AN50020

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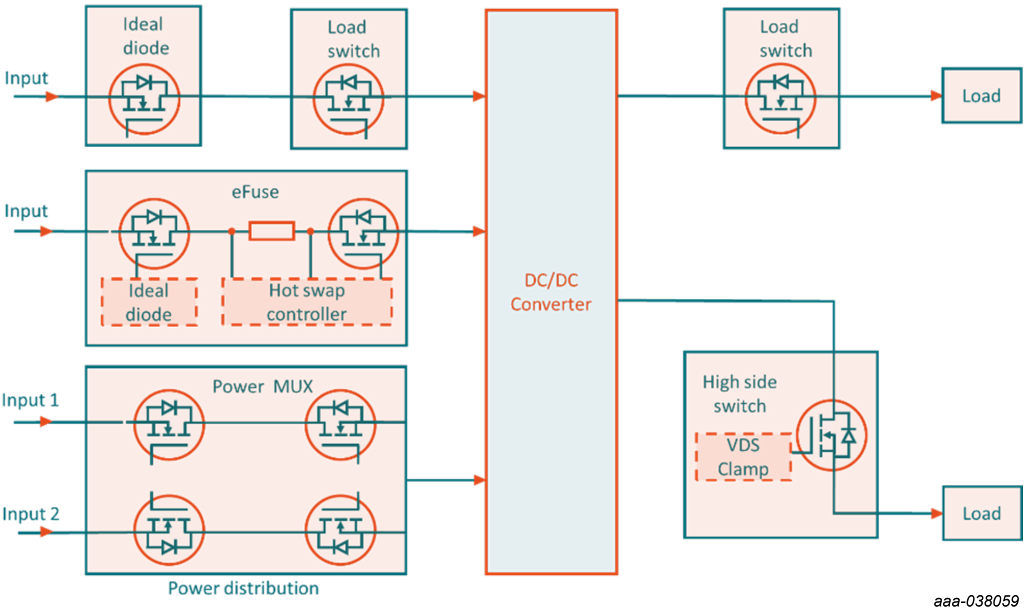
Application note

MOSFETs in Power Switch applications



Abstract: This application note presents the self-protective and diagnostic capabilities of MOSFET power switches. It also details their use cases, features, and some notes on increasing the current capability of a circuit via MOSFET paralleling. Applications of these devices are also provided to highlight their multifaceted functionality. See the accompanying Interactive Application Note page IAN50020.

Keywords: Power switch, MOSFET Power switch, 48V Battery System, MOSFET, Linear mode, Avalanche

1. Introduction

Electronic fusing is an essential concept of future power systems in achieving more flexibility, intelligence and security. Since the required performance of switches is changing, advanced power devices with built-in intelligence features such as self-protection and diagnostic functions are replacing traditional automotive relays. There are several challenges associated with mechanical relays: the need for longevity, decrease in size and weight, high-temperature operation and both audio and EMI noise reduction. For safety, large current switches use components such as fuses and fault detection circuits, not just relays.

By using an electronic power switch, the number of peripheral components necessary can be reduced. A large current load can be driven using less power compared to a mechanical relay. Additionally, the size is greatly reduced compared to an equivalent mechanical relay product. Moreover, since power switches do not have mechanical points of contact, there is no deterioration of characteristics from mechanical wear. A high level of reliability can be maintained even over prolonged use and can become maintenance-free. Furthermore, the diameter of the wire harness can be reduced because of the more precise and reliable over-current protection which helps to reduce the weight of the car body.

With these additional capabilities, the power switch becomes a solution that is an excellent candidate for the replacement of relays and fuses to meet the high functionality trends of today's applications.

1.1. Overview of power switch use cases and features

Table 1. Overview of power switch use cases and features

Features	Input power protection		Power distribution		Output power protection
	eFuse	Ideal diode	Load switches	Power Multiplexers	High side switches
Adjustable current limit	✓			✓	✓
Inrush current control	✓		✓	✓	✓
Short circuit protection	✓		✓	✓	✓
Current monitoring	✓				✓
Thermal shutdown	✓		✓	✓	✓
Driving an inductive load					✓
Reverse current blocking	✓	✓	✓	✓	
Reverse polarity protection	✓	✓		✓	✓
Overvoltage protection	✓			✓	
Load-dump compatibility	✓	✓			✓

2. Use cases of power switches

There are several power switch topologies with different functions that address different applications. Sometimes the MOSFETs are used in similar configurations, however due to their role, position in the system and level of integration they are named differently. In general, they can block voltage and current in the positive or negative direction. According to this, the functionality in Fig. 1 can be divided into two parts: forward and reverse blocking. Reverse blocking is not required if the switch is on the load side of the converter.

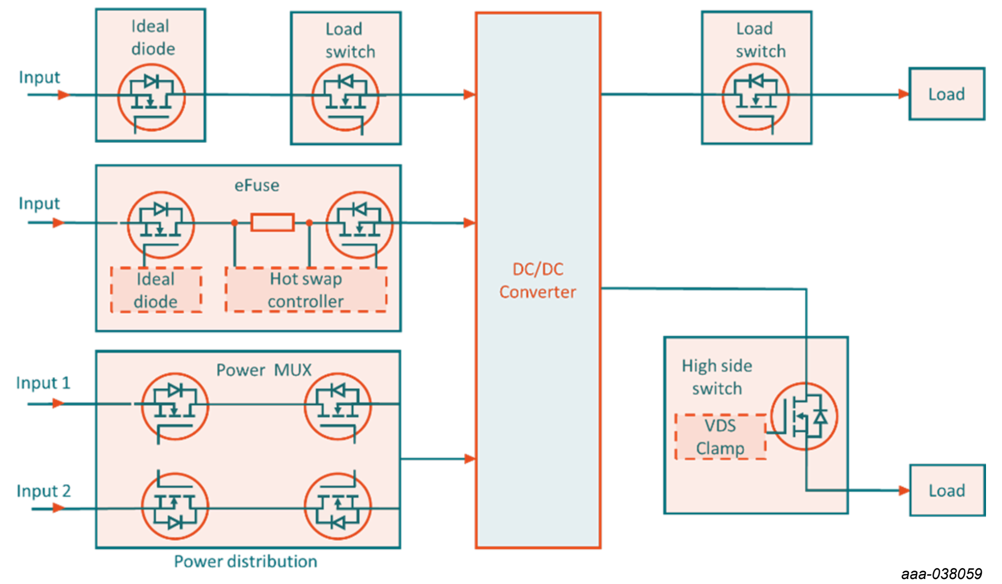


Fig. 1. MOSFET Power switch use cases

2.1. eFuse

eFuses (Internal FETs) are a replacement of the fuse and usually applied before the converter. Basically they are MOSFETs integrated inside the eFuse and therefore have more control over it, providing functions including current, voltage, and temperature measurement. Hence, they have the most integrated protections such as: under-voltage lockout, overvoltage protection, reverse current blocking, reverse polarity detection, current monitoring, and open load detection.

Compared to traditional fuses, the eFuse is more accurate, faster and can ‘repair’ itself without user interference. The fuse reaction time to various current levels can be set and it is more consistent than traditional fuses. Traditional fuses take much more time to react, implying a need for thicker cables. According to some estimates, wire harnesses can be reduced by up to 10 kg/car. Due to better consistency and controllability, the eFuses are more reliable than conventional fuses. However, if deemed necessary, a single high-current conventional fuse can be used to protect a group of eFuse protected applications, in the case a MOSFET fails short.

2.2. Load switches

Load switches are used for simple on/off functionality in power distribution and processor power sequencing. They can be placed before or after the converter. They have features such as inrush current control, quick output discharge, thermal shutdown, power good signal and short circuit protection.

2.3. Ideal diode

Ideal diodes replace diodes usually on the supply side. Since they reduce the voltage drop across the diode, they dissipate less power and result in lower temperatures. They have reverse current blocking and reverse polarity protection.

2.4. Power multiplexers

Power muxes are on the supply side. They prioritize between multiple power sources and therefore must also protect the power sources from each other as well as the converter. They support seamless switchover between power supplies without causing supply interruptions.

2.5. High-side switches

High-side switches are on the load side used for external, inductive loads. They have adjustable current limits and are used for output protection. Commonly used applications: HVAC modules, robotics and body control modules.

3. Product operation range

Using an external MOSFET has slightly decreased functionality compared with an integrated solution because some sensors are harder to implement – like temperature and current monitoring. Also, the number of components is higher than with the integrated solutions. However, the advantage is the extended operating range.

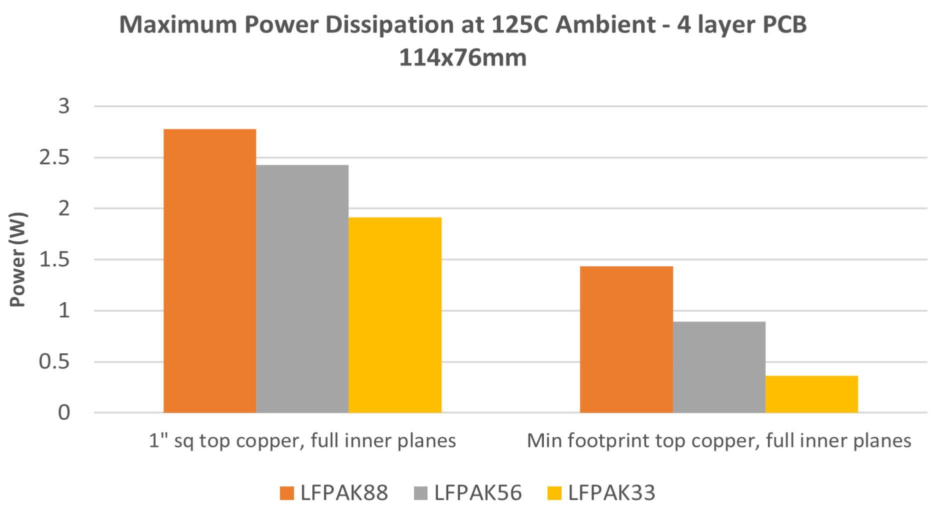


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Fig. 2. Maximum power dissipation of external MOSFETs on two 4-layer FR4 PCBs

Fig. 2 highlights the maximum power dissipation as simulated on a 4-layer FR4 114 mm x 76 mm PCB in still air. Two types of PCB are considered: one with a 1-inch square outer planes and full inner planes and another with minimum footprint outer and full inner planes. The current ratings are calculated for LFPAK33, LFPAK56 and LFPAK88 for the two PCB designs based on the maximum power dissipation allowed by the PCBs and the lowest RDS(on) of the components. The eFuse with integrated FETs is limited to a current of 15 A whereas the LFPAK33, LFPAK56 and LFPAK88 can operate in a higher current rating.

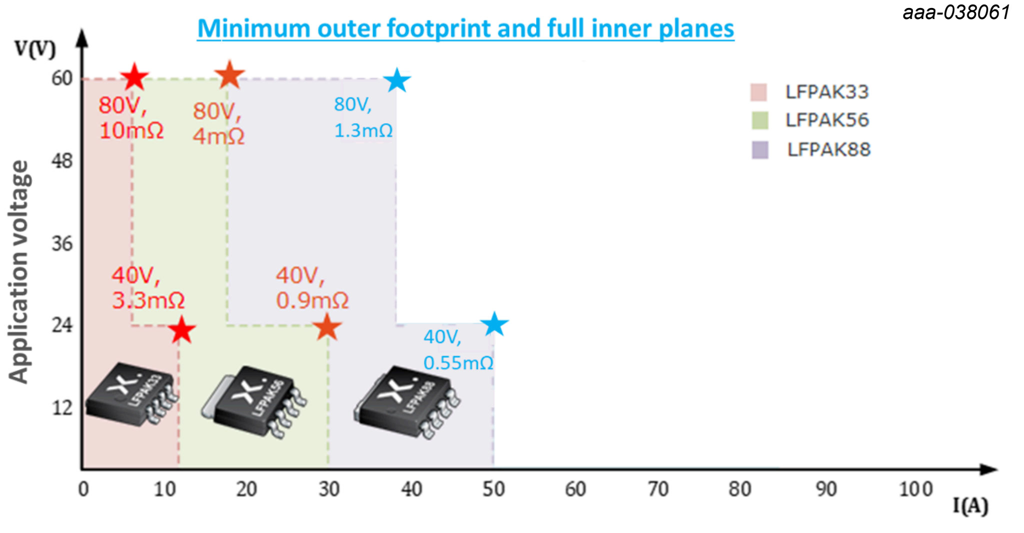


Fig. 3. Comparison of package current capabilities on a PCB with minimum footprint outer and full inner planes

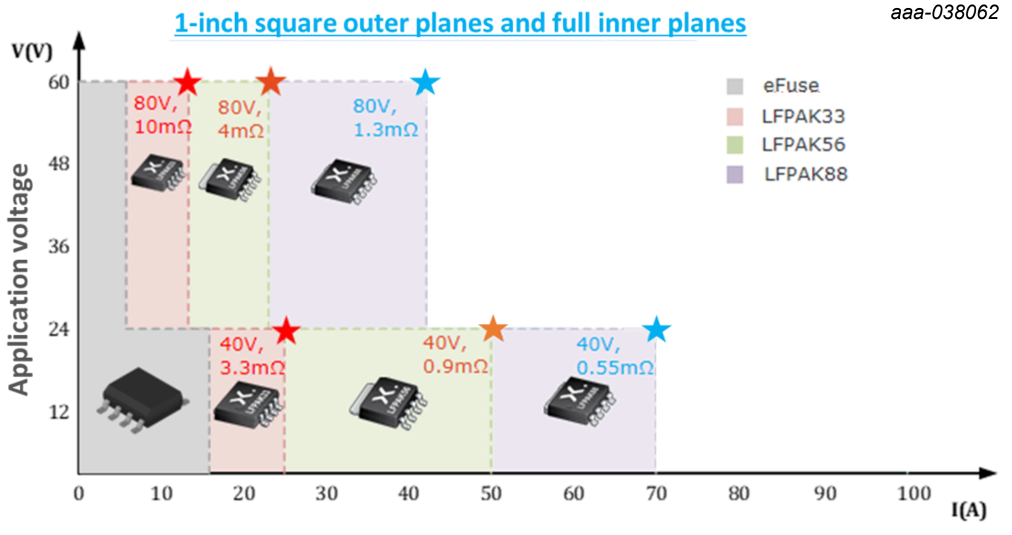


Fig. 4. Comparison of package current capabilities on a PCB with 1-Inch square outer and full inner planes

The ratings on the graphs are approximate and highly dependent on the application’s cooling arrangements. Increasing the package size also increases the possible current levels. The current ratings at higher voltages are lower, as the $R_{DS(on)}$ is higher. It can also be seen that the larger cooling area also results in larger current conduction, although this difference is minimized by the usage of full inner plates that distribute the heat along the PCB, making it a heatsink. If IMS (Insulated Metal Substrate) would be considered it would further increase the device’s capabilities.

LFPAK88 provides the highest current capability. In these specific cases, it can conduct up to 50 A - 70 A continuously. LFPAK88 is expected to have the best performance on the market in terms of both low $R_{DS(on)}$ and cooling performance, as it can accommodate the largest die and has the largest cooling surface.

4. Increasing current capability

4.1. Parallel MOSFETs

To further increase the current capability with set cooling conditions, the switches need to be paralleled.

The current carrying capability of MOSFETs can be increased by using several individual MOSFETs connected in parallel. Since MOSFETs have a Positive Temperature Coefficient (PTC), they can be paralleled easily. This will result in an effective reduction in $R_{DS(on)}$ that can still be driven by one gate output. Due to imbalance, the resulting current capability is not equal to the sum of the individual currents and a derating factor needs to be added.

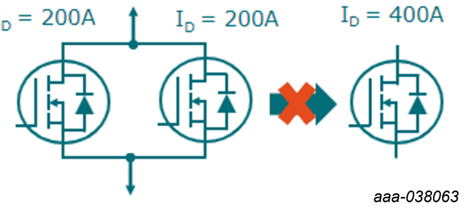


Fig. 5. **Parallel MOSFET block circuit diagram highlighting that the resulting current capability is not the sum of the individual currents**

When multiple MOSFETs are switched on and conducting normally, the MOSFET carrying the most current will experience the most heating. This will raise the $R_{DS(on)}$ compared to the other MOSFETs, resulting in a natural current balancing between the MOSFETs. However, this means that the resulting current cannot be simply doubled. The challenge is that one MOSFET may turn on faster than the other and carry more current due to threshold voltage differences. More information about paralleling MOSFETs can be found in application note AN50005 (Paralleling power MOSFETs in high power applications) and Interactive Application Note page IAN50005 .

4.2. Degradation

The real difficulties of paralleling become apparent when dynamic performance is assessed. The change in the temperature coefficient from positive to negative over V_{GS}, is caused by two competing effects.

The resistance of a MOSFET increases at higher temperatures due to lower electron mobility in the crystal lattice, causing a difference in the slope of the characteristics. However, the V_{th} of the MOSFET decreases at higher temperatures since more electrons have been excited into the conduction band of the MOSFET, shifting the curve to the left as illustrated in Fig. 6. The result is illustrated with the red dashed line on the transfer characteristics for 175 °C. For operations above ZTC (Zero temperature Coefficient), the temperature coefficient is negative. Hotter MOSFETs will draw less current and cool down, resulting in a stable current distribution. This applies to the conduction mode of operation.

Conversely, for an operation below ZTC, the temperature coefficient is positive. If one of the MOSFETs is operating at a higher temperature it will have a lower V_{th}. The MOSFET will turn on at lower V_{GS} and will carry more current. The same is true at turn-off. This needs attention and a single MOSFET should be able to handle the complete current for a short period of time.

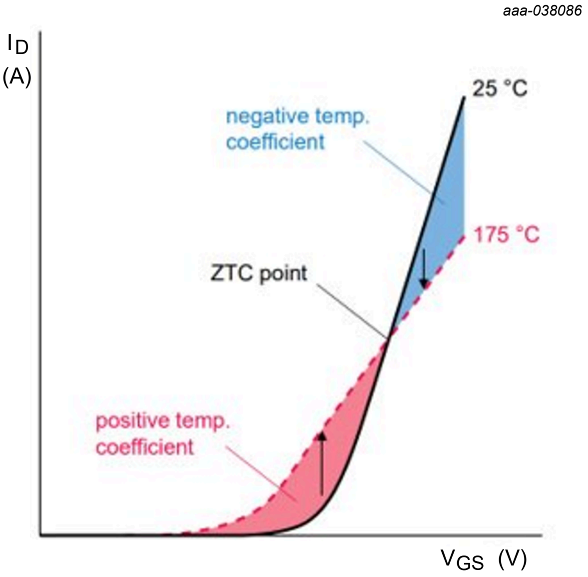


Fig. 6. Transfer characteristics for a hypothetical MOSFET, showing regions of positive and negative temperature coefficients.

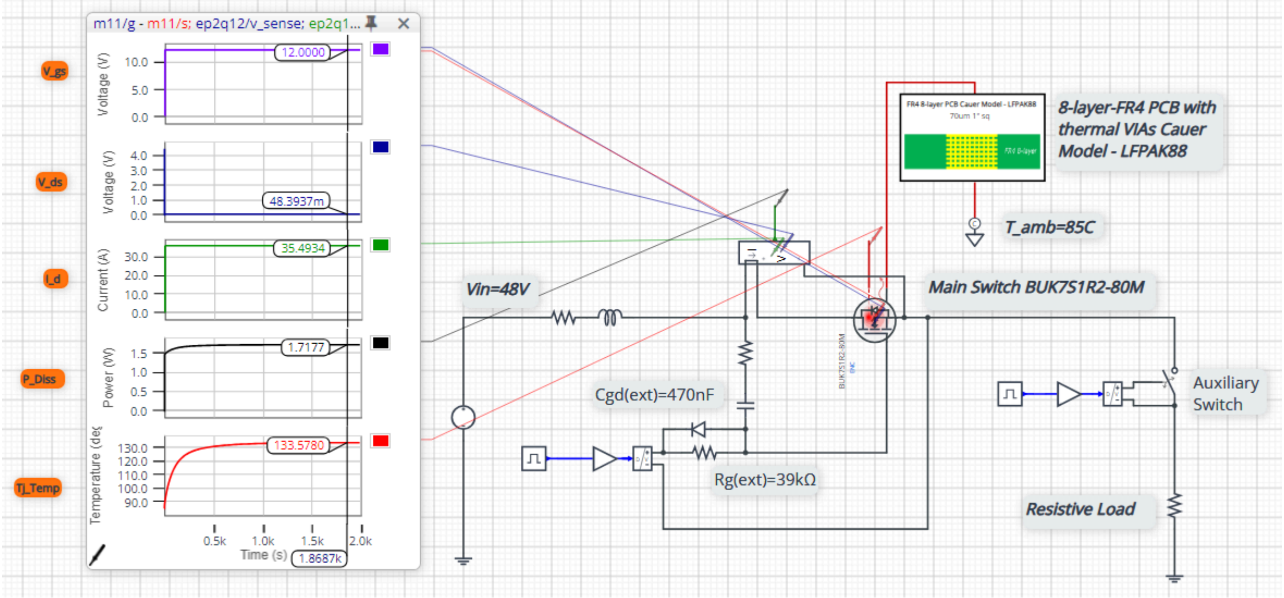
5. Power switch features

5.1. Adjustable current limit

Current limiting is essential in many systems to restrict transient overload currents to permissible levels. Traditional current-limiting solutions such as discrete resettable fuse circuits are inexpensive, but they are inferior in performance, as they cannot satisfy several key requirements such as accuracy, adjustability, repeatability, and consistent response time.

Resettable fuses are PPTC, (Polymeric Positive Temperature Coefficient) devices. They limit the current during an overload event and allow the current to flow after the event. However, they are limited to reaction time of several milliseconds. They are also affected by ambient temperature decreasing their accuracy. Finally, their resistance increases after every event, affecting repeatability. On the other hand, eFuses have several notable advantages compared to traditional methods as they provide quick, accurate and repeatable current limiting in addition to their over-temperature protection. At higher levels of power, external MOSFETs are used in conjunction with appropriate controller ICs.

The simulation shown in Fig. 7 demonstrates the conduction capability of the product BUK7S1R2-80M in a 48 V system, to see how the MOSFET thermally behaves, the curves on the left-hand side of the simulation show the electrical and thermal behavior of the device, demonstrating respectively the Gate-Source voltage, Drain-Source voltage, Drain current, Power dissipation, and Junction temperature. The MOSFET is switched on with a DC pulse and it is carrying ~35 A continuously. The last figure shows the junction temperature (T_j) of the MOSFET mounted on a typical 8-layer-FR4 PCB with thermal VIAs under natural convection at an ambient temperature equal to 85 °C. To increase the current conduction capability, additional thermal management procedures are required to ensure the MOSFET does not exceed its maximum operating temperature. This can include aspects such as forced cooling, heatsinks, etc.



Explore this simulation in the IAN50020 Interactive Application Note.

Fig. 7. Simulation 1. Demonstrating the current conduction capability of BUK7S1R2-80M N-MOSFET

5.2. Inrush current control

When a subsystem turns on, an inrush current initially flows to any capacitors or inductance at the load. If a switch turns on quickly, then the current may be large enough to interrupt other subsystems connected to the same input rail. In some cases, inrush current during a short period of time can irreversibly damage surrounding components or even the switch itself.

In Fig. 8, when the switch is enabled a large current spike rushes towards the output causing a voltage dip in the input supply. This voltage dip can cause the DC-to-DC converter to shut down, implying that the output voltage will decay until the input supply recovers within the normal operating range. A failure to manage inrush current can exceed safety restrictions and lead to compliance failures or damaged cables, connectors or fuses.

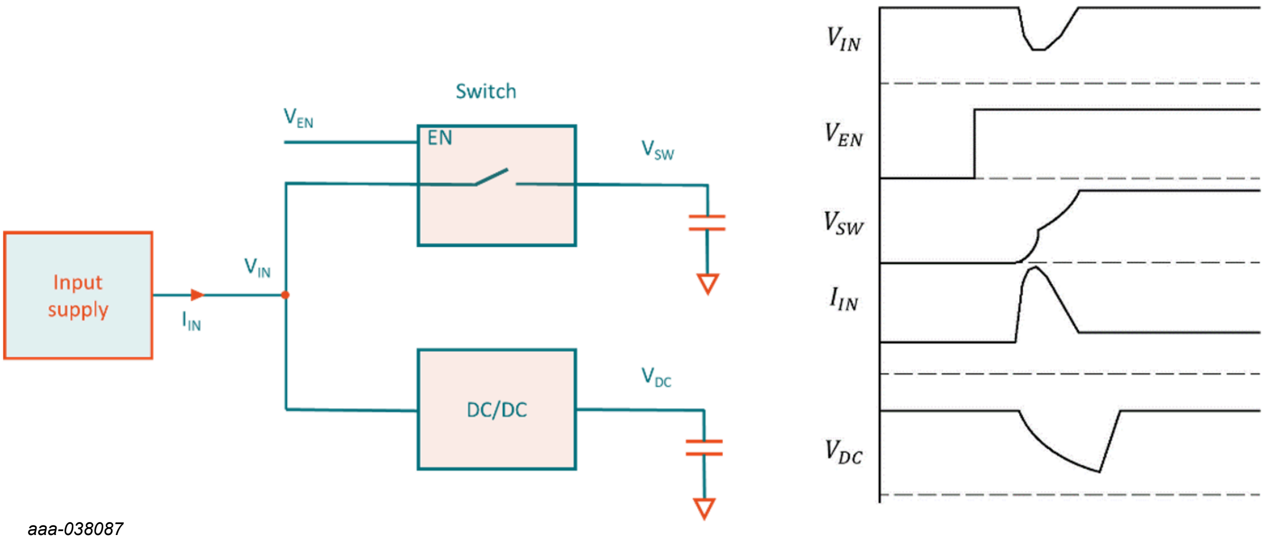


Fig. 8. Subsystem circuit block diagram and effects of inrush current on VSW_OUT

There are many ways to control the inrush current, either using passive elements like a series resistor with bypass switch or a series Negative Temperature Coefficient (NTC) thermistor to slowly charge the output, or using active elements such as MOSFETs to manage the slew rate at which the output voltage is rising. Current limiting can be approached by measuring the current directly or by controlling the slope of the output voltage. For an integrated device such as an eFuse, its temperature can be monitored and the current is limited once the junction temperature reaches a set limit. One of the most common ways to control the inrush current using MOSFET power switch is linear soft start also known as a dV/dt controller.

5.3. Derivation of the design equations for dV/dt control circuit

Controlling the output voltage rise time linearly means controlling a constant dV_{OUT}/dt rate. In this case, if C_{LOAD} is constant and dV_{OUT}/dt is a constant speed, then I_{INRUSH} will also be a constant according to the following equation:

$$I_{inrush\_max} = C_{Load}\frac{dV_{out}}{dt} \tag{1}$$

5.4. dv/dt design steps

The following steps show the equation to evaluate the passive circuitry to have proper dv/dt controller design.

1. Use Eq. 2 to find the time required to meet the inrush requirement:

$$\Delta t = C_{Load}\frac{V_{DD}}{I_{inrush}} \tag{2}$$

2. Find the gate–source plateau voltage, V_{plt}, required to supply the load current. Use the device transfer curve to find the plateau voltage if the data is available.

$$V_{plt} = V_{th} + \frac{I_{inrush}}{g_{fm(max)}} \tag{3}$$

   where, $g_{fm(max)}$ is the maximum transconductance to support the drain current.

3. Choose $C_{GD(ext)}$ based on following condition: $C_{GD(ext)} >> C_{GS} + C_{GD}$ (the values for C_{GS} and C_{GD} are obtained using the data sheet curves). We can either choose initial value of $R_{G(ext)}$ or $C_{GD(ext)}$, and design for the unknown. But in most cases, different values of resistor is easier to obtain than the capacitors.
   The constant V_{plt} allows the input current to flow through the feedback capacitance, $C_{GD(ext)}$, and its current is expressed as:

$$I_G = \frac{V_{GG} - V_{plt}}{R_{G(ext)}} \tag{4}$$

4. Find the gate current required using the following equation (the feedback capacitance $C_{GD(ext)}$ is chosen based on availability). Given that: $I_G \approx I_{CGD}$

$$I_{CGD} \approx C_{GD(ext)}\frac{dV_{DS}}{dt} \tag{5}$$

5. Substituting Eq.5 in Eq.4 we can find the external gate resistance:

$$R_{G(ext)} = \frac{V_{GG} - V_{plt}}{I_{CGD}} \tag{6}$$

6. Choose $R_{GD(ext)}$: $R_{G(ext)} >> R_{GD(ext)}$

Careful consideration should be given in the design to the fact that when the MOSFET turns power on and off it can exceed the FET's safe operating area (SOA) and damage itself. Most power FET manufacturers include a graph listing how much current the switch can handle at a given drain-to-source voltage, ambient temperature and pulse duration (Fig. 9).

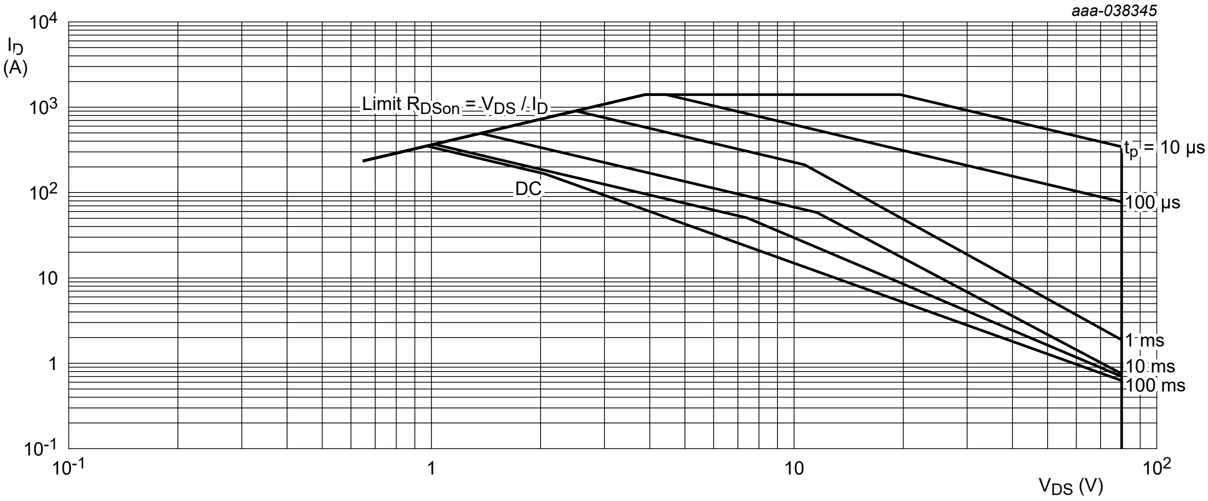
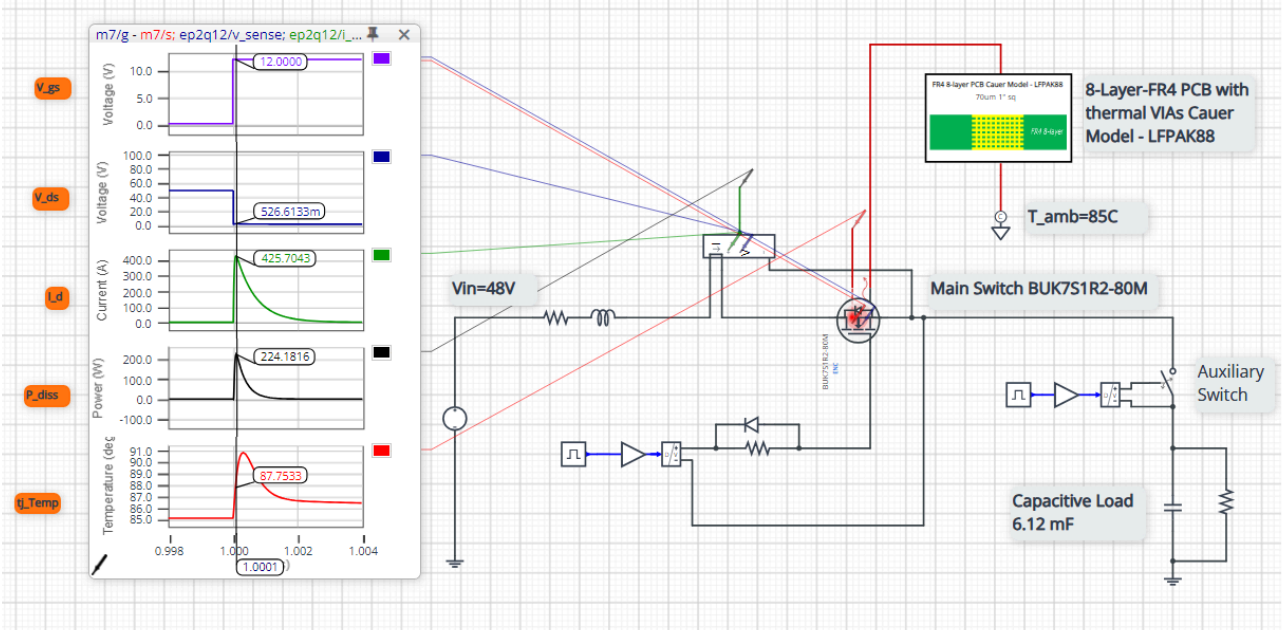


Fig. 9. SOA curve @25 °C from BUK7S1R2-80M data sheet

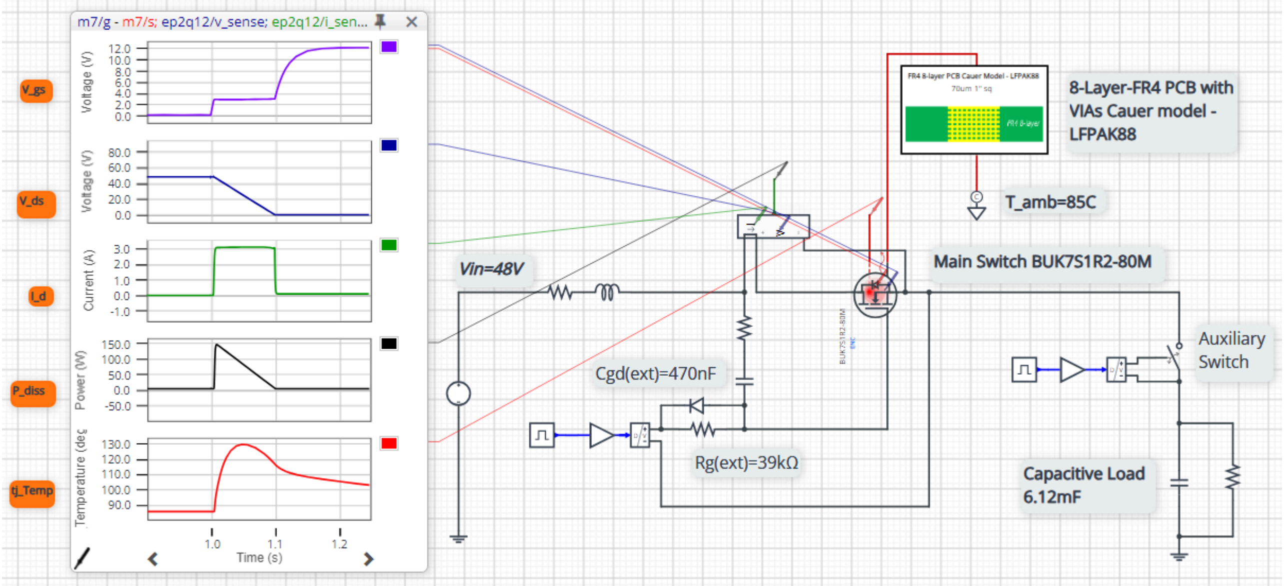
If a FET turns on quickly, into a large load capacitance, the total energy passing through the FET is one-half capacitance-voltage squared (½CV^2) during the turn on-time (t_{ON}) duration. This value can exceed the FET's SOA curve and damage the FET. If that same amount of energy is spread over a longer t_{ON}, then the FET has more time to dissipate that heat, hence reducing the chance of damage.

Fig. 11 shows the simulation of an N-MOSFET inrush current limiter using dv/dt control circuit. Before implementing the circuit, a bulky capacitor of a value of 6.12 mF is controlled by the same MOSFET without any limitation method. The inrush current can go up to ~425 A as shown in Fig. 10. As for the objective, we want to limit the inrush current down to ~3 A using dv/dt control circuit, applying the previous design steps the waveform on the left-hand side of Fig. 11 shows the results of the inrush limitation, in this application, the MOSFET has driven to a linear mode for ~100 ms showing consequently a very strong linear-mode performance. The waveforms also show also the power dissipation and the junction temperature of the MOSFET.



Explore this simulation in the IAN50020 Interactive Application Note.

Fig. 10. Simulation 2. Simulation results of inrush current without dv/dt control circuitry



Explore this simulation in the IAN50020 Interactive Application Note.

Fig. 11. Simulation 3. Active inrush current limiting using dv/dt control circuit for BUK7S1R2-80M N-MOSFET

5.5. Short circuit protection

Short-circuit protection is a safety requirement for all power distribution systems. Short circuits occur whenever a charged conductor makes physical contact to a grounded element in the system. Because the output impedance is unknown and often has an inductive element, the switch must be able to safely demagnetize the inductance.

As the short-circuit current ramps up, it causes resistive power losses in the MOSFET; however, these are relatively low as the MOSFET is in saturation mode with its minimum $R_{DS(on)}$. After the switch hits its current limit and turns off, the inductance in the wires creates a negative voltage spike that causes the voltage clamp in the switch to engage in the avalanche. While the inductance demagnetizes, this high V_{DS} causes the dissipation of the stored energy. A resistive partial short circuit can occur due to debris or corrosion, or even a load failure. In this case, there is a risk that the current will saturate before hitting the current limit.

A high, uncontrolled current flow would occur until the system hits thermal shutdown or a secondary method of current monitoring turns the system off. To prevent under-voltage lockout for the wider system, it is important that current thresholds are set low, inductances are minimized if possible and that the reaction is fast.

To prevent under-voltage lockout for the wider system, it is important that current thresholds are set low, inductances are minimized if possible and that the reaction is fast.

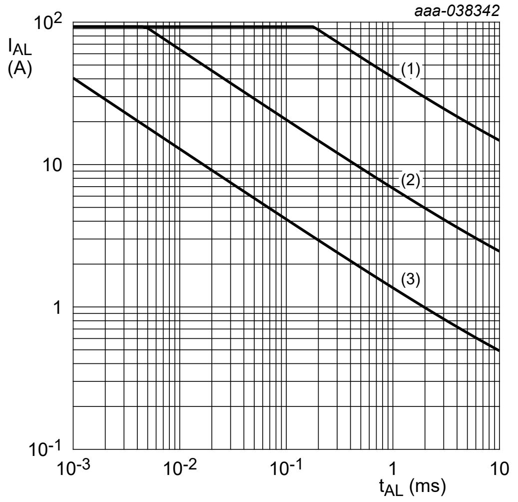
$$E = \frac{1}{2} L I_{PK}^{2} \left(\frac{V_{IN}}{V_{CLAMP} - V_{IN}} \right) \qquad (7)$$

Eq. 7 describes the energy dissipated while an inductive element is discharging through a clamp in series. The V_{CLAMP} of the high-side switch is device-dependent. This equation can be used to calculate the possible energy dissipation due to a large current and determine an inductive clamp that is sufficiently large to dissipate it.

Fig. 13 shows the simulation of a short circuit test where the source of the MOSFET is shorted directly to the ground through an auxiliary switch and very small impedance. When the short circuit happened, the output current ramped up quickly until it hit a 90 A current limit, at which point the switch recognized a short-circuit event and turned the MOSFET off, preventing dangerous current flow.

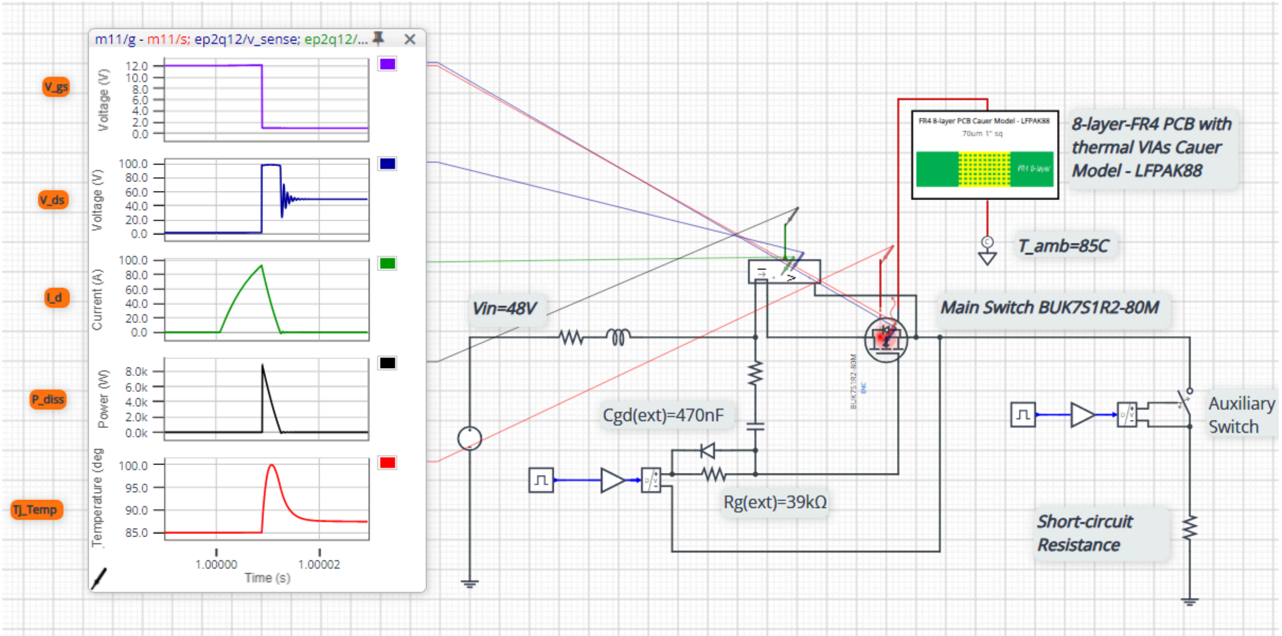
Because there is minimal series impedance, the rise and fall times of the short-circuit current are very quick, and the entire event is over in less than 15 µs. During the interruption, the MOSFET is driven into avalanche mode due to the input inductance energy kickback.

If the MOSFET is used as a short circuit protection without any flyback mechanism, the threshold current must be set to a very low value. This value will be highly restricted to the avalanche current limitation in the data sheet as demonstrated in Fig. 12.



(1) $T_{j(init)}$ = 25 ºC; (2) $T_{j(init)}$ = 150 ºC; Repetitive avalanche.

Fig. 12. Avalanche rating; avalanche current as a function of avalanche time from BUK7S1R2-80M data sheet



Explore this simulation in the IAN50020 Interactive Application Note.

Fig. 13. Simulation 4. Short-circuit current interruption using BUK7S1R2-80M N-MOSFET

5.6. Current monitoring

Many applications require output load current monitoring, though the actual needs vary from system to system. The most common reason to monitor basic electrical parameters such as voltage and current is for reporting and data-logging purposes. Some systems use load current measurements to implement real-time control. In such applications, accuracy is equally as important as high bandwidth and low latency.

It is also possible to perform diagnostics and identify faults in a system by looking at the current consumption of different sections and comparing this consumption to a threshold based on the expected value during normal operation.

Some systems may monitor an electrical parameter’s profile and look for changes in the time or frequency signature to predict impending faults. There are different types of current monitoring solutions based on the sensing element used (internal or external) and the type of output (analog or digital). Fig. 14 shows current monitoring with an external sense element.

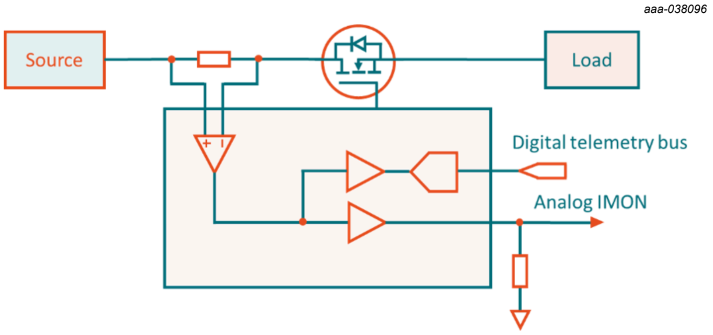


Fig. 14. Current monitoring with an external sense element

5.7. Thermal shutdown

Fault conditions in a system can cause a high junction temperature of a device, which can lead to permanent damage or degradation of its performance. Compared to an external MOSFET switch, an integrated eFuse may have the advantage of featuring a thermal shutdown circuit, which typically detects that the IC is overheating by measuring the absolute junction temperature of the hottest areas on the chip.

6. Applications

Automotive applications are known to have especially high MOSFET requirements since high-power loads must be supplied to confined spaces and high temperature environments. To address them, good switching performance combined with low on-state losses and thermal impedance are required. Power switches can be implemented to protect many of the loads in cars (e.g., motors, power converters, sensors, controllers) and energy sources (i.e., batteries). Some of the load functions can be implemented in the switch as well – like the flashing applications (e.g., indicator lights).

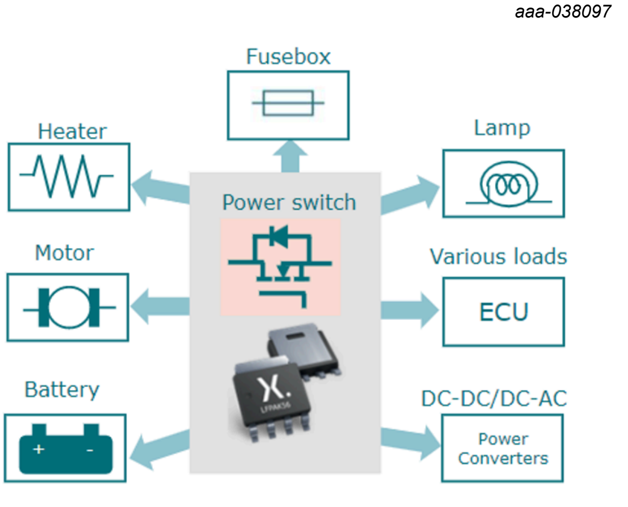


Fig. 15. Example automotive applications for power switches

6.1. Safely driving an inductive load

Inductive loads include relays, solenoids, electric motors and even loads connected through a long cable. Their impedance can be expressed as a series combination of a resistive and an inductive component. The resistance value determines the steady-state current while the inductive value determines the amount of stored magnetic energy. This stored magnetic energy in the inductor can cause system or component-level damage if improperly dissipated. Disconnecting an inductive load from an energized state creates a high-voltage spike that can lead to system damage.

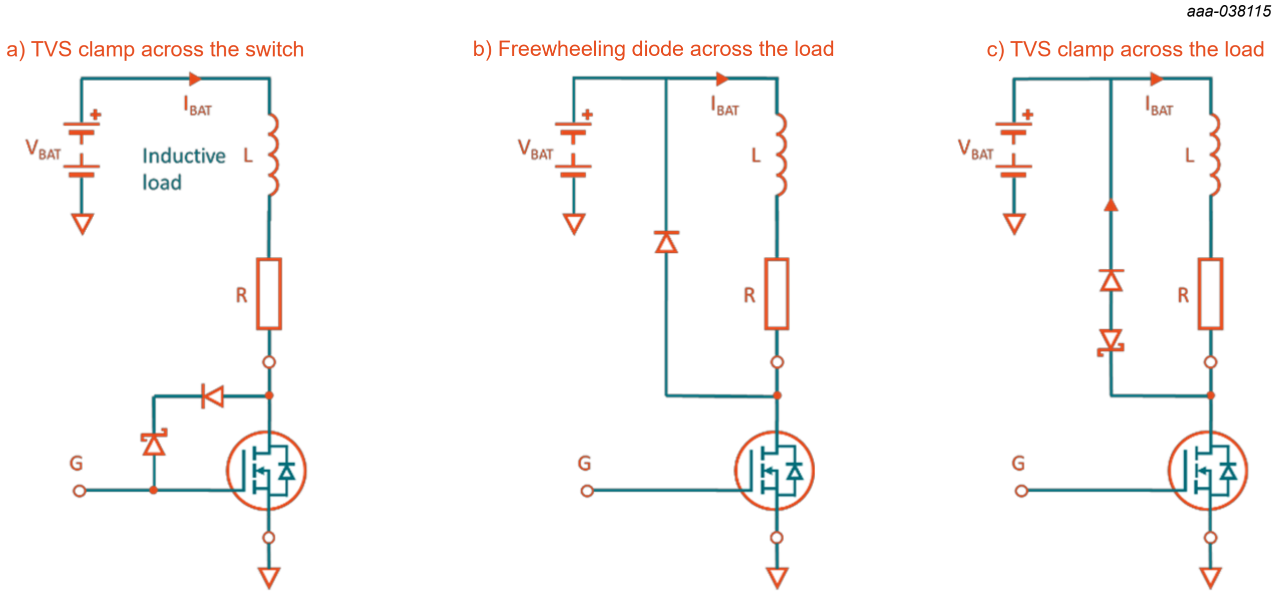


Fig. 16. Schematics for de-energizing an inductive load: (a) placing TVS clamp across a switch, (b) placing a freewheeling diode across the load, (c) placing TVS clamp across the load

Fig. 16 shows three methods to safely de-energize an inductive load using a clamp when disconnecting it from the voltage source:

- Placing a clamp across the switch, here the TVS clamp is connected to drain-gate of the MOSFET, as seen in Fig. 16(a), when the supply disconnected the inductor voltage starts to increase towards the bottom MOSFET V_{DS} breakdown, the TVS starts conducting and pulls the MOSFET gate up forcing it into its linear region, therefore in this application a careful consideration is required to operate within the SOA. This is the most effective method and covers most inductive loads.

- Placing a freewheeling diode across the inductive load, the freewheeling diode provides an alternative path for the current to flow out of the inductor when the MOSFET is turned off, preventing a voltage spike that could damage the MOSFET.
- Placing a clamp and diode across the inductive load, here the TVS clamp connected across the load instead of the power switch, the TVS clamp works by conducting current when the voltage across it exceeds the clamping voltage. This diverts the current away from the MOSFET and prevents the voltage spike from damaging it. Compared with the freewheeling diode method the TVS clamp method is more efficient and faster the fact that TVS diodes can conduct greater currents to the ground safely.
- Using MOSFET avalanche if the avalanche current versus avalanche time fits the data sheet graph

More information about automotive solenoids with different drive circuit topologies can be found in the following application note: AN50003 (Driving solenoids in automotive applications) and the Interactive Application Note page IAN50003.

6.2. Isolation switch (12 V, 300 A)

Fig. 17 shows a practical realization of an isolation switch, which is meant to support a power throughput of up to 3 kW from an upstream DC-to-DC converter to safely charge a 12 V battery at a current of up to 300 A. Due to the need for high-current capability, N-channel MOSFETs with higher voltage ratings. To support the 48 V input, 80 V MOSFETs can be used. These require a specialized control IC to drive them safely, such as the LTC4287 in this case. The IC can potentially control three pairs of back-to-back “by-pass FET” MOSFETs and one soft-start “start-up FET” MOSFET.

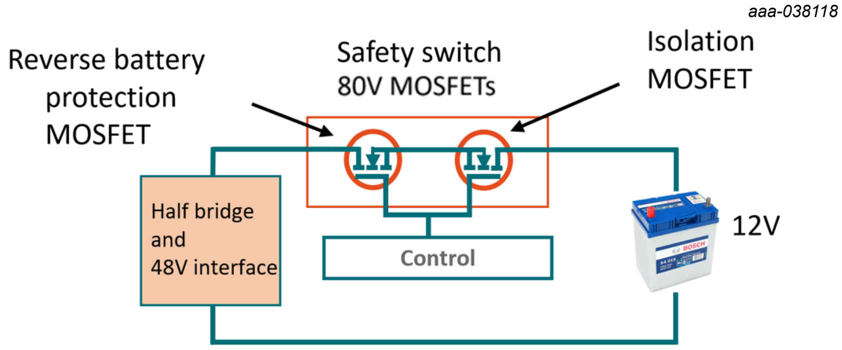


Fig. 17. Example use case of an isolation switch using N-channel MOSFETs

6.3. Protection switch (48 V, 60 A)

Fig. 18 shows another practical example of a protection switch, implemented using 6 N-channel MOSFETs in parallel. No reverse blocking capability is considered in this case, as the 48 V battery cannot be physically connected the wrong way round. Hence, there is no need to use the back-to-back configuration shown previously. To support the 48 V input, again 80 V MOSFETs can be used. Select the power MOSFET that best suits your system requirement

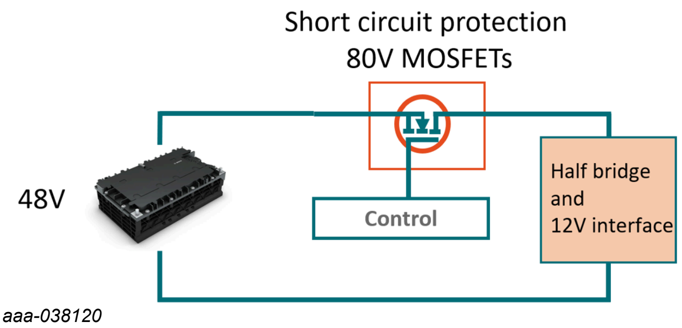


Fig. 18. Example use case for a protection switch using N-channel MOSFETs

6.4. Load switch and ideal diode (NMOS)

For high-current applications, it may be desirable to use N-channel MOSFETs, due to their superior performance in terms of reduced conduction losses, as well as the reduced cost. In this case, there is a need of a charge pump to drive the MOSFETs which can also be integrated into an ideal-diode controller (i.e., gate driver IC).

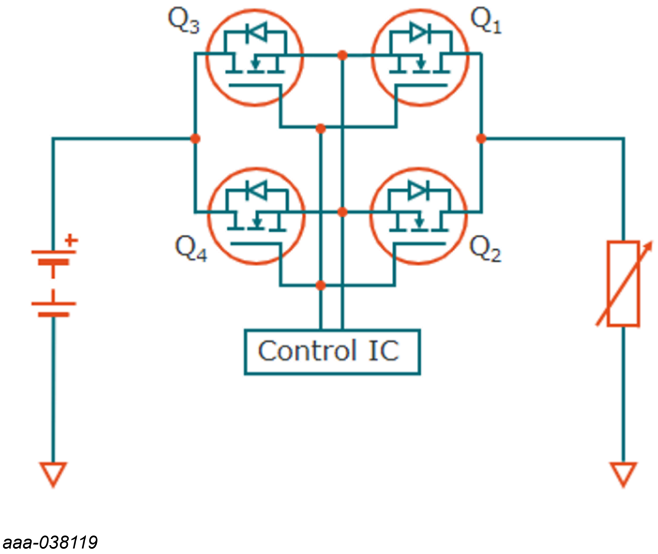


Fig. 19. Example circuit block diagram for high-current system protection using N-channel MOSFETs and an ideal-diode controller

Again, to achieve protection of the battery, a typical Schottky diode is replaced by MOSFETs Q1 and Q2 that serve as ideal diodes. Their forward-voltage drop can be controlled to ensure smooth current delivery without oscillation, even at light loads where the gate can be actively driven to maintain a stable voltage drop across the MOSFETs. A second pair of MOSFETs, Q3 and Q4, act as switches to control forward power flow. Power flow can be controlled in the forward direction, while retaining ideal diode behaviour in the reverse direction. The body-diodes of the 2 MOSFET pairs completely prohibit current flow when the MOSFETs are off.

6.5. Reverse polarity protection

Automotive battery-powered systems require protection from reverse polarity connections, which may be caused by accidental mis-wiring during servicing. Reverse voltages may also appear due to negative surge events, when an inductive load is disconnected or during transient input conditions. When this occurs, a large current flows through the Electrostatic Discharge (ESD) diode of microcontrollers, DC-to-DC converters or other integrated circuits and cause severe damage to battery-connected subsystems.

A reverse-connected battery can also damage polarised components such as electrolytic capacitors. The simplest and most inexpensive solution is to use a diode. Schottky diodes can accommodate more power due to their lower forward voltage drop. Other discrete solutions can be realized using a P-channel MOSFET in the supply path or an N-channel MOSFET in the ground return path. However, these solutions do not block reverse current due to large holdup capacitors. To counter this issue, dedicated controllers can be used to drive the N-channel MOSFET in the supply path by sensing and preventing reverse current flow.

The most efficient solution to eliminate reverse current flow is to use back-to-back MOSFETs. This approach effectively doubles the MOSFET $R_{DS(on)}$. When an eFuse is used instead of a discrete MOSFET, it may have a dedicated pin for driving an external MOSFET to create the back-to-back configuration.

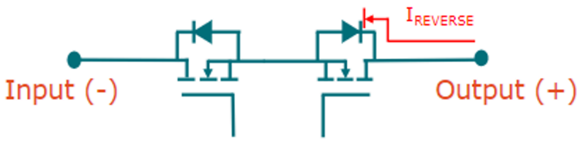


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Fig. 20. Example circuit block diagram for reverse current blocking

More information about reverse current blocking can be found in application note AN50001 (Reverse battery protection in automotive applications) and the Interactive Application Note page: IAN50001.

6.6. Over-voltage protection

Transient over-voltages are commonly caused by electrostatic discharge, voltage ringing from hot-plug events, or inductive switching surges from nearby power supplies. To protect against these, discrete components such as ESD, TVS or Zener diodes can be used. However, they can clamp and dissipate only a certain amount of energy before failing.

Continuous over-voltages may be caused by the failure or mis-wiring of upstream power supplies, or by the insertion of noncompliant adapters into a system. One method to protect against such conditions is overvoltage lockout. Integrated Power switches with this feature generally have a dedicated pin that monitors the input voltage rail through a configurable resistive divider. Once the voltage at the overvoltage lockout pin increases beyond a certain threshold, the internal comparator turns the pass FET off.Tadsasd.

6.7. Automotive load dump

In automotive applications, a load dump is a large transient pulse that occurs when a generator delivering current is suddenly disconnected from the system.

In modern automobiles, the alternator charges the battery and powers the vehicle’s electronics when the engine is running. The battery is connected in parallel with an alternator and other loads of a vehicle. It acts as a large capacitor, keeping the voltage at a steady 13.5 V. However, if the car battery is disconnected from the line, then the inductive nature of the alternator causes a very large voltage spike on the power line of the vehicle that could take almost half a second to dissipate. Since the alternator is always on when the engine is on, there is a high probability that a vehicle could experience this battery disconnection scenario.

A clamp can be used to dissipate the excess energy of the alternator and keep the voltage set at an appropriate level. For high-side integrated switches, the maximum accepted voltage is 40 V – 45 V depending on the switch. During a suppressed load-dump event, the transient will not break the switch, as it is lower than the maximum rating for the device. If an external MOSFET is used, then it also needs to have an appropriate voltage rating to withstand a high transient during a suppressed load dump.

6.8. Reverse polarity and over-voltage protection (PMOS)

Consider a USB charger which is powered from a car battery. There are several different options available for protecting the car charger from large voltage swings during normal operation, double battery jump starts or load dump when the battery is disconnected.

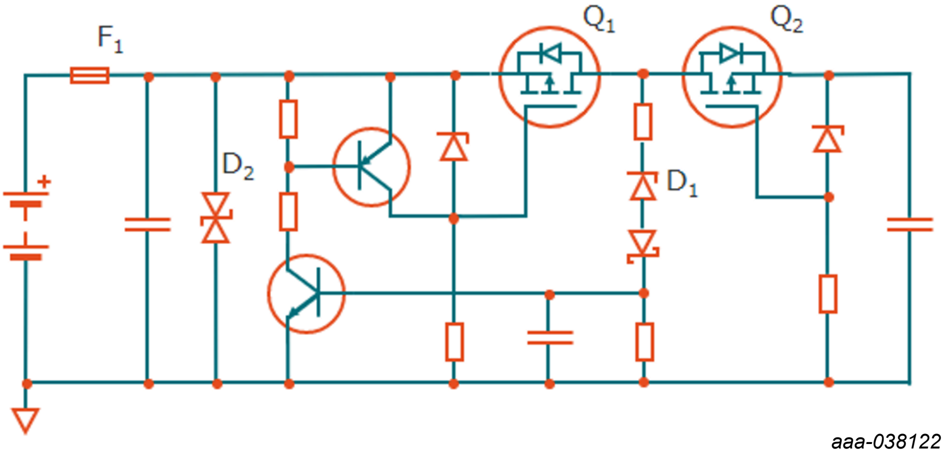

Fig. 21. Example circuit block diagram for overvoltage and reverse polarity protection using P-channel MOSFETs

One such solution shown is a combination of Zener diode and P-channel MOSFET to regulate the voltage to a desired value that is safe for the ICs or power stage of the charger, chosen to be 32 V. This allows use of ICs and switching MOSFETs with the appropriate ratings for the application, without the need to oversize them to withstand the occasional overvoltage stresses. In turn, this translates to a cost-effective and efficient overall system. To be able to handle 40 V surges, a 60 V P-Channel MOSFET is chosen. This provides some margin on the input voltage spikes and does not exceed the V_{DS} of the MOSFET. The second MOSFET provides protection against the reverse polarity connection of the input. For further protection against excessive over-voltage and catastrophic failures, an appropriately sized fuse is also used in conjunction with a bi-directional diode.

7. Summary

Compared to mechanical relays, the electronic power switch using power MOSFETs offers a variety of advantages and additional capabilities, which makes it an excellent solution to meet the high functionality trends of today’s applications.

These advanced power devices have several controllable features such as self-protection and diagnostic functions, which make them particularly attractive for modern automotive applications.

With their ability to be paralleled, power MOSFET switches can be implemented in adaptable and flexible solutions, providing various levels and forms of protection for power systems, such as current blocking, reverse polarity protection and protection against overvoltage conditions.

To explore the simulations mentioned in the application note visit the IAN50020 Interactive Application Note page.

8. Revision history

Table 2. Revision history

Revision number	Date	Description
1.0	2024-04-24	Initial version.

9. Legal information

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