AN3019
Photocoupler Used to Drive IGBTs and
Featuring Built-in Protection Functions

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1. Introduction

The recent rise in awareness of environmental issues and the corresponding demand for energy savings has seen an increase in the use of inverter technology in a wide range of fields, including industrial machinery, power equipment, and home appliances. The demand for industrial inverters such as general-purpose inverters and AC servos is growing strongly in the traditional European and North American markets and is also taking off in emerging markets. Demand for inverter technology is also expected to grow in the expanding “clean energy” fields of solar and wind power generation. One of the most common semiconductor devices used in these inverters is an IGBT (Insulated Gate Bipolar Transistor).

The PS9402 is a gate-driving photocoupler with built-in IGBT protection functions. The PS9402 integrates IGBT protection circuits that were previously attached externally, such as a load short-circuit protection circuit and a circuit to send fault signals to the microcontroller, and also provides an active Miller clamp to stop the IGBT in the event of malfunction. By integrating these circuits on the chip, the PS9402 simplifies the design of the peripheral IGBT driving circuits, enabling IGBTs with specifications of up to 1200 V and 100 A to be driven directly. The PS9402 is available in a 16-pin SOP (small outline package) (shown in Figure 1 below), contributing even further to system compactness.

This application note describes the features and applications of the PS9402.

2. Product overview

The equivalent circuit of the PS9402 is shown in Figure 2.1. The PS9402 contains two light-emitting diodes (LEDs) and two photo detector ICs. A GaAlAs LED is configured on the side that receives signals from the microcontroller, and a photo detector IC that contains a photo diode (PD), signal processing circuit, large-current output circuit and IGBT protection circuits (load short-circuit detector (DESAT), active Miller clamp, and UVLO) is configured on the side that outputs signals to the IGBT. The photo detector IC is fabricated with the Bi-CMOS process proven in other Renesas Electronics IGBT-driving photocouplers such as the PS9505, enabling both a high output current ($I_O = 2.5 A$ MAX.) and low circuit current ($I_{CC} = 2 mA$ TYP.), which enables high-temperature operation ($T_A = 110ºC$ MAX.). The PS9402 chip also includes a high-speed GaAlAs LED and high-speed photo detector IC, which are used for feeding back the load short-circuit fault signal to the microcontroller.

The features of the PS9402 are described on the following pages. Table 2.1 is a truth table for the PS9402’s logic circuits. For details of the PS9402’s electrical specifications, see the data sheet.
Features

- IGBT protection functions (load short-circuit protection (DESAT), active Miller clamp, UVLO)
- High output peak current: 2.5 A
- High-speed switching: $I_{PLH}, I_{PHL} = 200 \text{ ns MAX.}$
- Low power consumption: $I_{CCH}, I_{CCL} = 3 \text{ mA MAX.}$
- Low driving current: $I_{FHL} = 5 \text{ mA MAX.}$
- Low dissipation: $V_{OH} = V_{CC} – 3 \text{ V MIN.}$
- High temperatures supported: Up to 110ºC
- 8 mm creepage: 16-pin package
- Complies with international safety standards: UL, VDE, CSA
- High common mode transient immunity: $CMH, CML = 25 \text{ kV/µs MIN.}$

Table 2.1 Truth Table

<table>
<thead>
<tr>
<th>$I_F$</th>
<th>UVLO ($V_{CC2} – V_{EE}$)</th>
<th>DESAT (Pin 14: DESAT pin input)</th>
<th>FAULT (Pin 3: FAULT pin output)</th>
<th>$V_O$</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF</td>
<td>Not active (&gt; $V_{UVLO+}$)</td>
<td>Not active</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>ON</td>
<td>Not active (&gt; $V_{UVLO+}$)</td>
<td>Low (&lt; $V_{DESAT_{TH}}$)</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>ON</td>
<td>Not active (&gt; $V_{UVLO+}$)</td>
<td>High (&gt; $V_{DESAT_{TH}}$)</td>
<td>Low (FAULT)</td>
<td>Low</td>
</tr>
<tr>
<td>ON</td>
<td>Active (&lt; $V_{UVLO–}$)</td>
<td>Not active</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>OFF</td>
<td>Active (&lt; $V_{UVLO–}$)</td>
<td>Not active</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>
3. Description of operations and functions

3.1 Operational overview

Figure 3.1 shows an example of the IGBT driving circuit we recommend with the PS9402.

![PS9402 Circuit Diagram]

**Figure 3.1 Example of Operational Circuit Recommended for PS9402**

3.1.1 Normal operation

When the IGBT driving signal is put in to the PS9402’s LED (pins 5, 6, 7, and 8), the output voltage \( V_0 \) goes high (active-high operation: see Figure 3.2 below).

![Forward Current of PS9402 LED (I_f) vs. Output Voltage Waveform (V_OUT)]

**Figure 3.2 Forward Current of PS9402 LED (I_f) vs. Output Voltage Waveform (V_OUT)**

![Timing Chart When PS9402 Detects an Error]

**Figure 3.3 Timing Chart When PS9402 Detects an Error**
3.2 IGBT protection functions

3.2.1 Load short-circuit detector (DESAT)

DESAT is a circuit used to detect a fault (short-circuit) in the IGBT.

Figure 3.3 shows the timing chart when the PS9402 detects a fault. If a fault (short-circuit) occurs in the IGBT connected to the photocoupler, the IGBT’s collector current rises and the voltage between the IGBT’s collector and emitter (C-E voltage) surges. If this state continues, the IGBT will be damaged. It is therefore necessary to turn the IGBT off before the IGBT’s short-circuit tolerance limit (the time up to which the IGBT will not be damaged even if a short-circuit occurs) is reached.

The PS9402 detects an increase in the IGBT’s collector voltage (6.9 V TYP.) and turns the IGBT’s gate off up to 3 $\mu$s before the IGBT’s short-circuit tolerance time (generally 10 $\mu$s) elapses. On turning off the IGBT, the gate’s stored charge is discharged slowly via the PS9402’s dedicated MOSFET (known as a soft turn-off), preventing a large voltage spike from occurring. The PS9402 then sends a FAULT signal to the microcontroller to report the abnormal termination of the IGBT. (The FAULT signal output (pin 3) becomes high level during normal operation and low level when a fault occurs.)

After the mute time following the detection of a fault ($t_{\text{DESAT(MUTE)}}$) has elapsed, it enters the auto-recovery mode, and when the microcontroller sends, next time, an LED ON signal to the PS9402, the IGBT is turned back on.

Note: 1. See the data sheet of the IGBT you are using for the exact short-circuit tolerance time.

![Figure 3.4 DESAT Function](image)

3.2.2 Active Miller clamp

The active Miller clamp is used to allow the extra current that occurs due to parasitic capacitance to escape along a different route so that it does not cause the IGBT to malfunction.

When the IGBT connected to the photocoupler is off, the current (Miller current (ICG)) flowing to the Miller capacitor between the IGBT’s collector and gate (the CG Miller capacitor) may generate voltage at the gate, causing the IGBT to malfunction.

When IGBT <2> in the half-bridge circuit in Figure 3.5 is turned on, a steep voltage (dVCE/dt) is applied between the collector and emitter (CE) of IGBT <1>. At this time, Miller current (ICG) briefly flows to the gate resistor ($R_G$) of the IGBT and the Q1 MOSFET in the PS9402, via the CG Miller capacitor of IGBT <1>. This causes the gate voltage of IGBT <1> to rise, and if the gate voltage then exceeds the threshold voltage, a parasitic turn-on will occur, causing through-current to flow.
The active Miller clamp incorporated with the PS9402 allows this Miller current to escape via a different route, preventing a rise in the IGBT’s gate voltage and thereby preventing a parasitic turn-on of the IGBT and the accompanying through-current fault.

**Figure 3.5  Active Miller Clamp**

In terms of actual operation, the PS9402 monitors the gate voltage of the IGBT at the V\textsubscript{CLAMP} pin (pin 10) while the IGBT is off, and once the V\textsubscript{CLAMP} – V\textsubscript{EE} voltage reaches approximately 2 V, the clamp circuit starts operating, sending the Miller current to V\textsubscript{EE} via the Q3 MOSFET of the clamp circuit (clamp current (I\textsubscript{CL}) = 1.5 A TYP. when V\textsubscript{CLAMP} = V\textsubscript{EE} + 2.5 V). IGBT <1> therefore remains off.

### 3.2.3 UVLO (undervoltage lockout)

The UVLO circuit holds V\textsubscript{O} at low level when the PS9402’s power supply voltage is insufficient.

If the IGBT’s gate voltage (V\textsubscript{O} in the PS9402) drops during on state, the V\textsubscript{CE}\textsubscript{(sat)} of the IGBT becomes larger and it might cause a large amount of power to dissipate, leading to overheating and failure of the IGBT. To prevent this, if the PS9402 detects that its power supply voltage (V\textsubscript{CC2} – V\textsubscript{E}) is insufficient, it holds V\textsubscript{O} at low level to protect the IGBT.

As shown in Figure 3.6, when the PS9402’s power supply voltage (V\textsubscript{CC2} – V\textsubscript{E}) is low (when the power supply voltage is rising from 0 V), the PS9402 holds the V\textsubscript{O} output at low level until the voltage rises to V\textsubscript{UVLO\textsuperscript{+}}, even if the LED is on. Conversely, when the PS9402’s power supply voltage (V\textsubscript{CC2} – V\textsubscript{E}) is falling (changing to a negative voltage) the V\textsubscript{O} output is high level until the voltage reaches V\textsubscript{UVLO\textsuperscript{−}}, but if the voltage falls below V\textsubscript{UVLO\textsuperscript{−}}, the PS9402 pulls the V\textsubscript{O} output down to low level even if the LED is on.

Therefore, if the PS9402’s power supply voltage (V\textsubscript{CC2} – V\textsubscript{E}) falls below V\textsubscript{UVLO\textsuperscript{−}} (9.8 to 12.3 V) due to some error, the V\textsubscript{O} output of the PS9402 will go low even if the LED is on. When the power supply voltage (V\textsubscript{CC2} – V\textsubscript{E}) subsequently rises to above V\textsubscript{UVLO\textsuperscript{+}} (11 to 13.5 V), the V\textsubscript{O} output goes high again (with the LED on).
4. Sample design

4.1 Design of load short-circuit detector (DESAT)

Figure 3.1 shows an example of the operational circuit recommend for the PS9402. The load short-circuit detector (DESAT) consists of a DESAT diode (D_{DESAT}), a DESAT resistor (R_{DESAT}), and a blanking capacitor (C_{BLANK}).

The PS9402 detects the DESAT voltage (6.9 V TYP.) by using the charge current (I_{CHG}) from DESAT pin (pin 14) becomes 0 μA.

4.1.1 Blanking time

The blanking time is the time before the IGBT is fully turned on in which it is possible to stop the PS9402’s DESAT function operating.

Once the LED on the PS9402’s input side is on, and the V_{O} output goes high, the PS9402’s DESAT function starts sensing the voltage of its pin (pin 14). Here, actually, it takes some time for the IGBT connected to the PS9402 to turn on and for its VCE voltage to fall far enough that it is below the PS9402’s DESAT threshold after the PS9402’s output goes high. Therefore to prevent the PS9402 falsely detecting a load short-circuit when the IGBT is turned on, a blanking time must be specified.

The operation of the blanking circuit is shown in Figure 4.1 below. When the PS9402’s V_{O} output is low (when the IGBT is off) as shown in circuit diagram (a), a discharge current (I_{DISCHG}) flows to the DESAT pin of the PS9402 (pin 14) from the blanking capacitor (C_{BLANK}), and C_{BLANK} discharges. When the PS9402’s V_{O} output goes high (when the IGBT is turned on) as shown in circuit diagram (b), a charge current (I_{CHG}) flows from the DESAT pin (pin 14), charging the C_{BLANK} capacitor. Therefore, because the I_{CHG} current flows to C_{BLANK}, DESAT does not start operating, even though the IGBT collector voltage has not dropped sufficiently. When C_{BLANK} is fully charged as shown in the circuit diagram in (c), I_{CHG} flows to the IGBT collector, whose voltage has now fallen sufficiently, via the DESAT resistor and DESAT diode. In this state, if the IGBT collector voltage then rises and exceeds the PS9402 threshold, DESAT starts operating.
The blanking time is defined by equation \[4.1\] below, according to the values of:

- DESAT charge current \(I_{CHG} = 240 \, \mu A\) TYP.
- DESAT threshold voltage \(V_{DESAT} = 6.9 \, V\) TYP.
- Blanking capacitance \(C_{BLANK}\)

\[t_{BLANK} = \frac{C_{BLANK} \times V_{DESAT}}{I_{CHG}} \quad \cdots \cdots [4.1]\]

For example, if \(C_{BLANK}\) takes the standard recommended value of 100 pF, the blanking time is:

\[t_{BLANK} = \frac{100 \, pF \times 6.9 \, V}{240 \, \mu A} = 2.9 \, \mu s\] TYP.

It is necessary to select a capacitor with a capacitance value that suits the IGBT and other peripheral circuits you plan to use. When specifying the blanking time, therefore, be sure to carry out full evaluations using the actual device.

### 4.1.2 DESAT diode

As shown in Figure 4.1 (c), a forward current is applied to the DESAT diode to monitor the collector voltage when the IGBT is on. When the IGBT is off, however, the IGBT’s collector voltage is only several hundred volts, so be sure to select a high-tolerance fast-recovery diode whose specifications accord with the voltage used for the DESAT diode. Example diodes are shown in Table 4.1.

<table>
<thead>
<tr>
<th>Name</th>
<th>Manufacturer</th>
<th>Reverse Voltage VRM (V)</th>
<th>(trr (\mu s))</th>
</tr>
</thead>
<tbody>
<tr>
<td>RJU60C1SDPD</td>
<td>Renesas</td>
<td>600 V</td>
<td>60</td>
</tr>
<tr>
<td>BYM26E</td>
<td>Philips</td>
<td>1 000 V</td>
<td>75</td>
</tr>
<tr>
<td>MUR1100</td>
<td>Micro Commercial Components</td>
<td>1 000 V</td>
<td>75</td>
</tr>
</tbody>
</table>

### 4.1.3 DESAT threshold voltage

The threshold voltage of the PS9402’s DESAT pin (pin 14) is 6.9 V TYP. However, if one DESAT diode is connected as shown in Figure 3.1, the actual threshold voltage of the IGBT collector block is as follows, with the forward voltage of that diode indicated by \(V_F\):

\[V_{DESAT(Collector)} = 6.9 \, V - V_F\]
Note that the threshold voltage of the IGBT’s collector block can be lowered by connecting a Zener diode, as shown in Figure 4.2. In this case, the threshold voltage of the IGBT collector block is:

\[ V_{\text{DESAT(Collector)}} = 6.9 \, V - V_F - V_z \]

4.1.4 DESAT resistor
The free-wheel diode attached to the IGBT can sometimes cause a negative voltage to be applied briefly to the DESAT pin (pin 14), which in turn causes current to flow to the collector of the IGBT. It is therefore necessary to connect a DESAT resistor to restrict this current. The recommended resistance of the DESAT resistor is 100 \( \Omega \).

4.1.5 FAULT output
The FAULT pin is an open-collector output which should be connected to a 2.1 k\( \Omega \) resistor (RF). A filter capacitor (CF) has also been added to suppress momentary fluctuations in the signal caused by CMR noise. The FAULT signal output is high level during normal operation and low-level when a fault occurs.

4.2 Design of active Miller clamp
The active Miller clamp must be connected to the PS9402’s active Miller clamp pin (V_{Clamp}: pin 10) as close as possible to the IGBT’s gate in order to prevent parasitic turn-on of the IGBT due to a rise in the gate voltage caused by Miller current flowing through the gate resistor.

Figure 4.3 shows an example of how the active Miller clamp is connected when using a single power supply (negative power supply not used).
If the active Miller clamp is not required, such as when using a negative power supply, connect the VCLAMP pin to GND, as shown in Figure 4.4.

Figure 4.5 shows an example of connecting an active Miller clamp to the VCLAMP pin when a buffer circuit is connected externally. Connecting an external buffer is effective because the Miller current from the IGBT does not flow through the gate resistor (RG). In this case, however, the PS9402 clamp current is about 1.5 A, making it difficult to connect VCLAMP directly to the gate of a high-power IGBT. Check the estimated Miller current capacity and if the clamp current at VCLAMP is insufficient, externally connect a PNP transistor as shown in Figure 4.5.
4.3 Design of IGBT gate driver

Figure 4.6 shows an example IGBT gate driver that uses the PS9402. The gate resistor settings are described in 4.3.1 and 4.3.2 below.

4.3.1 Calculating the minimum resistance of the IGBT's external gate resistor (Rg)

(1) Calculation from the photocoupler side

The external gate resistor (Rg) must be selected so that the peak output current of the PS9402 (IOL(PEAK)) does not exceed its maximum rating. The minimum value of the gate resistor (Rg) can be approximated by using the following expression:

$$R_g \geq \frac{(V_{CC2} - V_{EE}) - V_{OL}}{I_{OL(PEAK)}} \cdots \cdots [4.3.1]$$

$V_{CC2} - V_{EE}$: PS9402 power supply difference ($V_{EE} = 0$ when not using a negative power supply)
V\text{OL} : PS9402's low-level output voltage

Calculate the minimum value of the external gate resistor (R'_G) under the following conditions:

- I\text{OL(PEAK)} = 2.5 A
- V\text{CC2} – V\text{EE} = 18 V
- Voltage drops to V\text{OL} = 2.5 V while I\text{OL} = 2.5 A.

Characteristics curves showing the relationship between the low-level output voltage (V\text{OL}) and low-level output current (I\text{OL}) are provided in Figure 4.7 for reference. These settings make allowances for operation under low temperatures (−40°C). Note that because the low-side MOSFET voltage drops more than the high-side MOSFET voltage in the PS9402, the minimum value of the external gate resistor (R'_G) is calculated based on the low-side MOSFET.

From equation [4.3.1]:

\[ R'_G \geq \frac{(V\text{CC2} – V\text{EE}) – V\text{OL}}{I\text{OL(PEAK)}} \]

\[ = \frac{(18 – 2.5)}{2.5} \]

\[ = 6.2 \, \Omega \]

![Figure 4.7 V\text{OL} vs. I\text{OL} Characteristics](image)

(2) Calculation from the IGBT side

The charge characteristics of the IGBT’s gate are described in the IGBT’s data sheet, but in general, the characteristics curve is as shown in Figure 4.8.
In this graph:

- $Q_{ge}$ is the charge between the gate and the emitter
- $Q_{cg}$ is the charge between the collector and the gate
- $Q_g$ is the total gate charge

The gate charge is expressed as follows:

$$Q = C \times V,$$

with $Q$ indicating the total charge.

The relationship between the gate capacitance, the switching time, and the gate driving current is as follows:

$$\frac{dQ}{dt} = C \times \frac{dV}{dt} = I$$

In this case, if $t_s$ represents the switching time required by the system, the current that must be supplied to the gate ($I_G$) is indicated by:

$$I_G = \frac{Q_g}{t_s}$$

Because a constant driving voltage $V_{(DR)}$ is used, the relationship between the gate peak current and the total gate resistance ($R_{G'}$) is as follows:

$$R_{G'} = \frac{V_{(DR)}}{I_G},$$

with $R_{G'}$ indicating the sum of the driver’s output impedance, the external gate resistance, and the gate’s own series resistance.

Therefore, in order to satisfy the switching time required by the system, the external gate resistance calculated from the photocoupler side ($R_G$) must be smaller than the total gate resistance calculated from the IGBT side ($R_{G'}$). If $t_s$ is unable to be satisfied, you will have to consider selecting a photocoupler that can drive a larger current, or attaching an external current amplifier (buffer).

### 4.3.2 Checking the allowable dissipation of the PS9402 and adjusting $R_G$

The power consumption of the PS9402 ($P_T$) is a total of the power consumption of the LED on the input side (primary side) ($P_D$) and the power consumption of the photo detector IC on the output side (secondary side) connected to the IGBT ($P_O$).

$$P_T = P_D + P_O \cdots \cdots [4.3.2]$$
(1) **LED power consumption**

The power consumption of the LED on the input side (primary side) \( (P_D) \) is calculated as follows:

\[
P_D = I_F \times V_F \times \text{Duty ratio} \quad \cdots \cdots [4.3.3]
\]

(2) **Photo detector IC power consumption**

The power consumption of the photo detector IC on the output side (secondary side) \( (P_O) \) is calculated as follows:

\[
P_O = P_{\text{Circuit}} + P_{\text{Switching}} \quad \cdots \cdots [4.3.4]
\]

\( P_{\text{Circuit}} \) is the circuit power consumption of the photo detector IC (the power consumed by \( I_{CC2} \)).

\( P_{\text{Switching}} \) is the power consumption of the photo detector IC required to charge and discharge the gate capacitor (the power consumed by \( I_O \)).

1. **Circuit power consumption of photo detector IC: \( P_{\text{Circuit}} \)**

\[
P_{\text{Circuit}} = I_{CC2} \times (V_{CC2} - V_{EE}) \quad \cdots \cdots [4.3.5]
\]

\( I_{CC2} \) is the circuit current supplied to the photo detector IC.

\( V_{CC2} - V_{EE} \) is the power supply difference of the photo detector IC.

2. **Power consumption of photo detector IC required to charge and discharge the IGBT gate capacitor**

\[
P_{\text{Switching}} = E_{\text{sw}}(R_G, Q_G) \times f_{SW} \quad \cdots \cdots [4.3.6]
\]

\( E_{\text{sw}}(R_G, Q_G) \) is the per-cycle power consumed when charging the IGBT gate capacitor (see Figure 4.9 and Figure 4.10).

\( f_{SW} \) is the switching frequency.

---

**Figure 4.9 PS9402**

\[
\begin{align*}
\text{Vo} & \quad \text{Io} \\
\text{Esw(on)} & = I_O \times (V_{CC} - V_{Vo}) \\
\text{Esw(off)} & = I_O \times V_{Vo} \\
\text{Esw(Qg,Rg)} & = \text{Esw(on)} + \text{Esw(off)}
\end{align*}
\]
3. Power consumption of photo detector IC
   From the calculations in [4.3.4], [4.3.5], and [4.3.6], the power consumption of the photo detector IC is as follows:

   \[ P_D = P_{\text{diCircuit}} + P_{\text{diSwitching}} = I_{CC2} \times (V_{CC2} - V_{EE}) + E_{\text{sw}}(R_G, Q_G) \times f_{SW} \ldots \cdot \cdot \cdot [4.3.7] \]

(3) Checking the allowable dissipation of the PS9402 and adjusting R_G

When used in the circuit shown in Figure 4.6, the power consumption of the PS9402 is as follows, calculated under the conditions of \( R_G = 6.2 \Omega \), Duty (MAX.) = 80%, \( Q_G = 500 \text{nC} \), \( f = 20 \text{kHz} \), \( I_f \) (MAX.) = 12 mA, and \( T_A = 85^\circ \text{C} \):

1. Power consumption of input side (primary side, LED) (\( P_D \))
   From the calculation in [4.3.3]:
   \[ P_D = I_f \times V_f \times \text{Duty ratio} = 12 \text{mA} \times 1.8 \text{V} \times 0.8 = 17.3 \text{mW} \]

2. Power consumption of output side (secondary side, photo detector IC) (\( P_D \))
   From the calculation in [4.3.7]:
   \[ P_D = I_{CC2} \times (V_{CC2} - V_{EE}) + E_{\text{sw}}(R_G, Q_G) \times f_{SW} = 3 \text{mA} \times 18 \text{V} + 2.8 \text{uJ} \times 20 \text{kHz} \]
   \[ = 54 \text{mW} + 56 \text{mW} \]
   \[ = 110 \text{mW} < 217.5 \text{mW} \]
   (absolute maximum allowable dissipation for photo detector IC when \( T_A = 85^\circ \text{C} \))

The gate resistance \( R_G \) has a significant effect on the performance of the IGBT, so be sure to select the right gate resistor for your gate driver design. A smaller gate resistance means faster switching to charge and discharge the IGBT’s input capacitor, which leads to lower switching dissipation. However, a smaller gate resistance also leads to a larger voltage variation \( (dV/dt) \) and current variation \( (di/dt) \) during switching. It is therefore important to evaluate the actual operation of the IGBT by referring to the relevant technical documents before selecting the gate resistor.
5. PS9402 peripheral circuits

5.1 Layout

1. To minimize floating capacitance between the primary side and the secondary side (the input and the output), be sure to place the circuits so that they are not too close to the primary-side and secondary-side wiring patterns on the board, and that there is no cross-wiring if multi-layer wiring is being used.

2. To prevent transient noise from the IGBT from affecting the PS9402, keep the IGBT collector/emitter circuit pattern and DC lines (P and N lines) of the inverter circuit through which a large current flows as far away as possible from the PS9402’s LED driver and VCC2 and VCC lines.

3. Place the bypass capacitors (with a capacitance of 0.1 uF or higher) between VCC and Vs on the primary side (input side) of the PS9402 and between VCC2 and VEE on the secondary side (output side) as close to the PS9402’s VCC1 (pin 2), Vs (pin 4), VCC2 (pin 13), and VEE (pins 9 and 12) pins as possible (in other words, keep the distance between the PS9402’s pins and the capacitor pins as short as possible).

5.2 LED driver

Design the LED driver so that the recommended current (I_F) and voltage (V_F) are applied to the LED. Table 5.1 shows the recommended operating conditions for the LED.

Table 5.1 Recommended Operating Conditions for PS9402 LED

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage (OFF)</td>
<td>V_F(OFF)</td>
<td>-2</td>
<td>-</td>
<td>0.8</td>
<td>V</td>
</tr>
<tr>
<td>Input voltage (ON)</td>
<td>I_F(ON)</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>mA</td>
</tr>
</tbody>
</table>

To ensure that the LED is turned off properly, even if common mode noise (CM_l) occurs, we recommend applying a reverse bias to the LED within the range indicated by the recommended operating conditions in Table 5.1. Similarly, to ensure that the LED is turned on properly, even if common mode noise (CM_H) occurs, we recommend specifying as large a LED current (I_F) as possible, within the range indicated by the recommended operating conditions in Table 5.1.

If it is not possible to apply a reverse bias to the LED while the LED is off, we recommend configuring the circuit so that the collector and emitter of the LED driver's output transistor are connected respectively to the anode and cathode of the PS9402’s LED, as shown in Figure 5.1 (a) below. This is to prevent a malfunction caused by the LED turning on briefly because a potential difference between the GND pins on the primary and secondary sides of the PS9402 has caused a displacement current to flow to the LED from the photo detector, which might occur if the conventional LED driver configuration shown in Figure 5.1 (b) is used. The configuration in Figure 5.1 (a) protects against this malfunction because the output transistor of the LED driver remains on when the LED is off, even if a displacement current flows to the LED from the photo detector, making it difficult for current to flow through the LED.
6. Specifying dead time

As shown in Figure 6.1, in the inverter circuit, IGBT 1 and IGBT 2 on the upper and lower arms alternately switch on and off, outputting a signal to the motor or other load. If there is insufficient dead time, IGBT 1 and IGBT 2 on the upper and lower arms switch on at the same time, causing a short-circuit current to flow, damaging the IGBTs (see Figure 6.2).

Dead time ($t_{\text{dead}}$) (see Figure 6.3) is specified in order to prevent IGBT1 (upper arm) and IGBT2 (lower arm) turning on at the same time, and is usually the difference between the maximum value of the total turn-off time of the PS9402 and the IGBT ($t_{\text{off, total MAX.}}$) and the minimum value of the total turn-on time of the PS9402 and the IGBT ($t_{\text{on, total MIN.}}$), or higher.

$$t_{\text{dead}} \geq t_{\text{off, total MAX.}} - t_{\text{on, total MIN.}}$$

$$= (t_{\text{PHL, MAX.}(\text{PC})} + t_{\text{off, MAX.}(\text{IGBT})}) - (t_{\text{PLH, MIN.}(\text{PC})} + t_{\text{on, MIN.}(\text{IGBT})})$$

$$= (t_{\text{PHL, MAX.}(\text{PC})} - t_{\text{PLH, MIN.}(\text{PC})}) + (t_{\text{off, MAX.}(\text{IGBT})} - t_{\text{on, MIN.}(\text{IGBT})})$$

$$= \text{PDD}_{\text{(PC)}} + (t_{\text{off, MAX.}} - t_{\text{on, MIN.}})_{\text{(IGBT)}}$$

In the above equation, (PC) is the response time of the PS9402 photocoupler and (IGBT) is the response time of the IGBT.
In the PS9402, the transmission delay time difference between any two parts has been prescribed to make specifying dead time easy (this time is $PDD = t_{PHL} - t_{PLH} = \pm 100$ ns). See the PS9402’s data sheet for details. Note that $PDD$ in the PS9402 must be measured under the same temperature and measurement conditions as $t_{PHL}$ and $t_{PLH}$. The board must therefore be laid out so that the ambient conditions of the upper and lower arms of the photocoupler are the same. Also be sure to thoroughly evaluate the dead time using the actual device, and allow a sufficient margin in your design.

7. Calculating the junction temperature

1. PS9402 thermal resistance model

Figure 7.1 shows the thermal resistance model of the PS9402. The model used has two heat sources: the LED and the photo detector IC.

Figure 7.1 PS9402 Thermal Resistance Model

- $T_{JE}$ ····· LED 1 junction temperature
- $T_{JD}$ ····· Photo detector IC 2 junction temperature
- $T_A$ ····· Ambient temperature
- $\theta_1$ ····· Thermal resistance between LED 1 and ambient air
- $\theta_2$ ····· Thermal resistance between LED 1 and photo detector IC 2
2. Junction temperature calculation

In the above model, the junction temperature of LED 1 and photo detector IC 2 is calculated as follows:

\[ T_{JE} = R_{11} x P_E + R_{12} x P_D + T_A \] \[ T_{JD} = R_{21} x P_E + R_{22} x P_D + T_A \] 

- \( P_E \): LED 1 power consumption
- \( P_D \): Photo detector IC 2 power consumption
- \( R_{11}, R_{12}, R_{21} \): Parameter of thermal resistance between LED 1 and ambient air (\( R_{11} = \theta_1 || (\theta_2 + \theta_3) \))
- \( R_{12}, R_{21} \): Parameter of thermal resistance between LED 1 and photo detector IC 2 (\( R_{12}, R_{21} = (\theta_1 x \theta_3) / (\theta_1 + \theta_2 + \theta_3) \))
- \( R_{22} \): Parameter of thermal resistance between photo detector IC 2 and ambient air (\( R_{22} = \theta_3 || (\theta_1 + \theta_2) \))

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<tr>
<th>Table 7.1 Thermal Resistance Parameters</th>
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<td>Thermal Resistance Parameters (°C/W)</td>
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<td>( R_{11} )</td>
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The following is an example of calculating the junction temperature using [7.1] and [7.2], with \( P_E = 17.3 \) mW, \( P_D (= P_O) = 110 \) mW, and \( T_A = 85^\circ C \):

\[ T_{JE} = R_{11} x P_E + R_{12} x P_D + T_A \]
\[ = 208^\circ C/W x 17.3 \text{ mW} + 90^\circ C/W x 110 \text{ mW} + 85^\circ C \]
\[ = 99^\circ C \]

\[ T_{JD} = R_{21} x P_E + R_{22} x P_D + T_A \]
\[ = 90^\circ C/W x 17.3 \text{ mW} + 154^\circ C/W x 110 \text{ mW} + 85^\circ C \]
\[ = 104^\circ C \]

Make sure that the junction temperature (\( T_{JE} \) and \( T_{JD} \)) does not exceed 125°C.

8. Summary

This application note describes the features and applications of the PS9402 photocoupler, which is an IGBT-driving photocoupler with built-in IGBT protection circuits. Please use this document when designing your system. The PS9402 aims to facilitate the design of inverter equipment—a market that is expected to grow significantly in the future—and contribute to reducing system scale. In addition to aggressively marketing the PS9402, Renesas Electronics also plans to continue developing photocouplers that support high-temperature operation and high-output devices.
Caution

GaAs Products

This product uses gallium arsenide (GaAs). GaAs vapor and powder are hazardous to human health if inhaled or ingested, so please observe the following points.

• Follow related laws and ordinances when disposing of the product. If there are no applicable laws and/or ordinances, dispose of the product as recommended below.

1. Commission a disposal company able to (with a license to) collect, transport and dispose of materials that contain arsenic and other such industrial waste materials.

2. Exclude the product from general industrial waste and household garbage, and ensure that the product is controlled (as industrial waste subject to special control) up until final disposal.

• Do not burn, destroy, cut, crush, or chemically dissolve the product.

• Do not lick the product or in any way allow it to enter the mouth.
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