INTELLIGENT MOSFETS ADD RELIABILITY

WHILE IMPROVING PERFORMANCE IN MEDICAL DESIGNS

EDMUND SUCKOW, FIELD APPLICATION ENGINEER AND MEDICAL SEGMENT MANAGER FOR NORTH AMERICA AT FAIRCHILD SEMICONDUCTOR, DISCUSSES LOAD SWITCH TECHNOLOGY AND ITS USE IN CURRENT POWER ARCHITECTURES, AND GIVES EXAMPLES OF ITS USE IN RECHARGEABLE, PORTABLE, MEDICAL APPLICATIONS

All medical applications require reliable performance while still providing technological advancements. As the level of competition increases among medical electronics makers and their end applications, feature sets are frequently added in haste without considering the implications of a possible failure. But at each step of the way for end applications, power is of critical importance.

Intelligent MOSFETs are one of the power enablers that have been increasing in popularity. Due to its simple drive requirements a standard P-channel FET is often used to switch power distribution nodes, connect charging paths, and allow for connector hot-swap and direct current flow among others. Because these devices are in the critical path, where failure results in sensors or processors being disabled, it is wise to invest in robust power switches.

Evolution of the Load Switch in Battery Applications

Ever since batteries have been introduced to electronics there's been a need for power isolation. By default, batteries used as a mobile power source means that they will be drained during use and must be recharged. Obviously, the circuit's power design directly impacts the time between normal use and charge time.

Battery technology has not seen any major improvements in recent years and promises no major breakthrough on the horizon. It is therefore up to IC (Integrated Circuit) technology to adhere to strict power consumption specifications to extend the operating time of an application.

Before we dive into load switches, we need to look at battery technology, the load on the battery and the need for load switches. To estimate the battery's life on a given charge is relatively simple to calculate if – and only if! – all current draw paths are known. It is often not the 100mA, controlled duty-cycle sensor that contributes to power depletion on its own, but the numerous < 1mA sinks that are always connected which slowly pry off energy. Also necessary to roughly add to the power equation, yet more difficult, are the transient spikes that take place when a given feature or sensor is enabled. These spikes are monitored in amplitude and duration, allowing an energy calculation for a general one-shot event, times the number of spikes. After all general loads are known, operating time calculations are straight forward.

At present, batteries are rated in mAh, instead of previous coulomb ratings, where a 1000mAh battery can supply 1A for one

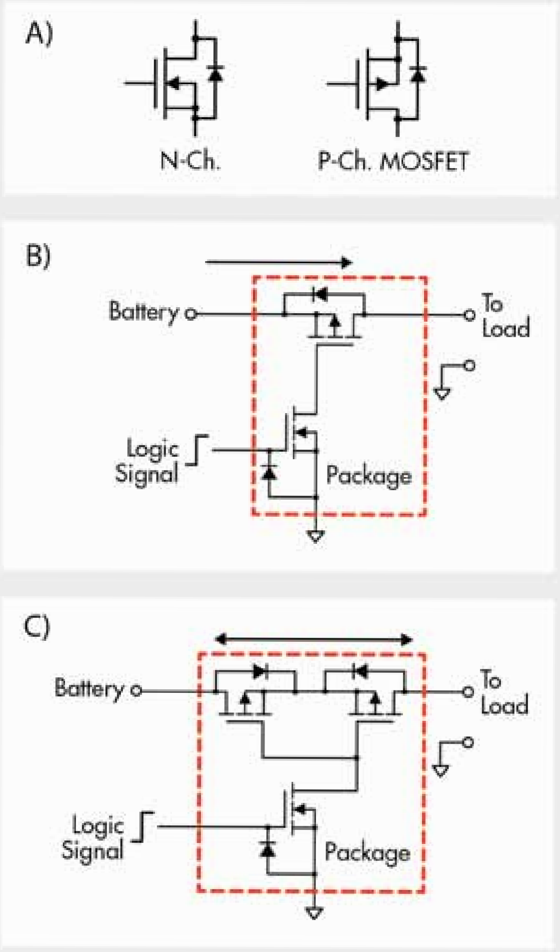

Figure 1: Conventional load switch representation showing (a) N and P-channel depictions; (b) simple load switch comprised of P-channel on high side with N-channel being driven by logic signals; and (c) dual N-channel on high side providing body diode current blocking when not enabled

hour or 100mA for 10 hours at its nominal battery voltage.

Battery operating time (h) = battery rating (mAh)/total current draw (mA)

When the operating current is distributed between a surge current, say 1500mA for 100ms, and a continuous current, for example a 20mA indicator LED for the remainder of the hour of operation, the average current for that hour can be calculated.

Average current per hour = (1.5A x 0.1s/3600s) + (0.020A x 3599.9s/3600s) = 20.04mA

Using this concept of power consumption in the time domain, it was quickly realized that load switches could be used to isolate continuous, but light, current draws. Sharp pulses for very short durations are not the main culprit, but the hundreds of uA current draws that add up if not isolated. This transition then leads to the importance of soft power ramps when power is enabled to downstream ICs to reduce undesirable large voltage spikes on the already fragile mAh battery rating.

A separate discussion can be carried on the impact of surges in power versus steady power draw. This impact on the battery can vary greatly with the chemical composition of the battery and the time between surges. It is generally accepted that surges of reasonable proportion can result in longer battery life than a light but continuous load. Please consult the battery supplier for specific guidance on this subject.

Also not discussed is the voltage decrease in the battery as it is drained. In the pure current based equations above, we assumed a constant Vbatt. Again, this depends on the battery technology. For alkaline primary batteries (non-rechargable), Vmax is 1.5V, where Vmin in most cases is assumed 0.9V. Rechargeable single cell Li-ion batteries are at a nominal state of 3.7V, yet can charge to 4.2V max, and still drop to Vmin of 2.5 to 3V, which can have a larger effect on the actual charge.

High Side and Low Side Switches

With the understanding of how current draws can deplete the battery level, we can now investigate the various methods of isolating downstream power consumption. Terms such as high side and low side switches will be used. High side implies that that switch will be in rail path and actually source current to the load, which is returning through the ground path. The low side switch is on the opposite side of the load and sinks current to the ground path.

Applying this simple switch theory to common FET types, Figure 1 shows the basic N-and P-channel MOSFET representations for load isolation, each having their advantages and disadvantages. Starting with the PN junction refresher image of section (a), we can quickly interpret section (b) as a P-channel on the high side. The N-channel is used to drive the gate to simplify logic input control.

The disadvantage of schematic (b) is the ability to forward bias the body diode if the load voltage was higher than the battery voltage. Schematic (c) eliminates this problem with dual P-channel FETs on the high side, a very common battery isolation approach for a main rail.

Why are N-channel FETs not used for high side switches? The textbook property of the N-channel FET is that for the switch to be enabled and in its linear region, the gate voltage must exceed the drain voltage by the given datasheet threshold voltage. Since the main rail in a battery application is often the highest rail available, a bootstrap or isolated drive approach must be employed. This incurs additional cost; however, this N-channel high-side switch approach is required for higher current applications.

Depending on the voltage range, N-channel FETs have a 20-50% reduction in Rds(on). Whereas with P-channel FETs, aside from losses due to Rds(on) and higher voltages (i.e. > 200V), they are either cost-prohibitive or simply not available due to technology limitations.

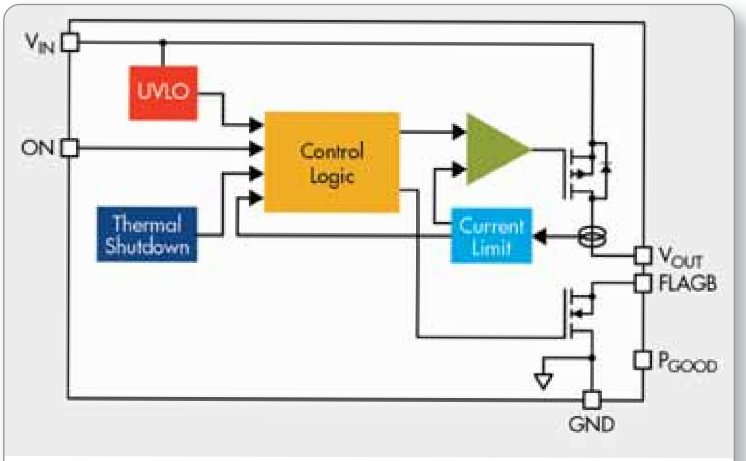

Figure 2: Typical internal block diagram of an Intellimax IC with P-channel based high side MOSFET and integrated feature set – current limit, thermal shutdown, under voltage lockout, error flag and logic voltage control

Intelligent MOSFET Technology Introduction

Conventional load switches are effective for most applications, but for the purposes of this article we are focusing solely on medical applications. These units require the utmost attention to reliability and in most cases are not rechargeable, resulting in diligent power consumption calculations and isolation.

At Fairchild Semiconductor, the intelligent MOSFET functionality is addressed in the Intellimax portfolio. Figure 2 shows the typical internal block diagram, though it does vary from device to device based on desired features.

This figure is P-channel based, seen in the high side path between Vin and Vout. Pin count is minimized to keep the package as small as possible. These devices can be as small as 1mm x 1mm Chip Scale Packaging (CSP), or in the popular leadless uPak also known as MLP. For prototype needs and less space-constrained designs, SC70, SOT23 and SO8 are also available.

The operating voltage, Vin, of intelligent MOSFETs varies by the process on which they were manufactured. For Fairchild's Intellimax line, recommended operating voltages range from 0.8V to 5.5V.

It is important to note the difference between input voltage and control voltage. The input voltage Vin is the actual rating for the high side load switch. The control voltage level, labeled ON in Figure 2, is the amount of voltage required to turn the load switch on. Figure 3 is taken from the Intellimax FPF1039 datasheet and shows the actual Von voltage required to turn the integrated P-channel FET on as it relates to the Vin supply voltage.

The datasheet specification adds buffer for process, voltage and temperature variations and states that Von must exceed 1.0V to enable the switch, and must be below 0.4V to disable the switch.

> *Intellimax FETs integrate a P-channel FET and a logic level driver to allow simple controlling of a reduced Rds(on) FET, when compared to an equivalent, combined P-channel/N-channel approach*

> *If precise current sensing and load disconnect is crucial, it is possible to add a small amount of inductance to the output. This will "buffer" the changes in current, di/dt, allowing the smart FET to more accurately sense a difference*

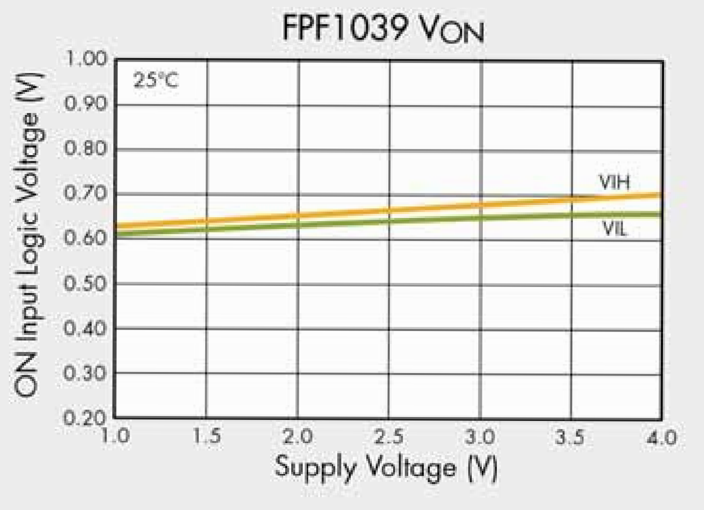

Figure 3: FPF1039 Von enabled thresholds for high and low levels as shown in the datasheet. The vertical axis is Von, while the horizontal axis shows the Vin or supply voltage

This results in a very simple drive circuit that can directly interface to a microprocessor. This Von specification varies between devices and may not always be as flat as that in Figure 3.

As mentioned earlier, this logic level Von enabled function interfaces easily to a microprocessor, but the thermal shutdown and over current protection (OCP), also interface well via the Flag pin. This feature is not integrated into the smallest Intellimax solutions, such as the FPF1039, so we turn to the FPF2303. This dual out load switch is capable of driving 1.3A loads; it is feature-rich and includes the Flag feature and reverse-current blocking. The Flag is an open drain logic level that can be tied directly to a status pin on a microprocessor. Reverse current blocking was shown in the conventional load switch figure but required a dual MOSFET approach. Fairchild's proprietary approach integrated this into the P-channel and is a bonus feature within the IC, requiring no external components.

Reverse current blocking is a must if there is ever an event where the load side of the switch could have a higher potential than the battery side. This can occur in systems having multiple batteries of the same initial voltage, or during voltage spike events. Large bulky capacitors also have a tendency to provide potential differences.

Feature Set

An often overlooked specification for load switches is the ESD rating, due to the fact that most MOSFETs of the past did not have integrated ESD-protection. Recently, ESD protection was added to discrete P-channel MOSFETs that are often used as simple cost-effective load switches. This came in the form of a back-to-back zener clamp on the gate of the FET. This adds capacitance to the gate, making it an unlikely candidate for a switching application (motor drive, power supply, etc), but did make the gate much more rugged with the 2K HBM (Human Body Model) zener addition.

Intellimax went even further and integrated an ESD structure into the intelligent FET, which doubled the ESD rating to 4KV HBM. Further ESD improvements are likely to come.

ESD is a valuable feature for medical applications since the boards are often shipped bare between assembly houses for detailed placement into plastic housing and hermetically-sealed enclosures. Each handling point is a potential risk to ESD-related failure, especially on pins and connectors interfacing off the board to a battery or mezzanine layer.

The next smart FET feature we should look into is what happens when the switch closes. A conventional load switch with a discrete P-channel simply closes and connects the input to the output, regardless whether a heavy load or large capacitance is burdening the output pin. In such an event, the input rail typically exhibits a voltage dip on the primary, which could affect delicate ADC (analog to digital converters) or sensors also tied to the rail for bias. In the past, R/C (resistor/capacitor) networks were added to the gates to slow down the turn-on, but this adds design time and size to the project. Intellimax supports a slew rate control feature to minimize rail interruptions on the input side by limiting in-rush current. Figure 4 shows an example of this in an empirical lab test. Note the effects on the Vin rail with the conventional P-channel approach on the left, versus Intellimax on the right.

Adding Reliability with Intelligent MOSFETs

Catastrophic events that require disconnecting the load from the input to prevent further damage is a key consideration when addressing reliability. Conventional load switches of the past are very straight-forward and offer no protection from current or thermal events. Current protection could be added but this would add a number of external components and require precise selection of tolerance on passive components. Even so, could the passive approach react in a short enough time to prevent downstream damage?

Thermal sensing is on a similar comparison basis. Over current and thermal shut-off event details vary from device to device. While some turn off immediately and require power to be cycled to reconnect to the load, others go though a re-try pattern continuously, turning back on after the temperature and current levels are deemed safe.

Review the datasheet closely to eliminate any confusion on device selection. For thermal shutdown on Intellimax devices – and most ICs in general – do not rely on this feature as standard practice. That is to say, if the application is anticipating thermal events during normal application, a separate temperature sense routine should be used. Relying on over temperature shutdown continuously may degrade the IC.

When sensing the over current event, the threshold level can be pre-set at the IC factory. The level can also be programmed externally with a resistor to ground on some intelligent load switches. While most have short circuit protection, more recent additions have much improved tolerances on specific current disconnects, ranging from 100mA to 2A. In just a few years, current detect tolerances have dropped from 30% to 10% accuracy.

When selecting the threshold level, note the minimum and maximum specifications that can vary over process, voltage and temperature. Current is very dynamic so a precise and consistent transition point is difficult to provide. It is also difficult to react to very slow current ramps when approaching the detection point. If precise current sensing and load disconnect is crucial, it is possible to add a small amount of inductance to the output. This will "buffer" the changes in current, di/dt, allowing the smart FET to more accurately sense a difference. The size of the inductor would directly reflect the sensitively of the current transition. After an over current event, each family of intelligent MOSFETs reacts differently. Some simply disconnect, others ramp down the current in predetermined steps, while some even provide a fixed voltage output at the safest sustainable current limit. Pay close attention to this specification during component selection.

Specification Comparison When Selecting Intelligent MOSFETs

After discussing the advantages, what are possible disadvantages or sensitive specifications that should be reviewed closely when selecting an intelligent MOSFET? The key value is the intelligence within the smart FET. Of course, power is required to sense current and drive the high side switch. This will be noted in the quiescent current specification in the datasheet, which is the actual current used within the IC to verify and drive the load switch. For Fairchild's Intellimax line, this spec is minimal at sub-1uA. There is also a leakage current listing that should be closely compared for those that are looking for the longest battery life.

The on resistance of the high side FET, labeled Rds(on), is the key number for calculating losses across the load switch. This Rds(on) will vary based on input voltage, since the same Vin is used to drive the high side FETs; so be realistic when targeting the Ron for a specific application. Do not compare the absolute lowest Rds(on) in two datasheets when the application will actually be operating at 50% the Vin used, to calculate the lowest Ron. Based on this Ron value, one can calculate the loss across the FET if the current needed by the load is known. For Intellimax, Rds(on) can range from 20mohms to 200mohm depending on the feature set and package size.

Another datasheet detail that can sometimes be overlooked is the maximum voltage of the high side FET. For the lowest in Rds(on), the Intellimax line limits the input voltage to 6V. This is perfect for battery-powered applications, either 3.7V rechargeable cells or AA battery packs.

Due to cell phone proliferation, the 3.7V single-cell Li-ion battery pack is becoming very common in portable medical applications. However, medical applications may also require fluid pumps or fans to operate of the core battery voltage. The most common battery here is a dual or triple stacked rechargeable cell, bringing the voltage to between 8V and 12V. In the past, discrete MOSFETs were used at these voltage levels. New developments have expanded intelligent FETs to higher voltages.

The AccuPower family from Fairchild is based on a 40V absolute max, 36V recommended process, and is a considerable leap in technology for mid-voltage applications. The first IC will be 100mhom technology with the same feature set Intellimax supports but will also include an adjustable current limit and a power-good (Pgood) pin. Because of the long voltage ramp, should the load be at 36V, the Pgood function will notify the microprocessor of an acceptable rail level on the output. Adjustable current limit opens up the applications within the medical field.

The AccuPower devices can be used to drive DC solenoids, fans, pumps etc. Even if the battery is at 12V, the L di/dt voltage spike across a dynamic wound load will easily surpass the breakdown of a 12V or even a 20V discrete FET. The 36V breakdown voltage supports these load types with battery voltages of 12V and possibly 24V. The FPF2700 is now available and supports such voltages.

Intelligent MOSFETs in Medical Applications

Regardless of the application, the trend for point-of-load isolation continues and intelligent MOSFETs are an enabler for higher performance and improved reliability. Maintaining the edge on a competitor's medical application requires quick feature-set implementation. Conventional P-channel FETs will continue to be used for simple switches but when reliability and time-to-market are key metrics during product design, do not overlook the recent advances in intelligent MOSFET technology. ●

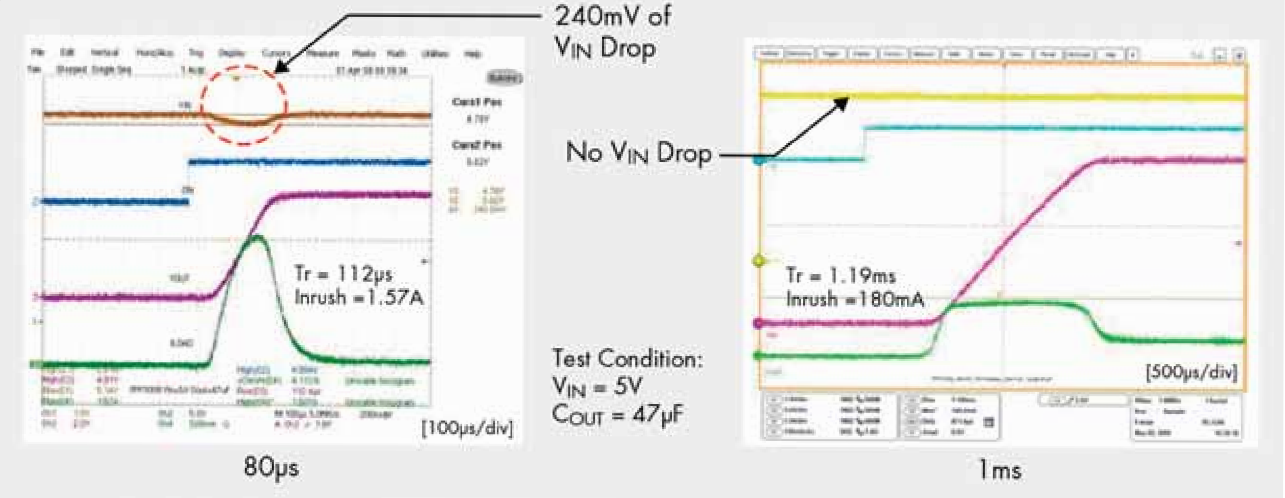

Figure 4: On the left is a conventional load switch with no current limit or in-rush control, i.e. there is no gate drive current control on the P-channel. A drop of 240mV is seen on input rail. The image on the right shows the integrated slew rate control feature of Intellimax with a flat Vin