# 5 kW Isolated Bidirectional DC-DC Converter

# SW guide

## RD167-SWGUIDE-01

TOSHIBA ELECTRONIC DEVICES & STORAGE CORPORATION

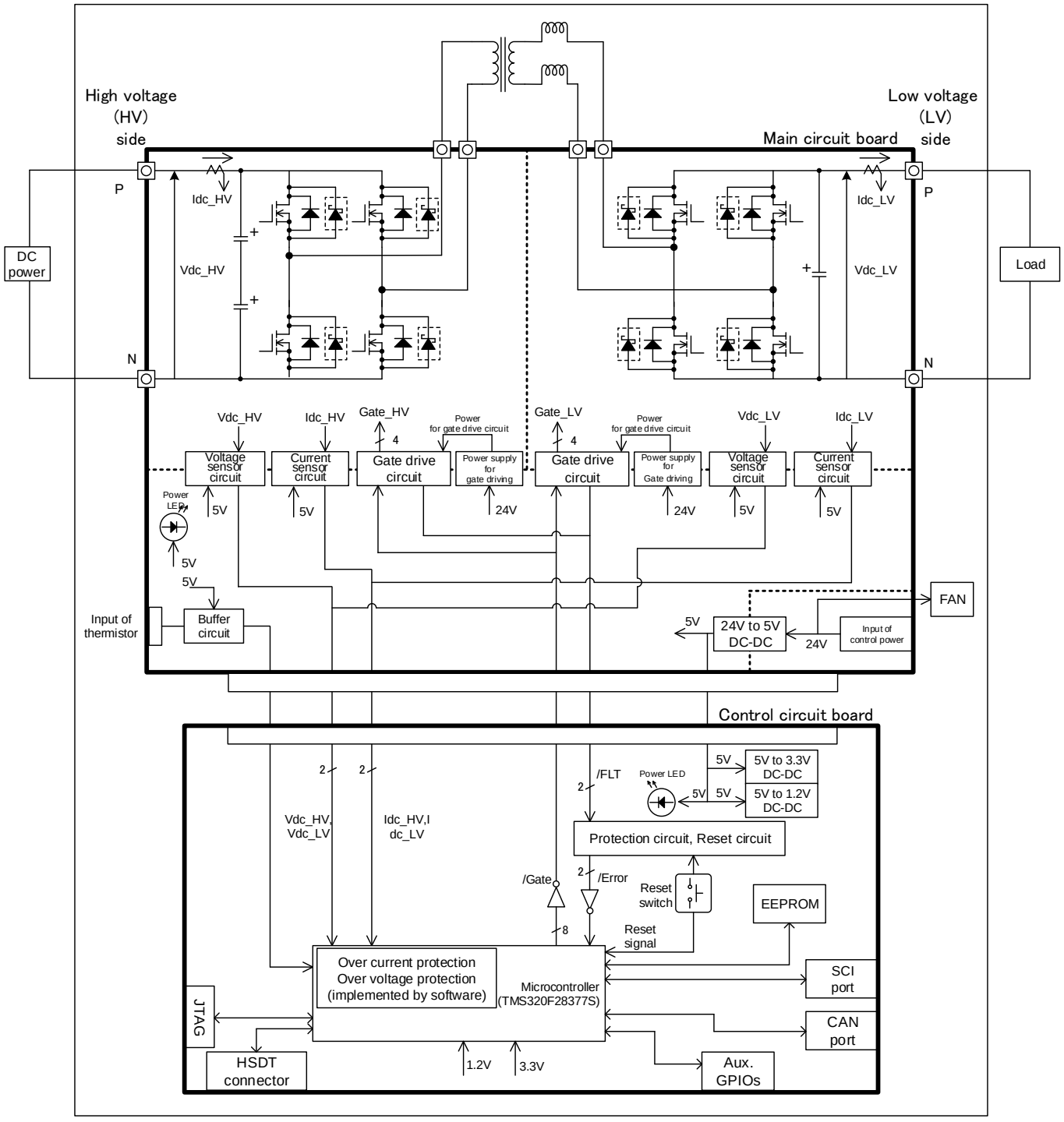
Table of Contents

# 1. Introduction

## 1.1. Overview

This document specifies software (SW) for the power controller of a 5 kW Isolated Bidirectional DC-DC Converter power supply (hereinafter referred to as "this power supply"). The hardware (HW) to be controlled by the SW specified in this guide is shown below.

<Overview of HW>



## 1.2. How to Use

・Procedure for use (example)

1. Turn on the control power supply 24 V.
2. Turn on the input DC power supply (750 V).

・Procedure for resetting and reusing after Error state

1. Disconnect the input DC power supply (750 V).
2. Press the reset switch or disconnect and reconnect the control power.
   (The reset switch is on the control board.)
3. Reconnect the input DC power supply (750 V).

The following is an overview of the power supply controller used with this power supply.

<Power Supply Controller>

TMS320F28377SPTP is used as the power supply controller.

1. Features

| Item | Description |
|---|---|
| Manufacturer | Texas Instruments |
| Model number | TMS320F28377SPTP |
| Package | 176pin, HLQFP, Pin-to-Pin 0.5 mm Pitch |
| Memory capacity | ROM : 1 MB (1word = 16bit)<br>RAM : 328 KB (1word = 16bit) |
| Maximum operating frequency | 200 MHz (XIN=20 MHz) |
| Timer | 32-bit timer counter × 3 channels |
| | Watchdog Timer (WDT) |
| PWM signal generation function | 6ch (of which 3ch are used)<br>Operating frequency 100 MHz |
| Comparator function | 8 channels (of which 3ch are used)<br>High-voltage side overvoltage protection<br>Low-voltage side overvoltage protection<br>Low-voltage side overcurrent protection |
| Communication Function | I2C × 1ch (used as interface with EEPROM)<br>CAN × 1 channel (not used with the standard SW of this power supply)<br>SCI ×2ch<br>(1ch is used for communication with HSDT-DP made by Headspring.<br>The other channel is not used with the standard SW of this power supply.) |
| A/D conversion | 12-bit sample-and-hold method × 4 modules<br>(8 input channels of the A/D conversion module) |
| EEPROM function | Manufacturer: Microchip Technology Model number: 24LC512-I/SM<br>(Not used with standard SW of this power supply) |
| IO Voltage | 3.3 V |
| Core voltage | 1.2 V |

2. Clock

The power supply controller uses the following clocks:

| External transmitter |
|---|
| 20 MHz |

3. Development environment

Code-development tools: Code Composer Studio of Texas Instruments

OS:Windows,Mac OS,Linux

Debug tool: HSDT-DP and HSDT-GUI made by Headspring

OS:Windows

# 2. Input/Output Signal

I/O signals are defined as follows.

| Port | Pin | Signal name | Function | I/O (Model) | Initial value | Other |
|---|---|---|---|---|---|---|
| GPIO0 | 160 | PWM1A_DSP160 | Generates reference clock required for waveform generation, no output | O (CMOS) | 0 | |
| GPIO1 | 161 | PWM1B_DSP161 | Generates reference clock required for waveform generation, no output | O (CMOS) | 0 | |
| GPIO2 | 162 | PWM2A_DSP162 | High voltage side leg A high side PWM gate signal | O (CMOS) | 0 | |
| GPIO3 | 163 | PWM2B_DSP163 | High voltage side leg A low side PWM gate signal | O (CMOS) | 0 | |
| GPIO4 | 164 | PWM3A_DSP164 | High voltage side leg B high side PWM gate signal | O (CMOS) | 0 | |
| GPIO5 | 165 | PWM3B_DSP165 | High voltage side leg B low side PWM gate signal | O (CMOS) | 0 | |
| GPIO6 | 166 | PWM4A_DSP166 | Generates reference clock required for waveform generation, no output | O (CMOS) | 0 | |
| GPIO7 | 167 | PWM4B_DSP167 | Generates reference clock required for waveform generation, no output | O (CMOS) | 0 | |
| GPIO8 | 18 | PWM5A_DSP18 | Low voltage side leg A high side PWM gate signal | O (CMOS) | 0 | |
| GPIO9 | 19 | PWM5B_DSP19 | Low voltage side leg A low side PWM gate signal | O (CMOS) | 0 | |
| GPIO10 | 1 | PWM6A_DSP1 | Low voltage side leg B high side PWM gate signal | O (CMOS) | 0 | |
| GPIO11 | 2 | PWM6B_DSP2 | Low voltage side leg B low side PWM gate signal | O (CMOS) | 0 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| GPIO12 | 4 | No signal assignment | - | - | - | |
| GPIO13 | 5 | No signal assignment | - | - | - | |
| GPIO14 | 6 | No signal assignment | - | - | - | |
| GPIO15 | 7 | No signal assignment | - | - | - | |
| GPIO16 | 8 | DO0_DSP8 | Digital signal output function (Not used with this power supply) | O (CMOS) | 0 | |
| GPIO17 | 9 | DO1_DSP9 | Digital signal output function (Not used with this power supply) | O (CMOS) | 0 | |
| GPIO18 | 10 | DO2_DSP10 | Digital signal output function (Not used with this power supply) | O (CMOS) | 0 | |
| GPIO19 | 12 | DO3_DSP12 | Digital signal output function (Not used with this power supply) | O (CMOS) | 0 | |
| GPIO20 | 13 | DO4_DSP13 | Digital signal output function (Not used with this power supply) | O (CMOS) | 0 | |
| GPIO21 | 14 | DO5_DSP14 | Digital signal output function (Not used with this power supply) | O (CMOS) | 0 | |
| GPIO22 | 22 | DO6_DSP22 | Digital signal output function (Not used with this power supply) | O (CMOS) | 0 | |
| GPIO23 | 23 | DO7_DSP23 | Digital signal output function (Not used with this power supply) | O (CMOS) | 0 | |
| GPIO24 | 24 | No signal assignment | - | - | - | |
| GPIO25 | 25 | No signal assignment | - | - | - | |
| GPIO26 | 27 | No signal assignment | - | - | - | |
| GPIO27 | 28 | No signal assignment | - | - | - | |

| | | | | | | |
|---|---|---|---|---|---|---|
| GPIO28 | 64 | No signal assignment | - | - | - | |
| GPIO29 | 65 | No signal assignment | - | - | - | |
| GPIO30 | 63 | No signal assignment | - | - | - | |
| GPIO31 | 66 | No signal assignment | - | - | - | |
| GPIO32 | 67 | No signal assignment | - | - | - | |
| GPIO33 | 69 | No signal assignment | - | - | - | |
| GPIO34 | 70 | No signal assignment | - | - | - | |
| GPIO35 | 71 | No signal assignment | - | - | - | |
| GPIO36 | 83 | CANRX_A_DSP83 | CAN communication reception function | I (CMOS) | 1 | |
| GPIO37 | 84 | CANTX_A_DSP84 | CAN communication transmission function | O (CMOS) | 0 | |
| GPIO38 | 85 | No signal assignment | - | - | | |
| GPIO39 | 86 | No signal assignment | - | - | | |
| GPIO40 | 87 | No signal assignment | - | - | | |
| GPIO41 | 89 | No signal assignment | - | - | | |
| GPIO42 | 130 | SDA_A_DSP130 | Data signal for I2C communication function | O/I (CMOS) | 1 | IFs to EEPROM |
| GPIO43 | 131 | SCL_A_DSP131 | Clock signal for I2C communication function | O (CMOS) | 1 | IFs to EEPROM |
| GPIO44 | 113 | No signal assignment | - | - | | |
| GPIO45 | 115 | No signal assignment | - | - | | |
| GPIO46 | 128 | No signal assignment | - | - | | |
| GPIO47 | 129 | No signal assignment | - | - | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| GPIO48 | 90 | No signal assignment | - | - | | |
| GPIO49 | 93 | No signal assignment | - | - | | |
| GPIO50 | 94 | DIO08_DSP94 | General-purpose digital input/output function (Not used with this power supply) | I (CMOS) | 1 | Function can be changed by SW |
| GPIO51 | 95 | DIO09_DSP95 | General-purpose digital input/output function (Not used with this power supply) | I (CMOS) | 1 | Function can be changed by SW |
| GPIO52 | 96 | DIO10_DSP96 | General-purpose digital input/output function (Not used with this power supply) | I (CMOS) | 1 | Function can be changed by SW |
| GPIO53 | 97 | DIO11_DSP97 | General-purpose digital input/output function (Not used with this power supply) | I (CMOS) | 1 | Function can be changed by SW |
| GPIO54 | 98 | No signal assignment | - | - | | |
| GPIO55 | 100 | No signal assignment | - | - | | |
| GPIO56 | 101 | No signal assignment | - | - | | |
| GPIO57 | 102 | No signal assignment | - | - | | |
| GPIO58 | 103 | SSO_DSP103 | Headspring HSDT-DP For SCOPE function SPI communication-Data Output | O (CMOS) | | |
| GPIO59 | 104 | SSI_DSP104 | Headspring HSDT-DP For SCOPE function SPI communication-Data Input | I (CMOS) | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| GPIO60 | 105 | SSCK_DSP105 | Headspring HSDT-DP<br>For SCOPE function<br>SPI communication-Clock<br>Output | O<br>(CMOS) | | |
| GPIO61 | 107 | SPISTEA_DSP10<br>7 | Headspring HSDT-DP<br>For SCOPE function<br>SPI communication-Sync<br>signal output | O<br>(CMOS) | | |
| GPIO62 | 108 | No signal<br>assignment | - | - | | |
| GPIO63 | 109 | No signal<br>assignment | - | - | | |
| GPIO64 | 110 | No signal<br>assignment | - | - | | |
| GPIO65 | 111 | No signal<br>assignment | - | - | | |
| GPIO66 | 112 | No signal<br>assignment | - | - | | |
| GPIO67 | 132 | DI0_DSP132 | High-voltage side gate driver<br>error signal<br>Input function | I<br>(CMOS) | 0 | |
| GPIO68 | 133 | DI1_DSP133 | Low-voltage side gate driver<br>error signal<br>Input function | I<br>(CMOS) | 0 | |
| GPIO69 | 134 | No signal<br>assignment | - | - | | |
| GPIO70 | 135 | No signal<br>assignment | - | - | | |
| GPIO71 | 136 | No signal<br>assignment | - | - | | |
| GPIO72 | 139 | BOOT1_DSP139 | Boot Mode Selector | I | - | |
| GPIO73 | 140 | DI2_DSP140 | Digital signal input function<br>(Not used with this power<br>supply) | I<br>(CMOS) | 0 | |
| GPIO74 | 141 | DI3_DSP141 | Digital signal input function<br>(Not used with this power<br>supply) | I<br>(CMOS) | 0 | |
| GPIO75 | 142 | DI4_DSP142 | Digital signal input function<br>(Not used with this power<br>supply) | I<br>(CMOS) | 0 | |

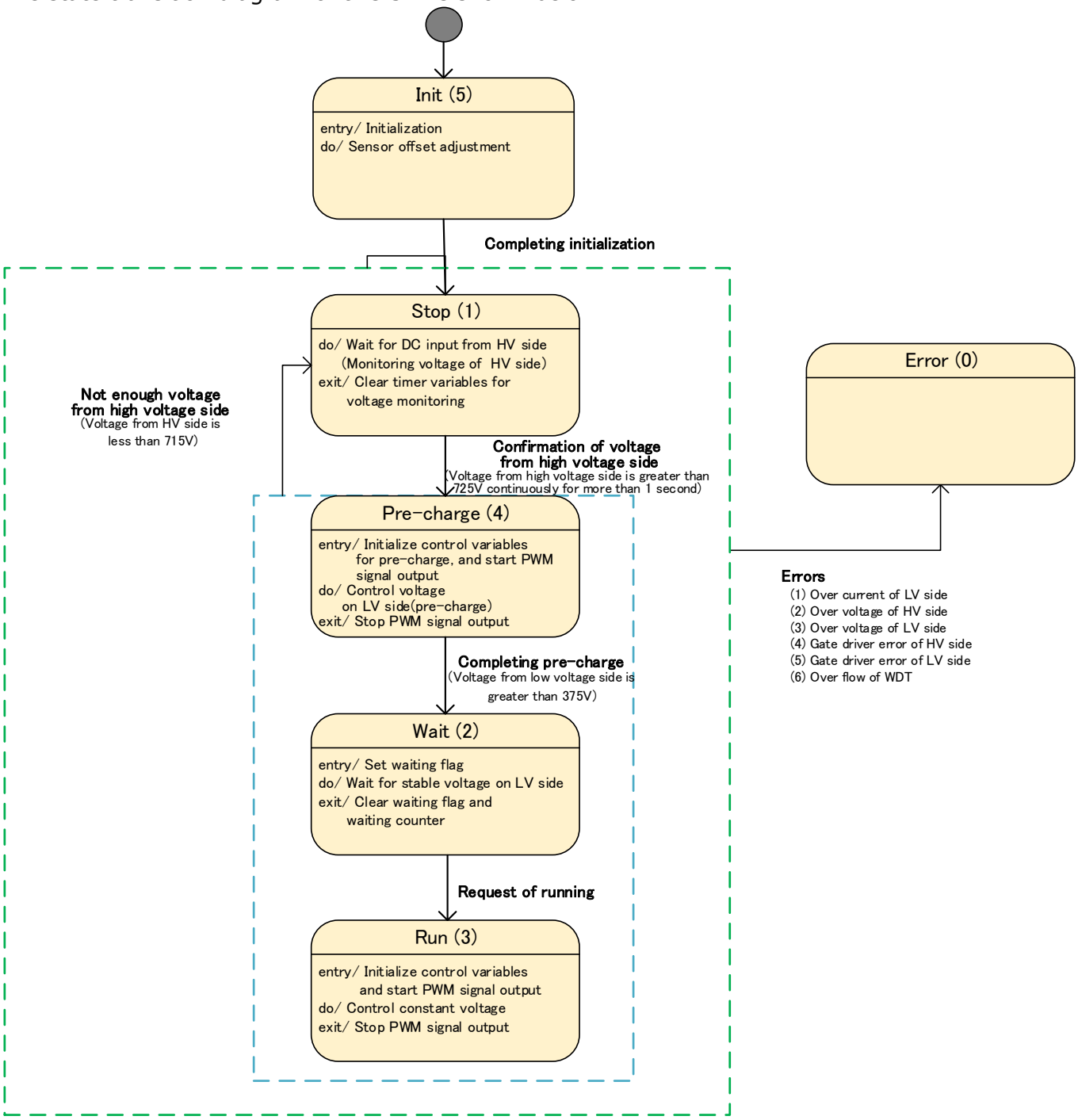
| | | | | | | |
|---|---|---|---|---|---|---|
| GPIO76 | 143 | DI5_DSP143 | Digital signal input function (Not used with this power supply) | I (CMOS) | 0 | |
| GPIO77 | 144 | DI6_DSP144 | Digital signal input function (Not used with this power supply) | I (CMOS) | 0 | |
| GPIO78 | 145 | DI7_DSP145 | Digital signal input function (Not used with this power supply) | I (CMOS) | 0 | |
| GPIO79 | 146 | No signal assignment | - | - | | |
| GPIO80 | 148 | No signal assignment | - | - | | |
| GPIO81 | 149 | No signal assignment | - | - | | |
| GPIO82 | 150 | No signal assignment | - | - | | |
| GPIO83 | 151 | No signal assignment | - | - | | |
| GPIO84 | 154 | SCITXDA_ DSP154 | Headspring HSDT-DP Debug communication function | | | |
| GPIO85 | 155 | SCIRXDA_ DSP155 | Headspring HSDT-DP Debug communication function | | | |
| GPIO86 | 156 | SCITX_B_ DSP156 | General purpose serial communication function (Not used with this power supply) | | | |
| GPIO87 | 157 | SCIRX_B_ DSP157 | General purpose serial communication function (Not used with this power supply) | | | |
| GPIO88 | 170 | No signal assignment | - | - | - | - |
| GPIO89 | 171 | DIO12_DSP171 | General-purpose digital input/output function (Not used with this power supply) | I (CMOS) | 1 | Function can be changed by SW |

| | | | | | | |
|---|---|---|---|---|---|---|
| GPIO90 | 172 | DIO13_DSP172 | General-purpose digital input/output function (Not used with this power supply) | I (CMOS) | 1 | Function can be changed by SW |
| GPIO91 | 173 | No signal assignment | - | - | | |
| GPIO92 | 174 | No signal assignment | - | - | | |
| GPIO93 | 175 | DIO14_DSP175 | General-purpose digital input/output function (Not used with this power supply) | I (CMOS) | 1 | Function can be changed by SW |
| GPIO94 | 176 | DIO15_DSP176 | General-purpose digital input/output function (Not used with this power supply) | I (CMOS) | 1 | Function can be changed by SW |
| GPIO 133 | 118 | No signal assignment | - | - | | |

# 3. State Transition

## 3.1. State Transition Diagram

The state transition diagram of this SW is shown below.



# 4. Constant, Variable Definition

## 4.1. Constant Definition

Define the constants as follows:

1. Constant for PWM function setting

| Constant name | Details |
|---|---|
| CARRIERFREQ_KHZ | Defines the frequency of the PWM signal in kHz. |
| INTERRUPT_MASK | Defines the execution cycle of the general control routine (described later). |
| DEADTIME_HV_NSEC | Defines the dead time of the high-voltage side PWM signal in ns units. |
| DEADTIME_LV_NSEC | Defines the dead time of the low-voltage side PWM signal in ns units. |

2. Constant for timer interrupt routine cycle setting

| Constant name | Details |
|---|---|
| TIMER0INTERVAL_US | Defines the execution period of the timer interrupt routine in μs units. |

3. Constant for sensor value setting

| Constant name | Details |
|---|---|
| VDCHV_GAIN<br>VDCHV_OFFSET | Set the reading voltage range of the high-voltage side voltage sensor circuit as follows.<br>((-VDCHV_GAIN) + VDCHV_OFFSET) ～ (VDCHV_GAIN + VDCHV_OFFSET)<br>Refer to 13. A/D transformation list for more information. |
| VDCLV_GAIN<br>VDCLV_OFFSET | Set the reading voltage range of the low-voltage side voltage sensor circuit as follows.<br>((-VDCLV_GAIN) + VDCLV_OFFSET) ～ (VDCLV_GAIN + VDCLV_OFFSET)<br>Refer to 13. A/D transformation list for more information. |
| IDCHV_GAIN<br>IDCHV_OFFSET | Set the reading current range of the high-voltage side current sensor circuit as follows.<br>((-IDCHV_GAIN) + IDCHV_OFFSET) ～ (IDCHV_GAIN + IDCHV_OFFSET)<br>Refer to 13. A/D transformation list for more information. |
| IDCLV_GAIN<br>IDCLV_OFFSET | Set the reading current range of the low-voltage side current sensor circuit as follows.<br>((-IDCLV_GAIN) + IDCLV_OFFSET) ～ (IDCLV_GAIN + IDCLV_OFFSET)<br>Refer to 13. A/D transformation list for more information. |

4. Constant for control

| Constant name | Details |
|---|---|
| VDCLVKP | Defines the value of proportional gain in PI control calculation of low-voltage side voltage. |
| VDCLVKI | Defines the value of the integral gain in PI control calculation of the low-voltage side voltage. |
| IDCLIMIT | Defines the limit value for the low-voltage side current setting value, which is the PI control calculation output of the low-voltage side voltage. |

5. Constant for HW parameter setting

| Constant name | Details |
|---|---|
| TRANS_TURNS_RATIO | Define the transformer winding ratio. |
| INDUCTANCE_uH | Define the value of the inductance of the reactor in μH. |
| Inductance_H | Define the value of the inductance of the reactor in H. |

## 4.2. State Definition

1. System status parameter (Model: SystemState)

| Constant name | Details |
|---|---|
| State_Error | State constant indicating that the system is in an Error state |
| State_Stop | State constant indicating that the system is Stop state |
| State_Wait | State constant indicating that the system is in Wait state |
| State_Run | State constant indicating that the system is in Run state |
| State_Precharge | State constant indicating that the system is in the Precharge state |
| State_Init | State constant indicating that the system is in the Initialization state |

2. Protective Status Constant (Model: ErrState)

| Constant name | Details |
|---|---|
| Err_IdcLV | Status constant indicating that the overcurrent of the low-voltage side current has been detected and the protection function has been activated |
| Err_VdcHV | Status constant indicating that the overvoltage of the high-voltage side voltage has been detected and the protection function has been activated |
| Err_VdcLV | Status constant indicating that the overvoltage of the low-voltage side voltage has been detected and the protection function has been activated |
| Err_FLTHV | Status constant indicating that the high-voltage side gate driver error signal was detected and protection function has been activated |

| | |
|---|---|
| Err_FLTLV | Status constant indicating that the low-voltage gate driver error signal was detected and the protection function has been activated |
| Err_WDT | State constant indicating that the protection function of the watchdog timer has been activated |
| Err_TRIP | State constant indicating that PWM has been tripped |

## 4.3. Constant Definition

1. Variables for sensor reading display

| Constant name | Details |
|---|---|
| VdcHV | Indicates the sensor (analog) value of the high-voltage side voltage. |
| VdcLV | Indicates the sensor (analog) value of the low-voltage side voltage. |
| IdcHV | Indicates the sensor (analog) value of the high-voltage side current. |
| IdcLV | Indicates the sensor (analog) value of the low-voltage side current. |

2. Sensor calculation value variable

| Constant name | Details |
|---|---|
| VdcHVRev | Indicates the reciprocal of the high-voltage calculated from VdcHVLPF. |
| VdcHVLPF | Indicates the output-value when a low-pass filter is applied to the sensor value VdcHV at the cutoff frequency VdcHVFc. |
| VdcHVFc | Indicates the cutoff frequency of the low-pass filter applied to the sensor value VdcHV. |
| VdcLVLPF | Indicates the output-value when a low-pass filter is applied to the sensor value VdcLV at the cutoff frequency VdcLVFc. |
| VdcLVFc | Indicates the cutoff frequency of the low-pass filter applied to the sensor value VdcLV. |
| IdcHVLPF | Indicates the output-value when a low-pass filter is applied to the sensor value IdcHV at the cutoff frequency IdcHVFc. |
| IdcHVFc | Indicates the cutoff frequency of the low-pass filter applied to the sensor value IdcHV. |
| IdcLVLPF | Indicates the output-value when a low-pass filter is applied to the sensor value IdcLV at the cutoff frequency IdcLVFc. |
| IdcLVFc | Indicates the cutoff frequency of the low-pass filter applied to the sensor value IdcLV. |
| GainAdjVdcHV | Indicates the gain correction value of the high-voltage side voltage sensor value. |
| OffsetAdjVdcHV | Indicates the offset correction value of the high-voltage side voltage sensor value. |
| GainAdjVdcLV | Indicates the gain correction value of the low-voltage side voltage sensor value. |
| OffsetAdjVdcLV | Indicates the offset correction value of the low-voltage side voltage sensor value. |
| GainAdjIdcHV | Indicates the gain correction value of the high-voltage side current sensor value. |
| OffsetAdjIdcHV | Indicates the offset correction value of the high-voltage side current sensor value. |

| | |
|---|---|
| GainAdjIdcLV | Indicates the gain correction value of the low-voltage side current sensor value. |
| OffsetAdjIdcLV | Indicates the offset correction value of the low-voltage side current sensor value. |
| FlagCalibEnd | 0: Indicates that the offset error correction process for each sensor has not been completed.<br>1:Indicates that the offset error correction process for each sensor is completed. |

3. Variables for protection and error status display

| Constant name | Details |
|---|---|
| ErrorState | Indicates a protection or Error state (not latched).<br>Bit0: Low-voltage side overcurrent protection status<br>Bit1: High-voltage side overvoltage protection status<br>Bit2: Low-voltage side overvoltage protection status<br>Bit3: Error signal detection status of the high-voltage side gate driver<br>Bit4: Error signal detection status of the low-voltage side gate driver<br>Bit5: Watchdog timer overflow status<br>Bit6: Trip status of PWMs |
| ErrorState_Latch | Indicates protection or Error status (latch).<br>Bit0: Low-voltage side overcurrent protection status<br>Bit1: High-voltage side overvoltage protection status<br>Bit2: Low-voltage side overvoltage protection status<br>Bit3: Error signal detection status of the high-voltage side gate driver<br>Bit4: Error signal detection status of the low-voltage side gate driver<br>Bit5: Watchdog timer overflow status<br>Bit6: Trip status of PWMs |
| ErrThrVdcHVHi_V | Indicates the overvoltage threshold of the high-voltage side voltage. |
| ErrThrVdcLVHi_V | Indicates the overvoltage threshold of the low-voltage side voltage. |
| ErrThrIdcLV_A | Indicates the overcurrent threshold (peak value) of the low-voltage side current. |
| FlagWDT | Indicates the overflow occurrence status of the watchdog timer. |

4. State transition variable

| Constant name | Details |
|---|---|
| State | Indicates the state of the system. It is assigned in the timer interrupt routine.<br>Type: SystemState |

| | |
|---|---|
| InitEnd | Indicates whether the initialization is complete.<br>0:Indicates that the initialization has not completed.<br>1:Indicates that the initialization is completed. |
| PrechargeThrVdcHV_V | Indicates the high voltage side voltage value for starting Precharge. |
| StopThrVdcHV_V | Indicates the high-voltage side voltage lower limit for operation. |
| RunStartStopReq | Variable that controls the transition between the Wait state and the Run state. |
| TimerMonitoringVdcHVON | Indicates the time in ms after the operable voltage is applied to the high-voltage side. |
| TimerMonitoringVdcHVOFF | Indicates the time in ms after the voltage drops to the voltage at which operation stops. |
| StepEntryRun | Indicates that the system is transitioning from the Wait state to the Run state. |
| FlagExitRun | Indicates that the system is transitioning from the Run state to the Error/Stop state. |
| StepEntryPrecharge | Indicates that the system is transitioning from the Stop state to the Precharge state. |
| FlagExitPrecharge | Indicates that the system is transitioning from the Precharge state to the Error/Stop state. |
| FlagEntryWait | Indicates that the system is in Wait state. |
| TimerEntryWait | Indicates the time after the transition to the Wait state in ms. |

5. Variable for low-voltage voltage control

| Constant name | Details |
|---|---|
| IdcLVLimitHi | Indicates the upper limit of the low-voltage side current setting value. |
| IdcLVLimitLo | Indicates the lower limit of the low-voltage side current setting value. |
| VdcLVRef | Indicates the low-voltage side voltage reference value. |
| ErrVdcLV | Indicates the deviation between VdcLVLPF and VdcLVRef. |
| VdcLVKp | Indicates the value of proportional gain in PI control calculation of low-voltage side voltage. |
| VdcLVKi | Indicates the value of the integral gain in PI control calculation of the low-voltage side voltage. |
| VdcLVTi | Indicates the time constant in PI control calculation of the low-voltage side voltage. |
| VdcLVPElement | Indicates the proportional component of the PI control operation of the low-voltage side voltage (proportional control output). |
| VdcLVIElement | Indicates the integral component of the PI control operation of the low-voltage side voltage (integral control output). |
| VdcLVPIElement | Indicates the sum of the proportional and integral components of the PI control operation of the low-voltage side voltage.<br>This value is substituted into IdcLVOut as the low-voltage side current setting value. |
| IdcLVOut | Indicates the low-voltage side current setting value. |
| ConstVdcRef | Indicates the target voltage for low-voltage side constant voltage control. |
| DeltaVdcLVRefRamp | Indicates the low-voltage side voltage setting value that increases with each control cycle when the low-voltage side voltage control is in soft start. |

6. PWM signal generation variable

| Constant name | Details |
|---|---|
| DutyHV | Indicates the duty ratio of the high-voltage side PWM signal in the Run state. |
| DutyLV | Indicates the duty ratio of the low-voltage side PWM signal in the Run state. |
| DutyPrecharge | Indicates the duty ratio of the high-voltage side PWM signal in the Precharge state. |
| PhaseShiftAngle | Indicates the phase difference of the PWM signal between the high-voltage side and low-voltage side in the Run state. |
| PhasePrecharge | Indicates the phase difference between each leg of the high-voltage side full bridge in the Precharged state. |

# 4. Initialization

## 4.1. Initialization Routine Execution Condition

The initialization routine is executed when the following conditions are met.

1. When the power is turned on for the first time
2. When the reset switch is pressed

## 4.2. Initialization Routine

The initialization routine is executed by executing Init() function. The following processing is performed.

| Processing order | Details of processing | Details of processing |
|---|---|---|
| 1 | TMS320F28377SPTP Initialization pin setting | Initializes the MCU (TMS320F28377SPTP) and sets pins. For pin setting, refer to the I/O signals described in 2 above. |
| 2 | Headspring HSDT-DP SCOPE function initialization and setting | Initialize and set so that SCOPE function of HSDT-DP made by Headspring can be used. |
| 3 | PWM function initialization and setting | Initialize the PWM function and set as follows.<br><br>・PWM frequency<br>Set to the same value as CARRIERFREQ_HZ (Hz)<br><br>・Dead time<br>High-voltage side: Set to the same value as DEADTIME_HV_NSEC (ns).<br>Low-voltage side: Set to the same value as DEADTIME_LV_NSEC (ns).<br><br>・PWM interrupt<br>Set interrupt function and interrupt timing |
| 4 | AD conversion function initialization and setting AD conversion value-range, offset setting | Initializes the AD conversion function and sets the AD conversion start timing to start upon receiving a conversion start trigger output from the PWM function.<br>For the range and offset settings, refer to 4.1 Constants for Sensor Value Setting in Constant Definition.4.1 |
| 5 | Comparator function initialization and setting | Initializes the comparator function and sets the operation to stop when one of the high-voltage side overvoltage, low-voltage side overvoltage, or low-voltage side overcurrent is detected. |

| | | |
|---|---|---|
| 6 | Watchdog timer initialization and setting | Initializes the watchdog timer function and stops operation if ClearWDT() function is not executed within 13.1 ms from last execution. |
| 7 | Timer function initialization and setting | Initializes the timer function and sets the interrupt routine to be executed at 1ms intervals. |
| 8 | Protection function initialization and setting | Output of the PWM signal stops when any of the high-voltage side overvoltage, low-voltage side overvoltage, low-voltage side overcurrent, high-voltage side and low-voltage side gate driver error signals is detected by the comparator. |
| 9 | Wait for system stabilization | Wait 1ms for the system to stabilize after processing of 1 to 8 is completed. |
| 10 | Interrupt function setting | Enables execution of general control routines and timer interrupt routines. |

# 5. Main Routine

This section describes the main routine process that is executed after the initialization function Init() is completed.
This SW generates interrupt at regular intervals and executes each subroutine.
If no interrupt processing has occurred, the main loop is executed.

| Subroutine name | Interrupt Function Name | Execution trigger, cycle | Details of processing |
|---|---|---|---|
| General control routine | PWMIntFunc | Trigger: PWM function<br>Cycle: 50 μs (at 20 kHz operation)<br>20 μs (at 50 kHz operation)<br>10 μs (at 100 kHz operation) | ・PWM signal output start/stop<br>・Read sensor value<br>・Low-pass filtering<br>・Reciprocal calculation of high-voltage side voltage<br>・Low voltage side voltage control<br>・Duty ratio, phase difference calculation<br>・Duty ratio, phase difference update |
| Timer interrupt routine | Timer0IntFunc | Trigger: Timer function<br>cycle: 1 ms | ・Error detection<br>・State transition<br>・Low-pass filtering<br>・Sensor offset correction |

## 5.1. Main Loop

This section shows the main loop processing of this SW.

| Processing order | Details of processing | Details of processing |
|---|---|---|
| 1 | Watchdog Timer Processing | Reset the watchdog timer counter and check the flag of the watchdog timer function.<br>If the watchdog timer counter is not reset within 13.1ms, the operation is stopped. |
| 2 | Digital signal input check | Check the input status of DI0, 1 and 2. |
| 3 | Headspring HSDT-DP SCOPE function update processing | Process for updating HSDT-DP SCOPE function manufactured by Headspring. |

## 5.2. General Control Routine

This SW has the following general control routines.
The generic control routine is executed by PWMIntFunc() function.

| Processing order | Details of processing | Details of processing |
|---|---|---|
| 1 | Read sensor value | Reads the value of the high-voltage side voltage, low-voltage side voltage, high-voltage side current, and low-voltage side current sensor. |
| 2 | Low-pass filtering | Low-pass filtering is performed on the high-voltage side voltage, low-voltage side voltage, high-voltage side current, and low-voltage side current sensor values. |
| 3 | Reciprocal calculation of high-voltage side voltage | The reciprocal of the high-voltage side voltage is calculated using the value obtained by low-pass filtering the high-voltage side voltage. |
| 4 | Low voltage control | The deviation between the value of VdcLVRef that is the low-voltage side voltage setting value and the value of VdcLVLPF is calculated, and the low-voltage side current setting value IdcLVOut is calculated by performing PI-control calculations.<br>This process is executed differently in the Precharge state and the Run state. |
| 5 | Phase difference calculation | Calculates the phase difference based on the low-voltage side current setting value.<br>The phase difference between the legs of the high-voltage side is calculated in the Precharge state, and the phase difference between the high-voltage side and low-voltage side is calculated in the Run state. |
| 6 | Phase difference update | The PWM waveform output is changed according to the calculated phase difference. |

## 5.3. Timer Interrupt Routine

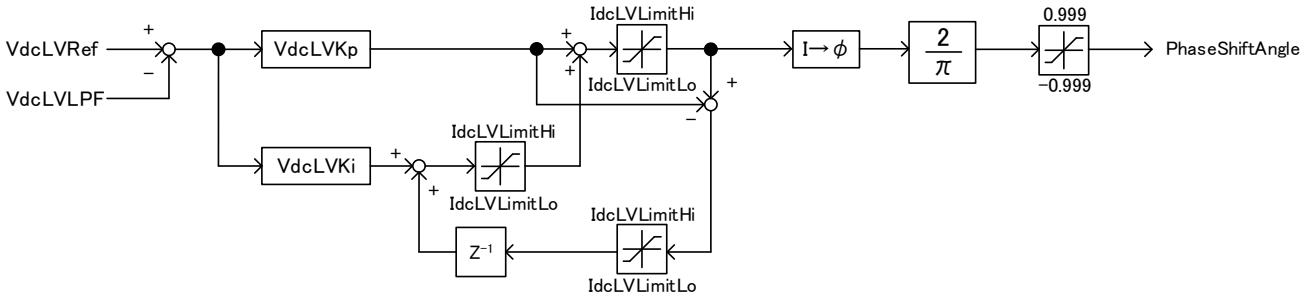
This SW has the following timer interrupt routines:
The timer interrupt routine is executed by Timer0IntFunc() function.

| Processing order | Details of processing | Details of processing |
|---|---|---|
| 1 | Multiple interrupt enable processing | If the general control processing routine occurs during the timer interrupt routine, the general control processing routine is set to take precedence. |
| 2 | Error determination processing | Check the status of DI0,1 (gate driver error signal), high-voltage side overvoltage, low-voltage side overvoltage, low-voltage side overcurrent, and of the watchdog timer, and determine the error status.<br>For details, see section 8, Error Determination Processing. |
| 3 | State transition processing | State of the system is changed according to the state at the time of processing, the result of error determination process, and the status of various variables.<br>For details, see section 3, State Transition Diagram. |
| 4 | Low-pass filter processing coefficient calculation processing | The coefficients of the low-pass filter to be applied to VdcHV, VdcLV, IdcHV, IdcLV are calculated. |
| 5 | Integral gain calculation processing | The integral gain used in the low-voltage side voltage control is calculated from the proportional gain and the time constant. |
| 6 | AD Conversion-Offset Error Correction Processing | When the system is in Init (initialization) state, the offset error is measured using the readings of the sensors before the DC power is turned on, and the correction process is performed. When the correction process is completed, FlagCalibEnd is changed to 1.<br>The above process is performed by CalibAdOffset().<br>If the state is not Init, the above process is not performed. |
| 7 | Multiple interrupt disable processing | If a general control processing routine occurs during a timer interrupt routine, then the setting that gives priority to the general control processing routine is canceled. |

The control block diagram of this SW is shown on the next page.

## 5.4. Control Block Diagram

The control block diagram of the entire power supply is shown below.



# 6. Error Processing

In this SW, when the high-voltage side overvoltage, low-voltage side overvoltage, low-voltage side overcurrent, gate driver DESAT signal detection or watchdog timer overflow occurs during the Stop state, Precharge state, Wait state, or Run state, the system transitions to Error state, and operation is stopped.

When the operation is stopped, the output of all PWM signals is stopped, and the operation is not restored until the reset switch is pressed or the control power is disconnected and reconnected.

To return to operation, perform the following procedure.

1. Disconnect the input DC power supply (High-voltage side or Low-voltage side).
2. Press the reset switch or disconnect and reconnect the control power again.
3. Connect the the input DC power supply (High-voltage side or Low-voltage side).

# 7. A/D Conversion List

A/D conversion table is shown below.

| Port | Pin | Measurement item | Data | A/D conversion Resolution | Filtering |
|---|---|---|---|---|---|
| ADCINA2 | 41 | High-voltage side Voltage | 12bit | 0.2286(V/LSB) | Low-pass filter circuit implemented in the control circuit<br>Cut-off frequency: 22 kHz |
| ADCIN14 (ADCIND14) | 44 | Low-voltage side Voltage | 12bit | 0.1152(V/LSB) | Low-pass filter circuit implemented in the control circuit<br>Cut-off frequency: 22 kHz |
| ADCINB2 | 48 | High-voltage side Current | 12bit | 0.02442(A/LSB) | Low-pass filter circuit implemented in the control circuit<br>Cut-off frequency: 22 kHz |
| ADCINC2 | 31 | Low-voltage side Current | 12bit | 0.04884(A/LSB) | Low-pass filter circuit implemented in the control circuit<br>Cut-off frequency: 22 kHz |

# Terms of Use

This terms of use is made between Toshiba Electronic Devices and Storage Corporation (“We”) and customers who use documents and data that are consulted to design electronics applications on which our semiconductor devices are mounted (“this Reference Design”). Customers shall comply with this terms of use. Please note that it is assumed that customers agree to any and all this terms of use if customers download this Reference Design. We may, at its sole and exclusive discretion, change, alter, modify, add, and/or remove any part of this terms of use at any time without any prior notice. We may terminate this terms of use at any time and for any reason. Upon termination of this terms of use, customers shall destroy this Reference Design. In the event of any breach thereof by customers, customers shall destroy this Reference Design, and furnish us a written confirmation to prove such destruction.

1. Restrictions on usage

1. This Reference Design is provided solely as reference data for designing electronics applications. Customers shall not use this Reference Design for any other purpose, including without limitation, verification of reliability.
2. This Reference Design is for customer's own use and not for sale, lease or other transfer.
3. Customers shall not use this Reference Design for evaluation in high or low temperature, high humidity, or high electromagnetic environments.
4. This Reference Design shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable laws or regulations.

2. Limitations

1. We reserve the right to make changes to this Reference Design without notice.
2. This Reference Design should be treated as a reference only. We are not responsible for any incorrect or incomplete data and information.
3. Semiconductor devices can malfunction or fail. When designing electronics applications by referring to this Reference Design, customers are responsible for complying with safety standards and for providing adequate designs and safeguards for their hardware, software and systems which minimize risk and avoid situations in which a malfunction or failure of semiconductor devices could cause loss of human life, bodily injury or damage to property, including data loss or corruption. Customers must also refer to and comply with the latest versions of all relevant our information, including without limitation, specifications, data sheets and application notes for semiconductor devices, as well as the precautions and conditions set forth in the "Semiconductor Reliability Handbook".
4. When designing electronics applications by referring to this Reference Design, customers must evaluate the whole system adequately. Customers are solely responsible for all aspects of their own product design or applications. WE ASSUME NO LIABILITY FOR CUSTOMERS' PRODUCT DESIGN OR APPLICATIONS.
5. No responsibility is assumed by us for any infringement of patents or any other intellectual property rights of third parties that may result from the use of this Reference Design. No license to any intellectual property right is granted by this terms of use, whether express or implied, by estoppel or otherwise.
6. THIS REFERENCE DESIGN IS PROVIDED "AS IS". WE (a) ASSUME NO LIABILITY WHATSOEVER, INCLUDING WITHOUT LIMITATION, INDIRECT, CONSEQUENTIAL, SPECIAL, OR INCIDENTAL DAMAGES OR LOSS, INCLUDING WITHOUT LIMITATION, LOSS OF PROFITS, LOSS OF OPPORTUNITIES, BUSINESS INTERRUPTION AND LOSS OF DATA, AND (b) DISCLAIM ANY AND ALL EXPRESS OR IMPLIED WARRANTIES AND CONDITIONS RELATED TO THIS REFERENCE DESIGN, INCLUDING WARRANTIES OR CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, ACCURACY OF INFORMATION, OR NONINFRINGEMENT.

3. Export Control

Customers shall not use or otherwise make available this Reference Design for any military purposes, including without limitation, for the design, development, use, stockpiling or manufacturing of nuclear, chemical, or biological weapons or missile technology products (mass destruction weapons). This Reference Design may be controlled under the applicable export laws and regulations including, without limitation, the Japanese Foreign Exchange and Foreign Trade Law and the U.S. Export Administration Regulations. Export and re-export of this Reference Design are strictly prohibited except in compliance with all applicable export laws and regulations.

4. Governing Laws

This terms of use shall be governed and construed by laws of Japan.