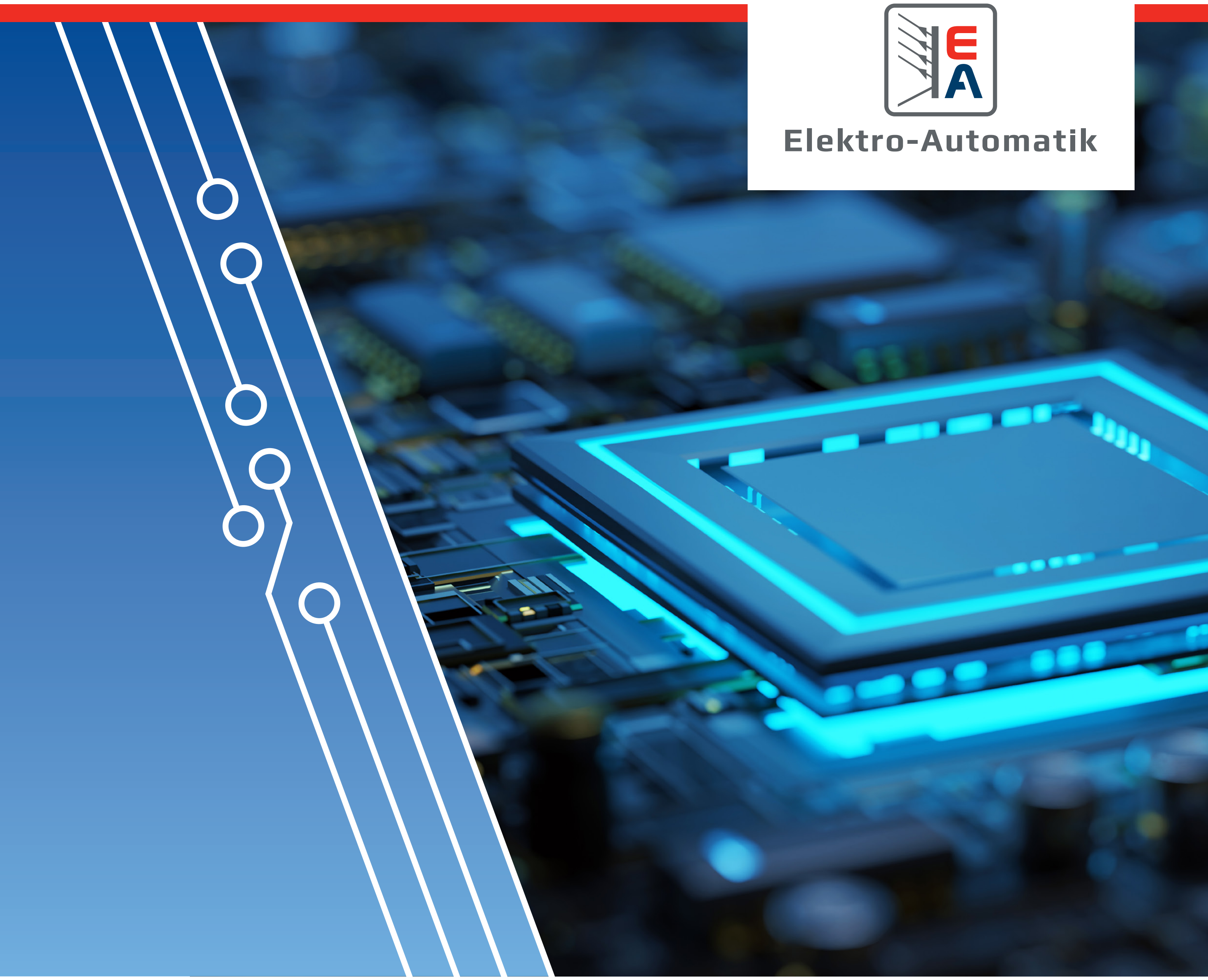
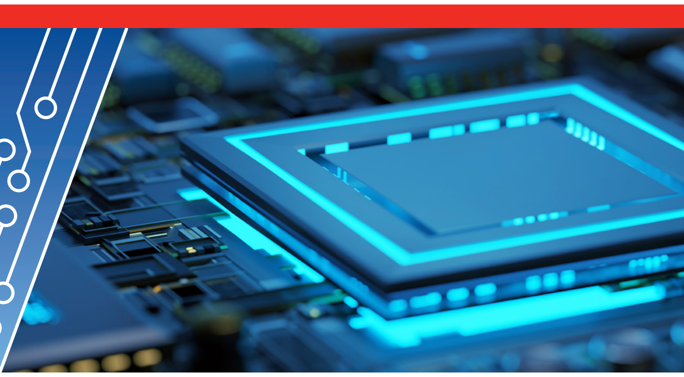
Elektro-Automatik



WHITE PAPER:
ENSURE PROTECTED, RELIABLE OPERATION FOR A DC POWER SUPPLY IN ANY LOAD CIRCUIT



Connecting a DC power supply to a load appears to be a simple, straightforward task. In many situations, this is true; however, other situations can prove challenging. While manufacturers of DC power supplies design their supplies to be stable when powering any type of load, that does not mean the power supply is impervious to certain load characteristics that can cause problems. An inductive or a capacitive load can apply energy to the power supply, which can damage the power supply's output stage. The output stage is designed to deliver power, not absorb it. Similarly, active loads, such as batteries, can deliver damaging power to a supply.

As well as delivering energy to the power supply, some capacitive loads, inductive loads and loads that generate substantial rapid changes in load current, can create conditions that lead to oscillation. Both the power supply and the load are susceptible to damage. Furthermore, testing is interrupted since the load is not getting a stable DC voltage for proper operation. Another factor that can cause conditions for oscillation is the wiring between the power supply and the load. Noise can couple into sensitive remote sense lines and interfere with the voltage control circuit.

This white paper will describe various types of loads that can be potentially hazardous to DC power supplies. Also, the following paragraphs will describe types of loads that can cause oscillation in a power supply-load circuit and wiring conditions that also can result in oscillation. For each type of load and circuit condition, we will offer solutions to these challenges. Our recommendations will ensure reliable power supply operation and load protection.

Inductive Loads

An inductive load can be an energy source that can feed into a power supply and damage the supply. Thus, power supplies must be protected from inductive loads such as motors, solenoids, and electromechanical relays. When a power supply applies voltage and current to an inductive load, a magnetic field builds up around the inductive load and becomes a source of potential energy. The potential energy, U in Joules, is $\frac{1}{2} \cdot L \cdot I^2$, where L is the inductance of the load in Henries, and I is the current through the load in Amps. When the power delivered to the load is removed, its magnetic field collapses and induces a current in the opposite polarity of the delivered current. The current creates a voltage spike determined by the equation $V = L \cdot di/dt$, which is the voltage developed across the inductor with inductance, L, and di/dt, the rate of change of the delivered current. Since di/dt is negative, the voltage spike has the opposite polarity of the delivered voltage. This reverse voltage spike goes under multiple names known as back EMF, counter EMF, or flyback voltage. The formula for the voltage across the inductive load indicates that the faster the current changes, the greater the magnitude of the voltage spike. The voltage spike can be much higher than the voltage the power supply was delivering. Thus, the back EMF from the inductive load can enter and damage the power supply.

Protect the power supply by putting a reverse bias diode across the output of the power supply. This diode is known as a flyback diode or a freewheeling diode. Connect the diode such that the cathode is connected to the high output of the supply, and the anode is connected to the low output terminal, as shown in Figure 1.

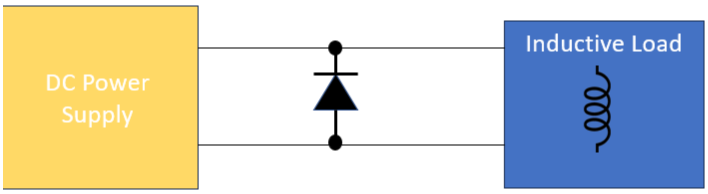
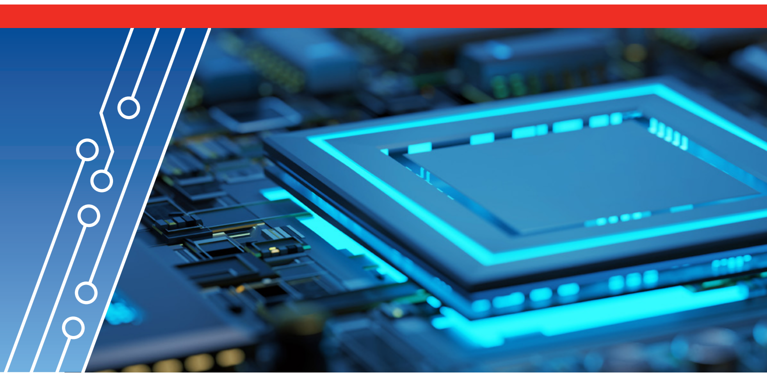


Figure 1. Use of a flyback diode to protect the power supply from back EMF.

When the power supply is delivering voltage to the load, the diode is reversed-biased and has no effect on the circuit. When the power supply output goes to a low value or turns off, the back EMF developed across the inductor forward biases the diode so that the current generated by the inductor flows through the diode and not the power supply. Thus, the freewheeling diode protects the power supply from the back EMF of the inductive load.



Capacitive Loads

A capacitive load such as a supercapacitor, a capacitor load bank or a filter can generate voltage spikes that can be hazardous to a power supply. Like an inductive load, a capacitive load stores potential energy, U in Joules, as $1/2 \cdot C \cdot V^2$, where C is the effective capacitance in Farads and V is the voltage across the capacitive load. When the power supply voltage falls below the voltage that had been on the load, the load delivers a current determined by $I = C \cdot dV/dt$. Again, the faster the voltage change rate, the higher the current directed at the power supply. The current surge develops a voltage in the circuit across the power supply. This reverse load current and voltage can damage the power supply.

To protect the power supply from this situation, add a series diode on the output of the power supply to keep reverse currents from capacitive loads out of the power supply. Connect the diode as shown in Figure 2. As long as the diode is forward-biased, current will flow from the power supply to energize the load. When the power supply voltage turns off or falls to a lower value than the voltage on the capacitive load, the diode will become back-biased and prevent the discharge of reverse current from the capacitive load into the power supply.

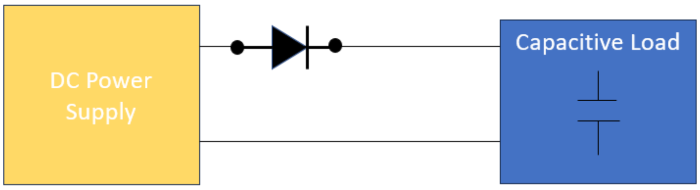


Figure 2. A series diode protects the power supply from capacitive load discharge.

Battery Loads

A battery is an electrochemical power source. DC Power supplies can test and charge rechargeable batteries. As a power source, a battery can be very damaging to a power supply. Hence, batteries and capacitive loads are similar. If the voltage on the battery exceeds the power supply voltage, the battery will discharge into the power supply just as the capacitive load does under a similar situation. Using the series diode, as shown in Figure 2, will protect the power supply from the battery discharge current.

PROTECTING THE BATTERY LOAD

While a battery can damage a power supply, the converse situation can also be true. The supply can damage the battery. If a battery is connected to a power supply for a charging application, a reverse polarity connection can immediately damage the battery, and the power supply current flows from the battery to the power supply. A reversed battery connection can easily occur in automated or semi-automated systems with batteries moving down manufacturing lines. A safe battery test system needs a polarity detection circuit and a contactor. The polarity detection circuit prevents the contactor from closing and applying power to the incorrectly connected battery. Figure 3 illustrates a battery polarity protection circuit.

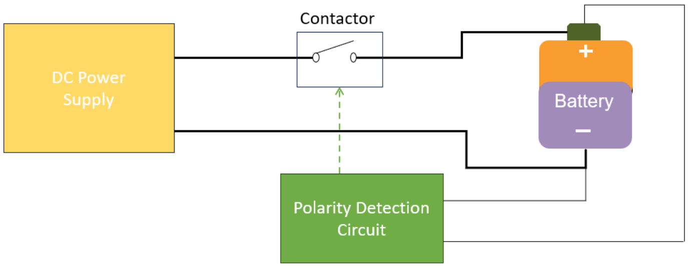
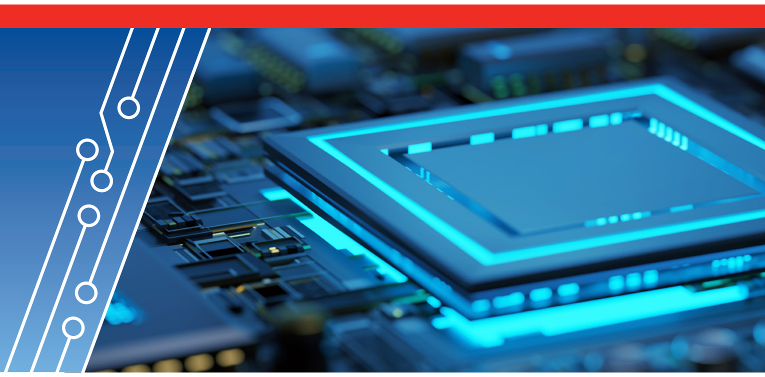


Figure 3. A polarity detection circuit controls a contactor to prevent applying power to a battery if the battery has been incorrectly connected into the circuit.

PROTECTING THE SUPPLY AND THE LOAD FROM OSCILLATION

Some types of loads can potentially cause the power supply to oscillate. Oscillations can potentially damage both the power supply and the load. The types of loads can be highly capacitive loads that can introduce phase shifts and impedance mismatches in the power supply–load circuit. An inductive load can also create instabilities. A third type of load that can cause an oscillation is one that has the characteristics of having fast step changes in current. An example is an electric motor drive system where the load current changes quickly during acceleration and deceleration.

As with harmonics, filters can mitigate the effects of highly reactive loads and loads with fast-changing characteristics. Figure 4 shows some possible filtering implementations. The capacitors connected to the load can provide a source of instantaneous current when a load has a nearly instantaneous



increase in current. This will help to stabilize the load voltage. The capacitors also provide decoupling and noise suppression. The Pi-filter adds an inductor that isolates the power supply from high-frequency noise and the high-frequency components generated by the load. This helps to improve circuit stability.

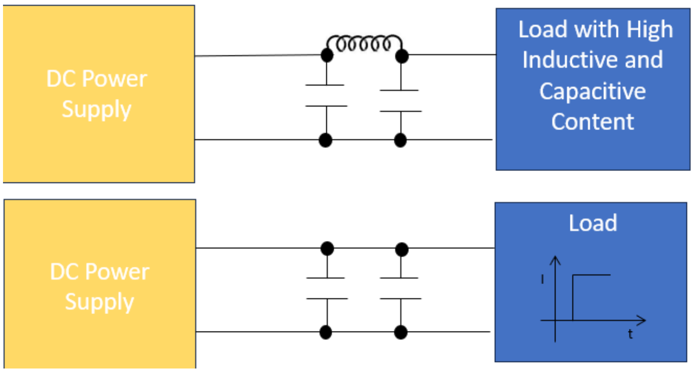


Figure 4. (Top figure) A Pi filter can isolate the power supply from high-frequency effects.

(Bottom figure). The capacitors, when charged, provide a source of current to stabilize the supply voltage when the load has a large instantaneous current increase.

The wiring between source and load can also be a source of oscillation. This can be true when using remote sensing to ensure that the voltage applied to the load is the programmed voltage. When the load draws high current, remote sensing compensates for voltage drops in the lead wires and other power supply–load circuit components.

The sense lines connect to a high-impedance input measurement circuit, essentially a voltmeter, so that the sense circuit does not draw any appreciable current from the load. The measurement circuit detects the noise and transfers that signal to the power supply error control circuitry. Any noise on the sense lines transfers to the input of the error amplifier. This can cause the output to oscillate with the noise. Figure 5 illustrates how remote sensing compensates for the voltage drops across load circuit lead wires.

While remote sensing, as shown in Figure 5, compensates for the voltage drop due to lead resistance, the figure oversimplifies the actual circuit the power supply is powering. Figure 6 depicts the more complete load circuit applied to the power supply. Test leads, whether they are unshielded or shielded wires, are actually a distributed network of resistance, inductance, and capacitance. The capacitance is effectively connected to the earth ground plane for unshielded wire or the shield if using shielded cable.

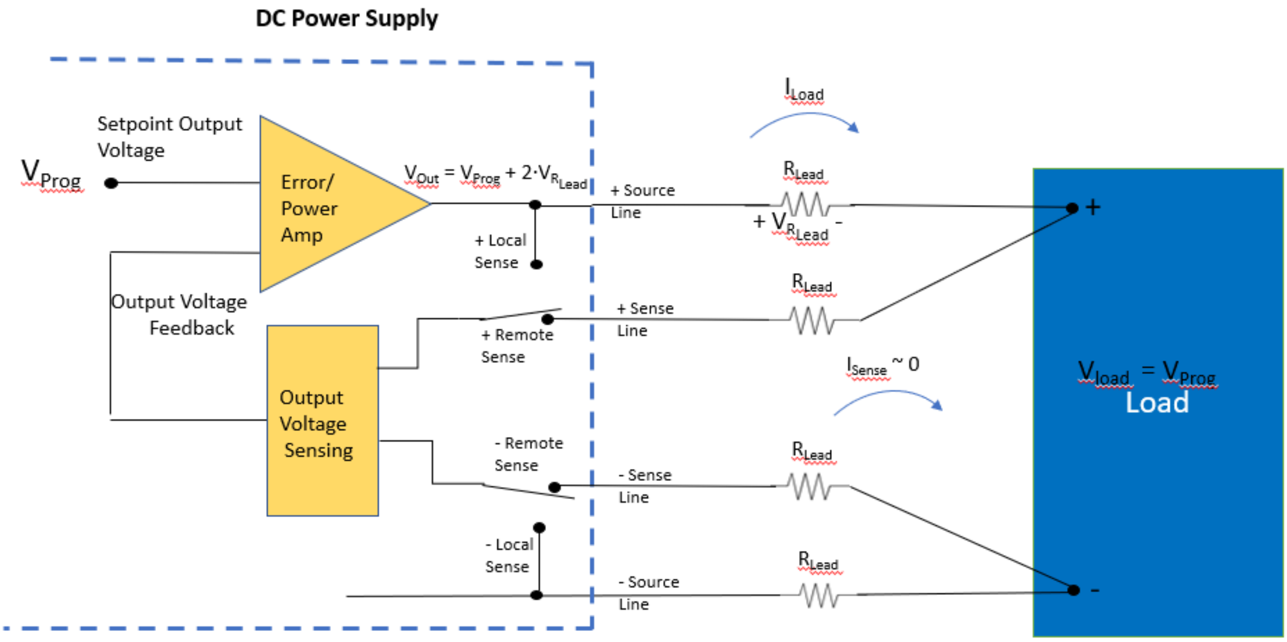
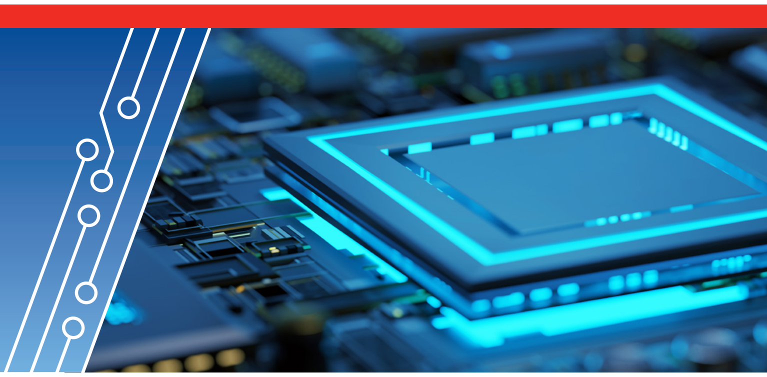


Figure 5. Remote sensing at the load enables the power supply to compensate for the voltage drop in the lead wires and ensure that the programmed voltage is applied to the load.



The reality is that the load is an R-L-C network. Even though the power supply is delivering DC voltage, no power supply output is noise-free, and this noise on an R-L-C network can lead to a resonance condition and oscillation. Eliminating the oscillation can be a difficult challenge, and there is no guaranteed, straightforward solution. Solving the problem requires a trial-and-error approach.

Here are some suggestions:

- If the oscillation is seen on the current output– add a damping circuit.
- If the oscillation is seen on the voltage output – try increasing the capacitance value either on the DC terminals of the power supply or on the device-under-test.
- Add capacitance with a small resistor on the DC + side.
- Reduce the length of the test leads between the power supply and load if that is possible.
- Use remote sense lines parallel to the source wires (preferably taped to the wires). If the sense line is connected in parallel to the source line, the source and sense lines influence each other in such a way that the phase shift of the measuring voltage caused by inductance is compensated, which removes the resonance basis for the voltage oscillation.
  - Twisting remote sense and source wires together can also help.
- Another option is to separate the source and sense wires as shown in Figure 7. Using twisted pair wire minimizes loop area and minimizes induced voltage in the sense lines. In addition, use shielded, twisted pair wire to keep external electromagnetic interference (EMI) out of the sense lines.

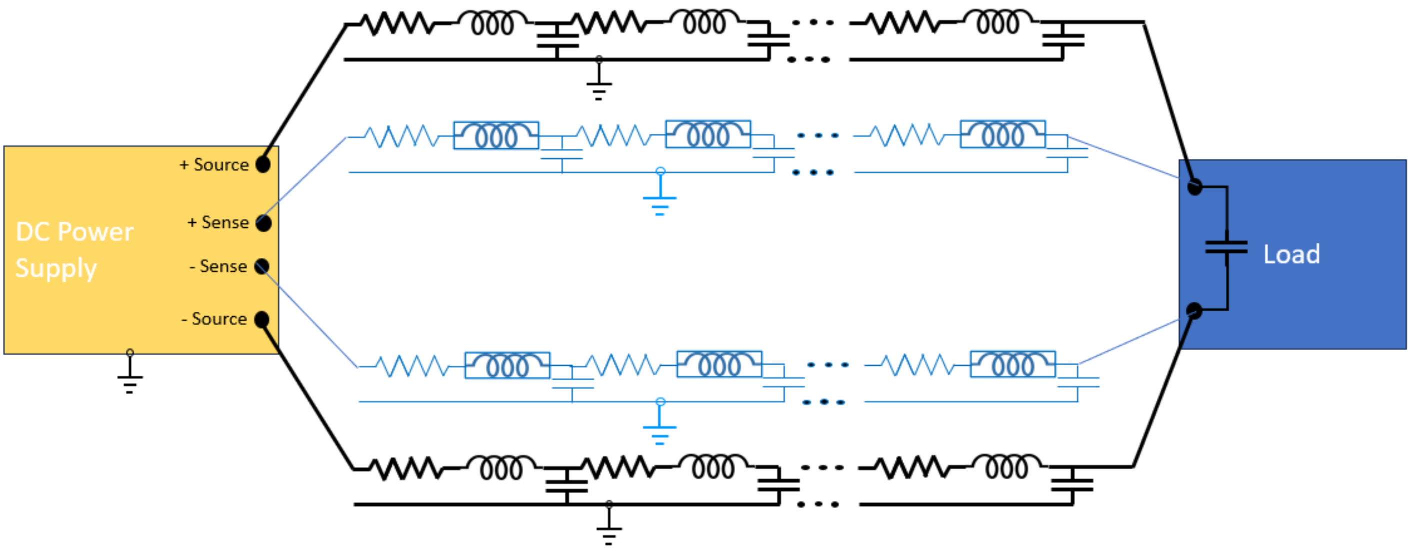
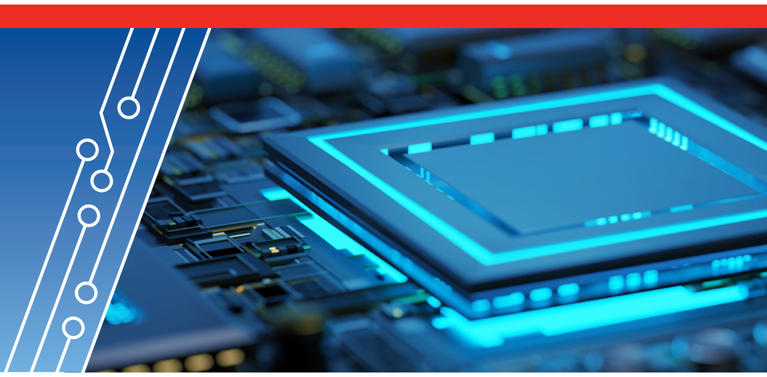


Figure 6. A power supply-load circuit with the source and sense lead wires represented as distributed R-L-C networks. Even though the power supply is delivering DC voltage, the circuit is essentially an AC network.



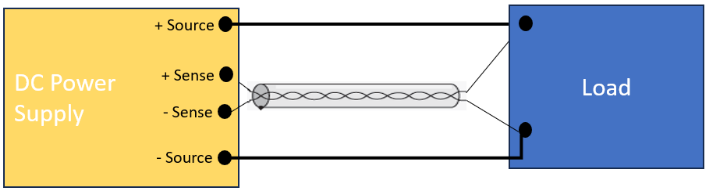


Figure 7. Another option for avoiding oscillation in some circuits: shielded, twisted pair, remote sense wires separate from the source wires.

Employing proper grounding techniques avoids the possibility that noisy ground currents can flow into the power supply wiring, creating instability in the voltage-sensing circuitry. Ensure that the power supply-load circuit is earth grounded at only one point, typically at the power supply. Figure 8, using the separate sense lead configuration, shows the ground current that can flow through the sense lines when both the load and the power supply are tied to earth ground and the two grounds are at a slightly different potential.

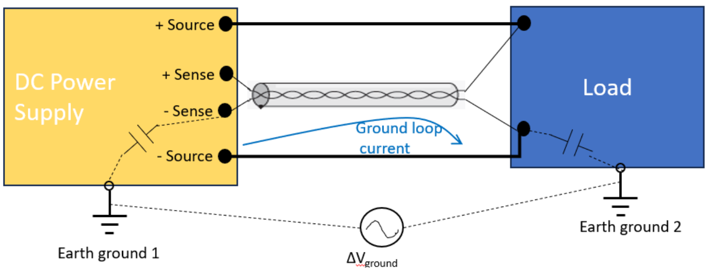


Figure 8. Noisy ground current enters the sense circuit when the DC power supply and load are at different voltages.

Keeping the wiring between the power supply and load as short as possible reduces the total distributed capacitance and inductance in the supply wires and lessens the possibility of oscillation. Shielding the wiring reduces the chances of picking up noise from external sources.

AN ALTERNATIVE TYPE OF POWER SUPPLY

An alternative to using external components to protect a supply is to consider a bi-directional power supply. A bi-directional power supply can be either a power supply or an electronic load. This type of power supply can safely absorb and deliver power. The bi-directional power supply can safely absorb power from capacitive loads, inductive loads, and active loads. A bi-directional power supply is cost-effective when a DC test circuit needs both source and load functionality at different times during a test protocol. One example of a bi-directional DC power supply is the EA Elektro-Automatik PSB 10000 with integrated, regenerative electronic load and true autoranging, which means that the full source and sink power of the devices is available over a wide operating range.

KNOW THE CHARACTERISTICS OF THE LOAD AND THE SUPPLY

While power supplies are designed to be stable sources of DC voltage, the type of load can interfere with power supply performance. Some load types have the potential to damage supplies. Other load types have characteristics that can cause the power supply to damage the load. Furthermore, loads and wiring to the load can cause oscillations, potentially damaging both the power supply and the load. It is essential to understand the characteristics of the load to ensure that the power supply–load circuit protects both the power supply and the load. The recommendations for guarding against conditions that can result in power supply and/or load failure will ensure reliable DC sourcing and safe energizing of a load.

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