Switching Characteristics of Logic Level HEXFET® Power MOSFETs

(HEXFET is a trademark of International Rectifier)

by Peter Wood

Introduction

Many applications require a power MOSFET to be driven directly from 5-volt logic circuitry. Standard power MOSFETs require about 10 volts gate drive for full enhancement, and are generally not suitable for direct interfacing to 5V logic unless an oversized MOSFET is employed.

International Rectifier logic level HEXFETs are specifically designed for operation from 5V logic. All logic level HEXFET power MOSFETs are fully enhanced at 5V gate voltage. As an additional bonus to the designer, they also have a guaranteed maximum value of on-resistance at 4V gate voltage.

This application note introduces logic level HEXFETs and explains their differences and similarities relative to standard HEXFETs. The important considerations for driving logic level HEXFETs are discussed and typical switching performance of these HEXFET power MOSFETs is illustrated by reference to various common logic drive circuits.

Comparison to Standard HEXFETs

The gate of a power MOSFET is isolated from the body by an insulating oxide. Logic level HEXFETs are new designs using a thinner gate oxide than standard HEXFETs. This has the following effects on the input characteristics:

Gate Threshold voltage is lower.

Transconductance is higher.

Input capacitance is higher.

Gate-source breakdown voltage is lower.

The thinner gate oxide is the basic means whereby full enhancement of the logic level HEXFET is achieved at 5V gate voltage, versus 10V for a standard HEXFET. The side effects are higher gate-source input capacitance, and lower gate-source breakdown voltage. The gate charge for full enhancement of the logic level HEXFET is, however, about the same as for a standard HEXFET because the higher input capacitance is counteracted by lower threshold voltage and higher transconductance.

While input characteristics are different, the output characteristics of the logic level HEXFET are essentially the same as for a standard HEXFET. Reverse transfer capacitance, on-resistance, drain-source breakdown voltage, avalanche energy rating, and output capacitance are all essentially the same.

Table 1 summarizes the essential comparisons between standard and logic level HEXFETs.

On-Resistance and Current Rating

On-Resistance

All logic level HEXFET power MOSFETs have the same guaranteed on-resistance at $V_{GS}=5V$ as their standard counterparts at $V_{GS}=10V$ (e.g., IRL530 has same $R_{DS(on)}$ as IRF530, IRLZ44 has same $R_{DS(on)}$ as IRFZ44, and so on). A second on-resistance value is also specified, at $V_{GS}=4V$. This is in recognition of the fact that some logic drive circuits do not deliver 5V because of their own saturation voltage drops.

TTL families, for example, do not actually deliver 5V in their V_{OH} condition, even into an open circuit. The 5V level can, however, be reached by the addition of a pull-up resistor from the output pin to the 5V bus, as illustrated in Figure 1. Without the pull-up resistor, the $R_{DS(on)}$ value at $V_{GS}=5V$ may not be attained, and the value specified at $V_{GS}=4V$ should be used for worst case design.

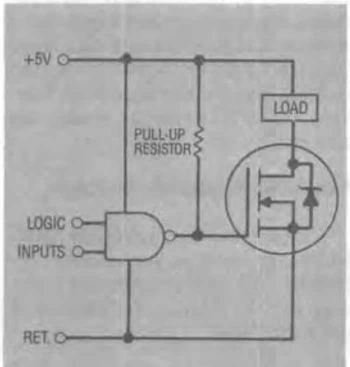


Figure 1. Pull-up resistor used to deliver 5V gate drive.

Table 1: Essential Comparisons of Standard and Logic Level HEXFETs

Characteristics and Ratings		Standard HEXFET (IRF Series)	Comparable Logic Level HEXFET (IRL Series)
Gate Threshold Voltage	$V_{GS(th)}$	2 – 4V	1 – 2V
On-Resistance	$R_{DS(on)}$	Logic level HEXFET has same value of at $R_{DS(on)}$ V_{GS} = 5V as standard HEXFET at V_{GS} = 10V $R_{DS(on)}$ of logic level HEXFET also specd at V_{GS} = 4V	
Transconductance	g_{fs}	Typically 39% larger for logic level HEXFET	
Input Capacitance	C_{iss}	Typically 33% larger for logic level HEXFET	
Output Capacitance	C_{oss}	Essentially the same	
Reverse Transfer Capacitance	C_{rss}	Essentially the same	
Gate Charge Gate-Source	Q_{gs}	Essentially the same	
Gate-Drain	Q_{gd}	Essentially the same	
Total	Q_g	Essentially same as V_{GS} = 10V	Essentially same at V_{GS} = 5V
Drain Source Breakdown Voltage	BV_{DSS}	Same	
Continuous Drain Current	I_D	Same	
Single Pulse Avalanche Energy	E_{AS}	Same	
Max Gate-Source Voltage	V_{GS}	±20V	±10V

Current Ratings

Just like standard HEXFETs, maximum current ratings are determined essentially by permissible power dissipation due to conduction losses. Since on-resistance and die size of a logic level HEXFET (at V_{GS}=5V) are the same as for the corresponding standard HEXFET, current ratings are also exactly the same.

Minimum Threshold Voltage

The gate threshold voltage of MOSFETs is inversely proportional to temperature. At high temperature it can approach the $V_{OL(max)}$ specification of the logic driver.

It is mandatory, therefore, that $V_{TH(min)}$ is always greater than $V_{OL(max)}$ of the various logic families in order to guarantee complete turn off.

International Rectifier logic level HEXFETs have a guaranteed minimum $V_{GS(th)}$ at T_J = 150°C of 0.6 Vdc, thus ensuring reliable operation with all common logic families where V_{OL} is specified at 0.5 Vdc (max).

Replacing Standard HEXFETs

Since a logic level HEXFET has the same $R_{DS(on)}$ and drain current ratings as its standard HEXFET counterpart, it can directly replace the standard device and its associated 10V drive circuitry. Thus, logic level HEXFETs are drop-in replacements for similar standard HEXFET part numbers (e.g., IRL530 for IRF530, etc.).

Driving Logic Level HEXFETs

Drive Impedance

The gate charge Q_g to switch a given drain current at a given drain-source voltage is about the same for logic level HEXFETs as for standard HEXFETs. Since the logic level HEXFET needs only one half the gate voltage, the drive energy is only about one half of that needed for the standard HEXFET. Since the gate voltage is halved, the gate drive resistance needed to deliver the gate charge in a given time is also halved, relative to a standard HEXFET. In other words, for the same switching speed as a standard HEXFET power MOSFET, the drive circuit impedance for the logic level HEXFET must be approximately halved.

The equivalence of switching times at one half the gate resistance for the logic level HEXFET is illustrated by the typical switching times for the IRL540 and the IRF540 HEXFETs shown in Table 2, using data sheet test conditions.

Table 2: Typical Resistive Switching Times for IRL540 and IRF540

Gate Resistance	Gate Voltage	Drain Current	Typical Values (ns)			
R_G (Ω)	V_{GS} (V)	I_D (A)	$t_{D\ on}$	t_r	$t_{D\ off}$	t_f
9	10	28	15	72	40	50
4.5	5	28	15	72	44	56

Inductance

As with all fast switching semiconductors, common mode inductance plays a significant role in switching performance.

The circuit shown in Figure 2a has poor switching performance due to the common mode inductance L_W (the wiring inductance). The circuit shown in Figure 2b has eliminated most of the common mode inductance by separately connecting the power return and the drive signal return to the source pin of the switching HEXFET. Thus, the load current I_D does not flow through any of the external wiring of the drive circuit; consequently, only the internal source inductance ℓ_s is common to both load and drive circuits.

The inferior switching performance of the circuit in Figure 2a is due to the fact that V_{GS} is reduced by $(\ell_s + L_W)$ di/dt, where di/dt is the rate of change of the drain current. If L_w can be eliminated from the drive circuit, V_{GS} can approach the applied drive voltage because only ℓ_s (the internal source inductance) is common.

It is important to understand that in the case of logic level HEXFETs, for which V_{GS} is 5V and not 10V, the loss of drive voltage due to common mode inductance has proportionately twice the effect as it would on a 10V drive signal, even though actual values of ℓ_s and L_w are the same.

In summary, for fast switching of logic level HEXFETs, two requirements must be met:

1. Driver must have low dynamic impedance.

2. Common mode inductances must be minimized.

Resistive Switching Tests

Test Set-Ups

In the following tests of switching performance, the physical layout of the test circuit was carefully executed so that common mode source inductance was minimized.

The following precautions were observed:

1. R_L was built by paralleling 0.5W resistors to achieve the desired load resistance (see Table 3).

2. To minimize inductance in the load circuit, a 10 μF low-ESR low-ESL capacitor was connected directly from $+V_{DD}$ to the source of the DUT.

3. To provide a low source impedance for the 5V gate pulse of the DUT, a 0.1 μF low-ESR low-ESL capacitor was connected directly between pin 14 and pin 7.

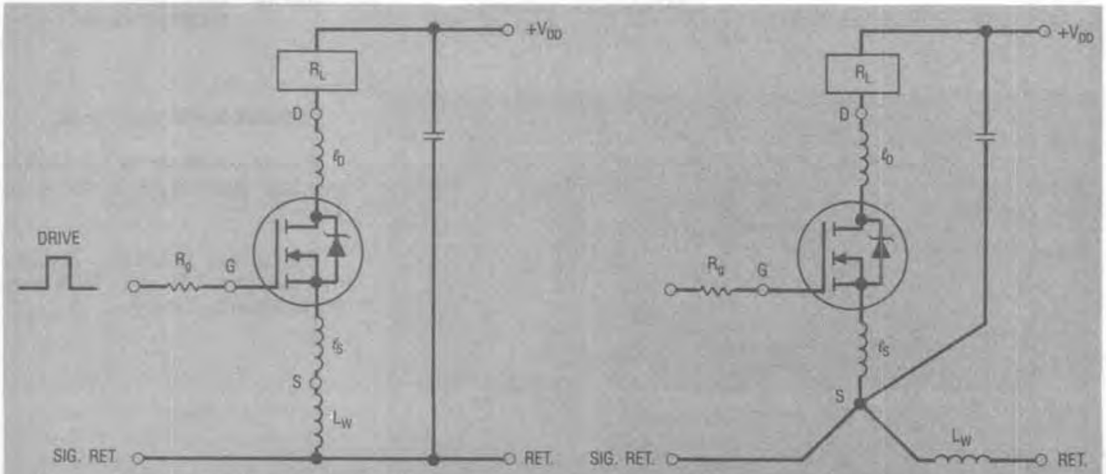


Figure 2a. High common mode inductance. **Figure 2b.** Minimum common mode inductance.

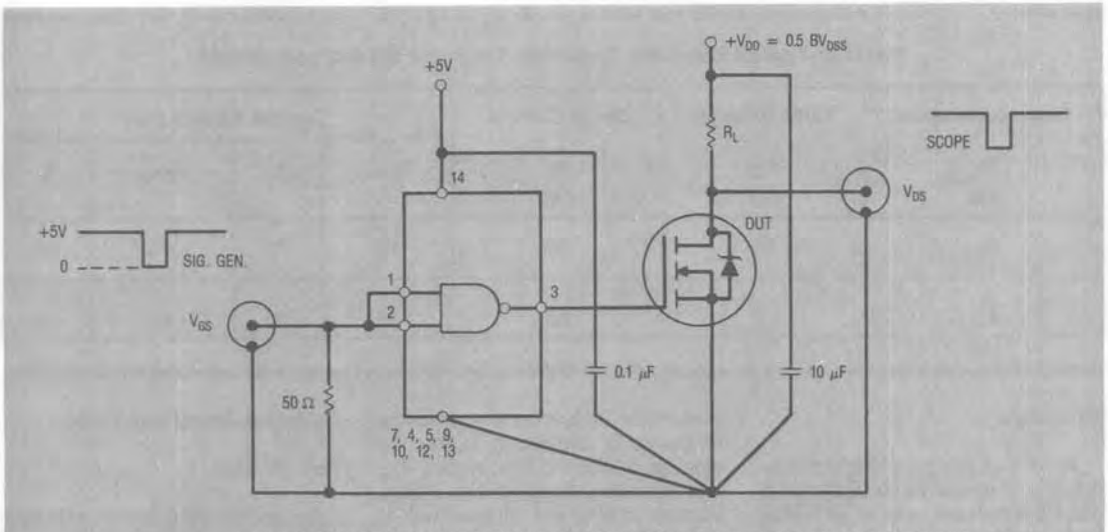


Figure 3. Switching test circuit. (Note: Logic level driver is one-quarter of quad nand gate.)

4. To provide minimum common mode impedance, the source of the DUT was the common return point of all ac and dc system grounds.

5. To reduce stray inductances and thus achieve maximum switching speeds, the physical size of the high current loop (R_L, DUT, 10 μF) was reduced to the smallest practical limits.

Logic Family Characteristics

There are basically three types of logic devices available today:

Bipolar

CMOS

ECL

Of these, only the 5 volt families are usable as logic level HEXFET drives, which rules out ECL. What is left is bipolar and CMOS (and their derivatives), so the following list represents most possible sources for HEXFET drive signals:

TTL GATES

DM7400N:	Standard TTL
74F00PC:	High Speed TTL
DM74S00N:	Schottky TTL
DM74LS00N:	Low Power Schottky TTL
DM74AS00N:	Advanced Schottky TTL

CMOS GATES

74AC00PC:	Advanced CMOS
74ACT00PC:	TTL Compatible CMOS
MM74HC00N:	Micro CMOS
MM74HCT00N:	TTL Compatible Micro CMOS

BIPOLAR

DS0026:	High Speed MOSFET Driver

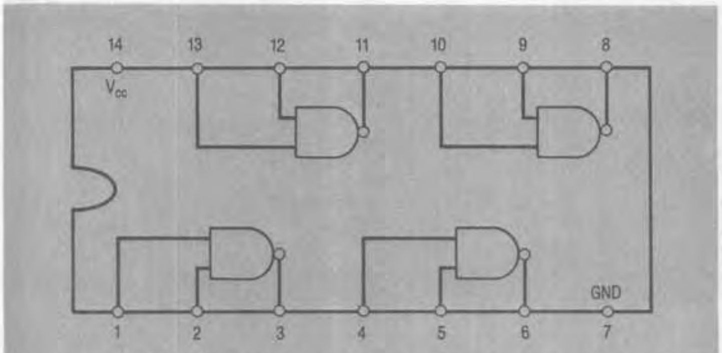


Figure 4. Typical dual input quad nand gate. (Note: For switching tests only one-quarter of the IC was used. All other gates were grounded.)

Resistive Switchtime Tests

The test conditions for the resistive switching performance is shown in Table 3.

The resistive switchtimes obtained with the above TTL and CMOS gates are tabulated in Table 4.

Table 3. Resistive Switching Conditions

LOGIC LEVEL HEXFET	SWITCHING VOLTAGE (V)	SWITCHING CURRENT (A)	$R_{DS(ON)}$ (Ω)	R_L* (Ω)
IRLZ14	30	8	0.24	3.25
IRLZ24	30	16	0.12	1.5
IRLZ34	30	24	0.06	1.2
IRLZ44	30	40	0.034	0.7
IRLZ514	50	5	0.60	9.5
IRLZ524	50	8	0.30	5.9
IRLZ524	50	12	0.18	4.0
IRLZ544	50	25	0.085	1.9

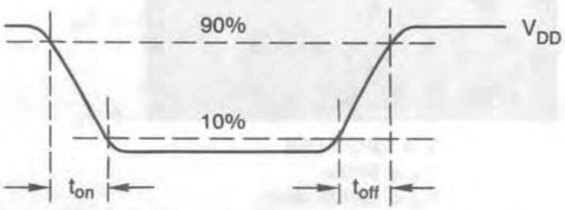
*Note: R_L values were made from parallel combinations of 0.5W carbon comp resistors

Table 4

Logic Family	Logic Level HEXFET, Resistive Load Switching (µs)															
Quad, Dual Input	IRLZ14		IRLZ24		IRLZ34		IRLZ44		IRL514		IRL524		IRL534		IRL544	
Nand Gate	t_{on}	t_{off}	t_{on}	t_{off}	t_{on}	t_{off}	t_{on}	t_{off}	t_{on}	t_{off}	t_{on}	t_{off}	t_{on}	t_{off}	t_{on}	t_{off}
DM7400N STANDARD TTL	0.173	0.013	0.663	0.026	0.700	0.076	1.491	0.146	0.151	0.022	0.238	0.041	0.283	0.060	0.616	0.124
7400 F00PC HIGH SPEED TTL	0.124	0.008	0.490	0.013	0.429	0.068	0.883	0.146	0.104	0.004	0.159	0.034	0.176	0.059	0.372	0.134
DM7400S00N SCHOTTKY TTL	0.133	0.092	0.543	0.020	0.503	0.032	1.068	0.142	0.116	0.006	0.183	0.041	0.212	0.057	0.441	0.132
DM74LS00N LOW POWER SCHOTTKY TTL	0.174	0.038	0.778	0.093	0.706	0.146	1.438	0.342	0.155	0.040	0.240	0.062	0.267	0.090	0.567	0.199
DM74S00N ADVANCED SCHOTTKY TTL	0.128	0.008	0.587	0.013	0.448	0.023	0.896	0.149	0.111	0.005	0.161	0.027	0.176	0.058	0.336	0.130
74AC00PC ADVANCED CMOS	0.012	0.007	0.120	0.012	0.126	0.027	0.251	0.139	0.036	0.004	0.052	0.028	0.066	0.055	0.126	0.125
74ACT00PC TTL COMPATIBLE CMOS	0.012	0.006	0.121	0.011	0.125	0.018	0.233	0.127	0.033	0.004	0.052	0.027	0.060	0.055	0.120	0.122
MM74HC00N MICRO CMOS	0.066	0.039	0.179	0.091	0.227	0.147	0.508	0.328	0.058	0.044	0.092	0.068	0.111	0.098	0.232	0.213
MM74HCT004 TTL COMPATIBLE MICRO CMOS	0.066	0.030	0.179	0.080	0.227	0.123	0.504	0.269	0.058	0.035	0.092	0.061	0.111	0.088	0.232	0.186
DS0026 HIGH SPEED MOSFET DRIVER	0.052	0.005	0.016	0.005	0.014	0.007	0.032	0.016	0.021	0.004	0.036	0.004	0.036	0.005	0.029	0.009

t_{on} = Time in microseconds from 90% to 10% V_{DD}

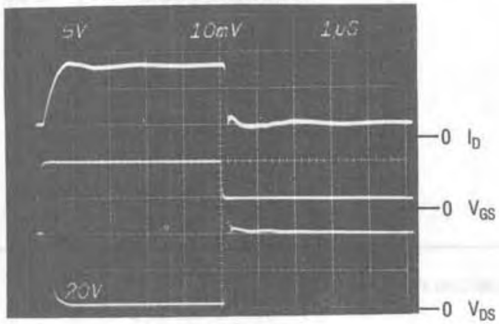
t_{off} = Time in microseconds from 10% to 90% V_{DD}



Typical Test Oscillograms

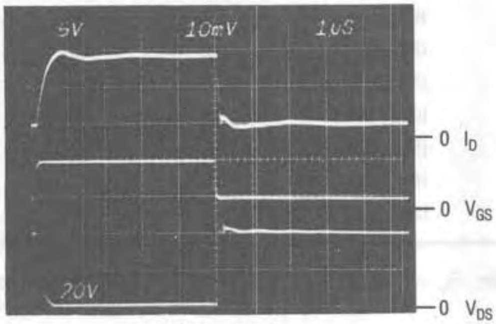
IRLZ24: 60V, 0.1 Ohm, N-Channel, TO-220 logic level HEXFET was driven by each of the logic families listed in Table 4 and the comparative, resistive switchtimes photographed.

DM7400N BIPOLAR TTL



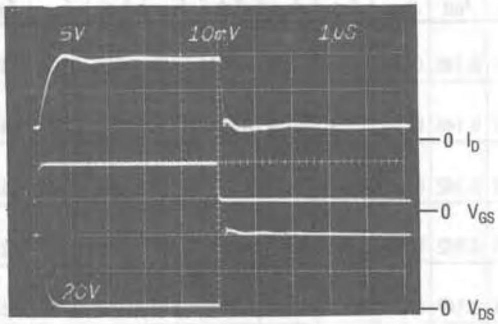
I_D @ 10A/DIV (16A)
V_{GS} @ 5V/DIV
V_{DS} @ 20V/DIV (40V)

74F00PC HIGH SPEED TTL



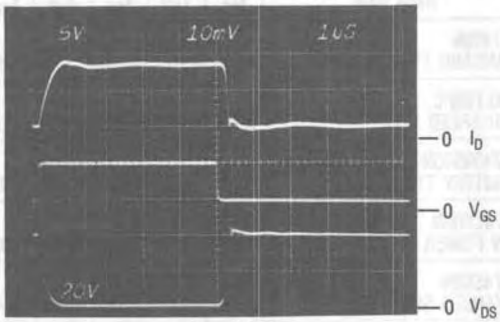
I_D @ 10A/DIV (18A)
V_{GS} @ 5V/DIV
V_{DS} @ 20V/DIV (40V)

DM74S00N SCHOTTKY TTL



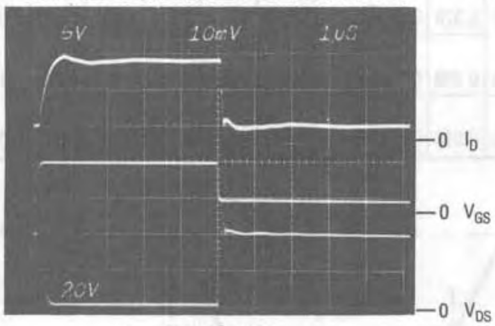
I_D @ 10A/DIV (18A)
V_{GS} @ 5V/DIV
V_{DS} @ 20V/DIV (40V)

DM74LS00N LOW POWER SCHOTTKY TTL



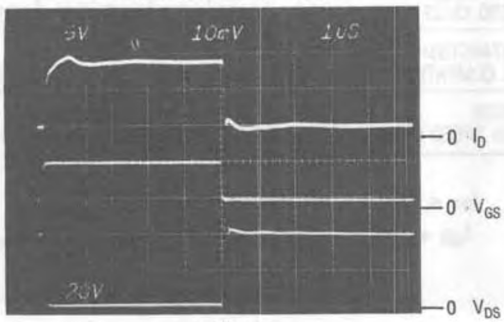
I_D @ 10A/DIV (17A)
V_{GS} @ 5V/DIV
V_{DS} @ 20V/DIV (40V)

DM74AS00N ADVANCED SCHOTTKY TTL



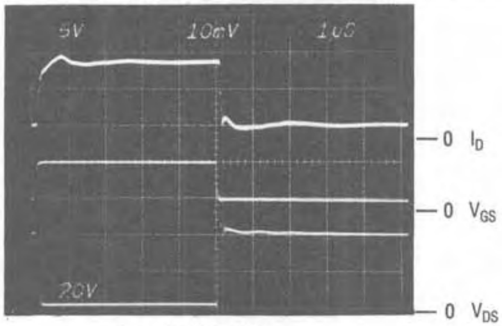
I_D @ 10A/DIV (18A)
V_{GS} @ 5V/DIV
V_{DS} @ 20V/DIV (40V)

74AA00PC ADVANCED CMOS



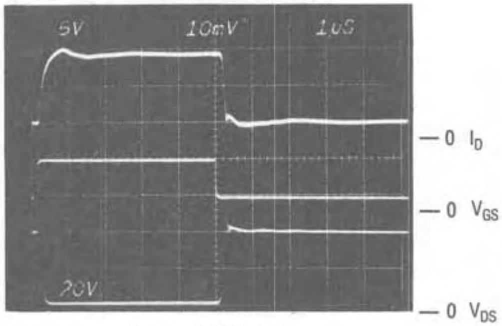
I_D @ 10A/DIV (18A)
V_{GS} @ 5V/DIV
V_{DS} @ 20V/DIV (40V)

74ACT00PC TTL COMPATIBLE CMOS



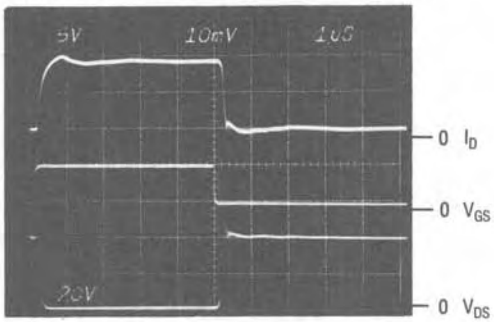
I_D @ 10A/DIV (17A)
V_{GS} @ 5V/DIV
V_{DS} @ 20V/DIV (40V)

MM74HC00N MICRO CMOS



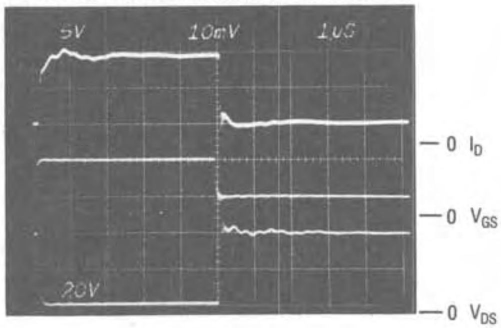
I_D @ 10A/DIV (18A)
V_{GS} @ 5V/DIV
V_{DS} @ 20V/DIV (40V)

MM74HCT00N TTL COMPATIBLE MICRO CMOS



I_D @ 10A/DIV (18A)
V_{GS} @ 5V/DIV
V_{DS} @ 20V/DIV (40V)

DS0026CN BIPOLAR HIGH SPEED DRIVER



I_D @ 10A/DIV (18A)
V_{GS} @ 5V/DIV
V_{DS} @ 20V/DIV (40V)