

HOW TO DRIVE MOSFETs AND IGBTs INTO THE 21ST CENTURY

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ABSTRACT

As the industry pushes for higher power levels and higher switching frequencies, power supplies, which use MOSFETs/IGBTs for power conversion, are being designed to their ultimate attainable efficiency, smallest footprint, size and weight. The subject of driving MOSFETs/IGBTs to their highest possible frequencies at the highest possible power levels, still providing protection, is multi-dimensional and requires knowledge of MOSFETs and IGBTs as well as circuit theory and how it applies to this discipline. Many topologies in high voltage converter, inverter and matrix converter applications require special techniques to drive MOSFETs and IGBTs. The paper deals with this subject and explains with examples how to face the challenges of tomorrow today.

1. INTRODUCTION

Modern Power Electronics makes liberal use of MOSFETs and IGBTs in many applications and, if the present trend is any indication, future will see more and more applications making use of MOSFETs and IGBTs. Although sufficient literature is available on characteristics of MOSFETs and IGBTs, practical aspects of driving them in specific circuit configurations at different power levels and at different frequencies require that design engineers pay attention to a number of aspects.

1.1 MOSFET AND IGBT TECHNOLOGY

Due to the absence of minority carrier transport, MOSFETs can be switched at much higher frequencies. The limit on this is imposed by two factors: transit time of electrons across the drift region and the time required to charge and discharge the input Gate and 'Miller' capacitances.

IGBT derives its advantages from MOSFET and BJT. It operates as a MOSFET with an injecting

region on its Drain side to provide for conductivity modulation of the Drain drift region so that on-state losses are reduced, especially when compared to an equally rated high voltage MOSFET. Advances and breakthroughs continue to improve performances of both devices. Lower parasitic capacitances, lower $R_{DS(on)}$, R_{Gint} , Q_g , R_{thjc} and faster switching times are being achieved in newer MOSFETs. Third generation IGBTs have lower forward voltage drop, lower gate Charge, lower t_{rr} of inverse parallel diode, shorter and lesser tail current, lower t_f , smaller E_{on} and E_{off} , improved current sharing amongst parallel devices and better R_{thjc} .

1.2 POWER LOSSES IN DRIVERS AND DRIVEN MOSFET/IGBT

For determining the power loss in a Driver while driving a power MOSFET, the best way is to refer to the Gate Charge Q_g vs. V_{GS} curve for different values of $V_{DS(off)}$.

$$P_{GATE} = V_{CC} * Q_g * f_{sw} \quad \text{Eq. 1.1}$$

Wherein, V_{cc} is the Driver's supply voltage, Q_g is the total Gate Charge of the MOSFET being driven and f_{sw} is the switching frequency. It is prudent then to choose a MOSFET with lower value of Q_g and it is here that of low Gate Charge MOSFETs are preferred because they as well as the drivers incur lower losses.

As far as switching losses in a MOSFET are concerned, there are some short time-intervals, during which finite V_{DS} and finite I_D coexist, albeit momentarily. When this happens during turn-on, the actual integration:

$$\int_0^{\infty} V_{DS}(t) I_D(t) dt \quad \text{Eq. 1.2}$$

Is defined as Turn-On switching energy loss. Likewise, during turn-off, when finite values of I_D and V_{DS} coexist, integration of:

$$\int_0^{\infty} V_{DS}(t) I_D(t) dt \quad \text{Eq.1.3}$$

Is called Turn-off switching energy loss in a MOSFET. Amongst the responsible parameters determining these switching energy losses, C_{iss} , C_{oss} and C_{rss} affect the turn-on and turn-off delays as well as turn-on and turn-off times.

For an IGBT, it would be similarly shown that:

$$\int_0^{\infty} V_{CE}(t)I_C(t)dt \quad \text{Eq. 1.4}$$

This equation represents switching energy loss. Needless to emphasize that the time interval for these integrals would be the appropriate time during which finite values of I_D and V_{DS} or V_{CE} and I_C coexist in a MOSFET or IGBT respectively. Thus average switching energy lost in the device can be computed as follows:

$$\text{MOSFET: } P_s = 1/2 * V_{DS} * I_D * f_{sw} * (t_{on} + t_{off}) \quad \text{Eq. 1.5}$$

$$\text{IGBT: } P_s = 1/2 * V_{CE} * I_C * f_{sw} * (t_{on} + t_{off}) \quad \text{Eq. 1.6}$$

Main emphasis in modern Power Electronics is on reducing total losses dissipated in devices and subsystems for achieving higher operating efficiency and more compact designs, reducing volume and weight of resultant systems. Thus, operation at higher and higher switching frequencies is now a necessity, and as a result, switching losses predominate in power-loss-budget in semiconductor switches. Reducing switching losses then becomes the single most crucial goal. Keeping this goal in mind, drive circuits should be so designed as to yield ultra fast rise (t_r) and fall times (t_f). Assuming sum of t_r and t_f be no more than 2% of the PWM period in hard switching applications, a Table:1 is prepared of 1000 Volts rated MOSFETs of three types: standard, Low Gate Charge types and F-Class, which are optimised for megahertz switching. Table: 1 shows, for a given f_{sw} , peak current required to drive it, recommended external gate resistor, total power loss in driver+gate resistor and the driver IC used - All for SMPS designs of 500W, 1KW and 2 KW ratings. While standard MOSFETs are optimally usable up to about 400 kHz, Low Gate Charge MOSFETs give adequate performance up to 800 kHz in hard switching SMPS applications.

Designing above 800 kHz in hard switching mode, the levels of RFI/EMI noise and switching losses are excessive and hence soft switching (resonant mode, in which sum of t_r and t_f should be no more than 10% of the total one cycle PWM period) is preferred. The third section of rows in Table:1, shows how F-Class MOSFETs

perform with the same driver ICs at 1MHz, 2 MHz and 4 MHz in resonant switching mode.

Both, in hard switching and in resonant switching modes, trying to achieve values of t_r and t_f less than what are assumed tend to generate higher electrical noise and oscillations in drain current, while increasing them will tend to reduce overall efficiency. One can appreciate that energy lost in gate drive system, say, @ $f_{sw} = 100$ kHz for a 500 W SMPS, is only 0.04% - a negligible value.

Table: 2 and Table: 3 show how a full range of driver ICs with peak current ratings from 2 Amps to 30 Amps can be used for a full range of MOSFETs with VDS rating of 60 Volts to 1000 Volts and B rating of 24 Amps to 340 Amps at different $f_{sw} = 50$ KHz, 100 KHz, 200 KHz, 400KHz and 800 KHz. Please note that * indicates that the driver IC (in TO-263 and/or TO-220 package) will need a heat sink. The availability of a 30 Amp driver IC opens doors to great many possibilities.

It is very important to understand that when 30 Amps peak current is required to drive a MOSFET/IGBT, it is never prudent to parallel two 14 Amp driver ICs, as this tends to allow momentary shoot through current from P-Channel MOSFET (Totem pole output stage) of one driver into N-Channel MOSFET (Totem pole output stage) of another driver due to mismatch in propagation delays between two drivers. Thus the importance of having a 30 Amps driver IC can't be overemphasized.

1.3 ADVANCES IN MOSFETs AND IGBTs

Extending the discussion further, we know that advances in Power MOSFET technology are giving dividends in the form of lower $R_{DS(on)}$ (that gives lower conduction losses), lower R_{Gint} (that improves switching speed), lower Q_g (that improves dynamic performance and requires less power from driver), lower transient thermal impedance (enabling higher power dissipation) and lower C_{iss} and lower gate to drain feedback capacitance C_{rss} and lower rise and fall times (enabling operation at still higher switching frequency).

Advances in IGBT technology centre around improving NPT technology by 'soft punch through' techniques, called the Third Generation NPT Technology. The dividends from such advances are multi-fold: lower cost, 20% lower on-state and 20% lower switching losses, better parallel current

sharing, lower thermal impedance, increased ruggedness to overloads, lower input capacitance and faster yet smoother turn-on and turn-off waveforms. It looks like a true win-win situation! Another path chosen by some manufacturers is Trench IGBTs, which also have improved $V_{CE(sat)}$ and switching losses.

2. TYPES OF DRIVERS

2.1 IC DRIVERS

Although there are many ways to drive MOSFET/IGBTs using hard-wired electronic circuits, IC Drivers offer convenience and features that attract designers. The foremost advantage is compactness. IC Drivers intrinsically offer lower propagation delay. As all important parameters are specified in an IC Driver, designers need not go through time consuming process of defining, designing and testing circuits to drive MOSFET/IGBTs. Another advantage is repeatability and predictability of performance, which can't be easily achieved in hardwired driver circuits.

2.2 TECHNIQUES AVAILABLE TO BOOST CURRENT OUTPUTS

Totem pole stage with N-Channel and P-Channel MOSFETs can be used to boost the output from an IC Driver. The disadvantage is that the signal is inverted and also there exists momentary shoot through when common gate voltage is in transition.

Totem pole arrangement using matched NPN-PNP transistors; on the other hand, offer many advantages, while boosting the output currents from IC Drivers. Shoot through phenomenon is absent in this case. The pair of transistors protects each other's base-emitter junctions and handle current surges quite well. One such arrangement is shown in Fig. (10). Here Q1 is a NPN transistor, while Q2 is a matched PNP transistor with appropriate collector current rating and switching speed to satisfy Drive requirement for the High Power IGBT. Another feature added is $-ve$ bias for guaranteed fast switch-off even in electrically noisy environment. This is done, by utilizing power supply with +15 and -5 Volts output, whose common ground is connected to the IGBT emitter.

The arrangement shown in Fig. (10) does a few more things in addition to boosting the output

current still higher. It allows one to choose different Turn-On and Turn-Off times by choosing different values of R_{gon} and R_{goff} . It allows for incorporating $-ve$ bias for reasons explained above. A pair of 18 V Zener diodes with their cathodes connected together protects the Gate-Emitter Junction of IGBT from voltage spikes.

2.3 TECHNIQUES TO GENERATE $-ve$ BIAS DURING TURN-OFF

The importance of $-ve$ bias during turn-off for practically all semiconductor switches cannot be overemphasized, as one may recall from the days of bipolar transistors. $-ve$ bias helps to quickly remove any charge on the C_{GS} and C_{GD} in the case of MOSFETs and IGBTs, thus considerably accelerating the turn-off mechanism.

It is important to understand that turn-on speed of a MOSFET or IGBT can be increased only up to a level matched by the reverse recovery of rectifiers or diodes in a power supply, because in an inductive clamped load (most common), turn-on of a MOSFET or IGBT coincides with turn-off (or reverse recovery completion) of the rectifier diode. Any turn-on faster than this does not help. Too fast a turn-on could also cause oscillation in the Drain or Collector current. However, it is always beneficial to have a Driver with intrinsic low turn-on time and then be able to tailor this with a series gate resistor. Turn-off phenomenon, on the other hand, does not have to wait for any other component in the subsystem. It is here that any enhancement technique can best be utilized. Although many IC drivers themselves feature extremely low turn-on and turn-off times, arrangement to provide $-ve$ bias during turn-off helps still faster turn-off and prevents false turn on even in electrically noisy environment.

Fig.(10) demonstrates one way of generating $-ve$ bias during turn-off. Fig. (14) shows how to generate $-ve$ bias in a transformer coupled Drive circuit arrangement. Here Zener diode can be chosen of appropriate voltage for giving that much $-ve$ bias (plus one diode drop) during turn-off. Another unique feature of circuit in Fig. (14) is its ability to maintain exact pulse wave shape across Gate and source. In Fig. (12) a method of using isolated DC to DC converter with outputs of +15 and -5 V is used to power IXD_414, while by connecting isolated ground of this DC to DC Converter to the emitter of the IGBT being driven, -5 V of $-ve$ bias during turn-off is ensured.

2.4 NEED FOR UNDERVOLTAGE PROTECTION

In Transfer Characteristics (I_D vs. V_{GS}) of a MOSFET, one can see that for values of V_{GS} below $V_{GS(th)}$, the drain current is negligible, but in this vicinity, the device is in its linear (Ohmic) region and concurrent application of large values of V_{DS} could cause considerable amount of localized heating of the junction. In short, when a MOSFET is being used as a switch, any operation in its linear region could cause overheating or device failure. Bringing the MOSFET quickly into its saturation from its off-state is the Driver's job. And, if V_{CC} is below the minimum required value, linear operation can ensue to the detriment of MOSFET. I hasten to add, however, that most PWM ICs, controller ICs and microcomputer ICs have this protection feature built-in and, if sharing the same V_{CC} bus, the Driver IC gets the benefit of this function being implemented elsewhere in the subsystem. Nevertheless, Driver ICs having this feature is an added benefit. The need of UV protection applies equally well to IGBTs.

2.5 OVERLOAD/SHORT CIRCUIT PROTECTION

Any operation of MOSFET/IGBT outside the Safe Operating Area (SOA) could cause overheating and eventual device failure and should be prevented by an electronic active monitoring and corrective arrangement.

Load or current sensing could be done by either a Hall Effect Sensor or by a Shunt resistor in series with source/emitter terminal. The voltage picked up, which is proportional to current, is low pass filtered and then compared to a preset limit. The comparator output could initiate turn-off of MOSFET/IGBT. A circuit to detect overload/short circuit is shown in Fig. (12), where the output FAULT will go low when it occurs.

All IXDD series of Drivers have an ENABLE pin, which, when driven low, say, by the FAULT output from this comparator, puts the final N-Channel and P-channel MOSFETs of the IXDD Driver in its TRISTATE mode. This not only stops any output from the Driver, but also provides an environment for implementing soft turn-off. There are two ways of doing this. Just by connecting a resistor of appropriate value from Gate to source/emitter, the C_{GS} gets

discharged through this resistor and, depending on the value of the connected resistor, soft turn-off of any duration can be achieved. Another way, as shown in the Fig. (2), is to use a signal MOSFET Q1 to pull down the Gate, when short circuit is detected. The resistor in series with this signal MOSFET determines the time duration of this soft turn-off. Soft turn-off helps protect IGBT/MOSFET from any voltage transients generated due to $L \cdot di/dt$ (or $L \cdot di/dt$) that could otherwise bring about avalanche breakdown. The PC board layout and Bill of Materials for this circuit are shown in Fig. (3).

For an IGBT, Desat detection (Desat = Desaturation of forward voltage drop) is a method used for short circuit/overload protection. When short circuit/overload occurs, the forward voltage drop of the IGBT (V_{CE}) rises to disproportionately high values. One must ignore the initial turn-on rise in V_{CE} , when output from Driver has still not risen to high enough value. Nevertheless, when V_{CE} rises to a level of, say, 7 Volts, in presence of sufficient Gate Drive voltage, it means the collector current I_C has risen to a disproportionately high value, signalling overload. When a voltage level higher than 6.5 Volts is detected, Gate signal can be softly turned off, resulting into soft turn-off of the IGBT. Fig. (12) shows how Desat feature can be wired into a total Driver Circuit, using also other features, such as Opto-isolation and -ve turn-off bias.

3. HIGH SIDE DRIVING TECHNIQUES

3.1 EMPLOYING CHARGE-PUMP AND BOOTSTRAP METHODS

For driving the upper MOSFET/IGBT in a phase leg employed in a bridge topology, a buck converter or a 2-transistor forward converter, low side drivers cannot be used directly. This is because the source/emitter of upper MOSFET/IGBT is not sitting at ground potential.

Fig. (5) shows how a charge pump creates a higher V_{CC} to be used for the driver IC for the Upper MOSFET/IGBT. Here the pair of N-Channel and P-Channel MOSFETs acts as switches, alternately connecting incoming supply voltage to output through capacitors and Schottky diodes, isolating it and almost doubling it. Switching frequency in several hundred KiloHertz is used and, therefore, low ripple isolated output voltage is available as DC Supply for the Driver of Upper MOSFET/IGBT. Fig. (7) illustrates how one IXD_404 can be used as charge pump, delivering 350 mA, and one IXD_408

as a Driver giving +/- 8 Amps, in conjunction with IXBD4410 and IXBD4411, for driving a phase leg of two IXFX50N50 MOSFETs. Fig. (8) shows how a charge pump delivering as much as 500 mA can be constructed using one IXD_404; and by utilizing one IXD_414, one can boost the output from IXBD4410 and IXBD4411 to +/- 14Amps for driving Size 9 high power MOSFETs and IGBTs or even MOSFET/IGBT module. Another method is the Bootstrap Technique as shown in Fig. (6). The basic bootstrap building elements are the level shift circuit, bootstrap diode DB, level shift transistor Q1, bootstrap capacitor CB and IXD_408 or IXD_414. The bootstrap capacitor, IXD_408/IXD_414 driver and the gate resistor are the floating, source-referenced parts of the bootstrap arrangement. The disadvantages of this technique are longer turn-on and turn-off delays and 100% duty cycle is not possible. Additionally the driver has to overcome the load impedance and negative voltage present at the source of the device during turn-off.

3.2 ACHIEVING GALVANIC ISOLATION BY USING OPTO-COUPPLERS TO DRIVE UPPER MOSFET/IGBT

For driving high side MOSFET/IGBT in any topology, opto-couplers can be used with following advantages:

1. They can be used to give a very high isolation voltage; 2500 to 5000 Volts of isolation is achievable by use of properly certified opto-couplers.
2. Signals from DC to several MHz can be handled by opto-couplers.
3. They can be easily interfaced to Microcomputers, DSPs or other controller ICs or any PWM IC.

One disadvantage is that the opto-coupler adds its own propagation delay. Another disadvantage of using an opto-coupler is that separate isolated power supply is required to feed the output side of the opto-coupler and the driver connected to it. However, isolated DC-to-DC Converters with few thousand Volts of isolation are readily available. These can be used to supply isolated and regulated +ve 15 V and -ve 5V to the output side of the opto-coupler and the Driver IC for driving Upper MOSFET/IGBT as is shown in Fig. (12) and Fig. (13). As can be seen, identical chain of opto-coupler, Driver and DC-to-DC Converters are used for even lower IGBTs. This is to guarantee

identical propagation delays for all signals so that their arrival time at the gate of IGBT bears the same phase relationships with one another as when they originated in the DSP.

3.3 USE OF TRANSFORMERS TO OBTAIN GALVANIC ISOLATION IN DRIVING UPPER MOSFET/IGBT

Using transformers to achieve galvanic isolation is a frequently used technique. Depending on the range of frequencies being handled and power rating (voltage and current ratings and ratios), transformers can be designed to be quite efficient. The gate drive transformer carries very small average power but delivers high peak currents at turn-on and turn-off of MOSFET/IGBT.

While designing or choosing a Gate Drive transformer, the following points should be kept in mind:

1. Average power being handled by the transformer should be used as a design guideline. Margin of safety should be taken into account, keeping in mind maximum volt-second product and allowing for worst-case transients with maximum duty ratio and maximum input voltage possible.
2. Employing bifilar winding techniques to eliminate any net DC current in any winding. This is to avoid core saturation.
3. If operation in any one quadrant of B-H loop is chosen, care should be taken for resetting the core.

Advantages of employing transformers for Gate Drive are:

1. There is no need for any isolated DC-to-DC Converter for driving an upper MOSFET/IGBT .
2. There is practically no propagation delay in a transformer to carry signals from primary side to the secondary side.
3. Several thousand volts of isolation can be built in between windings by proper design and layouts.

The disadvantages of using transformers for Gate Drive are:

1. They can be used only for time varying signals.
2. It is difficult to implement DESAT protection feature.

Two examples of gate Drive circuits, using transformers follow. In Fig. (11), a phase shift controller outputs its signals to the IXD_404 Dual Drivers, which in-turn, feed the transformers. The secondary windings of these transformers are coupled to the Gates of upper and lower MOSFETs

in an “H” Bridge topology. Fig. (14) shows another transformer coupled Gate Drive circuit employing DC restore technique to maintain same wave shape of original signal with added feature of -ve bias offered using a Zener in series with a fast diode across secondary.

4.0 DESIRABLE SPECIFICATIONS AND FEATURES OF ANY LOW AND HIGH SIDE DRIVER PAIRS, SUCH AS IXBD4410 AND IXBD4411

1. Under voltage and over voltage lockout protection for V_{cc} ;
2. dv/dt immunity of greater than ± 50 V/ns;
3. Galvanic isolation of 1200 Volts (or greater) between low side and high side;
4. On-chip negative gate-drive supply to ensure MOSFET/IGBT turn-off even in electrically noisy environments;
5. CMOS/HCMOS compatible inputs with hysteresis;
6. < 20 ns rise and fall times with 1000 pf load and < 100 ns rise and fall times with 10000 pf load;
7. < 100 ns of propagation delay;
8. > 2 Ampere peak output Drive Capability;
9. Automatic shutdown of output in response to over current and/or short-circuit;
10. Protection against cross conduction between upper and lower MOSFET/IGBT;
11. Logic compatible fault indication from both low and high-side drivers.

A suggested wiring diagram, making use of such a high/low side driver pair is shown in Fig. (4). This diagram is for a phase leg of MOSFETs or IGBTs. Likewise, the wiring diagram is to be repeated for each phase leg and hence one needs two such circuits for “H” Bridge and three such circuits for 3-Phase Bridge topologies

As can be seen in this schematic, to obtain galvanic isolation, it uses one ferrite core transformer for sending drive signals to IXBD4411 and another ferrite core transformer for receiving fault and status signals from IXBD4411. T1 represents both these transformers housed in one IC type package. To avoid saturation, capacitors are placed in series with each primary winding to which PWM pulse train is transmitted. 1200 Volts of isolation barrier is built in. Note the use of high voltage fast diode with required voltage rating to feed V_{cc} to upper driver.

Higher current MOSFET/IGBTs require higher drive currents, especially for operating them at high switching frequencies. For these applications, one can use IXD_408 or IXD_414, either in stand-alone mode or in conjunction with IXBD4410 and IXBD4411. It is easy to realize now that one can easily get all the facilities of feature-rich IXBD4410 and IXBD4411 and when higher drive current capability is called for, use them in conjunction with IXD_408 or IXD_409 or IXD_414. In case of a low-side MOSFET/IGBT, it is simple to use IXD_408 or IXD_414 alone. One such example is given in Fig. (7).

For driving upper MOSFET/IGBT of a phase leg, one of the approaches is to employ a charge pump. Two such application circuit schematics are shown in Fig. (7) and Fig. (8). In Fig. (7) output from IXBD4410/4411 is boosted up to ± 8 Amps using IXD_408 and the charge pump output is boosted to 350 mA, using one driver of IXD_404 for driving IXFK48N50 (rated at $I_d=48$ Amps and $V_d = 500$ Volts). In Fig. (8), the output from IXBD4410/4411 is boosted up to ± 14 Amps by IXD_414 to drive a Size 9 MOSFET IXFN80N50 (rated at $I_d = 80$ Amps and $V_d = 500$ Volts). IXD_404 can still adequately provide 500 mA for the charge pump circuit.

4.2 GENERAL REMARKS ABOUT MOSFET/IGBT IC DRIVERS

The most important strength of MOSFET/IGBT IC Drivers should be their ability to provide high currents needed to adequately drive today's and tomorrow's large size MOSFETs and IGBTs. Another important feature is that there should be no cross conduction in the output stage of the driver IC, thus saving transition power dissipation.

In addition, all these Drivers incorporate a unique facility to disable output by using the ENABLE pin. With the exception of the IXD_408, the ENABLE pin is tied high internally. When this pin is driven LOW in response to detecting an abnormal load current, the Driver output enters its Tristate (High Impedance State) mode and a soft turn-off of MOSFET/IGBT can be achieved. This helps prevent damage that could occur to the MOSFET/IGBT due to Ldi/dt over voltage transient, if it were to be switched off abruptly, “L” representing total inductance in series with Drain or Collector. A suggested circuit to accomplish this soft turn off upon detecting overload or short circuit is shown in Fig. (2). It is also possible to do this by an independent short circuit/overload detect circuit, which could be a part of the PWM or other controller IC. All one needs to do is to take

output signal (FAULT) from such a circuit and feed it into the ENABLE pin of Driver. A resistor R_P connected across Gate and Source or Gate and Emitter (as the case may be) would ensure soft turn-off of the MOSFET/IGBT, turn-off time being equal to $R_P(C_{GS} + C_{GD})$

4.2.1 LOW CURRENT DUAL IC DRIVERS

Fig. (11) shows an interesting application for a 4 Amp Dual driver IC in a Phase Shift PWM Controller application, in which galvanic isolation is obtained by using Gate Drive Transformers. Note that this Controller operates at a fixed frequency. Turn-off enhancement is achieved by using local PNP transistors in secondary of gate drive transformer.

For a vast number of low and medium current MOSFETs and IGBTs, 2 Amp to 4 Amp dual IC drivers provide a convenient tool and circuit simplicity, coupled with performance.

4.2.2 HIGH CURRENT IC DRIVERS

These are eminently suitable for driving higher current MOSFETs and IGBTs and larger size MOSFET/IGBT Modules. Many circuit schematics applying these in various topologies are possible and some of these are shown in different figures.

The 5 pin TO-263 surface mount version of some IC drivers can be soldered directly on to a copper pad on a printed circuit board for better heat dissipation. It is possible then to use these high current drivers for very high frequency switching application, driving high current MOSFET modules for a high power converter/inverter.

Fig. (1) shows a basic low side driver configuration. C1 is used as a bypass capacitor placed very close to pin No. 1 and 8 of the driver IC. Fig. (9) shows a method to separately control the turn on and turn off times of MOSFET/IGBT. Turn-on time can be adjusted by R_{gon} , while the turn-off time can be varied by R_{goff} . Schottky diodes facilitate this, by virtue of their very low forward voltage drop and low t_{rr} . The 18V, 400mW Zener diodes protect the Gate-Emitter junction of the IGBT. A careful layout of the PCB, making shortest possible length between output pin and IGBT Gate, while providing generous copper surface for a ground plane,

helps achieve fast turn-on and turn-off times without creating oscillation in the Drain/Collector current.

Fig. (9) shows another arrangement and includes a method for faster turn-off using a PNP transistor placed very close to the MOSFET Gate and Source. It is a good practice to tie the ENABLE pin of drivers to Vcc through a 10K resistor. This ensures that the driver always remains in its ENABLED mode except when driven low due to a FAULT signal. Again, this FAULT signal puts these two drivers into their TRISTATE output mode.

Fig. (10) shows a method to boost output from driver IC to a much higher level for driving very high power IGBT module. Here the turn-on and turn-off times can be varied by choosing different values of resistors: R_{gon} and R_{goff} . To provide -ve bias of 5 Volts, the IGBT emitter is grounded to the common of +15V and -5V power supply, which feeds +15V and -5 v to the IXD_408. Notice that the incoming signals must also be level shifted.

Fig. (12) shows a high current driver IC driving one IGBT of a Converter Brake Inverter (CBI) module. Here all protection features are incorporated. For High Temperature cut-off, a bridge circuit is used with the CBI module's thermistor. Comparator U3 compares voltage drop across the thermistor to the stable voltage from the Zener diode. P1 can be used to preset the cut-off point at which the comparator's output goes low. This is fed into the DSP as OVERTEMP signal.

Short circuit protection is provided by continuously monitoring the voltage drop across a SHUNT. Note that one end of SHUNT is connected to the power supply ground GND1. The voltage picked up from this SHUNT is amplified by a low noise Op Amp and is then compared to the stable voltage from the same Zener. When short circuit occurs, the comparator output (FAULT) goes low. 1% metal film resistors are used throughout in both these circuits to ensure precision and stability. C3 and C4 help in offering low pass filtering to avoid nuisance tripping.

Principle of DESAT sensing for detecting overload on an IGBT has been explained before in section 2.5 above. In the case of AC Motor Drive, each IGBT has to be protected from overload using separate DESAT sensing. Fig. (12) and Fig. (13) show the connection for each IGBT. DESAT sensing is done on the isolated side of each opto-coupler, while the resultant FAULT signal is generated on the common input side with respect to GND1. Each FAULT signal is open collector type and hence can be tied

together with other FAULT signals from other opto-coupler or from other comparators. The DSP will stop output drive signals when either FAULT or OVERTEMP signal goes low. When this happens, notice that IXD_414 offers a -ve bias of -5V to guarantee turn-off conditions, even in presence of electrical noise. -5V is applied to gate of each IGBT during turn-off even under normal operating conditions. After fault is cleared, the DSP can issue a RESET signal for resuming normal operation.

5.0 PRACTICAL CONSIDERATIONS

When designing and building driver circuits for MOSFET/IGBT, several practical aspects have to be taken care of to avoid unpleasant voltage spikes, oscillation or ringing and false turn-on. More often than not, these are a result of improper or inadequate power supply bypassing, layout and mismatch of driver to the driven MOSFET/IGBT.

As we understand now, turning MOSFET/IGBT on and off amounts to charging and discharging large capacitive loads. Suppose we are trying to charge a capacitive load of 10,000 pF from 0 to 15 VDC (assuming we are turning on a MOSFET) in 25 ns, using a 14 amp ultra high speed driver.

$$I = V \times C / t \quad \text{Eq. 5.1}$$

$$I = (15-0) \times 10000 \times 10^{-12} / 25 \times 10^{-9} = 6 \text{ A}$$

What this equation tells us is that current output from driver is directly proportional to voltage swing and/or load capacitance and inversely proportional to rise time. Actually the charging current would not be steady, but would peak around 9.6 Amps, well within the capability of 14 Amp driver. However, driver IC will have to draw this current from its power supply in just 25 ns. The best way to guarantee this is by putting a pair of by-pass capacitors (of at least 50 times the load capacitance) of complementary impedance curves in parallel, very close to the VCC pin of the driver IC. These capacitors should have the lowest possible ESR (Equivalent Series Resistance) and ESL (Equivalent Series Inductance). One good example of this is high quality surface mount type monolithic ceramic capacitors. Other preferred type is SMD Tantalum. One must keep the capacitor lead lengths to the bare minimum.. A smart way of accomplishing this is to solder

the capacitor across the Vcc and ground pin of driver IC from the bottom (solder side).

Another very crucial point is proper grounding. Drivers need a very low impedance path for current return to ground, avoiding loops. The three paths for returning current to ground are: 1. Between driver IC and the logic driving it; 2. between the driver IC and its own power supply; 3. between the driver IC and the source/emitter of MOSFET/IGBT being driven. All these paths should be extremely short in length to reduce inductance and be as wide as possible to reduce resistance. Also these ground paths should be kept distinctly separate to avoid returning ground current from the load to affect the logic line driving the driver IC. A good method is to dedicate one copper plane in a multilayered PCB to provide a ground surface. All ground points in the circuit should return to the same physical point to avoid generating differential ground potentials.

With desired rise and fall times in the range of 25 to 50 ns, extreme care is required to keep lengths of current carrying conductors to the bare minimum. Since every inch of length adds approximately 20 nH of inductance, a di/dt of 240 Amps/microsecond (used in the example calculation for Eq. 5.1) generates a transient Ldi/dt voltage of 4.8 volts per inch of wire length, which subtracts from the driver's output. The real effect will be a significant increase in rise time for every tiny increase in conductor length from output pin of driver to the Gate lead of MOSFET/IGBT. For example, one extra inch of conductor length could increase rise time from 20 ns to 70 ns, in an ultra high-speed gate drive circuit. Another detrimental effect of longer conductor length is transmission line effect and resultant RFI/EML. This inductance could also resonate with parasitic capacitances of MOSFET/IGBT, making it difficult to obtain clean current waveforms at rise and fall.

It is important to also keep in mind the fact that every MOSFET/IGBT has some inductance depending on the package style and design. The lower this value, the better is the switching performance, as this inductance is, in effect, in series with the source/emitter and the resulting negative feedback increases switching times.

While applying driver IC for any application, it is also necessary to compute power dissipated in the driver for a worst-case scenario. The total power dissipated in the driver IC is a sum of the following:

1. Capacitive load power dissipation;
2. Transition power dissipation;

3. Quiescent power dissipation.

For all IXD_series of drivers, transition power dissipation is absent due to a unique method (Patent pending) to drive the output N-Channel and P-Channel MOSFETs, practically eliminating cross conduction.

As described under section 1.2, a MOSFET/IGBT driver incurs losses. Let us derive formulae to compute this power loss in a driver:

$$PD(on) = \frac{D \times ROH \times V_{cc} \times Q_g \times f_{sw}}{ROH + R_{Gext} + R_{Gint}} \quad \text{Eq. 5.2}$$

$$PD(off) = \frac{(1-D) \times ROL \times V_{cc} \times Q_g \times f_{sw}}{ROL + R_{Gext} + R_{Gint}} \quad \text{Eq. 5.3}$$

where:

ROH = Output resistance of driver @ output High

ROL = Output resistance of driver @ output Low

f_{sw} = Switching frequency

R_{Gext} = resistance kept externally in series with

Gate of MOSFET/IGBT

R_{Gint} = Internal mesh resistance of MOSFET/IGBT

D = Duty Cycle (value between 0.0 to 1.0)

Q_g = Gate Charge of MOSFET/IGBT

$$\text{Total loss } PD = PD(on) + PD(off)$$

Note also that in general, R_{Gint} is small and can be neglected and that ROH = ROL for all IXD_drivers. Consequently, if the external turn-on and turn-off gate resistors are identical, the total driver power dissipation formula simplifies to:

$$PD = PD(on) + PD(off) = \frac{ROH \times V_{cc} \times Q_g \times f_{sw}}{ROL + R_{Gext}} \quad \text{Eq. 5.4}$$

Let us review with some examples:

Assume that we are driving an IXFN200N07 for a Telecom power supply application or for a UPS/Inverter application at a switching frequency of 20 kHz. Furthermore, R_{Gext} = 4.7 Ohms and gate supply voltage is 15V.

On page two of the IXD_409 Data sheet, we read the value of ROH = 1.5 Ohms (Maximum). For Q_g, refer to Data Sheet of the IXFN200N07 and go to Gate Charge vs. V_{GS} curve and look for value of Q_g at V_{cc} = 15 V. You can read it as

640 nC. Substituting these values into Eq. 5.4 yields:

$$PD = \frac{1.5 \times 15 \times 640 \times 20,000 \times 10^{-9}}{1.5 + 4.7}$$

$$PD = 46.45 \text{ mW}$$

Assuming an ambient of 50 °C in the vicinity of IXD_409PI, the power dissipation capability of IXD_409PI must be derated by 7.6mW/°C, which works out to be 190 mW. The maximum allowable power dissipation at this temperature becomes 975-190=785 mW. However, as calculated above, we will be dissipating only 46.45 mW so we are well within the dissipation limit of 785 mW.

If one increases f_{sw} to 500 kHz for a DC-to-DC Converter application, keeping other parameters the same as above, now the dissipation would be 1.16 W, which exceeds the specification for IXD_409PI. So in this case, it is recommended to use either the IXD_409YI (TO-263 package) or IXD_409CI (TO-220) package. Both these packages can dissipate about 17 W with proper heat sinking arrangement. The TO-263 is a surface mount package and can be soldered onto a large pad on a copper surface of a PCB for achieving good heat transfer. For TO-220 package, a heat sink can be used.

Let us take another example of a boost converter, using IXFK55N50 at V_{DS} = 250 VDC and at I_b = 27.5 Amps. Assuming f_{sw} = 500 kHz, V_{cc} = 12 V. From the curve of Gate Charge for IXFK55N50 in the Data Sheet one can determine that Q_g = 370 nC. Let us set R_{Gext} = 1.0 Ohm. We use IXD_414YI or IXD_414CI here, which can dissipate 12W. Here typical value of ROH = ROL = 0.6 Ohm. Substituting the above values in our equation, we compute the power dissipation to be:

$$PD = \frac{0.6 \times 12 \times 370 \times 500 \text{ kHz} \times 10^{-9}}{0.6 + 1.0 + 0.0}$$

$$PD = 0.83 \text{ W.}$$

With adequate air circulation, one may just be able to use the PDIP Package. However, it is recommended to use TO-263 or TO-220 package for reliable performance.

For the third example, considering driving a large size MOSFET module VMO 580-02F at f_{sw} = 250 kHz. Let V_{cc} = 10 V, ROH = ROL = 0.6 Ohm, R_{Gext} = 0.0 Ohm. We read that Q_g = 2750 nC at V_{cc} = 10 V off the VMO 580-02F data sheet. Now:

$$PD = \frac{0.6 \times 10 \times 2750 \times 250 \text{ kHz} \times 10^{-9}}{0.6 + 0.0 + 0.0}$$

$$PD = 6.86 \text{ W}$$

IXD_414YI (TO-263) or IXD_414CI (TO-220) can easily drive this load provided adequate heat sinking and proper airflow is maintained. Comments above for mounting TO-263 and/or TO-220 packages apply here as well. For derating use $0.1 \text{ W/}^{\circ}\text{C}$. So for an ambient temperature of 50°C , it works out to be 2.5 W. As the limit of IXD_414YI or IXD_414CI is 12 W, subtracting 2.5 W from this yields 9.5 W. So 6.86 W is still within limit. Thermal Impedance (Junction to Case) is 0.55°C/W for TO-263 and TO-220, hence a rise in case temperature should be within limit. If we increase V_{cc} to 15V, conduction losses in MOSFET could reduce due to lower $R_{DS(on)}$, but obtaining the same rise and fall times will incur more power loss in driver due to increased V_{cc} and Q_g . If that happens, approach described in Fig. (10) can be employed. Or possibility of using a 30 Amp driver can be investigated by power calculation as shown above.

6.0 ISOLATED GATE DRIVE FOR MOSFET/IGBT

Many applications of MOSFETs and IGBTs require an isolated Gate Drive Circuit. For example in H-Bridge and 3 -Phase Bridge inverters, the upper MOSFETs and IGBTs require an isolated gate drive, because the Source/Emitter of upper MOSFETs/IGBTs are not at the ground potential. Similarly in matrix converters, all bi-directional switches require isolated gate drive circuits.

Basically there are two popular techniques available to implement isolated gate drive. Fig.15 shows a method to implement an isolated gate drive, using Gate Drive Transformers. There are several advantages in using the gate drive transformers:

1. If properly wound and built, they can give adequate galvanic isolation.
2. Depending on the drive current and voltage required, they give step-up or step-down facility.
3. They are immune to dv/dt transients
4. They experience no propagation delays.
5. Using modern high permeability cores, tiny Gate Drive Transformers are now available that meet most stringent design specifications.
6. There is no need to have an isolated power supply.
7. Large duty cycle range of pulse widths is possible, say, from 1% to 99%.

8. High overall efficiency of gate drive is possible.

The two disadvantages are:

1. Gate drive transformers are not suitable for DC and very low frequency signals.
2. It is difficult to implement overload/short circuit protection for the upper MOSFET/IGBT.

As can be seen in Fig. (15), gate drive transformer's primary is fed from the output of a Driver IC. For 1:1 transformer, the peak output current and voltage on the secondary is the same as the Driver IC's output values. As explained in section 5.0 before, knowing the switching frequency, rise and fall times desired, gate resistor used, total gate charge for the MOSFET/IGBT and the voltage swing, one can calculate the peak currents in the transformer primary and secondary. Calculating the average values for these currents will enable one to either design the gate drive transformer or to enable one to select the appropriate commercially available gate drive transformers.

Almost all possible configurations of bi-directional switches employing IGBTs and FREDs (Fast Recovery Epitaxial Diodes) are shown in Fig.(15). When connected in series with the IGBT, the FRED gives reverse blocking capability to the bi-directional switch. When connected inversely across the IGBT, the FRED provides a path for the line current to flow in the reverse direction. Both techniques prevent reverse voltage application to the emitter of IGBT.

These bi-directional switches form nodes for matrix converters or for A.C. to D.C. converters. Driving IGBTs in these bi-directional switches can be easily implemented using the gate drive transformers, as shown in Fig. (15). As can be appreciated, R_1 , R_2 , R_3 and R_4 help wave shaping by facilitating core resetting. Z_1 , Z_2 , Z_3 and Z_4 protect the gate of IGBT from voltage spikes above 18.7 volts.

Another method uses opto-couplers, as illustrated in Fig. (16). As can be seen, opto-couplers need isolated power supply. However, they facilitate D.C. to several Mbits/sec of pulse rate and do provide kilovolts of isolation. Keeping the same chain of opto-coupler and Driver IC in each complementary signal path will nullify the effect of slight propagation delay through these opto-couplers and Driver ICs. It is assumed here that difference in propagation delays between two same type opto-couplers is negligible.

Opto-couplers have the following features:

1. Adequate galvanic isolation is possible. Many opto-couplers are U/L listed.
2. Most opto-couplers are compatible with TTL/CMOS/HCMOS inputs. Their outputs depend on Vcc of isolated power supply. They do need isolated power supply.
3. They are not immune to severe dv/dt transients.
4. Signals experience propagation delays through opto-couplers.
5. Large duty cycle range of pulse width is possible.
6. High overall efficiency of gate drive is possible.
7. Overload and short circuit protection can be easily implemented using either DESAT concept or current sense method. This is explained in section 4.2.2, using Fig. (12) and Fig. (13).

7. MATRIX CONVERTERS

Matrix converters afford great ease and convenience in AC-AC conversion, without the need for bulky energy storage components required in AC-DC-AC conversion. In addition, they allow regenerative energy to be fed back to Mains and feature sinusoidal input and output currents and controllable input current displacement factor.

A basic 3 phase to 3 phase matrix converter uses nine bi-directional switches as shown in Fig (17). Several different configurations of achieving bi-directional switches using IGBTs and FREDs are shown in Fig.(15) and Fig.(16). Each IGBT used in these bi-directional switches will require isolated gate drive and it is here that the real value and convenience of a gate drive transformer can be appreciated. It is difficult to imagine, use of opto-couplers, chiefly because of the need for isolated power supply.

Tiny gate drive transformers come really handy in this application, with all its attendant advantages as listed above.

8. CONCLUSION

With proliferating applications of modern power electronics worldwide, faster, more efficient and more compact MOSFETs and IGBTs are replacing older solid state and mechanical devices. The design of newer and more efficient techniques to turn these solid state devices on and off is a subject that requires thorough study and understanding of the internal structure and

dynamic processes involved in the working of MOSFET/IGBTs.

Main emphasis in modern Power Electronics is to reduce total losses dissipated in devices and subsystems for higher operating efficiency and achieving more compact designs, reducing volume and weight of resultant systems. Thus, operation at higher and higher switching frequencies is now a necessity, and as a result, switching losses predominate in the power-loss-budget in semiconductor switches. Reducing switching losses then becomes the single most crucial goal. Keeping this goal in mind, the MOSFET/IGBT Drivers should be designed so as to yield ultra fast rise and fall times, matching or exceeding that of the driven MOSFET/IGBTs. Propagation delay time should be extremely low, facilitating implementation of fast overload/short circuit protection. Most semiconductor switches that can withstand momentary overloads specify 10 us as the maximum allowable duration. From the instance of sensing overload/short circuit to the removal of gate signals, time elapsed should be less than 80% of the rated SCSOA time.

With the advent of IC Drivers for these fast MOSFET/IGBTs, the designer is relieved of the tedious task of designing elaborate driver circuits. Nevertheless, understanding these newer ICs, their strengths and limitations, is of paramount importance. Different configurations for particular topologies call for specific application knowledge. Illustrations are the best way to explain theory and applications of these Driver ICs.

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RECOMMENDED FURTHER READING

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Table: 1

Driving Standard IXYS MOSFETs														
		f_{PWM} = 100KHz				f_{PWM} = 200KHz				f_{PWM} = 400KHz				
Standard	Q _g in	Peak I _q in	R _q in	Total Pg	Gate	Peak I _q in	R _q in	Total Pg	Gate	Peak I _q in	R _q in	Total Pg	Gate	Rcmd Pwr
Mosfet	nC	Amp	Ohm	W	Drvr	Amp	Ohm	W	Drvr	Amp	Ohm	W	Drvr	Out
IXFH6N100	88	0.9	11.4	0.1	Dx402	1.8	5.7	0.3	Dx404	3.5	2.8	0.5	Dx404	500W
IXFH12N100	122	1.2	8.2	0.2	Dx402	2.4	4.1	0.4	Dx404	4.9	2	0.7	DD408	1KW
IXTK21N100	250	2.5	4	0.4	Dx404	5	2	0.8	DD408	10	1	1.5	Dx414*	2KW
Driving Q-Class MOSFETs														
		f_{PWM} = 200KHz				f_{PWM} = 400KHz				f_{PWM} = 800KHz				
Q-Class	Q _g in	Peak I _q in	R _q in	Total Pg	Gate	Peak I _q in	R _q in	Total Pg	Gate	Peak I _q in	R _q in	Total Pg	Gate	Rcmd Pwr
Mosfet	nC	Amp	Ohm	W	Drvr	Amp	Ohm	W	Drvr	Amp	Ohm	W	Drvr	Out
IXFH6N100Q	48	0.96	10.4	0.1	Dx402	1.9	5.2	0.28	Dx402	3.84	2.6	0.57	Dx404	500W
XFH12N100C	90	1.8	5.6	0.3	Dx404	3.6	2.8	0.5	DD408	7.2	1.4	1.1	Dx409*	1KW
XFH21N100C	170	3.4	2.9	0.5	Dx408*	6.8	1.5	1	Dx409*	13.6	0.7	2	Dx414*	2KW
Driving F-Class MOSFETs														
		f_{PWM} = 1MHz				f_{PWM} = 2MHz				f_{PWM} = 4MHz				
Q-Class	Q _g in	Peak I _q in	R _q in	Total Pg	Gate	Peak I _q in	R _q in	Total Pg	Gate	Peak I _q in	R _q in	Total Pg	Gate	Rcmd Pwr
Mosfet	nC	Amp	Ohm	W	Drvr	Amp	Ohm	W	Drvr	Amp	Ohm	W	Drvr	Out
IXFH6N100F	54	1.08	9.3	0.8	Dx402	2.16	4.6	1.6	DD408*	4.32	2.3	3.2	DD408*	500W
XFH12N100F	77	1.54	6.5	1.2	DD408*	3.08	3.2	2.3	DD408*	6.16	1.6	4.6	Dx409*	1KW
XFK21N100F	160	3.2	3.1	2.4	DD408*	6.4	1.6	4.8	Dx409*	12.8	0.8	9.6	Dx414*	2KW

Table: 2

Gate Driver Selection Table for HiPerFETs

$$tr + tf \text{ in \% of } tpwm = \sim 1 \%$$

Power Discretes/N-channel Power

Note: Gate Drivers Dx409 and Dx414* require heat sinks. All others without (*) don't require them.

Rg listed below are max. acceptable values for application; lower Rg values may be used.

HiPerFET Power MOSFETS						f _{PWM} = 50 KHz				f _{PWM} = 100 KHz				f _{PWM} = 200 KHz				f _{PWM} = 400 KHz				f _{PWM} = 800 KHz			
Device Type	V _{DSS} Max. V	I _D Amps	R _{Ds(on)} Ohms	Q _{G(on)} nC	G _g	f _{PWM} = 50 KHz				f _{PWM} = 100 KHz				f _{PWM} = 200 KHz				f _{PWM} = 400 KHz				f _{PWM} = 800 KHz			
						I _g Peak Amps	R _g Max Ohms	P _g Max Watts	Gate Driver Fmly	I _g Peak Amps	R _g Max Ohms	P _g Max Watts	Gate Driver Fmly	I _g Peak Amps	R _g Max Ohms	P _g Max Watts	Gate Driver Fmly	I _g Peak Amps	R _g Max Ohms	P _g Max Watts	Gate Driver Fmly	I _g Peak Amps	R _g Max Ohms	P _g Max Watts	Gate Driver Fmly
IXFR180N06	60	180*	0.005	420	2.1	5	0.32	Dx404	4.2	2.4	0.63	Dx409	8.4	1.2	1.26	Dx414*	16.8	0.6	2.52	Dx430*	33.6	0.3	5.04	Dx430*	
IXFN340N06	60	340*	0.003	600	3	3	0.45	Dx404	6	1.7	0.9	Dx409	12	0.8	1.8	Dx414*	24.0	0.4	3.6	Dx430*	48	0.2	7.2	Dx430*	
IXFH76N07-11	70	76	0.011	240	1.2	8	0.18	Dx402	2.4	4.2	0.36	Dx404	4.8	2.1	0.72	Dx409	9.6	1.0	1.44	Dx414*	19.2	0.5	2.88	Dx430*	
IXFH76N07-12	70	76	0.012	240	1.2	8	0.18	Dx402	2.4	4.2	0.36	Dx404	4.8	2.1	0.72	Dx409	9.6	1.0	1.44	Dx414*	19.2	0.5	2.88	Dx430*	
IXFK180N07	70	180*	0.006	420	2.1	5	0.32	Dx404	4.2	2.4	0.63	Dx409	8.4	1.2	1.26	Dx414*	16.8	0.6	2.52	Dx430*	33.6	0.3	5.04	Dx430*	
IXFK180N07	70	180*	0.006	420	2.1	5	0.32	Dx404	4.2	2.4	0.63	Dx409	8.4	1.2	1.26	Dx414*	16.8	0.6	2.52	Dx430*	33.6	0.3	5.04	Dx430*	
IXFK180N07	70	180*	0.006	420	2.1	5	0.32	Dx404	4.2	2.4	0.63	Dx409	8.4	1.2	1.26	Dx414*	16.8	0.6	2.52	Dx430*	33.6	0.3	5.04	Dx430*	
IXFN180N07	70	180*	0.007	480	2.4	4	0.36	Dx404	4.8	2.1	0.72	Dx409	9.6	1.0	1.44	Dx414*	19.2	0.5	2.88	Dx430*	38.4	0.3	5.76	Dx430*	
IXFR180N07	70	180*	0.006	420	2.1	5	0.32	Dx404	4.2	2.4	0.63	Dx409	8.4	1.2	1.26	Dx414*	16.8	0.6	2.52	Dx430*	33.6	0.3	5.04	Dx430*	
IXFN180N07	70	180*	0.006	420	2.1	5	0.32	Dx404	4.2	2.4	0.63	Dx409	8.4	1.2	1.26	Dx414*	16.8	0.6	2.52	Dx430*	33.6	0.3	5.04	Dx430*	
IXFN200N07	70	200*	0.006	480	2.4	4	0.36	Dx404	4.8	2.1	0.72	Dx409	9.6	1.0	1.44	Dx414*	19.2	0.5	2.88	Dx430*	38.4	0.3	5.76	Dx430*	
IXFN280N07	70	280*	0.006	420	2.1	5	0.32	Dx404	4.2	2.4	0.63	Dx409	8.4	1.2	1.26	Dx414*	16.8	0.6	2.52	Dx430*	33.6	0.3	5.04	Dx430*	
IXFN340N07	70	340*	0.004	600	3	3	0.45	Dx404	6	1.7	0.9	Dx409	12	0.8	1.8	Dx414*	24.0	0.4	3.6	Dx430*	48	0.2	7.2	Dx430*	
IXFR180N085	85	180*	0.007	320	1.6	6	0.24	Dx404	3.2	3.1	0.48	Dx404	6.4	1.6	0.96	Dx409*	12.8	0.8	1.92	Dx414*	25.6	0.4	3.84	Dx430*	
IXF180N085	85	180*	0.007	320	1.6	6	0.24	Dx404	3.2	3.1	0.48	Dx404	6.4	1.6	0.96	Dx409*	12.8	0.8	1.92	Dx414*	25.6	0.4	3.84	Dx430*	
IXFH280N095	85	280*	0.0044	600	3	3	0.45	Dx404	6	1.7	0.9	Dx409	12	0.8	1.8	Dx414*	24.0	0.4	3.6	Dx430*	48	0.2	7.2	Dx430*	
IXFE180N10	100	180*	0.008	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4	1.08	Dx409*	14.4	0.7	2.16	Dx430*	28.8	0.3	4.32	Dx430*	
IXFK180N10	100	180*	0.008	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4	1.08	Dx409*	14.4	0.7	2.16	Dx430*	28.8	0.3	4.32	Dx430*	
IXFN180N10	100	180*	0.008	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4	1.08	Dx409*	14.4	0.7	2.16	Dx430*	28.8	0.3	4.32	Dx430*	
IXFR180N10	100	180*	0.008	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4	1.08	Dx409*	14.4	0.7	2.16	Dx430*	28.8	0.3	4.32	Dx430*	
IXFN180N10	100	180*	0.008	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4	1.08	Dx409*	14.4	0.7	2.16	Dx430*	28.8	0.3	4.32	Dx430*	
IXFN230N10	100	230*	0.006	390	1.95	5	0.29	Dx404	3.9	2.6	0.585	Dx404	7.8	1.3	1.17	Dx409*	15.6	0.6	2.34	Dx430*	31.2	0.3	4.68	Dx430*	
IXFC80N10	100	80*	0.0125	230	1.15	9	0.17	Dx402	2.3	4.3	0.345	Dx404	4.6	2.2	0.69	Dx409	9.2	1.1	1.38	Dx414*	18.4	0.5	2.76	Dx430*	
IXFC80N10	100	80*	0.0125	230	1.15	9	0.17	Dx402	2.3	4.3	0.345	Dx404	4.6	2.2	0.69	Dx409	9.2	1.1	1.38	Dx414*	18.4	0.5	2.76	Dx430*	
IXFC80N10	100	80*	0.0125	230	1.15	9	0.17	Dx402	2.3	4.3	0.345	Dx404	4.6	2.2	0.69	Dx409	9.2	1.1	1.38	Dx414*	18.4	0.5	2.76	Dx430*	
IXFH80N10	100	80*	0.0125	230	1.15	9	0.17	Dx402	2.3	4.3	0.345	Dx404	4.6	2.2	0.69	Dx409	9.2	1.1	1.38	Dx414*	18.4	0.5	2.76	Dx430*	
IXFH80N10	100	80*	0.0125	230	1.15	9	0.17	Dx402	2.3	4.3	0.345	Dx404	4.6	2.2	0.69	Dx409	9.2	1.1	1.38	Dx414*	18.4	0.5	2.76	Dx430*	
IXFT80N10	100	80*	0.0125	230	1.15	9	0.17	Dx402	2.3	4.3	0.345	Dx404	4.6	2.2	0.69	Dx409	9.2	1.1	1.38	Dx414*	18.4	0.5	2.76	Dx430*	
IXFT80N10	100	80*	0.0125	230	1.15	9	0.17	Dx402	2.3	4.3	0.345	Dx404	4.6	2.2	0.69	Dx409	9.2	1.1	1.38	Dx414*	18.4	0.5	2.76	Dx430*	
IXFT80N10	100	80*	0.0125	230	1.15	9	0.17	Dx402	2.3	4.3	0.345	Dx404	4.6	2.2	0.69	Dx409	9.2	1.1	1.38	Dx414*	18.4	0.5	2.76	Dx430*	
IXFR150N15	150	105*	0.0125	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4	1.08	Dx409*	14.4	0.7	2.16	Dx430*	28.8	0.3	4.32	Dx430*	
IXFK150N15	150	150*	0.0125	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4	1.08	Dx409*	14.4	0.7	2.16	Dx430*	28.8	0.3	4.32	Dx430*	
IXFN150N15	150	150*	0.0125	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4	1.08	Dx409*	14.4	0.7	2.16	Dx430*	28.8	0.3	4.32	Dx430*	
IXFX150N15	150	150*	0.0125	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4	1.08	Dx409*	14.4	0.7	2.16	Dx430*	28.8	0.3	4.32	Dx430*	
IXFH74N20	200	74	0.03	280	1.4	7	0.21	Dx402	2.8	3.6	0.42	Dx404	5.6	1.8	0.84	Dx409*	11.2	0.9	1.68	Dx414*	22.4	0.4	3.36	Dx430*	
IXFT74N20	200	74	0.03	280	1.4	7	0.21	Dx402	2.8	3.6	0.42	Dx404	5.6	1.8	0.84	Dx409*	11.2	0.9	1.68	Dx414*	22.4	0.4	3.36	Dx430*	
IXFK80N20	200	80	0.03	280	1.4	7	0.21	Dx402	2.8	3.6	0.42	Dx404	5.6	1.8	0.84	Dx409*	11.2	0.9	1.68	Dx414*	22.4	0.4	3.36	Dx430*	
IXFR120N20	200	105	0.017	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4	1.08	Dx409*	14.4	0.7	2.16	Dx430*	28.8	0.3	4.32	Dx430*	
IXFK120N20	200	120	0.017	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4	1.08	Dx409*	14.4	0.7	2.16	Dx430*	28.8	0.3	4.32	Dx430*	
IXFN120N20	200	120	0.017	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4	1.08	Dx409*	14.4	0.7	2.16	Dx430*	28.8	0.3	4.32	Dx430*	
IXFX120N20	200	120	0.017	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4	1.08	Dx409*	14.4	0.7	2.16	Dx430*	28.8	0.3	4.32	Dx430*	
IXFN180N20	200	180	0.01	380	1.9	5	0.29	Dx404	3.8	2.6	0.57	Dx404	7.6	1.3	1.14	Dx409*	15.2	0.7	2.28	Dx430*	30.4	0.3	4.56	Dx430*	
IXFR100N25	250	87	0.027	300	1.5	7	0.23	Dx402	3	3.3	0.45	Dx404	6	1.7	0.9	Dx409*	12.0	0.8	1.8	Dx414*	24	0.4	3.6	Dx430*	
IXFK100N25	250	100	0.027	300	1.5	7	0.23	Dx402	3	3.3	0.45	Dx404	6	1.7	0.9	Dx409*	12.0	0.8	1.8	Dx414*	24	0.4	3.6	Dx430*	
IXFN100N25	250	100	0.027	300	1.5	7	0.23	Dx402	3	3.3	0.45	Dx404	6	1.7	0.9	Dx409*	12.0	0.8	1.8	Dx414*	24	0.4	3.6	Dx430*	
IXFX100N25	250	100	0.027	300	1.5	7	0.23	Dx402	3	3.3	0.45	Dx404	6	1.7	0.9	Dx409*	12.0	0.8	1.8	Dx414*	24	0.4	3.6	Dx430*	
IXFK73N30	300	73	0.045	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4	1.08	Dx409*	14.4	0.7	2.16	Dx430*	28.8	0.3	4.32	Dx430*	
IXFN73N30	300	73	0.045	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4	1.08	Dx409*	14.4	0.7	2.16	Dx430*	28.8	0.3	4.32	Dx430*	
IXFR90N30	300	75	0.033	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4	1.08	Dx409*	14.4	0.7	2.16	Dx430*	28.8	0.3	4.32	Dx430*	
IXFK90N30	300	90	0.033	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4	1.08	Dx409*	14.4	0.7	2.16	Dx430*	28.8	0.3	4.32	Dx430*	
IXFN90N30	300	90	0.033	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4	1.08	Dx409*	14.4	0.7	2.16	Dx430*	28.8	0.3	4.32	Dx430*	
IXFX90N30	300	90	0.033	360	1.8	6	0.27	Dx404	3.6	2.8	0.54	Dx404	7.2	1.4											

Table: 3

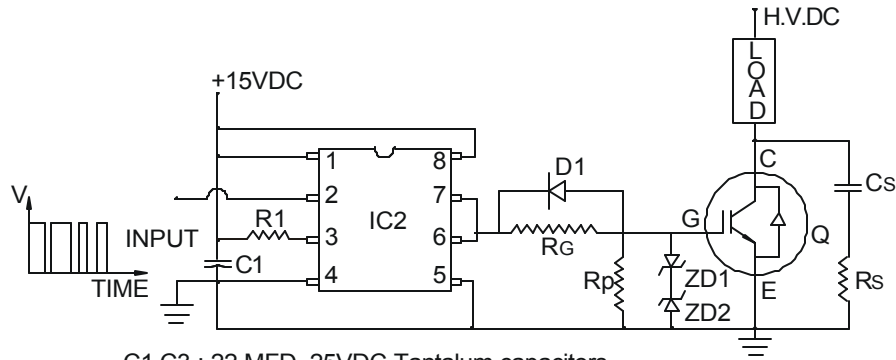
Gate Driver Selection Table for HiPerFETs $t_r + t_f$ in % of $t_{PWM} \sim 1\%$

Power Discretes/N-channel Power

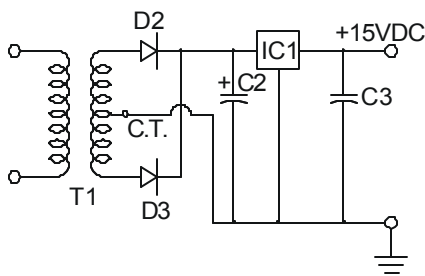
Note: Gate Drivers Dx409 and Dx414* require heat sinks. All others without (*) don't require them.

Rg listed below are max. acceptable values for application; lower Rg values may be used.

HiPerFET Power MOSFETS						f _{PWM} = 50 KHz				f _{PWM} = 100 KHz				f _{PWM} = 200 KHz				f _{PWM} = 400 KHz				f _{PWM} = 800 KHz			
Device Type	V _{DSS} Max. V	I _D Amps	R _{DS(on)} Ohms	Q _{G(on)} nC	f _{PWM} = 50 KHz				f _{PWM} = 100 KHz				f _{PWM} = 200 KHz				f _{PWM} = 400 KHz				f _{PWM} = 800 KHz				
					I _g Peak Amps	R _g Max Ohms	P _g Max Watts	Gate Driver Fmly	I _g Peak Amps	R _g Max Ohms	P _g Max Watts	Gate Driver Fmly	I _g Peak Amps	R _g Max Ohms	P _g Max Watts	Gate Driver Fmly	I _g Peak Amps	R _g Max Ohms	P _g Max Watts	Gate Driver Fmly	I _g Peak Amps	R _g Max Ohms	P _g Max Watts	Gate Driver Fmly	
IXFR50N50	500	43	0.1	330	1.65	6	0.25	Dx402	3.3	3.0	0.495	Dx404	6.6	1.5	0.99	Dx409*	13.2	0.8	1.98	Dx414*	26.4	0.4	3.96	Dx430*	
IXFK44N50~	500	44	0.12	270	1.35	7	0.20	Dx402	2.7	3.7	0.405	Dx404	5.4	1.9	0.81	Dx409*	10.8	0.9	1.62	Dx414*	21.6	0.5	3.24	Dx430*	
IXFN44N50~	500	44	0.12	270	1.35	7	0.20	Dx402	2.7	3.7	0.405	Dx404	5.4	1.9	0.81	Dx409*	10.8	0.9	1.62	Dx414*	21.6	0.5	3.24	Dx430*	
IXFN44N50U2**	500	44	0.12	270	1.35	7	0.20	Dx402	2.7	3.7	0.405	Dx404	5.4	1.9	0.81	Dx409*	10.8	0.9	1.62	Dx414*	21.6	0.5	3.24	Dx430*	
IXFN44N50U3**	500	44	0.12	270	1.35	7	0.20	Dx402	2.7	3.7	0.405	Dx404	5.4	1.9	0.81	Dx409*	10.8	0.9	1.62	Dx414*	21.6	0.5	3.24	Dx430*	
IXFK48N50	500	48	0.1	270	1.35	7	0.20	Dx402	2.7	3.7	0.405	Dx404	5.4	1.9	0.81	Dx409*	10.8	0.9	1.62	Dx414*	21.6	0.5	3.24	Dx430*	
IXFN48N50	500	48	0.1	270	1.35	7	0.20	Dx402	2.7	3.7	0.405	Dx404	5.4	1.9	0.81	Dx409*	10.8	0.9	1.62	Dx414*	21.6	0.5	3.24	Dx430*	
IXFN48N50U2**	500	48	0.1	270	1.35	7	0.20	Dx402	2.7	3.7	0.405	Dx404	5.4	1.9	0.81	Dx409*	10.8	0.9	1.62	Dx414*	21.6	0.5	3.24	Dx430*	
IXFN48N50U3**	500	48	0.1	330	1.65	6	0.25	Dx402	3.3	3.0	0.495	Dx404	6.6	1.5	0.99	Dx409*	13.2	0.8	1.98	Dx414*	26.4	0.4	3.96	Dx430*	
IXFR55N50	500	48	0.08	330	1.65	6	0.25	Dx402	3.3	3.0	0.495	Dx404	6.6	1.5	0.99	Dx409*	13.2	0.8	1.98	Dx414*	26.4	0.4	3.96	Dx430*	
IXFK50N50	500	50	0.1	330	1.65	6	0.25	Dx402	3.3	3.0	0.495	Dx404	6.6	1.5	0.99	Dx409*	13.2	0.8	1.98	Dx414*	26.4	0.4	3.96	Dx430*	
IXFN50N50	500	50	0.1	330	1.65	6	0.25	Dx402	3.3	3.0	0.495	Dx404	6.6	1.5	0.99	Dx409*	13.2	0.8	1.98	Dx414*	26.4	0.4	3.96	Dx430*	
IXFX50N50	500	50	0.1	330	1.65	6	0.25	Dx402	3.3	3.0	0.495	Dx404	6.6	1.5	0.99	Dx409*	13.2	0.8	1.98	Dx414*	26.4	0.4	3.96	Dx430*	
IXFE50N50	500	52	0.1	330	1.65	6	0.25	Dx402	3.3	3.0	0.495	Dx404	6.6	1.5	0.99	Dx409*	13.2	0.8	1.98	Dx414*	26.4	0.4	3.96	Dx430*	
IXFK55N50	500	55	0.08	330	1.65	6	0.25	Dx402	3.3	3.0	0.495	Dx404	6.6	1.5	0.99	Dx409*	13.2	0.8	1.98	Dx414*	26.4	0.4	3.96	Dx430*	
IXFN55N50	500	55	0.08	330	1.65	6	0.25	Dx402	3.3	3.0	0.495	Dx404	6.6	1.5	0.99	Dx409*	13.2	0.8	1.98	Dx414*	26.4	0.4	3.96	Dx430*	
IXFX55N50	500	55	0.08	330	1.65	6	0.25	Dx402	3.3	3.0	0.495	Dx404	6.6	1.5	0.99	Dx409*	13.2	0.8	1.98	Dx414*	26.4	0.4	3.96	Dx430*	
IXFE80N50	500	71	0.05	380	1.9	5	0.29	Dx404	3.8	2.6	0.57	Dx404	7.6	1.3	1.14	Dx409*	15.2	0.7	2.28	Dx430*	30.4	0.3	4.56	Dx430*	
IXFN75N50	500	75	0.055	380	1.9	5	0.29	Dx404	3.8	2.6	0.57	Dx404	7.6	1.3	1.14	Dx409*	15.2	0.7	2.28	Dx430*	30.4	0.3	4.56	Dx430*	
IXFN80N50	500	80	0.05	380	1.9	5	0.29	Dx404	3.8	2.6	0.57	Dx404	7.6	1.3	1.14	Dx409*	15.2	0.7	2.28	Dx430*	30.4	0.3	4.56	Dx430*	
IXFK48N55	550	48	0.11	330	1.65	6	0.25	Dx402	3.3	3.0	0.495	Dx404	6.6	1.5	0.99	Dx409*	13.2	0.8	1.98	Dx414*	26.4	0.4	3.96	Dx430*	
IXFN48N55	550	48	0.11	330	1.65	6	0.25	Dx402	3.3	3.0	0.495	Dx404	6.6	1.5	0.99	Dx409*	13.2	0.8	1.98	Dx414*	26.4	0.4	3.96	Dx430*	
IXFX48N55	550	48	0.11	330	1.65	6	0.25	Dx402	3.3	3.0	0.495	Dx404	6.6	1.5	0.99	Dx409*	13.2	0.8	1.98	Dx414*	26.4	0.4	3.96	Dx430*	
IXFK32N60~	600	32	0.25	325	1.625	6	0.24	Dx402	3.25	3.1	0.488	Dx404	6.5	1.5	0.975	Dx409*	13.0	0.8	1.95	Dx414*	26	0.4	3.9	Dx430*	
IXFN32N60~	600	32	0.25	325	1.625	6	0.24	Dx402	3.25	3.1	0.488	Dx404	6.5	1.5	0.975	Dx409*	13.0	0.8	1.95	Dx414*	26	0.4	3.9	Dx430*	
IXFK36N60	600	36	0.18	325	1.625	6	0.24	Dx402	3.25	3.1	0.488	Dx404	6.5	1.5	0.975	Dx409*	13.0	0.8	1.95	Dx414*	26	0.4	3.9	Dx430*	
IXFN36N60	600	36	0.18	325	1.625	6	0.24	Dx402	3.25	3.1	0.488	Dx404	6.5	1.5	0.975	Dx409*	13.0	0.8	1.95	Dx414*	26	0.4	3.9	Dx430*	
IXFR44N60	600	38	0.13	330	1.65	6	0.25	Dx402	3.3	3.0	0.495	Dx404	6.6	1.5	0.99	Dx409*	13.2	0.8	1.98	Dx414*	26.4	0.4	3.96	Dx430*	
IXFE44N60	600	40	0.13	330	1.65	6	0.25	Dx402	3.3	3.0	0.495	Dx404	6.6	1.5	0.99	Dx409*	13.2	0.8	1.98	Dx414*	26.4	0.4	3.96	Dx430*	
IXFK44N60	600	44	0.13	330	1.65	6	0.25	Dx402	3.3	3.0	0.495	Dx404	6.6	1.5	0.99	Dx409*	13.2	0.8	1.98	Dx414*	26.4	0.4	3.96	Dx430*	
IXFN44N60	600	44	0.13	330	1.65	6	0.25	Dx402	3.3	3.0	0.495	Dx404	6.6	1.5	0.99	Dx409*	13.2	0.8	1.98	Dx414*	26.4	0.4	3.96	Dx430*	
IXFX44N60	600	44	0.13	330	1.65	6	0.25	Dx402	3.3	3.0	0.495	Dx404	6.6	1.5	0.99	Dx409*	13.2	0.8	1.98	Dx414*	26.4	0.4	3.96	Dx430*	
IXFN60N60	600	60	0.08	380	1.9	5	0.29	Dx402	3.8	2.6	0.57	Dx404	7.6	1.3	1.14	Dx409*	15.2	0.7	2.28	Dx430*	30.4	0.3	4.56	Dx430*	
IXFK27N80	800	27	0.32	350	1.75	6	0.26	Dx404	3.5	2.9	0.525	Dx404	7	1.4	1.05	Dx409*	14.0	0.7	2.1	Dx430*	28	0.4	4.2	Dx430*	
IXFN27N80	800	27	0.32	350	1.75	6	0.26	Dx402	3.5	2.9	0.525	Dx402	7	1.4	1.05	Dx409*	14.0	0.7	2.1	Dx430*	28	0.4	4.2	Dx430*	
IXFR34N80	800	28	0.24	270	1.35	7	0.20	Dx402	2.7	3.7	0.405	Dx404	5.4	1.9	0.81	Dx409*	10.8	0.9	1.62	Dx414*	21.6	0.5	3.24	Dx430*	
IXFK34N80	800	34	0.24	270	1.35	7	0.20	Dx402	2.7	3.7	0.405	Dx404	5.4	1.9	0.81	Dx409*	10.8	0.9	1.62	Dx414*	21.6	0.5	3.24	Dx430*	
IXFN34N80	800	34	0.24	270	1.35	7	0.20	Dx402	2.7	3.7	0.405	Dx404	5.4	1.9	0.81	Dx409*	10.8	0.9	1.62	Dx414*	21.6	0.5	3.24	Dx430*	
IXFX34N80	800	34	0.24	270	1.35	7	0.20	Dx402	2.7	3.7	0.405	Dx404	5.4	1.9	0.81	Dx409*	10.8	0.9	1.62	Dx414*	21.6	0.5	3.24	Dx430*	
IXFN44N80	800	44	0.145	380	1.9	5	0.29	Dx404	3.8	2.6	0.57	Dx404	7.6	1.3	1.14	Dx409*	15.2	0.7	2.28	Dx430*	30.4	0.3	4.56	Dx430*	
IXFK25N90	900	25	0.33	240	1.2	8	0.18	Dx402	2.4	4.2	0.36	Dx404	4.8	2.1	0.72	Dx409	9.6	1.0	1.44	Dx414*	19.2	0.5	2.88	Dx430*	
IXFN25N90	900	25	0.33	240	1.2	8	0.18	Dx402	2.4	4.2	0.36	Dx404	4.8	2.1	0.72	Dx409	9.6	1.0	1.44	Dx414*	19.2	0.5	2.88	Dx430*	
IXFK25N90	900	25	0.33	240	1.2	8	0.18	Dx402	2.4	4.2	0.36	Dx404	4.8	2.1	0.72	Dx409	9.6	1.0	1.44	Dx414*	19.2	0.5	2.88	Dx430*	
IXFK26N90	900	26	0.3	240	1.2	8	0.18	Dx402	2.4	4.2	0.36	Dx404	4.8	2.1	0.72	Dx409	9.6	1.0	1.44	Dx414*	19.2	0.5	2.88	Dx430*	
IXFN26N90	900	26	0.3	240	1.2	8	0.18	Dx402	2.4	4.2	0.36	Dx404	4.8	2.1	0.72	Dx409	9.6	1.0	1.44	Dx414*	19.2	0.5	2.88	Dx430*	
IXFX26N90	900	26	0.3	240	1.2	8	0.18	Dx402	2.4	4.2	0.36	Dx404	4.8	2.1	0.72	Dx409	9.6	1.0	1.44	Dx414*	19.2	0.5	2.88	Dx430*	
IXFN39N90	900	39	0.22	390	1.95	5	0.29	Dx404	3.9	2.6	0.585	Dx404	7.8	1.3	1.17	Dx409*	15.6	0.6	2.34	Dx430*	31.2	0.3	4.68	Dx430*	
IXFH14N100	1000	14	0.75	220	1.1	9	0.17	Dx402	2.2	4.5	0.33	Dx404	4.4	2.3	0.66	Dx409	8.8	1.1	1.32	Dx414*	17.6	0.6	2.64	Dx430*	
IXFT14N100	1000	14	0.75	220	1.1	9	0.17	Dx402	2.2	4.5	0.33	Dx404	4.4	2.3	0.66	Dx409	8.8	1.1	1.32	Dx414*	17.6	0.6	2.64	Dx430*	
IXFX14N100	1000	14	0.75	220	1.1	9	0.17	Dx402	2.2	4.5	0.33	Dx404	4.4	2.3	0.66	Dx409	8.8	1.1	1.32	Dx414*	17.6	0.6	2.64	Dx430*	
IXFH15N100	1000	15	0.7	220	1.1	9	0.17	Dx402	2.2	4.5	0.33	Dx404	4.4	2.3	0.66	Dx409	8.8	1.1	1.32	Dx414*	17.6	0.6	2.64	Dx430*	
IXFT15N100	1000	15	0.7	220	1.1	9	0.17	Dx402	2.2	4.5	0.33	Dx404	4.4	2.3	0.66	Dx409	8.8	1.1	1.32	Dx					



C1,C3 : 22 MFD, 25VDC Tantalum capacitors
 C2 : 2200 MFD, 35VDC Electrolytic capacitors
 T1 : 220 VAC TO 15-0-15 VAC, 15VA control transformer
 or 110VAC TO 15-0-15 VAC, 15 VA Control Transformer.
 Q : IXLF19N250A



IC1 : 7815 Regulator
 IC2 : IXDN409 or IXDN414
 D1 : IN5817
 D2,D3 : IN4002
 ZD1,ZD2 : 18V, 400MW ZENERS
 RG1 : 3.3 ohms to 27 ohms
 depending on Turn-ON speed
 Rp : 2K2, ¼ W, 5%
 Cs, Rs : Snubber network to reduce IGBT switching
 losses. Value depends upon fsw. Suggest:
 Cs=0.1 MFD, Rs=10 to 33 ohms
 R1 : 10K, ¼ w

Fig. (1) Circuit schematic showing how to use IXDN409 or IXDN414 to drive an IGBT

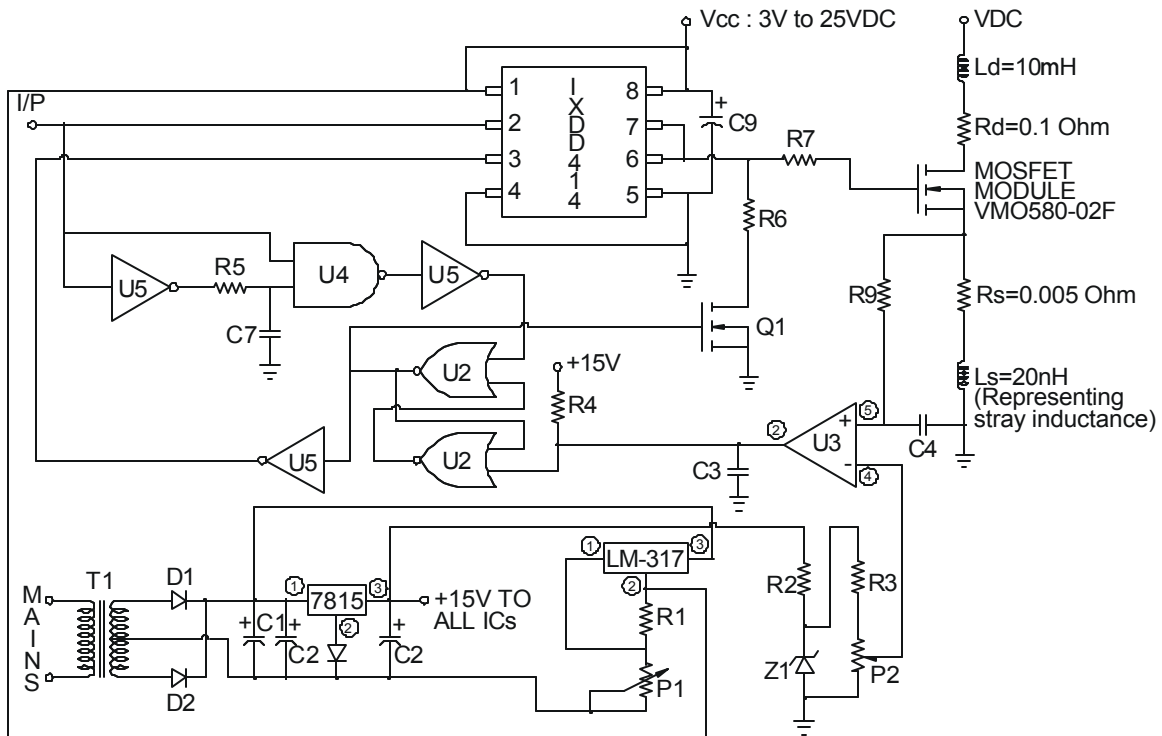
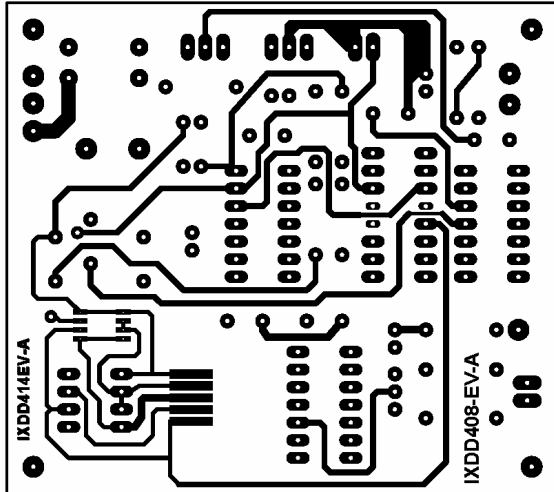
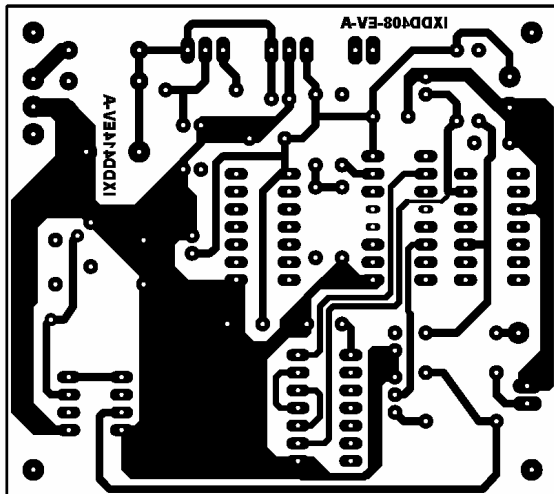
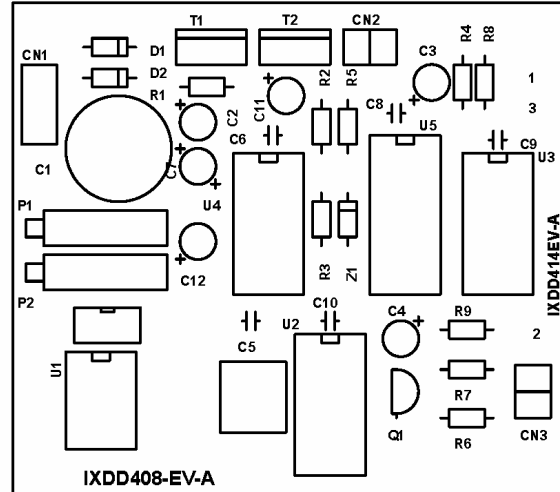


Fig. (2). Evaluation circuit to test IXDD408 and IXDD414 for soft turn off.



Component Side



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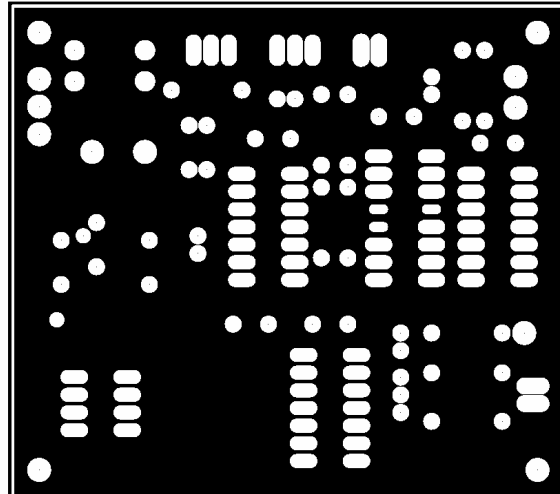


Fig. (3) Photographic +ve and -ve and component layout with silk seen diagram for Circuit of Fig.(2).

Bill of Materials for Fig.(2)

Resistors:

- R1: 240
- R2: 560
- R3: 10K
- R4: 5K
- R5: 1Meg
- R6: 1K5
- R7: Rg-T.B.D.
- R8: 1Meg

Trimmers:

- P1: 5K, 3006P Bourns or Spectrol
- P2: 1K, 3006P Bourns or Spectrol

Capacitors:

- C1: 1000 μ F;35VWDC
- C2: 22 μ F, 63 VWDC
- C3: 1pF, silver dipped mica
- C4: 100pF silver dipped mica
- C5: 0.1 μ F, 35WDC Tantalum
- C6: 0.1 μ F, 35VWDC Tantalum
- C7: 1pF silver dipped mica
- C8: 0.1 μ F, 35VWDC Tantalum
- C9: 0.1 μ F, 35VWDC Tantalum
- C10: 0.1 μ F, 35VWDC Tantalum

Diodes:

- D1: 1N4002 or BA 159
- D2: 1N4002 or BA 159

Zener Diodes:

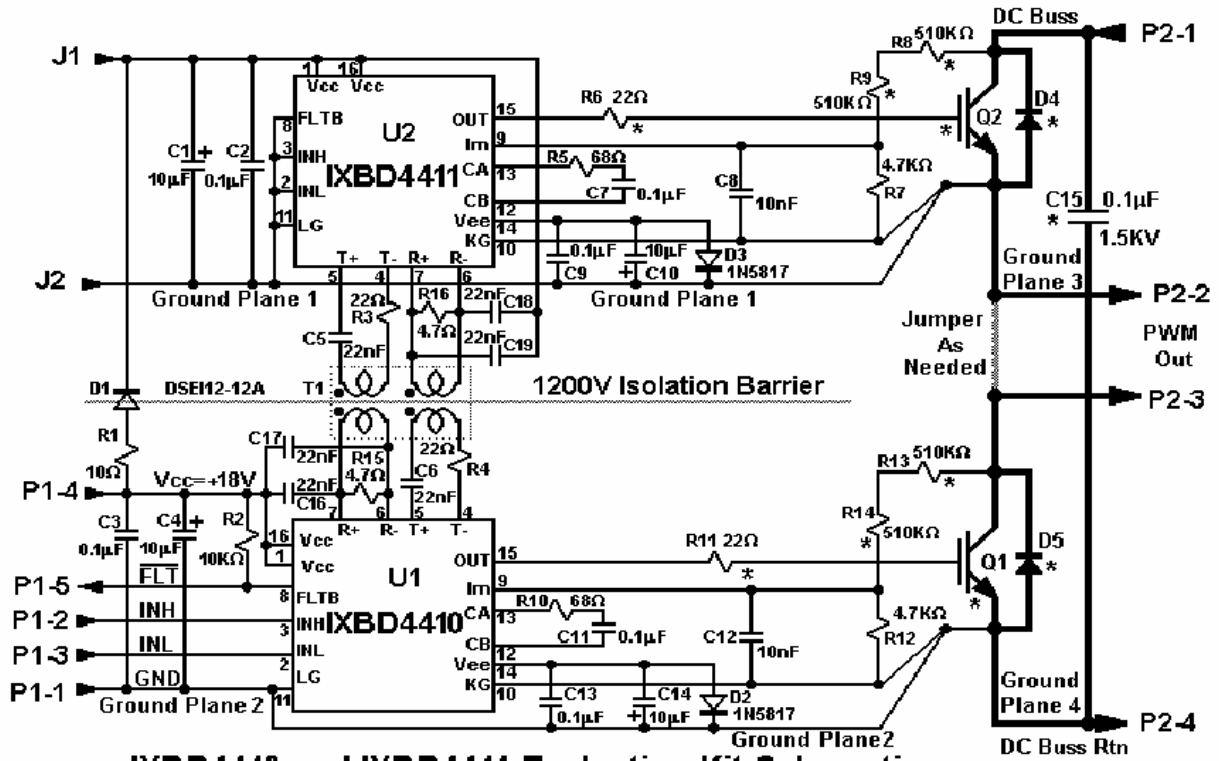
- 1. Z1: 1N821
- Voltage Regulators:
- 1. 7815
 - 2. LM317T

Transistors:

- 1. Q1: 2N7000

ICs:

- U1: IXDD408PI or IXDD414PI
 - U2: CD4001
 - U3: LM339
 - U4: CD4011
 - U5: CD4049
 - U6: IXDD408YI or IXDD414YI
- Note: Either use U1 or U6, but not both.



IXBD4410 and IXBD4411 Evaluation Kit Schematic

* Note: R6, R11, R8, R9, R13, R14, Q1, Q2, D5, D4, and C15 will vary in value and type depending on application.

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Fig.(4) A circuit schematic showing how to drive upper and lower MOSFETs in a phase leg topology using a Low and High side driver pair.

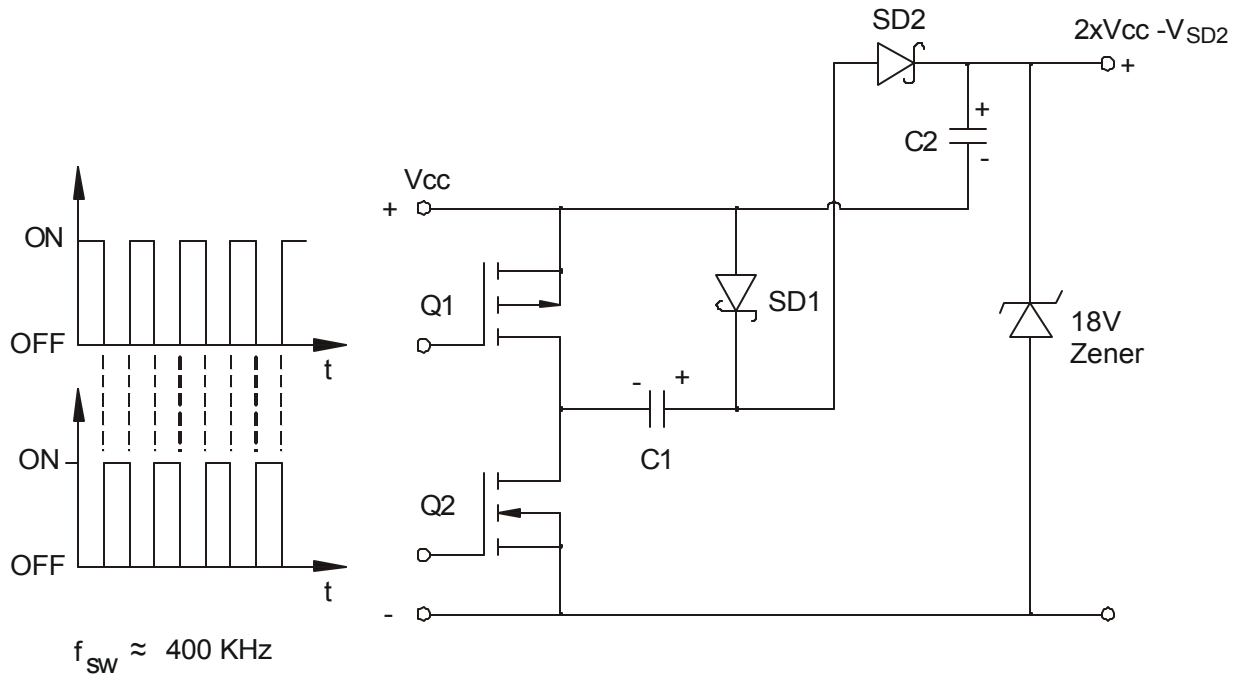
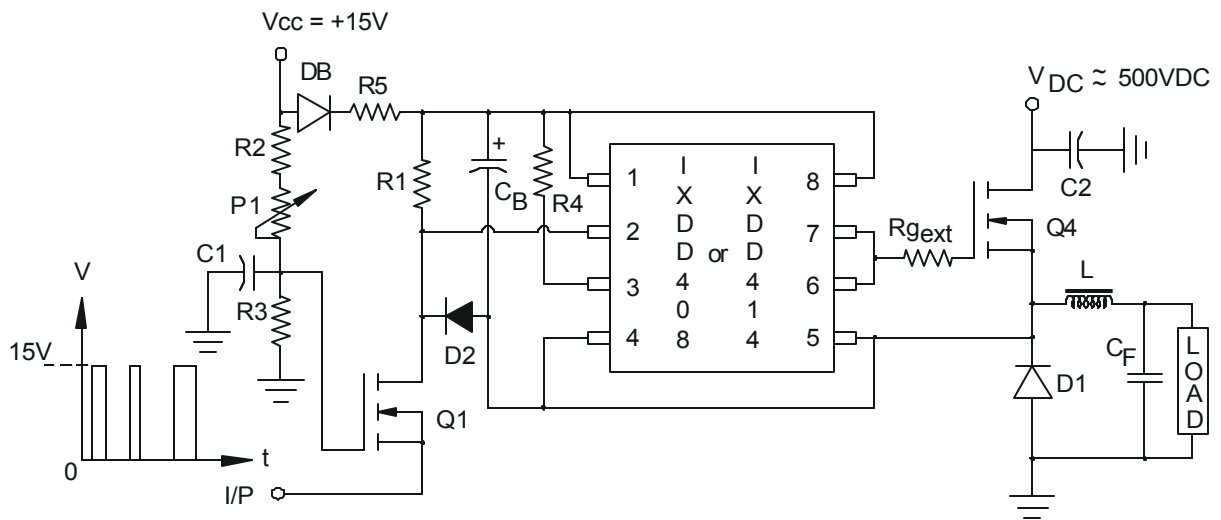


Fig. (5) Basic Charge Pump Doubler



Q1 : IXTU01N100, Q4=IXFH12N100F R_{gext}: 1.0 Ohm to 4.7 Ohm
 DB : DSEP9-06CR CF : GE A28F5601
 D1 : DSEC60-12A 0.1MFD,1000 Volts
 D2 : 1N5817 R1 : 1K
 C1 : 20MFD,25V R2 : 10K
 C2 : 20MFD,1000 Volts,CSI 10DC0020 R3 : 2K
 CB : 10MFD,25VDC R4 : 10K
 P1 : 5K Trim pot R5 : 1 Ohm
 L : 5μH,DALE IH-5

Fig. (6) Basic bootstrap gate drive technique

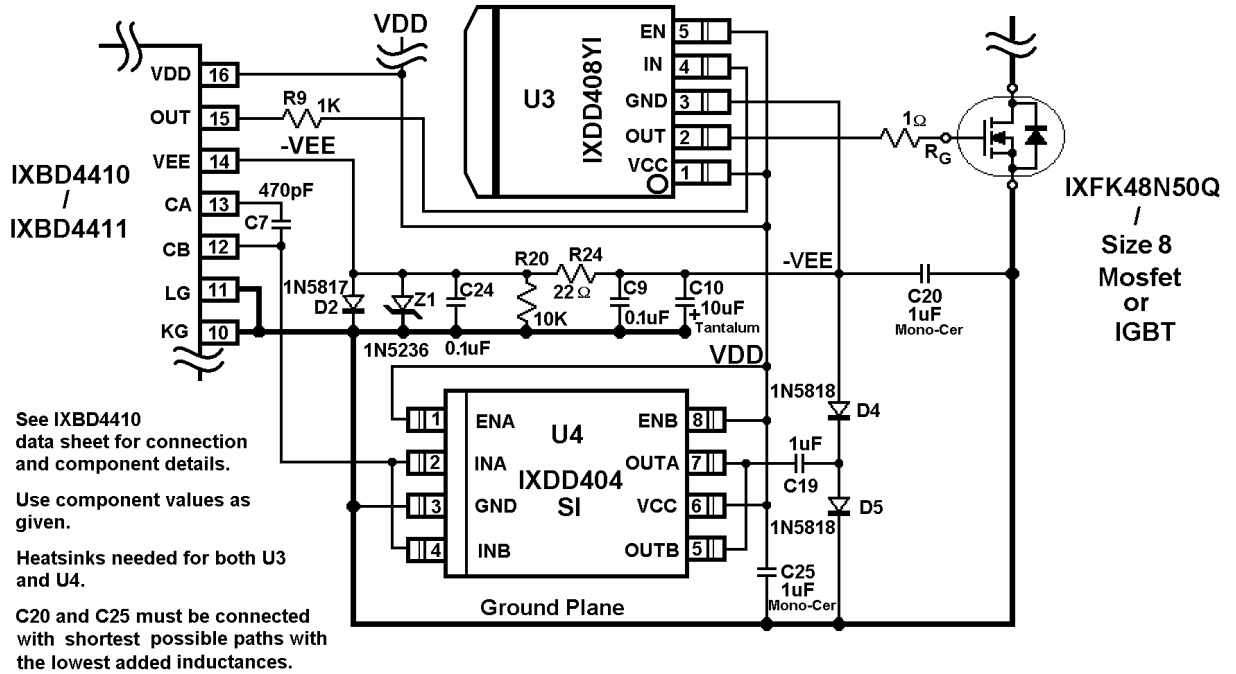


Fig.(7) Boosting output gate drive to +/-8 A and charge pump output to 350mA for 400kHz switching of size 9 devices with the IXBD4410/4411 gate driver chip set.

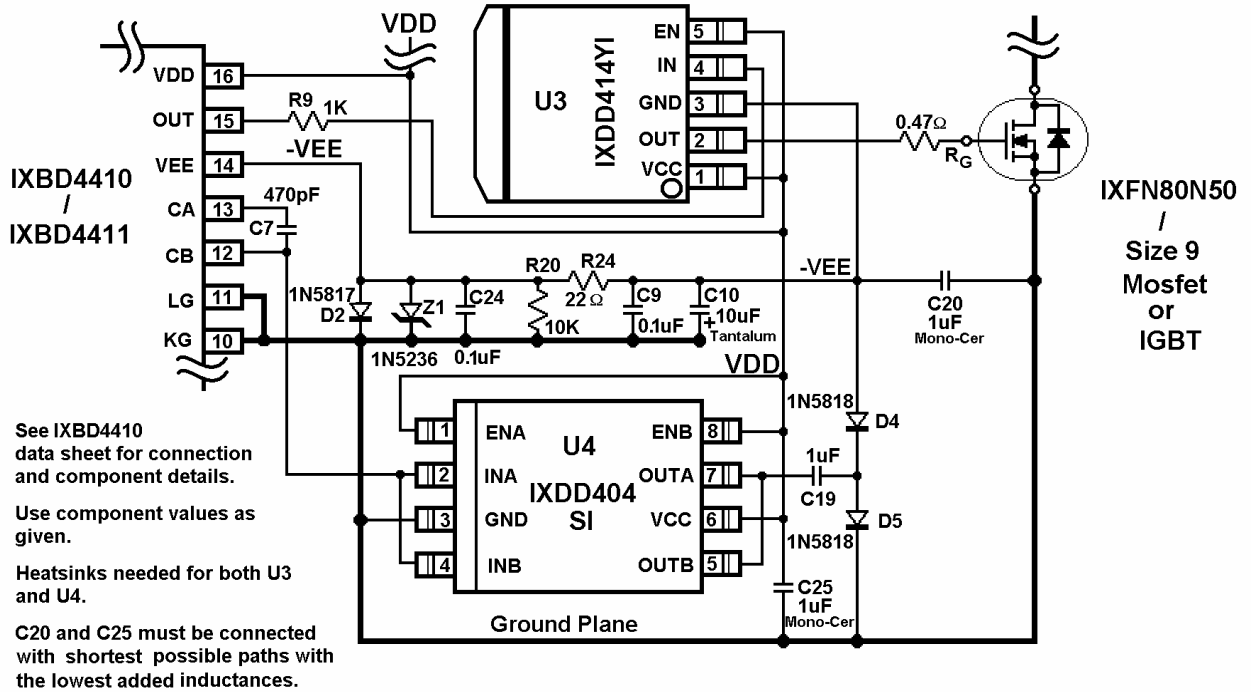


Fig.(8) Boosting output gate drive to +/-14 A and charge pump output to 500mA for 400kHz switching of size 9 devices with the IXBD4410/4411 gate driver chip set.

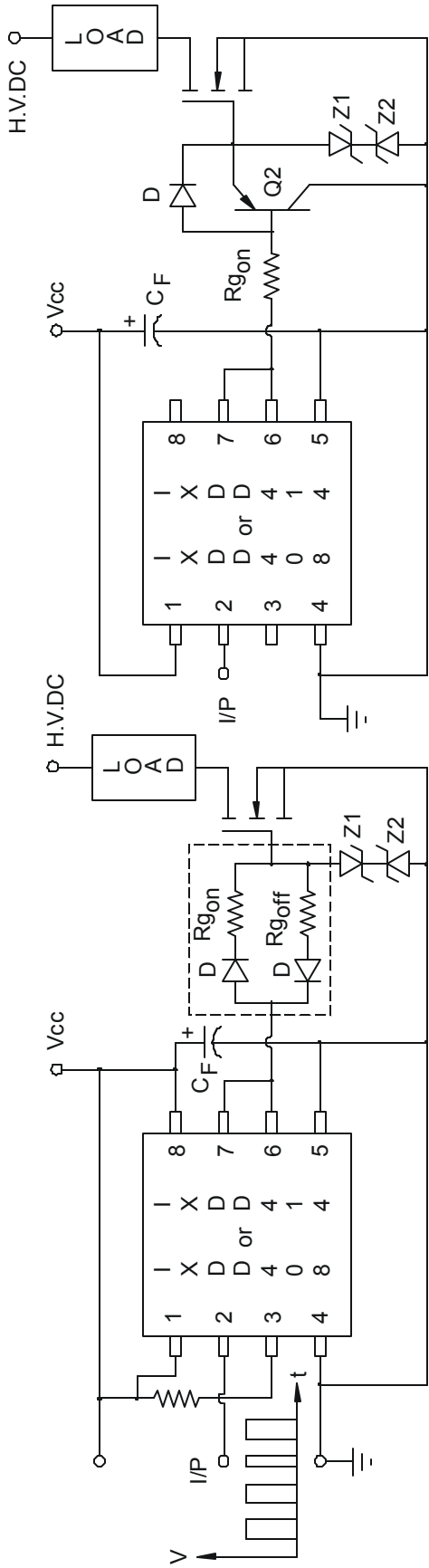


Fig (9) Turn-off enhancement methods.

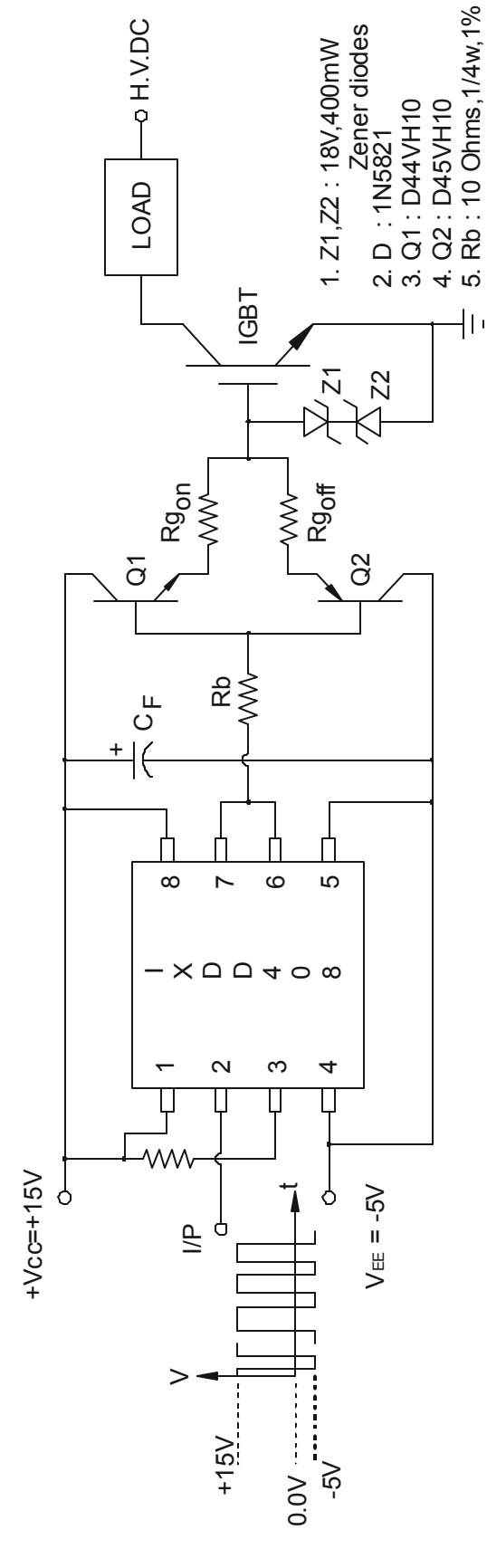


Fig. (10). Technique to boost current output and provide -ve bias to achieve faster turn off for high power MOSFET and IGBT Modules

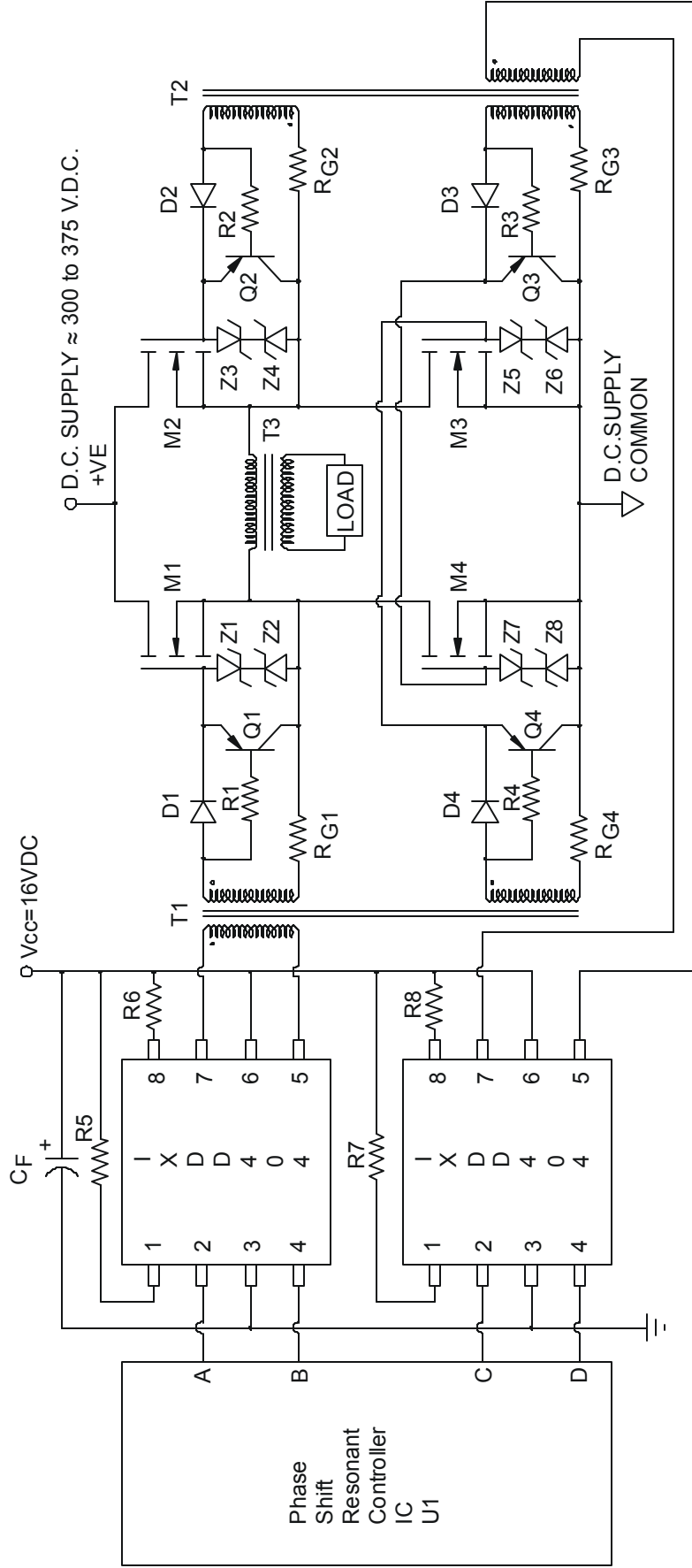


Fig. (11) Transformer coupled Gate Drive arrangement for "H" Bridge in a Phase Shift PWM Controller at fixed Switching frequency.

SUGGESTED PARTS:

1. U1 : T.I. UC 3875
2. T1,T2 : Coilcraft Part No. SD250-3 or Vanguard Pulse Transformer Part No: GD 203
3. Q1,Q2,Q3,Q4 : 2N2905A
4. D1,D2,D3,D4 : DSEP8-02A IXYS HiPerFRED
5. T3 : OUTPUT Transformer
6. CF : 22MFD,35 WVDC Tantalum Capacitor
7. R1,R2,R3,R4 : 560 Ohms, 1/4 w,1% Metal film
8. M1,M2,M3,M4 : IXFN55N50 IXYS HiPerFET or IXFN80N50 IXYS HiPerFET
9. Z1,Z2...Z8 : 18V, 400mW Zener diodes.
10. RG1,RG2,RG3,RG4 : 3.3 Ohms, 1/4 w, 1% Metal Film resistors.
11. R5,R6,R7,R8 : 10K, 1/4 w, 5%

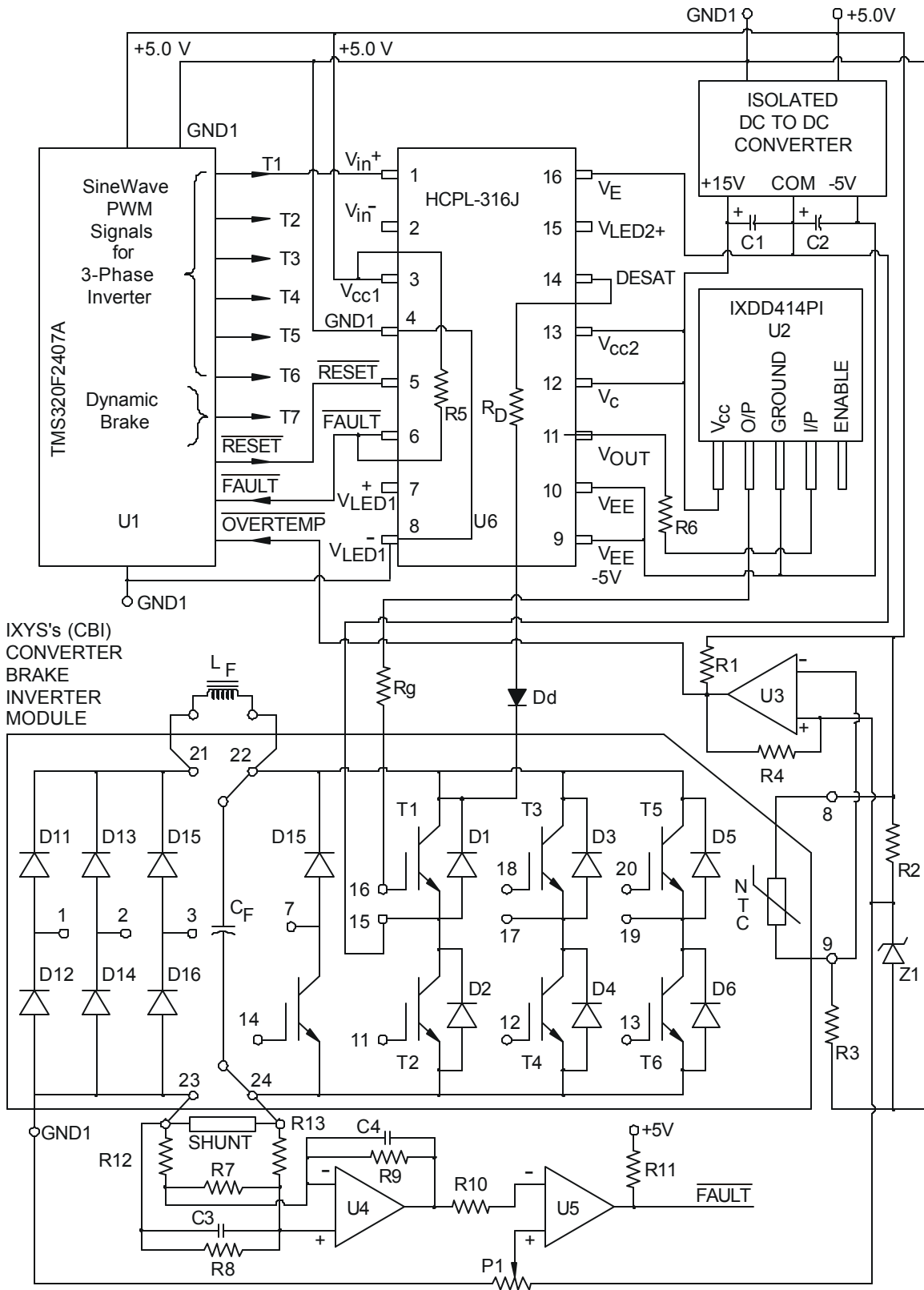
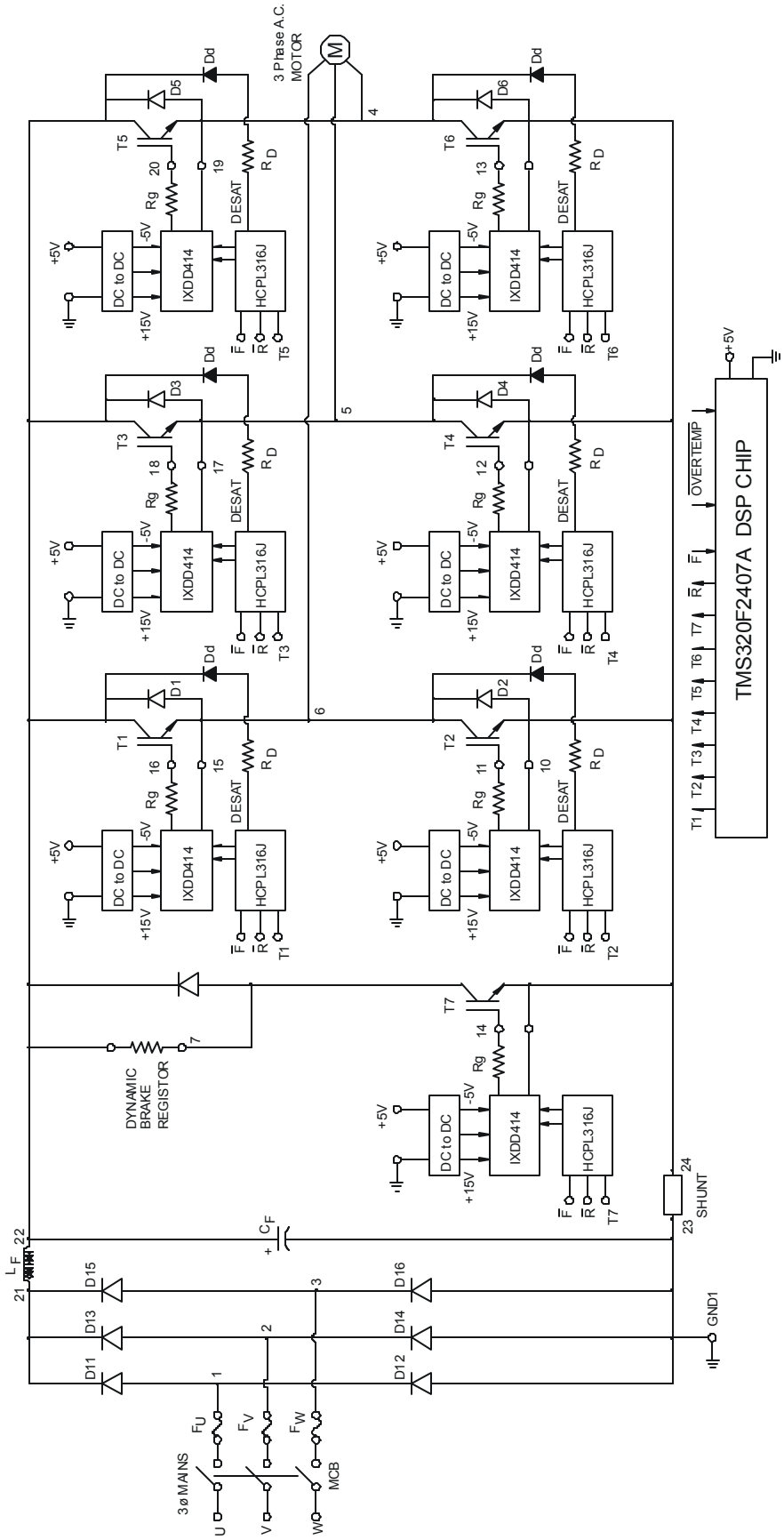


Fig. (12) 3-Phase AC Motor drive schematic showing how IXYS CBI (Converter-Brake-Inverter) Module can be driven by IXDD414 using opto-couplers. All protection features are incorporated.

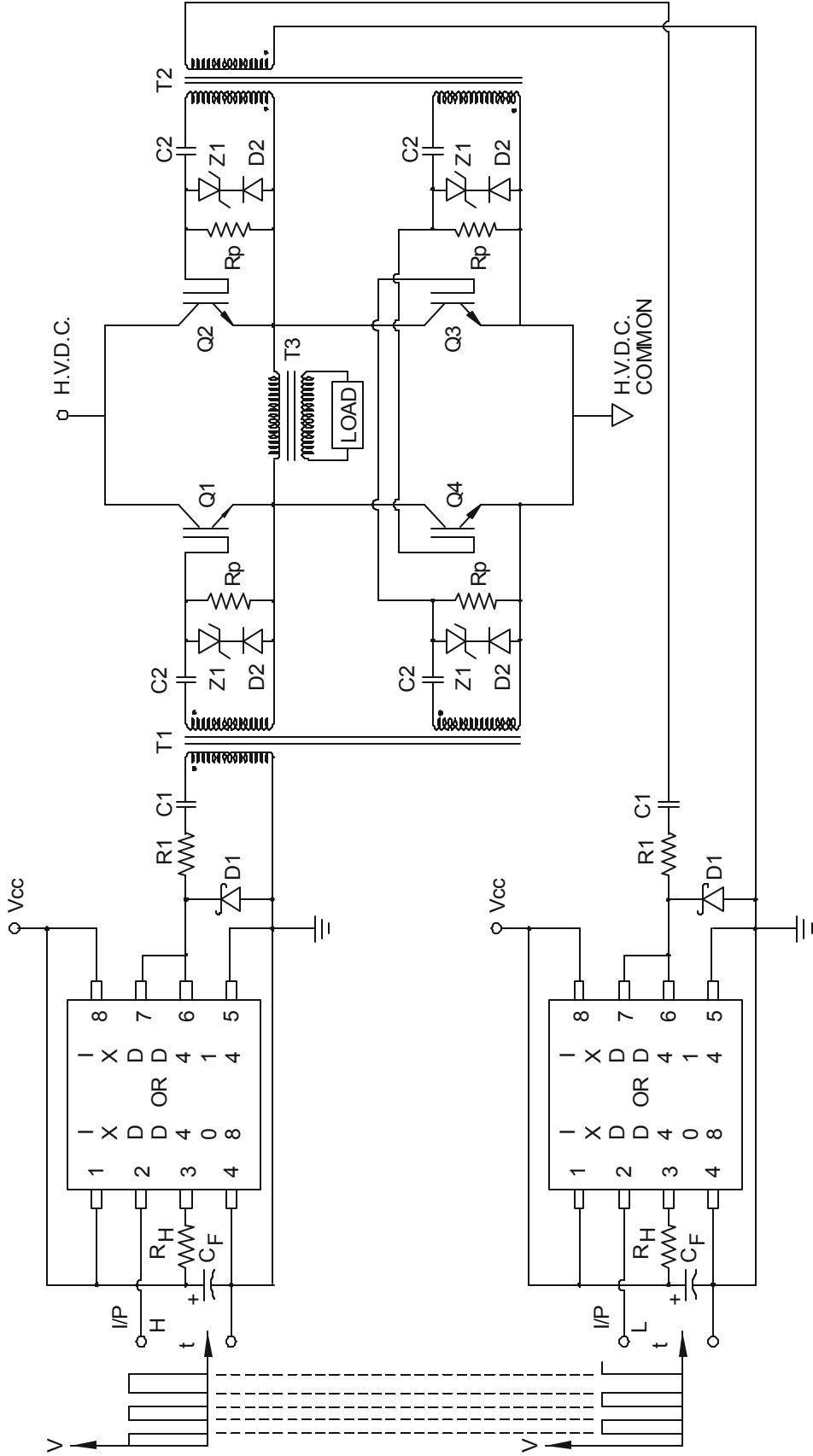


- NOTES: 1. ALL \bar{F} = FAULT SIGNALS ARE TIED TOGETHER (BEING OPEN COLLECTOR) AND FED INTO TMS320F2407A DSP CHIP.
 2. ALL \bar{R} = RESET SIGNALS ARE TIED TOGETHER AND FED TO HCPL-316J.
 3. OVERTEMP AND OVERLOAD/SHORT CIRCUIT FAULT SIGNALS ARE GENERATED AS PER FIG(16)
 OVERTEMP IS ALSO FED IN TMS320F2407A DSP CHIP.

FIG(13) XYS CONVERTER, BRAKE INVERTER (CBI) MODULE BEING DRIVEN BY IXDD414 WITH OPTO-COUPLER AND DESAT, OVERTEMP AND SHORT CIRCUIT/OVERLOAD PROTECTIONS.

Bill of Materials for Fig. (12) and Fig. (13)

R1, R3, R5, R10, R11: 10K, 1/4W, 1% MFR
R2: 560 Ohms, 1/4W, 1% MFR
R4: 2.2 Meg, 1/4W, 5%
R6: 100 Ohms, 1/4 W, 1% MFR
R7: 20K, 1/4W, 1% MFR
R8, R9: 61.9K, 1/4W, 1% MFR
R12, R13: 1.24K, 1/4W, 1% MFR
Rg: T.B.D. based on t_{on} and t_{off} & size of IGBT
RD: 100 Ohms, 1/4 w, 5%
P1: 10K, multi turn trimpot, Bourns 3006P or Spectrol
C3, C4: 33 pf, silver dipped mica
Dd: General Semiconductor make,
Type: RGP02-20E, 0.5 A, 2000 V, t_{rr} : 300 ns
Z1: Zener LM336, 2.5 Volt
U3, U5 : LM339 Comparator
U4 : LM-101 Op Amp
SHUNT : 75 mV @ full load current
LF: Gapped D C Choke for filtering rectified power
CF: Electrolytic Filter Capacitor with very low ESR & ESL and screw type terminals to handle high ripple current. Voltage rating is determined by DC Voltage plus AC ripple Voltage
CBI Module: IXYS Corporation Type Nos: MUBW 50-12A8 or any MUBW module from CBI 1, CBI 2 or CBI 3 series, depending on Motor H.P. rating.
U1: Texas Instrument's TMS320F2407A, FLASH programmable Digital Signal Processor with embedded software for AC Drive, using brake feature.
IXDD414 Driver chip: 7 are required to implement the AC Drive, using Brake feature.
HCPL316J (Opto-coupler): 7 are required to implement the AC Drive With Brake feature.
Isolated DC-to-DC Converter: 7 are required with specified isolation.



FIG(14) A Transformer coupled Gate Drive circuit employing D.C. restore technique and showing how to generate -ve bias during turn-off.

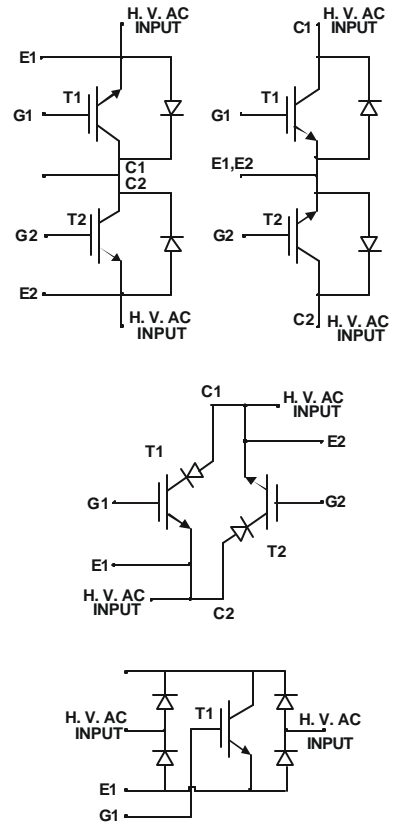
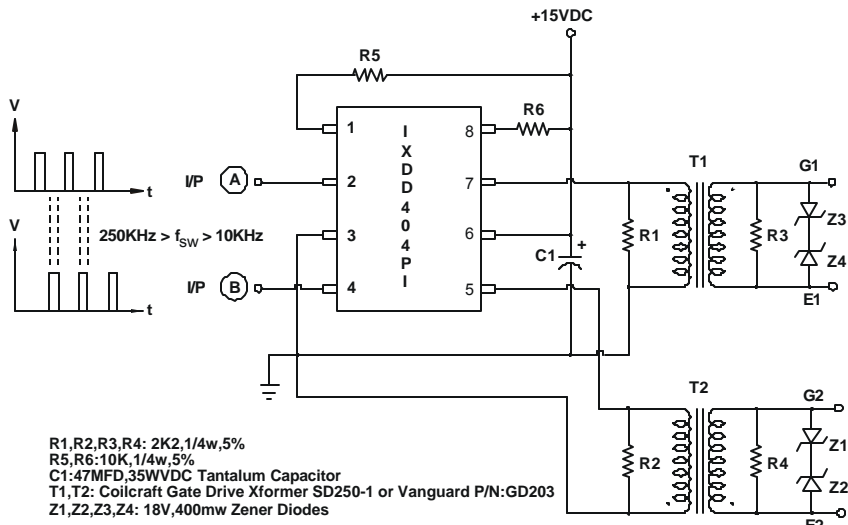


Fig (15) A Simple scheme to drive Bi-directional switches, using gate drive transformers to ensure galvanic isolation.

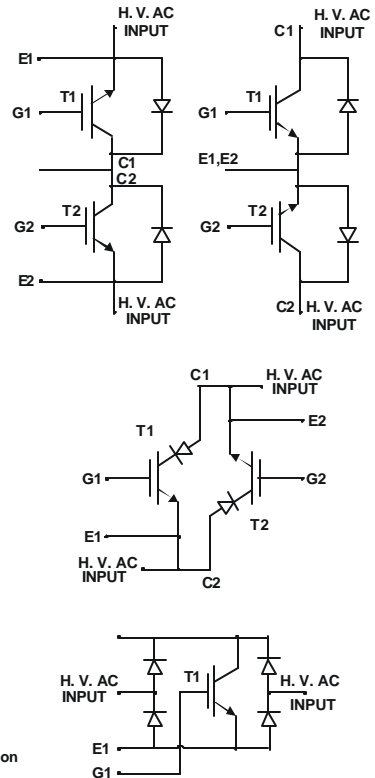
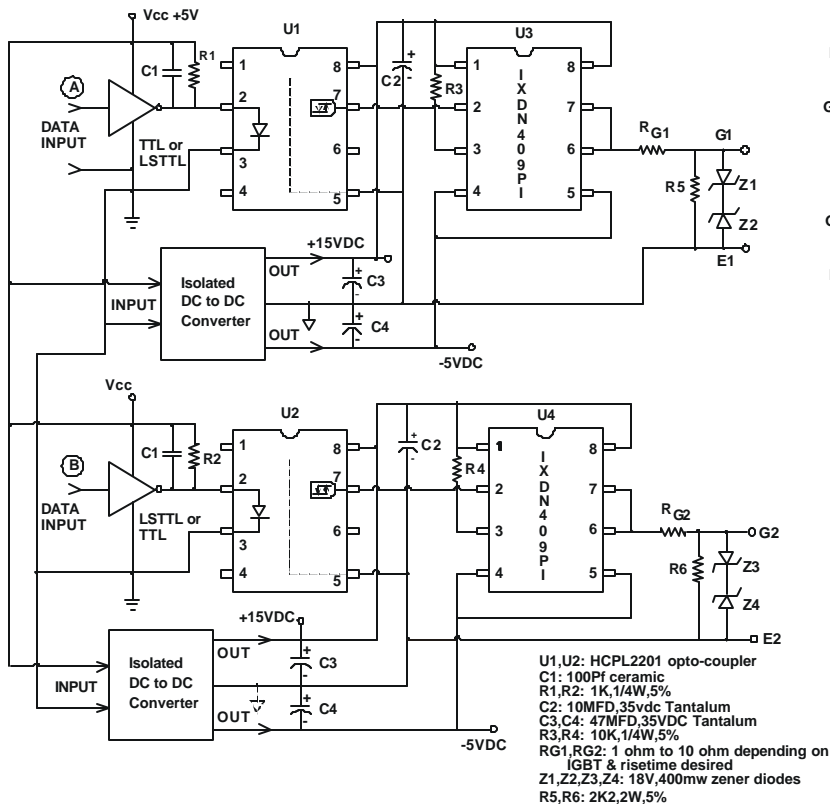


Fig.(16) A Scheme of driving Bi-directional switches with built-in galvanic isolation, using opto-couplers.

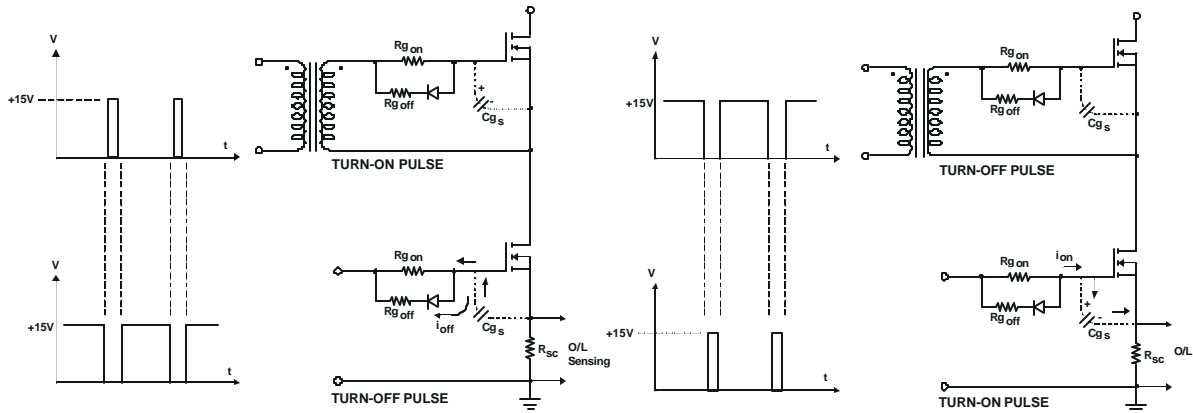


Fig.(17) Basic circuit showing use of pulse transformer to give isolation for upper MOSFET/IGBT in a phase leg configuration

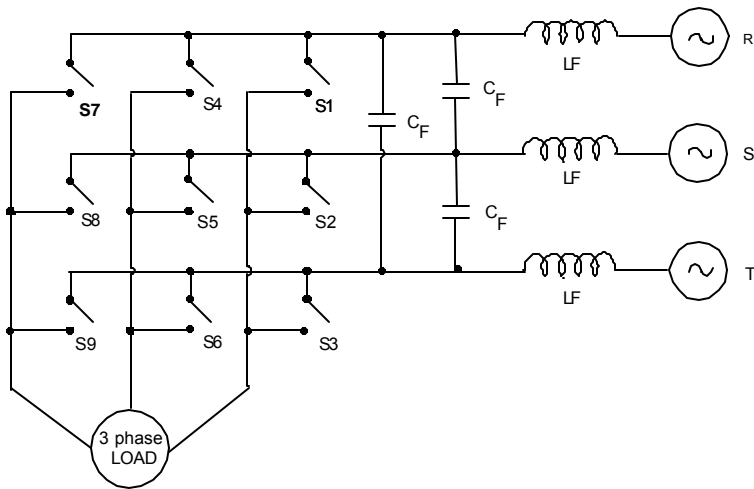


Fig.(18) Basic 3 Phase to 3 Phase matrix converter employing nine Bi-directional switches