Laboratory 3
Small-signal high frequency behavior of the common emitter BJT amplifier

Introduction

In this laboratory you will obtain practice characterizing the small-signal high frequency behavior of single-stage transistor amplifiers, with focus on the common emitter BJT amplifier. The specific topics that will be investigated include measurements of transistor $\beta$ and variation of $\beta$ with respect to bias current, impact of bias current on bandwidth and gain, impact of stage gain on bandwidth, effect of bypass capacitor values on bandwidth and gain, and general practice with characterizing amplifier bandwidth.

Part 1: Measure small-signal $\beta$ for the 2N2222A BJT

The 3 circuits shown below will be used to measure small-signal $\beta$ of the 2N2222A at collector bias currents of 5 mA, 0.5 mA and 0.05 mA.

A. Build the circuit

Obtain components for the 3 circuits shown below (only one 2N2222A is needed since all 3 circuits aren’t used at the same time). First construct the circuit in Fig. 1a and follow the procedure described below for determining small-signal $\beta$; this will provide the value for a bias current of 5mA. Then repeat for Figs. 1b and 1c to find $\beta$ for 0.5 mA and 0.05 mA, respectively. Note that these values will be used in Part 2 below.

![Circuits](image)

Figure 1: Circuits used to determine small-signal $\beta$ for several different bias currents
B. Procedure

First set $V_{DC}$ to obtain $V_{CE} = 3V$: this value of $V_{DC}$ should be recorded as $V_{DC1}$. The value of $V_{DC}$ should then be increased to obtain $V_{CE} = 2.5V$: this value of $V_{DC}$ should be recorded as $V_{DC2}$. The value of small-signal $\beta$ is then obtained as: 

$$\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{0.5}{R_C} \frac{V_{DC2} - V_{DC1}}{R_1}.$$

Note the values obtained for $\beta$ as well as describe the variation in $\beta$ as a function of bias current.

Part 2: Common Emitter Amplifier

A. Build the circuit

Obtain components for the circuit shown below (Fig. 2) and build the circuit on the experiment boards provided. Be careful to keep lead lengths as short as is reasonably possible as this reduces noise pickup and makes the amplifier less susceptible to instability. Also, observe polarity for the electrolytic capacitors. The purpose of the 0.2 $\mu$F (ceramic or plastic film) capacitors in parallel with the 10 $\mu$F electrolytic capacitors is to improve the operating frequency of the overall capacitor; i.e., electrolytic capacitors tend to have ideal capacitor-like behavior only up to 100 kHz or so, whereas plastic and ceramic capacitors have nearly ideal capacitor behaviors up to several tens of MHz.

Notice that the circuit configuration shown is for measurement of the output voltage (of the common-emitter stage) in response to a signal applied to the amplifier’s input.

Figure 2: Common-emitter amplifier circuit to be characterized at bias current of 5 mA.
B. Measure CE amplifier frequency behavior:

i) Quiescent point

Verify that \( V_{CE} \) is approximately 3 V and \( I_C \) is approximately 5 mA by measuring from collector to ground and then from collector to emitter (using the multimeter). If not, then check wiring to make sure it is correct.

ii) Small signal parameters

a) Voltage transfer versus frequency

Here the objective is to ascertain and plot the voltage gain (in dB) as a function of frequency - normally the plot is dB amplitude versus log frequency. In that regard the most important parameters to determine are mid-band amplitude and 3 dB frequencies, if we assume that the response is flat over the mid-band region (as is often the case).

Measurement 1

To begin the measurement adjust the signal generator for a sinusoidal signal of 50 kHz across \( R_2 \) of approximately 100 mV (peak-to-peak) amplitude, using the oscilloscope. Measure the signal amplitude at the output (using the oscilloscope) and record the value. For all experiments to be performed in Lab 3, 50 kHz should be a mid-band frequency, so \( 20 \log(x) \) (base ten) where \( x \) is output to input ratio represents the mid-band gain. Next, slowly sweep the oscillator up in frequency and down in frequency to observe variations in amplitude (on the oscilloscope). The amplitude should remain fairly flat except as the 3 dB frequencies are being approached (appearance should be approximately as shown in Fig. 3). Determine the 3 dB frequencies (where output amplitude is 0.707 of maximum) and indicate them on the plot. If there are substantial variations in amplitude between the 3 dB frequencies make note of that on the plot.

How do the values for mid-band gain, low frequency 3-dB point and high frequency 3-dB point compare with what is calculated (using the expressions shown in class)? Note that you can determine \( g_m \) and \( r_n \) accurately making use of the appropriate \( \beta \) that you determined in Part 1.

![Figure 3: Expected form of the amplitude versus frequency plot](image-url)
Measurement 2 - study of effect of gain on bandwidth

Place a short circuit across $R_{E1}$ and again plot the voltage transfer function as a function of frequency (noting mid-band gain and 3-dB frequencies). In this you should reduce the voltage output from the signal source by inserting a 120k$\Omega$ resistor at the output of the signal generator in series with the amplifier circuit to avoid clipping at the output. Again compare with predicted values and indicate how the predicted and measured values compare.

Measurement 3 - study of effect of bypass capacitor value on bandwidth and gain

Remove the 10$\mu$F capacitor across $R_{E2}$ (leave in place the short circuit across $R_{E1}$) and again plot the voltage transfer function as a function of frequency (noting mid-band gain and 3-dB frequencies). Again compare with predicted values and indicate how the predicted and measured values compare.

Study of effects of bias current on mid-band gain and bandwidth

bias current of 0.5 mA

Change the values of resistors $R_1$, $R_2$, $R_C$, $R_{E1}$, and $R_{E2}$ as shown in Fig. 4. Verify that this change of resistor values leaves $V_{CE}$ essentially unchanged but reduces the bias current to 0.5 mA, and repeat measurements 1 through 3 as described above.

Figure 4: Common-emitter amplifier circuit to be characterized at bias current of 0.5 mA.
bias current of 0.05 mA

Change the values of resistors $R_1$, $R_2$, $R_C$, $R_{E1}$, and $R_{E2}$ as shown in Fig. 5. Verify that this change of resistor values leaves $V_{CE}$ essentially unchanged but reduces the bias current to 0.05 mA, and repeat measurements 1 through 3 as described above.

![Common-emitter amplifier circuit](image)

Figure 5: Common-emitter amplifier circuit to be characterized at bias current of 0.05 mA.

Summarize, in a general way, how the 3 parameters, i.e., value of bypass capacitor across $R_{E2}$, mid-band gain (for a particular value of bias current), and level of bias current, impact the voltage transfer as a function of frequency.

This completes Laboratory Exercise 3.