1,A0 ;Add carry
DCT PINC M0,M0 ;Check carry

;*****
;*ANSWER3 STORE
;*****
    MOV.L R14,R7
    MOVY.W A0,@R7+ ;ANS3 store
    ADD #-2,R7

;*****
;*4-word calculation routine/ R4=#XRAM_ADD+2,R5=#WORKX+8,R6=#YRAM_ADD+2,R7=#WORKY+10
;*****
    PCLR Y1 MOVX.W @R5+R8,X1 ;dummy load
    PCLR M1 MOVX.W @R5,X1 ;(A0xC0)H load
    PADD X1,M0,A0
DCT PINC M1,M1
;Correction
    MOV.L #SIGNA,R0
    MOV.W @R0+,R1
    CMP/EQ R10,R1 ;Is A negative?
    BT HOSEI3_H
    PCOPY A1,M0
    PSUB A0,M0,A0 ;Subtract C0 (correction 2)
DCT PDEC M1,M1
    MOV.L #H'0,R12
    ADD #1,R12
HOSEI2_H:
    MOV.W @R0+,R1
    CMP/EQ R10,R1 ;Is C negative?
    BT HOSEI4_H
    PSUB A0,Y0,A0 ;Subtract A0 (correction 3)
DCT PDEC M1,M1
    ADD #1,R12
HOSEI3_H:

```

```

MOV.L      #2,R1
CMP/EQ    R1,R12                ;Are both A and C negative?
BF
MOV.W     #H'8000,R10
MOV.W     R10,@R5

                                MOVX.W @R5,X0

PCOPY    X0,M1                ;Add H'8000 (correction 1)
PADD     A0,M1,A0

;*****
;*ANSWER4 STORE
;*****
FIN:
                                MOVY.W A0,@R7 ;ANS4 store
EXIT:    BRA          EXIT
        NOP
MAIN_E:  NOP

```

## Data

```

;*****
;*          32-bit multiplication data (XRAM/YRAM)
;*****

        .SECTION XRAM,DATA,LOCATE=H'1000F000
XRAM_ADD: .XDATA.L      0.25002500 ;Multiplicand
WORKX:    .RES.W        6          ;Work area
CARRY:    .RES.W        1          ;Carry area
SIGNA:    .RES.W        1          ;For determining sign of multiplicand upper word A
SIGNC:    .RES.W        1          ;For determining sign of multiplier upper word C
SIGNB:    .RES.W        1          ;For determining sign of multiplicand lower word B
SIGND:    .RES.W        1          ;For determining sign of multiplier lower word D

        .SECTION YRAM,DATA,LOCATE=H'1001F000
YRAM_ADD: .XDATA.L      0.50005000 ;Multiplier
WORKY:    .RES.W        6          ;Work area
ANS:      .RES.W        4          ;Multiplication result storage area

```



# Section 8 Trigonometric Functions

## Overview

Calculating the trigonometric functions SIN(X) and COS(X).

## Description

### 1. Performing Trigonometric Functions

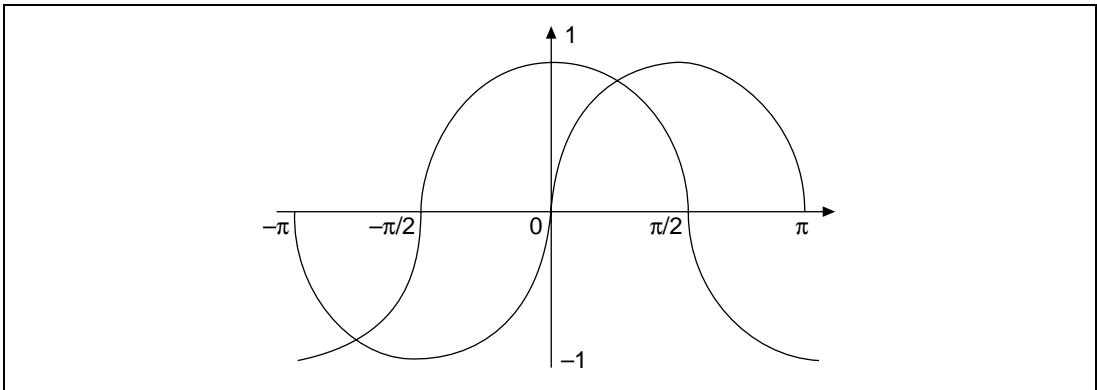
Figure 8.1 shows curves for SIN(X) and COS(X). If the angle range is  $-\pi \leq X \leq \pi$ , the relationships expressed in equation (1) exists.

$$\left. \begin{aligned} \text{SIN}(-X) &= -\text{SIN}(X) \\ \text{COS}(-X) &= \text{COS}(X) \end{aligned} \right\} \text{----- (1)}$$

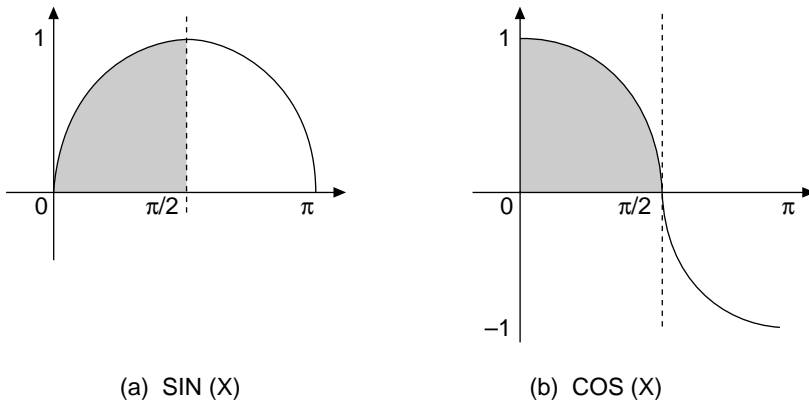
Using the relationships expressed in equation (1), the SIN(X) and COS(X) of  $-\pi \leq X \leq 0$  can be calculated by obtaining the SIN(X) and COS(X) of  $0 \leq X \leq \pi$  and processing the sign.

Next is figure 8.2 (a) and (b). The relationships of SIN(X) and COS(X), with  $X = \pi/2$  at the center, are expressed in equation (2).

$$\left. \begin{aligned} \text{SIN}(X + \pi/2) &= -\text{SIN}(\pi/2 - X) \\ \text{COS}(X + \pi/2) &= \text{COS}(\pi/2 - X) \end{aligned} \right\} \text{----- (2)}$$



**Figure 8.1 SIN(X) and COS(X) Curves**



**Figure 8.2 SIN(X) and COS(X) Curves with  $X = \pi/2$  at Center**

Based on the relationship between equations (1) and (2), the  $\sin(X)$  and  $\cos(X)$  of  $-\pi \leq X \leq \pi$  can be calculated by obtaining the  $\sin(X)$  and  $\cos(X)$  of  $0 \leq X \leq \pi$  and, finally, processing the sign. The example program divides  $0 \leq X \leq \pi/2$  into 128 segments. If  $X = n \cdot \pi/256 + \Delta X$  ( $n = 1, 2, \dots, 128$ ), the result is equation (3), based on the addition theorem of trigonometric functions.

$$\begin{aligned}
 \sin(X) &= \sin(n \cdot \pi/256 + \Delta X) \\
 &= \sin(n \cdot \pi/256) \cdot \cos(\Delta X) - \cos(n \cdot \pi/256) \cdot \sin(\Delta X) \\
 \cos(X) &= \cos(n \cdot \pi/256 + \Delta X) \\
 &= \cos(n \cdot \pi/256) \cdot \cos(\Delta X) - \sin(n \cdot \pi/256) \cdot \sin(\Delta X)
 \end{aligned}
 \left. \vphantom{\begin{aligned} \sin(X) \\ \cos(X) \end{aligned}} \right\} \text{----- (3)}$$

If we assume that in equation (3)  $\Delta X$  is extremely small and approximate that  $\sin(\Delta X) = \Delta X$  and  $\cos(\Delta X) = 1 - (\Delta X)^2/2$ , the result is equation (4).

$$\begin{aligned}
 \sin(X) &= \sin(n \cdot \pi/256) \cdot \{1 - (\Delta X)^2/2\} + \Delta X \cdot \cos(n \cdot \pi/256) \\
 \cos(X) &= \cos(n \cdot \pi/256) \cdot \{1 - (\Delta X)^2/2\} - \Delta X \cdot \sin(n \cdot \pi/256)
 \end{aligned}
 \left. \vphantom{\begin{aligned} \sin(X) \\ \cos(X) \end{aligned}} \right\} \text{----- (4)}$$

In other words, by calculating equation (4) using  $\Delta X$  and table data ( $n \cdot \pi/256$ ), we can obtain the  $\sin(X)$  and  $\cos(X)$  of  $0 \leq X \leq \pi/2$ . The final result is then obtained by performing sign processing.

## 2. Converting Input Values

Using conversion equation (5), the example program inputs to the DSP as angle parameters the input value  $X$  for the range  $-\pi \leq X \leq \pi$  and  $a$  for the range  $-1 \leq X < 1$ .

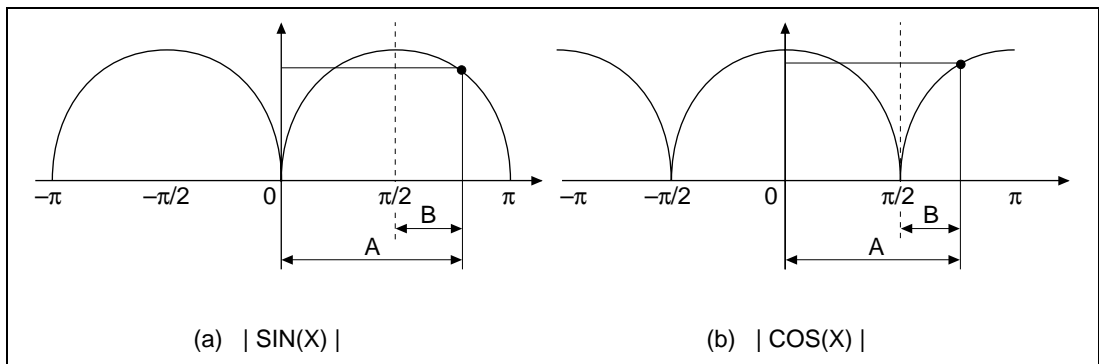
$$\left. \begin{array}{l} X = \pi \cdot a \\ a = X/\pi \end{array} \right\} \text{----- (5)}$$

$X$  unit: rad  
 $a$  unit: rad/ $\pi$

**Table 8.1 Relation Between Input Value  $a$  and Polarity**

Input Value	Result		
	SIN(X)	COS(X)	a
$-1 < a < -0.5$ ( $-\pi \leq X < -\pi/2$ )	Negative	Negative	$ a  > 0.5$
$-0.5 \leq a < 0$ ( $-\pi/2 \leq X < 0$ )	Negative	Positive	$ a  \leq 0.5$
$0 \leq a \leq 0.5$ ( $0 \leq X \leq \pi/2$ )	Positive	Positive	$ a  \leq 0.5$
$0.5 < a < 1$ ( $\pi/2 < X < \pi$ )	Positive	Negative	$ a  > 0.5$

Here the range  $0 \leq X \leq \pi/2$  corresponds to the range  $0 \leq a \leq 0.5$ . Also, the input value  $a$  is converted from the range  $-1 < a \leq 1$  to the range  $0 \leq a' \leq 0.5$ . Figure 8.3 shows the curves  $|\text{SIN}(X)|$  and  $|\text{COS}(X)|$ .



**Figure 8.3 Curves  $|\text{SIN}(X)|$  and  $|\text{COS}(X)|$**

When obtaining the SIN(X) and COS(X) of point A in figure 8.3, if we assume that  $A = \pi/2 + B$ , then  $a = 0.5 + b$ . Therefore, it is possible to obtain the deviation  $|b|$  relative to  $X = \pi/2$  using equation (6).

$$|b| = ||a| - 0.5| \text{ ----- (6)}$$

Next, based on deviation  $|b|$ , equation (7) is used to calculate the conversion of input value  $a$  for the range  $-1 < a \leq 1$  to  $a'$  for the range  $0 \leq a' \leq 0.5$ .

$$a' = |||a| - 0.5| - 0.5| \text{ ----- (7)}$$

### 3. a' Table Data

The example program uses a table with 128 cells. In other words, the range  $0 \leq a' \leq 0.5$  is divided into 128 equal segments. The difference in  $a'$  due to the angle of each segment is expressed in equation (8).

$$0.5/128 = 0.00390625 \text{ ----- (8)}$$

Table 8.2 shows the correspondence between table address  $n$  and  $a'$  in decimal notation and as 16-bit fixed-point expressions.

**Table 8.2 Relationship Between Table Address  $n$  and  $a'$**

Table Address $n$	$a'$															
	n/256; Decimal Notation rad]/ $\pi$	16-bit Fixed-point Expression														
		15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
0	0.00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0.00390625	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
2	0.00781250	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
3	0.01171875	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
4	0.01562500	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
⋮	⋮	⋮														
127	0.49609375	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0
128	0.50000000	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0

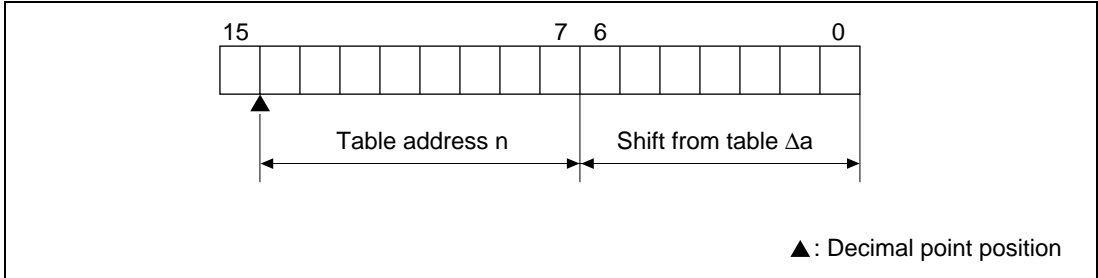


▲ : Decimal point position



#### 4. Method of Calculating $\Delta X$

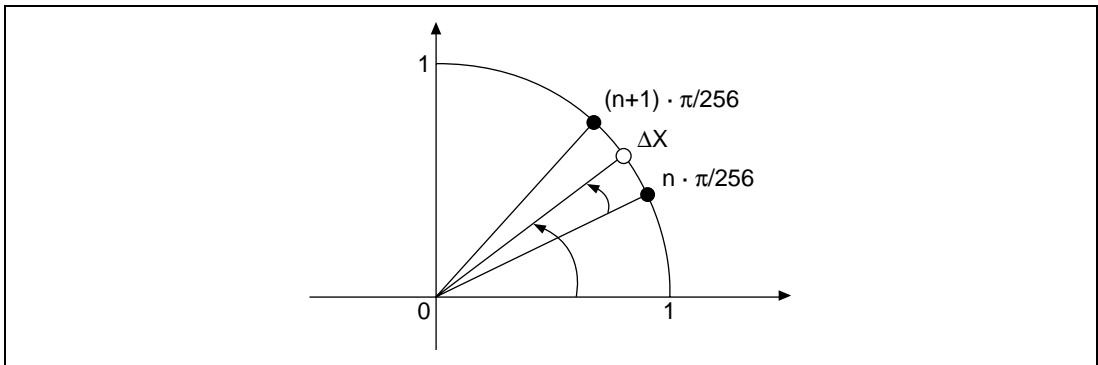
As shown in table 8.2, the upper nine bits of the a' data expressed in fixed-point format correspond to n, and the lower seven bits to the amount of shift from the table data  $\Delta a'$ . Figure 8.4 shows the bit structure of a'. By obtaining the value of a', it is possible to calculate the equation (2) table data address (the value of  $n \cdot \pi/256$ ) as well as  $\Delta X$  at the same time. Finally, table 8.1 is used for sign processing in order to obtain the SIN(X) and COS(X) of  $-\pi \leq X \leq \pi$ .



**Figure 8.4 Bit Structure of a'**

Figure 8.5 shows the relationship with the amount of shift between table values  $\Delta X$ . Table shift  $\Delta X$  can also be obtained by using the  $\Delta a$  of a' and equation (9).

$$\Delta X = \Delta a \cdot \pi \text{ ----- (9)}$$



**Figure 8.5 Relation With Amount of Shift Between Table Values**

## 5. Overflow Processing

If the calculation result is as shown in equation (10), an overflow occurs.

$$\left. \begin{array}{l} |\text{SIN}(X)| \geq 1 \\ |\text{COS}(X)| < 0 \end{array} \right\} \text{-----} (10)$$

In such cases the value is corrected using equation (11).

$$\left. \begin{array}{l} |\text{SIN}(X)| = 1 - 2^{-15} \\ |\text{COS}(X)| = 0 \end{array} \right\} \text{-----} (11)$$

## 6. Algorithm for Calculating Trigonometric Functions

The algorithm for calculating trigonometric functions is as follows.

- (1) Make initial settings.
- (2) Load input value  $a$ , calculate  $|| | a | - 0.5 | - 0.5 |$  to obtain  $a'$ .
- (3) Obtain logical product of above and #H'FF80 and calculate upper nine bits ( $n/256$ ) of  $a'$ . Then calculate  $n$  and set value in Y bus index register (R9).
- (4) Obtain logical product of above and #H'007F and calculate lower seven bits ( $\Delta a'$ ) of  $a'$ .
- (5) Calculate  $\pi \Delta a'$ ; calculate  $\Delta X$ .
- (6) Calculate  $1 - (\Delta X)^2/2$ . Load  $\sin(n \times \pi/256)$  and  $\cos(n \times \pi/256)$  from data table in YRAM.
- (7) Calculate  $\sin(X)$ .
- (8) Process sign of  $\sin(X)$ ; store  $\sin(X)$ .
- (9) Calculate  $\cos(X)$ .
- (10) Process sign of  $\cos(X)$ ; store  $\cos(X)$ .

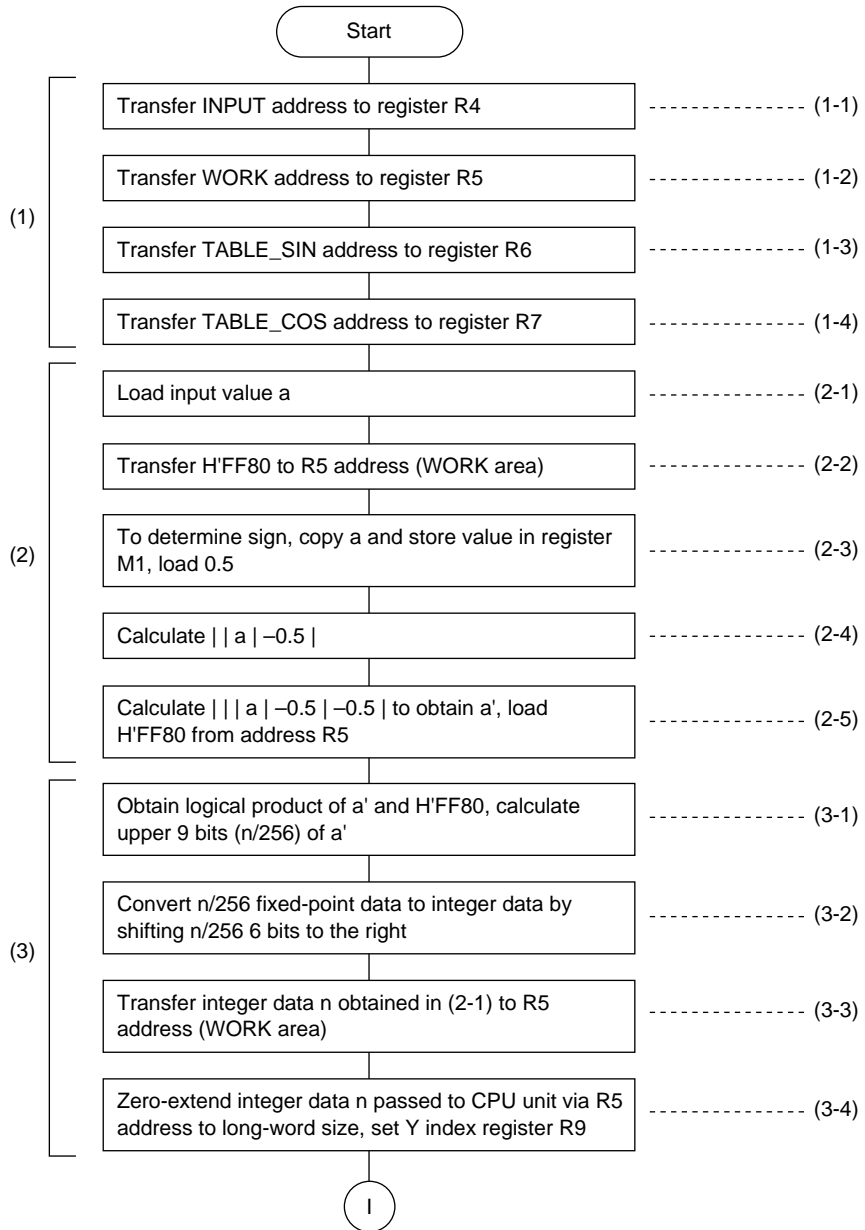
## Execution Example

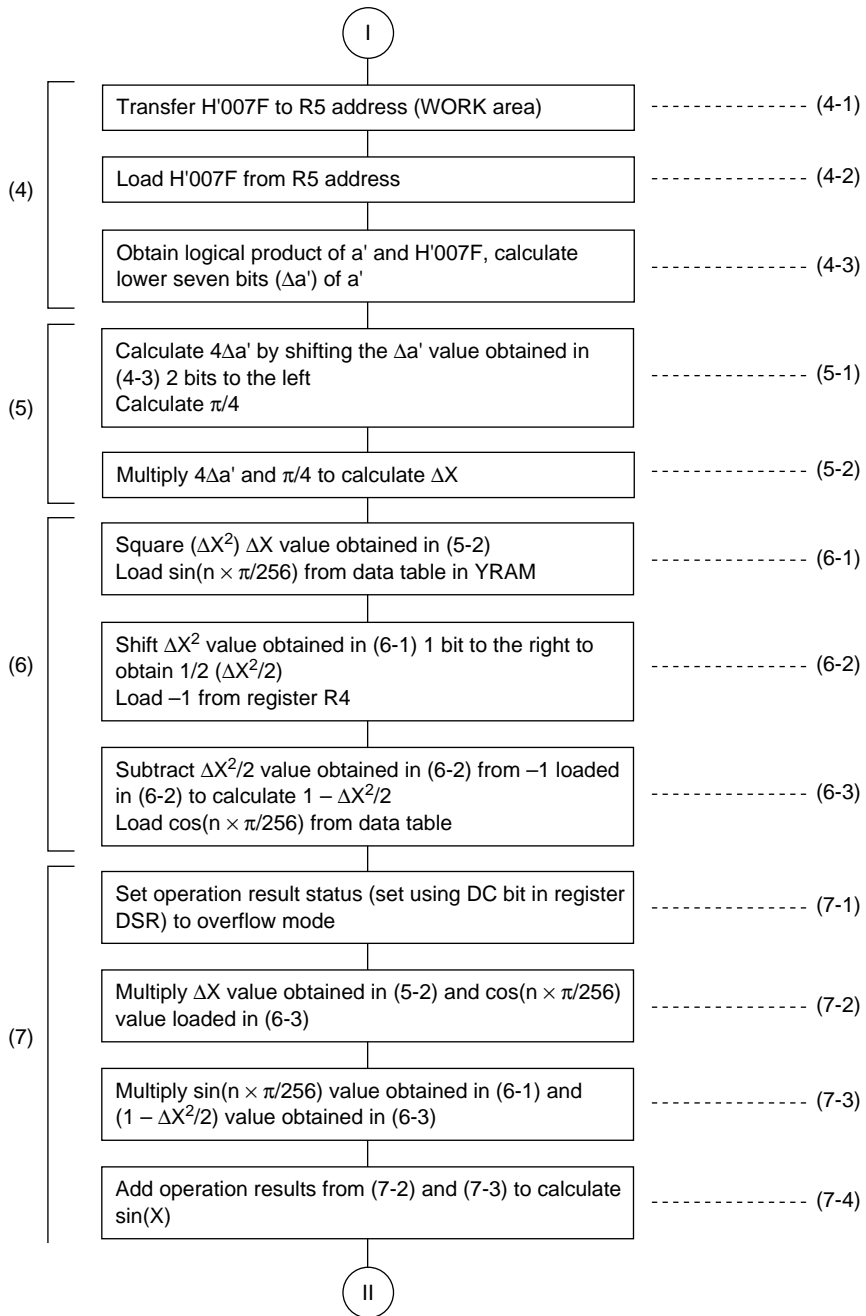
The  $\sin(X)$  and  $\cos(X)$  (OUTPUT) calculation results obtained based on the input value  $a$  (INPUT) are shown in table 8.3.

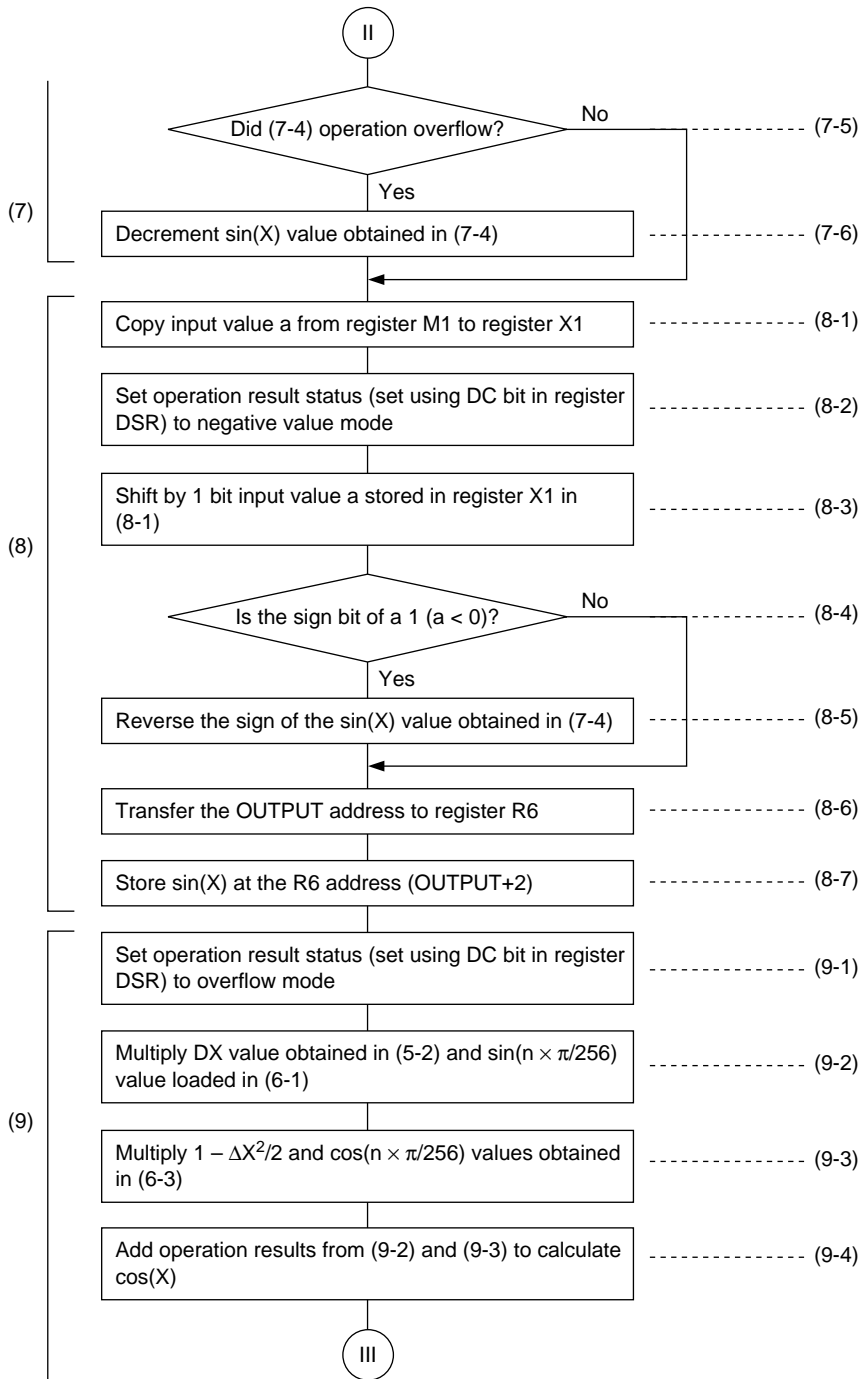
**Table 8.3**  $\sin(x)$ ,  $\cos(X)$  Calculation Results

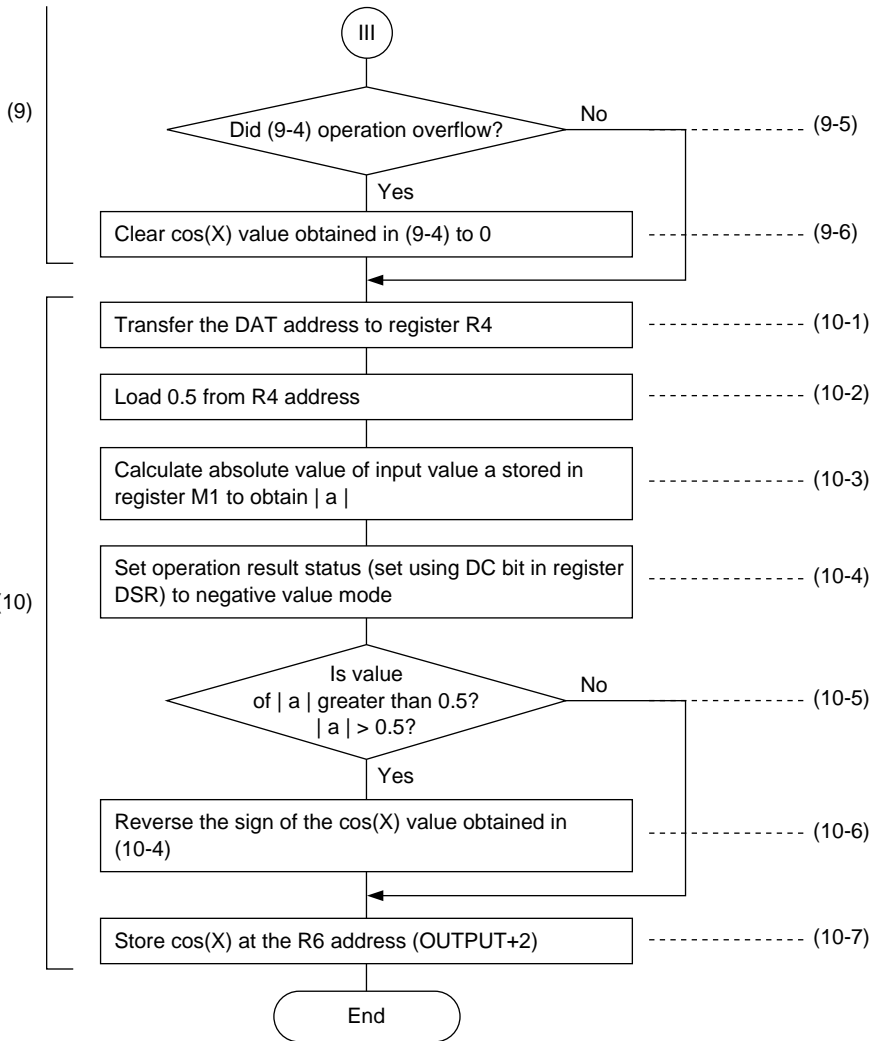
Angle $X^\circ$	Input Value ( $a = X/\pi$ )	Logical Value (decimal)		Logical Value (hexadecimal)		Output Value (hexadecimal)	
		$\sin(X)$	$\cos(X)$	$\sin(X)$	$\cos(X)$	$\sin(X)$	$\cos(X)$
0	0	0	1	H'0000	H'7FFF	H'0000	H'7FFF
30	0.16667	0.5	0.86603	H'4000	H'6EDA	H'3FFE	H'6ED9
45	0.25	0.70711	0.70711	H'5A82	H'5A82	H'5A82	H'5A82
89.5	0.49722	0.99996	0.00873	H'7FFE	H'011E	H'7FFD	H'011D
152	0.84444	0.46947	-0.88295	H'3C17	H'8EFC	H'3C19	H'8EFD
179.5	0.99722	0.00873	-0.99996	H'011E	H'8002	H'011C	H'8002
-40	-0.22222	-0.64279	0.76604	H'ADB9	H'620D	H'ADBB	H'620F
-75	-0.41667	-0.96593	0.25882	H'845D	H'2121	H'845D	H'2121
-137	-0.76111	-0.681	-0.73135	H'A8B4	H'A263	H'A8B5	H'A263
-180	-1	0	-1	H'0000	H'8000	H'0002	H'8001

# Flowchart









# Main Program

```
*****
;*          Trigonometric function routine
;*
;*          sinX,cosX
;*
*****
*****
;*          Initial setting routine
*****
MAIN:
    MOV.L    #INPUT,R4
    MOV.L    #WORK,R5
    MOV.L    #TABLE_SIN,R6
    MOV.L    #TABLE_COS,R7

*****
;*          a calculation routine
*****
                MOVX.W @R4,X0                ;a load
    MOV.L    #H'FF80,R0                ;For extracting upper 9 bits
                                                of a' (N $\times$  $\pi$ /64)
    MOV.W    R0,@R5
    MOV.L    #DAT,R4
    PCOPY   X0,M1                MOVX.W @R4+,X1                ;For determining sign of M1,
                                                load 0.5
    PCOPY   X1,Y1
    PSUB   X0,Y1,M0
    PABS   M0,A0                ;||a|-0.5|
    PSUB   A0,Y1,M0                ;|||a|-0.5|-0.5|
    PABS   M0,M0                MOVX.W @R5,X0                ;M0 = a', #H'FF80 load
*****
;*          n calculation, R6 setting routine
*****
    PAND   X0,M0,A0                ;A1 = n/256
    PSHA   #-6,A0                ;Convert fixed-point n to
                                                integer n
                MOVX.W A0,@R5                ;Pass integer n to CPU unit
    MOV.W   @R5,R1
    EXTU.W  R1,R1                ;
    MOV.L   R1,R9                ;

*****
;*           $\Delta$ a' calculation routine
*****
    MOV.L   #H'007F,R0                ;For extracting lower 7 bits
                                                of a' ( $\Delta$ a')
```



```

MOV.W      R0,@R5
MOVX.W @R5,X1 ;#H'007F load
PAND      X1,M0,Y1 ;Δa'
;*****
;*          ΔX calculation routine
;*****
PSHA      #2,Y1      MOVX.W @R4+,X1      ;4Δa', Δ/4 load
PMULS     X1,Y1,A1   ;Δa'× π
;*****
;*          1 - (ΔX2)/2calculation, sin(n × π/256) and cos(n × π/256) loading routine
;*****
PCOPY     A1,X0      MOVY.W @R6+R9,Y0 ;copy,dummy load
PMULS     A1,X0,M0   MOVY.W @R6,Y0 ;ΔX2,sin(n×π/256) load
PSHA      #-1,M0     MOVX.W @R4,X1 MOVY.W @R7+R9,Y1 ;ΔX2/2, -1 lode,dummy load
PSUB      X1,M0,A1   MOVY.W @R7,Y1 ;1-ΔX2/2,cos(n×π/256) load
;*****
;*          sin(X) calculation routine
;*****
MOV.L     #H'6,R0
LDS       R0,DSR ;Set overflow mode
PMULS     X0,Y1,M0 ;ΔX·cos(n×π/256)
PMULS     A1,Y0,A0 ;(1-(ΔX2)/2)·sin(n×π/256)
PABS      A0,A0
PADD      A0,M0,A0 ;A0 = sin(X)
DCT PDEC  A0,A0 ;If overflow occurs, sin(X) - 1
;*****
;*          sin(X) sign processing and storing routine
;*****
PCOPY     M1,X1
MOV.L     #H'0,R0,
LDS       R0,DSR ;Carry/borrow mode
PSHA     #1,X1
DCT PNEG  A0,A0 ;If a < 0, reverse sign
MOV.L     #OUTPUT,R6
MOVY.W   A0,@R6+ ;Store sin(X)
;*****
;*          cos(X) calculation routine
;*****
MOV.L     #H'6,R0
LDS       R0,DSR ;Set overflow mode
PMULS     X0,Y0,M0 ;ΔX·SIN(N×π/64)
PMULS     A1,Y1,A0 ;(1-(ΔX·ΔX)/2)·COS(N×π/64)
PABS      A0,A0
PSUB      A0,M0,A0
DCT PCLR  A0 ;If overflow occurs, clear cos(X) to 0

```

```

;*****
;*
;*****
cos(X) sign processing and storing routine
;*****

MOV.L    #DAT,R4
MOVX.W  @R4,X0          ;0.5 load
PABS    M1,M1          ;|a|
MOV.L    #H'2,R0
LDS     R0,DSR          ;Set negative value mode
PCMP    X0,M1
DCT     PNEG    A0,A0    ;If | a | < 0.5, reverse sign
MOVY.W  A0,@R6

EXIT:   BRA     EXIT
        NOP
MAIN_E: NOP

```

# Data

```
*****
;*          Trigonometric function data routine
*****

.SECTION XRAM,DATA,LOCATE=H'1000FF00

INPUT:      .RES.W      1                      ;External input data storage area
WORK:       .RES.W      1
DAT:        .XDATA.W    0.5,0.78540,-1
                                ;For calculating a', for calculating  $\pi/4 (1 - \Delta x^2/2)$ 

.SECTION YRAM,DATA,LOCATE=H'1001F800

TABLE_SIN:  .XDATA.W    0,0.01227,0.02454,0.03681,0.04907,0.06132 ;N/0 - 5
             .XDATA.W    0.07356,0.08580,0.09802,0.11022,0.12241 ;N/6 - 10
             .XDATA.W    0.13458,0.14673,0.15886,0.17096,0.18304 ;N/11 - 15
             .XDATA.W    0.19509,0.20711,0.21910,0.23106,0.24298 ;N/16 - 20
             .XDATA.W    0.25487,0.26671,0.27852,0.29028,0.30201 ;N/21 - 25
             .XDATA.W    0.31368,0.32531,0.33689,0.34842,0.35990 ;N/26 - 30
             .XDATA.W    0.37132,0.38268,0.39400,0.40524,0.41643 ;N/31 - 35
             .XDATA.W    0.42756,0.43862,0.44961,0.46054,0.47140 ;N/36 - 40
             .XDATA.W    0.48218,0.49290,0.50354,0.51410,0.52459 ;N/41 - 45
             .XDATA.W    0.53500,0.54532,0.55557,0.56573,0.57581 ;N/46 - 50
             .XDATA.W    0.58580,0.59570,0.60551,0.61523,0.62486 ;N/51 - 55
             .XDATA.W    0.63439,0.64383,0.65317,0.66242,0.67156 ;N/56 - 60
             .XDATA.W    0.68060,0.68954,0.69838,0.70711,0.71573 ;N/61 - 65
             .XDATA.W    0.72425,0.73265,0.74095,0.74914,0.75721 ;N/66 - 70
             .XDATA.W    0.76517,0.77301,0.78074,0.78835,0.79584 ;N/71 - 75
             .XDATA.W    0.80321,0.81046,0.81758,0.82459,0.83147 ;N/76 - 80
             .XDATA.W    0.83822,0.84485,0.85136,0.85773,0.86397 ;N/81 - 85
             .XDATA.W    0.87009,0.87607,0.88192,0.88764,0.89322 ;N/86 - 90
             .XDATA.W    0.89867,0.90399,0.90917,0.91421,0.91911 ;N/91 - 95
             .XDATA.W    0.92388,0.92851,0.93299,0.93734,0.94154 ;N/96 - 100
             .XDATA.W    0.94561,0.94953,0.95331,0.95694,0.96043 ;N/101 - 105
             .XDATA.W    0.96378,0.96700,0.97003,0.97294,0.97570 ;N/106 - 110
             .XDATA.W    0.97832,0.98079,0.98311,0.98528,0.98730 ;N/111 - 115
             .XDATA.W    0.98918,0.99090,0.99248,0.99391,0.99518 ;N/116 - 120
             .XDATA.W    0.99631,0.99729,0.99812,0.99880,0.99932 ;N/121 - 125
             .XDATA.W    0.99970,0.99992,1 ;N/126 - 128

TABLE_COS:  .XDATA.W    1,0.99992,0.99970,0.99932,0.99880,0.99812 ;N/0 - 5
             .XDATA.W    0.99729,0.99631,0.99518,0.99391,0.99248 ;N/6 - 10
             .XDATA.W    0.99090,0.98918,0.98730,0.98528,0.98311 ;N/11 - 15
             .XDATA.W    0.98079,0.97832,0.97570,0.97294,0.97003 ;N/16 - 20
             .XDATA.W    0.96700,0.96378,0.96043,0.95694,0.95331 ;N/21 - 25
             .XDATA.W    0.94953,0.94561,0.94154,0.93734,0.93299 ;N/26 - 30
             .XDATA.W    0.92851,0.92388,0.91911,0.91421,0.90917 ;N/31 - 35
             .XDATA.W    0.90399,0.89867,0.89322,0.88764,0.88192 ;N/36 - 40
```

```

.XDATA.W 0.87607,0.87009,0.86397,0.85773,0.85136 ;N/41 - 45
.XDATA.W 0.84485,0.83822,0.83147,0.82459,0.81758 ;N/46 - 50
.XDATA.W 0.81046,0.80321,0.76584,0.78835,0.78074 ;N/51 - 55
.XDATA.W 0.77301,0.76517,0.75721,0.74914,0.74095 ;N/56 - 60
.XDATA.W 0.73265,0.72425,0.71573,0.70711,0.69838 ;N/61 - 65
.XDATA.W 0.68954,0.68060,0.67156,0.66242,0.65317 ;N/66 - 70
.XDATA.W 0.64383,0.63439,0.62486,0.61523,0.60551 ;N/71 - 75
.XDATA.W 0.59570,0.58580,0.57581,0.56573,0.55557 ;N/76 - 80
.XDATA.W 0.54532,0.53500,0.52459,0.51410,0.50354 ;N/81 - 85
.XDATA.W 0.49290,0.48218,0.47140,0.46054,0.44961 ;N/86 - 90
.XDATA.W 0.43862,0.42756,0.41643,0.40524,0.39400 ;N/91 - 95
.XDATA.W 0.38268,0.37132,0.35990,0.34842,0.33689 ;N/96 - 100
.XDATA.W 0.32531,0.31368,0.30201,0.29028,0.27852 ;N/101 - 105
.XDATA.W 0.26671,0.25487,0.24298,0.23106,0.21910 ;N/106 - 110
.XDATA.W 0.20711,0.19509,0.18304,0.17096,0.15886 ;N/111 - 115
.XDATA.W 0.14673,0.13458,0.12241,0.11022,0.09802 ;N/116 - 120
.XDATA.W 0.08580,0.07356,0.06132,0.04907,0.03681 ;N/121 - 125
.XDATA.W 0.02454,0.01227,0 ;N/126 - 128

```

```

OUTPUT: .RES.W 2 ;External output data storage area

```

# Section 9 Matrix Operations

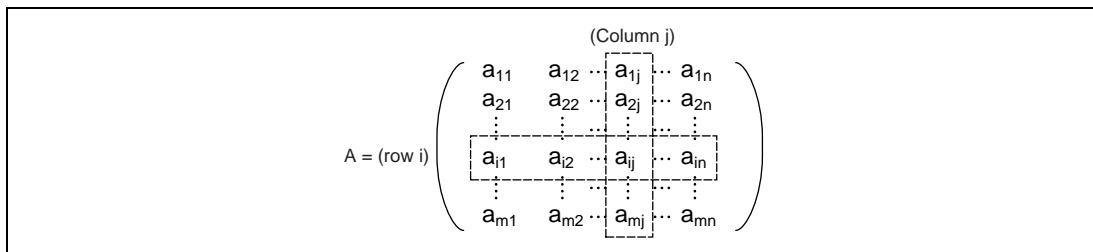
## Overview

Matrix A (3, 3) and matrix B (3, 3) are multiplied to obtain a 32-bit precision matrix product C (3, 3). Matrixes A and B are set in XRAM and YRAM beforehand. Matrix product C is stored beginning at YRAM address H'1001FF00.

## Description

### 1. Method of Expressing Matrixes

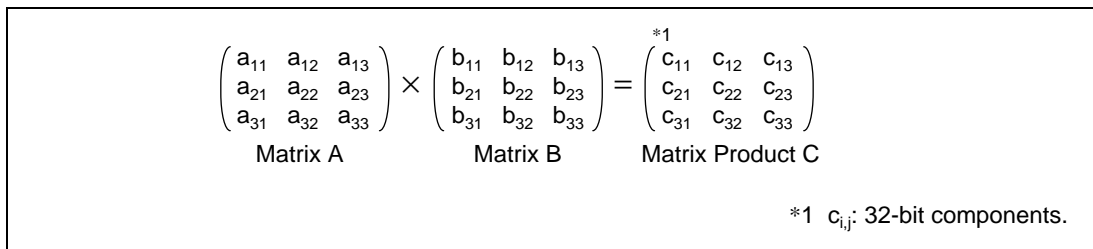
Figure 9.1 shows matrix A (n,m). The element  $a_{ij}$  is a component of matrix A. Horizontal rows of components are called rows, which are numbered from the top as row1, row2, row3, ..., row i, ... and so on. Vertical columns of components are called columns, which are numbered from the left as column 1, column 2, column 3, ... column j, ... and so on. The components in the position where row I and column k intersect is called component (i,j). Component (i,j) of matrix A (n,m) is expressed as  $a_{i,j}$ .



**Figure 9.1 Matrix A**

### 2. Method of Calculating Matrix Product

Figure 9.2 shows the expression of the components of matrix A  $\times$  matrix B = matrix product C.



**Figure 9.2 Expression of Components of Matrix A  $\times$  Matrix B = Matrix Product C**

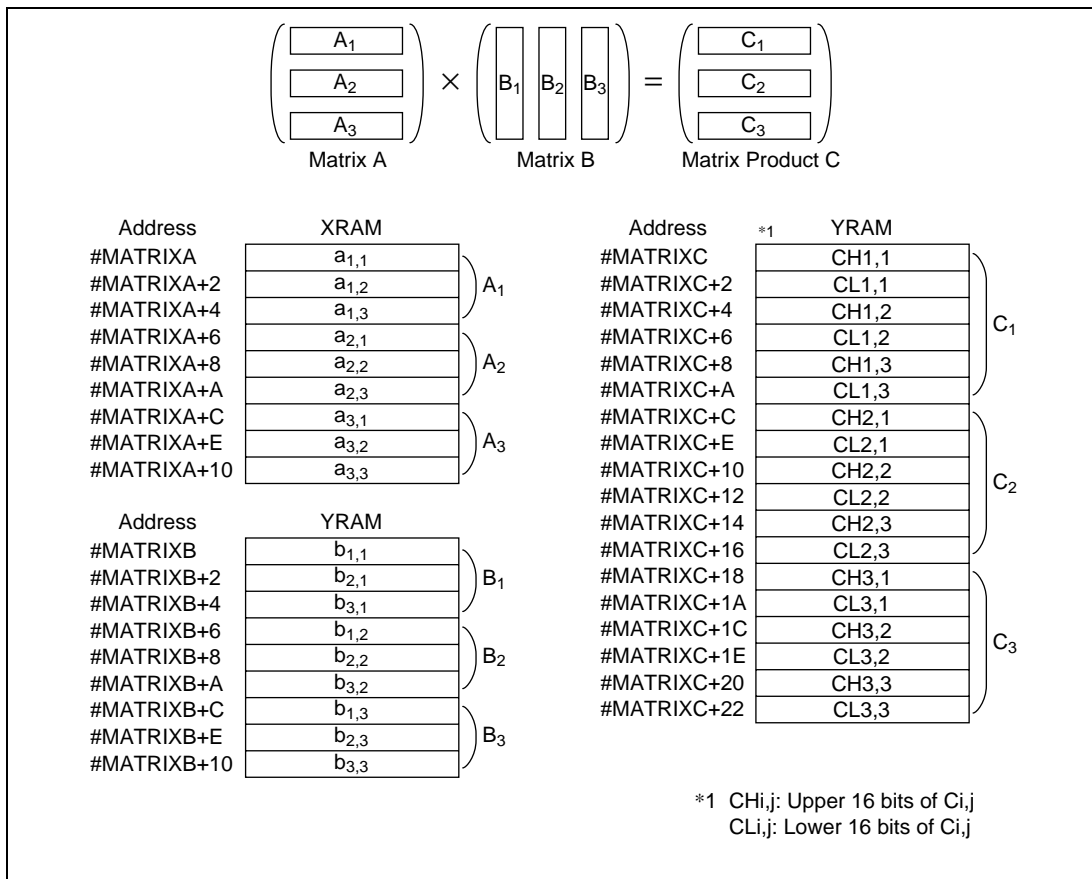
The components  $c_{ij}$  of matrix product C are obtained using the following equation.

$$C_{n,m} = \sum_{i=1}^3 (a_{n,i} \times b_{i,m})$$

The components  $c_{ij}$  of matrix product C are obtained by performing a sum of products calculation on row components  $a_{ni}$  of matrix A and column components  $b_{im}$  of matrix B.

### 3. Method of Storing Matrix A, Matrix B, and Matrix Product C Components

The components  $c_{nm}$  of matrix product C are obtained by performing a sum of products calculation on row components  $a_{ni}$  of matrix A and column components  $b_{im}$  of matrix B. The example subroutine, in order to increase the processing speed, stores the elements in XRAM and YRAM as shown in figure 9.3

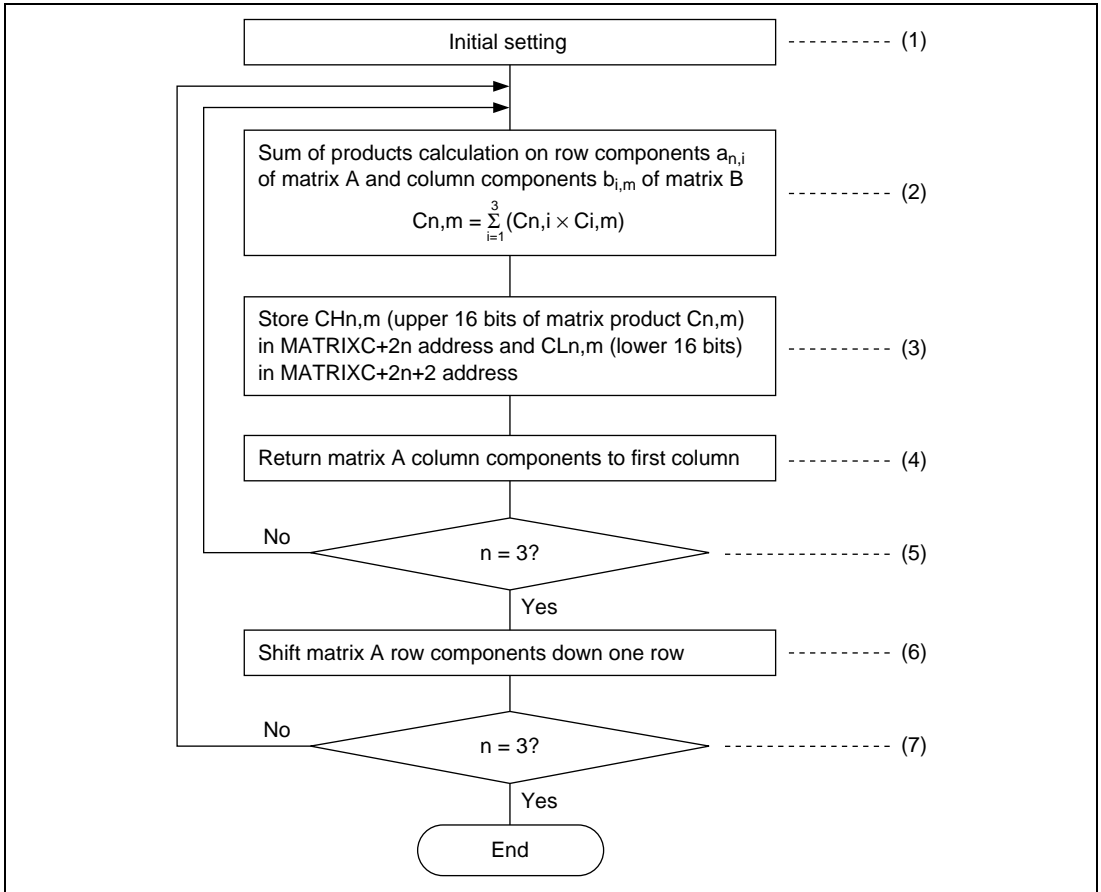


**Figure 9.3 Memory Map with Matrix A, Matrix B, and Matrix Product C Components Stored**

#### 4. Algorithm for Calculating Matrix Product C

Figure 9.4 shows the algorithm for calculating matrix product C. The details of the algorithm are described below.

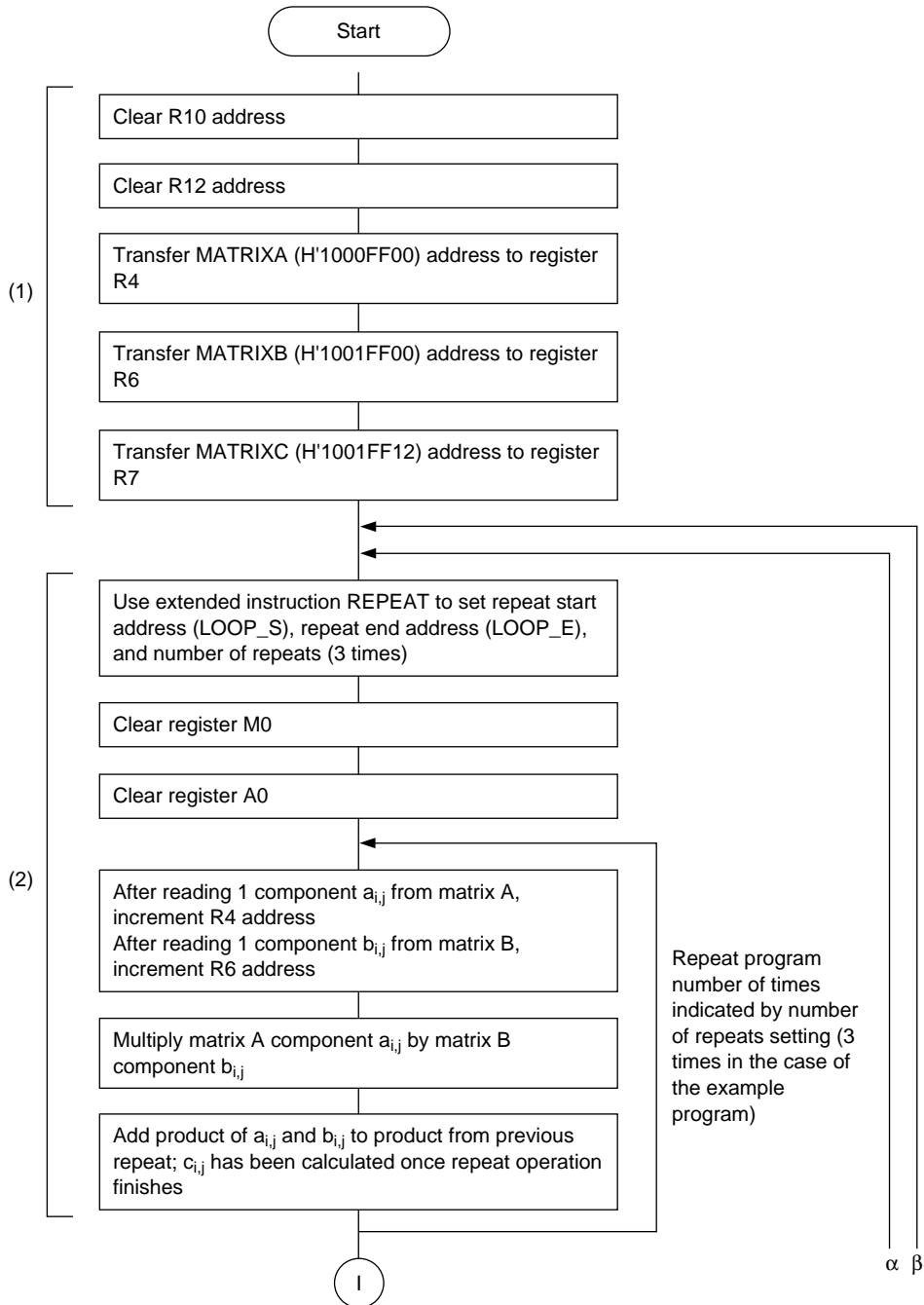
- (1) Clear counter registers, store matrix A in the X address register (R4) and matrix B in the Y address registers (R6, R7), set the addresses for storing the components of matrix product C.
- (2) Perform sum of products calculation on row components  $a_{n,i}$  of matrix A and column components  $b_{i,m}$  of matrix B.
- (3) Store  $CH_{n,m}$  (upper 16 bits of matrix product  $C_{n,m}$ ) in  $MATRIXC+2n$  address and  $CL_{n,m}$  (lower 16 bits) in  $MATRIXC+2n+2$  address.
- (4) Return matrix A column components to first column.
- (5) Determine if one row of matrix product  $C_{n,m}$  has been calculated. If n is not 3, return to process (2). If n is 3, move to process (6).
- (6) Shift matrix A row components down one row.
- (7) Determine if all three rows of matrix product C have been calculated. If n is not 3, return to process (2). If n is 3, all of matrix product  $C_{n,m}$  has been calculated and processing ends.

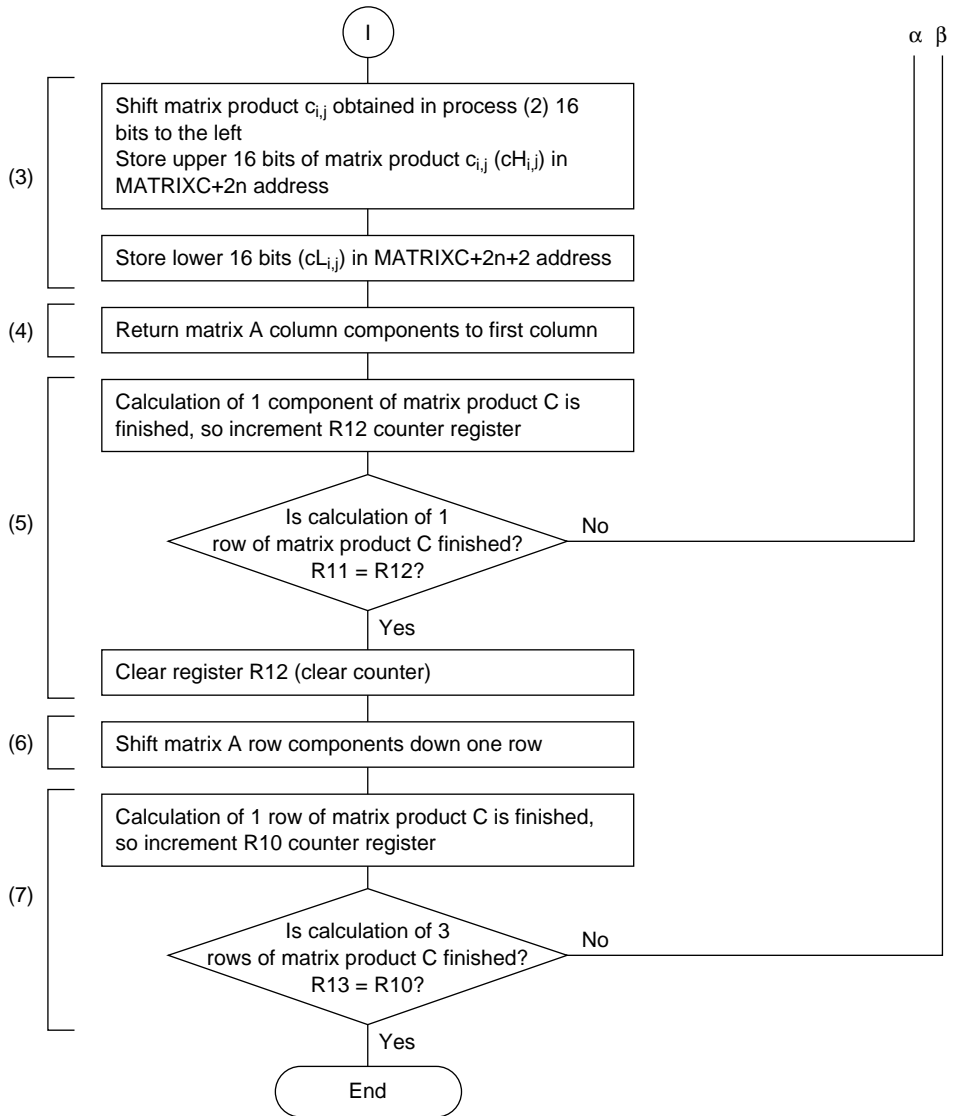


**Figure 9.4 Algorithm for Calculating Matrix Product C**



# Flowchart





# Main Program

```
matrix.src
;*****
;*          Matrix operation routine
;*
;*          [A][B]=[C]
;*
;*****
MAIN:  MOV.L      #0,R10
      MOV.L      #0,R12
      MOV.L      #MATRixa,R4
      MOV.L      #MATRixB,R6
      MOV.L      #MATRixC,R7
;*****
;Calculate all components/R10, R13
;*****
      MOV.L      #3,R13          ;Set repeat value (number of rows)
MATORIX:
;*****
;Calculate row components of n'th row
;*****
      MOV.L      #3,R11          ;Set repeat value (number of columns)
RETSU:
;*****
;Calculate 1 component
;*****
      BSR        SEIBUN
      NOP
      BSR        STORE
      NOP
;*****
      ADD        #-6,R4          ;Return address to first column of row i
                                ;of matrix A
      ADD        #1,R12          ;Increment counter each time 1 component
                                ;of 1 row of matrix product C is
                                ;calculated
      CMP/EQ     R11,R12        ;Is sum of products calculation for 1 row
                                ;of matrix product C finished?
      BF         RETSU
      MOV.L      #0,R12          ;Clear counter
;*****
      ADD        #6,R4
      MOV.L      #MATRixB,R6
      ADD        #1,R10          ;Increment counter when sum of products
                                ;calculation for 1 row of matrix product C
                                ;is finished
      CMP/EQ     R13,R10        ;Is sum of products calculation for last
                                ;row of matrix product C finished?
```

```

        BF                MATORIX
;*****

EXIT:   BRA              EXIT
        NOP

;*****
;Matrix C 1 component calculation routine
;*****
SEIBUN:
        REPEAT LOOP_S,LOOP_E,#3                ;Number of rows in matrix [A]
                                                ;is number of repeats

        PCLR            M0                      ;Clear for repeat
        PCLR            A0

LOOP_S:
                                                MOVX.W @R4+,X0 MOVY.W @R6+,Y0 ;aij,bij load
        PMULS          X0,Y0,M0
LOOP_E: PADD            A0,M0,A0
        RTS
        NOP
;*****
;Matrix C 1 component storage routine
;*****
STORE:  PSHA           #16,A0                  MOVY.W A0,@R7+ ;Store upper bits of ci,j
                                                MOVY.W A0,@R7+ ;Store lower bits of ci,j

        RTS
        NOP
;*****
MAIN_E: NOP

```

## Data

```

*****
;*          Matrix operation data (XRAM/YRAM)
*****
        .SECTION XRAM,DATA,LOCATE=H'1000FF00
MATRIXA: . XDATA.W      0.5,0.125,0.5,0.125,0.5,0.125,0.5,0.125,0.5

        .SECTION YRAM,DATA,LOCATE=H'1001FF00
MATRIXB: . RES.W        0.25,0.0625,0.25,0.0625,0.25,0.0625,0.25,0.0625,0.25
MATRIXC: . RES.W        18

```

# Section 10 Inner Product

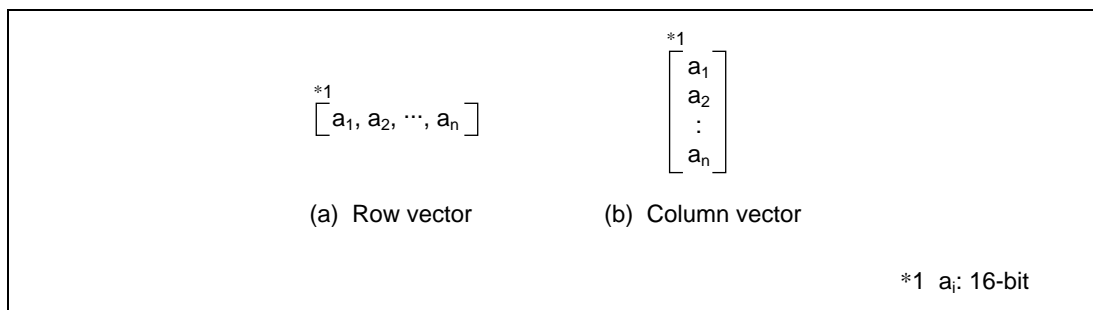
## Overview

The inner product (32-bit precision) of two non-zero  $n$ -dimensional space vectors,  $a$  (16-bit components) and  $b$  (16-bit components), is calculated. The  $n$ -dimensional space vectors  $a$  and  $b$  are set in XRAM and YRAM beforehand. The inner product of  $a$  and  $b$  is stored in YRAM at address H'1001FF00.

## Description

### 1. Method of Expressing Space Vectors

Figure 10.1 shows an expression of the components of  $n$ -dimensional space vector  $a$ . An  $n$ -dimensional space vector can be thought of as a vector consisting of a group of  $n$  real numbers. There are two ways of expressing the components of a vector: as a row vector and as a column vector.



**Figure 10.1** Expression of Components of  $n$ -dimensional Space Vector  $a$

## 2. Method of Calculating Inner Product

Figure 10.2 shows an expression of the components of the inner product of n-dimensional space vectors  $a$  and  $b$ . Here the inner product of vectors  $a$  and  $b$  is expressed as  $(a,b)$ .

$$\begin{array}{l} \begin{array}{c} *1 \\ \left[ a_1, a_2, \dots, a_i, \dots, a_n \right] \\ \text{n-dimensional} \\ \text{space vector} \\ \text{Row vector } a \end{array} \times \begin{array}{c} *1 \\ \left[ \begin{array}{c} b_1 \\ b_2 \\ \vdots \\ b_i \\ \vdots \\ b_n \end{array} \right] \\ \text{n-dimensional} \\ \text{space vector} \\ \text{Column vector } b \end{array} = \begin{array}{c} *2 \\ a_1b_1 + a_2b_2 + \dots + a_ib_i + \dots + a_nb_n \end{array} \end{array}$$

\*1  $a_i$ : 16-bit  
\*1  $b_i$ : 16-bit  
\*2 32-bit

**Figure 10.2 Expression of Components of Inner Product of n-dimensional Space Vectors  $a$  and  $b$**

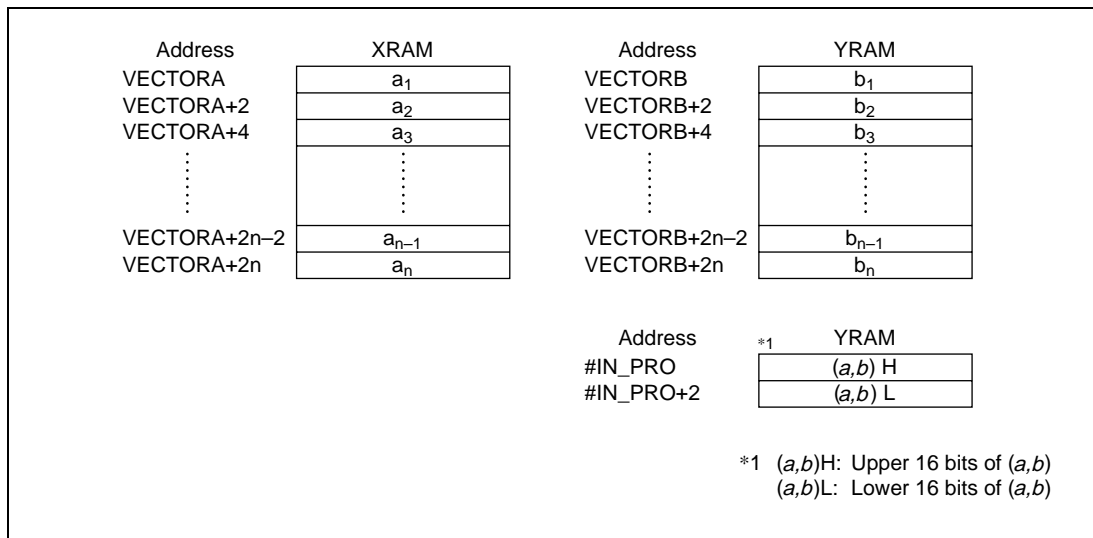
The inner product  $(a,b)$  is obtained using the following equation.

$$(a,b) = \sum_{i=1}^n a_i b_i$$

Using the above equation, the inner product  $(a,b)$  is obtained by performing a sum of products calculation on components  $a_i$  of space vector  $a$  and components  $b_i$  of space vector  $b$ .

### 3. Method of Storing Inner Product $(a,b)$ of n-dimensional Space Vectors $a$ and $b$

Figure 10.3 shows the method of storing the inner product  $(a,b)$  components of n-dimensional space vectors  $a$  and  $b$ , which are set in XRAM and YRAM.

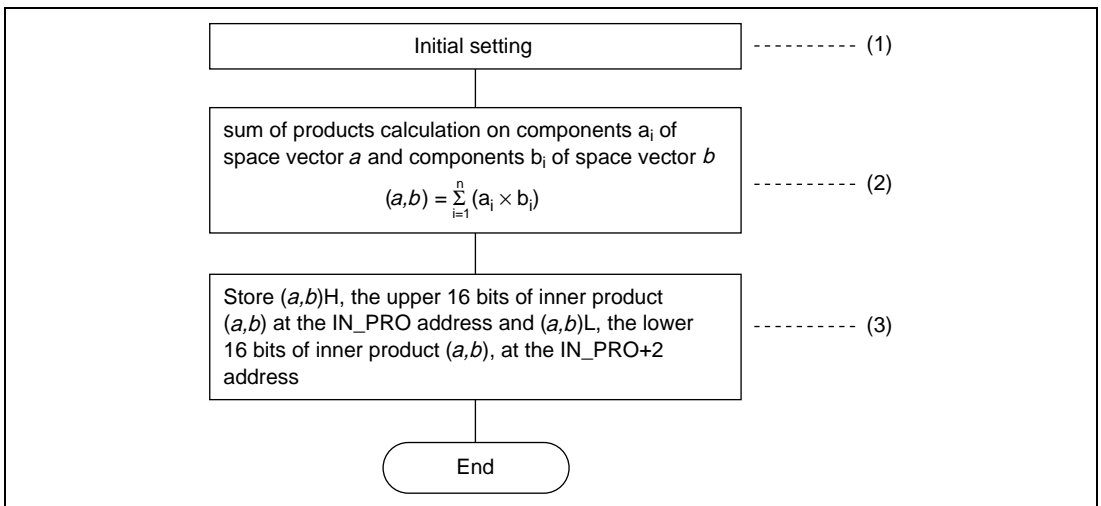


**Figure 10.3 Method of Storing Inner Product  $(a,b)$  of n-dimensional Space Vectors  $a$  and  $b$**

#### 4. Algorithm for Calculating Inner Product

Figure 10.4 shows the algorithm for calculating the inner product  $(a,b)$ . The details of the algorithm are described below.

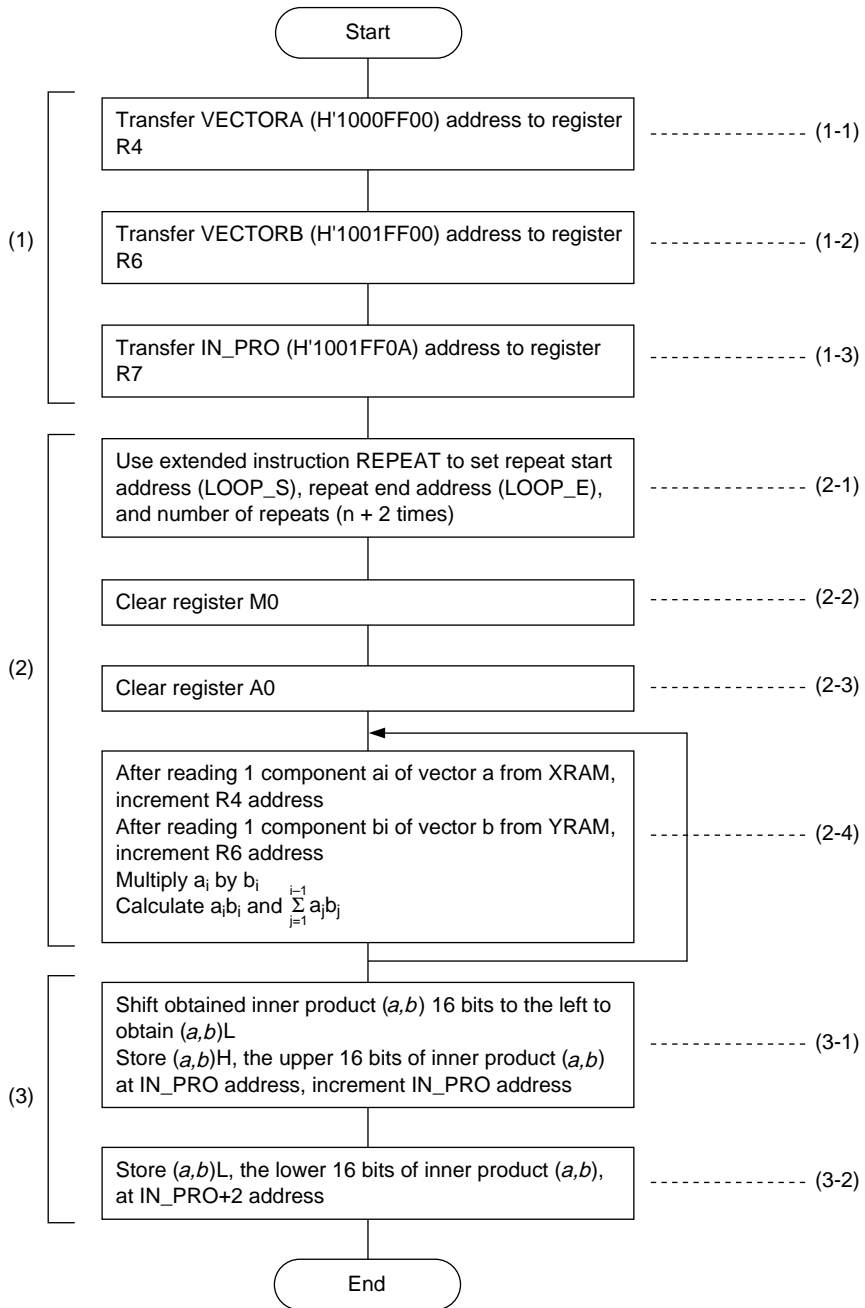
- (1) Set the addresses where the space vector  $a$  and  $b$  components are stored as well as the address for storing the inner product of  $a$  and  $b$  in X address register (R4) and Y address registers (R6, R7).
- (2) Perform a sum of products calculation on components  $a_i$  of space vector  $a$  and components  $b_i$  of space vector  $b$ .
- (3) Store  $(a,b)H$ , the upper 16 bits of inner product  $(a,b)$  at the IN\_PRO address and  $(a,b)L$ , the lower 16 bits of inner product  $(a,b)$ , at the IN\_PRO+2 address. This completes the process.



**Figure 10.4 Algorithm for Calculating Inner Product**



# Flowchart



## Main Program

This program calculates the inner product for the three-dimensional space vector { $a_i, b_i$  ( $i = 1, 2, 3$ )}.

```
in_pro.src
;*****
;*                               Inner product calculation routine
;*
;*                               (a,b)=a1b1+a2b2+a3b3
;*
;*****
;*****
;*                               Initial setting routine
;*****
MAIN:   MOV.L   #VECTORA,R4
        MOV.L   #VECTORB,R6
        MOV.L   #IN_PRO,R7

;*****
;*                               Sum of products calculation routine
;*****
        REPEAT LOOP_S,LOOP_S,#5                ;Number of components in vector a
                                                + 2 is number of repeats

        PCLR   A0
        PCLR   M0
        PCLR   X0
        PCLR   Y0

LOOP_S: PADD   A0,M0,A0  PMULS  X0,Y0,M0  MOVX.W @R4+,X0  MOVY.W @R6+,Y0 ;ai,bi load

;*****
;*                               Inner product storage routine
;*****
STORE:  PSHA   #16,A0                          MOVY.W A0,@R7+ ;Store upper bits
of inner product

                                                MOVY.W A0,@R7 ;Store lower bits
of inner product

EXIT:   BRA    EXIT
        NOP
MAIN_E: NOP
```

## Data

```
;*****  
;*          Inner product calculation data (XRAM/YRAM)  
;*****  
          .SECTION XRAM,DATA,LOCATE=H'1000FF00  
VECTORA:  .XDATA.W      0.5,0.125,0.5,0,0  
  
          .SECTION YRAM,DATA,LOCATE=H'1001FF00  
VECTORB:  .XDATA.W      0.25,0.0625,0.25,0,0  
IN_PRO:   .RES.W        2
```



# Section 11 Square Root

## Overview

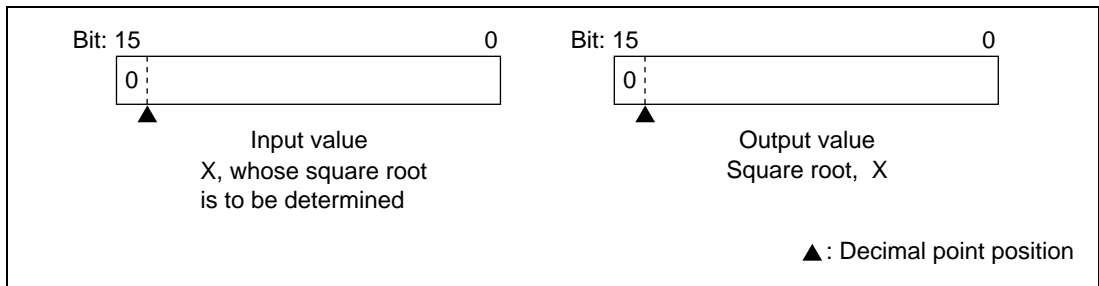
A 16-bit fixed-point square root calculation is performed and a square root with 15-bit precision is obtained.

## Description

### 1. I/O Value Data Format

Figure 11.1 shows the data format for I/O values. The value, X, whose square root is to be determined is input in 16-bit format with its uppermost bit set to 0. However, it is also necessary to perform normalization on X before calculating the square root.

The square root,  $\sqrt{X}$ , is output in 16-bit (1 word) format with the uppermost bit set to 0.



**Figure 11.1 I/O Value Data Format**

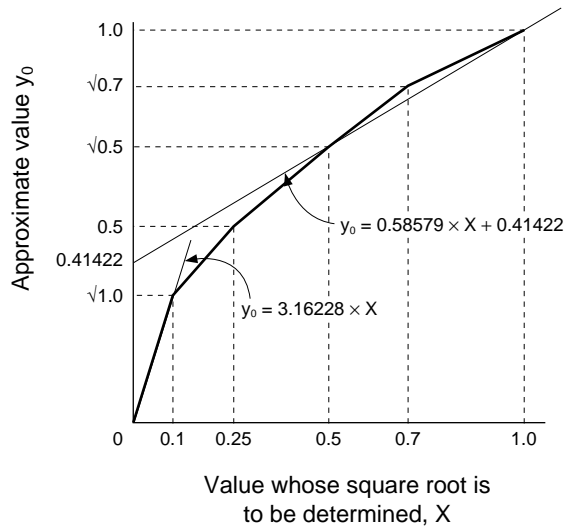
### 2. Method of Calculating Square Root

Figure 11.2 illustrates the square root function. The example program calculates an approximate value for the square root of X using a polyline graph of the sort shown in Figure 11.2 Square Root Function. Next, a gradualization equation is used to converge on a more accurate value. This is the method used to calculate the square root,  $\sqrt{X}$ .

Once normalization is performed on X, the range that can be taken by X, the value whose square root is to be calculated, is as follows.

$$0 \leq X < 1.0$$
$$(H'00000 \leq X \leq H'7FFF)$$

In the square root function shown in Figure 11.2, the slope of the polyline graph is created by a combination of comparatively gentle sections greater than 0.1 and steep sections less than 0.1, resulting in approximation equations (1) and (2). Using these two equations, an approximate square root value ( $y_0$ ) is obtained.



**Figure 11.2 Square Root Function**

Input value  $X > 0.1$

$$y_0 = 0.58579 \times X + 0.41422 \text{ ----- (1)}$$

Input value  $X \leq 0.1$

$$y_0 = 3.16228 \times X \text{ ----- (2)}$$

(The actual program uses  $y_0 = 0.79057 \times X \times 2^2$ .)

Note that equation (2) cannot be used without modification for fixed-point calculation.

Therefore, normalization is performed and it is used as  $y_0 = 0.79057 \times X \times 2^2$ .

Next, the value  $y_0$  obtained with approximation equations (1) and (2) is assigned to gradualization equation (3) to obtain a more accurate square root value,  $\sqrt{X}$ .

$$y_0 = \sqrt{X} = 1/2 (y_0 + X/y_0) \text{ ----- (3)}$$

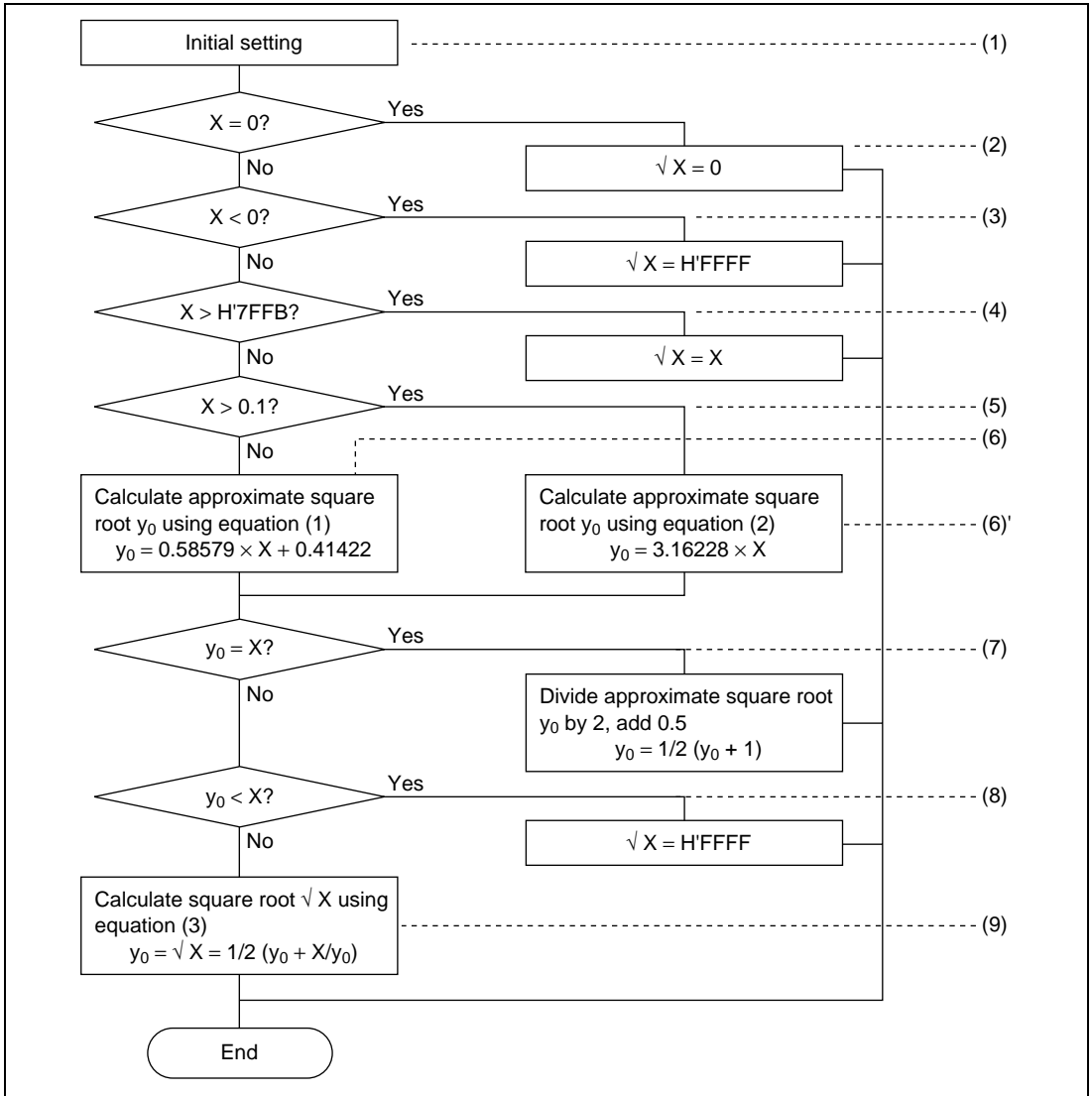
Here, in item 2 of equation (3), since the value whose square root is being calculated,  $X$ , has been normalized,  $X/y_0$  must be a normalized value in order to  $y_0 > X$  after the calculations of equations (1) and (2). In the sample program gradualization equation (3) is performed three times, resulting in a square root value with 15-bit precision.

### 3. Algorithm for Fixed-point Square Root Calculation

The algorithm for fixed-point square root calculation is described below.

- (1) Initial settings are performed.
- (2) It is determined whether  $X$ , the value whose square root is to be calculated, is not 0. If  $X$  is 0, the square root,  $\sqrt{X}$ , is given as 0 and processing ends.
- (3) It is determined whether  $X$ , the value whose square root is to be calculated, is a negative number. If  $X$  is a negative number, the square root,  $\sqrt{X}$ , is given as H'FFFF and processing ends.
- (4)  $X$ , the value whose square root is to be calculated, is compared to H'7FFB to determine whether it is larger or smaller. If  $X > \text{H}'7\text{FFB}$ , the square root,  $\sqrt{X}$ , is given as  $\sqrt{X}(=X)$  and processing ends.
- (5)  $X$ , the value whose square root is to be calculated, is compared to 0.1 to determine whether it is larger or smaller. If  $X > 0.1$ , processing continues with (6). If  $X \leq 0.1$ , processing continues with (6)'.
- (6) Equation (1) is used to calculate approximate square root  $y_0$ . Processing continues with (7).
- (6)' Equation (2) is used to calculate approximate square root  $y_0$ . Processing continues with (7).
- (7) Approximate square root  $y_0$  is compared to  $X$ , the value whose square root is being calculated, to determine whether it is larger or smaller. If  $y_0 = X$ , approximate square root  $y_0$  is divided by 2, 0.5 (H'4000) is added, the result is given as the square root,  $\sqrt{X}$ , and processing ends.
- (8) If the comparison in (7) shows that  $X$ , the value whose square root is being calculated, is greater than approximate square root  $y_0$ , gradualization equation  $X/y_0$  is not performed. In this case the square root,  $\sqrt{X}$ , is given as H'FFFF and processing ends.
- (9) Gradualization equation (3) is used to calculate square root value  $y$ , which is given as the square root,  $\sqrt{X}$ , and processing ends.

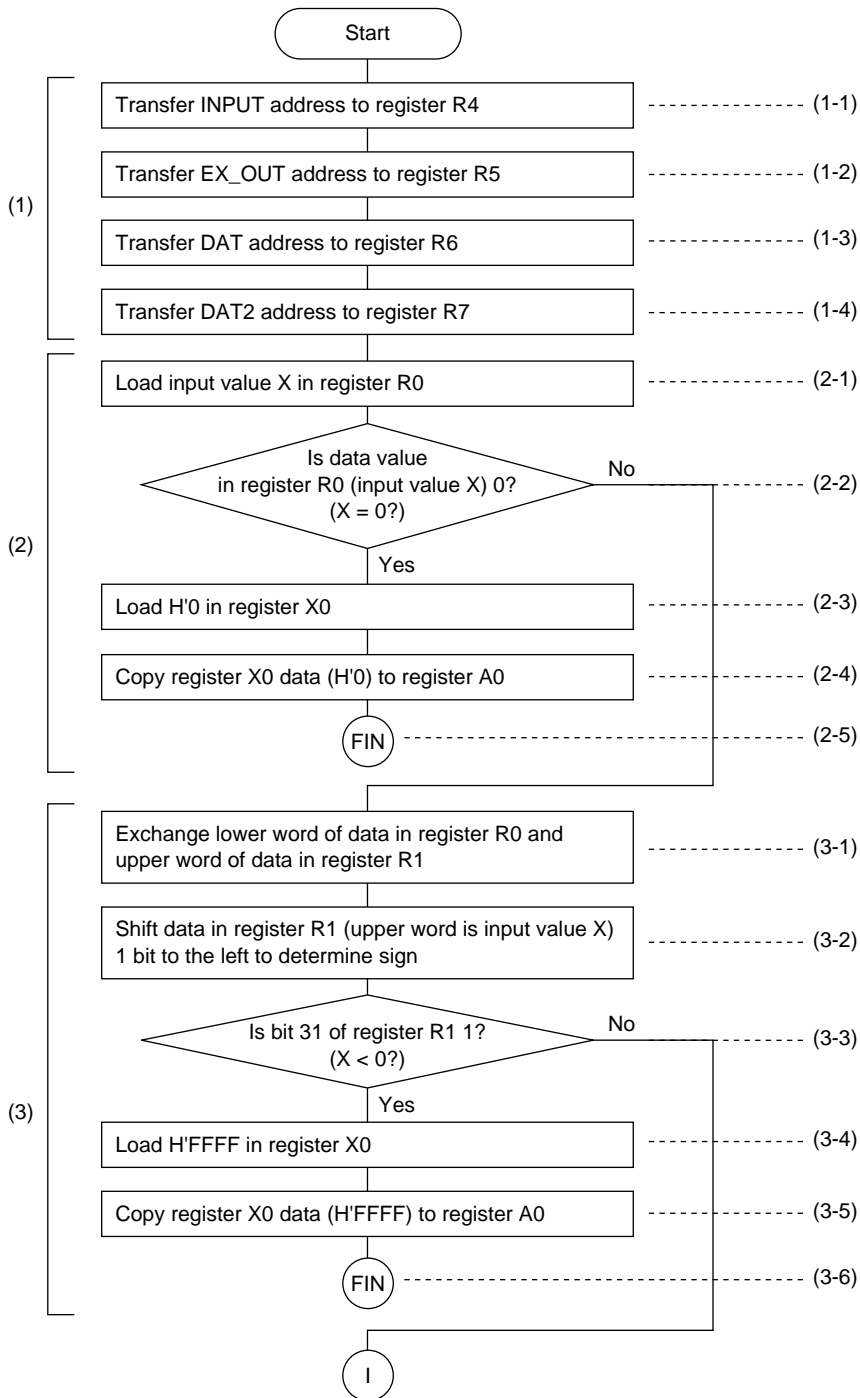
Figure 11.3 shows the algorithm used for calculating the square root.

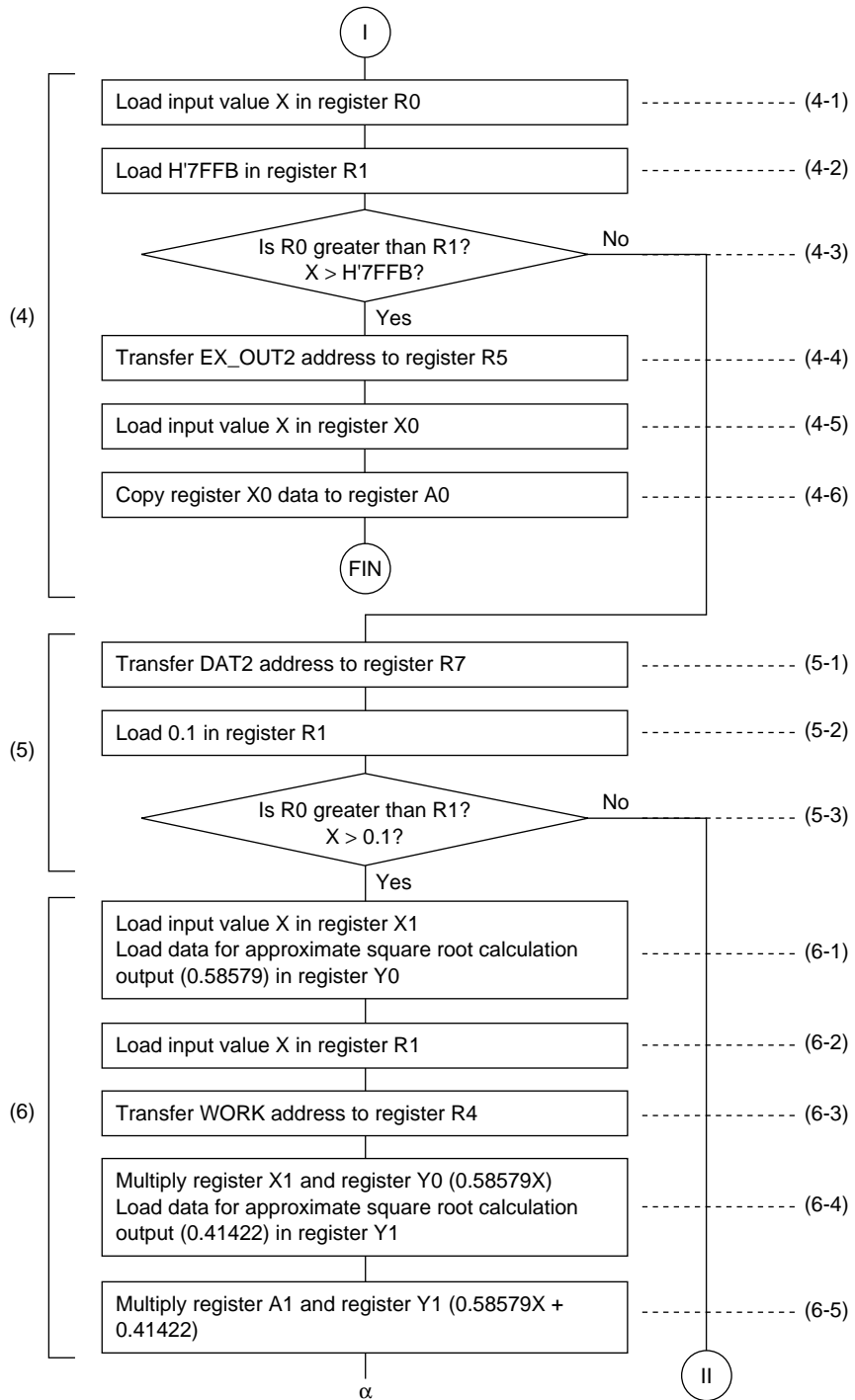


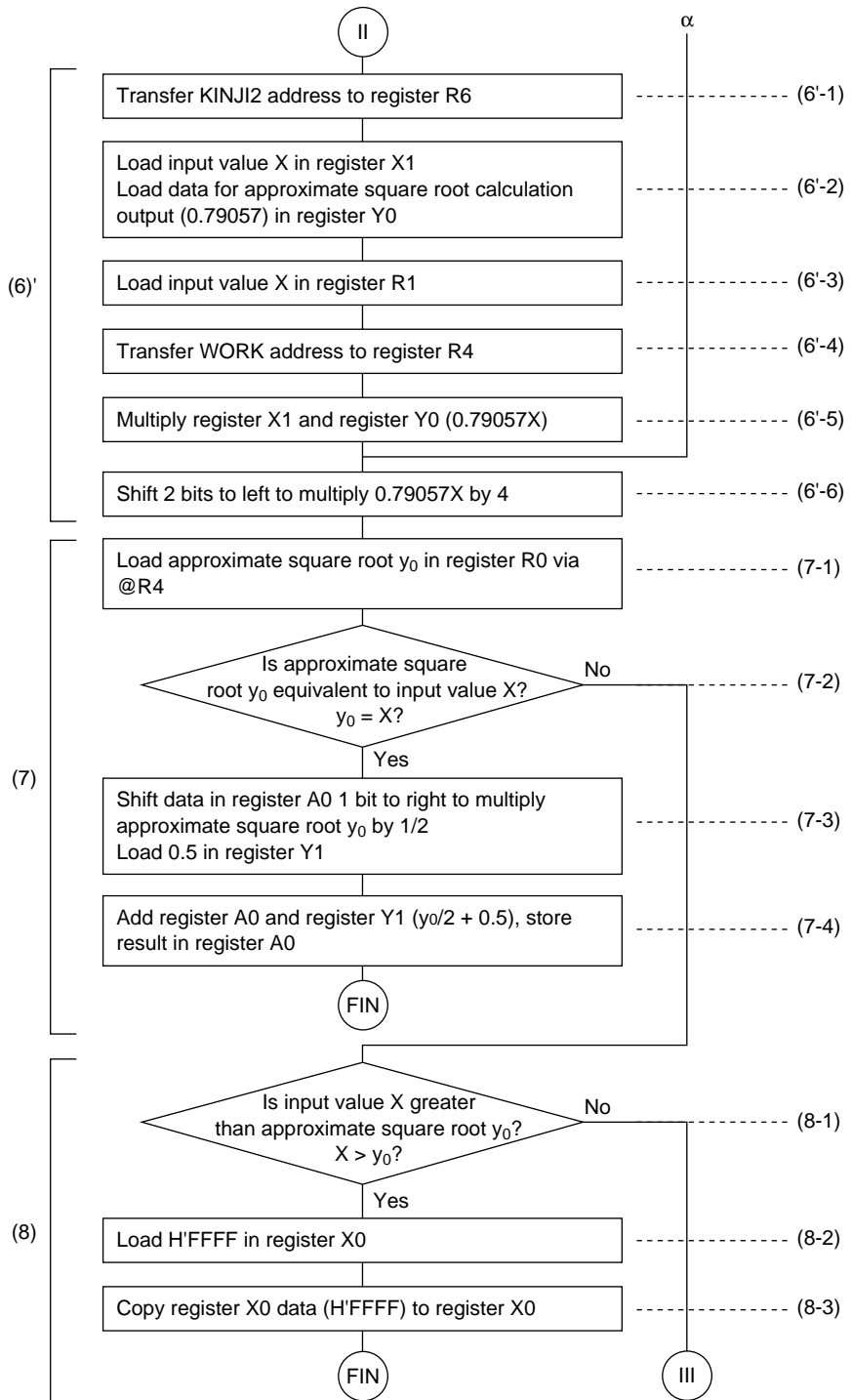
**Figure 11.3 Algorithm for Calculating Square Root**

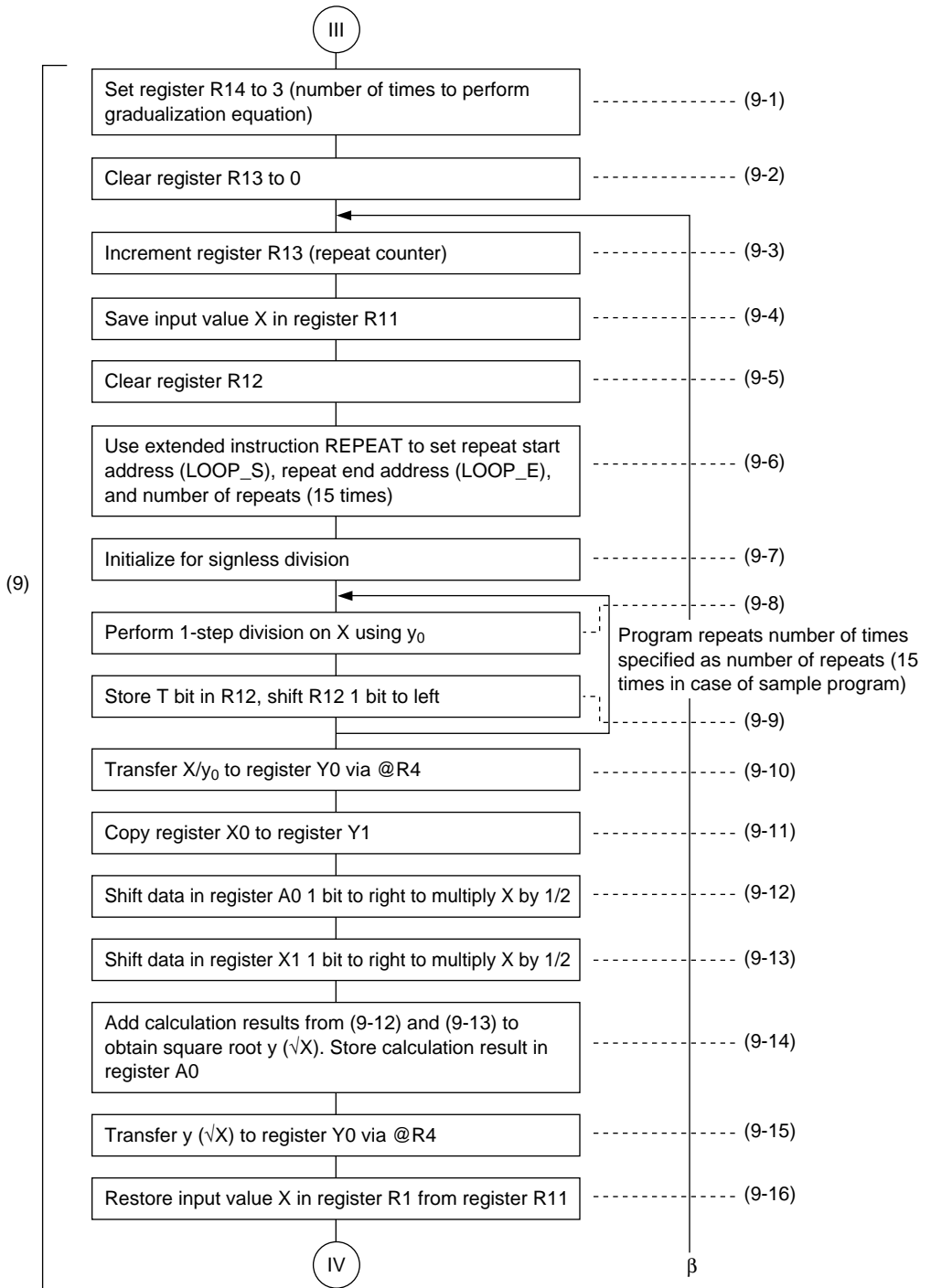


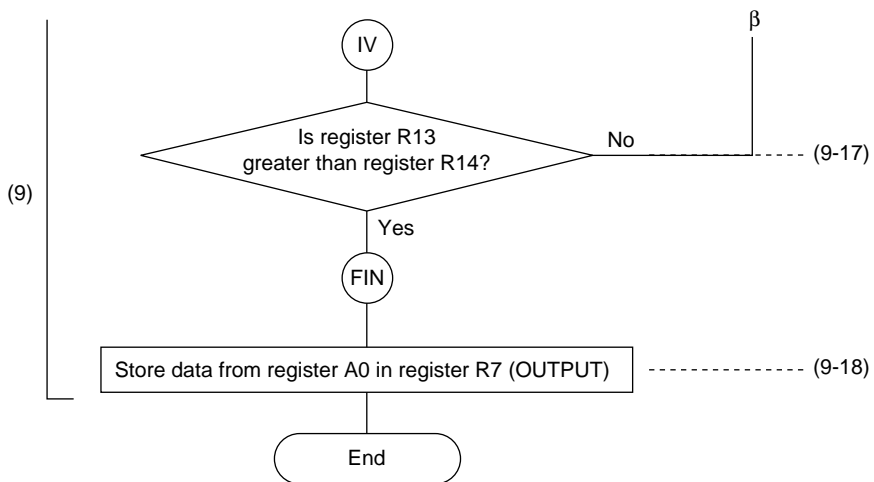
# Flowchart











# Main Program

```
rout.src
;*****
;*                               Square root calculation routine
;*
;*                               √x
;*
;*****
;*****
;*                               Initial setting routine
;*****
MAIN:
    MOV.L    #INPUT,R4
    MOV.L    #EX_OUT,R5
    MOV.L    #KINJ11,R6
    MOV.L    #DAT1,R7

;*****
;*                               Zero check of value to have square root calculated routine
;*****
    MOV.W    @R4,R0
    CMP/EQ   #0,R0
    BF      ZERO_CH          ;If zero, do following
processing
    MOVX.W   @R4,X0

    PCOPY   X0,A0
    BRA     FIN              ;End of processing
    NOP

;*****
;*                               Negative value check of value to have square root calculated routine
;*****
ZERO_CH:
    SWAP    R0,R1
    SHAL    R1
    BF      MINUS_CH        ;If negative, do following
                                processing
    MOVX.W   @R5,X0

    PCOPY   X0,A0
    BRA     FIN              ;End of processing
    NOP

;*****
;*                               Comparison of value to have square root calculated and F'7FFB routine
;*****
MINUS_CH:
```

```

MOV.W      @R4,R0                ;X load
MOV.W      @R7,R1                ;H'7FFB load
CMP/GT     R1,R0                 ;R0 > R1 ?
BF         EQU_SEL               ;If X > F'7FFB, do following
                                   processing
MOV.L      #EX_OUT2,R5
                                   MOVX.W @R5,X0                ;X load
PCOPY     X0,A0
BRA       FIN
NOP

;*****
;*           Approximation equation selection routine
;*****
EQU_SEL:
MOV.L      #DAT2,R7
MOV.W      @R7,R1
CMP/GT     R1,R0
BF         Y0_PRO2               ;If X ≤ 0.1, jump

*****
;*           Approximate square root y0 calculation routine
;*****
Y0_PRO1:
                                   MOVX.W @R4,X1 MOVY.W @R6+,Y0 ;Load input value X (value to
                                   have square root calculated)
                                   for use in calculating
                                   approximate square root
MOV.W      @R4,R1                ;Keep input value X (value to
                                   have square root calculated)
                                   in R1
MOV.L      #WORK,R4
PMULS     X1,Y0,A1                MOVY.W @R6+,Y1 ;0.58579X,0.41422 load
PADD      A1,Y1,A0                ;0.58579X+0.41422 -> y0
BRA       HIKAKU
NOP

;*****
;*           Approximation equation (2) y0 calculation routine
;*****
Y0_PRO2:
MOV.L      #KINJI2,R6
                                   MOVX.W @R4,X1 MOVY.W @R6+,Y0 ;Load input value X (value to
                                   have square root calculated)
                                   for use in calculating
                                   approximate square root
MOV.W      @R4,R1                ;Keep input value X (value to
                                   have square root calculated)
                                   in R1
MOV.L      #WORK,R4

```

```

PMULS X1,Y0,A1          MOVY.W @R6+,Y1 ;0.58579X,0.41422 load
PSHA  #2,A0             ;0.58579X+0.41422 -> y0

```

```

*****
;*          Comparison of approximate square root and value to have square root
calculated routine/Part 1
;*****

```

HIKAKU:

```

          MOVX.W A0,@R4          ;Pass to CPU unit

MOV.W    @R4,R0
CMP/EQ   R0,R1                  ;Approximate square root y0 =
                                input value X (value to have
                                square root calculated)?

BF       NOT_EQ                 ;If y0 ≠ X, do following
                                processing

PSHA    #-1,A0                  MOVY.W @R6,Y1 ;y0/2,0.5 load
PADD    A0,Y1,A0                ;y0/2-0.5
BRA     FIN                      ;End of processing
NOP

```

```

;*****
;*          Comparison of approximate square root and value to have square root
calculated routine/Part 2
;*****

```

NOT\_EQ:

```

CMP/GT   R0,R1
BF       NOT_GT                 ;If y0 < X, do following
                                processing

                                MOVX.W @R5,X0 ;H'FFFF load

PCOPY   X0,A0
BRA     FIN
NOP

```

```

;*****
;*          Square root y calculation using gradualization equation routine
;*****

```

NOT\_GT:

```

MOV.L    #3,R14                 ;Set number of repeats
MOV.L    #0,R13

```

LENEAR\_LP:

```

ADD      #1,R13                 ;Increment counter

MOV      R1,R11                 ;push X
MOV.L    #0,R12                 ;Clear register R12
REPEAT   LOOP_S,LOOP_E,#15
DIV0U    ;Signless initialization

```

LOOP\_S:

```

DIV1     R0,R1                  ;R1/R0

```

LOOP\_E:



```

ROTCL          R12                                ;Store T bit
MOV.W         R12,@R4

                                MOVX.W @R4,X0

PCOPY X0,Y1
PSHA #-1,A0                                       ;y0/2
PSHA #-1,Y1                                       ;(X/y0)/2
PADD A0,Y1,A0

                                MOVX.W A0,@R4

MOV.W         @R4,R0
MOV          R11,R1                                ;pop X

CMP/GT       R14,R13
BF           LENEAR_LP                             ;If set number of repeats has
                                                    been performed, escape

FIN:  MOV.L   #OUTPUT,R7

                                MOVY.W A0,@R7 ;Store square root  $\sqrt{X}$ 

EXIT:  BRA    EXIT
      NOP
MAIN_E: NOP

```

## Data

```

;*****
;*                               Square root calculation data (XRAM/YRAM)
;*****

        .SECTION XRAM,DATA,LOCATE=H'1000FF00
INPUT:  .RES.W    1                                ;External input data storage area
WORK:   .RES.W    1                                ;Work area
EX_OUT: .DATA.W   H'FFFF                           ;Output value if input value X < 0
EX_OUT2: .XDATA.W 1                                ;Output value if input value X > H'7FFB

        .SECTION YRAM,DATA,LOCATE=H'1001FF00
KINJI1: .XDATA.W  0.58579,0.41422,0.5             ;Approximation equation (1)
KINJI2: .XDATA.W  0.79057                         ;Approximation equation (2)
DAT1:   .DATA.W   H'7FFB
DAT2:   .XDATA.W  0.1
OUTPUT: .RES.W    1                                ;External output data storage area

```

## Execution Example

The input values for X (INPUT) and the square root  $\sqrt{X}$  values calculated (OUTPUT) are shown in table 11.1.

**Table 11.1 Square Root  $\sqrt{X}$  Calculation Results (3 Executions of Gradualization Equation)**

<b>Input Value X (decimal)</b>	<b>Input Value X (hexadecimal)</b>	<b>Logical Value (decimal) <math>\sqrt{X}</math></b>	<b>Logical Value (hexadecimal) <math>\sqrt{X}</math></b>	<b>Output Value (hexadecimal) <math>\sqrt{X}</math></b>
0.9999	H'7FFC	0.99995	H'7FFE	H'7FFF
0.99987	H'7FFB	0.99993	H'7FFD	H'7FFD
0.85	H'6CCD	0.92195	H'7602	H'7602
0.523	H'42F1	0.72319	H'5C91	H'5C90
0.34	H'2BB5	0.5831	H'4AA3	H'4AA2
0.136	H'1168	0.36878	H'2F34	H'2F33
0.087	H'0B23	0.29496	H'25C1	H'25C1
0.01	H'0147	0.1	H'0CCD	H'0CC9
0	H'0000	0	H'0000	H'0000
-0.7	H'A667	—	—	H'FFFF

# Section 12 Square Mean Error

## Overview

The square mean error of two variables, a[i] (16-bit components) and b[i] (16-bit components), is calculated.

$$(i = 1, 2, \dots, n)$$

## Description

### 1. Method of Obtaining Square Mean Error

In order to obtain the square mean error, first the error e[i] for the two variables, a[i] and b[i], must be considered. The relevant equation is given as equation (1) below.

$$*1 \quad e[i] = a[i] - b[i] \text{ ----- (1)}$$

$$(i = 1, 2, \dots, n)$$

Next, the error distribution  $Se^2$  is obtained. The error distribution  $Se^2$  can be calculated by dividing the sum total of the squares of the errors e[i] by the number of components (n). The components of the squares of the errors e[i] can be expressed as follows.

$$1/n \cdot \sum e[i]^2 = 1/n \cdot (a[1] - b[1])^2 + (a[2] - b[2])^2 + \dots + (a[n] - b[n])^2$$

The error distribution  $Se^2$  can be obtained using equation (2) below.

$$Se^2 = 1/n \cdot \sum_{i=1}^n (a[i] - b[i])^2 \text{ ----- (2)}$$

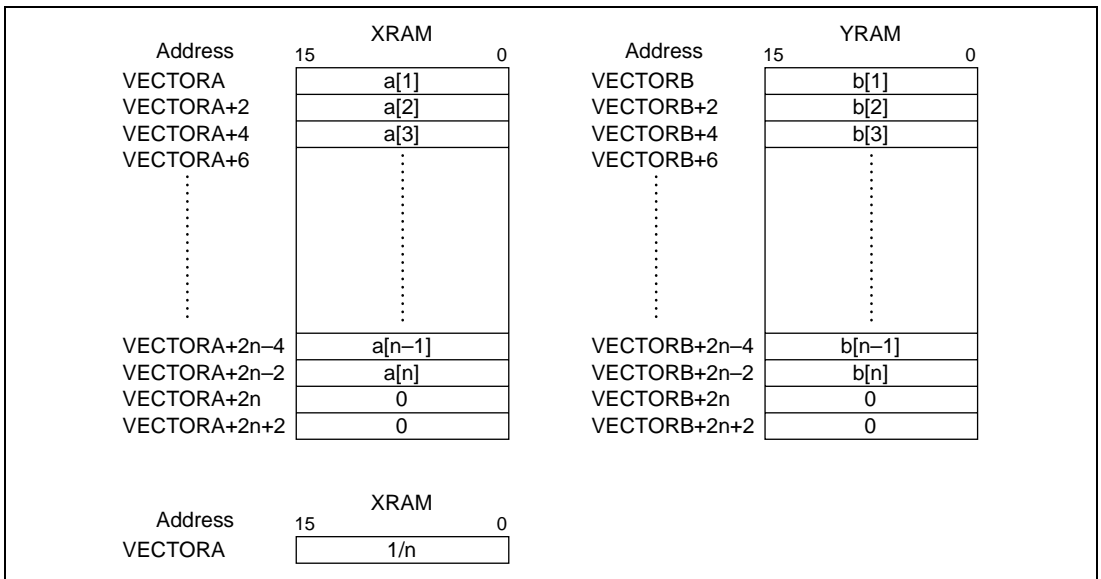
The square mean error  $E[Se^2]$  is expressed as the square root of the error distribution  $Se^2$ . The relevant equation for obtaining the square mean error  $E[Se^2]$  is shown as equation (3) below.

$$E[e^2] = \sqrt{1/n \cdot \sum_{i=1}^n (a[i] - b[i])^2} \text{ ----- (3)}$$

- \*1 a[i]: 16-bit
- b[i]: 16-bit
- e[i]: 16-bit

## 2. Method of Storing Components of Variables a[i] and b[i]

On order to obtain the square mean error, it is first necessary to calculate the sum total of the squares of the errors  $e[i]$ . To increase processing speed, the components of  $a[i]$  and  $b[i]$  are stored in XRAM and YRAM ahead of time as shown in figure 12.1. Note that 0 is stored in  $VECTORA+2n$ ,  $VECTORA+2n+2$ ,  $VECTORB+2n$ , and  $VECTORB+2n+2$  of XRAM and YRAM. The example program will not run properly if zeros are not stored in these locations. For division by the number of components  $n$ , the numeric value  $1/n$  is stored in XRAM. The actual program does not use a DSP instruction, but rather multiplies values by  $1/n$ .



**Figure 12.1 Memory Map of Storage of Variables a[i] and b[i], Etc.**

### 3. Algorithm for Calculating Square Mean Error

The algorithm used to calculate the square mean error is described below.

- (1) Perform initial settings.
- (2) Set items (2) and (3) so that the number of repeats is number of elements  $n + 2$ . Two extra repeats are added since the following four instructions run in parallel.

Calculate  $e[i]^2 + \sum_{j=1}^{i-1} e[j]^2$ , calculate  $e[i]$ , load  $a[i]$ , load  $b[i]$

- (3) Calculate the error  $e[i]$  for  $a[i]$  and  $b[i]$ .
- (4) Divide  $\sum_{i=1}^n (a[i] - b[i])^2$ , which was obtained using processes (2) and (3), by  $n$ .
- (5) Calculate the square root of the input error distribution  $Se^2$ . This yields the square mean error and completes the processing. (For details, see 3. Algorithm for Fixed-point Square Root Calculation in 11. Square Root.)

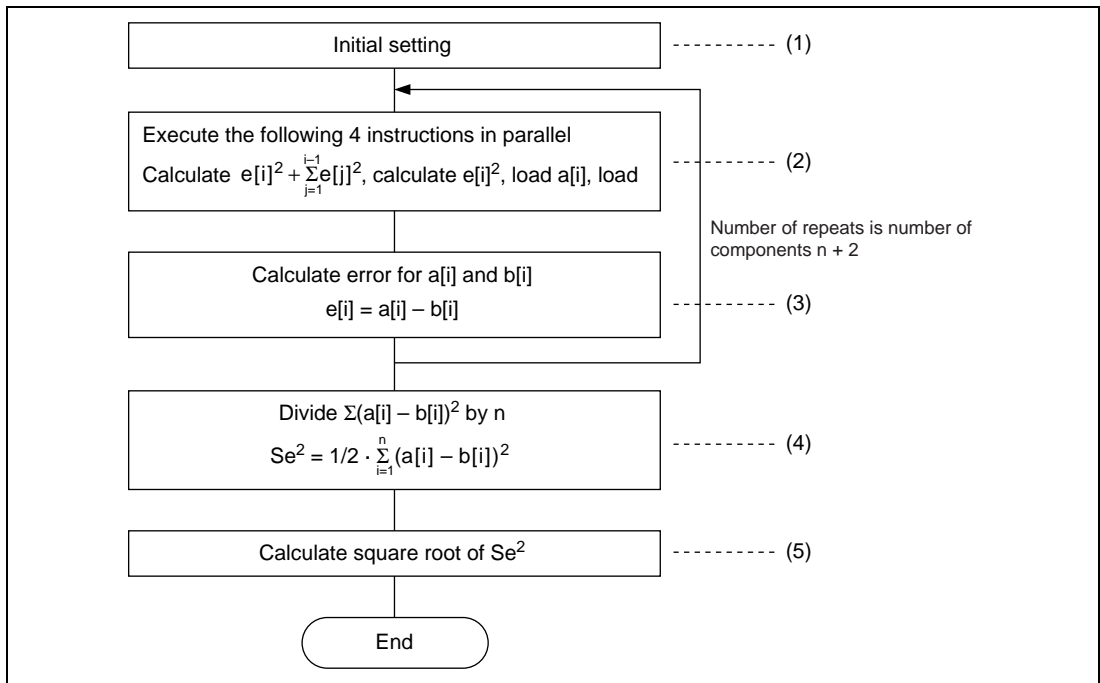
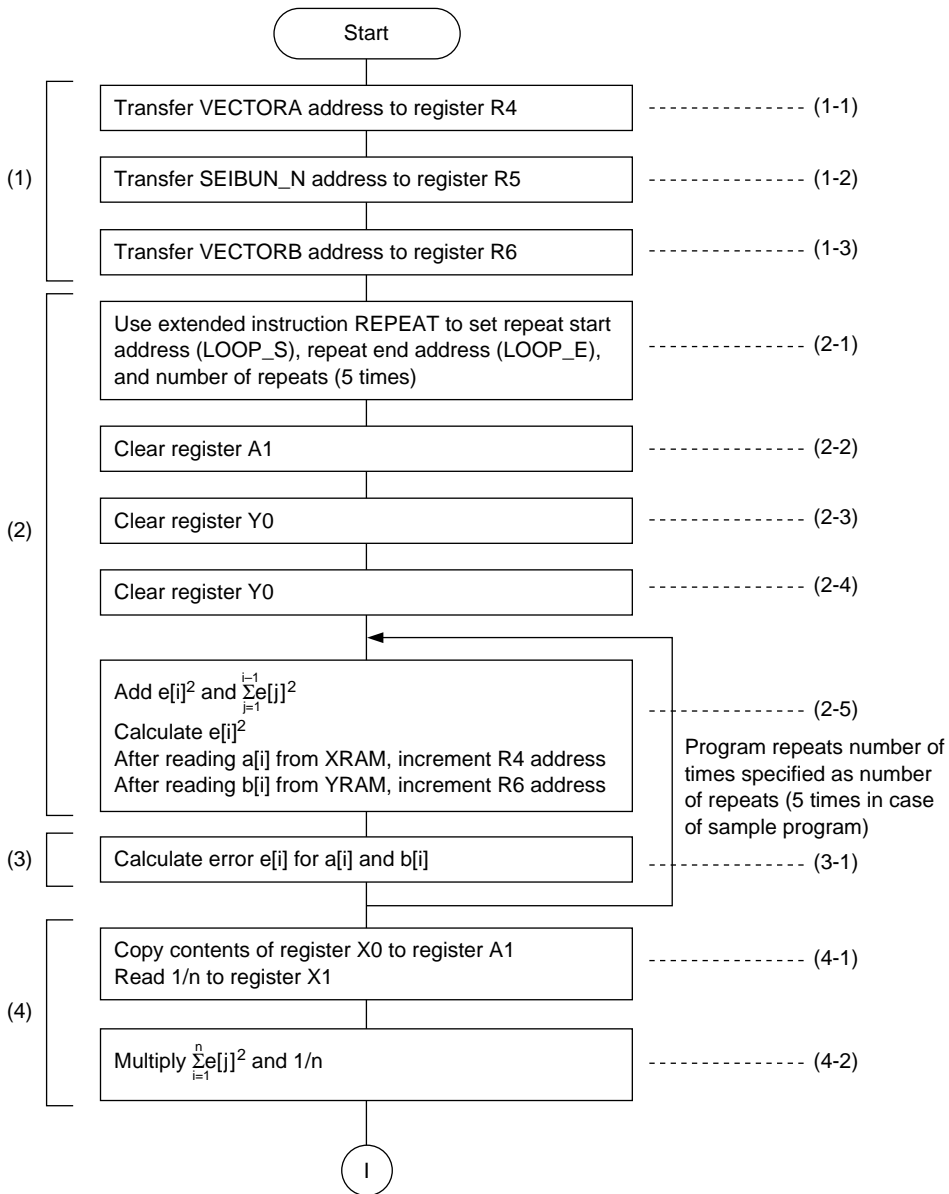
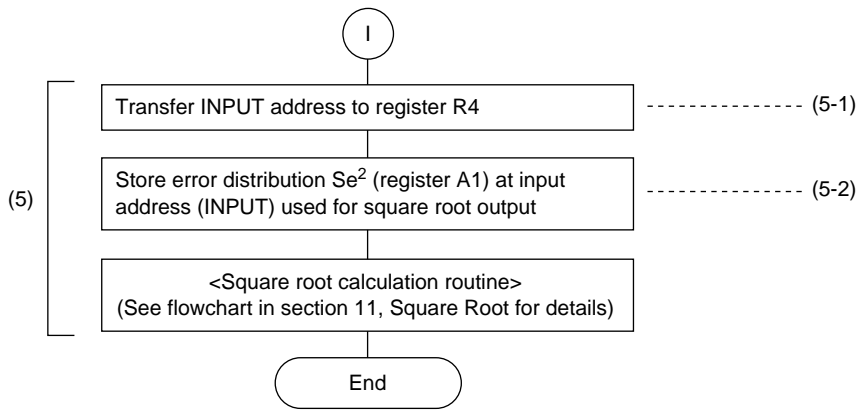


Figure 12.2

# Flowchart





# Main Program

The example program calculates the square mean error using three components {a[i], b[i] (i = 1, 2, 3)}

```

squ_ave.src
;*****
;*          Square mean routine
;*
;*          a[i],b[i]
;*
;*****
;*****
;*          Initial setting routine
;*****
MAIN:
    MOV.L    #VECTORA,R4
    MOV.L    #SEIBUN_N,R5
    MOV.L    #VECTORB,R6

;*****
;*          Error distribution calculation routine
;*****
    REPEAT  LOOP_S,LOOP_E,#5                ;Number of repeats is number of
                                           ;vector a components + 2

    PCLR    A1
    PCLR    Y0
    PCLR    A0

LOOP_S:
    PADD    A0,Y0,Y0  PMULS    A1,A1,A0  MOVX.W @R4+,X0  MOVY.W @R6+,Y1;a[i],b[i]load
LOOP_E:
    PSUB    X0,Y1,A1

    PCOPY   Y0,A1                MOVX.W @R5,X1        ;1/3 load
    PMULS   X1,A1,A1            ;0.33333 x Σ(a[i] - b[i])2

;*****
;*          Value to have square root calculated storage routine
;*****
    MOV.L    #INPUT,R4
                                           MOVX.W A1,@R4 ;

;*****
;*          Square root calculation routine
;*****
;*****
;*          Initial setting routine

```



```

;*****
SEMI_MAIN:
    MOV.L      #EX_OUT,R5
    MOV.L      #DAT,R6
    MOV.L      #DAT2,R7

;*****
;*           Zero check of value to have square root calculated routine
;*****
    MOV.W      @R4,R0
    CMP/EQ     #0,R0
    BF         ZERO_CH

                                MOVX.W @R4,X0                ;H'0 load
    PCOPY      X0,A0                ;
    BRA        FIN                    ;End of processing
    NOP

;*****
;*           Negative value check of value to have square root calculated routine
;*****
ZERO_CH:
    SWAP       R0,R1
    SHAL       R1
    BF         MINUS_CH                ;If negative, do
following processing
                                MOVX.W @R5,X0                ;H'FFFF load
    PCOPY      X0,A0
    BRA        FIN                    ;End of processing
    NOP

;*****
;*           Comparison of value to have square root calculated and F'7FFB
routine
;*****
MINUS_CH:
    MOV.W      @R4,R0                ;X load
    MOV.W      @R7,R1                ;H'7FFB load
    CMP/GT     R1,R0                ;R0 > R1 ?
    BF         EQU__SEL                ;If R1 is greater, jump
    MOV.L      #EX_OUT2,R5
                                MOVX.W @R5,X0                ;X load
    PCOPY      X0,A0
    BRA        FIN
    NOP

;*****
;*           Approximation equation selection routine

```

```

;*****
EQU_SEL:
    MOV.L      #DAT2,R7
    MOV.W      @R7,R1
    CMP/GT    R1,R0
    BF        Y0_PRO2

;*****
;*          Approximation equation (1) y0 calculation routine
;*****
Y0_PRO1:
                                MOVX.W @R4,X1  MOVY.W @R6+,Y0 ;Load input value X
                                (value to have square
                                root calculated) for use
                                in calculating
                                approximate square root
    MOV.W      @R4,R1          ;Keep input value X
                                (value to have square
                                root calculated) in R1

    MOV.L      #WORK,R4
    PMULS     X1,Y0,A1          MOVY.W @R6+,Y1 ;0.58579X,0.41422 load
    PADD      A1,Y1,A0          ;0.58579X+0.41422-> y0
    BRA       HIKAKU
    NOP

;*****
;*          Approximation equation (2) y0 calculation routine
;*****
Y0_PRO2:
    MOV.L      #KINJI2,R6  MOVX.W @R4,X1  MOVY.W @R6+,Y0 ;Load input value X
                                (value to have square
                                root calculated) for use
                                in calculating
                                approximate square root
    MOV.W      @R4,R1          ;Keep input value X
                                (value to have square
                                root calculated) in R1

    MOV.L      #WORK,R4
    PMULS     X1,Y0,A0          ;0.79057 × X
    PSHA      #2,A0            ;(0.79057 × X) × 4

;*****
;*          Comparison of approximate square root and value to have square root
calculated routine/Part 1
;*****
HIKAKU:
                                MOVX.W A0,@R4          ;Pass to CPU unit

    MOV.W      @R4,R0
    CMP/EQ    R0,R1            ;Approximate square root
                                = input value X (value
                                to have square root
                                calculated)?

```

```

        BF                NOT_EQ
        PSHA              #-1,A0                MOVY.W @R6,Y1    ;y0/2,0.5 load
        PADD              A0,Y1,A0            ;y0/2-0.5
        BRA               FIN
        NOP

;*****
;*                      Comparison of approximate square root and value to have square root
calculated routine/Part 2
;*****
NOT_EQ:
        CMP/GT           R0,R1
        BF               NOT_GT
                                MOVX.W @R5,X0                ;H'FFFF load
        PCOPY            X0,A0
        BRA              FIN
        NOP
;

;*****
;*                      Square root y calculation using gradualization equation routine
;*****
NOT_GT:
        MOV.L            #3,R14                ;Set number of repeats
        MOV.L            #0,R13
LENEAR_LP:
        ADD              #1,R13                ;Increment counter

        MOV              R1,R11
        MOV.L            #0,R12
        REPEAT           DIV_S,DIV_E,#15
        DIV0U            ;Signless initialization
DIV_S:
        DIV1             R0,R1                ;R1/R0
DIV_E:
        ROTCL            R12                ;Store T bit
        MOV.W            R12,@R4
                                MOVX.W @R4,X0
        PCOPY            X0,Y1
        PSHA              #-1,A0                ;y0/2
        PSHA              #-1,Y1            ;(X/y0)/2
        PADD              A0,Y1,A0
                                MOVX.W A0,@R4
        MOV.W            @R4,R0
        MOV              R11,R1

        CMP/GT           R14,R13
        BF               LENEAR_LP

```

```

FIN:    MOV.L    #OUTPUT,R7

                                                MOVY.W A0,@R7    ;Store square root  $\sqrt{x}$ 

EXIT:   BRA     EXIT
        NOP
MAIN_E: NOP

```

## Data

```

;*****
;*                               Square mean calculation data (XRAM/YRAM)
;*****

        .SECTION XRAM,DATA,LOCATE=H'1000FF00
VECTERA: .XDATA.W    0.5,0.125,0.5,0,0
SEIBUN_N: .XDATA.W    0.33333                ;1/number of components (n)

;* For calculating square root *
INPUT:   .RES.W      1
WORK:    .RES.W      1
EX_OUT:  .DATA.W     H'FFFF
EX_OUT2: .XDATA.W    1

        .SECTION YRAM,DATA,LOCATE=H'1001FF00
VECTERB: .XDATA.W    0.25,0.0625,0.25,0,0

;; * For calculating square root *
KINJI1:  .XDATA.W    0.58579,0.41422,0.5    ;Approximation equation (1)
KINJI2:  .XDATA.W    0.79057                ;Approximation equation (2)
DAT1:    .DATA.W     H'7FFB
DAT2:    .XDATA.W    0.1
OUTPUT:  .RES.W      1

```

# Section 13 Effects of DSP Instructions on Program Performance

The number of execution cycles required by each function program file is listed in tables 13.1 and 13.2.

The test conditions used for table 13.1 were as follows: an E8000 (SH7612) emulator was used, the main program of each program file was allocated to XRAM, and the data was allotted to XRAM and YRAM.

The test conditions used for table 13.2 were as follows: a simulator (SH-DSP) was used, the main program of each program file was allocated to XROM, and the data was allotted to XRAM and YRAM.

**Table 13.1 Performance of Programs Employing DSP Instructions**

<b>Program Filename</b>	<b>Function</b>	<b>No. of Execution Cycles</b>	<b>Notes</b>
pmuls32.src	32-bit multiplication	116	
tri_fun.src	Trigonometric function	62	
matrix.src	Matrix operation	238	3 × 3 matrix operation
in_pro.src	Inner product	15	3-dimensional space vectors
rout.src	Square root	104	
squ_ave.src	Square mean error	114	n = 3 (3 components)

**Table 13.2 Performance of Programs Employing DSP Instructions**

<b>Program Filename</b>	<b>Function</b>	<b>No. of Execution Cycles</b>	<b>Notes</b>
pmuls32.src	32-bit multiplication	172	
tri_fun.src	Trigonometric function	80	
matrix.src	Matrix operation	378	3 × 3 matrix operation
in_pro.src	Inner product	21	3-dimensional space vectors
rout.src	Square root	272	
squ_ave.src	Square mean error	292	n = 3 (3 components)

---

## **SH-DSP Software Application Note**

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