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STK541UC60C-E



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Application Note

1. Product synopsis

This application handbook is intended to provide practical guidelines for the **STK541UC60C-E** use.

The STK541UC60C-E is Intelligent Power Module (IPM) based upon ON's Insulated Metal Substrate Technology (IMST) for 3-phase motor drives which contain the main power circuitry and the supporting control circuitry. The key functions are outlined below:

- Highly integrated device containing all High Voltage (HV) control from HV-DC to 3-phase outputs in a single small SIP module.
- Output stage uses IGBT/FRD technology and implements Under Voltage Protection (UVP) and Over Current Protection (OCP) with a Fault Detection output flag. Internal Boost diodes are provided for high side gate boost drive.
- Externally accessible embedded thermistor for substrate temperature measurement.
- All control inputs and status outputs are at low voltage levels directly compatible with microcontrollers.
- Single control power supply due to Internal bootstrap circuit for high side pre-driver circuit.
- Mounting points are available on SIP package

A simplified block diagram of a motor control system is shown in Figure 1.

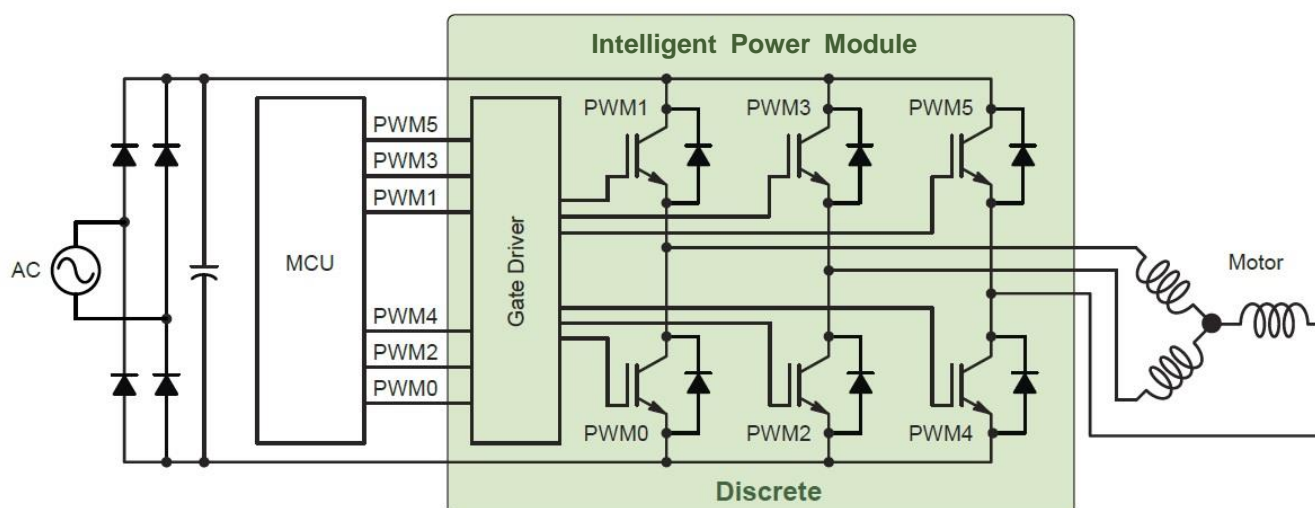


Figure 1. Motor Control System Block Diagram

2. Product description

Table1. gives an overview, for a detailed description of the packages refer to Chapter 6.

| | |
|-------------------|----------------------|
| Device | STK541UC60C-E |
| Feature | single shunt |
| Package | SIP1 – Vertical pins |
| Voltage (VCEmax.) | 600V |
| Current (Ic) | 10A |
| Peak current (Ic) | 20A |
| Isolation voltage | 2000V |
| Shunt resistance | 33mΩ |

Table 1. Device Overview

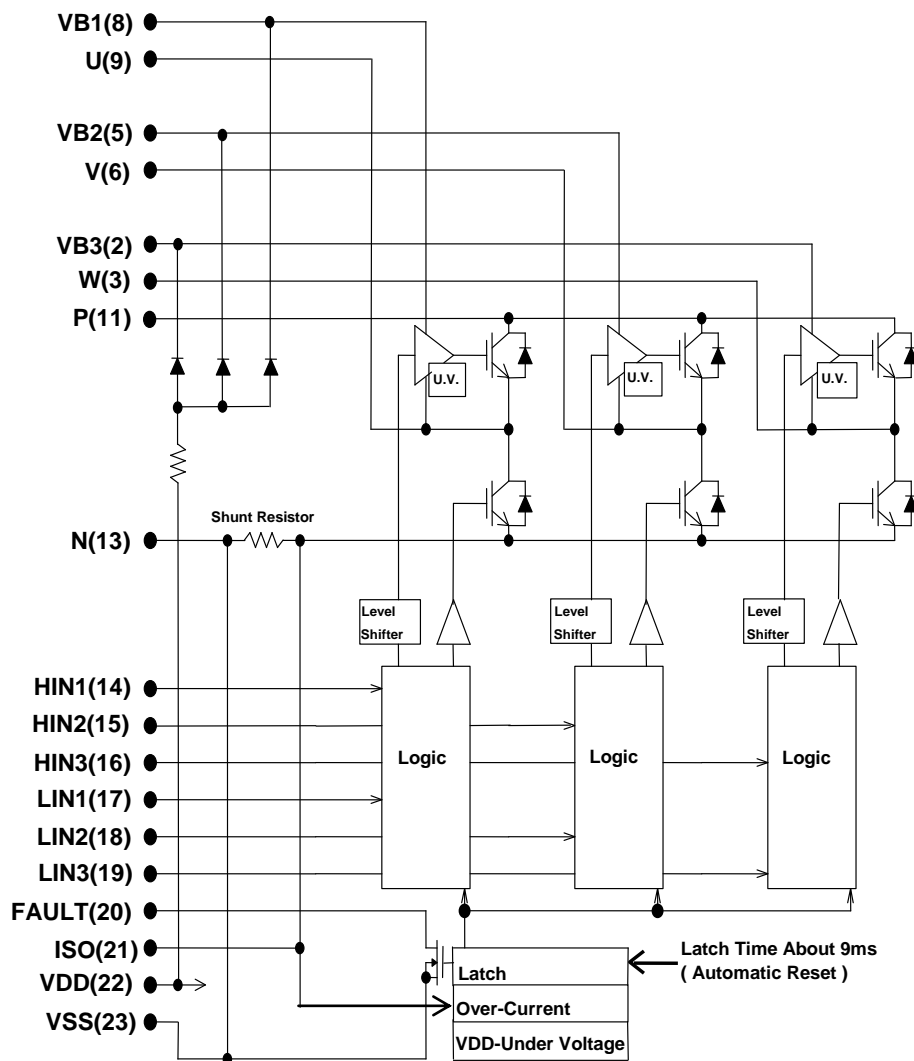


Figure 2. STK541UC60C-E equivalent circuits

The high side drive is used with a bootstrap circuit to generate the higher voltage needed for gate drive. The Boost diodes are internal to the part and sourced from VDD (15V). There is an internal level shift circuit for the high side drive signals allowing all control signals to be driven directly from Vss levels common with the control circuit such as the microcontroller without requiring external level shift such as opto isolators.

3. Performance test guidelines

The following Chapter gives performance test method shown in Figures 3 to 7.

3.1. Switching time definition and performance test method

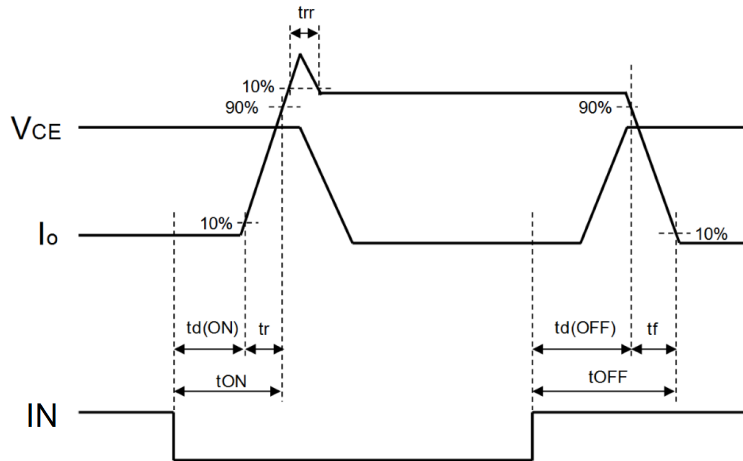


Figure 3. Switching time definition

Ex) Lower side U phase measurement

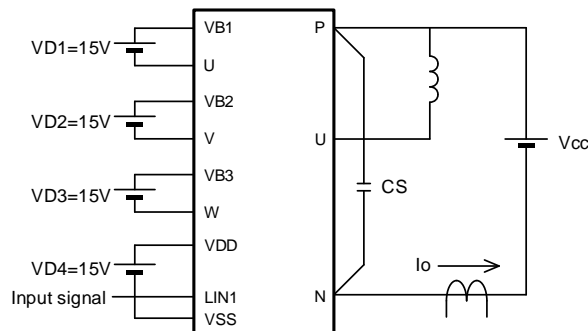


Figure 4. Evaluation circuit (Inductive load)

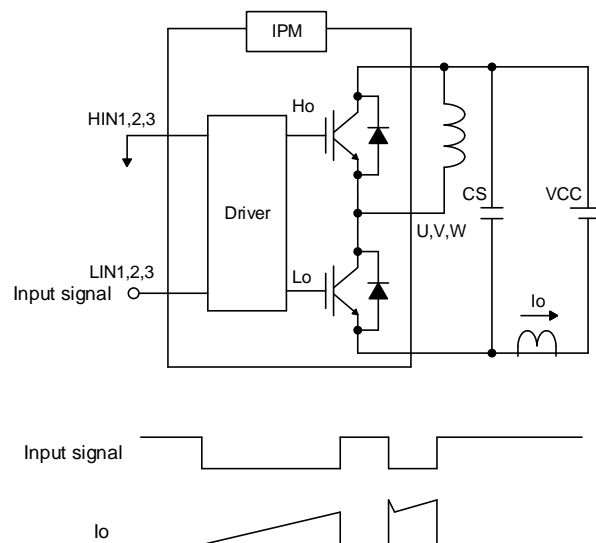


Figure 5. Switching loss circuit

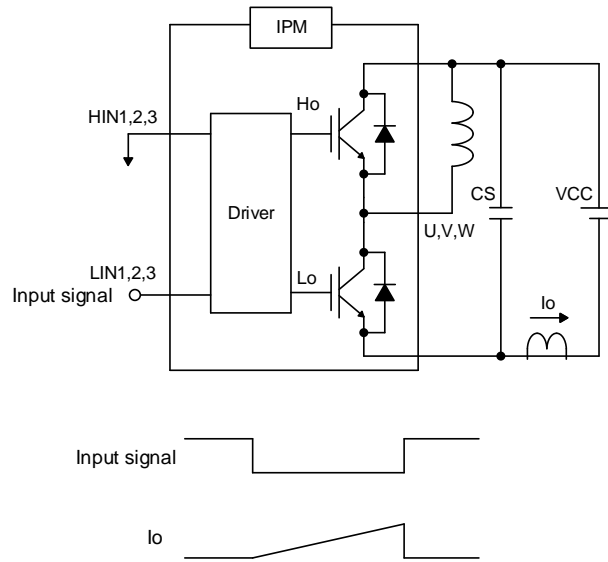


Figure 6. R.B.SOA circuit

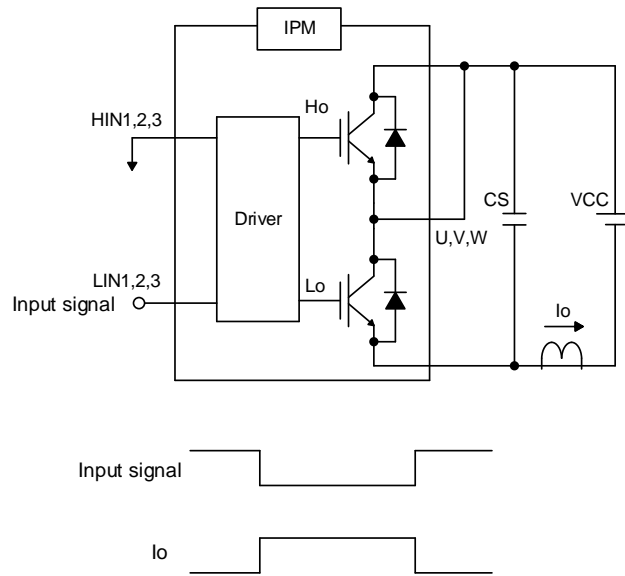


Figure 7. S.C.SOA circuit

4. Protective functions and Operation Sequence

This chapter describes the protection features.

- over current protection
- short circuit protection
- under Voltage Lockout (UVLO) protection
- cross conduction prevention

4.1. Over current protection

Over current protection is implemented by measuring the voltage across a shunt resistor to the negative supply terminal. In case of an OCP fault the gate drivers are shut down internally and the external Fault signal becomes active (low).

Once activated by a fault condition the FAULT signal output returns to inactive (and is pulled high by the external resistor) when the fault condition is over and the fault clear time (FLTCLR) has passed. This implies that the system microcontroller needs to disable all input signals to the module by driving them low upon detection of a fault condition.

Note 1: One should be aware that the “N” and the “VSS” pins are internally connected. Therefore an external short between these pins can cause the OCP level to be lower than desired.

Note 2: In order to prevent false OCP events due to switching noise and recovery current – a blanking time of some microseconds is implemented. This blanking time will also filter repetitive short high current pulses without tripping the OCP.

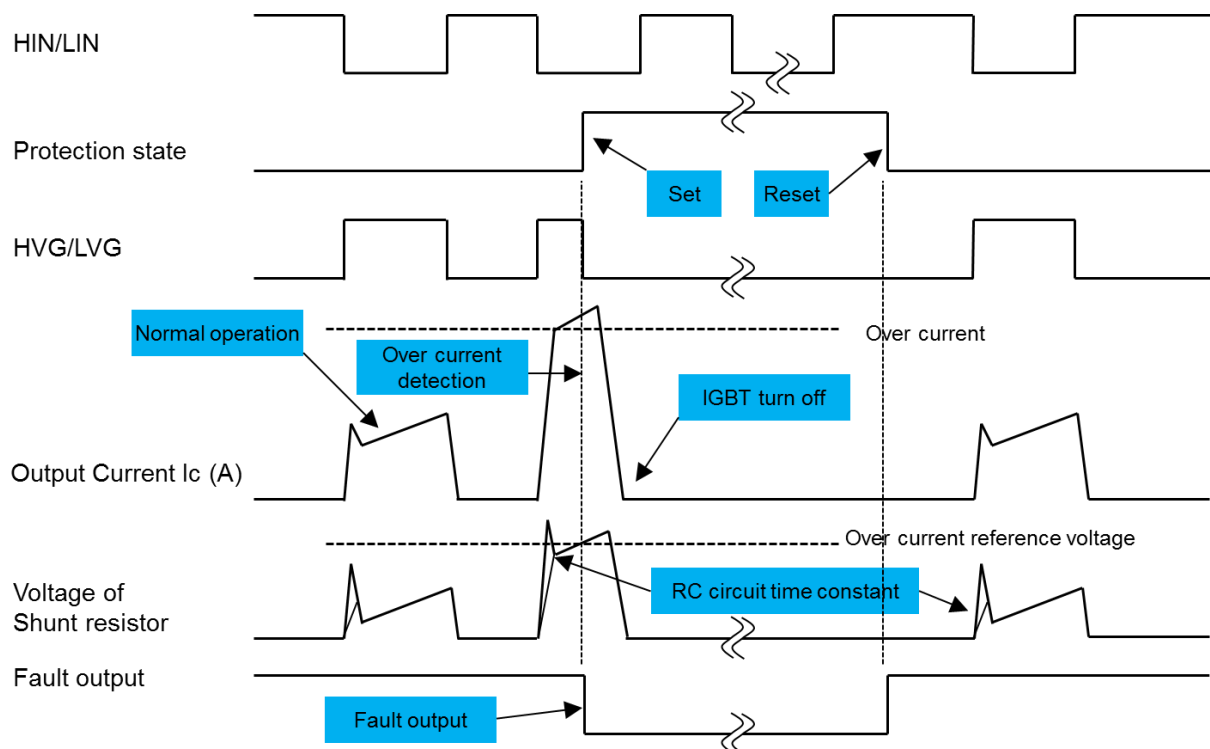


Figure 8. Over current protection Timing chart

4.2. Under Voltage Lockout Protection

The UVLO protection is designed to prevent unexpected operating behavior as described in Table 2. Both High-side and Low-side have UV protecting function. However the fault signal output only corresponds to the Low-side UVLO Protection. During the UVLO state the fault output is continuously driven (low).

| VDD Voltage (typ. Value) | Operation behavior |
|--------------------------|--|
| < 12.5V | As the voltage is lower than the UVLO threshold the control circuit is not fully turned on. A perfect functionality cannot be guaranteed. |
| 12.5 V – 13.5 V | IGBTs can work, however conduction and switching losses increase due to low voltage gate signal. |
| 13.5 V – 16.5 V | Recommended conditions |
| 16.5 V – 20.0 V | IGBTs can work. Switching speed is faster and saturation current higher, increasing short-circuit broken risk. |
| > 20.0 V | Control circuit is destroyed. Absolute max. rating is 20 V. |

Table 2. Module operation according to control supply voltage

The sequence of events in case of a low side UVLO event (IGBTs turned off and active fault output) is shown in Figure 9. Figure 10 shows the same for a high side UVLO (IGBTs turned off and no fault output).

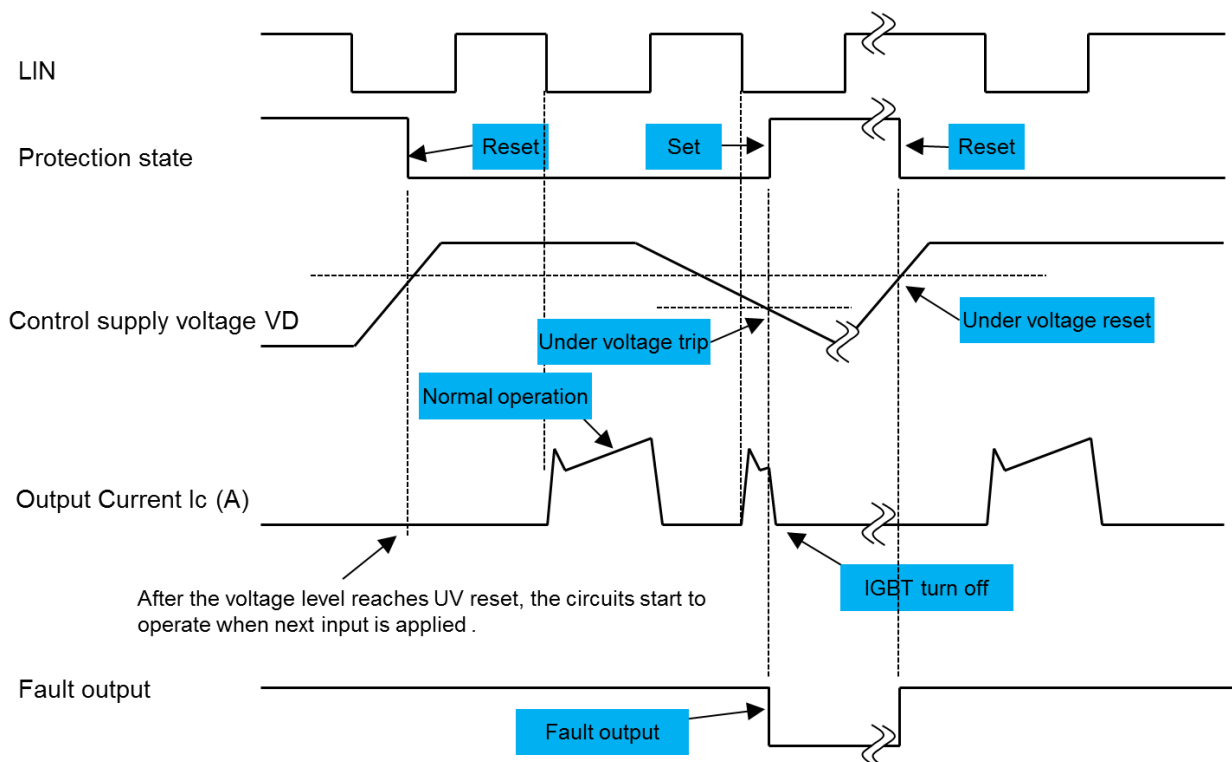


Figure 9. Low side UVLO timing chart

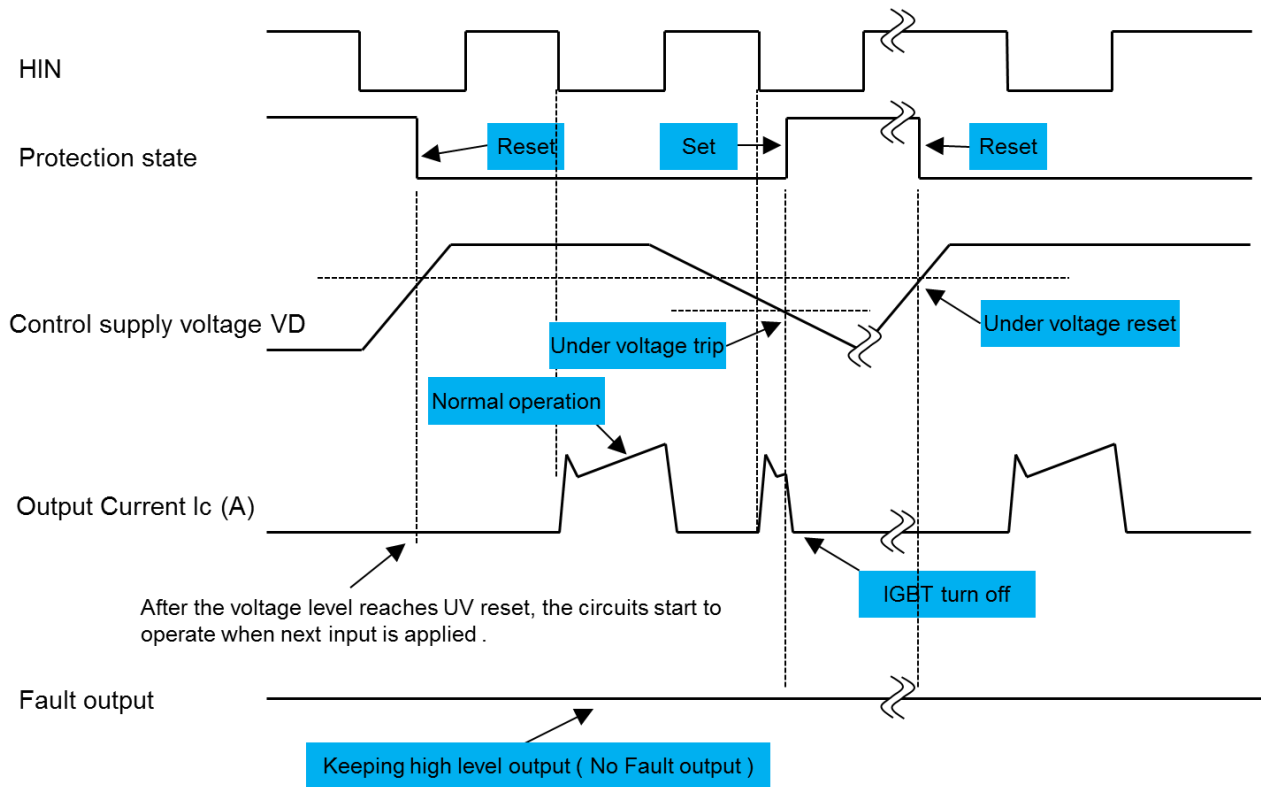


Figure 10. High side UVLO timing chart

4.3. Cross conduction prevention

The STK541UC60C-E module implement a cross conduction prevention logic at the pre-driver to avoid simultaneous drive of the low- and high-side IGBTs as shown in Figure 11.

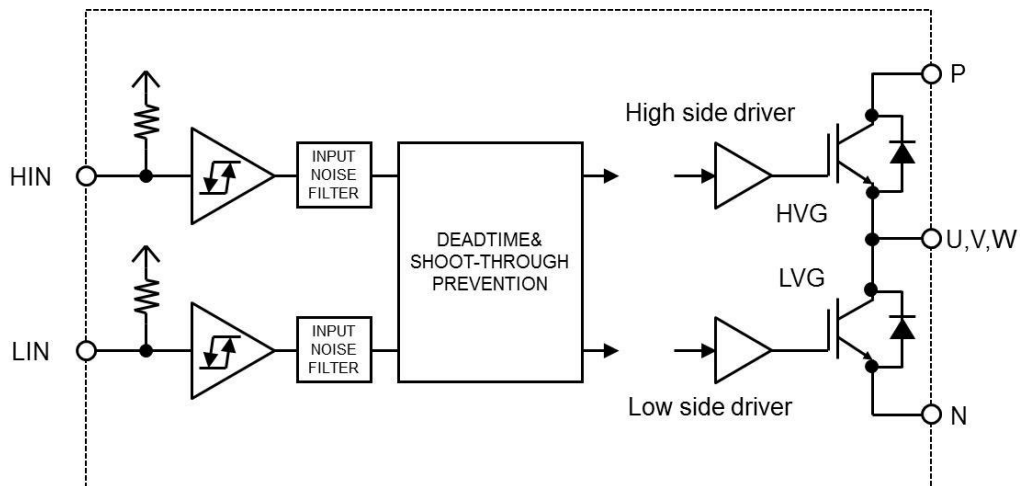


Figure 11. Cross Input Conduction Prevention

In case of both high and low side drive inputs are active (Low) the logic prevents both gates from being driven – a corresponding timing diagram can be found in Figure 12 below.

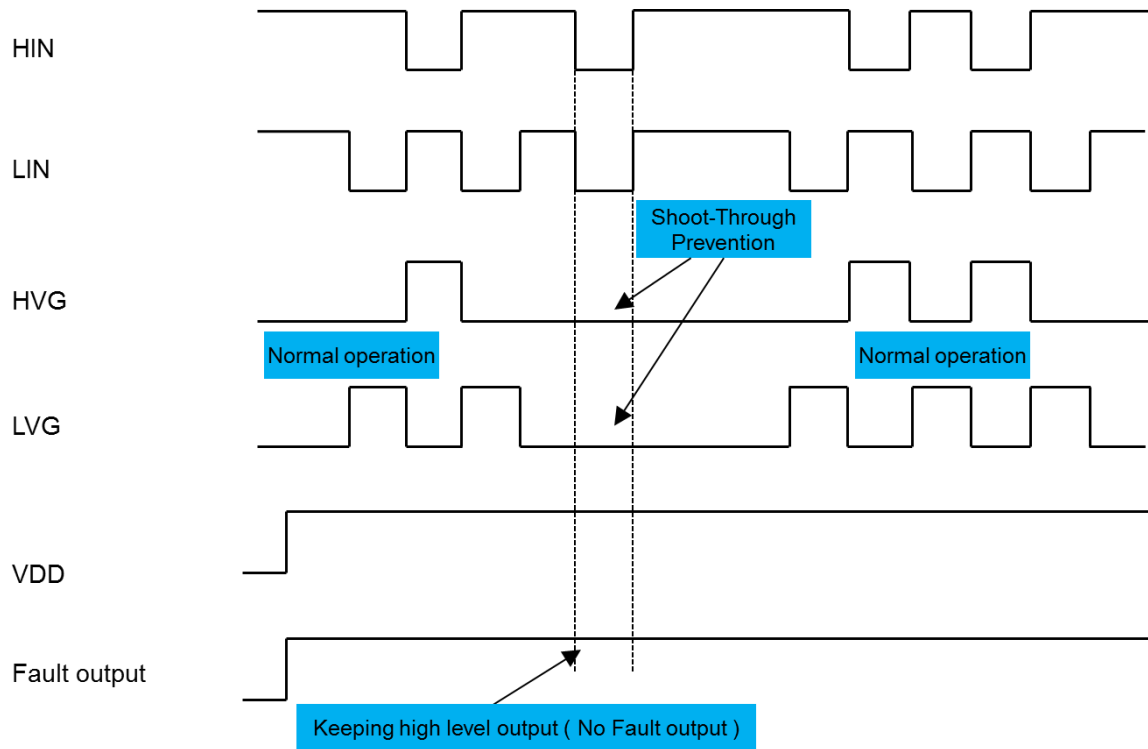


Figure 12. cross conduction prevention timing diagram

Even so cross conduction on the IGBTs due to incorrect external driving signals is prevented by the circuitry the driving signals (HIN and LIN) need to include a “dead time”. This period where both inputs are inactive between either one becoming active is required due to the internal delays within the IGBTs. Figure 13 shows the delay from the HIN-input via the internal HVG to high side IGBT, the similar path for the low side and the resulting minimum dead time which is equal to the potential shoot through period:

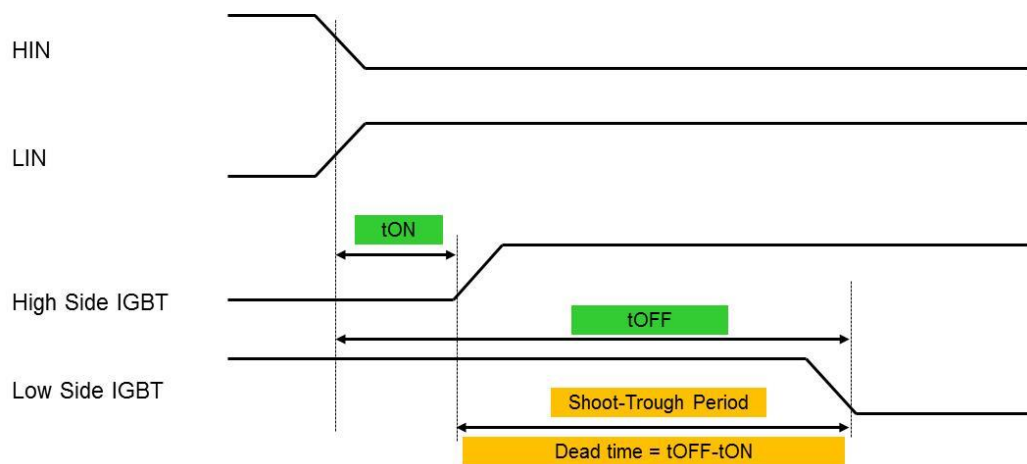


Figure 13. Shoot Trough Period

5. PCB design and mounting guidelines

This chapter provides guidelines for an optimized design and PCB layout as well as module mounting recommendations to appropriately handle and assemble the IPM.

5.1. Application (schematic) design

The following figure 14 gives an overview of the external circuitry's functionality when designing with the STK541UC60C-E module.

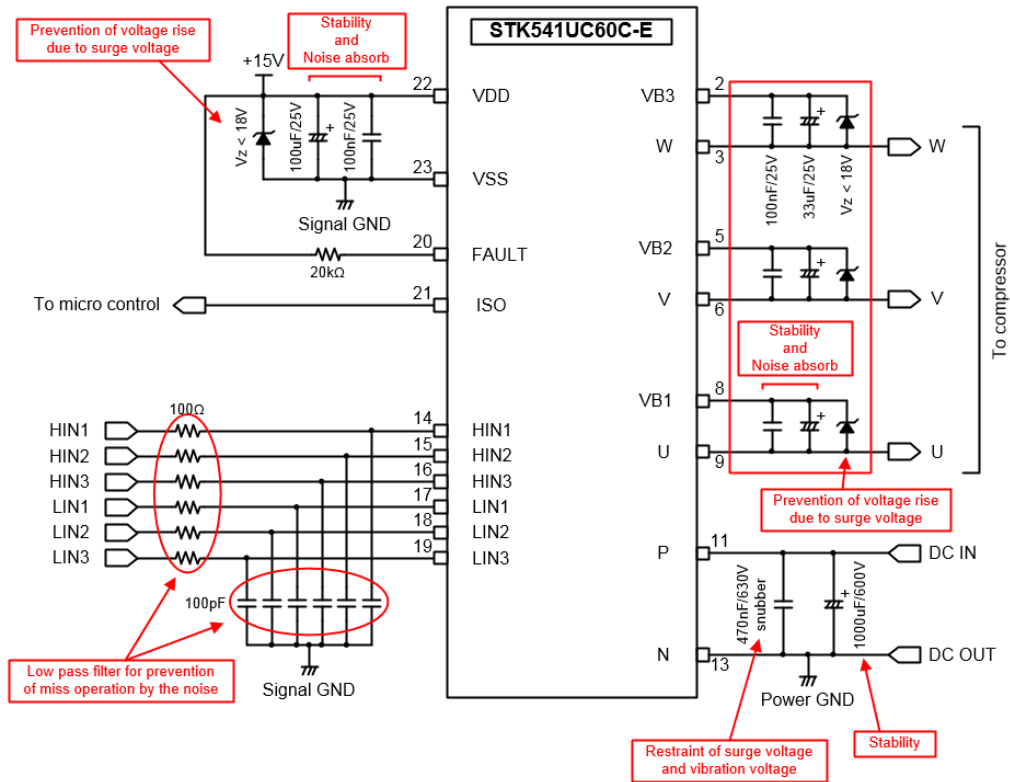


Figure 14. STK541UC60C-E application circuit

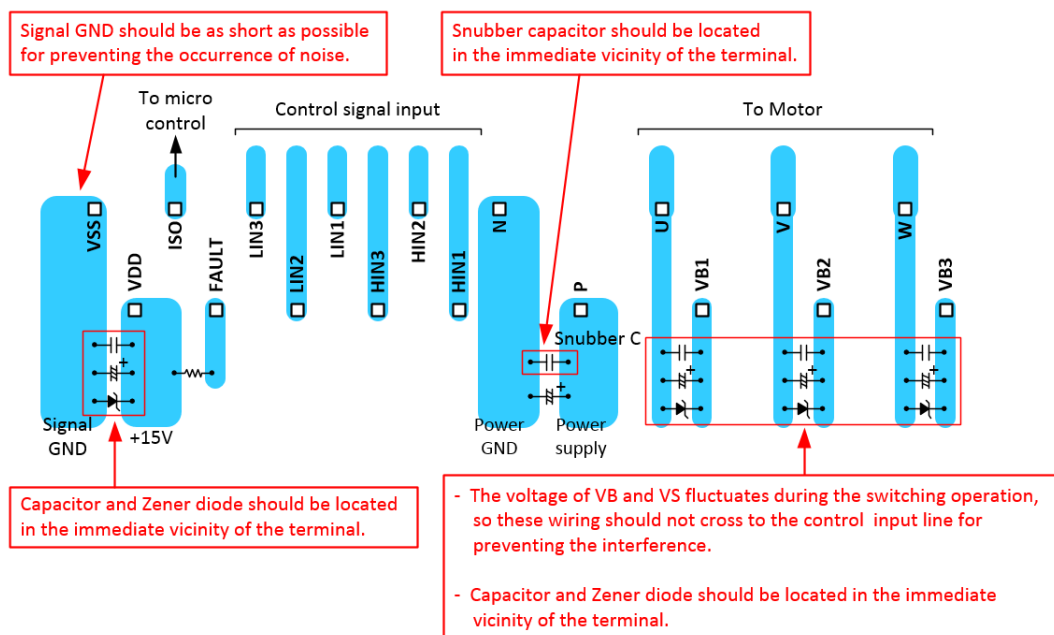


Figure 15. PCB design reference

5.2. Pin by pin design and usage notes

This section provides pin by pin PCB layout recommendations and usage notes. For a complete list of module pins refer to the datasheet or Chapter 6.

P , N These pins are connected with the main DC power supply. The applied voltage is up to the Vcc level. Overvoltage on these pins could be generated by voltage spikes during switching at the floating inductance of the wiring. To avoid this behavior the wire traces need to be as short as possible to reduce the floating inductance. In addition a snubber capacitor needs to be placed as close as possible to these pins to stabilize the voltage and absorb voltage surges.

U, V, W These terminals are the output pins for connecting the 3-phase motor. They share the same GND potential with each of the high side control power supplies. Therefore they are also used to connect the GND of the of the bootstrap capacitors. These bootstrap capacitors should be placed as close to the module as possible.

VDD, VSS These pins connect with the circuitry of the internal protection and pre-drivers for the low-side power elements and also with the control power supply of the logic circuitry. Voltage to input these terminals is monitored by the under voltage protection circuit. The VSS terminal is the reference voltage for the control inputs signals as well as Fault and ISO. VSS is connected with the “N” terminal internally. The main circuit does typically not draw current from VSS.

When the “N” and “VSS” pins are connected externally care must be taken to select a single connection point as close as possible to the IC. In case of multiple connections to these pins and longer traces being used, the overcurrent protection level may become low. Therefore this should be avoided.

VB1, VB2, VB3 The VBx pins are internally connected to the positive supply of the high-side drivers. The supply needs to be floating and electrically isolated. The boot-strap circuit shown in Figure 16 forms this power supply individually for every phase. Due to integrated boot resistor and diode (RB & DB) only an external boot capacitor (CB) is required.

CB is charged when the following two conditions are met.

- ① Low-side signal is input
- ② Motor terminal voltage is low level

The capacitor is discharged while the high-side driver is activated.

Thus CB needs to be selected taking the maximum on time of the high side and the switching frequency into account.

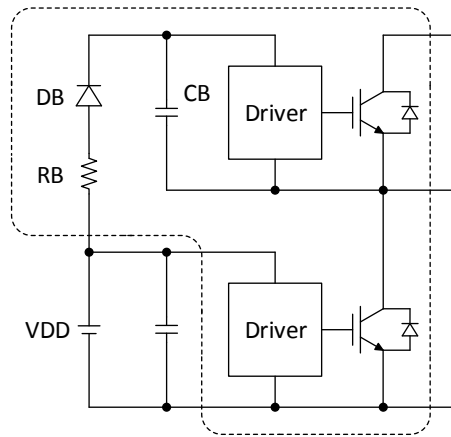


Figure 16. Boot Strap Circuit

The voltages on the high side drivers are individually monitored by the under voltage protection circuit. In case an UVP event is detected on a phase its operation is stopped.

Typically a CB value of less or equal 47uF ($\pm 20\%$) is used. In case the CB value needs to be higher an external resistor (of apx. 20 Ω or less) should be used in series with the capacitor to avoid high currents which can cause malfunction of the IPM.

HIN1, LIN1, HIN2, LIN2, HIN3, LIN3

These pins are the control inputs for the power stages. The inputs on HIN1/HIN2/HIN3 control the high-side transistors of U/V/W, and the inputs on LIN1/LIN2/LIN3 control the low-side transistors of U/V/W respectively. The input are active Low and the input thresholds V_{IH} and V_{IL} are 5V compatible to allow direct control with a microcontroller system

Simultaneous activation of both low and high side is prevented internally to avoid shoot through at the power stage. However, due to IGBT switching delays the control signals must include a dead-time.

The equivalent input stage circuit is shown in Figure 17.

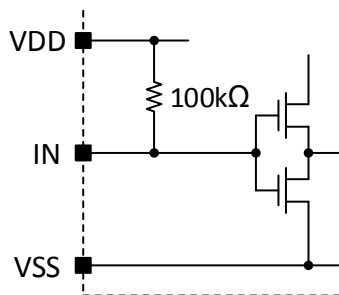


Figure 17. Internal Input Circuit

For fail safe operation the control inputs are internally tied to VDD via a 100k Ω (typ) resistor.

The output might not respond when the width of the input pulse is less than 1 μ s (both ON and OFF).

Fault

The Fault pin is an active low input and open-drain output. It is used to indicate an internal fault condition of the module and also can be used to disable the module operation. The I/O structure is shown in Figure 18.

The internal sink current I_{oSD} during an active fault is nominal 2mA @ 0.1V. Depending on the interface supply voltage the external pull-up resistor (R_P) needs to be selected to set the low voltage below the VIL trip level.

For the commonly used supplies V_P :

$V_P = 15V \rightarrow R_P \geq 20k\Omega$

$V_P = 5V \rightarrow R_P \geq 6.8k\Omega$

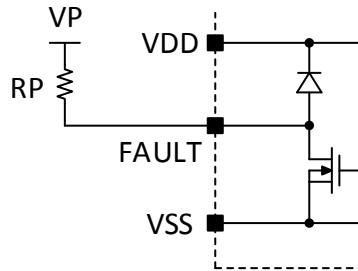


Figure 18. Fault Connection

For a detailed description of the fault operation refer to Chapter 4.

Note: The Fault signal does not latch permanently. The modules operation is automatically re-started after the causing protection event end and after the minimum of the fault timeout(6ms). Therefore the input needs to be driven low externally activated as soon as a fault is detected.

ISO

The ISO pin allows monitoring the output voltage of the integrated current sense amplifier. This pin is usually left unconnected. Any external circuitry needs to have an impedance higher than 5.6k Ω .

Note: In case this pin is shorted to VSS – current sensing will not function.

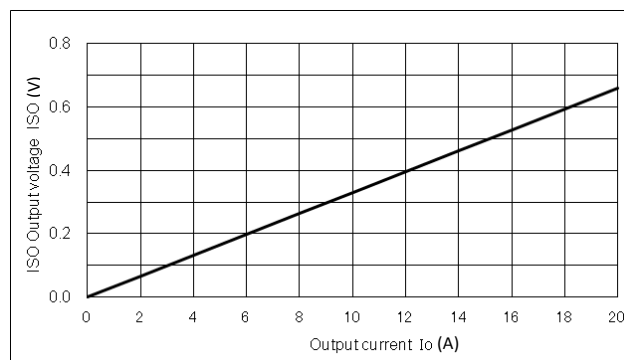


Figure 19. The output current (I_o) vs ISO characteristics

5.3. Heat sink mounting and torque

If a heat sink is used, insufficiently secure or inappropriate mounting can lead to a failure of the heat sink to dissipate heat adequately. This can lead to an inability of the device to provide its inherent performance, a serious reduction in reliability, or even destruction, burst and burn of the device due to overheating.

The following general points should be observed when mounting IPM on a heat sink:

1. Verify the following points related to the heat sink:
 - There must be no burrs on aluminum or copper heat sinks.
 - Screw holes must be countersunk.
 - There must be no unevenness in the heat sink surface that contacts IPM.
 - There must be no contamination on the heat sink surface that contacts IPM.
2. Highly thermal conductive silicone grease needs to be applied to the whole back (aluminum substrate side) uniformly, and mount IPM on a heat sink. Upon re-mounting apply silicone grease(100um to 200um) again uniformly.
3. For an intimate contact between the IPM and the heat sink, the mounting screws should be tightened gradually and sequentially while a left/right balance in pressure is maintained. Either a bind head screw or a truss head screw is recommended. Please do not use tapping screw. We recommend using a flat washer in order to prevent slack. The standard heat sink mounting condition of an STK541UC60C-E is as follows.

| Item | Recommended Condition |
|-----------|--|
| Pitch | 56.0±0.1mm (Please refer to Package Outline Diagram) |
| Screw | diameter : M3 Bind machine screw, Truss machine screw, Pan machine screw |
| Washer | Plane washer The size is D:7mm, d:3.2mm and t:0.5mm (Fig.2) JIS B 1256 |
| Heat sink | Material : copper or Aluminum Warpage (the surface that contacts IPM) : -50 to 100 μm Screw holes must be countersunk. No contamination on the heat sink surface that contacts IPM. |
| Torque | Final tightening : 0.6 to 0.9Nm Temporary tightening : 20 to 30 % of final tightening |
| Grease | Silicon grease Thickness : 100 to 200 μm Uniformly apply silicon grease to whole back. (Fig.3) |

Table 3. heat sink mounting

Fig 1 : mount IPM on a Heat Sink

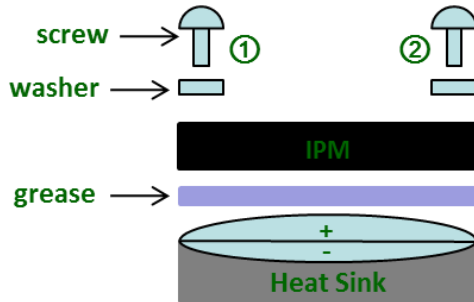


Fig 2 : size of washer

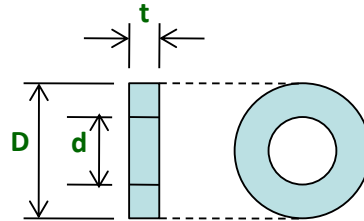
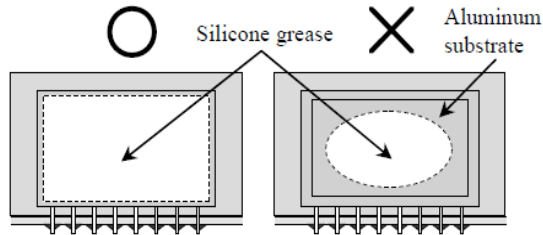


Fig 3 : About uniformly application



Steps to mount an IPM on a heat sink

1st: Temporarily tighten maintaining a left/right balance.

2nd : Finally tighten maintaining a left/right balance.

5.4. Mounting and PCB considerations

In designs in which the printed circuit board and the heat sink are mounted to the chassis independently, use a mechanical design which avoids a gap between IPM and the heat sink, or which avoids stress to the lead frame of IPM by an assembly that a moving IPM is forcibly fixed to the heat sink with a screw.

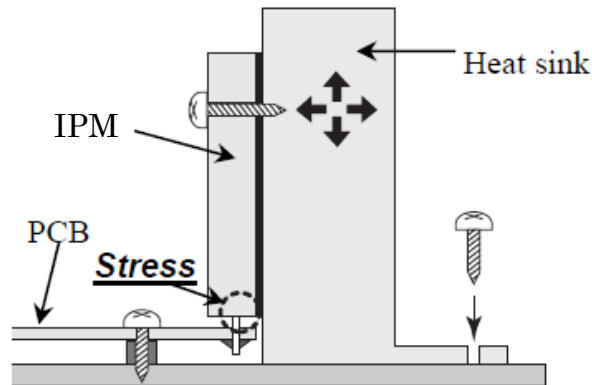
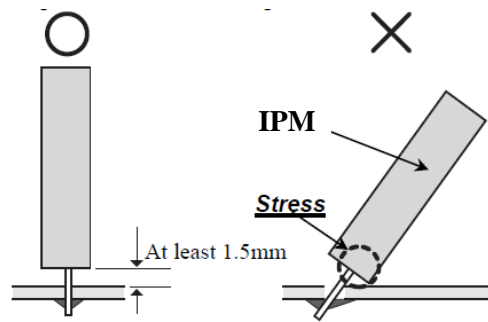


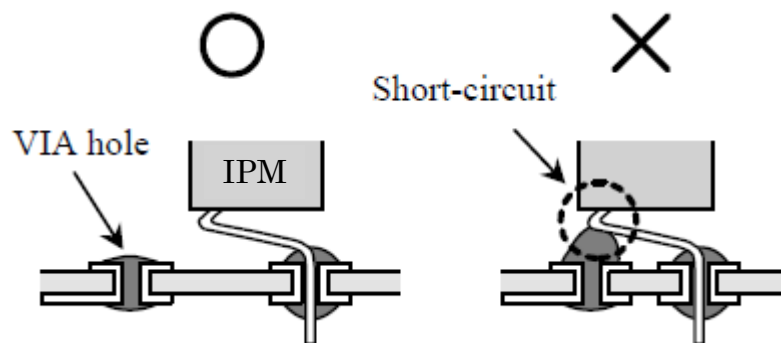
Figure 20. Fix to Heat Sink

Maintain a separation distance of at least 1.5 mm between the IPM case and the printed circuit board. In particular, avoid mounting techniques in which the IPM substrate or case directly contacts the printed circuit board.

Do not mount IPM with a tilted orientation. This can result in stress being applied to the lead frame and IPM substrate could short out tracks on the printed circuit board. Always mount the IPM vertically. If stress is given by compulsory correction of a lead frame after the mounting, a lead frame may drop out. Be careful of this point.



When designing the PCB layout take care that the bent part portion of the lead frame pins does not short-circuit to VIA holes or tracks on the PCB.



Since the use of sockets to mount IPM can result in poor contact with IPM leads, we strongly recommend making direct connections to PCB.

IPMs are flame retardant. However, under certain conditions, it may burn, and poisonous gas may be generated or it may explode. Therefore, the mounting structure of the IPM should also be flame retardant.

Mounting on a Printed Circuit Board

1. Align the lead frame with the holes in the printed circuit board and do not use excessive force when inserting the pins into the printed circuit board. To avoid bending the lead frames, do not try to force pins into the printed circuit board unreasonably.
2. Do not insert IPM into printed circuit board with an incorrect orientation, i.e. be sure to prevent reverse insertion. IPM may be destroyed, exploded, burned or suffer a reduction in their operating lifetime by this mistake.
3. Do not bend the lead frame.

5.5. Cleaning

IPM has a structure that is unable to withstand cleaning. As a basic policy, do not clean independent IPM or printed circuit boards on which an IPM is mounted.

6.2. Pin Out Description

| Pin | Name | Description |
|-----|-------|---|
| 1 | NA | none |
| 2 | VB3 | High Side Floating Supply Voltage 3 |
| 3 | W | Output 3 - High Side Floating Supply Offset Voltage |
| 4 | NA | none |
| 5 | VB2 | High Side Floating Supply voltage 2 |
| 6 | V | Output 2 - High Side Floating Supply Offset Voltage |
| 7 | NA | none |
| 8 | VB1 | High Side Floating Supply voltage 1 |
| 9 | U | Output 1 - High Side Floating Supply Offset Voltage |
| 10 | NA | none |
| 11 | P | Positive Bus Input Voltage |
| 12 | NA | none |
| 13 | N | Negative Bus Input Voltage |
| 14 | HIN1 | Logic Input High Side Gate Driver - Phase 1 |
| 15 | HIN2 | Logic Input High Side Gate Driver - Phase 2 |
| 16 | HIN3 | Logic Input High Side Gate Driver - Phase 3 |
| 17 | LIN1 | Logic Input Low Side Gate Driver - Phase 1 |
| 18 | LIN2 | Logic Input Low Side Gate Driver - Phase 2 |
| 19 | LIN3 | Logic Input Low Side Gate Driver - Phase 3 |
| 20 | Fault | Fault Signal Output |
| 21 | ISO | Current Sensing Monitor |
| 22 | VDD | +15V Control Power Supply |
| 23 | VSS | Negative Control Power Supply |

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