How to Select a MOSFET – Load Switching

TEXAS INSTRUMENTS

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"Two roads diverged in a yellow wood, marked FemtoFET and SOT-23, So I chose the path of FemtoFET to shrink my PCB" – Robert Frost (I think)

MOSFETs are being used as load switches more than they are being used in any other application, in volumes in the hundreds of millions at a time. I should probably start with exactly how I am defining "load switch" here. For the sake of this post, consider a load switch any small-signal FET whose only function in a system is to pass along (or block) some low-current (<1A) signal to another board component. Battery-protection MOSFETs have very similar functionality, but represent a unique subset of load-switch applications that can also carry much higher currents.

Our applications team has a word for load switch FETs – "pixie dust" – to describe the somewhat ubiquitous way that they can be "sprinkled" over a system after most of the design is complete. That perhaps does these tiny powerhouses a disservice, in that they are also often the glue that holds the electronic system together.

The small signals that these devices carry are generally on the order of a few hundred milliamps such that in theory, there is no reason that the function can't be integrated. However, custom integrated circuits (ICs) can be more costly, such that once a design is complete, it is easier to implement a few of these small signal FETs rather than requesting or redesigning a custom IC. Given that, there are typically two fundamental requirements for these devices: that they be cheap and small. Which of these requirements is the most critical will dictate what type of MOSFET is most appropriate for your design.

If cost is the most important factor, small-form-factor packages like the small-outline transistor (SOT) series (SOT-23, SOT-26, SOT-323, SOT-523) will be the most preferable option. These devices have a PCB footprint from 2.6mm^2 to 10mm^2, on-resistances in the range of several hundred milliohms to a few ohms, and can handle currents up to roughly half an amp (depending on the resistance). They are comprised of large protruding leads and a somewhat bulky package (see Figure 1). While some industrial designers prefer the external leads, as they make for simple board mounting and enable easy visual inspection for a solder connection, the strongest appeal of these FETs is their low cost (think a penny or less). I should note that TI really doesn't have any offerings for MOSFETs in these packages, or intention to play in this commoditized space.
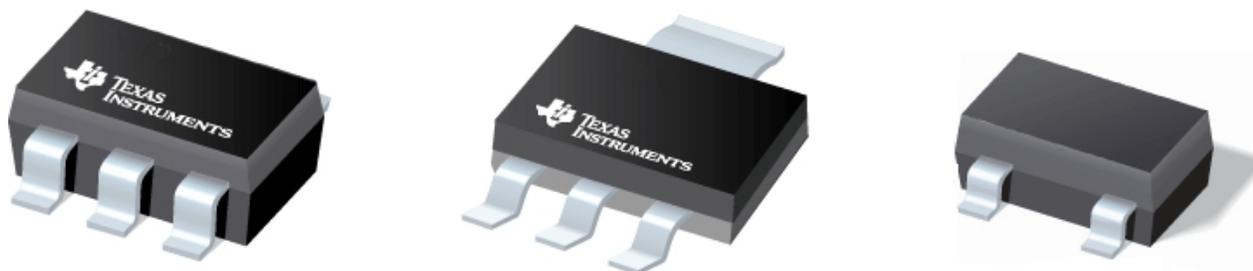

Figure 1. Several SOT packages (not drawn to scale)

On the other hand, if reducing the PCB space taken up by many extraneous small-signal transistors is the biggest concern, a better solution is either a bare-die chip-scale package (CSP) or land grid array (LGA) device. TI carries a wide variety of these types of devices, the most popular being from our FemtoFET product line (Figure 2). These devices have an ultra-small footprint, offering size options all the way down to just under 0.5mm^2. This tiny form factor inevitably means high junction-to-ambient thermal impedance through the PCB. However, with resistances that can be one to two orders of magnitude less than the larger-footprint

SOIC package devices, the reduced conduction losses more than make up for the slight increase in thermal impedance, enabling higher current-handling capability in some cases greater than 1A.
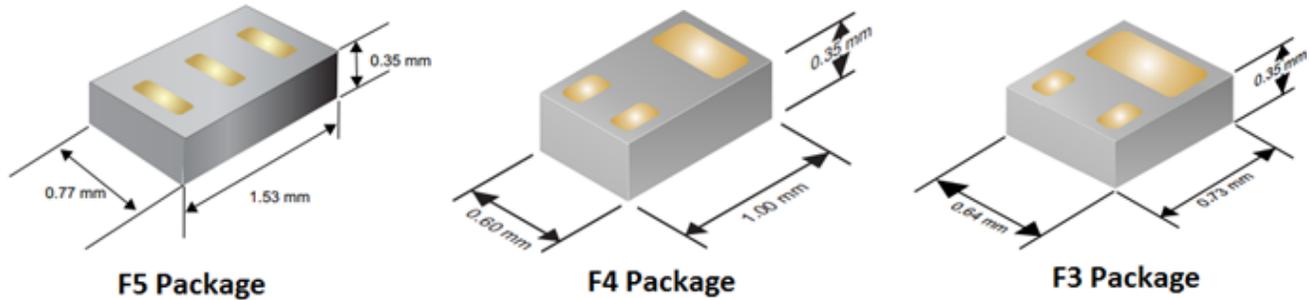

Figure 2. Three different FemtoFET package offerings (not drawn to scale)

Before selecting which of the above roads to travel down, I offer two final caveats. The first is that before committing to a FemtoFET (or some other ultra-small device), you should check your PCB manufacturing capabilities. Some industrial manufacturing processes prefer a larger pitch between mounting pads (hence the preference for SOT devices). Others can handle pitches down to 0.5mm (like the F5 FemtoFET family), while personal electronics manufacturers can often handle pitches down to 0.35mm (supported by the F4 and F3 FemtoFET packages).

I've spoken at length about current ratings before, but because the sole purpose of a load switch is to carry small currents, it's worth revisiting one more time. As usual, the best practice is to ignore the front-page current ratings, and instead work backwards from how much power loss you think your system will permit the FET to dissipate.

Most data sheets will provide a junction-to-ambient thermal impedance ($R_{\theta JA}$) for a minimum and maximum copper (Cu) PCB scenario. Using the minimum Cu as a worst case is the safest bet, although if you know the end board dimensions, you could try to interpolate an $R_{\theta JA}$ between the minimum and maximum Cu impedances provided on the data sheet. Then, using Equation 1 below, and knowledge of the end equipment's worse-case ambient environment, you can calculate how much power the FET can handle, and therefore current as well:

$$P_{Max} = \frac{T_{J,\,Max} - T_A}{R_{\theta JA}}$$

(1)

One nice thing about load-switch applications is that the device is either on or off. Therefore – unlike all the other applications I've discussed to this point in this series – all of the power losses are due to conduction losses (I^2R).

Finally, I would be remiss if I did not mention that TI offers an array of integrated load switch solutions in between a basic discrete FET and a more complex PMIC, which you can learn more about here. This post pertains specifically to those applications where a discrete FET could adequately satisfy the demands of your design but ultimately, your design should choose the level of integration most appropriate.

Thanks for reading. In the next post, I'll take a more in-depth look at a subset application of load switches that I mentioned at the beginning: FETs used for battery protection.

Additional Resources
- For more information about FemtoFET devices, check out Kevin O'Connell's blog post, "FemtoFET MOSFETs: small as sand but it's all about that pitch."
- Although Kevin touches on it in his post, for a more thorough explanation of how to mount these tiny devices, read the "FemtoFET Surface Mount Guide."
- Finally, in the blog post, "Shrink your industrial footprint with new 60V FemtoFETs," I discussed the first 60V FemtoFET industrial load switch, the CSD18541F5.

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