MINI PROJECT 2

TRANSISTOR AMPLIFIERS

Objectives

To develop familiarity with the transistor's hybrid-π model and issues surrounding the biassing of transistors as well as to analyse and measure the characteristics of three important transistor amplifiers using 3 commonly available transistors.

Introduction

In this project, we examine two of the basic transistor amplifier circuits and one multi-transistor amplifier.

The bipolar junction transistor can be modelled for small signal operation using the hybrid-π model, shown in Figure 2.1. Under the assumption of small signals, the transistor is assumed to work in its active region. Large signals can cause the transistor to enter the saturation or cut-off modes, where the hybrid-π model no longer describes the circuit's operation.

We examine three amplifiers; the common emitter, the common base, and the cascode. These three amplifiers are shown in figures 2.2, 2.3, and 2.4, respectively.

This project consists of four parts. The transistors that you will be using/considering in your designs are the 2N2222A, 2N3904, and 2N4401. The data sheets for these transistors may be obtained from the manufacturers' web sites (e.g., the 2N3904 and 2N4401 data sheets can be downloaded from the Fairchild Semiconductor web site) or otherwise found on the web.

References:

ELEC 301 Course Notes.
Standard Values List http://ecee.colorado.edu/~mcclurel/resistorsandcaps.pdf
A. Sedra and K. Smith, "Microelectronic Circuits," 5th, 6th, or 7th Ed., Oxford University Press, New York.

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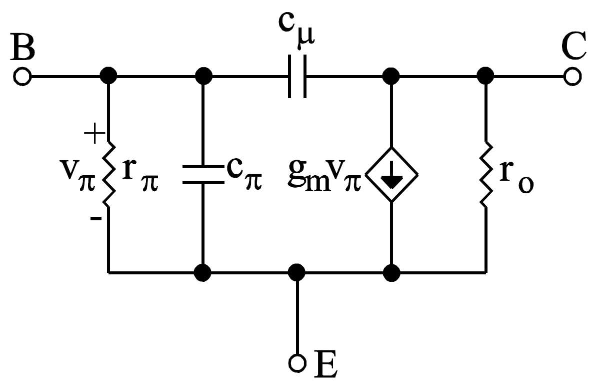

Figure 2.1. The Hybrid-π Transistor Model.

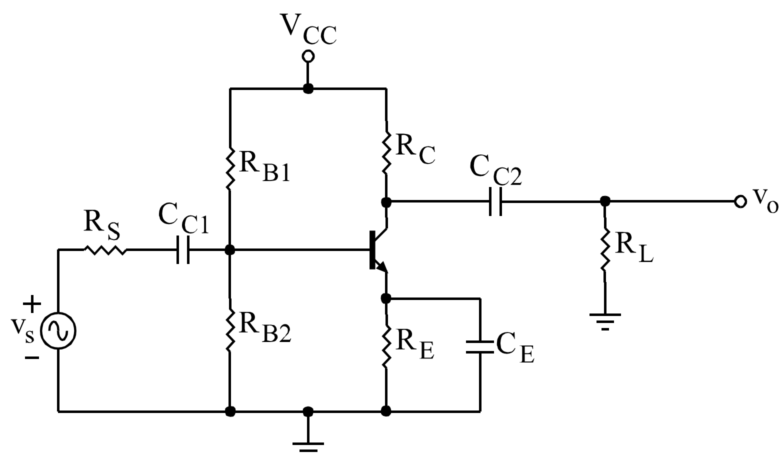

Figure 2.2. The Common-Emitter Amplifier.

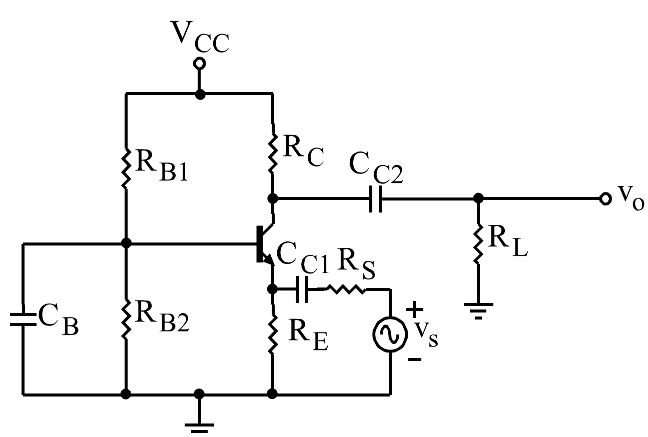

Figure 2.3. The Common-Base Amplifier.

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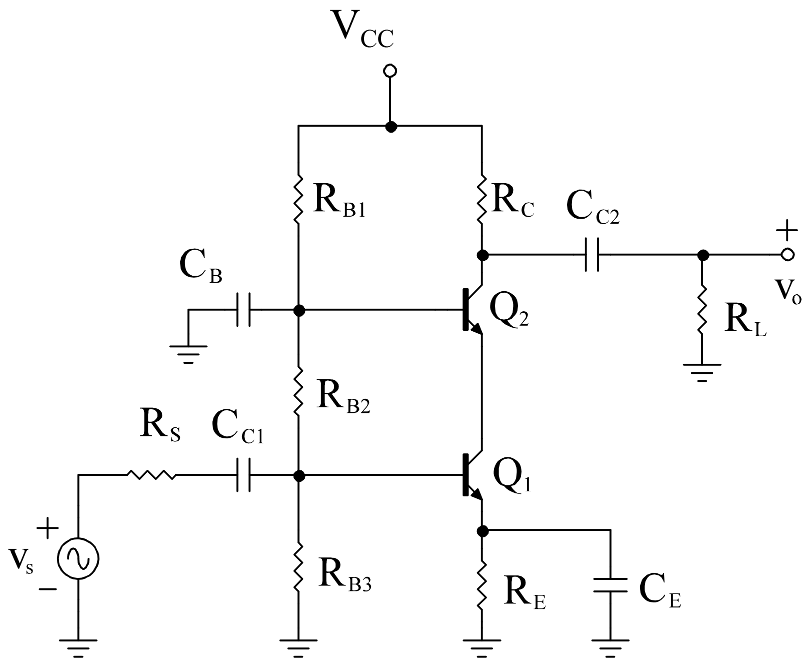

Figure 2.4. The Cascode Amplifier.

Background
The hybrid-π model contains five elements: r_π, c_π, c_μ, g_m and r_o (r_x and r_μ have been ignored). You can also ignore the small-signal capacitances, c_π and c_μ, at low and mid-band frequencies. The other model element values are either calculated based on the bias conditions (g_m) or can be obtained from the measured "h-parameters". The h-parameter values may be obtained from the data sheets provided by the transistor's manufacturer and may depend on the bias point. For example, $g_m = I_C/V_T$, where I_C is the collector bias current and V_T is the thermal equivalent of voltage given by $V_T = kT/q$, where k is Boltzmann's constant, T is the temperature in degrees Kelvin, and q is the charge on an electron in Coulombs. Also, r_π is given by $r_\pi = \beta/g_m$, where β is the common-emitter current gain of the transistor. Here we should note that, by definition, β is the same as the h-parameter h_{FE}. h_{FE} is available in transistor data sheets and is given for various bias points (often it is also plotted as a function of the bias point).

There are three main configurations in which single transistors may be connected to amplify signals. The convention is to name each configuration after the node that is shunted to the common voltage at mid band, i.e., to V_{CC} or ground. The three configurations are the common-emitter, the common-base, and the common-collector amplifiers. Another useful amplifier is the cascode in that it can be made to exhibit the best characteristics of both the common emitter and the common base amplifiers.

In the following sections, you will design a bias networks for the common emitter, common collector, and cascode amplifiers. You will the characterize the response of each type of amplifier.

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Part 1

a) Download the data sheet for the 2N2222A from the web. Find the values of the parameters h_{fe}, h_{ie}, and h_{oe} for V_{CE} = 10V, I_C = 1 mA, f = 1kHz, and T = 25ºC (you may have to look at more than 1 datasheet to find all of these). The "h-parameter model" is another model for the BJT commonly used for low frequency analysis. These "h-parameters" correspond to β, r_π, and r_o in the hybrid-π model, respectively, and give us the low-frequency, small-signal parameters of the hybrid-π model at a specific bias point (in your hybrid-π model, you may use h_{FE} for h_{fe}).

b) Using your simulation software obtain plots for I_B vs V_{BE} and I_C vs V_{CE} with I_B as the variable parameter for the 2N2222A transistor and using these plots calculate r_π, β, and r_o for V_{CE} = 5V and I_C = 1 mA. In your report, compare these "measured" (calculated from the curves) values with those given in the data sheet. Using the I_C vs V_{CE} plot, estimate V_A (the Early voltage). Calculate g_m.

c) Figure 2.5 shows a simple bias network for an npn transistor amplifier. With proper selection of the values of R_{B1}, R_{B2}, R_C, and R_E we can bias the transistor in its active region. Use V_{CC} = 15 V and I_C = 1 mA in the following.

   i) First use the "measured" (calculated from the curves) parameters, from part b) above, for a 2N2222A transistor to bias the circuit for V_{CE} = 5V.

   ii) Then use the 1/3 rule to bias the circuit.

   iii) Now, choose the closest commonly available resistors to those that you calculated using the 1/3rd rule and place them in your circuit[1] and measure the d.c. operating point.

   iv) In your report, compare the d.c. operating point values that you obtained in parts i), ii), and iii) above and comment on any observations that you made.

d) Repeat part c) with the 2N2222A replaced by the 2N3904 and the 2N4401.[2]

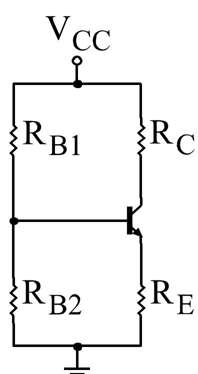

Figure 2.5

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[1]See, for example, http://ecee.colorado.edu/~mcclurel/resistorsandcaps.pdf

[2]For part 1d interpret the instructions as follows: For each of the two additional transistor models, place the new transistors in the circuits that you used in part 1b and recalculate the "measured parameters." Then place the new transistor model in your circuit from parts 1c(i) and 1c(ii) and measure the operating point. In other words, you don't need to re-bias the circuit, but you do need to report on how different transistors with different parameters behave in the original bias circuits (this is why you need to calculate those parameters using the methods in part 1b, so that you can see and report on how tolerant, or intolerant, the biasing solution is to variations in transistor parameters).

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Part 2

Using the closest commonly available resistors to those that you calculated using the 1/3rd rule, and assuming that you have been given three 10uF capacitors for the coupling and by-pass capacitors, layout the Common Emitter amplifier in your simulation software, using a 2N2222A transistor and a 50Ω source resistance, and do the following:

a) Plot the Bode plots for magnitude and phase for a sufficient bandwidth so that you can identify all of the poles and all of the zeros and compare your estimates of the locations of the poles and zeros with your calculated locations.

b) Using the Bode plot, pick a mid band frequency. Using this frequency, adjust the amplitude of the input signal to your amplifier until you feel that the output signal, viewed in the time domain, is becoming non-linear (you can vary the amplitude of the input signal and plot the voltage transfer curve, amplitude of v_o vs v_s).

c) Measure the input impedance of your amplifier at mid band (include everything other than the 50Ω source resistance) and compare this with the input impedance that you calculate.

d) Repeat parts a) and b) above for each of the other transistors and select the transistor that you feel gives the best performance (justify your choice in your report).

Part 3

Repeat Part 2 sections a), b), and c) above for the Common Base amplifier.

Part 4

Layout the cascode amplifier shown in figure 2.4 using your simulation software and 2N2222A transistors. The minimum specifications for this amplifier are given in table 2.1. Assume that the source resistance used is 50Ω and that there is a 50kΩ load at the output of the amplifier.

Table 2.1 Cascode Amplifier Specifications.

$\mathbf{R_{out}}$ (maximum value at mid band)	$\mathbf{R_{in}}$ (range of values at mid band)	$\mathbf{\lvert A_v \rvert}$(minimum value at mid band)	$\mathbf{f_L}$ (maximum value for low-f cut-in)
5 kΩ	5-10 kΩ	50	500 Hz

You are required to bias the cascode for V_{CC} = 10V as well as calculate the component values for the circuit. Once you have the calculated component values for the bias, you should change them to the closest commonly available resistance values. Using a 100 μF for C_B, you should then calculate all other resistance and/or capacitance values for your circuit. You are also required to obtain the desired small-signal parameters for your circuit.

a) Measure the d.c. operating point of your cascode amplifier.

b) Plot the Bode plots for magnitude and phase and compare your estimates of the locations of the ω_{L3dB} and ω_{H3dB} with your calculated values.

c) Using the Bode plot, pick a mid band frequency. Using this frequency, adjust the amplitude of the input signal to your amplifier until you feel that the output signal, viewed in the time domain, is becoming non-linear (you can vary the amplitude of the input signal and plot the voltage transfer curve, amplitude of v_o vs v_s).

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d) Measure the input impedance of your amplifier at mid band (include everything other than the 50Ω source resistance) and compare this with the input impedance that you calculate.

e) Repeat parts b) and c) above for each of the other transistors and select the transistor that you feel gives the best performance (justify your choice in your report).

<u>Report</u> — The report for this project should document the circuits that have been "built" and "tested." For each circuit, tabulate the calculated and simulated values. Discuss any observations that you made. You should present your calculations and/or data in the order that it was requested in this project sheet. In other words, present the calculations/data for Part 1a followed by the calculations/data for Part 1b, etc. The discussion for each part should be included following the calculations/data for that part, i.e., your discussion for Part 1 should come before you present your calculations/data for Part 2. Also, a filled-in, dated, and signed Mini Project Cover Sheet[3] should be attached to the front of your report.

[3]Download, fill in, and sign a "Mini Project Cover Sheet" from the course web site.

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