EXPERIMENT 2

RC COUPLED CE AMPLIFIER

I. OBJECTIVES

-To provide the student with all aspects of the frequency response of capacitor-coupled BJT amplifiers.
-To explore the effect of the coupling and bypass capacitors in low frequency.
-To explore the effect of the junction capacitance at higher frequencies.

II. INTRODUCTION AND THEORY

The design procedure of any discrete amplifier can be summarized in the following steps:

- Choose the circuit's configuration that suits the application
- DC design: this part is necessary to define the biasing and the stability of the chosen circuit configuration.
- AC design: to determine the necessary parameters that are needed for the application such as amplifier gain and bandwidth.

In this experiment we will concentrate on the AC design and briefly cover the aspect of the DC design.

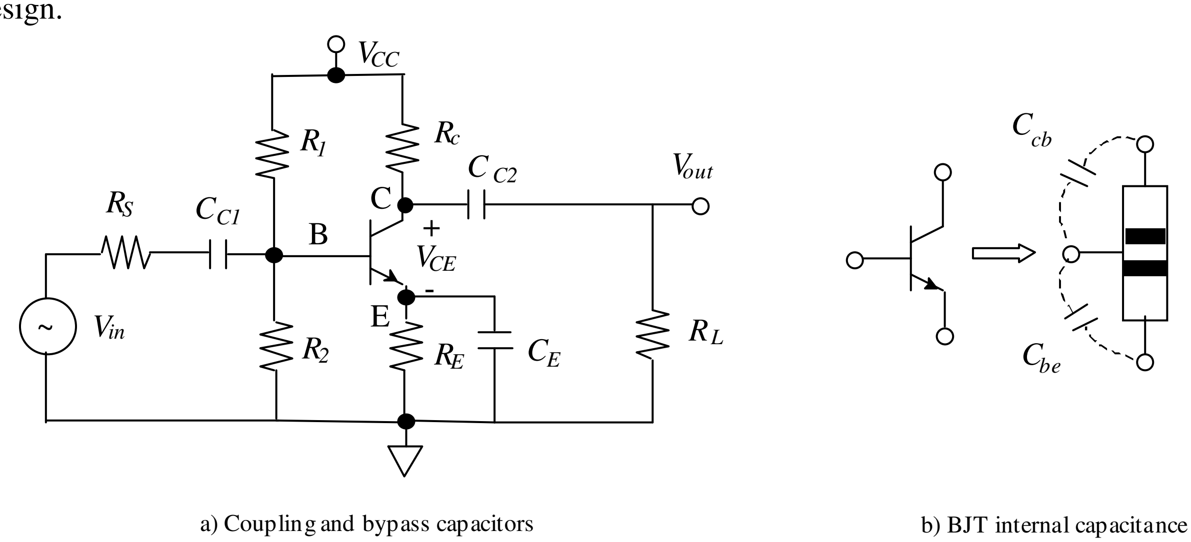


Figure **1**

A single stage common –emitter amplifier is shown in figure 1-a. The biasing circuit consists of two resistors *R*1 and *R*2. It is called the self-biasing technique and allows us to use a single power supply. The resistance R_E is necessary to improve the stability of the amplifier, but on the other hand it reduces the gain. Therefore, a capacitor is connected across R_E to preserve the DC characteristics of the amplifier while eliminating the negative effect of the R_E on the gain in AC operation. This capacitor is called bypass capacitor C_E. Other capacitors C_{C1} and C_{C2} are used to block the DC current from going in and out of the amplifier stage. This is necessary to maintain the quiescent point of the amplifier stage in the desired location, which is determined by the DC design procedure. These capacitors are called coupling capacitors.

The above-mentioned capacitors are a lumped element that exist and can be seen and touched in the circuit. Other capacitances cannot be seen or touched only their effects can be observed and must be taken into consideration. This type of capacitance is called a junction or an internal capacitance of the BJT. In general, any two pieces of material (usually conductors or semiconductors) pasted together with insulator material in between will have a capacitance which manifests its effect at high frequencies. This capacitance is not a lumped element as mentioned before. The internal or junction capacitances C_{cb} and C_{be} limit the high frequency performance of any active device such as BJT, op-amp, microprocessors, and etc. The high frequency limit of the active devices is referred as f_T in their data sheets, where f_T is the frequency at which the gain becomes unity.

The values of the coupling and bypass capacitors must be as high as possible to eliminate any performance degradation in low frequencies. They are in the range of 1-100 uF. On the other hand, it is preferred to have a very low value of the internal capacitance. However, as a circuit designer, we do not have control over the values of the junction or internal capacitance of the device. They only depends on the type of the technology used in the fabrication of the device, the type and the dimension of the active device (BJT, CMOS, and etc.), and the impurity of the semiconductor material.

Figure 2 shows the typical frequency response of an amplifier stage. The basic regions of the response are as follows: low frequency region where the equivalent impedance of the coupling capacitors and bypass are not zero, midband region where the coupling and bypass effect has disappeared but the internal capacitances can be ignored, and the high frequency region where the effects due to the internal capacitances of the device start to show up. The amplifier transfer function or the overall gain is a frequency dependent function as given below

$$T.F = \frac{v_{out}}{v_{in}} = A(jw)$$

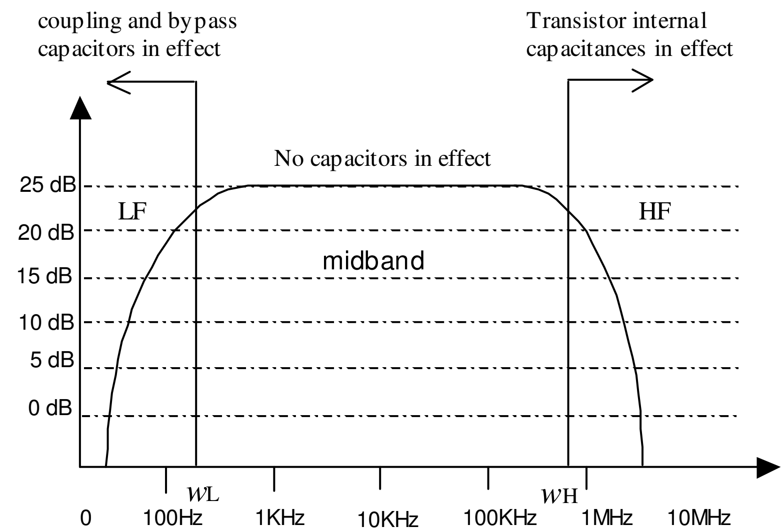


Figure **2** General frequency response of the amplifier

Note that: the gain of the amplifier falls off at low and high frequencies and is nearly constant at the midband. The general transfer function or the overall gain of the amplifier can be expressed in terms of a frequency dependent functions $F_L(jw)$ and $F_H(jw)$. These two functions are responsible for the fall off of the gain at the low and the high frequency regions. The general form of the amplifier gain is given by

$$\frac{v_{out}}{v_{in}} = A(j\omega) = A_M F_L(j\omega) F_H(j\omega)$$

The bandwidth and the figure of merit of the amplifier are defined as follows.
The amplifier **bandwidth**, $BW = \omega_H - \omega_L$, where ω_L and ω_H are the low and the high 3dB points as shown in figure 2.
A figure of merit for the amplifier is its **gain-bandwidth** product, $GB \equiv A_M(\omega_H - \omega_L)$, where A_M is the magnitude of the midband gain in volts/volt.

The figures below show equivalent circuits for the amplifier shown in figure 1-a. To determine the upper and lower 3dB points from the equivalent circuit use the superposition theorem to obtain the time constant due to the presence of each capacitance in the circuit. The time constant of the capacitor C_i is given by

$$\tau = C_i R_{io}$$

Where R_{io} is the Thevenin equivalent resistance seen by C_i.

When calculating a given time constant for a given capacitor we need to specify an assumption about the other capacitors. Suppose we are estimating ω_L and wish to find the time constant for capacitor C_{C1}. To do this, we remove C_{C1} from the circuit and find the resistance seen across the terminals where it was connected *assuming that C_{C2} and C_E can be treated as short circuits.* We repeat this procedure for the other two coupling/bypass capacitors giving us three time constants. An estimate of the lower -3dB bandwidth, ω_L is:

$$\omega_L = \sum_{i=1}^{3} \frac{1}{R_i C_i}$$

For more information on this method, please see 10.1.2 Method of Short-Circuit Time Constants in Sedra/Smith, 7th ed.

To find ω_H we can use a similar procedure call the Method of Open-Circuit Time Constants, described in section 10.4.3 in the text. In this method, we assume that other capacitors are open when calculate the Thevenin resistance associated with a given capacitor. The time constants are combined as follows to estimate ω_H :

$$\omega_H = \frac{1}{\sum_{i=1}^{N} R_i C_i}$$

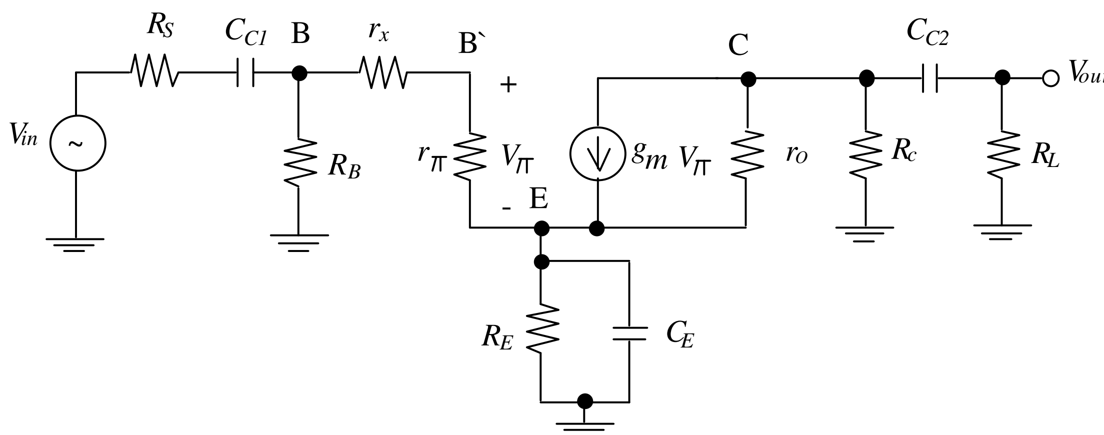


Figure **3** Equivalent circuit at low frequencies region for the amplifier in figure 1-a

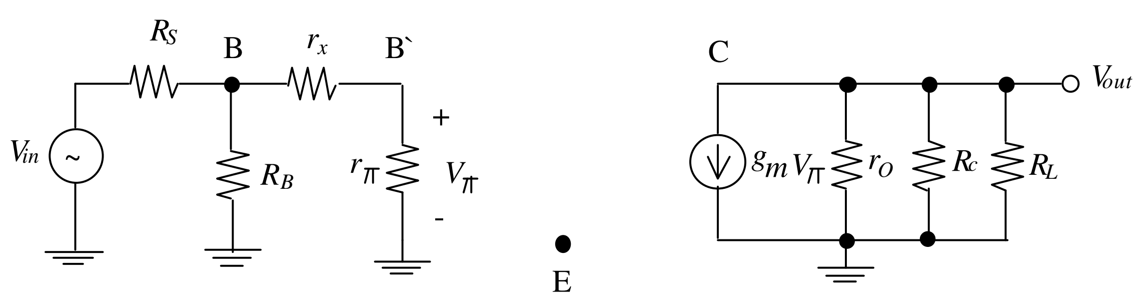


Figure **4** Equivalent circuit at midband region for the amplifier in figure 1-a

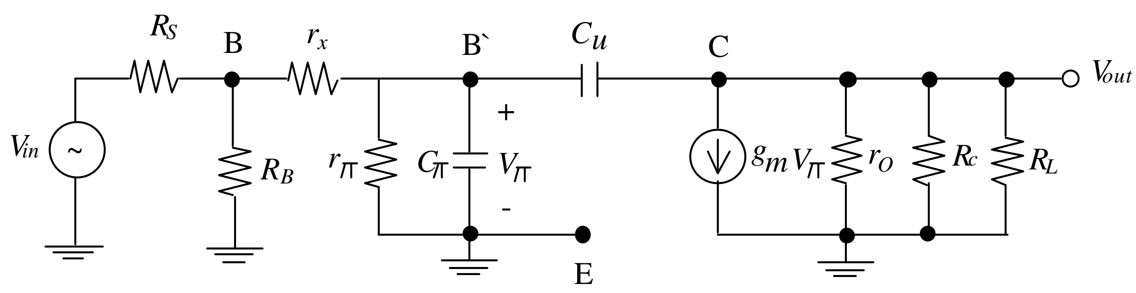


Figure **5** Equivalent circuit at high frequencies region for the amplifier in figure 1-a

The low frequency analysis of the multistage amplifiers can be simplified by replacing each amplifier stage with the equivalent input and output resistance as shown in figure 6.

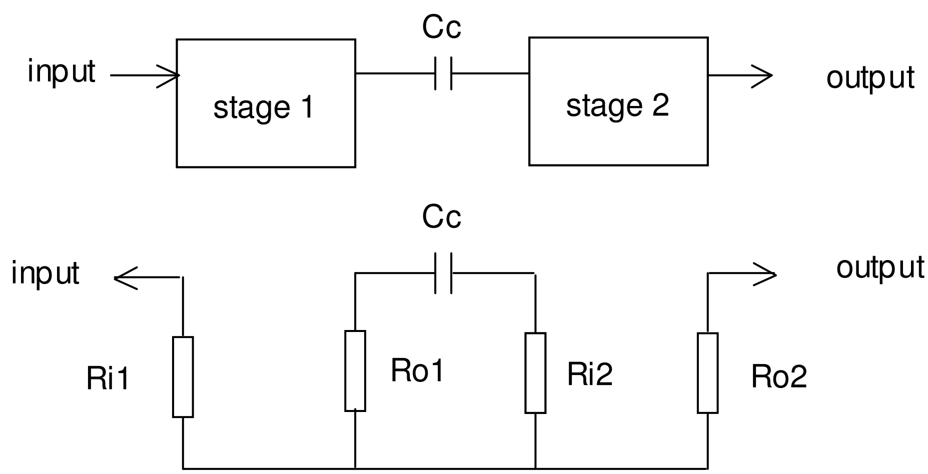


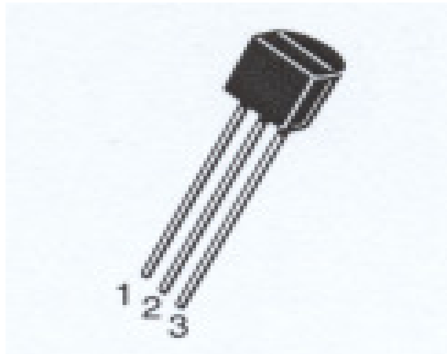
Figure **6** Multistage amplifier

The maximum rating and pin connection for P2N2222A BJT are given below. Please note that the data sheet of the transistor is in the appendix.

Maximum Ratings of P2N2222A Bipolar Transistor

V_{CE}	I_C	β	P_D	Freq
(V)	(mA)	max./typical	(mW)	(MHz)
40	800	300/100	500	300

BJT pinout is given below. Pin 1= Emitter, Pin 2=Base, Pin 3=Collector



III. PROCEDURE

1- Build the circuit shown in figure 1(a) using the following components listed in the table below

R1	R2	R_E	R_C	R_S	R_L	V_{CC}	C_{C1}	C_{C2}	C_E
75K	33K	4.7K	4.7K	1K	10K	15V	0.1μF	0.1μF	0.1μF

While assembling the circuit, use the 3-legged transistor mount for the BJT.

2- Conduct a DC measurement to determine the location of the operating point and β. In other words you need to measure I_C, V_{CE}, and I_B.

3- Apply a sinusoidal signal to the input and adjust the amplitude so that the output waveform has no distortion (The amplitude adjustment must be done in the midband region). Perhaps an amplitude of 25mV (50 mV peak-to-peak) would work. Please note that the amplitude of the input signal will be kept constant during this experiment.

4- Sketch the amplitude response as a function of the input signal frequency. (Use a semi-log graph paper in which the frequency is located on horizontal axis (log scale) and the amplitude is in dB located on the vertical axis (linear scale) as shown in figure 2. (Take extra points on the curve whenever you encounter a significant change in output while the input is kept constant).

5- Repeat steps 3 and 4 using $C_{C1}=C_{C2}=C_E=22\mu F$.

6- Tabulate all the above data.

IV. QUESTIONS

1- What is the maximun allowable ac output swing in step 3?

2- What is the figure of merit of the amplifier?

3- Discuss the influence of the bypass, coupling, internal, and stray capacitances on the frequency response.

4- What is the purpose of capacitor's C_{C1} and C_{C2}?

5- In Fig.1 (a) C_E = 0.1 μF. This value is changed to 22 μF in step 5. Based on your theoretical knowledge, how do you expect the lower 3 dB to change when C_E is increased to 22 μF?

6- Does C_E have any effect on upper 3 dB point?