SH7216 Group

Overview of Power Conditioner Demo System

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Introduction

This application note gives an overview of the power conditioner demonstration system (hereafter called this demo system). It represents one of applications for the SH7216 group of microcomputers. It is digitally controlled by SH7216 on-chip peripheral functions.

Target Device

SH7216

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1. Preface

Recently, there has been an accelerating environmental commitment to reduce CO_2 emissions for the prevention of global warming. As a result, an increasing number of systems for generating renewable electric power are being developed and disseminated. Among these are solar energy generation systems recognized as clean energy sources which do not discharge CO_2. They are proliferating worldwide while the legal systems in various countries are being improved to support solar energy deployment.

A solar energy generation system consists of a photovoltaic (PV) panel and a power conditioner system (PCS). The photovoltaic panel converts solar radiation into DC electricity. The power conditioner system converts this DC electricity into AC electricity available for home use and then supplies it to the electrical power system. Figure 1 presents an overview of such a solar energy generation system.

The power conditioner mainly includes two power converters: a DC boost converter (DC/DC converter) and an AC inverter (DC/AC converter). The DC boost converter increases the DC voltage from the photovoltaic panel and applies the boosted voltage to the AC inverter. This inverter converts that voltage into the 100 VAC/220 VAC voltages for delivery to outside devices. To increase the generating efficiency, the power conditioner uses maximum power point tracking (MPPT) technology which enables it to obtain maximum energy depending on the characteristics of the photovoltaic panel. When supplying power to the power system, the power conditioner adjusts the voltage phase, enhances the output quality (by eliminating voltage variations and harmonics) and provides safety protection.

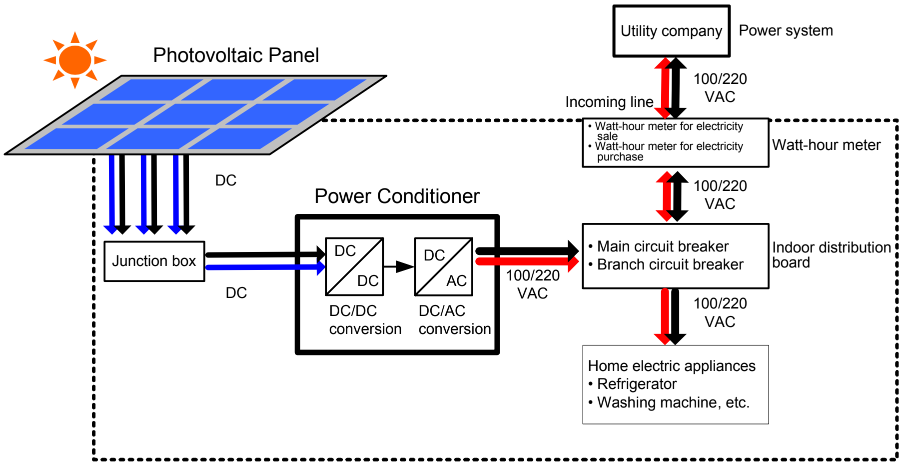


Figure 1 Solar Energy Generation System

1.1 System Overview

This demo system is stand-alone equipment not connected to the electrical power system. The two main components of this demo system, a DC boost converter (DC/DC converter) and an AC inverter (DC/AC converter), are digitally controlled by SH7216 on-chip peripheral functions.

Figure 2 presents an external view of this demo system.

The whole system is put into an attaché case. The panel inside the case includes a power connector for providing 100 VAC power for the whole system and power switches for turning the 100 VAC power on and off.

There are control switches on the power conditioner circuit board, which are available to start the system processing. Operating these switches starts the DC boost converter and AC inverter, thereby rotating the AC fan.

Figure 2 External View of the Power Conditioner Demo System

Figure 3 shows the configuration of the power conditioner demo system.

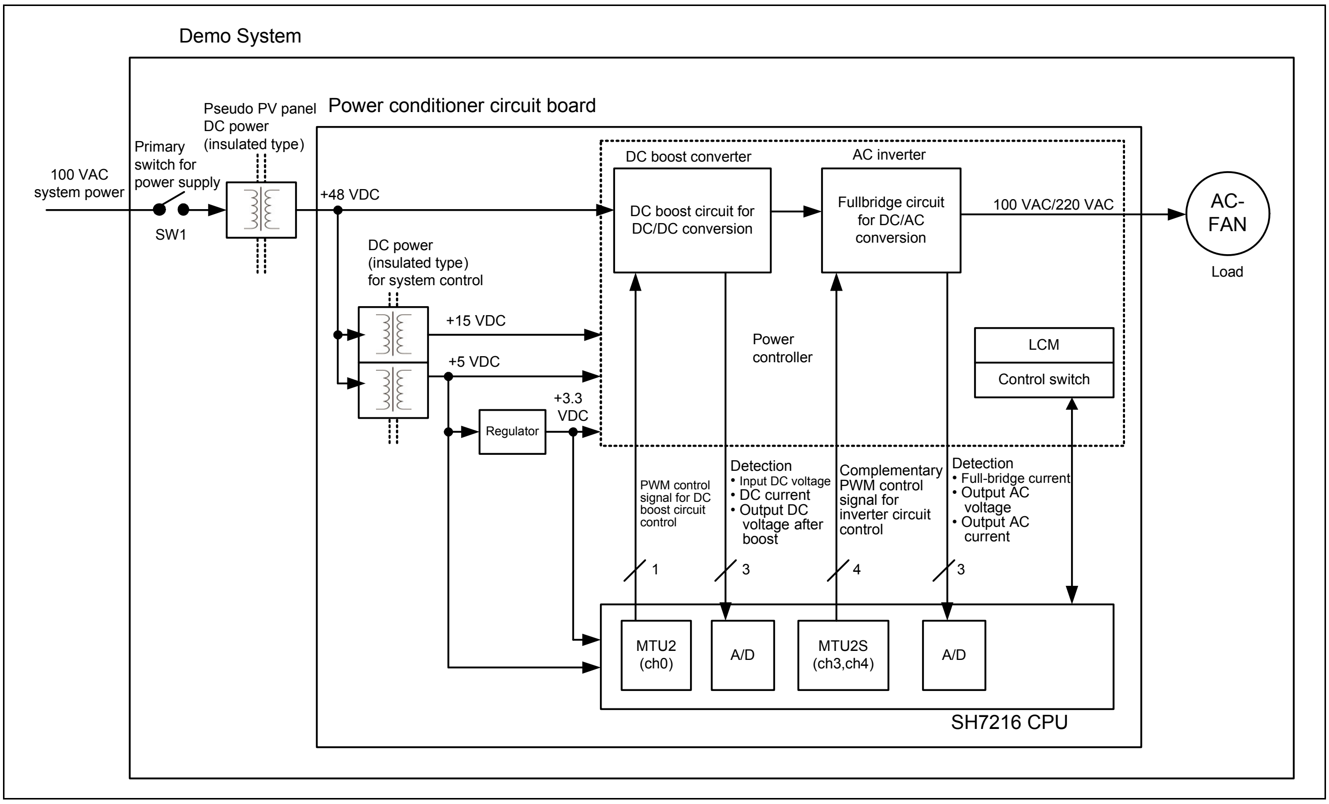


Figure 3 System Configuration

This demo system consists of a main power switch (SW1), a pseudo PV panel DC power supply unit, a power conditioner circuit board, and an output load.

Turning on the main power switch starts the system power supply to the pseudo PV panel DC power supply unit.

The pseudo PV panel DC power supply unit generates 48 VDC power as a pseudo PV panel voltage and supplies it to the DC boost converter and the DC power unit for system control on the power conditioner circuit board.

An AC-FAN is connected as a load.

The power conditioner circuit board consists of an SH7216 CPU section, a power controller, and a system power supply unit.

(1) SH7216 CPU Section

This controls the entire system. Among the SH7216 on-chip peripheral functions, it uses the timer to control the switching elements in the DC boost converter and AC inverter. It also uses the A/D converter to detect voltage and current.

(2) Power controller

The power controller includes the DC boost converter and AC inverter. Also included are the control switches and liquid crystal display module (LCM).

The DC boost converter accepts an input voltage of 48 VDC. The DC boost converter converts the input DC voltage into a higher output voltage and applies this output voltage to the subsequent AC inverter. The AC inverter converts the DC voltage into an AC voltage and produces the 100 VAC/220 VAC output. As a result, an AC fan (load) connected to the AC output pin rotates.

(3) System power supply

The system power supply unit generates +15 VDC, +5 VDC, and +3.3 VDC power as the system control DC power supply for the SH7216 CPU section and control circuits.

1.2 System Specifications

Table 1 shows the system specifications.

Table 1 System Specifications

Item	Specifications
System input voltage	100 VAC/220 VAC • 100 VAC/220 VAC applied to the pseudo PV panel DC power supply
Power conversion	(1) DC boost converter (DC/DC converter) Boosts DC voltage (i.e., converts 48 VDC into 200 VDC/400 VDC). (2) AC inverter (DC/AC converter) Generates AC voltage (i.e., converts 200 VDC and 400 VDC into 100 VAC and 220 VAC, respectively).
Output AC voltage	• 100 VAC/220 VAC Sine wave output connected to AC-AN (output load)
Continuous AC output	• 44 W (0.2 A × 220 VAC)
AC output frequency	• 50 Hz or 60 Hz (selected with the control switch)
AC output load	AC fan • Voltage: 220 VAC (50/60 Hz frequency, 13.5/12 W input power, 0.07/0.06 A current) • Model No.: 109S087 • Manufacturer: Sanyo Denki Co., Ltd.
Power switches (SW1)	System power switches (for turning the 100 VAC/220 VAC power on and off) • SW1: Primary switch for the system power supply
Control switches (sw1 to sw7)	Start and stop the DC boost converter and AC inverter. • sw1: (Unused) • sw2: Start • sw3: Stop • sw4: Reserved • sw5: Switches between AC output frequencies (50 Hz and 60 Hz). • sw6: Specifies the CPU operating mode and output voltage. • sw7: Resets the SH7216 CPU.
Piezo-electric buzzer	Generate a system startup sound and a warning sound which signals the occurrence of an abnormality.
SH7216 CPU	SH7216 (SH2A-FPU; model name: R5F72167ADFA) used for system control. • CPU clock: 200 MHz max (input clock: 12.5 MHz) • On-chip flash memory: 1024 Kbytes • On-chip RAM: 128 Kbytes

2. System Startup

2.1 State Transitions

To start the system operation, use the main power switches and control switch. Figure 4 shows the state transitions which occur during the system operation.

For system startup, turn on the main power switch (SW1). This supplies power to the SH7216 CPU board and peripheral control circuits, resulting in the system being initialized. When the initialization completes, the system enters a state where it waits for startup.

While the system is waiting for startup, you can turn on the control start switch (sw2). Doing this starts the DC boost converter and then the AC inverter. Upon completion of the AC inverter startup, 100 VAC/220 VAC power generated by this inverter is output to rotate the AC fan connected to the AC output pin.

Turning on the control stop switch (sw3) stops the rotation of the AC fan. This switch operation also stops the DC boost converter and AC inverter. Then, the system waits for startup.

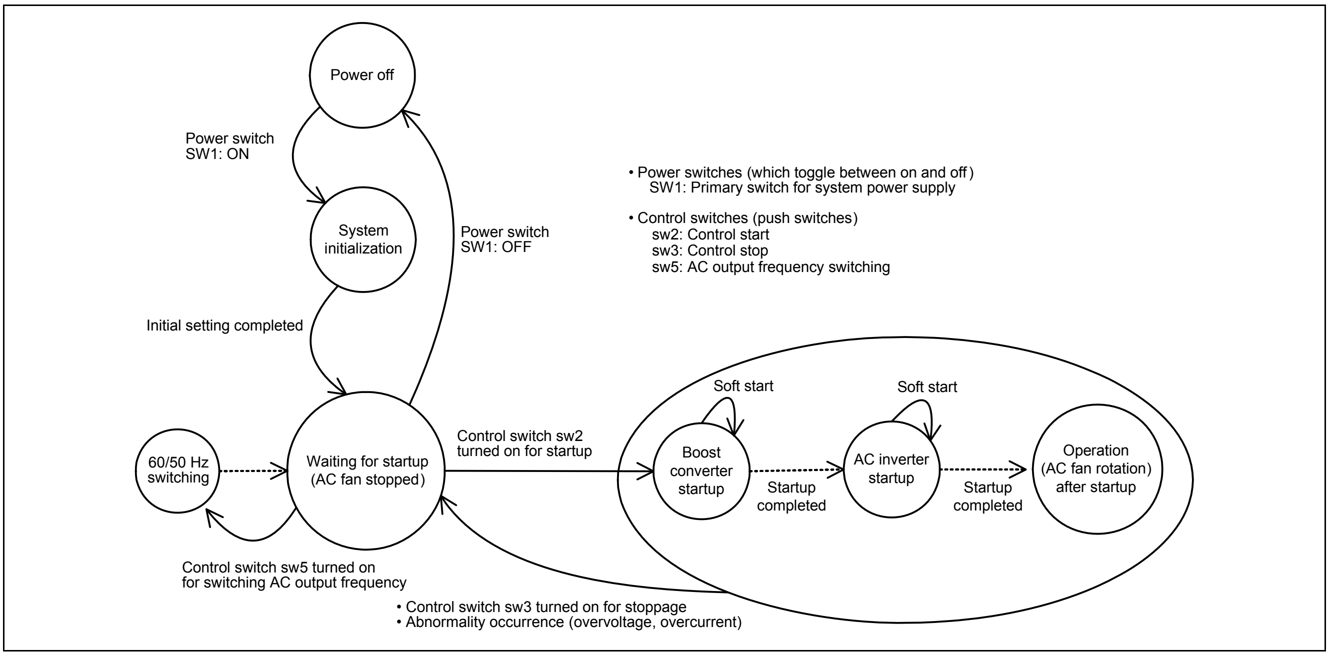


Figure 4 System Operation States

2.2 Power Switches

Table 2 lists the functions of the power switches for this system. These switches, which toggle between on and off, are arranged on the panel in the case.

Table 2 Functions of the Power Switches

Item	Description
SW1	• Primary switch for the system power supply • When turned on, this switch supplies 100 VAC/220 VAC power to the pseudo PV panel DC power supply. It generates a DC voltage (48 VDC) to be supplied to the DC boost converter and the system control DC power supply. This power supply applies ±15 VDC, + 5 VDC and + 3.3 VDC to all control circuits in the system including the SH7216.

2.3 Control Switches

Table 3 lists the functions of the control switches. These push switches and DIP switches are mounted on the power conditioner circuit board. Use them to start and stop the DC boost converter and AC inverter.

Turning on (pushing) the control start switch (sw2) starts the DC boost converter and then AC inverter so that the AC fan rotates.

Turning on (pushing) the control stop switch (sw3) stops the control operation of the DC boost converter and AC inverter as well as the rotation of the AC fan.

Table 3 Control Switch Functions

Item	Description
sw1	(Unused)
sw2	• Control start switch • When turned on, this switch starts the DC boost converter and then the AC inverter. It also starts the rotation of the AC fan.
sw3	• Control stop switch • When turned on, this switch stops the DC boost converter, AC inverter and AC fan.
sw4	Reserved
sw5	• AC output frequency selection switch Each time you turn on this switch, it switches between the frequencies of the sine-wave AC output voltage. Turn on this switch only when the DC boost converter and AC inverter are not driven. 50 Hz or 60 Hz can be selected with this switch. The initial value for system startup is 60 Hz.
sw6-1,2,3 (DIP switches)	• SH7216 CPU mode selection switch • This switch selects the operating mode for the SH7216 CPU. Set switches (1, 2, 3) to (ON, OFF, OFF) to specify single-chip mode.
sw6-4 (DIP switch)	• Boost and AC inverter output voltage switch • This switch selects the boost voltage (200 V or 400 V) and the AC inverter output voltage (100 VAC or 220 VAC). Turned off: 400 V for boost voltage and 220 VAC for output voltage Turned on: 200 V for boost voltage and 100 VAC for output voltage
sw7	• SH7216 CPU reset switch • When turned on, this switch applies a power-on reset to the SH7216 CPU.

3. System Functions

3.1 DC Boost Converter

3.1.1 Configuration

Figure 5 shows the configuration of the system's DC boost converter.

This DC boost converter generates a DC voltage greater than its input DC voltage. Then, it applies the post-boost voltage to the subsequenct AC inverter.

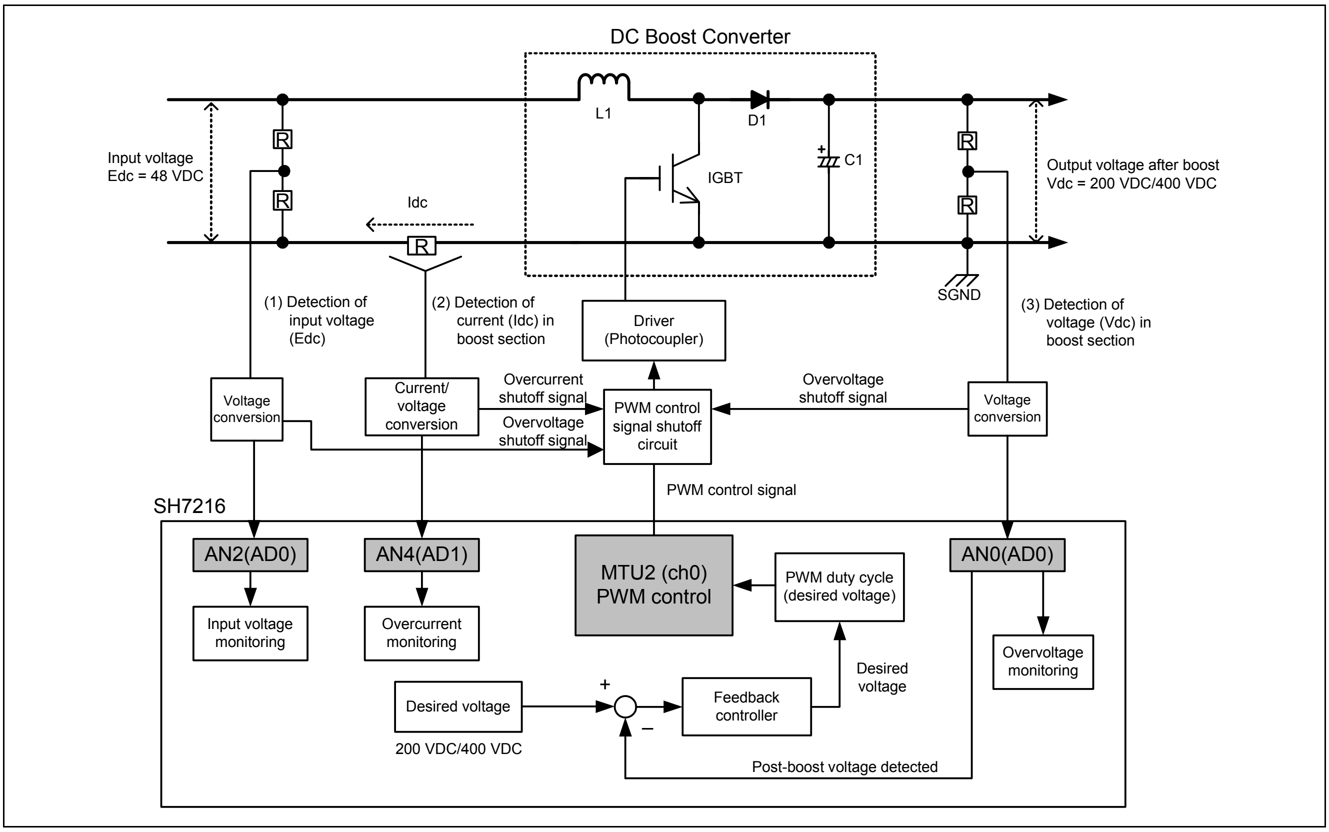


Figure 5 DC Boost Converter

The DC boost converter (non-insulated DC/DC converter) consists of a switching element (IGBT), a choke coil (L1), a diode (D1) and a capacitor (C1).

When the switching element is on, current flows into the choke coil so that it stores electric energy. When the switching element becomes off, the choke coil tends to maintain the current flow in it. This causes a voltage across the ends of the choke coil. The output voltage is increased by the amount of that voltage in the coil. The capacitor is charged to the boosted voltage via the diode. The diode prevents reverse current flow due to the capacitor voltage being greater than the input voltage. The post-boost voltage is adjusted by turning this switching element on and off (according to its on-duty ratio).

To turn the switching element on and off, this demo system uses pulse width modulation (PWM) control provided via the timer (MTU2) which is an SH7216 on-chip peripheral.

The post-boost output voltage is adjusted to the target value by feedback control. This output voltage is detected by the A/D converter (ADC) which is also an SH7216 on-chip peripheral. Then, the deviation between this output voltage and the desired voltage (target value) is determined. The desired PWM duty cycle is calculated from that deviation for feedback control. The post-boost output voltage is adjusted by controlling the on/off timing of the switching element with the desired duty cycle and PWM output provided by the MTU2.

Figure 6 shows the configuration of the feedback controller, which consists of two linear IIR (infinite impulse response) filters connected in a cascade structure.

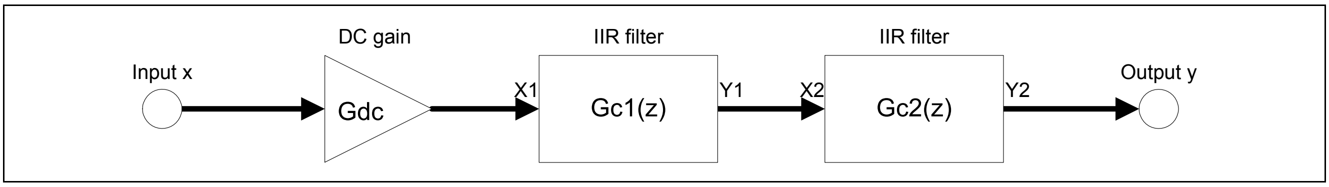


Figure 6 Feedback Controller

The following shows the transfer function of the above IIR filters.

$$\mathrm{Gc(s)} = \frac{(1+\dfrac{s}{\omega zi})(1+\dfrac{s}{\omega zd})}{(1+\dfrac{s}{\omega pi})(1+\dfrac{s}{\omega pd})}$$

ωzi: Zero frequency (integral) [Hz]
ωzd: Zero frequency (differential) [Hz]
ωpi: Pole frequency (integral) [Hz]
ωpd: Pole frequency (differential) [Hz]

The above transfer function is converted into the following difference equations.

Gc1 (z): Y1[n] = A10*X1[n] + A11*X1[n-1] + B11*Y1[n-1]
Gc2 (z): Y2[n] = A20*X2[n] + A21*X2[n-1] + B21*Y2[n-1]

$$\mathrm{A10} = \frac{AZd+1}{APd+1} \qquad \mathrm{A11} = \frac{-AZd+1}{APd+1} \qquad \mathrm{B11} = \frac{APd-1}{APd+1}$$

$$\mathrm{A20} = \frac{AZi+1}{APi+1} \qquad \mathrm{A21} = \frac{-AZi+1}{APi+1} \qquad \mathrm{B21} = \frac{APi-1}{APi+1}$$

fs: Switching frequency [Hz]

$$\mathrm{AZd:}\ \frac{fs}{fzd*\pi}$$

$$\mathrm{APd:}\ \frac{fs}{fpd*\pi}$$

$$\mathrm{AZi:}\ \frac{fs}{fzi*\pi}$$

$$\mathrm{APi:}\ \frac{fs}{fpi*\pi}$$

X1 and X2 are data input to the filters, and Y1 and Y2 are output data. Modifying parameters A10, A11, A20, A21, B11, and B21 can adjust the filter operation.

Table 4 outlines the DC boost converter.

Table 4 DC Boost Converter Outline

Item	Description
Control method	Non-insulated DC boost converter (chopper-type DC/DC converter)
Input voltage	48 VDC
Output voltage	200 VDC/400 VDC
PWM carrier cycle	50 µs IGBT switching period (PWM carrier frequency: 20 kHz)

3.1.2 Multi-function Timer Pulse Unit 2 (MTU2)

To control the switching operation of the DC boost converter, PWM signals are generated by the multi-function timer pulse unit 2 (MTU2) which is an SH7216 on-chip peripheral. These signals are available to control the on/off timing of the IGBT. The operation mode for the MTU2 channel 0 should be PWM mode 1.

Table 5 shows the functional settings for the MTU2.

For details about the MTU2, see the section on the MTU2 in the *SH7214 Group, SH7216 Group User's Manual: Hardware (REJ09B0543).*

Table 5 Functional Settings for the MTU2

Item	Description
Channel used	Channel 0
MTU2 module operating clock	50 MHz
Operating mode	PWM mode 1 (registers set up for buffered operation)
PWM carrier cycle	50 µs (PWM carrier frequency: 20 kHz)
PWM resolution	20 ns (= 1/50 MHz)
Interrupt processing	Compare-match interrupt for the TGRB compare-match register (Interrupt processing performed once per PWM carrier cycle)
Output pin	TIOC0A (PB1) output pin • Initial output = Low, Active level = High • IGBT PWM control IGBT switching controlled via the driver (photocoupler)

Figure 7 shows a PWM waveform output by the MTU2.

In PWM1 mode, the MTU2 sets the PWM duty cycle and PWM carrier cycle in the compare-match registers, and then outputs a PWM signal from the timer output pin.

Software calculates the PWM duty cycle. The calculated value is set in the MTU2 register and then updated using a compare-match interrupt generated every PWM carrier cycle.

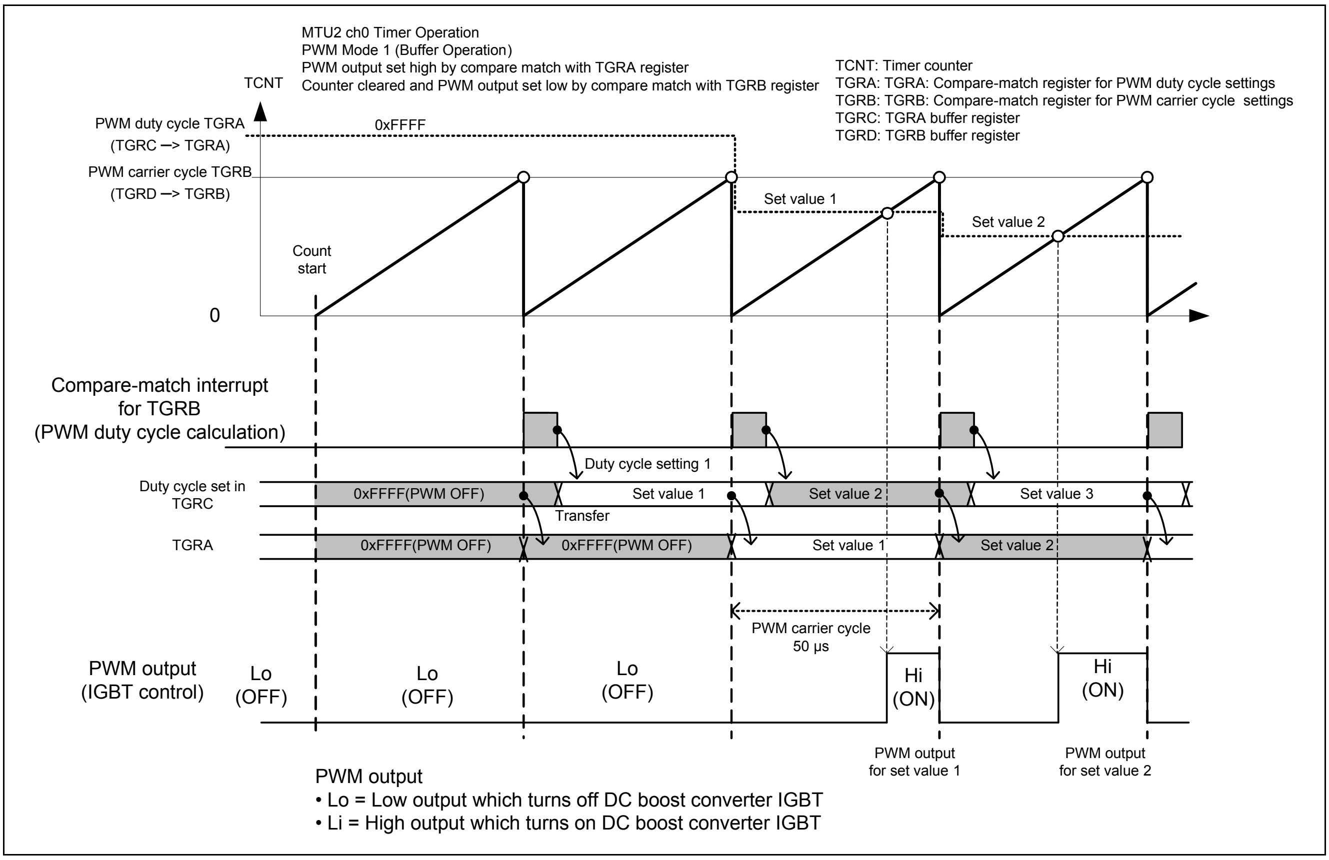


Figure 7 PWM Output Waveform of MTU2 Channel 0

3.1.3 DC Boost Converter Startup

Figure 8 shows how the DC boost converter starts.

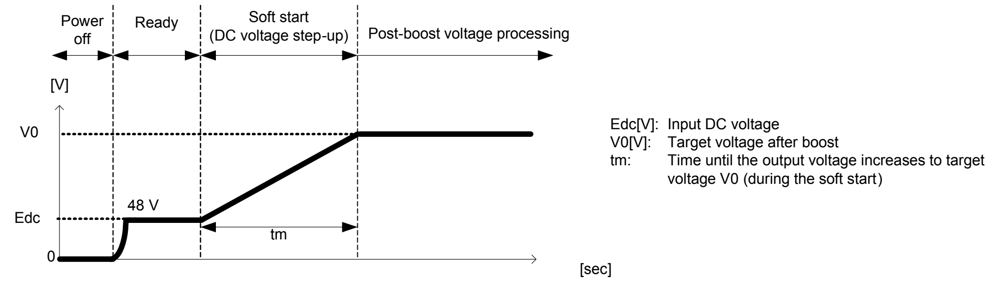


Figure 8 DC Boost Converter Startup

(1) Power off

This is the state when the main power switch (SW1) is off.

(2) Ready state

When you turn on the main power switch (SW1), DC voltage is applied to the input of the DC boost converter. The output voltage of this converter increases up to the input DC voltage.

(3) Soft start (boost process)

After you turn on the sw2, the DC boost converter performs the DC boost process which is a soft start. During the soft start period, the output voltage slowly increases to the target value (desired voltage after boost). This restricts an inrush current which flows at startup.

When the DC boost converter is performing a soft start, the subsequent AC inverter is stopped.

(4) Final output (post-boost process)

Upon completion of the soft start, the subsequent AC inverter is activated for output of an AC voltage. The DC boost converter adjusts the post-boost output voltage to the target value by controlling the switching element (IGBT) on/off time with the PWM signal. For this adjustment, feedback control is provided.

3.1.4 DC Boost Process Flow

Figure 9 outlines the flow of the DC boost process.

The switching element in the DC boost converter is controlled by the PWM signal from the MTU2. MTU2 channel 0 generates a compare-match interrupt per cycle of the PWM carrier. Software in the processing routine for this interrupt calculates the PWM duty cycle in accord with the stage of DC boost converter processing (ready, boost, or post-boost). On completion of interrupt processing, the calculated value is set in the PWM duty register of the MTU2.

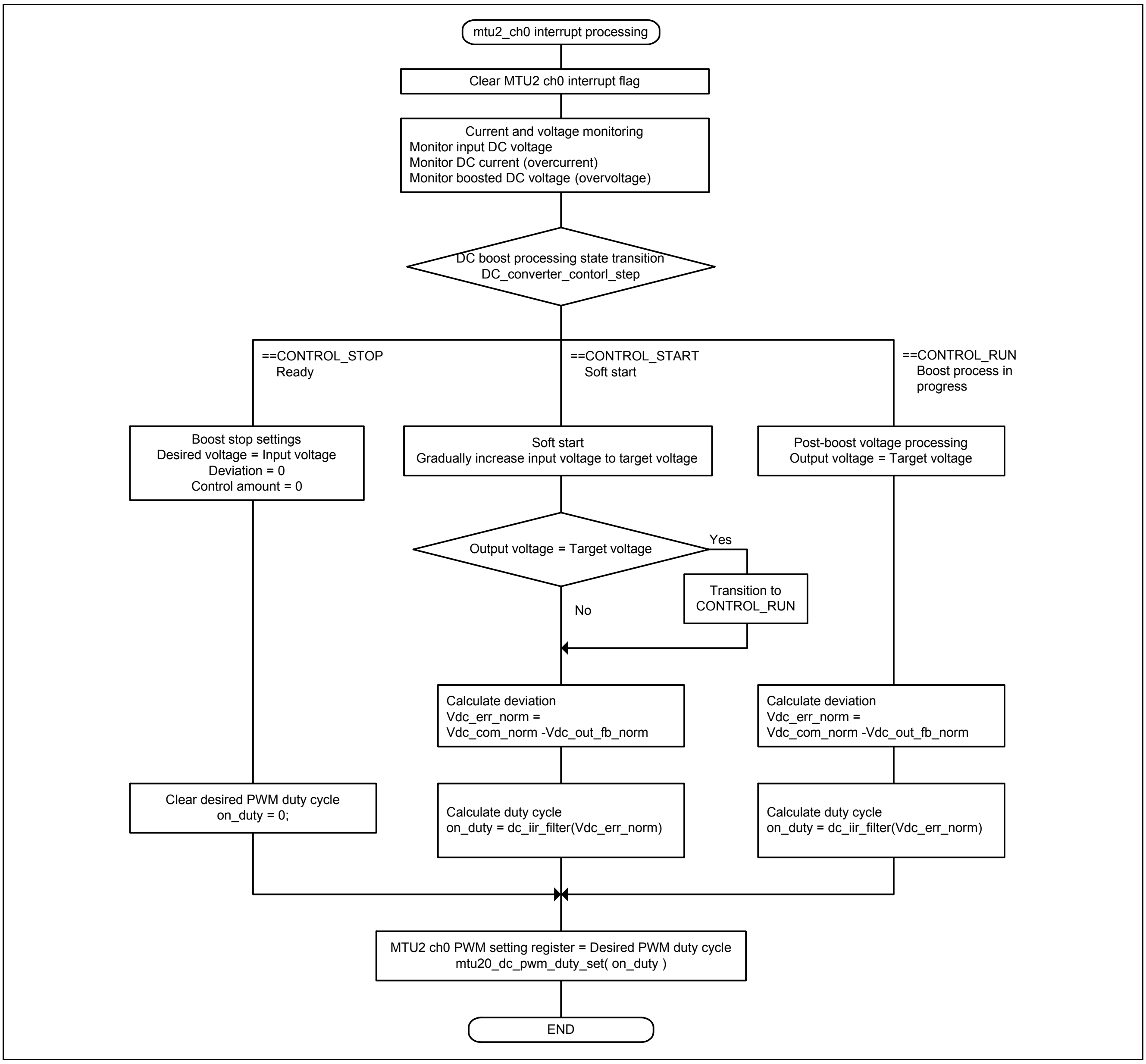


Figure 9 DC Boost Control Flow (Interrupt Processing)

3.2 AC Inverter

3.2.1 Configuration

Figure 10 shows the configuration of this system’s AC inverter.

The AC inverter generates a sine-wave AC voltage from a DC voltage. The input for the AC inverter is a voltage boosted by the DC boost converter. The AC fan (load) rotates with the 100 VAC/220 VAC voltage generated by the AC inverter.

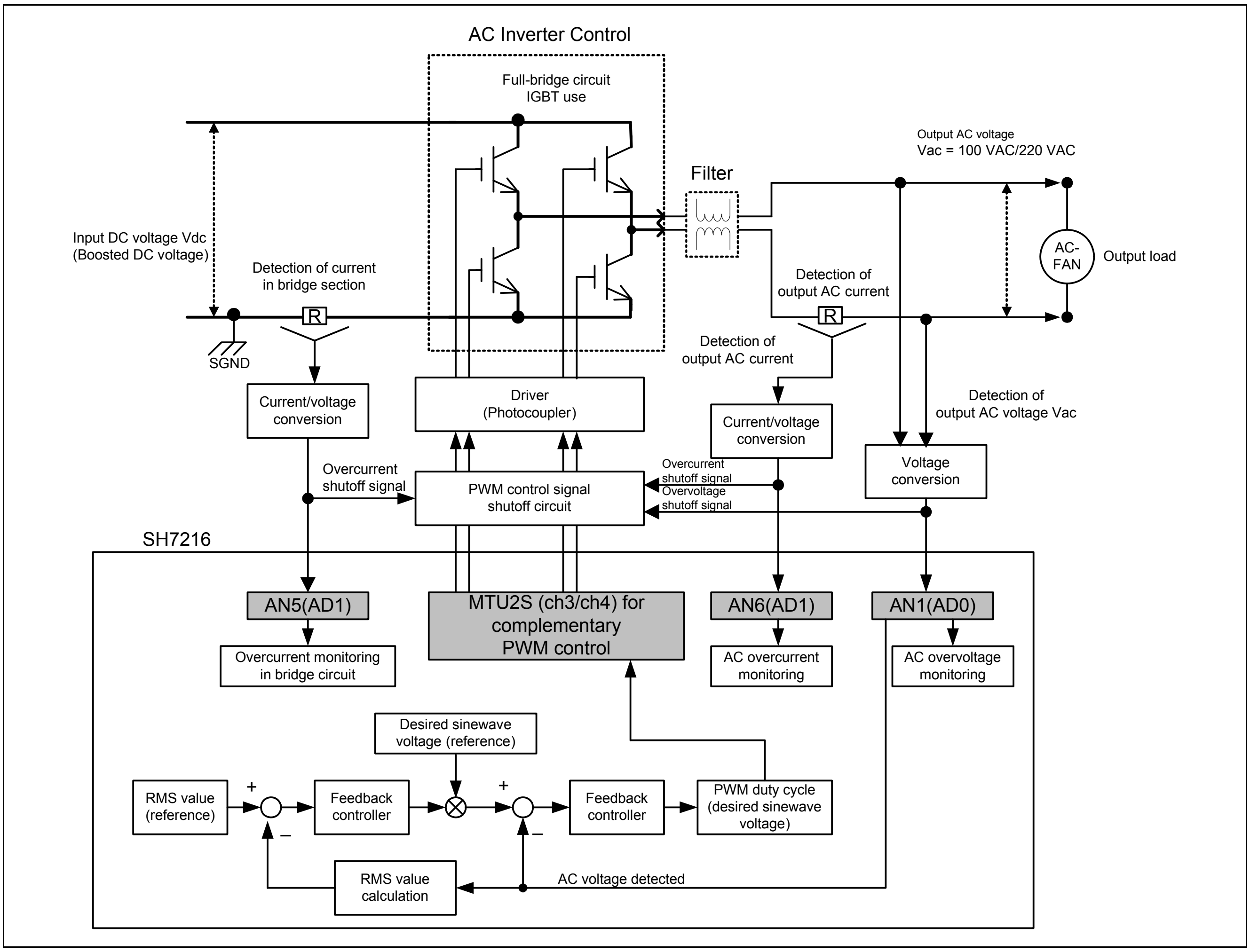


Figure 10 AC Inverter

The AC inverter is a full-bridge circuit which includes four switching elements (IGBTs). It serves as a non-insulated DC/AC converter. Drivers (photocoupler) drive the high-side and low-side IGBTs.

The multi-function timer pulse unit 2S (MTU2S) serving as an SH7216 on-chip peripheral generates on/off control signals for the IGBTs.

The AC inverter converts its output AC voltage into a sine-wave AC voltage by feedback control. The output AC voltage is detected by an A/D converter (ADC) serving as an SH7216 on-chip peripheral. In feedback control, the RMS value of the AC output voltage is calculated from the detected voltage, and then the deviation from the reference RMS value is obtained. After that, the deviation from the reference sine-wave voltage (desired voltage) is calculated to obtain the desired voltage value. This value is converted into the duty cycle of a PWM control signal, which is then set in the MTU2S register. The MTU2S controls the on/off timing of the IGBTs in complementary PWM mode.

The feedback controller used in the AC inverter is equivalent to the one used in the DC boost converter. See figure 6.

Table 6 outlines the AC inverter.

Table 6 AC Inverter Outline

Item	Description
System	Non-insulated sine-wave inverter (full-bridge control)
Input voltage	200 VDC/400 VDC (output voltage of the DC boost converter)
Output voltage	Sine-wave AC voltage (100 ACVrms, ±141 V peak voltage) (220 ACVrms, ±311 V peak voltage)
Continuous output	44 W (0.2 A × 220 VAC)
Output frequency	50 Hz/60Hz (selectable)
PWM carrier cycle	50 μs Switching cycle of the IGBTs in the full-bridge circuit (PWM carrier frequency: 20 kHz)

3.2.2 Multi-function Timer Pulse Unit 2S (MTU2S)

The AC inverter is a full-bridge circuit which uses IGBTs. The switching operation of these IGBTs is controlled by using the multi-function timer pulse unit 2S (MTU2S) which is an SH7216 on-chip peripheral.

PWM waveforms are generated when channels 3 and 4 of the MTU2S are in complementary PWM mode. In this mode, PWM signals with up to three phases can be output along with corresponding inverse signals (from up to six pins) without overlap between the positive and inverse signals. The control of the full-bridge circuit involves four output pins for two phases.

Table 7 shows the functional settings for the MTU2S.

For details about the MTU2S, see the section on the MTU2S in the *SH7214 Group, SH7216 Group User's Manual: Hardware (REJ09B0543)*.

Table 7 Functional Settings for MTU2S Channels 3 and 4

Item	**Description**	
Channels used	Channels 3 and 4	
MTU2S module operating clock	100 MHz	
Operating mode	Complementary PWM mode 3 (data transfer to the compare register at the crest and trough of the counter value)	
PWM carrier cycle	50 µs (PWM carrier frequency: 20 kHz)	
PWM resolution	20 ns (1/100 MHz × 2)	
Short-circuit prevention interval (dead time)	1500 ns	
Interrupt	Compare-match interrupt for the TGRA3 compare-match register (a compare-match interrupt is generated every PWM carrier cycle)	
A/D conversion trigger	Compare match with the TGRA3 register starts the A/D converter (A/D_0, A/D_1).	
Output pins	TIOC3BS(PD10)	• Complementary PWM1 positive output • Initial output = Low, Active level = High • High-side (positive) IGBT control (via the driver (photocoupler))
	TIOC3DS(PD11)	• Complementary PWM1 inverse output • Initial output = High, Active level = High • Low-side (inverse) IGBT control (via the driver (photocoupler))
	TIOC4BS(PD13)	• Complementary PWM3 positive output • Initial output = Low, Active level = High • High-side (positive) IGBT control (via the driver (photocoupler))
	TIOC4DS(PD15)	• Complementary PWM3 inverse output • Initial output = High, Active level = High • Low-side (inverse) IGBT control (via the driver (photocoupler))
	TIOC4AS(PD12)	Unused. Provided for I/O port setting.
	TIOC4CS(PD14)	Unused. Provided for I/O port setting.

3.2.3 Complementary PWM Mode of the MTU2S

Figure 11 shows the waveform which is output from the MTU2S in complementary PWM mode.

The carrier modification schemes available for PWM control include sawtooth modulation and triangular modulation. The MTU2S uses the triangular modulation technique for complementary PWM mode. With this technique, changes are made to the PWM duty cycles for the left and right sides of the triangular waveform’s center line.

If the positive side (high-side) and inverse side (low-side) IGBTs in the AC full-bridge inverter turn on (conductive) at the same time, current flows through a short circuit. This might overheat the elements and destroy the circuits. To inhibit this short circuit current, the PWM signals include dead time which prevents the positive side and inverse side IGBTs from turning on at the same time. In complementary PWM mode of the MTU2S, a complementary PWM signal with dead time can be generated by specifying the dead time in the special register for dead time setting.

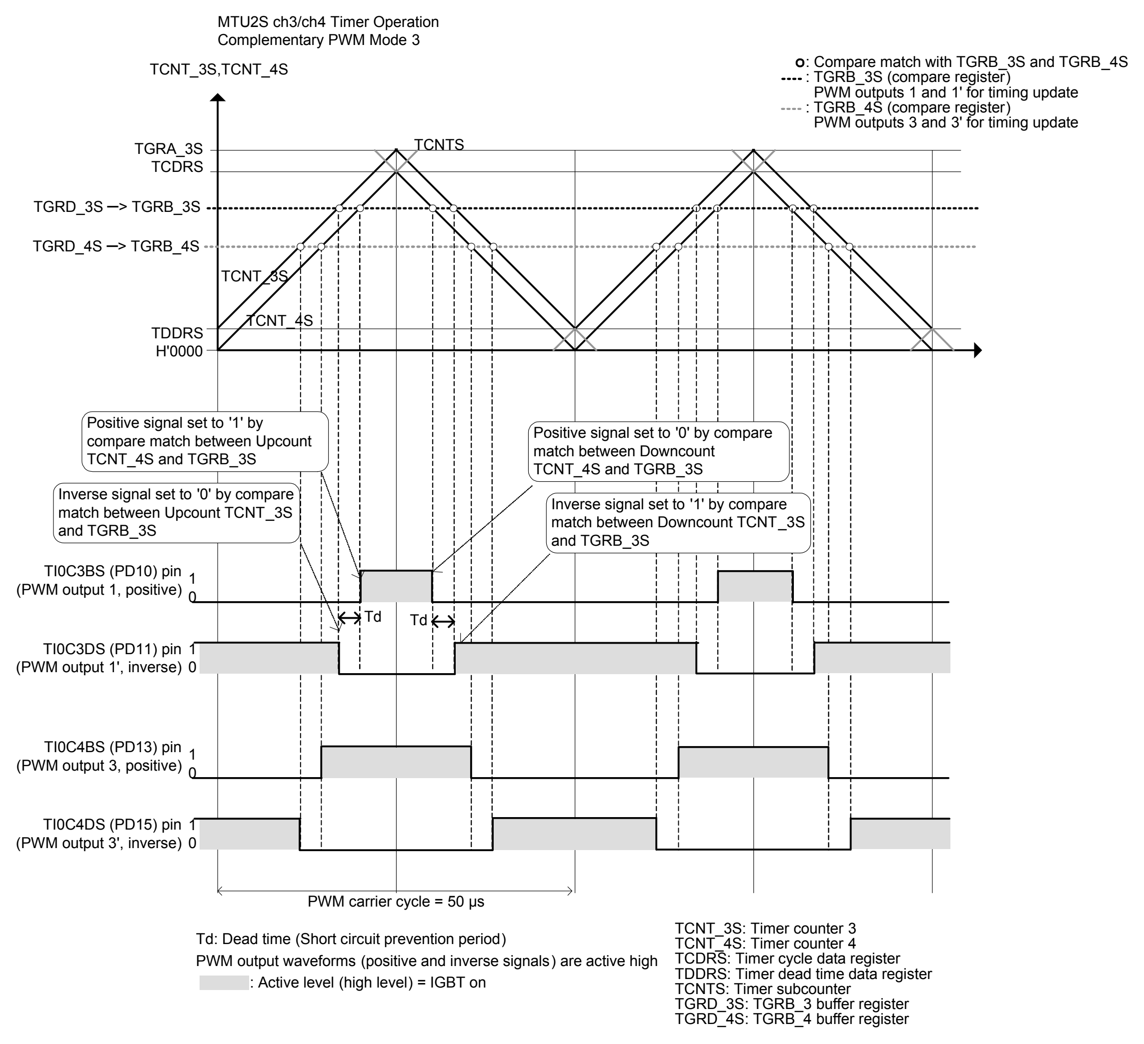


Figure 11 Waveform Output in Complementary PWM Mode of the MTU2S

In complementary PWM mode, the MTU2S performs triangular modulation. Figure 12 shows the PWM signals for triangular modulation. Triangular modulation involves comparison between triangular carrier and output signal waves for generating positive and inverse PWM signals. The duty ratios of these PWM signals are determined depending on the height of the signal wave. The external switching element is turned on and off with these PWM signals to control the output voltage with a duty ratio of 0% to 100%.

The switching operation of the IGBTs in the AC inverter is controlled by these complementary PWM signals to produce a sine-wave output voltage. Software for the SH7216 calculates the PWM duty cycles per cycle of the MTU2S carrier and places the values in the MTU2S registers.

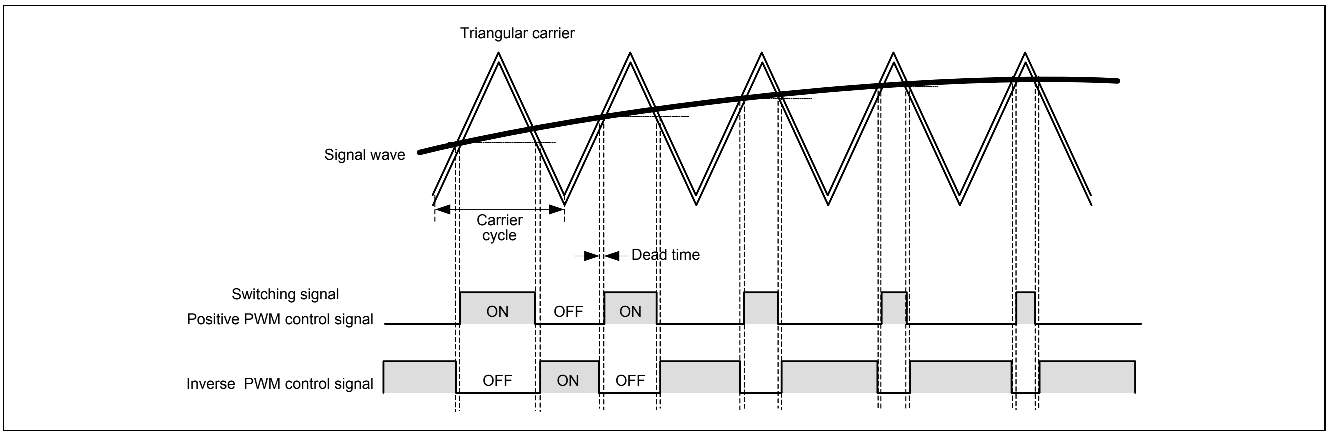


Figure 12 Relationship between the Triangular Carrier Wave and PWM Signals for Triangular Modulation

Figure 13 shows the connection between the complementary PWM output pins on the SH7216 and full-bridge circuit.

The MTU2S module on the SH7216 outputs the complementary PWM signals to control the full-bridge circuit. The 3.3 V complementary PWM signals from the SH7216 are converted into 5.0 V signals, which are then applied to drivers (photocouplers). The drivers directly drive the IGBTs in the full-bridge circuit.

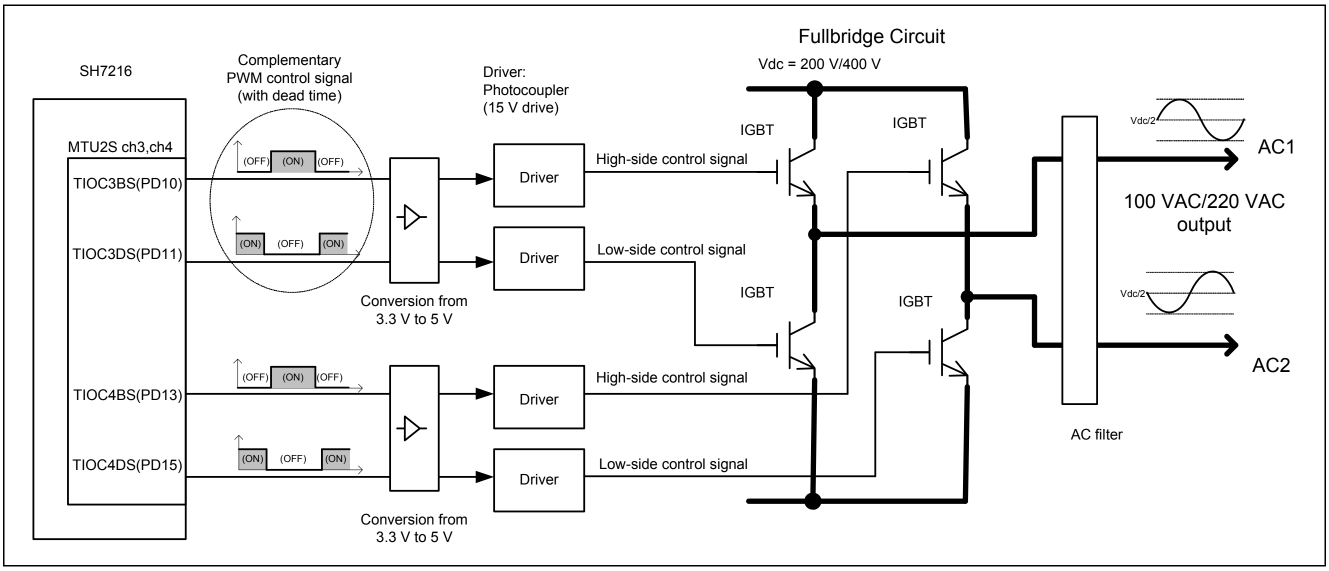
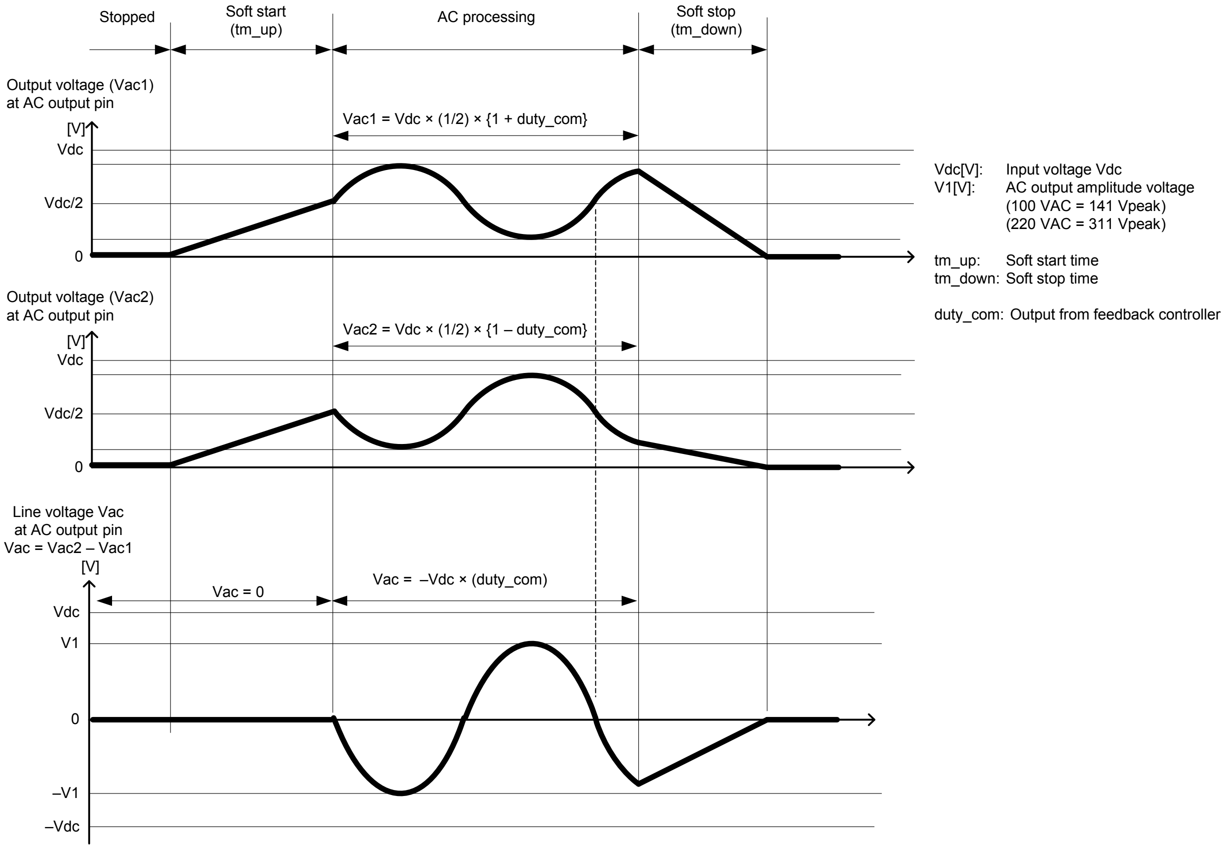


Figure 13 Connection between the MTU2S and Inverter Circuit

3.2.4 AC Inverter Startup and Output Voltages

Figure 14 shows the AC inverter startup stage and AC voltage waveforms of AC processing.

As this figure shows, the AC inverter performs a soft start and then outputs sine-wave AC voltages.



Vdc[V]: Input voltage Vdc
V1[V]: AC output amplitude voltage (100 VAC = 141 Vpeak) (220 VAC = 311 Vpeak)

tm_up: Soft start time
tm_down: Soft stop time

duty_com: Output from feedback controller

Figure 14 AC Inverter Startup Stage and AC processing AC Voltages

The AC inverter starts up after the DC boost converter completes the boost process.

(1) Stopped state

The complementary PWM control signals are used for controlling the AC output pins (AC1 and AC2) on the AC inverter. The duty ratios of these PWM control signals are duty1 and duty2. When the AC inverter is stopped, these duty ratios are set to the values below.

$$\begin{cases} \text{duty1} = 0 \\ \text{duty2} = 0 \end{cases}$$

Voltages on the two AC output pins of the AC inverter are Vac1 and Vac2. The line voltage between the output pins is Vac. When the AC inverter is stopped, its output voltages which depend on the PWM duty ratios are calculated as shown below. The voltage between the output pins is fixed to 0 V.

$$\begin{cases} \text{Vac1} = \text{Vdc} \times \text{duty1} = 0 \\ \text{Vac2} = \text{Vdc} \times \text{duty2} = 0 \end{cases}$$

$$\text{Vac} = \text{Vac2} - \text{Vac1} = 0$$

(2) Soft start

The AC inverter performs a soft start when it starts up. It increases the output voltages at a fixed rate until they become half the DC voltage, Vdc. This soft start restricts sudden voltage variations at startup.

The PWM duty ratios are set as follows for the soft start. They are increased from 0% to 50% (1/2) at a fixed rate.

$$\begin{cases} \text{duty1} = \frac{1}{2} \times \text{J1} \\ \text{duty2} = \frac{1}{2} \times \text{J1} \end{cases}$$

$$\text{J1} = 0 \rightarrow 1.0$$

Output AC voltages Vac1 and Vac2 as well as line voltage Vac are calculated from the PWM duty ratios as shown below. During the soft start, the same potential is applied to the two AC output pins, resulting in line voltage Vac being 0 V.

$$\begin{cases} \text{Vac1} = \text{Vdc} \times \text{duty1} = \text{Vdc} \times \frac{1}{2} \times \text{J1} \\ \text{Vac2} = \text{Vdc} \times \text{duty2} = \text{Vdc} \times \frac{1}{2} \times \text{J1} \end{cases}$$

$$\text{Vac} = \text{Vac2} - \text{Vac1} = 0$$

(3) AC processing

Upon completion of the soft start, the AC inverter outputs sine-wave AC voltages from the AC output pins. These voltages are centered around 1/2 of the DC voltage, Vdc. The phase difference between them is 180 degrees. At this time, line voltage Vac is equal to a sine-wave AC voltage.

The PWM duty ratios for AC processing operation are set as follows to obtain sine waves.

$$\begin{cases} \text{duty1} = \frac{1}{2}(1 + \text{duty\_com}) \\ \text{duty2} = \frac{1}{2}(1 - \text{duty\_com}) \end{cases}$$

duty_com: Feedback controller output

duty_com = –1.0[min.] ~ +1.0 [max.]

Output voltages Vac1 and Vac2 on the AC output pins as well as line voltage Vac are calculated from the PWM duty ratios as follows. Line voltage Vac is a sine-wave AC voltage at a frequency of 50 Hz or 60 Hz.

$$\begin{cases} \text{Vac1} = \text{Vdc} \times \text{duty1} = \text{Vdc} \times \frac{1}{2}(1 + \text{duty\_com}) \\ \text{Vac2} = \text{Vdc} \times \text{duty2} = \text{Vdc} \times \frac{1}{2}(1 - \text{duty\_com}) \end{cases}$$

$$\text{Vac} = \text{Vac2} - \text{Vac1} = -\text{Vdc} \times \text{duty\_com}$$

The amplitude voltage of the sine-wave 100 VAC voltages is ±141 V. If the DC voltage, Vdc, applied to the AC inverter is 200 VDC, duty_com is approximately as follows.

$$\frac{\text{V1}}{\text{Vdc}} = \frac{141\ [\text{V}]}{200\ [\text{V}]} \cong 0.705 \rightarrow \text{duty\_com} = -0.705 \sim +0.705$$

The amplitude voltage of the sine-wave 220 VAC voltages is ±311 V. If the DC voltage, Vdc, applied to the AC inverter is 400 VDC, duty_com is approximately as follows.

$$\frac{\text{V1}}{\text{Vdc}} = \frac{311\ [\text{V}]}{400\ [\text{V}]} \cong 0.778 \rightarrow \text{duty\_com} = -0.778 \sim +0.778$$

This duty_com is adjusted for feedback control required for output AC voltage compensation.

(4) Soft stop

The AC inverter performs a soft stop when it stops. It retains the PWM duty ratio immediately before it is stopped and then decreases the PWM duty ratio at a fixed rate. This soft stop restricts sudden voltage variations on the AC output terminal at stopping.

The PWM duty ratios are set as follows for the soft stop. They are decreased at a fixed rate.

$$\begin{cases} \text{duty1} = \frac{1}{2}(1 + \text{duty\_com}) \times \text{J1} \\ \text{duty2} = \frac{1}{2}(1 - \text{duty\_com}) \times \text{J1} \end{cases}$$

duty_com: Retains the output from the feedback controller immediately before stopping

$\text{J1} = 1.0 \rightarrow 0$

Output AC voltages Vac1 and Vac2 as well as line voltage Vac are calculated from the PWM duty ratios as shown below. During a soft stop, the absolute value of line voltage Vac decreases at a fixed rate.

$$\begin{cases} \text{Vac1} = \text{Vdc} \times \text{duty1} = \text{Vdc} \times \frac{1}{2}(1 + \text{duty\_com}) \times \text{J1} \\ \text{Vac2} = \text{Vdc} \times \text{duty2} = \text{Vdc} \times \frac{1}{2}(1 - \text{duty\_com}) \times \text{J1} \end{cases}$$

$$\text{Vac} = \text{Vac2} - \text{Vac1} = -\text{Vdc} \times \text{duty\_com} \times \text{J1}$$

$\text{J1} = 1.0 \rightarrow 0$

Upon completion of the soft stop operation, the AC inverter moves to the stopped state.

3.2.5 AC Inverter Control Flow

Figure 15 shows the flow of AC inverter control.

Software in the processing routine for the compare-match interrupt from channel 3 of the MTU2S calculates and sets the duty cycles of the PWM control signals for the AC inverter. The interrupt is generated per cycle of the PWM carrier.

Every time the processing routing is run, the PWM duty cycle is calculated in accord with the state of AC-inverter processing (stopped, soft start, AC processing, or soft stop) and set in the MTU2S registers.

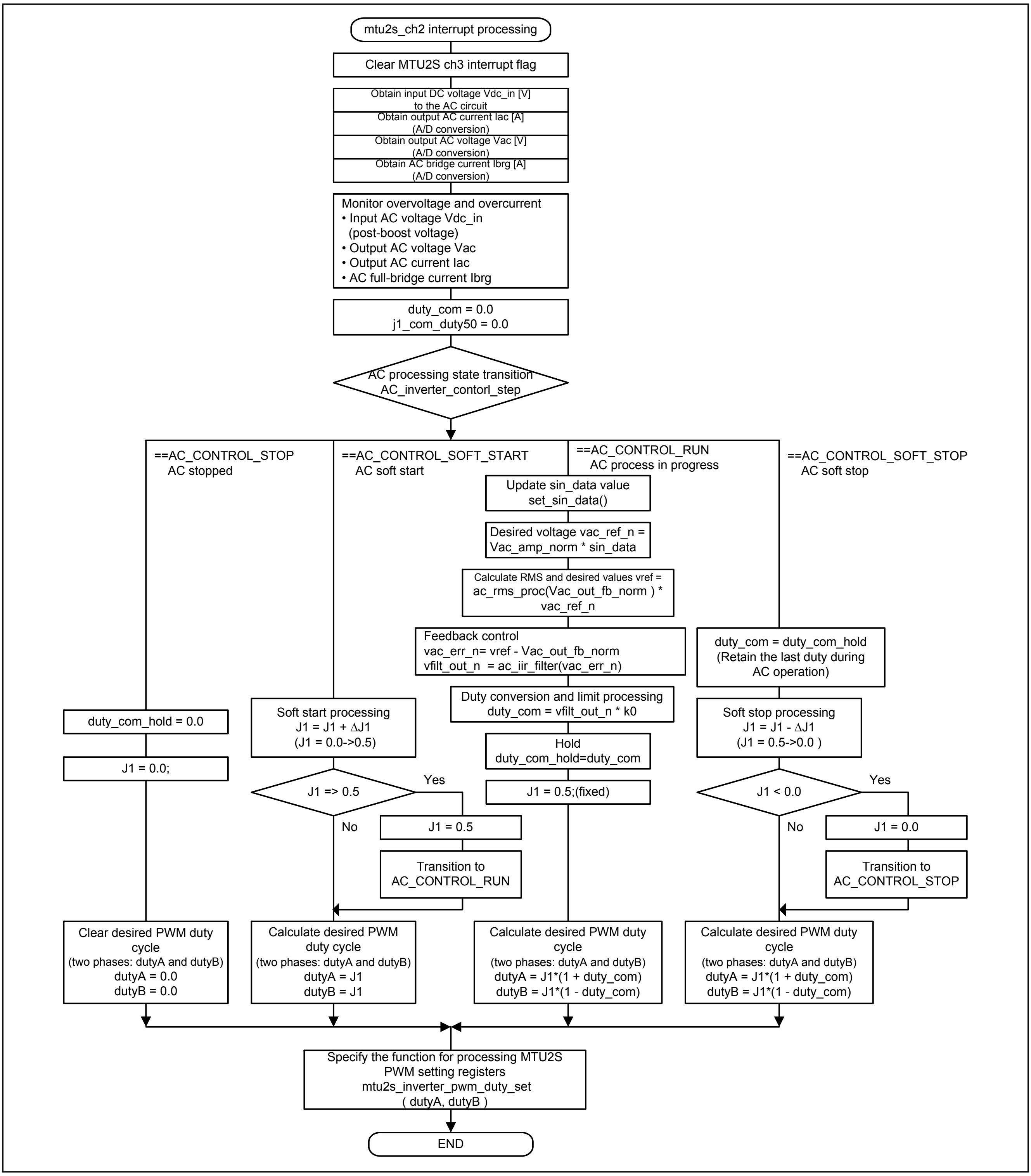


Figure 15 AC Inverter Control Flow (Interrupt Processing)

3.3 Detection of Voltage, Current and Temperature

3.3.1 Configuration

Using the A/D converter units which are SH7216 on-chip peripherals, this system detects the analog values of voltage and current in the DC boost converter and AC inverter. The A/D converter units convert these analog values into digital values.

Figure 16 shows the connection between the detection circuits and A/D converter units. Table 8 lists the values converted by these units.

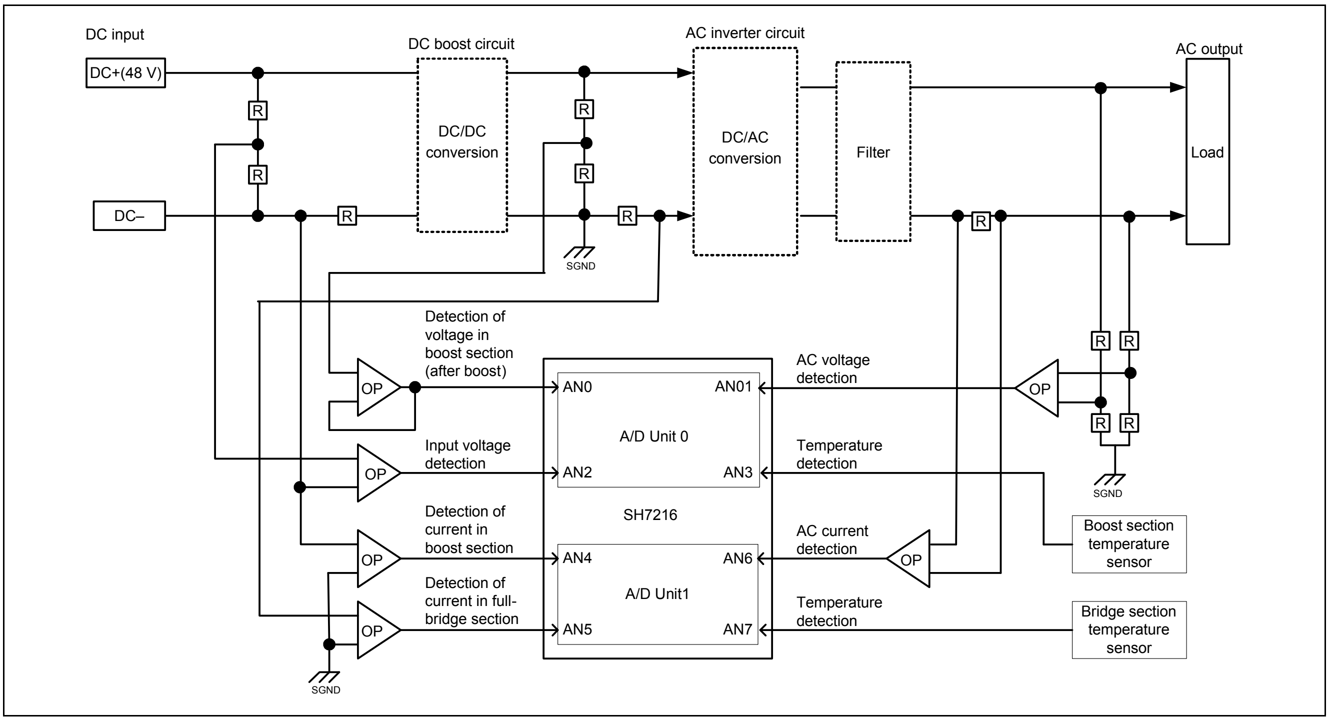


Figure 16 A/D Converter Units Connected

Table 8 Values Converted by the A/D Converter Units

Item	A/D pin (module)	Description	Conversion ratio (A/D voltage/ internal quantity)
Input voltage detected	AN2 (A/D_0)	Input DC voltage Ed V Ed = 48 V	0 to 3.33 [V] → 0 to 70 [V]
Voltage detected in boost section	AN0 (A/D_0)	Post-boost voltage, Vdc, detected in the DC boost section, Vdc = 200/400 V	0 to 2.85 [V] → 0 to 450 [V]
Current detected in boost section	AN4 (A/D_1)	Current, Idc A, detected in the DC boost section	0 to 3.74 [V] → 0 to 3.85 [A]
Current detected in full-bridge section	AN5 (A/D_1)	Current, Ibrg A, detected in the full-bridge section	0 to 3.23 [V] → 0 to 11.9 [A]
Output AC voltage detected	AN1 (A/D_0)	Absolute value of output AC voltage, Vac Vrms, detected	0 to 3.73 [V] → 0 to 341 [Vpeak]
Output AC current detected	AN6 (A/D_1)	Output AC current, Iac A	0 to 3.98 [V] → 0 to 0.30 [A]
Temperature detected in boost section	AN3 (A/D_0)	Temperature of the IGBT in the DC boost section	0.47 to 2.94 [V] → 125 to 0 [°C]
Temperature detected in full-bridge section	AN7 (A/D_1)	Temperature of the IGBTs in the fullbridge inverter circuit	0.47 to 2.94 [V] → 125 to 0 [°C]

3.3.2 A/D Converter Units

The SH7216 contains two 12-bit A/D converter units of sequential comparison type. They have a total of eight input channels (four channels × two units).

Table 9 shows the functional settings for the A/D converter (ADC) units.

For details about the A/D converter units, see the section on the A/D Converter in the *SH7214 Group, SH7216 Group User's Manual: Hardware (REJ09B0543).*

Table 9 Functional Settings for the A/D Converter (ADC) Units

Item	Description	
Channels used	A/D module 0 (A/D_0)	A/D module 1 (A/D_1)
A/D module operating clock	50 MHz	50 MHz
Operating mode	• 1-cycle scan mode Analog inputs 0 to 3 (AN0 to AN3) are scanned in one cycle.	• 1-cycle scan mode Analog inputs 4 to 7 (AN4 to AN7) are scanned in one cycle.
A/D conversion trigger	Compare-match interrupt (with 50 μs cycle) for TGRA3 of MTU2S ch3 (in complementary PWM mode)	←
Interrupt after A/D conversion	• None	• None
Dedicated sample-and-hold circuit	• Disabled (ADBYPSCR.SH = 0). A typical impedance conversion circuit is used for channels 0, 1 and 2.	• Not provided. A typical impedance conversion circuit is used.
A/D conversion time	4300 μs	←
Input pins	AN0 (channel 0): Used AN1 (channel 1): Used AN2 (channel 2): Used AN3 (channel 3): Used	AN4 (channel 4): Used AN5 (channel 5): Used AN6 (channel 6): Used AN7 (channel 7): Used

3.3.3 A/D Converter Startup

The A/D converter units can start A/D conversion by using compare-match signals from the MTU2S (SH7216 on-chip peripherals). They can perform A/D conversion at a constant frequency without software processing.

A/D module 0 (for channels 0, 1, 2 and 3) starts A/D conversion by using compare match at the peak of the counter value from MTU2S channels 3 and 4 in complementary PWM mode. Likewise, A/D module 1 (for channels 4, 5, 6 and 7) starts A/D conversion by using the compare match at the peak of the counter value from MTU2S channels 3 and 4 in complementary PWM mode.

Figure 17 is a timing diagram of the startup of A/D modules 0 and 1.

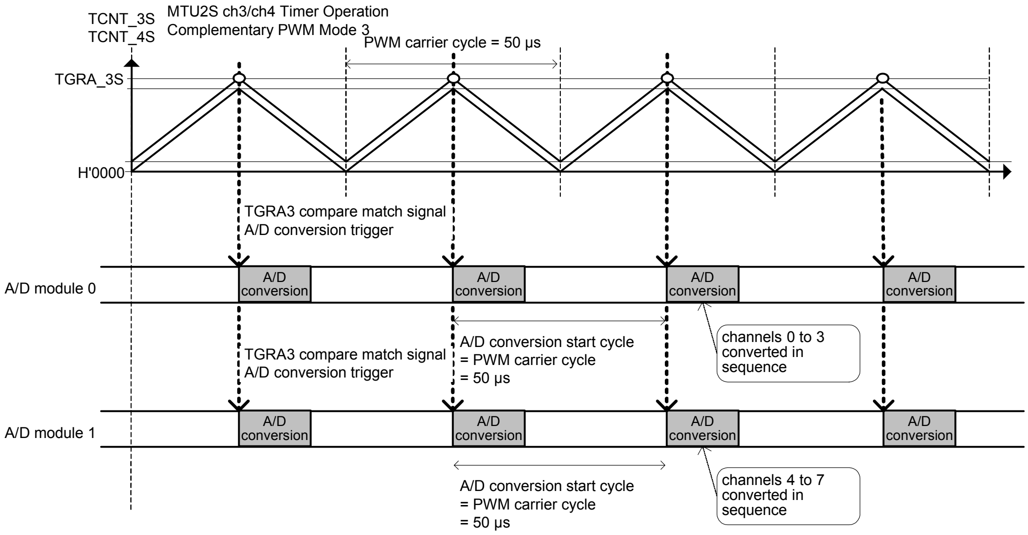


Figure 17 A/D Converter Startup

3.4 Protection Functions

For system protection, this system relies on hardware to detect any overvoltage and overcurrent in the DC boost converter and AC inverter.

The A/D converter in the SH7216 converts the analog values of voltage and current in the DC boost converter and AC inverter into digital values. Software can therefore restrict increases in the voltage and current. However, if software implements this processing, it takes too long to shut off the PWM control signals because it needs to be responsible for various functions such as A/D conversion, PWM control signal shutoff decision upon abnormality occurrence and control value setup for PWM output. Thus, a hardware circuit checks for abnormalities. If the hardware circuit detects a sudden voltage or current increase, it shuts off the PWM control signals without using software. To protect the DC boost converter against damage, this system needs to stop it as soon as possible after detecting its abnormality.

Figure 18 shows the protection circuit for the DC boost converter and AC inverter.

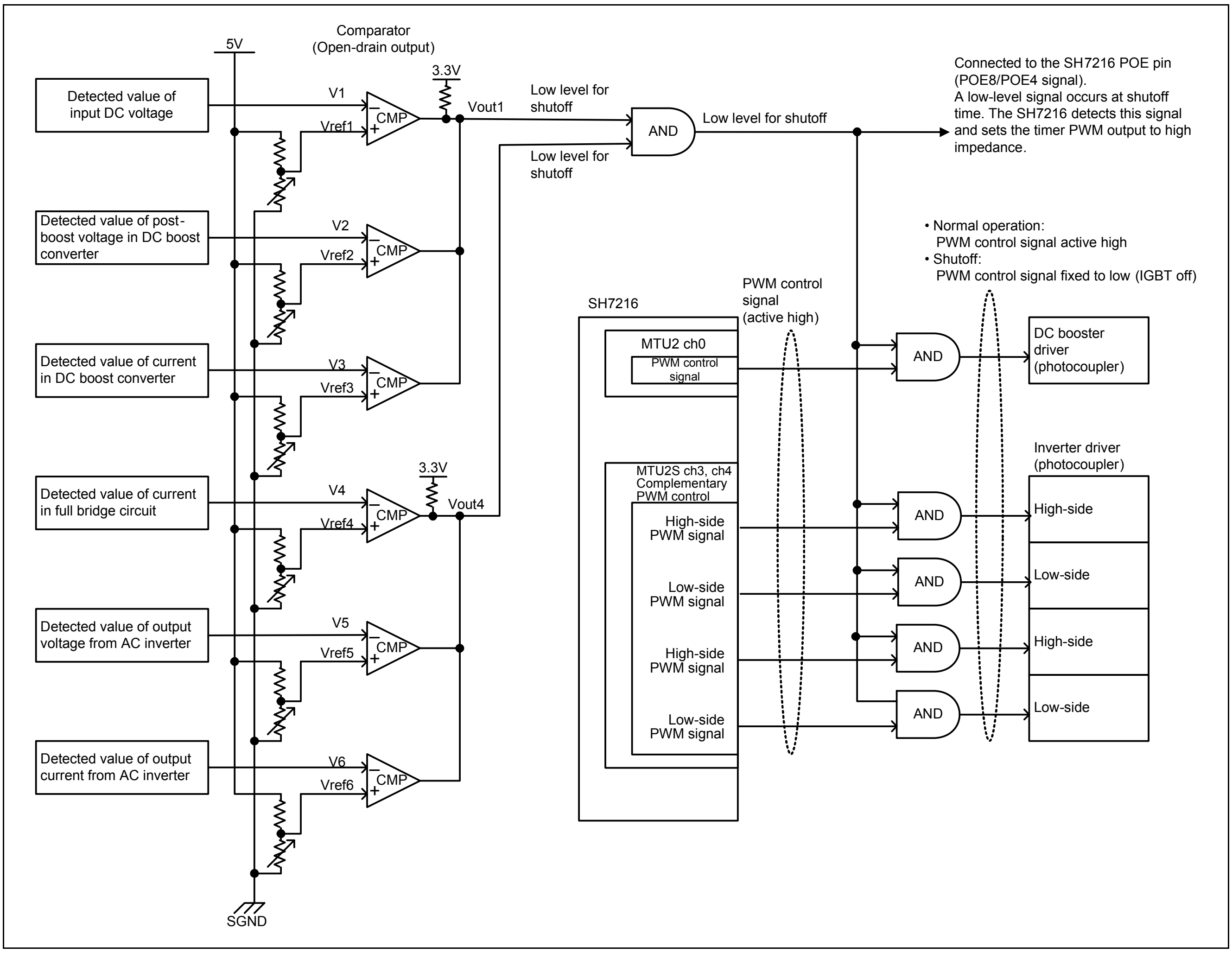


Figure 18 Protection Circuit for the DC Boost Converter and AC Inverter

3.4.1 DC Boost Converter Protection

The system monitors the input DC voltage, post-boost DC voltage, and DC current in the DC boost converter. If a voltage or a current is abnormal, hardware shuts off the PWM signals and stops the boost converter and AC inverter process.

(1) Detection of abnormal input DC voltage
(2) Detection of abnormal post-boost DC voltage
(3) Detection of abnormal DC current

A comparator compares detected voltage or current Vm with threshold Vrefm (m = 1 to 3). Output signal Vout1 from the comparator is used to control the PWM signal shutoff circuit.

— If Vm < Vrefm (m = 1 to 3), Vout1 is set to a high level and the IGBT is controlled with the PWM control signals.
— If Vm > Vrefm (m = 1 to 3), Vout1 is set to a low level and the DC boost operation and AC inverter operation are forcibly stopped. At this time, the system judges that the voltage is abnormally increasing. Then, it fixes the PWM control signals at a low level and turns the IGBT off. The shutoff threshold (reference voltage) is set via a variable resistor.

The abnormality detection signal for DC boost converter is input to the SH7216 POE8/POE4 pins separate from the PWM signal shutoff circuit. If a low-level signal is detected on the POE8 input pin, the Port Output Enable 2 (POE2) feature which is an SH7216 on-chip peripheral can set the PWM output pin for MTU2 channel 0 to high impedance, thereby disabling the drive of the DC boost converter. Likewise, if a low-level signal is detected on a POE4 input pin, the POE2 can set the complementary PWM output pins for MTU2S channels 3 and 4 to high impedance, thereby stopping the control signals for the AC inverter.

3.4.2 AC Inverter Protection

The system monitors the full bridge circuit current, output voltage, and output current in the AC inverter. If a current or a voltage is abnormal, hardware shuts off the PWM signals and stops the boost process and AC inverter process.

(1) Detection of abnormal current in the full-bridge circuit
(2) Detection of abnormal output voltage
(3) Detection of abnormal output current

A comparator compares detected voltage or current Vn with threshold Vrefn (n = 4 to 6). Output signal Vout4 from the comparator is used to control the PWM signal shutoff circuit.

— If Vn < Vrefn (n = 4 to 6), Vout4 is set to a high level and the IGBT is controlled with the PWM control signals.
— If Vn > Vrefn (n = 4 to 6), Vout4 is set to a low level and the DC boost operation and AC inverter operation are forcibly stopped. At this time, the system judges that the voltage is abnormally increasing. Then, it fixes the PWM control signals at a low level and turns the IGBT off. The shutoff threshold (reference voltage) is set via a variable resistor.

The abnormality detection signal for AC inverter is input to the SH7216 POE8/POE4 pins separate from the PWM signal shutoff circuit. If a low-level signal is detected on the POE8 input pin, the Port Output Enable 2 (POE2) feature which is an SH7216 on-chip peripheral can set the PWM output pin for MTU2 channel 0 to high impedance, thereby disabling the drive of the DC boost converter. Likewise, if a low-level signal is detected on a POE4 input pin, the POE2 can set the complementary PWM output pins for MTU2S channels 3 and 4 to high impedance, thereby stopping the control signals for the AC inverter.

3.4.3 Port Output Enable 2 (POE2) Feature

If overvoltage or overcurrent is detected in the DC boost converter or AC inverter, the Port Output Enable 2 (POE2) feature, which is an SH7216 on-chip peripheral, sets the pins for the PWM signals from the SH7216 to high impedance to stop the control operation.

Tables 10 and 11 show the functional settings for the POE2 feature.

For details about the POE2 feature, see the section on the Port Output Enable 2 (POE2) in the *SH7214 Group, SH7216 Group User's Manual: Hardware (REJ09B0543).*

Table 10 Functional Settings for the POE2 Feature (POE8 Pin)

Item	Description
Pin	POE8 (PE4) input pin
POE8 pin function	Accepts request signals which set to high impedance the channel 0 pins for the MTU2 (PE0/TIOC0A, PE1/TIOC0B, PE2/TIOC0C, PE3/TIOC0D, PB1/TIOC0A, PB2/TIOC0B, PB3/TIOC0C and PB4/TIOC0D).
POE8 signal required	Low-level sampling on the POE8 pin.
Interrupt	POE8 interrupt
Usage	Used to set the TIOC0A (PB1) output pin of the IGBT-controlling MTU2 (channel 0) to high impedance to stop the PWM control if overvoltage or overcurrent occurs in the DC boost converter or AC inverter.

Table 11 Functional Settings for the POE2 Feature (POE4 Pin)

Item	Description
Pin	POE4 (PA20) input pin
POE4 pin function	Accepts request signals which set to high impedance the large-current pins for the MTU2S (PE5/TIOC3BS, PE6/TIOC3DS, PE0/TIOC4AS, PE1/TIOC4BS, PE2/TIOC4CS, PE3/TIOC4DS, PD10/TIOC3BS, PD11/TIOC3DS, PD12/TIOC4AS, PD13/TIOC4BS, PD14/TIOC4CS, PD15/TIOC4DS, PD29/TIOC3BS, PD28/TIOC3DS, PD27/TIOC4AS, PD26/TIOC4BS, PD25/TIOC4CS and PD24/TIOC4DS).
POE4 signal required	Low-level sampling on the POE4 pin.
Interrupt	POE4 interrupt
Usage	Used to set the complementary PWM control signal output of the IGBT-controlling MTU2S (channels 3 and 4) to high impedance to stop the control if overvoltage or overcurrent occurs in the DC boost converter or AC inverter. Applicable pins • TIOC4BS(PD13), TIOC4DS(PD15) • TIOC3BS (PD10), TIOC3DS (PD11)

3.4.4 Protection by Software

The A/D converter on the SH7216 detects voltage and current in the DC boost converter and AC inverter and converts the detected analog values into digital values. If the voltage or current is abnormal, software determines whether stoppage is necessary. If it is necessary, software stops the control operation for the boost converter or AC inverter.

(1) DC boost converter protection

The input DC voltage and output DC voltage and current in the DC boost converter are monitored. Software stops this converter in the following cases:

— When the input DC voltage is outside a predetermined voltage range.
— When the output DC voltage exceeds a predetermined upper limit.
— When the DC current exceeds a predetermined upper limit.

(2) AC inverter protection

The system monitors the current in the full bridge circuit, output voltage, and output current in the AC inverter. Software stops this inverter in the following cases:

— When the current flowing in the full bridge circuit exceeds a predetermined upper limit.
— When the peak value of the output AC voltage exceeds a predetermined upper limit.
— When the peak value of the output AC current exceeds a predetermined upper limit.

(3) Protection against abnormal temperature

The temperatures of the IGBTs in the DC boost converter and AC full-bridge inverter are monitored. If these temperatures abnormally increase, the system stops the control operation for device protection.

4. Peripheral Functions

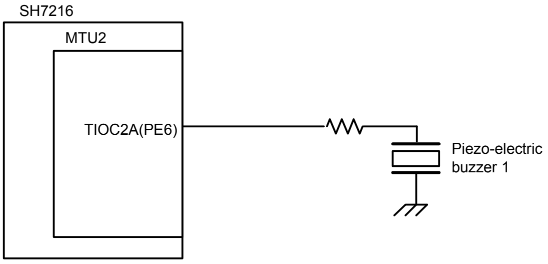
4.1 Piezo-electric Buzzer

There is a piezo-electric buzzer on this system. There is externally excited piezo-electric sounder to generate a warning sound which signals the occurrence of an abnormality.

To control the switching operation of the piezo-electric buzzer involves PWM control signals from the SH7216's multi-function timer pulse unit 2 (MTU2). Channel 2 of the MTU2 is set to PWM mode, thereby generating periodic PWM control signals.

Figure 19 shows the connection between the MTU2 and piezo-electric buzzer. Table 12 shows the functional settings for channel 2 of the MTU2.

For details about the MTU2, see the section on the MTU2 in the *SH7214 Group, SH7216 Group User's Manual: Hardware (REJ09B0543)*.



Piezo-electric buzzer (sounder) specifications
- Manufacturer: Murata Manufacturing Co., Ltd.
- Product No.: PKM17EWH2001
- Acoustic pressure level: 72 dB or more
- Acoustic pressure level requirements: 3 Vp-p, 2 kHz, square wave, 10 cm

Figure 19 Piezo-electric Buzzer Connected

Table 12 Functional Settings for the MTU2 Channel 2

Item	Description
Channel used	Channel 2 (for controlling piezo-electric buzzer 1 with the PWM control signal)
MTU2 module operating clock	50 MHz
Operating mode	PWM mode 1
PWM carrier cycle	500 μs (PWM carrier frequency: 2 kHz) for channel 2
PWM duty cycle	50% for channel 2
PWM resolution	20 ns (= 1/50 MHz)
Interrupt	None
Output pin	TIOC2A (PE6) for channel 2 • Initial output = Low, Active level = High • PWM output for controlling piezo-electric buzzer 1

4.2 Liquid Crystal Display Module (LCM)

There is a liquid crystal display module (LCM) on this system. The LCM displays system operation status and error status.

Figure 20 shows the connection between the SH7216 and LCM. To control the LCM involves not only the I/O port functions of the SH7216 but also software processing. The LCM is initialized when this system is initialized at startup.

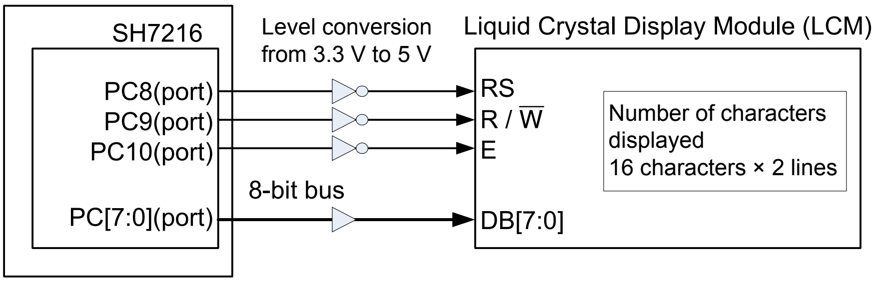


Figure 20 LCM Connected

5. Sample Program

5.1 Outline

This section describes the sample program, especially the initial settings of the SH7216 on-chip peripheral features used in the DC boost converter and AC inverter in this demo system and the voltage processing in the DC boost converter and AC inverter.

- Processing in DC boost converter

  Sets channel 0 of multi-function timer pulse unit 2 (MTU2) to PWM mode and provides PWM control for the DC boost converter (switching element).
- Processing in AC inverter

  Sets channels 3 and 4 of multi-function timer pulse unit 2S (MTU2S) to complementary PWM mode and provides PWM control for the AC inverter (full bridge circuit).
- Voltage detection

  Detects the input/output voltage of the DC boost converter and the output AC voltage from the AC inverter through the A/D converter (ADC).

5.2 Applicable Conditions

- MCU: SH7216 [R5F72167]
- Operating frequency: Internal clock: Iϕ = 200 MHz
  - Bus clock: Bϕ = 50 MHz
  - Peripheral clock: Pϕ = 50 MHz
  - MTU2S clock: Mϕ = 100 MHz
  - AD clock: Aϕ = 50 MHz
- MCU operating mode: Single chip mode
- Integrated development environment: Renesas Electronics High-performance Embedded Workshop Version 4.08.00.011
- C compiler: Renesas Electronics SuperH RISC engine Family C/C++ compiler package for SuperH RISC engine family V.9.03 Release 02
- Compiler options: (-cpu=sh2afpu -fpu=single*1 -include="$(WORKSPDIR)\inc" -object="$(CONFIGDIR)\$(FILELEAF).obj" -debug -gbr=auto -chgincpath -errorpath -global_volatile=0 -opt_range=all -infinite_loop=0 -del_vacant_loop=0 -struct_alloc=1 -nologo)

Note: *1 The floating-point mode in the SH2A-FPU is set to single mode (-fpu=single), and all floating-point operations are done as single-precision floating-point numbers (float type).

5.3 Configuration of Sample Program

This section describes the configuration of the sample program.

5.3.1 Initial Settings

Table 13 shows the SH7216 initial setting files in the sample program. These files were created from the template files in a new project for the SH7216 created through the integrated development environment (High-performance Embedded Workshop).

Table 13 SH7216 Initial Setting Files

File	Description
resetprg.c	Reset processing • Executes the main function (main()) after the reset processing.
vecttbl.c	Definition of vector tables for on-chip peripheral module interrupts
vect.h	Header definition for vector tables
intprg.c	Definitions of functions for processing on-chip peripheral module interrupts
stbcr_init.c	Initial settings of power-down mode for on-chip peripheral modules Releases on-chip peripheral modules from standby mode.
cpg.c	Settings of the clock pulse generator (CPG) Specifies the internal clock for the SH7216 and operating frequencies for on-chip peripheral modules.
dbsct.c	Initialization processing for sections B and R
hwsetup.c	Initial settings for on-chip peripheral modules
intc_init.c	Settings of priority levels for on-chip peripheral module interrupts
stacksct.h	Definitions of stack sizes
iodefine.h	Definitions of registers in the SH7216 on-chip peripheral modules
typedefine.h	Definitions of type conversion for variables

5.3.2 Main Function

Table 14 shows the processing of the main function. It is the first function to be executed after a reset, and it makes initial settings of the SH7216 on-chip peripheral modules and system operation. Upon completion of settings, execution enters a loop and waits until a timer (MTU2 or MTU2S) interrupt occurs. All control of the DC boost converter and AC inverter is done through timer interrupt processing.

Table 14 Processing of Main Function

File	Function	Description
main.c	main(void)	Main function • Initial settings of DC boost converter and AC inverter • Initial settings of A/D converter • Settings of A/D offset for output AC voltage • Initial settings of MTU2 timer (channel 0) • Initial settings of MTU2S timer (channels 3 and 4) • Settings of priority levels for on-chip peripheral module interrupts • Synchronous start of MTU2 and MTU2S timer counters

5.3.3 Settings of On-Chip Peripheral Modules

Table 15 shows the setting files and processing functions used for the SH7216 on-chip peripheral modules in the sample program.

- Settings of MTU2 (channel 0) features (control of DC boost converter)
- Settings of MTU2S (channels 3 and 4) features (control of AC inverter)
- Settings of A/D converter features (detection of voltage)

Table 15 Setting Files and Processing Functions for SH7216 On-Chip Peripheral Modules

File	Function	Description
mtu2_ch0.c mtu2_ch0.h	mtu2_ch0_init(void)	Initial settings of MTU2 (channel 0) • Sets the MTU2 to PWM mode. • PWM carrier frequency: 20 kHz • Executes PWM control of the DC boost converter.
	mtu2_ch0_mtu2s_sync_start(void)	Start of timer counters • Starts the timer counters in the MTU2 (channel 0) and MTU2S (channels 3 and 4) in synchonization.
	mtu20_dc_pwm_duty_set(float)	Settings of PWM signal output from MTU2 (channel 0) — Argument to the function: PWM duty cycle [0.0 to 1.0 (0% to 100%)] • Sets the timer register to the PWM duty cycle for controlling the DC boost converter.
	mtu2_ch0_pfc_set(void)	Settings of MTU2 (channel 0) timer pins • Switches the pin function from the IO port pins to the timer output pins.
	mtu2_ch0_pfc_off(void)	Settings of MTU2 (channel 0) timer pins • Switches the pin function from the timer output pins to the I/O port input pins.
mtu2s_ch3_4.c mtu2s_ch3_4.h	mtu2s_ch34_init(void)	Initial settings of MTU2S (channels 3 and 4) • Sets the MTU2S to complementary PWM mode. • PWM carrier frequency: 20 kHz • Executes PWM control of the AC inverter.
	mtu2s_inverter_pwm_duty_set (float , float)	Settings of complementary PWM signal output from MTU2S (channels 3 and 4) — Arguments 1 and 2 to the function: PWM duty cycle [0.0 to 1.0 (0% to 100%)] • Sets the timer register to the PWM duty cycle for controlling the AC full bridge circuit in the AC inverter.
	mtu2s_ch34_set_pfc(void)	Settings of MTU2S (channels 3 and 4) timer pins • Switches the pin function from the IO port pins to the timer output pins.
	mtu2s_ch34_set_pfc_off(void)	Settings of MTU2S (channels 3 and 4) timer pins • Switches the pin function from the timer output pins to the I/O port input pins.
adc.c adc.h	adc01_init(void)	Initial settings of ADC (modules 0 and 1) • Specifies the operation of the A/D converter. • Specifies the A/D conversion start trigger (source for starting conversion). • Specifies the A/D input pins for detecting voltage in the DC boost converter and AC inverter.

5.3.4 Processing in DC Boost Converter

Table 16 shows the setting files and processing functions used to control the DC boost converter.

All control of the DC boost converter is processed through the timer interrupt (int_mtu2_tgib0() function) of the MTU2 (channel 0). The interrupt is generated in every PWM carrier cycle and executes the following processing.

- Controls the startup processing (stop, soft start, and start) for the DC boost converter.
- Fetches the detected values of input DC voltage and DC boost voltage (A/D-converted values).
- Executes the voltage feedback controller (DC) processing and calculates the PWM duty cycle (desired value).
- Stores the PWM duty cycle (desired value) in the timer register in the MTU2 (channel 0).

For the procedure for controlling the DC boost converter, see figure 9, DC Boost Control Flow (Interrupt Processing).

Table 16 Setting Files and Processing Functions for DC Boost Converter

File	Function	Description
DC_converter.c DC_converter.h	int_mtu2_tgib0(void)	MTU2 (channel 0) compare match interrupt processing • Executes the startup processing of the DC boost converter. • Executes the voltage feedback controller (DC) processing and calculates the PAWN duty cycle (desired value). • Stores the PWM duty cycle in the timer register in the MTU2 (channel 0).
dc_iir_inline.c dc_iir_inline.h	dc_iir_filter_init(void)	Initial settings of the voltage feedback controller (DC) • Specifies the parameters for the controller (the values to be set are defined in the header file).
	dc_iir_filter_clear(void)	Clearing of the internal variables for the voltage feedback controller (DC).
	dc_iir_filter(float)	Voltage feedback controller (DC) — Argument to the function: Deviation of the DC boost voltage — Return value from the function: PWM duty cycle • This controller (IIR filter) executes voltage feedback processing for the DC boost converter. • Calculates the PWM duty cycle (desired value) for controlling the DC boost converter from the deviation of the DC boost voltage (difference between the detected and target values).

5.3.5 Processing in AC Inverter

Table 17 shows the setting files and processing functions used to control the AC inverter.

All control of the AC inverter is processed through the timer interrupt (int_mtu2s_tgia3() function) of the MTU2S (channels 3 and 4). The interrupt is generated in every PWM carrier cycle and executes the processing shown below. The AC inverter uses two voltage feedback controllers (ACrms and AC),

- Controls the startup processing (stop, soft start, start, and soft stop) for the AC inverter.
- Fetches the detected value of output AC voltage (A/D-converted value).
- Calculates the RMS value of output AC voltage.
- Executes the voltage feedback controller (ACrms) processing and calculates the RMS value (desired value) of output AC voltage.
- Executes the voltage feedback controller (AC) processing and calculates the PWM duty cycle (sine wave) for controlling the AC inverter.
- Stores the PWM duty cycle (sine wave) in the timer registers in the MTU2S (channels 3 and 4).

For the procedure for controlling the AC inverter, see figure 15, AC Inverter Control Flow (Interrupt Processing).

Table 17 Setting Files and Processing Functions for AC Inverter

File	Function	Description
AC_inverter.c AC_inverter.h	int_mtu2s_tgia3(void)	MTU2S (channels 3 and 4) compare match interrupt processing • Executes the startup processing of the AC inverter. • Processes the output AC voltage (RMS) (calculates the RMS value and executes the voltage feedback controller (ACrms) processing). • Executes the voltage feedback controller (AC) processing. • Stores the PWM duty cycle in the timer registers in the MTU2S (channels 3 and 4).
	select_AC_Hz_init(void)	Frequency setting for the output AC voltage (sine wave) • Frequency: 60 [Hz]
	set_sin_data_clear(void)	Initialization of the sine value
	float set_sin_data(void)	Calculation of the sine value — Return value from the function: sine value [-1.0 to 1.0]
ac_rms_control.c ac_rms_control.h	ac_rms_proc_init(void)	Initial settings of the processing for the output AC voltage (RMS)
	float ac_rms_proc(float)	Processing of the output AC voltage (RMS) — Argument to the function: Detected value of the output AC voltage — Return value from the function: Desired value of the output AC voltage (RMS) • Calculates the RMS value (detected value) of the output AC voltage from the output AC voltage (detected value). • Executes the voltage feedback controller (ACrms) processing and calculates the RMS value (desired value) of the output AC voltage.
ac_rms_iir_inline.c ac_rms_iir_inline.h	ac_rms_iir_filter_init(void)	Initial settings of the voltage feedback controller (ACrms) • Specifies the parameters for the controller (the values to be set are defined in the header file).
	ac_rms_iir_filter_clear(void)	Clearing of the internal variables for the voltage feedback controller (ACrms)
	ac_rms_iir_filter(float)	Voltage feedback controller (ACrms) — Argument to the function: Deviation of the output AC voltage (RMS) — Return value from the function: Desired value of the output AC voltage (RMS) • This is a voltage feedback controller (IIR filter) for controlling the RMS value of the output AC voltage. • Calculates the desired value of the output AC voltage (RMS) from the deviation of the output AC voltage (RMS) (difference between the target and detected values).

Table 17 Setting Files and Processing Functions for AC Inverter (cont.)

File	Function	Description
ac_iir_inline.c ac_iir_inline.h	ac_iir_filter_init(void)	Initial settings of the voltage feedback controller (AC) • Specifies the parameters for the controller (the values to be set are defined in the header file).
	ac_iir_filter_clear(void)	Clearing of the internal variables for the voltage feedback controller (AC).
	ac_iir_filter(float)	Voltage feedback controller (AC) — Argument to the function: Deviation of the output AC voltage — Return value from the function: PWM duty cycle (sine wave) • This is a voltage feedback controller (IIR filter) for controlling the output AC voltage into the sine-wave shape. • Calculates the PWM duty cycle (sine wave) for controlling the AC inverter from the deviation of the output AC voltage (difference between the detected and target values).

5.3.6 Common Files

Table 18 shows the setting files and processing functions used in common in the system.

Table 18 Setting Files and Processing Functions

File	Function	Description
common.h	—	Common header file for the system (definitions of constants) • Constants for controlling the DC boost converter • Constants for controlling the AC inverter • Constants for conversion from A/D-converted values to voltage
DCAC_control.c DCAC_control.h	set_Edc_volt_data(void)	Calculation of input DC voltage • Calculates the DC voltage input to the DC boost converter from the A/D conversion results.
	set_Vdc_out_fb_volt_data (void)	Calculation of DC boost voltage • Calculates the DC boost voltage in the DC boost converter from the A/D conversion results.
	set_Vac_out_fb_volt_data (void)	Calculation of output AC voltage • Calculates the output AC voltage of the AC inverter from the A/D conversion results.
	set_Vac_ad_offset_data12 (void)	Setting of A/D offset value • Starts the A/D conversion at system startup and specifies the A/D offset value for the output AC voltage.
param_set.c param_set.h	param_set(void)	Initial value settings for system control variables • Specifies the target value for the DC boost voltage of the DC boost converter. • Specifies the target value for the output AC voltage of the AC inverter • Specifies the voltage limit values.

6. Documents for Reference

- Hardware Manual
  SH7214 Group, SH7216 Group Hardware Manual (REJ09B0543)
  (The most up-to-date version of this document is available on the Renesas Electronics Website.)

- Software Manual
  SH-2A, SH2A-FPU Software Manual (REJ09B0051)
  (The most up-to-date version of this document is available on the Renesas Electronics Website.)

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Revision Record

		Description	
Rev.	**Date**	**Page**	**Summary**
1.00	May 19, 2010	—	First edition issued
2.00	Mar 25, 2011	—	Thoroughly-revised

General Precautions in the Handling of MPU/MCU Products

The following usage notes are applicable to all MPU/MCU products from Renesas. For detailed usage notes on the products covered by this manual, refer to the relevant sections of the manual. If the descriptions under General Precautions in the Handling of MPU/MCU Products and in the body of the manual differ from each other, the description in the body of the manual takes precedence.

1. Handling of Unused Pins
   Handle unused pins in accord 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 one with a different type number, confirm that the change will not lead to problems.
   — The characteristics of MPU/MCU in the same group but having different type numbers may differ because of the differences in internal memory capacity and layout pattern. When changing to products of different type numbers, implement a system-evaluation test for each of the products.

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Renesas Electronics America Inc.
2880 Scott Boulevard Santa Clara, CA 95050-2554, U.S.A.
Tel: +1-408-588-6000, Fax: +1-408-588-6130

Renesas Electronics Canada Limited
1101 Nicholson Road, Newmarket, Ontario L3Y 9C3, Canada
Tel: +1-905-898-5441, Fax: +1-905-898-3220

Renesas Electronics Europe Limited
Dukes Meadow, Millboard Road, Bourne End, Buckinghamshire, SL8 5FH, U.K
Tel: +44-1628-585-100, Fax: +44-1628-585-900

Renesas Electronics Europe GmbH
Arcadiastrasse 10, 40472 Düsseldorf, Germany
Tel: +49-211-65030, Fax: +49-211-6503-1327

Renesas Electronics (China) Co., Ltd.
7th Floor, Quantum Plaza, No.27 ZhiChunLu Haidian District, Beijing 100083, P.R.China
Tel: +86-10-8235-1155, Fax: +86-10-8235-7679

Renesas Electronics (Shanghai) Co., Ltd.
Unit 204, 205, AZIA Center, No.1233 Lujiazui Ring Rd., Pudong District, Shanghai 200120, China
Tel: +86-21-5877-1818, Fax: +86-21-6887-7858 / -7898

Renesas Electronics Hong Kong Limited
Unit 1601-1613, 16/F., Tower 2, Grand Century Place, 193 Prince Edward Road West, Mongkok, Kowloon, Hong Kong
Tel: +852-2886-9318, Fax: +852 2886-9022/9044

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

Renesas Electronics Singapore Pte. Ltd.
1 harbourFront Avenue, #06-10, keppel Bay Tower, Singapore 098632
Tel: +65-6213-0200, Fax: +65-6278-8001

Renesas Electronics Malaysia Sdn.Bhd.
Unit 906, 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 Korea Co., Ltd.
11F., Samik Lavied' or Bldg., 720-2 Yeoksam-Dong, Kangnam-Ku, Seoul 135-080, Korea
Tel: +82-2-558-3737, Fax: +82-2-558-5141

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