Dealing with Common Mode Noise in DC/DC Converters

Introduction

It may or may not be realistic to test or use an isolated DC/DC converter with the input and output grounds tied together at some remote point, but let's discuss what happens anyway so we can make an informed decision.

The Origin of Common Mode Noise

A DC/DC converter is comprised of a power chopper on the input that chops the DC input voltage into an AC signal that is transferred across a transformer. The AC is then rectified back into DC for the output (see Figure 1).

The transformer is made from concentric windings on top of each other for the primary and secondary windings, so there is quite a bit of capacitance from input to output on the transformer.
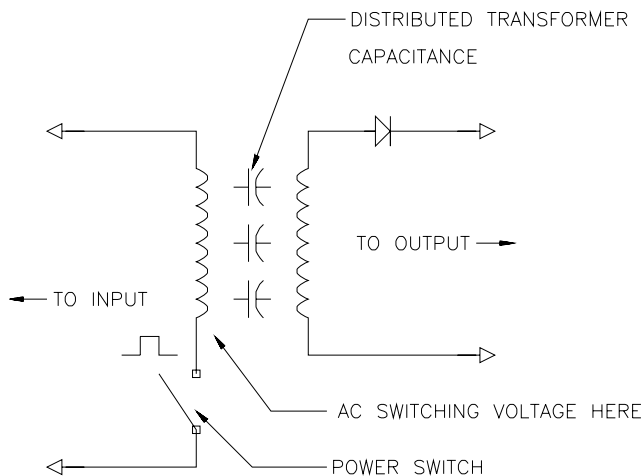

Figure 1.
The dV/dT caused by the power switch in turn causes a current to flow from the input to the output circuit through the distributed capacitance of the transformer. The trick is to keep this current out of your circuit.

Each time the input chopper switches, a large dV/dT is impressed by the input stage across the transformer I/O capacitance. This in turn, causes a current to want to flow from input to output through the transformer capacitance.

This current flows twice each switching cycle and it must find a path back to the input "source." The current is commonly called the "Common Mode Current" since it can flow through any or all of the I/O pins individually or at the same time (see Figure 2).

With no external current path from input to output, (i.e. the converter is driving isolated resistors that have very little capacitance back to the input) the common mode current is contained in the converter and flows through the stray capacitance from the input to the output, causing no further problems.
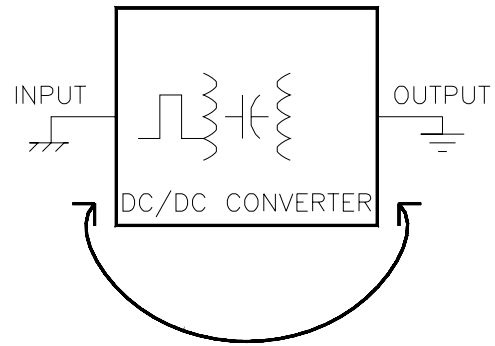

Figure 2.
The common mode current must flow somewhere. Ideally the path is contained inside the converter (through stray capacitance).

Adding An External Current Path

When an external current path is introduced to the converter, such as a wire from the input to output grounds, the current will tend to want to flow through this lower impedance connection. This can be OK as long as the inductance of this connection is very low. For, as we have seen, the current is a dI/dT caused by a dV/dT. If there is appreciable inductance in the external path, the dI/dT will cause a voltage ($V = L \times dV/dT$) to be developed between the grounds. This will show up as voltage noise at either the input or output terminals. So, this wire connection should have as low a value of inductance as possible. This usually dictates short length and a small total "loop area" (see Figure 3).
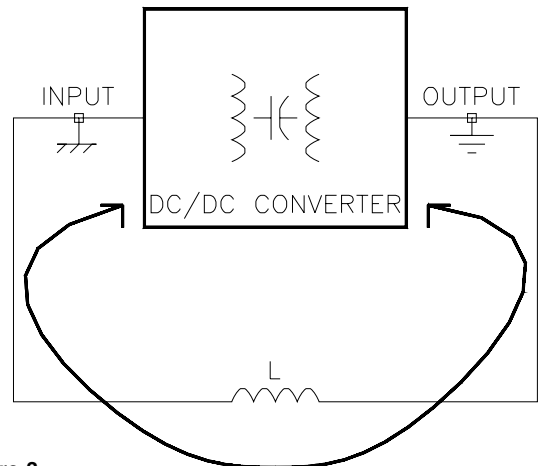

Figure 3.
If an external path is added to the converter's grounds, the resulting added inductance, while small, can cause appreciable dV/dT or voltage noise to the system. This can manifest itself as input or output noise or it may even upset the operation of the converter. The trick is to make this connection either zero inductance or keep the common mode current from flowing in this connection.

How To Make A Common Ground System Work

There are several strategies to reduce the effect of the common mode currents when the input and output grounds must be tied together for system reasons.

1.   Tie the ground connection directly between the I/O pins with no intervening wiring length that will add inductance (see Figure 4a).

2.   Use a DC connection only and block the AC component of the common mode noise. Strangely enough, this can be done by using a Low Q inductor between the grounds. The key is that this inductor must have sufficient impedance at the switching frequency to be at least 5 to 10 times larger in impedance than the measured stray circuit capacitance's impedance. To keep the Q low (necessary to prevent resonant peaking of the impedance), use a 100 ohm to 10K ohm shunt resistor across the inductor. This method gives a solid DC ground but blocks the common mode current from flowing in the connection (see Figure 4b).

3.   Block the common mode current from flowing out of the converter by using a common mode choke on the input side. These devices are often incorrectly referred to as a BALUN (meaning BALanced to UNbalanced transmission line impedance transformer). They are, however, typically a small high permeability, ferrite or MPP torrid that is wound with two windings. These devices present a very low impedance to any normal mode signal flowing through the lines (DC current, for example). However, they present a very large impedance to any common mode signals that try to flow through both windings in phase, such as the DC/DC converter's common mode current (see Figure 4c).

4.   Rethink the whole situation of using an isolated converter in the application. Non-isolated converters generally cost less, have higher power densities and have fewer parts which translates to higher reliability.
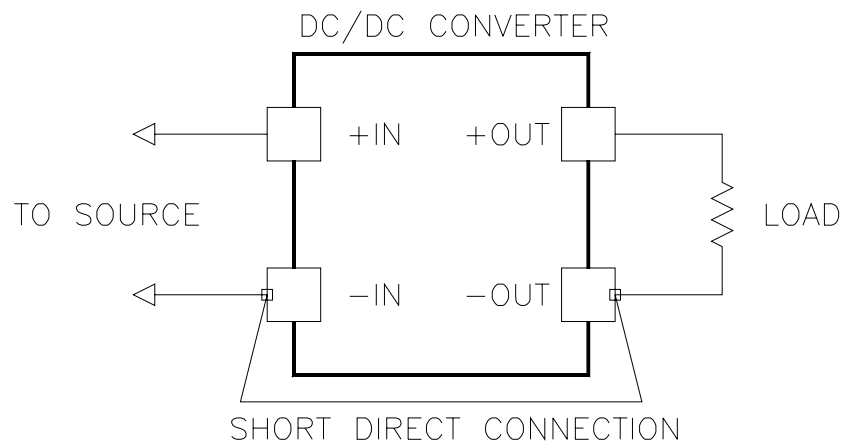

Figure 4a.

As we have seen, if a connection must be made between the I/O grounds, make it as close to zero inductance as possible. This usually means the connection should be short and directly between the module's pins.

DC/DC CONVERTER

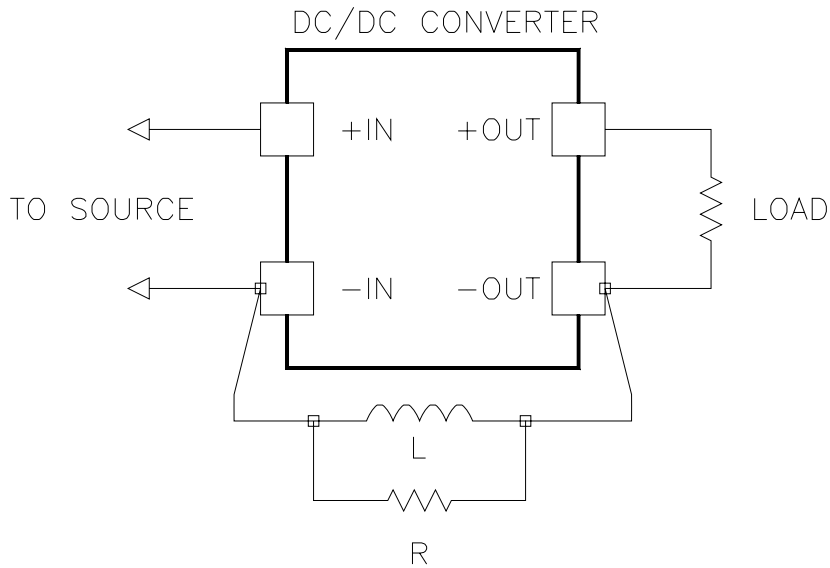+IN   +OUT

TO SOURCE   LOAD

−IN   −OUT

L

R

Figure 4b.

Strangely enough, adding a large enough inductor in the grounding path can provide an effective AC block to the common mode currents, while still allowing a good solid DC ground connection. The inductors impedance at the switching frequency (and above) must be much greater than the circuit stray capacitances. The shunt resistor prevents any resonant peaking of the inductor by lowering its Q.
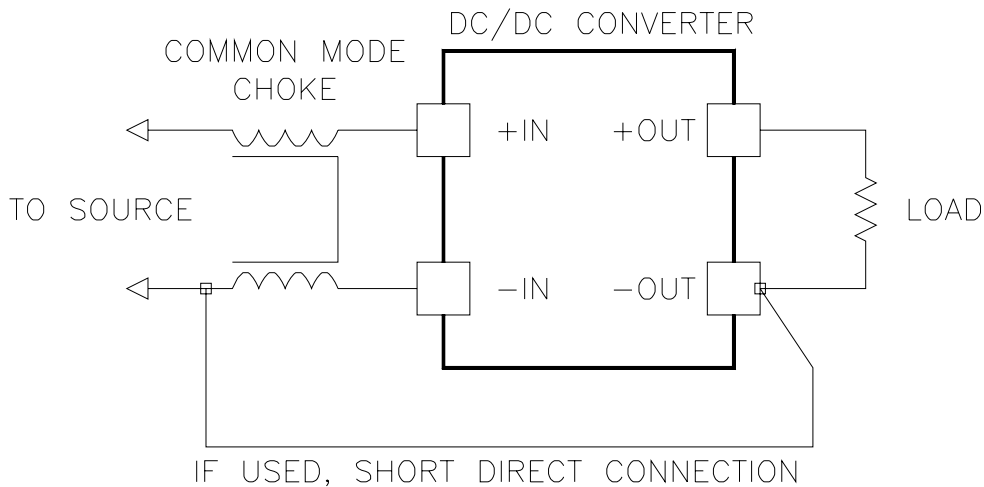
COMMON MODE
CHOKE

DC/DC CONVERTER

+IN   +OUT

TO SOURCE   LOAD

−IN   −OUT

IF USED, SHORT DIRECT CONNECTION

Figure 4c.

A common mode choke on the input side of the converter presents a high impedance to any signal trying to flow out of both input pins at the same time, such as the common mode switching current. By using a properly designed common mode choke, the ground connection becomes much less important because the common mode current is forced to flow inside the converter where it belongs.

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Testing DC/DC Converters

For testing purposes, a known common mode impedance can be very useful for providing a stable testing environment and allowing direct measurement of the common mode current. Figure 5 presents such a fixture. When a 50 ohm terminated scope is in the circuit, the common mode current can be read directly as I (amps) = Vscope (volts)/25 (ohms). When the scope is disconnected, the scope port should be terminated into a 50 ohm plug.
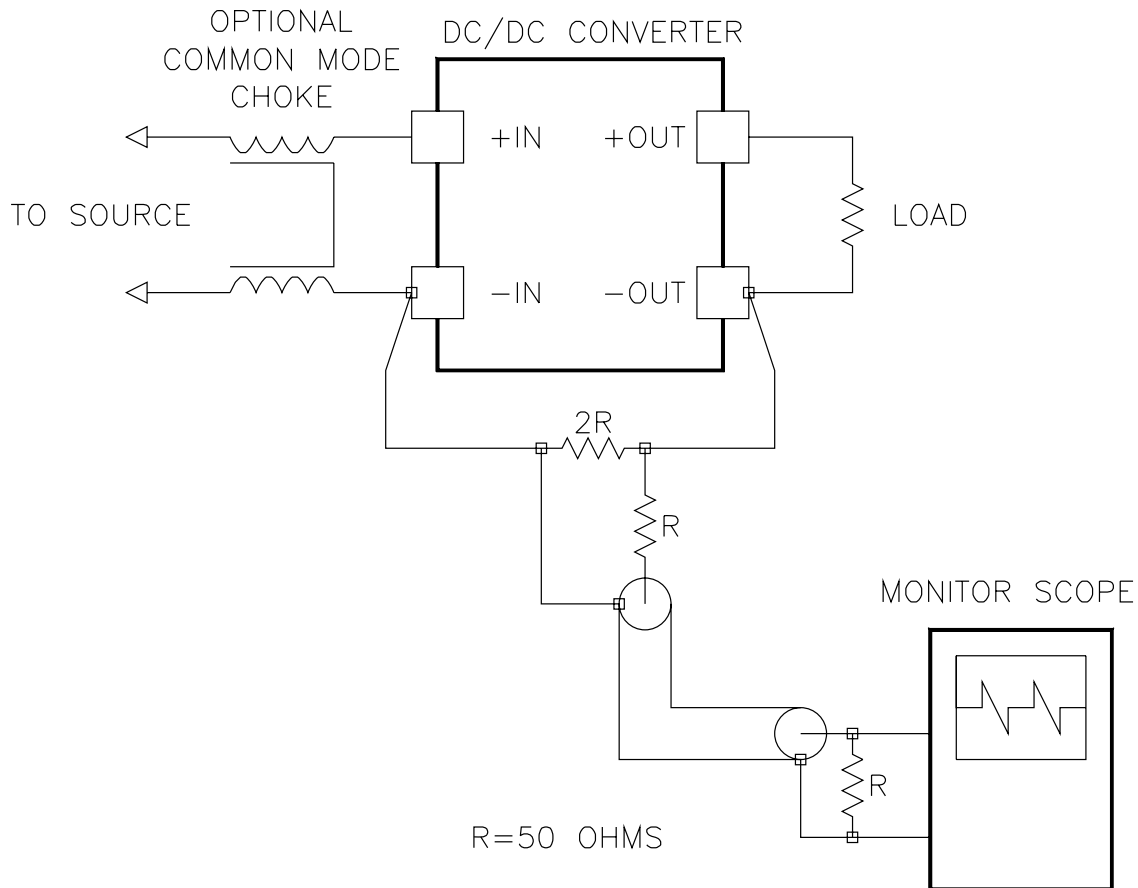

Figure 5.

In testing DC/DC converters, it is useful to have a controlled impedance environment for repeatability in measurements. The circuit shown is a 50 ohm terminated system that can measure currents to well over 100 MHz if it is constructed using good RF techniques. The current read on the scope is: I (amps) = Vscope (volts) / 25 (ohms). The common mode choke might be needed if the load is not a simple resistor as shown. Remember, active loads that are plugged into the AC line provide a low impedance path for the common mode currents to flow. The current will flow right back down the AC line through the scope and/or the AC power supply. The common mode choke prevents these currents from flowing, allowing direct "real" measurements. Remember, these currents have frequency components well into the 100's of Megahertz, therefore, good analog and RF techniques are needed to accurately measure and keep common mode currents from ruining your whole day!

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