Application of IC Drivers in Future Power Electronic Systems

Advances 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 for reaping all the benefits. **Abhijit D. Pathak, Sam Ochi, IXYS Corporation, Santa Clara, USA, and Andreas Laschek-Enders, IXYS GmbH, Lampertheim, Germany**

FRANCAIS

Les progrès se poursuivent dans la technologie des transistors MOS à effet de champ et des transistors bipolaires de puissance à porte isolée ainsi que dans les stratégies de commande afin d'améliorer l'efficacité et de réduire la taille des dispositifs au maximum. Il est donc impératif de disposer d'une technologie correspondante d'entraînements à transistors MOS à effet de champ/ transistors bipolaires de puissance à porte isolée pour tirer pleinement parti des avantages qui en découlent. **Abhijit D. Pathak, Sam Ochi, IXYS Corporation, Santa Clara, USA et Andreas Laschek-Enders, IXYS GmbH, Lampertheim, Allemagne**

DEUTSCH

Kontinuierliche Fortschritte bei MOSFETs und IGBTs sowie deren Ansteuerungsstrategien führen weiter zu den Zielen höherer Effizienz und Kompaktheit. Dazu ist es allerdings erforderlich, angepasste MOSFET/IGBT-Treibertechnologie zur Erzielung aller Vorteile einzusetzen. **Abhijit D. Pathak, Sam Ochi, IXYS Corp., Santa Clara, USA, and Andreas Laschek-Enders, IXYS GmbH, Lampertheim, Germany**

Three unique Power Management ICs have been developed by IXYS - a 30A Driver, a 45MHz Driver and a 6A high-/low-side phase-leg driver. These drivers deliver the required di/dt, minimise switching and conduction losses, possess enhanced dv/dt immunity, offer under-voltage (UV) and over-voltage (OV) features and over-load (OL)/de-saturation (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 article describes many technical issues in applying these 'first of a kind' products in modern day power electronics.

ADVANTAGES OF IC DRIVERS

The main emphasis in modern power electronics is on reducing total losses dissipated in devices and sub-systems 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 (t_r) and fall times (t_f).

Although there are many ways to drive MOSFET/IGBTs using hard-wired electronic circuits, IC drivers [1] offer convenience and features that attract designers (see Figure 1). Some of the advantages are compactness, shortest
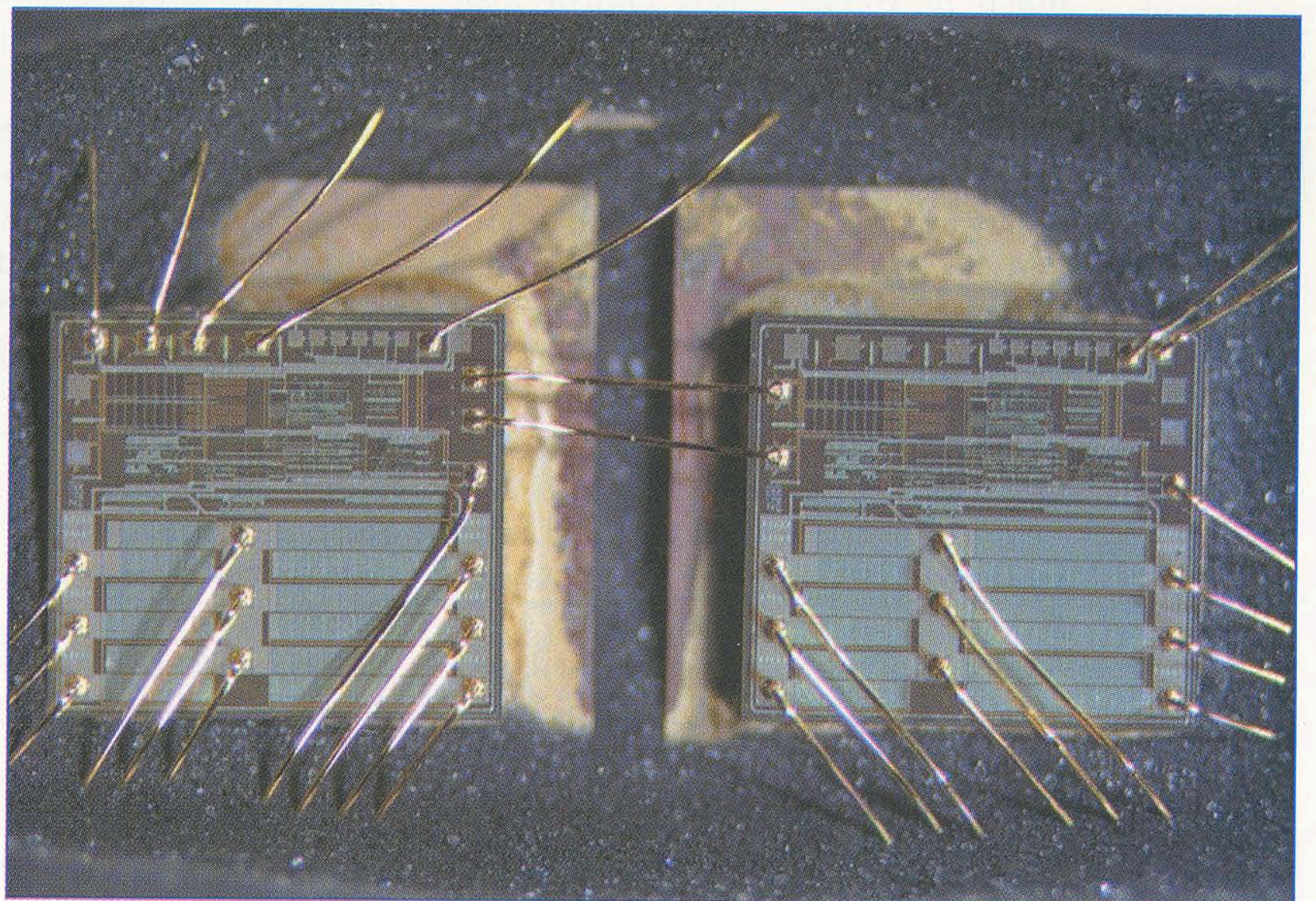

Figure 1 (above). 6A high and low-side driver IC IX6R11 layout

propagation delays, shorter rise and fall times, repeatability and predictability of performance, and savings in time and resources.

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 into the control logic. IC drivers intrinsically offer shorter propagation delays. This is due to the geometry, which results into smaller distances traversed by signals. 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. Another advantage is repeatability and predictability, which can't be easily achieved in hard-wired driver circuits. 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. Availability of PSpice models of IC Drivers is an added benefit for designers. 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 resource and reduces 'time to market' for finished products.

UNIQUENESS OF 30A IC DRIVER

As we know, turning MOSFET/IGBT on and off amounts to charging and discharging large capacitive loads. Suppose we are trying to charge a capacitive load of 30,000pF from 0 to 15VDC (representing a large MOSFET or IGBT) in 25ns, using an ultra High Speed IC driver, then the average current, according to equation 1:

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

$$I = \frac{(15-0) \times 30,000 \times 10^{-12}}{25 \times 10^{-9}} \quad (1)$$

$$I = 18A$$

What equation 1 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 a real circuit, the charging current would not be steady, but would peak around 29.0A. 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 30A driver IC not only overcomes these limitations but also opens doors to great many other possibilities. It is very important to understand that when 30A of peak current is required to drive a very large MOSFET/IGBT, it is never prudent to parallel two driver ICs rated at 15A each, 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 30A driver IC:

1. t_{rise} < 20ns and t_{fall} < 18ns at V_{cc} = 15VDC and load capacitance C_L = 15000pf
2. Input Voltage range -5V to V_{cc} + 0.3V
3. V_{cc} = 8.5VDC to 35VDC
4. Output Resistance R_{OH} = 0.3W, R_{OL} = 0.2Ω at V_{cc} = 18V
5. On-time propagation delay 41ns at C_L = 5600pf, V_{cc} = 18V
6. Off-time propagation delay 35ns at C_L = 5600pf, V_{cc} = 18V
7. Output Current I_{PEAK} = 30A at V_{cc} = 18V

For an example, consider driving the MOSFET module VMO650-01E, rated at 100V/650A. Assume f_{sw} = 250kHz. Let V_{cc} = 12V, R_{OH} = 0.3Ω, R_{OL} = 0.2Ω, R_{Gext} = 0.0Ω. We find that Q_g = 2700nC at V_{cc} = 12V from the VMO650-01F data sheet. Now driving power (in watts) is according to equation 2:

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

$$P_D = \frac{0.25 \times 12 \times 2700 \times 250,000 \times 10^{-9}}{0.2 + 0.0 + 0.0} \quad (2)$$

$$P_D = 10.13\,W$$

where

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

For IXDD430, the 30A driver IC housed in TO-220 or TO-263 package and mounted on a good heatsink 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 30A driver to drive them. It is also possible to operate a large MOSFET up to even 1.0MHz using this same driver IC.

It is interesting to note here the blip on the V_{cc} trace (Ch. 2) in Figure 2. Despite

an excellent bypass arrangement, it is difficult to get rid of slight dip on the V_{cc} rail. This occurs due to stray inductances, which are hard to eliminate totally. But the 36.2A peak establishes IXDD430 driver's intrinsic capability of delivering 30A peak current into a MOSFET/IGBT.

45MHZ DRIVER FOR RF MOSFETS

With the increasing popularity of RF MOSFETs in industrial and communication applications, arrival of IXDD415, 45MHz driver IC is welcome. Its salient specifications are:
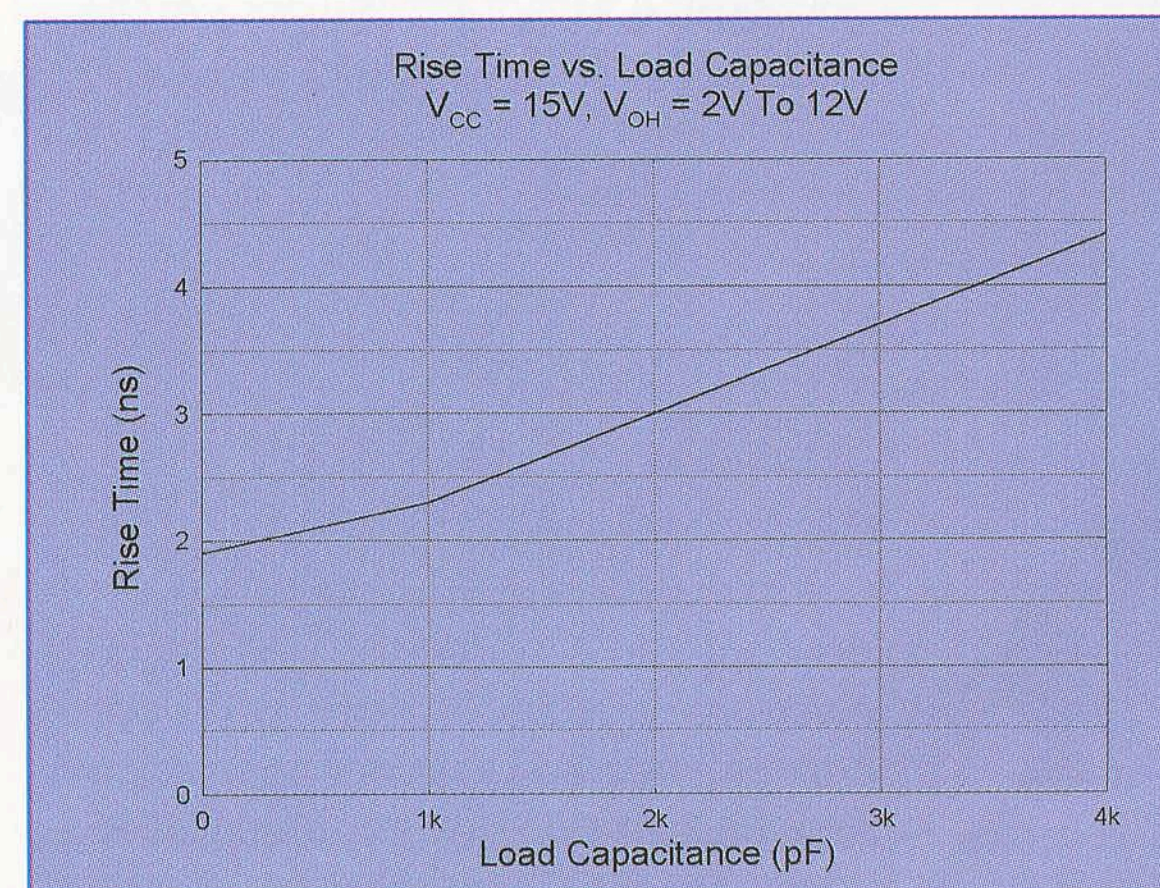
1. t_{rise} =2.3ns and t_{fall} = 2.1ns at V_{cc} = 15VDC and load capacitance C_L = 1000pf,
2. Input Signal Voltage range -5V to V_{cc} +0.3V,
3. V_{cc} = 8VDC to 30VDC,
4. Output Resistance R_{OH} = 0.8Ω, R_{OL} = 0.8Ω at V_{cc} =15V,
5. On-time propagation delay 32ns at C_L = 4000pf, V_{cc} =15V,
6. Off-time propagation delay 29ns at C_L = 4000pf, V_{cc} = 15V,
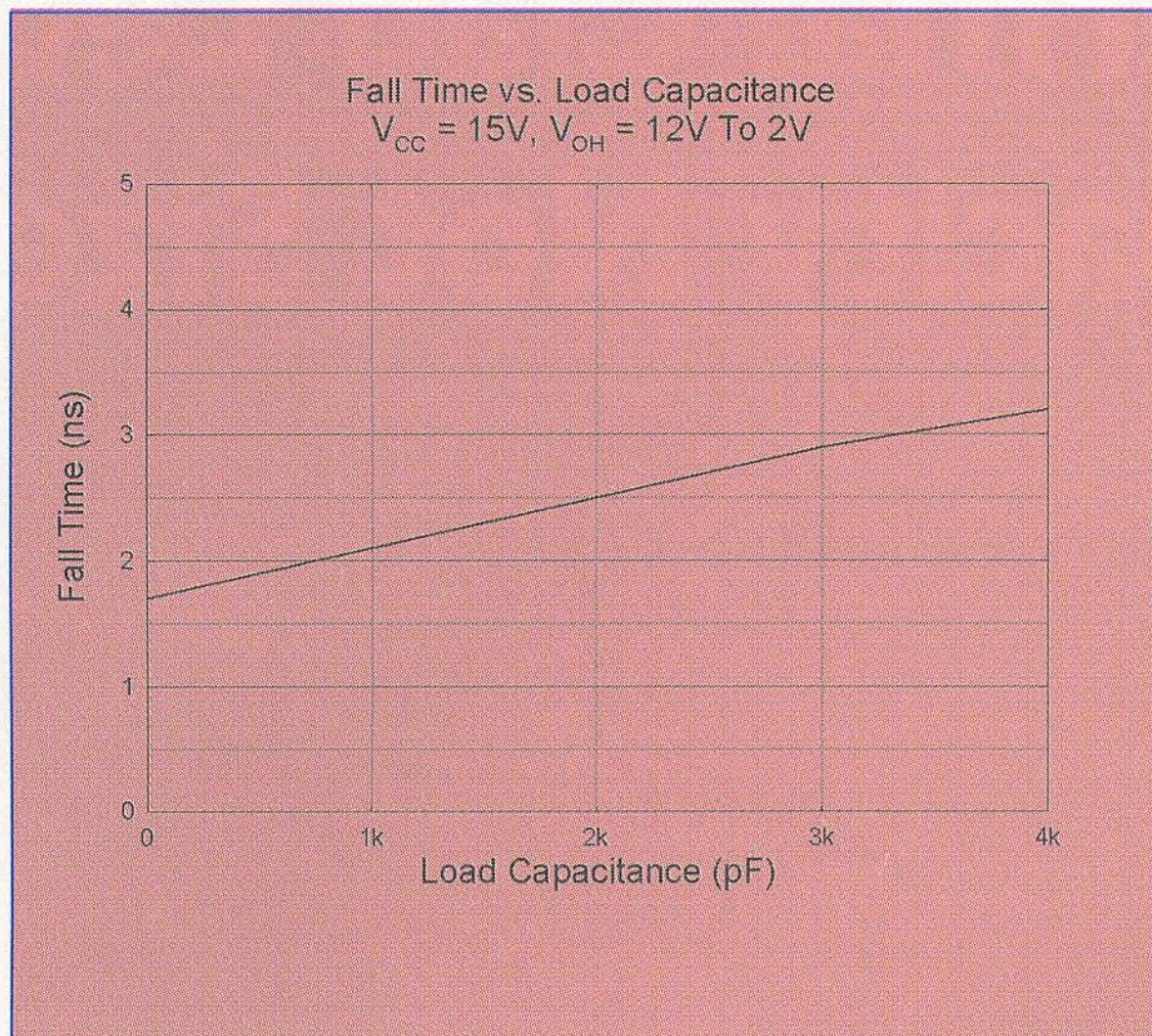7. Output Current I_{PEAK} = 15A at V_{cc} = 15V.

The intrinsic rise and fall times of IXDD415, the 45MHz driver IC with

Figure 2 (right). Output current pulse (Ch.1) of 36.5A with trise <10ns (into a 30nF capacitor, measured across a 0.2Ω SMD resistor) from 30A driver
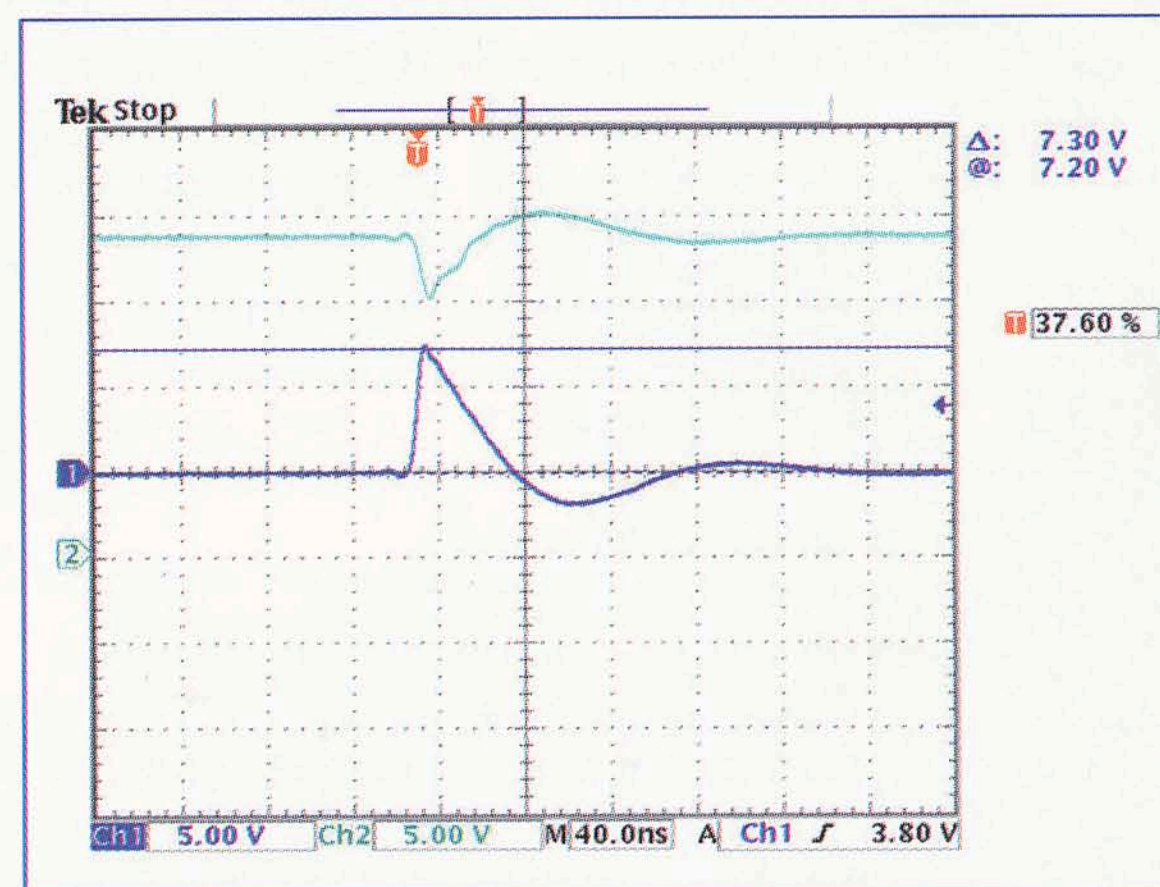
Figure 3 (right). Rise time versus Load Capacitance for 45MHz driver

Figure 4 (left). Fall time versus Load Capacitance for 45MHz Driver

Fall Time vs. Load Capacitance
V_{CC} = 15V, V_{OH} = 12V To 2V

[Figure: Fall Time (ns) vertical axis 0 to 5, Load Capacitance (pF) horizontal axis 0 to 4k]

various load capacitances are shown in Figures 3 and 4 respectively.

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, necessitates great care in planning and execution. The four key issues are: circuit loop inductance, power supply bypassing, PCB layout and 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 V_{cc} and ground pins of driver IC. Driver IC's bypass capacitor value can be calculated from equation 3 as follows:

$$C_{BYPASS} = \frac{I_q \times \dfrac{d}{t_{sw}} + Q_g}{V_{ripple}} \qquad (3)$$

where,

I_q = quiescent current drawn from V_{cc},
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 V_{cc}.

As an example, let us assume we want to drive New Generation Q2-Class HiPerFET Power MOSFETs with Fast Intrinsic Diode IXFB38N100Q2 with low gate charge and extremely low $R_{DS(on)}$: I_q = 25mA, d = 0.5, Q_g = 230nC. Now letting tolerable ripple on the V_{cc} = 25mv for a V_{cc} =15 VDC, we can calcu-

late according to equation 4 the required value of bypass capacitor:

$$C_{BYPASS} = \frac{.025 \times \dfrac{0.5}{100,000} + 230 \times 10^{-9}}{25 \times 10^{-3}} \qquad (4)$$

$$C_{BYPASS} = 14.2 \times 10^{-6}$$

It is a good idea to place few bypass capacitors in parallel totaling a value more than 14.2µF. This helps reduce ESR and ESL of the resultant capacitor.

It is extremely important to choose the correct bypass capacitor. The correct capacitor type is an X7R MLCC ceramic capacitor, preferably surface mount version, with bypassing done directly at the power supply and power ground pins of the driver IC. 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) from driver IC and the logic driving it; 2) from the driver IC and its own power supply; 3) from 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. 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 3ns, extreme care is required to keep lengths of current carrying conductors to the bare minimum. Empirical value for conductor trace's partial inductance is according to

equation 5:

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

where

l = inductance in nH/inch,
h = height of conductor trace above ground plane in inch,
w = width of the conductor trace in inch.

If we assume h = 0.01 inch and w=0.04 inch, then l=2.26nH/inch of trace length, which translates to 0.089nH/mm. A di/dt of 5A/ns (assuming the 45MHz driver IC pumps 15A peak into the MOSFET gate in just 3.0ns) generates a transient voltage (lx di/dt) of 4.4V per cm of trace length, which subtracts from the driver's output. It is a good idea, therefore, to keep V_{cc} of driver to about 20VDC. 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 (trace) 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 the 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 [3] (see Figure 5).

Both drivers have an ENABLE pin [2], 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 allows implementation of soft turn-off. There are two ways of doing this. Connecting a resistor 'R' of appropriate value from Gate to Source of the MOSFET being driven gives the CGS capacitor a discharge path. The soft turn-off time is determined by R x CGS. Alternatively, 'R' can be connected in series with the Drain of a tiny MOSFET, such as 2N7000. This combination is connected

IXAN0007

across the Gate and Source terminals of the power MOSFET being turned off. Now when over-load or short circuit occurs, another comparator turns on the 2N7000. The power MOSFET is thus switched off softly, the turn-off time being determined again by R x CGS.

HIGHEST CURRENT RATED LOW AND HIGH-SIDE DRIVER

When using low side drivers for driving phase leg, half-bridge and three-phase bridge configurations, the upper MOSFET/IGBT driver needs to be electrically isolated. IX6R11, the new 6A 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 kilohertz. 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 <25ns and tfall <17ns at V_{cc} = 15VDC and load capacitance C_L = 2000pf,
2. V_{INH} 9.5V to V_{cc} + 0.3V; V_{INL}: 0V to 6V,
3. V_{cc} = 10V to 35V,
4. I_{GO}^+ or I_{GO}^- output short circuit current: +6A or –6A at V_{IN} = 0V, V_{GO} = 15V, pulse width <10us,
5. dv/dt immunity ±50V/ns,
6. immune to negative voltage transients,
7. immunity to latch-up over entire operating range,
8. matched rise and fall times; 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 2.0A. Introduction of 6.0A floating high side driver with bootstrap power supply along with a low

Figure 5 (right).
Rise time = 2.2ns at
V_{cc} = 15VDC,
C_L = 1nF, fsw = 1MHz
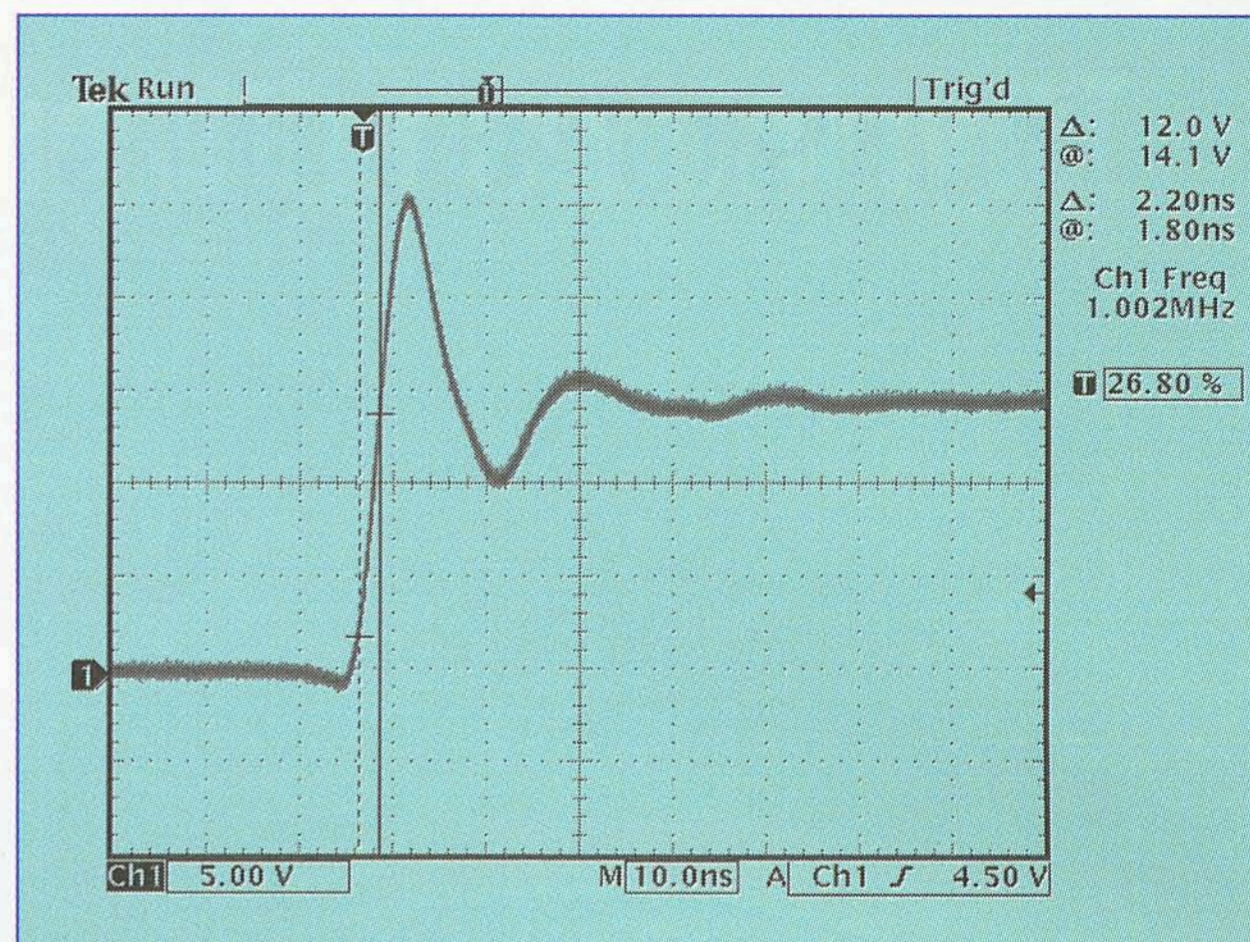
side driver, will result in more compactness, greater convenience and lower cost, while covering wider area of applications. Another very useful feature of this 6A driver is that its intrinsic power dissipation is less than the older 2A high and low-side drivers, thus making it beneficial to apply it in applications, requiring higher switching frequencies at higher power levels.

It becomes very convenient to design many power electronic subsystems using MOSFETs and IGBTs driven by MOSFET/IGBT Drivers, if the PSpice Model of every device is available. With this view in mind PSpice Models of these and many other IC drivers are made available under http://www.ixys.com/pspice01.asp.

CONCLUSION

The future growth of power electronics depends upon device technology, improved heat dissipation methods; novel and efficient control techniques and improved drivers. This article has described three unique drivers. The 30A driver, IXDD430, is unique by virtue of highest current rating in IC form. IXDD415, the 45MHz dual driver is

also an IC driver with highest frequency specification with IPeak of 15A per channel. IX6R11, the 6A high- and low-side driver is the first such driver in 6A class. Use of IX6R11 precludes the need for additional booster stage while driving high current MOSFET/IGBTs in phase-leg configuration. With the aid of these drivers one can optimally design power electronics systems with advanced MOSFETs and IGBTs.

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