

EMI Filter Basics

DC-DC Converters, EMI Filters
& Accessories for Aerospace,
Defense, and Space Systems

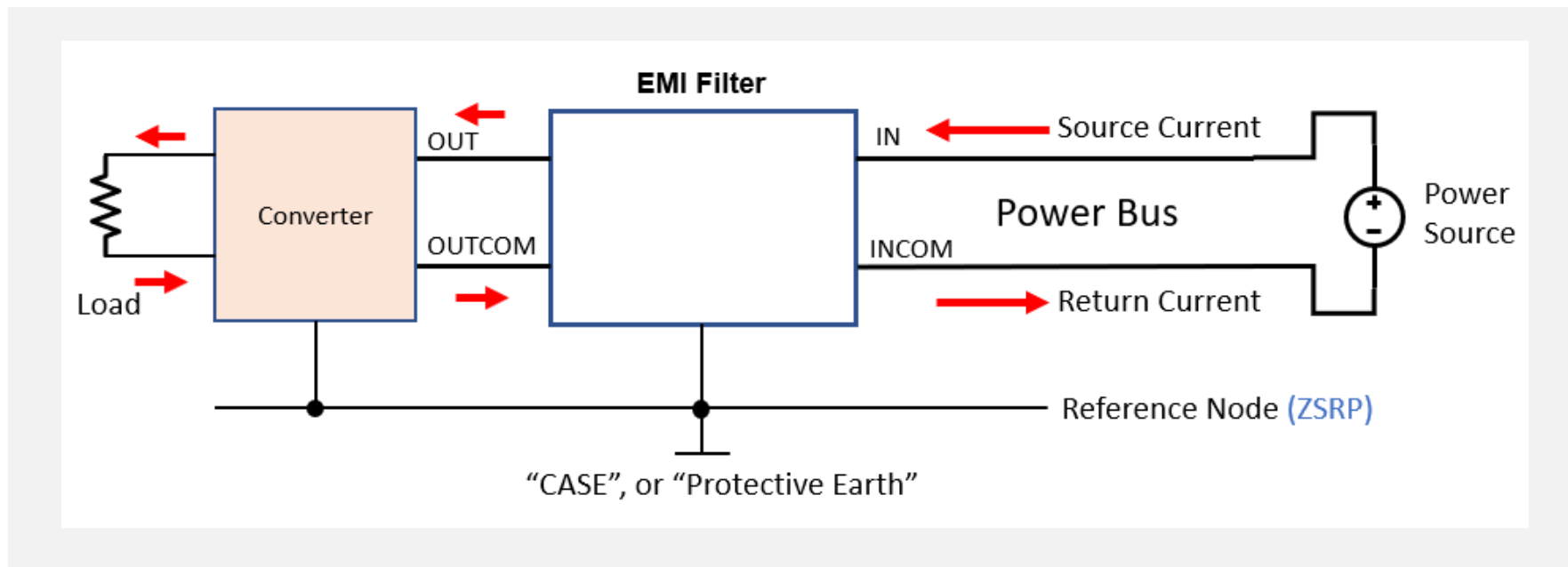


MIL-STD-461 Conducted Emissions Measurements



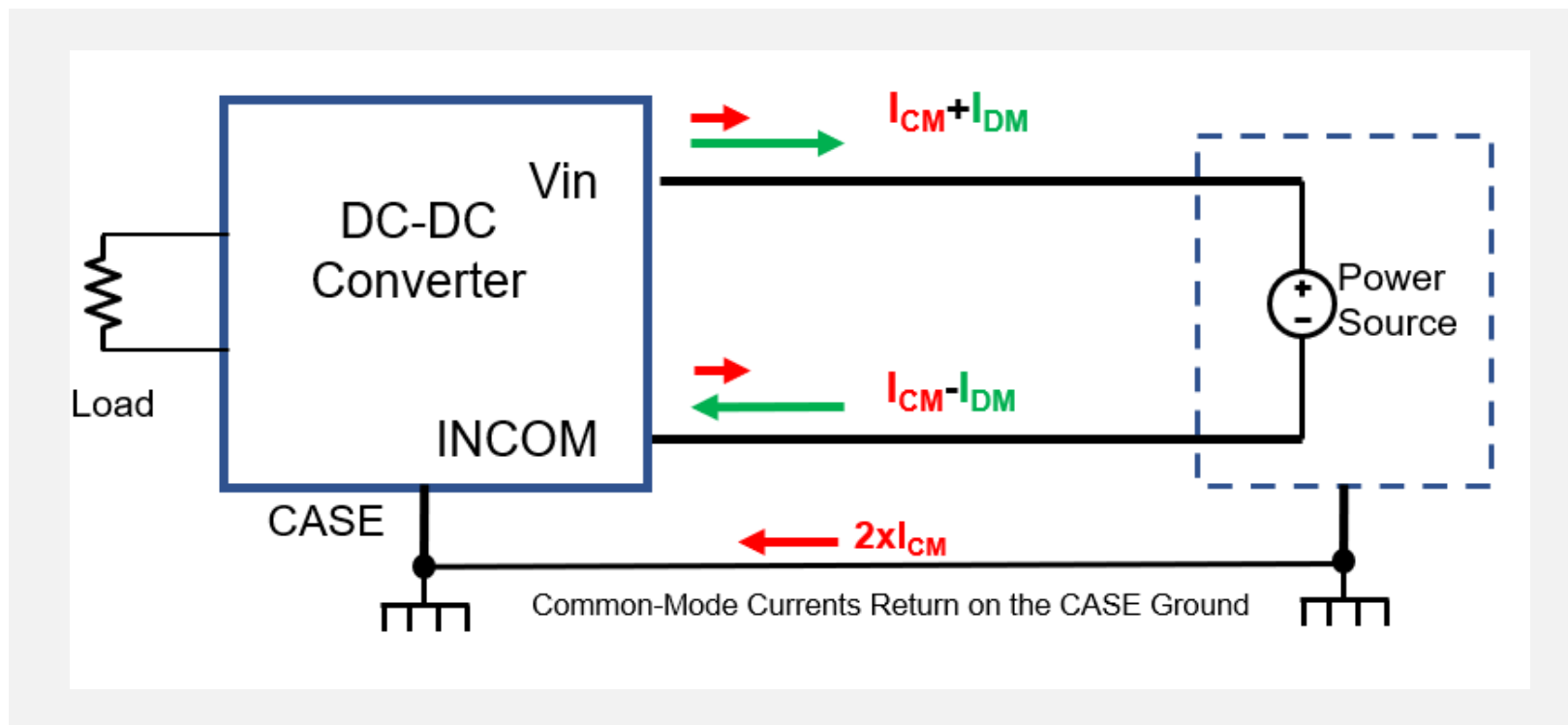
EMI Filters are Four-Port Networks

- ▶ VPT's EMI filters are four-port networks with CASE as a zero-signal reference plane (ZSRP) ("Ground").
- ▶ INCOM and OUTCOM are not "grounds" but rather "returns".
- ▶ Noise and spurs generated by the converter have both differential-mode (DM) and common-mode (CM) components relative to the CASE ground.
- ▶ VPT EMI filters are designed to attenuate both types of noise and reduce mode conversion.



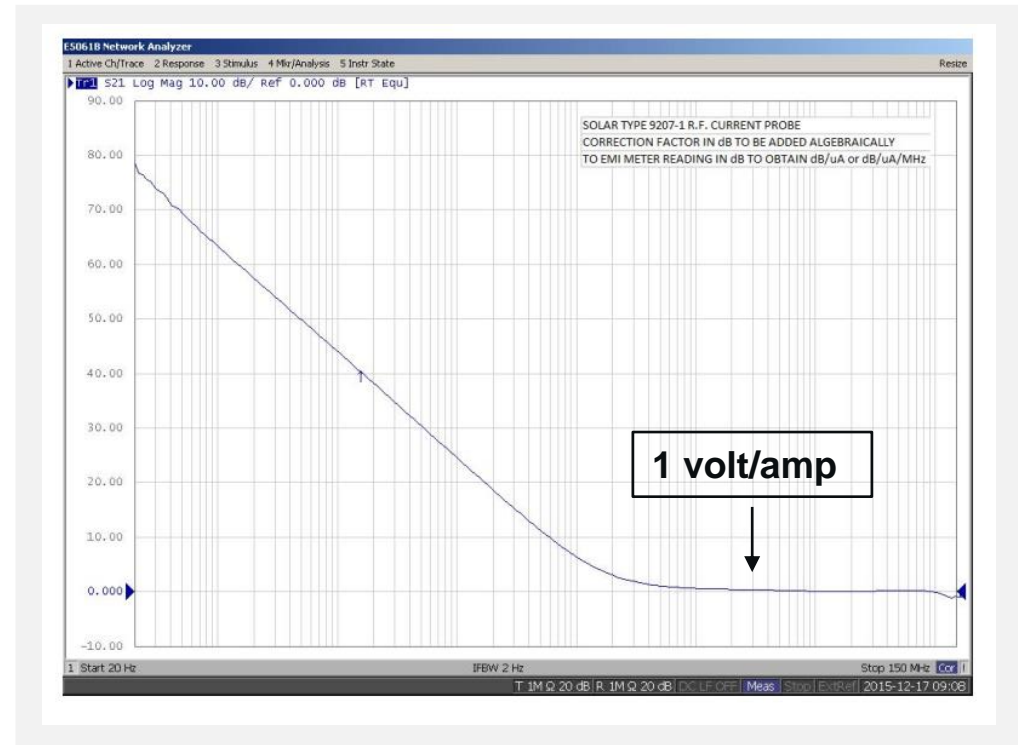
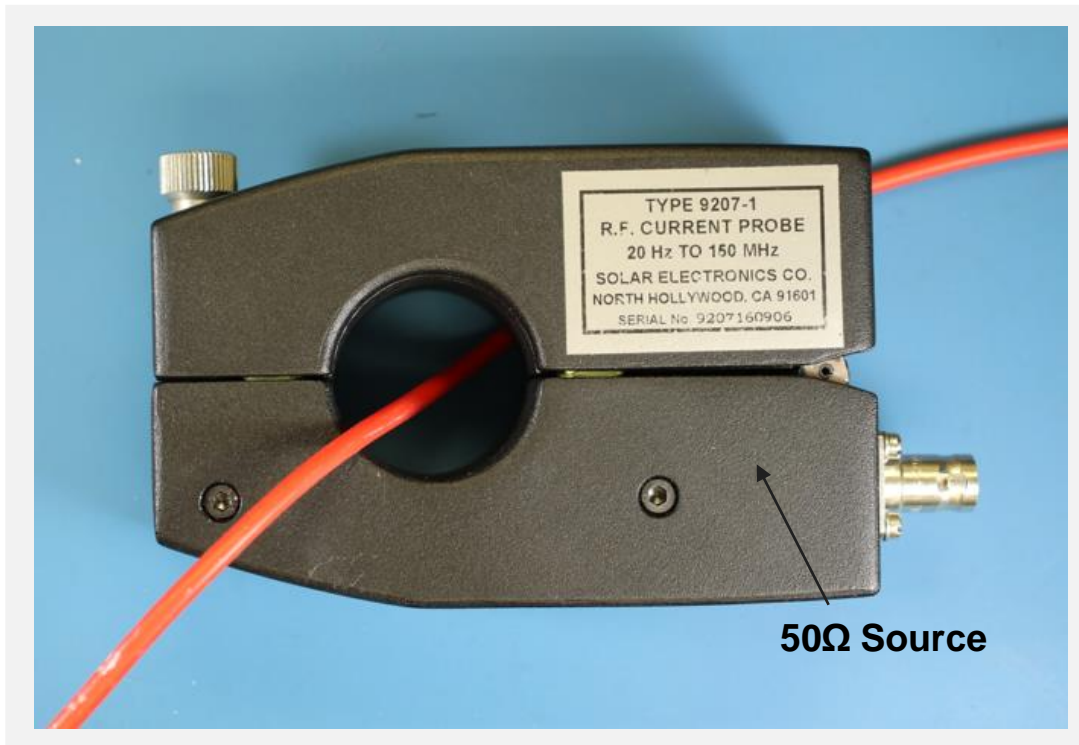
Common-Mode vs. Differential Mode Currents

- ▶ Differential-Mode (DM) currents return on the power line.
 - Caused by the charging and discharging of magnetic components in the converter.
- ▶ Common-Mode (CM) currents return on the protective earth ground.
 - During switch transitions, parasitic inductances/capacitances discharge and induce current spikes on both V_{in} and INCOM.

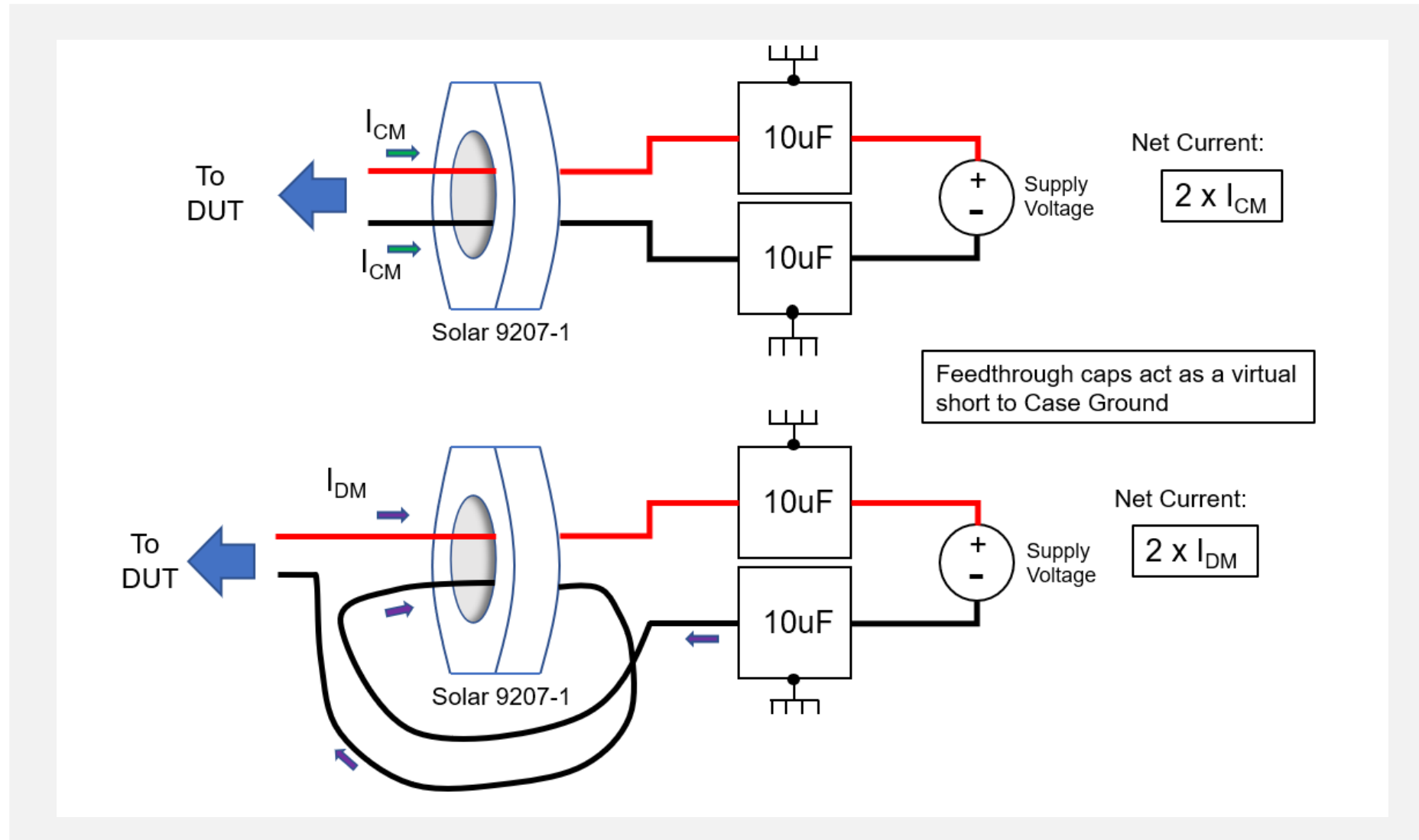


CE03 (1967): Current Probe + Feedthrough Caps

- ▶ Calibrated, clamp type toroidal transformer converts current to a voltage with a 50Ω source impedance.
- ▶ Current probes are characterized by a transimpedance.
 - Example: Solar 9207-1 transimpedance typically 1 V/A.
- ▶ CE03 is still in use because LISNs have resonant frequencies > 10 MHz.



Isolating CM and DM Currents – CE03

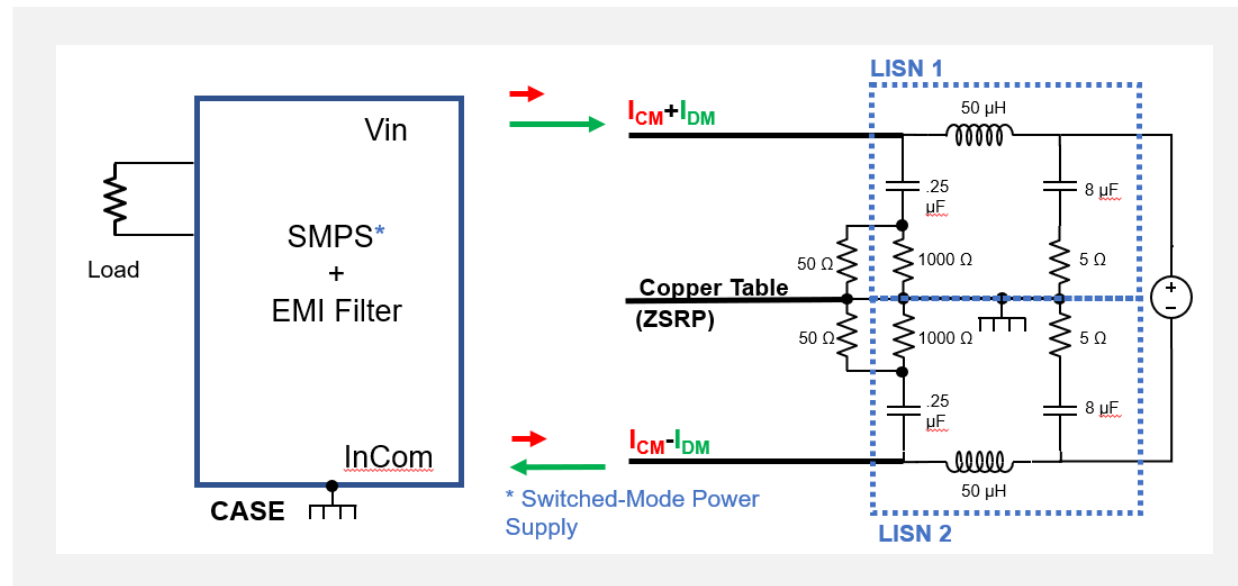


LISNs (CE102, 1990's to present)

- ▶ Line Impedance Stabilization Network (LISN)
 - Intended to control and standardize the power source impedance presented to the EMI Filter + DC-DC Converter.
 - LISNs filter some incoming power line noise.
 - CE03 in some ways does not present a “fair” load to the EMI filter.

Inside the LISN

- ▶ The 50Ω resistors represent the measurement receiver input impedance.
- ▶ At frequencies >100kHz, you can assume the 50μH LISN input impedance is **50 Ω** from Line-In to table ground.
- ▶ The 5μH LISN impedance does not approach 50 Ω until ~10 MHz.
- ▶ Total differential mode power: $P_{DM} = (I_{DM})^2 * 100 \Omega$
- ▶ Total common mode power: $P_{CM} = (2I_{CM})^2 * 25 \Omega$



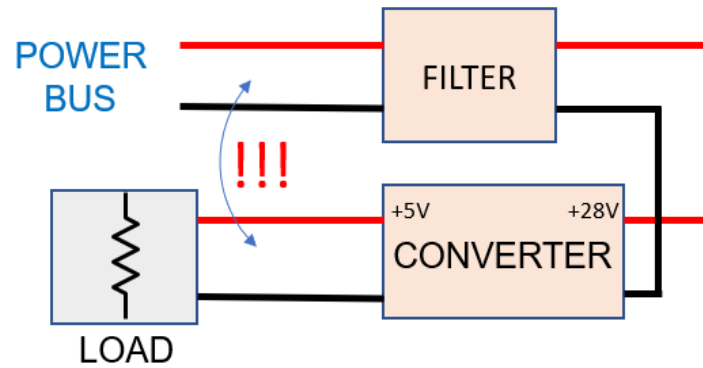
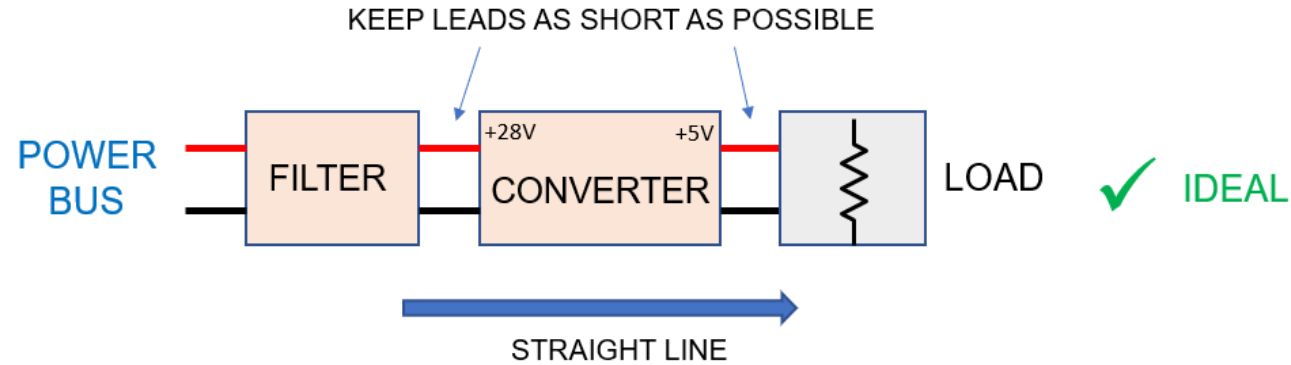
Layout Recommendations and Precautions



Proper Layout is CRITICAL!

- ▶ Typical VPT EMI filter attenuation is 50-80dB, 500KHz and above.
- ▶ Remember: MIL-STD-461G mandates $EMI < 1 mV_{rms}$ for frequencies $>500KHz$.
- ▶ MIL-STD-461C: $EMI < 10 \mu A_{rms}$ for frequencies $>2MHz$.
- ▶ A poor layout can easily couple these voltages/currents onto your power bus, even with a filter present.

Power System Setup



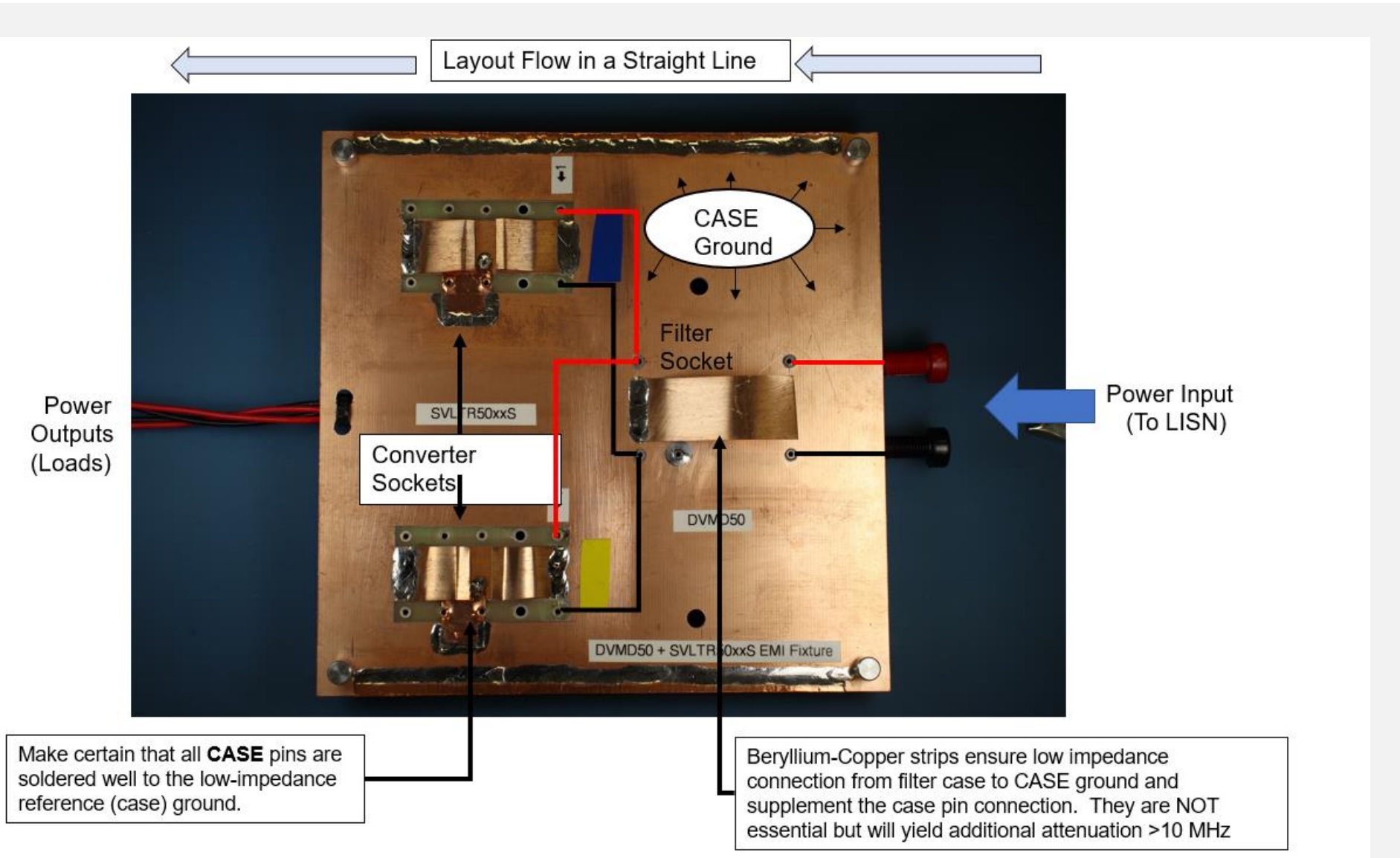
REMEMBER: The converter output ALSO contains switching noise which can contaminate your power bus!

If you must route converter outputs near the power bus, pour CASE ground between lines to reduce crosstalk.

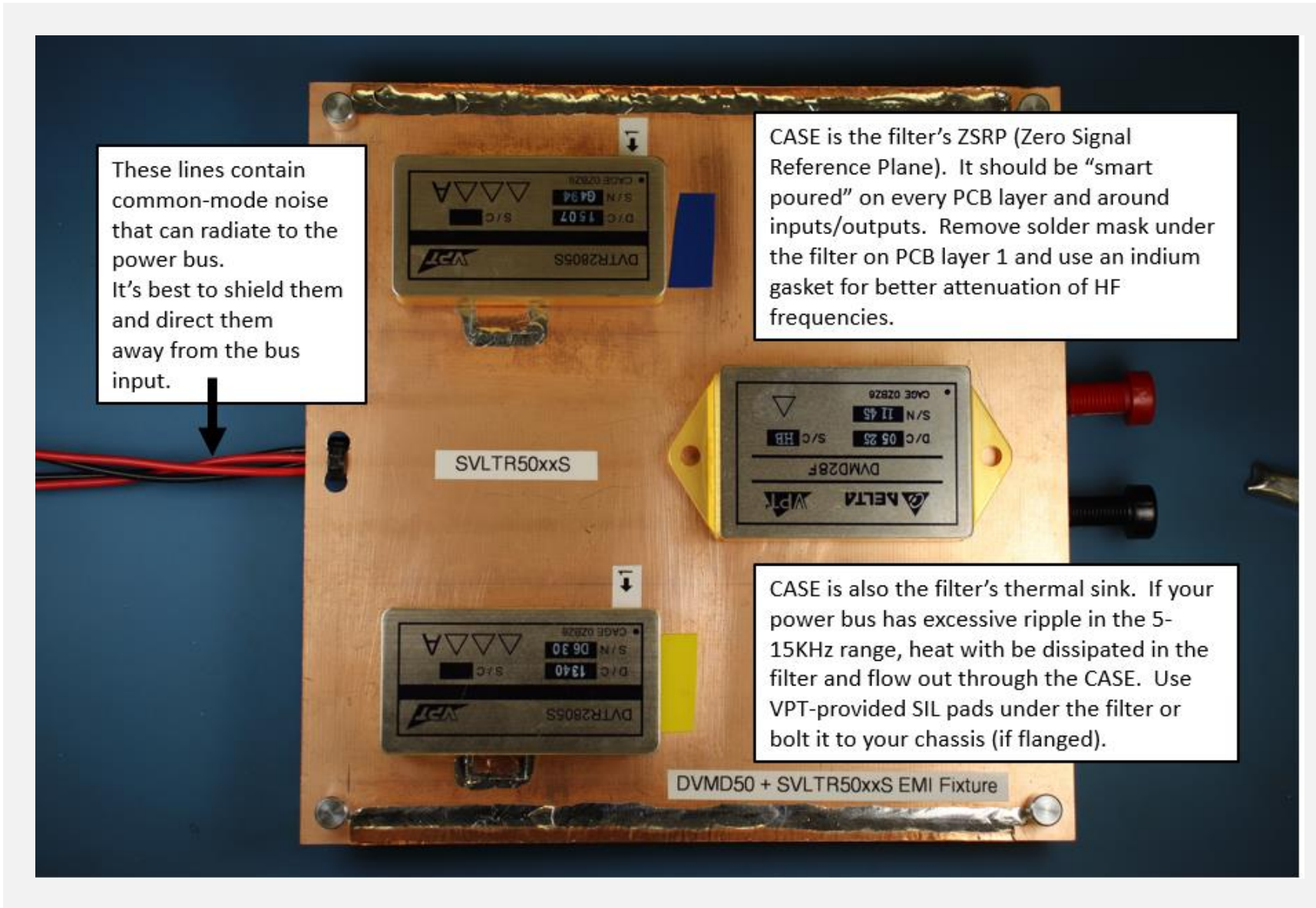
Better: Place power bus and outputs on different PCB layers and pour CASE ground on a mid-layer between them.

REQUIRES CAREFUL LAYOUT!
REMEMBER, CASE is your Zero-Signal Reference Plane.

CASE Ground Placement

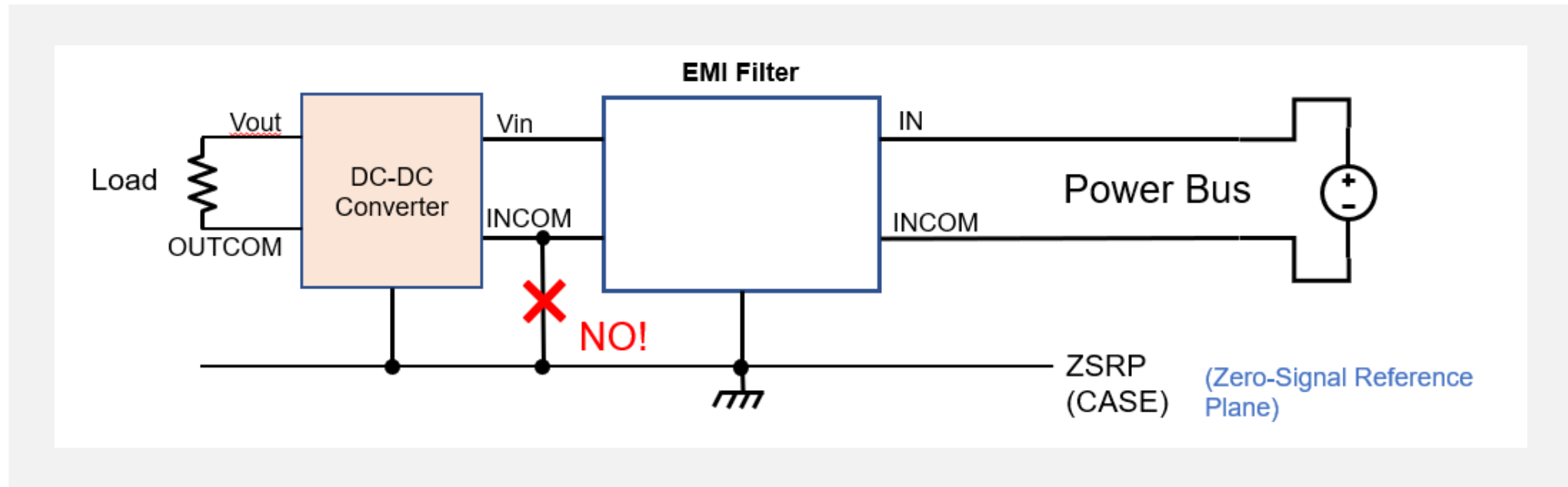


Additional Notes on CASE Ground



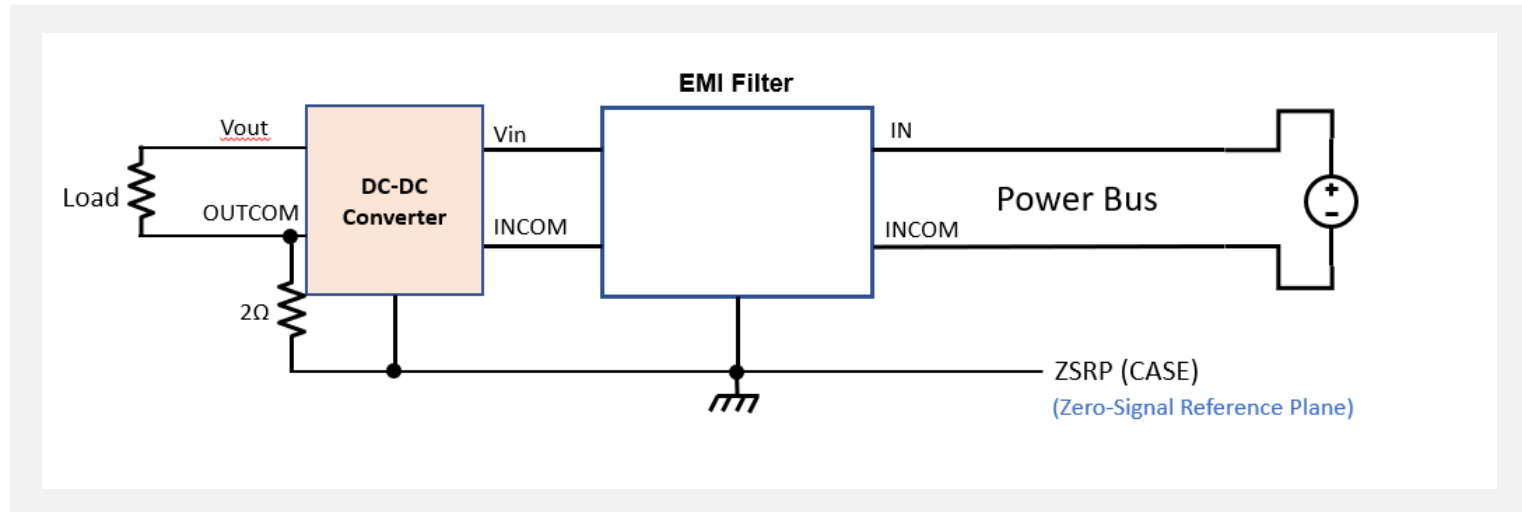
DO NOT Connect INCOM to CASE!

- ▶ The above connection will:
 - Short out any common-mode shunt elements, thereby reducing CM attenuation.
 - Produce a BALUN (BALanced-UNbalanced) structure, converting common-mode noise into differential-mode noise.
- ▶ In other words, this connection causes **MODE CONVERSION**.



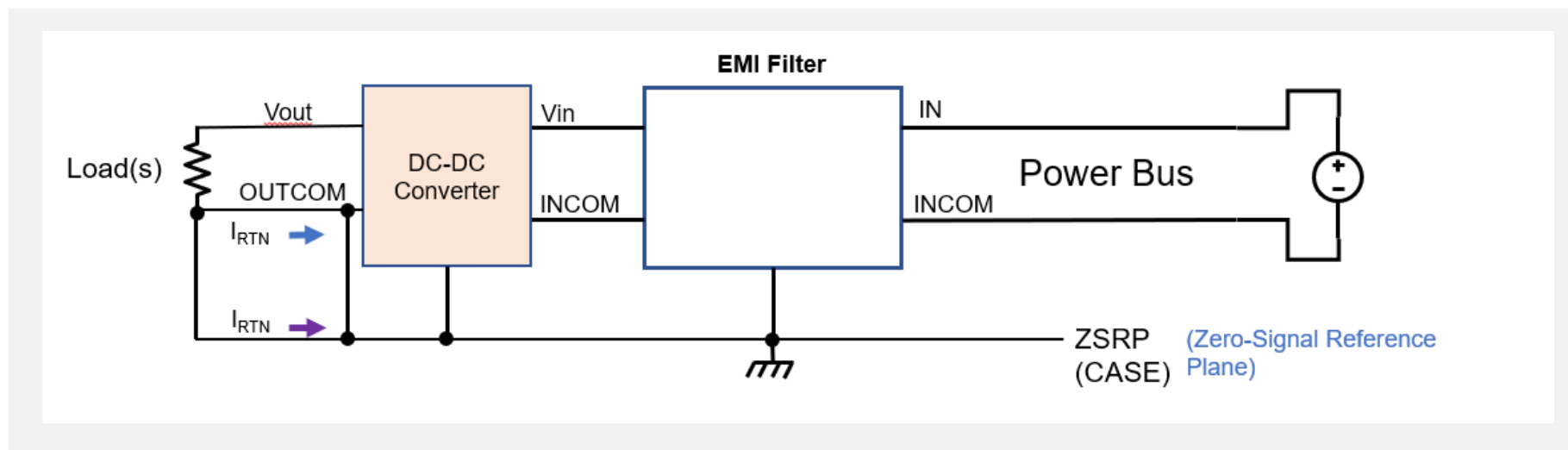
Single-Point Ground: Load to CASE

- ▶ In most cases, this connection is permissible.
- ▶ However, customer EMI test results may differ from VPT's published results.
 - VPT conducts all EMI testing according to MIL-STD-461's published guidelines.
 - In MIL-STD-461C,E-G, the load is FLOATING.
 - Connect Load to CASE with a wire or 2Ω resistor to improve EMI margin.
- ▶ It is not possible to model the effects of grounding a load to CASE for every possible combination of factors, but VPT makes every effort to ensure that this connection works for our customers.



NOT RECOMMENDED Multi-Point Connections: Load to CASE

- ▶ Maintain a signal-free ground plane
- ▶ Zero impedance grounds do not exist
- ▶ High currents returning on the case can create voltage drops that contaminate the CASE ground.
- ▶ Low-frequency currents return along the path of least resistance.
- ▶ High-frequency currents return along the path of least inductance.

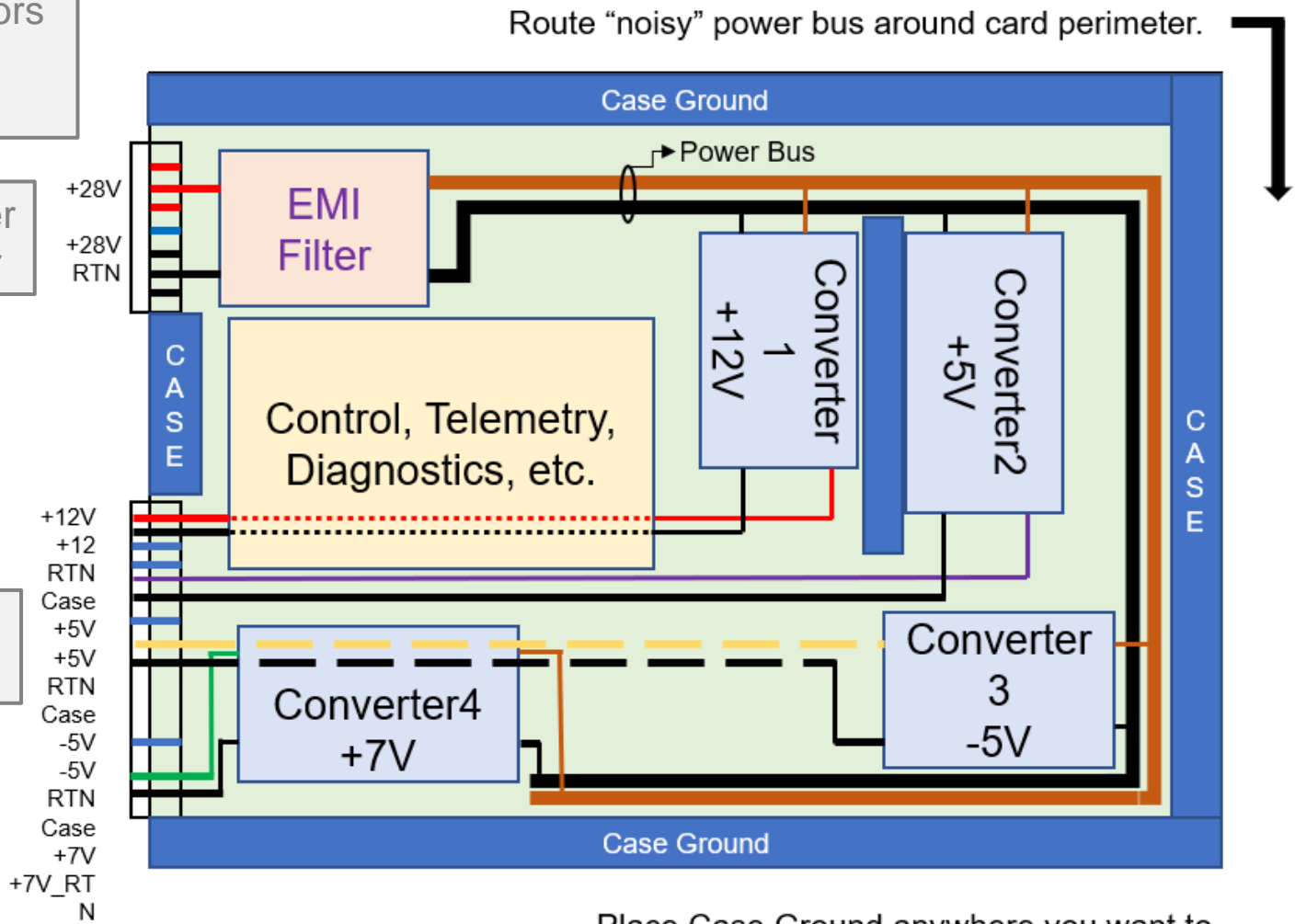


Example Power Distribution PCB

Use separate connectors for power inputs and outputs.

Input Power Connector

Output Power Connector

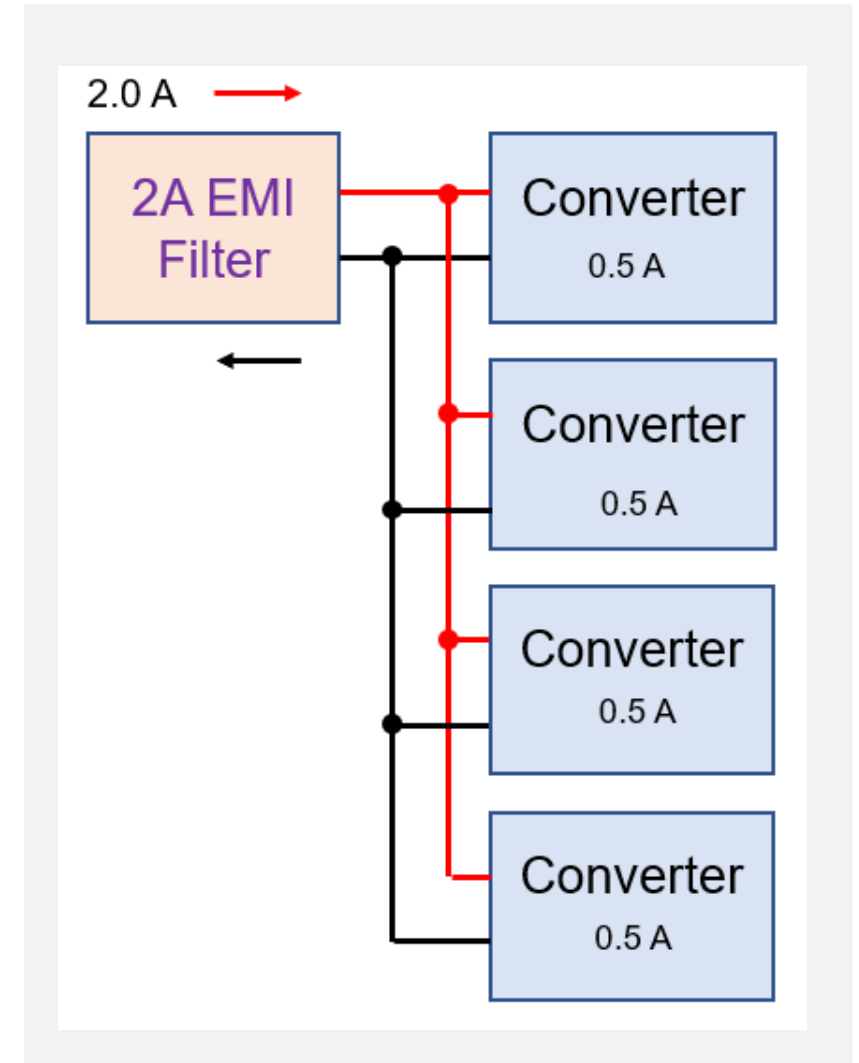


Route "noisy" power bus around card perimeter.

Place Case Ground anywhere you want to minimize crosstalk.

Beware “Overloading” EMI Filters!

- ▶ This EMI filter can handle the rated current.
- ▶ **BUT – you may not pass MIL-STD-461!**
- ▶ Most VPT filters are tested with two attached converters (refer to filter datasheet).
- ▶ Assuming identical converters, each added converter will increase the noise by 3dB .
- ▶ If the converters are synchronized noise will increase 6dB with each added converter.
- ▶ Loading EMI filters in this manner must be done on a trial-and-error basis.
- ▶ Additional components placed outside VPT’s EMI filter may help you meet spec in custom arrangements.

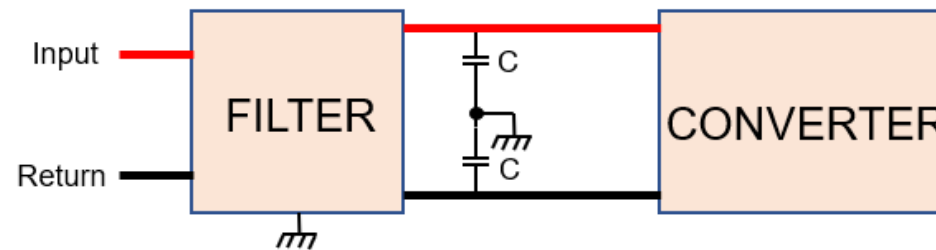


How to Improve EMI Filter Performance

All VPT filters are tested using MIL-STD-461 methodology. Although we strive to provide adequate margin over spec, some customer installations may require additional components to improve attenuation.

If more Common-Mode attenuation is needed:

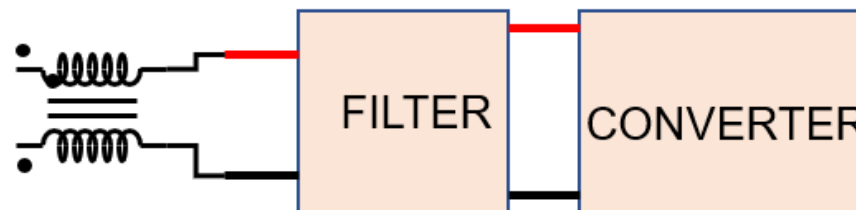
Add "Y"
Caps



C: 10-33nF, 500V,
X7R

and/or
:

Add
CM
Choke

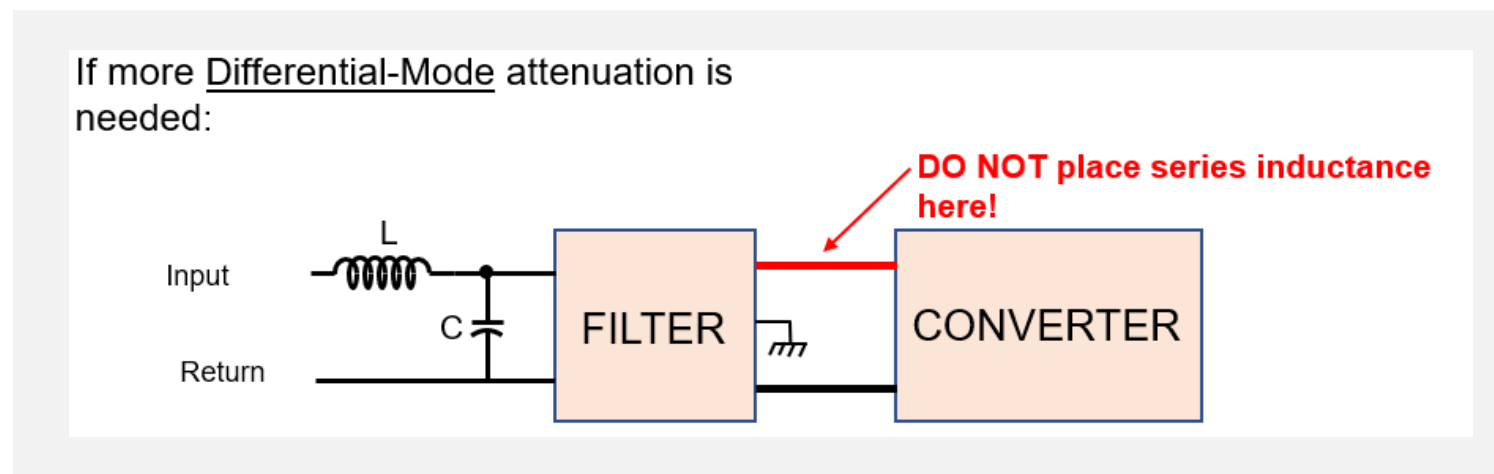


Ferrite μ_r : 4000-6000

Wire gauge appropriate
for input current; fill core
with evenly-spaced turns.

How to Improve EMI Filter Performance (Cont'd)

- ▶ Most VPT filters contain an internal cap for the external inductance to “work against”, so in most cases only the inductor is necessary.
- ▶ Use an air gap toroid inductor.
- ▶ Core Size: DC flux density < 2000G
- ▶ Inductance: 1-5 μH (use less inductance in high-power converters).
- ▶ Do not place series inductance at the filter output (to converter).
- ▶ For emissions above 1 MHz, use a ferrite bead (100-600 Ω) instead of an inductor.



Conducted Susceptibility

Do I need a heat sink under the EMI filter?



Power Supply Ripple Considerations

- ▶ All VPT EMI filters are designed with resistive components capable of withstanding CS101 power supply ripple indefinitely.
- ▶ If excessive ripple is expected near a filter resonant frequency, mount the filter on a heat sink.
- ▶ EMI filter resonant frequencies vary by product and lie in the 5-15KHz range.
- ▶ Resonant frequencies also vary with DC bias.

Conclusion

- ▶ EMI filter performance will vary by installation.
- ▶ MIL-STD-461C-G is a near-ideal test environment.
- ▶ VPT EMI filters are 4-port networks where CASE is the zero-signal reference plane.
- ▶ Maintain a low-impedance path in your layout for Common-Mode currents to return to their source.
- ▶ CASE ground can be used to shield against crosstalk on PCB layouts.
- ▶ Install filter as close to the converter(s) as possible and in a straight line if possible.
- ▶ Avoid routing outputs next to your power bus without a CASE layer between them.
- ▶ Beware connecting more than two converters to a single filter, especially if your converters are synchronized.
- ▶ Following these best practices for conducted emissions will also improve **radiated emissions**.

Learn More

How to get in touch

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Visit www.vptpower.com/data/datasheets/ to find the appropriate datasheet for your specific EMI filter.