ANALOG DEVICES

AN-362
APPLICATION NOTE

ONE TECHNOLOGY WAY • P.O. BOX 9106 • NORWOOD, MASSACHUSETTS 02062-9106 • 617/329-4700

Ask the Applications Engineer—9

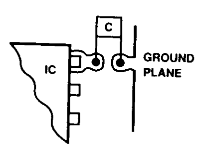
by James Bryant

VARIOUS TOPICS

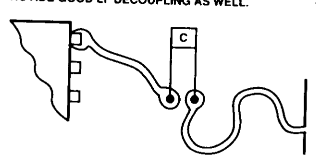
by James Bryant

Q. Tell me something about supply decoupling.

A. All precision analog integrated circuits, even low-frequency ones, contain transistors having cutoff frequencies of hundreds of MHz; their supplies must therefore be decoupled to the ground return at high frequency—as close to the IC as feasible to prevent possible instability at very high frequencies. The capacitors used for such decoupling must have low self-inductance, and their leads should be as short as possible (surface-mounted chip ceramic capacitors of 10- to 100 nF are ideal, but leaded chip ceramics are generally quite effective if the lead length is kept to less than 2 mm.



IDEAL HF DECOUPLING HAS
1. LOW INDUCTANCE CAPACITOR (MONOLITHIC CERAMIC)
2. MOUNTED VERY CLOSE TO THE IC
3. WITH SHORT LEADS
4. AND SHORT, WIDE PC TRACKS
IT MAY BE SHUNTED WITH A TANTALUM BEAD ELECTROLYTIC TO PROVIDE GOOD LF DECOUPLING AS WELL.



THIS SORT OF THING IS USELESS!

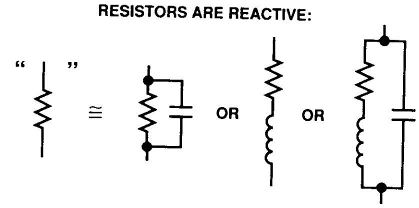
Low-frequency decoupling is also important, since the PSR (power-supply rejection) is normally specified at dc and will deteriorate appreciably with increasing power-supply ripple frequencies. In some high-gain applications, feedback through the common power-supply impedance can lead to low-frequency instability ("motorboating"). However, low-frequency decoupling at each IC is not often necessary.

Supply decoupling does more than prevent instability. An op-amp is a *four-terminal* device (at least), since there must be a return path for both input signals and the output circuit. It is customary to consider the common terminal of both op-amp supplies (for op-amps using ± supplies) as the output signal-return path, but in fact, one of the supplies will be the de facto return path at higher frequencies, and the decoupling of the amplifier's supply terminal for this supply must take into consideration both the necessity of normal high-frequency decoupling and the routing of the output ground.†

Q. In "Ask the Application Engineer," you're always describing non-ideal behavior of integrated circuits. It must be a relief to use a simple component like a resistor and know that you have a near-ideal component.

A. I only wish that a resistor was an ideal component, and that that little cylinder with wire ends behaved just like a pure resistance. Real resistors also contain imaginary resistance components—in other words they're reactive. Most resistors have a small capacitance, typically 1-3 pF, in parallel with their resistance, although some types of film resistors, which have a spiral groove cut in their resistive film, may be inductive, with inductances of a few tens or hundreds of nH.

RESISTORS ARE REACTIVE:



Of course, wirewound resistors are generally inductive rather than capacitive (at least, at the lower frequencies). After all, they consist of a coil of wire. It is commonplace for wirewound resistors to have inductances of several microhenrys or tens of microhenrys, and even so-called "non-inductive" wirewound resistors, which consist of N/2 turns wound clockwise and N/2 turns wound anticlockwise, so that the inductances of the two half windings cancel out, have a residual inductance of a microhenry or even more. (For higher-resistance-value types, above 10 kΩ or so, the residual reactance may be capacitive rather than inductive, and the capacitance will be higher—by up to 10 pF—than a standard film or composition resistor.) These reactances must be considered carefully when designing high frequency circuits which contain resistors.

†This issue is developed in detail in the free application note, "An IC amplifier user's guide to decoupling, grounding, and making things go right for a change," by Paul Brokaw.

Reprinted from Analog Dialogue 25–1 1991

Q. But many of the circuits you describe are for making precision measurements at DC or very low frequencies. Stray inductance and capacitance don't matter in such applications, do they?

A. They actually do. Since transistors (either discrete or within ICs) have very wide bandwidths, if such circuits are terminated with reactive loads, they may sometimes oscillate at frequencies of hundreds or thousands of MHz; bias shifts and rectification associated with the oscillations can have devastating effects on low-frequency precision and stability.

Even worse, this oscillation may not appear on an oscilloscope, either because the oscilloscope bandwidth is too low for such a high frequency to be displayed, or because the scope probe's capacitance is sufficient to stop the oscillation. It is always wise to use a wideband (LF to 1.5 GHz or more) spectrum analyzer to verify the absence of parasitic oscillations in a system. Such checks should be made while the input is varied throughout its whole dynamic range, since parasitic oscillations may sometimes occur over a narrow range of inputs.

Q. Are there any problems with the resistance of resistors?

A. The resistance of a resistor is not fixed but varies with temperature. The temperature coefficient (TC) varies from a few parts per million per degree Celsius (ppm/°C) to thousands of ppm/°C. The resistors with the best stability are wirewound or metal film types, and the worst are carbon composition.

Large temperature coefficients are sometimes useful (an earlier "Ask the Applications Engineer"* mentioned how a +3,500-ppm/°C resistor can be used to compensate for the kT/q term in the equation for the behavior of a junction diode). But in general, the variation of resistance with temperature is likely to be a source of error in precision circuits.

If the accuracy of a circuit depends on the matching of two resistors having different TCs, then, no matter how well-matched at one temperature, they will not match at another; and even if the TCs of two resistors match, there is no guarantee that they will remain at the same temperature. Self-heating by internal dissipation, or external heating from a warm part of the system, will result in a mismatch of temperature, hence resistance. Even with high quality wirewound or metal-film resistors these effects can result in matching errors of several hundred (or even thousand) ppm. The obvious solution is to use resistors which are fabricated in close proximity on the same substrate whenever good matching is necessary for system accuracy. The substrate may be the silicon of a precision analog IC or a glass or metal thin-film substrate. In either case, the resistors will be well-matched during manufacture, will have well-matched TCs, and will be at nearly the same temperature because of their proximity.