

Straight Facts about Linear MOSFETs and their Applications

Linear-mode applications such as class-A audio amplifiers, active DC-link discharge, battery charge-discharge, inrush current limiter, low-voltage DC motor control or electronic loads demand the power MOSFETs to be operated within the current saturation region. Standard MOSFETs are prone to ETI when used in linear-mode applications leading to possible device destruction. Linear MOSFETs are the most appropriate choice for linear-mode applications to ensure reliable operation.

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Introduction – What is linear-mode operation and why is it required

Power MOSFET's output characteristic can be divided in to three distinct regions namely ohmic region, non-linear region, and saturation or active region as displayed in Figure 1. In the ohmic region, the drain current I_D is directly proportional to the drain-source voltage V_{DS} for a given gate-source voltage V_{GS} . The MOSFET acts as a resistor in this operation mode with a value equal to its on-state resistance $R_{DS(ON)}$. In the non-linear region, the MOSFET's resistance behaves non-linearly and the rate of increase of I_D with V_{DS} slows down. In the active region, the MOSFET's channel is saturated with majority charge carriers. In this region, I_D is independent of V_{DS} . I_D is governed only by V_{GS} and it remains constant for any given V_{DS} . In other words, the MOSFET exhibits the behavior of a constant current sink. This operating mode is commonly known as linear operation mode of power MOSFETs. In this operating mode, the MOSFETs typically dissipate higher power levels than they would in the more common switched-mode applications due to simultaneous occurrence of high voltage and current[1].

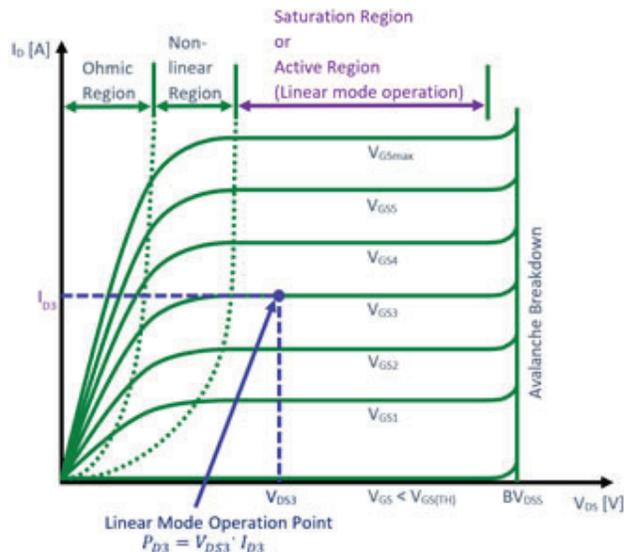


Figure 1: Power MOSFET Output Characteristics

Why standard MOSFETs are not suitable for linear-mode operation

In practice, the junction temperature T_{vj} is not uniform across the power MOSFET die. Typically, the temperature at the edge of the MOSFET die, where it is soldered to the mounting tab of a power package, is lower than in the center of the die. This is the result of lateral heat flow. Die temperature variations are mostly harmless in switched-mode operation. However, these variations can trigger

catastrophic failure in linear-mode operation. Large power dissipation P_D in linear-mode gives rise to electro-thermal instability (ETI) when the rate of power generation is higher than the rate of power dissipation. ETI can be understood as the result of a positive-feedback mechanism on the surface of a power MOSFET forced into linear-mode of operation:

1. There is a local increase in junction temperature T_{vj}
2. Increasing chip temperature causes local decrease in the gate threshold voltage $V_{GS_{TH}}$ because of its negative temperature coefficient
3. Decreasing threshold voltage causes an increase in local current density J_{DS} such that
4. The increase in current density causes an increase in local power dissipation, which leads to a further local increase in junction temperature

As depicted in Figure 2, the MOSFET equivalent circuit contains the parasitic NPN-transistor which is inherently formed by the sequence of n- and p-doped areas. Depending on the duration of the power pulse, heat transfer conditions, and design of the MOSFET's cells, ETI may cause a concentration of all drain-current into a current filament and formation of a hot spot. This normally causes MOSFET cells in the affected areas to lose gate control and turns on the parasitic transistor with subsequent destruction of the device [2].

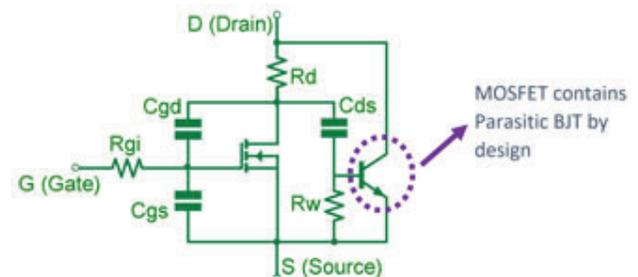


Figure 2: MOSFET Equivalent Circuit

Littelfuse Offering in Linear MOSFETs

In response to the problems caused by ETI, Littelfuse has developed a range of power MOSFET structures and processes that provide an extended Forward Bias Safe Operating Area (FBSOA) by eliminating the positive feedback loop. These devices are known as Linear MOSFETs L and L2 family within Littelfuse's MOSFET product portfolio [5]. The design of these Linear MOSFETs features a non-uniform distribution of transistor cells, as well as cells with different threshold voltages [3]. Every transistor cell is designed with a ballast resistor at its source to limit its current. The parasitic transistor of each cell is heavily bypassed so that it will not turn on even under extreme electrical stress conditions. The linear MOSFETs designed in this way achieve an extended FBSOA capability by suppress-

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Board area and weight are becoming limiting factors as power demands increase. Reducing size and weight can **cut the total cost of ownership** by making **installation and maintenance both easier and quicker**.

Part number	General description	Supply voltage max (V)	Key features	Output current max (A)	High side $R_{DS(on)}$ (m Ω)	Low side $R_{DS(on)}$ (m Ω)
MASTERGAN1	High power density 600V half-bridge high voltage driver with two 650V enhancement mode GaN HEMTs	11	Undervoltage lockout, interlocking function, overtemperature, Bootstrap diode	10	150	150
MASTERGAN2				6.5	225	150
MASTERGAN3				4	225	450
MASTERGAN4				6.5	225	225
MASTERGAN5				4	450	450



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ing the positive feedback that leads to electro-thermal instability [4]. Linear MOSFETs from Littelfuse are available in wide voltage and current ranges in numerous discrete packages as displayed in Table 1. The MOSFET families Linear L and Linear L2 differ primarily in terms of operating voltage and channel resistance $R_{DS(ON)}$. There are no special gate drive requirements for linear MOSFETs. The IXYS gate driver family IXD_604 can be used for this purpose which is available in a standard 8-pin DIP, 8-pin SOIC, 8-pin Power SOIC with an exposed metal back and an 8-pin DFN (D2) package.

Linear MOSFETs L and L2 Family		
	Available Voltage Range	Available Current Range
	75V – 2500V	2A – 240A
Available Packages		

Table 1: Littelfuse Linear MOSFET Portfolio

FBSOA comparison: Standard vs. Linear MOSFET

The Forward Bias Safe Operating Area (FBSOA) is a datasheet Figure of Merit (FOM) that defines the maximum allowed operating points. It is important for the safe operation of MOSFETs to operate within limits of the FBSOA. The typical FBSOA characteristic is bound by the $R_{DS(ON)}$ limit line, current limit line, power limit line, and voltage limit line as represented in Figure 3. By comparing the datasheets of a standard MOSFET and a linear MOSFET, it is evident that the linear MOSFET exhibits the extended FBSOA which means its maximum power handling points for any given pulse widths are shifted towards the voltage limit line as illustrated in Figure 3. The typical nature of linear-mode operation demands high power dissipation in the device. By comparing both the FBSOAs it is evident that linear MOSFETs can handle 24%, 31%, 48%, 73% and 118% higher power compared to standard MOSFET for 25µs, 100µs, 1ms, 10ms pulse width and continuous operation (DC) respectively. Therefore, the linear MOSFETs are more suitable devices for linear mode applications than standard MOSFETs.

FBSOA comparison: Littelfuse Linear MOSFET vs. Competition's MOSFET

In the linear-mode applications, MOSFETs are usually operated at low frequencies with long pulse widths of 10ms or more. The linear MOSFET IXTH2N150L, a 1500V 2A TO-247 packaged device, which is one of the most popular devices in electronic load applications,

was tested and compared in the lab to the nearest competition device, a 1500V 2.5A TO-247 packaged component. The FBSOA measurement set-up consists of an apparatus which generates a power pulse for measurements, the Device Under Test (DUT) mounted on a copper heat-sink, and a thermo couple for case temperature T_C measurement as depicted in Figure 4a. The Maximum power which the device can withstand was measured for different pulse widths on both DUTs. Figure 4b shows the quantitative comparison between both device in terms of maximum power withstand capability

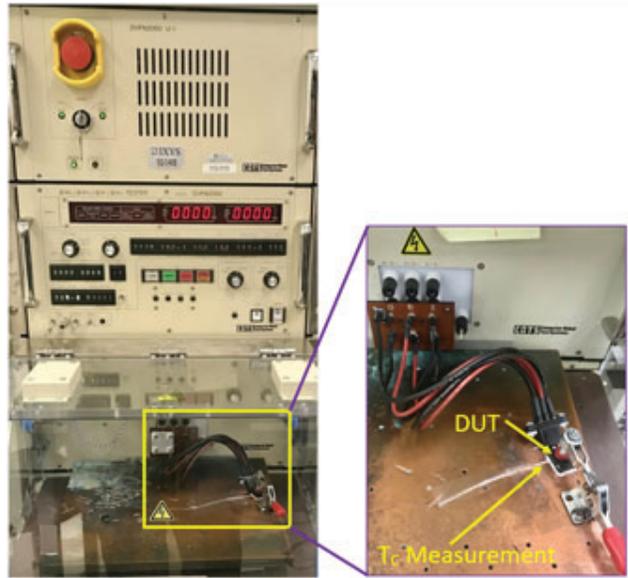


Figure 4a: Datasheet FBSOA Comparison: Standard MOSFET IXTH30N60P vs. Linear MOSFET IXTH30N60L2

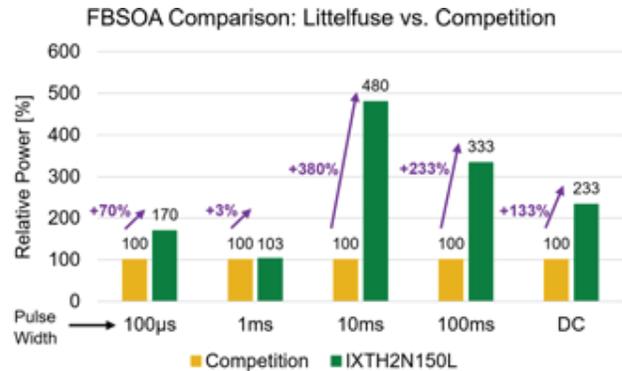


Figure 4b: FBSOA Comparison: Competition vs. Littelfuse Linear MOSFET

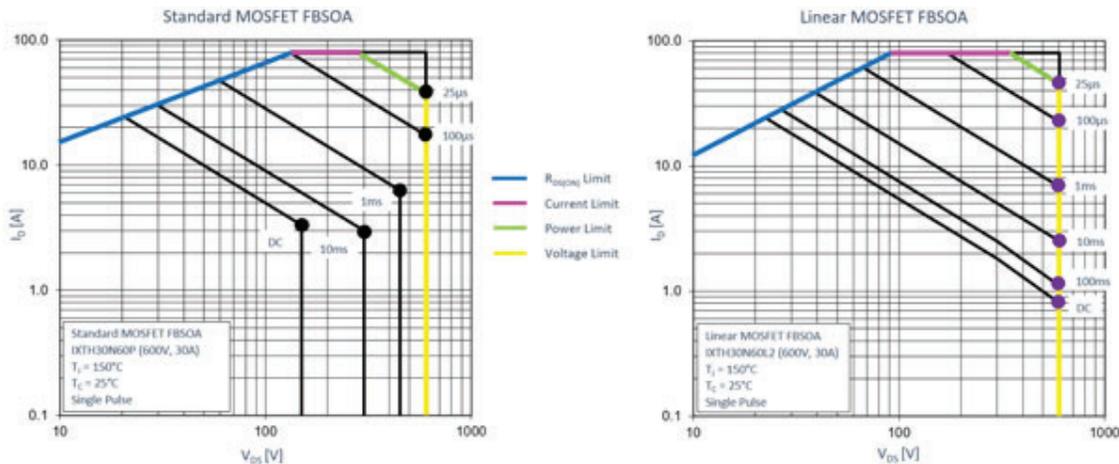


Figure 3: Datasheet FBSOA Comparison: Standard MOSFET IXTH30N60P vs. Linear MOSFET IXTH30N60L2

ity using various pulse widths. It can be observed that the Littelfuse device is able to handle significantly higher power than the competing device, especially for long pulse widths $\geq 10\text{ms}$ and continuous operation. Such robust performance translates into the improvement of overall system reliability in linear-mode applications.

Application Example: Electronic Load

An electronic load is a test instrument which sinks current. It is commonly used to test power sources such as DC-DC converters, fuel-cells, batteries, solar panels, or power supplies under various loading conditions. Figure 5 represents the simplified schematic of an electronic load. The DUT is loaded with the desired current via the control voltage V_{control} set point. The linear MOSFETs (S1, S2, ... , Sn) act as a variable resistor which regulate the current through the load. The MOSFETs are usually arranged in parallel to cater higher power. Apart from linear MOSFETs and gate drivers, Littelfuse offers also additional components that are commonly found in electronic loads. Diagrammed in figure-5, fast acting fuses (F1, F2,..., Fn), unidirectional and bidirectional transient voltage suppressors (TVS, TVS1, TVS2,..., TVSn), and NTCs for semiconductor temperature monitoring (NTC1, NTC2,..., NTCn) are all products within the Littelfuse portfolio [5].

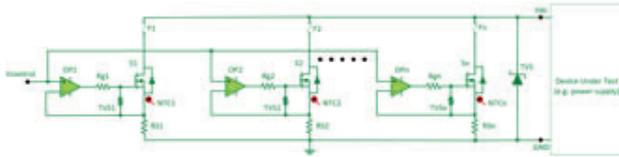


Figure 5: Simplified Schematic of an electronic load based on linear MOSFETs

Conclusion

Linear-mode applications demand the power MOSFETs to be operated within the current saturation region. Standard MOSFETs are prone to ETI when used in linear-mode applications leading to possible device destruction. Linear MOSFETs are the most appropriate solution for linear-mode applications to ensure reliable operation. The FBSOA comparison between a Littelfuse linear MOSFET and the nearest competition reveals the superior power handling capability of the Littelfuse device. The reasons why Littelfuse linear MOSFETs are the most preferred choice is because all the linear devices are 100% tested to guarantee FBSOA, long term availability of parts and high-power dissipation capability thanks to its low thermal resistance junction-to-case R_{thJC} . Littelfuse is the most reliable partner, offering major components such as linear MOSFETs, gate drivers, high-speed fuses, TVS diodes and temperature sensing solutions in the entire value chain of linear-mode applications.

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