RX24T Group, RX24U Group

Example of Settings for Triangle-Wave Complementary PWM Output with Duty Ratio of 0% or 100% Using GPT

Summary

The RX24T Group and RX24U Group each incorporate a general PWM timer (GPT) module consisting of a four-channel 16-bit timer. This application note describes the settings for generating triangle-wave complementary PWM output with a duty ratio of 0% or 100% using the GPT.

Target Devices

- RX24T Group, chip version B
- RX24U Group

When using this application note with other Renesas MCUs, careful evaluation is recommended after making modifications to comply with the alternate MCU.

Contents

1. Specifications

This application note describes the settings for using triangle-wave PWM mode 1 (16-bit transfer at trough). It also describes settings for changing the duty ratio while a program is running. The sample code makes settings for one phase only. If three-phase output is required, make settings in like manner for channels 1 and 2 as well.

- GPT channel 0 is used.
- Pins P71 and P74 are used.
- The positive-phase waveform of the complementary PWM output is output on the GTIOC0A pin (P71), and the negative-phase waveform is output on the GTIOC0B pin (P74).
- The output settings of the GTIOC0A and GTIOC0B pins are as follows:
  GTIOC0A: Initial output is low, output toggled at compare match, output retained at the end of the cycle.
  GTIOC0B: Initial output is high, output toggled at compare match, output retained at the end of the cycle.
- The GPT count clock frequency is 80 MHz (PCLKA = 80 MHz).
  The carrier period is set to 1.64 ms.
- The dead time is set to 51 μs.
- PWM duty-cycle setting values are updated at the crest using the overflow interrupt (GTCIV0).

The sample code described in this application note is contained in two projects: rx24u_gpt_sample1 and rx24u_gpt_sample2.

Figure 1.1 is a PWM output diagram for rx24u_gpt_sample1.

Figure 1.2 is a PWM output diagram for rx24u_gpt_sample2.

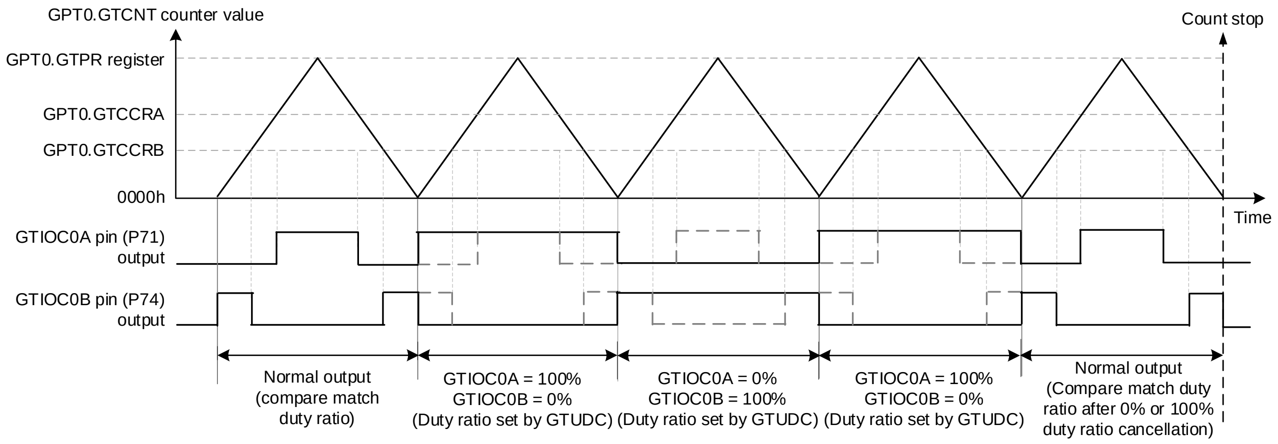

Figure 1.1 PWM Output Produced by rx24u_gpt_sample1

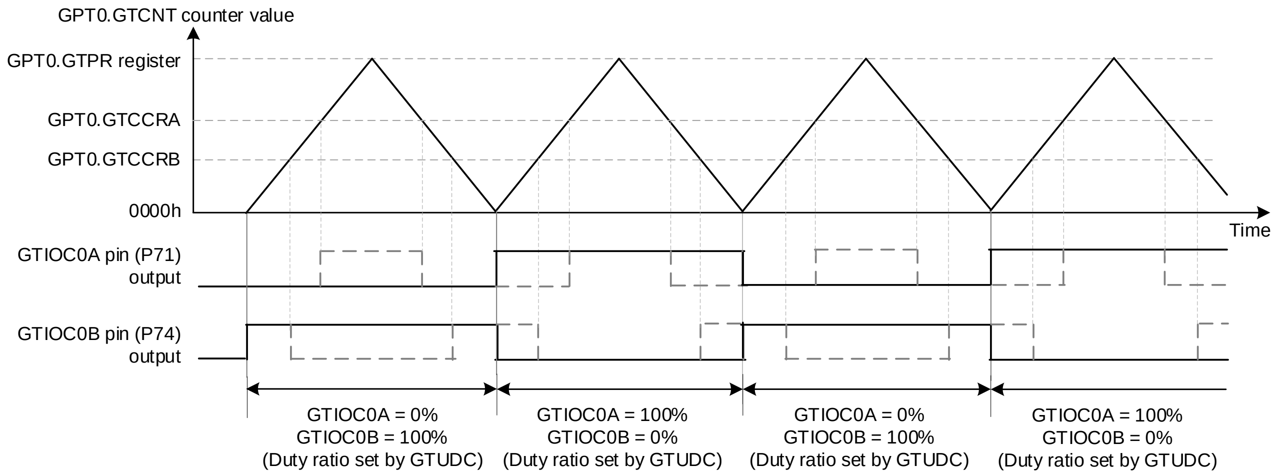

Figure 1.2 PWM Output Produced by rx24u_gpt_sample2

Figure 1.3 is a flowchart of the sample code. This application note describes the settings for generating triangle-wave complementary PWM output and for setting the duty ratio.

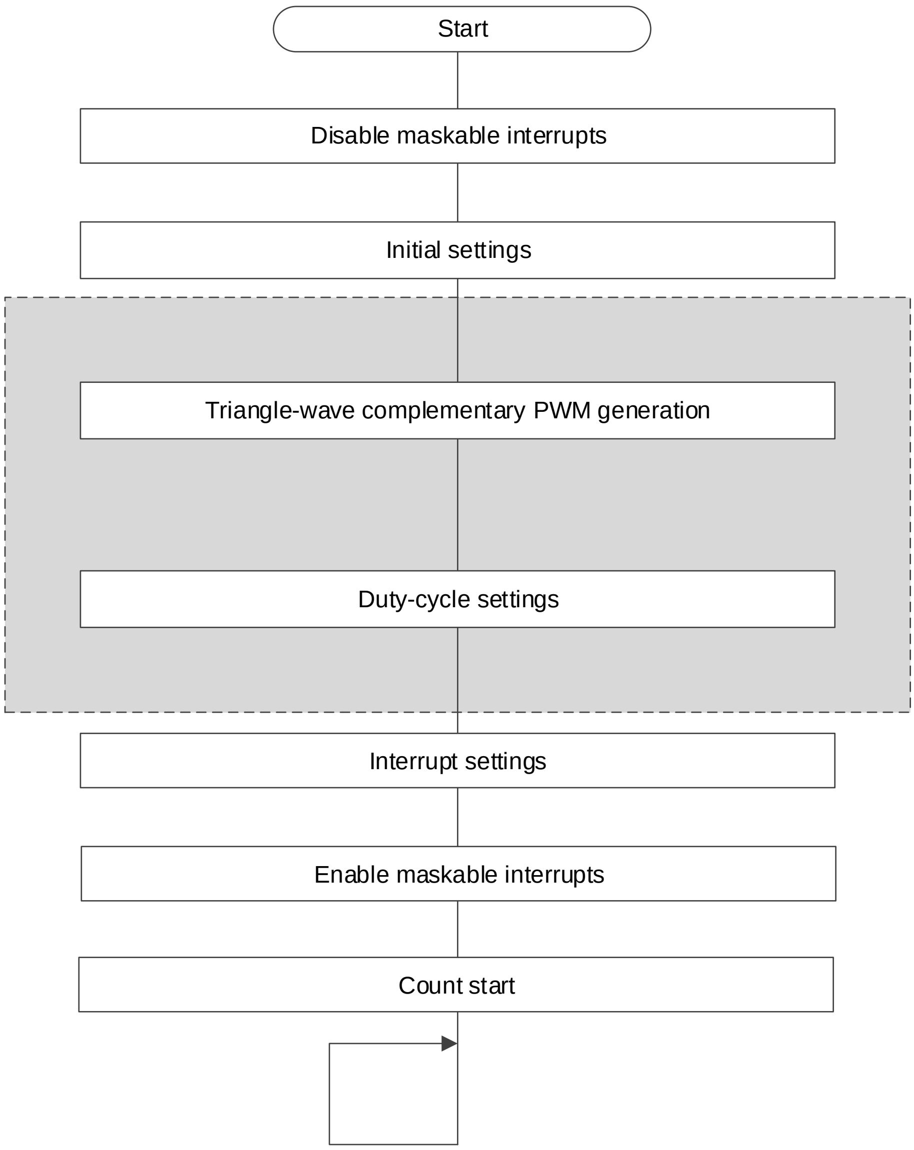

Figure 1.3 Flowchart of Sample Code

2. Operation Confirmation Conditions

The operation of the sample program referenced in this application note has been confirmed under the following conditions.

Table 2.1 Operation Confirmation Conditions

Item	Description
MCU used	R5F524UEADFB (RX24U Group)
Operating frequency	Main clock: 20 MHz PLL: 80 MHz (Main clock ×1/2 ×8) HOCO: Stopped LOCO: 4 MHz System clock (ICLK): 80 MHz (PLL ×1/1) Peripheral module clock A (PCLKA): 80 MHz (PLL ×1/1) Peripheral module clock B (PCLKB): 40 MHz (PLL ×1/2) Peripheral module clock D (PCLKD): 40 MHz (PLL ×1/2) FlashIF clock (FCLK): 20 MHz (PLL ×1/4)
Operating voltage	3.3 V
Integrated development environment	Renesas Electronics e^2 studio Version 7.6.0
C compiler	Renesas Electronics C/C++ Compiler Package for RX Family V3.01.00
	Compiler option The integrated development environment default settings are used.
iodefine.h version	V1.0H
Endian order	Little endian, big endian
Operating mode	Single-chip mode
Processor mode	Supervisor mode
Sample code version	Version 1.00
Board used	Renesas Starter Kit for RX24U (product No.: RTK500524USxxxxxBE)

3. Related Application Note

Application notes related to this application note are listed below.

RX24U Group Initial Settings Example Rev. 1.00 (R01AN3425)

The initial settings function accompanying the above application note is used in the sample code described in this application note. The revision number is current as of the time this application note was created.

If a newer version is available, replace the initial settings function with the newest version. Visit the Renesas Electronics website to confirm and download the latest version.

4. Software

This section describes the duty ratio settings for triangle-wave complementary PWM output.

4.1 Triangle-Wave Complementary PWM Generation

The following setting procedure is used for triangle-wave complementary PWM generation as shown in Figure 4.1.

1. Release module stop for the GPT.
   MSTPCRA.MSTPA7 = 0
   In order to make settings in (write to) MSTPCRA, it is necessary to set the PRCR register to enable writes to MSTPCRA.
2. Stop counter operation.
   GTSTR.CST0 = 0
3. Set the count mode to triangle-wave complementary PWM mode 1.
   GTCR.MD = 100b
4. Use the timer prescaler setting to select PCLK as the source clock:
   GTCR.TPCS = 000b
5. Set the period to FFFFh × 2.
   GTPR ← FFFFh
   For triangle-wave operation the count period is the GTPR register value × 2.
6. Set the initial counter value.
   GTCNT = 0000h
7. Set the GTIOC pin functions.
   GTIOR.GTIOA = 000011b
   (initial output is low, output toggled at compare match, output retained at the end of the cycle)
   GTIOR.GTIOB = 010011b
   (initial output is high, output toggled at compare match, output retained at the end of the cycle)
8. Initialize the GPT I/O pins. (See 4.8.6.)
9. Enable output on GTIOCnA and GTIOCnB pins.
   GTONCR.OAE = 1
   GTONCR.OBE = 1
10. Disable compare capture register buffer operation.
    GTBER.CCRA = 0
    GTBER.CCRB = 0

11. Make settings to compare capture registers.
    GTCCRA = 7FFFh
    GTCCRB = 7000h
    GTCCRC = 7FFFh (same value as GTCCRA)
    GTCCRD = 7FFFh (same value as GTCCRA)
    GTCCRE = 7000h (same value as GTCCRB)
    GTCCRF = 7000h (same value as GTCCRB)

    Set GTCCRA and GTCCRB such that GTCCRA > 0000h, GTCCRA < GTPR, GTCCRB > 0000h, and GTCCRB < GTPR.
    If settings are made manually without using the automatic dead time setting function, set the dead time to a value equal to GTCCRA − GTCCRB.
    GTCCRC, GTCCRD, GTCCRE, and GTCCRF are not used as compare capture registers or as buffer registers in the sample code, so the code that makes settings to these registers is not actually necessary. It is included as a template for settings, however.

After the triangle-wave complementary PWM generation settings are completed, a waveform is generated as shown in Figure 4.1 when the GPT I/O pins are initialized and count start occurs.

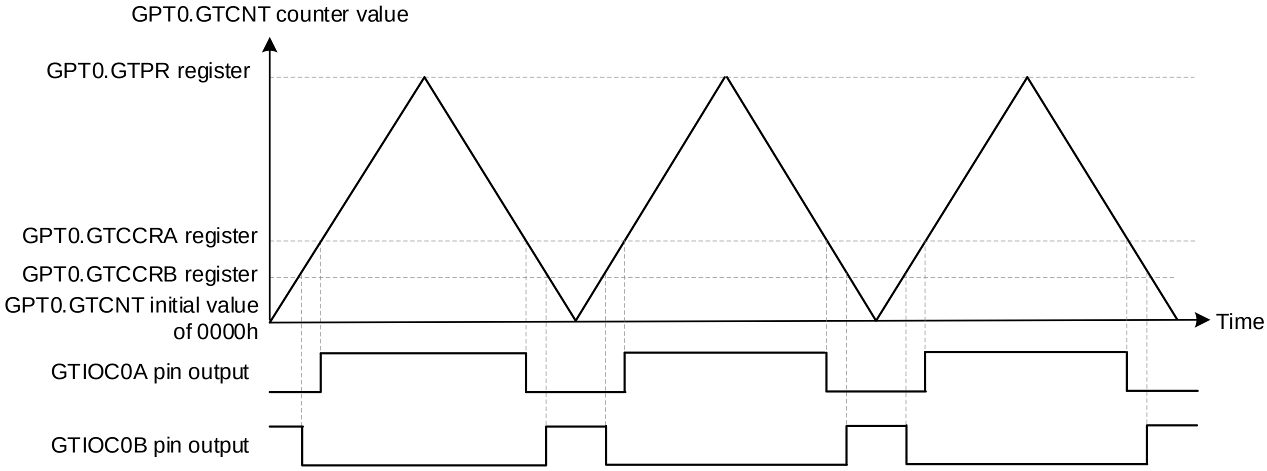

Figure 4.1 Triangle-Wave Complementary PWM Mode 1 Signal Generation Example (GTCCRA > GTCCRB)

4.2 0% or 100% Duty-Cycle Setting

The general PWM timer count direction register (GTUDC) of the GPT is used to make settings related to the output duty ratio. By making settings to this register it is possible to change from a user-defined duty ratio to 0% or 100% and then change back to a user-defined duty ratio. (See Table 4.1.)

Table 4.1 General PWM Timer Count Direction Register (GTUDC) Settings

Bit Name	Description
GTIOCx pin output duty setting bits (OADTY[1:0] and OBDTY[1:0])	0 x: The setting value of the timer compare capture register determines the output duty ratio of the GTIOCA and GTIOCB pins. 1 0: The output duty ratio of the GTIOCA and GTIOCB pins is 0%. 1 1: The output duty ratio of the GTIOCA and GTIOCB pins is 100%.
GTIOCx pin output duty forced setting bits (OADTYF and OBDTYF)	0: If the value of this bit is 0 and the value of the OADTY[1:0]/ OBDTY[1:0] bits is changed while count operation is stopped, the duty-cycle setting changed during the first count operation is not reflected and the duty-cycle setting changed at the underflow is reflected instead. If the value of this bit is 0 and the value of the OADTY[1:0]/OBDTY[1:0] bits is changed during count operation, the duty-cycle setting changed at the underflow is reflected. 1: If the value of this bit is 1 and the value of the OADTY[1:0]/ OBDTY[1:0] bits is changed while count operation is stopped, the duty-cycle setting changed during the first count operation is reflected. If the value of this bit is 1 and the value of the OADTY[1:0]/OBDTY[1:0] bits is changed during count operation, the duty-cycle setting changed at the underflow is reflected.
Output after release of GTIOCx pin output 0%/100% duty-cycle setting bits (OADTYR and OBDTYR)	0: The function selected by the GTIOB[3:2] bits is applied to the output value when the duty-cycle is set after cancellation of the 0 or 100% duty-cycle setting. 1: The function selected by the GTIOB[3:2] bits is applied to the compare match output value which is masked after cancellation of the 0 or 100% duty-cycle setting. Note: The values GTIOA[5:0] = 000011b and GTIOB[5:0] = 010011b shown in 4.2 specify that GTIOR.GTIOm[3:2] = 00, and the output is retained at the end of the cycle when GTIOR.GTIOm[3:2] = 00. The output retained at the end of the cycle is dependent on the settings of OADTYR and OBDTYR.

4.2.1 Setting the Duty Ratio in Sample Code rx24u_gpt_sample1

After count operation starts the GTUDC.OADTY[1:0] and GTUDC.OBDTY[1:0] bits are set to 00b to set the compare match output duty ratio of the GTIOC0A and GTIOC0B pins. The GTCIV0 interrupt handler is used to change the duty ratio at the crest. The duty ratio setting is changed at each crest (overflow) of the triangle wave by the GTCIV0 interrupt handler, and this change is reflected in the output at the next trough (underflow). The GTCIU0 interrupt handler is used to stop the counter at the trough.

The output after the duty ratio (0% or 100%) is canceled is selected by the OADTYR and OBDTYR bits. Refer to Table 4.2 for the correspondences between settings and output. Figure 4.2 shows the output waveform result when using rx24u_gpt_sample1.

Table 4.2 Duty-Cycle Setting Selections and Output Waveforms

Project Used	Register Settings	Output Waveform
rx24u_gpt _sample1	GTDUC.OADTYR = 0 GTDUC.OBDTYR = 0	Inverted waveform output after cancellation of duty ratio (0% or 100%) GTIOC0A: See (B) in Figure 4.2. GTIOC0B: See (D) in Figure 4.2.
	GTDUC.OADTYR = 1 GTDUC.OBDTYR = 1 (Settings in sample code)	Non-inverted waveform output after cancellation of duty ratio (0% or 100%) GTIOC0A: See (A) in Figure 4.2. GTIOC0B: See (C) in Figure 4.2.

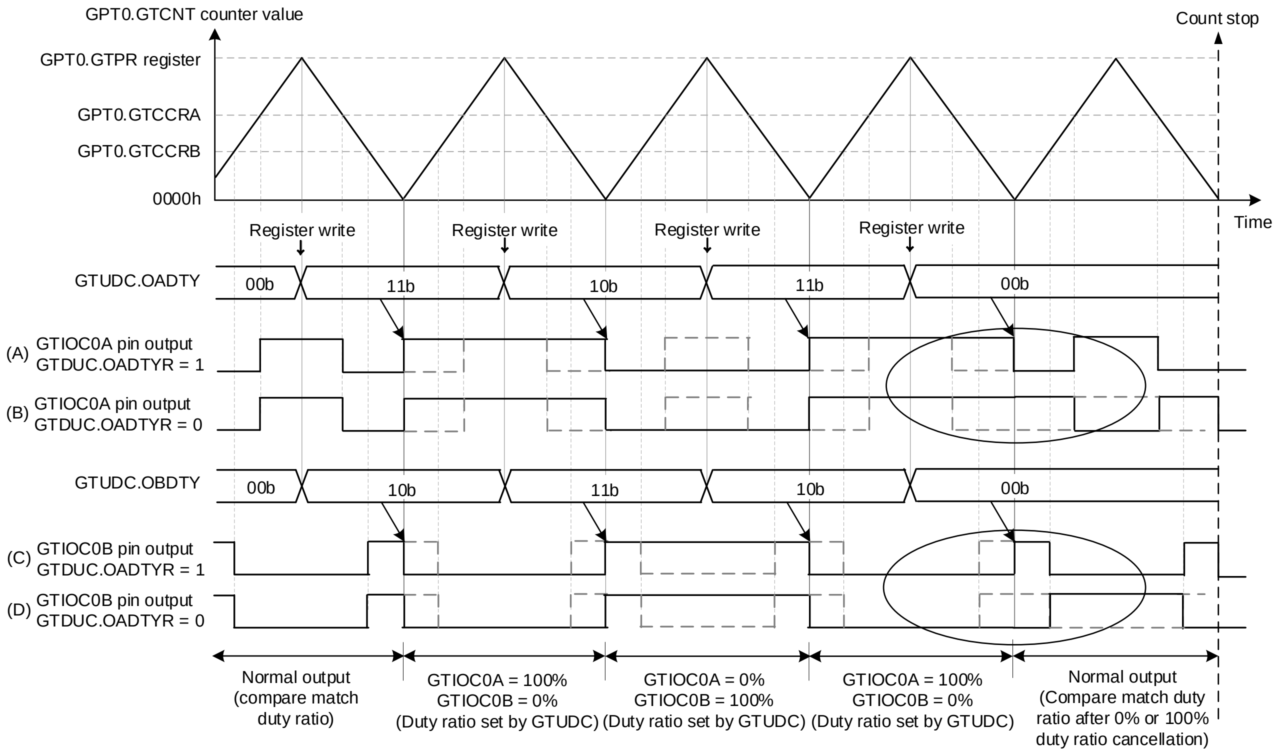

Figure 4.2 Example of Settings for Duty Ratio (Count Operation) and Output After Duty Ratio Cancellation

4.2.2 Setting the Duty Ratio in Sample Code rx24u_gpt_sample2

After count operation starts the GTUDC.OADTY[1:0] bits are set to 10b and the GTUDC.OBDTY[1:0] bits to 11b to set the duty ratio of the GTIOC0A pin to 0% and the duty ratio of the GTIOC0B pin to 100%. Setting the OADTYF and OBDTYF bits to 1 causes the duty ratio that has been set to be reflected immediately after count operation starts. The GTCIV0 interrupt handler is used to change the duty ratio at the crest. The duty ratio setting is changed at each crest (overflow) of the triangle-wave by the GTCIV0 interrupt handler, and this change is reflected in the output at the next trough (underflow). The duty ratio settings are changed each triangle-wave cycle, changing the duty ratio from 0% to 100% or from 100% to 0%.

Figure 4.3 shows the result when using rx24u_gpt_sample2.

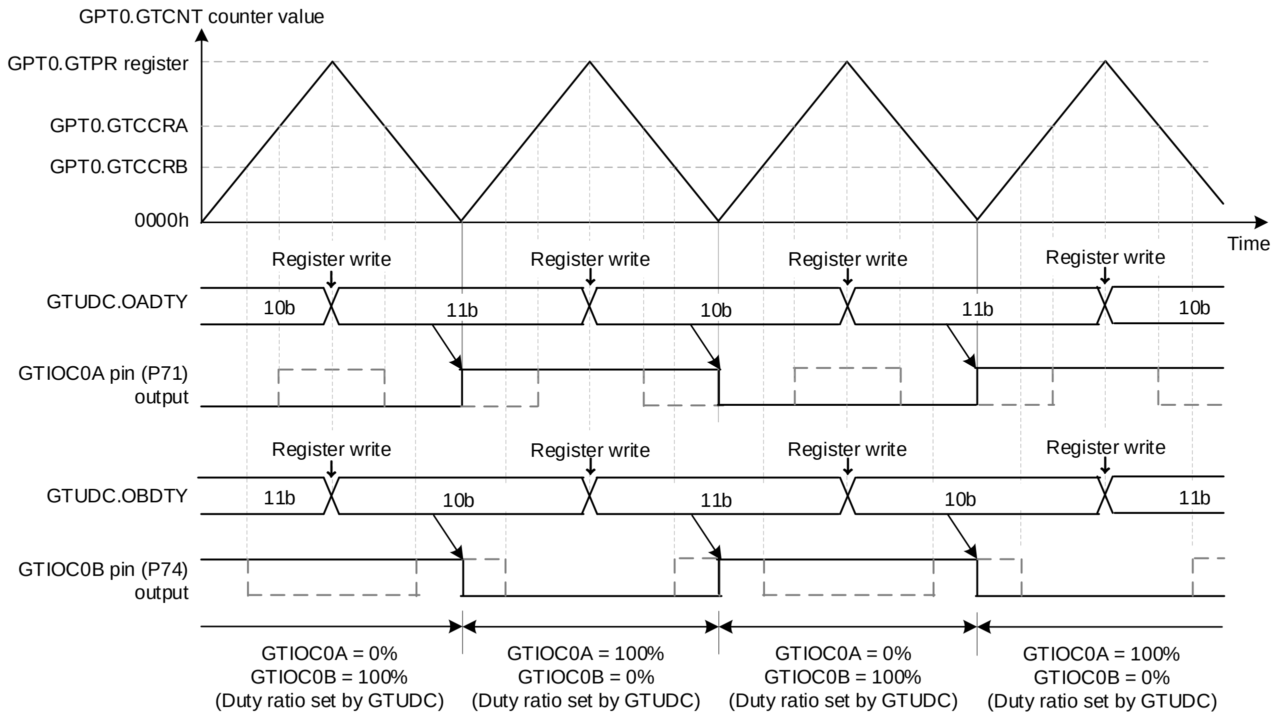

Figure 4.3 Example of Initial Duty Ratio (Count Stop) Setting and Its Reflection in Output after Count Operation Start

4.3 File Composition

Table 4.3 lists the files used in the sample code. Files generated by the integrated development environment are not included in this table.

Table 4.3 Files Used in Sample Code

Project Name	File Name	Outline
Common (GPT-related functionality)	main.c	Main processing routine
rx24u_gpt _sample1	r_gpt_triangle_wave_pwm_1.c	Definition of functions for PWM generation and duty ratio setting
	r_gpt_triangle_wave_pwm_1.h	Header file of r_gpt_triangle_wave_pwm_1.c
rx24u_gpt _sample2	r_gpt_triangle_wave_pwm_2.c	Definition of functions for PWM generation and duty ratio setting
	r_gpt_triangle_wave_pwm_2.h	Header file of r_gpt_triangle_wave_pwm_2.c
Common (functions related to initial settings)	r_init_stop_module.c	Disable peripheral modules running after a reset
	r_init_stop_module.h	Header file of r_init_stop_module.c
	r_init_port_initialize.c	Initial nonexistent port settings
	r_init_port_initialize.h	Header file of r_init_port_initialize.c
	r_init_clock.c	Initial clock settings
	r_init_clock.h	Header file of r_init_clock.c

4.4 Option-Setting Memory

Table 4.4 lists the option-setting memory settings in the sample code. If necessary, change the values to match your system.

Table 4.4 Option-Setting Memory Settings in Sample Code

Symbol	Address	Setting Value	Description
OFS0	FFFF FF8Fh to FFFF FF8Ch	FFFF FFFFh	IWDT stops after a reset.
OFS1	FFFF FF8Bh to FFFF FF88h	FFFF FFFFh	Voltage monitor 0 reset disabled after a reset. HOCO oscillation disabled after a reset.
MDE	FFFF FF83h to FFFF FF80h	FFFF FFFFh	Little endian

4.5 Variables

Table 4.5 lists the global constant variables defined in the sample code.

Table 4.6 lists static variables used in the interrupt handlers of GTICV0 and GTICU0.

Table 4.5 Constants Used in rx24u_gpt_sample1 and rx24u_gpt_sample2 Sample Code

Project Name	Constant Name	Value	Description
rx24u_gpt _sample1	g_duty_output_tbl_a [ ]	{0x03, 0x02, 0x03, 0x00}	Duty ratio value set in GTIOCA
	g_duty_output_tbl_b [ ]	{0x02, 0x03, 0x02, 0x00}	Duty ratio value set in GTIOCB
rx24u_gpt _sample2	g_duty_output_tbl_a [ ]	{0x03, 0x02}	Duty ratio value set in GTIOCA
	g_duty_output_tbl_b [ ]	{0x02, 0x03}	Duty ratio value set in GTIOCB

Table 4.6 Static Variables Used in Interrupt Handlers of GTICV0 and GTICU0

Type	Variable Name	Initial Value	Function
uint8_t	s_duty_cnt_v	0	Used for duty ratio setting count to set duty ratio by GTICV0
	s_duty_cnt_u	0	Used for duty ratio setting count to stop counter by GTICU0

4.6 Functions

Table 4.7 lists the functions related to initial settings. Table 4.8 lists the functions related to the GPT.

Table 4.7 Functions Related to Initial Settings

Function Name	Outline
r_init_stop_module.c	Disable peripheral modules running after a reset
r_init_port_initialize.c	Initial nonexistent port settings
r_init_clock.c	Initial clock settings

Table 4.8 Functions Related to GPT

Function Name	Outline
main	Main processing routine
R_GPT0_TriangleWavePWMGeneration	Triangle-wave complementary PWM generation
R_GPT0_TriangleWavePWMDuty	Duty-cycle settings
R_GPT0_Interrupt	Interrupt settings
R_GPT0_CountStart	Count start
gpt_port_init	GPT I/O pin initialization
Excep_GPT0_GTCIV0	GTCIV0 interrupt handler
Excep_GPT0_GTCIU0	GTCIU0 interrupt handler

4.7 Function Specifications

The table below lists the specifications of the GPT-related functions listed in Table 4.8. For the specifications of the functions related to initial settings listed in Table 4.7, refer to RX24T Group Initial Settings Example (R01AN2837) or RX24U Group Initial Settings Example (R01AN3425), referenced in 7, Reference Documents.

main	
Outline	Main processing routine
Header	None
Declaration	void main(void)
Description	Performs initial settings after a reset (clock settings, disable peripheral modules running after a reset, and nonexistent port settings), settings to generate triangle-wave complementary PWM output and duty-cycle settings (0% or 100%), GPT I/O pin initialization, interrupt settings, count operation start settings.
Arguments	None
Return Value	None
Remarks	None

R_GPT0_TriangleWavePWMGeneration	
Outline	Triangle-wave complementary PWM generation
Header	r_gpt_triangle_wave_pwm_1.h, r_gpt_triangle_wave_pwm_2.h
Declaration	void R_GPT0_TriangleWavePWMGeneration (void)
Description	Performs settings necessary for triangle-wave PWM generation. Sets channel 0 to triangle-wave complementary PWM mode 1.
Arguments	None
Return Value	None
Remarks	None

R_GPT0_TriangleWavePWMDuty	
Outline	Triangle-wave complementary PWM duty-cycle settings
Header	r_gpt_triangle_wave_pwm_1.h, r_gpt_triangle_wave_pwm_2.h
Declaration	void R_GPT0_TriangleWavePWMDuty(void)
Description	Sets the duty ratio.
Arguments	None
Return Value	None
Remarks	None

R_GPT0_Interrupt	
Outline	Interrupt settings
Header	r_gpt_triangle_wave_pwm_1.h, r_gpt_triangle_wave_pwm_2.h
Declaration	void R_GPT0_Interrupt(void)
Description	Makes IR, IPR, and IEN settings, and enables the GPT’s GTCIV0 and GTCIU0 interrupts.
Arguments	None
Return Value	None
Remarks	None

R_GPT0_CountStart	
Outline	Count start
Header	r_gpt_triangle_wave_pwm_1.h, r_gpt_triangle_wave_pwm_2.h
Declaration	void R_GPT0_CountStart(void)
Description	Starts count operation on GPT0.
Arguments	None
Return Value	None
Remarks	None

gpt_port_init	
Outline	GPT I/O pin initialization
Header	None
Declaration	static void gpt_port_init (void)
Description	Sets pins as GPT I/O pins. Makes POE settings before and after the above settings. The pins are in the high-impedance state while GPT pin settings are performed.
Arguments	None
Return Value	None
Remarks	None

Excep_GPT0_GTCIV0	
Outline	GTCIV0 interrupt handler
Header	None
Declaration	void Excep_GPT0_GTCIV0 (void)
Description	An interrupt is generated at each crest of the triangle-wave. This function changes the duty ratio setting.
Arguments	None
Return Value	None
Remarks	None

Excep_GPT0_GTCIU0	
Outline	GTCIU0 interrupt handler
Header	None
Declaration	void Excep_GPT0_GTCIU0 (void)
Description	An interrupt is generated at each trough of the triangle-wave. This function stops the counter after the specified period has elapsed.
Arguments	None
Return Value	None
Remarks	This function is used in rx24u_gpt_sample1 only.

4.8 Flowcharts

4.8.1 Main Processing Routine

Figure 4.4 shows a flowchart of the main processing routine.

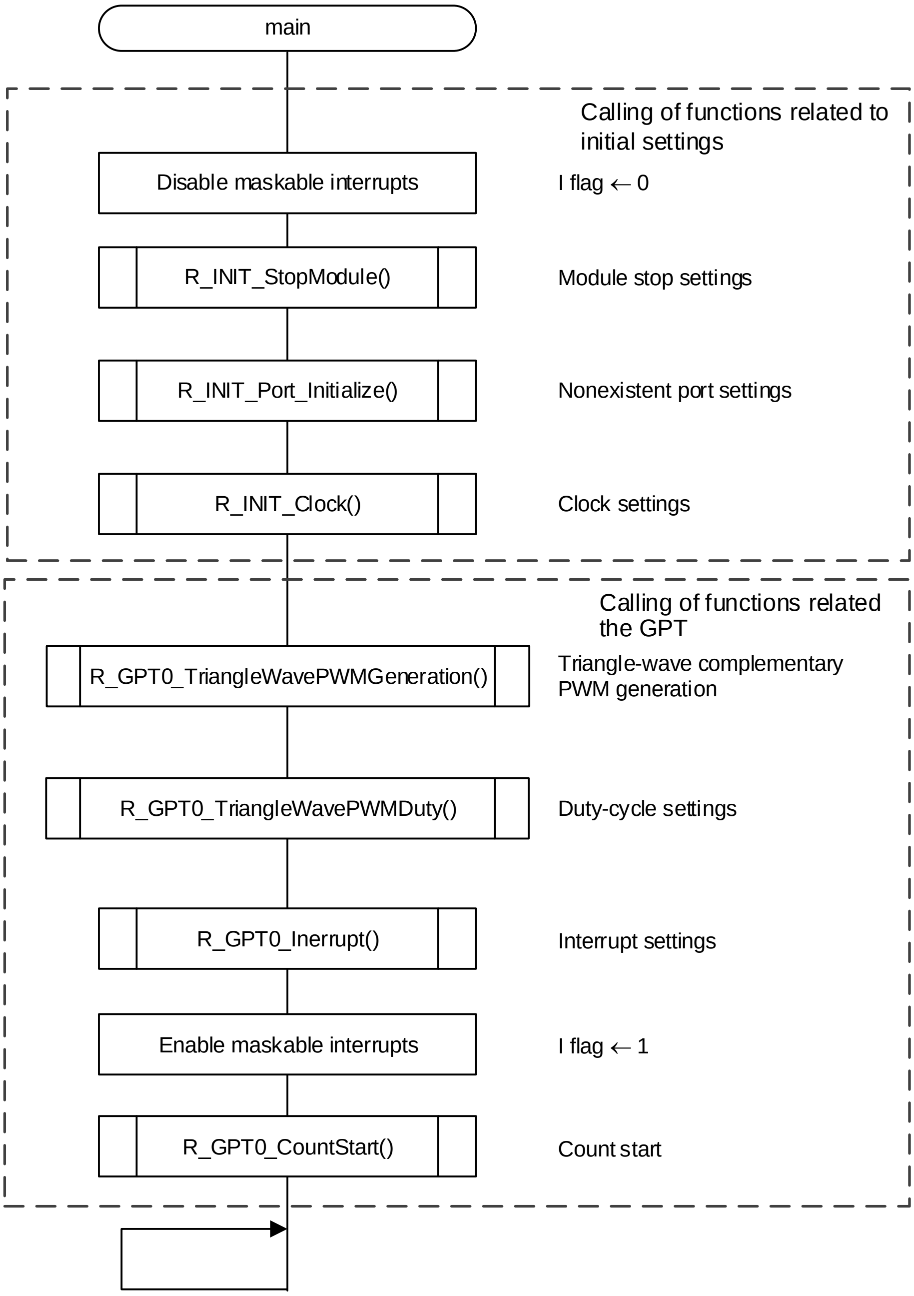

Figure 4.4 Main Processing Routine

4.8.2 Triangle-Wave Complementary PWM Generation

Figure 4.5 shows a flowchart of triangle-wave complementary PWM generation.

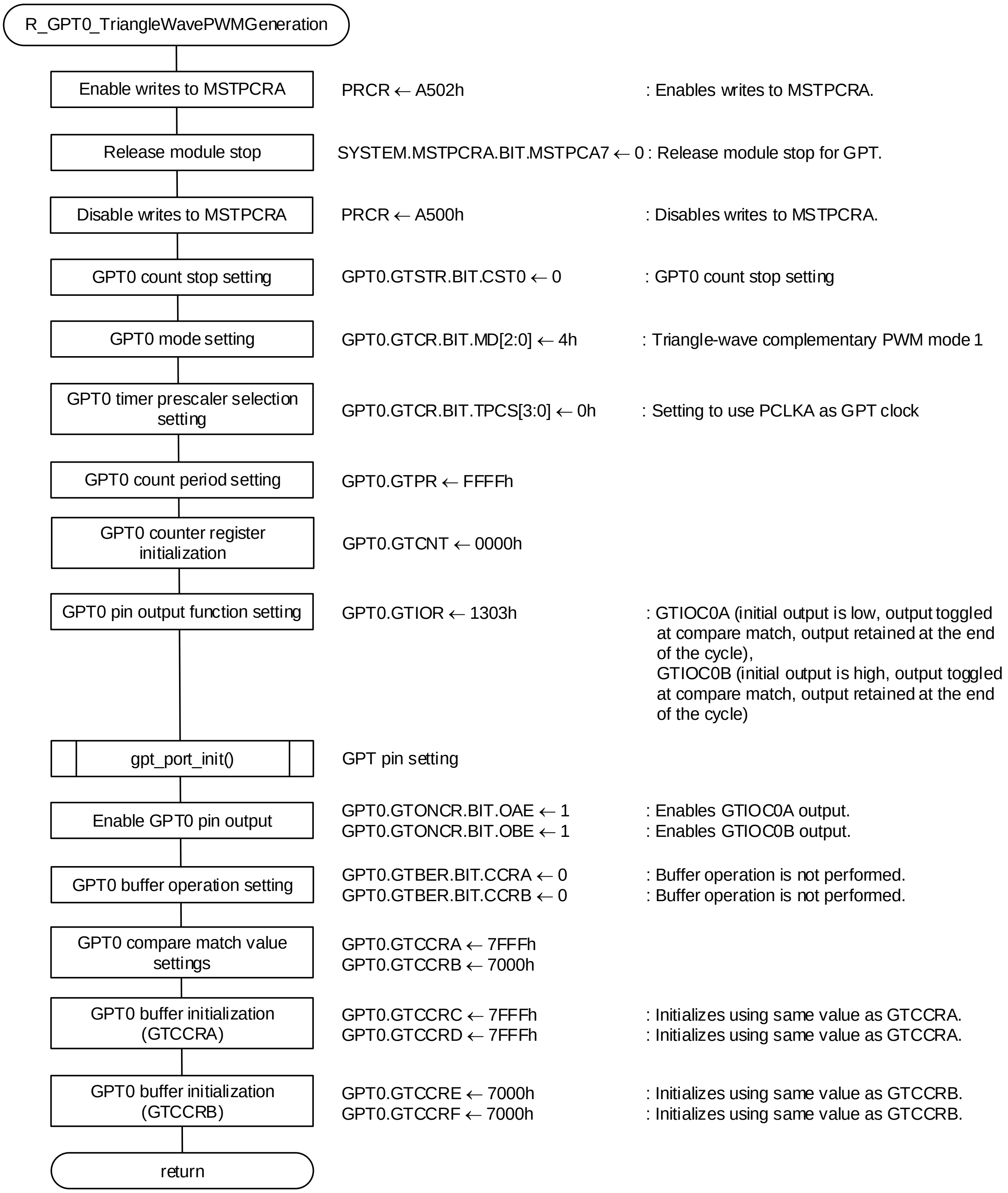

Figure 4.5 Triangle-Wave Complementary PWM Generation

4.8.3 Duty-Cycle Settings

Figure 4.6 shows a flowchart of duty-cycle setting.

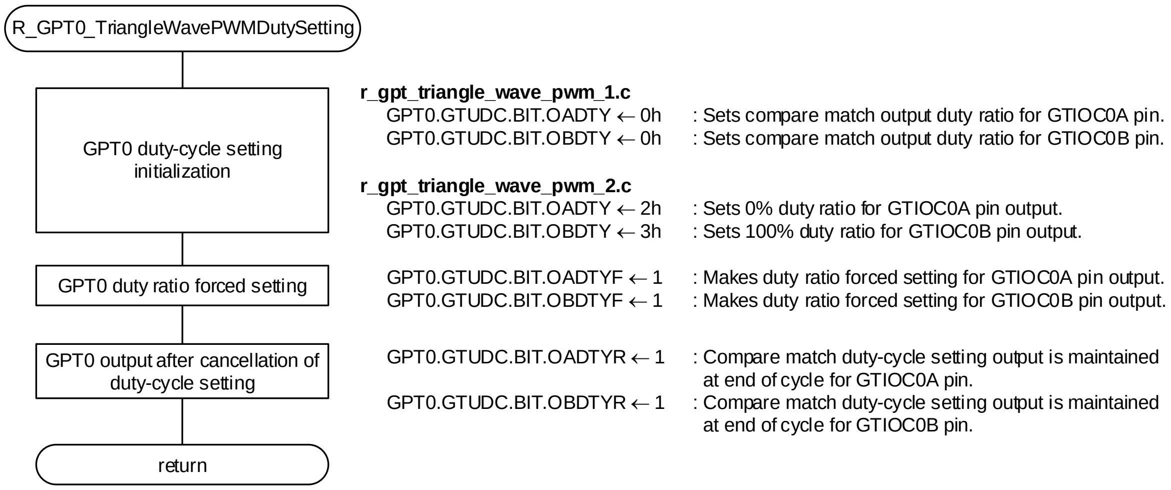

Figure 4.6 Duty-Cycle Settings

4.8.4 Interrupt Settings

Figure 4.7 shows a flowchart of interrupt setting.

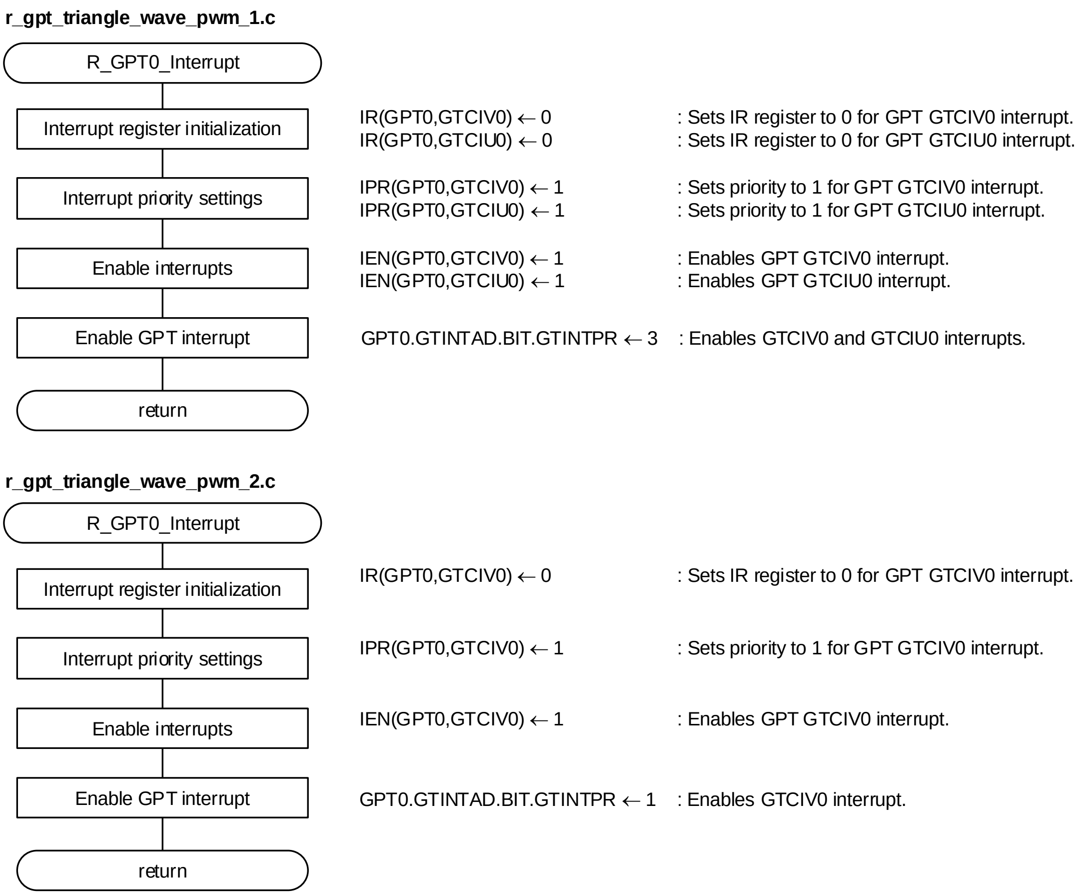

Figure 4.7 Interrupt Settings

4.8.5 Count Start

Figure 4.8 shows a flowchart of GPT0 count operation start processing.

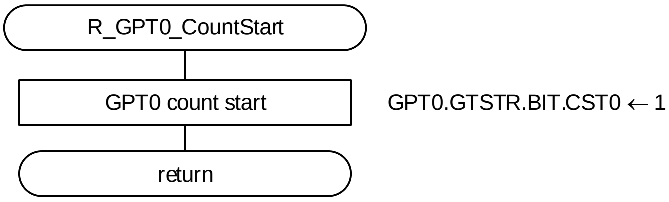

Figure 4.8 Count Start

4.8.6 GPT I/O Pin Initialization

Figure 4.9 shows a flowchart of GPT0 I/O pin (P71 and P74) initialization.

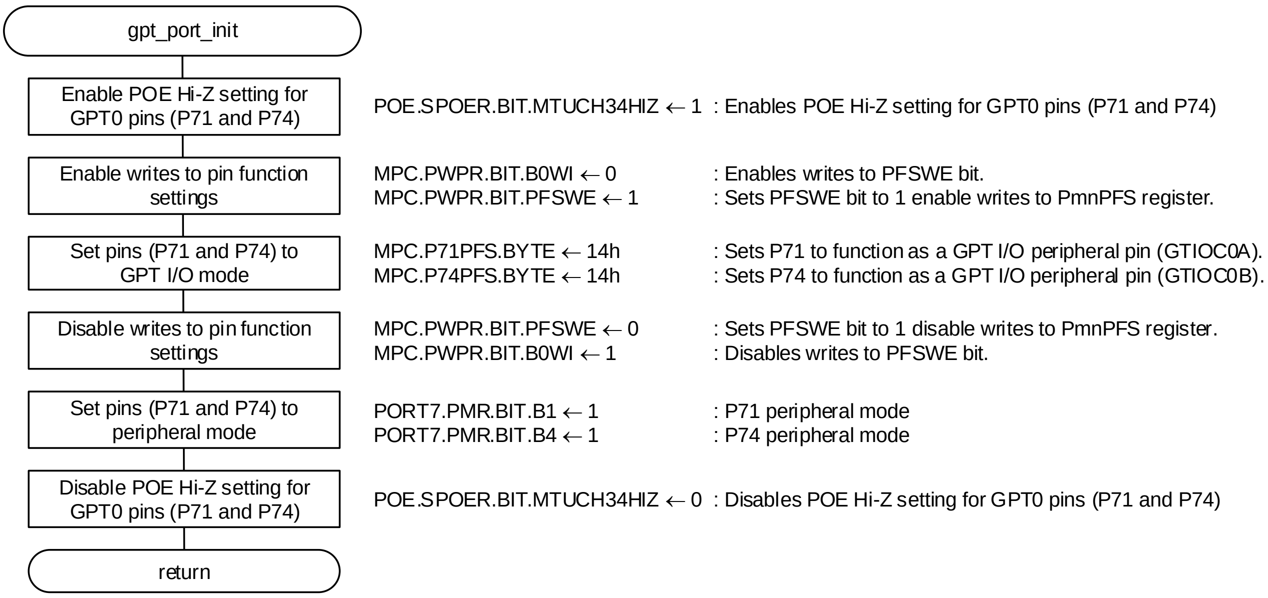

Figure 4.9 GPT I/O Pin Initialization

4.8.7 GTCIV0 Interrupt Handler

Figure 4.10 shows a flowchart of the GTCIV0 interrupt handler.

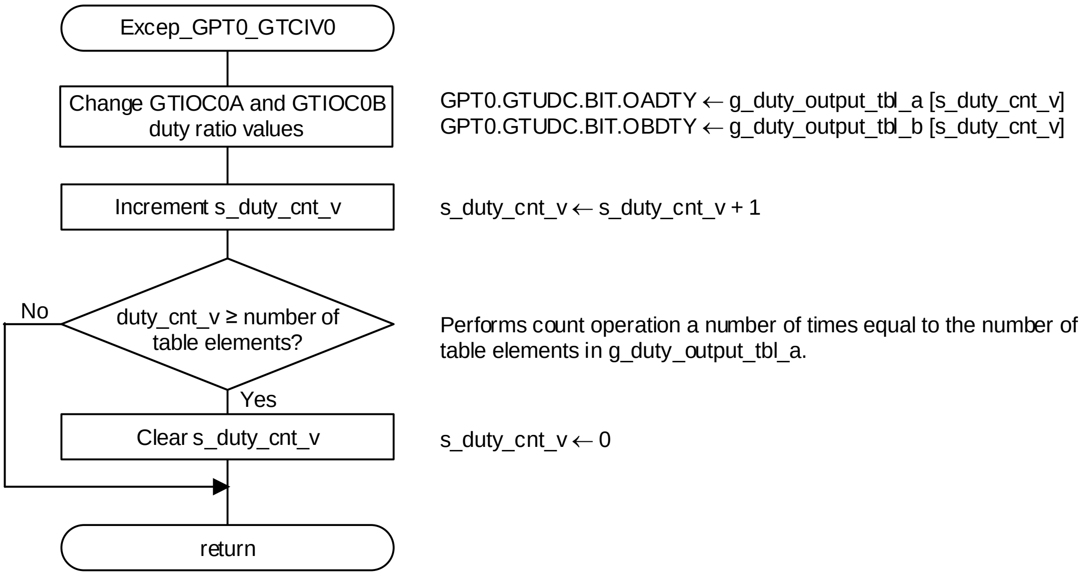

Figure 4.10 GTCIV0 Interrupt Handler

4.8.8 GTCIU0 Interrupt Handler

Figure 4.11 shows a flowchart of the GTCIU0 interrupt handler. This function is used in rx24u_gpt_sample1 only.

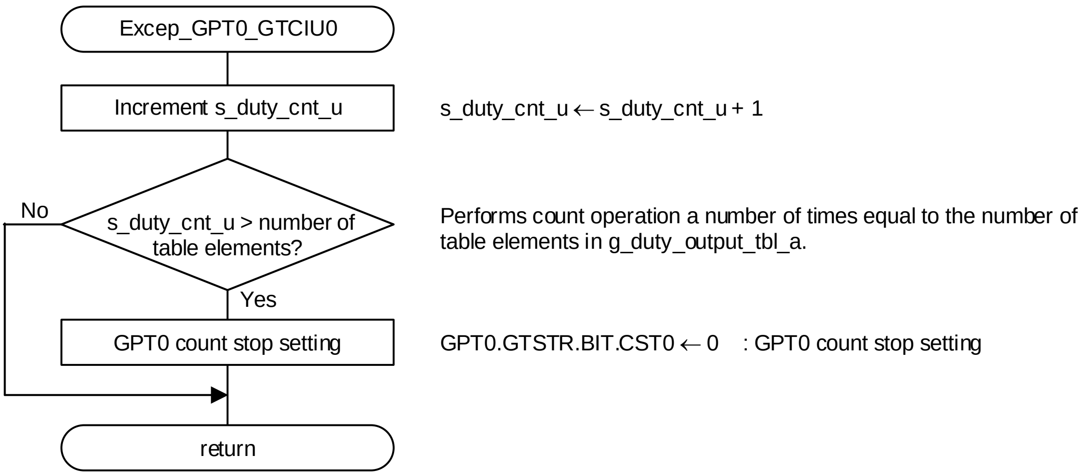

Figure 4.11 GTCIU0 Interrupt Handler

5. Importing a Project

After importing the sample project, make sure to confirm build and debugger setting.

5.1 Importing a Project into e² studio

Follow the steps below to import your project into e² studio. Pictures may be different depending on the version of e² studio to be used.

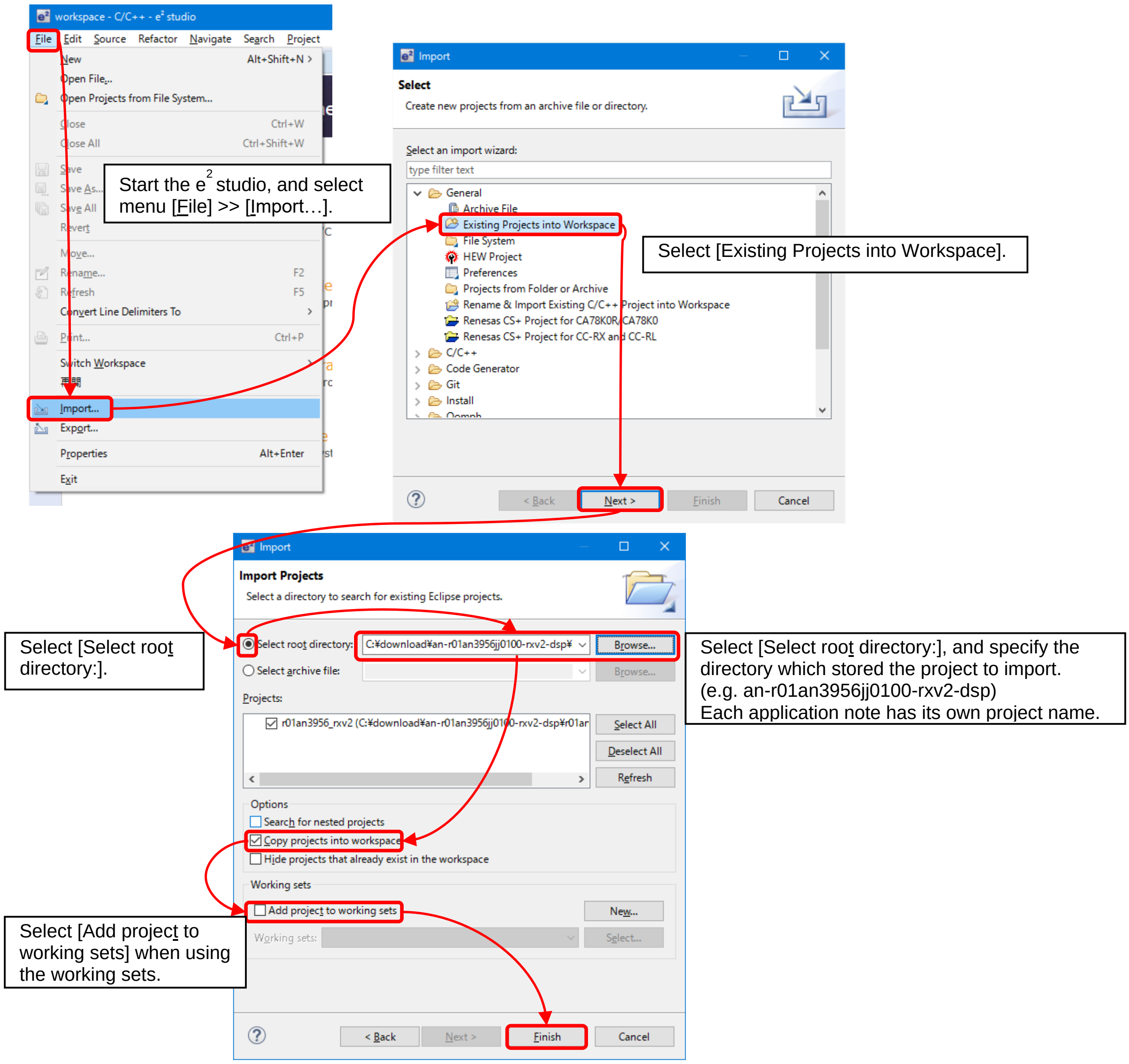

Figure 5.1 Importing a Project into e² studio

5.2 Importing a Project into CS+

Follow the steps below to import your project into CS+. Pictures may be different depending on the version of CS+ to be used.

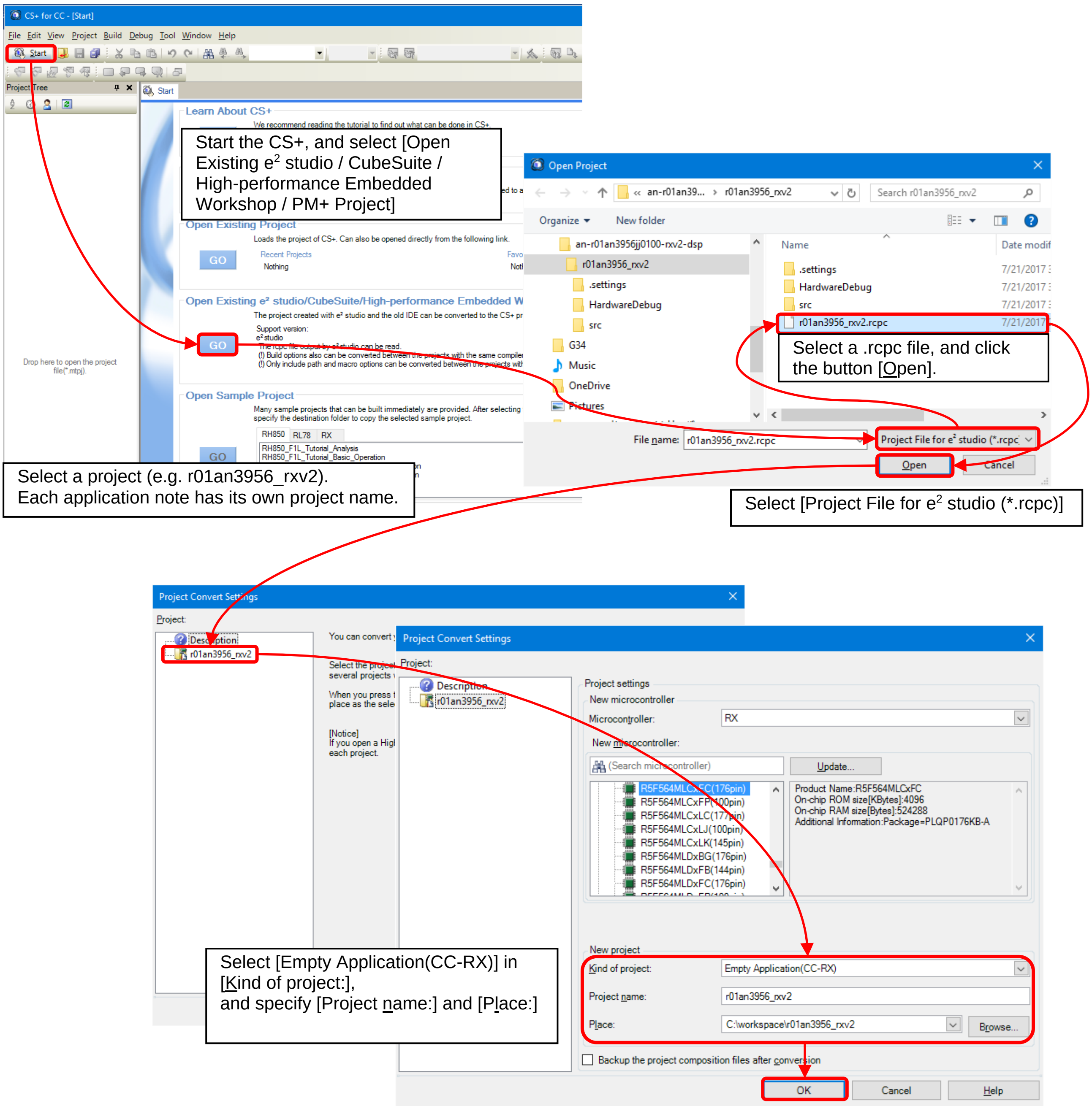

Figure 5.2 Importing a Project into CS+

6. Sample Code

Sample code can be downloaded from the Renesas Electronics website.

7. Reference Documents

User's Manual: Hardware
RX24T Group User's Manual: Hardware (R01UH0576)
(The latest version can be downloaded from the Renesas Electronics website.)

RX24U Group User's Manual: Hardware (R01UH0658)
(The latest version can be downloaded from the Renesas Electronics website.)

Technical Update/Technical News
(The latest version can be downloaded from the Renesas Electronics website.)

User's Manual: Development Tools
RX Family CC-RX Compiler User's Manual (R20UT3248)
(The latest version can be downloaded from the Renesas Electronics website.)

Revision History

Rev.	Date	Description	
		Page	**Summary**
1.00	Dec.10.19	—	First edition issued

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. Precaution against Electrostatic Discharge (ESD)

   A strong electrical field, when exposed to a CMOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop the generation of static electricity as much as possible, and quickly dissipate it when it occurs. Environmental control must be adequate. When it is dry, a humidifier should be used. This is recommended to avoid using insulators that can easily build up static electricity. Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work benches and floors must be grounded. The operator must also be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions must be taken for printed circuit boards with mounted semiconductor devices.
2. Processing at power-on

   The state of the product is undefined at the time 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 time 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 time 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 time when power is supplied until the power reaches the level at which resetting is specified.
3. Input of signal during power-off state

   Do not input signals or an I/O pull-up power supply while the device is powered off. The current injection that results from input of such a signal or I/O pull-up power supply may cause malfunction and the abnormal current that passes in the device at this time may cause degradation of internal elements. Follow the guideline for input signal during power-off state as described in your product documentation.
4. 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 the 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.
5. Clock signals

   After applying a reset, only release the reset line after the operating clock signal becomes stable. When switching the clock signal during program execution, wait until the target clock signal is 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. Additionally, 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.
6. Voltage application waveform at input pin

   Waveform distortion due to input noise or a reflected wave may cause malfunction. If the input of the CMOS device stays in the area between V_{IL} (Max.) and V_{IH} (Min.) due to noise, for example, the device may malfunction. Take care to prevent chattering noise from entering the device when the input level is fixed, and also in the transition period when the input level passes through the area between V_{IL} (Max.) and V_{IH} (Min.).
7. Prohibition of access to reserved addresses

   Access to reserved addresses is prohibited. The reserved addresses are provided for possible future expansion of functions. Do not access these addresses as the correct operation of the LSI is not guaranteed.
8. Differences between products

   Before changing from one product to another, for example to a product with a different part number, confirm that the change will not lead to problems. The characteristics of a microprocessing unit or microcontroller unit products in the same group but having a different part number might differ in terms of 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.

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