

Depletion-mode Power MOSFETs: The Forgotten MOS

Power MOSFETs are most often used in switched-mode applications where they function as an on-off switch. However, in applications such as start-up circuits in SMPS, surge and high voltage protection, reverse polarity protection, or solid-state relay, the power MOSFETs are required to be operated as normally 'on' switch when the gate-to-source voltage V_{GS} is zero. The power MOSFET which functions as normally 'on' switch when $V_{GS}=0V$ is known as the depletion-mode MOSFET.

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The difference between enhancement-mode and depletion-mode MOSFETs

The first noticeable difference is in the circuit symbols of enhancement-mode (EM) and depletion-mode (DM) devices as depicted in figure 1. The EM-device has no conduction at $V_{GS}=0V$, the conduction starts at gate-to-source threshold voltage $V_{GS(th)}$. In contrast the DM-device's channel is fully conducting at $V_{GS}=0V$. For the EM-device, the drain current I_D increases when $V_{GS}>V_{GS(th)}$. In case of a DM-device, the current increases when $V_{GS}>0$. The EM-device ceases conduction at $V_{GS}<V_{GS(th)}$. Whereas for the DM-device, negative gate voltage V_{GS} reduces the current I_D and the device stops conducting at gate-to-source cut-off voltage $V_{GS(off)}$. Figure 1 illustrates the major differences between both the MOSFETs in terms of their output characteristics.

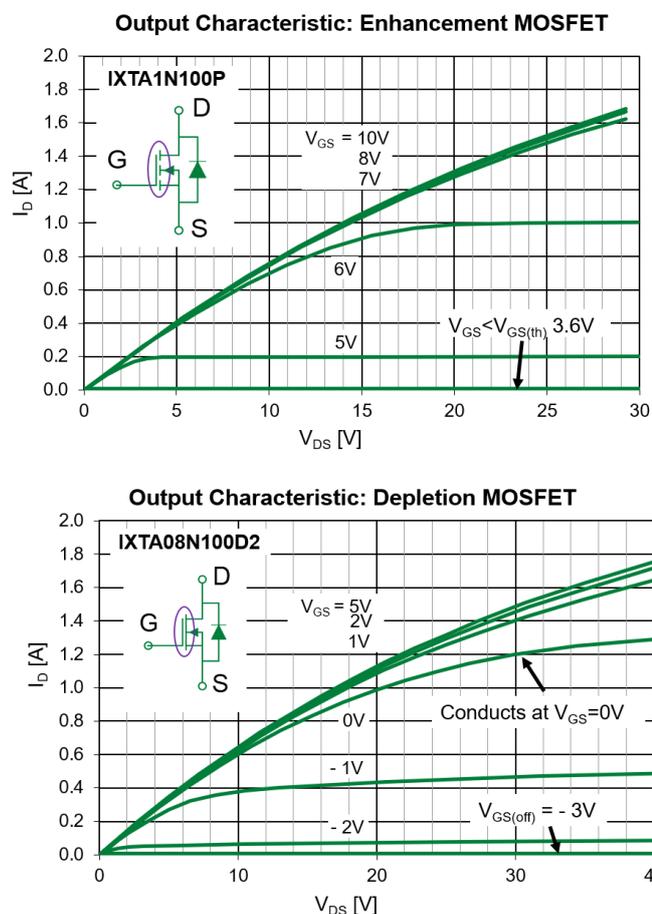


Figure 1: Difference between the enhancement-mode and depletion-mode MOSFETs

The EM device cannot replace the DM device in certain applications because they do not conduct at zero gate voltage V_{GS} . Moreover, the gate drive circuit is not required at all in some applications involving depletion MOSFET device because the gate gets biasing from the circuit where it is implemented. This will save overall system cost along with reduced complexity and improved reliability thanks to the linear mode operation capability of depletion MOSFETs.

Depletion-mode MOSFET products

The Littelfuse depletion-mode power MOSFETs are built with a structure called vertical double-diffused MOSFET (DMOSFET). All these devices can sustain linear mode operation thanks to their extended Forward Bias Safe Operating Area (FBSOA) making them highly reliable in end applications [1][2]. Littelfuse's depletion-mode MOSFETs are known as Depletion D, Depletion D2, and Depletion CPC product families [4]. Figure 2 gives an overview about the diverse depletion-mode product portfolio.

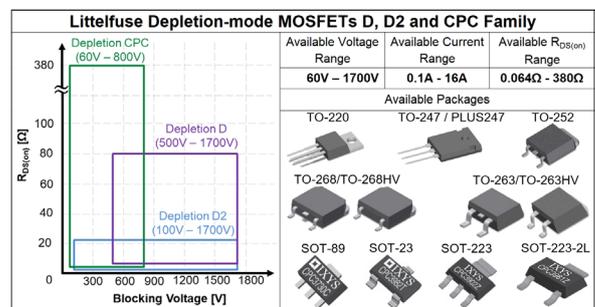


Figure 2: Littelfuse depletion-mode MOSFET product portfolio

Unlike EM devices, DM devices are not used for high-speed switching. Usually, EM devices are not capable of linear mode operation except linear MOSFETs [1] whereas all the D and D2 family devices are capable of sustaining linear mode operation thanks to their extended FBSOA. High-voltage depletion MOSFET products with a 2500V rating are currently under development. Applications such as high voltage (HV) test equipment, power supply, ramp generator, insulation resistance test equipment or auxiliary power supplies for HV power transmission system need such depletion MOSFETs. Figure 3 illustrates the leadership position of Littelfuse depletion-mode MOSFETs in the market.

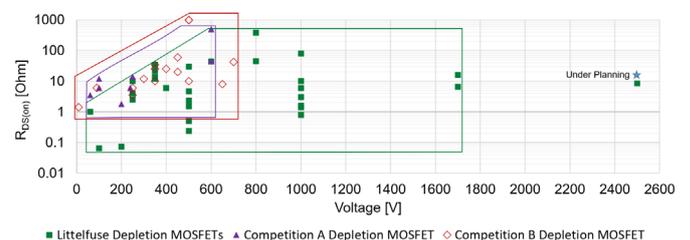


Figure 3: Littelfuse depletion-mode MOSFET market leadership

Applications of depletion-mode power MOSFETs

The following applications are uniquely suitable for the depletion-mode MOSFETs [3].

1. Start-up circuit of a Switched Mode Power Supply - SMPS

The conventional start-up circuit approach of an SMPS is via power resistor and a Zener diode. In this approach, even after the start-up phase, the power resistor consumes power continuously. This results in excessive heat on PCB, poor efficiency, and limited input voltage operating range of an SMPS. Alternatively, the depletion-mode MOSFET based approach can be adopted as depicted in figure 4. The depletion MOSFET provides the initial current required by the PWM IC to kick-start the operation. After the start-up phase, the auxiliary winding will generate the required power for the PWM IC. During normal operation, the depletion MOSFET draws minimal power because of its low quiescent current. The main advantage of this approach is theoretically zero power dissipation after the start-up sequence leading to improvement in overall efficiency. Moreover, it occupies a smaller area on PCB and enables a wide input DC voltage range which is essential for many applications such as solar inverters.

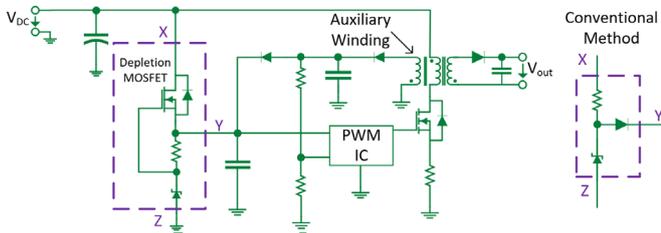


Figure 4: Depletion-mode MOSFET in SMPS start-up circuit

2. Surge protection for linear voltage regulators

Linear voltage regulators provide power to small analog circuits, CMOS ICs, or any other load requiring low current where the input voltage V_{in} comes directly from a bus voltage. This might have large voltage variations including high voltage spikes due to the application's environment. The depletion MOSFET can be used to implement surge protection in linear voltage regulator circuits as illustrated in figure 5. The MOSFET is connected in source follower configuration. The voltage on the source will follow the voltage on the gate. The depletion MOSFET's conduction is dependent solely on its gate voltage and is independent of its drain voltage. This configuration is used to mitigate any voltage transient up to the withstand capability of the device voltage rating V_{DS} . The advantage of a depletion MOSFET based solution is the wide DC operation voltage range V_{in} and minimal power dissipation thanks to low quiescent current of the MOSFET. The possible use of such protection is in telecommunication circuits to mitigate transients caused by lightning strikes. Another possibility could be in automotive and aviation electronics application to mitigate transient caused by inductive loads.

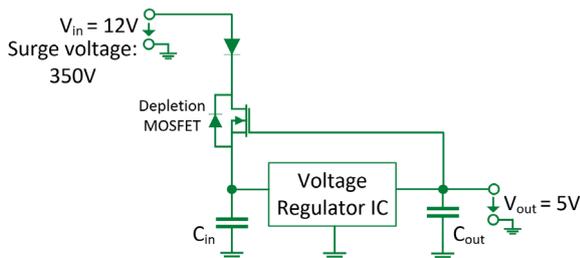


Figure 5: Surge protection circuit using depletion-mode MOSFET

3. Constant current source

The depletion MOSFET can be used to implement a constant current source as depicted in figure 6. It provides constant current to the load depending on the value of the resistor R and gate cut-off voltage $V_{GS(off)}$. The current I_D is thus independent of the voltage

V_{in} . The current is equivalent to $I_D \approx \frac{V_{GS(off)}}{R}$. Such current sources can be in LED array driver, trickle charger circuit to maintain battery charge for surveillance systems, or to charge capacitors at constant rate.

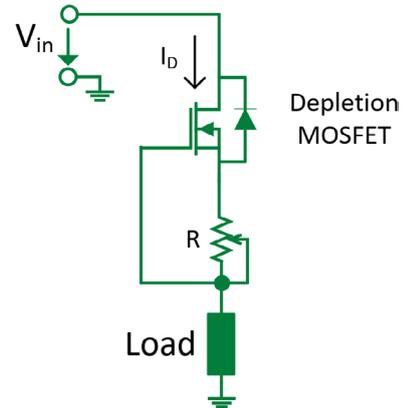


Figure 6: Constant current source using depletion-mode MOSFET

4. High-voltage ramp generator

Applications such as automatic test equipment require high-voltage ramps with a linear relationship between output voltage and time. The depletion MOSFET can be configured to design a high voltage ramp generator as illustrated in figure 7. The constant current source charges the capacitor C via resistor R1 and generates a voltage ramp, V_{out} across the capacitor. The linear MOSFET can be turned on with a control signal to reset the ramp voltage discharging the capacitor to zero through R2. Resistor R2 is used to limit the discharge current for the linear MOSFET to operate within its SOA rating.

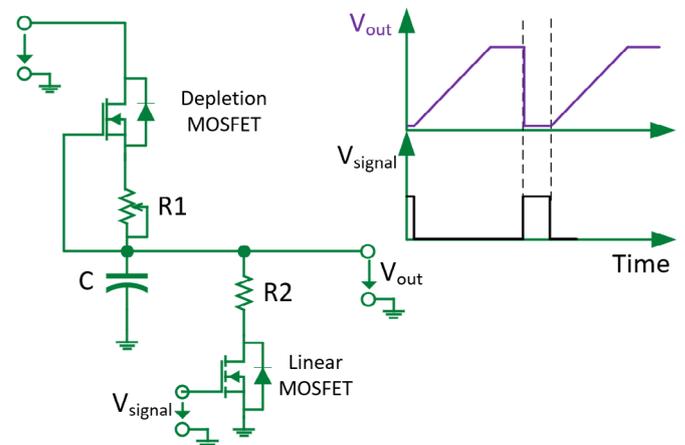


Figure 7: High voltage ramp generator using depletion-mode MOSFET

5. High-voltage protection circuit

The depletion MOSFET can be used to protect measurement instruments against destructively high voltage caused by accidental connection of measurement probes to high voltage V_{meas} (figure 8). In such events, the MOSFETs S1 and S2, configured in back-to-back configuration, will protect the instrument by limiting the current. This will give the protection against positive as well as negative voltages across the probe. The possible use of such a circuit is in bench-top or hand-held instruments.

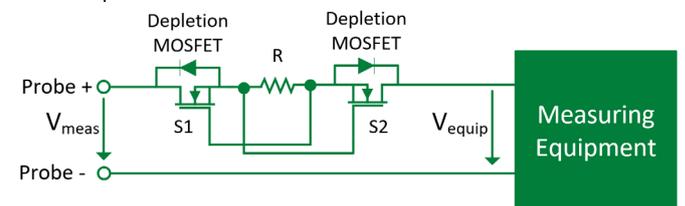


Figure 8: High voltage protection circuit using depletion-mode MOSFET

6. Solid state relay

The depletion MOSFETs are excellent to implement solid state relays (SSR) for load switching in place of electro-mechanical relays (EMR) as illustrated in figure 9. The important advantages of an SSR are immunity to magnetic fields, higher reliability due to the absence of mechanical contacts, enablement of smooth operation thanks to elimination of contact chattering, and space saving on PCB. Applications such as medical equipment, industrial automation, measurement and test equipment and consumer electronics are examples where SSRs are widely used.

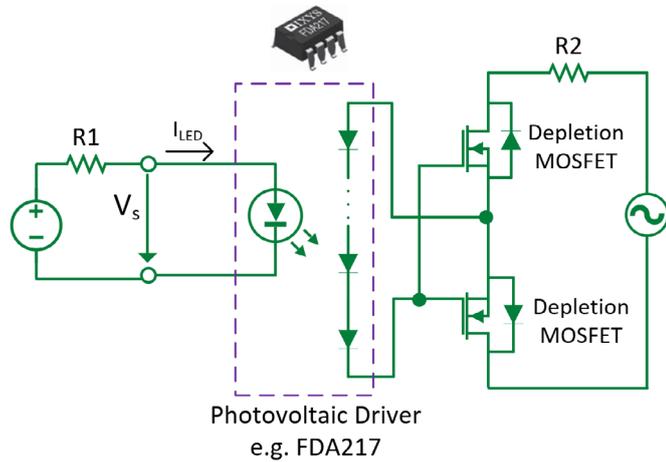


Figure 9: Solid state relay using depletion-mode MOSFET

Conclusion

The depletion-mode MOSFETs can be used whenever application demands current at zero gate voltage. These devices are almost forgotten despite having numerous practical applications. Littelfuse has the widest range of these, from 60V to 1700V and the only manufacturer offering high current depletion MOSFETs. The applications highlighted in this article will help the designers to select these devices in various industrial applications leading to efficiency improvement and increased system reliability.

References

- [1] Article: Straight Facts about Linear MOSFETs and their Applications; October -2021 issue; <https://www.bodospower.com/>
- [2] White Paper: 'MOSFETs Withstand Stress of Linear Mode Operation'; www.littelfuse.com.
- [3] Depletion-Mode Power MOSFETs and Applications; <https://www.ixys.com/Documents/AppNotes/IXAN0063.pdf>
- [4] Littelfuse offering on Depletion MOSFETs, Gate drivers; www.littelfuse.com.

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