Applications for depletion MOSFETs

About this document

Scope and purpose

Depletion MOSFETs, unlike enhancement MOSFETs, are in an on-state even at 0 V of gate-to-source voltage (V_{GS}). This feature makes them suitable for using as a constant current source as well as in other ways. This application note explains how depletion MOSFETs can be used in different applications.

Intended audience

This document is intended for electronic equipment designers.

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1 What is a depletion MOSFET?

As depletion MOSFETs are in the on-state (i.e. they can conduct current) even when the gate-to-source voltage (V_{GS}) is zero. This can be best shown by comparing the transfer characteristics of enhancement and depletion MOSFETs.

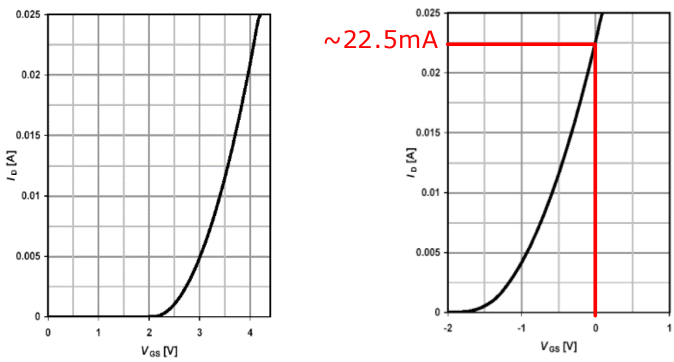

Figure 1 Transfer charateristics of enhancement (BSS127) and depletion (BSS126) MOSFETs

Static characteristics						
Drain-source breakdown voltage	$V_{(BR)DSS}$	V_{GS}=-5 V, I_D=250 µA	600	-	-	V
Gate threshold voltage	$V_{GS(th)}$	V_{DS}=3 V, I_D=8 µA	-2.7	-2.0	-1.6	

Figure 2 Screenshot from the datasheet for BSS126

Figure 1 illustrates an example of the transfer characteristics of both devices. For a MOSFET, the gate-to-source voltage (V_{GS}) should be higher than the gate-to-source threshold voltage ($V_{GS(th)}$) in order to conduct current through it. For an N-channel enhancement MOSFET $V_{GS(th)}$ is above 0 V. Therefore, even at V_{GS} of 0 V, a depletion MOSFET can conduct current. To turn off a depletion MOSFET the V_{GS} should be lower than the (negative) $V_{GS(th)}$. This is clearly shown in schematic symbols for both. Figure 3 below shows the schematic symbols for enhancement and depletion MOSFETs respectively.

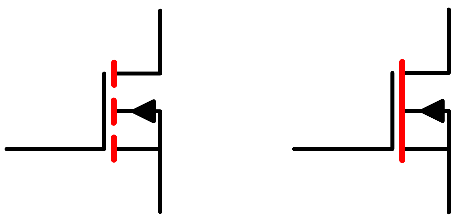

Figure 3 Differences in schematic symbols – enhancement (left) and depletion (right) MOSFET

The symbols for enhancement and depletion MOSFETs show a difference in the second vertical line from the left, marked in red. For the enhancement MOSFET this line is discontinuous. This shows that the MOSFET is switched off with a V_{GS} = 0 V. With a V_{GS} = 0 V a depletion MOSFET can conduct current, and this is shown by the dashed line.

2 How to use a depletion MOSFET

Shorting gate and source, as shown in Figure 4, results in a load current independent of the applied drain-to-source input voltage. For a BSS126 this current is typically 22.5 mA.

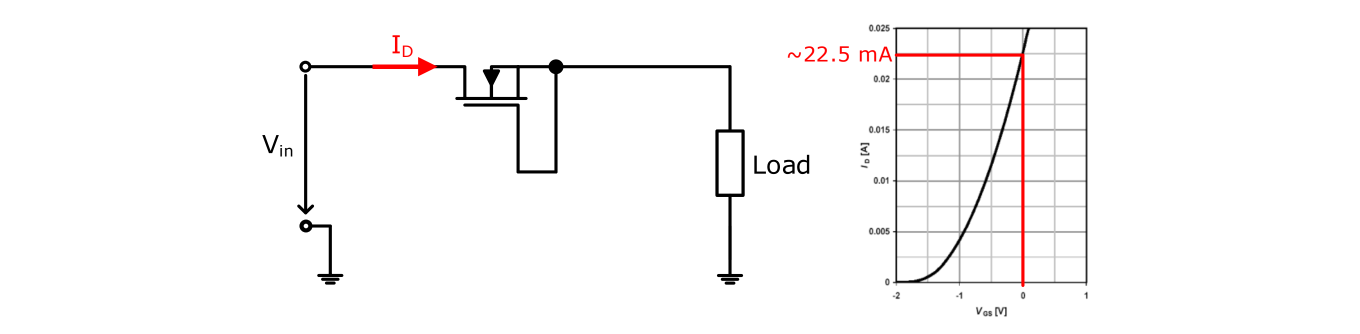

Figure 4 Typical BSS126 drain current with V_{GS} = 0 V

2.1 Adjusting the drain current

If the drain current at V_{GS} = 0 V is too high a simple source resistor must be added to the circuit.

Figure 5 shows this arrangement. Assuming a drain current of 4 mA the gate-to-source must be -1 V, i.e. the resistor's value is calculated using Ohm's law by R = 1 V / 4 mA ~ 250 Ω.

This is valid for a typical BSS126. In reality the device's tolerances have to be taken into account

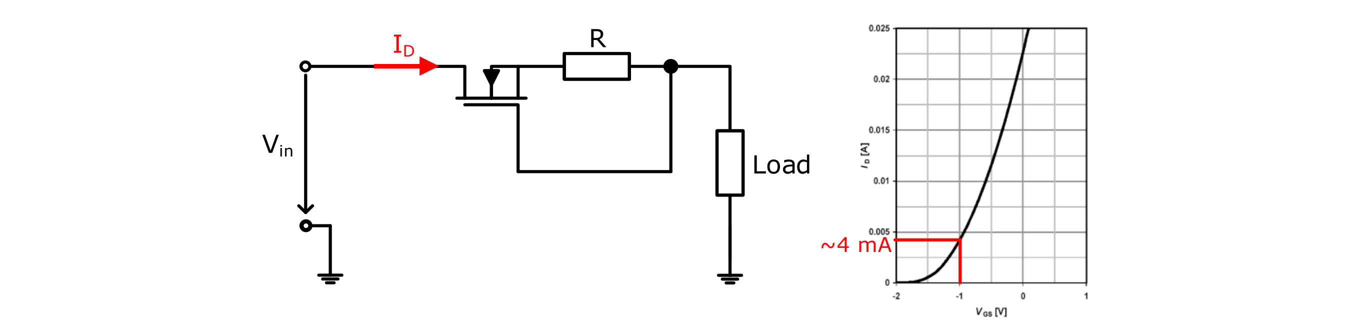

Figure 5 BSS126 with adjusted drain current

2.2 Depletion MOSFET in a start-up circuit

Depletion MOSFETs are widely used in a start-up circuit of auxiliary power supplies.

To power up a PWM IC in a flyback circuit a very common method is shown in Figure 6.

A resistor is connected between the positive rail (for example the rectified mains voltage or a PFC voltage) and the IC's capacitor, C. Typically this capacitor's value is between 10 µF and 100 µF. The start-up time shouldn't be too long.

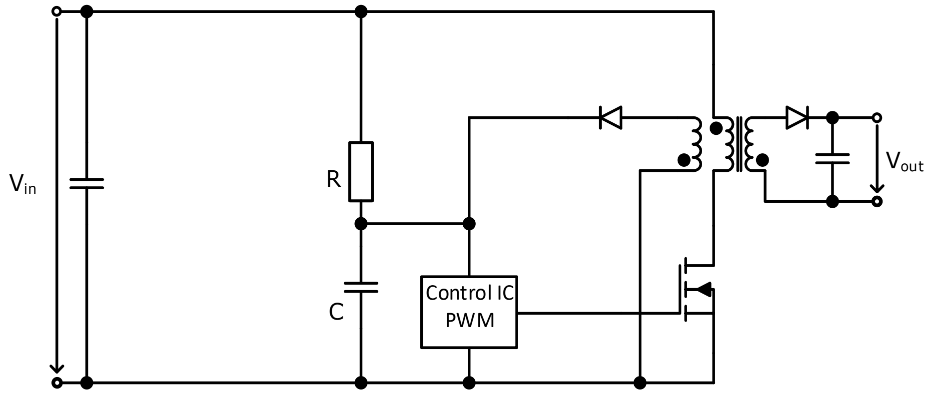

Figure 6 **Flyback with control IC and simple resistor start-up circuit**

Example: V_{in} = 400 V, C = 47 µF, IC's start-up voltage V_{IC} = 10 V

Assuming the use of SMD resistors the power losses are limited to 0.25 W, i.e. R ≥ (400 V)^2 / 0.25 W ~640 kΩ.

The resulting current is calculated by T_{start} ~400 V / 640 kΩ = 625 µA.

The start-up time T_{start} = C * V / I = 22 µF * 10 V / 625 µA = 0.352 s.

If this circuit is used at low-line voltage, e.g. ~110 V, the start-up time is increased to ~1 s, which in many applications is too long.

Additionally most PWM ICs already sink several hundred µA before they reach the start-up threshold, resulting in an even longer start-up time with this resistor arrangement.

The start-up time can be optimized by decreasing the values of R and/or C.

Decreasing the resistance increases the losses, while decreasing C is sometimes not possible.

A much more elegant solution is the use of a depletion MOSFET, as shown in Figure 7.

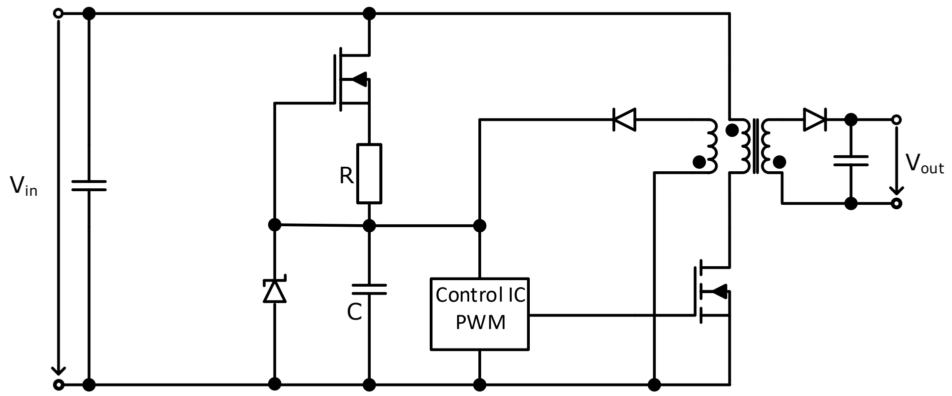

Figure 7 **Flyback with control IC with a depletion MOSFET, adjusted drain current**

Now the start-up time is independent of the input voltage.

This circuit can be further optimized by adding a few SMD devices – see Figure 8.

How to use a depletion MOSFET

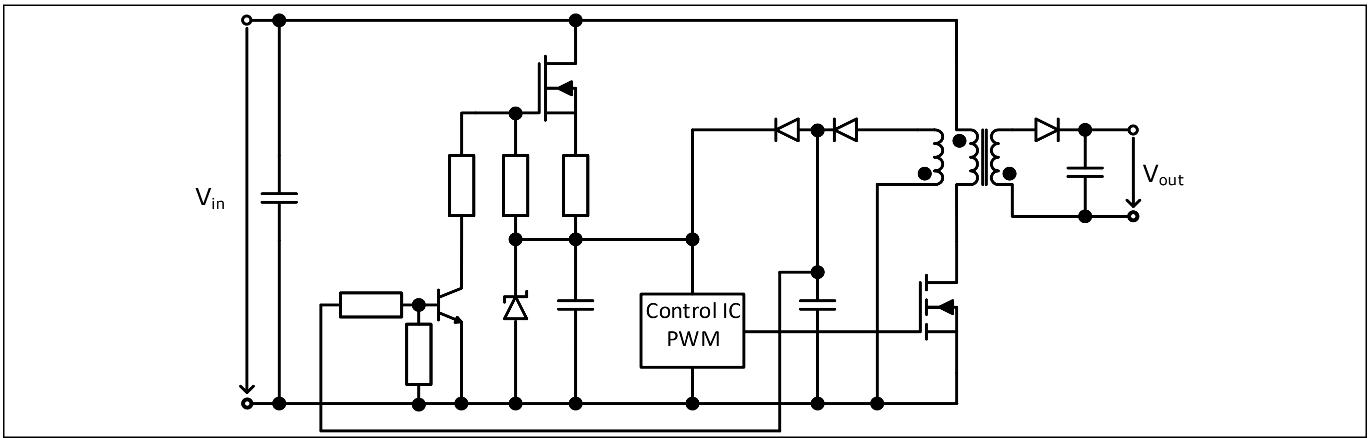

Figure 8 Flyback with control IC with a depletion MOSFET, adjusted drain current and without standby losses

The depletion MOSFET with adjusted drain current powers up the IC. If the voltage delivered by the auxiliary winding is high enough the NPN transistor is triggered, pulling down the gate of the depletion MOSFET below its threshold voltage and switching it completely off.

Example: The depletion MOSFET BSS126 (600 V, 700 Ω, SOT-23) is a good choice. A reasonable start-up time for many applications is 200 ms or shorter. Assuming a PWM IC's standby current of 100 µA and a capacitor's value of 47 µF the start-up current I_D is calculated to:

I_D = C * V / t + 100 µA = 22 µF * 10 V /200 ms + 100 µA = 1.2 mA

The depletion MOSFET is switched off shortly after the start-up time of 200 ms so the Z_{thJA} can be used to check if the device is used within its thermal limits.

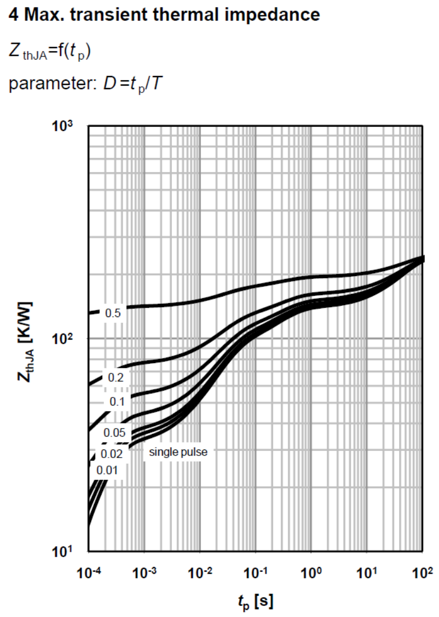

Figure 9 Z_{thJA} diagram – BSS126

For 200 ms the Z_{thJA} is around 120 K/W on a standard PCB. With V_{in} = 400 V and an I_D = 1.2 mA the losses are P = 400 V * 1.2 mA = 480 mW. The temperature rise during the start-up time is now calculated to ΔT = 480 mW * 120 K/W = 57.6 K. A temperature rise of 57.6 K is absolutely acceptable.

2.3 Linear regulators

A depletion MOSFET can also be used as a pass transistor for a linear regulator. Figure 10 shows a linear regulator circuit using a depletion MOSFET plus a Zener diode.

In the circuit, Q_1 acts as a source follower where the source voltage follows the gate voltage (V_G) minus the gate-to-source voltage. V_{GS} increases with increasing drain current. Thus, with a fixed gate voltage, the source voltage will drop with increasing load current. For design purposes, V_{GS} under saturation and cut-off conditions (0 V and $V_{GS(th)}$, respectively) can be used. These values can be readily obtained from the datasheet, and Figure 11 shows the cut-off and saturation conditions of the Infineon BSS169. Bias current for the Zener diode is determined by V_{GS}/R. The Zener diode sets the gate voltage and should be selected to provide a source voltage within the range determined, taking into account the variances of V_{GS} with load.

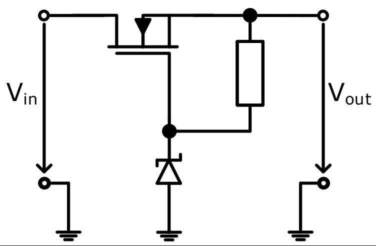

Figure 10 Depletion MOSFET as a linear regulator

The point to be noted here is that the MOSFET's saturation current must be higher than the required load and bias currents, otherwise the device can be stressed or destroyed due to over-current.

Static characteristics						
Drain-source breakdown voltage	$V_{(BR)DSS}$	V_{GS}=-10 V, I_D=250 µA	100	-	-	V
Gate threshold voltage	$V_{GS(th)}$	V_{DS}=3 V, I_D=50 µA	-2.9	-2.2	-1.8	

Figure 11 Gate threshold voltage for BSS169

2.3.1 Example

The application above can be explained more clearly with an example. Consider a regulator with 5 V output at 5 mA of output current from 24 V input using Infineon's depletion MOSFET BSS169.

With a 3.3 V Zener diode the output voltage varies due to the MOSFET's $V_{GS(th)}$ spread of 4.7 V to 5.5 V. The resulting power dissipation of the BSS169 is calculated to 0.1 W, which is an acceptable value and well below the specified power limit.

2.3.2 Other examples

A constant current source can be used in many different applications. A few examples are listed below:

- A constant current source is useful to generate a bias current that is independent of the voltage across it. It can be used to charge a capacitor at a constant rate, generating a linear ramp for timing purposes.
- A constant current source can be used as a trickle charger to maintain battery charge state.
- A constant current source can be used as a current limiter when the current is below the limit.

How to use a depletion MOSFET

- A constant current source can also be used as a linear LED driver for driving LED strings typically up to 20 mA. Figure 12 shows a linear LED driver circuit using a depletion MOSFET and a series resistor.

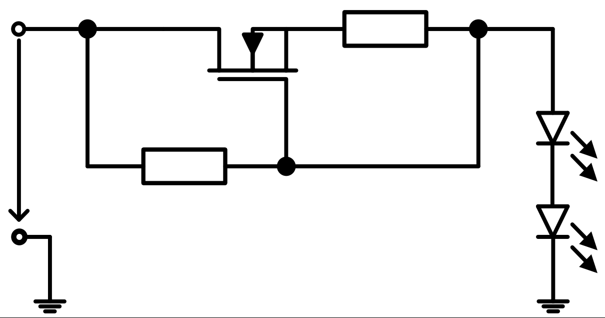

Figure 12 Depletion MOSFET as a linear LED driver

3 Depletion MOSFETs from Infineon

Infineon offers depletion MOSFETs in SOT-223 and SOT-23 packages, with breakdown voltages ranging from 60 V to 600 V. Table 1 shows Infineon's depletion MOSFET portfolio:

Table 1

Part number	Package	BV_{DSS} [V]	$R_{DS(on)}$ [Ω]	$V_{GS(th),max}$ [V]	$V_{GS(th),min}$ [V]	$I_{DSS,min}$ at V_{GS} = 0 V [mA]
BSP149	SOT-223	200	1.8	-1	-2.1	140
BSP129	SOT-223	240	6	-1	-2.1	55
BSP179	SOT-223	400	24	-1	-2.1	20
BSP135	SOT-223	600	45	-1	-2.1	20
BSS159N	SOT-23	60	3.5	-2.4	-3.5	130
BSS169	SOT-23	100	6	-1.8	-2.9	90
BSS139	SOT-23	250	14	-1	-2.1	30
BSS126	SOT-23	600	7	-1.6	-2.7	7

For Infineon's depletion MOSFETs $V_{GS(th)}$ is spread across five sorted bands. Each band has a distribution of 0.2 V and is assigned with an identification letter. Limits for each sorted band vary from $V_{GSth,min}$ to $V_{GSth,max}$. Figure 13 shows an example of the $V_{GS(th)}$ bands of BSP149.

Threshold voltage $V_{GS(th)}$ sorted in bands[2)]

J	$V_{GS(th)}$	V_{DS}=3 V, I_D=8 µA	-1.8	-	-1.6	V
K			-1.95	-	-1.75	
L			-2.1	-	-1.9	
M			-2.25	-	-2.05	
N			-2.4	-	-2.2	

Figure 13 Threshold voltage bands

Please note:

A single specific band cannot be ordered separately. However, it can be requested that each reel contains only one band of $V_{GS(th)}$.

Revision history

Document version	Date of release	Description of changes

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