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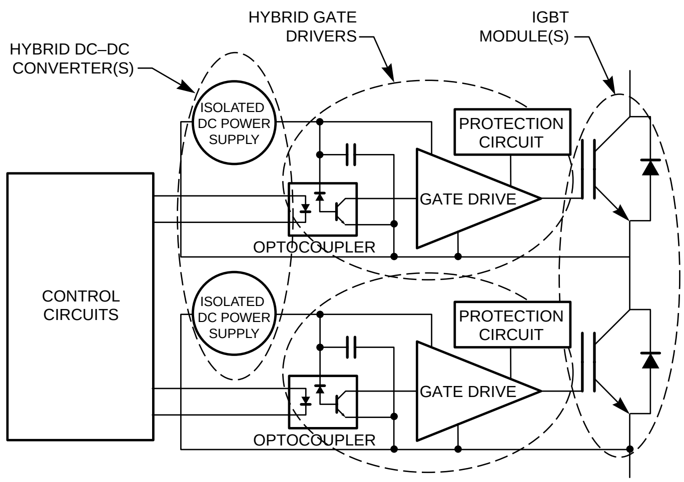
5.0 Driving IGBT Modules

When using high power IGBT modules it is often desirable to completely isolate control circuits from the gate drive. A block diagram of this type of gate drive is shown in Figure 5.1. This circuit provides isolation for logic level control and fault feedback signals using optocouplers and separate isolated floating power supplies for each gate drive circuit. There are a number of advantages to this type of gate drive topology including:

(1) Stable on and off drive driving voltages that are independent of the power device switching frequency and duty.
(2) Easily adapted to provide very high output currents for large IGBT modules.
(3) Power circuit switching noise and high voltages are isolated from control circuits.
(4) Local power is available for protection circuits such as desaturation detectors.

To help simplify design of fully isolated gate drive circuits Powerex has developed a family of hybrid circuits that provide the required gate drive, short circuit protection, and isolated power for efficient reliable operation of Powerex IGBT modules.

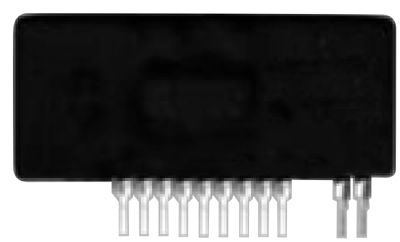
Figure 5.1 Fully Isolated Gate Drive



5.0.1 Hybrid Gate Drivers

Powerex offers seven hybrid SIP (single-in-line-package) circuits for IGBT module gate drive. All seven devices provide isolation for control input signals by means of built in high speed opto-couplers. The opto-couplers have been selected to provide 2500V_{RMS} isolation and immunity to power circuit common mode transient noise of better than 15kV/µs. This feature allows convenient common referencing of high and low side control signals. The high speed opto-isolation is designed for applications with operating frequencies up to 30kHz. The hybrid gate drivers feature output stages designed to provide the pulse currents necessary for efficient switching of Powerex IGBT modules. All drivers are designed to provide a substantial off state bias of -5V to -12V in order to insure robust noise immunity. Hybrid gate drivers simplify gate drive design by minimizing the number of components required. In addition to high performance gate drive many of the drivers also provide short circuit protection. Table 5.1 lists the key features and typical application range for Powerex's family of hybrid gate drivers. Figure 5.2 is a photograph of an M57962L gate driver with built in short circuit protection.

Figure 5.2 M57962L Gate Driver



5.0.2 Hybrid Power Supplies

In order to simplify the task of generating isolated power supplies for hybrid gate drivers Powerex has developed two isolated DC-to-DC converters. The characteristics of these DC-to-DC converters are summarized in Table 5.2. Powerex DC-to-DC converters are designed with minimum interwinding capacitance in order to minimize dv/dt coupled noise. The M57145L-01 is a single-in-line isolated DC-to-DC converter that produces a regulated +15.8V/-8.2V output from an input of 12V to 18V DC. A photograph of the M57145L-01 is shown in Figure 5.3. The M57994-01 generates five isolated outputs which can supply isolated power for multiple gate drivers in single and three phase bridge topologies. The M57994-01 also provides an additional +/-15V auxiliary supply to power system control circuits such as hall effect sensors.

5.1 Basic Gate Drivers (M57957L, M57958L)

Powerex offers two basic opto-isolated hybrid gate drivers. These drivers consist of a high speed opto-coupler for input signal isolation followed by a current boosting output stage. The output stage is designed to provide the high pulse currents necessary for efficient switching of high current IGBT modules.

Figure 5.3 M57145L-01

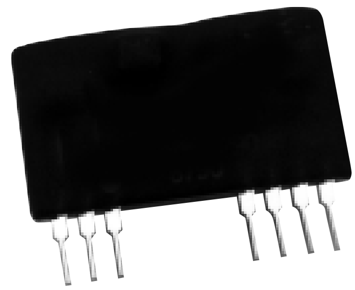


Table 5.1 Recommended Gate Driver Applications

Type	Protection Scheme	Soft Shutdown	Output Current	Recommended Application (Module Type and Ratings)	Usable Application Range* (Module Type and Ratings)
M57957L	None	NA	+/-2.0A	600V up to 150A 1200V, 1400V, 1700V up to 75A U-Series, H-Series and K-Series	600V up to 300A 1200V, 1400V, 1700V up to 150A U-Series, H-Series and K-Series
M57958L	None	NA	+/-5.0A	600V up to 300A 1200V, 1400V, 1700V up to 150A U-Series, H-Series and K-Series	600V up to 600A 1200V, 1400V, 1700V up to 300A U-Series, H-Series and K-Series
M57159L-01	Desaturation Detection	Yes	+/-1.5A	600V up to 100A 1200V, 1400V, 1700V up to 50A U-Series, H-Series and K-Series	600V up to 300A 1200V, 1400V, 1700V up to 150A U-Series, H-Series and K-Series
M57959L	Desaturation Detection	Yes	+/-2.0A	600V up to 150A 1200V, 1400V, 1700V up to 75A U-Series, H-Series and K-Series	600V up to 300A 1200V, 1400V, 1700V up to 150A U-Series, H-Series and K-Series
M57962L	Desaturation Detection	Yes	+/-5.0A	600V up to 300A 1200V, 1400V, 1700V up to 150A U-Series, H-Series and K-Series	600V up to 600A 1200V, 1400V, 1700V up to 300A U-Series, H-Series and K-Series
M57962CL-01	Desaturation Detection	Adjustable	+/-5.0A	600V up to 300A 1200V, 1400V, 1700V up to 150A U-Series, H-Series and K-Series	600V up to 600A 1200V, 1400V, 1700V up to 300A U-Series, H-Series and K-Series
M57160AL-01	RTC Detection	Adjustable	+/-5.0A	600V up to 300A 1200V up to 150A F-Series	600V up to 600A 1200V up to 300A F-Series

*The usable range depends on the application's operating frequency. For highest swithing efficiency with modules outside the recommended range a booster range can be added as shown in Section 5.7 to increase the peak output current.

Table 5.2 Isolated DC-to-DC Converter Power Supplies

Type	Input Voltage	Output Voltages	Output Current	Isolation Voltage
M57145L-01	12V - 18V	1 x +15.8V/-8.2V	100mA	2500VRMS
M57994-01	10V - 32V	4 x +15V/-8.5V 1 x +15V/-15V	100mA 200mA	Primary to Secondary 2500VRMS Secondary to Secondary 1500 VRMS

5.1.1 Application Circuit for M57957L and M57958L

An internal schematic and example application circuit for the M57957L and M57958L are shown in Figures 5.4 and 5.5. For optimum performance parasitic inductance in the gate drive loop must be minimized. This is accomplished by connecting the 47µF decoupling capacitors as close as possible to the pins of the hybrid driver and by minimizing the lead length between the drive circuit and the IGBT. The zeners shown should be rated at about 18 volts and be connected as close to the IGBT's gate as possible. These zeners protect the gate during switching and short circuit operation.

The gate driver has a built in 185 ohm input resistor that is designed to provide proper drive for the internal opto isolator when V_{IN} = 5V. If other input voltages are desired an external resistor should be added to maintain the proper opto drive current of 16mA. The value of the required external resistor can be computed by assuming the forward voltage drop of the opto diode is 2V. For example:

If 15V drive is required then

R_{ext} = (15V - 2V) ÷ 16mA - 185Ω = 630Ω.

5.2 Gate Drivers with Short Circuit Protection

Powerex IGBT modules are designed to survive low impedance short circuits for a minimum of 10µs. In many cases it is desirable to implement short circuit protection as part of the gate drive circuit in order to provide the fast response required for reliable protection against severe low impedance short circuits. Powerex hybrid gate drivers provide this protection by two different means. The M57159L-01, M57959L, M57962L and M57962CL-01 use desaturation detection as described in Section 5.2.1. The M57160AL-01 uses a new method of protection called RTC detection. RTC detection works exclusively with Powerex F-Series IGBT modules. This new short circuit protection scheme and its inherent advantages are described in Section 5.5.4.

5.2.1 Desaturation Detection

Figure 5.6 shows a block diagram of a typical desaturation detector. In this circuit, a high voltage fast recovery diode (D1) is connected to the IGBT's collector to monitor the collector to emitter voltage. When the IGBT is in the off state, D1 is reverse biased and the (+) input of the comparator is pulled up to the positive gate drive power supply which is normally +15V. When the IGBT turns on, the comparators (+) input is pulled down by D1 to the IGBT's VCE(sat). The (–) input of the comparator is supplied with a fixed voltage (V_{TRIP}) which is typically set at about 8V. During normal

Figure 5.4 Internal Schematic Diagram of M57957L and M57958L

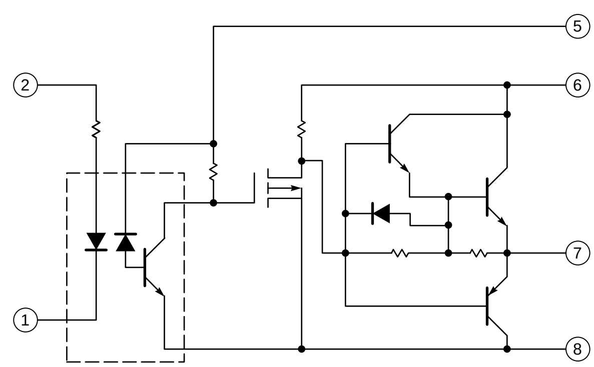


Figure 5.5 Application Circuit for M57957L and M57958L

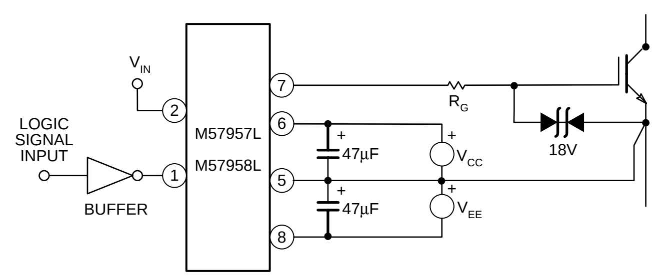
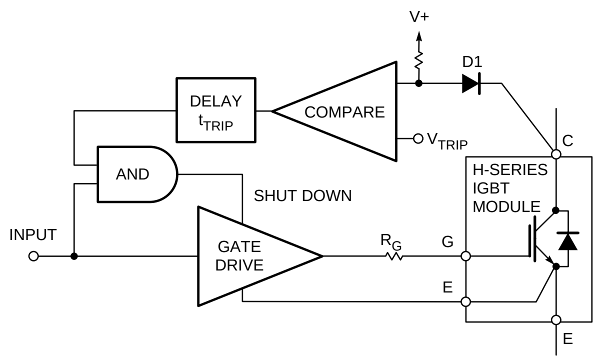


Figure 5.6 Desaturation Detector

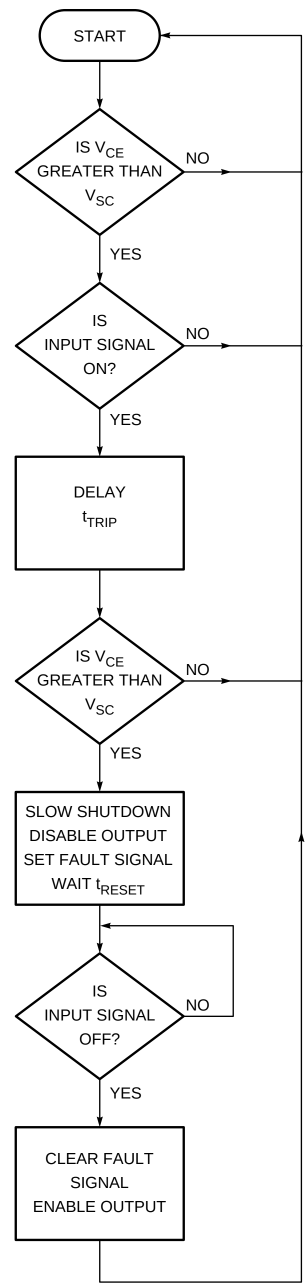


switching the comparators output will be high when the IGBT is off and low when the IGBT is on. If the IGBT turns on into a short circuit, the high current will cause the collector-emitter voltage to rise above V_{TRIP} even though the gate of the IGBT is being driven on. This abnormal presence of high V_{CE} when the IGBT is supposed to be on is often called ***desaturation***. Desaturation can be detected by a logical AND of the driver's input signal and the comparator output. When the output of the AND goes high a short circuit is indicated. The output of the AND is used to command the IGBT to shut down in order to protect it from the short circuit. A delay (t_{TRIP}) must be provided after the comparator output to allow for the normal turn on time of the IGBT. The t_{TRIP} delay is set so that the IGBTs V_{CE} has enough time to fall below V_{TRIP} during normal turn on switching. If t_{TRIP} is set too short, erroneous desaturation detection will occur. The maximum t_{TRIP} delay is limited by the IGBT's short circuit withstanding capability. For Powerex H-Series and F-Series IGBT modules the maximum safe limit is 10µs.

5.2.2 Operation of Powerex Desaturation Detectors (M57159L-01, M57959L, M57962L, M57962CL-01)

Powerex offers four SIP hybrid integrated circuit gate drivers that implement desaturation detection. The available drivers are outlined in Table 5.1. All drivers are single-in-line-packaged and have outlines similar to the M57962L shown in Figure 5.2. Figure 5.7 is a flow diagram showing the logical operation of Powerex desaturation detectors. As described, the driver monitors the V_{CE} of the IGBT. The driver detects a short circuit condition when V_{CE} remains greater than V_{TRIP} for longer than t_{TRIP} after the input on signal is applied. When a desaturation is detected, the hybrid gate driver performs a soft shut down of the IGBT and starts a timed (t_{RESET}) 1.5ms lock out. The soft turn-off helps to limit the transient voltage that may be generated while interrupting the large short circuit current flowing in the IGBT. During the lock out a fault feedback signal is asserted and all input signals are ignored. Normal operation of the driver will resume after the lock-out time has expired and the control input signal returns to its off state. A block diagram for the Powerex desaturation detector operation is shown in Figure 5.8.

Figure 5.7 Protection Circuit Operation



5.2.3 Application Circuit for Powerex Desaturation Detectors

Figure 5.9 is an example application circuit for Powerex hybrid gate drivers with desaturation detection. Applicable types include M57159L-01, M57959L, M57962L and M57962CL.

In order to deliver the pulse current necessary for efficient switching, C1 and C2 must have low impedance and the circuit layout must minimize inductance. C1 and C2 should be located as close as possible to the pins of the hybrid gate driver. C1 and C2 must be selected to have low enough impedance to provide the pulse current necessary for efficient operation of the IGBT module being driven. When using low impedance type electrolytic capacitors 10µF is usually sufficient for small modules while larger modules may require as much as 100µF.

The series gate resistor (R_G) is selected based on the application requirements and module type being used. Details about selecting R_G can be found in Section 4.6 of this application note. The back-to-back 18V zener diodes connected from G to E are recommended to protect the IGBT's gate from dangerous transient voltages.

Pins 3, 9 and 10 are used for factory testing and must not be connected to any external circuits.

Pin 2 can be used to adjust the desaturation trip time (t_{TRIP}) by connecting C_{TRIP} as shown in Figure 5.9. Figure 5.10 shows the relationship between C_{TRIP} and t_{TRIP} for M57959L and M57962L. Similar curves for the other gate drivers can be found on the individual detailed data sheets. The driver's default trip time (no C_{TRIP} connected, pin 2 open) will work for most applications. However, when modules are used with relatively large Rg the driver may incorrectly detect a short circuit. The false trip occurs because it takes longer than t_{TRIP} for the device to reach an on state voltage less than V_{TRIP}. For these applications extending t_{TRIP} may be necessary.

Pin 7 is used for adjustment of the slow shutdown speed on M57962CL-01. This adjustment may be necessary in some applications to limit transient voltages during a short circuit shutdown. Usually, this is only

Figure 5.8 Block Diagram for M57959L

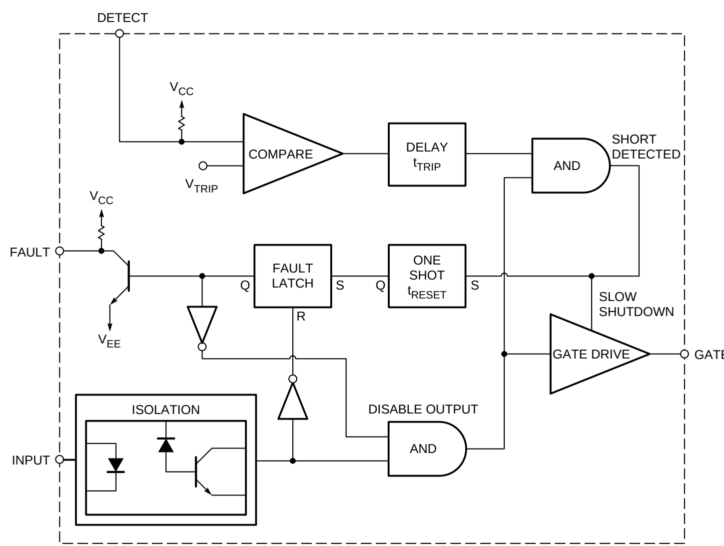
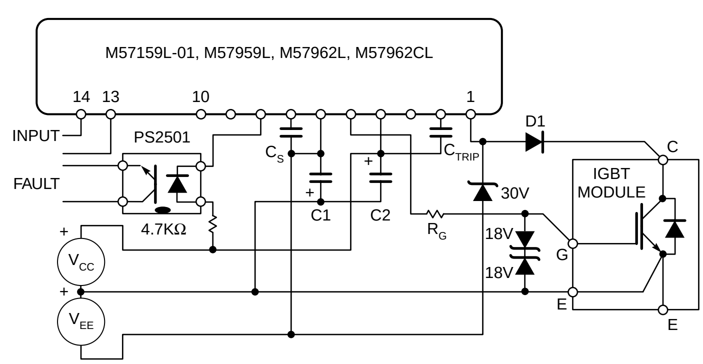


Figure 5.9 Application Circuit for Powerex Desaturation Detector



V_{CC}, V_{EE}: +15V/-10V Typical (See data sheet for usable limits.)
R_G: Adjust for application requirements (See IGBT module application notes.)
C1, C2: 10µF-100µF low impedance electrolytic
D1: Ultra fast recovery t_{rr} <100ns, high voltage V_{rrm} >V_{CES} (IGBT)
C_{trip}: 0-15nF adjusts desaturation trip time (t_{trip})
C_S: Adjusts slow shutdown speed (M57962CL-01 only)

necessary when a booster stage is being used with the driver to drive large modules. More information about this adjustment can be found on the M57962CL-01 detailed data sheet. M57159L-01, M57959L and M57962L do not support this function and pin 7 of these drivers must not be connected to any external circuits.

The detect diode D1 must be an ultra fast recovery diode with a current rating of at least 100mA and a blocking voltage equal to or greater than the V_{CES} rating of the IGBT module being used. The 30V zener diode connected to pin 1 is necessary to protect the hybrid IC from high voltages during reverse recovery of D1.

The input circuit between pins 13 and 14 consists of the built-in optocoupler's LED in series with a 185Ω resistor. This combination is designed to provide approximately 16mA of drive current when a control signal of 5V is applied. If another control voltage is desired the required external current limiting resistor can be calculated by assuming the forward voltage drop of the optocoupler's photodiode is 2V. For example, if 15V drive is desired the required external resistor would be:

(15V - 2V) ÷ 16mA - 185Ω = 630Ω.

5.2.4 RTC Detection

Powerex F-Series, trench gate, IGBT modules have a built in RTC (Real Time Control) circuit to limit short circuit current and maintain 10µs short circuit withstanding capability. The RTC circuit limits the short circuit current by pulling down the gate voltage when excessive collector current is detected. An RTC detector circuit, as shown in Figure 5.11 can detect the activation of the RTC circuit. The RTC detector is similar to a desaturation detector except that the comparators (–) input is connected to the gate of the IGBT module. The (+) input of the comparator is supplied with a fixed voltage (V_{TRIP}) that is typically set at about three volts below the positive gate drive supply voltage. In the normal on state, the voltage on the gate of the IGBT is nearly equal to the positive gate drive supply voltage, which exceeds V_{TRIP} and makes the comparator output low. In the off state the gate voltage is nearly equal to the negative gate drive supply voltage which is less than V_{TRIP} making the comparator output high. If a short circuit occurs, the RTC circuit inside the F-Series IGBT module will activate and pull the gate voltage down. If the gate voltage becomes less than V_{TRIP} when the IGBT is being commanded on, the RTC has been activated. The RTC operation is detected by a logical AND of the gate driver's input signal and the comparators output. When the output of the AND goes high a short circuit is indicated. The output of the AND is used to command the IGBT to shut down in order to protect it from the short circuit. A delay (t_{TRIP}) must be provided after the comparators output to allow for the normal rise of gate voltage at turn on. The t_{TRIP} delay is set so that the gate voltage has enough time to exceed V_{TRIP} during normal turn on switching. If t_{TRIP} is set too short erroneous short circuit detection will occur. The maximum t_{TRIP} delay is limited by the IGBT's short circuit withstanding capability. For Powerex F-Series IGBT modules this limit is 10µs.

Figure 5.10 Short Circuit Trip Delay Time vs. C_{TRIP}

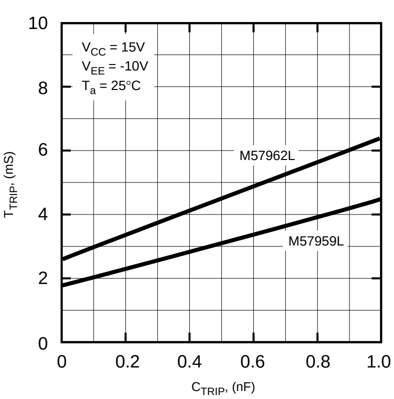
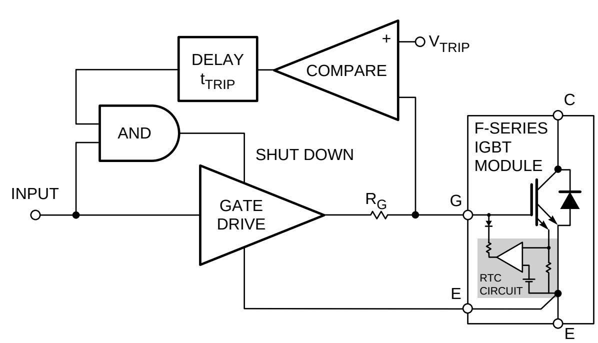


Figure 5.11 RTC Detector



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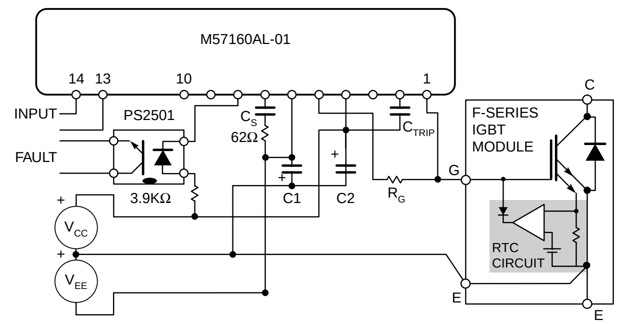
5.2.5 Operation of Powerex RTC Detector (M57160AL-01)

The Powerex M57160AL-01 hybrid gate drive circuit implements RTC detection as described in Section 5.2.4. The M57160AL-01 is a single-in-line package similar to the M57962L shown in Figure 5.2. As described above, the driver monitors the V_{GE} of the IGBT. The driver detects a short circuit condition when V_{GE} remains less than V_{TRIP} (typically V_{CC} - 3V) for longer than t_{TRIP} after the input on signal is applied. When RTC activation is detected the hybrid gate driver performs a soft shut down of the IGBT and starts a timed (t_{RESET}) 1.5ms lock out. The soft turn-off helps to limit the transient voltage that may be generated while interrupting the short circuit current flowing in the IGBT. During the lock out a fault feedback signal is asserted and all input signals are ignored. Normal operation of the driver will resume after the lock-out time has expired and the control input signal returns to its off state. This protection scheme is superior to conventional desaturation detection because it avoids the need for a high voltage detection diode, and reduces spacing requirements on the gate drive printed circuit board. In addition, noise immunity is improved because the driver is not connected to the high voltage on the IGBT's collector.

5.2.6 Application Circuit for RTC Detector (M57160AL-01)

An example application circuit for the M57160AL-01 is shown in Figure 5.12. In order to deliver the pulse current necessary for efficient switching C1 and C2 must have low impedance and the circuit layout must minimize inductance. C1 and C2 should be located as close as possible to the pins of the hybrid gate driver. C1 and C2 must be selected to have low enough impedance to provide the pulse current necessary for efficient operation of the IGBT module being driven. When using low impedance type electrolytics 10µF is usually sufficient for small modules while larger modules may require as much as 100µF.

Figure 5.12 Application Circuit for Powerex RTC Detector



V_{CC}, V_{EE}: +15V/-10V Typical (See data sheet for usable limits.)
R_g (minimum 2 ohms): Adjust for application requirements (See IGBT module application notes.)
C1, C2: 10µF-100µF low impedance electrolytic

The series gate resistor (R_G) is selected based on the application requirements and module type being used. Details about selecting R_G can be found in Section 4.6 of this application note. The minimum allowable R_G from M57160AL-01 is 2.0ohm. If a smaller value is desired, a booster stage must be added. (See Section 5.7) The back-to-back zener diodes from G to E that are normally recommended are not required with the M57160AL-01 and F-Series IGBT modules.

Pins 3, 9 and 10 are used for factory testing and must not be connected to any external circuits.

Pin 2 can be used to adjust the RTC detection time (t_{TRIP}) by connecting C_{TRIP} as shown in Figure 5.12. Curves showing the relationship between C_{TRIP} and t_{TRIP} for M57160AL-01 can be found on the detailed data sheet. The driver's default trip time (no C_{TRIP} connected, pin 2 open) will work for most applications. However, when modules are used with relatively large Rg the driver may incorrectly detect a short circuit. The false trip occurs because it takes longer than t_{TRIP} for the gate voltage to become greater than V_{TRIP}. For these app-lications extending t_{TRIP} may be necessary.

Pin 7 is used for adjustment of the slow shutdown speed on M57160AL-01. This adjustment may be necessary in some applications to limit transient voltages during a short circuit shutdown. Usually, this is only necessary when a booster stage is being used with the driver to drive large modules. More information about this adjustment can be found on the M57160AL-01 detailed data sheet.

The input circuit between pins 13 and 14 consists of the built-in optocoupler's LED in series with a 185Ω resistor. This combination is designed to provide approximately 16mA of drive current when a control signal of 5V is applied. If another control voltage is desired the required external current limiting resistor can be calculated by assuming the forward voltage drop of the optocoupler's photodiode is 2V. For example, if 15V drive is desired the required external resistor would be:

(15V - 2V) ÷ 16mA - 185Ω = 630Ω.

5.3 Output Current Limit

When using hybrid gate drivers R_G must be selected such that the output current rating (I_{OP}) is not exceeded. If R_G is computed using Equation 5.1 then I_{OP} will not be exceeded under any condition.

Equation 5.1
Conservative equation for minimum R_G

$$R_{G(MIN)} = (V_{CC} + V_{EE})/I_{OP}$$

Example:
With V_{CC} = 15V and $-V_{EE}$ = 10V $R_{G(MIN)}$ for M57958L will be:

$$R_G = (15V + 10V)/5A = 5 \text{ ohms}$$

In most applications this limit is unnecessarily conservative. Considerably lower values of R_G can usually be used. The expression for $R_{G(MIN)}$ should be modified to include the effects of parasitic inductance in the drive circuit, IGBT module internal impedance and the finite switching speed of the hybrid drivers output stage. Equation 5.2 is an improved version of Equation 5.1 for $R_{G(MIN)}$.

Equation 5.2
Improved equation for $R_{G(MIN)}$

$$R_{G(MIN)} = (V_{CC} + V_{EE})/I_{OP} - (R_G)_{INT} - \varnothing$$

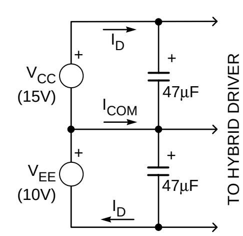
Large IGBT modules that contain parallel chips have internal gate resistors that balance the gate drive and prevent internal oscillations. The parallel combination of these internal resistors is $R_{G(INT)}$. $R_{G(INT)}$ ranges from 0.75 ohm in large IGBT modules like CM600HA-24H to 3.0 ohms in smaller modules like CM150DY-12H with two parallel chips. The value of ∅ depends on the parasitic inductance of the gate drive circuit and the switching speed of the hybrid driver. The exact value of ∅ is difficult to determine. It is often desirable to estimate the minimum value of R_G that can be used with a given hybrid driver circuit and IGBT module by monitoring the peak gate current while reducing R_G until the rated I_{OP} is reached. The minimum restriction on R_G often limits the switching performance and maximum usable operating frequency when large modules outside of the drivers optimum application range are being driven.Further steps to address this issue are provided in Section 5.7.

5.4 Power Supply Requirements

Power is usually supplied to hybrid IGBT gate drivers from low voltage DC power supplies that are isolated from the main DC bus voltage. Isolated power supplies are required for high side gate drivers because the emitter potential of high side IGBTs is constantly changing. Isolated power supplies are often desired for low side IGBT gate drivers in order to eliminate ground loop noise problems. The gate drive supplies should have an isolation voltage rating of at least two times the IGBTs V_{CES} rating (i.e. V_{ISO} = 2400V for 1200V IGBT). In systems with several isolated supplies intersupply capacitances must be minimized in order to avoid coupling of common mode noise. The recommended power supply configuration for Powerex hybrid IGBT gate drivers is shown in Figure 5.13. Two supplies are used in order to provide the on- and off-bias for the IGBT. The recommended on bias supply (V_{CC}) voltage is +15V and the recommended off-bias supply voltage (V_{EE}) is -10V.

Normally these supplies should be regulated to ±10% however operation within the range indicated on the individual driver data sheets is acceptable. Electrolytic or tantalum decoupling capacitors should be connected at the power supply input pins of the

Figure 5.13 Hybrid Driver Power Supply



hybrid driver. These capacitors supply the high pulse currents required to drive the IGBT gate. The amount of capacitance required depends on the size of the IGBT module being driven.

5.4.1 Supply Current

The current that must be supplied to the IGBT driver is the sum of two components. One component is the quiescent current required to bias the drivers internal circuits. The current is constant for fixed values of V_{CC} and V_{EE}. The second component is the current required to drive the IGBT gate. This current is directly proportional to the operating frequency and the total gate charge (Q_G) of the IGBT being driven. With small IGBT modules and at low operating frequencies the quiescent current will be the dominant component. The amount of current that must be supplied to the hybrid driver when V_{CC} = 15V and V_{EE} = -10V can be determined from Equations 5.3 and 5.4.

Equation 5.3
Required supply current for M57957L and M57958L

$$I_D = Q_G \times f_{PWM} + 13mA$$

Equation 5.4
Required supply current for M57959L and M57962L

$$I_D = Q_G \times f_{PWM} + 18mA$$

Where:

I_D = Required supply current
Q_G = Gate charge (See Section 4.6.3)
f_{PWM} = Operating frequency

5.4.2 Single Supply Operation

The current drawn from V_{CC} (I_D+) is nearly equal to the current drawn from V_{EE} (I_D-). Only a small amount of current flows in the common connection (I_{COM}). In many applications it is desirable to operate the hybrid driver from a single isolated supply. An easy method of accomplishing this is to create the common potential using a resistor and a zener diode. In order to size the resistor for minimum loss we must first determine the current flowing in the common connection (I_{COM}). In M57957L and M57958L a common connection current of about 2.5mA is required to bias internal circuits. In M57959L and M57962L about 3.5mA flows from the detect pin through the IGBT to the common connection. The circuit in Figure 5.14 uses a zener supply designed for about 5mA to supply the common current. This circuit allows operation of Powerex hybrid drivers from a single isolated 25 volt DC supply.

When the power supply circuit shown in Figure 5.14 is used with M57957L and M57958L the required bias voltage at pin 5 of the hybrid driver appears after a delay caused by the 2.7kW resistor and the 47µF capacitor. This delay may cause these drivers to generate an ON output pulse during power up. In applications where the main DC bus voltage is applied before the gate drive power supplies are on and stabilized the circuit in Figure 5.15 should be used.

The voltage of the single supply and the zener diode can be varied to allow use of standard supplies. For example, if a 24V DC-to-DC converter is to be used then a 9V zener diode would give +15/-9 which is acceptable for all of the hybrid gate drivers. The two limiting factors that need to be observed if changes are made are:

(1) Voltages must be within the allowable range specified on the gate driver data sheet and

(2) The turn on supply should be 15V +/-10% for proper IGBT performance.

Figure 5.14 Single Supply Operation of Hybrid IGBT Drivers

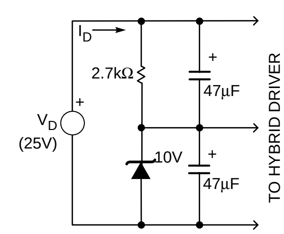
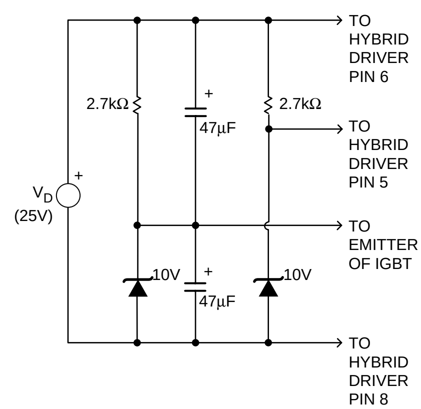


Figure 5.15 Improved Power Supply Circuit for M57957L and M57958L



5.5 Total Power Dissipation

The hybrid IGBT driver has a maximum allowable power dissipation that is a function of the ambient temperature. With V_{CC} = 15V and V_{EE} = -10V the power dissipated in the driver can be estimated using Equation 5.5.

Equation 5.5
Total power Dissipation

$$P_D = I_D \times (V_{CC} + V_{EE})$$

The power computed using Equation 5.5 can then be compared to the derating curves shown in Figures 5.16 through 5.19 to determine the maximum allowable ambient temperature. The power computed using Equation 5.5 includes the dissipation in the external gate resistor (R_G). This loss is outside the hybrid driver and can be subtracted from the result of Equation 5.5. The dissipation in R_G is difficult to estimate because it depends on drive circuit parasitic inductance, IGBT module type and the hybrid driver's switching speed. In most applications the loss in R_G can be ignored. Direct use of Equation 5 will result in a conservative design with the included loss of R_G acting as a safety margin. When operating large modules at high frequencies the limitations on ambient temperature may be significant.

Additional derating information for other hybrid gate drives can be found on the individual detailed data sheets.

5.6 Operational Waveforms

Figure 5.20 is a typical waveform showing the gate to emitter voltage during a slow shutdown for M57962L. Approximately 2.4ms after the detect input (pin 1) voltage exceeds V_{SC} the gate to emitter voltage is slowly brought to zero in about 2ms. Figure 5.21 shows the collector-emitter voltage (V_{CE}) and collector current (I_C) for an IGBT module during a short circuit. This waveform shows the effectiveness of the slow shutdown in controlling transient voltage.

5.7 Driving Large IGBT Modules

In order to achieve efficient and reliable operation of high current, high voltage IGBT modules, a gate driver with high pulse current capability and low output impedance is required. Powerex hybrid gate drivers are designed to perform this function as stand alone units in most applications. However, for optimum performance with large modules, it may be necessary to add an output booster stage to the hybrid gate driver.

Figure 5.16 Derating Curve for M57957L

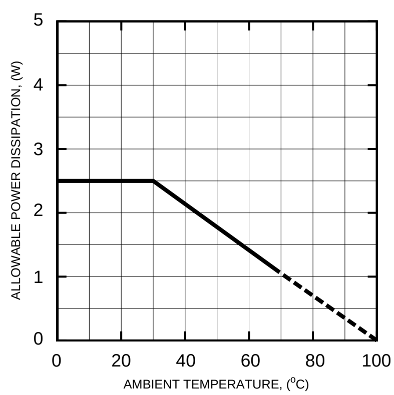


Figure 5.17 Derating Curve for M57958L

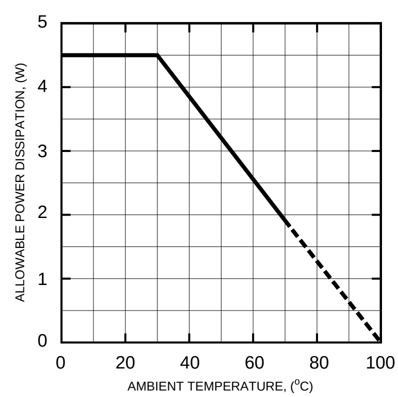


Figure 5.18 Derating Curve for M57959L

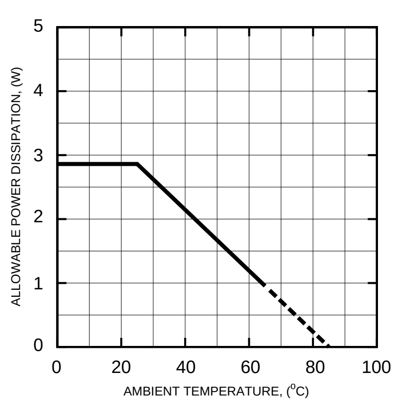
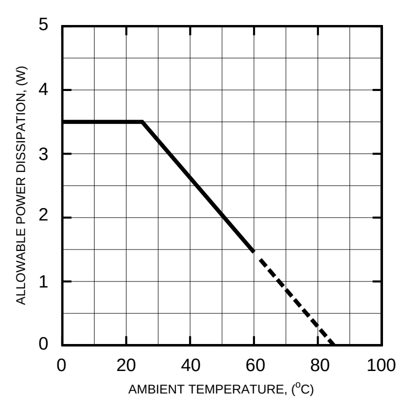


Figure 5.19 Derating Curve for M57962L



When using the hybrid gate drivers as stand alone units with IGBT modules outside the range specified in Table 5.1, three things must be considered. First, the maximum peak output current rating of the hybrid gate driver places a restriction on the minimum value of R_G that can be used. For example, the minimum allowable R_G for M57962L is about 5 ohms (for additional information refer to Section 5.3). This value is higher than the recommended value for many large IGBTs. Using R_G larger than the data sheet value will cause an increase in $t_{d(on)}$, $t_{d(off)}$, t_r and turn-on switching losses. In high frequency (more than 5kHz) applications these additional losses are usually unacceptable. Second, even if the additional losses and slower switching times are acceptable, the drivers allowable power dissipation must be considered. At an ambient temperature of 60°C, the M57962L is permitted to dissipate a maximum of about 1.5W (for more information refer to Section 5.5). If a CM600HA-24H is being used, the driver will dissipate 1.5W at a switching frequency of 14kHz. In this case, operation at a higher frequency than 14kHz will cause the driver to overheat. Lastly, the driver's slow shutdown becomes less effective when it is used with large devices. This occurs because current that flows to the gate through the relatively high reverse transfer capacitance (C_{res}) of large devices can not be absorbed by the driver. Its output impedance is not low enough. The slow shutdown may become less slow and a larger turn-off snubber capacitor may be required. This third limitation is perhaps the most serious. In some cases, the hybrid driver may completely lose control of the gate voltage and allow it to climb above 15V. If this happens, the short circuit durability of the IGBT module may be compromised.

All of the limitations outlined above can be overcome by adding a discrete npn/pnp complimentary output stage to the hybrid driver. One possible implementation is shown in Figure 5.23.

The NPN and PNP booster transistors should be fast switching (t_f < 200nS) and have sufficient current gain to deliver the desired peak output current. Table 5.3 lists some combinations of booster transistors that can be used in the circuit shown in Figure 5.23. Normally, either M57958L or M57962L is used to drive the booster stage. However, if the gain of the booster transistors is sufficiently high the lower current M57957L and M57959L can be used. If very high gain or Darlington type transistors are used in the booster stage care must be exercised to avoid oscillations in the output stage. It may become necessary to add resistance from base to emitter on the booster transistors as shown in Figure 5.24. In addition, when darlingtons are used the turn-on supply may need to be increased in order to compensate for the additional voltage drop across the booster stage.

Figure 5.22 shows an example output waveform with a booster constructed using D44VH10/D45VH10. For this example, an output impedance

Figure 5.20 V_{GE} and V_{DETECT} Waveform

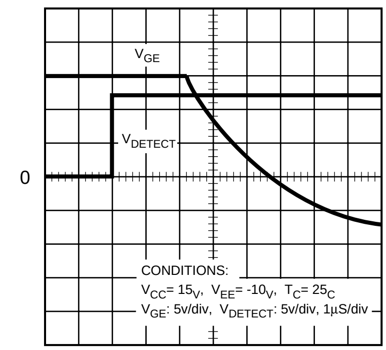


Figure 5.21 Short Circuit Shutdown Waveform

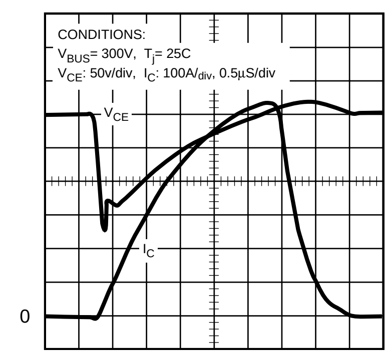
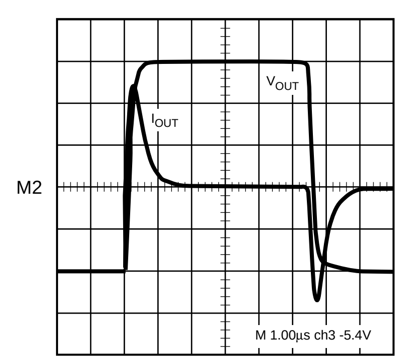


Figure 5.22 Output Waveform, I_{OUT} = 5A/div, V_{OUT} = 5V/div, T = 1µs/div



of 1ohm was used to drive a capacitive load of 300nF. The circuit shown in Figure 5.23 shows the output booster being used with M57962L. This output booster stage can be used with M57958L if short circuit protection is not needed.

5.8 Application Examples

Fully isolated gate drive circuits can be easily designed by combining hybrid gate drive circuits with hybrid DC-to-DC converter modules. Combining these circuits typically involves designing a printed circuit board with appropriate shielding and support components. Figure 5.25 shows two examples of prototype circuit boards that demonstrate how a fully isolated gate driver can be implemented with hybrid circuits. The following sections describe three examples of fully isolated gate drive.

5.8.1 Fully Isolated Gate Drive for Dual IGBT Modules

The Powerex BG2B driver board is a prototype of a fully isolated gate drive circuit designed to drive 50A to 400A dual IGBT modules. A pair of POWEREX M57159L-01, M57959L-01, M57962L/CL or M57160AL-01 supply gate drive

Figure 5.23 Example Circuit for Driving Large IGBT Modules

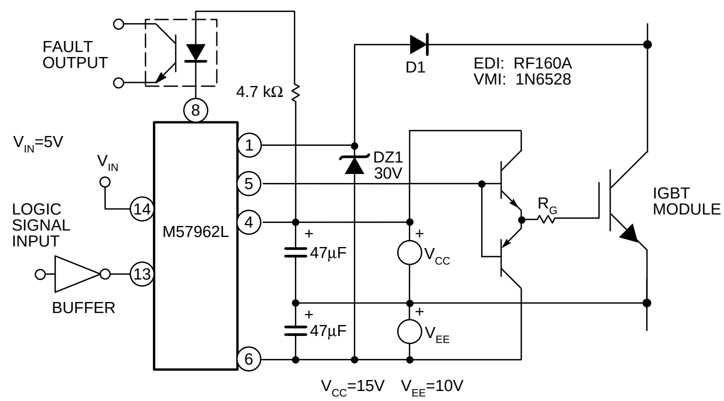


Figure 5.24 Alternate Booster Stage Configuration

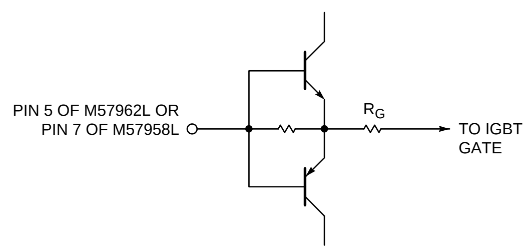


Figure 5.25 BG1A and BG2B Gate Drive Prototype Boards

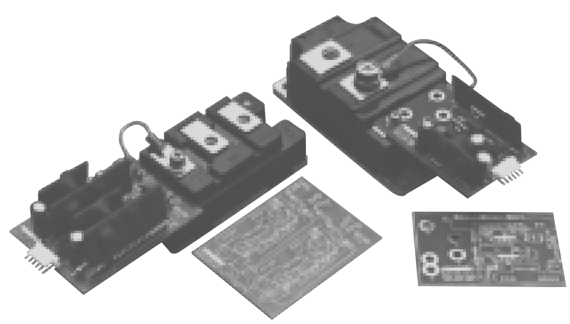


Table 5.3 Booster Stage Transistors

npn Transistor	pnp Transistor	Peak Current	V_{CEO}	Manufacturer	Package
MJD44H11	MJD45H11	15A	80V	Motorola	Surface Mount
D44VH10	D45VH10	20A	80V	Motorola	TO-220
MJE15030	MJE15031	15A	150V	Motorola	TO-220
MJE243	MJE253	8A	100V	Motorola	TO-255
2SC4151	2SA1601	30A	40V	Shindengen	Isolated TO-220
ZTX851	ZTX951	20A	80V	Zetex	TO-92

depending on the application requirements. A pair of onboard M57145L-01 regulated DC-to-DC converters supply isolated +15.8/-8.2V power for the gate drivers. Control on/off signals are optically isolated using the hybrid gate drivers built in optocoupler. Optocouplers are also provided to isolate the fault feedback signal. All isolation is designed for a minimum 2500VRMS between the input and output. Figure 5.26 shows the full schematic for the BG2B gate drive board. The jumpers (J1,J2) allow the board to accept both desaturation detectors and the RTC detector M57160AL-01 by connecting the detect pin (pin 1) of the hybrid gate driver to the gate of the IGBT module. The fault outputs of the two gate drives are combined in to a single fault signal that will pull low if either gate driver detects a short circuit.

Figure 5.27 shows the circuit board layout for the BG2B. The driver board has been designed to mount directly to the 0.110" gate and auxiliary emitter terminals on the IGBT module. A universal hole pattern allows the gate driver to fit all Powerex U-Series and F-Series IGBT modules.

Figure 5.28 shows a typical interface circuit for the BG2B gate driver board. All pins on the 6 position MTA-100 connector are electrically isolated from the IGBT module. +VL is normally connected to the 5V logic power supply. When the IN1 or IN2 inputs are pulled low approximately 15ma flows from the +5V supply through the optocoupler inside the hybrid gate drivers and the respective IGBT gate drive goes to the on state. If a short circuit fault occurs the FO will be pulled low by the opto-transistor and will remain low for a minimum of 1ms. To insure reliable noise free operation an RC filter with a time constant of approximately 10µs should be connected to the FO output as shown in Figure 5.28. The +Vs pin must be supplied with 12V to 18V DC to provide power for the onboard DC-to-DC converters.

Figure 5.26 Schematic of BG2B Driver Board

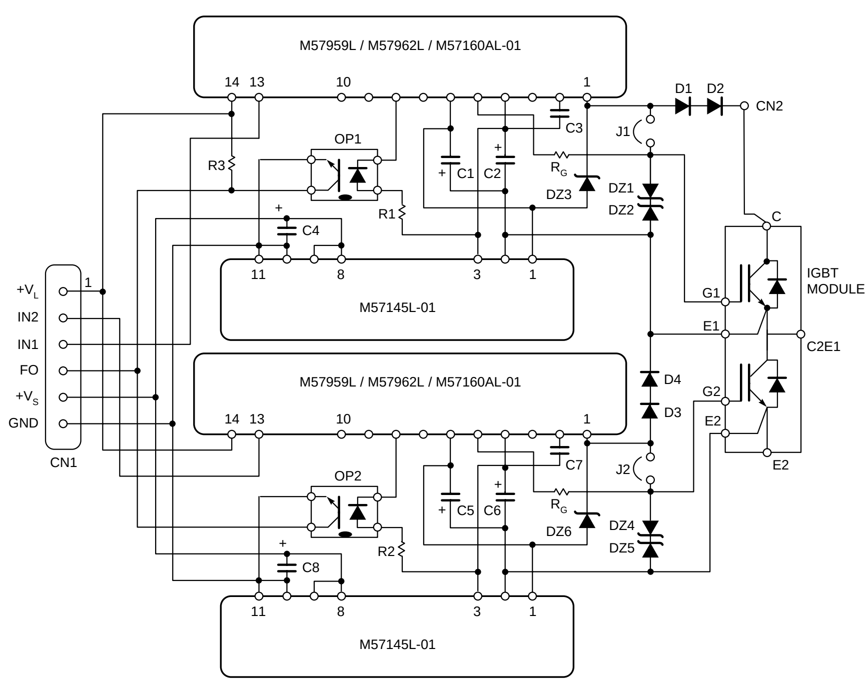


Figure 5.27 BG2B Printed Circuit Layout

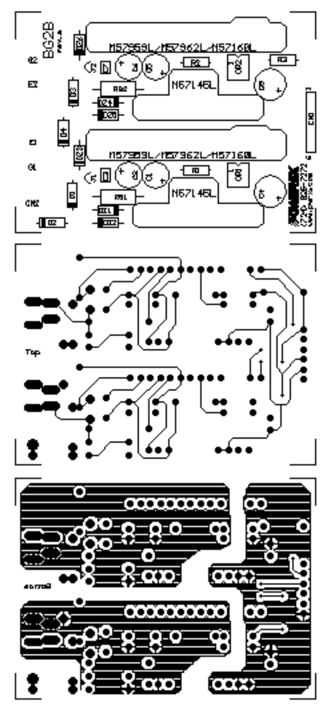


Figure 5.28 BG2B Interface Circuit

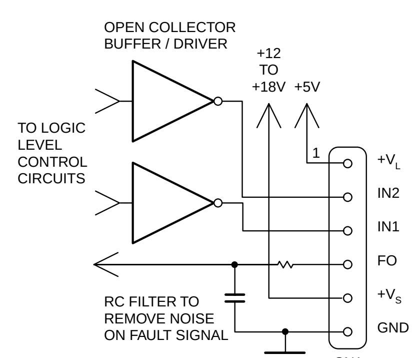


Figure 5.29 Schematic of BG1A Driver Board

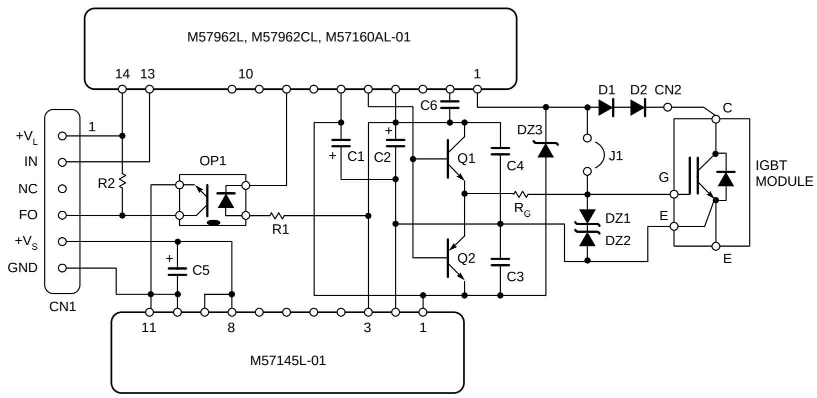
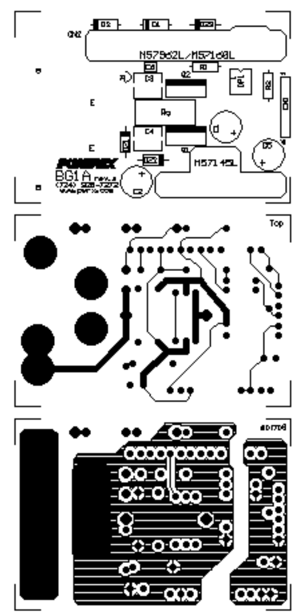


Figure 5.30 BG1A Printed Circuit Layout



If multiple driver boards are used in a system they can all be powered from a single 12V to 18V power supply.

5.8.2 A Fully Isolated Gate Driver for Large Single IGBT Modules

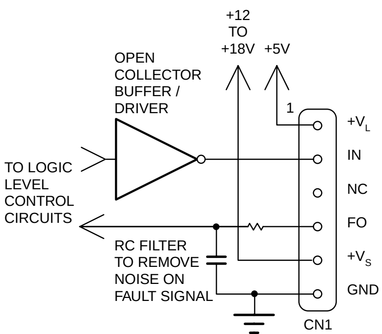
BG1A is a fully isolated gate drive circuit designed to drive high current single IGBT modules. Gate drive is supplied by a Powerex M57962L/CL or an M57160L-01 hybrid gate driver with a complementary emitter follower power booster. The circuit can deliver up to 20A peak for efficient switching of modules rated up to 1200A. The onboard M57145L-01 regulated DC-to-DC converter supplies isolated power for the hybrid gate driver. With an input of 12V to 18V DC the converter provides a +15.8/-8.2V output with $2500V_{RMS}$ isolation. The control on/off signal is optically isolated using the hybrid gate drivers built in optocoupler. An optocoupler is also provided to isolate the fault feedback signal. All isolation is designed for a minimum 2500VRMS between the input and output.

Figure 5.29 shows the full schematic for the BG1A gate drive board. The jumper (J1) allows the board to accept both desaturation detectors and the RTC detector M57160AL-01 by connecting the detect pin (pin 1) of the hybrid gate driver to the gate of the IGBT module. A complementary emitter follower output stage boosts the output current of the hybrid gate driver to provide efficient drive for IGBT modules with very large input capacitance. The isolated power supply has been decoupled with both low impedance electrolytics and 1µF stacked film capacitors in order to minimize the impedance to the IGBT gate.

Figure 5.30 shows the circuit board layout for the BG1A. The driver board has been designed to mount directly to the gate and auxiliary emitter screw terminals on large single IGBT modules. A universal hole pattern allows the gate driver to fit all Powerex U-Series and F-Series single IGBT modules as well as 800A, 1000A and 1200A H-Series modules.

Figure 5.31 shows a typical interface circuit for the BG1A gate driver board. All pins on the 6 position MTA-100 connector are electrically isolated from the IGBT module. +VL is normally connected to the 5V logic power supply. When the IN input is pulled low approximately 15ma flows from the +5V supply through the optocoupler inside the hybrid gate driver and the IGBT gate drive goes to the on state. If a short circuit fault occurs the FO will be pulled low by the opto-transistor and will remain low for a minimum of 1ms. To insure reliable noise free operation an RC filter with a time constant of approximately 10µs should be connected to the FO output as shown in Figure 5.31. The +Vs pin must be supplied with 12V to 18V DC to provide power for the onboard DC-to-DC converter. If multiple driver boards are used in a system they can all be powered from a single 12V to 18V power supply.

Figure 5.31 BG1A Interface Circuit



5.8.3 Isolated Gate Drive for Single Phase and Three Phase Circuits

In order to simplify the task of generating the multiple isolated power supplies that are required in single or three phase inverter applications Powerex has developed the M57994-01. The M57994-01 is a 7 Watt isolated DC-to-DC converter designed to provide power for Powerex hybrid IGBT gate drivers. When supplied with an input voltage of 10V to 32V DC the M57994-01 will produce four isolated +15V/-8.5V outputs suitable for use with Powerex M57957L, M57958L, M57959L, M57962L hybrid IGBT gate drivers. In addition, the M57994-01 also provides an isolated +15V/-15V auxiliary output to power system control circuits such as hall effect current sensors or isolation amplifiers for bus voltage sensing. The isolation between the primary and secondary outputs of the M57994-01 has been optimized to provide the high dv/dt noise immunity needed in IGBT power circuits. Figure 5.32 is a block diagram of the M57994-01 and Figure 5.33 shows the dimensions of the module. Figure 5.34 shows a typical application of the M57994-01 supplying power for M57959L/M57962L gate drivers in a three phase inverter. In this circuit the low side drivers are all supplied from one of the M57994-01 outputs. This is usually acceptable for lower power applications using six pack IGBT modules. For higher power applications ground loop noise may necessitate the use of an additional M57994-01. See Section 3.2.3 for additional information. Figure 5.35 shows the M57994-01 supplying power for the hybrid gate drivers in a single phase bridge application.

Figure 5.32

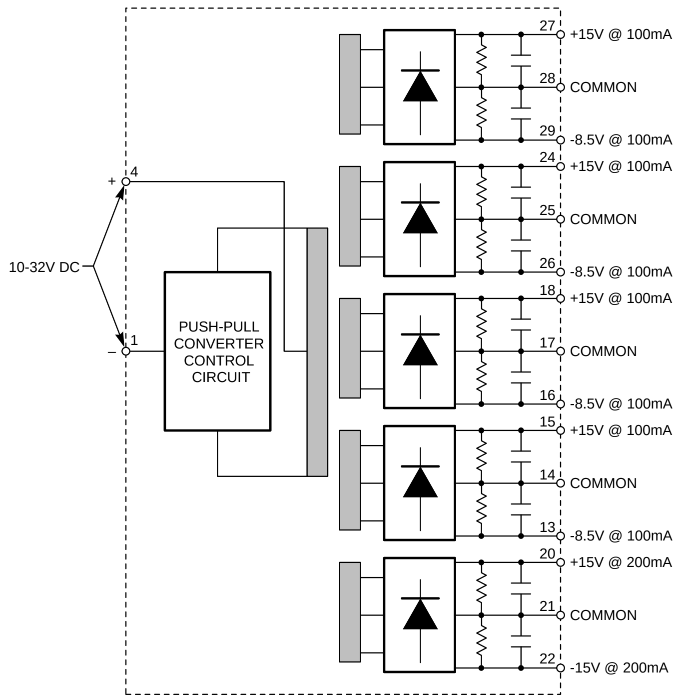


Figure 5.33

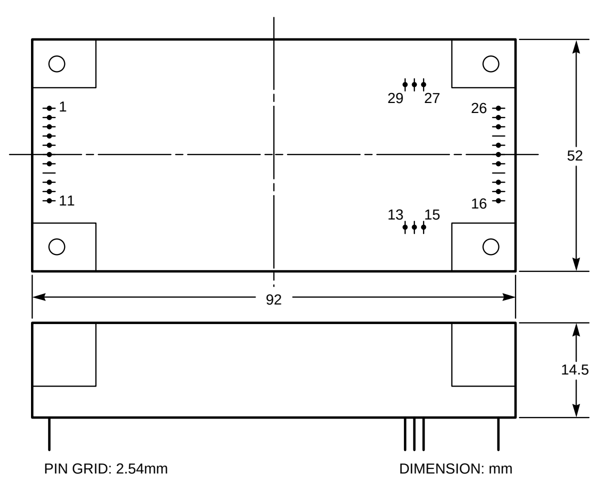
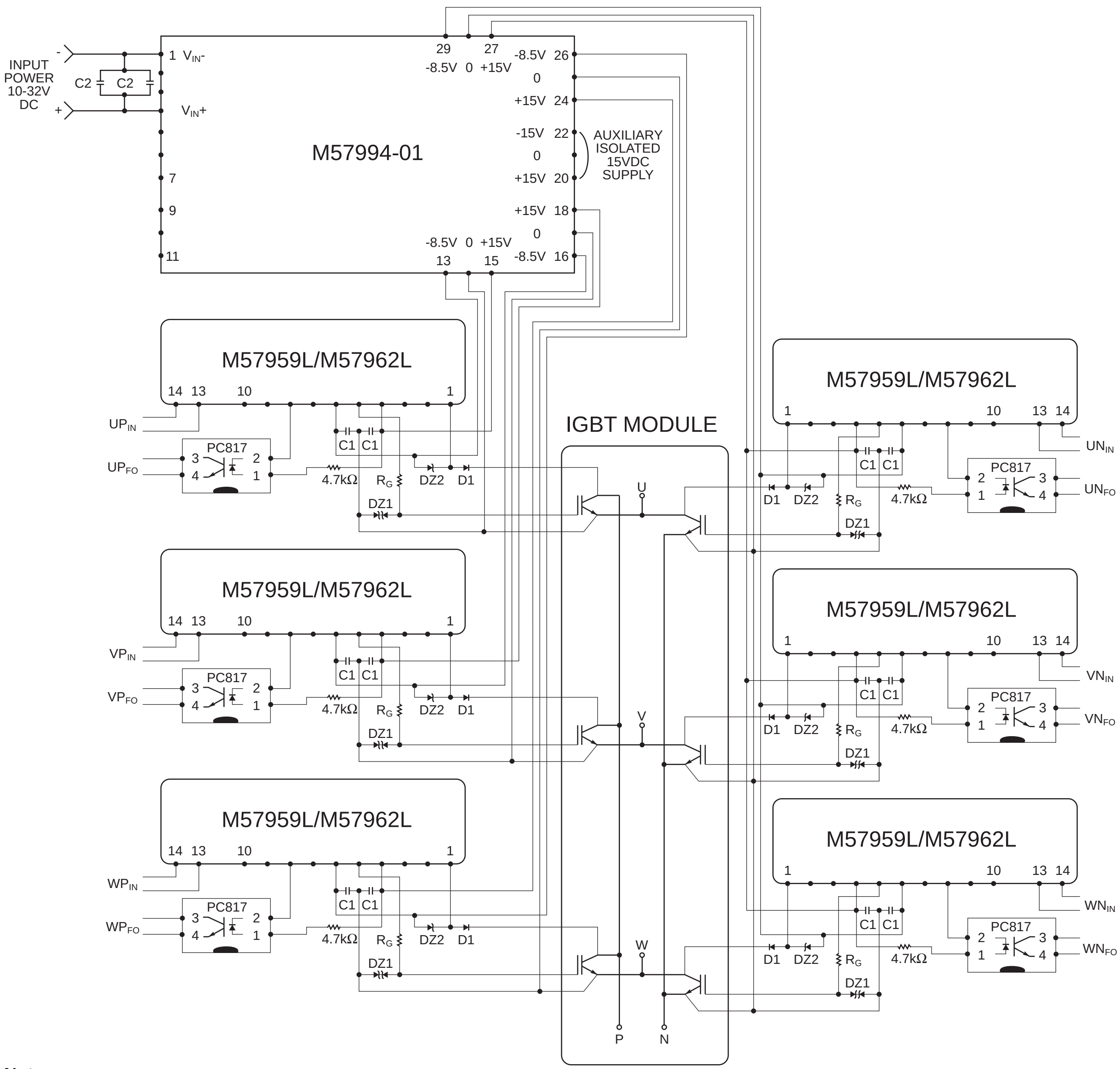


Figure 5.34



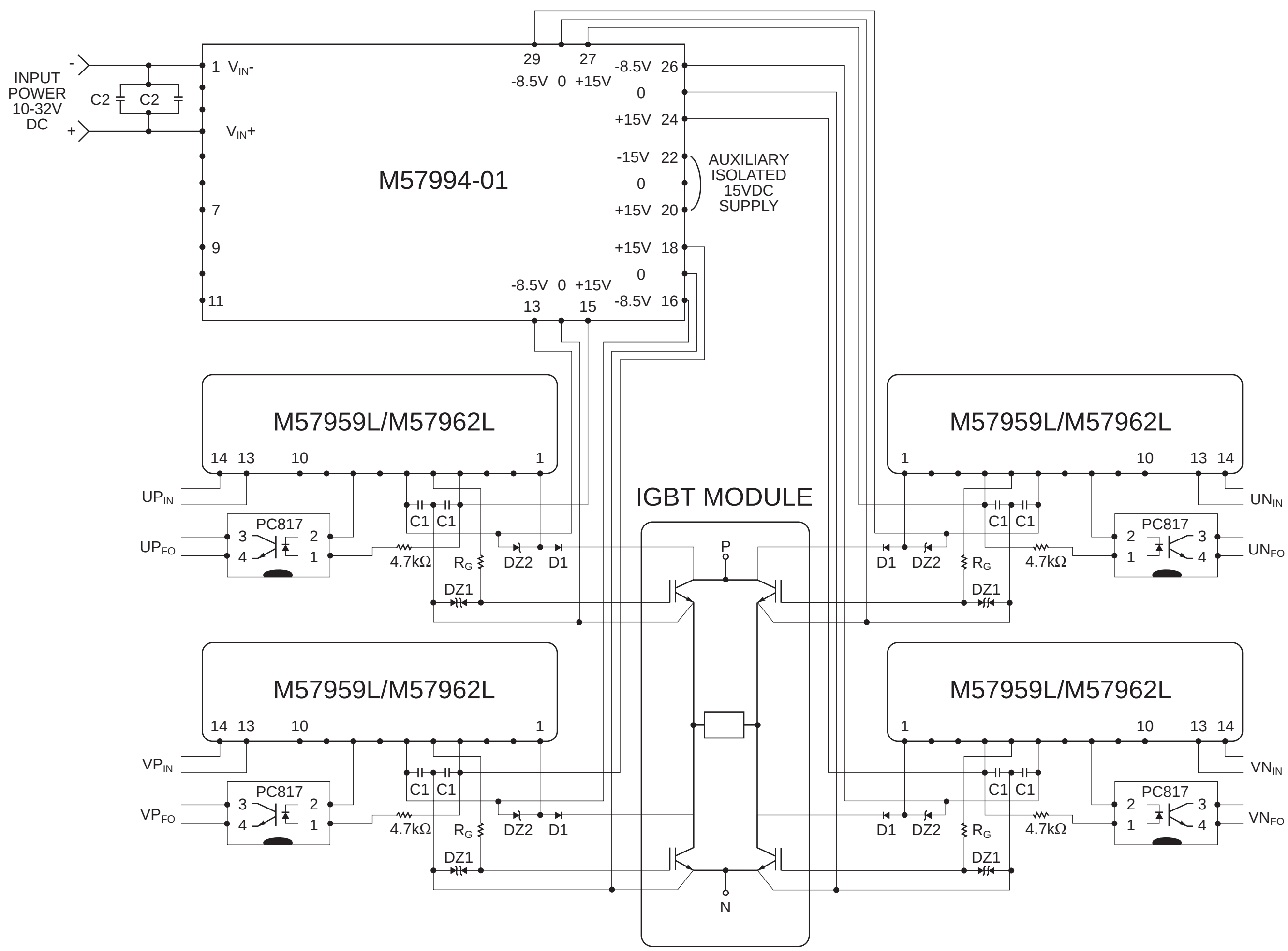
Notes:

- DZ1: 16V-18V, DZ2: 30V
- D1: $V_{rrm} = V_{ces}$ (IGBT), Fast Recovery (100ns)
- C1: 10~100µF (depending on wiring layout and IGBT), Low ESR Type, C2: 330µF 50V Typical
- UP_{IN}, VP_{IN}, WP_{IN}, UN_{IN}, VN_{IN}, WN_{IN} are isolated on/off control inputs. +5V on pin 14, Gnd on pin 13 turns IGBT on.
- UP_{FO}, VP_{FO}, WP_{FO}, UN_{FO}, VN_{FO}, WN_{FO} are fault signals indicating that the short circuit protection was activated.

Caution:

- M57994-01 does not have output over current protection. Permanent damage may occur if maximum output current ratings are exceeded.
- Input decoupling capacitors (C2) must be selected with sufficient ripple current capability for full load condition. Experimental verification is recommended.

Figure 5.35



Notes:

- DZ1: 16V-18V, DZ2: 30V
- D1: $V_{rrm} = V_{ces}$ (IGBT), Fast Recovery (100ns)
- C1: 10~100μF (depending on wiring layout and IGBT), Low ESR Type, C2: 330μF 50V Typical
- UP_{IN}, VP_{IN}, WP_{IN}, UN_{IN}, VN_{IN}, WN_{IN} are isolated on/off control inputs. +5V on pin 14, Gnd on pin 13 turns IGBT on.
- UP_{FO}, VP_{FO}, WP_{FO}, UN_{FO}, VN_{FO}, WN_{FO} are fault signals indicating that the short circuit protection was activated.

Caution:

- M57994-01 does not have output over current protection. Permanent damage may occur if maximum output current ratings are exceeded.
- Input decoupling capacitors (C2) must be selected with sufficient ripple current capability for full load condition. Experimental verification is recommended.