Ask The Applications Engineer—10

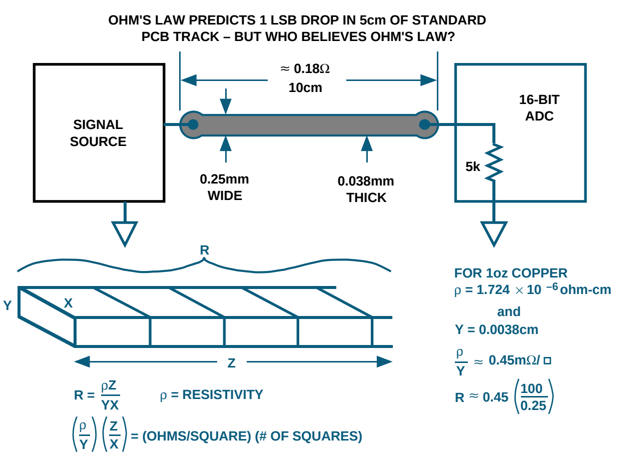
by James Bryant

Q. In the last issue of Analog Dialogue you told us about some of the problems of a simple resistor. [More will appear in a future issue.] *Surely there must be some component that behaves exactly as I expected it to. How about a piece of wire?*

A. Not even that. You presumably expect your piece of wire or length of PC track to act as a conductor. But room-temperature superconductors have not yet been invented, so any piece of metal will act as a low-valued resistor (with capacitance and inductance, too) and its effect on your circuit must be considered.

Q. Surely the resistance of a short length of copper in small-signal circuits is unimportant?

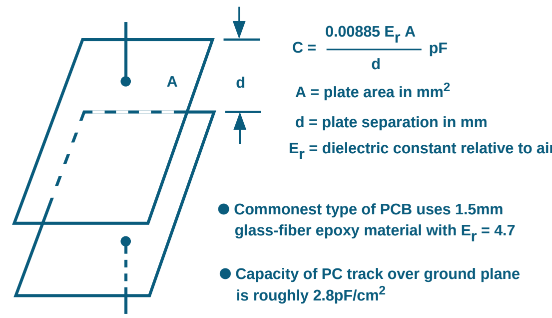
A. Consider a 16-bit a/d converter with 5-kΩ input impedance. Suppose that the signal conductor to its input consists of 10 cm of typical PC track—0.25 mm (0.010") wide and 0.038 mm (0.0015") thick. This will have a resistance of approximately 0.18 Ω at room temperature, which is slightly less than 2×2^{-16} of 5 kΩ; this introduces a gain error of 2 LSB of full scale.



One might argue that the problem would be reduced if PC tracks were made wider—and indeed, in analog circuitry it's almost always better to use wide tracks; but many layout drafters (and PC Design programs) prefer minimum-width tracks for signal conductor. In any case it's especially important to *calculate* the track resistance and its effect in every location where it might cause a problem.

Q. Doesn't the capacitance of the extra width of track to metal on the board's underside cause a problem?

A. Rarely. Although the capacitance of PC tracks is important (even in circuits designed for low frequencies, since LF circuits can oscillate parasitically at HF) and should always be evaluated, the extra capacitance of a wider track is unlikely to cause a problem if none existed previously. If it is a problem, small areas of ground plane can be removed to reduce ground capacitance.



Q. Hold it! What's a ground plane?

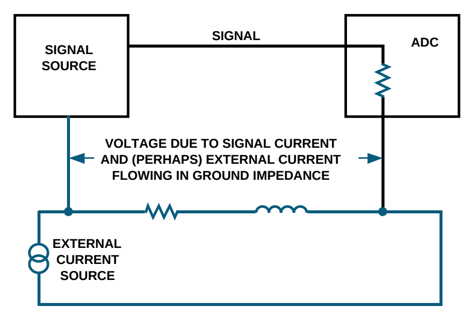
A. If one entire side of a PCB (or one entire layer, in the case of a multi-layer PCB) consists of continuous copper which is used as ground this is known as a "ground plane." It will have the least possible resistance and inductance of any ground configuration. If a system uses a ground plane, it is less likely to suffer ground noise problems.

Q. I have heard that ground planes are hard to manufacture.

A. Twenty years ago there was some truth in this. Today improvements in PC adhesives, solder resists and wave-soldering techniques make the manufacture of ground-plane PCB's a routine operation.

Q. You say that a system using a ground plane is "less likely" to suffer ground noise problems. What remaining ground noise problems does it not cure?

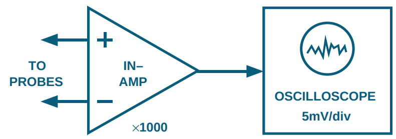
A. The basic circuit of a system having ground noise is shown in the diagram. Even with a ground plane the resistance and inductance will not be zero—and if the external current source is strong enough it will corrupt the precision signal.



The problem is minimized by arranging the PCB so that high currents do not flow in regions where ground voltages can corrupt precision signals. Sometimes a break or slot in a ground plane can divert a large ground current from a sensitive area—but breaks in a ground plane can also reroute signals into sensitive areas, so the technique must be used with care.

Q. How do I know what voltage drops are present in a ground plane?

A. They should generally be measured; however, it is sometimes possible to calculate them from the resistance of the ground plane material (standard 1 oz copper has resistance of 0.45 mΩ/square) and the length through which currents flow, but the calculation can be complicated. At DC and low frequencies (dc-50 kHz), voltage drops can be measured with an instrumentation amplifier such as the AMP-02 or the AD620.



The amplifier is set to a gain of 1,000 and connected to an oscilloscope with a gain of 5 mV/div. The amplifier may be powered from the same supply as the circuit being tested—or from its own supply—but the grounds of the amplifier, its supply if separate, and the oscilloscope must be connected to the power ground of the circuit under test at the power supply.

The voltage between any two points on the ground plane may then be measured by applying the probes to those points. The combination of the amplifier gain and oscilloscope sensitivity give a measurement sensitivity of 5 µV/div. Amplifier noise will swell the oscilloscope trace to a band about 3 µV wide but it is still possible to make measurements with about 1-µV resolution—sufficient to identify most low-frequency ground noise problems; and identification is 80% of a cure.

Q. *Are there any cautions about performing this test?*

A. Any alternating magnetic fields which thread the probe leads will induce voltages in them. This can be tested by short-circuiting the probes together (and resistively to ground to provide a bias current path) and observing the oscilloscope trace; ac waveforms observed that result from inductive pickup may be minimized by repositioning the leads or taking steps to eliminate the magnetic field. It is also essential to ensure that the ground of the amplifier is connected to the system ground; without this connection the amplifier, with no return path for bias current cannot work; grounding also ensures that this connection does not disturb the current distribution that is being measured.

Q. *What about measuring HF ground noise?*

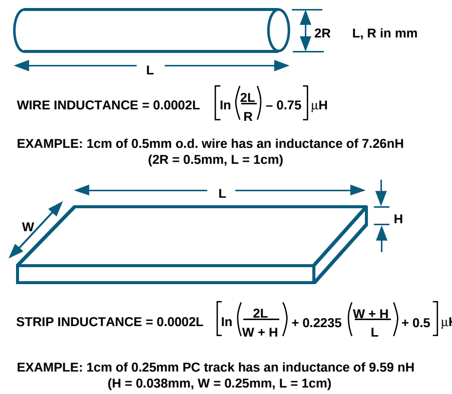
A. It is hard to make a suitable instrumentation amplifier with wide bandwidth, so at HF and VHF a passive probe is more suitable. This consists of a ferrite toroid (6-8 mm OD) wound with two coils of 6-10 turns each. One coil is connected to the input of a spectrum analyzer, the other to the probes, to make a high-frequency isolating transformer.

The test is similar to the LF one but the spectrum analyzer displays noise as an amplitude-frequency plot. While this differs from time-domain information, sources of noise may be easier to identify by their frequency signatures; in addition, the use of a spectrum analyzer provides at least 60 dB more sensitivity than is possible with a broadband oscilloscope.

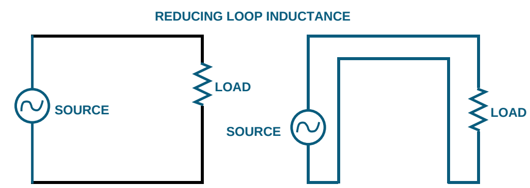
Q. *What about the inductance of wires?*

A. The inductance of wire- and PC-track leads should not be overlooked at higher frequencies. Here are some approximations for calculating the inductance of straight wires and runs.

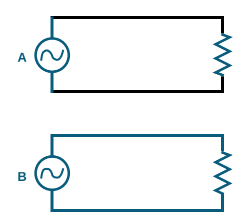
For example, 1 cm of 0.25-mm track has an inductance of 10 nH.



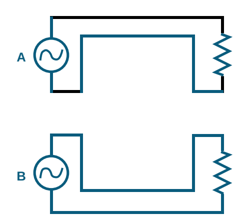
But inductive reactance is generally much less of a problem than stray flux cutting inductive loops and inducing voltages; loop area must be minimized, since voltage is proportional to it. In wired circuits this is easily done using twisted pairs.



In boards, leads and return paths should be close together; quite small changes in layout will often minimize the effect.



In this circuit, mutual inductance will couple energy from high-level source A into low-level circuit B.



Reducing area and increasing separation will minimize the effect.

Usually, all that is necessary is to minimize loop area and maximize the distance between potentially interfering loops. Occasionally magnetic shielding is required, but it is expensive and liable to mechanical damage; avoid it whenever possible.

REFERENCES

The Best of Analog Dialogue 1967-1991. Norwood MA: Analog Devices (1991), pp. 120-129, 193-195. Contains many additional references.

Mixed-Signal Design Seminar Notes. Norwood MA: Analog Devices (1991). Contains additional References.