Basic of isolated power device pre-driver (TLP5231 Operation and Protective Function Setting)

Overview

This document describes the basics of isolated power device pre-driver TLP5231, a type of gate driver for power MOSFET and IGBT gate control. Gate drivers can be broadly divided into single-function driver and multi-function driver. Those two kinds of driver also drive power device directly and via buffers. The types via buffers are called pre-drivers. This document describes the basics of operation and protective functions unique to pre-driver TLP5231, which has dual-outputs.

Contents

1. Overview

The isolated power device pre-driver is a type of gate driver coupler, a photocoupler for driving the gates of power MOSFET and IGBT that are the mainstream power devices.

Power MOSFET and IGBT are indispensable devices for today's lives. Those power devices control motors for elevators, electric vehicles, and drones, for example, by switching between large currents ranging from a few amperes to several 100 amperes and voltages ranging from several tens of volts to several 100 volts. The timing for operating the power device is output as a signal from the controller IC represented by the microcomputer. Still, the power device cannot be driven directly by the microcomputer. For example, operating the power device requires a current of several amps to 10 amps and a voltage of 10 to 30V, but normal microcomputers do not handle this current or voltage.

The gate driver coupler is a dedicated isolator (optical semiconductor) that mediates controller ICs and power devices. It amplifies a small control signal of several volts and a few milliamps delivered by the microcomputer to an output voltage of 10 volts or higher and an output current of several amps to drive the power device. It directly turns the gate of the power device on and off.

Isolated power device pre-driver is also a type of gate driver coupler. Still, they cannot be connected directly to the gate terminal of a power device due to the features described later. For this reason, we categorize this product into pre-driver categories.

The gate driver coupler includes a single-function gate driver coupler that only drives the gate of the power device and a multi-function gate driver coupler that adds various functions to the single-function gate driver coupler. We call the multi-function gate driver coupler a smart gate driver-coupler. The isolated power device pre-driver covered in this application note also categorized as smart gate driver coupler since it has built-in protection features

2. Application

2.1. Application Examples

Inverter motor control, PV inverter, EV charging station, Uninterruptible power supply,
Industrial inverter, General-purpose inverter, AC servo amplifier, DC brushless motor drive

2.2. Example of Inverter Applications

The gate driver controls the power module on and off while isolating the MCU and the power device module.

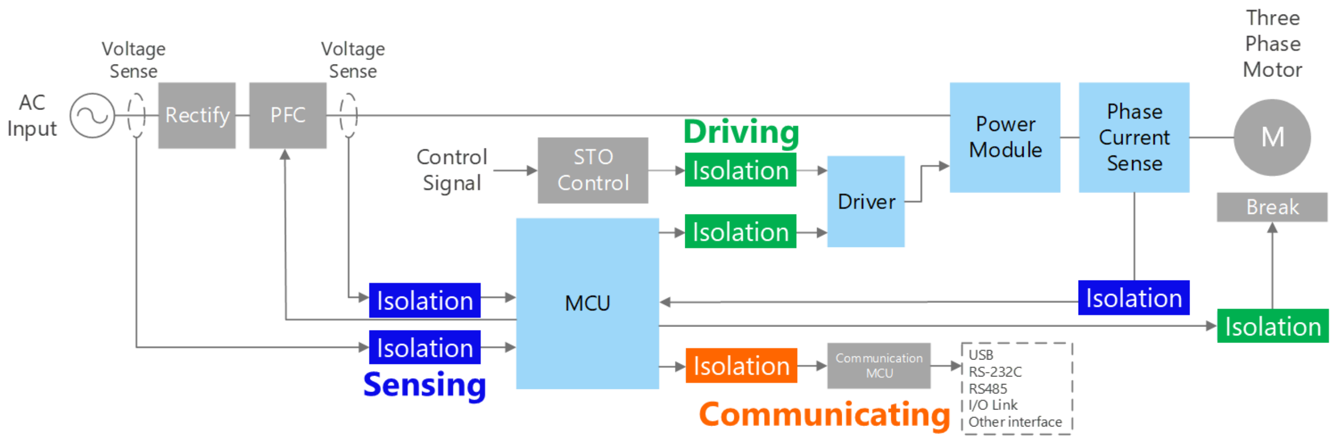


Fig. 2 Examples of Inverter System Applications

3. Functional Classification of Gate Drivers

Semiconductors that drive power devices directly are commonly referred to as gate driver ICs, and gate driver couplers are also included in this gate driver IC as shown in Fig. 3.1. Among the gate driver ICs, according to the application circuit, there are three-phase drivers, half-bridge drivers, full-bridge drivers, and low-side/high-side drivers.

In this application circuit classification, there are two as even larger classifications. One is an isolated type, which electrically separates the controller IC from the power device. The other one is a non-isolated type. The isolated type and the non-isolated type are used separately for the withstanding voltage of the power device. Generally, the non-isolated type is used for the low voltage MOSFET of 100V or less or MOSFET of 200 to 300V, the high withstanding voltage MOSFET of 600V needs the non-isolated or isolated type. Much higher voltage, for example, 1200V withstanding voltage IGBT needs the isolated type.

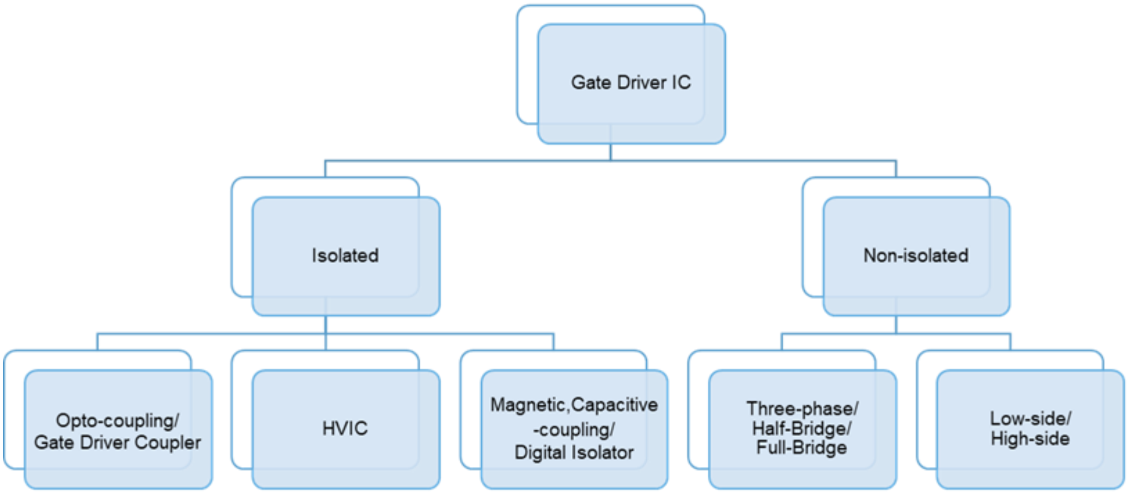


Fig. 3.1 Gate Driver Types

In applications requiring isolation, it is possible to drive the power device using a non-isolated gate driver IC, but a separate isolator is required to provide isolation. This means that there is an additional semiconductor component between the controller IC and the power device.

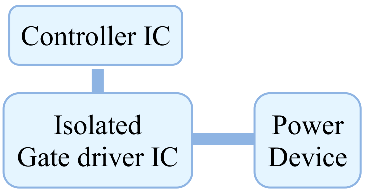


Fig. 3.2 When Using Isolated Gate Driver ICs

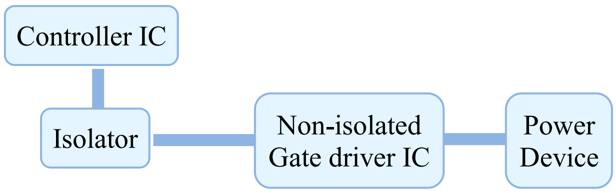


Fig. 3.3 When Using Non-Isolated Gate Driver ICs

Gate driver couplers are isolated gate driver ICs used mainly in combination with a power MOSFET of 600V withstand voltage and an IGBT of 1200V withstand voltage because of their high insulation performance and ease of use.
Although the isolation voltage is slightly lower, some high-voltage ICs are electrically isolated inside the chip. They are also used in conjunction with high-voltage MOSFET of 600V or IGBT of 1200V withstand voltage. In recent years, digital isolator-type gate driver ICs with magnetic and capacitive insulation are also commercialized, which have the same performance as optical isolation.
This application note deals with opto-isolated gate driver couplers. The structural differences between single-function and smart gate driver-coupler are written in section 5.2, (Link).

4. Protection Function of Isolated Power Device Pre-driver

As outlined, the Isolated Power Device Pre-Driver TLP5231 is a similar category of Smart Gate Driver Coupler with built-in power device protection. This section explains the general protection functions.

4.1. Overcurrent DESAT Detection Method

Inverter circuits, the main application of gate driver couplers, usually consist of three rows of two stages, top and bottom, and a total of six gate driver couplers are used. If the upper and lower power devices arranged in series are turned on at the same time due to some trouble, as shown in Fig. 4.1, a high-voltage power supply of several 100V will be short-circuited. This abnormal situation is generally called “arm short”, and a large current of several 100A or more may flow and cause smoking, ignition, or destruction.

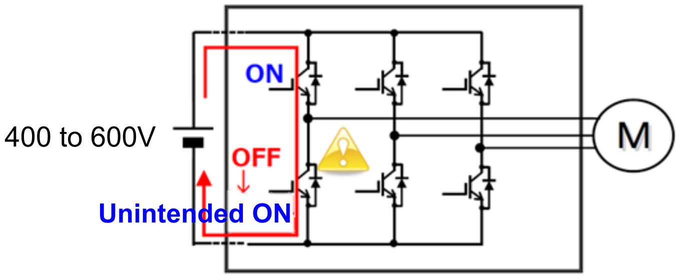


Fig. 4.1 Arm Short Fault in Inverter Circuit

Protecting power devices that handle high voltages and large currents from over currents caused by short-circuit anomalies is very important from the viewpoint of preventing smoking, ignition, and breakage.

The short-circuit tolerance is the time from when an overcurrent flows until the flow destroys the power device. It is necessary to shut off the overcurrent within the short-circuit tolerance.

Although the short-circuit tolerance varies depending on the power device, recent advances in embedding process shrink in power device have resulted in an increasing number of examples requiring protection in a short time to shut off the overcurrent within 1 to 5µs.

The isolated power device pre-driver has an over-current protection function that detects abnormality by monitoring the voltage of the power device that increases in conjunction with the current when an excessive current flows due to some irregularity in the power device, and stops the operation of the power device.

As shown in Fig. 4.2, the voltage across the collector-emitter of IGBT and drain-source of MOSFET is monitored via a high-voltage diode. The voltage drop across the monitored power device is used to estimate the current by converting the I-V static curve of the power device. For this estimation, I_C-V_{CE} curve or I_D-V_{DS} curve of the power device is mandatory.

To monitor the collector or drain terminals directly, definitely needs to insert a high reverse withstand voltage fast recovery diode of several 100V or 1000V or higher. This method is called DESAT (de saturation) detection method, and it is difficult to directly monitor the current, but it has the advantage of being relatively simple and inexpensive to compose.

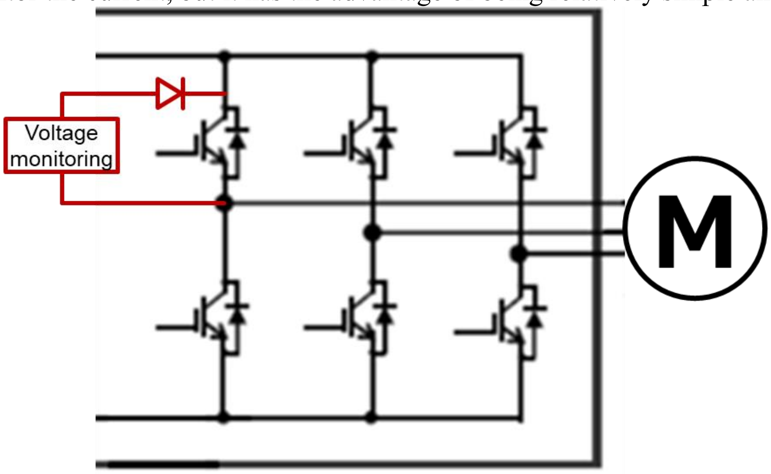


Fig. 4.2 Image of $V_{CE(sat)}$ DESAT Detection Method Current Monitor

4.2. Operation of Detecting DESAT (de saturation)

Fig. 4.3 shows the sequence of protection operation when DESAT is detected, taking TLP5231 as an example.

① Overcurrent occurs in the power device (here IGBT).
② $V_{CE(sat)}$ rises in response to overcurrent, and protective operation starts when DESAT threshold voltage exceeds 7.5V (min).
③ Turn on external MOSFET for soft turn-off to slowly discharge gate of IGBT and turn off IGBT.
④ Transmits error (FAULT) signal to controller IC.

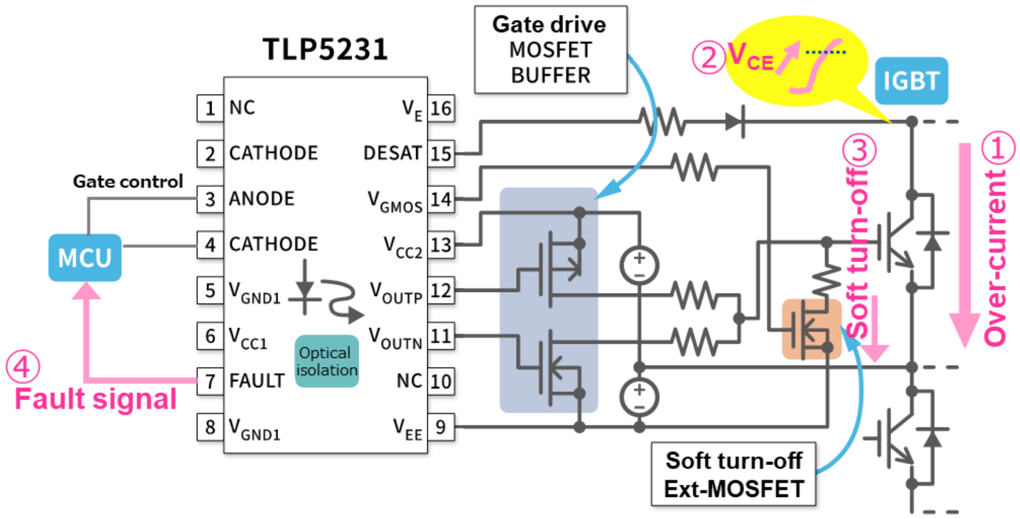


Fig. 4.3 Sequence of protective operation when DESAT is detected

The operation of DESAT detection is described below.

Fig. 4.4 shows the looping of the current that monitors DESAT.

When IGBT is turned on normally and the collector current is applied, DESAT terminal outputs the blanking capacitor charging current I_{CHG} as a constant current source and superimposes the monitoring current between the collector and emitter of IGBT through the resistor R_{DESAT} and the high reverse withstand voltage diode D_{DESAT}.

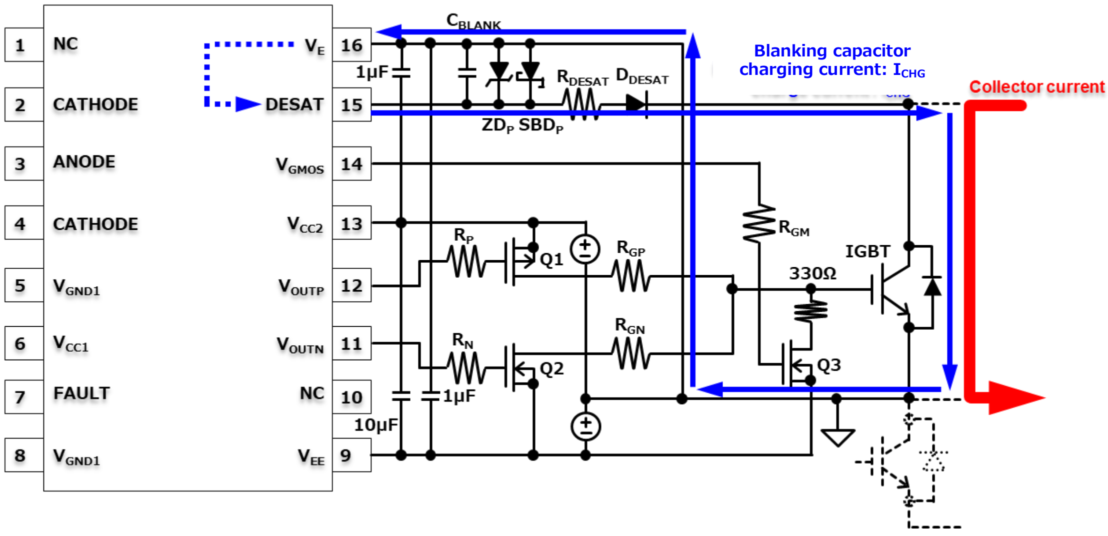


Fig. 4.4 Operation of DESAT Detecting Method

For D_{DESAT}, I_{CHG} is the only forward current that can flow, so a low-capacity (around 100mA) diode is sufficient. However, you should select a low-junction-capacitance diode with a reverse withstand voltage that is high enough than IGBT collector-emitter voltage (V_{CES}) and to prevent false positives. When diodes are placed in series, the junction-capacitance becomes the inverse of the number in series, which is effective from the viewpoint of junction-capacitance reduction. However, the reverse withstand voltage when IGBT is turned off may not be applied evenly to diodes in series due to variations in the leakage current of individual diodes. Therefore, you must have a diode with a higher reverse withstand voltage than V_{CES} of IGBT.

4.3. Operation of Blanking Capacitor (C_{BLANK})

The previous section explains that the presence or absence of overcurrent can be detected by outputting the blanking capacitor charging current (I_{CHG}) from DESAT terminal and monitoring V_{ce} of IGBT. This section describes the points that must be taken into consideration when designing the overcurrent detection circuit.

DESAT terminal is connected to the collector terminal of IGBT through a high withstand voltage diode (D_{DESAT}). If IGBT collector voltage fluctuates due to external noise when IGBT is ON, DESAT voltage may fluctuate through the junction capacitance of D_{DESAT}. If this DESAT voltage fluctuation exceeds DESAT threshold (8.0V typical), protective operation starts and IGBT is softly turned off. Although DESAT terminals of TOSHIBA's smart gate driver couplers, including TLP5231, are equipped with noise filters, the noise generated by the high-voltage inverter circuit tends to become large, so we recommend that a blanking capacitor (C_{BLANK}) shown in Fig. 4.5 be added to form a low-pass filter.

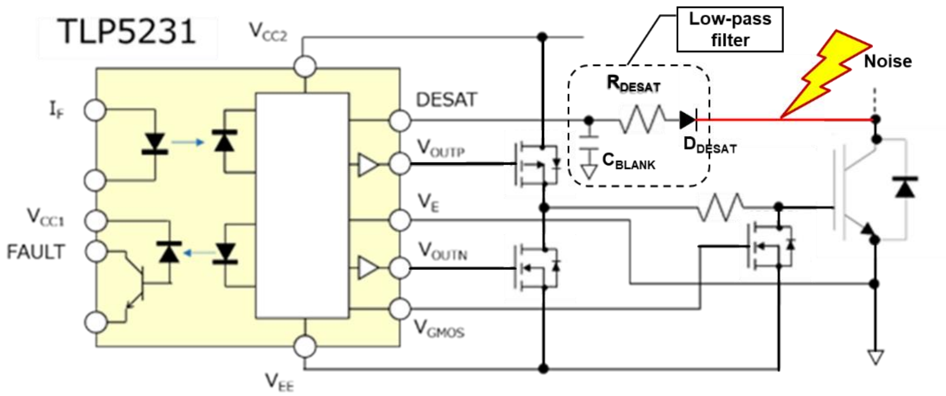
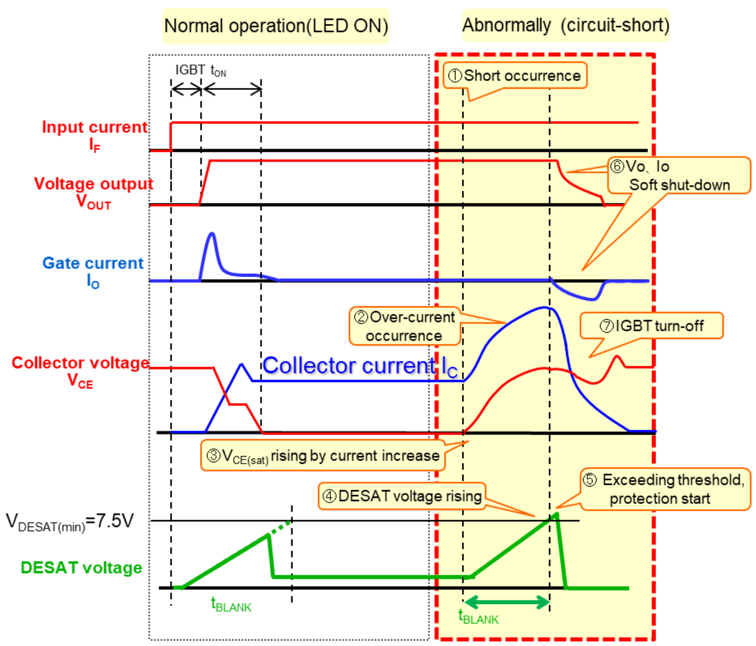


Fig. 4.5 Noise filter configuration by adding DESAT Capacitor (C_{BLANK})

As a tradeoff from adding this C_{BLANK}, there is a delay when $V_{CE(SAT)}$ reaches DESAT threshold voltage in the event of a short-circuit failure.

Assuming that the time from the occurrence of a short circuit to DESAT threshold voltage is the blanking time (t_{BLANK}), the current-voltage operation image of the smart gate driver coupler and IGBT is as shown in Fig. 4.6.



This chart is a reference to indicate simulative protective actions

Fig. 4.6 Timing Chart Image of IGBT and Smart Gate Driver Coupler in Case of Short Circuit

If IGBT's $V_{CE(SAT)}$ spikes due to an overcurrent caused by a short-circuit, it will exceed the power supply voltage of the constant current source and I_{CHG} will not flow to the IGBT.

Since the current loop is interrupted, DESAT terminal voltage rises toward the open voltage in a short time, and the protection starts beyond the threshold voltage. At this time, if there is a C_{BLANK}, I_{CHG} lost in the destination will flow, and delay will happen for the time to charge the C_{BLANK}.

4.4. UVLO Function (Under Voltage Lock Out: Under voltage malfunction prevented)

This function monitors the voltage of the gate power supply. When the voltage falls below the operating threshold voltage UVLO threshold (V_{UVLO}) set for each driver coupler, V_O or V_{OUT} terminal is fixed at a low level and the gate output is shut off as shown in Fig. 4.7.

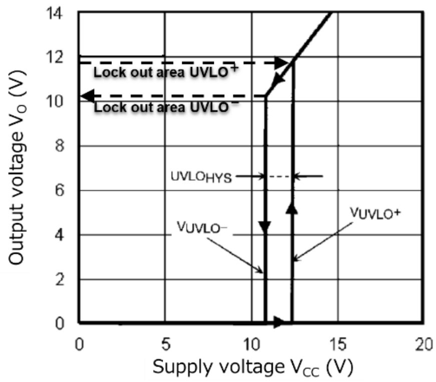


Fig. 4.7 UVLO Operation of Gate Driver Coupler

This is a function to prevent the power device from passing current between the collector and emitter or between the drain and source with insufficient gate voltage, and is intended to prevent damage from overheating. In particular, the power supply of the upper gate drive circuit requires a floating power supply. For example, if the power is supplied by capacitor which composed in a bootstrapped circuit, care should be taken not to drop the voltage of the capacitor below UVLO threshold (V_{UVLO}) due to the consumption of the gate drive circuit.

TLP5231 monitors the voltage of both positive ($V_{CC2} – V_E$) and negative power supplies ($V_E – V_{EE}$) on the secondary side. If the voltage is lower than UVLO threshold, it stops the gate output. When the positive power supply voltage exceeds UVLO threshold and the negative power supply voltage also exceeds UVLO threshold, it outputs the gate voltage. UVLO takes precedence over all functions then TLP5231 starts operating after releasing UVLO.

Consider the power supply voltage shown in Fig. 4.8 when the LED input signal is High. In this situation, the positive power supply (V_{CC2}-V_E) has exceeded UVLO threshold V_{UVLOP+} first, but the negative power supply (V_E-V_{EE}) has not exceeded UVLO threshold V_{UVLON+}. Therefore, FAULT is turned High to inform the primary side of an error.

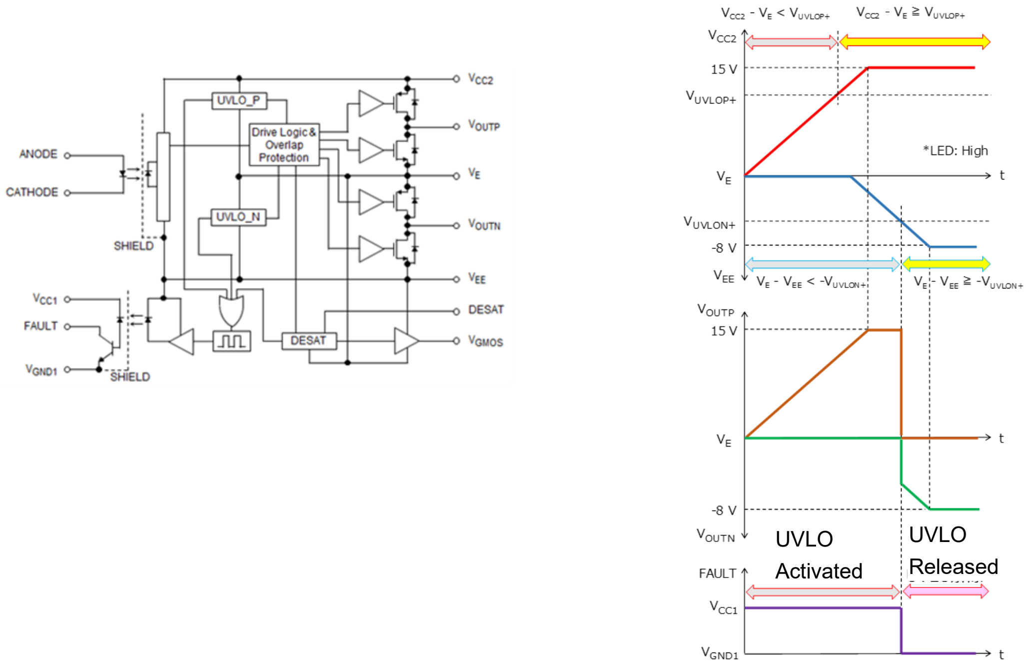


Fig. 4.8 Relationship between power supply voltage and V_{OUTP}, V_{OUTN}, FAULT output

5. Features of Pre-driver TLP5231

5.1. Outline of TLP5231 and Example of Application Circuit

TLP5231 is a photocoupler for driving medium and high current IGBT/MOSFET with built-in overcurrent detection and soft turn-off function. Provides over-current protection with DESAT short-circuit detection that monitors the collector voltage of the medium to high current IGBT or the drain voltage of MOSFET. This function detects overcurrent and soft-turns off IGBT/MOSFET gate-voltage. This soft turn-off prevents fatal over currents due to power device's high-side/low-side through short circuits.

In addition, conventional smart gate driver couplers have only a function stopping the operation when a UVLO is detected, but this TLP5231 can monitor the gate power supply abnormality by outputting a failure signal to the primary side even when the UVLO is detected.

In addition, TLP5231 drives the gates of Power MOSFET and medium-high-current IGBT through the complementary MOSFET buffers (for amplification) of the P-channel and N-channel, so that current flows only during charging and discharging of the buffer MOSFET gates to reduce power dissipation. Furthermore, by varying the size of the external complementary MOSFET buffer, the gate currents required by the various IGBTs/MOSFETs can be designed. By combining TLP5231 with MOSFET buffers and IGBT/MOSFET, the product lineup can be covered according to the power size of the system, which helps reduce the designing burden.

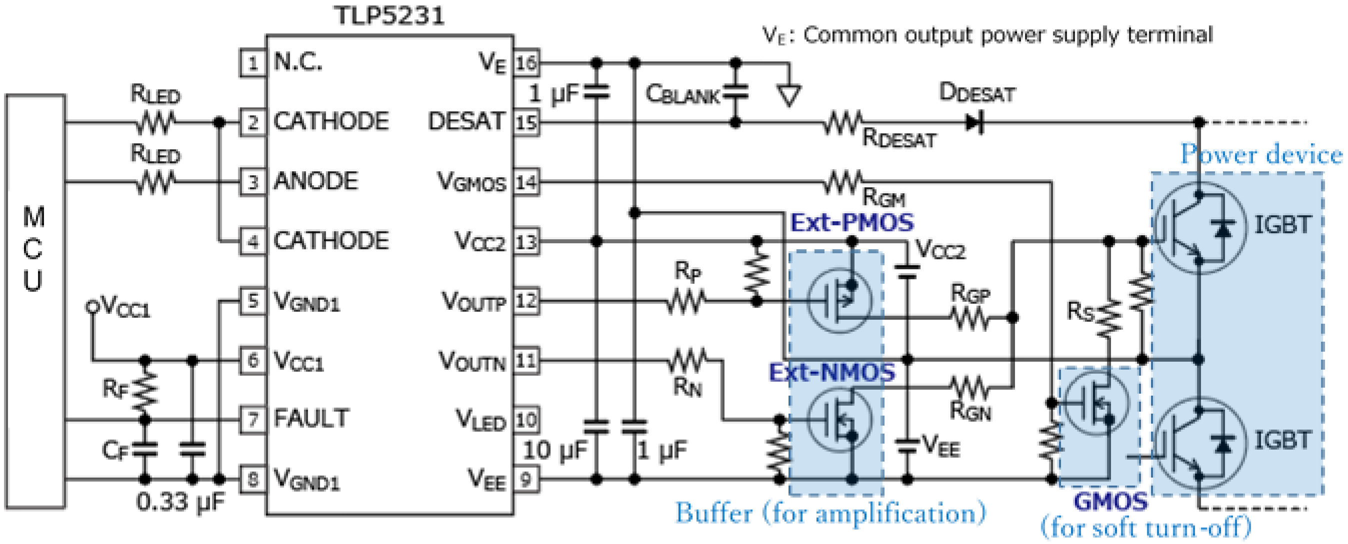


Fig. 5.1 Application circuit example of TLP5231

Ext-PMOS : P-channel MOSFET (for current buffer)
Ext-NMOS : N-channel MOSFET (for current buffer)
GMOS : N-channel MOSFET (for soft turn-off control)

NOTE: This application circuit example is for reference only, and should be thoroughly evaluated when designing for mass production. In addition, it does not permit the use of industrial property.

TLP5231 has two outputs to drive these MOSFET separately so that they can be used as pre-drivers to drive power devices via external P/N-channel MOSFET (Fig. 5.2.a).

For a single-output type gate driver (Fig. 5.2.b), the top row of external MOSFET for driving the gate of a power device with a large rating is N-channel and the bottom row is P-channel. At this time, the voltage applied to the gate of the power device does not become full swing because the high-level voltage drops by $V_{DS(ON)}$ of the N-channel MOSFET.

The dual-output type (Fig. 5.2.a) drives the P/N channel MOSFET separately, allowing full swing operation of the gate voltage of the power device.

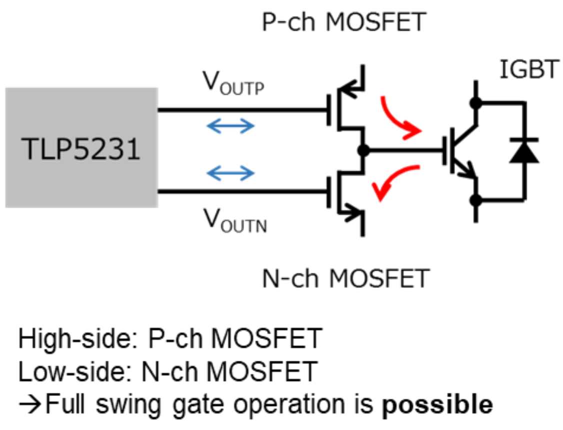


Fig. 5.2.a Dual-Output Gate Driver

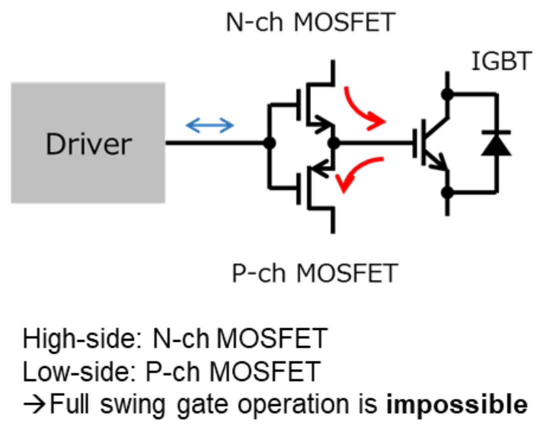


Fig. 5.2.b Single-Output Gate Driver

We also offer single-output smart gate driver coupler TLP5214A. Table 5 compares TLP5214A and TLP5231 features. Fig. 5.3 also shows the difference between the peripheral circuits.

Table 5 Differences between TLP5231 and TLP5214A functions

Comparison term	TLP5231	TLP5214A
Secondary side output	**Dual output (negative logic)** ***External P/N-channel MOSFET drive**	Single output (positive logic)
Power supply voltage (secondary side)	**Three rails: V_{CC2} (Positive Power), V_E (Common), and V_{EE} (Negative Power)**	Two rails of V_{CC2}, V_{EE} (available in V_{EE}=V_E)
Output peak current (max)	±2.5 A	±4.0 A
Active Timing Control (Note 1)	External P/N Channel MOSFET Simultaneous ON prevention	-
Power element desaturation detection	Built-in (Detect between DESAT-V_E)	Built-in (Detect between DESAT-V_E)
Soft turn-off	**Controllable (external)**	Fixed (built-in)
UVLO function	For positive/negative power supply Two UVLO circuits for V_{CC2} and V_{EE} based on V_E	For positive power supply only (V_E reference V_{CC2})
Mute time (Protected) (Note 2)	0.68 to 1.7 ms	7 μs (minimum)
Feedback function	When $V_{CE(sat)}$ desaturation is detected **UVLO status**	When $V_{CE(sat)}$ desaturation is detected

(Note 1) Active timing control: Control is performed so that the external P-channel and N-channel MOSFET do not turn ON simultaneously. Control is performed so that the P channel MOSFET is turned on after the N channel MOSFET is turned off, and the N channel MOSFET is turned on after the P channel MOSFET is turned off.

(Note 2) Mute time: When the protection function is activated, the input LED signal is not accepted for a certain period of time. During this time, the protection operation is maintained.

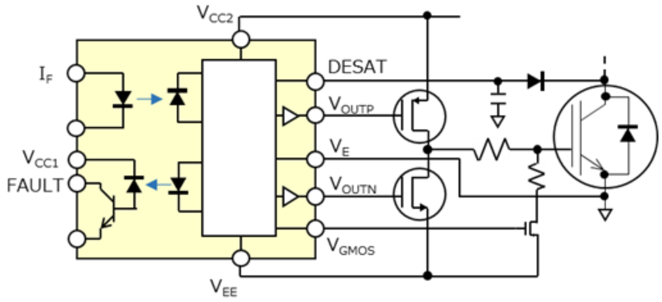


Fig. 5.3. a TLP5231 Peripheral Circuits

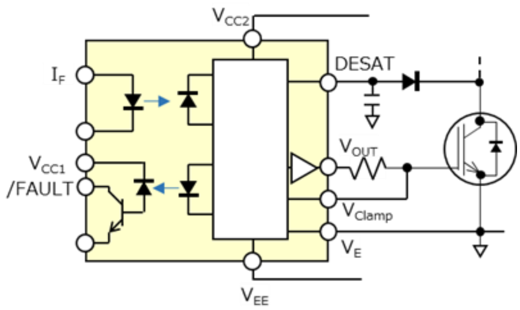


Fig. 5.3. b TLP5214A Peripheral Circuits

5.2. Comparison of TLP5231 and Single-Function Gate Driver Internal Structure

TLP5231 and single-function gate driver, which are optically isolated, the light-emitting diode chip and light-receiving IC chip are sealed with epoxy-resin. And the insulation distance of 0.4mm is guaranteed in order to provide reliable isolation. It can meet safety standards for a wide range of applications, from industrial equipment to various IT equipment.

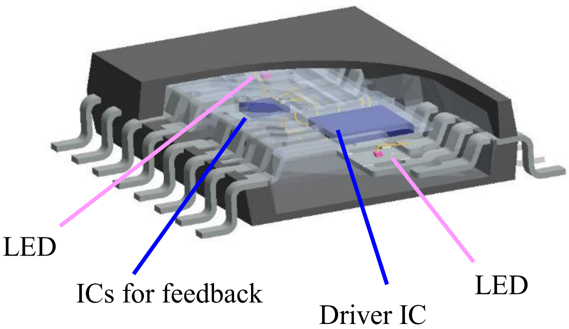


Fig. 5.4.a Smart Gate Driver Coupler Internal Structure

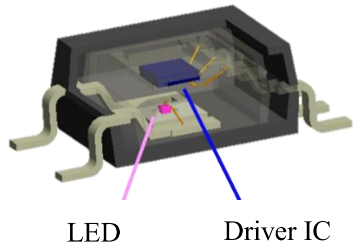


Fig. 5.4.b Single-Function Gate Driver Coupler Internal Structure

The smart gate driver coupler optically couples the driver IC that includes peripheral circuit, and feedback IC to the LED, as shown in Fig. 5.4.a. On the other hand, the protective function of the single-function gate driver coupler is only UVLO function described in Section 4, and the internal structure is also simple as shown in Fig. 5.4.b. Therefore, the protection function as a system must be designed separately from the gate driver, if necessary.

5.3. Derating of Dead-time Design

TLP5231 has two output lines for controlling MOSFET buffers Q1 and Q2, and provides a time difference (non-overlapping time) between ON/OFF signals of Q1 and Q2 to ensure dead time when both Q1 and Q2 are turned off. This eliminates the need for dead-time design, which was difficult with the buffer configuration in bipolar transistors, and prevents switching loss in simultaneous on-state generation.

- P-/N-channel Complementary-Dual-output with built-in active timing control suitable for driving buffer MOSFET.
- Buffer MOSFET dead-time designs are much easier, helping to reduce switching losses.

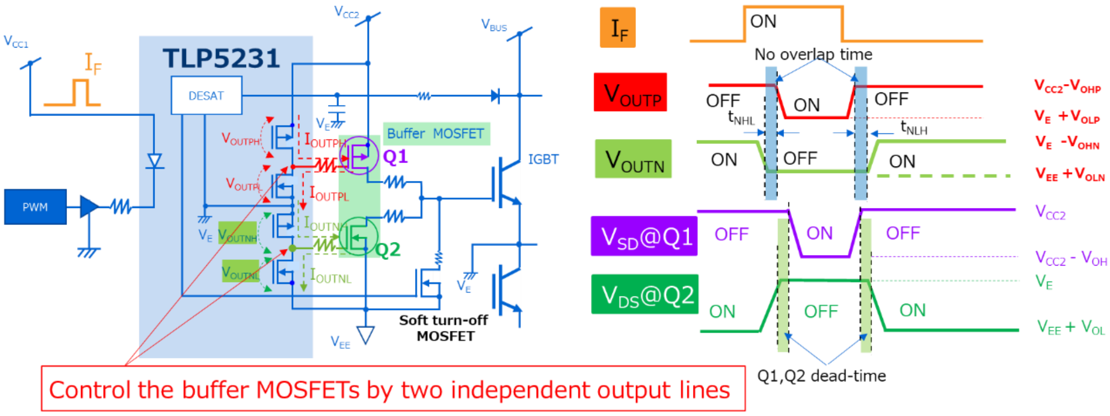


Fig. 5.5 Timing image of dead time

5.4. Protective Design (improved flexibility of soft turn-off design)

TLP5231 requires additional MOSFET for soft turn-off in the event of a fault. This soft turn-off MOSFET does not share any routing (line) with the buffer MOSFETQ2, so it can be designed flexibly without worrying about the trade-off with normal turn off operation. When protecting a new material power device (SiC MOSFET) with a low short-circuit tolerance, fast turn-off may be required, contrary to the present IGBT. For this case, use a larger MOSFET for soft turn-off.

- The gate soft turn-off time when an overcurrent occurs can be controlled by an external circuit configuration.
- MOSFET for soft turn-off can be attached independently from the normal turn off operation, and the speed of normal off operation can be reduced.

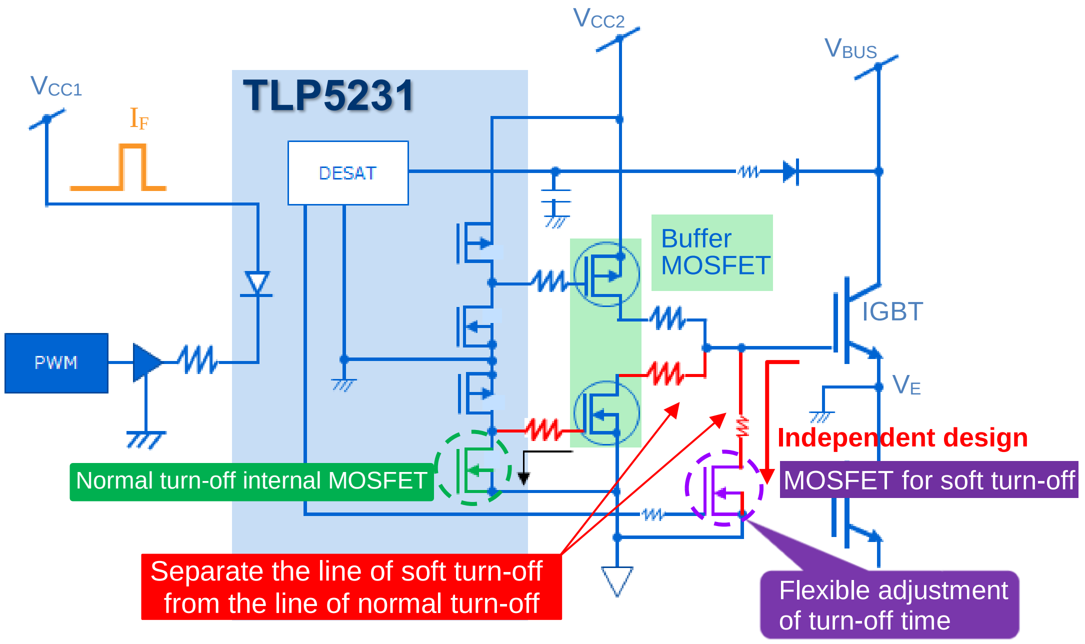


Fig. 5.6 Soft turn-off circuit connection

5.5. Protection Design (fault signal auto-reset)

The gate circuit of power device that control high voltage is very noisy and often results in misdetection of DESAT monitors. One example is stopping the system when a fault signal is detected more than once in order to separate the noise false positives and overcurrent caused by the fault. In this case, if the recovery from the abnormal stop is the auto-reset type, there is no need to issue a reset signal from the MCU every time for the fault signal. Simplify the operation by stopping the system after counting a specific number of fault signals. As a result, system operation stability is improved.

- Outputs a fault signal to the primary side when UVLO is detected and overcurrent is detected by the collector voltage (DESAT) monitor.
- Reset signal wiring from the controller is not required.

6. Example of Circuit Design Using TLP5231

6.1. Example of Inverter Application Circuit

Fig. 6.1 shows an example of inverter application circuit of TLP5231. Although there are three phases of U, V, and W, the circuit configuration is common to all phases, so the U phase is shown as a representative in Fig. 6.1.b and Fig. 6.1.c. Table 6.1 shows the output specifications of this circuit example.

Table 6.1 Output Specifications

Positive Power Supply (V_{CC2})	15	V
Negative Power Supply (V_{EE})	-8	V
Drive frequency	20	kHz

※ The drive frequency is affected by the wiring length connected to the motor. Check and adjust the frequency on the final product.

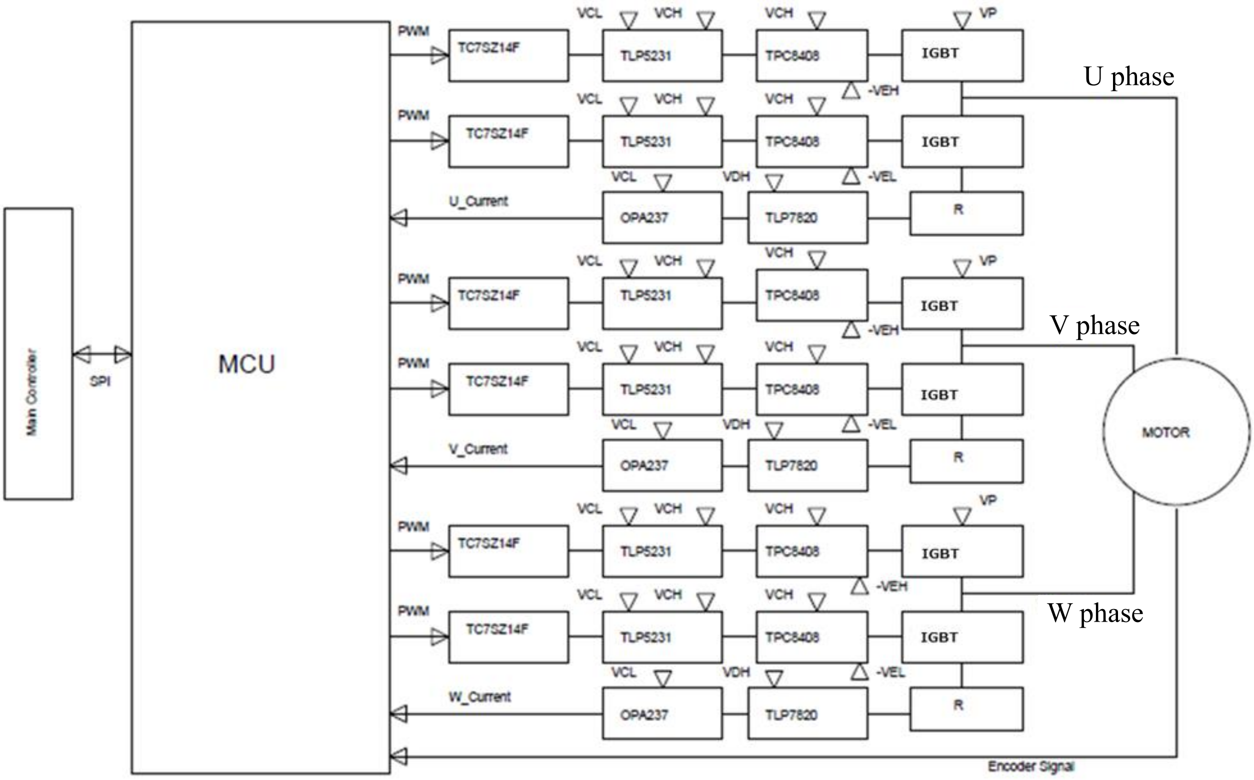


Fig. 6.1.a TLP5231 Inverter Application Block Diagram

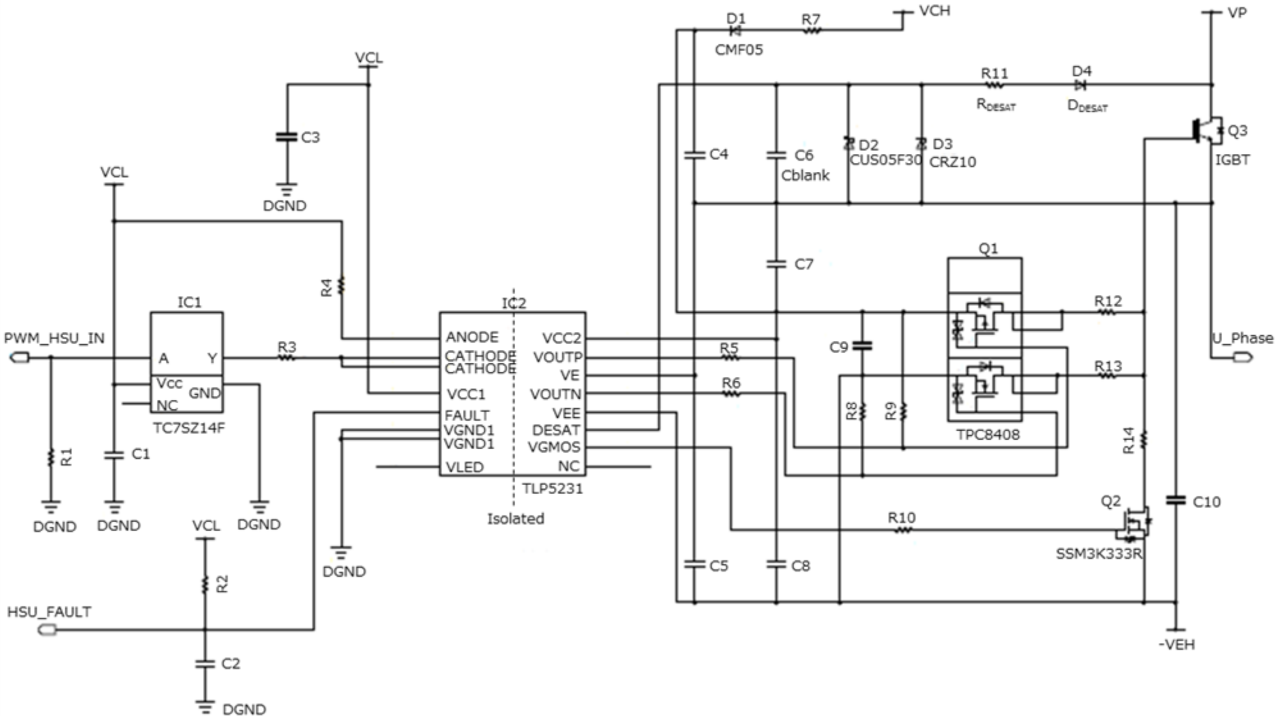


Fig. 6.1.b TLP5231 Inverter Application U-Phase (High Side)

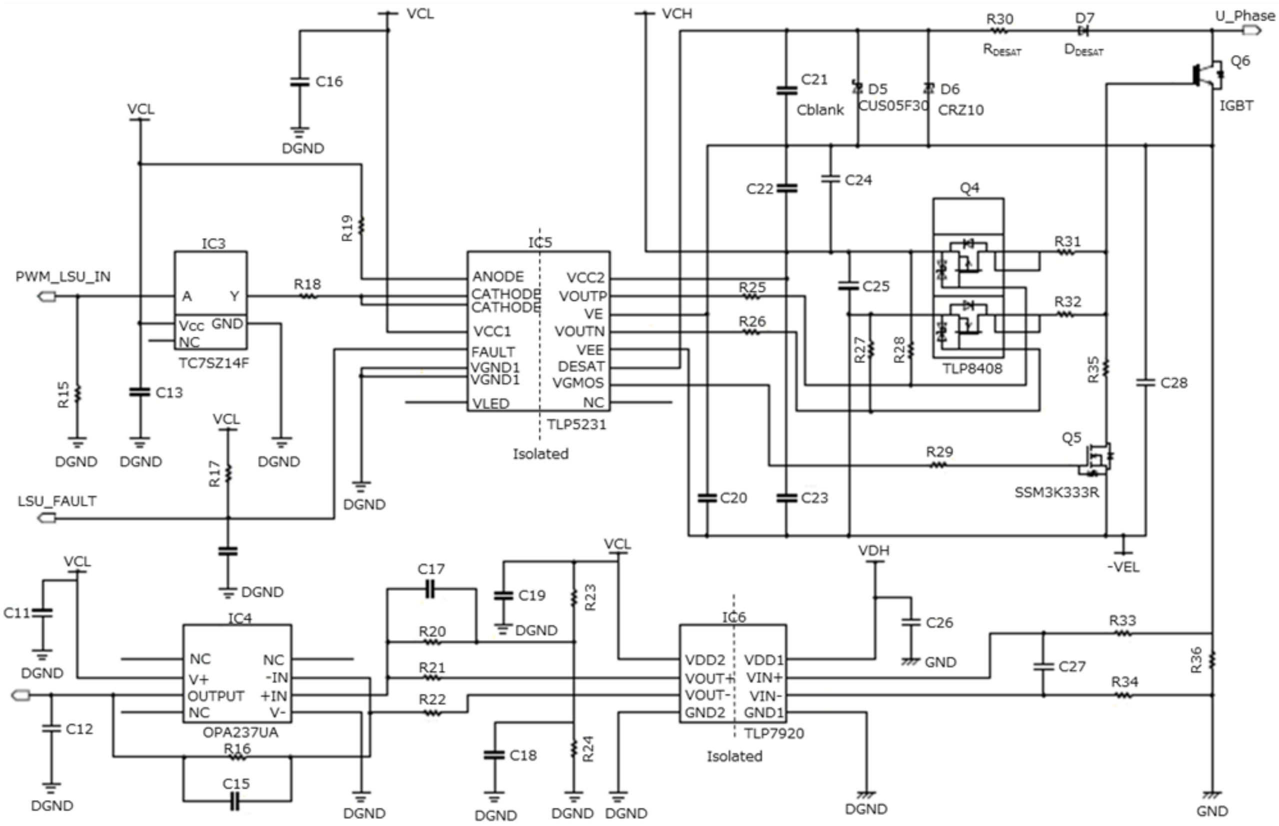


Fig. 6.1.c TLP5231 Inverter Application U-phase (Low Side)

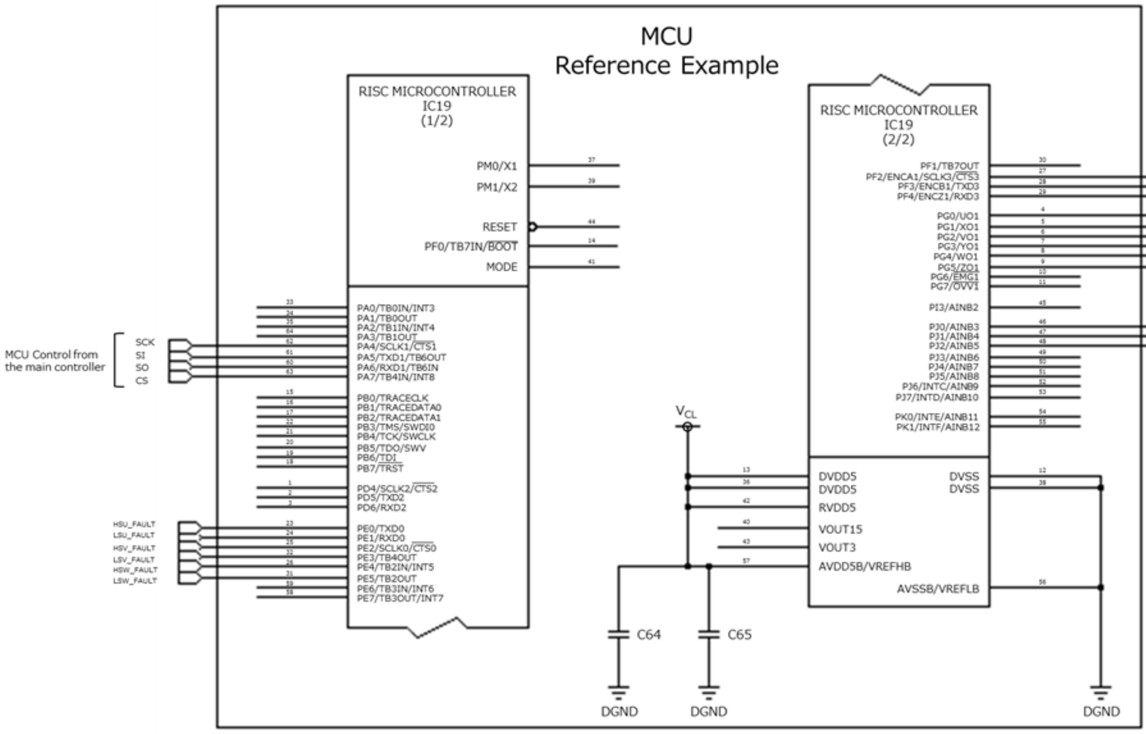


Fig. 6.1.d Typical MCU for TLP5231 Inverter Application

6.2. Selection of external MOSFET

The selection of the output current rating I_{pw_charge} of the external buffer MOSFET (Ext-PMOS, Ext-NMOS) for power device gate drive is calculated by the gate charge Q_g and charge-time t_{pw_charge} required to drive the power device.

$$I_{pw\_charge} = \frac{Q_g}{t_{pw\_charge}}$$

Consider driving IGBT of 1200V/600A. If Q_g is 3500 nC and the charge duration is 500 ns,

$$I_{pw\_charge} = \frac{3500nC}{500ns} = 7A$$

The peak current shall be about twice this value. Table 6.2 shows an example of selecting an external buffer MOSFET size and a MOSFET size for soft turn-off according to the power device you want to drive. Note that the withstand voltage of these MOSFET can be selected accordingly to the power supply voltage $|V_{CC2}\text{-}V_{EE}|$.

Table 6.2 External MOSFET Selection

Part number in the circuit diagram	Q3/Q6	Q1/Q4		Q2/Q5
Power device	**IGBT**	**Ext-PMOS**	**Ext-NMOS**	**GMOS**
Pattern 1	600V/ 50A (Q_g=300nC)	-2A(DC)	2A(DC)	2A(DC)
Pattern 2	1200V/ 200A (Q_g=2000nC)	-5A(DC)	5A(DC)	5A(DC)
Pattern 3	1200V/ 600A (Q_g=3500nC)	-10A(DC)	10A(DC)	10A(DC)

6.3. Selection of MOSFET for Soft Turn-off and Setting of Soft Turn-off Time

Use an external MOSFET(GMOS) to slowly shut off the gate after the short circuit of the power device ($V_{CE(sat)}$) is detected by DESAT terminal. Slowly turning off the gate suppresses the spike-voltage (=|L• di/dt|) caused by the parasitic inductance of the wire so as not to destroy the power device.

Since the power device gate charge must be pulled out, it is recommended to use an N-channel MOSFET with a gate voltage/drain current rating equivalent to that of Ext-NMOS as shown in Table 6.2 for the rating of MOSFET(GMOS) for soft turn-off.

The gate-voltage V_G of the power elements decreases exponentially with time, as shown in the following equation.

$$V_G = (V_{CC2} + |V_{EE}|) \times exp\left(\frac{-t}{C_{in} \times R_S}\right) - |V_{EE}|$$

Here,

t: Time, C_{in}: input capacitance of the power device, R_s: resistance between the gate of the power device and soft turn-off MOSFET

However, since the output voltage of the external buffer MOSFET is a full-swing operation, the default value is the power supply voltage, and $R_{DS(on)}$ of GMOS is sufficiently small to be ignored.

When C_{in}=40nF, R_s=180Ω, V_{CC2}=15V, V_{EE} =-8 V, V_G changes as shown in Fig. 6.2.

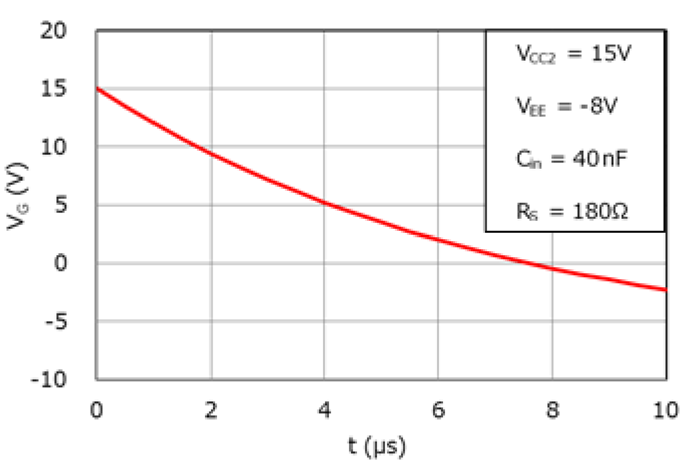


Fig. 6.2 Example of gate voltage change of power devices (soft turn-off)

If, for example, V_G is sufficiently lower than V_{th} of the power device and the time to drop to 2V is set to the soft turn-off time t_{STO}, the above equation is transformed,

$$t_{STO} = -C_{in} \times R_S \times \ln\left(\frac{2 + |V_{EE}|}{V_{CC2} + |V_{EE}|}\right) = -40nF \times 180\Omega \times \ln\left(\frac{2 + |-8|V}{15V + |-8|V}\right) ≒ \mathbf{6.0\mu s}$$

And t_{STO} can be calculated.

6.4. Setting the blanking capacitor charge current and DESAT detect voltage

DESAT monitoring circuit based on the blanking capacitor charge current I_{CHG} is calculated as follows.

If IGBT is taken as GT40QR21 and the designed collector current is taken as 20A, $V_{CE(SAT)}$ is estimated to be approximately 1.8 V from V_{GE}=15V curve in the Fig. 6.3. Note that V_{GE}=15V curve is selected as the minimum-gate design-voltage for typical IGBT. If V_F of DESAT Diode D_{DESAT} is 2.4V and I_{CHG} from DESAT terminal of TLP5231 is 540µA, R_{DESAT} is 3 k ohms, the voltage drops at DESAT terminal and V_E terminal (IGBT emitter potential) is:

$V_{DESAT(ON)} = V_{CE(SAT)} + V_{F(DDESAT)} + (R_{DESAT} \times I_{CHG})$

$= 1.8\ V + 2.4\ V + (3000\Omega \times 540\mu A) = 5.82\ V$

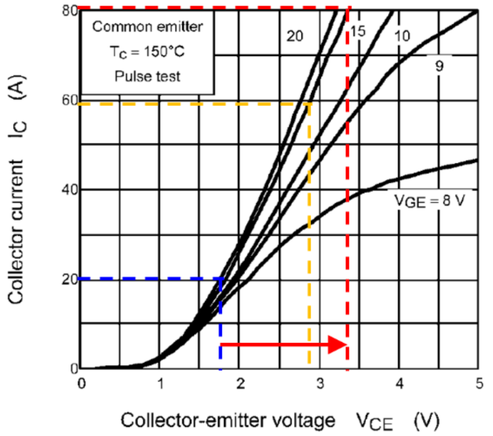


Fig. 6.3 Characteristic curve of I_C-V_{CE} in IGBT (GT40QR21)

If a short circuit occurs for some reason and the current flowing through IGBT increases along the static characteristics curve, $V_{DESAT(ON)}$ increases from 5.82V.

When this $V_{DESAT(ON)}$ exceeds 7.5V (min), TLP5231 judges it as abnormal and activates the protective function.

For V_{CE} of GT40QR21 at this time,

$V_{CE(SAT)} = V_{DESAT(ON)} - V_{F(DDESAT)} - (R_{DESAT} \times I_{CHG})$

$= 7.5V - 2.4V - 1.62V = 3.48V$

Therefore, after the collector current exceeds 80A from the static characteristic curve, it is recognized as a DESAT state and enters the protective operation.

6.5. Setting the Blanking Capacitor (C_{BLANK})

Section 4.3 explains how to set the blanking time t_{BLANK} shorter than IGBT short-circuit tolerance t_{SC}.

t_{BLANK} between the start of C_{BLANK} charging and the start of the protective operation is calculated from the saturation voltage $V_{CE(sat)}$ of IGBT and the forward voltage V_F of DESAT Diode and the voltage drop of R_{DESAT}.

$t_{BLANK} = \{C_{BLANK} \times (V_{DESAT(ON)} - (V_{CE(sat)} + V_F + I_{CHG} \times R_{DESAT}))\} / I_{CHG}$

Note that t_{BLANK} must be shorter than IGBT short-circuit tolerance t_{sc} along with the soft shutdown duration.

Referring to the case from the previous session, assuming that C_{BLANK} is 100pF

$t_{BLANK} = \{C_{BLANK} \times (V_{DESAT(ON)} - (V_{CE(sat)}+V_F+I_{CHG}\times R_{DESAT}))\}/I_{CHG}$

$= \{100pF \times (7.5V - (1.8V + 2.4V + 540\mu A \times 3k\Omega))\}/540\mu A$

$= \{100pF \times (7.5V - 5.82V)\} / 540\mu A = 0.31\mu s$

Since it is less than 1 µs, if the short-circuit tolerance is 5µs or more, there is no problem. For example, if C_{BLANK} is changed to 500pF and V_F is reduced to 1V for enhancing anti-noise measures,

$\{500pF \times (7.5V - (1.8V + 1.0V + 540\mu A \times 3k\Omega))\}/ 540\mu A$

$= \{500pF \times (7.5V - 4.42V)\} / 540\mu A = 2.85\mu s$

As it will be delayed above, care must be taken when designing.

7. Example of Operation Waveforms Using TLP5231

Using the power device shown in Table 7.1, external buffer MOSFET, and soft turn-off MOSFET, the circuit shown in Fig. 7.1 was used to evaluate the double-pulse operation. Double-pulse testing is a widely used technique for evaluating the switching properties of power devices such as MOSFET and IGBT. This time, we conducted a double-pulse test using TLP5231 as gate driver, and confirmed the switching waveform of IGBT. The circuit of the evaluation board is shown in Fig. 7.2, and the constant setting is shown in Table 7.2.

Table 7.1 Device used for operation test

Power device IGBT	Buffer MOSFET		MOSFET for soft turn-off GMOS
	Ext-PMOS	Ext-NMOS	
IGBT Module Made by Fuji Electric 7MBR150XRE120-50(1200V/ 150A)	TPC8407 $I_{D(MAX)}$=-7.4A	TPC8407 $I_{D(MAX)}$=9A	SSM3K333R $I_{D(MAX)}$=6A

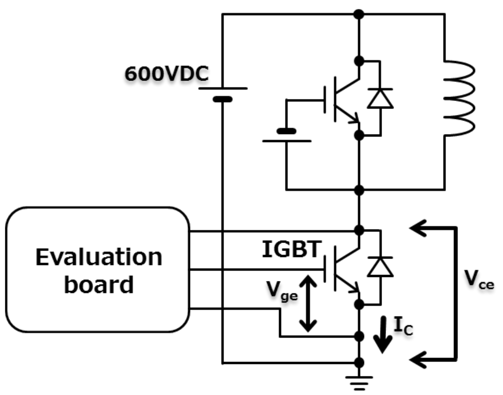


Fig. 7.1 Normal operation check circuit

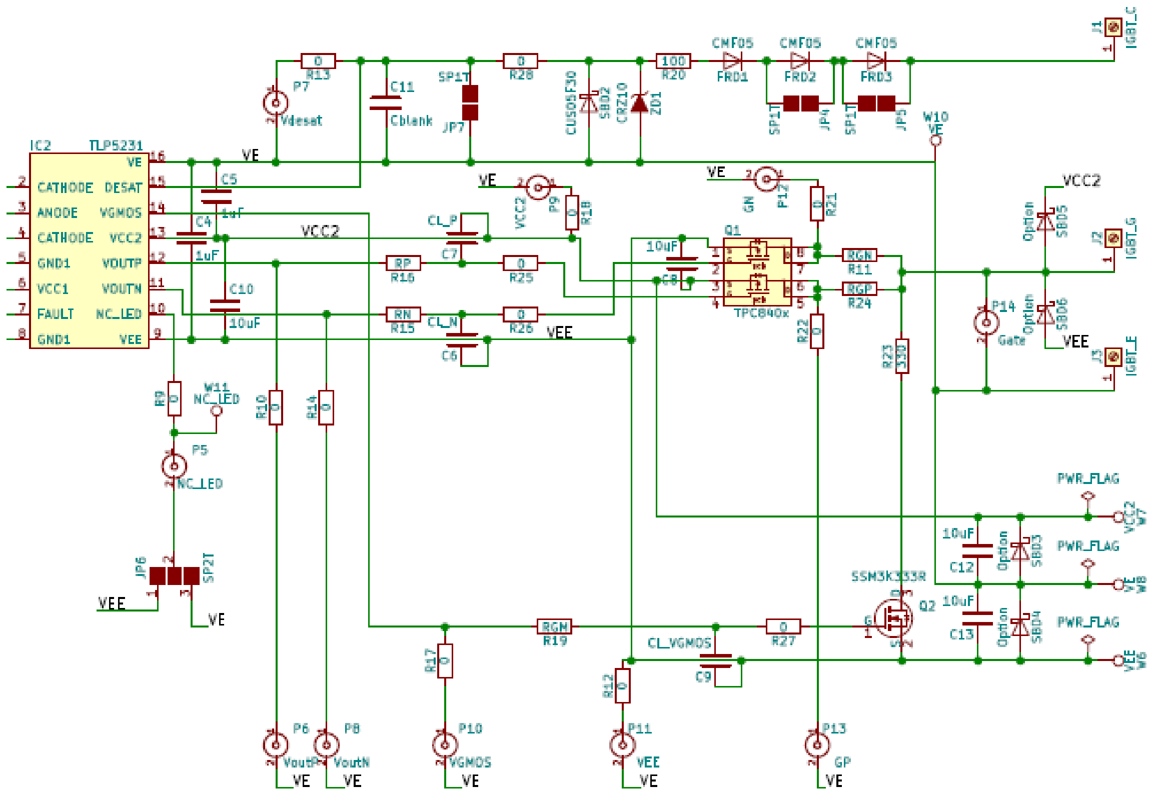


Fig. 7.2 Evaluation Board Circuit

Table 7.2 TLP5231 Evaluation board constant setting

Type	Part code	Constant	Unit	Remarks
Gate Positive Power Supply	V_{CC2}	15V	V	IGBT Positive Gate Supply Voltage
Gate negative power supply	V_{EE}	-15V	V	IGBT Negative Gate Power Supply Voltage
Resistance	R16	4.7	Ω	Buffer input resistor (P side) RP
Resistance	R15	4.7	Ω	Buffer input resistor (N side) RN
Resistance	R24	20	Ω	Gate resistor RGP for IGBT on
Resistance	R11	10	Ω	Gate resistor RGN for IGBT off
Resistance	R19	10	Ω	MOSFET gate resistor for soft turn-off
Resistance	R23	330	Ω	Gate resistor for IGBT soft turn-off
Resistance	R20	100	Ω	DESAT resistor
Capacitor	C11	100	pF	Blanking capacitor
Diode	FRD1	1000	V	CMF05(VRRM:1000V)
Diode	FRD2	1000	V	CMF05(VRRM:1000V)

Fig. 7.3 below shows the overall waveform of normal operation. Fig. 7.4 and Fig. 7.5 show the enlarged waveforms of the red frames (b) and (c).

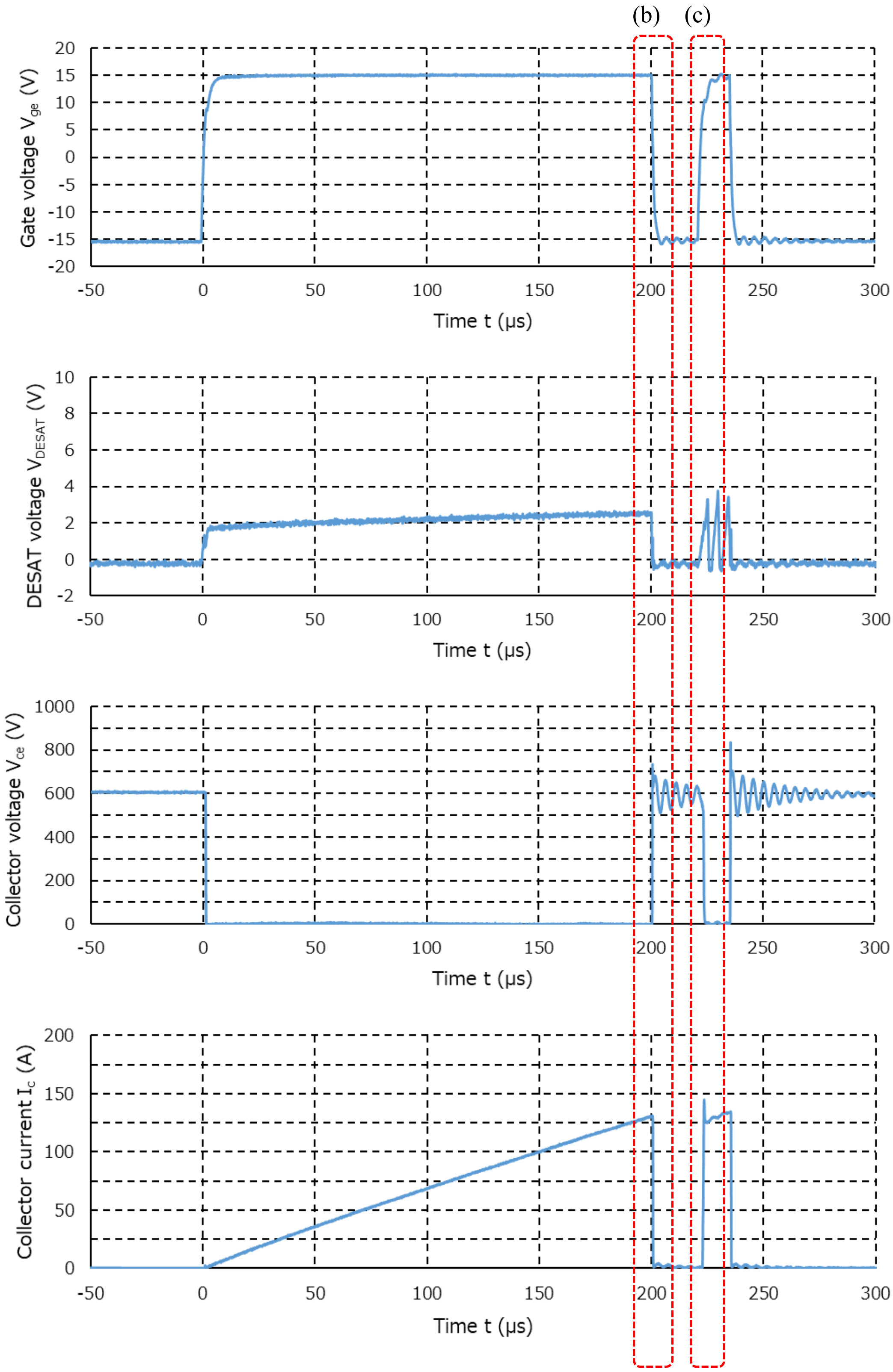


Fig. 7.3 Overall waveform of normal switching operation (a)

Fig. 7.4 below shows an enlarged waveform of the red frame (b).

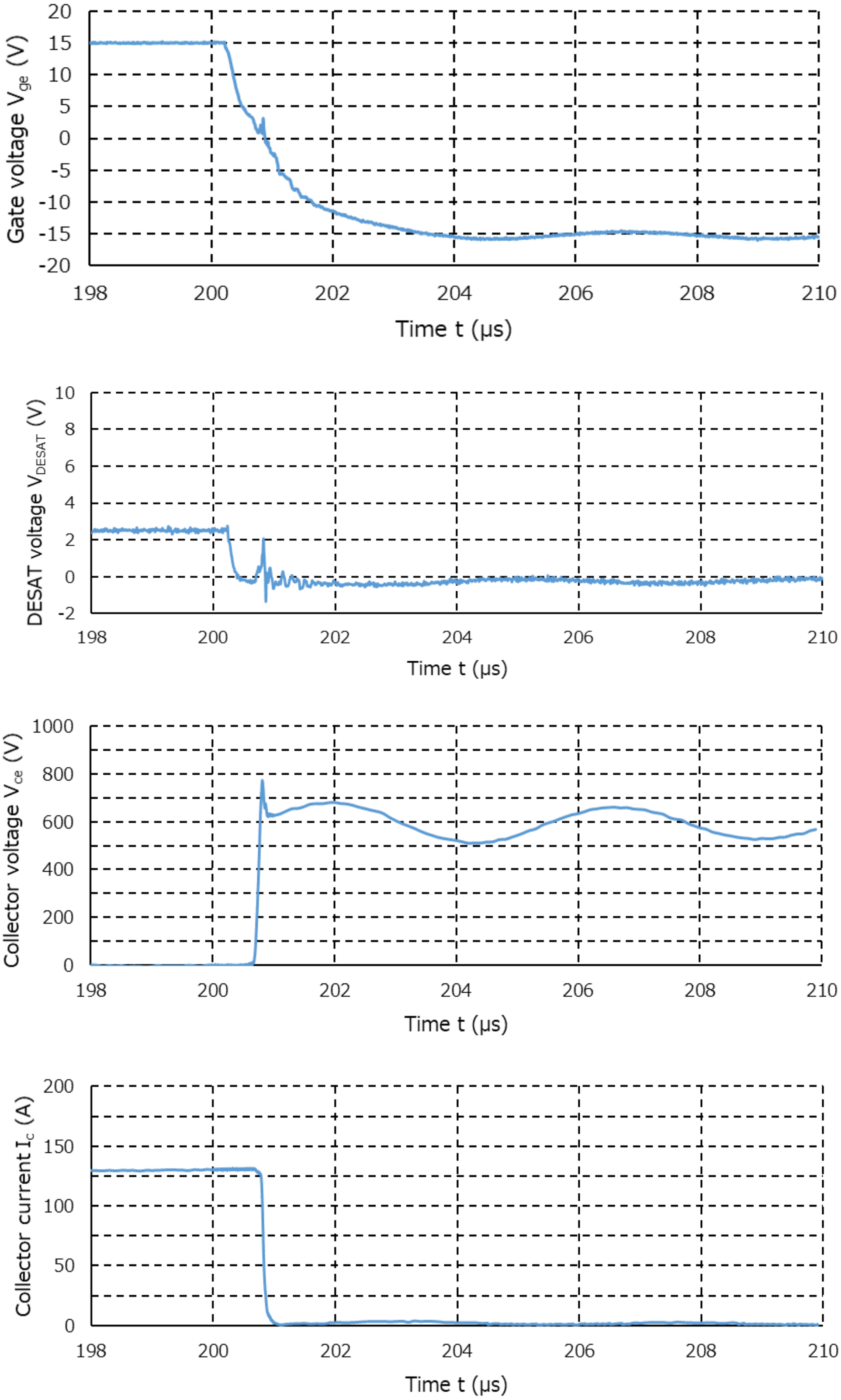


Fig. 7.4 Enlarged waveform (b)

Normal switching operation turn-off

Fig. 7.5 below shows a waveform obtained by enlarging the red frame (c) described above. No particular problems are found, and you can confirm that TLP5231 correctly drives the gate.

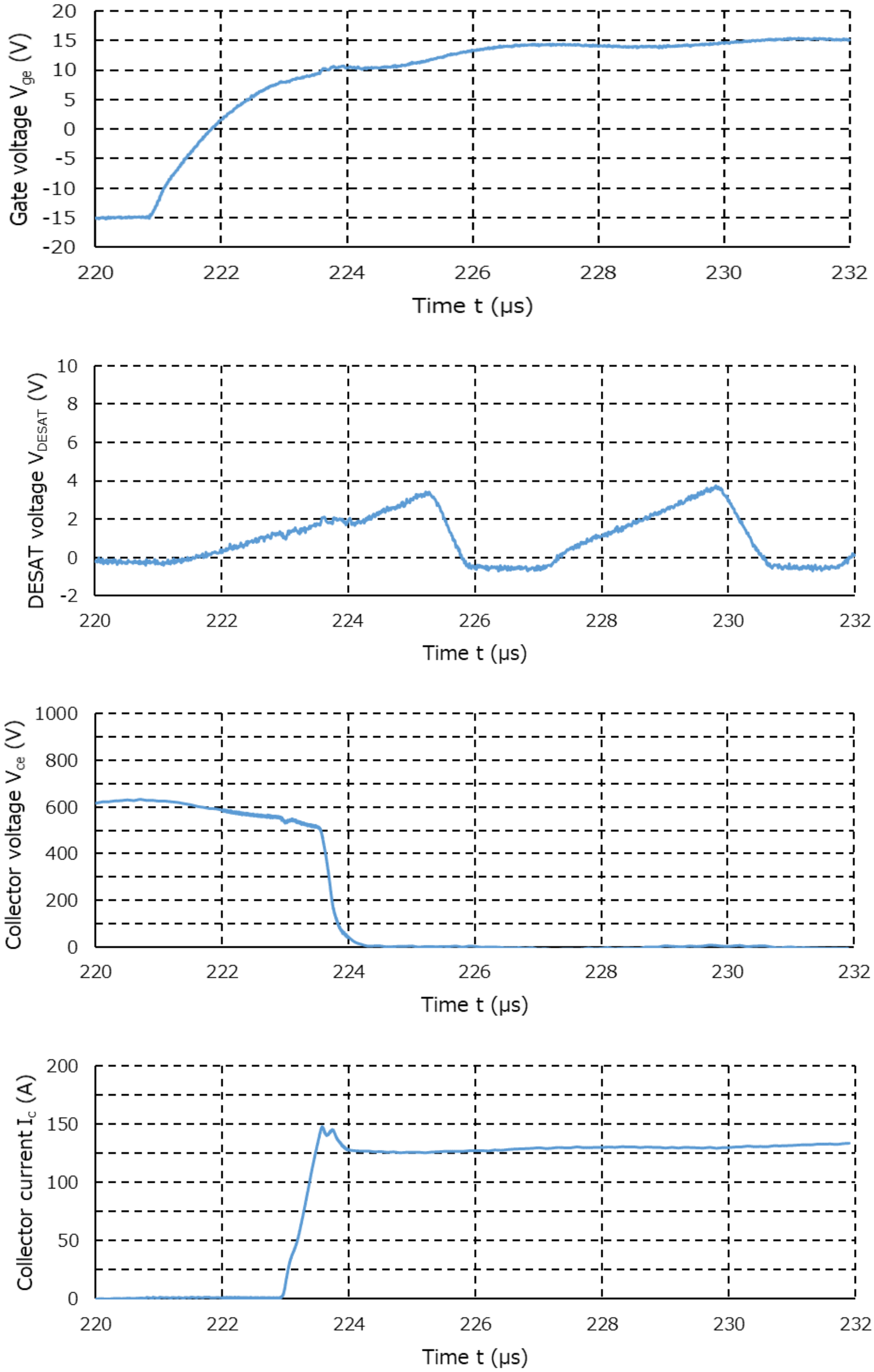


Fig. 7.5 Enlarged waveform (c)

Normal switching operation turn-on

We then verified the operation of IGBT short-circuit by the circuit shown in Fig. 7.6. Fig. 7.7 shows the verification waveform. Soft turn-off starts about 5μs after the short-circuit current flows, and it can be confirmed that the short-circuit protection operates normally without destruction of IGBT.

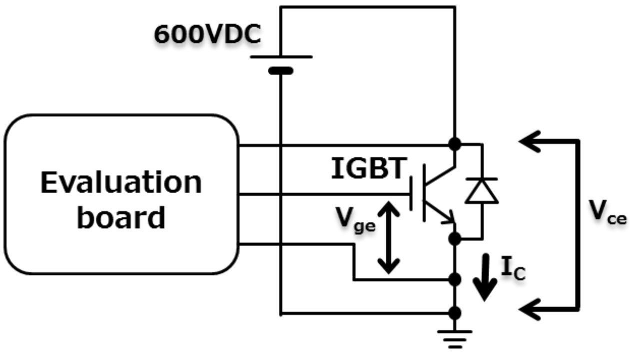


Fig. 7.6 IGBT Short-Circuit Protection Validation Circuit

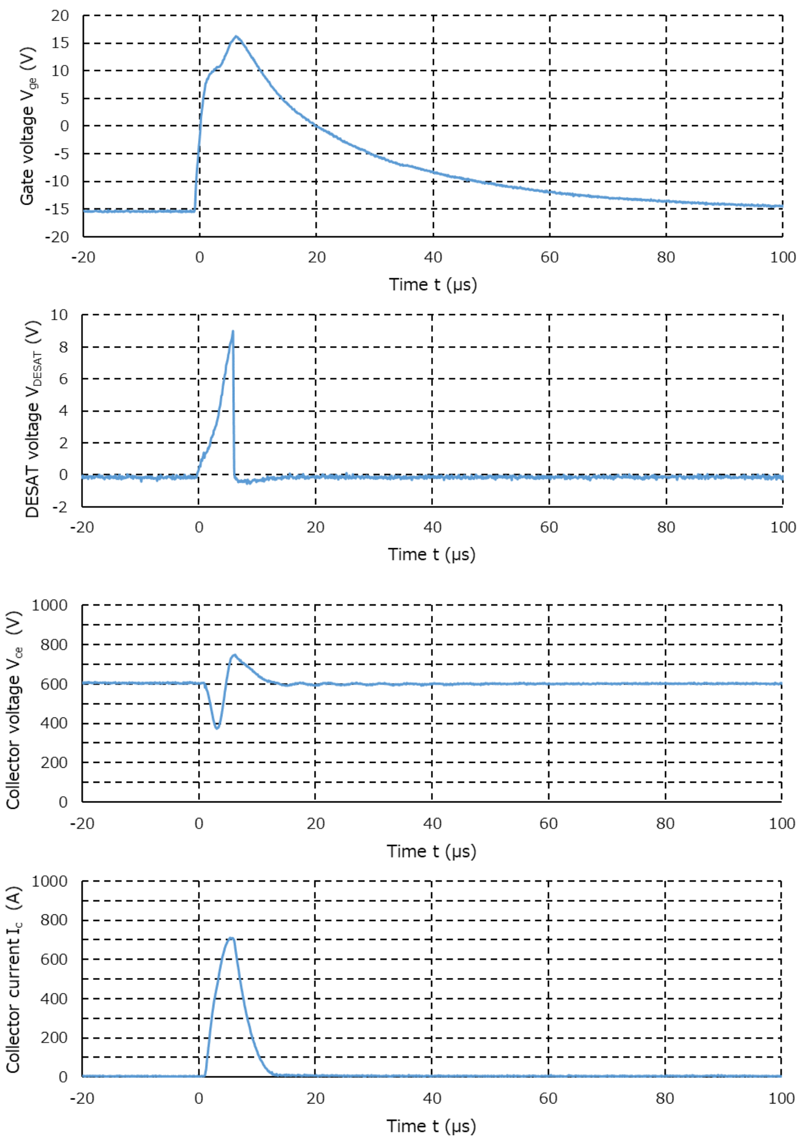


Fig. 7.7 IGBT Short-Circuit Protection Operation Waveform

Changelog

Version information	Date	Content of change
Rev. 1.0	2021-10-28	First edition

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