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.

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

- $V_{GS} = 10V$
- $t_{(transition)} = 25\text{nsec}$

Find: Gate drive current, $I_G$.

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

$$ I_G = Q_G/t_{(transition)} = 50 \times 10^{-9}/25 \times 10^{-9} = 2.0\text{A} $$
Table 1 is a guideline for matching various Microchip MOSFET drivers to Industry-standard HEXFETs.

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

Note: Typical values for T_A = 25°C.

TABLE 1A: Selecting MOSFET drivers.
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.

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

TABLE 1B: MOSFET die size vs. suggested drive family.
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<sub>DD</sub>. 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.
Information contained in this publication regarding device applications and the like is intended through suggestion only and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications. No representation or warranty is given and no liability is assumed by Microchip Technology Incorporated with respect to the accuracy or use of such information, or infringement of patents or other intellectual property rights arising from such use or otherwise. Use of Microchip's products as critical components in life support systems is not authorized except with express written approval by Microchip. No licenses are conveyed, implicitly or otherwise, under any intellectual property rights.

Microchip received QS-9000 quality system certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona in July 1999. The Company's quality system processes and procedures are QS-9000 compliant for its PICmicro® 8-bit MCUs, KSzLow code hopping devices, Serial EEPROMs and microperipheral products. In addition, Microchip's quality system for the design and manufacture of development systems is ISO 9001 certified.
AMERICAS
Corporate Office
2335 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200 Fax: 480-792-7277
Technical Support: 480-792-7627
Web Address: http://www.microchip.com

Rocky Mountain
2335 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7966 Fax: 480-792-7456

Atlanta
500 Sugar Mill Road, Suite 200B
Atlanta, GA 30350
Tel: 770-640-0034 Fax: 770-640-0307

Boston
2 Lan Drive, Suite 120
Westford, MA 01886
Tel: 978-692-3848 Fax: 978-692-3821

Chicago
333 Pierce Road, Suite 180
Itasca, IL 60143
Tel: 630-285-0071 Fax: 630-285-0075

Dallas
4570 Westgrove Drive, Suite 160
Addison, TX 75001
Tel: 972-818-7923 Fax: 972-818-7924

Tri-Atra Office Building
32265 Northwestern Highway, Suite 190
Farmington Hills, MI 48334
Tel: 248-538-2250 Fax: 248-538-2260

Kokomo
2767 S. Albright Road
Kokomo, Indiana 46902
Tel: 765-864-8360 Fax: 765-864-8387

Los Angeles
18201 Von Karman, Suite 1090
Irvine, CA 92612
Tel: 949-263-1888 Fax: 949-263-1889

New York
150 Motor Parkway, Suite 202
Hauppauge, NY 11788
Tel: 631-273-5305 Fax: 631-273-5335

San Jose
Microchip Technology Inc.
2107 North First Street, Suite 590
San Jose, CA 95131
Tel: 408-436-7950 Fax: 408-436-7955

Toronto
6285 Northam Drive, Suite 108
Mississauga, Ontario L4V 1X5, Canada
Tel: 905-673-0699 Fax: 905-673-0699

ASIA/PACIFIC
Australia
Microchip Technology Australia Pty Ltd
Suite 22, 41 Rawson Street
Epping 2121, NSW
Australia
Tel: 61-2-9868-6733 Fax: 61-2-9868-6755

China - Beijing
Microchip Technology Consulting (Shanghai) Co., Ltd., Beijing Liaison Office
Unit 915
Bei Hui Wan Tai Bldg.
No. 6 Chaoyangmen Beidajie
Beijing, 100027, No. China
Tel: 86-10-85282100 Fax: 86-10-85282104

China - Chengdu
Microchip Technology Consulting (Shanghai) Co., Ltd., Chengdu Liaison Office
Rm. 2401, 24th Floor,
Ming Xing Financial Tower
No. 88 TIDU Street
Chengdu 610016, China
Tel: 86-28-6766200 Fax: 86-28-6766599

China - Fuzhou
Microchip Technology Consulting (Shanghai) Co., Ltd., Fuzhou Liaison Office
Unit 701, World Trade Plaza
No. 71 Wusi Road
Fuzhou 350001, China
Tel: 86-591-7530506 Fax: 86-591-7530521

China - Shanghai
Microchip Technology Consulting (Shanghai) Co., Ltd.
Room 701, Bldg. B
Far East International Plaza
No. 317 Xian Xia Road
Shanghai, 200005
Tel: 86-21-6275-5700 Fax: 86-21-6275-5060

China - Shenzhen
Microchip Technology Consulting (Shanghai) Co., Ltd., Shenzhen Liaison Office
Rm. 1315, 13/F, Shenzhen Kerry Centre,
Renminnan Lu
Shenzhen 518016, China
Tel: 86-755-2350361 Fax: 86-755-2366086

Hong Kong
Microchip Technology Hong Kong Ltd.
Unit 901-6, Tower 2, Metroplaza
223 Hing Fong Road
Kwai Fong, N.T., Hong Kong
Tel: 852-2401-1200 Fax: 852-2401-3431

India
Microchip Technology India
India Liaison Office
Divyasree Chambers
1 Floor, Wing A (A3/A4)
No. 11, O’Shaugnessey Road
Bangalore, 560 025, India
Tel: 91-80-2290061 Fax: 91-80-2290062

Japan
Microchip Technology Japan K.K.
Benex S-1 6F
3-18-20, Shinjyokohama
Kohoku-Ku, Yokohama-shi
Kanagawa, 222-0033, Japan
Tel: 81-45-471-6166 Fax: 81-45-471-6122

Korea
Microchip Technology Korea
168-1, Youngbo Bldg. 3 Floor
Samsung-Dong, Kangnam-Ku
Seoul, Korea 135-882
Tel: 82-2-554-7200 Fax: 82-2-558-5934

Singapore
Microchip Technology Singapore Pte Ltd.
200 Middle Road
#07-02 Prime Centre
Singapore, 188980
Tel: 65-6335-8870 Fax: 65-6335-8850

Taiwan
Microchip Technology Taiwan
11F-3, No. 207
Tung Hua North Road
Taipei, 105, Taiwan
Tel: 886-2-2717-7175 Fax: 886-2-2545-0139

EUROPE
Denmark
Microchip Technology Nordic ApS
Regus Business Centre
Lastrup høj 1-3
Ballerup DK-2750 Denmark
Tel: 45 4420 9895 Fax: 45 4420 9910

France
Microchip Technology SARL
Parc d’Activite du Moulin de Massy
43 Rue du Saule Trapu
Batiment A - l’er Etage
91300 Massy, France
Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79

Germany
Microchip Technology GmbH
Gustav-Heinemann Ring 125
D-81739 Munich, Germany
Tel: 49-89-627-144 0 Fax: 49-89-627-144-49

Italy
Microchip Technology SRL
Centro Direzionale Colleoni
Palazzo Taurus 1 V. Le Colleoni 1
20041 Agrate Brianza
Milan, Italy
Tel: 39-039-65791-1 Fax: 39-039-6899883

United Kingdom
Arizona Microchip Technology Ltd.
505 Eskdale Road
Winnersh Triangle
Wokingham
Berkshire, England RG41 5TU
Tel: 44 118 921 5869 Fax: 44-118 921-5820

© 2002 Microchip Technology Inc.