

Reverse Polarity Protection Using a P-Channel MOSFET

Companion Documentation for the Reverse Polarity Protection Board v2

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<https://ufelectronics.eu/product/reverse-polarity-protection-board-v2/>

The Reverse Polarity Protection Board is a compact utility PCB designed to protect DC-powered circuits against accidental reverse polarity connections. By using a P-channel MOSFET instead of a conventional series diode, the board achieves extremely low voltage loss while remaining configurable for supply voltages from 5 V to 48 V.

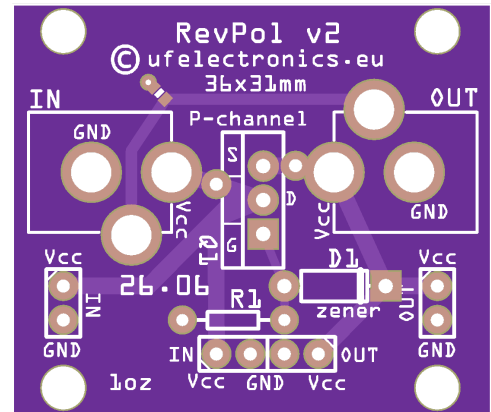
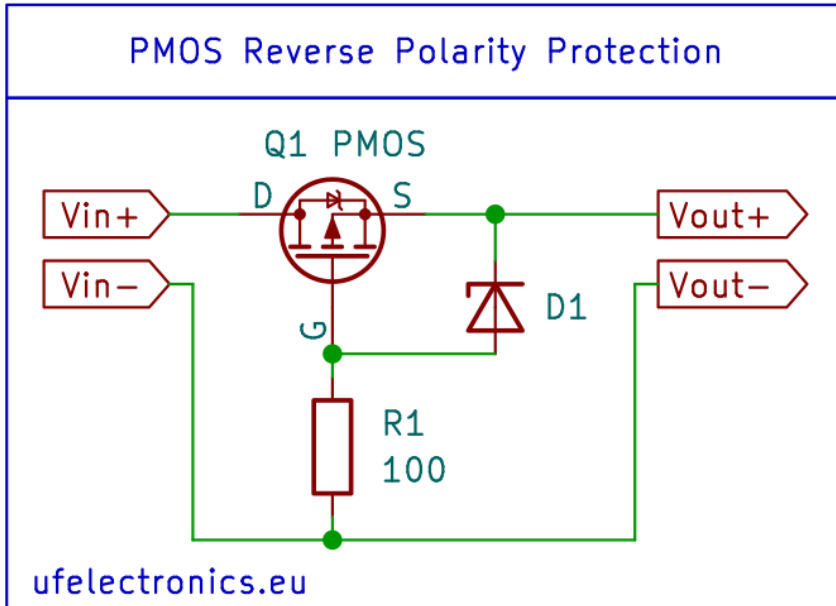
Features:	• Optional zener protection • Through-hole construction • Breadboard integration • Compact PCB
• Ultra-low voltage drop • Reverse polarity protection • Configurable for 5–48 V	

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The Board

The PCB follows partly the same layout philosophy used throughout the ufelectronics.eu boards. Signal traces remain visible on the component side, while the opposite side provides a continuous ground plane.



The protection circuit itself consists of only three functional components.

Despite its simplicity, these components provide highly efficient reverse polarity protection with very little voltage loss during normal operation.

The board is suitable both as a permanent installation and as a reusable building block for larger projects.

Power Connections

Power enters the board from the IN connector and leaves through the OUT connector.

Additional VCC and GND pin headers are provided along the lower edge of the PCB, making it easy to integrate the board with breadboards, prototype systems or other PCBs.

This allows the Reverse Polarity Protection Board to become a reusable front-end power module that can be connected to many different projects.

Breadboard Integration

The optional pin headers along the lower edge make it possible to plug the board directly into a breadboard or connect it to another PCB using standard 2.54 mm pin headers.

This simplifies evaluating the protection circuit before incorporating it into a permanent design.

How the Circuit Works

At first glance, the circuit appears almost too simple to work. It consists of only a P-channel MOSFET, a gate resistor and, for higher supply voltages, an optional zener diode. Nevertheless, these three components provide highly efficient reverse polarity protection with only a very small voltage drop during normal operation.

The key to understanding the circuit lies in the MOSFET's internal body diode.

Every power MOSFET contains a body diode as part of its internal construction. This diode cannot be removed and is always present, even though it is usually not shown on the simplified circuit symbol. The orientation of this diode determines how the circuit behaves during power-up and when the supply polarity is reversed.

Correct Polarity

When the supply is connected with the correct polarity, the source terminal of the P-channel MOSFET is connected to the positive supply voltage.

Initially, before the MOSFET has turned on, current flows through the internal body diode. Although this introduces a small voltage drop, it is only temporary and lasts for a very short time.

Because the gate resistor pulls the gate towards ground, the gate voltage becomes lower than the source voltage. This creates a negative gate-to-source voltage (V_{GS}), causing the MOSFET to turn on.

Once the MOSFET is fully enhanced, current no longer flows primarily through the body diode. Instead, it flows through the MOSFET channel, whose resistance is extremely low. The voltage drop across the protection circuit therefore falls from the diode's forward voltage to only a few millivolts, depending on the MOSFET's on-resistance and the load current.

The protection circuit now behaves almost like an ordinary piece of wire.

Reverse Polarity

If the supply is accidentally connected backwards, the source terminal becomes negative with respect to the drain.

In this situation, the internal body diode is reverse biased and therefore blocks current flow. At the same time, the gate-to-source voltage is no longer able to turn the P-channel MOSFET on.

With both the body diode and the MOSFET channel blocking current, virtually no current reaches the protected circuit.

As a result, the load is isolated from the reversed supply, preventing damage to the connected electronics.

Why the Body Diode Is Important

The body diode is sometimes misunderstood because, at first glance, it appears to point in the "wrong" direction.

In reality, its orientation is exactly what makes this protection circuit work. It allows a small initial current to flow when the supply is connected correctly, enabling the MOSFET to turn on. Once the MOSFET is conducting, the body diode is effectively bypassed by the low-resistance MOSFET channel.

When the supply polarity is reversed, the body diode blocks current completely, preventing the MOSFET from turning on and isolating the load from the reversed supply.

Together, the body diode and the MOSFET channel provide an elegant form of reverse polarity protection that combines the simplicity of a diode with the very low voltage drop of a fully enhanced MOSFET.

The three operating modes

Correct polarity	Normal Operation	Reverse Polarity
A small current initially flows through the MOSFET's body diode. The gate resistor pulls the gate low, creating a negative gate-to-source voltage and turning the MOSFET on.	Once the MOSFET is fully enhanced, almost all current flows through the MOSFET channel. The body diode is effectively bypassed, resulting in a very low voltage drop.	Reversing the supply reverse-biases the body diode and prevents the MOSFET from turning on. Current is therefore blocked and the load is protected.

Choosing a MOSFET from a datasheet

At first glance, a MOSFET datasheet can appear overwhelming. It is not unusual for a modern power MOSFET to have ten or more pages of electrical characteristics, graphs and application information. Fortunately, selecting a suitable MOSFET for this reverse polarity protection circuit is much simpler than it first appears.

Don't be intimidated by a 20-page datasheet. For this application, the six specifications below are usually all you need to select an appropriate P-channel MOSFET.

1. Maximum Drain-Source Voltage - V_{DS}

This is the maximum voltage the MOSFET can withstand between its drain and source terminals. Choose a device whose V_{DS} rating comfortably exceeds the highest supply voltage expected in your application.

2. Maximum Gate-Source Voltage - $V_{GS(max)}$

This specification tells you the largest gate-to-source voltage the MOSFET can safely tolerate. Most power MOSFETs are rated for ± 20 V. If your supply voltage can exceed this value, a gate protection zener diode should be included to prevent the MOSFET gate from being overstressed.

3. On-Resistance - $R_{DS(on)}$

$R_{DS(on)}$ is the resistance of the MOSFET when it is fully turned on. Lower values result in lower voltage drop, reduced power dissipation and improved efficiency. For reverse polarity protection, this is usually one of the most important specifications.

4. Continuous Drain Current - I_D

The continuous drain current specifies the maximum current the MOSFET can carry under the conditions stated in the datasheet. Select a device with a current rating comfortably above the maximum load current expected in your circuit.

Remember that the quoted value often assumes an ideal heatsink or PCB, so allowing a generous safety margin is good engineering practice.

5. Package

The package determines how easily the MOSFET can dissipate heat and how it can be mounted. Small packages such as SOT-23 are suitable for relatively low currents and compact designs. Larger packages such as TO-220 or TO-252 (DPAK) are generally better suited to higher currents because they can dissipate more heat. Choose a package that matches both your current requirements and the available PCB space.

6. Thermal Resistance

If your application carries several amperes of current, it is worth checking the MOSFET's thermal resistance. A lower thermal resistance allows heat to be transferred more effectively from the silicon junction to the surrounding environment, helping the MOSFET operate at a lower temperature. For low-current applications, this parameter is usually of secondary importance.

What Can Usually Be Ignored?

MOSFET datasheets often contain many additional graphs and specifications, including switching times, gate charge, capacitances, avalanche energy and reverse recovery characteristics. These parameters are important in high-frequency switching power supplies and motor controllers, but they have little influence on a reverse polarity protection circuit operating at DC.

For most applications described in this documentation, selecting a suitable MOSFET simply means checking:

1. Maximum V_{DS}

2. Maximum V_{GS}
3. $R_{DS(on)}$
4. Continuous drain current (I_D)
5. Package
6. Thermal resistance (for higher power applications)

Once these specifications are satisfied, the remaining pages of the datasheet can usually be ignored for this particular application.

Comparing Reverse Polarity Protection Methods

There are several ways to protect an electronic circuit against accidental reverse polarity. The simplest solution is a series diode, while more advanced designs often use a P-channel MOSFET.

Each method has advantages and disadvantages, and the most suitable solution depends on the application.

Comparison table

Method	Typical Voltage Drop	Efficiency	Component Count	Complexity	Typical Applications
Silicon diode	0.6–1.0 V	Low	1	Very Low	General-purpose circuits
Schottky diode	0.2–0.5 V	Good	1	Very Low	Battery-powered equipment
P-channel MOSFET	10–200 mV*	Excellent	2–3	Low	Low-loss and higher-current circuits

* Depends on the MOSFET's $R_{DS(on)}$ and the load current.

Silicon Diode

The silicon diode is the traditional solution for reverse polarity protection. It is inexpensive, easy to understand and requires only a single component. The drawback is its relatively large forward voltage drop, typically around 0.7 V. At higher currents, this results in noticeable power dissipation and reduces the voltage available to the load. For low-current applications powered from higher voltages, this may not be a significant problem.

Schottky Diode

A Schottky diode operates in much the same way as a silicon diode but has a lower forward voltage drop, typically 0.2–0.5 V. This improves efficiency and reduces heating. For many battery-powered projects, a Schottky diode is an excellent compromise between simplicity and performance. However, its voltage drop remains substantially higher than that of a suitably chosen MOSFET.

P-Channel MOSFET

Instead of relying on a diode's forward voltage, the MOSFET behaves like a very small resistor once it has turned on.

The resulting voltage drop is determined by

$$V_{DS} = I \times R_{DS(on)}$$

For modern MOSFETs with a low on-resistance, this voltage drop is often only a few tens of millivolts.

As a result:

- More supply voltage reaches the load.
- Less power is converted into heat.
- Higher currents can be handled efficiently.
- Battery life may be improved.

The only disadvantage is that the circuit requires a few more components than a single diode. For many applications, this small increase in complexity is more than justified by the improved efficiency.

For low-current applications, a silicon or Schottky diode may be perfectly adequate. However, when minimizing voltage loss and power dissipation is important - particularly in battery-powered or higher-current designs - a P-channel MOSFET is often the preferred solution.

Three Design Examples Follow

One of the main advantages of a P-channel MOSFET over a diode is its extremely low voltage drop.

Whereas a silicon diode typically drops about 0.7 V and a Schottky diode around 0.3-0.5 V, a suitably chosen MOSFET may drop only a few tens of millivolts under the same load current.

This means more of the supply voltage reaches the load, less power is dissipated as heat, and the circuit operates more efficiently.

The exact voltage drop depends on the MOSFET's on-resistance, $R_{DS(on)}$, and the load current according to $V_{DS} = I_D \times R_{DS(on)}$.

The following pages will go over three design examples.

- **Example 1:** 5-12 V systems (no zener required)
- **Example 2:** 12-24 V systems (introduces the zener and explains why it is needed)
- **Example 3:** 24-48 V systems (shows how to size the resistor for higher voltages and discusses resistor and zener power dissipation)

Design Example 1: 5-12 V systems (no zener required)

The Reverse Polarity Protection Board can be configured for different supply voltages simply by selecting suitable components. This section explains how to design the circuit for supply voltages between **5 V and 12 V**.

The design process consists of three simple steps:

1. Select the P-channel MOSFET.
2. Decide whether a zener diode is required.
3. Choose the gate resistor.

Step 1 - Selecting the P-Channel MOSFET

The P-channel MOSFET is the active component responsible for protecting the circuit. It acts as an almost ideal switch, producing only a very small voltage drop compared to an ordinary protection diode.

When selecting a MOSFET, three parameters are important.

- Maximum Drain-Source Voltage (V_{DS})
- Maximum Drain Current
- On-Resistance ($R_{DS(on)}$)

Maximum Drain-Source Voltage (V_{DS})

The MOSFET must be able to withstand the highest supply voltage that may ever be connected. For a circuit operating from 5 V to 12 V, a device rated for **20 V or 30 V** is usually sufficient. Higher voltage ratings may also be used, but are generally unnecessary for low-voltage applications.

Maximum Drain Current

Choose a MOSFET that can safely carry more current than your load requires.

For example:

Load Current	Suggested MOSFET Rating
200 mA	≥ 1 A
1 A	≥ 3 A
3 A	≥ 5 A
5 A	≥ 10 A

Using a generous safety margin improves reliability and reduces heating.

On-Resistance (RDS(on))

The MOSFET behaves like a very small resistor when turned on. Lower resistance means lower power dissipation.

For example, a MOSFET with

$$\mathbf{RDS(on) = 20\ m\Omega}$$

carrying

$$\mathbf{2\ A}$$

dissipates

$$P = I^2 \times R$$

which becomes

$$P = 2^2 \times 0.02 = 0.08\ W$$

Only 80 mW is converted into heat.

Whenever possible, choose a MOSFET with the lowest practical RDS(on).

Step 2 - Is a Zener Diode Required?

The purpose of the zener diode is to protect the MOSFET gate from excessive gate-to-source voltage (VGS).

Most P-channel MOSFETs specify

$$\mathbf{Maximum\ VGS = \pm 20\ V}$$

This means the gate must never be more than 20 V above or below the source. For a supply voltage of only **5-12 V**, this limit is never exceeded.

Even at 12 V, the largest possible gate-to-source voltage is approximately

$$\mathbf{-12\ V}$$

which is well within the $\pm 20\ V$ rating.

Therefore:

A zener diode is normally not required for 5-12 V applications.

Leaving the zener footprint unpopulated is perfectly acceptable.

Step 3 - Selecting the Gate Resistor

The resistor simply pulls the MOSFET gate towards ground whenever power is applied. Unlike bipolar transistors, MOSFET gates require almost no steady-state current. Consequently, the resistor value is not critical.

Typical values are:

Resistor	Typical Use
10 k Ω	Fast turn-on
22 k Ω	General purpose
47 k Ω	Lower current consumption
100 k Ω	Very low standby current

For most circuits, **47 k Ω** provides an excellent compromise between switching speed and power consumption.

Recommended Component Values

For most 5-12 V applications, the following components provide an excellent starting point.

Component	Recommended Value
P-channel MOSFET	20-30 V VDS rating
RDS(on)	As low as practical
Gate Resistor	47 k Ω
Zener Diode	Not fitted

Why No Zener?

Many reverse polarity protection circuits found online always include a zener diode. This is often done because the same circuit is intended to operate over a wide range of supply voltages, such as 12 V, 24 V and 48 V systems.

For supplies limited to **5-12 V**, the gate-to-source voltage never approaches the maximum rating of a typical P-channel MOSFET. Omitting the zener therefore simplifies the circuit without reducing reliability.

The zener diode becomes important only when the supply voltage can exceed the MOSFET's maximum allowable gate-to-source voltage, which is commonly ± 20 V.

Design Example 2: 12-24V Supply

Many industrial, automotive and hobby projects operate from supply voltages between **12 V and 24 V**. At these voltages, the P-channel MOSFET still provides an excellent reverse polarity protection solution, but one additional component now becomes important: the **gate protection zener diode**.

The design procedure remains simple and consists of three steps.

1. Select the P-channel MOSFET.
2. Select the zener diode.
3. Calculate the gate resistor.

Step 1 - Selecting the P-Channel MOSFET

The MOSFET should comfortably withstand the highest expected supply voltage while carrying the maximum load current.

Maximum Drain-Source Voltage (VDS)

Although the circuit may normally operate from a 24 V supply, power supplies are not always exactly 24 V. Batteries can be fully charged, adapters can have poor regulation, and voltage spikes may occur. For this reason, it is good practice to choose a MOSFET with a higher voltage rating than the normal operating voltage.

For a 12-24 V system, a **40 V or 60 V** MOSFET is usually a good choice.

Maximum Drain Current

The MOSFET should always be capable of carrying more current than the load requires. A comfortable safety margin reduces heating and improves reliability.

On-Resistance (RDS(on))

Power dissipation is determined by the MOSFET's on-resistance.

For example:

- Load current: **3 A**
- RDS(on): **25 mΩ**

Power dissipation becomes

$$P = I^2 \times R \quad \Rightarrow \quad P = 3^2 \times 0.025 = 0.225 \text{ W}$$

Only 225 mW is dissipated in the MOSFET.

Whenever possible, choose the lowest practical RDS(on).

Step 2 - Why Is a Zener Diode Now Needed?

This is the first supply range where the gate protection zener becomes useful.

Most P-channel MOSFETs specify a maximum gate-to-source voltage of

$\pm 20\text{ V}$

If the gate were connected directly to ground while operating from a 24 V supply, the gate-to-source voltage would become approximately

-24 V

which exceeds the MOSFET's maximum rating.

Although the MOSFET may continue working for some time, repeated operation beyond this limit can permanently damage the thin gate oxide layer. A zener diode connected between the gate and source prevents this from happening.

Whenever the gate-to-source voltage reaches the zener voltage, the zener begins conducting and limits the voltage seen by the MOSFET gate.

The MOSFET is therefore protected regardless of further increases in supply voltage.

Selecting the Zener Voltage

The zener voltage should always be lower than the MOSFET's maximum gate-source voltage.

Typical choices are:

Zener Voltage	Suitable For
10 V	Logic-level MOSFETs
12 V	General-purpose circuits
15 V	High-voltage MOSFETs

For most 12-24 V applications, a **12 V zener diode** is an excellent choice.

It provides plenty of protection while still allowing the MOSFET to turn fully on.

Step 3 - Calculating the Gate Resistor

The resistor supplies the current required by the zener diode whenever the input voltage exceeds the zener voltage.

The resistor value is calculated from

$$R = (V_{IN(max)} - V_Z) / I_Z$$

where

- $V_{IN(max)}$ is the highest expected input voltage
- V_Z is the zener voltage
- I_Z is the desired zener current

A zener current of approximately **1-2 mA** is usually sufficient.

Example Calculation

Assume

- Maximum supply voltage: **24 V**
- Zener voltage: **12 V**
- Desired zener current: **1.5 mA**

Then

$$R = (24 - 12) / 1.5 \text{ mA}$$

which gives

$$R = 8 \text{ k}\Omega$$

The nearest preferred value is

8.2 k Ω or 10 k Ω

Both are suitable.

Checking the Resistor Power

The resistor dissipates only a small amount of power.

With a 12 V voltage drop across an 8.2 k Ω resistor, the current is approximately 1.46 mA

The resistor power becomes

$$P = V \times I$$

$$P = 12 \times 1.46 \text{ mA}$$

$$P \approx 18 \text{ mW}$$

Even a standard ¼ **W resistor** has a large safety margin.

Checking the Zener Power

The zener dissipates

$$P = V_Z \times I_Z$$

Using the previous example,

$$P = 12 \times 1.46 \text{ mA}$$

$$P \approx 18 \text{ mW}$$

Again, this is far below the rating of even the smallest commonly available zener diodes.

Recommended Component Values

The following components provide a good starting point for most 12-24 V designs.

Component	Recommended Value
P-channel MOSFET	40-60 V VDS rating
Maximum VGS	±20 V
RDS(on)	As low as practical
Gate Resistor	8.2-10 kΩ
Zener Diode	12 V, 500 mW

Summary

Compared to a 5-12 V design, the addition of the zener diode is the only significant difference. At 24 V, the gate-to-source voltage of the MOSFET can exceed its safe operating limit if left unprotected. The zener diode prevents this by clamping the gate voltage to a safe level, while the resistor limits the zener current. Together, these two inexpensive components greatly improve the robustness of the reverse polarity protection circuit without affecting its normal operation.

Design Example 3: 24-48V Supply

Industrial control systems, telecommunications equipment and battery-powered systems often operate from supply voltages between **24 V and 48 V**.

At these voltages, the Reverse Polarity Protection Board requires careful component selection. The MOSFET must withstand the higher input voltage, the zener diode must protect the MOSFET gate, and the gate resistor must be chosen so that neither the resistor nor the zener dissipates excessive power.

Fortunately, the design procedure remains straightforward.

1. Select the P-channel MOSFET.
2. Select the zener diode.
3. Calculate the gate resistor.
4. Verify the resistor and zener power dissipation.

Step 1 - Selecting the P-Channel MOSFET

The MOSFET should comfortably exceed both the maximum operating voltage and the expected load current.

Maximum Drain-Source Voltage (VDS)

For supplies up to **48 V**, it is good engineering practice to allow some safety margin. A MOSFET with a **60 V** rating is usually suitable. If the supply may experience switching transients or inductive voltage spikes, an **80 V or 100 V** MOSFET provides additional protection.

Maximum Drain Current

Select a device capable of carrying more current than your application requires. For reliable operation, a safety margin of at least **two times** the expected load current is recommended.

On-Resistance (RDS(on))

Power loss inside the MOSFET is determined by its on-resistance.

For example,

- Load current: **5 A**
- RDS(on): **20 mΩ**

The power dissipation is

$$P = I^2 \times R \Rightarrow$$

$$P = 5^2 \times 0.020 = 0.50 \text{ W}$$

Half a watt is easily manageable for many TO-220 devices, although a heatsink may be desirable depending on the application.

Step 2 - Selecting the Zener Diode

The gate oxide inside a MOSFET is extremely thin and can be permanently damaged if the maximum gate-to-source voltage is exceeded.

Most P-channel MOSFETs specify

$$\text{Maximum } V_{GS} = \pm 20 \text{ V}$$

Without a zener diode, applying a 48 V supply would produce approximately

$$V_{GS} = -48 \text{ V}$$

which is more than twice the allowable limit.

A zener diode connected between the gate and source prevents this by clamping the gate voltage to a safe value.

Choosing the Zener Voltage

The zener voltage should be comfortably below the MOSFET's maximum V_{GS} rating.

Typical choices are:

Zener Voltage	Typical Application
12 V	General-purpose designs
15 V	Higher-voltage MOSFETs

For most 24-48 V systems, a **12 V zener** is recommended. This provides a generous safety margin while allowing the MOSFET to turn fully on.

Step 3 - Calculating the Gate Resistor

Unlike the lower-voltage examples, the resistor must now be calculated rather than simply selected. The resistor limits the current flowing through the zener diode whenever the input voltage exceeds the zener voltage.

The required resistance is

$$R = (V_{IN(max)} - V_Z) / I_Z$$

where

- $V_{IN(max)}$ is the highest expected input voltage
- V_Z is the zener voltage
- I_Z is the desired zener current

A zener current of approximately **1-2 mA** is normally sufficient. Higher currents provide no additional protection and simply waste power.

Example Calculation

Assume

- Maximum supply voltage: **48 V**
- Zener voltage: **12 V**
- Desired zener current: **2 mA**

Then

$$R = (48 - 12) / 2 \text{ mA}$$

which gives

$$R = 18 \text{ k}\Omega$$

The nearest preferred resistor values are

18 k Ω or 22 k Ω

Both are suitable.

Step 4 - Checking the Resistor Power

The resistor dissipates power whenever the zener diode is conducting.

The resistor voltage is

$$V_R = V_{IN(max)} - V_Z$$

which becomes

$$V_R = 48 - 12 = 36 \text{ V}$$

The resistor current is

$$I = 36 \text{ V} / 18\,000 \, \Omega$$

$$I = 2 \text{ mA}$$

The resistor power is therefore

$$P = V \times I$$

$$P = 36 \times 2 \text{ mA}$$

$$P = 72 \text{ mW}$$

Even a standard $\frac{1}{4}$ **W resistor** provides a comfortable safety margin.

Step 5 - Checking the Zener Power

The zener dissipates

$$P = V_Z \times I_Z$$

which becomes

$$P = 12 \text{ V} \times 2 \text{ mA}$$

$$P = 24 \text{ mW}$$

Again, this is far below the rating of a common **500 mW zener diode**.

Recommended Component Values

The following values provide a good starting point for most 24-48 V applications.

Component	Recommended Value
P-channel MOSFET	60-100 V VDS rating
Maximum VGS	± 20 V
RDS(on)	As low as practical
Gate Resistor	18-22 k Ω
Zener Diode	12 V, 500 mW

Why Not Use a Smaller Resistor?

A common misconception is that increasing the zener current improves protection. In reality, once the zener diode is operating within its specified range, additional current provides little or no benefit.

For example, using a **4.7 k Ω** resistor instead of **18 k Ω** increases the zener current to approximately **7.7 mA** at 48 V.

The MOSFET is not better protected, but both the resistor and the zener dissipate significantly more power. A larger resistor reduces power consumption while still allowing the zener to clamp the gate voltage effectively.

Summary

For 24-48 V systems, all three components become important design choices. The MOSFET must have an adequate drain-source voltage rating, the zener diode protects the sensitive gate oxide from excessive gate-source voltage, and the resistor is calculated to provide sufficient zener current without unnecessary power loss. By selecting these components carefully, the same reverse polarity protection circuit can be adapted for a wide range of industrial and battery-powered applications while maintaining excellent efficiency and reliability.

Suggestions?

Have suggestions for improvements, or need a personalized PCB design? - Feel free to get in touch:

Contact

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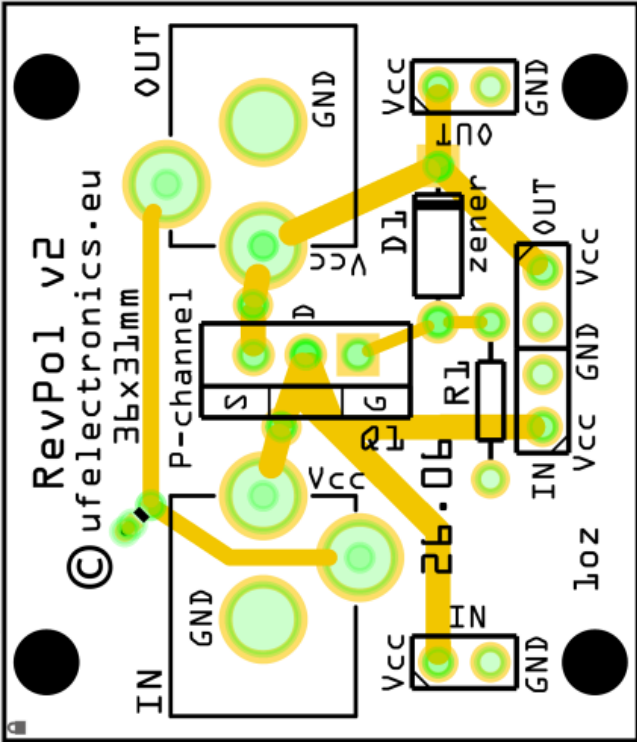
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Assembly Sheet

Reverse Polarity Protection Board - v2 - Assembly Sheet				
Circuit	Vers. / Date :		Value	
			Value	
	Q1			
	R1			
	D1			
Notes	Vcc:			