Feedback Capacitors

Purpose

Purposes for adding capacitor in the feedback loop of opamps:

Improve stability:

Real op-amps are not ideal. An op-amp already contains internal poles and phase shift. External components (wiring capacitance, probe capacitance, transistor gates, ADC inputs, photodiodes, etc.) add even more phase shift. Too much phase shift in the feedback loop can turn negative feedback into positive feedback at high frequency → oscillation. The capacitor helps by reducing the amplifier gain at high frequencies before the phase shift becomes dangerous.

Create a low-pass response:

The resistor and capacitor form a frequency-dependent feedback network. At low frequencies: capacitor is effectively open gain is set by the resistor ratio normally. At high frequencies: capacitor impedance decreases, feedback becomes stronger, closed-loop gain drops

Reduce noise

Wide bandwidth means more noise.By limiting bandwidth, the capacitor reduces: RF pickup, broadband noise, switching spikes, EMI susceptibility

Compensate for input capacitance:

This is extremely common in: oscilloscope probes, photodiode amplifiers, high impedance sensors, differential probes, transimpedance amplifiers, etc. Input capacitance introduces another pole that can destabilize the circuit. The feedback capacitor creates a compensating zero/pole pair.

Size of the capacitor

There is no universal value. The value depends on:

- feedback resistor value
- op-amp bandwidth and phase margin
- input capacitance
- desired bandwidth

- required settling time
- noise requirements

How to calculate?

CASE 1 — Simple bandwidth limiting

Adding Cf creates a low-pass filter in the feedback path.The cutoff frequency is approximately:

```
fc = 1 / (2π * Rf * Cf)
```

So:

- larger capacitor → lower bandwidth
- larger resistor → lower bandwidth

CASE 2 — Compensation for input capacitance

This is more subtle and very important in fast/high-impedance circuits. Suppose the inverting node has capacitance:

- op-amp input capacitance
- PCB stray capacitance
- cable capacitance
- transistor gate capacitance

This capacitance together with Rin creates a pole:

```
fp = 1 / (2π * Rin * Cin )
```

This pole can destroy phase margin. A feedback capacitor introduces a zero that compensates it. A common approximation is:

```
Cf ≈ Cin * (Rin / Rf)
```

This is widely used as a starting point.

CASE 3 — Transimpedance amplifiers

For photodiodes and probes, the feedback capacitor is often mandatory. Without it: huge peaking, oscillation, ringing, etc. The optimal value depends on:

- op-amp GBP
- total input capacitance
- feedback resistor

A common approximation:

```
Cf ≈ SQRT( Cin / ( 2π * Rf * GBW  ) )
```

where: GBW = op-amp gain-bandwidth product Cin = total input capacitance

But in practice this is usually refined using:

- SPICE simulation
- phase margin analysis
- bench tuning