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AN-8020
Integrated Slew Rate Controlled Switch Optimizing 1V Core in Mobile Systems

FPF1018, IntelliMAX™, a slew-rate-controlled load switch, guarantees that mobile systems operate with more reliable and stable power at very low voltage core line for steady and transient operations than current existing discrete solutions.

Mobile System Power Trend and Requirements

Recent mobile systems require the very low voltage core, realized by smaller process geometries, to employ more function blocks with low power consumption and improve performance of micro-processors. For the mobile systems to perform properly, low voltage power must be delivered efficiently and stably, even with high currents, whether it's transient or steady state. As needed core voltage decreased, it became important to conform to stringent regulations and transient specifications. In fact, V_{CORE} of MAPs (multimedia application processors) in mobile applications is becoming lower and MAPs with V_{CORE} of 1V have appeared, which requires stable power within range of 0.9V ~ 1.1V at least. Figure 1 describes an example power block of MAP that has 1V cores. 1V is converted by buck converter from battery and delivered to V_{CC1} for Function Block 1 and the other 1V line goes to V_{CC2} passing through load switch. In this kind of mobile application, load switch for V_{CORE} as low as 1V in mobile system must satisfy a few conditions to deliver low voltage power efficiently and follow the strict regulation for stable operation of chipsets.

First, R_{ON} (on state resistance) of the switch should be low enough to give enough head room to V_{CORE}, which could have 1V with ±3% or ±5% variance due to the characteristics of buck converter, to ensure that it never causes abnormal operation of the function block. Second, a reliable load switch prevents inrush currents to drop the input voltage whose line is connected to the other V_{CORE} line to drop below 0.9V and to cause malfunction of the other function block during startup operation. Last, when switch turns off, the discharge path of the load switch helps to discharge the remaining voltage at the output capacitors to enable reliable power off and keep the chipset from abnormal operations.

Although these solutions; such as low R_{ON}, inrush current control, and discharge function, can be embodied in discrete components; an integrated load switch is recommended in mobile applications. This application note examines and explains the methods to maintain stable power of the chipset; compares and analyzes FPF1018, an integrated load switch with a V_{IN} range of 0.8~1.8V to optimize 1V core line, and discrete solutions; and explains why integrated, very low voltage rated, slew rate controlled, load switch is necessary in mobile applications.

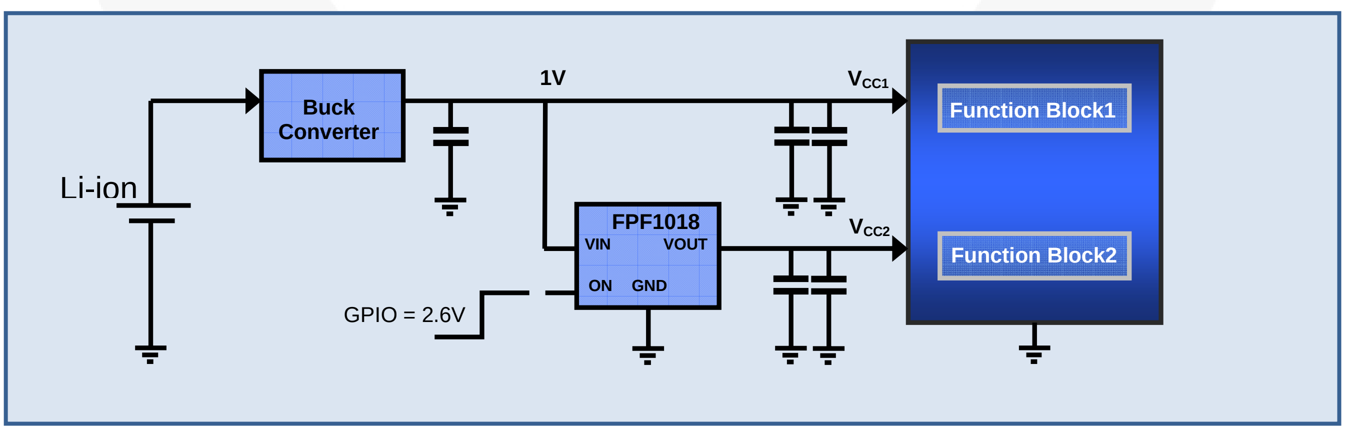

Figure 1. 1V Power to V_{CORE} of Chipset in Mobile Systems

Low Power Consumption and Stable Steady-State Operation

One of the most important things that determine efficient power is R_{ON}, which causes voltage drop across the switch and affects V_{CORE} of the chipset directly and power consumption of switch during operations. For this reason, mobile systems mostly use N-ch devices with low R_{ON} for discrete solutions or integrated load switches, such as FPF1018, since $R_{DS(on)}$ of P-ch devices is higher compared to N-ch FET with the same die size and provides less head room for V_{CORE} line and higher power consumption. This section compares R_{ON}, voltage drop, and power consumption across the integrated load switch, FPF1018, and an N-ch FET and explains why securing enough head room is important. In the case of MAP applications, a regulator produces 1V power that varies between 0.95V and 1.05V from battery and the chipset's allowable core voltage has a tolerance of ±10%, which means it has 0.05V head room for the worst case. The voltage across the load switch decreases the head room for stable operation of MAP.

Table 1. V_{out} and P_d Comparison

	V_{IN} (V)	V_{OUT} (V)	I_{LOAD} (A)	R_{ON} (mΩ)	P_D (mW)
N-ch FET	1.00	0.97	0.30	96.70	8.70
FPF1018	1.000	0.987	0.300	40.000	3.600

Figure 2 and Figure 3 depict an integrated load switch and discrete solution. As shown in Table 1, the measured R_{ON} of FPF1018 and N-ch FET in a SC-70 package with similar dimensions to the FPF1018 in a 2X2 MLP package are 40mΩ and 96.7mΩ, respectively, when input voltage is 1V, GPIO voltage is 2.6V, and load current is 300mA for both cases. In the case of FET, if V_{GS} of 2.6V is applied and 1V is applied to V_{IN} pin, the voltage across the FET is 30mV and power consumption is 8.7mW. The 30mV voltage drop gives only 21mV margin to operate stably when V_{IN} is 0.95 from buck converter in the worst case. Whereas, in the case of FPF1018, when V_{IN} of 0.95V (the worst case) is applied and V_{ON} is 2.6V, there's only 12mV voltage drop and power consumption of 3.6mW across the switch, which are very low values compared to discrete solution. This gives 38mV head room for the margin. Even though buck converter is under unstable conditions, FPF1018 guarantees reliable operation during steady-state operations with low R_{ON}. So with a very low voltage operating load switch, FPF1018 guarantees more reliable on-state operation and less power consumption of load switch and gives more head room for V_{CORE} margin delivered to processors.

Stable Operation During Startup

The basic purpose of using load switches in mobile system is to save power and lengthen battery life by shutting off the switch when the function block is not being used. As shown in Figure 6, Function Block2 can be turned on/off by the usage needs. Due to this fundamental characteristic of the load switch, the systems would be in startup often when system needs to enable function block, which means this turn-on characteristic is one of the important factors that can affect system operation. In fact, if rising time of V_{CORE} is fast and has big capacitive load, a surge current (inrush current) would occur into the output capacitors, which stabilize the V_{CORE} and chipset operation during steady-state operation. While this inrush current charges the output capacitors up, it causes input voltage to drop below the minimum voltage range of 0.9V, which guarantees stable operation of chipset. This condition may turn off or reset the other functional blocks connected to the same 1V line, which is the situation described in Figure 6. For the system to turn Function Block2 in Figure 6 on stably and not to cause abnormal behaviors of Function Block1 while it is working, rise time could be adjusted.

$$I_{total} = I_C + I_{LOAD} = C_{OUT}\frac{dV_{out}}{dt} + \frac{V_{out}}{Z_{LOAD}} \quad (1)$$

C_{OUT} should be large enough for stable steady-state operation and cannot be smaller than that set by the system, but the rise time of V_{CORE} can be adjusted. According to Equation 1, long enough rising time guarantees the system can reduce inrush current and make input voltage droop negligible. In discrete solutions, rise time could be lengthened by adding a resistor and capacitor on the gate pin, such as shown in Figure 3. Adding resistor and capacitor makes FET turn on slowly.

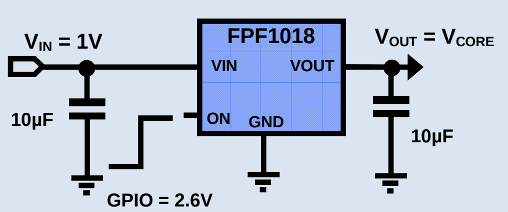

Figure 2. Integrated Load Switch

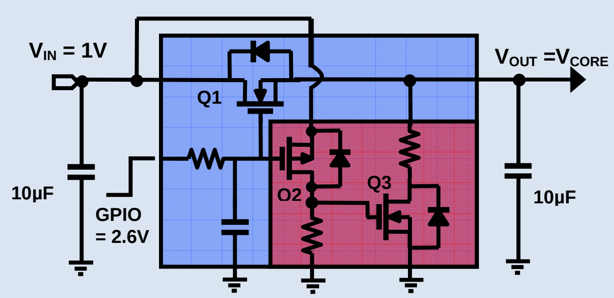

Figure 3. Discrete Solution

To compare V_{IN} drops in two situations; short rise time and long rise time, note Figure 4 and Figure 5. Figure 4 shows that without additional RC components, V_{IN} drop is 440mV, which can cause problems with Function Block1 in Figure 6. It needs one resistor and one capacitor more, which occupy PCB (printed circuit board) space, at the gate pin to lengthen the V_{OUT} rising time, reduce inrush current, and minimize the V_{IN} drop; but it needs trial and error to find the appropriate RC values for the application.

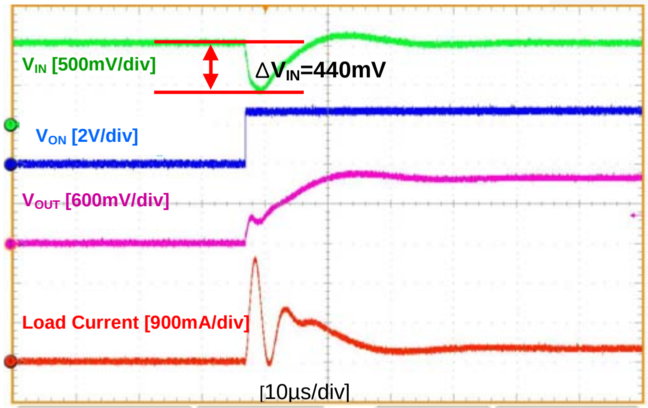

Figure 4. Turn-On: N-ch FET without RC at Gate

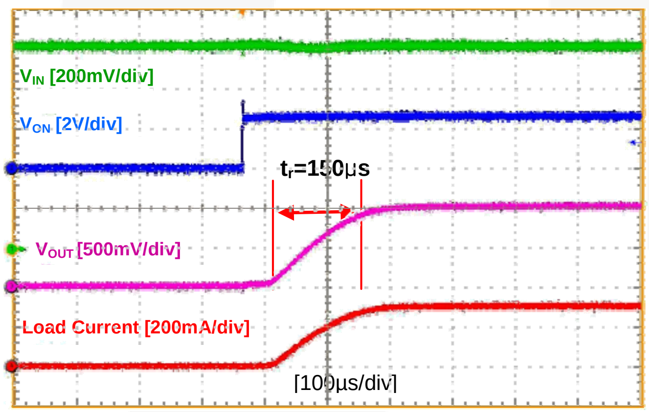

Figure 5. Turn-On: FPF1018

On the other hand, FPF1018, a monolithic slew-rate-controlled switch, has built-in long slew rate of 150µs, which minimizes V_{IN} droop. As seen Figure 5, it has long enough rise time to minimize V_{IN} drop and guarantee stable normal operation of Function Block 1 in Figure 6 during startup. The long slew rate of FPF1018 offers more reliable startup operation without additional passive components over discrete solutions with less PCB space.

Reliable Power Off

Power switches are used for powering for operation, and isolation for power saving. The discharge path of a load switch makes sure there are no charges stored and voltage remaining at output capacitors that can cause abnormal operations of chipsets after turn-off. When Function Block2 in Figure 6 and the switch are turned off, the load condition is under no-load condition and load capacitors would discharge naturally. But natural discharging takes a very long time, as shown in Figure 7, if the load capacitors are big enough. If V_{CORE} is still alive, the system may register the function block as still in on state and command it to operate. This creates a malfunction in this situation because function block is not powered. To avoid this abnormal operation after switch turning-off, V_{CORE} must be pulled down to ground immediately.

Figure 7 shows the remaining voltage of discrete solution due to a large output capacitor at V_{OUT} after turn-off and Figure 8 shows V_{OUT} decreasing down to 0V fast during turn-off. For discrete solutions, discharge function could be realized by placing appropriate FETs and resistors at the output of load switch, but this discharge function by discrete components takes larger area on the PCB than the one implemented in a monolithic load switch. A discrete solution is described in the red box, in Figure 3, and needs two more resistors, one more P-ch FET, and one more N-ch FET, while monolithic load switches don't need any extra components on PCBs. Figure 9 and Figure 10 show the space difference between the load switches composed of discrete components and a monolithic load switch and additional components on PCB for each solution.

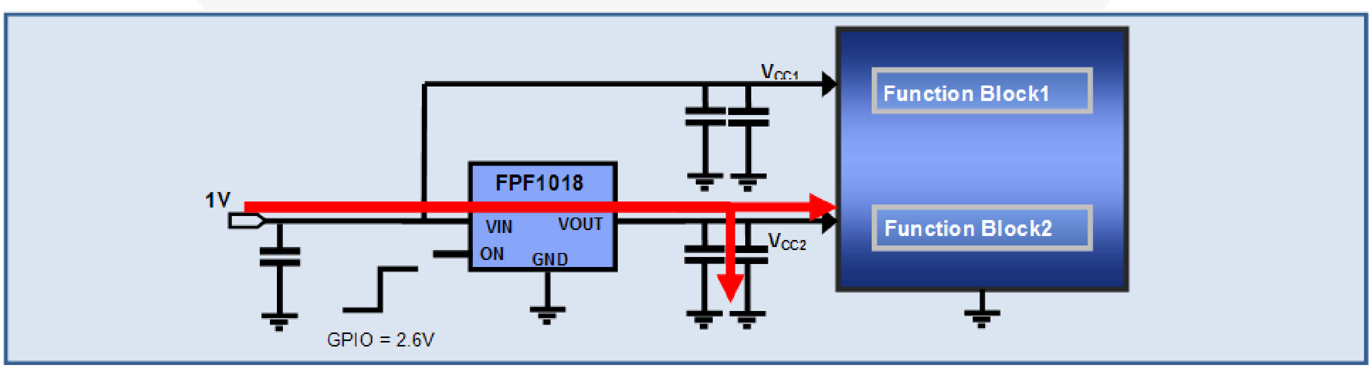

Figure 6. Current Flowing Path During Turn-On

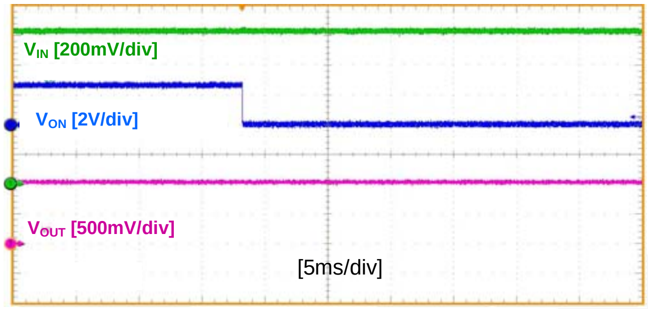

Figure 7. Turn-Off: N-ch FET without Discharge Function at No Load

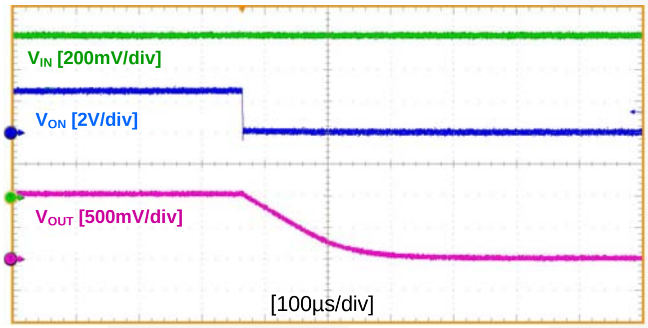

Figure 8. Turn-Off: FPF1018 at No Load

Constituting a discharge path at 1V power supply line with discrete components, note that the discrete discharge path would not be perfect due to $V_{GS(th)}$ of N-ch MOSFET, Q3 in Figure 3. Typical $V_{GS(th)}$ of N-ch FET is 0.7V, but $V_{GS(th)}$ ranges from 0.4 (minimum) to 1.5V (maximum) with normal distribution. Although most products used for mobile system have a $V_{GS(th)}$ less than 1V, it is possible that $V_{GS(th)}$ of some MOSFETs resides above 1V, which may not allow to activate discharge path. So the discharge path with discrete solution is not perfect with N-ch FET with $V_{GS(th)}$ of 1.5V maximum. Unfortunately there's no FET with maximum $V_{GS(th)}$ less than 1V in current semiconductor industry. So the discharge path for 1V core is not perfect with discrete components. However, FPF1018, an integrated load switch, ensures reliable discharge with internal 60Ω pull-down resistor and takes a very small PCB space, which is crucial for mobile applications.

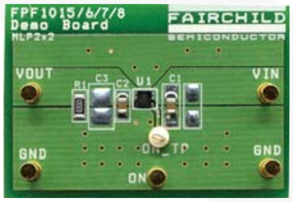

Figure 9. FPF1018 Evaluation Board

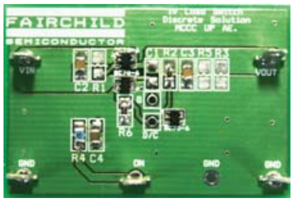

Figure 10. Discrete Solution Evaluation Board

Conclusion

This application note covered features and functions of the lowest V_{IN} rated load switch in current industry, FPF1018, over discrete solutions in mobile system and necessities of them. To conform to the strict regulations and transient operation specifications, it would be necessary for load switch to have low R_{ON}, long enough slew rate, and perfectly guaranteed discharge path. These features and functions give FPF1018 decided advantages over discrete solutions at 1V core in mobile systems.

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FPF1015/6/7/8 — IntelliMAX™ 1V Rated Advanced Load Management Products

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