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Driving Power MOSFETs in High-Current, Switch Mode Regulators

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DRIVING THE MOSFET

The low on-resistance and high current carrying capability of power MOSFETs make them preferred switching devices in SMPS power supply design. However, designing with these devices is not as straightforward as with their bipolar counterparts.

Unlike bipolar transistors, power MOSFETs have a considerable gate capacitance that must be charged beyond the threshold voltage, $V_{GS(TH)}$, to achieve turn-on. The gate driver must provide a high enough output current to charge the equivalent gate capacitance, C_{EI}, within the time required by the system design.

HOW MUCH GATE CURRENT?

The most common error in calculating gate current is confusing the MOSFET input capacitance, C_{ISS}, for C_{EI} and applying the equation....

$$I = C(dv/dt)$$

to calculate the required peak gate current. C_{EI} is actually much higher, and must be derived from the MOSFET manufacturer's total gate charge, Q_G, specifications.

The total gate charge, Q_G, that must be dispensed into the equivalent gate capacitance of the MOSFET to achieve turn-on is given as:

$$Q_G = Q_{GS} + Q_{GD} + Q_{OD}$$

where:

Q_G is the total gate charge
Q_{GS} is the gate-to-source charge
Q_{GD} is the gate-to-drain Miller charge
Q_{OD} is the "overdrive charge" after charging the Miller capacitance.

The curve of Figure 1 is typical of those supplied by MOSFET manufacturers. Notice that in order to achieve strong turn-on, a V_{GS} well above that required to charge C_{EI} (and well above $V_{GS(TH)}$) is required. The equivalent gate capacitance is determined by dividing a given V_{GS} into the corresponding total gate charge. The required gate drive current (for a transition within a specified time) is determined by dividing the total gate charge by the desired transition time.

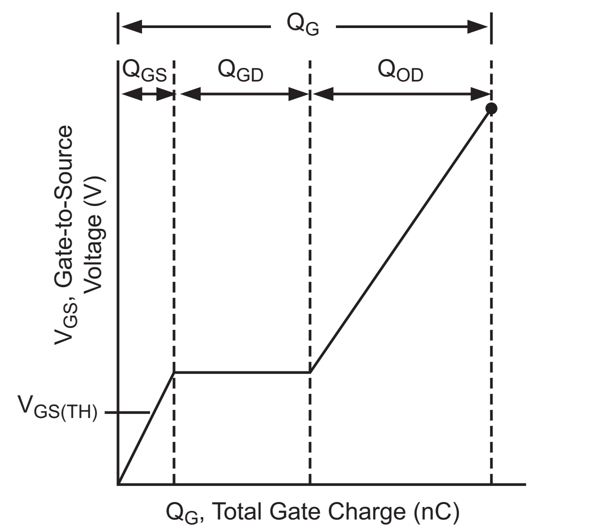

FIGURE 1: Gate charge characteristics.

In equation form:

$$Q_G = (C_{EI})(V_{GS})$$

and

$$I_G = Q_G/t_{(transition)}$$

where:

Q_G is the total gate charge, as defined above
C_{EI} is the equivalent gate capacitance
V_{GS} is the gate-to-source voltage
I_G is the gate current required to turn the MOSFET on in time period $t_{(transition)}$
$t_{(transition)}$ is the desired transition time

For example:

Given: N-Channel MOSFET
$V_{GS} = 10V$
t (transistion) = 25nsec

Find: Gate drive current, I_G.

From the MOSFET manufacturer's specifications, $Q_G = 50nC$ at $V_{GS} = 10V$. Using $I_G = Q_G/t_{(transition)}$:

$$I_G = Q_G/t_{(transition)} = 50 \times 10^{-9}/25 \times 10^{-9} = 2.0A$$

Table 1 is a guideline for matching various Microchip MOSFET drivers to Industry-standard HEXFETs.

Device No.	Drive Current (Peak)	Output Number and Type		Rated Load (pF)	Rise Time @ Rated Load (nsec)	Fall Time @ Rated Load (nsec)	Rising Edge Prop. Delay (nsec)	Falling Edge Prop. Delay (nsec)	Latch-Up Proof	Input Protected to 5V Below GND Rail
		Inverting	Non-Invert.							
TC1410	0.5A	Single		500	25	25	30	30	Yes	Yes
TC1410N	0.5A		Single	500	25	25	30	30	Yes	Yes
TC1411	1.0A	Single		1000	25	25	30	30	Yes	Yes
TC1411N	1.0A		Single	1000	25	25	30	30	Yes	Yes
TC1426	1.2A	Dual		1000	23	17	36	43	Yes	No
TC1427	1.2A		Dual	1000	23	17	36	43	Yes	No
TC1428	1.2A	Single	Single	1000	23	17	36	43	Yes	No
TC4467	1.2A	— Quad NAND —		470	15	15	40	40	Yes	Yes
TC4468	1.2A	— Quad AND —		470	15	15	40	40	Yes	Yes
TC4469	1.2A	— Quad AND with INV—		470	15	15	40	40	Yes	Yes
TC4426	1.5A	Dual		1000	19	19	20	40	Yes	Yes
TC4426A	1.5A	Dual		1000	25	25	30	30	Yes	Yes
TC4427	1.5A		Dual	1000	19	19	20	40	Yes	Yes
TC4427A	1.5A		Dual	1000	25	25	30	30	Yes	Yes
TC4428	1.5A	Single	Single	1000	19	19	20	40	Yes	Yes
TC4428A	1.5A	Single	Single	1000	25	25	30	30	Yes	Yes
TC1412	2.0A	Single		1000	18	18	35	35	Yes	Yes
TC1412N	2.0A		Single	1000	18	18	35	35	Yes	Yes
TC1413	3.0A	Single		1800	20	20	35	35	Yes	Yes
TC1413N	3.0A		Single	1800	20	20	35	35	Yes	Yes
TC4423	3.0A	Dual		1800	23	25	33	38	Yes	Yes
TC4424	3.0A		Dual	1800	23	25	33	38	Yes	Yes
TC4425	3.0A	Single	Single	1800	23	25	33	38	Yes	Yes
TC4420	6.0A	Single		2500	25	25	55	55	Yes	Yes
TC4429	6.0A		Single	2500	25	25	55	55	Yes	Yes
TC4421	9.0A	Single		10000	60	60	30	33	Yes	Yes
TC4422	9.0A		Single	10000	60	60	30	33	Yes	Yes

Note: Typical values for $T_A = 25°C$.

TABLE 1A: Selecting MOSFET drivers.

MOSFET Size	Die Size (mm)	C_{EI} of MOSFET (pF)	Suggested Driver Family (@ 12V)	Faster Rise/Fall Times
Hex 0	0.89 x 1.09	400	TC1426/4426/4469	
Hex 1	1.75 x 2.41	750	TC1426/4426/4469	
Hex 2	3.40 x 2.21	1500	TC1426/4426/4469	TC4423
Hex 3	4.44 x 2.79	3000	TC1426/4426	TC4423
Hex 4	7.04 x 4.32	6000	TC4423	TC4429
Hex 5	6.45 x 6.45	12,000	TC4423	TC4429
Hex 6	283 x 321 mil	15,000	TC4429/4420	TC4421/4422
Hex 7	283 x 348 mil	16,000	TC4429/4420	TC4421/4422
Parallel Modules	Various	Up to 48,000	TC4421/4422	

TABLE 1B: *MOSFET die size vs. suggested drive family.*

WHY DEDICATED MOSFET DRIVERS?

Traditional SMPS controllers have on-board drivers suitable for some applications. Typically, these drivers have peak output currents of 1A or less, limiting their scope of applications. In addition, the heat generated in these drivers causes the on-chip reference voltage to change.

The need for “smarter” power supplies are forcing SMPS controllers to grow in sophistication. Many newer SMPS controllers are fabricated in smaller geometry CMOS process technologies, precluding the use of high voltage (i.e. voltages greater than 12V). In such cases, the external MOSFET driver also acts as a level shifter, translating TTL-compatible levels to MOSFET drive voltages. A device like the TC4427A for example, furnishes a rail-to-rail output voltage swing (from a maximum V_{DD} of 18V) from an input swing of V_{IL} = 0.8V and V_{IH} = 2.4V.

Latch-up immunity is another consideration. Latch-up immunity is particularly important in that the driven MOSFETs typically drive inductive circuits that generate significant “kickback” currents. MOSFET drivers like the TC4427 can withstand as much as 0.5A of reverse output current without damage or upset.

Protection against shoot-through current is still another consideration, especially in higher speed SMPS designs. Shoot through currents are usually caused by excessively long driver rise, fall or propagational delay times; causing both the high side and low side MOSFETs to be on for a brief instant. Current “shoots through” (hence the name) from the supply input to ground, significantly degrading the overall supply efficiency. The use of dedicated MOSFET drivers minimizes this problem in two ways:

1. MOSFET gate drive rise and fall times must be symmetrical, and as short as possible. A driver like the TC4427 has a specified t_R and t_F of approximately 19nsec into a 1000pF load. A higher peak output current driver may be selected to achieve more aggressive rise and fall times if so desired.
2. The propagational delay times through the driver must be short (and matched for higher speed designs) to ensure symmetrical turn-on and turn-off delays of both the high side and low side MOSFET.

The TC4427A for example, has rising and falling edge propagation delay times matched to within 2nsec (see Figure 2). These delays track each other with both voltage and temperature. Microchip’s 2nsec skew is among the best available (competing devices have skews at least 4 times larger; drivers integrated on board the SMPS controller are worse yet).

These concerns (and related cost and reliability concerns) usually point in the direction of an external, dedicated driver, as opposed to an integrated or external discrete component driver solution.

TYPICAL APPLICATIONS

Portable Computer Supply

One common application that exploits the design benefits of dedicated MOSFET drivers is a switching power supply for portable systems, such as those found in notebook computer applications. The circuit topology of a high efficiency, synchronous buck converter is shown in Figure 3. It accepts an input voltage range of 5V to 30V to accommodate AC/DC adapters (14V to 30V) or a battery supply (7.2V to 10.8V).

The TC1411N acts as a low side driver, and is powered from a +5V supply to minimize turn-off delay due to gate "overdrive charge." The high side driver in Figure 3 is a TC4431, which has a peak output current of 1.5A. The TC1411N has a peak output current capability of 1A. They can drive MOSFETs capable of 10A continuous drain current in 30nsec.

Desktop PC Power Supply

Desktop power supplies also benefit from the use of dedicated MOSFET drivers (Figure 4). The synchronous stepdown converter shown is common for CPUs requiring greater than 6A of DC current. It also accommodates custom voltages not accommodated by the current “silver box” supplies. Efficiency is not as large a concern, since this supply is line-powered.

The topology shown is simpler than that of Figure 3. The TC4428A serves as a high-side/low-side driver powered from the same V_{DD}. N-Channel MOSFETs are used to save cost. The TC4428A has sufficient output current to drive a 10A (continuous drain current) MOSFET active in 25nsec.

SUMMARY

Power MOSFETs are desirable as switching elements in SMPS designs because of their low on-resistance and high current carrying capability.

Using dedicated MOSFET drivers results in a more optimized SMPS design. Drivers integrated on-board the SMPS controller are advantageous only for low sophistication, low output power designs. External drivers fashioned from discrete active and passive components have neither the repeatable high performance, nor the low cost of a dedicated monolithic driver circuit. Dedicated drivers like those offered by Microchip feature fast rise, fall and delay times, and are available in a wide variety of topologies to suit virtually every application.

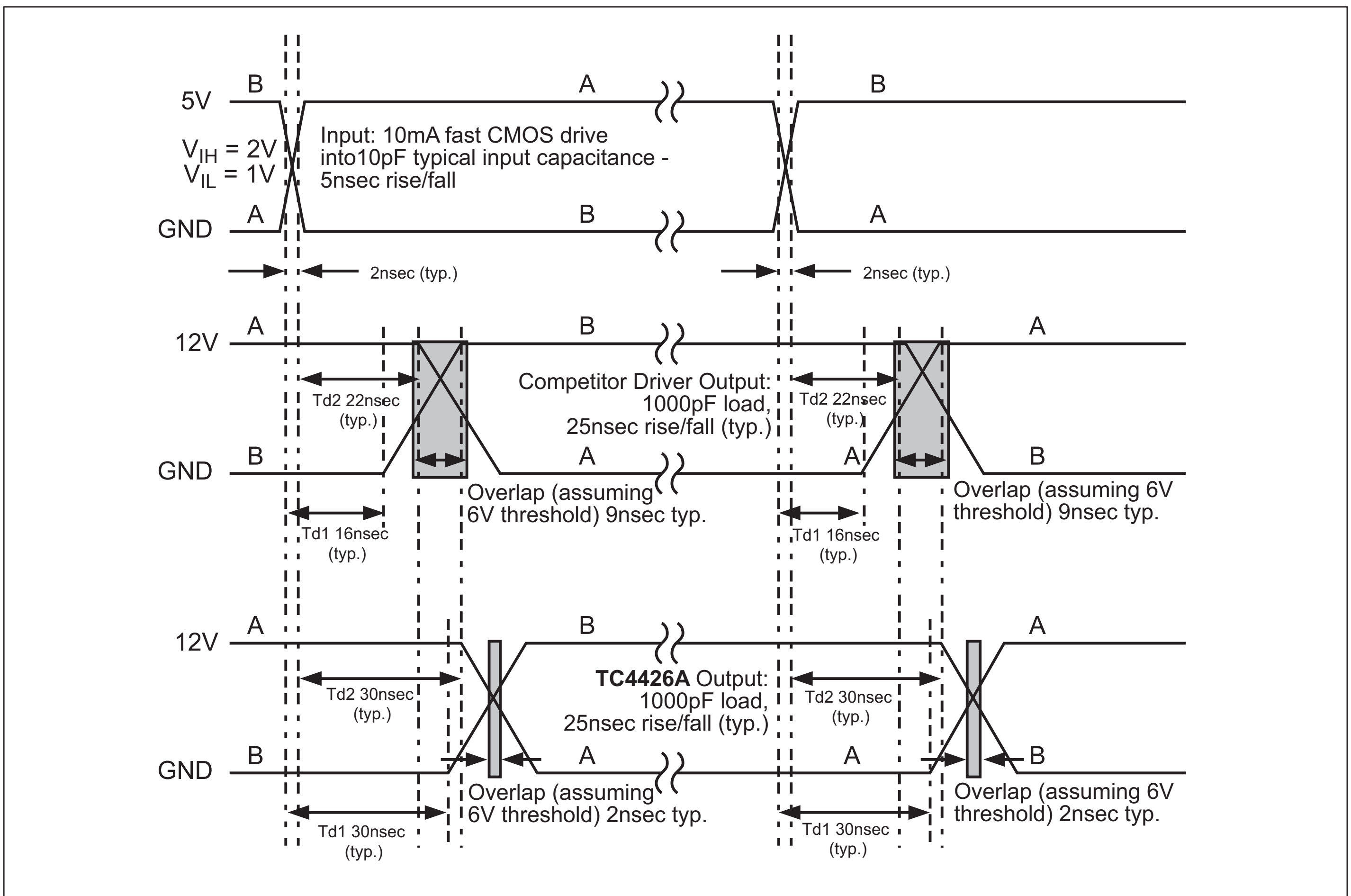

FIGURE 2: Matched delay times of the TC4426A reduce overlap times resulting in reduced shoot-through currents.

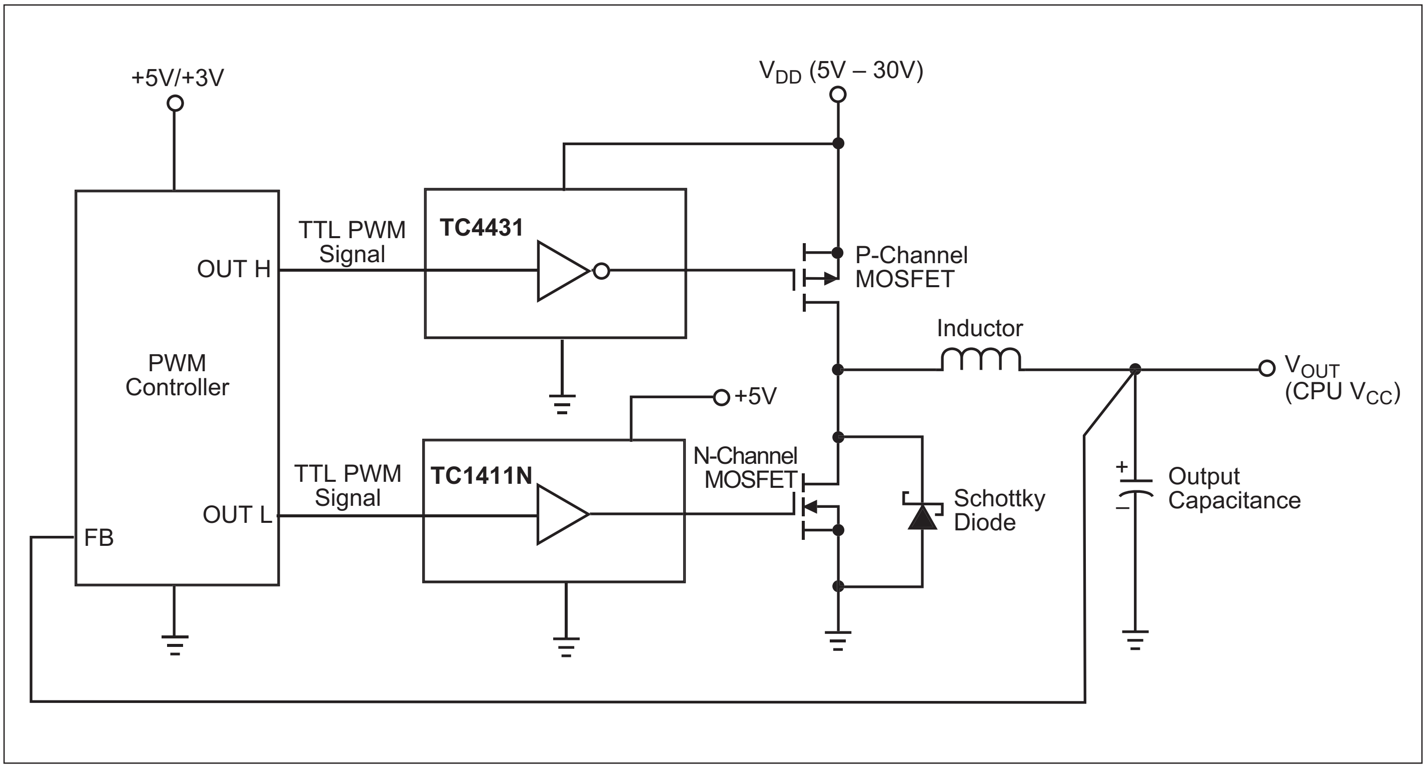

FIGURE 3: Portable CPU power supply.

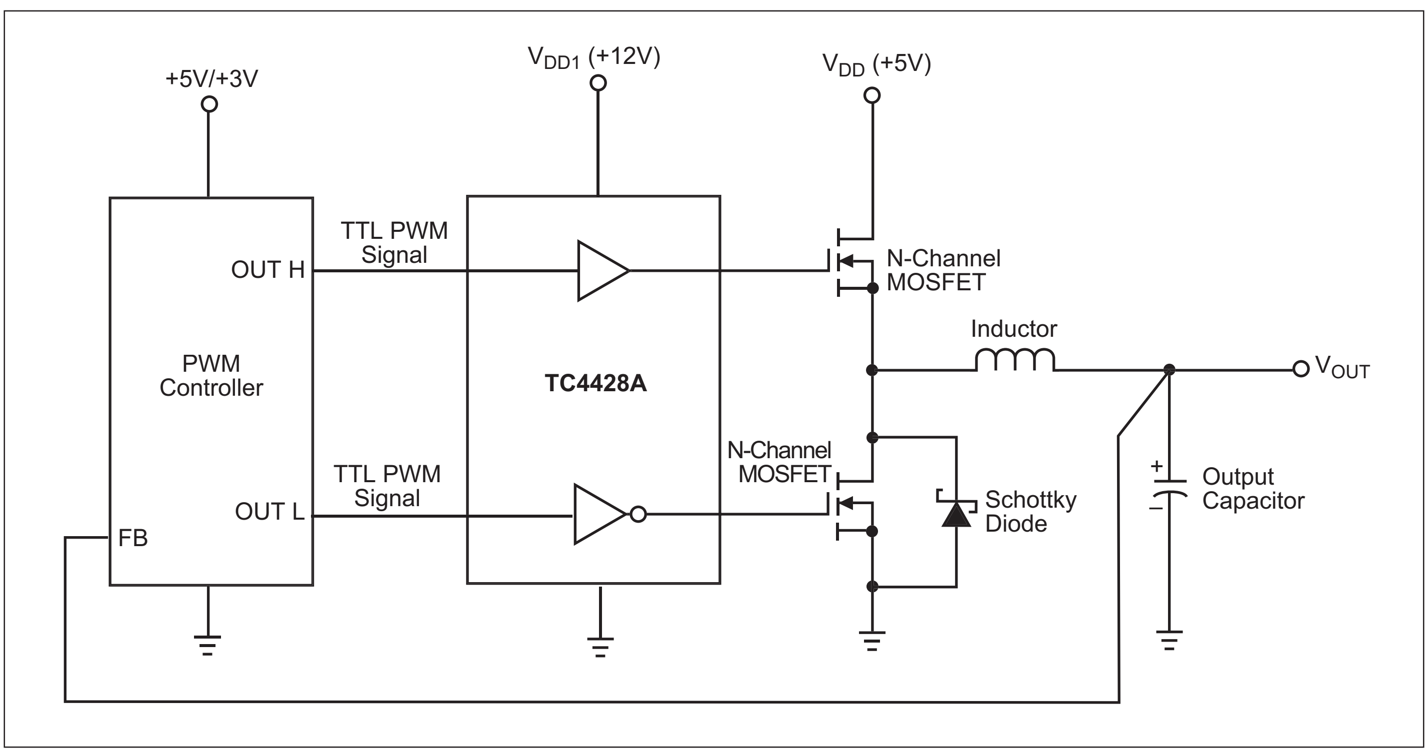

FIGURE 4: Desktop CPU power supply.

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