Inverter Circuit for IH Cooker

Design Guide

RD206-DGUIDE-01

TOSHIBA ELECTRONIC DEVICES & STORAGE CORPORATION
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1. Introduction

This Design Guide describes how to design the various circuitry and layout of IH Cooker (hereafter referred to as this reference design) using GT20N135SRA IGBT designed for Home Appliances.

If a component is indicated as “Not Mount” in the bill of materials, then it is not mounted on the PCB, even if the part number is written in the circuit diagram.

Mounting locations are provided on the PCB for adjusting the value of various circuit components at the time of circuit design.

1.1. IGBT Used

**GT20N135SRA**

Toshiba’s IGBT (GT20N135SRA) used in this application are designed specifically to be used with home appliance applications to provide most operational and economical efficiency. High-speed switching, High maximum junction temperature and Low saturation voltage are some key features of GT20N135SRA IGBT.

Main features of GT20N135SRA IGBT are:

- High-speed switching:  $t_f = 0.25 \, \mu s$ (typ.) ($I_C = 40 \, A$)
- Low saturation voltage:  $V_{CE(sat)} = 1.60 \, V$ (typ.) ($I_C = 20 \, A$, $T_a = 25 \, ^\circ C$)
- High junction temperature:  $T_j = 175 \, ^\circ C$ (max)
- Monolithically integrated freewheeling diode (FWD)

Main Applications of GT20N135SRA IGBT are:

- Voltage-Resonant Inverter Switching Applications
- Soft Switching Applications
- Induction Cooktops and Home Appliance Applications

![TO-247 Package](image-url)
2. Circuit Design

This section describes the main points of circuit design of this power supply. Refer to RD206-SCHEMATIC-01 for the actual schematic and to RD206-BOM-01 for the bill of materials.

2.1. Main Board Circuit Diagram

Fig. 2.1 shows the circuit diagram of main board.
2.2. IGBT Circuit

Fig. 2.2 shows the circuit and components around GT20N135SRA IGBT.

Fig. 2.2 Inverter Related Circuit
2.2.1. Voltage-Resonant Soft Switching of the IGBT

Fig. 2.3 describes the Voltage-Resonant Soft Switching operation. When the IGBT turns on, current flows through the heating coil. When the IGBT turns off, the heating coil and the resonance capacitor go into resonance, causing sinusoidal voltage to be applied on the IGBT. The direction of resonance between heating coil and resonance capacitor reverses, causing the resonance capacitor voltage to offset the smoothing capacitor voltage. When this happens, current begins to flow through the Resonance Capacitor—Smoothing Capacitor—FWD—Resonance Capacitor loop. During this period, the collector-emitter voltage (\(V_{CE}\)) of the IGBT is equal to the forward voltage (\(V_F\)) of the freewheeling diode (FWD), which is almost zero. At this time, the IGBT turns back on. As a result, current flows through the heating coil from the input side again. This sequence keeps repeating.

Above operation repeats to continue the resonant operation. PPGTA register value (PPGTA_copy to PPGTA) is calculated in order to achieve the target power.

**Fig. 2.3 Voltage-Resonant Soft Switching of the IGBT**
2.2.2. IGBT Gate Drive

Fig. 2.4 shows IGBT gate-drive circuitry.

Since the IGBT gate drive pulse signal (PPG) output from the MCU is an open-drain output, it is externally pulled up by R11 and the voltage limiting zener diode D4, so that it becomes a L level output (approx. 0 V) when IHpulse signal is on and a H level output (approx. 5.1 V) when IHPulse is off.

The gate drive circuit has a push-pull (totempole) circuit configuration. When PPG is at the L level, the bipolar transistor Q3 is turned off, and the base potentials of Q2 and Q4 are about 18 V. Therefore, the Q2 side is turned on, the base voltage to IGBT (Q1) is applied via R3 and R4, the gate charge is injected, and Q1 is turned on. When PPG is at the high level, Q3 is turned on, and the base potentials of Q2 and Q4 are about 0 V, so Q4 is turned on. The gate charges of IGBT (Q1) are emitted through R20 and R23, and Q1 is turned off.

The zener diode of D5 is used to protect the gate potential of Q1 up to 18 V.

Although the gate resistor R13 is 0 Ω in this design, check the actual switching waveform, etc., and adjust the resistance value if necessary.
2.3. Power Supply for IGBT

The IH Cooker is powered by AC 220 V (AC 180 V~AC 264 V) which is rectified by a bridge-diode to make DC as shown in the figure below.

Fig. 2.5 Power Supply for IGBT
2.3.1. Current Detection using Active Low-Pass Filter

Current is detected by using a 20 mΩ resistor, which is connected to the diode bridge. Since the voltage generated by 20 mΩ resistor is low, amplification is performed using Op.Amp inside the HT45F0058 MCU. However, since the switching frequency of the IGBT is between 20 kHz and 30 kHz, the current cannot be measured directly. Since bridge rectification is performed, the waveform has a frequency of 100 Hz (10 ms cycle), which is twice the AC power frequency of 50 Hz. Therefore, a filter is used to measure the current value using only the DC component.

The steps for current detection using active low-pass filter are described in the following Fig. 2.5.
1. Figure shows a waveform of 20 kHz to 30 kHz because of IGBT switching.
2. Filtering is performed using an inverting amplifier with first order Low Pass Filter. The gain is considered so that the output voltage when the current consumption is 10 A falls within the setting range (CVREF4) of the comparison voltage VR4 of CMP3. Refer to Fig. 2.4.
3. Diode and Capacitor are used to make the signal more stable.
4. Voltage divider circuit is used to adjust the signal voltage level.
5. RC filter is used to filter the signal again. Output is sent to ADC.
6. Firmware is used to filter the ADC output signal.

Since the rating of fuse on board is 10 A, the overcurrent detection (E7 error) value needs to be 10 A or less; therefore, 9.8 A is set as the threshold value.
2.3.2. Voltage and Overvoltage Detection

Fig. 2.6 shows the circuit used for detection of Voltage and Overvoltage.

The output voltage of diode-bridge is lowered using the voltage divider resistor circuit. The signal from left voltage divider circuit shown below is filtered using a LPF and then sent to the ANI1 pin for reading voltage value. (This signal is shown by green color in the figure below.)

This device reads the following at every 20 ms interval:

AC power supply voltage → pot bottom temperature → current → IGBT temperature

The ADC takes 10 samples with 1 ms interval between samples. Then the average of 8 samples is taken after excluding the maximum / minimum values. It takes 10 ms for taking 10 samples, which is same as one cycle of the full-wave rectifier output.

The right voltage divider and LPF is used for detecting the Overvoltage. Output voltage (shown by red in above image) of this circuit is sent to comparator CMP2 for Overvoltage detection. If CMP2 interrupt is detected, the IGBT is turned off. In addition, if this interrupt does not recur for 3 seconds, normal operation is restored.
2.4. Temperature Detection
In this IH Cooker, Thermistors are used to detect temperature of IGBT and cooking pot bottom.

2.4.1. IGBT Temperature Detection
Thermistor for measuring the temperature of IGBT is mounted on the PCB near IGBT. Thermistor is connected in a voltage divider configuration and ADC is used to read its output voltage. Fig. 2.7 shows the circuit diagram and thermistor position.

![Fig. 2.7 IGBT Temperature Detection](image)

2.4.2. Cooking Pot Bottom Temperature Detection
The thermistor for measuring the temperature of the bottom of the cooking pot is mounted in the center of the IH coil. Thermistor is connected in a voltage divider configuration and ADC is used to read its output voltage. Fig. 2.8 shows the circuit diagram and thermistor position.

![Fig. 2.9 Cooking Pot Bottom Temperature Detection](image)
2.5. MCU (HT45F0058)

HT45F0058 MCU is used for controlling the operation of this IH Cooker.

2.5.1. MCU Pin Assignment

The selected function of each pin is shown in the Fig. 2.9 and the description of each Pin assignment given in the Table 2.1.

![Fig. 2.10 MCU Pin Function](image)

**Table. 2.1 MCU Pin Assignment**

<table>
<thead>
<tr>
<th>Pin</th>
<th>Pin Name</th>
<th>I/O</th>
<th>Selected Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PPG</td>
<td>OD</td>
<td></td>
<td>For IGBT drive circuit</td>
</tr>
<tr>
<td>2</td>
<td>PB3/PPGIN/CP0N/AN0</td>
<td>I</td>
<td>CP0N</td>
<td>IH coil voltage detection comparator 0 (-) input</td>
</tr>
<tr>
<td>3</td>
<td>PA3/TCO/CP0P/AN9</td>
<td>I</td>
<td>CP0P</td>
<td>IH coil voltage detection comparator 0 (+) input</td>
</tr>
<tr>
<td>4</td>
<td>PA6/CP2N/AN6</td>
<td>I</td>
<td>CP2N</td>
<td>Comparator 2 (-) input</td>
</tr>
<tr>
<td>5</td>
<td>PA7/CP2P/AN5</td>
<td>I</td>
<td>AN5</td>
<td>For IGBT temperature-sensing thermistor</td>
</tr>
<tr>
<td>6</td>
<td>PA5/CP1N/AN7</td>
<td>O</td>
<td>PA5</td>
<td>Serial Out for Debug (TXD)</td>
</tr>
<tr>
<td>7</td>
<td>PB2/OVPI1/AN1</td>
<td>I</td>
<td>OVPI1/AN1</td>
<td>For comparator and ADC used for overvoltage detection</td>
</tr>
<tr>
<td>8</td>
<td>VSS/AVSS</td>
<td></td>
<td>+5 V</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>VDD/AVDD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>PA2/OPROUT/AN2/ICPCK/OCDSCK</td>
<td>I/O</td>
<td>AN2/ICPCK</td>
<td>Bottom temperature detection thermistor/for writing MCU</td>
</tr>
<tr>
<td>11</td>
<td>PB1/PCK/C1VO/C3VO</td>
<td>O</td>
<td>PCK</td>
<td>For FAN control</td>
</tr>
<tr>
<td>12</td>
<td>PA0/ICPDA/OCDSDA</td>
<td>I/O</td>
<td>PA0/ICPDA</td>
<td>For 12C-bus SDA / For writing to MCU</td>
</tr>
<tr>
<td>13</td>
<td>PB4/C0VO/AN3</td>
<td>I/O</td>
<td>PB4</td>
<td>For 12C-bus SCL</td>
</tr>
<tr>
<td>14</td>
<td>PA4/AN4/VREF</td>
<td>I</td>
<td>AN4</td>
<td>Input for current detection (from op amp output)</td>
</tr>
<tr>
<td>15</td>
<td>PA1/OPOUT/AN8</td>
<td>O</td>
<td>OPOUT</td>
<td>Operational amplifier output for current detection</td>
</tr>
<tr>
<td>16</td>
<td>PB0/OPINN/OPINP</td>
<td>I</td>
<td>OPINN</td>
<td>Operational amplifier (-) input for current detection</td>
</tr>
</tbody>
</table>
2.5.2. MCU Clock System Diagram

Fig. 2.10 shows the clock system diagram of HT45F0058 MCU.

Fig. 2.11 MCU Clock System Diagram

2.6. I2C Communication

The MCU of main board communicates with the control board using I2C-bus, and this I2C-bus function is implemented using software control of GPIO.

2.6.1. I2C Communication Protocol

Fig. 2.11 show the I2C communication protocol used in this system.

Fig. 2.12 I2C Communication Protocol
Details of various I2C protocol parameters used while sending data to the control board (sending IH operation status information) are as follows:

**IGBT_Value**

<table>
<thead>
<tr>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGBT_D7</td>
<td>IGBT_D6</td>
<td>IGBT_D5</td>
<td>IGBT_D4</td>
<td>IGBT_D3</td>
<td>IGBT_D2</td>
<td>IGBT_D1</td>
<td>IGBT_D0</td>
</tr>
</tbody>
</table>

Upper 8-bit read value of A/D converter AN5 (IGBT temperature sensing thermistor).

**BOT_Value**

<table>
<thead>
<tr>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOT_D7</td>
<td>BOT_D6</td>
<td>BOT_D5</td>
<td>BOT_D4</td>
<td>BOT_D3</td>
<td>BOT_D2</td>
<td>BOT_D1</td>
<td>BOT_D0</td>
</tr>
</tbody>
</table>

Upper 8-bit read value of A/D converter AN2 (pot bottom temperature-sensing thermistor).

**IH_Status**

<table>
<thead>
<tr>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
</tr>
</thead>
</table>

Status of this equipment, etc.

- **B_ChkSum[2:0]** (Byte checksum)
  - B_ChkSum[2] = bit2(STATUS[2]) inverted
  - B_ChkSum[1] = bit1(STATUS[1]) inverted
  - B_ChkSum[0] = bit0(STATUS[0]) inverted

- **POT_Chk** (Pot check)
  0 With pot
  1 Without ladle

- **STATUS[3:0]** (IH Error status)
  - 0000(0h) Normal operation
  - 0001(1h) Reserved
  - 0010(2h) Circuit failure (overcurrent, no synchronization)
  - 0011(3h) IGBT overheat (110 °C or higher)
  - 0100(4h) IGBT temperature sensor (thermistor) failure
  - 0101(5h) Heating surface (IH coil) overheat (188 °C or higher)
  - 0110(6h) Heating surface (IH coil) temperature sensor (thermistor) failure
  - 0111(7h) AC-input overcurrent (above 9.8 A)
  - 1000(8h) AC-input overvoltage (270 V or more)
  - 1001(9h) AC-input low voltage (less than 150 V)
  - 1010(Ah) I2C-bus communication failure (this error is not implemented)
  - 1011(Bh) Reserved
  - 1111(Fh) Reserved
Details of various I2C protocol parameters used while receiving data from the control board (receiving IH operation control information) are as follows:

### Control_Set

<table>
<thead>
<tr>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
</tr>
</thead>
</table>

Status of the equipment, etc.

- **B_ChkSum[3:0]** (Byte checksum)
  - \( B_{\text{ChkSum}[2]} = \text{bit3}(\text{OnOffCnt}) \) inverted
  - \( B_{\text{ChkSum}[1]} = \text{bit1}(\text{Buz[1]}) \) inverted
  - \( B_{\text{ChkSum}[0]} = \text{bit0}(\text{FanCnt}) \) inverted

#### OnOffCnt (ON / OFF Control)
- Power ON/OFF control.
  - 0 OFF
  - 1 ON

#### Bzz[1:0] (Buzzer Control)
- Buzzer control.
  - 00 Silence
  - 01 200 ms sound
  - 10 sound 2 times
  - 11 1 second sound

#### FanCnt (FAN Control)
- Air cooling fan control.
  - 0 Air cooling fan stop
  - 1 Air cooling fan ON

### Power_Set

<table>
<thead>
<tr>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
</tr>
</thead>
</table>

Power Set is used for heating power control.
- 0d clear power
  - 5d 100 W
  - 15d 300 W
  - 30d 600 W
  - 50d 1000 W
  - 60d 1200 W
  - 70d 1400 W
  - 80d 1600 W
  - 90d 1800 W
  - 100d 2000 W

### Mode_Set

<table>
<thead>
<tr>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
</tr>
</thead>
</table>

Used to describe Continuous power or intermittent power.
- MSet[7:0] (Mode set)
  - 01h Continuous operation
  - 02h Intermittent operation
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