# Unique MOSFET/IGBT Drivers and Their Applications in Future Power Electronic Systems

Abhijit D. Pathak[1], Member, IEEE Sam Ochi[2]
[1]Applications Engineering Department, IXYS Corporation, Santa Clara, CA, U.S.A.
[2]Research and Development Department, IXYS Corporation, Santa Clara, CA, U.S.A.

*Abstract*—**Advances and breakthroughs continue in MOSFET and IGBT device technology and control strategies to accomplish goals of efficiency and compactness. It is imperative then to have matched MOSFET/ IGBT Driver technology and techniques for reaping all the benefits. This paper describes three unique Power Management ICs: a 30 Amp Driver, a 45 MHz Driver and a 6 Amp High/Low Side Phase-leg Driver. These Drivers deliver the required di/dt, minimize switching and conduction losses, enhance dv/dt immunity, offer UV, OV, features and OL/DESAT protections with soft turn-off using a novel ENABLE function. Unique circuitry is built-in to avoid cross conduction in the output stage of the Driver IC. The paper describes many technical issues in applying these "first of a kind" products in modern day power electronics.**

*Keywords*: **MOSFET/IGBT Drivers, 30A Driver, 45 MHz Driver, 6 A High/Low Side Driver**

## I. Introduction

Main emphasis in modern Power Electronics is on reducing 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 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 (tr) and fall times (tf).

## I. 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.

Advantages:

1. Compactness
2. Shortest propagation delays
3. Shorter Rise and Fall Times
4. Repeatability and Predictability of performance
5. Convenience
6. Savings in Time and Capital

*1) Compactness*: The foremost advantage is compactness. Use of IC Drivers results in much smaller sized circuits and those sub-systems utilizing multiple drivers benefit the most. Many desirable features, such as UV, OV, OL and DESAT can be built in control logic.

*2) Propagation Delays*: IC Drivers intrinsically offer shorter propagation delays. This is due to the geometry, which results into smaller distances traversed by signals.

*3) Shorter Rise and Fall Times:* Due to the same reasons of geometry and shorter conduction paths, the outputs from IC drivers intrinsically produce lower rise and fall times for given capacitive loads

*4) Repeatability and Predictability of Performance*: Another advantage is repeatability and predictability, which can't be easily achieved in hard-wired driver circuits.

*5) Convenience:* Designing MOSFET/IGBT Driver circuits with IC Drivers offers great convenience in planning and designing PCB layout, building and testing prototypes and, finally, in fewer parts needed for production.

*6) Savings in Time and Capital:* 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. This results in substantial savings in time and capital and reduces "time to market" for finished products.

## III Unique 30 Amp Driver

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 30,000 pF from 0 to 15 VDC (assuming we are turning on a large MOSFET or IGBT) in 25 ns,

$$I = \frac{\Delta V \times C}{\Delta t}$$

$$I = \frac{(15-0)\times 30{,}000\times 10^{-12}}{25\times 10^{-9}}$$

$$I = 18A$$

using an ultra high speed IC driver, then the current:

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.

In real life situation, the charging current would not be steady, but would peak around 28.8 Amps. Up until now the only way of producing fast rising peak currents of this magnitude was to use a booster stage of matched NPN/PNP bipolar transistors or N-Channel/P-Channel MOSFETs with their attendant short comings. Availability of a 30 Amp driver IC not only overcomes these limitations but also opens doors to great many other possibilities. It is very important to understand that when 30 Amps of peak current is required to drive a very large MOSFET/IGBT, it is never prudent to parallel two 15 Amp driver ICs, as this tends to allow momentary shoot through current from P-Channel MOSFET of output stage of one driver into N-Channel MOSFET of another driver's output stage due to mismatch in propagation delays between the two drivers. Let us look at some of the key specifications of this 30 Amp Driver IC:

1. $t_{rise}$ < 20 ns and $t_{fall}$ < 18 ns @ Vcc = 15 VDC and load capacitance $C_L$= 15000pf
2. Input Voltage Range: -5 V to Vcc+0.3 V
3. Vcc=8.5 VDC to 35 VDC
4. Output Resistance: $R_{OH}$ = 0.3 Ohm, $R_{OL}$= 0.2 Ohm @Vcc = 18 V
5. On-time propagation delay: 41 ns
6. @ $C_L$=5600pf, Vcc=18V
7. Off-time propagation delay: 35 ns
8. @ $C_L$=5600pf, Vcc=18V
9. Output Current $I_{PEAK}$= 30 A @Vcc=18 V
10. Immunity to latch-up over entire operating range
11. Matched rise and fall times

For an example, consider driving a large size MOSFET module VMO650-01F, rated at $I_D$ = 650 A, $V_{DSS}$ =100 V at fsw = 250 kHz. Let Vcc = 12 V, $R_{OH}$ = 0.3 Ohm, $R_{OL}$ = 0.2 Ohm, $R_{Gext}$= 0 Ohm. We find that Qg =2700 nC at Vcc = 12 V from the VMO650-01F data sheet. Now:

$$P_D = P_{D(on)} + P_{D(off)} = \frac{R_{eff} \times V_{cc} \times Q_g \times f_{sw}}{R_{OL} + R_{Gext} + R_{Gint}}$$

$$P_D = \frac{0.25 \times 12 \times 2700 \times 250{,}000 \times 10^{-9}}{0.2 + 0.0 + 0.0}$$

$$P_D = 10.13$$

Where,

$$R_{eff} = \frac{R_{OH} + R_{OL}}{2}$$

$R_{Gext}$= resistance connected between output of the Driver and the Gate of MOSFET Module.

For the 30 Amp Driver IC housed in TO-220 or TO-263 package and mounted on a good heat sink the temperature rise would be well within limit. Considering the power dissipation capability, it is even possible to operate these types of MOSFET modules in parallel and still use a single 30 A driver to drive them. It is also possible to operate a large MOSFET up to even 1.0 MHz, using this 30 A Driver IC.

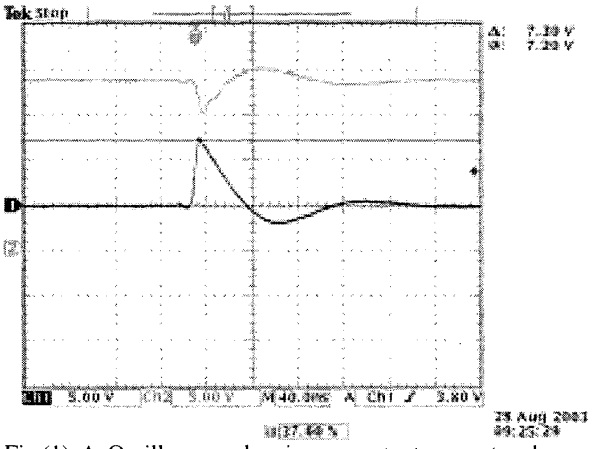


Fig.(1) A Oscillogram showing an output current pulse (Ch.1) of 36.5 A with trise < 10ns (into a 30 nF capacitor, measured across a 0.2 Ohm SMD resistor) from 30 A Driver

It is interesting to note here the blip on the Vcc trace (Ch.2) in the oscillogram in Fig.(1). Despite an excellent Bypassing arrangement, it is difficult to get rid of slight dip on the Vcc rail. This occurs due to stray inductances, which are hard to eliminate totally. But the 36.2 A peak establishes the 30 A Driver's intrinsic capability of delivering 30 A peak current into a MOSFET/IGBT, which represent a dynamic capacitive load.

## IV 45 MHZ DRIVER

With popularity of RF MOSFETs in industrial and communication applications, arrival of 45 MHz Driver IC is welcome. Its salient specifications are:

1. $t_{rise}$ =2.3 ns and $t_{fall}$ = 2.1 ns @ Vcc = 15 VDC and load capacitance $C_L$= 1000pf
2. Input Signal Voltage Range: -5V to Vcc+0.3 V
3. Vcc = 8 VDC to 30 VDC
4. Output Resistance: $R_{OH}$ = 0.8 Ohm, $R_{OL}$= 0.8 Ohm @Vcc =15 V
5. On-time propagation delay: 32 ns @ $C_L$= 4000pf, Vcc =15 V
6. Off-time propagation delay: 29 ns @ $C_L$= 4000pf, Vcc =15V
7. Output Current $I_{PEAK}$ = 15 A @Vcc=15 V
8. Immunity to latch-up over entire operating range
9. Matched rise and fall times
10. $f_{max}$ = 45 MHz

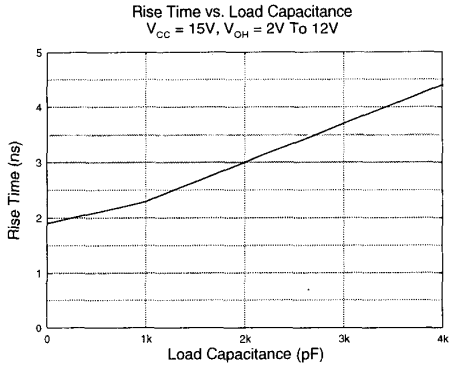


Fig.(2) Rise time vs.Load Capacitance for 45 MHz Driver

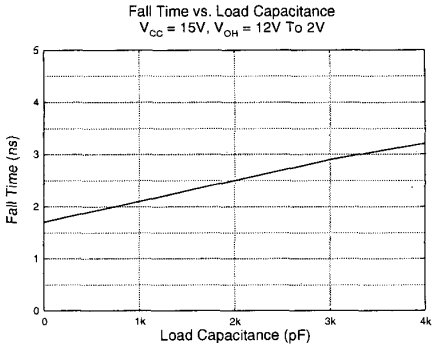


Fig. (3) Fall time vs. Load Capacitance for 45MHz Driver

The intrinsic rise and fall times of the 45 MHz driver IC with various load capacitances is shown in Fig. (2) and Fig. (3) respectively.

## V PRACTICAL CONSIDERATIONS

Operation of MOSFETS in Class D and E amplifiers, HF and RF applications, as well as other applications requiring ultra fast rise and fall times or short minimum pulse widths, require great care in planning and execution. The four key issues are circuit loop inductance, power supply bypassing, circuit layout, adequate grounding and shielding.

The current path from power supply positive to ground defines the loop, which will generate the inductive term. This loop must be kept as short as possible. One method of accomplishing this is to use few tiny capacitors and solder them snugly on the Vcc and ground pins of Driver IC. Driver IC's Bypass capacitor value can be Calculated by:

$$C_{BYPASS} = \frac{I_q \times \frac{d}{f_{sw}} + Q_g}{V_{ripple}}$$

Where, $I_q$ = quiescent current drawn from Vcc
$d$ = Duty cycle of the PWM waveform
$Q_g$ = Total gate charge of the MOSFET
$F_{sw}$ = Switching frequency
$V_{ripple}$ = tolerable ripple level on the Vcc .

Another very crucial aspect 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 and to reduce inductance and be as wide as possible to reduce resistance. A good method is to dedicate a copper plane in a multilayered PCB to provide a ground surface under the gate drive circuit. However this ground plane should be tied to the power ground plane at the Source/Emitter terminal of the MOSFET/IGBT to avoid generating differential ground potentials.

With desired rise and fall times in the range of 2 to 3 ns, extreme care is required to keep lengths of current carrying conductors to the bare minimum. Empirical formulae for conductor trace's partial inductance is:

$$l = 5 \times \ln\left(\frac{2 \times \pi \times h}{w}\right)$$

where, $l$ = inductance in nanohenries
h = height of conductor trace above ground plane
w = width of the conductor trace

If we assume h=10 mil and w=40 mil, then $l$=2.26 nH/inch of trace length, which translates to 0.089 nH/mm, a di/dt of 5 A/ns (assuming the 45 MHz Driver IC pumps 15 Amps peak into the MOSFET gate in just 3.0 ns) generates a transient Ld*I*/dt voltage of 4.4 volts per cm of trace length, which subtracts from the driver's output. It is a good idea, therefore, to keep Vcc of Driver to about 20 VDC. If it is not possible to minimize trace length from output pin of Driver IC to the gate of MOSFET, then one can increase the trace width to minimize the loop inductance. The real effect will be a significant increase in rise time for every tiny increase in conductor length (between output pin of Driver IC to the Gate lead of MOSFET/IGBT). Another detrimental effect of longer conductor length is transmission line effect and resultant RFI/EMI. 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 keep in mind the fact that every MOSFET/IGBT also 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.

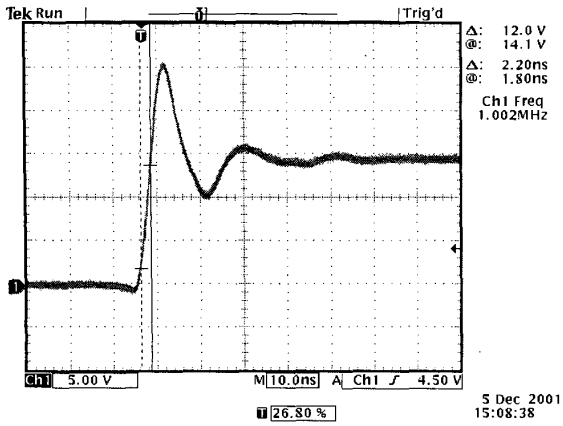


Fig. (4) Rise time=2.2 ns @ Vcc=15VDC, $C_L$=1nF, fsw=1 MHz

## VI. ENABLE FUNCTION

Both the above drivers (30 Amp Driver and 45 MHz Driver) have an ENABLE pin, which, when driven low, say, by the FAULT output from a comparator, puts the internal N-Channel and P-channel MOSFETs of the 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 "R" of appropriate value from Gate to Source of the MOSFET, being driven, the $C_{GS}$ capacitor gets a discharge path, the soft turn-off time, being determined by $RxC_{GS}$. Alternatively, "R" is connected in series with Drain of a tiny MOSFET, such as 2N7000. This combination is connected across the Gate and Source terminals of the Power MOSFET, being turned off. Now when Overload or short circuit occurs, another comparator turns on 2N7000. The power MOSFET is thus switched off softly, the turned off time being determined again by R x $C_{GS}$.

## VII. 6 A HIGH AND LOW SIDE DRIVER

When using low side drivers for driving phase leg, half-bridge and 3-phase bridge configurations, the upper MOSFET/IGBT driver needs to be electrically isolated. The new 6 Amp High and Low Side Driver not only does away with any Opto-coupler or Gate Drive Transformer, but also does not require any totem pole booster stage for driving large MOSFETs or IGBTs up to several hundred KHz switching frequency. It is a floating high side driver with boot-strap power supply along with a low side driver and has many other useful features:

1. trise < 25 ns and tfall < 17 ns @ Vcc = 15 VDC and load capacitance CL= 2000pf;
2. $V_{INH}$: 9.5V to Vcc+0.3V; $V_{INL}$: 0V to 6V;
3. Vcc= 10V to 35 V;
4. $I_{GO}^+$ or $I_{GO}^-$ output short circuit current: +6 A or −6 A @ $V_{IN}$ = 0V, $V_{GO}$ = 15V, Pulse Width <10us;
5. dv/dt immunity: ±50 V/ns;
6. Immune to negative voltage transients;
7. Immunity to latch-up over entire operating range;
8. Matched rise and fall times;
9. Matched propagation delays for both outputs

Until now the maximum output current from floating high side driver with boot-strap power supply along with a low side driver was 2.0 A. Introduction of 6.0 A floating high side driver with boot-strap power supply along with a low side driver, will result in more compactness, greater convenience and lower cost, while covering wider area of applications. Another very useful feature of this 6 A Driver is that its intrinsic power dissipation is less than the older 2 A High and Low Side Drivers, thus making it beneficial to apply it in applications, requiring higher switching frequencies at higher power levels.

## VII. CONCLUSION

The future growth of power electronics depends upon device technology, improved heat dissipation methods, novel and efficient control techniques and improved drivers. This paper has described three unique drivers. The 30 A Driver is unique by virtue of highest current driver in IC form. The 45 MHz Driver is also an IC Driver with highest frequency specification with $I_{peak}$ of 15 A. The 6 A High and Low Side Driver is the first such Driver in 6A class. With the aid of these drivers one can optimally design power electronics systems with advanced MOSFETs & IGBTs.

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