Unit 32 Small signal amplifiers

- Lower case v or i is used to represent small signals or variations about a mean DC operating point of value V or I.
- A small signal applied to a transistor causes the instantaneous operating point to move along a load line.
- The amplification is represented by A. A negative value for A implies that the output signal waveform is inverted.
- In a common emitter amplifier, the emitter is common to the input and the output ports for small signals.
- In a common base amplifier, the base is common to the input and the output ports for small signals.
- In a common collector amplifier, the collector is common to the input and the output ports for small signals.

The discussion of transistor circuits in earlier units has only covered the DC biasing of transistors into the middle of their working range so that the emitter-base junction is forward biased and the base-collector junction is reverse biased. No signal has, as yet, been applied to the transistor.

In this unit we examine ways of getting some useful signal gain from the transistor circuit. We first define a small signal as a fluctuation in voltage or current about an operating or bias point and we will use lower case i or v, with appropriate subscripts for emitter, base, collector etc., to represent these small signals. These small signals are superimposed on the DC bias voltages and currents. They modulate the currents and voltages in the transistor and can be amplified by the action of the transistor.

Consider the circuit in Figure 32.1 (a) which has already been discussed in Example 31.1. The collector voltage and current were calculated to be $V_C = 7.7\,\text{V}$ and $I_C = 2.3\,\text{mA}$ and this (I_C, V_C) pair is indicated as the operating point on the load line in Figure 32.1 (b).

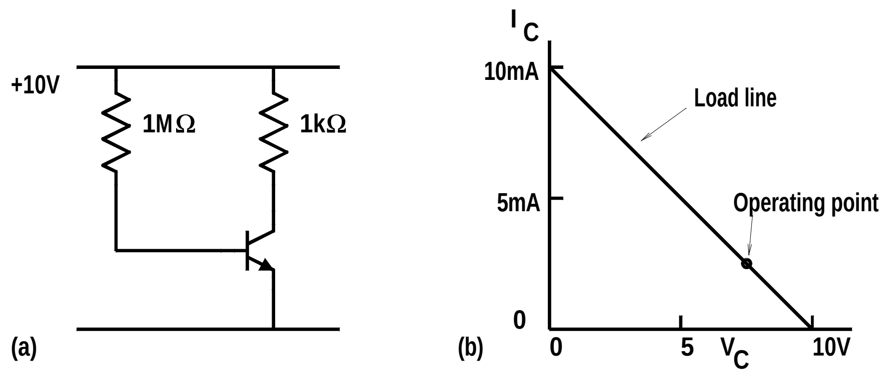

Figure 32.1: Transistor load line.

Suppose we could change or modulate the base current in some way. The relationship between the resulting collector current and collector voltage would still be:

$$V_C = V_{supply} - I_C R_C = 10\,\mathrm{V} - I_C \times 1\,\mathrm{k}\Omega$$

which is a straight line. This straight line is easily drawn on the I_C–V_C diagram. When $I_C = 0$, $V_C = 10\,\mathrm{V}$ and for a short circuit across the transistor $V_C = 0$ and $I_C = \frac{10\ V}{R_C} = 10\,\mathrm{mA}$. We can therefore draw the load line on the V_C–I_C diagram as shown in Figure 32.1 (b). The calculated operating point also lies on this load line. Any variation in the signal to the base which we can impose only causes the (V_C, I_C) value to move up or down along this load line.

Our requirement is that we can bias the transistor so that it is at an operating point towards the middle of this load line and that we have a method of superimposing some small variation on the base current or voltage of the transistor which will cause the operating point to vary along the load line without disturbing the mean DC bias values.

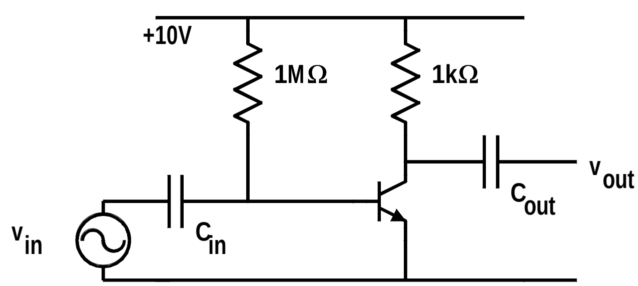

Figure 32.2: Method of coupling in small signals.

This can be achieved by using the circuit shown in Figure 32.2 where we superimpose an input signal, v_{in}, from a function generator onto the DC bias signal, V_B, at the base by using a capacitor to couple in the signal. The capacitor prevents the function generator from shorting out the DC bias voltage but the capacitor also acts as a low value impedance for the small input signal from the function generator, v_{in}, allowing the signal to be superimposed on the DC base bias. (Review Example 27.2, which shows a similar example of superposition for a diode circuit.)

Without going into detailed calculations of the magnitudes of the signals, it can be seen that the sequence of changes is:

- An increased voltage at the base causes an increased base current.
- The increased base current is amplified by the transistor with a current gain, β, and gives a larger emitter current.
- The larger emitter current gives a nearly equal change in the collector current.
- The increased collector current gives an increased voltage drop across the collector resistor, R_C.
- The increased voltage drop across the collector resistor gives a decrease of the collector voltage.
- This decrease in the collector voltage implies an inversion of the signal.

If a capacitor is connected to the collector as C_{out} in Figure 32.2, then the DC component of the output voltage can be removed to leave only the time varying small signal output voltage, v_{out}.

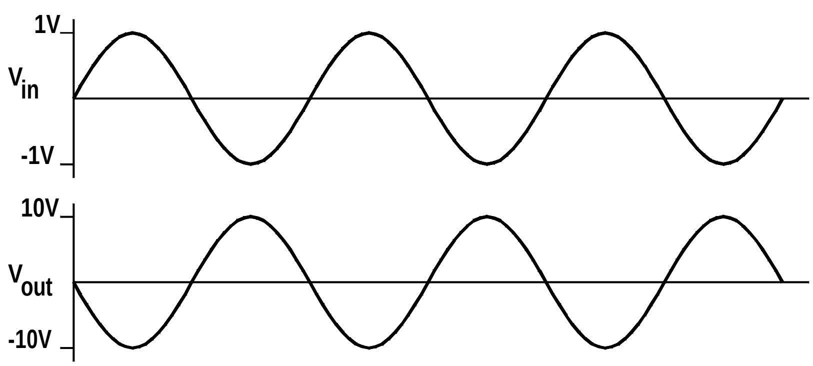

Figure 32.3: Oscilloscope trace of input and output signals for $A = -10$.

If the values of the resistors are chosen correctly then the output signal, v_{out}, may be an inverted and amplified version of the input signal, v_{in}, and we can then define a small signal amplification:

$$A = \frac{v_{out}}{v_{in}}$$

A negative value for A implies signal inversion, that is a positive going input signal gives a negative going output signal and vice versa. The magnitude of A gives the ratio of the amplitudes of the two signals. Figure 32.3 shows the signals which would be observed with an oscilloscope connected to an amplifier for which the gain is $A = -10$. Note the scaling of the voltage axes and also the inverted output waveform.

In an amplifier, the input signal, v_{in}, is applied via two wires and the output signal, v_{out}, is taken out via two wires. We can then say that the amplifier is a two port device where the input port has two connections and the output port has two connections. This is shown in Figure 32.4 (a).

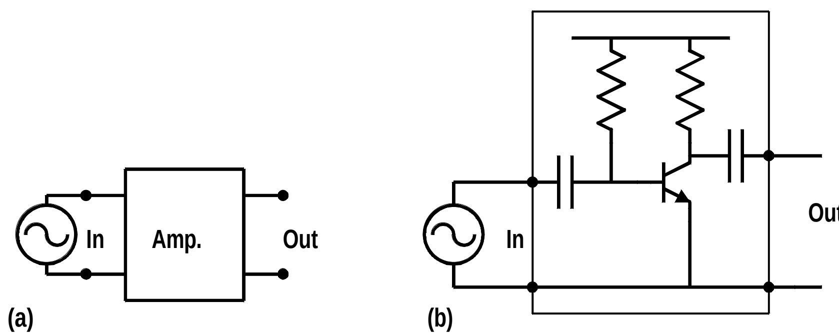

Figure 32.4: Two port amplifier.

However, transistors have only three connections (E, B and C) so one of the transistor connections must be common to both the input and output ports as is shown for the amplifier in Figure 32.4 (b). In this case, the common transistor terminal is the emitter and this type of amplifier is therefore called a common emitter amplifier. The emitter need only be common to the input and output for small signals. In this circuit example the emitter is actually connected to both the input and output. However, in some circuits the common terminal is only common to the input and output for small signals with the connection being made with a capacitor, either directly to ground or via the capacitor in the power supply.

If we take the most general transistor bias configuration, such as that discussed in Example 31.3, then the three possible amplifier configurations are as shown in Figure 32.5.

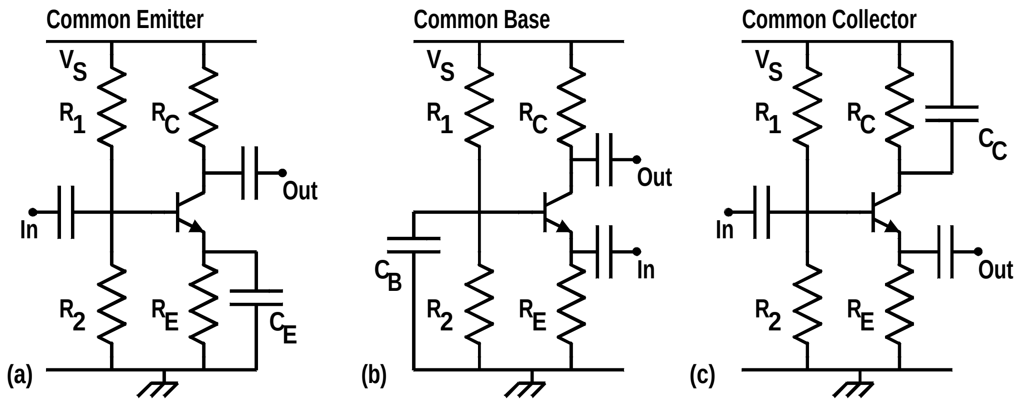

Figure 32.5: Common emitter, base and collector configurations.

For the common emitter circuit in Figure 32.5 (a) the emitter is grounded via the C_E so the emitter voltage does not vary in the presence of small signals at the input. The R_E and C_E act as a high pass filter with a corner frequency lower than the lowest signal frequency which is to be amplified in the circuit. The input signal is applied to the base and the amplified signal is taken from the collector.

For the common base amplifier in Figure 32.5 (b), the base is grounded for small signals via the C_B. Note that the C_B does not disable the DC base bias of the transistor. The input signal is applied at the emitter. A positive going input signal causes the V_{BE} to reduce thus reducing the emitter and collector currents in the transistor. This gives an increase in the collector voltage and therefore the sign of the amplification, A, is positive denoting no inversion. This type of common base amplifier has applications in high frequency and in radio frequency amplifiers.

For the common collector amplifier in Figure 32.5 (c) the collector is grounded via the C_C and the capacitor in the output of the power supply. A positive signal applied to the base causes the base current to increase and this causes the emitter current to increase. This gives increased voltage across the R_E and therefore the emitter voltage follows the base voltage. This type of amplifier is sometimes called an emitter follower. A consequence of this emitter following action is that the voltage amplification of this circuit is $+1$ or slightly less than $+1$. The current gain is, however, quite high and also the input impedance of the circuit is high. The applications of this circuit are as input stages where high input impedances are required and as output stages where the low output impedance or the capability for driving high currents into loads is needed.

32.1 Problems

32.1 Identify the two terminals of the input port and the two terminals of the output port for each of the three amplifiers shown in Figure 32.5.

32.2 Identify the circuit type (common emitter, base or collector) for each of the circuits shown in Figure 32.6. In each case, apply a sinusoidal signal of amplitude 10 mV and frequency 5 kHz to the input and give a roughly scaled sketch of the output voltage waveform.

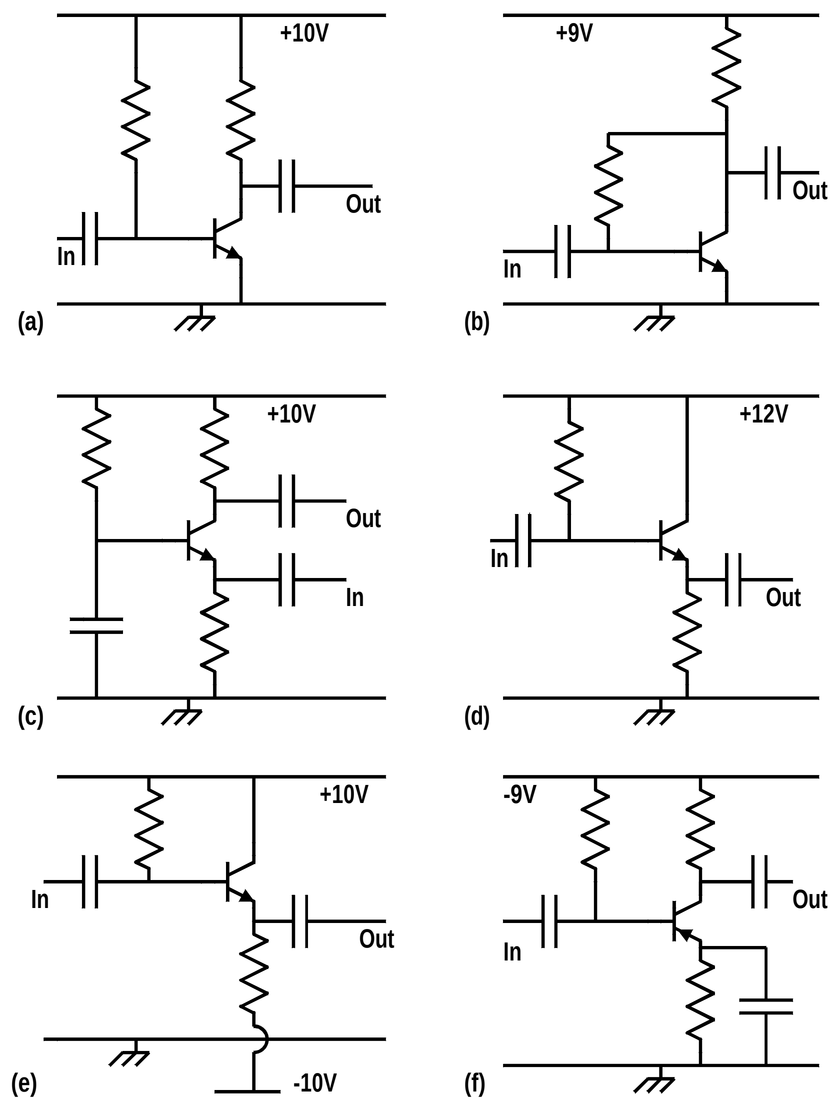

Figure 32.6: Problem 32.2.

32.3 Plot the load line for the circuit shown in Figure 32.7 and indicate the position of the operating point on the load line.

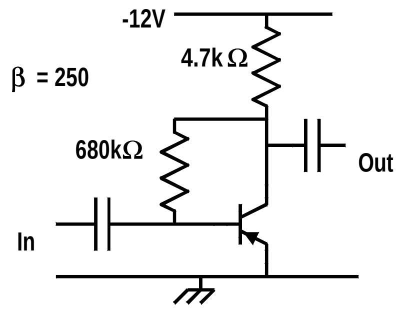

Figure 32.7: Problem 32.3.

32.4 Identify the type of circuit shown in Figure 32.8 and describe the operation of the circuit and the circuit characteristics.

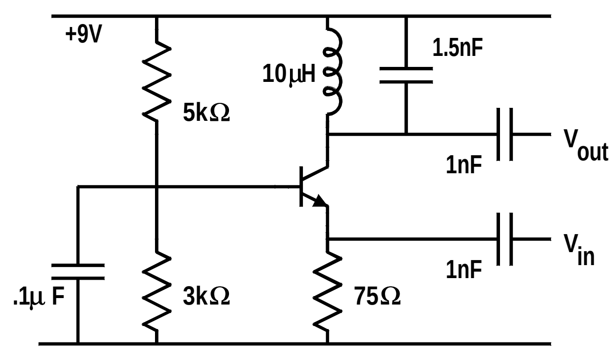

Figure 32.8: Problem 32.4.

32.5 In the circuit shown in Figure 32.9, V_{in} is varied from 0 V to +10 V. Plot a graph showing the variation of V_{out} as a function of V_{in}.

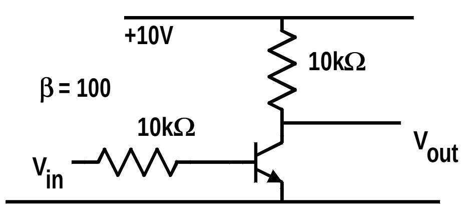

Figure 32.9: Problem 32.5.