THE GEORGE WASHINGTON UNIVERSITY

WASHINGTON, DC

SCHOOL OF ENGINEERING AND APPLIED SCIENCE
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
ECE 2115: ENGINEERING ELECTRONICS LABORATORY

Tutorial #5:
Designing a Common-Emitter Amplifier

BACKGROUND

There are two popular types of Common-emitter amplifiers:

1. Common-Emitter Amplifier without Emitter Degeneration
   - Sometimes called ***grounded emitter*** or simply ***common-emitter***
   - This is the type you built in Lab 6
2. Common-Emitter Amplifier with Emitter Degeneration
   - Sometimes called ***common-emitter with emitter resistor***
   - There are three possible configurations of this circuit:
     i. Non-bypassed emitter resistor
     ii. Bypassed emitter resistor with series external emitter resistor
     iii. Bypassed emitter resistor with parallel external emitter resistor

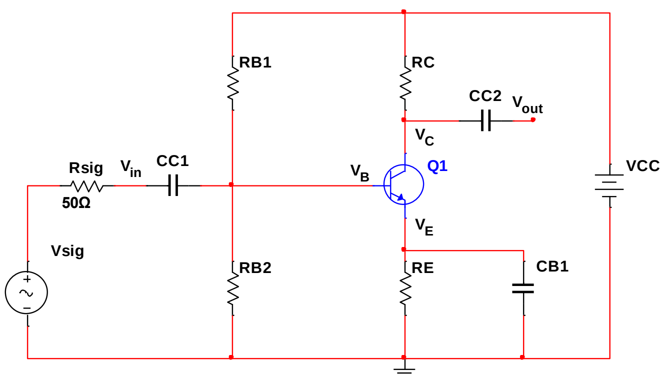

Figure 1 – CE without Emitter Degeneration

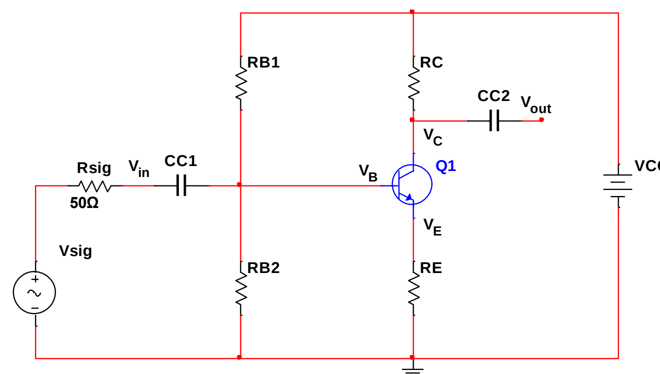

Figure 2 – CE with Emitter Degeneration (no bypass cap)

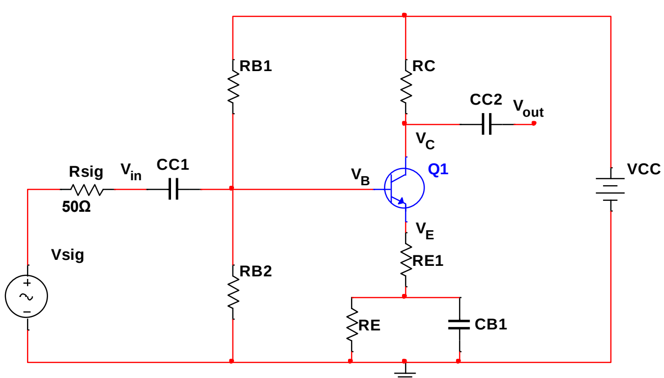

Figure 3 – CE with Emitter Degeneration Series Resistor

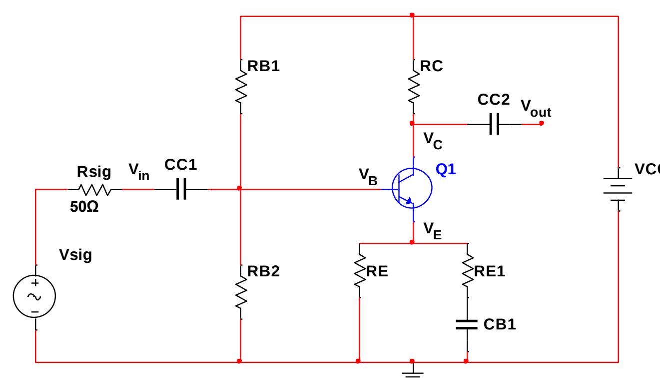

Figure 4 – CE with Emitter Degeneration Parallel Resistor

The two forms of the common-emitter amplifier and their various configurations have their own advantages and disadvantages when compared to one another. From the perspective of this tutorial, we will concentrate on the way "gain" is controlled for each of the circuits. No matter the configuration, for any common-emitter amplifier, the ***input*** **signal** is always through the ***base*** **terminal**, the ***output*** is always taken from the ***collector*** **terminal**, and the ***emitter*** is always **"common"** to both the input and output.

For Type 1 (CE without emitter degeneration) from **Figure 1**, the bypass capacitor $\mathbf{C_{B1}}$ shorts the **emitter** to **ground** for high frequency signals, hence the name "**grounded emitter**." This amplifier is discussed in Sedra p.427-431. The voltage gain of this amplifier (when no load is present) is $A_v = -g_m R_C$. The designer can only control the value of R_C, and to some extent g_m, to control the voltage gain of the amplifier. This is the type you built in Lab 6 during the common-emitter portion of the lab.

For Type 2a (CE with emitter degeneration – non-bypassed emitter resistor) shown in **Figure 2**, there is no bypass capacitor. The emitter terminal is "common" to both the input and output through the resistor connected to the emitter (R_E). The emitter resistor (R_E) serves to give bias stability to the circuit. This amplifier is discussed in Sedra p.432-435. The gain of this amplifier when no load is present is $A_v = -\alpha \frac{R_C}{r_e + R_E}$ or more simply $A_v \approx -\frac{R_C}{r_e + R_E}$. The designer can now use R_C and R_E to control the voltage gain of the amplifier.

For Type 2b (CE with emitter degeneration – bypassed emitter resistor with series emitter resistor) shown in **Figure 3**, the bypass capacitor shorts the resistor R_{E1} to ground for high frequency signals. The emitter terminal is "common" to both the input and output through the resistor (R_{E1}). The emitter resistor (R_{E1}) serves to give bias stability to the circuit. This amplifier is not discussed in Sedra. The gain of this amplifier when no load is present is $A_v \approx -\frac{R_C}{r_e + R_{E1}}$. The designer typically leaves R_C and uses R_{E1} to control the voltage gain of the amplifier.

For Type 2c (CE with emitter degeneration – bypassed emitter resistor with parallel emitter resistor) shown in **Figure 4**, the bypass capacitor shorts the resistor R_{E1} to ground for high frequency signals. Typically, R_{E1} is much smaller than R_E, making it so R_E is bypassed by comparison to R_{E1}. R_{E1} is an easier "path to ground" than for AC signals. The emitter terminal is "common" to both the input and output through the resistor (R_{E1}). This amplifier is not discussed in Sedra. The gain of this amplifier when no load is present is $A_v \approx -\frac{R_C}{r_e + R_{E1}}$. The designer typically leaves R_C and uses R_{E1} to control the voltage gain of the amplifier. The advantage of this design is that R_{E1} serves no purpose in the DC biasing of the amplifier, so the designer only sets the value of R_{E1} after the DC bias has been determined for the amplifier.

Students are encouraged to use any of the common-emitter amplifier configurations shown above in labs and projects. Type 2 will be covered in this tutorial because it is stable, easiest to bias, and the gain can be adjusted without affecting its DC bias.

INSTRUCTIONS

Designing a Common-Emitter Amplifier with Emitter Degeneration Parallel Emitter Resistor

Problem: Design a common-emitter amplifier using the 2N3904 transistor that meets the following specs:

- I_C = 2mA
- V_{CC} = 30V
- A_V (unloaded) = -50 V/V
- R_{in} = 4kΩ
- R_L = 1kΩ
- V_{in} = 10mV @ 10kHz

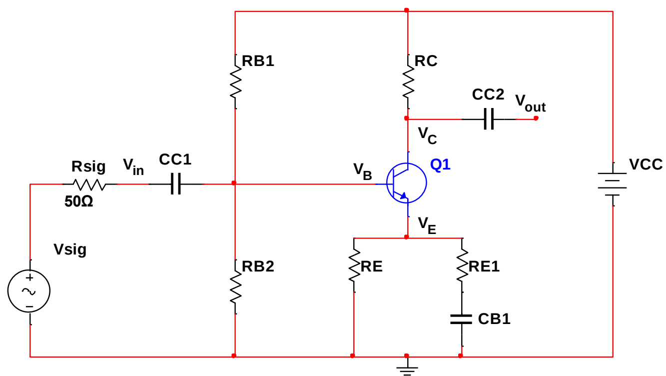

Figure 1.1 – Complete Common-Emitter Amplifier

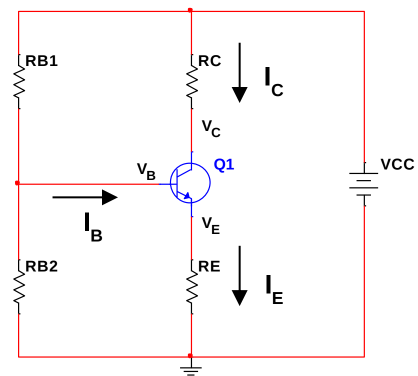

Figure 1.2 – Common-Emitter Amplifier (DC Only)

1. **Begin** with the skeleton of the amplifier we would like to design shown in **Figure 1.1**.
   a. Our goal as designers will be to determine values for R_C, R_E, R_{E1}, R_{B1}, R_{B2}, C_{C1}, C_{C2}, and C_{B1} based on the specs given. We begin by determining the values of R_C, R_E, R_{B1}, and R_{B2} to provide DC bias to the transistor. Then, we view the circuit from an AC perspective to determine the size of R_{E1} to set the 'gain' for the amplifier.

   b. From a DC perspective, the amplifier looks like the circuit in **Figure 1.2**. This is because the impedance of C_{C1}, C_{C2}, and C_{B1} at DC (≈ 0Hz) is nearly infinite. So, the capacitors look like open circuits at DC. This is why R_{E1} disappears from the circuit.

   c. **Figure 1.2** looks just like what we did in Lab 6, except we are now solving the problem in reverse.

2. **Determine** the value of R_C.
   a. Because we take the output voltage from V_C, we start with the equation for V_C:

$$V_C = V_{CC} - I_C R_C$$

   b. The maximum output voltage we can have when I_C = 0mA is 30V (V_{CC}). The minimum output voltage we can have when I_C is at its highest, which makes V_C = 0V. We want the AC signal that comes out to "swing" symmetrically around the mid-point (½ V_{CC}).

$$\text{We set } \boldsymbol{V_C} = \tfrac{1}{2}V_{CC} = \tfrac{1}{2}30V = \mathbf{15V}$$

   c. Since I_C is given as 2mA, we can use Ohm's Law to determine R_C:

$$\boldsymbol{R_C} = \frac{V_{CC} - V_C}{I_C} = \frac{30V - 15V}{2mA} = \mathbf{7.5k\Omega}$$

3. **Determine** the **"Q" point** of the transistor.
   a. From the test bench we created in Lab 5 to characterize the 2N3904 transistor, we perform a parametric sweep simulation to obtain the IV curve for the transistor. We sweep V_{CE} from 0 to V_{CC} (30V). I have swept current I_B from 0 to 20uA, in steps of 2.3uA. I used trial and error until I was able to get a curve to tell me what I_B was when I_C = 2mA and V_{CE} = 15V.

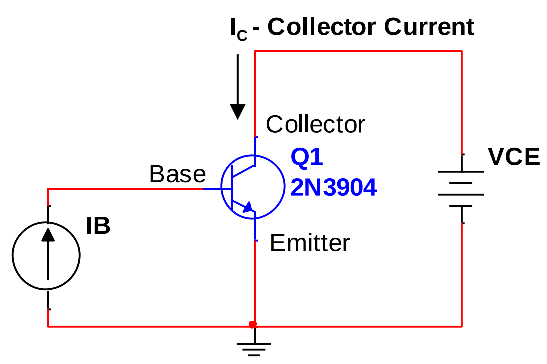

Figure 1.3 – BJT Test Circuit

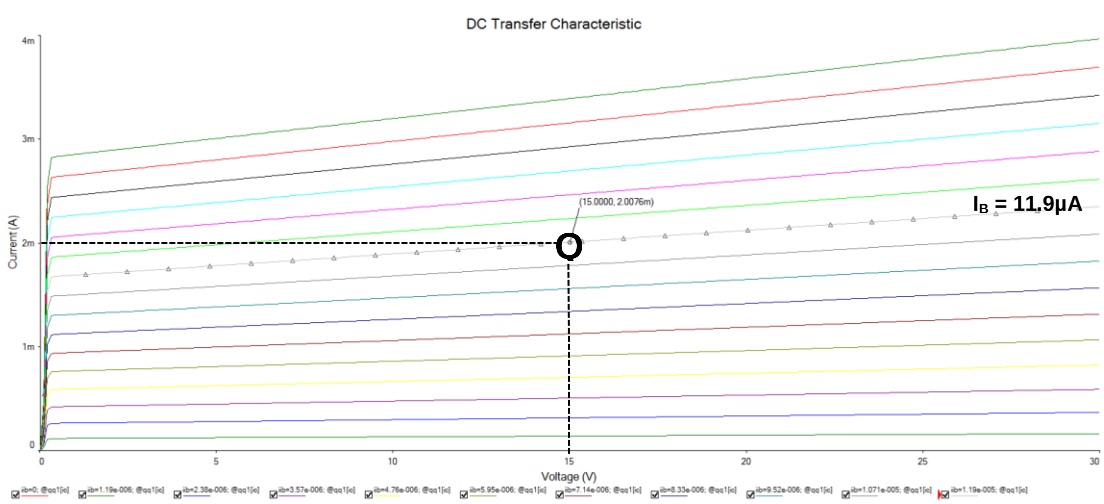

Figure 1.4 – IV Curve (I_C vs. V_{CE}) for the 2N3904 BJT

In the specs, we were told I_C = 2mA. We determined that V_C = 15V in the last step. That is our "**quiescent value**" or **Q value**. From the IV curve, we can see that the 2N3904 transistor will supply ~2mA of current when the base current is set to I_B = 11.9μA. With this information, we can determine I_E, R_{B1}, R_{B2}, and R_E. So far we know:

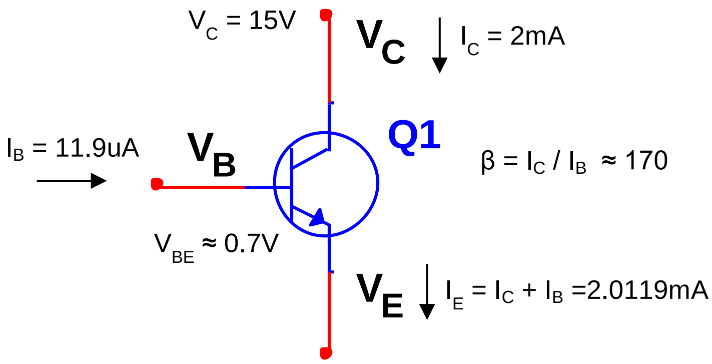

Figure 1.5 – DC Bias State for the 2N3904

4. **Find R_E, V_E, and V_B.**
   a. As a rule of thumb for this type of common-emitter amplifier, we make R_E 10% of R_C.

$$\boldsymbol{R_E} = 10\% R_C = 0.1 * 7.5k\Omega = \mathbf{750\Omega}$$

   b. From Ohm's Law, we can find V_E and V_B:

$$\boldsymbol{V_E} = I_E R_E = 2.0119mA * 750\Omega \approx \mathbf{1.5V}$$
$$\boldsymbol{V_B} = V_E + V_{BE} = 1.5V + 0.7V \approx \mathbf{2.2V}$$

5. **Use V_{CC}, V_B, I_B,** and **R_{in}** to find **R_{B1}** and **R_{B2}.**
   a. Our goal is to deliver **11.9uA** to the base of the transistor. **R_{B1}** and **R_{B2}** must be properly sized to achieve this goal.
   b. We generate three equations to find **R_{B1}** and **R_{B2}**.
   c. Since **R_{B1}** and **R_{B2}** are in parallel (as we learned from Lab 6's tutorial), we know:

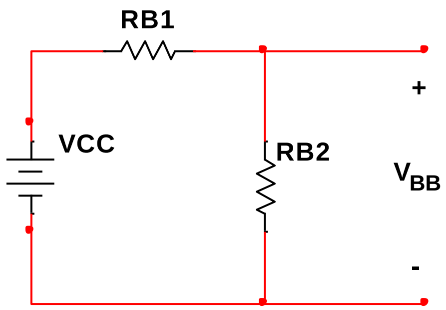

Figure 1.6 – Finding Thévenin Equivalent

The Thévenin Voltage (V_{BB}) is:

$$V_{BB} = \left(\frac{R_{B2}}{R_{B1} + R_{B2}}\right) V_{CC} \quad (1)$$

The Thévenin Resistance (R_B) is:

$$R_B = R_{B1} || R_{B2} = \frac{R_{B1} R_{B2}}{R_{B1} + R_{B2}} \quad (2)$$

d. Using the Thévenin equivalent resistance (R_B) for R_{B1} and R_{B2} (as we did in Lab 6), we know our circuit can be redrawn to look like this:

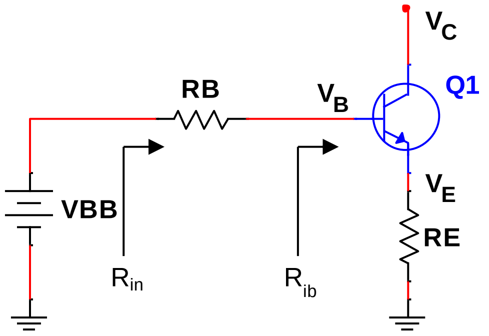

Figure 1.7 – Redrawn with Thévenin Equivalent

Using Ohm's Law:

$$I_B = \frac{V_{BB} - V_B}{R_B}$$

$$V_{BB} = I_B R_B + V_B \qquad (3)$$

e. In **Equations 1-3**, we know $\mathbf{V_{CC}}$, $\mathbf{I_B}$, and $\mathbf{V_B}$, but we do not know $\mathbf{R_{B1}}$, $\mathbf{R_{B2}}$, $\mathbf{R_B}$, or $\mathbf{V_{BB}}$. Therefore, we have ***four*** unknowns, but only ***three*** equations. We need to find the value of one of these variables to solve for them all. We can use the given spec value for R_{in}(DC) to find the value of R_B.

f. From the Thévenin equivalent figure above, we can see that:

$$R_{in} = R_B || R_{ib} \qquad (4)$$

g. R_{ib} is the input resistance looking into the **base** of the transistor. Since only R_E is attached to the emitter at DC (because R_{E1} + C_{B1} appears as an infinite load at DC), we can use the value found in Sedra on p. 457 for R_{ib}:

$$R_{ib} = (\beta + 1)(r_e + R_E)$$

We know from Sedra (p. 407), that:

$$\boldsymbol{r_e} = \frac{V_T}{I_E} = \frac{26mV}{2.0119mA} \approx \mathbf{13\Omega}$$

This makes R_{ib}:

$$\begin{aligned} \boldsymbol{R_{ib}} &= (\beta + 1)(r_e + R_E) \\ &= (171)(13\Omega + 750\Omega) \\ &\approx \mathbf{130k\Omega} \end{aligned}$$

h. Using R_{ib} and R_{in}, from **Equation 4**, we can solve for $\mathbf{R_B}$:

$$R_B = \frac{R_{in} R_{ib}}{R_{ib} - R_{in}} \approx 3.9k\Omega$$

i. With R_B found, we can use **Equations 1-3** and some algebra to find R_{B1} and R_{B2}:

$$\begin{aligned} R_{B1} &= 51.8k\Omega \\ R_{B2} &= 4.2k\Omega \end{aligned}$$

j. All the biasing resistors, currents, and voltages have now been found!

6. **Use R_{E1}** to set the **gain** for the common-emitter amplifier.
   a. The gain for this type of common-emitter amplifier is (with no load attached):

$$A_V(unloaded) = -\left(\frac{R_C}{r_e + R_E||R_{E1}}\right)$$

   b. The specs require A_V(unloaded) to be equal to -50, so with some algebra, we can solve for $\mathbf{R_{E1}}$:

$$\boldsymbol{R_{E1} = 168\Omega}$$

7. **Determine** the **gain** when the load is attached.
   a. The gain for this type of common-emitter amplifier is (with load attached):

$$A_V(loaded) = -\left(\frac{R_C||R_L}{r_e + R_E||R_{E1}}\right) \approx -6$$

8. **Set** values for $\mathbf{C_{C1}}$, $\mathbf{C_{C2}}$, and $\mathbf{C_{B1}}$.
   a. The impedance of a capacitor is $Z_C = \frac{1}{j2\pi fC}$. We can use this knowing that we want $\mathbf{C_{C1}}$, $\mathbf{C_{C2}}$, and $\mathbf{C_{B1}}$ to all look like "shorts" at 10kHz (the input frequency), and select a value that we have in the ECE 2115 kit.