

Hybrid Circuits Simplify IGBT Module Gate Drive

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Abstract:

This paper will review the typical gate drive requirements for the latest generation of high power IGBT modules and present simplified implementations of the required circuits using newly developed hybrid integrated circuit (HIC) building blocks. A newly developed circuit that provides short circuit protection without desaturation detection will also be presented.

I. INTRODUCTION

In high power IGBT module applications it is usually desirable to use completely isolated gate drive circuits. A typical implementation of this type of gate drive is shown in figure 1. This circuit provides isolation of logic level control and fault feedback signals using optocouplers and separate isolated power supplies for each gate driver. There are a number of advantages to this topology including: (1) Stable on and off drive driving voltages that are independent of the power device switching duty. (2) Capable of providing 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 detection. The main disadvantages of this type of driver are the cost, complexity and board space required for all of the isolated power supplies. In addition, these circuits can be difficult to develop due to the severe requirements for noise immunity and high isolation voltage. To simplify the design of isolated gate drive Powerex/Mitsubishi has developed several new hybrid integrated circuits that supply gate drive, short circuit protection and isolated gate drive power. This paper will describe the characteristics and operation of these newly developed hybrid circuits.

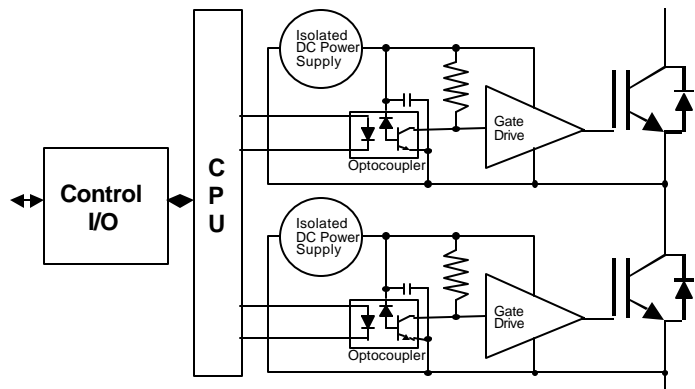


Figure 1: Fully Isolated Gate Driver

II. GENERAL GATE DRIVE REQUIREMENTS FOR HIGH POWER IGBT MODULES

The main components of a typical gate drive circuit are illustrated in the simplified circuit schematic shown in figure 2. The primary function of the gate drive circuit is to convert logic level control signals into the appropriate voltage and current for efficient, reliable, switching of the IGBT module. An output driver stage consisting of small power MOSFETs or bipolar transistors performs the conversion by alternately connecting the IGBT's gate to the appropriate on (V_{ON}) and off (V_{OFF}) voltages. The driver stage devices and series gate resistance R_G must be selected to provide the appropriate peak current for charging and discharging the IGBT's gate. Most gate drive circuits also provide isolation so that the logic signals are not connected to the dangerous high voltage present in the power circuit. The driver must also be immune to the severe electromagnetic noise produced by the fast switching, high

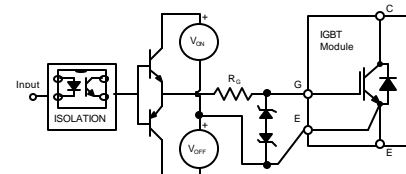


Figure 2: Basic Gate Drive Circuit

voltage, high current IGBT power circuit. Careful layout and component selection is critical to avoid problems with coupled noise. The following sections will review the critical requirements for large IGBT module gate drive.

A. Turn-On Voltage (V_{ON})

In order to establish collector to emitter conduction in an IGBT module a positive voltage must be applied to the gate. The absolute maximum voltage that can safely be applied to the IGBT's gate is usually specified on the device data sheet. For Powerex H-Series and F-Series IGBT modules this voltage is 20V. Application of voltages greater than 20V may cause breakdown of the gate oxide resulting in permanent damage to the device. The 20V upper limit must be restricted even further if short circuit survival is required. The short circuit withstand time (t_W) of a given device is inversely proportional to the product of applied voltage and short circuit current. The short circuit current increases with increasing gate voltage thus degrading the withstand time. Powerex IGBTs are guaranteed to survive a low impedance short circuit for 10 μ s with an applied gate voltage of 15V \pm 10%.

The usable lower limit for the on state gate voltage is decided by the devices transconductance or gain and acceptable switching losses. Figure 3 shows a typical output characteristics for a Powerex 1200V, 100A F-series IGBT. For this device it can be seen that a gate voltage of about 10V is enough to support the devices peak current rating ($I_{CM} = 2 \times I_{RATED}$). A gate voltage of 10V would be sufficient to fully turn the device on but it may not be sufficient to obtain efficient switching. If 10 volts were used for V_{ON} a long dynamic saturation (slow turn-on) will result because the gate voltage takes a long time to reach 10V as it exponentially charges through the series gate resistance. For optimum performance Powerex recommends a turn-on gate voltage of 15V \pm 10%. Using a voltage in this range will ensure that the device stays fully saturated and switches on efficiently while maintaining good short circuit durability.

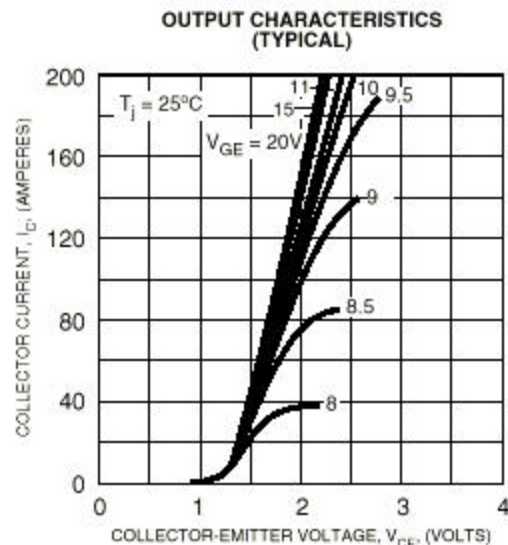


Figure 3: IGBT Module Output Characteristic

B. Turn-Off Voltage

A substantial off bias of at least -5V is recommended for large IGBT modules. Use of an off bias voltage will reduce turn-off losses and provide additional dv/dt noise immunity. Large IGBT modules generally require a stronger off bias than other power MOS devices for two reasons. First, IGBTs typically operate at higher voltages resulting in increased dv/dt coupling of switching noise. Secondly, large IGBT modules that are constructed from parallel chips have internal gate resistors in series with each chip. Even if a low impedance short is applied at the modules external terminals, voltage can develop at the gate of the IGBT chip when miller effect current flows through the internal resistors.

For Powerex IGBT modules an off bias in the -5V to -15V range is recommended. Like voltages greater than +20V, voltages more negative than -20V must be avoided because they may damage the IGBT's gate.

C. Series Gate Resistance

The external series gate resistance (R_G) has a significant effect on the IGBT's dynamic performance. The IGBT is switched on and off by charging and discharging its gate capacitance. A smaller series gate resistor will charge and discharge the gate capacitance faster resulting in increased switching speed and reduced switching losses. In addition to decreased switching losses a lower series gate resistance also helps to improve dv/dt noise immunity. Smaller series gate resistors more effectively shunt away miller effect and dv/dt coupled noise currents that could cause dangerous voltages to appear on the IGBT's gate.

The minimum value of the series gate resistor for turn on is usually limited by the recovery characteristics of the free wheel diode. In hard switching inductive load circuits the di/dt stress at free wheel diode recovery is a function of the series gate resistance. If the di/dt stress becomes too high the free wheel diode may become "snappy" resulting in undesirable oscillations, high recovery currents, and transient voltages. Powerex F-Series IGBT modules have a newly developed proton beam irradiated soft recovery diode that virtually eliminates these effects. A larger series gate resistance may be desirable to help reduce transient voltage during turn-off switching. Unfortunately, in most cases the series gate resistance must be increased substantially to have any significant impact on the turn-off fall time. Usually, such an increase in series gate resistance will result in poor dv/dt noise immunity and excessive switching losses. It is usually better to reduce transient voltages with improved power circuit layout and/or snubber designs.

Giving consideration to all of the above issues, Powerex publishes a recommended range of gate resistance for all H-Series and F-Series IGBT modules. The lowest value in the recommended range is the value used in the conditions for switching times on the device data sheet. The maximum value is normally ten times the minimum.

D. Gate Drive Power

When switching, the IGBT consumes power from the gate drive power supply. The amount of power consumed is a function of operating frequency, on and off bias voltages and total gate charge. The average current that must be supplied by the gate drive power supply is given by:

$$I_S = Q_G \times f \quad \text{Where:}$$

Q_G = is total gate charge
 f = is frequency of operation.

The total gate charge can be obtained from published curves. Figure 4 shows a gate charge curve for a 600A, 1200V F-Series IGBT module. The total gate charge for the transition of gate voltage from zero to +15V can be read directly from the curve (6500nC). For the transition from 0 to -15V we extend the Q_G curve along its initial slope as shown to obtain an additional 2000nC. For operation of this device at 10kHz the required supply current is:

$$I_S = 8500\text{nC} \times 10\text{kHz} = 85\text{mA}$$

The total power that must be supplied by the gate drive power supply is simply $I_S \times \Delta V_G$. For the CM600HU-24F with $\pm 15\text{V}$ gate drive this power is:

$$P_G = 85\text{mA} \times 30\text{V} = 2.55\text{W}$$

Considering the size of this device (600A, 1200V) this drive power is quite small.

E. Peak Drive Current

Even though the average drive power is small, efficient switching of large IGBT modules requires high peak currents. If we assume that the gate drive circuit is infinitely fast and that its output impedance and inductance are negligible, the peak gate current is given by:

$$I_{G(\text{PEAK})} = \Delta V_G \div R_G$$

For the CM600HU-24F the minimum recommended R_G is 1.0 ohm. From the equation above we get a peak drive current for $\pm 15\text{V}$ gate drive of:

$$I_{G(\text{PEAK})} = 30\text{V} \div 1.0\Omega = 30\text{A}$$

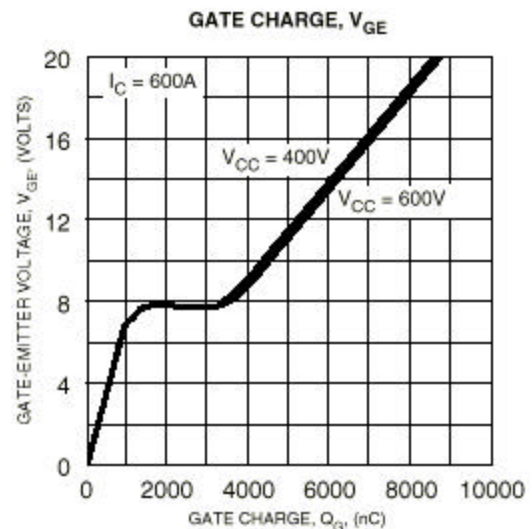


Figure 4: Total Gate Charge Characteristic

The actual peak current is usually considerably less than this value because the assumptions made above are not generally true. However, designing the gate drive circuit for this theoretical maximum output current is usually a good general practice.

III. GATE DRIVE CIRCUIT DESIGN

Now that the basic requirements for reliable, efficient gate drive have been reviewed we can turn our attention to circuit design issues. The layout and component selection for the gate drive are critical to achieve the operating characteristics outlined above.

A. Maintaining dv/dt Noise Immunity

IGBT gate drive circuits are subjected to high common mode dv/dt . The driver circuit layout must minimize parasitic capacitances between adjacent drive circuits in order to prevent $C \times dv/dt$ coupling of noise. The isolating interface for the gate drive signals must be designed with appropriate noise immunity. If a pulse transformer is used, its interwinding capacitance must be small. If optocouplers are used they must have isolation that is designed for both high common mode voltage and transient noise immunity. Optocouplers should have a guaranteed minimum common mode transient noise immunity of $10\text{kV}/\mu\text{s}$ specified at a common mode voltage (V_{CM}) of at least 1000V . The layout of the isolating interface must minimize parasitic capacitance between the primary and secondary. Use of ground plane shield layers can be very helpful in controlling noise coupled through stray capacitances by the high dv/dt of the power circuit. If twisted pair gate drive leads are used the pairs should be kept separated from each other. If they must be bundled shielded cables with the shield tied to emitter potential of the IGBT being driven should be used. In general minimizing gate drive lead length will help to prevent noise coupling. Minimum length wiring also helps to achieve the high peak drive currents needed for efficient switching. The best practice is to mount the driver circuit directly on the IGBT module.

B. Controlling On and Off Gate Voltages

Control of the steady-state on and off gate voltage is easily accomplished through appropriate regulation of the gate drive power supply. However, during switching, and especially during short circuit operation miller effect currents cause $i \times R$ voltage on the series gate resistor and $L \, di/dt$ voltage on gate driver parasitic inductance. These voltages can add to the normal on-state gate voltage causing a surge voltage on the gate. During switching, gate voltage surges must be maintained less than the devices maximum gate voltage rating (usually 20V). Under short circuit conditions gate voltage surges will cause degradation of short circuit withstanding capability by allowing higher than normal currents to flow. In order to control gate voltage surges it is often desirable to implement gate voltage clamping on the gate side of the series gate resistor. The simplest form of the gate voltage clamping is back-to-back zener diodes connected from gate to emitter as shown in Figure 2. In order for the gate voltage clamping circuit to be effective it must be connected as close as possible to the gate and emitter terminals of the IGBT module. For 15V gate drive 16V to 18V zeners are typically used. An even more effective clamping circuit is shown in Figure 5. In this circuit the gate voltage is diode clamped to a local capacitor charged to the turn-on gate voltage. Gate voltage clamping becomes critical with larger IGBT modules because miller effect currents are more severe. Long gate drive leads also aggravate gate voltage surges making gate voltage clamping even more necessary.

Powerex trench gate F-series IGBT modules have gate voltage clamping zeners built into the internal RTC circuit. This circuit combined with the lower reverse transfer capacitance of the trench IGBT chip eliminates the need for external gate voltage clamping circuits in most applications.

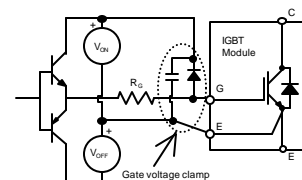


Figure 5: Gate Voltage Clamp

C. Isolated Power Supplies

As shown in Figure 2 the gate drive circuit requires V_{ON} and V_{OFF} DC power supplies. In most high power applications it is necessary to provide isolated power supplies that can float as needed to the emitter potential of the IGBT being driven. Isolated power supplies are required for the high side gates in single and three phase inverter circuits because the emitter potential of the high side IGBT changes when the low side IGBT is switched. Isolated power supplies are also recommended for low side gate drive in high power applications in order to avoid noise caused by $L \times di/dt$ voltages induced in the stray inductance of the negative DC bus. The gate drive power supply should have high voltage insulation designed to reliably withstand the high voltages in the power circuit. It is also critical that the power supplies have minimum capacitance between each other and the logic circuits in order to avoid dv/dt induced noise. A common source of unwanted capacitance is adjacent or overlapping windings on the power supplies isolation transformer.

In order to simplify the task of generating the isolated power supplies Powerex has developed a single-in-line isolated DC to DC converter. The M57145L-01 shown in Figure 6 produces a regulated +15.8V/-8.2V output from an input of 12V to 18V DC. This new DC to DC converter is designed to work in conjunction with Powerex hybrid IC gate drivers.



Figure 6: M57145L-01

IV. SHORT CIRCUIT PROTECTION

Powerex IGBT modules are designed to survive low impedance short circuits for a minimum of 10 μ s. In many cases it is desirable to implement the short circuit protection in the gate drive circuit in order to provide the fast response required for protection against severe low impedance short circuits. Typically this protection has been provided by collector emitter voltage sensing or so called “desaturation detection”. The operation of the desaturation detector will be explained in detail below. With Powerex F-Series IGBT modules another technique, “RTC detection” can also be used. This new short circuit protection scheme and its inherent advantages will also be presented below.

A. Desaturation Detection

Figure 7 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 $V_{CE(sat)}$. The (-) input of the comparator is supplied with a fixed voltage (V_{TRIP}) which is typically set at about 8V. During normal 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

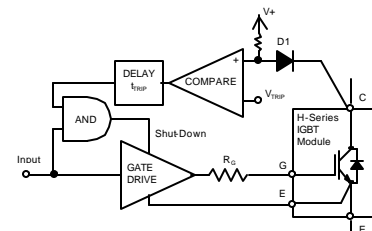


Figure 7: Desaturation Detector



Figure 8: M57962L

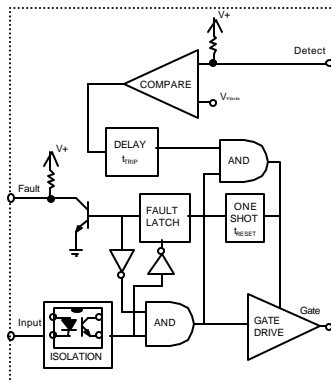


Figure 9: Powerex Desaturation Detector

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 this limit is 10 μ s.

Powerex offers several hybrid integrated circuit gate drivers that implement desaturation detection. The available drivers are outlined in Table 1. All of the drivers in table 1 are single in line packaged and have outlines similar to the M57962L shown in Figure 8. A block diagram for the Powerex desaturation detector operation is shown in Figure 9. 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 waveform showing the operation of the gate driver with a Powerex CM100DY-24H IGBT module is shown in figure 10. A new desaturation detector, the M57962CL-01, is an improved version of the very popular M57962L. This new driver has added provisions to adjust both the t_{TRIP} time and the speed of the slow shutdown as shown in Figure 11.

Table 1: Powerex Hybrid Gate Drivers With Short Circuit Protection				
Type	Protection Scheme	Soft Shutdown	Output Current	Comments
M57159L-01	Desaturation Detection	Yes	+/-1.5A	New – Low Cost
M57959L	Desaturation Detection	Yes	+/-2.0A	
M57962L	Desaturation Detection	Yes	+/-5.0A	
M57962CL-01	Desaturation Detection	Adjustable	+/-5.0A	New – Adjustable soft shutdown and improved fault latching circuit
M57160L-01	RTC Detection	Adjustable	+/-5.0A	New – For use with F-Series IGBT Modules

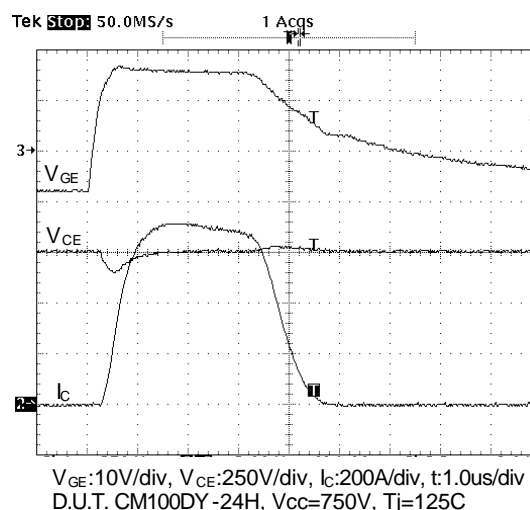
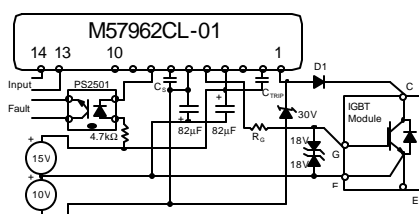
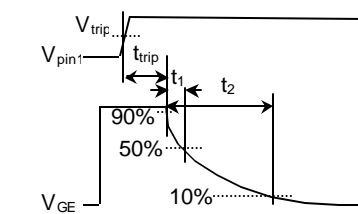
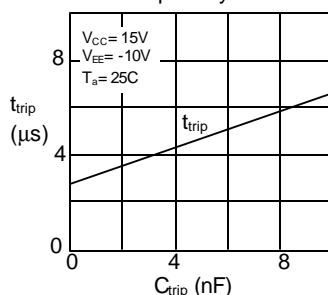


Figure 10: Operation of Desaturation Detector



Short Circuit Trip Delay Time vs. C_{trip}



Slow Shutdown Speed (t_1 , t_2) vs. C_s

Figure 11: Operation of the M57962CL-01 Desaturation Detector

B. RTC Detection

Powerex F-Series trench gate IGBT modules have a built in RTC (Real Time Control) circuit which limits short circuit current and maintains 10 μ s short circuit durability. When excessive current flows in the device the RTC circuit activates and reduces the gate voltage in order to limit the short circuit current. The operation of the RTC circuit can be detected as shown in Figure 12. The RTC detector is similar to the 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}) set at about three volts below the positive gate drive supply voltage. In the normal on state, the gate of the IGBT is at nearly the positive supply voltage, which exceeds V_{TRIP} and makes the comparator output low. In the off state the gate voltage is at nearly 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 10 μ s.

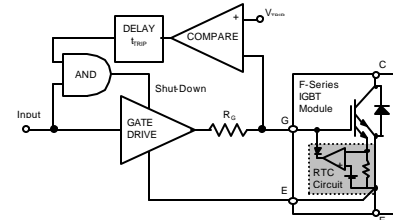


Figure 12: RTC Detector

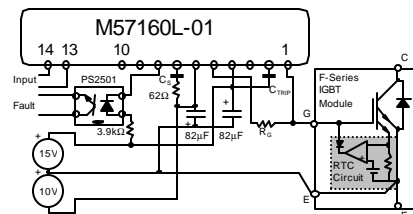


Figure 13: M57160L-01 RTC Detector

The newly developed M57160L-01 hybrid gate driver circuit implements RTC detection as described above. A circuit diagram is shown in Figure 13. This protection scheme is superior to conventional desaturation detection because it avoids the need for high voltage components 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.

V. APPLICATION EXAMPLES

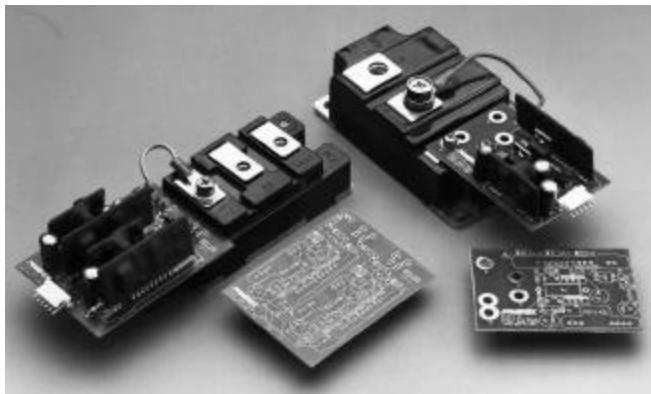


Figure 14: BG1A and BG2B Gate Driver Boards

Hybrid circuits for gate drive, short circuit protection and isolated power have been presented. Combining these circuits to make fully isolated gate drive, as shown in Figure 1, involves designing a printed circuit board with appropriate shielding and support components. Figure 14 shows two prototype circuit boards that demonstrate how a fully isolated gate driver can be implemented using these hybrid circuits. These two prototype circuits will be discussed in detail below.

A. BG2B - A Fully Isolated Gate Driver for Dual IGBT modules

BG2B is 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 M57160L-01 supply gate drive 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 15 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 M57160-01 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 16 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. Table 2 provides guidance for selecting components to populate the board. Of particular importance is the selection of the electrolytic power supply decoupling capacitors C1-C6. These must be low impedance type in order to get good peak gate currents. It is generally advisable to use long life

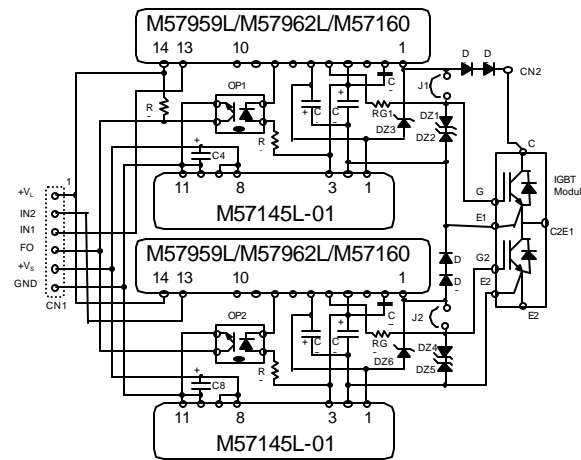


Figure 15: Schematic of BG2B Driver Board

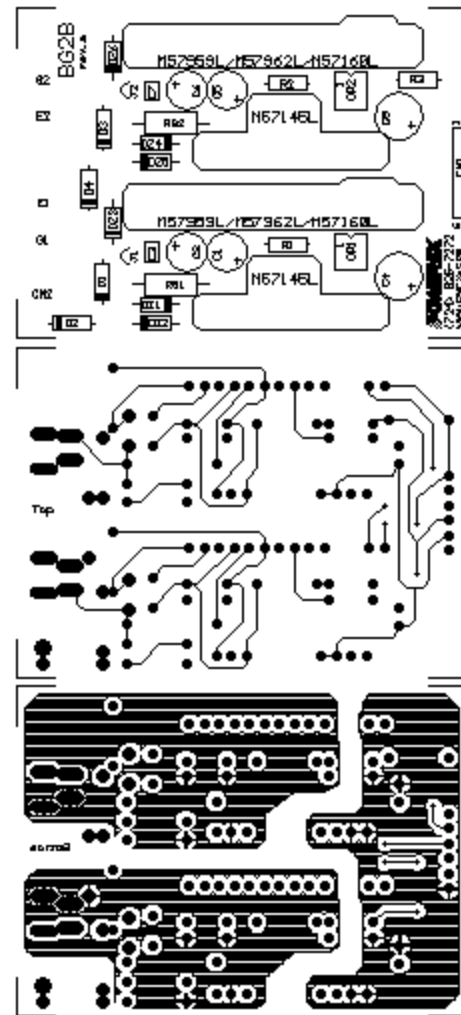


Figure 16: BG2B Printed Circuit Layout

Table2: BG2B Component Selection Guide			
Designation	Description	Value	Example Type
C1, C2, C5, C6	Power supply decoupling capacitors. Low impedance long life type.	82μF 35V	Panasonic FC EEUFC1V820
C4, C8	DC to DC converter input decoupling capacitor. Low impedance long life type	150μF 35V	Panasonic FC EEUFC1V151
C3, C7	Optional - For adjustment of short circuit protection trip time.	0 to 10nF 50V	muRata RPE Series
R1, R2	Current limit for fault opto	4.7K .25W	
R3	Pull up for fault output	4.7K .25W	
RG1, RG2	Series gate resistor - See Powerex IGBT application notes	30 to 100Ω 0.5W to 1W	
D1, D2, D3, D4	Collector voltage detection diodes. Vrrm greater than IGBT Vces rating.	1A, 1000V tr<100ns	Motorola MUR1100E
DZ1, DZ2, DZ4, DZ5	Gate protection zeners	17V, 0.5W	1N5247
DZ3, DZ6	Detect pin protection zener	30V, 0.5W	1N5256
OP1, OP2	Opto for fault signal isolation		NEC PS2501
CN1	MTA100 6 position right angle header with locking ramp		AMP 640457-6
CN2	1/4" Ring Lug on 2" Wire		AMP 34151
J1, J2	Insert when using M57160L-01 with F-Series IGBT modules and omit D1-D4 and DZ1-DZ6		



B. BG1A – A Fully Isolated Gate Driver for Large Single IGBT Modules

Figure 18 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 M57160-01 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 $1\mu\text{F}$ satchled film capacitors in order to minimize the impedance to the IGBT gate.

types because of the high temperatures that are often present in power electronic circuits.

Figure 17 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

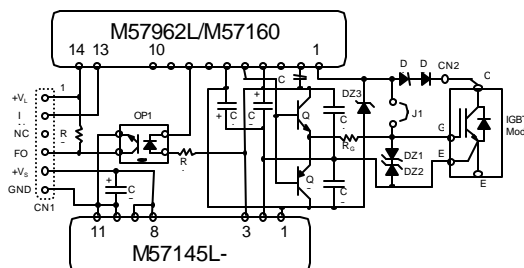


Figure 18: Schematic of BG1A Driver Board

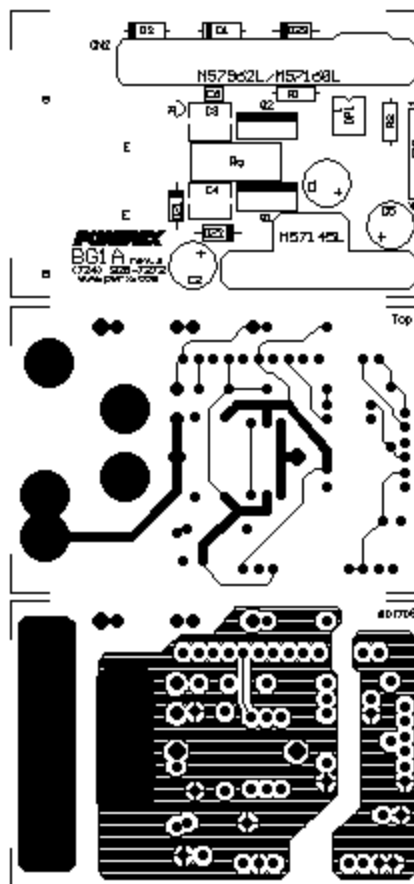


Figure 19: BG1A Printed Circuit Layout

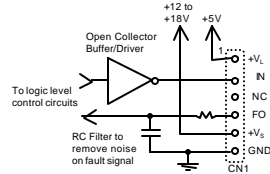


Figure 20: BG1A Interface Circuit

order to get good peak gate currents. It is generally advisable to use long life types because of the high temperatures that are often present in power electronic circuits.

Figure 20 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 10 μ s should be connected to the FO output as shown in figure 20. 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.

Table 3: BG1A Component Selection Guide			
Designation	Description	Value	Example Type
C1,C2	Power supply decoupling capacitors. Low impedance long life type.	150 μ F 35V	Panasonic FC EEUFC1V151
C3,C4	Low ESR polyester film or ceramic decoupling capacitors	1 μ F 50V	Panasonic ECQV1H105JL
C5	DC to DC converter input decoupling capacitor. Low impedance long life type	150 μ F 35V	Panasonic FC EEUFC1V151
C6	Optional - For adjustment of short circuit protection trip time.	0 to 10nF 50V	muRata RPE Series
R1	Current limit for fault opto	4.7K .25W	
R2	Pull up for fault output	4.7K .25W	
RG	Series gate resistor - See Powerex IGBT application notes	0.5 Ω to 33 Ω 0.5W to 2W	
D1, D2	Collector voltage detection diodes. V _{rrm} greater than IGBT V _{ces} rating.	1A, 1000V t _r < 100ns	Motorola MUR1100E
DZ1, DZ2	Gate protection zeners	17V, 0.5W	1N5247
DZ3	Detect pin protection zener	30V, 0.5W	1N5256
Q1	NPN Booster transistor	15A, 80V	Motorola D44VH10
Q2	PNP Booster transistor	15A, 80V	Motorola D45VH10
OP1	Opto for fault signal isolation		NEC PS2501
CN1	MTA100 6 position right angle header with locking ramp		AMP 640457-6
CN2	5/16" Ring Lug on 3.5" wire		AMP 34151
J1	Insert when using M57160L-01 with F-Series IGBT modules and omit D1, D2, DZ1-DZ3		

VI. CONCLUSION

The basic requirements for gate drive of high power IGBT modules have been reviewed. Hybrid circuits designed to implement the necessary power supplies, gate drive and protection were introduced. Finally, example circuit boards using the hybrid circuits to make completely isolated gate drivers for high current IGBT modules were presented.

VII. REFERENCES

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