Technical Note #2

Low Voltage Ripple Concerns

It is helpful to understand the relationships between current ripple and voltage ripple on current regulated precision power supplies. Often, there are discrepancies between these two values that do not appear reconcilable. It can be shown that the major contributors to the differences are:

- Power Supply Output Impedance
- Load Characteristics
- Magnetic Loop Areas

Power Supply Output Impedance

By definition, any current regulated power source has a high output impedance. It almost always achieves this by virtue of a feedback circuit maintaining the output current at a predetermined amount. The high gain of this circuit, equates to near infinite impedance at DC. But alas, because these circuit gains must be rolled off to stabilize the feedback loops, this high impedance is quickly reduced. Additionally, output capacitors, commonly found in the power supplies produce a decreasing impedance as the frequency increases. Thus, as the frequency increases above DC the power supply is reduced to being a more and more like a voltage regulator.

In applications requiring current controlled ramps, pulses, or other dynamic responses, the frequency response of the current control loop is of vital importance. In most steady state applications however, these effects are rarely a concern.

Another property of current regulators is that they can be paralleled for higher currents. As additional current is introduced into a circuit, an ideal current regulator will maintain a constant current, however, the load **voltage** will increase in proportion to the added current.

What is important to note here, is that any outside “interference” appears as load **voltage**. Such voltage can be either DC or AC. An ideal current regulator can do **nothing** to remove this effect, for by doing so, it would be voltage regulating!

Load Characteristics

All loads, when including the connecting cables, are inductive in nature. The total inductance presented to the power supply is $L_{cables}+L_{load}$. Because of this inductive nature, the load has a higher AC impedance than its DC impedance. What this means is that the load cables are connecting a high impedance power supply to a high impedance load. No wonder it picks up garbage so easy! The reactance of any inductive circuit is $2\pi f l$. This can be many times greater than the DC resistance of the loads. Sometime it's hard to imagine that large high current, low voltage systems can have such high impedances, but they do. This fact makes voltage ripple looks considerable greater than it should. Many inductive loads (magnets, for example) may have a fraction of an ohm of DC resistance, yet have several 10's of ohms of reactance at 60 hertz. Thus, a small amount of current ripple is entirely consistent with having many, many millivolts of voltage ripple.

Cable Connections

It is easy to assume that the cables used to connect load are resistive. It is actually more correct to understand them as inductors. For example, consider 0000 cable. One thousand feet of this cable has 49mΩ, and inductance of 540 µh[1]. The LR corner (where inductive reactance equals resistance) is $\frac{R}{2\pi l}$ or 14.4 hertz in this case. This can easily be confirmed using common reactance paper. At a 60 hertz line frequency, even "resistive" cables connected to "resistive" loads exhibit more impedance than one might expect.

Magnetic Loop Area

The same reason for twisting pairs of signal leads also apply to load cables. Realizing that it is impracticable to "twist" cables (or sometimes bus bars), the only good answer is to keep them "bundled" together. Lenz's Law states that voltage will be induced into a loop in proportion to its loop area, number of turns and change of flux over time. Specifically,

$V = -10^{-8} nA \frac{dB}{dt}$ where V is in volts, n is the number of turns, and A is the loop area in cm^2. If cables were separated enough to have only a **one** square foot loop area, and this loop is exposed to only **one** gauss of AC field, more than **3 mv** of ripple would be generated. This voltage will appear across the load terminals and the power supply terminals according to their relative impedances.

Additional Filtering

On many occasions, it becomes necessary to add additional filtering at the load side of the cables. This is especially true in case where cable lengths are very long. In these cases, the inductance of the cable can be an advantage. By adding capacitors across the load itself, the cables/capacitor become an LC filter (the cables' resistance also help, by making an RC filter). Adding the same capacitor across the power supply terminals will do little or nothing.

Conclusion

On any practical circuit, there will always be discrepancies in what the voltage ripple seems to say versus the current ripple. These discrepancies are easy to understand in light of the above mentioned factors. Voltage ripple is easy to pick up in high impedance circuits. Voltage ripple is related to AC load impedance, not to DC resistance. Loop areas of load cables must be kept to an absolute minimum. Consider the DC load cables part of the precision circuitry, dress them away from AC fields, keep lengths as short as possible, etc. Also, consider adding additional filtering as close to the load as possible.

[1] The inductance of round conductors is $L = .0051l\left[2.30\log_{10}\frac{4l}{d} - 1\right]$ where l is the length and d is the diameter. A good rule of thumb is that conductors of all diameters have inductance of approximately 0.5µh/foot.