Two-Stage Op-Amp Overview

1. What is a Two-Stage Op-Amp?

A two-stage operational amplifier has:

• Stage 1: Differential amplifier with active load.

• Stage 2: Common-source gain stage.

• Compensation capacitor (Miller compensation) for stability.

2. Why Two Stages?

• High DC gain.

• Easy to stabilize with Miller capacitor.

• Good for moderate-to-high bandwidth and precision analog circuits.

3. Basic Equations:

Let gm1, ro1 = transconductance and output resistance of stage 1.

Let gm2, ro2 = transconductance and output resistance of stage 2.

DC Gain:

$A = (gm1 * ro1) * (gm2 * ro2)$

Gain Bandwidth (GBW):

$GBW \approx gm1 / (2\pi * Cc)$

Dominant Pole:

$p1 \approx 1 / (ro1 * (Cin + Cc(1 + A2)))$

Non-Dominant Pole:

$p2 \approx 1 / (ro2 * (CL + Cc))$

Phase Margin (approx):

$PM \approx 180° - \arctan(GBW/p2)$

4. Design Steps:

1. Set specifications (gain, GBW, PM, power, load).

2. Choose tail current for differential pair.

3. Set gm1 from GBW requirement.

4. Choose compensation capacitor Cc.

5. Size transistors to meet gain.

6. Verify poles and adjust Cc for PM ~ 60°.

7. Check slew rate $SR \approx I/Cc$.

5. Stability Techniques:

• Miller capacitor.

• Series resistor (nulling resistor).

• Feed-forward zero.

• Output buffer for heavy loads.

6. Layout Notes:

• Common-centroid for input differential pair.

• Symmetric current mirrors.

• Guard rings.

• Minimize parasitic capacitances at high-impedance nodes.