Capacitive Loads and Phase Margin

by Farhana Sarder - 08-02-2017

Why does my op amp oscillate when I connect a capacitor on the output?

Driving a capacitive load with an op amp can be tricky. If the load capacitance is too high, this can cause instability, making the op amp output oscillate. Having adequate phase margin is essential for stability. As load capacitance increases, phase margin decreases. If you are seeing an op amp output oscillate, the first thing to look at is the load.

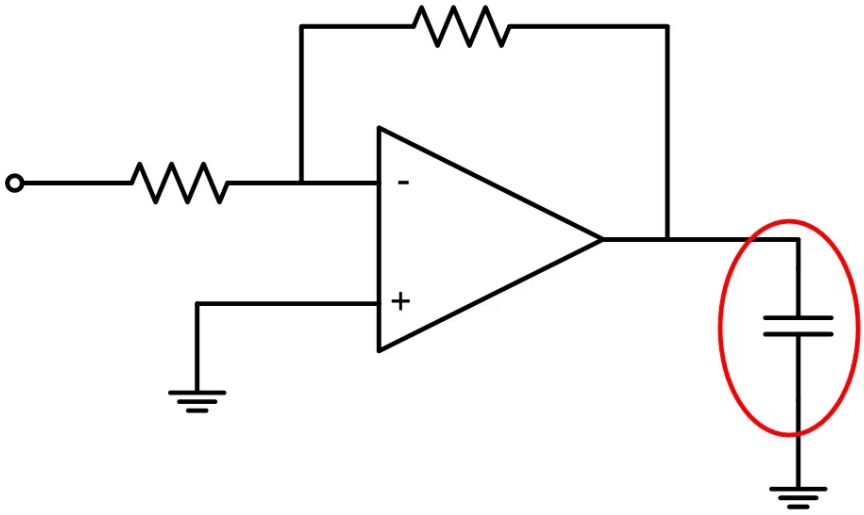

Figure 1. Capacitive loads on an op amp output can cause oscillation

The load capacitance can include any capacitors connected to the output well as any external or parasitic capacitances contributed by the system, including the PCB and probes. This capacitance adds a phase lag, reducing phase margin. Combined with the internal output resistance, the load capacitance creates a pole, shifting the gain and phase plot. This behavior is shown in Figure 2.

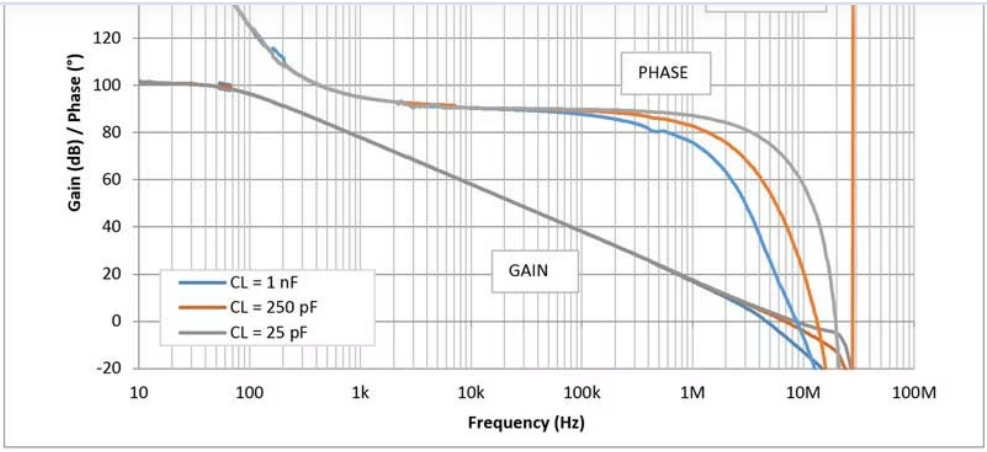

Figure 2. NCS2005 Gain and Phase versus Frequency.

For example, the ON Semiconductor NCS2005 is an 8 MHz operational amplifier designed to drive capacitive loads up to 1 nF. Notice how the phase margin starts dropping away faster as the load capacitance increases. With a 1 nF load capacitance, the phase margin drops to about 25-30°, which is the minimum phase margin that a system should be designed for according to rule of thumb. A smaller load capacitance of 25 pF pushes the pole to higher frequencies on the gain and phase plots, improving the phase margin to 65°.

Another way to improve the phase margin is by adding a small series resistor at the output. Typically, a resistor value between 10 Ω to 50 Ω is used. This series resistor essentially helps isolate the output of the op amp from the load capacitor. The feedback is taken from the output of the op amp before the series resistor. The external series resistor is usually larger than the output resistance of the op amp, so the phase shift is predominantly seen by the series resistor instead of the op amp. Possible disadvantages of this technique may include DC errors due to the added resistor or a limited frequency response from the low-pass filter that is created with the external R and C, but there are other (more complicated) techniques that avoid this.

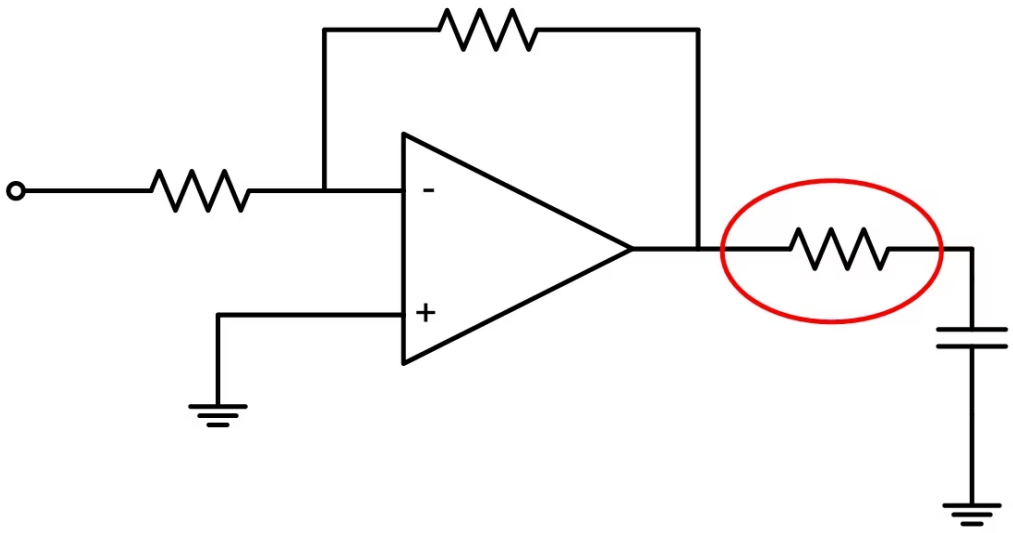

Figure 3. Adding a resistor before the capacitor can help improve phase margin

Finally, another way of improving the phase margin is to increase the closed loop gain of the circuit. Unity gain is the most sensitive to instability because of the low output impedance.