Electrical and Computer Engineering — ELEC 301

MINI PROJECT 2

BIASSING AND THE COMMON EMITTER AMPLIFIER

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 an important transistor amplifier using 3 commonly available transistors.

Introduction

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.

In this mini project, we examine two basic single transistor amplifier circuits, the common emitter and common base amplifiers. These amplifiers are shown in figures 2.2 and 2.3, respectively.

This project consists of three 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 Resistor and Capacitor Values List from the Other Mini Project Related Handouts Module on CANVAS.
A. Sedra and K. Smith, "Microelectronic Circuits," 5th (or higher) Ed., Oxford University Press, New York.

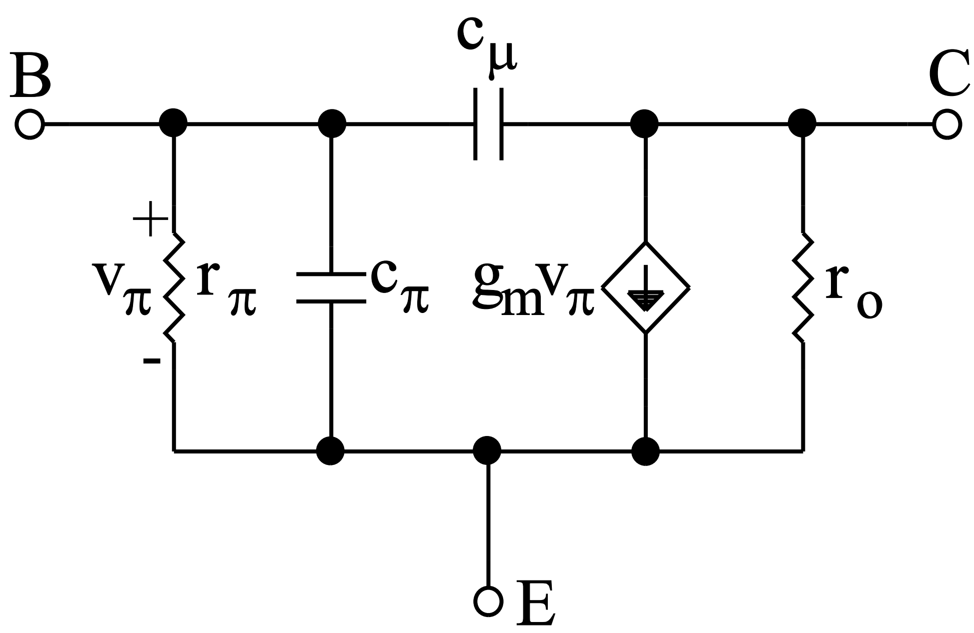

Figure 2.1. The Hybrid-π Transistor Model.

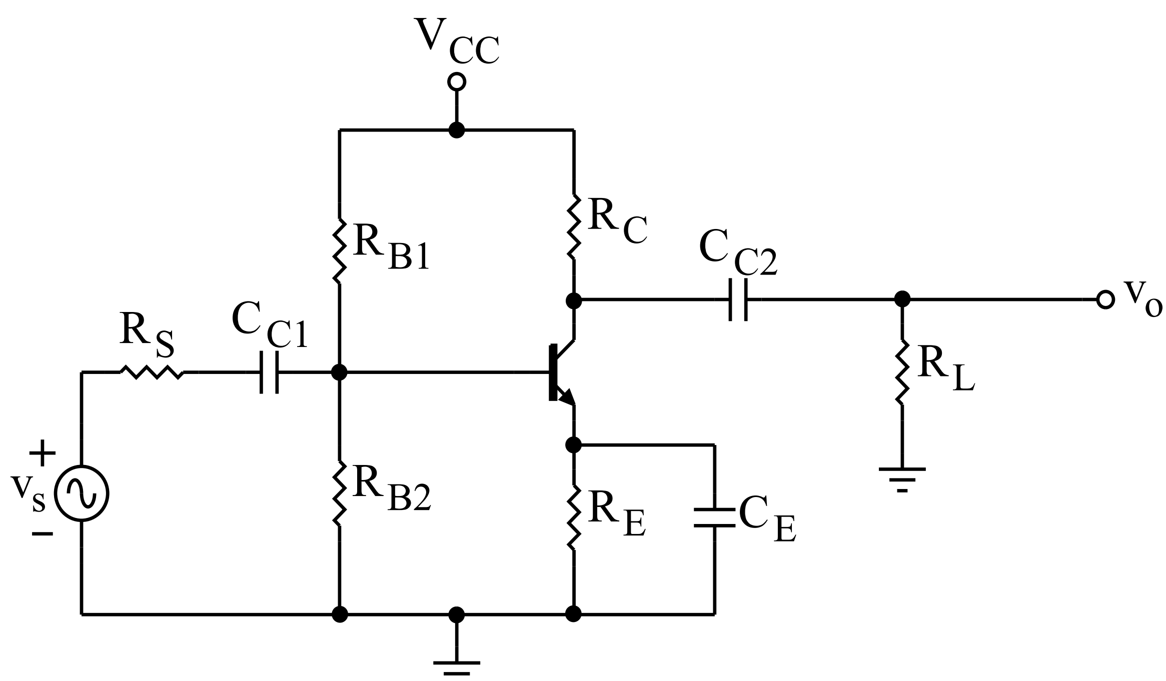

Figure 2.2. The Common-Emitter Amplifier.

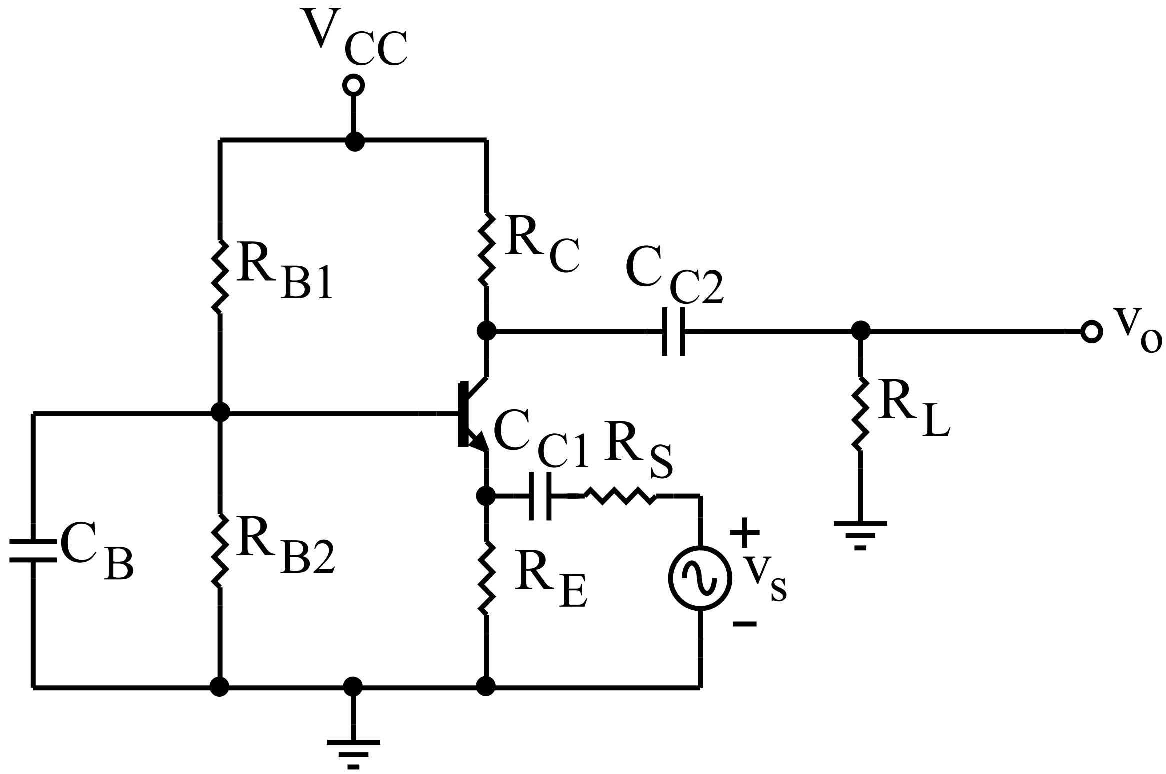

Figure 2.3. The Common-Base Amplifier.

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 (e.g., g_m) or can be obtained from the "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 at d.c. 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 (CE), the common-base (CB), and the common-collector amplifiers (CC); the collector amplifier is not covered in this mini project.

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

Part 1

a) Download the data sheet for the 2N3904 from the web. Find the values of the small signal 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 the small signal parameters β, r_π, and r_o in the hybrid-π model, respectively, and give us the small-signal parameters of the hybrid-π model at specific bias points (in your hybrid-π model, you may use h_{FE} for h_{fe}).

b) Using your simulation software, obtain plots for i) I_B vs V_{BE}, ii) I_C vs V_{CE} with I_B as the variable parameter, and iii) I_C vs V_{CE} with V_{BE} as the variable parameter for the 2N3904 transistor and using these plots calculate β, r_π, g_m, and r_o for V_{CE} = 5V and I_C = 1 mA and estimate V_A (the Early voltage). In your report, compare these "measured" (calculated from the curves) values with those given in the data sheet.

c) Figure 2.4 shows a simple bias network for an npn transistor amplifier (works for both the CE and CB amplifiers). 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 2N3904 transistor to bias the circuit for a value of V_{CE} of 4V or less and for $R_E = R_C/2$ (i.e., do not use the 1/3 rule here) and measure the d.c. operating point.
   ii) Then use the 1/3 rule to bias the circuit and measure the d.c. operating point.
   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) Use the circuit that you obtained for part c-iii) and replace the 2N3904 with the 2N2222A and the 2N4401 transistors and compare the d.c. operating points that you obtained for the three transistors.

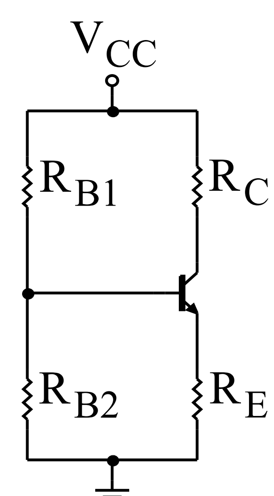

Figure 2.4

[1]Only use component values listed in the sheet obtainable at: http://ecee.colorado.edu/~mcclurel/resistorsandcaps.pdf

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 2N3904 transistor, a 50Ω source resistance, and a load resistor $R_L = R_C$, 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 (both low frequency and high frequency) and all of the low frequency zeros and compare your estimates of the locations of the poles and zeros with your calculated locations[2]. Then, repeat this for the 2N4401 transistor.

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). Then, repeat this for the 2N4401 transistor.

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. Then, repeat this for the 2N4401 transistor.

d) Measure the output impedance of your amplifier at mid band (keep the 50Ω source resistance in the circuit when you measure the output impedance) and compare this with the output impedance that you calculate. Then, repeat this for the 2N4401 transistor.

e) Using your results from part a) above, select the transistor, either the 2N3904 or the 2N4401, that you feel gives the best performance (justify your choice in your report).

Part 3

Repeat Part 2 sections a), b), c), and d) above for the Common Base amplifier for the 2N2222A transistor only.

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[2] c_π and c_μ can be approximated using the SPICE model parameters (see your simulation software to obtain these parameters):

$$c_\pi \approx 2 * CJE + TF * g_m \quad \text{and} \quad c_\mu \approx \frac{CJC}{\left(1 + \frac{V_{CB}}{VJC}\right)^{MJC}}$$

Report — (i) 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. (ii) Your report should adhere to the Criteria (Instructions) for Uploaded Mini Projects that can be found on the course's CANVAS web site. (iii) Remember, for any of your Mini Project marks to be recorded, you must have submitted one filled-in, dated, and initialed and signed ELEC 301 Academic Integrity Acknowledgement Sheet, that can be found on the course's CANVAS web site (you only need to submit this one time during the term).

