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ENSC 320 Electric Circuits II

Hints for Successful Op Amp Circuit Designs

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When you are doing your job as an engineer or when you are doing your lab project, you need to implement a circuit that works properly. Most of the techniques that you learn in class or from books assume ideal situations. However, imperfect components and environments might cause undesirable effects on the performance of your circuit. Our goal here is to introduce some techniques to deal with the restrictions of a real situation.

If designers don't observe some special precautions, especially with high-bandwidth opamps or high gain amplifiers, the circuit can easily become unstable. Most common instability problems are caused by the fluctuations in the reference points of the circuit (ground and power supplies) or by the poor choice and reliability of the components. The designers must understand these issues and know how to avoid them.

I. Components

We will first cover the technique involving the choice and application of different circuit components.

A. Wires

The wires that connect the power supply to the circuit should be twisted lightly (Figure 1). This way the area of the wire loop is small, so the presence of an electromagnetic field in the environment will cause smaller variations in the input voltage. However, the wires should not be twisted too much because then each wire would be like an inductor itself.

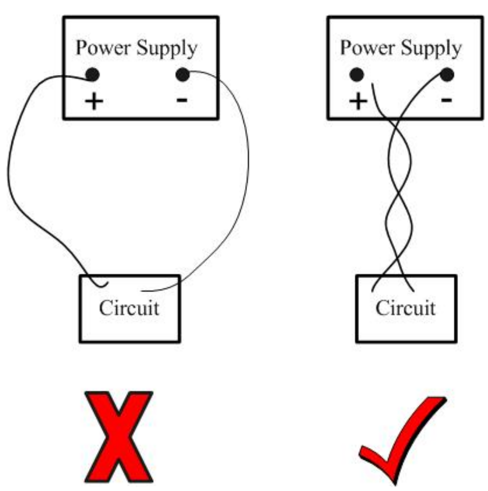

Figure 1 Connecting power supply to the circuit

The wires on a circuit should also be as short as possible to reduce the resistance and inductance. Further, even fairly short line lengths in the supply or signal paths can be long enough to amount to a significant portion of a wavelength at high frequencies. These lines can act as antennas, radiating the signal into other portions of the pc board, causing instability and crosstalk. For example, at 1 GHz, a 2.8-in. (71-mm) line is very close to one-quarter wavelength, and it can radiate very effectively into other circuitry.

B. Opamps

You should to choose the right opamp for to your application. You should check the manuals for the noise figure and bandwidth of the device. As a general rule the bandwidth of the chip should be about ten times the required bandwidth of the circuit. High speed opamps are usually more sensitive and can become unstable more easily, so you should not use them if it is not necessary. You should also note that generally, when there are several opamps on one IC – for example, a quad pack - thermal noise is higher than the case where only one opamp is on the IC.

C. Resistors

Metal film resistors are more precise and generate less noise than carbon resistors, so they are typically used in low noise applications. Lower value resistors are attractive, because they produce less noise than higher value resistors. Even a small amount of noise picked up by a marginally stable circuit can trigger sustained oscillation. On the other hand, if the resistors are too low, they can overload the opamp output circuit – it can source or sink only so much current. Figure 2 shows an example of this situation. If R_2 is very small, the current from the output to the negative input terminal might overload the opamp. Typical values in active filter work range from about 1kΩ to 1 MΩ.

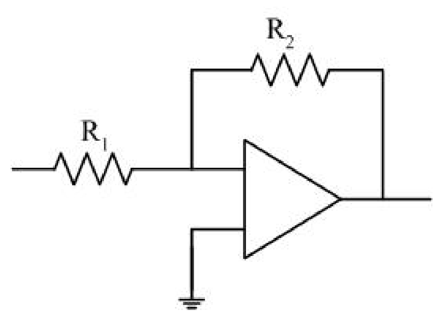

Figure 2 Example of the case where resistors cannot be chosen too small

D. Capacitors

Charging a large capacitor can also overload the circuit, since there is a limit on the amount of current an opamp can source or sink. Here there is an interplay with the choice of resistor. Consider Figure 3, a simple first order RC filter. Its cutoff frequency (1/2πRC) can be realized by various combination of R and C – but the small R, large C combination is doubly dangerous. On the other hand, in low noise design, you try to keep R small. There’s no free lunch.

Capacitors should also be chosen according to the application. Electrolytic capacitors are polarized – take care to mount them in the circuit the correct way round. Large electrolytics also suffer from high leakage and have a limited life, even as little as 1000 hours. These capacitors are typically larger than 1 μF and are usually used for power supply decoupling and low frequency applications. Decoupling simply means that the capacitor is place across the DC power supply lines between the power source and the circuit. It acts as a reservoir of charge to stabilize the voltage at that point, so that fluctuations in either the power supply do not affect the circuit, and vice versa.

Polycarbonate and polyester capacitors are more stable. They usually have lower values and are good for use in the implementation of filters. Ceramic capacitors usually come in smaller values about several pF and are popular in high frequency applications.

Every real capacitor also contains inductance and resistance and this imperfection will limit the operational frequency of the capacitor. Because of these potential problems, most high-speed circuits built today use surface-mount chip capacitors, which have very low internal inductance, so their useful frequency range is much higher.

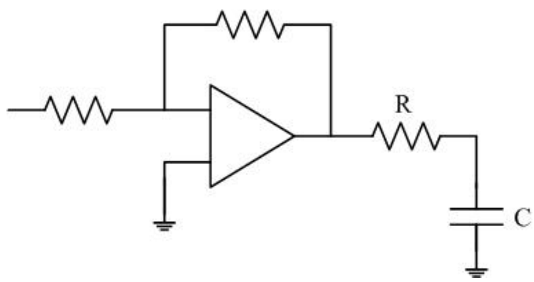

Figure 3 Example of the case where capacitor cannot be chosen too large

E. Inductors

If there are several inductors in the circuit, try to make sure that adjacent inductors are placed at a 90 degree angle. This will minimize the cross talks between the inductors.

II. Stability of the Reference Points of the Circuits

Effective grounding, bypassing, and decoupling are all essential to preserving circuit stability. All three have closely related applications.

A. Grounding

Grounding" effectively creates a common signal "sink" by providing a low-inductance signal-return path. Keep all connections as short as possible, and to directly ground all components to the pc-board ground using separate, very short ground wires, or a common ground plane. Avoid daisy-chain grounds, where a ground wire connects to one component and then directly off to another, then another, forming a "chain" of grounds. Because these components are all grounded at different points along the wire, each component's "grounding point" will be at a slightly different potential. This can introduce some very strange effects, including "motor boating" (low-frequency audio oscillations) and other forms of instability. It can also cause DC circuit errors. Even though these may only be a few millivolts, if they occur at the input of a high-gain amplifier, they can add up to a large DC error at the output.

B. Decoupling and Bypassing

The power supply rail should be as low impedance as possible to avoid resistive voltage drop. As we mentioned before it should also be short to minimize the inductance. Power-supply bypassing with a capacitor transfers most of the RF energy present on the power-supply lines to ground. This minimizes signal transfers between amplifier stages via the common power-supply line. Finally, power-supply decoupling, normally an RC low-pass filter in the power-supply line, is even more effective in preventing RF energy from flowing between amplifier stages that share a common supply line.

Large decoupling capacitors should be placed at the point of entry of DC power to avoid fluctuations in the supply voltage. Practical values of this capacitor are 1 – 100 μF. If the circuit holds several opamps, a relatively small local 0.1 μF bypass capacitor can be used at each opamp's power supply pins (see Figure 4). Keep these capacitors as close to the opamp pins as possible. Without bypassing, variations in the instantaneous current drain by the opamp produce corresponding small voltage variations in the power supply line, which has a small, but non-zero, resistance.

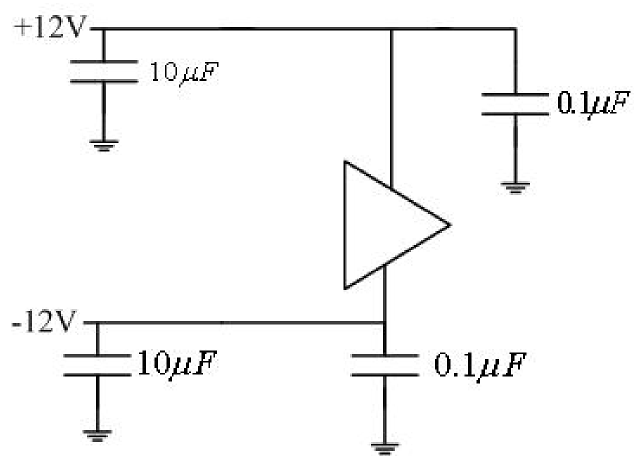

Figure 4 Bypassing capacitors

Issues of power-supply decoupling are similar to those of power-supply bypassing, except that the emphasis is on minimizing any transfer of unwanted RF (radio frequency) signals between ICs, or discrete amplifier stages, via the power-supply lines. Signal transfer between stages is very undesirable as it may lead to intermodulation distortion, crosstalk, and instability. One solution is to add a small resistance in series with each IC's power-supply line (10 Ω or less). In conjunction with the bypass capacitor, it makes a lowpass filter with cutoff frequency lower than RF, so that the RF energy is dissipated in the resistor. On the other hand, and as noted above, resistance in the supply lines is undesirable, since normal fluctuations of opamp current demand in the lower frequency range occupied by the desired signals can produce fluctuations of supply voltage to the chip. In this case (where you want decoupling at RF but good power supply regulation for desired signals), there may be a free lunch: replacing the resistor in the supply line with a small inductor of low internal resistance. This creates a more effective decoupling filter, since inductors block high frequencies. Small ferrite beads are commonly used for this purpose, as they're very low cost and have no significant series resistance

Reference

R. Gawel, " Proper design techniques solve high speed opamp stability problems," Downloadable at *http://www.elecdesign.com/Articles/Index.cfm?ArticleID=1478&pg=1,* January 2002