Laboratory 2

Simple Transistor Amplifiers: Lecture 2

2.1 Common Emitter Amplifier: DC Bias

2.1.1 Theory

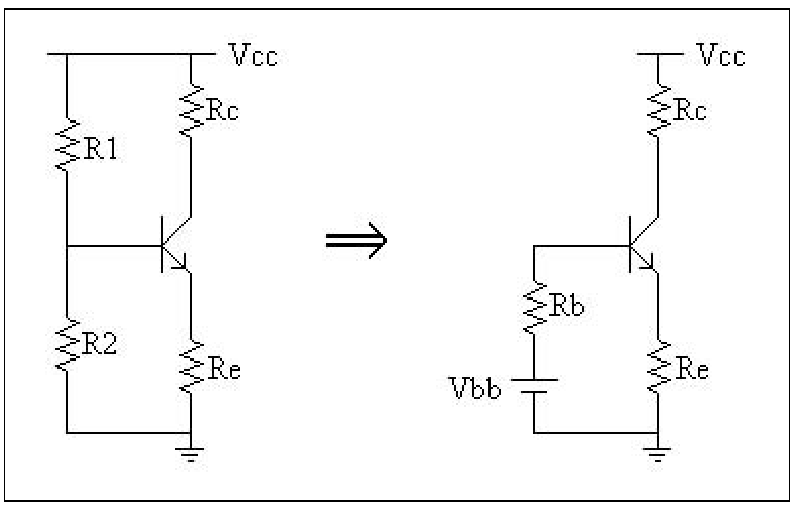

Figure 2.1: Determining DC Bias

Using KVL on the base emitter loop,

$$V_{BB} = I_B R_B + I_E R_E + V_{BE} \tag{2.1}$$

where $R_B = R_1 || R_2$ and $V_{BB} = \frac{V_{CC} R_2}{R_1 + R_2}$.

The B-E loop gives one equation and three unknowns I_E, V_{BE} and I_B.

Use

$$\beta I_B = I_C,$$
$$I_C \approx I_E$$
$$V_{BE} \approx 0.7V$$

Substitute into for I_E, V_{BE} and I_B.

$$V_{BB} = \frac{I_C}{\beta} R_B + I_C R_E + 0.7 \tag{2.2}$$

Obtain the following equation for I_C in terms of known parameters.

$$I_C = \frac{V_{BB} - 0.7}{\frac{R_B}{\beta} + R_E} \tag{2.3}$$

With I_C determined, V_C and V_E are readily obtained by observing that:

$$V_C = V_{CC} - I_C R_C \tag{2.4}$$

$$V_E = I_E R_E \tag{2.5}$$

$$V_B = V_E + 0.7 \tag{2.6}$$

2.2 CE Amp Small Signal Voltage Gain at Midband Frequencies

2.2.1 Theory: Approximate Analysis

CE configuration is useful for amplifying small signal voltages.

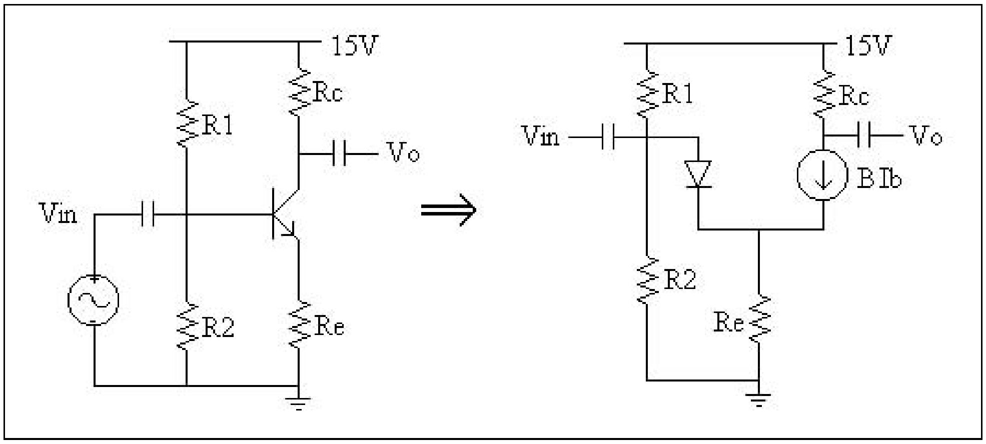

Figure 2.2: Common Emitter Amplifier

Voltage gain is $A_v = \frac{v_{out}}{v_{in}} = \frac{\Delta V_c}{\Delta V_b}$.
Base-emitter loop gives:

$$V_b = I_c R_E + V_{be} \tag{2.7}$$

Make small change in V_b:

$$\Delta V_b = \Delta I_c R_E + \Delta V_{be} \tag{2.8}$$

Look at the collector voltage V_C. From KVL we have

$$V_c = V_{CC} - I_c R_C \tag{2.9}$$

Since V_{CC} represents a DC power supply $\Delta V_{CC} = 0$

$$\Delta V_c = -\Delta I_c R_C \tag{2.10}$$

Taking the ratio $\frac{v_{out}}{v_{in}} = \frac{\Delta V_c}{\Delta V_b}$ for the voltage gain yields: of ΔV_{be}, is:

$$A_V = \frac{v_{out}}{v_{in}} = \frac{\Delta V_c}{\Delta V_b} = \frac{-\Delta I_c R_C}{\Delta V_b + \Delta I_c R_E} \tag{2.11}$$

Very Useful Approximation

ΔV_{be} is almost always very small. Therefore, a zero order approximation can often be made to neglect ΔV_{be} compared with $\Delta I_c R_E$ to yield:

$$\Delta V_b \approx \Delta I_c R_E \tag{2.12}$$

$$\frac{v_{out}}{v_{in}} \approx -\frac{I_c R_C}{I_c R_E} \tag{2.13}$$

or

$$\frac{v_{out}}{v_{in}} \approx -\frac{R_C}{R_E} \tag{2.14}$$

Note, with this approximation, the voltage gain of a CE amp can be read directly from the circuit diagram.

2.2.2 Theory: Accounting for ΔV_{be} in the CE Amp

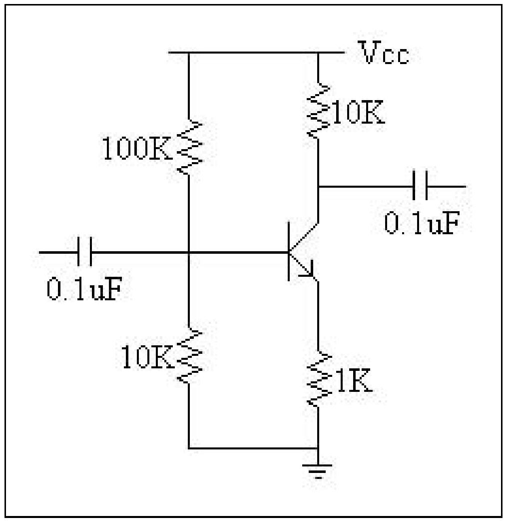

Figure 2.3: CE Circuit for small signal gain

We R_E is small or even zero ΔV_{be} can not be neglected in small signal analysis.

$$A_V = \frac{v_{out}}{v_{in}} = \frac{\Delta V_c}{\Delta V_b} = \frac{-\Delta I_c R_C}{\Delta V_b + \Delta I_c R_E} \tag{2.15}$$

Find ΔV_{be}:

Start with V_{be} and I_c.

$$I_c = \beta I_s e^{\frac{V_{be}}{V_T}} \tag{2.16}$$

Using Taylor series we can obtain the small signal change in I_c that results in a small change in V_{be}.

$$\Delta I_c = \frac{\partial I_c}{\partial V_{be}} \Delta V_{be} \tag{2.17}$$

Performing the differentiation and using 2.16, leads to

$$\Delta I_c = \frac{I_C}{V_T}|_{I_C} \Delta V_{be} \tag{2.18}$$

$\frac{\partial I_c}{\partial V_{be}}|_{I_C}$ is defined as the small signal transconductance of the BJT, which is designated as g_m.

g_m is given for a specific I_C which is determined by the DC bias condition.

$$g_m = \frac{\partial I_c}{\partial V_{be}}|_{I_C} = \frac{I_C}{V_T} \tag{2.19}$$

Small signal change in V_{be} is

$$\Delta V_{be} = \frac{\Delta I_c}{g_m} \tag{2.20}$$

Substitute $\frac{\Delta I_c}{g_m}$ for ΔV_{be} in Equation (2.27), and take the ratio $\frac{\Delta V_c}{\Delta V_b}$.

Voltage gain, while including the effect of ΔV_{be}, is:

$$A_V = \frac{v_{out}}{v_{in}} = \frac{\Delta V_c}{\Delta V_b} = \frac{-R_C}{\frac{1}{g_m} + R_E} \tag{2.21}$$

When $R_E = 0$ in the above equation the gain would be:

$$A_V = -g_m R_C \tag{2.22}$$

2.3 CE Amp Voltage Amplifier Equivalent Circuit, Input Resistance and Output Resistance

2.3.1 Input Resistance:

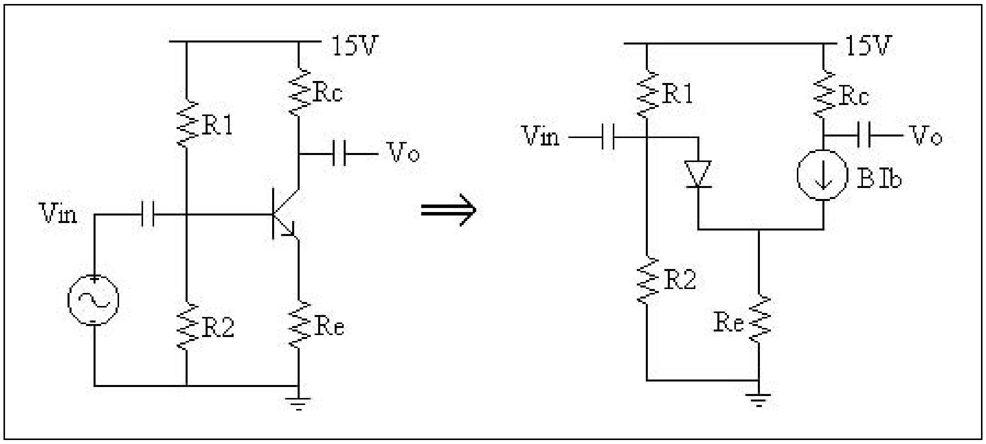

Figure 2.4: Common Emitter Amplifier

The input resistance is the resistance seen by the current source or voltage source which drives the circuit.

For example, Fig. 2.4, the impedance seen by sinusoidal input signals looking into the capacitor is:

$$Z_{in} = \frac{1}{j\omega C_1} + R_B || R_{TB} \tag{2.23}$$

R_{TB} is the resistance looking into the base of the transistor.

$R_B = R_1 || R_2$

At midband frequencies $\frac{1}{j\omega C_1} \approx 0$, so

$$R_{in} = R_B || R_{TB} \tag{2.24}$$

R_B can be read directly from the circuit.

Determine R_{TB}.

$$R_{TB} = \frac{\Delta V_b}{\Delta I_b} \tag{2.25}$$

Find ΔV_b;

Base emitter loop gives

$$V_b = I_e R_E + V_{be} \tag{2.26}$$

Use $I_e \approx I_c$ Make small change in V_b:

$$\Delta V_b = \Delta I_c R_E + \Delta V_{be} \tag{2.27}$$

Use $\Delta V_{be} = \frac{\Delta I_c}{g_m}$ to obtain

$$\Delta V_b = \frac{\Delta I_c}{g_m} + \Delta I_c R_E \tag{2.28}$$

Now, recalling that $\Delta I_b = \frac{\Delta I_c}{\beta}$, and dividing ΔV_b by ΔI_b, we obtain

$$R_{TB} = \frac{\Delta V_b}{\Delta I_b} = \frac{\beta}{g_m} + \beta R_E \tag{2.29}$$

Very good approximation

Since $\frac{1}{g_m}$ is usually much smaller than R_E, when an emitter resistor is present $R_{TB} \approx \beta R_E$.

It is interesting to observe that the resistance looking into the base is usually fairly large since it contains the multiplicative factor β.

2.3.2 Output Resistance of CE Amp

Output resistance is an indication of a source's ability to drive a load impedance.

An ideal voltage source has zero output resistance.

An ideal current source has infinite output resistance.

To find the output resistance of the CE amplifier, we ground the input and drive the output.

From the circuit in Fig. 2.3, the output resistance is then $R_C||R_{TC}$, where R_{TC} is the resistance looking into the collector.

Since, at this time, we are considering the collector to be modeled as an ideal current source (neglecting r_o for now,

$$R_o \approx R_C.$$

2.3.3 Voltage Amplifier Equivalent Circuit

We have determined CE:

Voltage gain,

Input resistance

Output resistance

Now represent CE amp a simple two-port circuit in Fig 2.5

$R_{in} = (r_\pi + \beta R_E)||R_B$; $R_{out} = R_C$; and the open circuit output voltage given by $v_{out} = A_V v_{in}$.

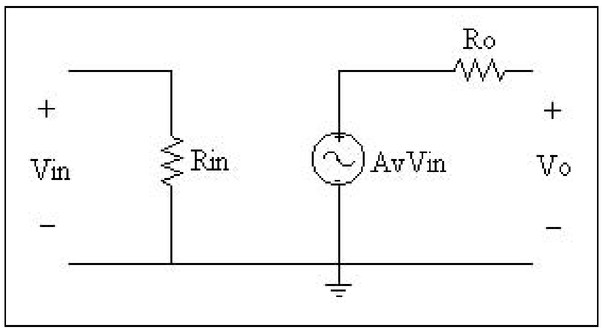

Figure 2.5: Two-Port Equivalent Amplifier Circuit