Unit 33 Small signal amplification

- The small signal voltage amplification of a common emitter amplifier is given by:

$$A_V = -\frac{I_E}{25\,\mathrm{mV}} \times R_C$$

- The input impedance is given by:

$$R_{in} = \beta \times \frac{25\,\mathrm{mV}}{I_E}$$

In the last unit we saw how various configurations of transistor and resistors can give amplification of small signals which are applied to the input port of the amplifier. In this unit we show how the numerical value of the voltage amplification, A_V, can be calculated for the case of the common emitter amplifier. It is important to distinguish between the current gain, β, of the transistor and the amplification, A_V, of the complete transistor circuit. The amplification of the circuit is determined by the value of β for the transistor in conjunction with the values of the resistors used in the circuit.

Consider the stripped down circuit shown in Figure 33.1 (a). We presume that the transistor is suitably biased, that is that the emitter-base junction is forward biased and that the base-collector junction is reverse biased. For clarity we have omitted the bias resistors from the diagram.

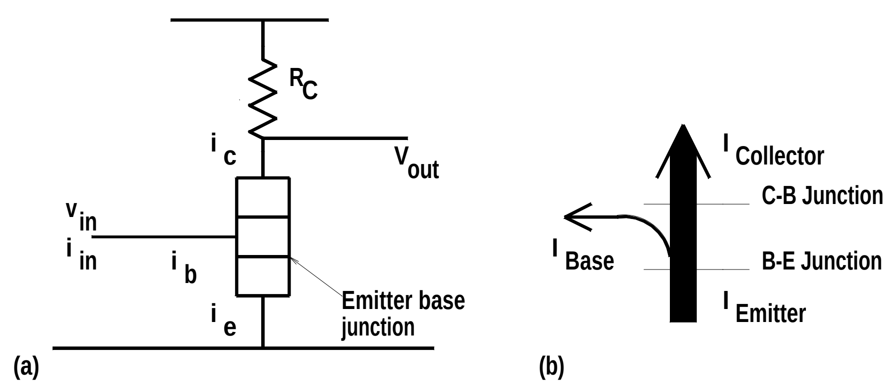

Figure 33.1: Relative magnitudes of currents in a transistor.

Consider only the small signals which we represent by the lower case letters, v and i. The small input voltage signal, v_{in}, and the resulting current signal, i_{in}, are applied to the circuit at the input port. We can then define an input resistance for small signals:

$$R_{in} = \frac{v_{in}}{i_{in}}$$

We also have the equalities $v_b = v_{in}$ and $i_b = i_{in}$.

It is assumed that the input signals are small enough that any deviation from a linear approximation is negligible. This can be very easily checked in the final circuit by using an oscilloscope to observe the output waveform. If the output waveform changes only in amplitude as the input signal amplitude is increased then the system is effectively a linear system. If the shape of the output waveform becomes distorted then the system is nonlinear.

The change in the voltage at the base appears as a change in the voltage across the emitter-base junction. This gives a change in the current through the emitter-base junction of i_e. In words, a change in the **base** voltage gives a change in the **emitter** current which flows through the emitter-base junction. Most of this emitter current flows on through the base region to the collector with only a small fraction appearing as i_b. This is indicated by the line thickness in the diagram in Figure 33.1 (b).

The emitter-base junction has a dynamic resistance which is given by the equation:

$$R_{DYN} = \frac{25\,\mathrm{mV}}{\text{Junction current}} = \frac{25\,\mathrm{mV}}{I_E}$$

Note that we use the DC value, I_E, of the emitter current through the junction in this equation. (Review Unit 27.) So we now have:

$$\begin{aligned} \frac{v_b}{i_e} &= R_{DYN} = \frac{25\,\mathrm{mV}}{I_E} \\ \text{which gives} \quad v_{in} &= v_b = i_e \times \frac{25\,\mathrm{mV}}{I_E} \end{aligned}$$

but we also have an output voltage signal:

$$v_{out} = -i_c \times R_C \approx -i_e \times R_C$$

Now we can get the small signal voltage amplification for the common emitter amplifier circuit as:

$$A_V = \frac{v_{out}}{v_{in}} = -\frac{i_e \times R_C}{i_e \times \frac{25\,\mathrm{mV}}{I_E}} = -\frac{I_E}{25\,\mathrm{mV}} \times R_C$$

The negative sign indicates that the signal is inverted. The unexpected feature of this result is that it does not contain any explicit reference to the current gain, β, of the transistor.

Now consider the input resistance. We have:

$$
\begin{aligned}
R_{in} &= \frac{v_{in}}{i_{in}} = \frac{v_b}{i_b} \\
&= \frac{i_e \times \frac{25\,\mathrm{mV}}{I_E}}{i_b} \\
&= \frac{\beta \times i_b \times \frac{25\,\mathrm{mV}}{I_E}}{i_b} \\
&= \beta \times \frac{25\,\mathrm{mV}}{I_E}
\end{aligned}
$$

So the input resistance is β times the dynamic resistance of the emitter-base junction.

33.1 Example

33.1 Calculate the amplification and the input resistance of the circuit shown in Figure 33.2. Use $\beta = 200$.

Give a sketch of the signals which would be observed on an oscilloscope connected in turn to each of the nodes of the circuit.

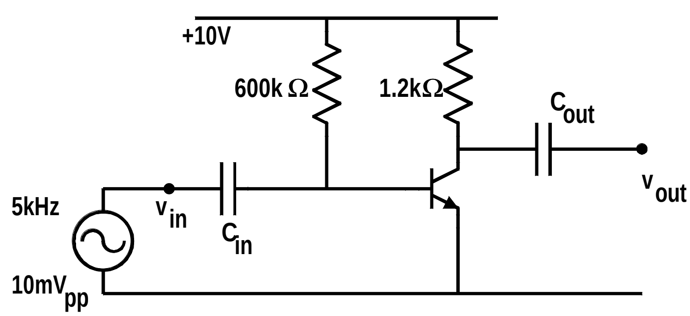

Figure 33.2: Example 33.1.

It is necessary to determine the DC operating conditions for the circuit.

$$
\begin{aligned}
V_E &= 0\,\mathrm{V} \\
V_B &= 0.7\,\mathrm{V}
\end{aligned}
$$

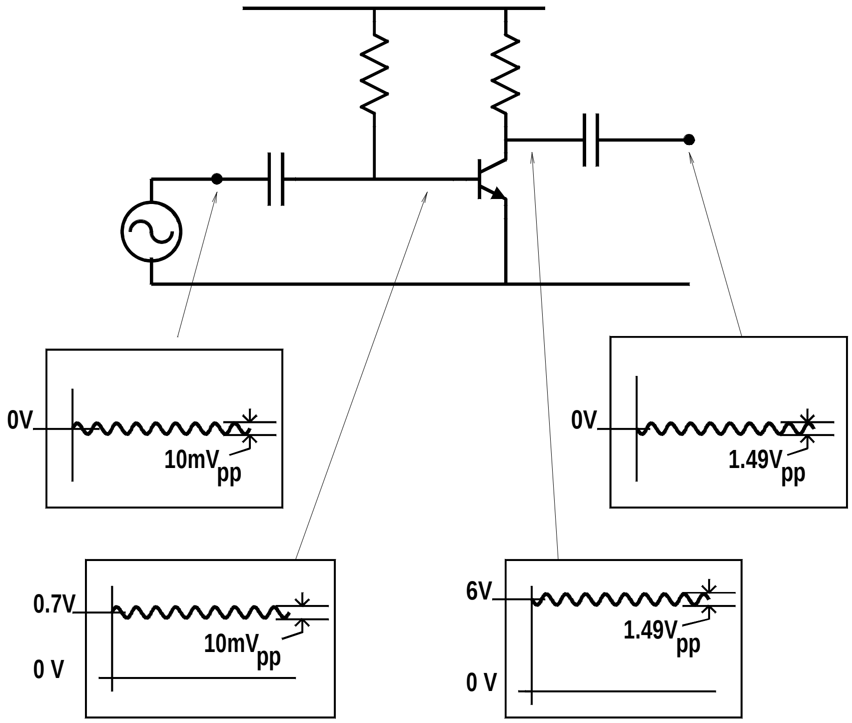

Figure 33.3: The signals at various points in a common emitter amplifier.

$$
\begin{aligned}
10\,\mathrm{V} &= I_B \times 600\,\mathrm{k}\Omega + 0.7\,\mathrm{V} \\
I_B &= \frac{9.3}{600\,\mathrm{k}\Omega} = 15.5\,\mu\mathrm{A} \\
I_E &= I_C = \beta \times I_B = 3.1\,\mathrm{mA} \\
V_C &= 10\,\mathrm{V} - I_C \times R_C = 10\,\mathrm{V} - 3.1\,\mathrm{mA} \times 1.2\,\mathrm{k}\Omega \\
&= 6.28\,\mathrm{V}
\end{aligned}
$$

Now calculate the small signal voltage amplification.

$$
\begin{aligned}
A_V &= -R_C \times \frac{I_E}{25\,\mathrm{mV}} = -1200 \times \frac{3.1\,\mathrm{mA}}{25\,\mathrm{mV}} \\
&= -149 \\
R_{in} &= \beta \times \frac{25\,\mathrm{mV}}{I_E} = 200 \times \frac{25\,\mathrm{mV}}{3.1\,\mathrm{mA}} \\
&= 1.6\,\mathrm{k}\Omega
\end{aligned}
$$

If the signal frequency is high enough for the impedance of the C_{in} to be negligible compared with $1.6\,\mathrm{k}\Omega$ then the small signal input impedance is resistive and $1.6\,\mathrm{k}\Omega$. Otherwise we have an effective high pass filter at the input to the amplifier which blocks DC and low frequency AC signals from reaching the transistor. This gives an amplifier frequency response (review Unit 16) with a corner frequency at:

$$f_c = \frac{1}{2\pi C_{in} R_{in}}$$

The signals which would be observed at the nodes of the circuit with an oscilloscope are shown in Figure 33.3. The solid horizontal line in the oscilloscope tracings indicates the 0 V reference on the oscilloscope screen. The peak-to-peak amplitudes of the input and output signals are indicated. If possible you should try out this circuit in the laboratory and verify these oscilloscope observations. Note the phase inversion between the input and output signals corresponding to the negative sign in $A_V = -149$.

33.2 Problems

33.1 Calculate the small signal voltage amplification for the transistor amplifier shown in Figure 33.4. The current gain for the transistor is $\beta = 250$. Plot the load line for the transistor and mark the DC operating point. Indicate the maximum and minimum excursion along the load line for a sinusoidal input signal of $12\,\text{mV}_{\text{pp}}$ and of frequency 5 kHz.

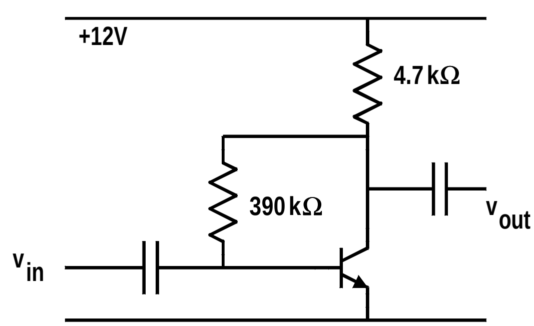

Figure 33.4: Problem 33.1.

33.2 Calculate the small signal amplification for the circuit shown in Figure 33.5. Give scaled sketches of the voltage waveforms which you would observe with an oscilloscope connected to points A, B, C and D in the circuit when a $10\,\text{mV}_{\text{pp}}$, 5 kHz sinusoidal signal is applied at the input.

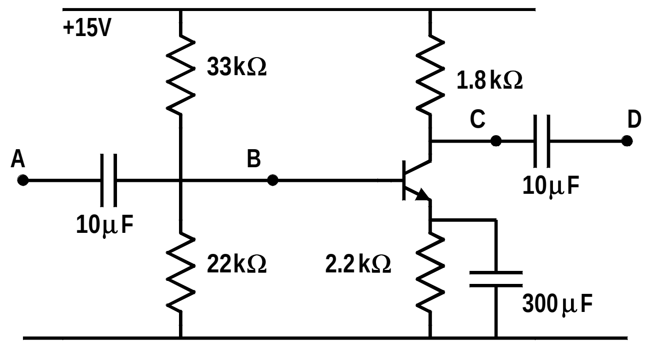

Figure 33.5: Problem 33.2.

33.3 Analyze the circuit shown in Figure 33.6 and derive the equation for the small signal voltage amplification of the circuit. You should follow the procedure used in the text but note that R_E is in series with the emitter-base junction. What is the amplification when $R_E = 25\,\Omega$?

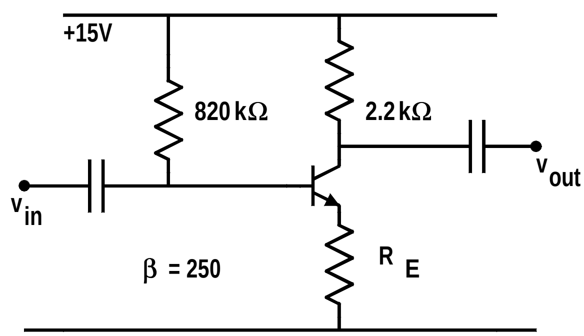

Figure 33.6: Problem 33.3.