

## Thoughts on Reverse Power Protection using Power MOSFETs

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The use of power MOSFETs to protect against polarity reversal is a novel use of these devices, and brings an important but little-known device feature to light. The circuits in this discussion are based on Maxim Semiconductor's *Application Note 636*, and are also referenced in *Hands On Radio Experiment #120* in January 2013 QST Magazine.

The Maxim application note doesn't really explain how these work, but a closer inspection of the circuits should make you do a double take. On first blush, it appears that the MOSFETs are actually inserted *backwards* into the circuit; how can these possibly work? Well, they do work quite well, so let's examine them more closely.

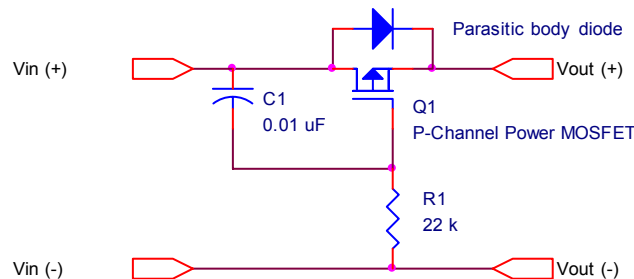


Figure 1: High-Side Switching using P-Channel Device

In Figure 1, the P-channel device is connected so that the drain is towards the positive voltage source, and the source towards the relatively negative load. Usually a P-channel MOSFET is connected with positive voltage at the source, and more negative voltage at the drain. Very strange; this circuit has the device in "backwards!"

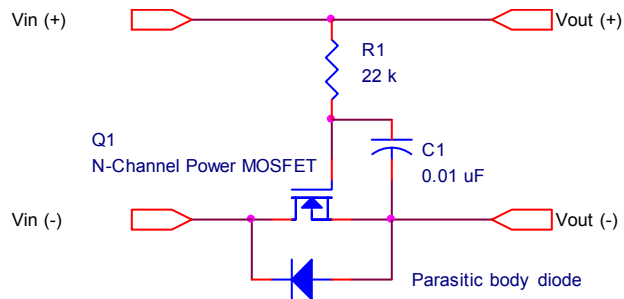
There is a parasitic "body diode" between the drain and source of the power MOSFET. This diode does not normally conduct unless a positive voltage appears across the drain-to-source of the device, as might happen when an inductive load is switched off. The implication in Figure 1 is *even if  $Q_1$  does not turn on in this "reverse" configuration, the body diode within  $Q_1$  will conduct and power will be transmitted to the load* (with a relatively high forward voltage drop of 0.7 V or more, of course).

$Q_1$  is turned "on" by the negative voltage placed on the gate through  $R_1$ . Even though the MOSFET is "backwards," it still conducts because the gate is negative with respect to the source (and channel).  *$Q_1$  therefore appears as a very low forward resistance in this mode, and the body diode does not conduct.*

When the input polarity is reversed,  $Q_1$  remains "off" because the gate is now forced positive with regard to the channel, and the load is effectively disconnected. The body diode is also reverse-biased in this condition. The load is thereby protected from the reversed power supply voltage.

*The implication here is that power MOSFETs will conduct equally well in either direction, as long as the gate to channel potential is enough to keep the device on. Even an AC signal can be coupled through the devices, with care (more on that in a minute).*

The addition of  $R_1$  and  $C_1$  in Figure 1 improve the ruggedness of the circuit by protecting the gate of  $Q_1$  from electrostatic discharge, always a concern with these devices. A device such as the IRF4905 would do a great job in this application; it's rated  $R_{DS(ON)}$  is only 0.02 ohms - - that's only a 0.4 v drop at a load of 20 A. That's pretty impressive performance - - and remember, if that's not good enough, you can readily add a second IRF4905 in parallel to drop the effective  $R_{DS(ON)}$  resistance even more!



*Figure 2: Low-Side Switching using N-Channel Device*

If interruption of the negative-ground line is not an issue, the N-channel version of Figure 2 is better, as N-channel devices have lower  $R_{DS(ON)}$  than their P-channel equivalents. This circuit works on exactly the same principles as the circuit of Figure 1.

### *Switching a Medium-Power AC Signal with a MOSFET*

The circuit of Figure 3 isn't the most practical in the world, but demonstrates that AC signal switching is indeed possible with these devices. The Figure 3 circuit is a medium-power speaker switch that could replace a mechanical relay in some applications.

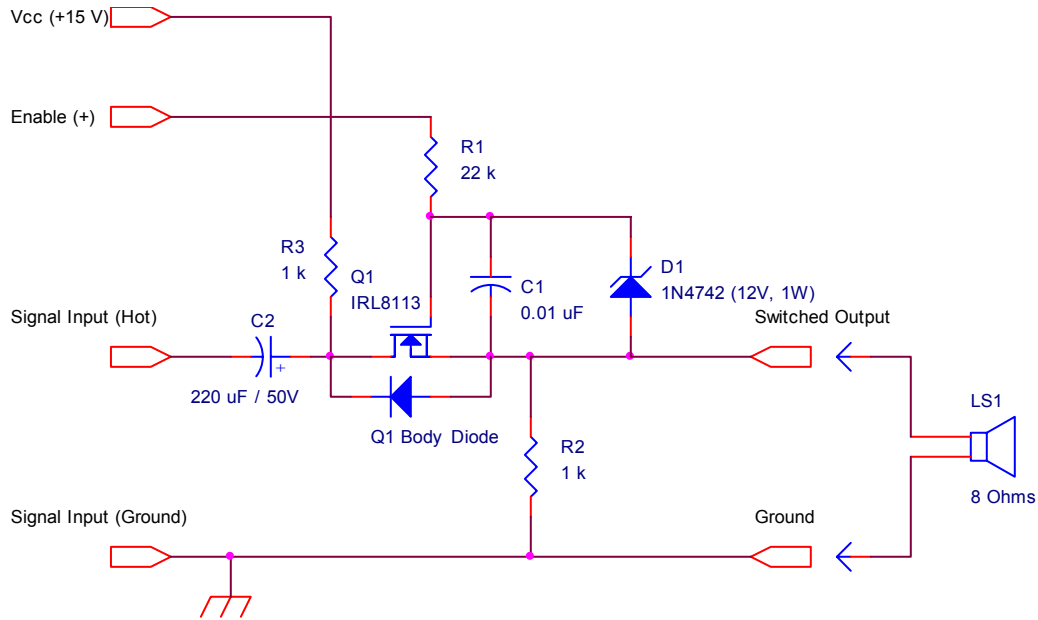


Figure 3: Solid State Speaker Switch using a power MOSFET.

The MOSFET in Figure 3 is switched on by applying a positive voltage ( $V_{cc}$ ) to the ENABLE input, which pulls the gate electrode up to  $V_{cc}$  through  $R_1$ . Since the MOSFET channel is at DC ground potential (ensured by  $R_2$  and/or the loudspeaker), it turns on and passes the signal through to the speaker. As long as the positive peak input signal voltage is less than or equal to  $[V_{cc} - V_{gs(sat)}]$ , the signal is passed with very low distortion, just as if it was passing through a very low value resistor.

The voltage  $V_{gs(sat)}$  varies from device to device, and is the minimum voltage between the gate and source to ensure full device turn-on. For the IRL8113 in this circuit, it's around 4 to 6 volts. If the input signal rises too close to  $V_{cc}$ , the MOSFET will begin to shut off, since the channel is carrying the signal voltage and the gate-to-channel potential is reduced on the positive half cycle. Figure 4 shows the voltage at the load for the above circuit with an audio input power of about 7 watts (21 volts p-p into 8 ohms). The signal is being passed with very low distortion.

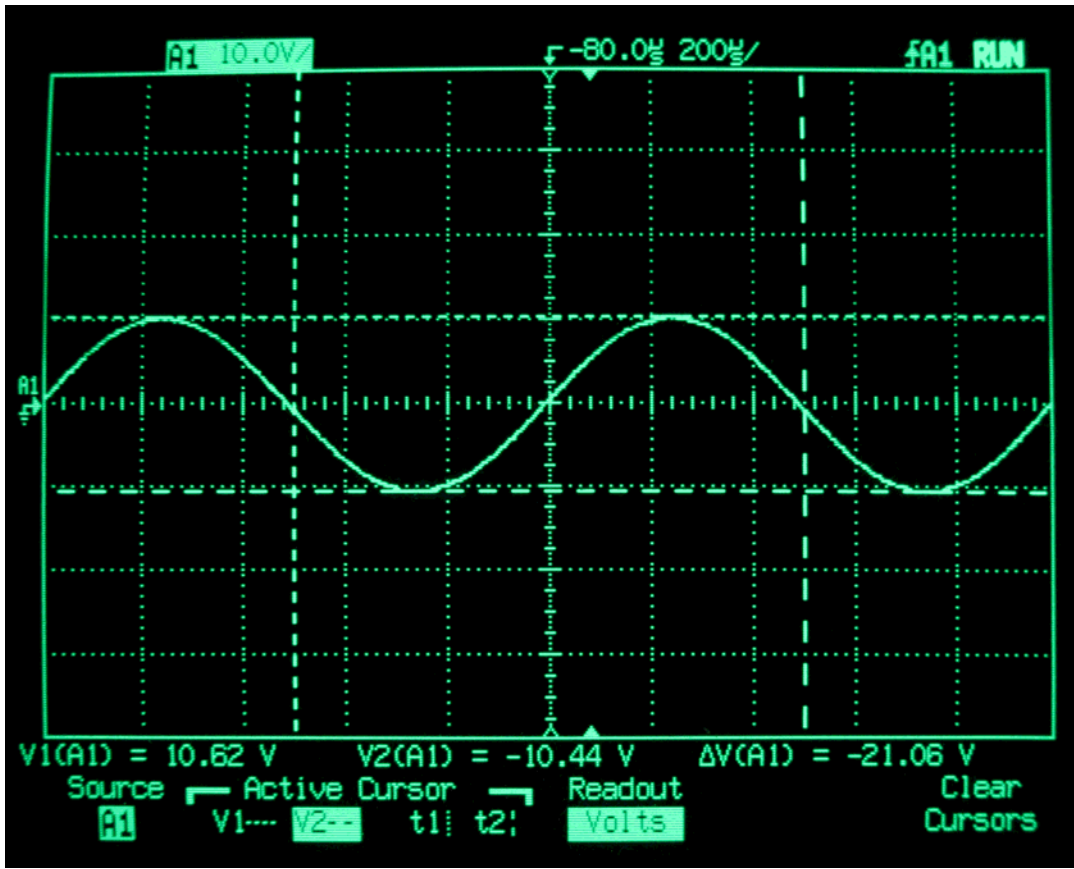


Figure 4: 21 Volt p-p Signal at the Load with the MOSFET Turned On

Turning off  $Q_1$  during the entire AC cycle is the challenging facet of this circuit. Of course, pulling the ENABLE input to ground turns off the MOSFET channel, but that pesky body diode between drain and source will still be in the way, causing a nice half-wave rectified version of the audio to be passed to the speaker unless we can get it out of the circuit.

No problem, though; an easy solution is to allow the drain of  $Q_1$  to be at a large positive voltage when the device is meant to be off. Resistor  $R_3$  pulls the drain up to  $V_{cc}$  when the MOSFET is off, while  $C_2$  blocks the DC voltage from the input source. This technique effectively reverse-biases the body diode, at least to a value of  $V_{cc}$  plus one diode drop. Figure 5 shows the MOSFET drain signal when the ENABLE input is grounded. It is the same input signal as before, but now rides on 15 volts DC.

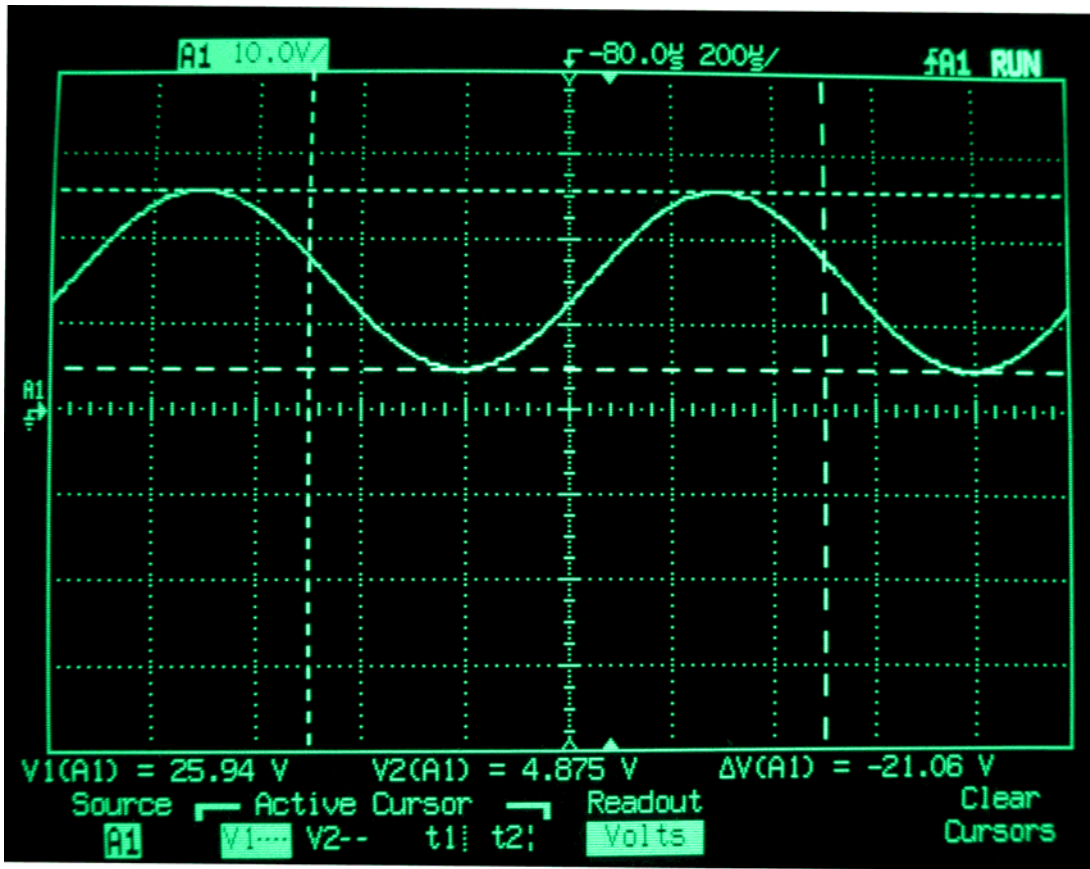


Figure 5: MOSFET Drain Signal with ENABLE Turned Off

A  $V_{cc}$  value of 15 volts is enough to block about 21 V p-p of audio. What limits this? There are two factors. First, if the signal passes too far below ground (remember, the gate is grounded in the OFF state), the MOSFET will start to turn on, passing distorted snippets of audio to the load.

The second limitation is the breakdown voltage of the body diode between drain and source. With the MOSFET in the OFF state, the source is held at approximately zero volts by the low-resistance load. The drain voltage, then, is the input signal riding on the  $V_{cc}$  DC bias (15 volts in this example). In our circuit, using an IR8113L MOSFET, the body diode is actually a Zener with a breakdown voltage of around 30 volts. This means that the positive half cycle can only be 15 volts peak (or less) before Zener conduction occurs, which again will pass distorted bits of audio to the load.

Note that with  $V_{cc}=15$  V, about 15 mA of static DC current flows into the loudspeaker through  $R_3$  when the MOSFET is on. It's probably possible to increase  $R_3$  to 5 k or 10 k to greatly reduce this unwanted current.

$D_1$  is absolutely necessary for protecting the gate of  $Q_1$ . Without it, a high-level audio signal at the input might cause the gate-to-source voltage  $V_{gs}$  to exceed the maximum permitted for the device (about 20 volts, typically), causing instant failure of the device.

*Conclusion*

In conclusion, power MOSFETs can be very effective for reverse polarity protection. Yes, they are more expensive than a diode, but the performance gain of reduced voltage drop may justify the cost in certain cases, especially where every millivolt of DC supply voltage counts.

Would you really want to use a power MOSFET as a speaker switch? No, probably not - - a relay is still a much better solution - - but it's an excellent demonstration of the ability of a power MOSFET to act like a very low value resistor, and conduct equally well in both directions. That's a fact that's not advertised in the data books that you can now add to your toolbox of circuit knowledge!