RX Family

Digital Power Conversion (LLC Resonant Converter (DC-DC Converter))

Summary

This application note is intended to describe how to drive and control LLC Resonant Converter, which is a DC-DC converter using RX66T group or RX26T group, and how to use motor control development support tool [RMW]*1. LLC Resonant Converter Board described in this application note is a board that operates on Base Board(P13178-C0-001) of 50Hz 100V 100W Power Board Kit *2. For further information on Base Board(P13178-C0-001) and digital power control, please refer to the Digital Power Conversion (UPS (CCM Interleaved PFC, Chopper DC-DC Converter)) (R01AN6465) of separate application notes.

These sample programs are only to be used as reference and Renesas Electronics Corporation does not guarantee the operations. Please use them after carrying out a thorough evaluation in a suitable environment.

Note 1: RMW is an abbreviation for Renesas Motor Workbench.

2: 50Hz 100V 100W power board kit is made by Desk Top Laboratories Inc.

Operation Check Device

The operation of the sample program is checked with the following devices.

RX family RX66T Group (R5F566TEADFH)
RX family RX26T Group (R5F526TFDGFP)

It is also applicable to RX family that has the resources described in this application note or equivalent peripheral functions. (RX72T, RX24T, RX24U, RX72M, RX72N, RX66N, etc.)

Target Sample Program

The sample program for this application note is shown below.

- RX66T_P13178_LLC_CSP_RV100 (IDE: CS+)
- RX66T_P13178_LLC_E2S_RV100 (IDE: e^2studio)
- RX26T_P13178_LLC_CSP_RV100 (IDE: CS+)
- RX26T_P13178_LLC_E2S_RV100 (IDE: e^2studio)

Reference Materials

- RX66T Group User's Manual: Hardware (R01UH0749)
- RX26T Group User's Manual: Hardware (R01UH0979)
- Renesas Motor Workbench User's Manual (R21UZ0004)
- Digital Power Conversion (UPS (CCM Interleaved PFC, Chopper DC-DC Converter)) (R01AN6465)
- Digital Power Conversion (Totem Pole Interleaved PFC (AC-DC Converter)) (R01AN6877)

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1. Overview

This application note describes how to control and implement bidirectional LLC resonant converter of DC-DC converter in a digital-power-control *1 using RX66T group or RX26T group. This section also explains how to use motor control development support tool [RMW].

Note 1: Digital power control means AC-DC converters, DC-DC converters, and DC-AC inverters. Please refer to Digital Power Conversion (UPS (CCM Interleaved PFC, Chopper DC-DC Converter)) (R01AN6465) in the separate application notes for more information.

1.1 Development Environment

Table 1 and Table 2 show the development environment of the software subject to this application note.

Table 1 Hardware Development Environment

Microcomputer	Evaluation Board (50Hz 100V 100W Power Board Kit *1)	
	Board name	**Model**
RX66T (R5F566TEADFH) OR RX26T (R5F526TFDGFP)	RX66T CPU Card OR RX26T CPU Card	P05701-C0-038 OR P05701-C0-068
	Base Board	P13178-C0-001
	Bidirectional LLC Resonant Converter Board (DC-DC Board)	P13178-C0-006 (Applicable board in this application notes)

Table 2 Software Development Environment

Device	IDE Version	RX Smart Configurator *3	Toolchain version *2
RX66T	CS+: V8.09.00	Version 2.16.0	CC-RX: V3.05.00
	e^2studio:2023-01	e^2studio plug-in version	
RX26T	CS+:V8.10.00	Version 2.19.0	CC-RX: V3.05.00
	e^2studio:2023-10	e^2studio plug-in version	

Note
1. 50Hz 100V 100W power board kit is made by Desk Top Laboratories Inc. If you have any questions about the solution, please contact Desk Top Laboratories Inc.
2. If the same version as the toolchain (C compiler) specified in the project does not exist in the import destination, the toolchain is not selected and an error occurs. Check the toolchain selection status in the project settings screen.
   Refer to FAQ 3000404 for the selection procedure.
   (https://en-support.renesas.com/knowledgeBase/18398339)
3. This project does not use the generated code by this tool.

2. LLC Resonant Converters Overview

LLC resonant converter shown in Figure 1 is an isolated DC-DC converter. Isolated types include forward, flyback, push-pull, and bridge types, but this LLC resonant converters are classified as bridge types. The big difference from the usual bridge system is that L and C resonant tanks exist. There are two resonant frequencies for L and C, one of which fluctuates depending on the load. Therefore, if the L and C resonant circuit constants are not determined according to the load specifications, resonance will be disengaged, causing not only a large switching loss but also a breakdown of the power semiconductor in the worst case. In addition, LLC resonant converter introduced in this application note is a bidirectional circuit, which is a circuit that supports BUCK operation (high-voltage to low-voltage conversion) and BOOST operation (low-voltage to high-voltage conversion). Therefore, LLC resonant converter for this application has a resonant tank on the secondary side. In this application note, the BOOST operation is PWM controlled rather than PFM controlled in view of maximal efficiency. This LLC resonant circuit is relatively difficult to design than a circuit without a resonant tank. However, since zero-volt switching is performed by the resonant circuit, high-efficiency and low-noise switching can be realized with less switching loss. On the other hand, since the resonant operation is PFM controlled, the noise frequency is also changed by switching. Therefore, it is difficult to cut the noise components with a fixed noise filter. However, unlike PWM control method, the noise is relatively low, so the hardware-design is also relatively easy. In general, bidirectional LLC resonant converter uses on a carrier frequency of several hundred khz on both the primary side (Q1, Q2, Q3, Q4) and the secondary side (Q5, Q6, Q7, Q8). Therefore, the power semiconductor uses such as SIC that can be switched at a carrier frequency of several hundred kHz. However, on this application note used the MOSFET (RJK1001) of RENESAS, a relatively high speed switching with low "on resistor", on the secondary side of the low voltage.

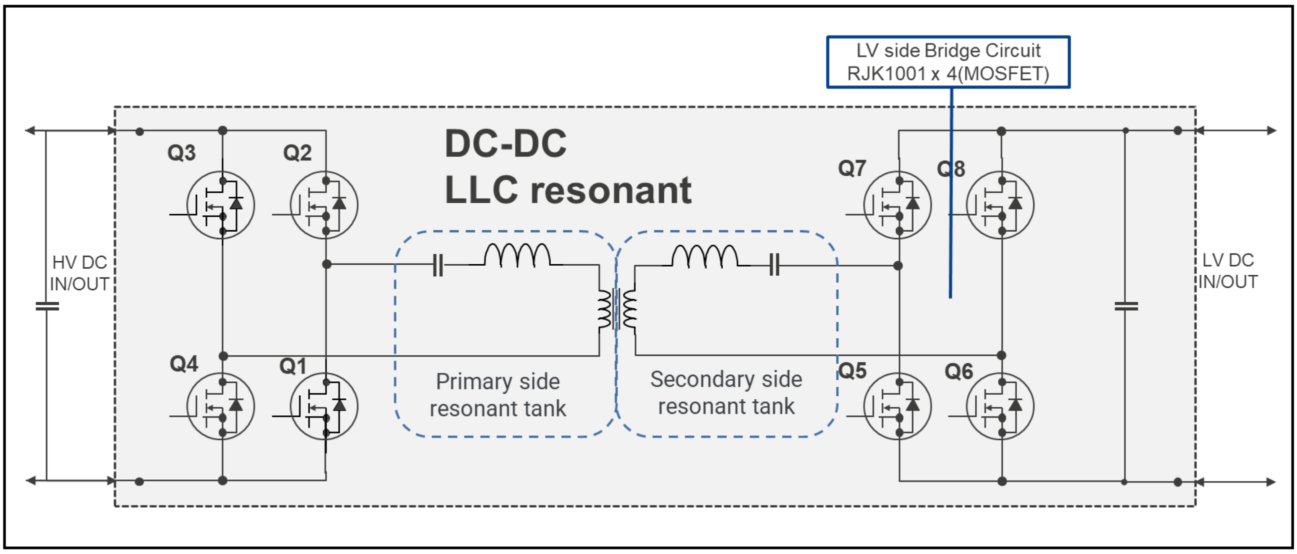


Figure 1 Schematic Diagram of Bidirectional LLC Resonant Converters

2.1 Outline of LLC Resonant Converters Operation

LLC resonant converters are roughly classified into 10 modes, however this application note shows six operating modes except for the transient period, as shown in Figure 2 and Figure 3. Complementary PWM control is performed on the primary and secondary sides with a bridge-circuit configuration. As shown in Figure 4, Complementary PWM control is "the high side (Q3) of the left leg and the low side (Q1) of the right leg" are the same signal, and "the low side (Q4) of the left leg and the high side (Q2) of the right leg" are the same signal. Control with a phase difference of 180 degrees while maintaining complementary PWM relationship by these signals.

*: In this application note, the following signals are assigned.

For HV side (primary side)

・High side (Q3) on the left leg and low side (Q1) on the right leg : GTIOC4A of RX66T/RX26T GPTW

・Low side (Q4) on the left leg and high side (Q2) on the right leg : GTIOC5B of RX66T/RX26T GPTW

For LV side (secondary side)

・High side (Q7) on the left leg and low side (Q6) on the right leg : GTIOC0A of RX66T/RX26T GPTW

・Low side (Q5) on the left leg and high side (Q8) on the right leg : GTIOC1B of RX66T/RX26T GPTW

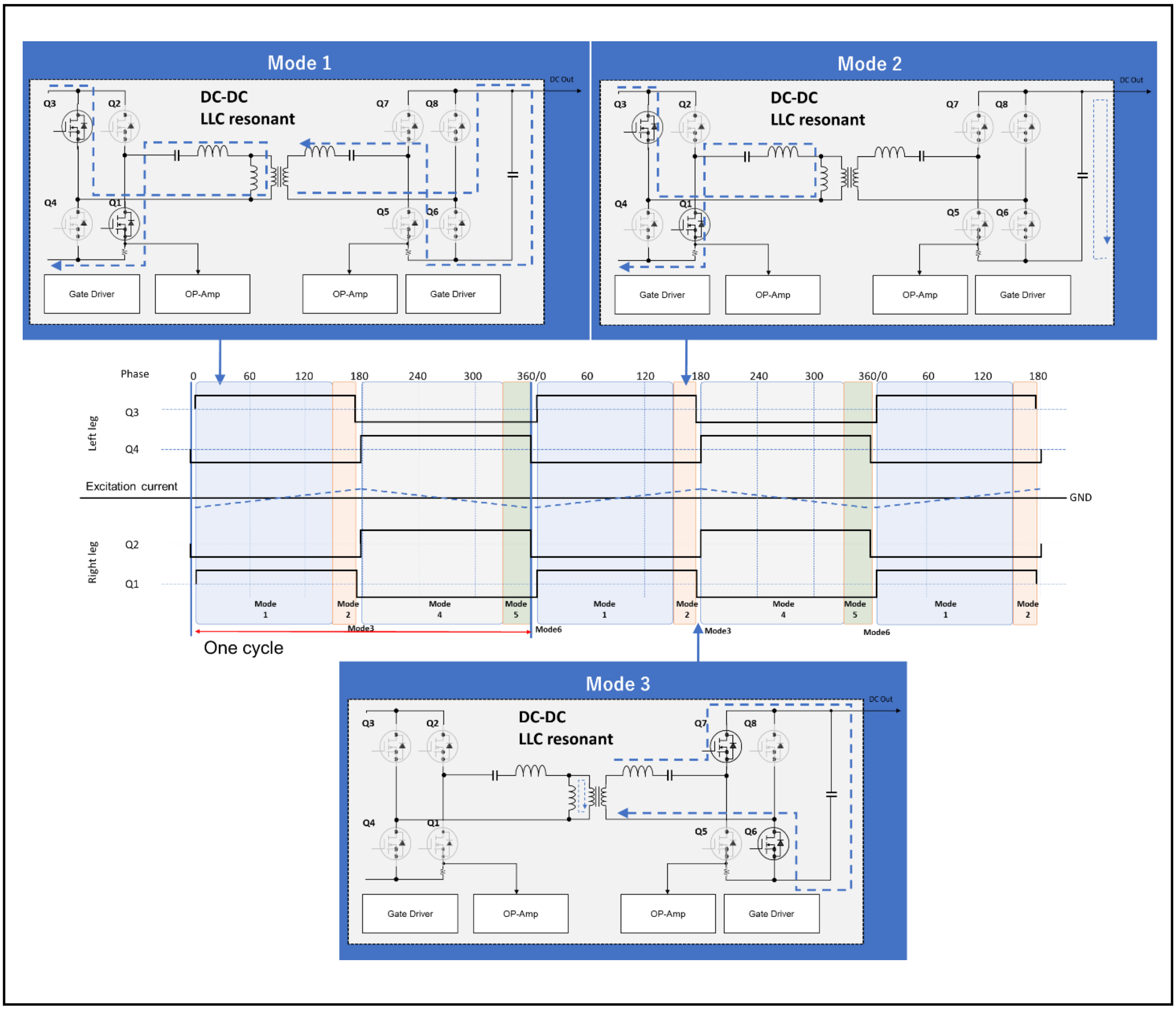


Figure 2 Outline of LLC Resonant Converter Operation 1

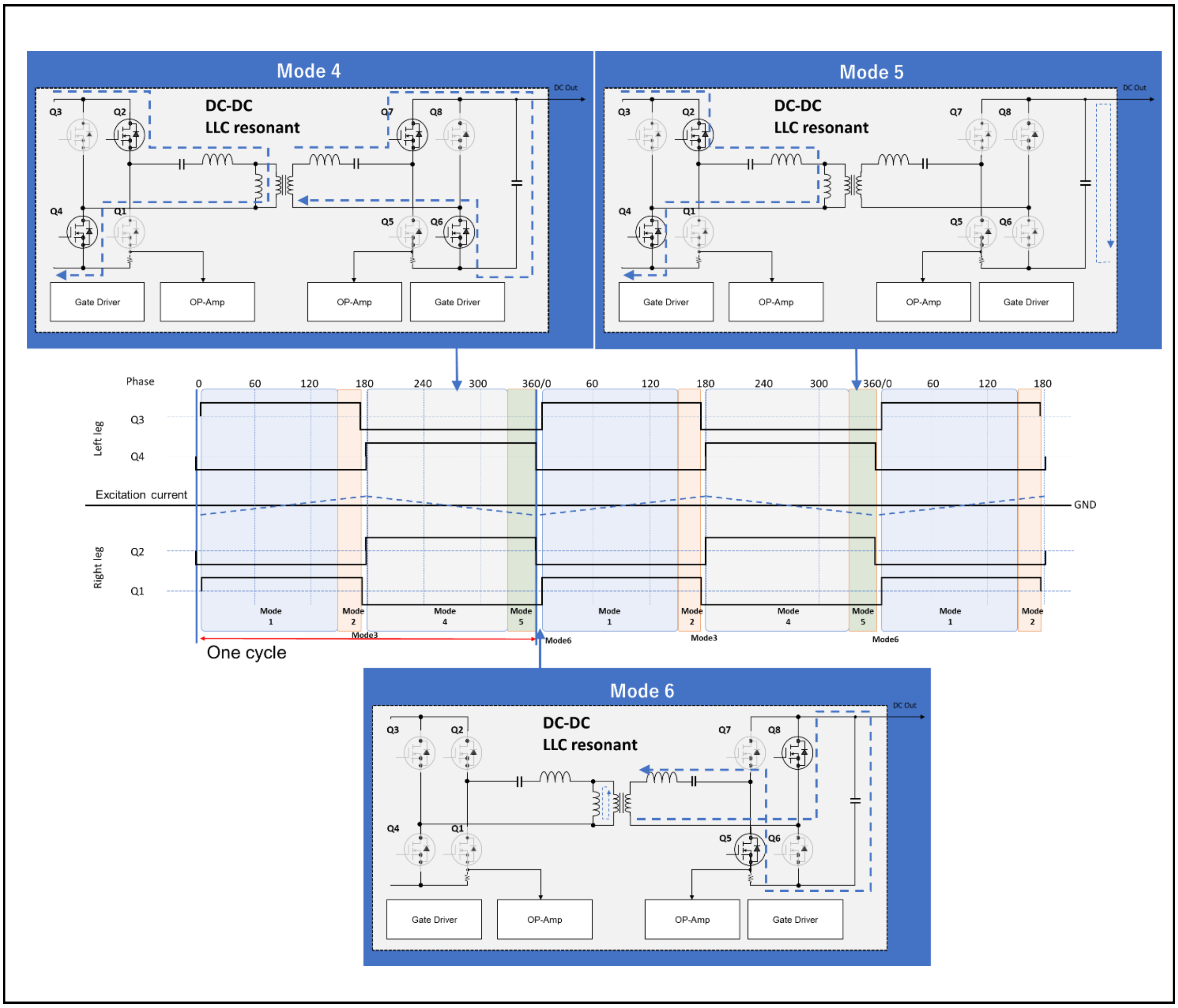


Figure 3 Outline of LLC Resonant Converter Operation 2

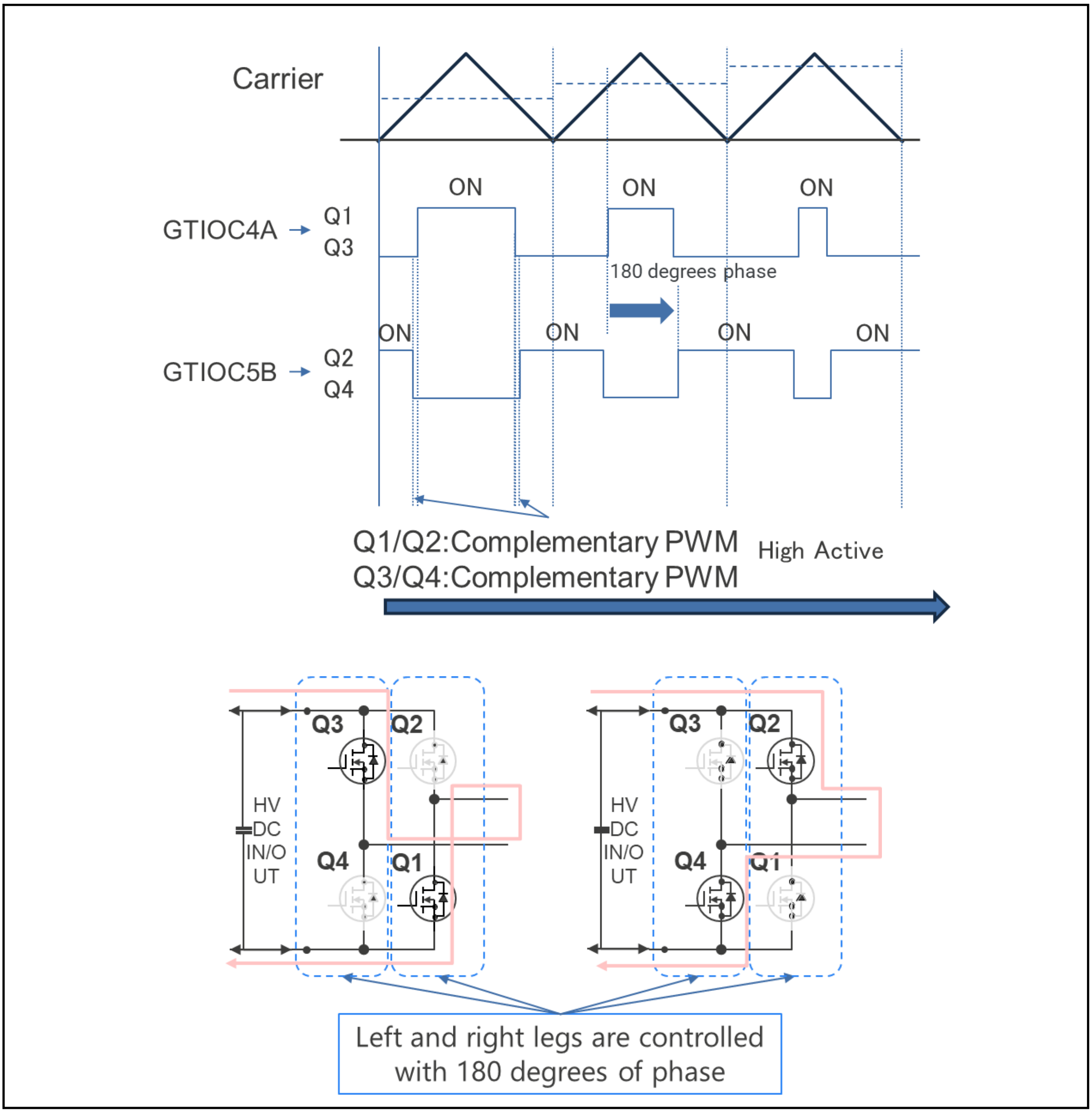


Figure 4 Switching Waveform of LLC Resonant Converter

3. Hardware Description

LLC Resonant Converter Board is a board that runs on Base Board of 50Hz 100V 100W power board kit. It consists of three boards as shown in Table 3. Base Board is a baseboard into which various converters (AC-DC, DC-DC) and inverter boards (DC-AC) are inserted. Each board is controlled by a RX66T/RX26T CPU Card. In this application note, only DC-DC converter board (LLC resonant converter board) is mounted and controlled. LLC Resonant Converter Board hardware specifications are listed in Table 4.

Table 3 List of Boards Used

No.	Board name	Model name	Remarks
1	CPU Card (Select from the right)	P05701-C0-038	CPU Evaluation Board with R5F566TEADFH
		P05701-C0-068	CPU Evaluation Board with R5F526TFDGFP
2	Base Board	P13178-C0-001	Power supply board that serves as a base for inserting various power supply boards
3	DC-DC Board	P13178-C0-006	DC-DC converter board (LLC resonant converter board)

Table 4 LLC Resonant Converter Board Hardware Specifications

Item	Specifications	Remarks
Input voltage	300V	
Output voltage	24V	
Output power	140W Max	
Circuit method	Bidirectional LLC	
LLC switching-frequency	100kHz Over	Dead-time 0.5us
Efficiency	Max96% or more	140W
Protection	Overvoltage protection	Low pressure: 30V High pressure: 350V
	Undervoltage protection	High pressure: 250V Low pressure: 22V
Status display	7Seg method + LED indication	Error information and operation status display (shown in Base Board)

3.1 Hardware Configuration

Figure 5 shows the configuration diagram of Base Board of 50Hz 100V 100W power board kit, LLC Resonant Converter Board, and RX66T/RX26T CPU Card used in this application note. Figure 6 to Figure 8 show the external views of each board, and Table 5 shows Base Board connector list.

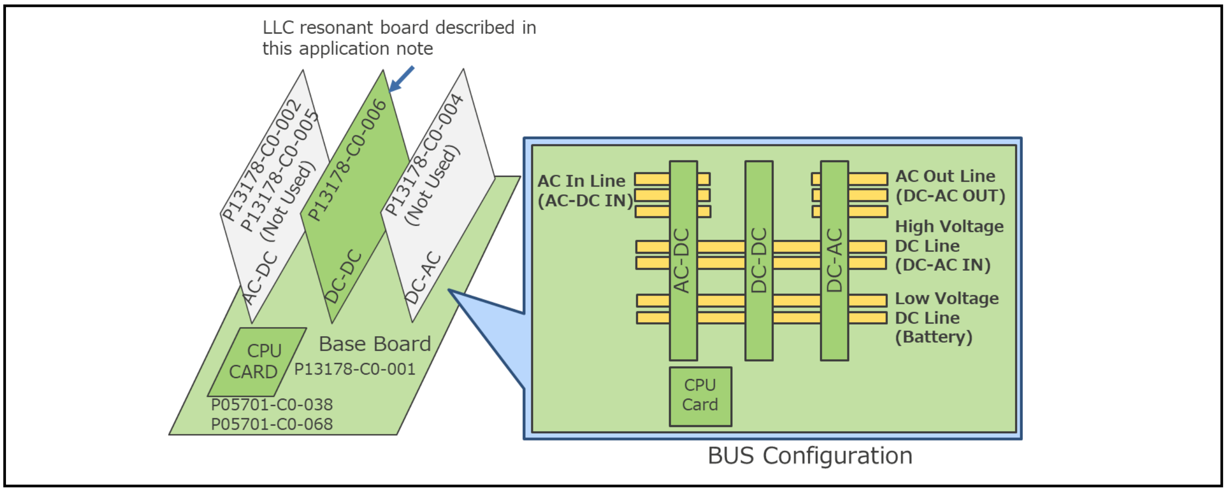


Figure 5 Board Configuration Diagram

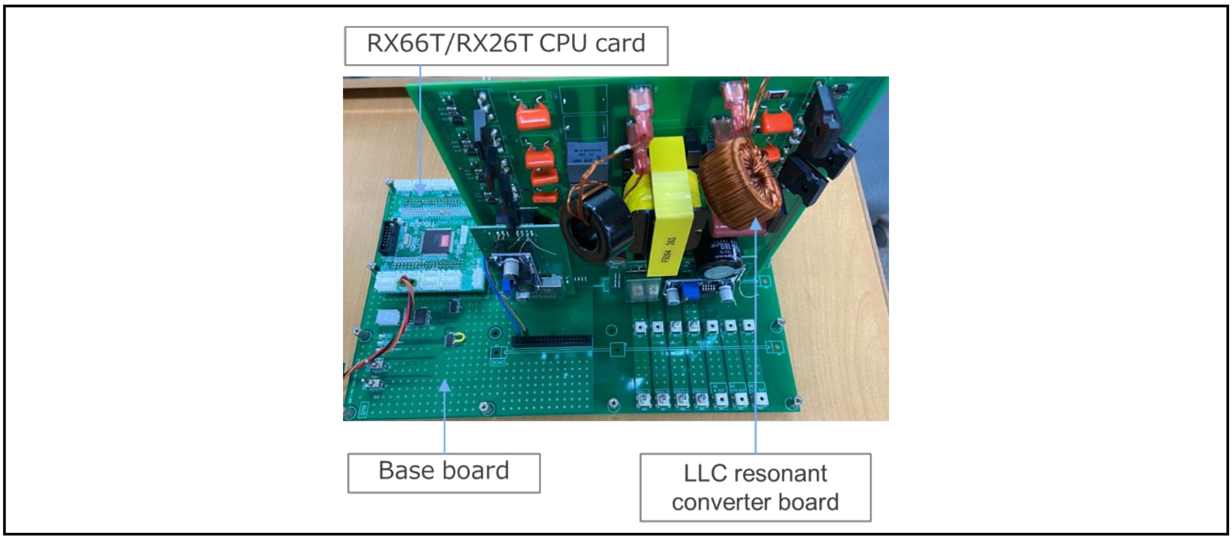


Figure 6 Overall Configuration External View

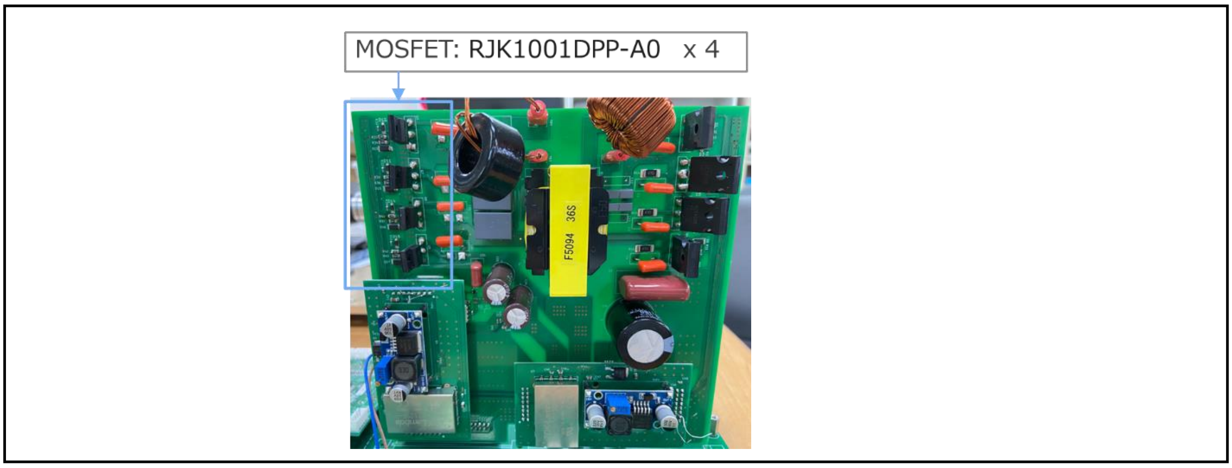


Figure 7 LLC Resonant Converter Board External View

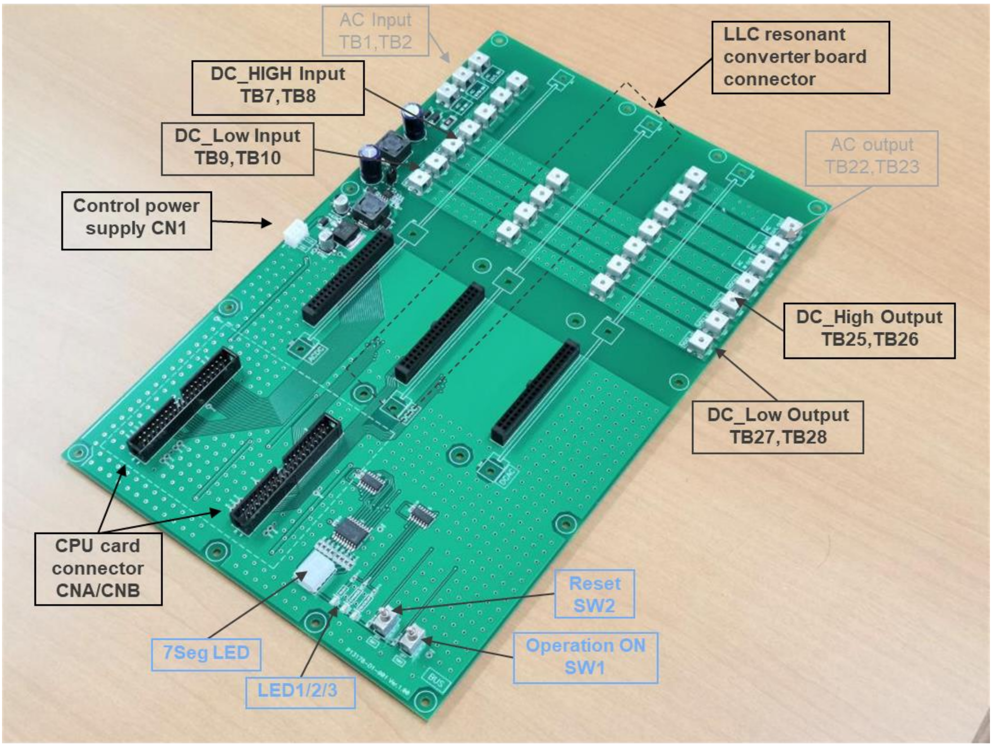


Figure 8 Base board External View

Table 5 Base Board Connectors

Terminal name	Defined	Remarks
TB7, TB8	High-voltage input	Common to output side
TB9, TB10	Low pressure input	Common to output side
TB25, TB26	High-voltage output	Common to input side
TB27, TB28	Low pressure output	Common to input side
CAN / CNB	CPU Card connector	RX66T (P05701-C0-038) OR RX26T (P05701-C0-068)

3.2 Configuration of MCU Function

The configuration of MCU function is shown in Figure 9.

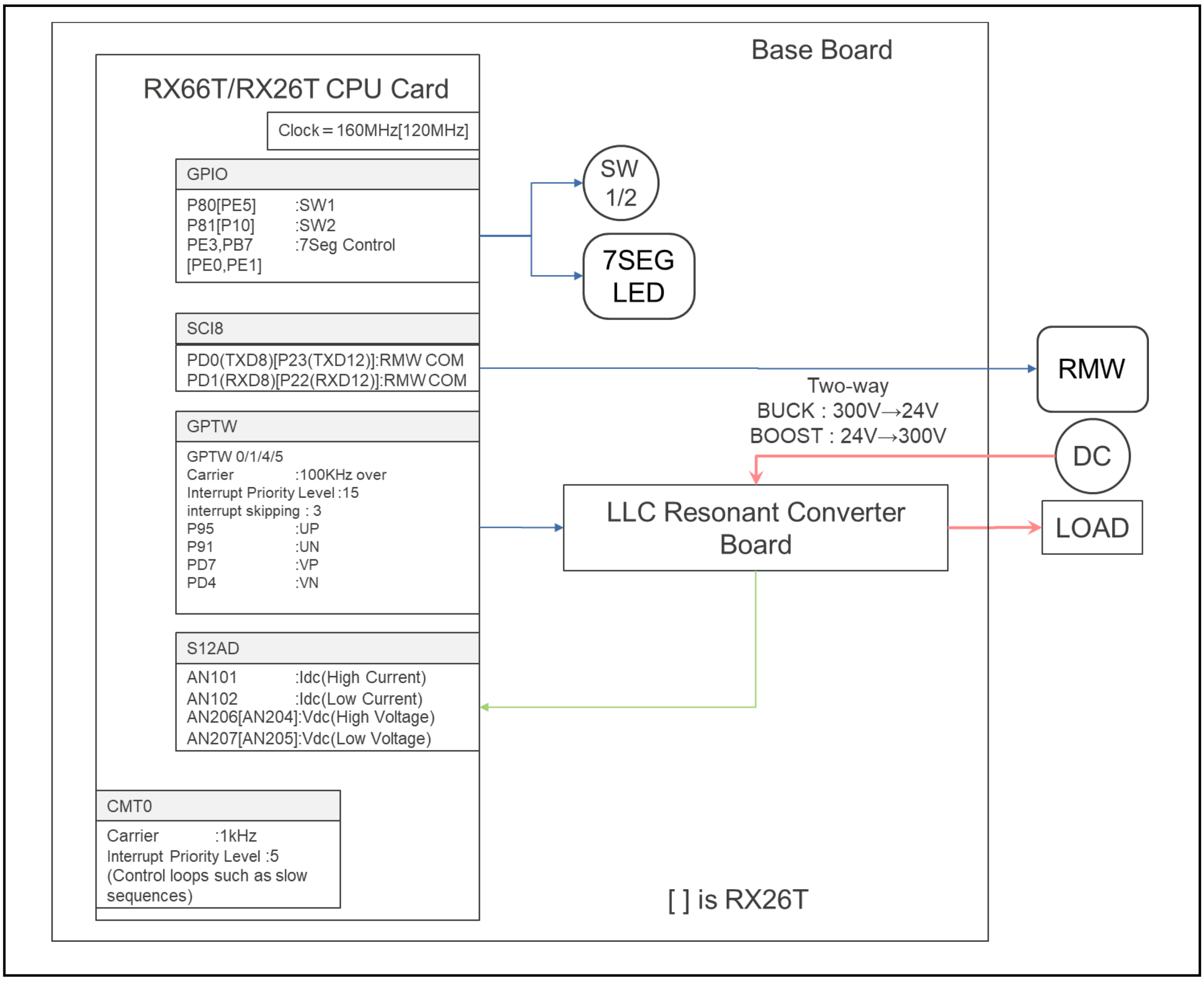


Figure 9 MCU Function Connection Configuration Diagram

3.3 MCU Peripheral Function

Table 6 shows the peripheral functions of RX66T/RX26T used in this system.

Table 6 List of Peripheral Functions Used

MCU modular	Function
12-bit AD (S12ADH)	HV/LV current (S12AD1 - AN101 / AN102) HV/LV voltage (RX66T:S12AD2 - AN206 / AN207) (RX26T:S12AD2 - AN204 / AN205)
Interval timer (CMT)	1ms interval timer (CMT0)
PWM output timer (GPT0 / 1 / 4 / 5)	Complementary PWM outputting and cycle vary depending on the operation mode. Control cycle: Voltage is controlled by interrupt skipping count to 3.

3.4 Pin Interface

Table 7 lists the pin interfaces of RX66T/RX26T used in this systemand Table 8 lists Q1～Q8 drive pin combinations of the bridgecircuit.

Table 7 RX66T/RX26T Pin Interfaces

Module name	Used resources	RX66T Port name	RX26T Port name	Function
GPIO		P80	PE5	SW1
		P81	P10	SW2
		PE3, PB7	PE1, PE0	Including 7Seg Control (LED)
SCI	SCI8 [SCI12]	PD0(TXD8)	P23 (TXD12)	RMW communication (send)
		PD1(RXD8)	P22 (RXD12)	RMW communication (receive)
GPT	GPT0 GPT1 GPT4 GPT5	PD7(GTIOC0A)		UP (LV side- control)
		PD4(GTIOC1B)		VN (LV side- control)
		P95(GTIOC4A)		UP (HV side- control)
		P91(GPIOC5B)		VN (HV side- control)
S12ADH	S12AD1 S12AD2	P45 (AN101)		Idc (HV)
		P46 (AN102)		Idc (LV)
		P60 (AN206)	P50 (AN204)	Vdc (HV)
		P61 (AN207)	P51 (AN205)	Vdc (LV)

Table 8 RX66T/RX26T Q1～Q8 Drive Terminal Combination

Primary (HV)/ Secondary side (LV side)	MOSFET(SiC) Symbol name	Drive signal name	Connector terminal name	MCU Pin	Generic name
HV	Q2(SiC)	PWM_RH	22_VN2_P91	P91(GTIOC5B)	VN
	Q1(SiC)	PWM_RL	26_UP2_P95	P95(GTIOC4A)	UP
	Q3(SiC)	PWM_LH	26_UP2_P95	P95(GTIOC4A)	UP
	Q4(SiC)	PWM_LL	22_VN2_P91	P91(GTIOC5B)	VN
LV	Q7	PWM_RH_B	39_RESERVE1	PD7(GTIOC0A)	UP
	Q5	PWM_RL_B	40_RESERVE2	PD4(GTIOC1B)	VN
	Q8	PWM_LH_B	40_RESERVE2	PD4(GTIOC1B)	VN
	Q6	PWM_LL_B	39_RESERVE1	PD7(GTIOC0A)	UP

3.5 User Interface

Table 9 shows a list of the user interfaces of this system, and Table 10 shows a list of errors.

Table 9 List of User Interfaces

Item	Interface component	Function
Run switch 1	Toggle switch (SW1)	BOOST/BUCK operation command ON :BUCK operation (300V→24V) OFF: BOOST operation (24V→300V)
Run switch 2	Toggle switch (SW2)	Start/stop command OFF⇒ON : RUN operation OFF : STOP & Error clearing operation
Operation display	Red LED1	Displaying start/stop or error Lit: Activated Off: Stopped or fault
Error status display	7Seg LED	Error flag (1 to 255) is displayed in 5 digits per second. See Table 10 for error flags. (Example) Error 016 (0x0010) 0 display/sec ->1 display/sec -> 6 display/sec -> blank display/sec -> blank display/sec

Table 10 Error Flags

Error flag display	Error description	Set value	Error flag (hex)
0 6 4 □ □	HV overvoltage protection	350V	0x0040
0 3 2 □ □	LV overvoltage protection	30V	0x0020
1 2 8 □ □	HV undervoltage protector	250V	0x0080
0 1 6 □ □	LV undervoltage protector	22V	0x0010

□:Blank display

4. Software Description

Software-process of this application note is divided into DC-DC converter control block (LLC resonant converter) and user interface control block. The user interface controls set the parameters required to control LLC resonant converter and communicate with Renesas Motor Workbench. LLC resonant converter performs complementary PWM to switch the switching devices according to the loading conditions. The software module configuration is shown in Figure 10.

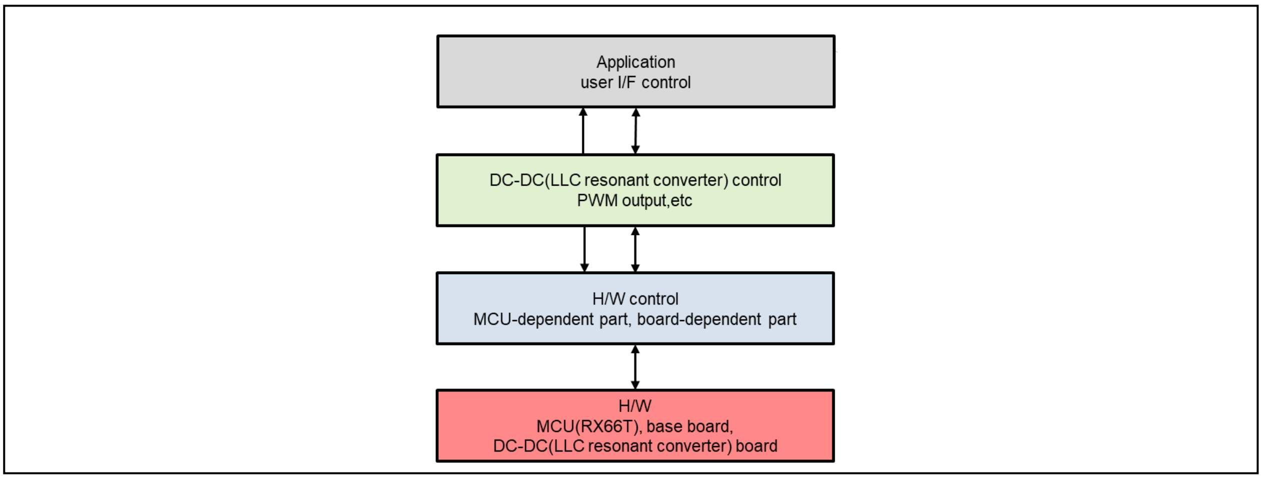


Figure 10 Module Configuration

4.1 Software Configuration

Table 11 shows the folder and file structure.

Table 11 Folder and File Structure

Folder name	File name	Description
src	main.c	Main functions, user interface control
	intprg.c	Interrupt handler
	r_pwr_control.c	Initialization process
	r_pwr_interrupt.c	Interrupt process
	r_pwr_LLC_ctrl.c	LLC control software
	r_pwr_control.h	Error parameter related defined
	r_pwr_interrupt.h	Control parameter defined
	r_pwr_LLC_ctrl.h	LLC parameter defined
src\REL_src	resetprg.c	Process at power-on
	dbsct.c	B, R section-setting
	sbrk.c	Memory allocation process
	vecttbl.c	Vector table initialization process
	iodefine.h	IO register defined
	sbrk.h	Allocation size defined
	stacksct.h	Stack area size defined
	typedefine.h	Type defined
	vect.h	Vector defined
src\PWR_IOLIB	r_pwr_IOLIB_AD.c	S12AD related process
	r_pwr_IOLIB_CLOCK.c	Operation clock setting process
	r_pwr_IOLIB_CMT.c	CMT related process
	r_pwr_IOLIB_INV_GPT_AD.c	GPTW related process
	r_pwr_IOLIB_IO.c	I/O relation process [Only RX26T version]
	r_pwr_MATHLIB.c	Arithmetic operation related process
	r_pwr_IOLIB.h	MCU dependent part defined
	r_pwr_MATHLIB.h	Arithmetic operation related defined
src\ICS_LIB	ICS2_RX66T.h [ICS2_RX26T.h]	Communication relation defined for RMW tools
	ICS2_RX66T.lib [ICS2_RX26T.lib]	Communication library for RMW tools

4.2 State Transition

Figure 11 shows the state transition diagram in the application note target software. The software subject to this application note manages the system status in three modes: "STOP Mode", "ERROR Mode" and "RUN Mode". The operation details are shown below.

■Normal Operation

(1)When the power is turned on, it goes through "Power On Reset" and transitions to "STOP Mode" and enters standby status.

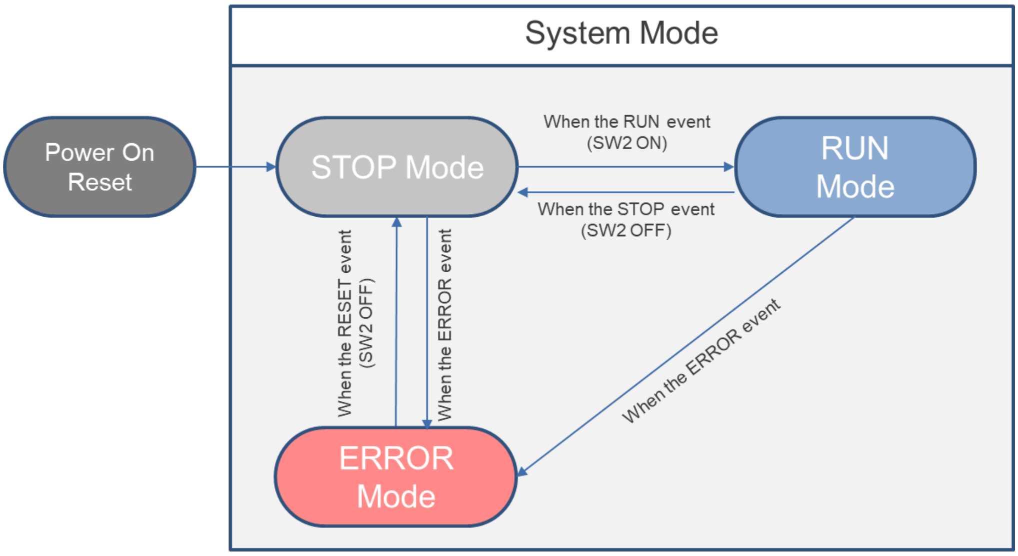
(2)Switch to "RUN Mode" in SW2 OFF→ON and execute DC-DC converter control (LLC resonant converter). DC-DC converter control performs back/boost operation in SW1. (See Table 9for details)

(3)All process are terminated by SW2 OFF, the status changes to "STOP Mode", and the system enters the standby status.

■When an Error Occurs

(1)When an error occurs, it transits to "ERROR Mode" and enters the standby status with "ERROR Mode". Refer to Table 10 Error Flags for details of the error.

(2)By resetting SW2 (OFF), it changes to "STOP Mode" and enters the standby status.



Error event	Error event occurrence value
HV overvoltage protection	350V
LV overvoltage protection	30V
HV undervoltage protector	250V
LV undervoltage protector	22V

Figure 11 State Transition Diagram

4.3 Content of Control

As shown in the control signal wiring diagram in Figure 12, the software process of this application note sets GPT0/1, GPT4/5 of RX66T/RX26T GPTW to triangle-wave PWM mode1. GPT4/5 control the primary side of HV, and GPT0/1 control the secondary side of LV. Since both the primary and secondary sides have a bridge-circuit configuration, complementary PWM control is performed. In the case of the primary side, Complementary PWM control is "the high side (Q3) of the left leg and the low side (Q1) of the right leg" are the same signal, and "the low side (Q4) of the left leg and the high side (Q2) of the right leg" are the same signal. Control with a phase difference of 180 degrees while maintaining complementary PWM relationship by these signals (see Figure 4 for details). When the primary is in resonant operation (during BUCK operation), the carrier frequency is fixed to 125KHz and PWM control is performed in order to perform soft-start operation. Then, PFM control is performed to vary the carrier frequency for resonant operation. Duty of PWM is fixed at 40% and the carrier frequency is controlled between 102KHz～125KHz. When operating on the secondary side (during BOOST operation), this application note performs PWM control in view of the maximum efficiency. Figure 13 shows the control logic diagram, and Figure 14 shows the relation between the switching frequency and Duty in BUCK operation and BOOST operation.

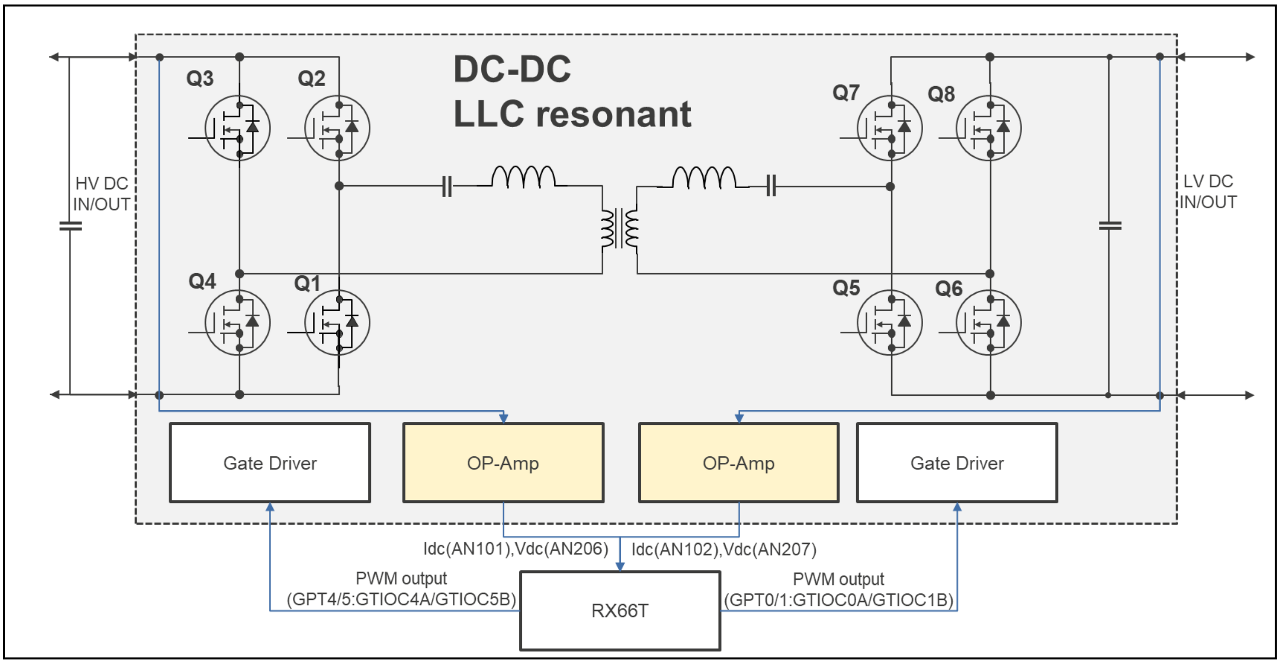


Figure 12 Circuit Configuration and Control Signal Wiring Diagram of LLC Resonant Converter Control Unit

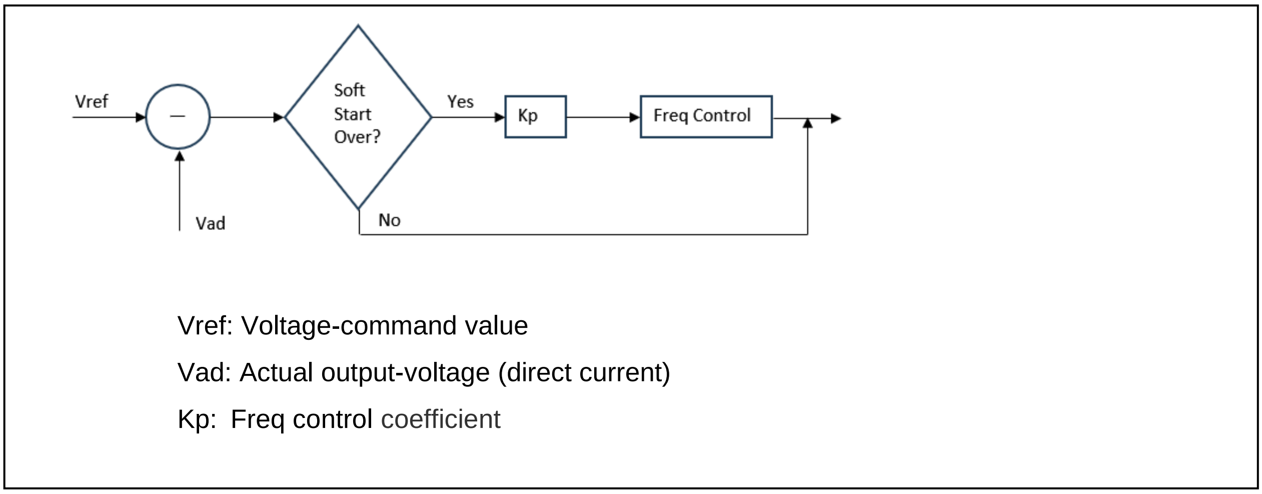


Figure 13 LLC Resonant Converter Control Logic Diagram

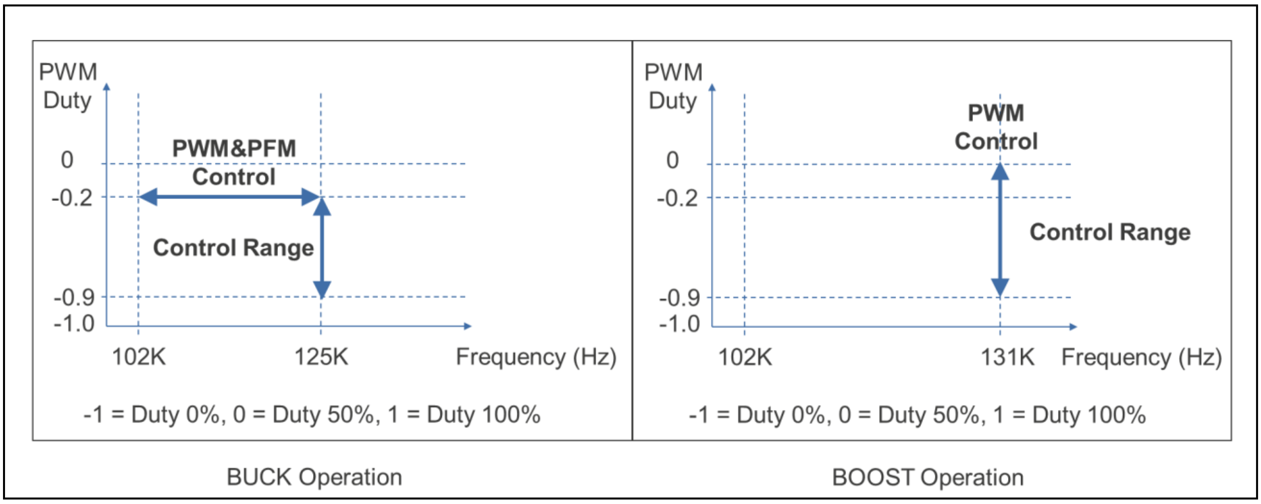


Figure 14 Relation Between Switching Frequency and Duty During BUCK/BOOST Operation

4.4 List of Functions

The function list of this control program is shown below. Some functions are provided as extensions (functions not used in this software) so that they can be easily incorporated by the user. Refer to Notes in the list below for the unused functions.

Table 12 Functions

File		Function				Note
Path	Name	Name	Arguments	Return Type	Overview	
src	main.c	main	void	void	Main functional	
	r_pwr_control.c	r_pwr_User_Ctrl_Init	void	void	Parameter setting	
		r_pwr_User_CustomIO_init	void	void	IO initialization process	
		r_pwr_Seg_Control	uint16_t data	void	Functions for displaying 7seg	
	r_pwr_interrupt.c	Interrupt_CMT0	void	void	1kHz Interrupt, Input/Error Display and Sequence	
		Interrupt_GPT4_carrier	void	void	PWM interrupt process, check of ADC, setting of PWM and error-checking are performed. PFM cycle is variable. Interrupt skipping count is 3.	
		r_pwr_check_error_curloop	void	void	Error checking	
		r_pwr_error_stop	void	void	Error process	
	r_pwr_LLC_ctrl.c	r_pwr_LLC_Control_HV	void	void	BUCK control function	
		r_pwr_LLC_Control_HV_Init	void	void	BUCK control initialization process	

		r_pwr_LLC_Control_LV	void	void	BOOST control function	
		r_pwr_LLC_Control_LV_Init	void	void	BOOST control initialization process	
src\PWR_IOLIB	r_pwr_IOLIB_AD.c	r_pwr_ad_S12AD0_init	uint16_t mode	void	S12AD initialization process (Not Use)	Not use
		r_pwr_ad_S12AD1_init	uint16_t mode	void	S 12 AD 1 initialization process	
		r_pwr_ad_S12AD2_init	uint16_t mode	void	S 12 AD 2 initialization process	
		r_pwr_ad_S12AD0_set_channel	uint32_t ch_list	void	S12AD channels setting (Not Use)	Not use
		r_pwr_ad_S12AD1_set_channel	uint32_t ch_list	void	S12AD1 channels setting	
		r_pwr_ad_S12AD2_set_channel	uint32_t ch_list	void	S12AD2 channels setting	
		r_pwr_ad_S12AD0_set_range	int16_t ch, int16_t offset, float range	void	S12AD offset and range setting (Not Use)	Not use
		r_pwr_ad_S12AD1_set_range	int16_t ch, int16_t offset, float range	void	S12AD1 offset and range setting	
		r_pwr_ad_S12AD2_set_range	int16_t ch, int16_t offset, float range	void	S12AD2 offset and range setting	
	r_pwr_IOLIB_CLOCK.c	r_pwr_CLOCK_init	void	void	Operation clock setting	
	r_pwr_IOLIB_CMT.c	r_pwr_interval_CMT0_init	uint16_t freq	void	CMT0 initialization process	
		r_pwr_interval_CMT1_init	uint16_t freq	void	CMT1 initialization process (Not Use)	Not use
		r_pwr_interval_CMT2_init	uint16_t freq	void	CMT2 initialization process (Not Use)	Not use
		r_pwr_interval_CMT3_init	uint16_t freq	void	CMT3 initialization process (Not Use)	Not use
	r_pwr_IOLIB_INV_GPT_AD.c	r_pwr_inverter_GPT0145_init	uint32_t usFreqCarrier, uint32_t usDeadtime, uint32_t usDecimation	void	GPT0/1/4/5 initialization process for LLC resonant control PWM	
		r_pwr_inverter_GPT0145_set	float ref0, float ref1,	void	GPT0/1/4/5 compare and cycle setting for LLC resonant control	

		_uvw_3shunt_VariCar	float ref4, float ref5, float FreqCar		PWM	
	r_pwr_IOLIB_IO.c	r_pwr_User_CustomIO_init	void	void	Board I/O initialization [RX66T version is included in r_pwr_control.c]	
	r_pwr_MATHLIB.c	r_pwr_limit_PN	float data, float limitp, float limitn	float	Data range limit process	
		r_pwr_limit	float data, float limit	float	Negative data range limit process	
		r_pwr_Inv_Calc_Lpf	float * input_lpf, float input, float k_filter	void	LPF computation	
src\REL_src	Resetprg.c	PowerON_Reset_PC	void	void	Power-on reset process	
	Sbrk.c	Sbrk	size_t size	_SBYTE *	Memory area allocation process	

4.5 List of Variables

The following table lists the global variables used in this control program.

Table 13 List of Variables

File	Variable Name	Description
r_pwr_interrupt.c	g_u2_Mode_Input	Operation mode control and display 0 : STOP 1 : BUCK mode RUN command 2 : During BUCK mode operation 3 : BOOST mode RUN command 4 : During BOOST mode operation
	g_u2_TimeSetting_Offset	Variable for setting calibration time at start
	g_u2_TimeCnt_Offset	Calibration count value at startup
	g_f_ErrLevel_OV_LLC_pri	HV high-voltage protection-level
	g_f_ErrLevel_OV_LLC_sec	LV high-voltage protection-level
	g_f_ErrLevel_UV_LLC_sec	LV undervoltage protection-level
	g_f_ErrLevel_UV_LLC_pri	HV undervoltage protection-level
	g_u2_ErrorFlag_CurLoop	Error Flag
	g_f_LLC_HCur	HV current
	g_f_LLC_LCur	LV current
	g_f_LLC_HCur_offset	HV current offset
	g_f_LLC_LCur_offset	LV current offset

	g_f_LpfFactor_CurrentOff	Filter coefficient in offset calculation
	g_f_LLC_HV	HV voltage
	g_f_LLC_LV	LV voltage
	g_ics_cnt	Thinning count for RMW indication
	g_u2_seg_data	7Seg indication data
	g_u2_seg_time	Count-value for 7Seg indication cycle
	g_u2_seg_error_temp	Buffer value of the error part of 7Seg indication data
	g_u2_led1_display g_u2_led2_display g_u2_led3_display	LED1/2/3 data for viewing
	g_u2_sw1_status g_u2_sw2_status_old g_u2_sw2_status	SW1/2 input data
	g_u2_Run_Mode	Operation mode setting value (BUCK/BOOST)
r_pwr_LLC_ctrl.c	g_f_LLC_Mu_Ref g_f_LLC_Mv_Ref g_f_LLC_Mw_Ref	GPT outputting duty setting variable
	g_f_LLC_Freq	GPT outputting PWM cycle setting
	g_f_Kp_mod_pri	Duty rate of change of soft start in BUCK operation
	g_f_Kp_mod_sec	Kp for Duty change during BOOST operation
	g_f_Kp_freq_pri	Kp for cycle change during BUCK operation
	g_f_integ_freq	Integral value of the voltage difference
	g_f_integ_limit	Limit of voltage difference integration
	g_u2_flag_soft	Soft-Start Status Indication Flag for BUCK operation

4.6 Macro Defined List

The following table lists the macro defined used in this control program.

Table 14 Macro Defined List

File	Defined	Set value	Remarks
r_pwr_interrupt.h	SEG_TIME_ALL	5000	Sets the total duration for 7SEG view. (Setting prohibited for 3 seconds or less (time = set value/1000))
r_pwr_control.h	FLAG_ERROR_LLC_SEC_OV	0x0020	LV overvoltage Error Flag
	FLAG_ERROR_LLC_SEC_UV	0x0010	LV low-voltage error flag
	FLAG_ERROR_LLC_PRI_OV	0x0040	HV overvoltage Error Flag
	FLAG_ERROR_LLC_PRI_UV	0x0080	HV low-voltage error flag
r_pwr_LLC_ctrl.h	PRI_VOL_REF	300	HV voltage command (V)
	SEC_VOL_REF	24	LV voltage command (V)
	PRI_FREQ_MIN	102000	Min. operating frequency (Hz) during BUCK operation
	PRI_FREQ_MAX	125000	Max. operating frequency (Hz) during BUCK operation
	SEC_FREQ_MAX	131000	BOOST-frequency operation (Hz)
	PRI_MOD_MIN	-0.9	Min duty setting during BUCK operation ([-1,1] is the maximum range, 50% when set to 0)
	PRI_MOD_MAX	-0.2	Max duty setting during BUCK operation ([-1,1] is the maximum range, 50% when set to 0)
	PRI_SYNC_MIN	-0.9	Synchronous rectification Min duty setting during BUCK operation ([-1,1] is the maximum range, 50% when set to 0)
	PRI_SYNC_MAX	-0.3	Synchronous rectification Max duty setting during BUCK operation ([-1,1] is the maximum range, 50% when set to 0)
	SEC_MOD_MIN	-0.9	Min duty setting during BOOST operation ([-1,1] is the maximum range, 50% when set to 0)
	SEC_MOD_MAX	0.0	Max duty setting during BOOST operation ([-1,1] is the maximum range, 50% when set to 0)
	SEC_SYNC_ON_0	-0.05	LV reference duty for setting HV synchronous rectifier duty during Boost operation ([-1,1] is the maximum range, 50% when set to 0)

	SEC_SYNC_ON_1	-0.15	LV reference duty for setting HV synchronous rectifier duty during Boost operation ([-1,1] is the maximum range, 50% when set to 0)
	SEC_SYNC_ON_2	-0.3	LV reference duty for setting HV synchronous rectifier duty during Boost operation ([-1,1] is the maximum range, 50% when set to 0)
	SEC_SYNC_MOD_0	-0.9	HV synchronous rectifier duty setting during BOOST operation ([-1,1] is the maximum range, 50% when set to 0)
	SEC_SYNC_MOD_1	-0.4	HV synchronous rectifier duty setting during BOOST operation ([-1,1] is the maximum range, 50% when set to 0)
	SEC_SYNC_MOD_2	-0.35	HV synchronous rectifier duty setting during BOOST operation ([-1,1] is the maximum range, 50% when set to 0)
	SEC_SYNC_MOD_3	-0.3	HV synchronous rectifier duty setting during BOOST operation ([-1,1] is the maximum range, 50% when set to 0)

4.7 Control Flow

4.7.1 Main Process

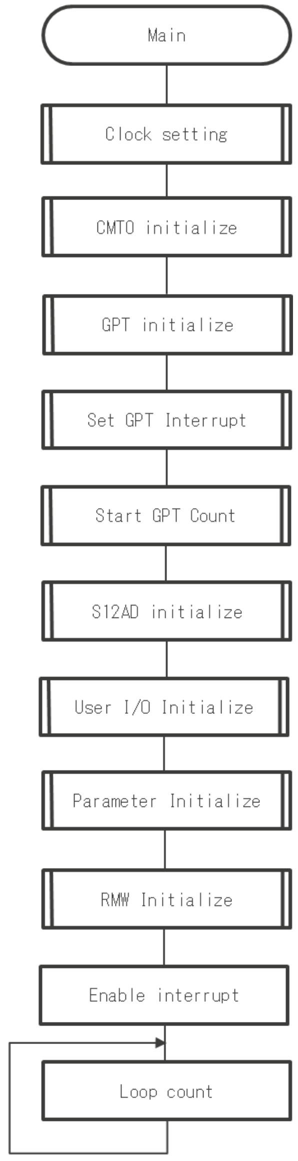


Figure 15 Main Process

4.7.2 1kHz Cycle Sequence

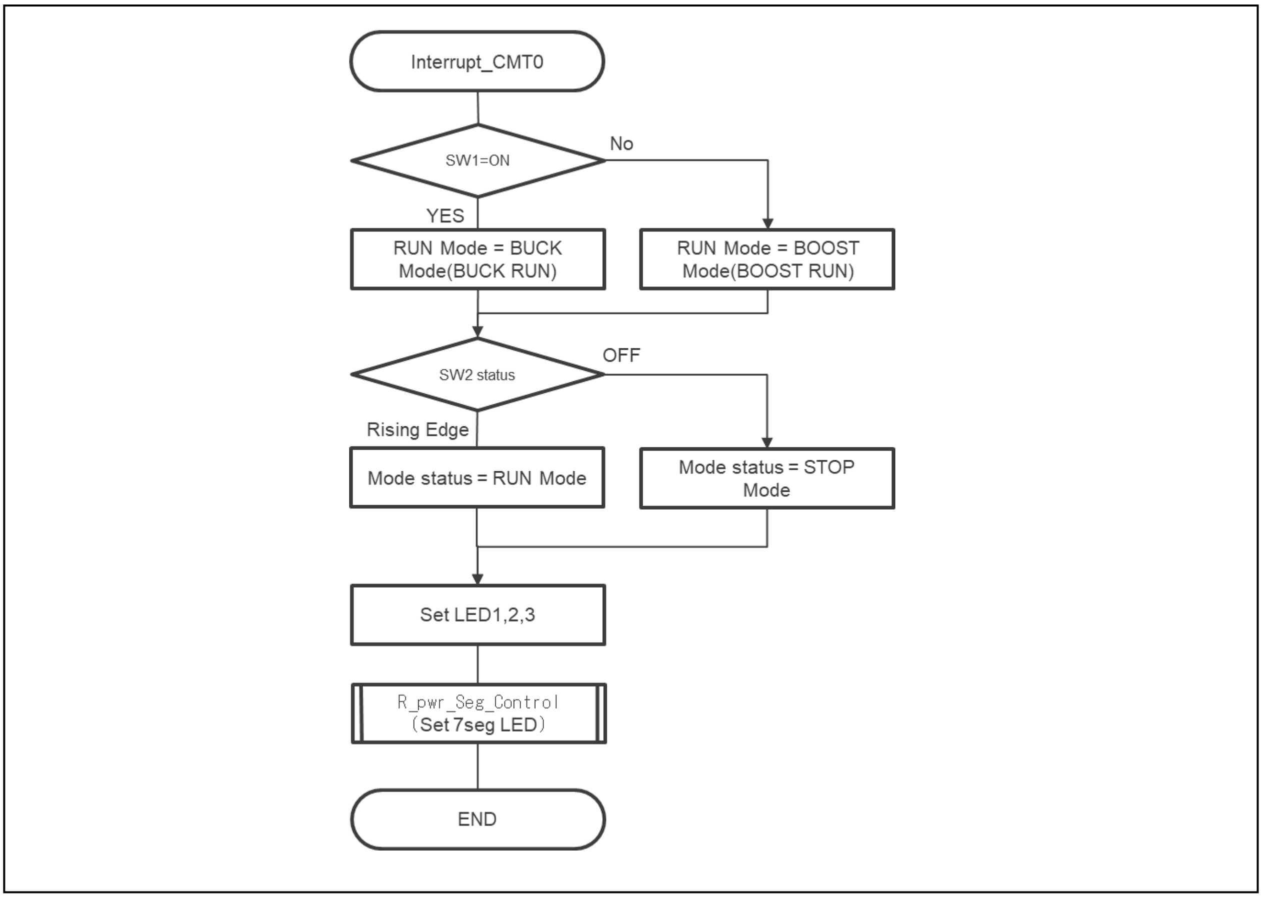


Figure 16 1kHz Cycle Sequence (CMT0 Interrupt Process)

4.7.3 Carrier Cycle Control Process

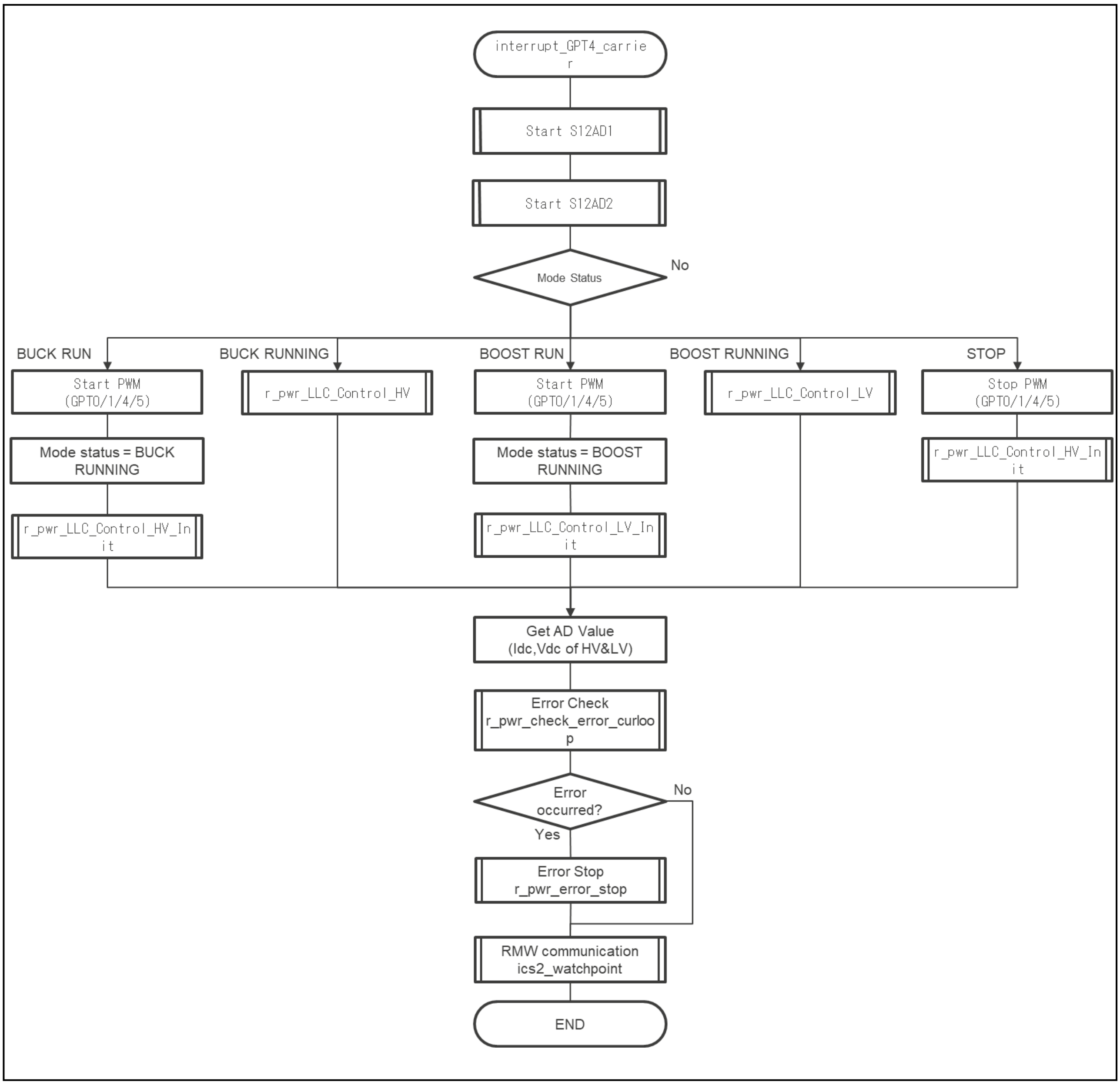


Figure 17 Carrier Cycle Control Process (GPTW4 Interrupt Process)

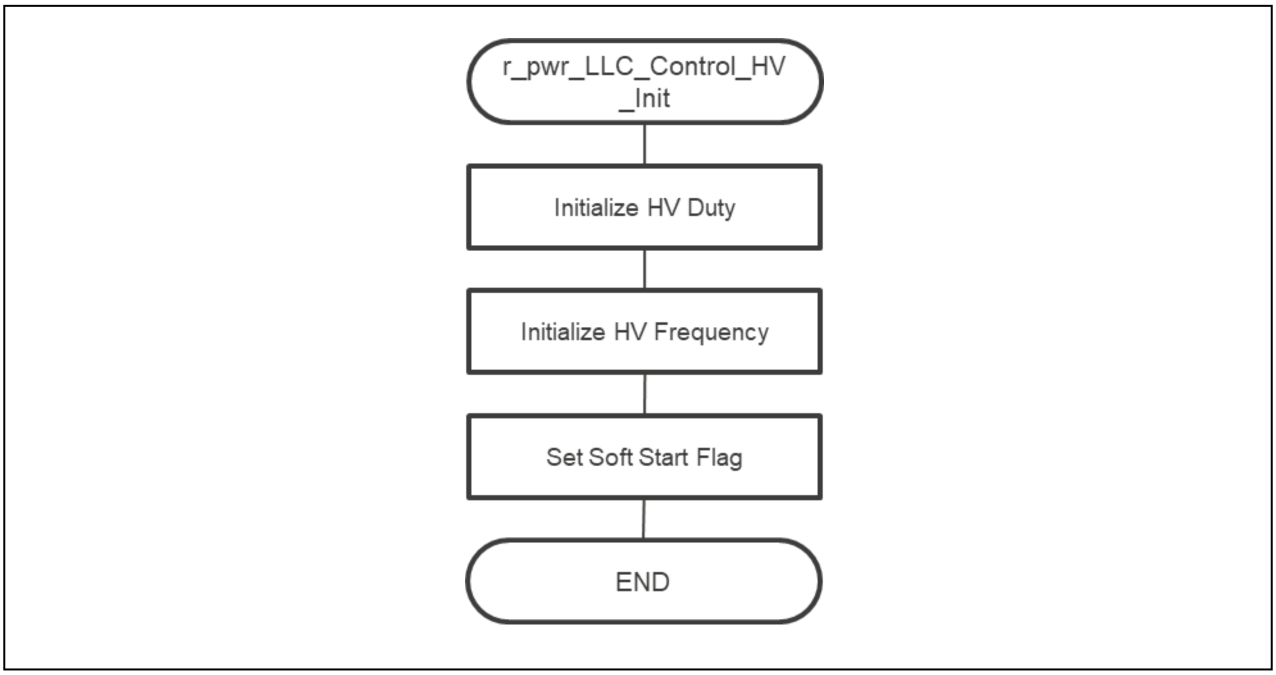


Figure 18 BUCK RUN Control Process

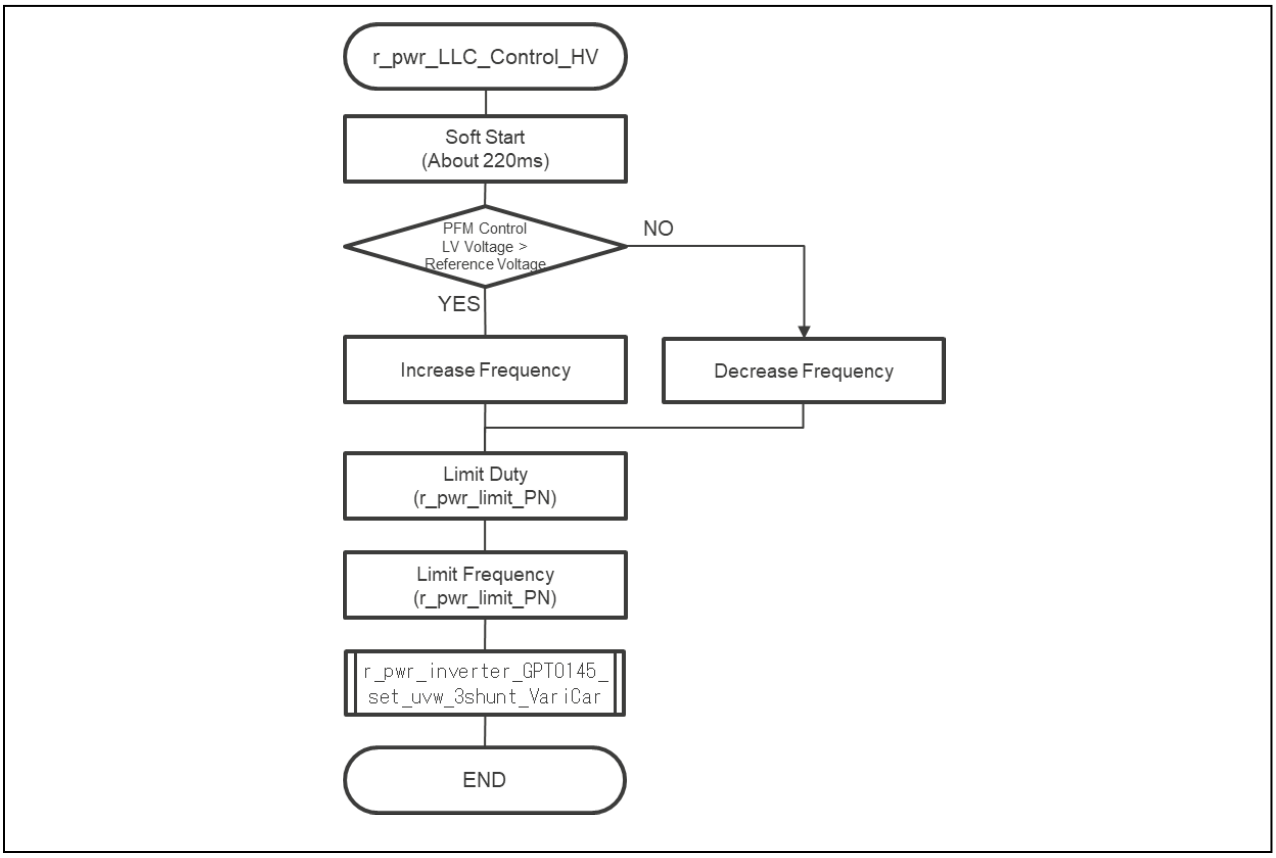


Figure 19 BUCK RUNNING Control Process

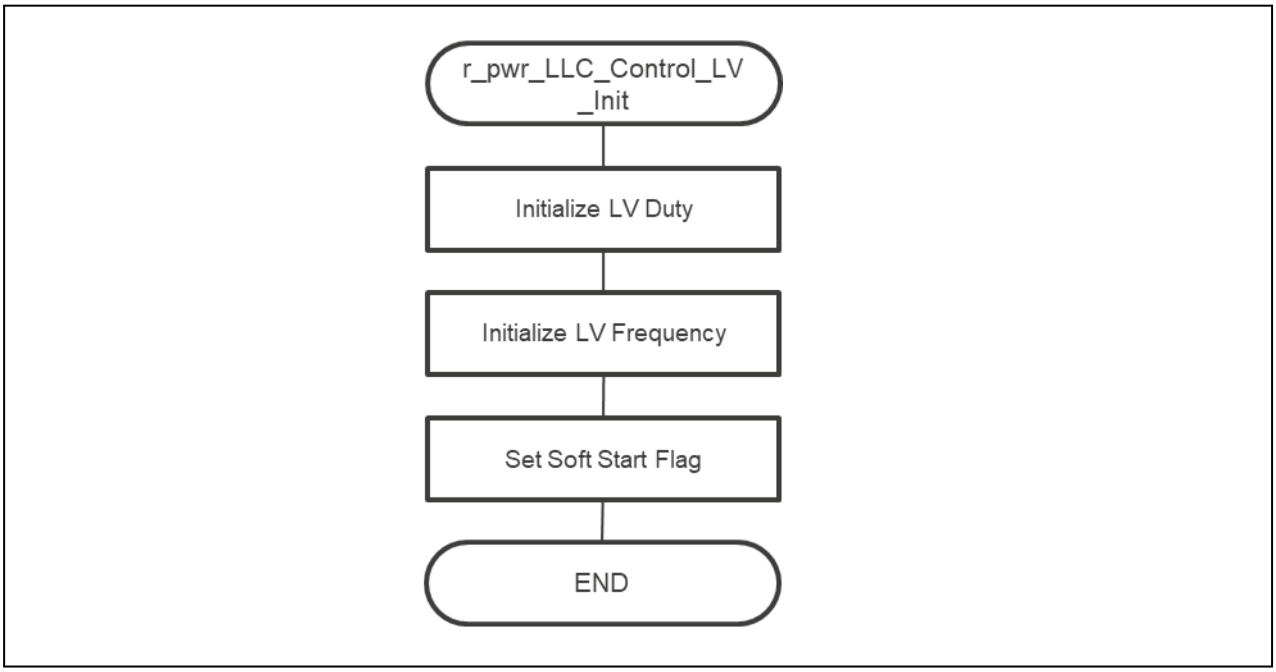


Figure 20 BOOST RUN Control Process

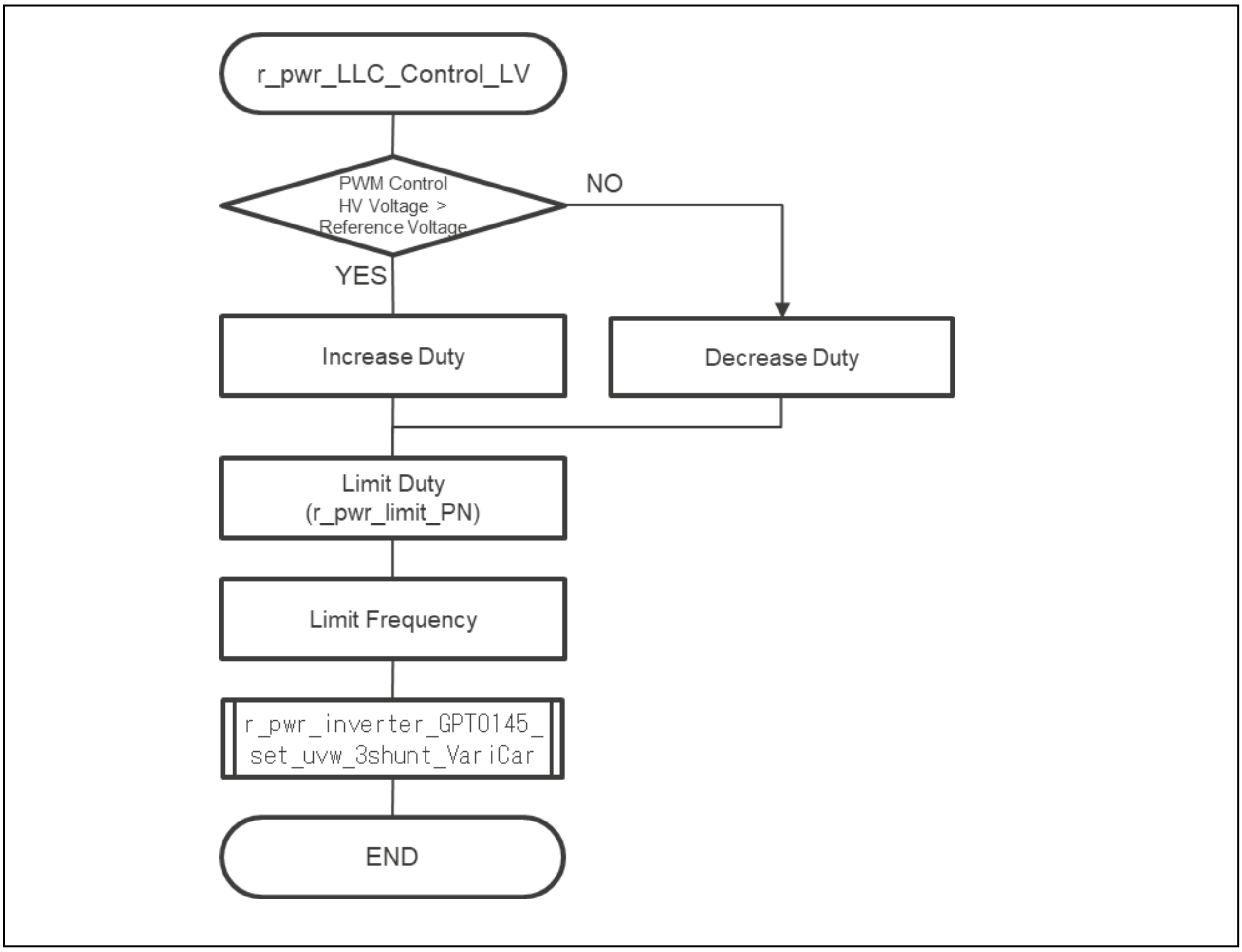


Figure 21 BOOST RUNNING Control Process

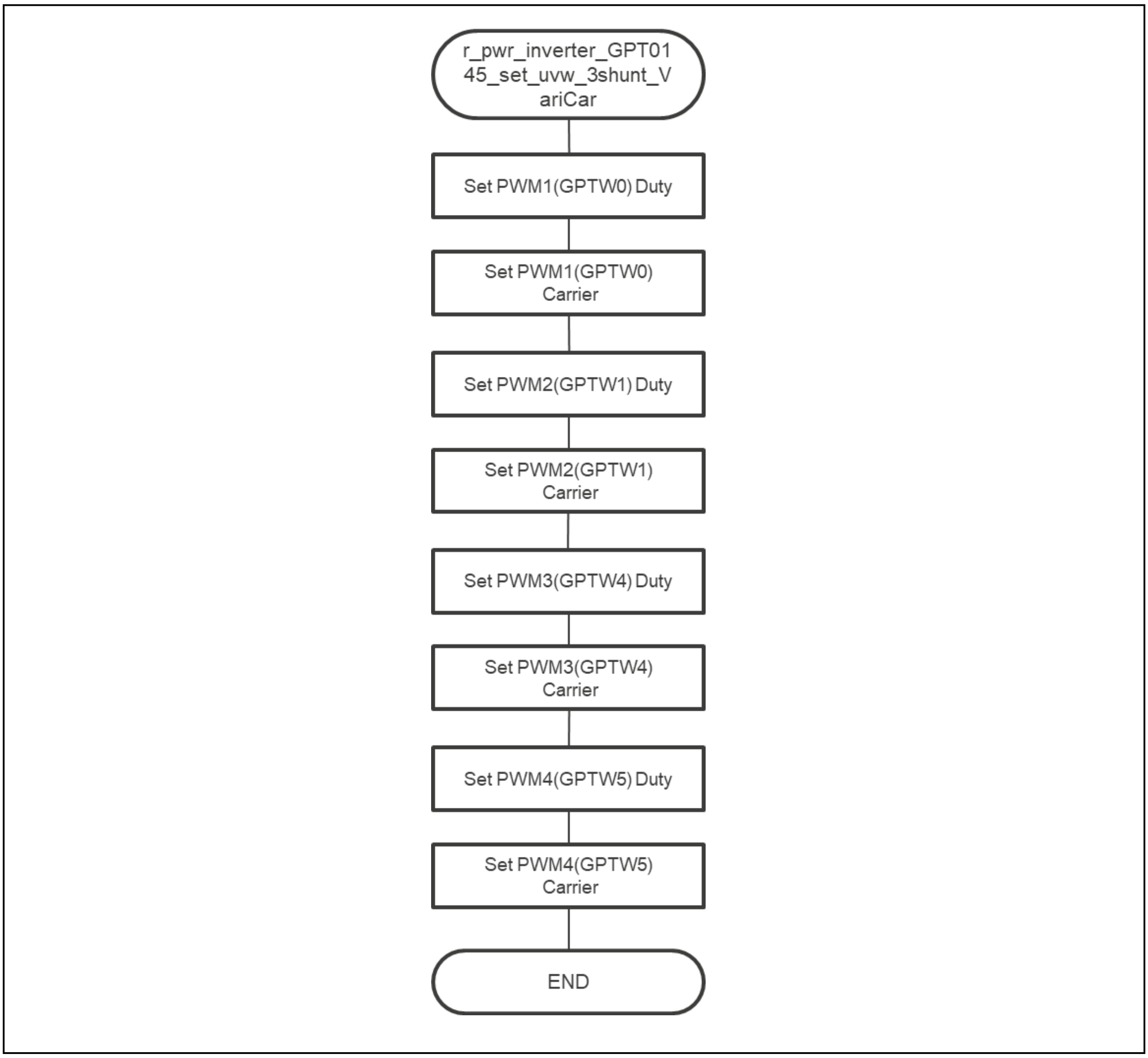


Figure 22 GPTW0,1 / 4,5 Duty Setting Process

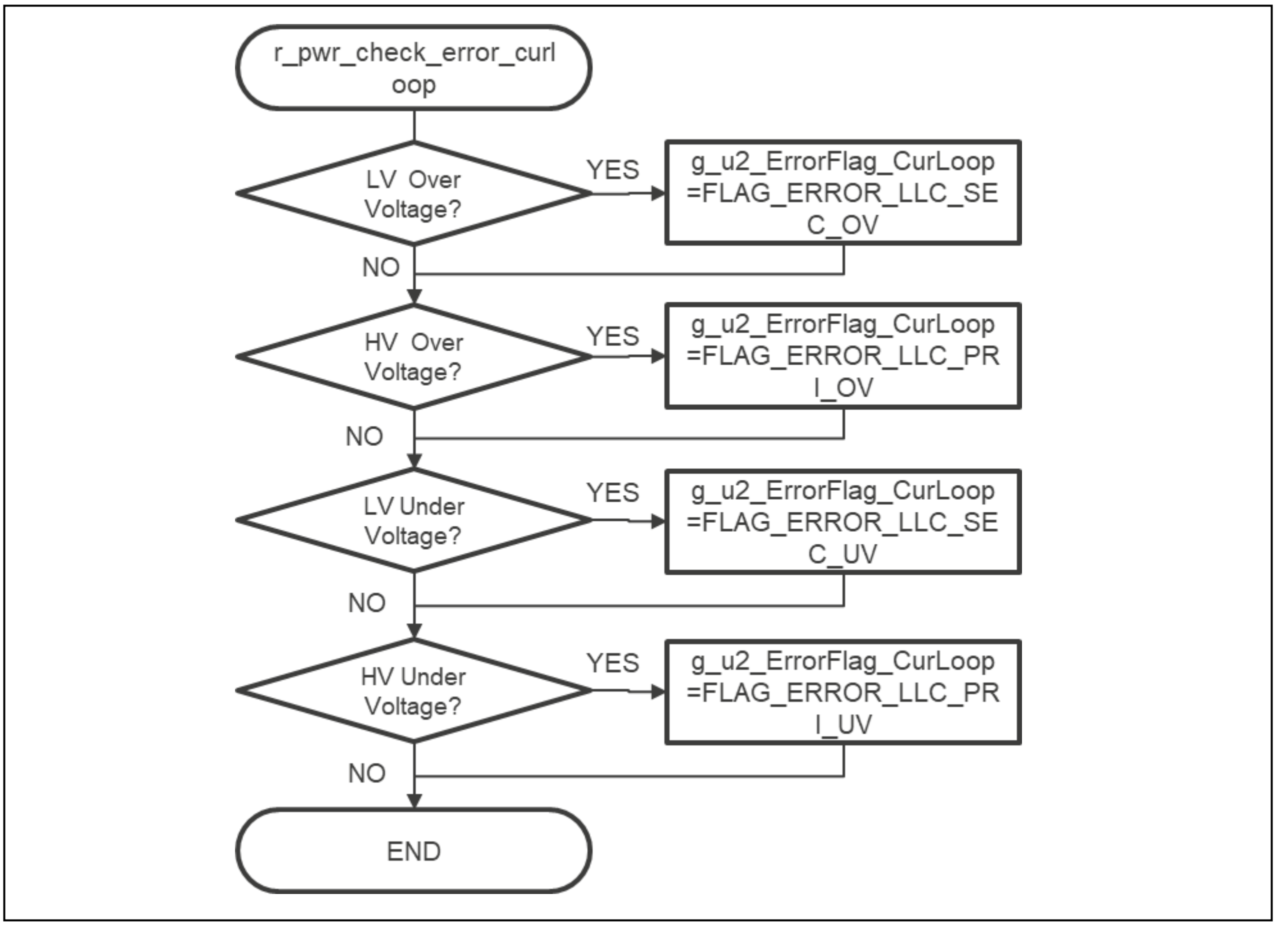


Figure 23 Current Cycle Error Check Process

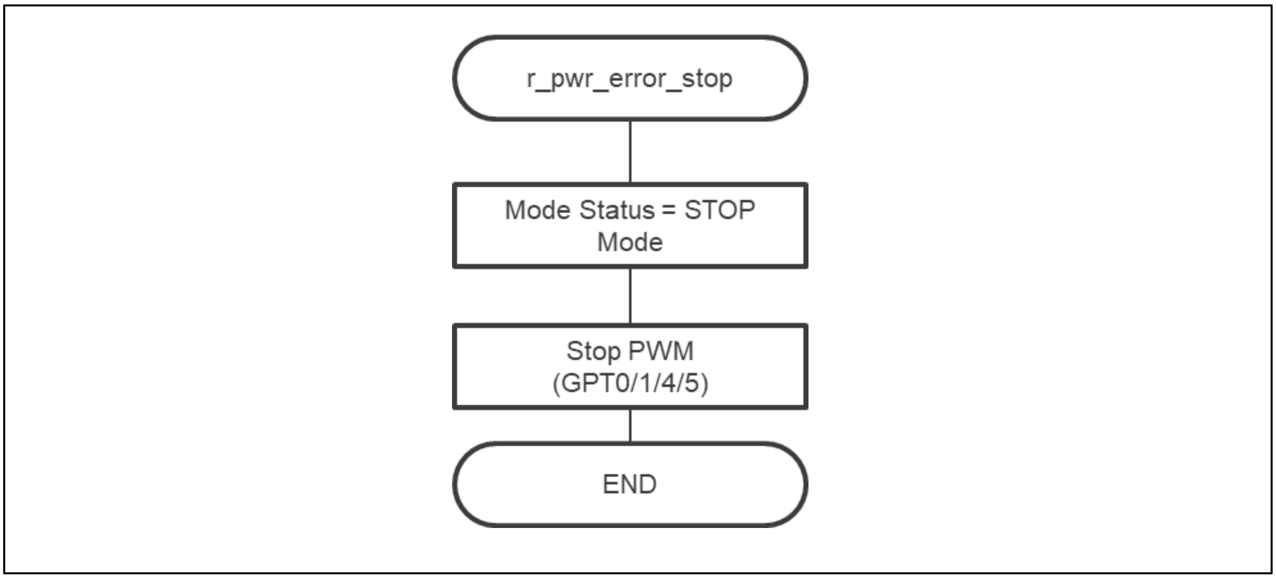


Figure 24 Error Stop Process

5. Renesas Motor Workbench, Motor Control Development Support Tool

5.1 Overview

In the target software of this application note, the motor control development support tool "Renesas Motor Workbench" is used as the status monitor. For the variables that can be monitored, refer to 4.5 Variable List. Figure 25 shows the operating environment of "Renesas Motor Workbench" and Figure 26 shows the outside view of the window of "Renesas Motor Workbench". For more information on how to use this function, refer to the "Renesas Motor Workbench User's Manual (R21UZ0004)". Also, obtain the motor control support tool "Renesas Motor Workbench" from our website.

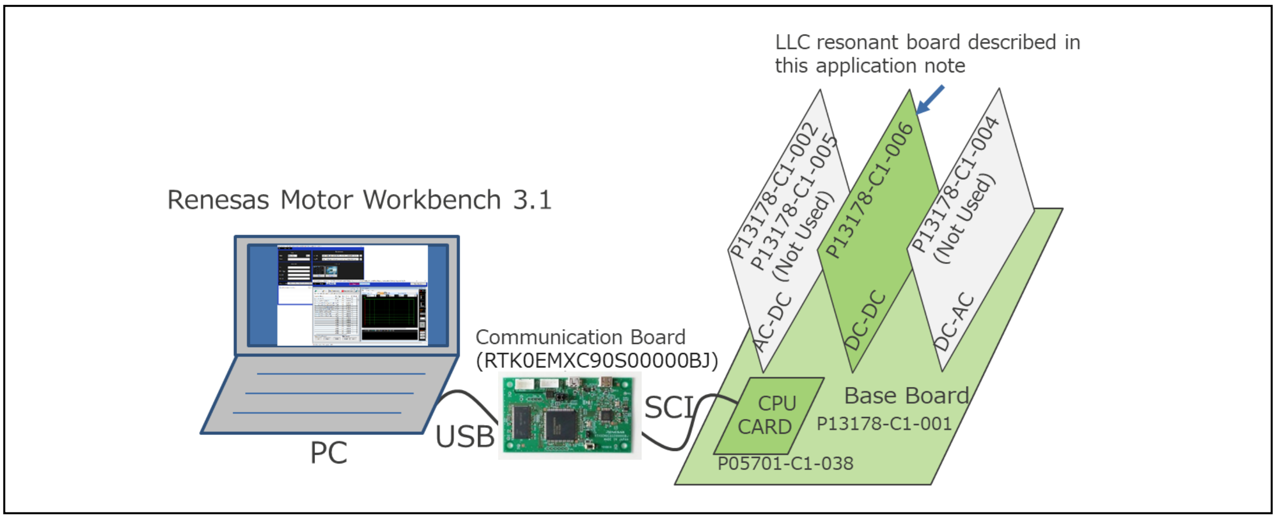


Figure 25 Renesas Motor Workbench Operating Conditions

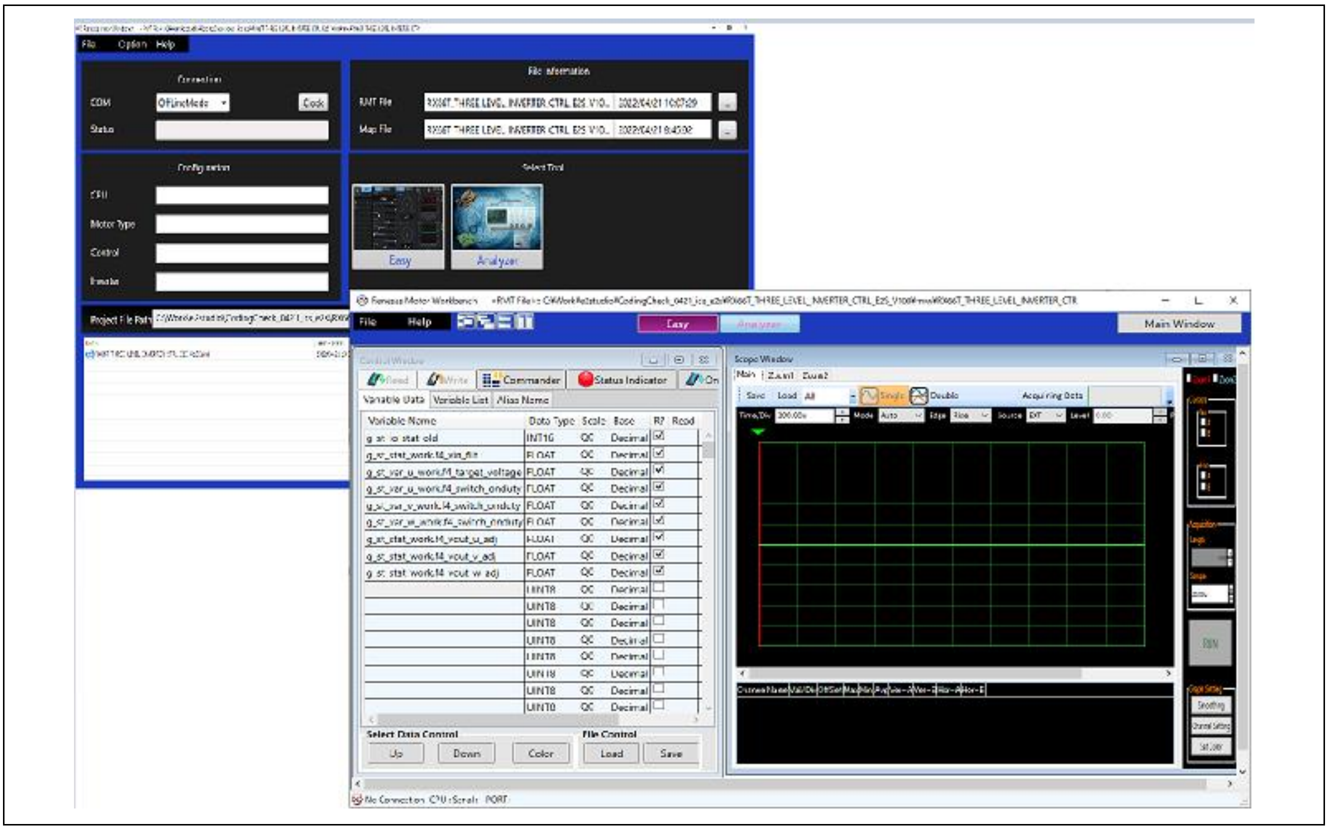


Figure 26 View of Renesas Motor Workbench

How to use Renesas Motor Workbench motor control tool

① Click the tool icon to launch the tool.

② Select [RMTFile] → [Open RMT File] from MENU on Main Panel.
Import RMT files in the "ics" folder of the project folder.

③ Use the "Connection" COM to select COM of the connected kit.

④ Click "Analyzer" in the upper-right corner of Select Tool to open Analyzer function window.

5.2 Analyzer List

The global variables are used for displaying waveforms when Analyzer user interface is used.

Refer to Table 13 Variable List for the target variables.

6. Measurement Data

Figure 27 shows the measuring environment of LLC resonant converter in this application note. The measurement results are shown in 6.1, and the response test results are shown in 6.2.

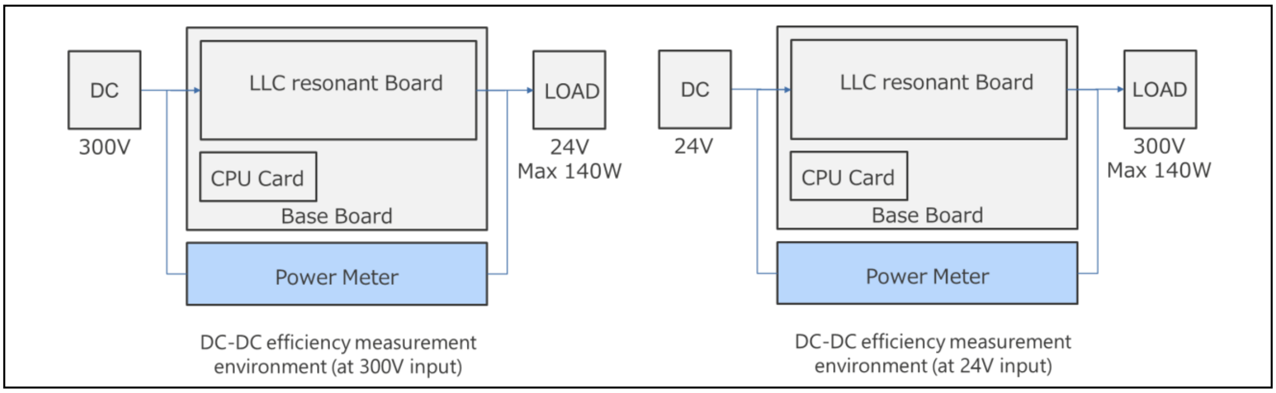


Figure 27 DC-DC Efficiency Measuring Environment (When Inputting 300V/24V)

6.1 Results of Efficiency Measurement

■Measurement Conditions

・The load is an electronic load.

Measure the efficiency when the output power of 300V input (BACK operation) is about 24 to 138W. Measure the efficiency when the output power of 24V input (BOOST operation) is about 33 to 151W. The maximum efficiency during BUCK operation has achieved about 96.8 %, The maximum efficiency during BOOST operation has achieved about 92.16 %. Table 15 and Figure 28 show measurement results at back operation, Table 16 and Figure 29 show measurement result at boost operation.

Table 15 Measured Efficiency in BUCK Operation

Input voltage (V)	Input current (A)	Output voltage (V)	Output current (A)	Efficiency
300.3	0.084	23.71	1.01	94.93%
300.11	0.327	23.58	4.03	96.8%
300.11	0.485	22.81	6.04	94.7%

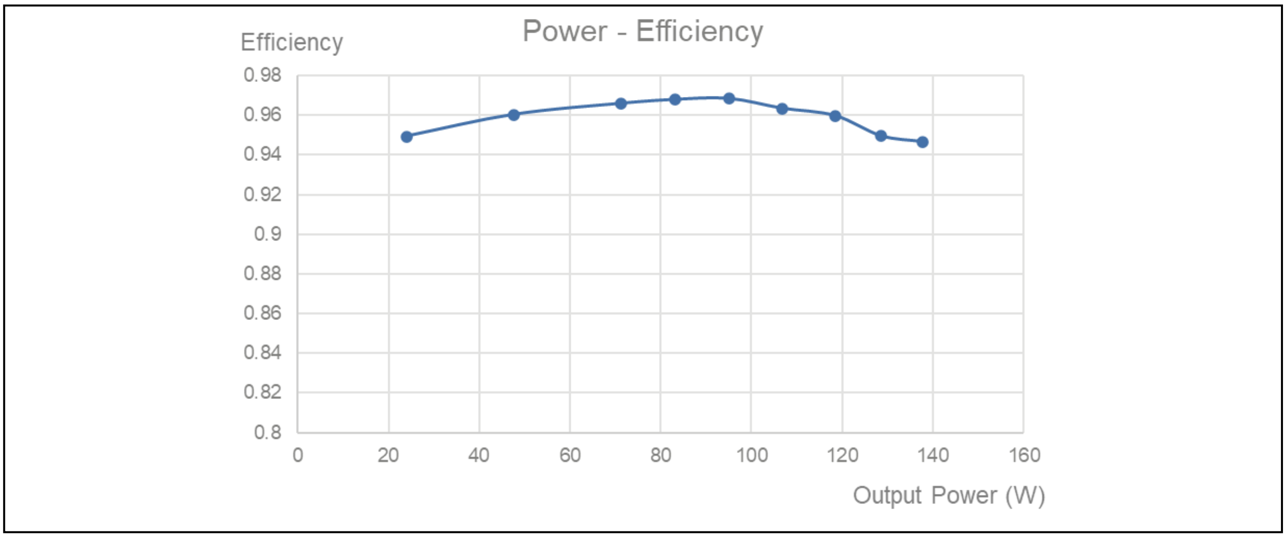


Figure 28 Efficiency Against Power Output in BUCK Operation

Table 16 Measured Efficiency in BOOST Operation

Input voltage (V)	Input current (A)	Output voltage (V)	Output current (A)	Efficiency
23.92	1.55	295.57	0.11	87.69%
23.78	4.24	295.44	0.312	91.42%
23.64	6.93	294.3	0.513	92.16%

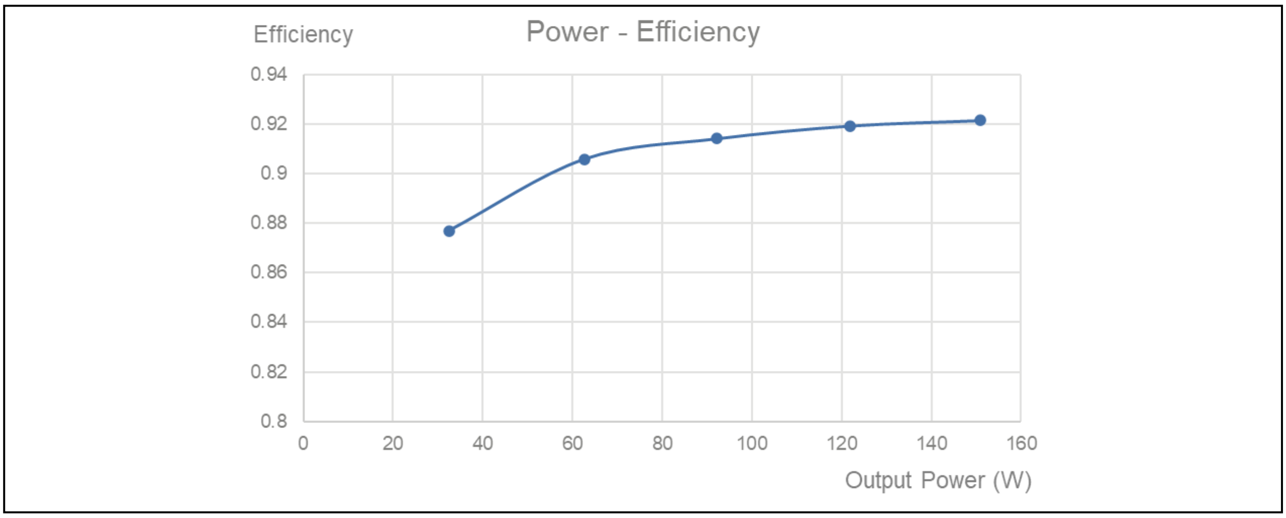


Figure 29 Efficiency Against Output Power in BOOST Operation

6.2 Response Test Results

Figure 30 and Figure 31 show the waveforms when the electronic loads are changed from 0%⇒100% and 100%⇒0% in BUCK operation and BOOST operation.

The output-voltage is stable even if the load fluctuates, and it can be seen that it functions as a DC-DC convertor without any problem.

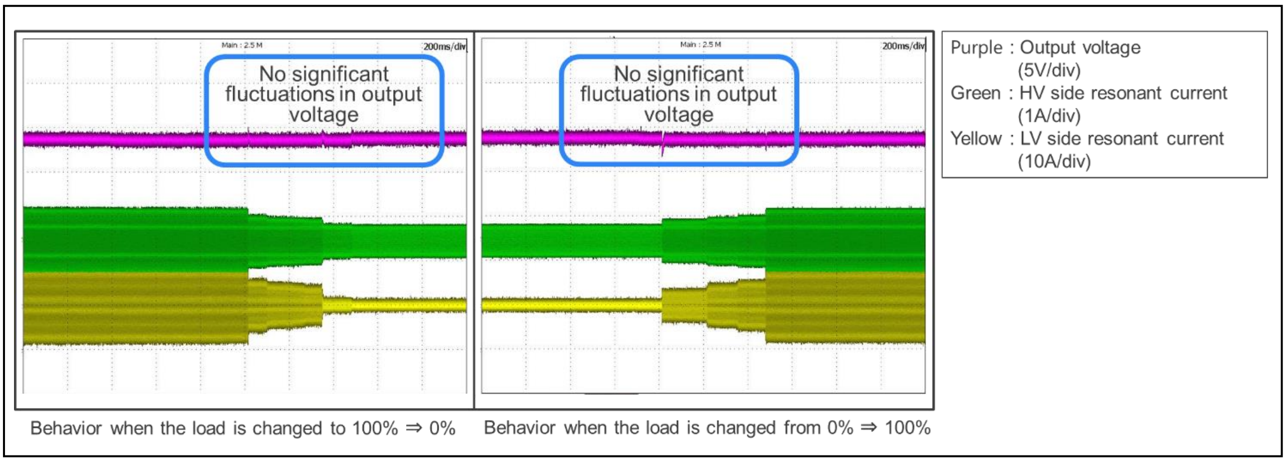


Figure 30 Output-waveform When Load Fluctuates in BUCK Operation (300V→24V Operation)

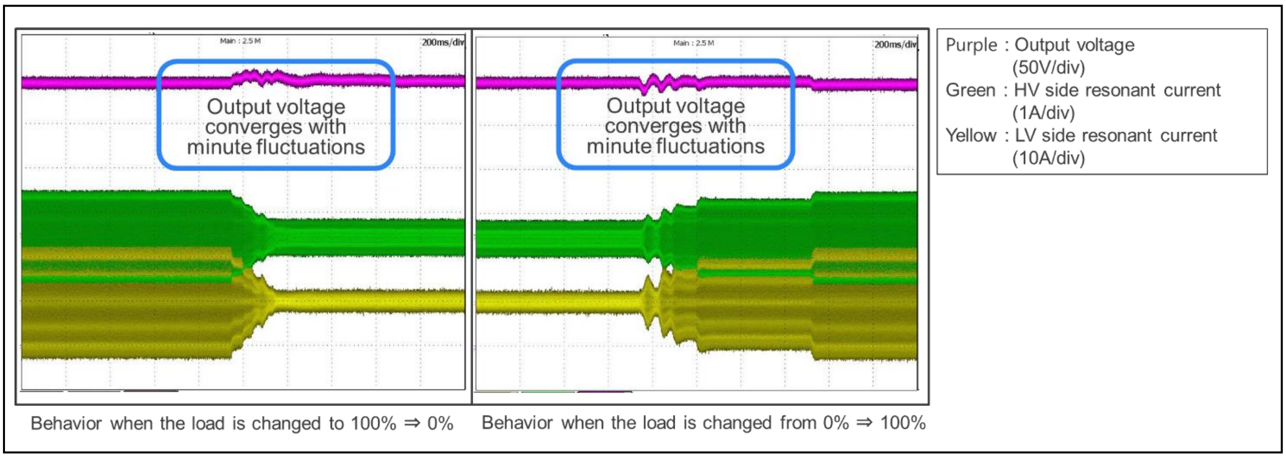


Figure 31 Output-waveform When Load Fluctuates in BOOST Operation (24V→300V Operation)

Revision History

Rev.	Date	Description	
		Page	**Summary**
1.00	Oct.17.23	-	First Edition
1.10	Feb.23.24	All	Added RX26T explanation by the addition of the RX26T version project.

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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