Application Note

AN-1
Board Layout for High-Speed Amplifiers

Introduction

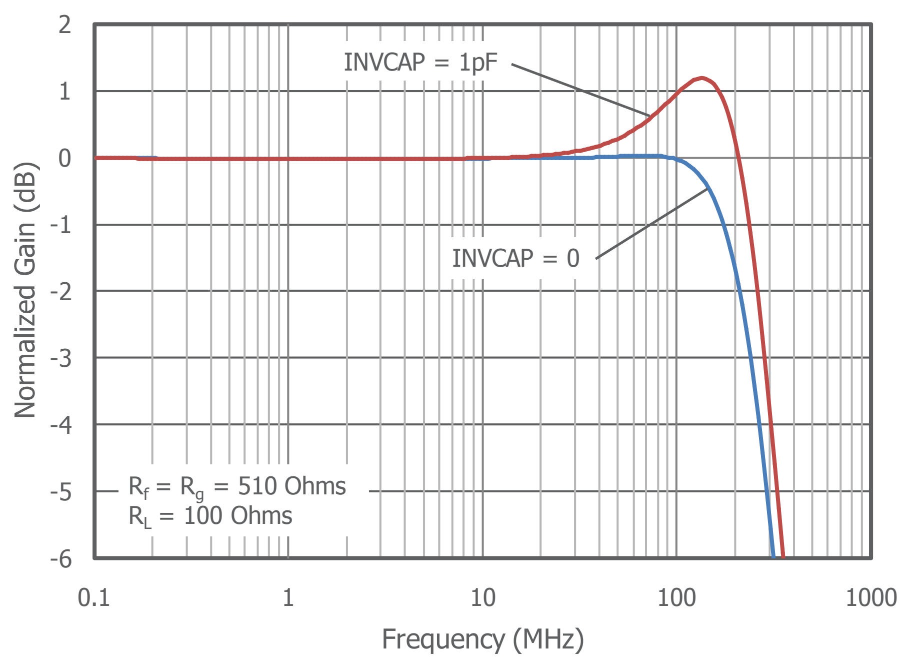
Building a circuit with bandwidths in the megaHertz (MHz) range makes board layout very important, becoming more so as the bandwidth increases. Note that **signal** bandwidth is not the only important factor; bandwidth of the active components that **exceed** signal bandwidth can be just as important. Parasitic and nonlinear effects beyond signal bandwidth can cause excess noise, overdriven stages, higher than expected distortion and even DC offsets due to asymmetric slew rates.

Parasitic Capacitance on Signal Traces

Parasitic capacitance can cause amplifiers to peak and in extreme cases oscillate. Fractions of a picofarad can control details of gain flatness and bandwidth. Whole picofarads can cause more gross effects. In general terms, capacitance is minimized by increasing distance between wires (reducing trace to trace capacitance) and minimizing trace length (reducing trace to ground capacitance).

One of the most critical nodes to minimize parasitic capacitance on is the inverting input of an op amp. This is due to the interaction of parasitic capacitance with the feedback and gain set resistors, R_f and R_g. Many amplifiers are used at low gain, with relatively high R_f and R_g. Capacitance from the inverting input to ground is in parallel with R_g, and directly impacts the op amp closed loop transfer function. In addition, this capacitance can add a pole to the loop transmission, making the feedback unstable. It doesn't take much; here is what happens when one extra picoFarad is added (R_f, R_g = 510 Ohms):

CLC2600 AC Response vs. Inverting Input Capacitance



A small amount of parasitic capacitance cannot be avoided. Cadeka parts are measured in an application board with a realistic layout, having 0.5 to 1 pF of parasitic capacitance on the inverting input. This amount of parasitic is present for specifications and plots in Cadeka data sheets. A layout that adds **additional** picoFarads is what hurts. Minimize extra parasitic capacitance by putting components that are connected to the inverting input as close to it as is reasonable. Don't run any traces connected to the inverting input pin over a distance—it doesn't take much to add a picoFarad or two. Remove ground and power planes from the vicinity of the inverting input to reduce ground capacitance (see Cadeka evaluation board layouts).

The non-inverting input of a high speed amplifier is often driven from a lower impedance than the inverting input (whose driving impedance is $R_f||R_g$). The non-inverting input is typically driven by another, relatively low impedance amplifier or by a terminated transmission line (50 or 75 Ohms/2). This makes the non-inverting input less sensitive to parasitic capacitance.

Another pin which can be sensitive to capacitance is the output. This sensitivity is caused by the (internal) output impedance of the amplifier interacting with a load capacitance, causing an additional pole in the feedback loop transmission (See "AN-2: Driving Capacitive Loads" application note). In general, amplifiers become more sensitive to parasitic effects as the bandwidth increases.

Trace to trace capacitance can cause undesired coupling between sections of a circuit. High impedance traces (at the input pins) are much more affected by coupling than low impedance traces (outputs). Focus on possible coupling to high impedance traces, minimizing it by adding distance between traces where possible. Another approach is to put a ground trace between two signal traces—this causes the parasitic to be a capacitance to ground rather than to another signal carrying trace.

Given how sensitive high speed amplifiers are to capacitance, you can imagine the huge effect most sockets have on AC response. Sockets with small, short pin receptacles may sometimes be used, but are not recommended. The type with a locking arm and spring contacts are definitely not recommended for high speed amplifiers.

Power Supply Bypassing

Correct bypassing can greatly improve the AC response of an amplifier circuit. For each supply, there should be a high frequency bypass capacitor very close to each amplifier (usually 0.1uF or 0.01uF). A second, larger value capacitor can serve a section of the printed circuit (PC) board, spaced several centimeters apart. The small, high frequency capacitor has a large impact on the response; total lead and trace length should be a few millimeters or less, including both amplifier to capacitor and capacitor to ground plane trace length.

Parasitic Issues in Grounding

As mentioned earlier, ground and power planes should be removed from the vicinity of the inverting input pin. For very high speed amplifiers (>50MHz), removing ground plane from around the output pin is also a good idea.

There are other issues to consider in component grounding. Ground planes are not ideal conductors; they are made up of a mesh of parasitic resistance and inductance. A current in the ground plane will flow in multiple paths, distributed relative to the conductance of each path. As the current flows through the ground plane impedance, it causes varying signal voltages to appear throughout the plane. The signal levels are quite small, but can have an impact on sensitive circuits.

Harmonic distortion (mostly the even harmonics) can be very sensitive to ground current routing, especially at high gains. Current leaving the output of an amplifier flows to the load and returns to the power supply bypass capacitors according to polarity. Since multiple supply pins ($+V_S$ and $-V_S$) are not usually located next to each other, the ground current return path varies depending on polarity. Some of this current will route past the input grounds, with one supply having a stronger effect due to ground current routing. This causes one polarity of the input signal to be altered, but not the other polarity, leading to additional even harmonic distortion (2^{nd}, 4^{th}, 6^{th}, etc.). Minimize this by rotating the bypass capacitors so that their ground connections are towards the output rather than the inputs. A very good approach for triple and quad bypassing is to ground the positive and negative bypass capacitors at a common point, forcing all polarities of return currents to flow by the same paths.

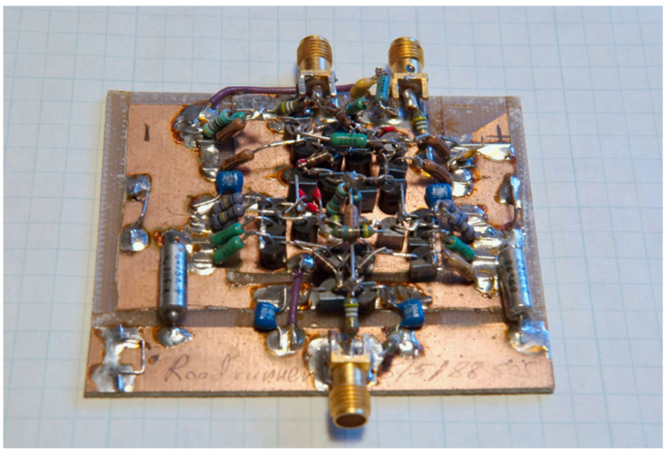
Input and Output Connections

In addition to capacitance affecting the amplifier, long input and output traces or wires can corrupt signals due to self inductance and capacitance. This can cause the trace itself to have an AC response that varies with frequency from one end of the trace to the other. The best solution for this, where the length is unavoidable, is to use a controlled impedance connection. This consists of termination resistors at both input and output, with a length of transmission line between the terminating resistors. The transmission line can be made from microstrip if the signal remains on the same PC board or coaxial cable if the signal leaves the board. Typically, traces longer than a few centimeters benefit from using a controlled impedance connection.

Breadboarding

A breadboard (no PC board, just components wired together through the air above a ground plane) is especially important in the early phases of constructing a circuit. It can often be made much more quickly than a PC board. In addition, a carefully constructed breadboard will have the smallest parasitics possible, and will show the maximum performance achievable for a given circuit. Wires running through the air generally have much lower capacitance than traces on a board. Building critical sections of the circuit by hand can speed both PC board design (minimize iterations) and provide a performance goal (such as gain flatness and distortion) for the PC board.

A good start for a breadboard is to glue the amplifier package to a piece of copper clad board upside down (dead bug) using cyanoacrylate glue. Next, add high frequency bypass capacitors and other pin to ground components from the amplifier pins to the ground plane. Pin to pin components (such as Rf) come next, followed by input and output connections. Be careful attaching cables to connectors—it is very easy to put a crack



in surface mount components due to mechanical stress on the connection. The cracks are nearly invisible.

Here is an example breadboard:

Leads are kept short in any parts of the circuit conducting signal currents. A hand built breadboard with good performance makes first pass PC board success much more likely.

Cadeka evaluation boards for common configurations are available to speed customer evaluation, but they don't fully replace breadboards and prototyping of your actual circuit.

For additional information regarding our products, please visit CADEKA at: cadeka.com

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