Low-threshold MOSFETs can alleviate power-hungry portable devices

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For many years, manufacturers of circuitry aimed at power-management applications have struggled to keep pace with the demands of end-system users. An increasing number of portable electronic products with heightened levels of functionality demand peak performance and challenge designers to achieve the highest efficiency possible within the device's physical bounds. Although the battery industry has been developing alternative technologies with higher energy capacity than conventional NiCd batteries, it is nowhere close to delivering the power requirements of new-generation portable devices. Thus, portable applications have led to innovative developments in low-power circuit designs so that design engineers can ensure that the end system uses battery resources as efficiently as possible. Obviously, to keep up with that demand, IC manufacturers continue to drive innovation to help reduce power consumption in portable devices.

When maximum performance from a DSP or microprocessor isn't necessary, the core supply voltage can be lowered to operate at a reduced clock frequency. More and more new-generation low-power applications are implementing this technique to maximize system power conservation. The formula PC ~ (V_c) * F describes the power consumption of a DSP core, where PC is core power consumption, V_c is core voltage, and F is the core clock frequency. Lowering the internal clock frequency can reduce power consumption; lowering the core supply voltage can reduce it even further.

While these design parameters will provide users with a compelling and functional package, they will also impose stringent requirements on power management circuitry. This is forcing manufacturers and designers to develop new architectures that can deliver more power with greater efficiency for increased battery life at about the same level of cost.

While many design factors affect the performance of new power-hungry portable devices, this article focuses on power MOSFETs–the most common power switches for low-voltage applications–to illustrate the impact of the latest silicon breakthroughs on increasing power requirements. To explain the impact of these advancements, it helps to understand some critical parameters of power MOSFETs.

Channel on-resistance $(r_{ds(on)})$ is controlled by the electric field present across and along the channel. Channel resistance is mainly determined by the gate-to-source voltage difference. When V_{gs} exceeds the threshold voltage $(V_{gs(th)})$, the FET starts to turn on. Many operations call for switching a point to ground. The resistance of a power MOSFET channel is related to its physical dimensions by the formula R = ρ L/A, where ρ is resistivity, L is the length of the channel, and A is W * T, the cross-sectional area of the channel.

In the usual FET structure, L and W are fixed by device geometry, while channel thickness T is the distance between the depletion layers. The position of the depletion layer can be varied either by the gate-source bias voltage or by the drain-source voltage. When T is reduced to zero by any combination of V_{gs} and V_{ds}, the depletion layers from the opposite sides come in contact, and the incremental channel resistance $(r_{ds(on)})$ approaches infinity.

Figure 1 explains the $r_{ds(on)}$ versus V_{gs} characteristic. Region I corresponds to the condition when the accumulative charge is not sufficient to cause an inversion. Region II corresponds to the condition where sufficient charge is present to invert a portion of the *p* region, forming the channel, but not enough that the "space charge" effect is important. Region III corresponds to the charge-limited condition where $r_{ds(on)}$ does not change appreciably as the gate-body potential is raised.

The threshold voltage $(V_{gs(th)})$ is a parameter used to

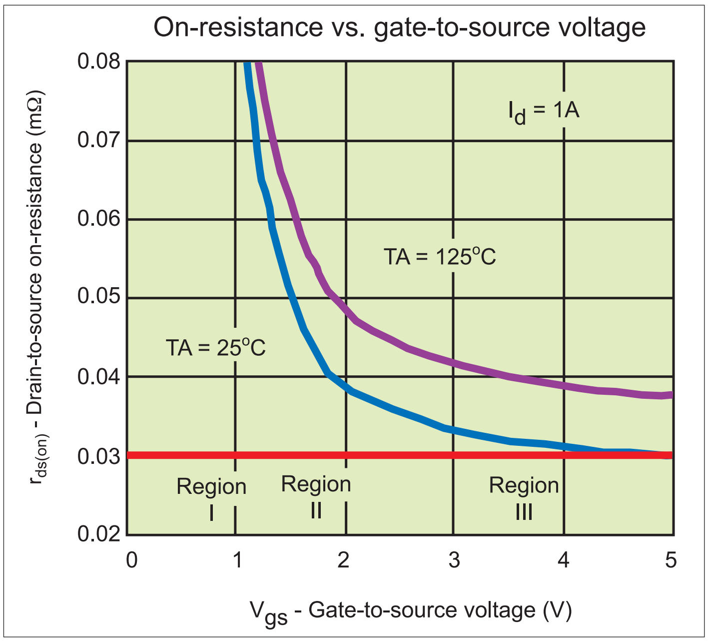

Figure 1: When T is reduced to zero by any combination of Vgs and Vds, depletion layers from the opposite sides come in contact.

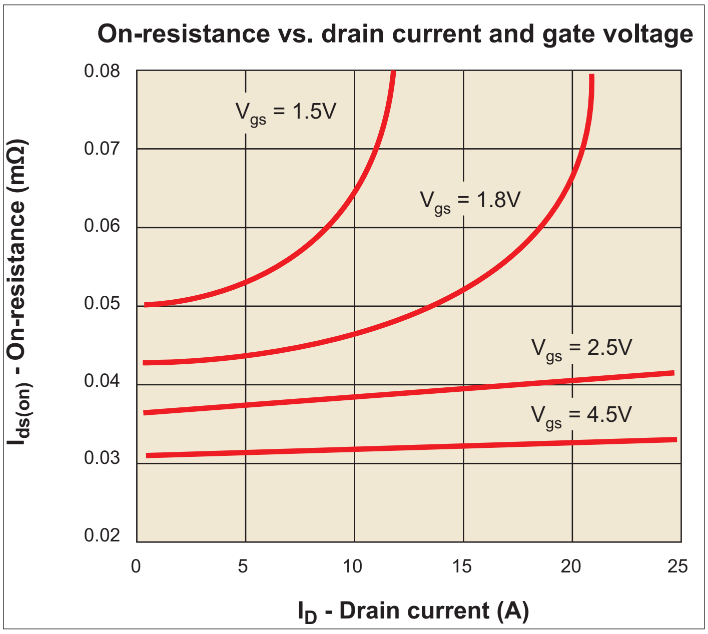

Figure 2: V_{gs} controls the magnitude of the saturated I_d, with increases in V_{gs} resulting in higher values of constant I_d.

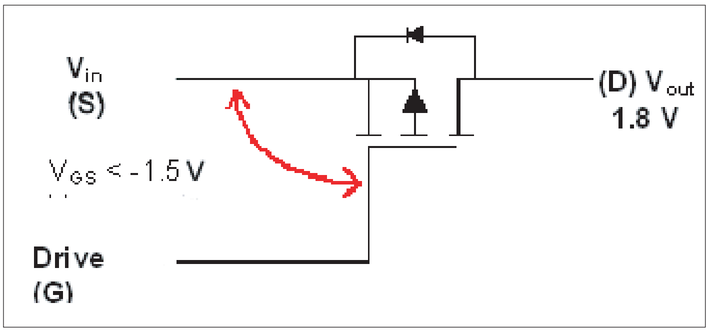

Figure 3: With a rated $r_{ds(on)}$ at 1.5V, the drive circuit doesn't require a level shift to turn on the MOSFET.

describe how much voltage is needed to initiate the channel conduction. V_{gs} controls the magnitude of the saturated I_d, with increases in V_{gs} resulting in higher values of constant I_d, whereas smaller values of V_{gs} as described in Figure 2, will make the operating area closer to the "knee."

High-speed performance and low-power operation can be achieved by using low-threshold voltage transistors. By using low-threshold power MOSFETs in a signal path, the supply voltage (V_{DD}) can be lowered to reduce the switching power dissipation without affecting the performance. That's why, to address the ever-increasing demand to minimize power consumption and increase battery life, many ASICs found in portable electronics systems are designed to operate at core supply voltages of about 1.5V. Until now, however, the lack of power MOSFETs with guaranteed turn-on operation at such low voltages has made it difficult for designers to take advantage of these low voltages in applications less than 1.8V without using level-shifting circuitry, which adds complexity while increasing power consumption. Vishay Siliconix has a family of power MOSFETs with on-resistance ratings at 1.5V. Reducing the $V_{gs(th)}$ point allows the driver voltage to turn on the switch from a lower-output voltage, decreasing the need for a level shifting.

For operation at 125°C (which is typical in portable applications), existing MOSFET designs have to maintain the MOSFET threshold as high to prevent the MOSFET from turning itself on.

Figure 4 compares a high-threshold MOSFET (e.g. Si-4392DY) and a low-threshold MOSFET (e.g. Si3499DV). The low-threshold MOSFET technology from Vishay Siliconix guarantees functionality (fully turned on at 1.5V V_{gs}) by design over the whole operating temperature range.

When it comes to portable devices and cellphones, there is no end in sight to the demand for new multimedia features. However, for designers struggling to deliver higher data capabilities while juggling the power requirements of next-generation portable devices, the advanced silicon and packaging technology of today's power MOSFETs may bring the required edge in delivering power efficiency, ultracompact size and low cost required to make these multimedia phones a reality.

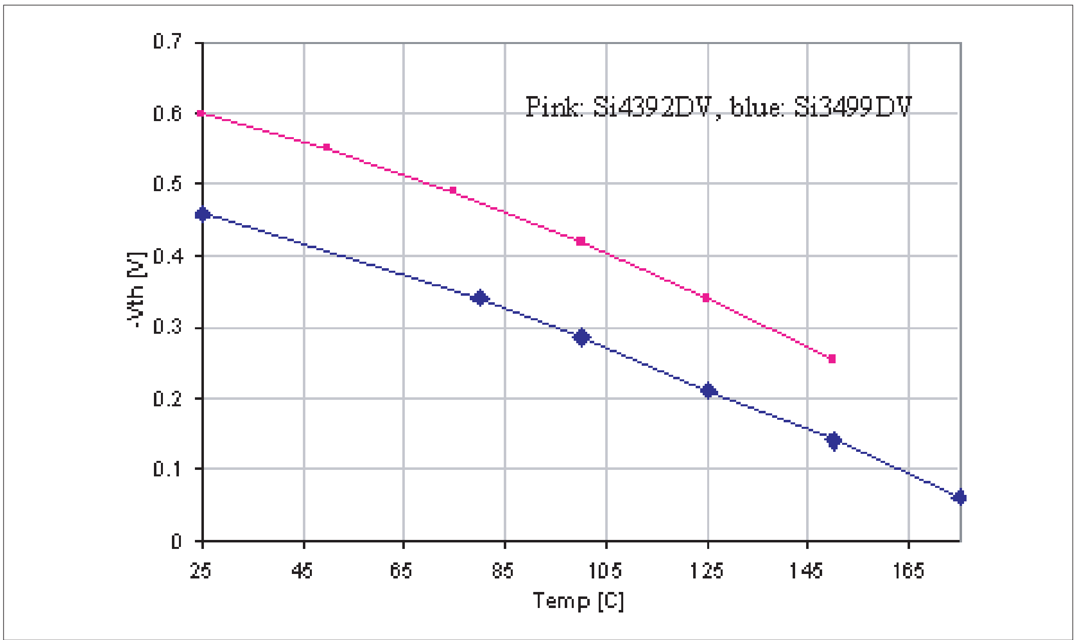

Figure 4: For operation at 125°C, the existing MOSFET designs had to maintain the MOSFET threshold high.