EE 330 Laboratory 8
Discrete Semiconductor Amplifiers

Spring 2019

Contents

Note:

This lab will be split up over 2 weeks. For the 1st half (week 8) you will perform the exercise up to Part 3b. For the 2nd half (week 9) you will finish the rest of the exercises. An individual lab report is expected for each half, due a week from lab date. So lab report for 1st half is due on week 9, and the lab report for 2nd half is due on week 10. Separate deliverables lists are available at the end of this lab manual.

Objective:

The objective of this laboratory experiment is to become familiar with applications of MOS and Bipolar transistors as small-signal amplifiers. Both BJTs and MOSFETs are semiconductor devices that can be used in both analog and digital applications. In this lab, MOS transistors will come from the EDU1000 MOSFET array. The BJT that will be used is the PN2222 .

In this experiment, you will be measuring waveforms, operating points, and gains. All of these measurements should be made with the oscilloscope. The multimeter that is on the laboratory bench should not be used for any measurements in this experiment.

Discussion:

Although the major emphasis in this course has been on integrated devices, discrete transistors will be used in this experiment.

Components Needed:

PN2222 BJT, EDU1000 transistor array, and any operational amplifier you are familiar with (LM324, LMC660, etc). Data sheets for these components are posted on the EE 330 class web site.

Source of error:

You might notice that your theoretical and experimental numbers will not match exactly. This could happen for multiple reasons. One of which is that the actual resistance of your resistors are different than their nominal value. Another factor is the parameters of EDU1000 vary and are not exactly what is mentioned in the data sheet. You are encouraged to think of more sources of error that will cause your experimental data to not match your theoretical one.

Part 1 Voltage Controlled Amplifier

The circuit shown serves as a voltage controlled amplifier when the transistor M_1 is biased to operate in the triode region. Use any NMOS from EDU1000. The transistor is effectively a resistor with one end connected to ground and the other end connected to feedback network. As the dc voltage VCONT changes, the effective resistance of transistor changes, and the gain of the amplifier changes as well.

$$R_{FET} = \frac{V_{ds}}{I_D} = \left[\mu_n * C_{OX} * \frac{W}{L} * (V_{gs} - V_T)\right]^{-1}$$

From information obtained in the datasheet, determine R so that the voltage gain is 30 with VCONT = 2.5V. Use the long channel NMOS on your MOS array. **Choose V_{in} so that your output won't be clipped**. What does V_{CONT} need to be changed to for a gain of 10? Experimentally verify the operation of this circuit. Use ± 15V biasing for the op amp.
Remember to set your Function Generator to 'High Z' from 'Output Menu'.

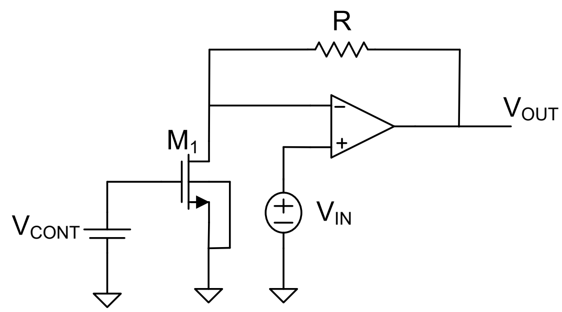
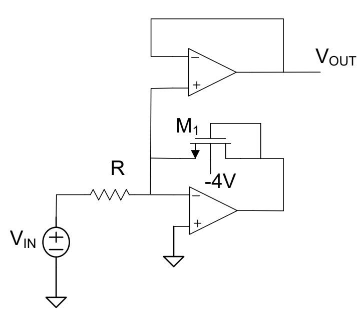
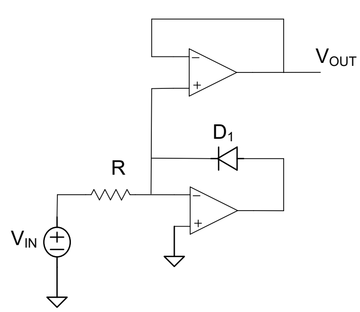


Fig. 1. Voltage Controlled Amplifier.

Part 2 A Nonlinear Application

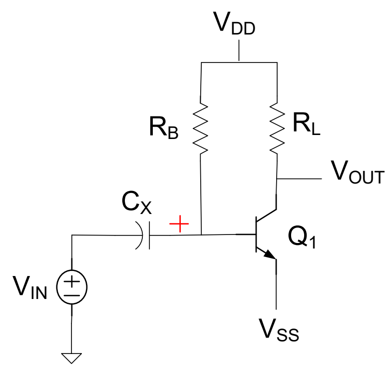
Two circuits are shown. Analytically predict the relationship between VOUT and VIN for $-2V < V_{IN} < 2V$ and verify experimentally. Also predict the output if the input is a 1KHz sinusoidal waveform of 4V p-p value and experimentally verify. Use an n-channel MOSFET from the EDU1000 for M_1 and use a 1N4148 diode for D_1. Comment on what useful functions these circuits provide. Use ± 6V biasing for the op amp. You can choose any resistor in the 1 kΩ - 100 kΩ range for R. (Hint: The connection of Gate to Drain of a MOSFET is often termed a "diode-connected" transistor).





Part 3 Common-Emitter Amplifier

A Common-Emitter amplifier is shown. The value of β for the PN2222 varies considerably from one device to another. In the data sheet that is linked on the class web page, the parameter β is designated as h_{FE}. The large variations in the values of this parameter should be apparent from the data sheet. You will need to measure the value of β for your transistor. The coupling capacitor should be large; in the 1uF range or larger. Note the polarity of the electrolytic coupling capacitor is critical.



Capacitor Coupled Common Emitter Amplifier

a. Use a large resistor for R_B (over 300kΩ) and measure the I_C and I_B current when $V_{DD} = 12V$, $V_{SS} = 0V$, and R_L to 5KΩ. Use $I_c = \beta I_B$ to calculate the $\beta\ (or\ h_{fe})$ of your device. Connecting the capacitor and V_{in} is not necessary for this step.

b. After this value for β is measured, determine the value of R_B necessary to establish a quiescent collector current of 1mA when $V_{DD} = 12V$, $V_{SS} = 0V$, and R_L to 5KΩ .

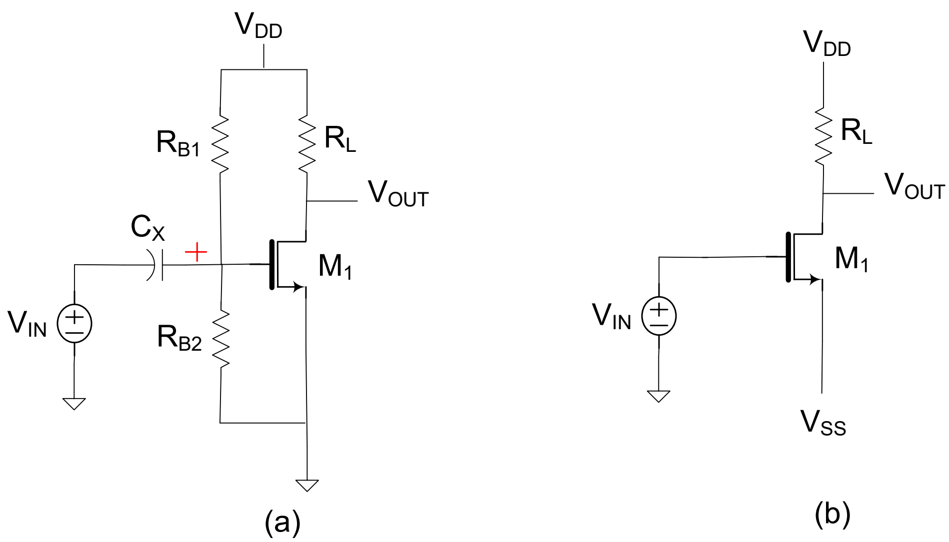
END OF LAB FOR WEEK 8

c. Add capacitor if you did not initially, measure V_{out}, and calculate your gain. Compare the theoretical small-signal voltage gain with what is measured for this circuit. In this measurement, use a 1KHz sinusoidal input signal with the input amplitude adjusted so that the output signal swing is 4Vpp.

d. Gradually increase the amplitude of the input until clipping distortion is observed on the output. How big can the output signal be without clipping?

Part 4 Common Source Amplifier

Two common-source amplifiers are shown below. The one on the left uses the resistors R_{B1}, R_{B2} the capacitor C_X, and the voltage source V_{DD} for biasing. The one on the right uses the two voltage sources V_{DD} and V_{SS} for biasing.



Common Source Amplifiers

Derive an expression for and compare the voltage gains of **these two amplifiers** if the transistor is operating in the saturation region. **Then build and test one of the two**. When building the amplifier, use $V_{DD} = 5V, R_L = 10K$ and design for a voltage gain of -5. Select the remaining components to achieve the required gain. Test the circuits with a sinusoidal input voltage of 100mV 0-P and frequency of 1KHz. Compare the measured voltage gain with the calculated gain.

Part 5 Amplifier Design

Build and test a small-signal voltage amplifier using the BJT as the active device with a small signal gain of -10 that can drive a 5K load resistor. If you use the circuit of Part 3, the resistor R_L can be considered as the load.

Deliverables for 1st half (Due on week 9):

- Verification Sheet
- Introduction:
  - Discuss what is done in lab
  - Discuss why is it useful
- Part 1 – Voltage Controlled Amplifier:
  - Explain how this circuit works
  - Show how you calculated R
  - Picture of your output
  - Analyze your output, compare theoretical and experimental results
  - Show how you calculated V_{cont} to get a gain of 10
  - Picture of your output
  - Analyze your output, compare theoretical and experimental results
- Part 2 – Nonlinear Application:
  - Show your analytical prediction/Explain how this circuit works
  - Show 2 outputs: one for each circuit
  - Discuss how these circuits are useful
- Part 3 – Common-Emitter Amplifier
  - Explain how you obtained β, mention any relevant measurements
  - Show how you calculated R_B, compare theoretical and experimental I_C
- Conclusion:
  - Discuss what you learned in lab
  - Add any comments on what you liked or what would you want to see changed

Deliverables for 2nd half (Due on week 10):

- Verification Sheet
- Introduction:
  - Discuss what is done in lab
  - Discuss why is it useful
- Part 3 – Common-Emitter Amplifier
  - Show your theoretical small signal calculation
  - Picture of your output
  - Analyze your output, compare theoretical and experimental results
  - Show a picture of clipping and mentioned the max V_{out} that can be used without clipping
  - Discuss why clipping is bad
- Part 4 – Common Source Amplifier:
  - Show your derivations for voltage gains for both amplifiers
  - Mention your choice of amplifier and all relevant values and how you obtained them
  - Picture of your output
  - Analyze your output, compare theoretical and experimental results
- Part 5 – Amplifier Design
  - Mention your design architecture all relevant values and how you obtained them
  - Picture of your output
  - Analyze your output, compare theoretical and experimental results
- Conclusion:
  - Discuss what you learned in lab
  - Add any comments on what you liked or what would you want to see changed