EE 330 Lab 10
Basic Transistor Amplifiers

Spring 2024

The Electrical and Computer Engineering Department will be undergoing an ABET review next year as part of the six-year cycle of reviews of all ABET accredited programs. As part of that review, Rubrics have been established for assessing student outcomes. Meeting the expected outcomes can be done in different ways but often involves identifying parts of courses where students demonstrate specific skills. This laboratory experiment focuses on one group of critical outcomes, denoted as Student Outcome 6, specifically; "experimentation, analysis and interpretation of data, and use of engineering judgement to draw conclusions." The Rubric associated with Student Outcome 6 is appended to this experiment along with a table for entering your assessment of how you meet the outcome requirements. Please attach the table that is appended as the last page of this experiment to your report and place an X in one column of each row. Please include a very brief description (one or two sentences would be appropriate) that identify what in this experiment supports your self assessment.

Contents

Objective

The objective of this lab is to become familiar with applications of MOS and Bipolar transistors as small-signal amplifiers. 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 lab bench should not be used for any measurements.

Checkpoints

1. Oscilloscope results showing V_{OUT} with a sinusoidal input when M_1 is used
2. Oscilloscope results showing the gain of the circuit in Part 3
3. Oscilloscope results showing the gain of the circuit in Part 4
4. Oscilloscope results showing the gain of the circuit in Part 5

Part 1: A Nonlinear Application

Two circuits are shown below. Analytically predict the relationship between V_{OUT} and V_{IN} for $-2V < V_{IN} < 2V$ and verify experimentally. Also predict the output if the input is a 1KHz sinusoidal waveform of $4V_{0\text{-}P}$ and experimentally verify. Use a long-channel n-channel MOSFET from the EDU1000 array for M_1, a 1N4148 diode for D_1, and a LM324 for the op-amp. Let $R_1 = 2.2K\Omega$. Comment on what useful functions these circuits provide. Use $\pm 6V$ biasing for the op-amp.

Hint: The connection of gate to drain of a MOSFET to form a one-port circuit is often termed a "diode-connected" transistor.

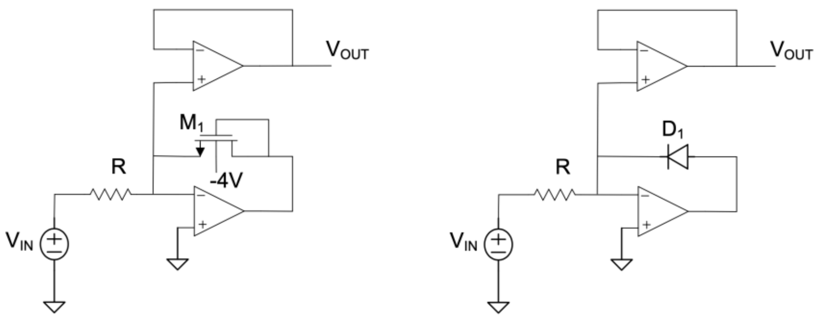

Figure 1: "Diode-Connected" Transistor vs Diode Op-amp Circuit

Part 2: Common-Emitter Amplifiers

The amplifier shown below is one of the most basic and most useful amplifier structures. For reasons that will become apparent later, it is termed a common-emitter amplifier. 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. Use the steps below to help guide you in the measurement process. The coupling capacitor should be large; in the $1\mu F$ range or larger. The polarity of the electrolytic coupling capacitor is critical and the the polarity for this circuit is as indicated with the "+" symbol.

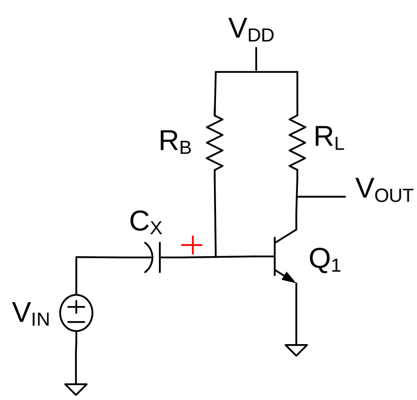

Figure 2: Capacitor-Coupled Common-Emitter Amplifier

a) Measure β of the transistor using the circuit of Fig. 2. In this measurement be sure that the transistor Q_1 is operation in the forward active region. When operating in the forward active region, $I_C = \beta I_B$ so β can be obtained by taking the ratio of the I_C to I_B. (A convenient value for the supply voltages is V_{DD}=12V). Since the measurements are to be made with the oscilloscope, the currents can be obtained by taking the difference of the two voltages across the appropriate resistors and dividing by the value of the resistor.

b) After β is measured, bias this circuit (by choosing the appropriate value of R_B) to operate a quiescent collector current of $1mA$ when $V_{DD} = 12V$, and $R_L = 4.7k\Omega$.

c) Derive an expression for the small-signal voltage gain of this circuit in terms of the device model parameters and the quiescent operating point.

d) Measurement the small-signal voltage gain of this circuit when biased to operate with a quiescent collector current of 1mA. In this measurement, use a $1KHz$ sinusoidal input signal with the input amplitude adjusted so that the output signal swing is $4V_{PP}$. Compare the measured gain with the theoretical gain calculated in part c).

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

f) Return the output signal swing to $4V_{PP}$. Utilize the DFT function on the oscilloscope, observe the frequency spectrum of your output signal. Now, increase your input signal until your output clips again. Observe how the frequency spectrum of your output signal changes with the amount of signal clipping. What changes?

Part 3: Common-Source Amplifier

Two widely used single-transistor MOS amplifiers are shown below. For reasons that will become apparent later, these are termed common-source amplifiers. 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.

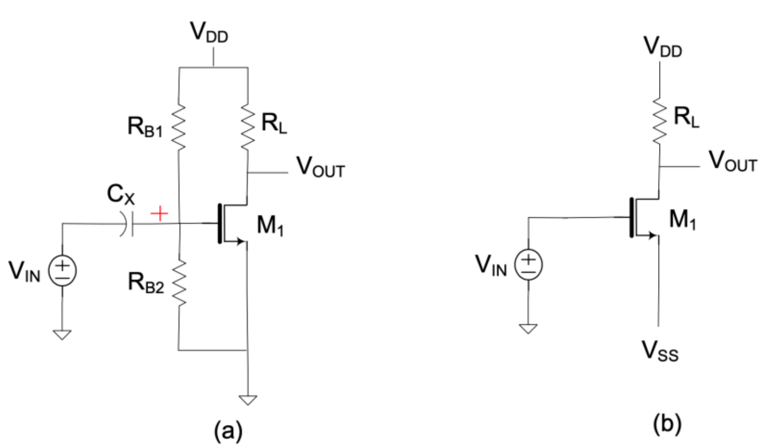

Figure 3: Common-Source Amplifiers

The MOSFET model parameters (V_{TH}, μC_{OX}, λ) for the transistor were measured in a previous experiment. Since you will not be using the same EDU 1000 device, in this part of the experiment, use the values of the model parameters given in the EDU 1000 datasheet.

a) Derive an expression for the voltage gain of these two amplifiers in the small-signal parameter domain.

b) Express the voltage gain of these two amplifiers in terms of the model parameters and the excess bias voltage as the Q-point, $V_{EB} = V_{GSQ}-V_{TH}$. Assume you will be using the Long-Channel transistor in the EDU1000 that has W/L=60µm/3µm.

c) Design one of these two amplifier circuits using the long-channel transistor in the EDU 1000 for a voltage gain of -5 with V_{DD}=5V and R_L=10KΩ.

d) Test the circuit you designed in part c) with a sinusoidal input of 100mVp-p and frequency 1KHz. Compare the gain you measure with the design value of -5.

Part 4: Amplifier Design

Build and test a small-signal voltage amplifier using the NMOS transistor as the active device that has a small-signal gain of -10 that can drive a $20K\Omega$ load resistor. You have a single 5V supply voltage available for this design and any number of resistors and capacitors in addition to the Long-Channel NMOS transistor that is available in the EDU 1000.

Student outcome 6: an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions				
Performance Indicators	(1 pt) Unsatisfactory	(2 pts) Developing	(3 pts) Satisfactory	(4 pts) Exemplary
A. Develop Experiment	No plan for data collection; does not properly identify tools needed for experiments	Experimental plan is incomplete, and partially correct; able to identify some tools needed for experiments, but unable to identify their proper use	Experimental plan is correct but incomplete; needs some assistance in identifying tools needed for experiments and their use	Experimental plan is correct and complete; does not need assistance in identifying tools and their use in experiments
B. Conduct Experiment	Does not follow experimental procedure; does not know how to operate tools properly; poor documentation of data	Experimental procedure is partly followed; makes many mistakes in operating tools; documentation is partly complete	Experimental procedure is mostly followed; requires some guidance in operating tools; documentation is mostly complete	All experimental procedures are followed; does not require guidance or assistance in operating tools; documentation is complete
C. Analyze Data	Data collection is disorganized and incomplete; no identification of functional or measurement errors	Data collection is partly complete and organized; identifies some functional or measurement errors without root causes	Data collection is mostly complete and organized; identifies functional and/or measurement errors with some root causes	Data collection is complete and well organized; functional and measurement errors are absent or identified with correct root causes
D. Interpret Data	Does not relate experimental data to knowledge or theory	Some understanding of data in relation to knowledge or theory	Mostly successful in relating experimental data to knowledge or theory	Experimental data are related to knowledge or theory
E. Draw Conclusions Using Engineering Judgment	No conclusion, or completely incorrect conclusions	Conclusions are partly correct	Conclusions are mostly correct and mostly complete and there was evidence of using engineering judgment	Conclusions are correct and complete, with engineering judgment applied throughout

Student Outcome 6: an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions

Performance Indicator	Unsatisfactory	Developing	Satisfactory	Exemoplary
A. Develop Experiment				
B. Conduct Experiment				
C. Analyze Data				
D. Interpret Data				
E. Draw Conclusions				

Support Statements

Indicator A

Indicator B

Indicator C

Indicator D

Indicator E