RL78/G14

Haptic Feedback Control by a Piezoelectric Actuator CC-RL

R01AN4632EJ0100
Rev.1.00
Dec 17, 2018

Introduction

This application note describes an example to drive piezoelectric haptic actuators.
The timer array unit and D/A converter of the RL78/G14 are used in this application note.

Target Device

RL78/G14

When applying the sample program covered in this application note to another microcomputer, modify the program according to the specifications for the target microcomputer and conduct an extensive evaluation of the modified program.

Contents

1. Specifications 4
1.1 Method of driving the piezoelectric actuator 4
1.2 Method of generation of control waveform 5
1.3 Driving waveform frequencies and amplitude modulation patterns 5
1.4 Method of calculation of device frequency and amplitude 6
1.5 Examples of reproduction of tactile stimuli 6

2. Conditions of Operation Confirmation Test 7

3. Hardware 7
3.1 Example of Hardware Configuration 7
3.2 Used Pins 7

4. Software Explanation 8
4.1 Operation Outline 8
4.2 Option Byte Settings 9
4.3 Constants 9
4.4 Global Variables 10
4.5 Functions 10
4.6 Function Specifications 11
4.7 Flowcharts 14
4.7.1 Initialization Function 14
4.7.2 System Initial Setting 15
4.7.3 CPU Initial Setting 16
4.7.4 Timer Array Unit Initial Setting 20
4.7.5 CPU Initial Setting 22
4.7.6 External maskable interrupt Initial Setting 31
4.7.7 D/A Converter initial setting 33
4.7.8 Main Processing 36
4.7.9 Main Initial Setting 37
4.7.10 External Maskable Interrupt Operation Start Function 38
4.7.11 D/A Conversion Value Setting Function 38
4.7.12 D/A Converter Operation Start Function 39
4.7.13 INTC0 Interrupt 40
4.7.14 Starting output square wave 41
4.7.15 Frequency Setting of Output Wave 42
4.7.16 Duration Setting of Output Wave 43
4.7.17 TAU00 Operation Start Function 44
4.7.18 TAU01 Operation Start Function 45
4.7.19 TAU00 Interrupt 45
4.7.20 TAU01 Interrupt 46

4.7.21 Stopping output square wave 46
4.7.22 TAU00 Operation Stop Function 47
4.7.23 TAU01 Operation Stop Function 47

5. Sample Code 48

1. Specifications

In this application note, a timer array unit (TAU), a D/A converter (DAC), and an amplifier are used to control a piezoelectric actuator of a type consisting of a piezoelectric element and a vibrating plate. A square wave generated by the timer array unit is amplitude-modulated by the D/A converter to generate a control waveform. Moreover, a voltage obtained by amplifying the control waveform using the amplifier is applied to the piezoelectric actuator.

Table 1.1 shows the required peripheral functions and their uses.

Table 1.1 Used Peripheral Functions and Purposes

Peripheral Functions	Purposes
Timer Array Unit Channel 0	To generate square wave
Timer Array Unit Channel 1	To measure output duration
D/A converter	To modulate wave amplitude
External maskable interrupt (INTP0)	As trigger of when to output wave

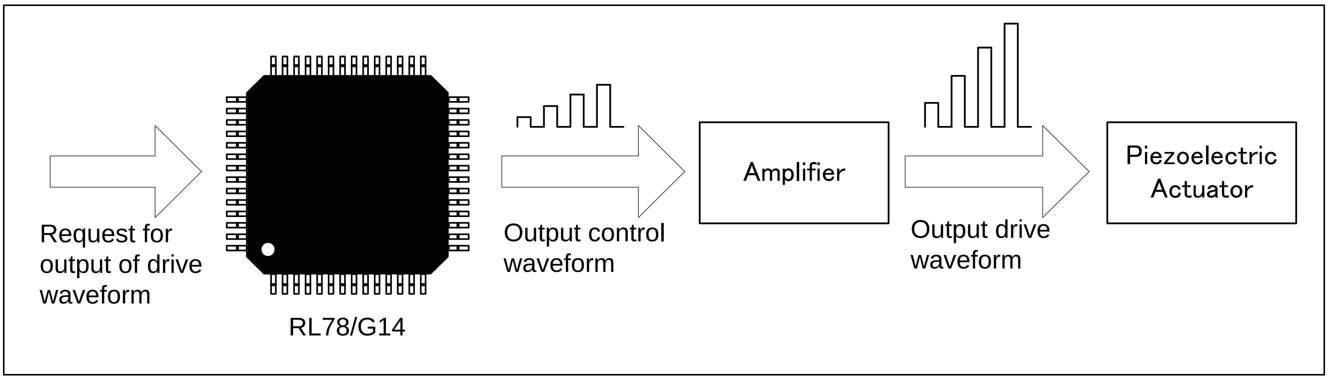

Figure 1.1 Outline to drive piezoelectric actuator

1.1 Method of driving the piezoelectric actuator

When a voltage is applied to a piezoelectric element, the element is warped or deformed according to the applied voltage. Moreover, a piezoelectric element has a polarity; when the direction of application of the voltage is reversed, the element is deformed in the opposite direction.
This piezoelectric effect can be utilized to cause the piezoelectric element to vibrate, by repeatedly changing an electrical potential applied across to two electrodes in a short period of time.
In this application note, to obtain stronger haptic feedback, a square wave that has larger voltage change than other waveforms per unit time is used as the driving waveform. A timer array unit and a D/A converter are used to change the control waveform frequency and amplitude over time. Moreover, the control waveform is amplified up to a voltage at which the piezoelectric element can generate vibrations that can be felt by a human. In this application note, voltages up to a maximum ±12 V are applied to the electrodes of the piezoelectric element, in accordance with the characteristics of the piezoelectric element used.

1.2 Method of generation of control waveform

The interval timer/square wave output function of the timer array unit is used. Using the square wave output, a waveform with a duty ratio of 50% is output. Moreover, the D/A converter is used to modulate the amplitude of the square wave.

In this application note, the tactile receptor characteristics of humans are considered. The control wave frequency can be varied in the range 1 to 1000 Hz. The control wave amplitude can be varied over 256 levels, which is the resolution of the 8-bit D/A converter. By changing the amplitude, the intensity of vibrations of the piezoelectric element can be adjusted.

1.3 Driving waveform frequencies and amplitude modulation patterns

As indicated in equations (1.1) to (1.6) and , Figure 1.2 as the driving waveform frequencies and the amplitude modulation patterns, patterns a to c were prepared. The parameters used are indicated in Table 1.2 below.

Table 1.2 parameters used in calculation of output frequency and amplitude

parameters	contents
f_{FROM}	Frequency of waveform at the start of output
f_{TO}	Frequency of waveform at the end of output
A_{FROM}	Amplitude of waveform at the start of output
A_{TO}	Amplitude of waveform at the end of output
t_{DRIVE}	Output duration of square wave

Pattern a: linear modulation

$$\mathrm{frequency}(t) = (\mathrm{f}_{TO} - \mathrm{f}_{FROM})\frac{t}{t_{DRIVE}} + \mathrm{f}_{FROM}, \qquad 0 \le t \le t_{DRIVE} \tag{1.1}$$

$$\mathrm{amplitude}(t) = (\mathrm{A}_{TO} - \mathrm{A}_{FROM})\frac{t}{t_{DRIVE}} + A_{FROM}, \qquad 0 \le t \le t_{DRIVE} \tag{1.2}$$

Pattern b: square modulation

$$\mathrm{frequency}(t) = (\mathrm{f}_{TO} - \mathrm{f}_{FROM})\left(\frac{t}{t_{DRIVE}}\right)^2 + \mathrm{f}_{FROM}, \qquad 0 \le t \le t_{DRIVE} \tag{1.3}$$

$$\mathrm{amplitude}(t) = (\mathrm{A}_{TO} - \mathrm{A}_{FROM})\left(\frac{t}{t_{DRIVE}}\right)^2 + A_{FROM}, \qquad 0 \le t \le t_{DRIVE} \tag{1.4}$$

Pattern c: square root modulation

$$\mathrm{frequency}(t) = (\mathrm{f}_{TO} - \mathrm{f}_{FROM})\sqrt{\frac{t}{t_{DRIVE}}} + \mathrm{f}_{FROM}, \qquad 0 \le t \le t_{DRIVE} \tag{1.5}$$

$$\mathrm{amplitude}(t) = (\mathrm{A}_{TO} - \mathrm{A}_{FROM})\sqrt{\frac{t}{t_{DRIVE}}} + A_{FROM}, \qquad 0 \le t \le t_{DRIVE} \tag{1.6}$$

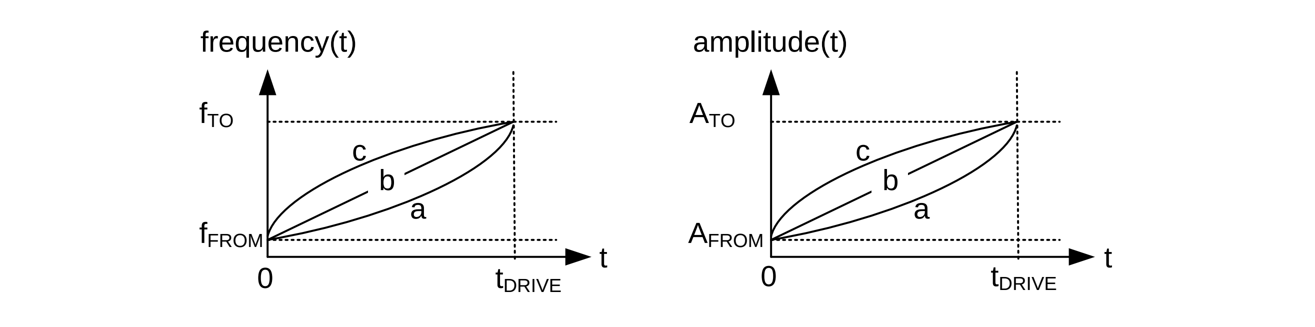

Figure 1.2 image of each modulation pattern

1.4 Method of calculation of device frequency and amplitude

In order to measure the time t in equations (1.1) to (1.6), channel 1 of the timer array unit 0 is used, and

$$\frac{t}{t_{DRIVE}}$$

is set to

$$1-\frac{TCR01}{TDR01}$$

to calculate the frequency and amplitude.

1.5 Examples of reproduction of tactile stimuli

Table 1.3 and Figure 1.3 indicate D/A converter output waveforms that reproduce pseudo-tactile stimuli when a button is pressed and is released.

Table 1.3 Setting parameters

parameters	press	release
fFROM	100 Hz	300 Hz
fTO	300 Hz	100 Hz
AFROM	0 V	VDD V
ATO	VDD V	0 V
tDRIVE	100 ms	125 ms
Modulation pattern	a	a

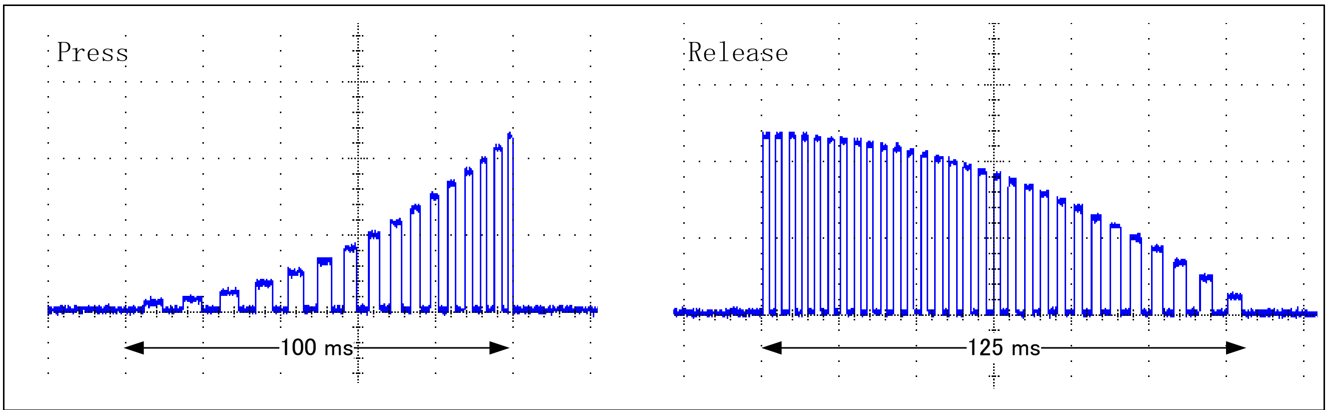

Figure 1.3 Output waveform of tactile stimuli reproduction example.

2. Conditions of Operation Confirmation Test

The sample code with this application note runs properly under the conditions below.

Table 2.1 Operation Confirmation Conditions

Items	Contents
MCU	RL78/G14（R5F104PJA）
Operating frequencies	High-speed on-chip oscillator clock: 32MHz
Operating voltage	5.0V LVD operations (VLVD): reset mode 2.81V (2.75V)
Integrated development environment (CS+)	CS+ for CC V7.00.00
C compiler (CS+)	CC-RL V1.07.00
Integrated development environment (e2 studio)	e2 studio V7.1.0
C compiler (e2 studio)	CC-RL V1.07.00

3. Hardware

3.1 Example of Hardware Configuration

Figure 3.1 shows an example of the hardware configuration used in this application note.

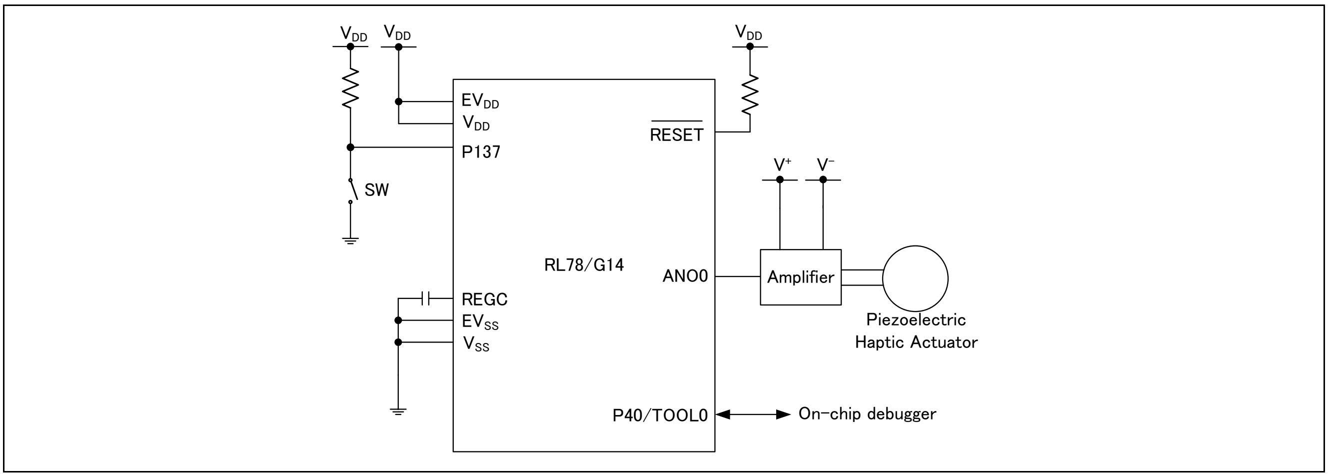

Figure 3.1 Hardware Configuration

Note: 1. This simplified circuit diagram was created to show an overview of connections only. When actually designing your circuit, make sure the design includes sufficient pin processing and meets electrical characteristic requirements. (Connect each input-only port to V_{DD} or V_{SS} through a resistor.)

3.2 Used Pins

Table 3.1 shows list of used Pins and assigned functions.

Table 3.1 List of Pins and Functions

Pin Name	Input/Output	Function
P137/INTP0	Input	Connected to switch
ANO0	Output	Output control waveform

4. Software Explanation

4.1 Operation Outline

In the sample program with this application note, MCU shifts to STOP mode after initialization of Timer Array Unit, D/A Converter and External Maskable Interrupt.
MCU returns from STOP mode by external interrupt. And after outputting the control waveform to the piezoelectric element, shifts to STOP mode again.

The details are shown in ① to ⑨ below.

① Initialize the Timer Array Unit

<Conditions for setting channel 0>

- Timer operation mode is set to Interval Timer.
- Interval time is set to 10ms by the Timer data register (TDR).
- Timer output is disabled by the Timer output enable register (TOE).
- Interval time interrupt (INTTM00) is enabled.

<Conditions for setting channel 1>

- Timer operation mode is set to Interval Timer.
- Interval time is set to 1000ms by the timer data register (TDR).
- Timer output is disabled by the Timer output enable register (TOE).
- Interval time interrupt (INTTM01) is enabled.

② Initialize the External Maskable Interrupt

<Conditions for setting External Maskable Interrupt>

- Use P137/INTP0 pin.
- Select both rising and falling edges as valid edge.

③ Initialize the D/A Converter

<Conditions for setting D/A Converter>

- Set D/A converter operation mode to Normal mode
- Set D/A conversion value setting register to 0.

④ Enable the External maskable interrupt.

⑤ Enable maskable interrupts.

⑥ MCU is shifted to STOP mode.

⑦ MCU returns from STOP mode by external interrupt.

⑧ Judge whether the input signal is rising edge or falling edge, and output waveform pattern according to the result.

⑨ MCU is shifted to STOP mode after the output is done.

Steps ⑦ to ⑨ are repeated

4.2 Option Byte Settings

Table 4.1 lists the option byte settings.

Table 4.1 Option Byte Settings

Address	Setting Value	Contents
000C0H/010C0H	1110 1111B	Operation of Watchdog timer is stopped （counting is stopped after reset.）
000C1H/010C1H	0111 1111B	LVD operation (VLVD): reset mode Detection voltage: Rising edge = 2.81V, Falling edge = 2.75V
000C2H/010C2H	1110 1000B	HS mode, High-speed on-chip oscillator clock: 32 MHz
000C3H/010C3H	1000 0100B	On-chip debugging enabled

4.3 Constants

Table 4.2 lists the constants that are used in this sample program.

Table 4.2 Constants in the sample program

Constant Name	Setting Value	Contents
FREQ_TAU00	62500	Count clock frequency of TAU00
FREQ_TAU01	62500	Count clock frequency of TAU01
FREQ_OUTPUT_WAVE_MAX	1000	Max frequency of output square wave
FREQ_OUTPUT_WAVE_MIN	1	Min frequency of output square wave
TIME_OUTPUT_WAVE_MAX	1000	Max duration of output square wave
TIME_OUTPUT_WAVE_MIN	1	Min duration of output square wave
SW_ON	0	Port level when the switch is pressed
SW_OFF	1	Port input level when the switch is released

4.4 Global Variables

Table 4.3 lists the global variables.

Table 4.3 Global Variables

Type	Variable Name	Contents	Functions used in
uint8_t	g_wave_output_enable	Whether a square wave is being output	r_main(), start_wave(), stop_wave(),
uint16_t	g_frequency_from	Frequency of waveform at the start of output	r_tau0_channel0_interrupt(), start_wave(),
uint16_t	g_frequency_to	Frequency of waveform at the end of output	r_tau0_channel0_interrupt(), start_wave(),
uint8_t	g_gain_from	Amplitude of waveform at the start of output	r_tau0_channel0_interrupt(), start_wave(),
uint8_t	g_gain_to	Amplitude of waveform at the end of output	r_tau0_channel0_interrupt(), start_wave(),
uint16_t	g_duration	Output duration	start_wave(),
uint8_t	g_transition_pattern	Modulation pattern	r_tau0_channel0_interrupt(), start_wave(),
uint8_t	g_wave_toggle	control variable for outputting square wave	r_tau0_channel0_interrupt(), start_wave(),

4.5 Functions

Table 4.4 lists the functions.

Table 4.4 Functions

Function Name	Outline
main	Main processing
R_MAIN_UserInit	Main initial setting
set_frequency	Set frequency of output waveform.
set_duration	Set duration output waveform
start_wave	Start output of square wave
stop_wave	Stop output of square wave
r_tau0_channel0_interrupt	Interrupt handler of TAU00
r_tau0_channel1_interrupt	Interrupt handler of TAU01
r_intc0_interrupt	Interrupt handler ofINTC0

4.6 Function Specifications

This part describes function specifications of the sample code.

[Function Name]	r_main
Outline	Main processing
Header	—
Declaration	—
Description	After calling R_MAIN_UserInit(), shift to STOP mode.
Arguments	None
Return value	None
Remarks	None

[Function Name]	R_MAIN_UserInit
Outline	Main initial setting
Header	—
Declaration	static void R_MAIN_UserInit(void);
Description	Enable interrupt processing by the EI instruction. Next, set initial value to the D/A conversion value setting register (DACS) and enabled/A conversion operation.
Arguments	None
Return value	None
Remarks	None

[Function Name]	set_frequency	
Outline	Function to set frequency of output waveform.	
Header	r_cg_timer.h	
Declaration	void set_frequency(uint16_t frequency);	
Description	Set TDR00 register the value to the frequency designated by argument.	
Arguments	frequency	Output frequency (1 ~ 1000 [Hz])
Return value	None	
Remarks	None	

[Function Name]	set_duration	
Outline	Function to set duration output waveform	
Header	r_cg_timer.h	
Declaration	void set_duration(uint16_t duration);	
Description	Set TDR01 register the value to the duration designated by argument.	
Arguments	duration	Output duration (1 ~ 1000 [ms])
Return value	None	
Remarks	None	

[Function Name]	start_wave	
Outline	Function to start outputting square wave	
Header	r_cg_timer.h	
Declaration	void start_wave(uint16_t frequcney_from, uint16_t frequency_to, uint16_t gain_from, uint16_t gain_to, uint16_t inteval, uint16_t transition_pattern);	
Description	start output square wave with designated frequency, amplitude, and duration by arguments.	
Arguments	frequency_from	Frequency of waveform at the start of output (1-1000 [Hz])
	frequcney_to	Frequency of waveform at the end of output (1 - 1000[Hz])
	gain_from	Amplitude of waveform at the start of output (0-255)
	gain_to	Amplitude of waveform at the end of output (0-255)
	duration	Output duration (1 ~ 1000 [ms])
	transition_pattern	Modulation pattern (LINEAR, SQUARE, SQUARE_ROOT)
Return value	None	
Remarks	None	

[Function Name]	stop_wave	
Outline	Function to stop output of square wave	
Header	r_cg_timer.h	
Declaration	void stop_wave(void);	
Description	Stop output of square wave	
Arguments	None	
Return value	None	
Remarks	None	

[Function Name]	r_tau0_channel0_interrupt
Outline	Interrupt handler of TAU00
Header	None
Declaration	static void __near r_tau0_channel0_interrupt(void);
Description	Interrupt handler of TAU00
Arguments	None
Return value	None
Remarks	None

[Function Name]	r_tau0_channel1_interrupt
Outline	Interrupt handler of TAU01
Header	None
Declaration	static void __near r_tau0_channel1_interrupt(void);
Description	Interrupt handler of TAU01
Arguments	None
Return value	None
Remarks	None

[Function Name]	r_intc0_interrupt
Outline	Interrupt handler of INTC0
Header	None
Declaration	static void __near r_intc0_interrupt(void);
Description	Interrupt handler of INTC0
Arguments	None
Return value	None
Remarks	None

4.7 Flowcharts

Figure 4.1 shows an overall flow of the sample code.

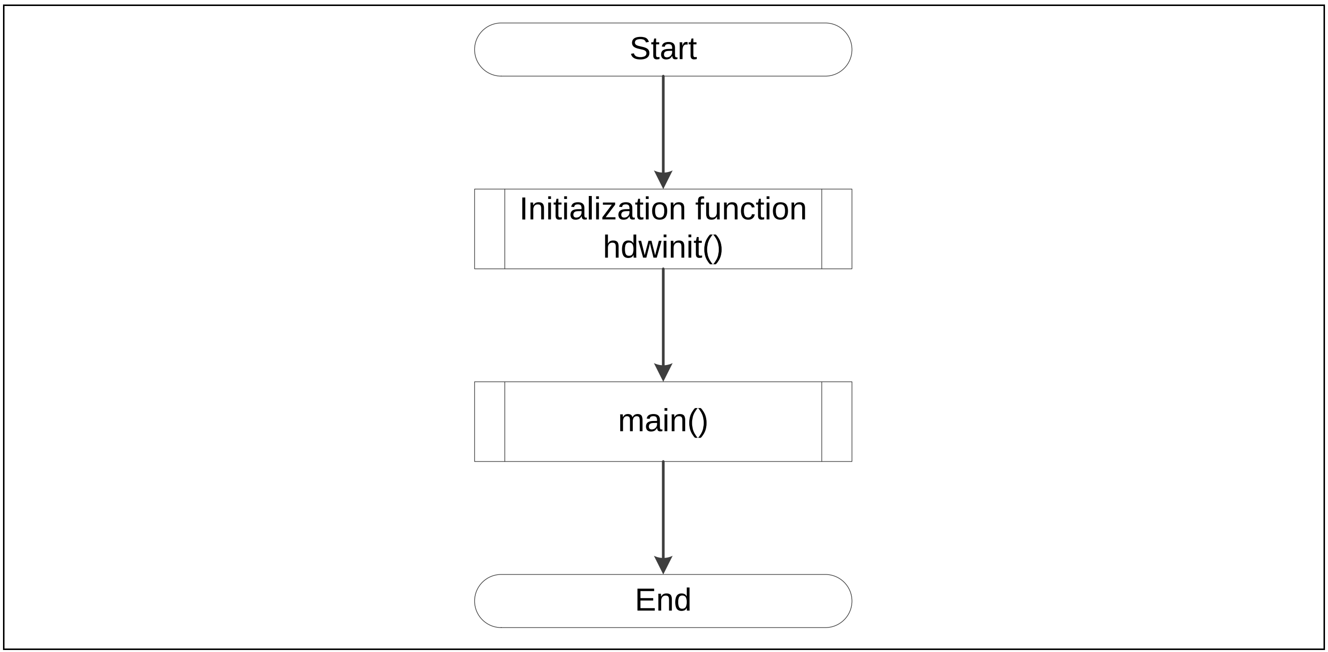

Figure 4.1 Overall Flow

4.7.1 Initialization Function

Figure 4.2 shows the flowchart of the initialization function.

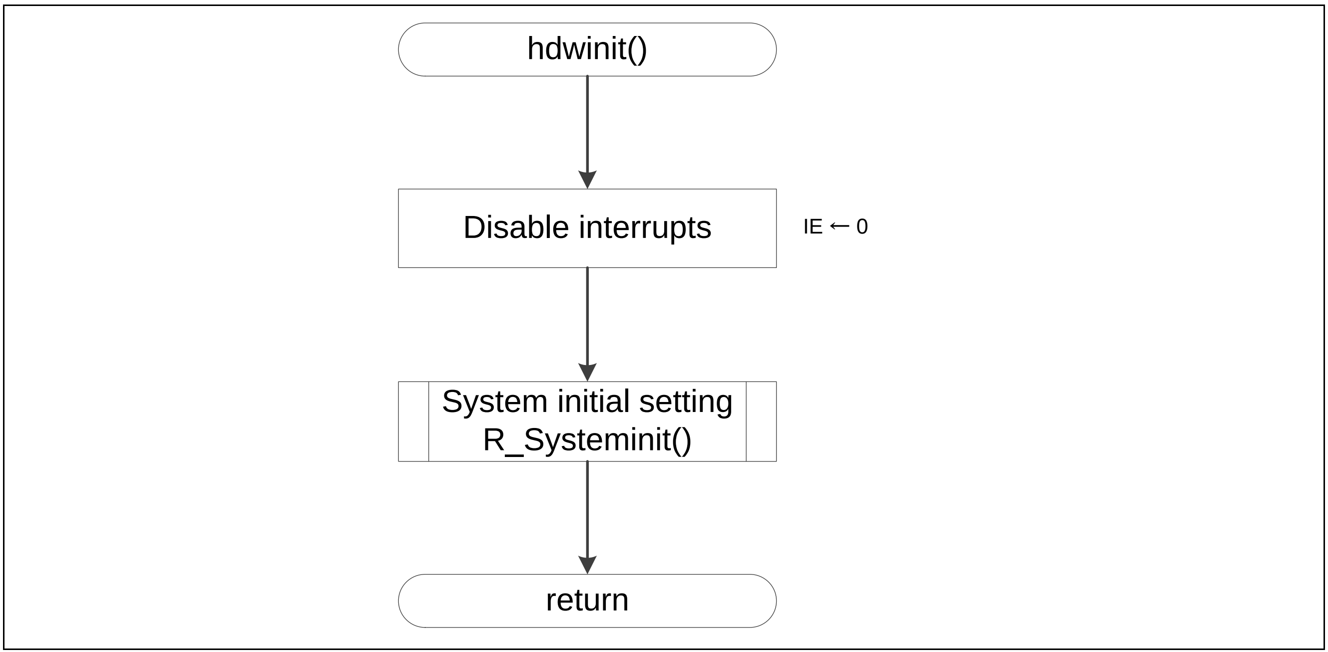

Figure 4.2 Initialization Function

4.7.2 System Initial Setting

Figure 4.3 shows the flowchart of the system initial setting.

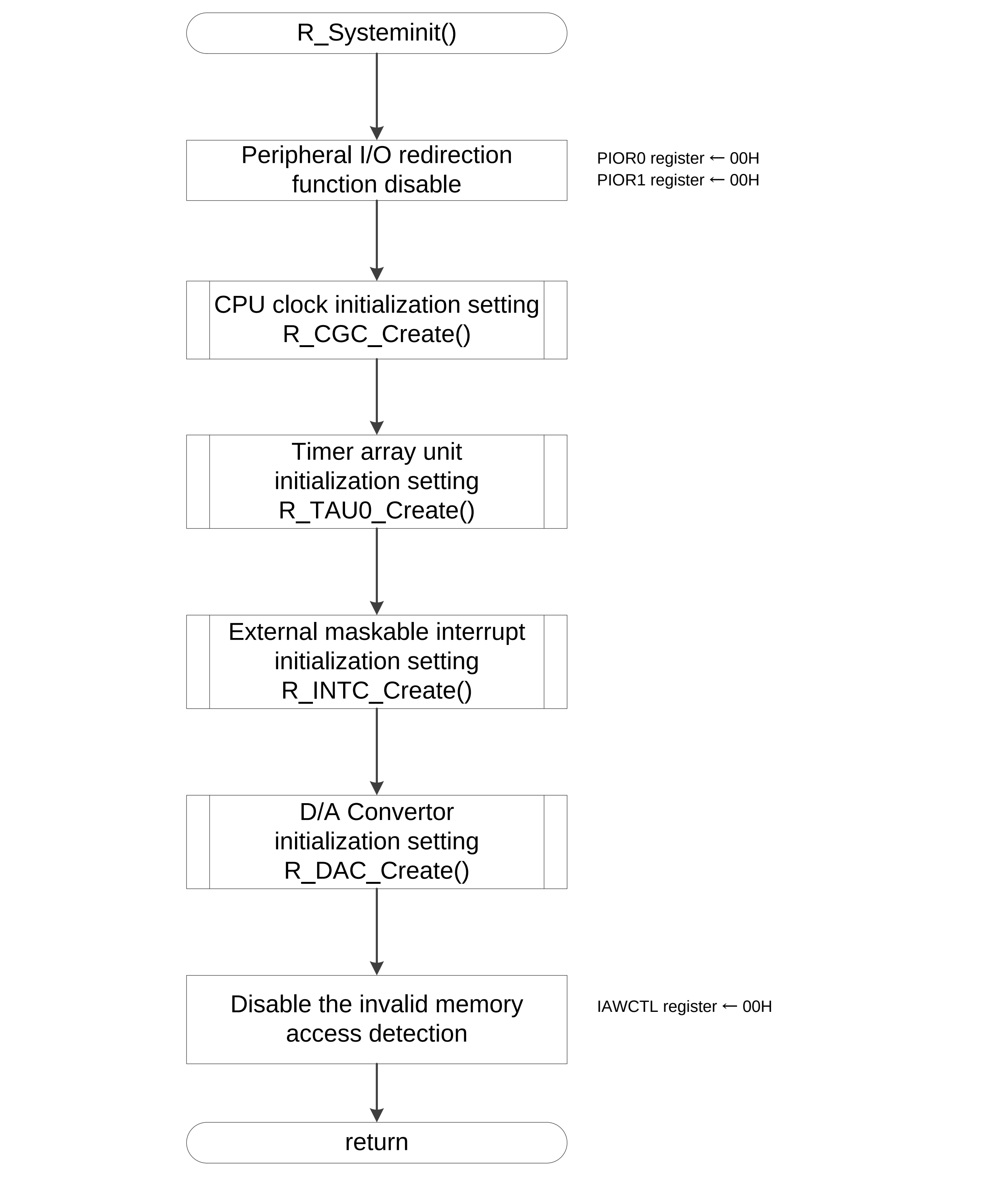

Figure 4.3 System initial setting

4.7.3 CPU Initial Setting

Figure 4.2 shows the flowchart of the CPU initial setting.

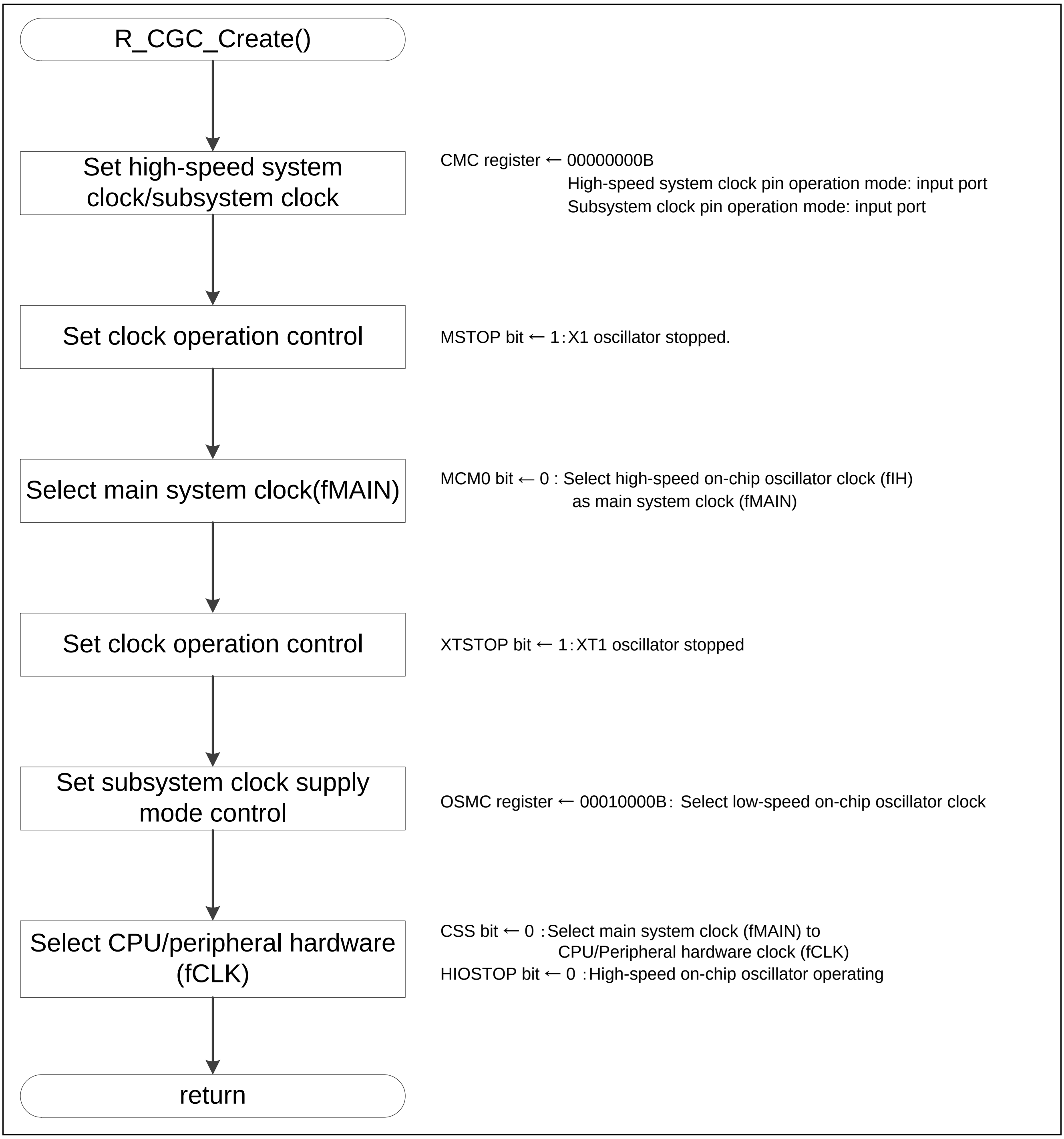

Figure 4.4 CPU Initial Setting

Clock operation mode setting

- Clock operation mode control register (CMC)
  High-speed system clock pin operation mode: input port mode
  Subsystem clock pin operation mode: input port mode

Symbol: CMC

7	6	5	4	3	2	1	0
EXCLK	OSCSEL	EXCLKS	OSCSELS	0	AMPHS1	AMPHS0	AMPH
0	**0**	**0**	**0**	0	**0**	**0**	**0**

Bits 7-6

EXCLK	OSCSEL	**High-seed oscillation clock pin operation mode**	**X1/P121 Port**	**X2/EXCLK/P122 Port**
0	**0**	**Input port mode**	**Input port**	
0	1	X1 oscillation mode	Crystal/ceramic resonator connection	
1	0	Input port mode	Input port	
1	1	External clock input mode	Input port	External clock input

Bits 5-4

EXCLKS	OSCSELS	**Subsystem clock pin operation mode**	**XT1/P123 Pin**	**XT2/EXCLKS/P124 Pin**
0	**0**	**Input port mode**	**Input port**	
0	1	XT1 oscillation mode	Crystal resonator connection	
1	0	Input port mode	Input port	
1	1	External clock input mode	Input port	External clock input

Bits 2-1

AMPHS1	AMPHS0	**XT1 oscillator oscillation mode selection**
0	**0**	**Low-power consumption oscillation (default)**
0	1	Normal oscillation
1	0	Ultra-low power consumption oscillation
1	1	Setting prohibited

Bit 0

AMPH	**Control of X1 clock oscillation frequency**
0	**1MHz ≤ f_X ≤ 10MHz**
1	10MHz < f_X ≤ 20MHz

Note: Refer to the RL78/G14 User's Manual (Hardware version) for details on how to set registers.

Operation control of clocks

- Clock operation status control register (CSC)

  High-speed system clock operation control: X1 oscillator stopped

  Subsystem clock operation control: XT1 oscillator stopped

  High-speed on-chip oscillator clock operation control: High-speed on-chip oscillator

Symbol: CSC

7	6	5	4	3	2	1	0
MSTOP	XTSTOP	0	0	0	0	0	HIOSTOP
1	**1**	0	0	0	0	0	**0**

Bit 7

MSTOP	High-speed system clock operation control		
	X1 oscillation mode	**External clock input mode**	**Input port mode**
0	X1 oscillator operating	External clock from EXCLK pin is valid	**Input port**
1	**X1 oscillator stopped**	External clock from EXCLK pin is invalid	

Bit 6

XTSTOP	Subsystem clock operation control		
	XT1 oscillation mode	**External clock input mode**	**Input port mode**
0	XT1 oscillator operating	External clock from EXCLKS pin is valid	**Input port**
1	**XT1 oscillator stopped**	External clock from EXCLKS pin is invalid	

Bit 0

HIOSTOP	High-speed on-chip oscillator clock operation control
0	**High-speed on-chip oscillator operating**
1	High-speed on-chip oscillator stopped

Note: Refer to the RL78/G14 User's Manual (Hardware version) for details on how to set registers.

System clock control setting

- System clock control register (CKC)

Select the high-speed on-chip oscillator clock as a CPU/peripheral hardware clock.

Symbol: CKC

7	6	5	4	3	2	1	0
CLS	CSS	MCS	MCM0	0	0	0	0
0	**0**	**0**	**0**	0	0	0	0

Bit 6

CSS	Selection of CPU/peripheral hardware clock (f_{CLK})
0	**Main system clock (f_{MAIN})**
1	Subsystem clock (f_{SUB})

Bit 4

MCM0	Main system clock (f_{MAIN}) operation control
0	**Selects the high-speed on-chip oscillator clock (f_{IH}) as the main system clock (f_{MAIN})**
1	Selects the high-speed system clock (f_{MX}) as the main system clock (f_{MAIN})

Note: Refer to the RL78/G14 User's Manual (Hardware version) for details on how to set registers.

4.7.4 Timer Array Unit Initial Setting

Figure 4.5 and Figure 4.6 shows the flowchart for the timer array unit initial setting.

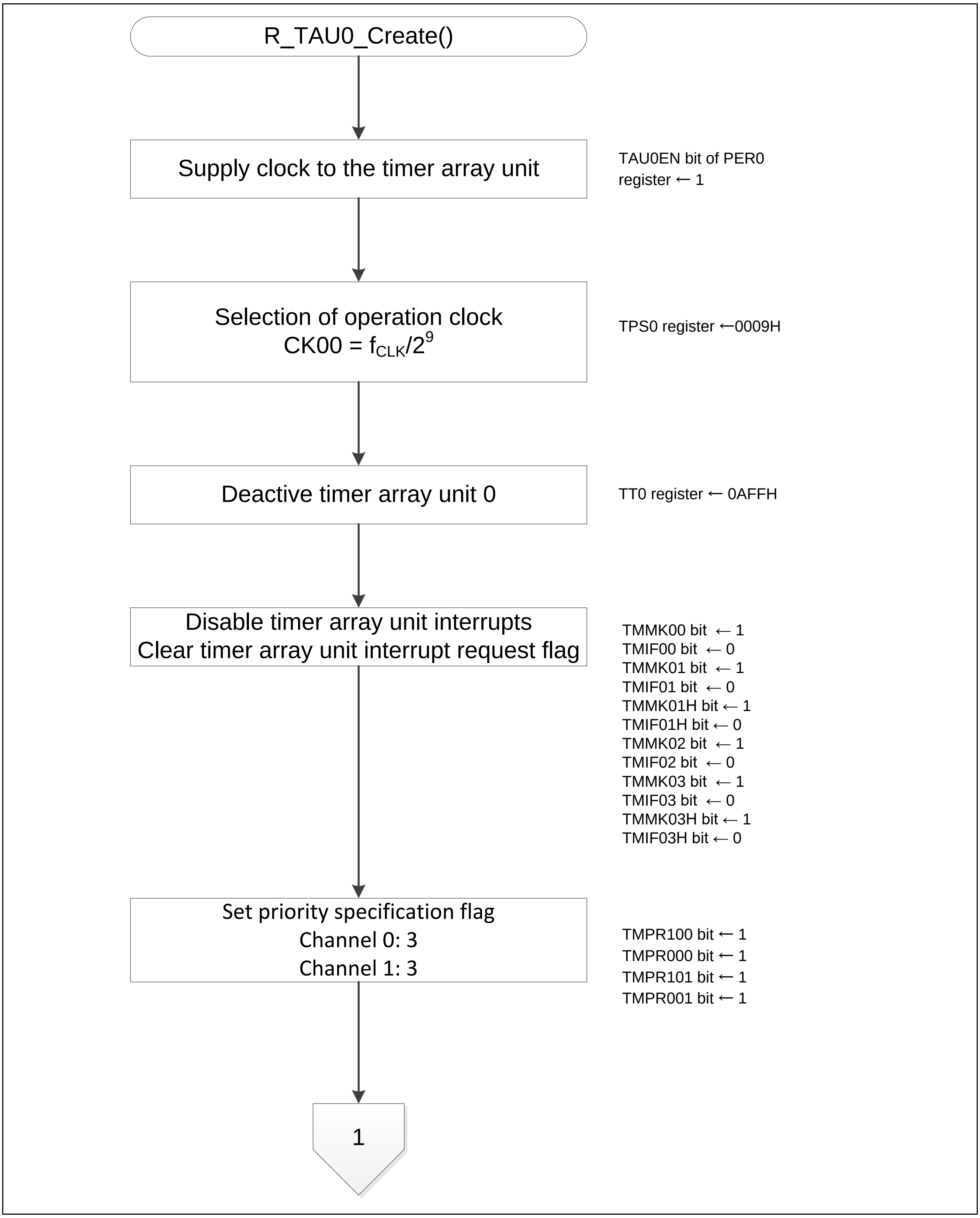

Figure 4.5 CPU Initial Setting

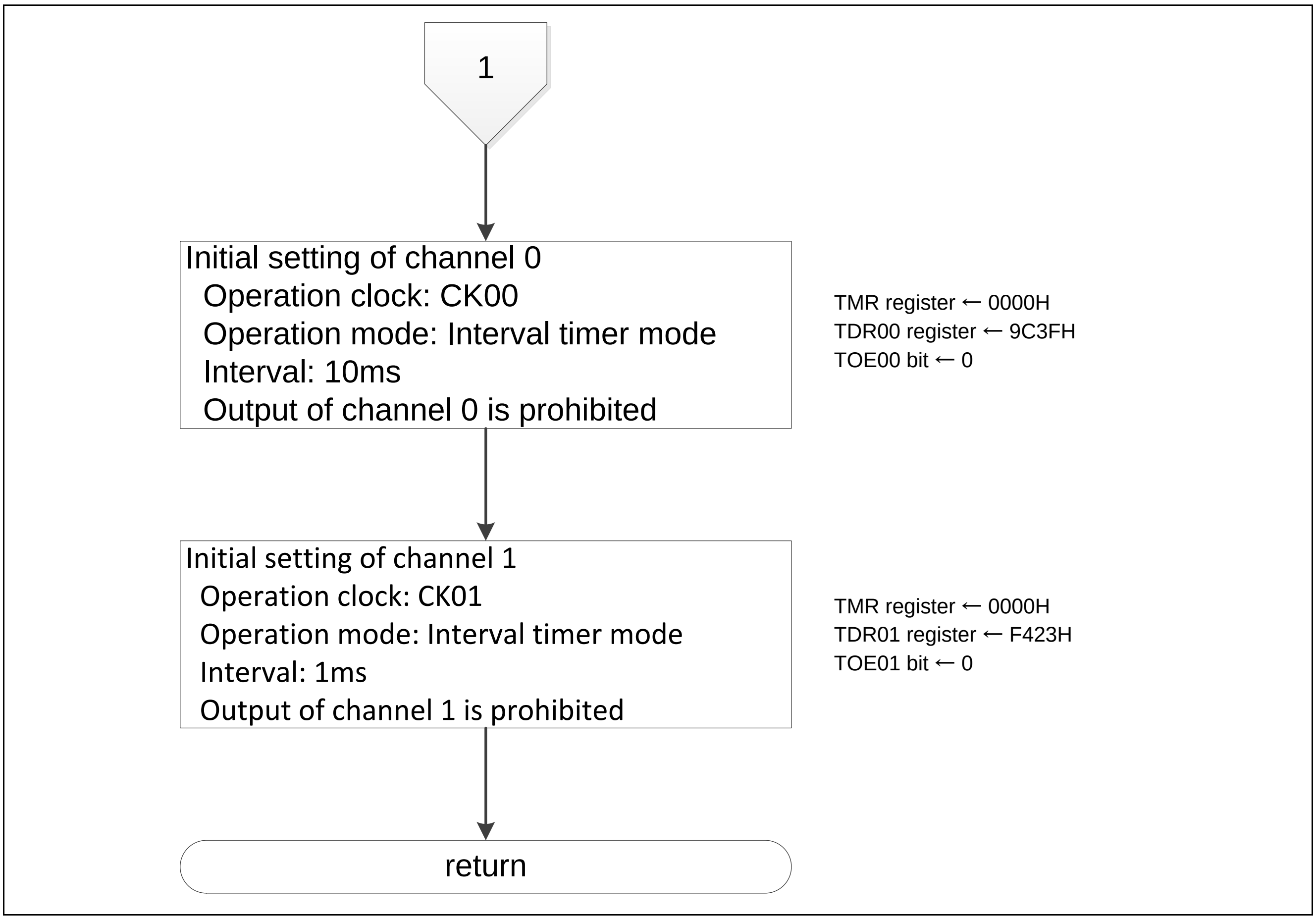

Figure 4.6 CPU Initial Setting

4.7.5 CPU Initial Setting

Figure 4.2 shows the flowchart of the CPU initial setting.

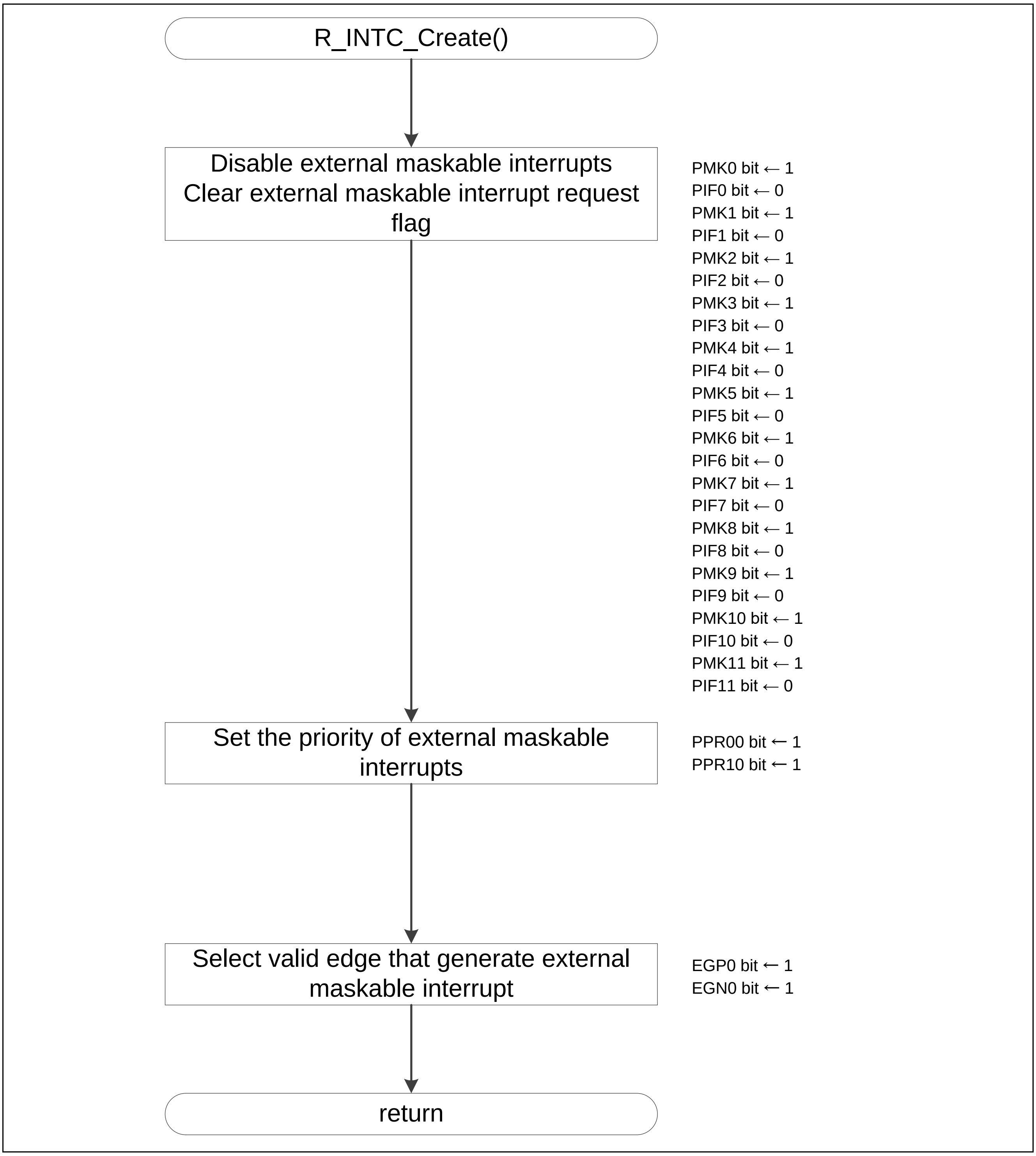

Figure 4.7 CPU Initial Setting

Clock supply to timer array unit started

- Peripheral enable register 0 (PER0)

Clock supply to timer array unit

Symbol: PER0

7	6	5	4	3	2	1	0
RTCEN	IICA1EN	ADCEN	IICA0EN	SAU1EN	SAU0EN	TAU1EN	TAU0EN
x	x	x	x	x	x	x	**1**

Bit 0

TAU0EN	Control of timer array 0 unit input clock
0	Stops supply of input clock.
1	**Supplies input clock.**

Operation clock setting

- Timer clock select register 0 (TPS0)

Selection of operation clock (CK00)

Symbol: TPS0

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	PRS 031	PRS 030	0	0	PRS 021	PRS 020	PRS 013	PRS 012	PRS 011	PRS 010	PRS 003	PRS 002	PRS 001	PRS 000
0	0	**0**	**0**	0	0	**0**	**0**	**1**	**1**	**0**	**1**	**1**	**0**	**0**	**1**

PRS 003	PRS 002	PRS 001	PRS 000	Operation Clock (CK00) Selection					
					f_{CLK} = 2MHz	f_{CLK} = 5MHz	f_{CLK} = 10MHz	f_{CLK} = 20MHz	f_{CLK} = 32MHz
0	0	0	0	f_{CLK}	2MHz	5MHz	10MHz	20MHz	32 MHz
0	0	0	1	$f_{CLK}/2$	1MHz	2.5MHz	5MHz	10MHz	16 MHz
0	0	1	0	$f_{CLK}/2^2$	500kHz	1.25MHz	2.5MHz	5MHz	8 MHz
0	0	1	1	$f_{CLK}/2^3$	250kHz	625kHz	1.25MHz	2.5MHz	4 MHz
0	1	0	0	$f_{CLK}/2^4$	125kHz	312.5kHz	625kHz	1.25MHz	2 MHz
0	1	0	1	$f_{CLK}/2^5$	62.5kHz	156.2kHz	312.5KHz	625KHz	1 MHz
0	1	1	0	$f_{CLK}/2^6$	31.25kHz	78.1kHz	156.2kHz	312.5kHz	500 kHz
0	1	1	1	$f_{CLK}/2^7$	15.62kHz	39.1kHz	78.1kHz	156.2kHz	250 kHz
1	0	0	0	$f_{CLK}/2^8$	7.81kHz	19.5kHz	39.1kHz	78.1kHz	125 kHz
1	**0**	**0**	**1**	$f_{CLK}/2^9$	**3.91kHz**	**9.76kHz**	**19.5kHz**	**39.1kHz**	**62.5 kHz**
1	0	1	0	$f_{CLK}/2^{10}$	1.95kHz	4.88kHz	9.76kHz	19.5kHz	31.25 kHz
1	0	1	1	$f_{CLK}/2^{11}$	976Hz	2.44kHz	4.88kHz	9.76kHz	15.6 kHz
1	1	0	0	$f_{CLK}/2^{12}$	488Hz	1.22kHz	2.44kHz	4.88kHz	7.81 kHz
1	1	0	1	$f_{CLK}/2^{13}$	244Hz	610Hz	1.22kHz	2.44kHz	3.91 kHz
1	1	1	0	$f_{CLK}/2^{14}$	122Hz	305Hz	610Hz	1.22kHz	1.95 kHz
1	1	1	1	$f_{CLK}/2^{15}$	61Hz	153Hz	305Hz	610Hz	977 Hz

Note: Refer to the RL78/G14 User's Manual (Hardware version) for details on how to set registers.

Channel stop control

- Timer channel stop register 0 (TT0)

Stop the counting operation of each channel

Symbol: TT0

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	TT H03	0	TT H01	0	TT 07	TT 06	TT 05	TT 04	TT 03	TT 02	TT 01	TT 00
0	0	0	0	1	0	1	0	1	1	1	1	**1**	**1**	**1**	**1**

Bit 3

TT03	**Operation stop trigger of channel 3**
0	TE03 bit is cleared to 0 and the count operation is stopped.
1	**Operation is stopped (stop trigger is generated).**

Bit 2

TT02	**Operation stop trigger of channel 2**
0	TE02 bit is cleared to 0 and the count operation is stopped.
1	**Operation is stopped (stop trigger is generated).**

Bit 1

TT01	**Operation stop trigger of channel 1**
0	TE01 bit is cleared to 0 and the count operation is stopped.
1	**Operation is stopped (stop trigger is generated).**

Bit 0

TT00	**Operation stop trigger of channel 0**
0	TE00 bit is cleared to 0 and the count operation is stopped.
1	**Operation is stopped (stop trigger is generated).**

Note: Refer to the RL78/G14 User's Manual (Hardware version) for details on how to set registers.

Timer array unit 0 channel 0 initialization

- Timer mode register 00 (TMR00)

Selection of operation mode, Selection of start trigger,
Selection of operation clock

Symbol: TMR00

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CKS 001	CKS 000	0	CCS 00	0	STS 002	STS 001	STS 000	CIS 001	CIS 000	0	0	MD 003	MD 002	MD 001	MD 000
0	**0**	0	**0**	0	**0**	**0**	**0**	**0**	**0**	0	0	**0**	**0**	**0**	**0**

Bits 15-14

CKS001	CKS000	Selection of operation clock (f_{MCK}) for channel 0
0	**0**	**Operation clock CKm0 set in timer clock selection register m (TPSm)**
0	1	Operation clock CKm2 set in timer clock selection register m (TPSm)
1	0	Operation clock CKm1 set in timer clock selection register m (TPSm)
1	1	Operation clock CKm3 set in timer clock selection register m (TPSm)

Bit 12

CCS00	Selection of channel 0 operation clock (f_{TCLK})
0	**Operation clock (f_{MCK}) set in bits CKS000 and CKS001**
1	Valid edge of input signal from TI00 pin

Bits 10-8

STS 002	STS 001	STS 000	Setting start or capture trigger of channel 0
0	**0**	**0**	**Only software trigger start is valid (other trigger sources are unselected)**
0	0	1	Valid edge of TI00 pin input is used as both the start trigger and capture trigger
0	1	0	Both edges of TI00 pin input are used as the start trigger and capture trigger
1	0	0	Interrupt signal of master channel is used (when using slave channel with simultaneous channel operation function)
Other than above			Setting prohibited

Note: Refer to the RL78/G14 User's Manual (Hardware version) for details on how to set registers.

Symbol: TMR00

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CKS 001	CKS 000	0	CCS 00	0	STS 002	STS 001	STS 000	CIS 001	CIS 000	0	0	MD 003	MD 002	MD 001	MD 000
0	**0**	0	**0**	0	**0**	**0**	**0**	**0**	**0**	0	0	**0**	**0**	**0**	**0**

Bits 7-6

CIS 001	CIS 000	Selection of TI00 pin input valid edge
0	**0**	**Falling edge**
0	1	Rising edge
1	0	Both edges (when low-level width is measured)
1	1	Both edges (when high-level width is measured)

Bits 3-0

MD 003	MD 002	MD 001	MD 000	Operation mode of channel 0
0	**0**	**0**	**0**	**Interval timer mode (Timer interrupt is not generated when counting is started).**
			1	Interval timer mode (Timer interrupt is generated when counting is started）.
0	1	0	0	Capture mode (Timer interrupt is not generated when counting is started).
			1	Capture mode (Timer interrupt is generated when counting is started).
0	1	1	0	Event counter mode (Timer interrupt is not generated when counting is started).
1	0	0	0	One-count mode (Start trigger is invalid during counting operation).
			1	One-count mode (Start trigger is valid during counting operation).
1	1	0	0	Capture & one-count mode (Timer interrupt is not generated when counting is started Start trigger is invalid during counting operation).
Other than above				Setting prohibited

Note: Refer to the RL78/G14 User's Manual (Hardware version) for details on how to set registers.

Timer array unit 0 channel 1 initialization

- Timer mode register 01 (TMR01)

Selection of operation mode, Selection of start trigger,
Selection of operation clock

Symbol: TMR01

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CKS 011	CKS 010	0	CCS 01	SPLIT 01	STS 012	STS 011	STS 010	CIS 011	CIS 010	0	0	MD 013	MD 012	MD 011	MD 010
0	**0**	0	**0**	0	**0**	**0**	**0**	**0**	**0**	0	0	**0**	**0**	**0**	**0**

Bits 15-14

CKS011	CKS010	Selection of operation clock (f_{MCK}) for channel 1
0	**0**	**Operation clock CKm0 set in timer clock selection register m (TPSm)**
0	1	Operation clock CKm2 set in timer clock selection register m (TPSm)
1	0	Operation clock CKm1 set in timer clock selection register m (TPSm)
1	1	Operation clock CKm3 set in timer clock selection register m (TPSm)

Bit 12

CCS01	Selection of channel 1 operation clock (f_{TCLK})
0	**Operation clock (f_{MCK}) set in bits CKS010 and CKS011**
1	Valid edge of input signal from TI01 pin

Bit 11

SPLIT01	Selection of 8 or 16-bit timer operation for channel 1
0	**Operates as 16-bit timer.**
1	Operates as 8-bit timer.

Bits 10-8

STS 012	STS 011	STS 010	Setting start or capture trigger of channel 1
0	**0**	**0**	**Only software trigger start is valid (other trigger sources are unselected)**
0	0	1	Valid edge of TI00 pin input is used as both the start trigger and capture trigger
0	1	0	Both edges of TI00 pin input are used as the start trigger and capture trigger
1	0	0	Interrupt signal of master channel is used (when using slave channel with simultaneous channel operation function)
Other than above			Setting prohibited

Note: Refer to the RL78/G14 User's Manual (Hardware version) for details on how to set registers.

Symbol: TMR01

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CKS 011	CKS 010	0	CCS 01	SPLIT 01	STS 012	STS 011	STS 010	CIS 011	CIS 010	0	0	MD 013	MD 012	MD 011	MD 010
0	**0**	0	**0**	0	**0**	**0**	**0**	**0**	**0**	0	0	**0**	**0**	**0**	**0**

Bit 7-6

CIS 011	CIS 010	Selection of TI01 pin input valid edge
0	**0**	**Falling edge**
0	1	Rising edge
1	0	Both edges (when low-level width is measured)
1	1	Both edges (when high-level width is measured)

Bit 3-0

MD 013	MD 012	MD 011	MD 010	Operation mode of channel 1
0	**0**	**0**	**0**	**Interval timer mode (Timer interrupt is not generated when counting is started).**
			1	Interval timer mode (Timer interrupt is generated when counting is started）.
0	1	0	0	Capture mode (Timer interrupt is not generated when counting is started).
			1	Capture mode (Timer interrupt is generated when counting is started).
0	1	1	0	Event counter mode (Timer interrupt is not generated when counting is started).
1	0	0	0	One-count mode (Start trigger is invalid during counting operation).
			1	One-count mode (Start trigger is valid during counting operation).
1	1	0	0	Capture & one-count mode (Timer interrupt is not generated when counting is started Start trigger is invalid during counting operation).
Other than above				Setting prohibited

Note: Refer to the RL78/G14 User's Manual (Hardware version) for details on how to set registers.

Timer counter control

- Timer data register 00 (TMR00)

Set the compare value to "0270H" which can measure 10 milliseconds.

Symbol : TDR00

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**1**	**1**	**0**	**0**	**0**	**0**

- Timer data register 00 (TMR00)

Set the compare value to "F423H" which can measure 1000 milliseconds.

Symbol : TDR01

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	**1**	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**1**

Configuring the output value for the timer output pin

- Timer output register 0 (TO0)

Configure the output value for the timer output pin for each channel.

Symbol: TO0

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	0	TO07	TO06	TO05	TO04	TO03	TO02	TO01	TO00
0	0	0	0	0	0	0	0	x	x	x	x	x	x	**0**	**0**

x: bits that do not change

Bits 1-0

TO0n	Channel n timer output
0	Timer output value is 0
1	**Timer output value is 1**

Note: Refer to the RL78/G14 user's manual (hardware) for details on individual registers.

Enabling the timer output

- Timer output enable register 0 (TOE0)

Enable/disable the timer output for each channel.

Symbol: TOE0

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	0	TOE07	TOE06	TOE05	TOE04	TOE03	TOE02	TOE01	TOE00
0	0	0	0	0	0	0	0	x	x	x	x	x	x	**0**	**0**

x: bits that do not change

Bits 1-0

TOE0n	Timer output enable/disable of channel n
0	**The TO0n operation stopped by count operation (timer channel output bit).** **Writing to the TO0n bit is enabled.** **The TO0n pin functions as data output, and it outputs the level set to the TO0n bit.** **The output level of the TO0n pin can be manipulated be software.**
1	The TO0n operation enabled by count operation (timer channel output bit). Writing to the TO0n bit is disabled (writing is ignored). The TO0n pin functions as timer output, and the TOE0n bit is set or reset depending on the timer operation. The TO0n pin outputs the square-wave or PWM depending on the timer operation.

Note: Refer to the RL78/G14 User's Manual (Hardware version) for details on how to set registers.

4.7.6 External maskable interrupt Initial Setting

Figure 4.3 shows the flowchart of the external maskable interrupt initial setting.

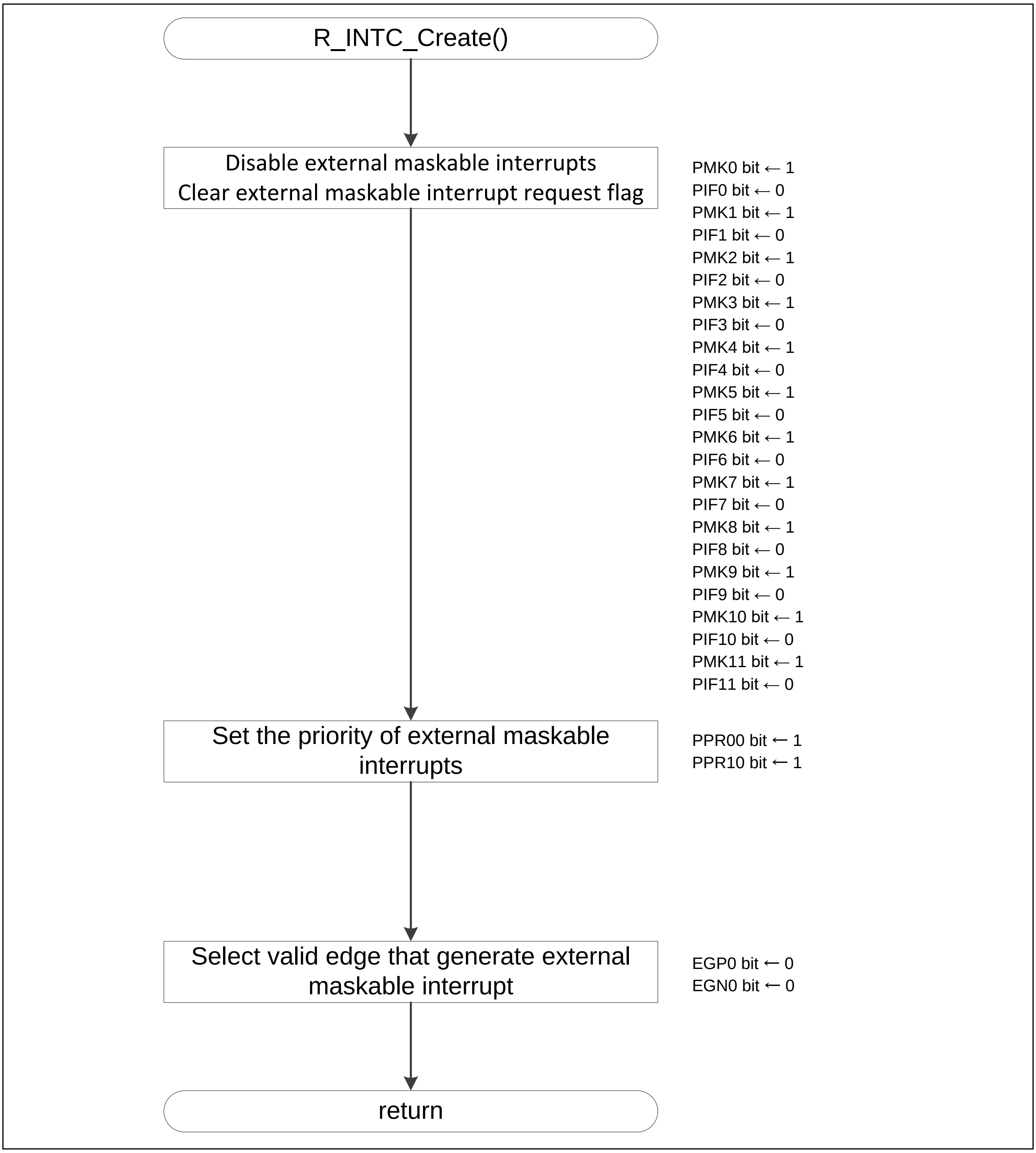

Figure 4.8 External maskable interrupt initial setting

Set edge detection of INTP0 pin

- External interrupt rising edge enable register 0 (EGP0)
  Set valid edge of INTP0 pin.

Symbol: EGP0

7	6	5	4	3	2	1	0
EGP7	EGP6	EGP5	EGP4	EGP3	EGP2	EGP1	EGP0
0	0	0	0	0	0	0	**1**

Symbol: EGN0

7	6	5	4	3	2	1	0
EGN7	EGN6	EGN5	EGN4	EGN3	EGN2	EGN1	EGN0
0	0	0	0	0	0	0	**1**

Bit 0

EGP0	EGN0	INTP0 pin valid edge selection
0	0	Edge detection disabled
0	1	Falling edge
1	0	Rising edge
1	**1**	**Both rising and falling edges**

Note: Refer to the RL78/G14 User's Manual (Hardware version) for details on how to set registers.

4.7.7 D/A Converter initial setting

Figure 4.3 shows the flowchart of the D/A Converter initial setting.

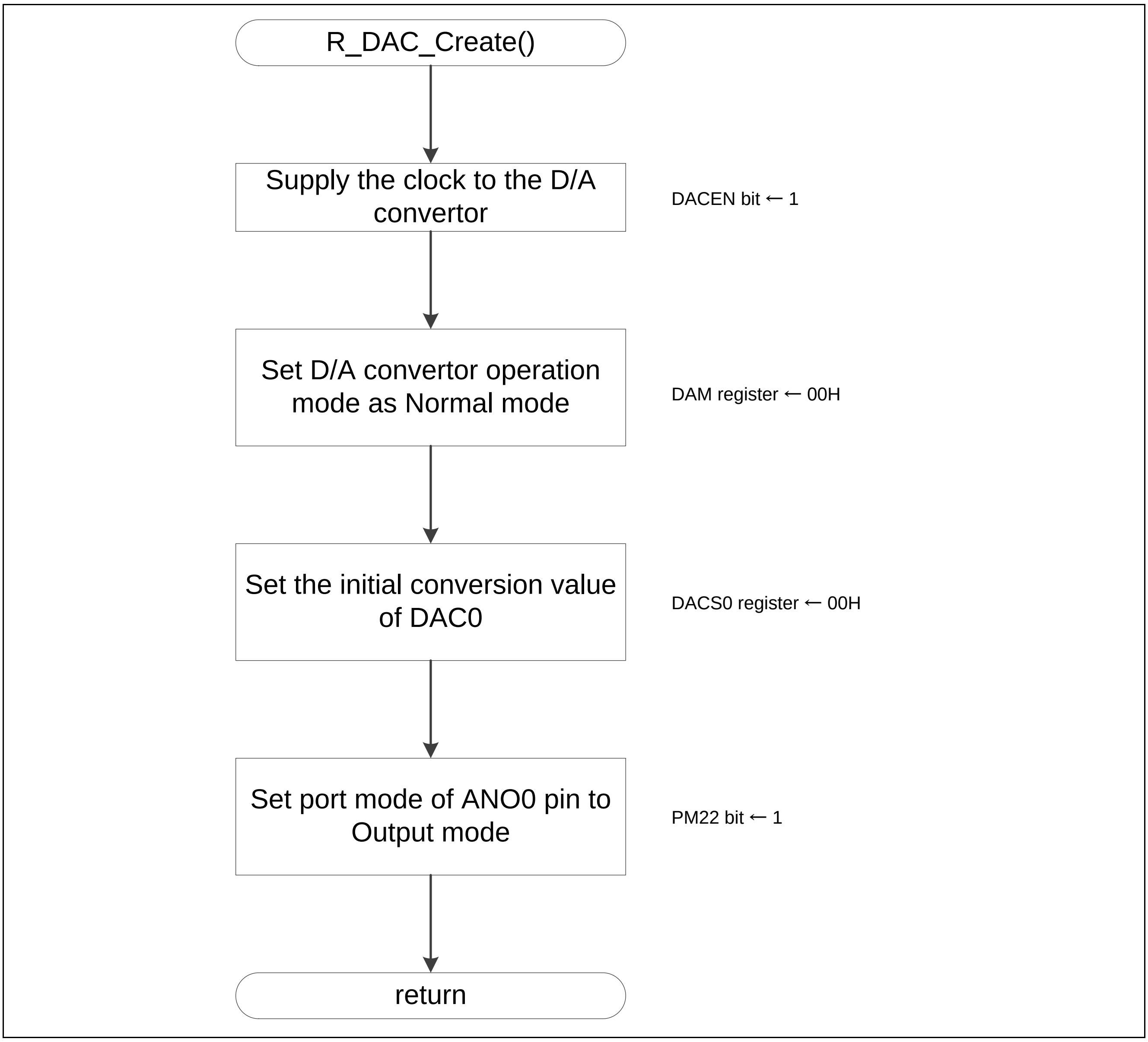

Figure 4.9 D/A converter initial setting

Enable providing a clock to the D/A converter.

- Peripheral Enable Register 1 (PER1)

Symbol : PER1

7	6	5	4	3	2	1	0
DACEN	TRGEN	CMPEN	TRD0EN	DTCEN	0	0	TRJ0EN
1	x	x	x	x	x	x	x

x: bits that do not change

Bit 7

DACEN	Control of D/A converter input clock
0	Stops input clock supply.
1	**Supplies input clock.**

Set the D/A converter to normal mode.

- D/A Converter Mode Register (DAM)

Symbol: DAM

7	6	5	4	3	2	1	0
0	0	DACE1	DACE0	0	0	DAMD1	DAMD0
0	0	0	0	0	0	0	**0**

Bit 0

DAMD0	D/A converter operation mode selection
0	**Normal mode**
1	Real-time output mode

Initialize the DAC0 conversion value.

- D/A Conversion Value Setting Register 0 (DACS0)

Set 000H to the D/A conversion value.

Symbol: DACS0

7	6	5	4	3	2	1	0
DACS07	DACS06	DACS05	DACS04	DACS03	DACS02	DACS01	DACS00
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**

—	Function
Bits 7 to 0	The relation between the resolution and analog output voltage (VANO0) of the D/A converter are as follows. VANO0 = Reference voltage for D/A converter × (DACS0) / 256

Note: Refer to the RL78/G14 user's manual (hardware) for details on individual registers.

Set the ANO0 pin function

- Port Mode Register 2 (PM2)

Symbol: PM2

7	6	5	4	3	2	1	0
PM27	PM26	PM25	PM24	PM23	PM22	PM21	PM20
x	x	x	x	x	**1**	x	x

x: bits that do not change

Bit 2

PM22	P22 pin I/O mode selection
0	Output mode (output buffer on)
1	**Input mode (output buffer off)**

Note: Refer to the RL78/G14 user's manual (hardware) for details on individual registers.

4.7.8 Main Processing

Figure 4.10 shows the flowchart of the main processing.

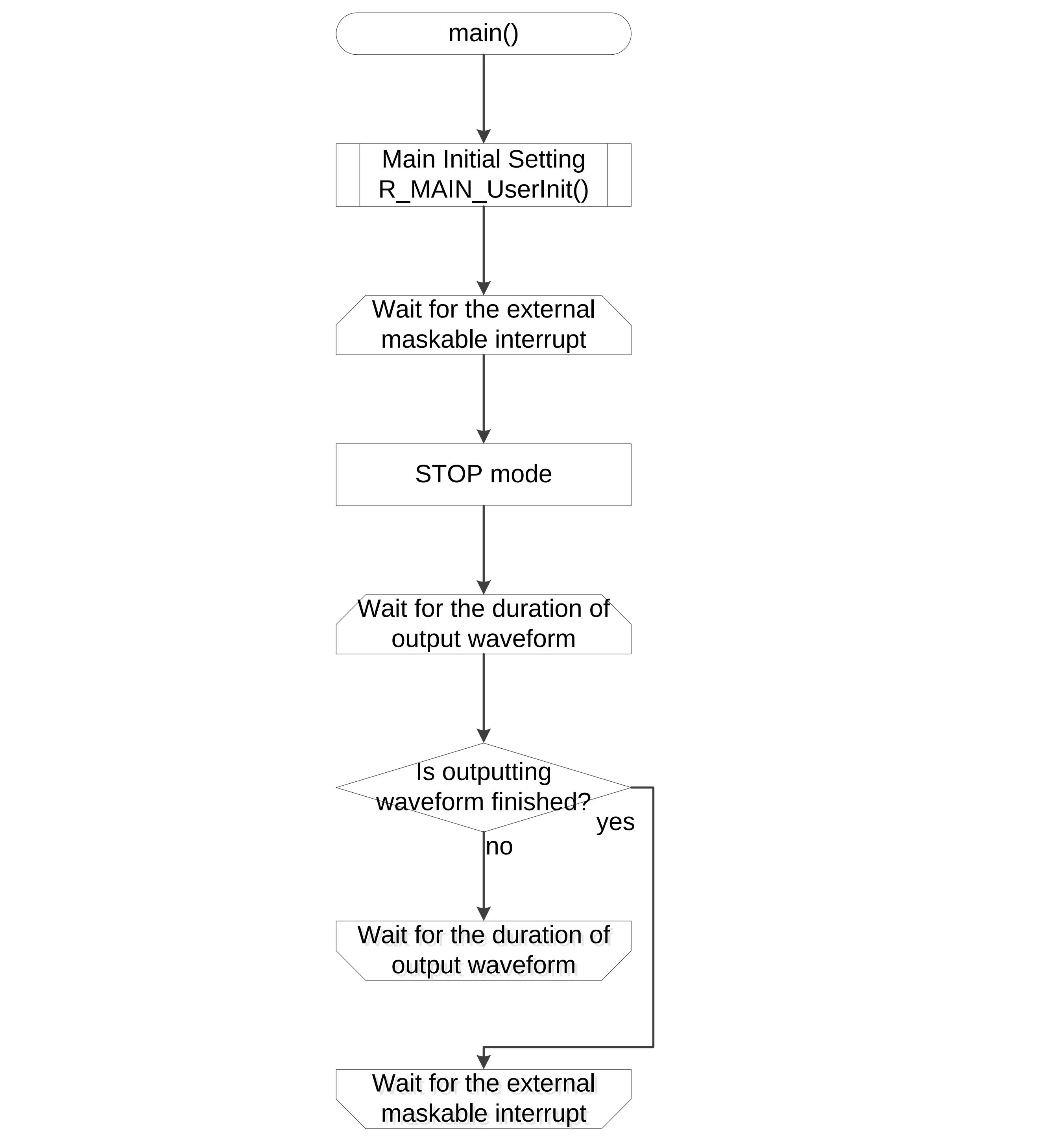

Figure 4.10 Main processing

4.7.9 Main Initial Setting

Figure 4.11 shows the flowchart of the main initial setting.

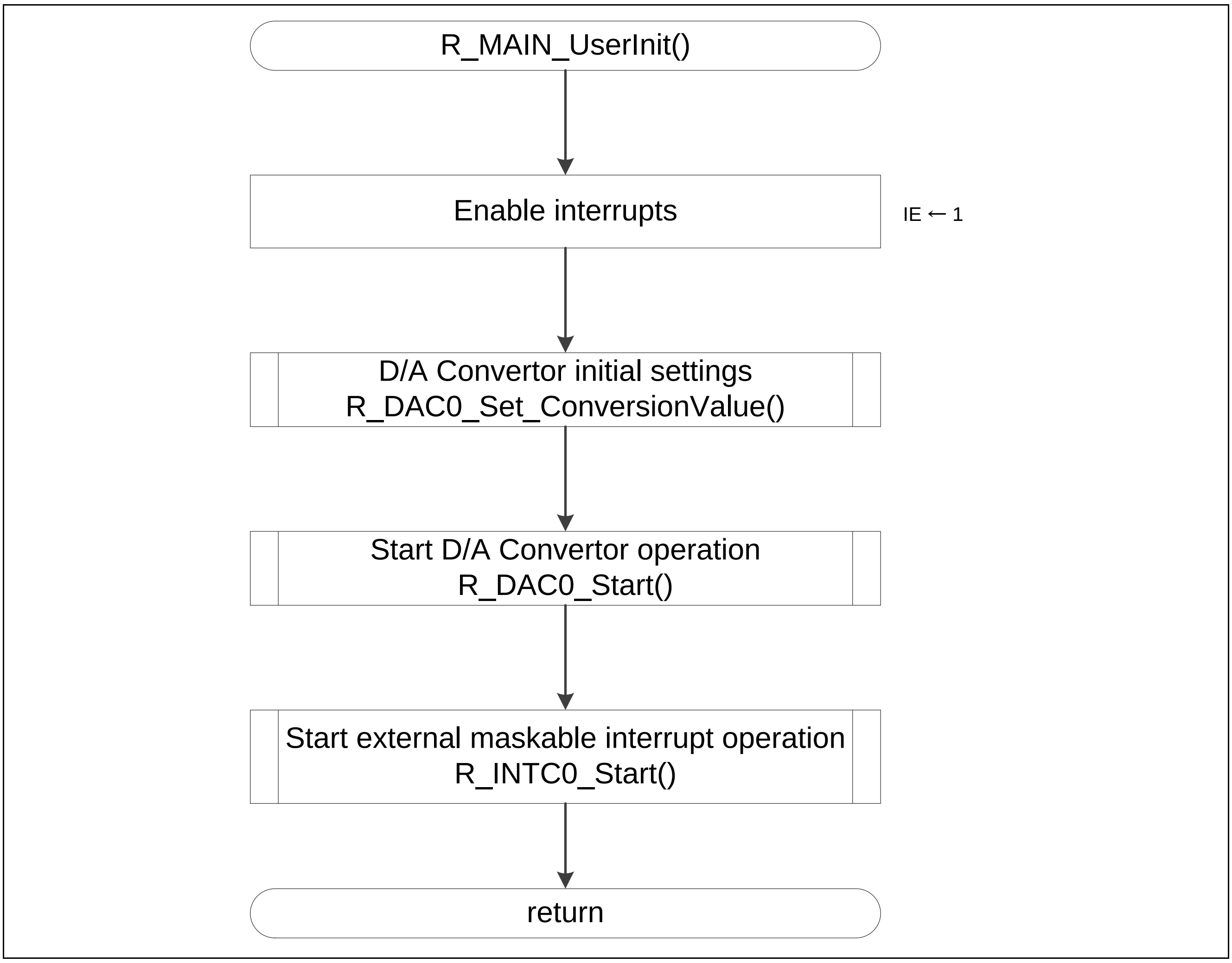

Figure 4.11 Main initial setting

4.7.10 External Maskable Interrupt Operation Start Function

Figure 4.12 shows the flowchart of the external maskable operation start function.

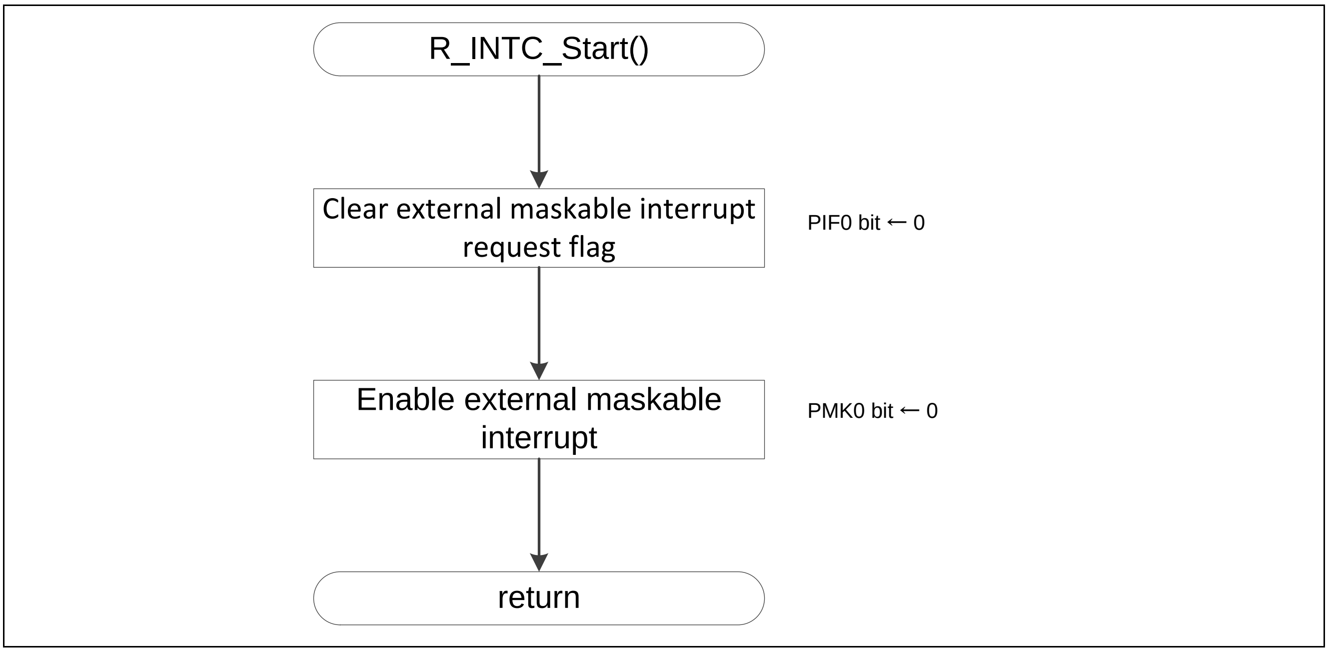

Figure 4.12 external maskable operation start function

4.7.11 D/A Conversion Value Setting Function

Figure 4.13 shows the flowchart of DAC0 conversion value setting.

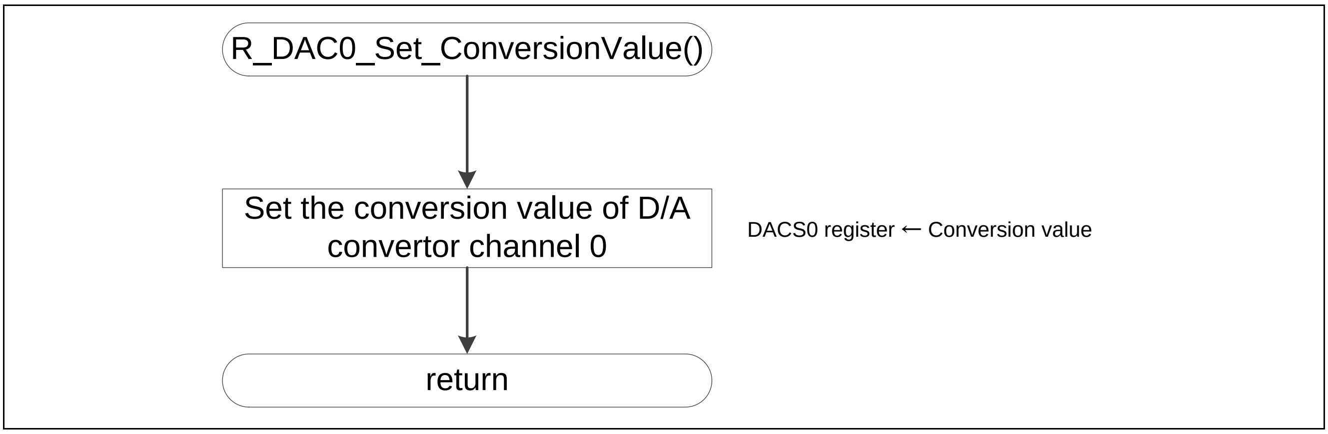

Figure 4.13 D/A conversion value setting function

4.7.12 D/A Converter Operation Start Function

Figure 4.14 shows the flowchart of D/A converter operation start function.

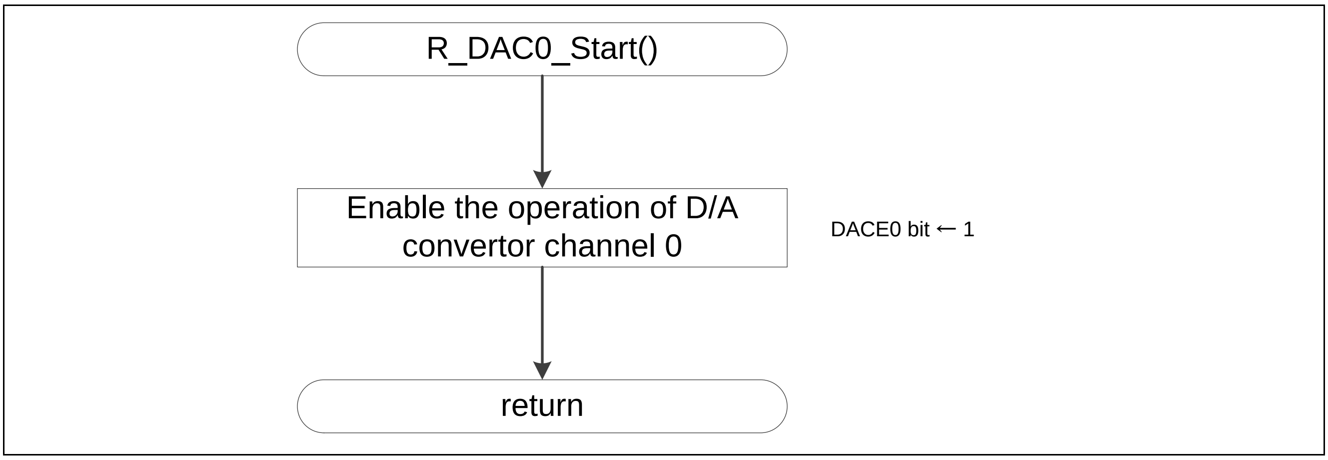

Figure 4.14 D/A converter operation start function

Enable D/A conversion

・D/A Converter mode register (DAM)

Symbol：DAM

7	6	5	4	3	2	1	0
0	0	DACE1	DACE0	0	0	DAMD1	DAMD0
x	x	x	**1**	x	x	x	x

x: bits that do not change

Bit 4

DACE0	D/A conversion operation control
0	Stops D/A conversion operation
1	**Enables D/A conversion operation**

Note: Refer to the RL78/G14 User's Manual (Hardware version) for details on how to set registers.

4.7.13 INTC0 Interrupt

Figure 4.15 shows the flowchart of INTC0 interrupt.

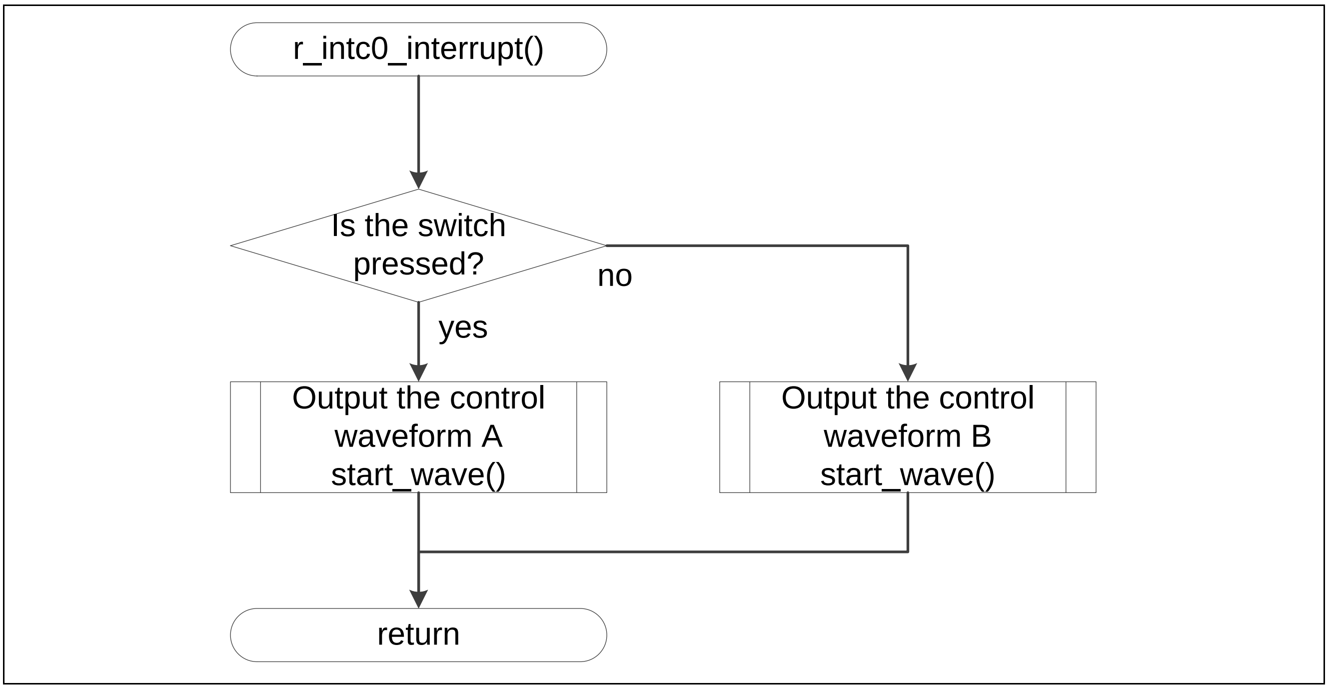

Figure 4.15 INTC0 interrupt

4.7.14 Starting output square wave

Figure 4.16 shows the flowchart of starting output square wave.

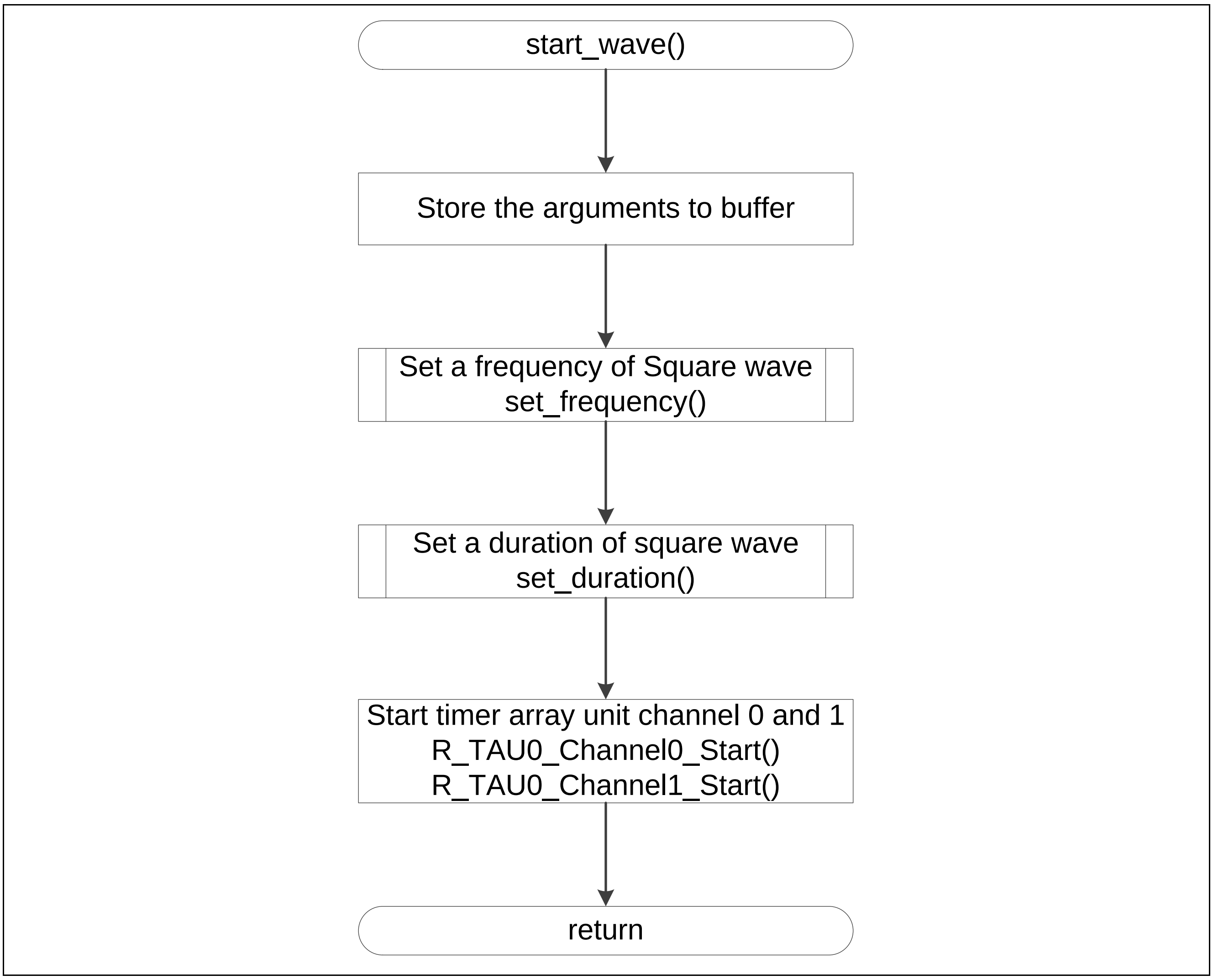

Figure 4.16 Starting output square wave

4.7.15 Frequency Setting of Output Wave

Figure 4.17 shows the flowchart of frequency setting of output wave.

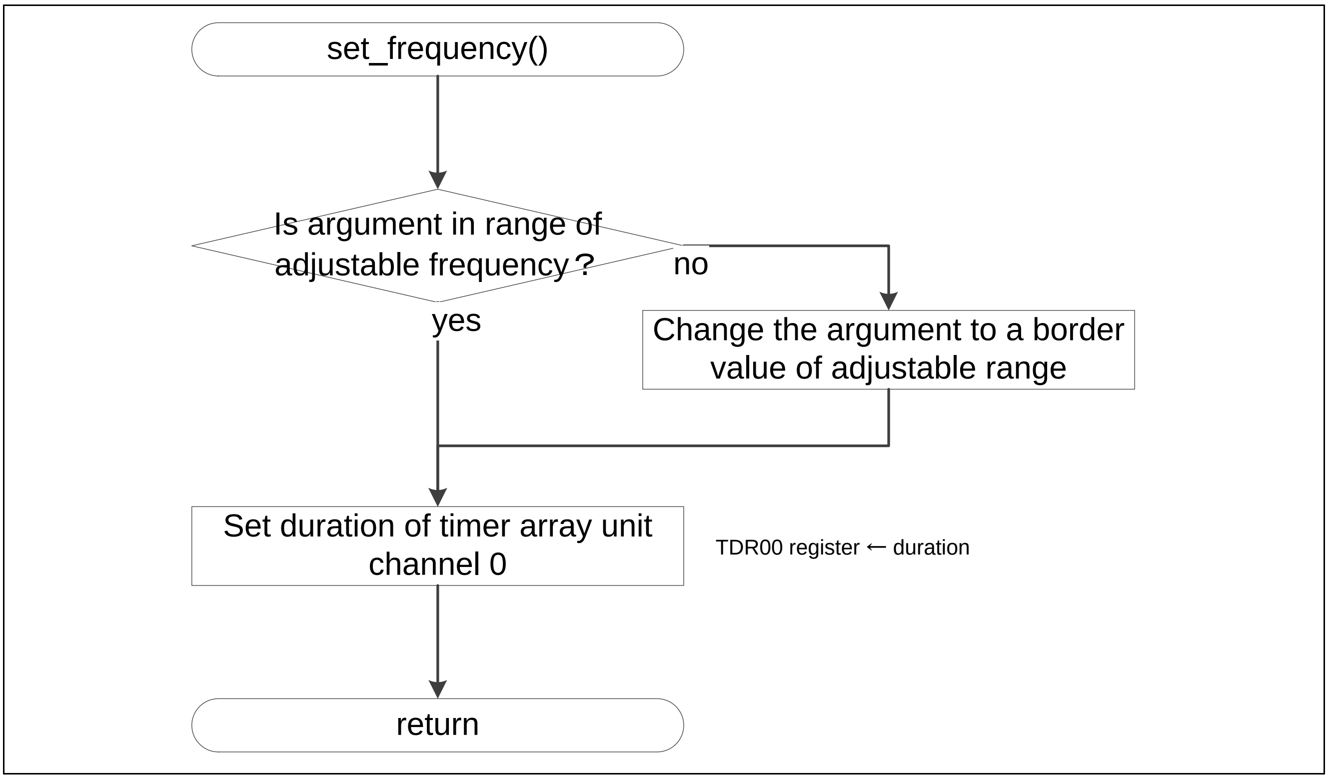

Figure 4.17 Frequency setting of output wave

4.7.16 Duration Setting of Output Wave

Figure 4.18 shows the flowchart of duration setting of output wave.

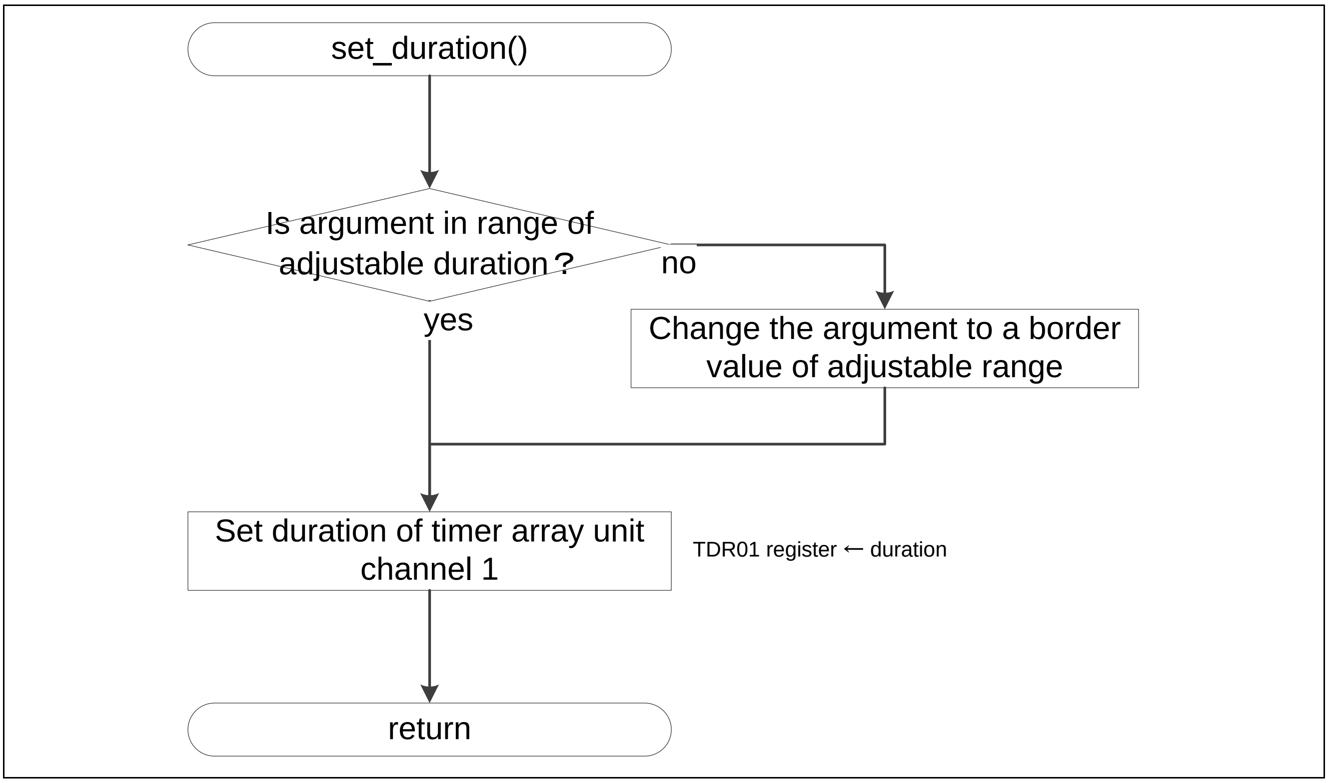

Figure 4.18 Duration setting of output wave

4.7.17 TAU00 Operation Start Function

Figure 4.19 shows the flowchart of TAU00 operation start function.

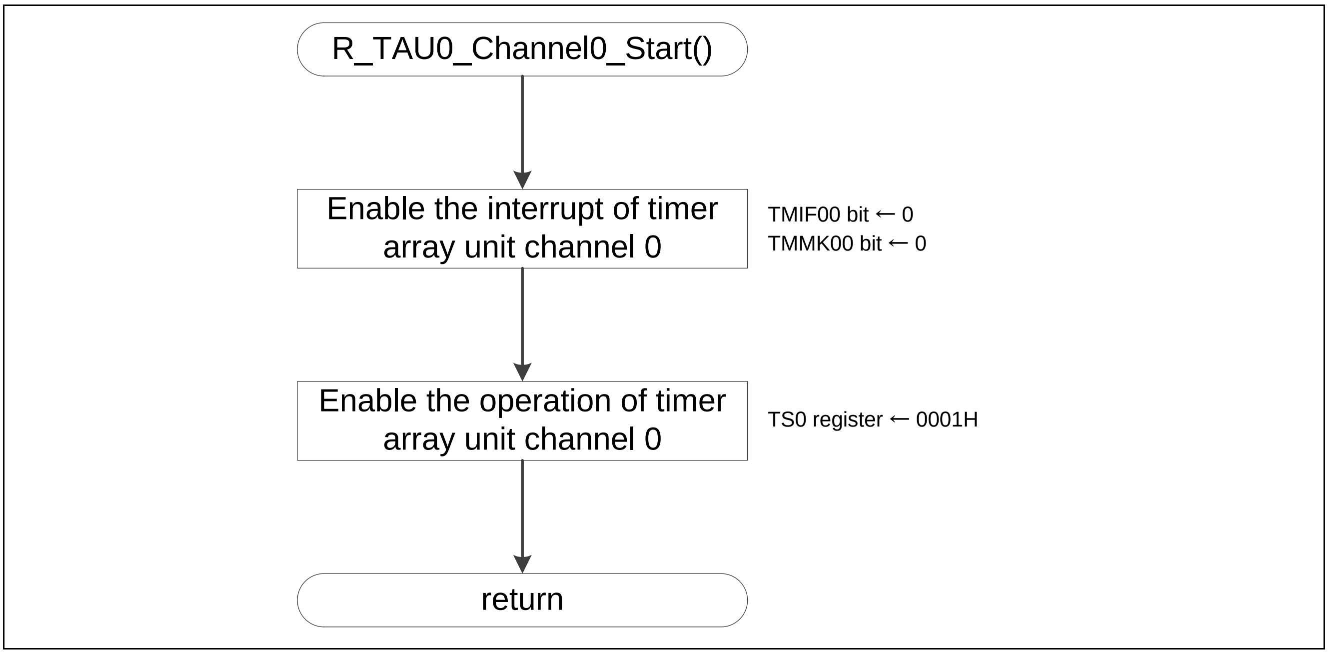

Figure 4.19 TAU00 operation start function

Start count operation

・Timer Channel Start Register（TS0）

Symbol : TS0

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	TS H03	0	TS H01	0	0	0	0	0	TS 03	TS 02	TS 01	TS 00
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	**1**

x: bits that do not change

Bit 0

TS00	Operation enable (start) trigger of channel 0
0	No trigger operation
1	**The TE00 bit is set to 1 and the count operation becomes enabled. The TCR00 register count operation start in the count operation enabled state varies depending on each operation mode**

Note: Refer to the RL78/G14 User's Manual (Hardware version) for details on how to set registers.

4.7.18 TAU01 Operation Start Function

Figure 4.20 shows the flowchart of TAU01 operation start function.

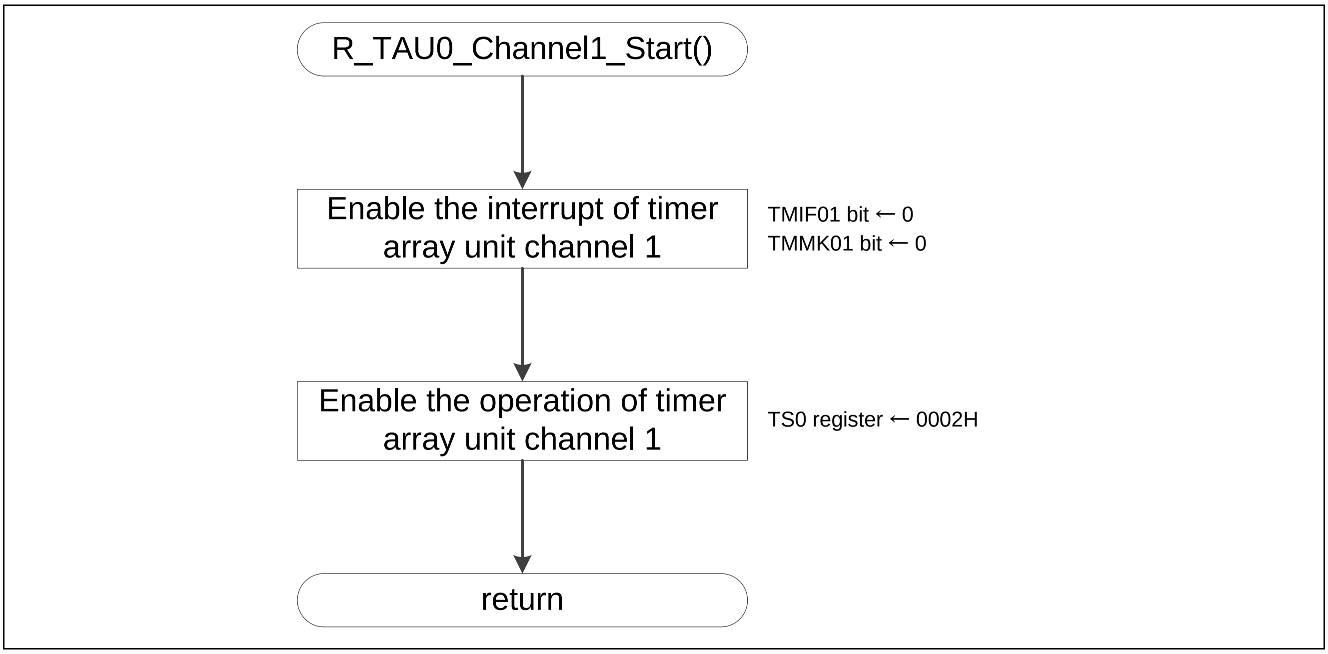

Figure 4.20 TAU01 operation start function

4.7.19 TAU00 Interrupt

Figure 4.21 shows the flowchart of TAU00 interrupt.

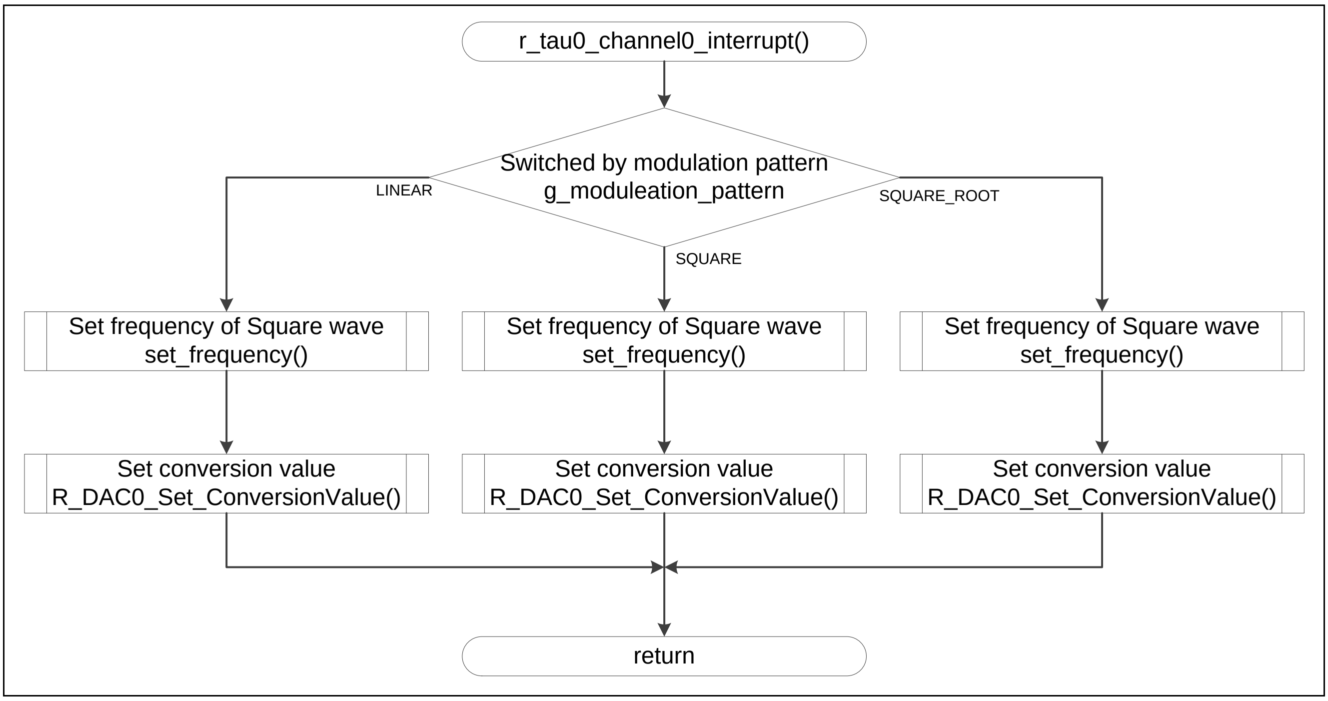

Figure 4.21 TAU00 interrupt

4.7.20 TAU01 Interrupt

Figure 4.22 shows the flowchart of TAU01 interrupt.

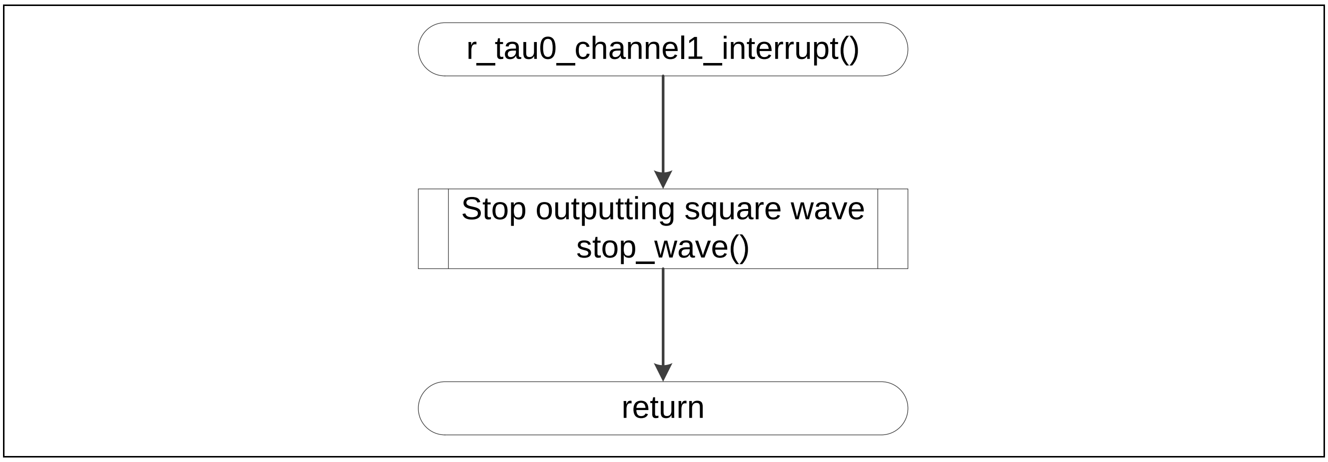

Figure 4.22 TAU01 interrupt

4.7.21 Stopping output square wave

Figure 4.23 shows the flowchart of stopping output square wave.

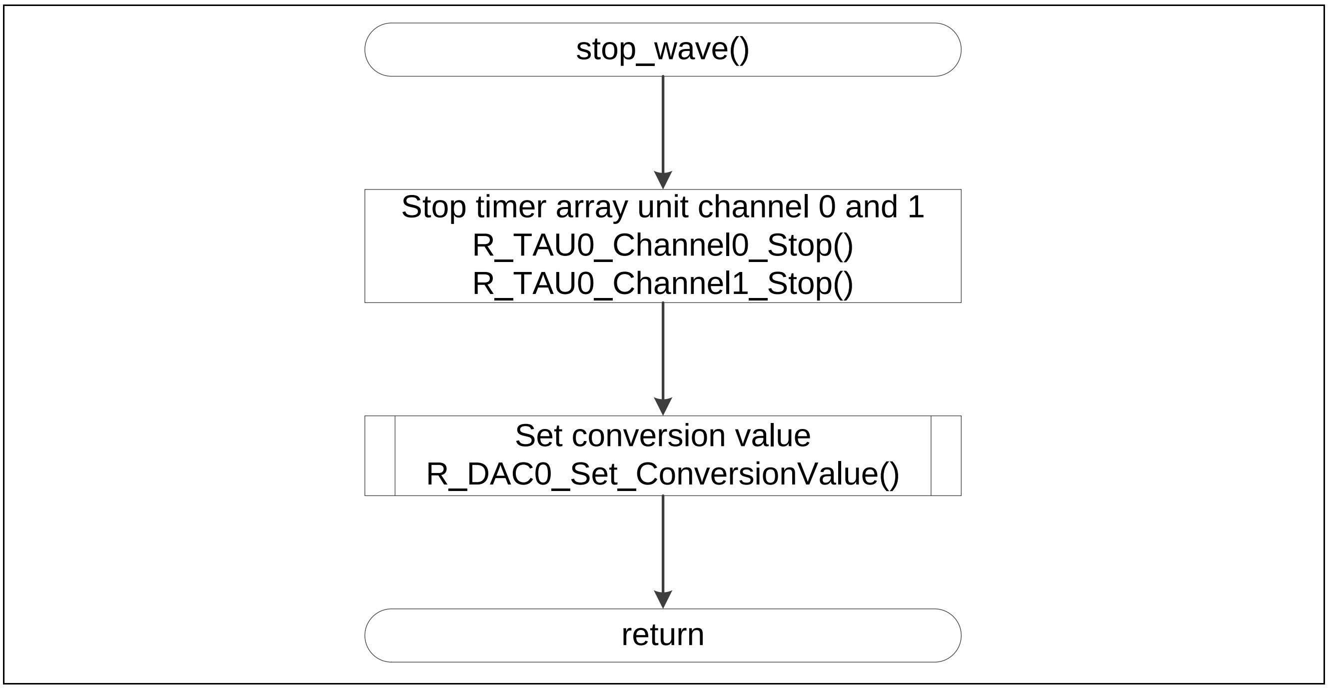

Figure 4.23 Stopping output square wave

4.7.22 TAU00 Operation Stop Function

Figure 4.24 shows the flowchart of TAU00 operation stop function

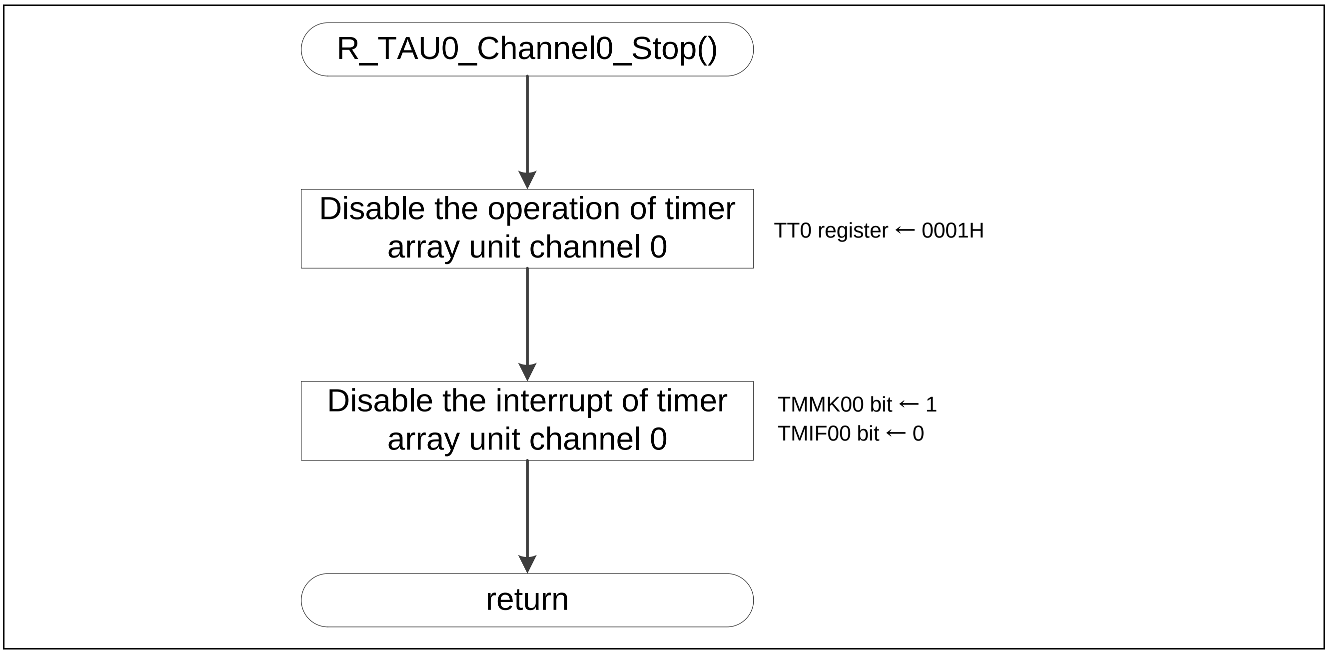

Figure 4.24 TAU00 operation stop function

4.7.23 TAU01 Operation Stop Function

Figure 4.25 shows the flowchart of TAU01 operation stop function.

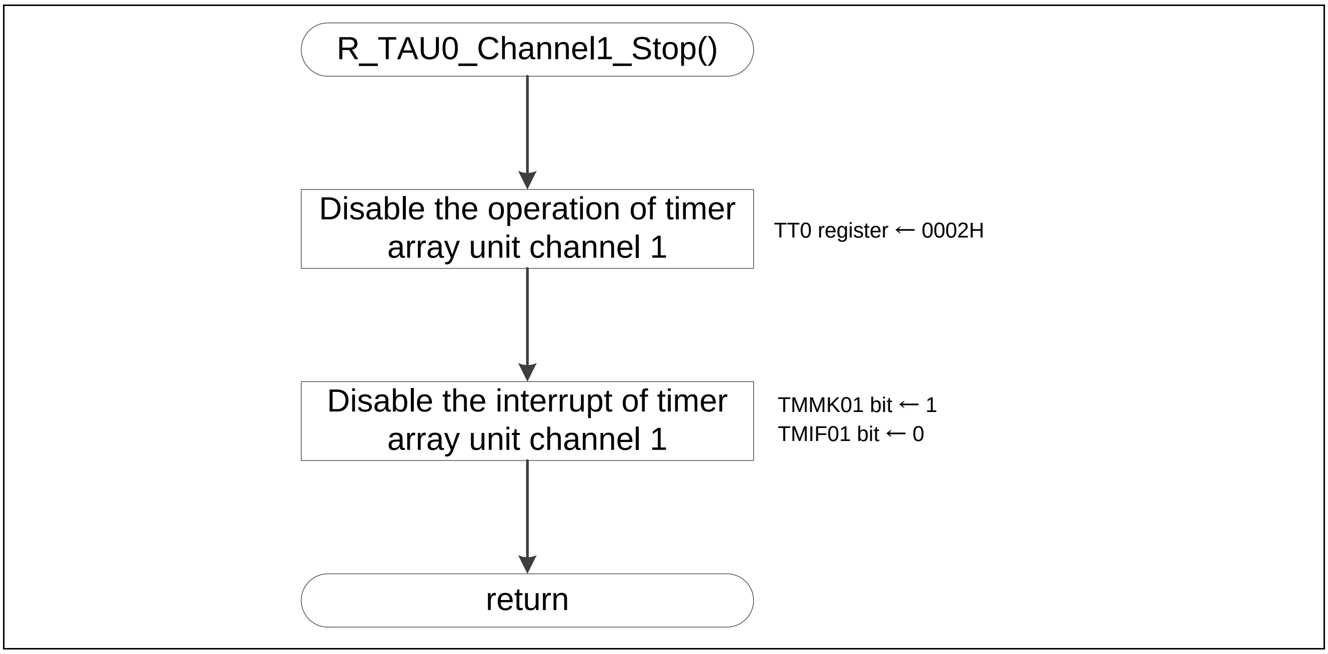

Figure 4.25 TAU01 operation stop function

5. Sample Code

Sample code can be downloaded from the Renesas Electronics website.

Website and Support

Renesas Electronics Website
http://www.renesas.com/

Inquiries
http://www.renesas.com/contact/

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Dec. 17, 2018	—	First edition

General Precautions in the Handling of Microprocessing Unit and Microcontroller Unit Products

The following usage notes are applicable to all Microprocessing unit and Microcontroller unit products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Handling of Unused Pins

   Handle unused pins in accordance with the directions given under Handling of Unused Pins in the manual.

   — The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible. Unused pins should be handled as described under Handling of Unused Pins in the manual.
2. Processing at Power-on

   The state of the product is undefined at the moment when power is supplied.

   — The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the moment when power is supplied.
   In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the moment when power is supplied until the reset process is completed.
   In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the moment when power is supplied until the power reaches the level at which resetting has been specified.
3. Prohibition of Access to Reserved Addresses

   Access to reserved addresses is prohibited.

   — The reserved addresses are provided for the possible future expansion of functions. Do not access these addresses; the correct operation of LSI is not guaranteed if they are accessed.
4. Clock Signals

   After applying a reset, only release the reset line after the operating clock signal has become stable. When switching the clock signal during program execution, wait until the target clock signal has stabilized.

   — When the clock signal is generated with an external resonator (or from an external oscillator) during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Moreover, when switching to a clock signal produced with an external resonator (or by an external oscillator) while program execution is in progress, wait until the target clock signal is stable.
5. Differences between Products

   Before changing from one product to another, i.e. to a product with a different part number, confirm that the change will not lead to problems.

   — The characteristics of Microprocessing unit or Microcontroller unit products in the same group but having a different part number may differ in terms of the internal memory capacity, layout pattern, and other factors, which can affect the ranges of electrical characteristics, such as characteristic values, operating margins, immunity to noise, and amount of radiated noise. When changing to a product with a different part number, implement a system-evaluation test for the given product.

SALES OFFICES Renesas Electronics Corporation http://www.renesas.com

Refer to "http://www.renesas.com/" for the latest and detailed information.

Renesas Electronics Corporation
TOYOSU FORESIA, 3-2-24 Toyosu, Koto-ku, Tokyo 135-0061, Japan

Renesas Electronics America Inc.
1001 Murphy Ranch Road, Milpitas, CA 95035, U.S.A.
Tel: +1-408-432-8888, Fax: +1-408-434-5351

Renesas Electronics Canada Limited
9251 Yonge Street, Suite 8309 Richmond Hill, Ontario Canada L4C 9T3
Tel: +1-905-237-2004

Renesas Electronics Europe Limited
Dukes Meadow, Millboard Road, Bourne End, Buckinghamshire, SL8 5FH, U.K
Tel: +44-1628-651-700

Renesas Electronics Europe GmbH
Arcadiastrasse 10, 40472 Düsseldorf, Germany
Tel: +49-211-6503-0, Fax: +49-211-6503-1327

Renesas Electronics (China) Co., Ltd.
Room 1709 Quantum Plaza, No.27 ZhichunLu, Haidian District, Beijing, 100191 P. R. China
Tel: +86-10-8235-1155, Fax: +86-10-8235-7679

Renesas Electronics (Shanghai) Co., Ltd.
Unit 301, Tower A, Central Towers, 555 Langao Road, Putuo District, Shanghai, 200333 P. R. China
Tel: +86-21-2226-0888, Fax: +86-21-2226-0999

Renesas Electronics Hong Kong Limited
Unit 1601-1611, 16/F., Tower 2, Grand Century Place, 193 Prince Edward Road West, Mongkok, Kowloon, Hong Kong
Tel: +852-2265-6688, Fax: +852 2886-9022

Renesas Electronics Taiwan Co., Ltd.
13F, No. 363, Fu Shing North Road, Taipei 10543, Taiwan
Tel: +886-2-8175-9600, Fax: +886 2-8175-9670

Renesas Electronics Singapore Pte. Ltd.
80 Bendemeer Road, Unit #06-02 Hyflux Innovation Centre, Singapore 339949
Tel: +65-6213-0200, Fax: +65-6213-0300

Renesas Electronics Malaysia Sdn.Bhd.
Unit 1207, Block B, Menara Amcorp, Amcorp Trade Centre, No. 18, Jln Persiaran Barat, 46050 Petaling Jaya, Selangor Darul Ehsan, Malaysia
Tel: +60-3-7955-9390, Fax: +60-3-7955-9510

Renesas Electronics India Pvt. Ltd.
No.777C, 100 Feet Road, HAL 2nd Stage, Indiranagar, Bangalore 560 038, India
Tel: +91-80-67208700, Fax: +91-80-67208777

Renesas Electronics Korea Co., Ltd.
17F, KAMCO Yangjae Tower, 262, Gangnam-daero, Gangnam-gu, Seoul, 06265 Korea
Tel: +82-2-558-3737, Fax: +82-2-558-5338

Colophon 7.2