ECE4902 Lecture 12

How to Increase Open Loop Gain?

Improving Performance: Cascode Op-amp *
  Tradeoff:  
    + Higher node impedance
    - Reduced signal swing

2-Stage Op-Amp
  CL, Phase Margin Issue

1-stage op-amp (Johns & Martin 6.2)
  Improving Performance: Cascode

* Bandgap Voltage Reference

( * Optional Lab Circuit )

Hand In:
HW 5

Handout:
Op-Amp Slides
Cascode Op-Amp
Bandgap Voltage Reference
  Principle
  Circuit
Review: Small signal (ac) model of 2-stage op-amp
Complete transfer function, stability plot

Increasing node impedance at 1st stage output does not affect phase margin! Separate gain, stability problems
Cascode Op-Amp (Optional Lab 10)

Start with your previous op-amp, compensated. Hook it up for an inverting gain of 100. Use a 10mV input sine wave at 100Hz to get an output swing of around 1V. The nice thing about doing it this way is you can look directly at the signal at the - input, which is close to ground, and view it up close on the scope: since there's no DC component, expanding to the max scale will not shoot the signal off the screen.

Without the cascode, your open loop gain of about 1000 should give a 1mV sine wave at the - input. With the scope probe on 1X and the scope on 2mV/division, you should be able to (barely) see a signal at the - input. Record the signal amplitude as best you can, then do the cascode as indicated below:

**CASCODE GOES HERE**

![Diagram of Cascode Op-Amp](image_url)
To cascade the internal node, you'll need a fourth CD4007 chip. Connect it as shown here:
2-Stage Op-Amp Phase Margin vs. $C_{LOAD}$

- $C_{LOAD} = 10\text{pF}, 100\text{pF}, 1000\text{pF}$
- Phase margin $\phi_M$ degrades as $C_{LOAD}$ increases
1-Stage ("gm-C" "transconductor") Op-Amp

- Only one high impedance node: \( C_{\text{LOAD}} \) compensates
1-Stage ("gm-C" "transconductor") Op-Amp

- $C_{LOAD} = 1000\text{pF}, 10000\text{pF}: \phi_M$ same as $C_{LOAD}$
- Unity gain frequency $f_T$ worse, but always stable
1-Stage Problem

• Lousy DC gain ≈ 90 (39 dB)
• Solution: Add cascode to high impedance node
1-Stage with Cascodes
1-Stage with Cascodes

- \( C_{LOAD} = 1000pF, 10000pF: \phi_M \) same as \( C_{LOAD} \uparrow \)
- Unity gain frequency \( f_T \) worse, but always stable
Bandgap Voltage Reference (Optional Lab 11)

Motivation: DC Bias
$T = 0^\circ \text{K}$
(Absolute Zero)

**Figure 6.** Typical base-to-emitter voltage characteristic vs temperature for each transistor.
Here's the bandgap circuit covered in lecture:

The CA3046 is a 5 NPN transistor array. Its data sheet is available on the course website.