Unit 34 Transistor circuit building blocks

The characteristic features of the principal transistor circuit building blocks are:

- **Common emitter amplifier:** $A_V \approx -200$, $R_{in} \approx 3\,\mathrm{k}\Omega$
- **Emitter follower:** $A_V \approx 1$, R_{in} is high, R_{out} is low.
- **Push-pull emitter follower:** $A_V \approx 1$, high output current drive capability, symmetrical performance.
- **Differential amplifier:** Amplifies DC signals.
- **Current mirror:** Nearly constant current, used as high resistance load resistor or active load.
- **Tuned amplifier:** Frequency at which maximum amplification occurs determined by $f = \frac{1}{2\pi\sqrt{LC}}$.

In this unit we will give a brief treatment of the principal transistor circuit building blocks which are used in linear analog circuit systems. These circuit blocks or modules constitute a minimum set of such blocks that can be combined to form more complex circuits which have increased functionality.

Common emitter amplifier. We have already analyzed the performance of the common emitter amplifier in Unit 33 so we will not discuss the circuit further but just include the result in the summary.

Emitter follower. The emitter follower or common collector is shown in Figure 34.1. A signal applied at the base changes the base voltage. The emitter voltage follows the base voltage up or down maintaining a nearly constant emitter-base voltage of 0.7 V. The result is that the voltage gain is 1 or slightly less than 1. (A good analogy here is that of a tow truck and trailer. The trailer does not normally overtake the tow truck!)

The input impedance of the emitter follower is calculated as follows. A small input voltage v_{in} causes a base voltage v_b which gives base current i_b. The current across the emitter-base junction and also in R_E is $i_e = \beta i_b$. This current through the emitter-base junction and R_E in series gives a voltage at the base of:

$$v_b = i_e \left(\frac{25\,\mathrm{mV}}{I_E} + R_E \right) = \beta i_b \left(\frac{25\,\mathrm{mV}}{I_E} + R_E \right)$$

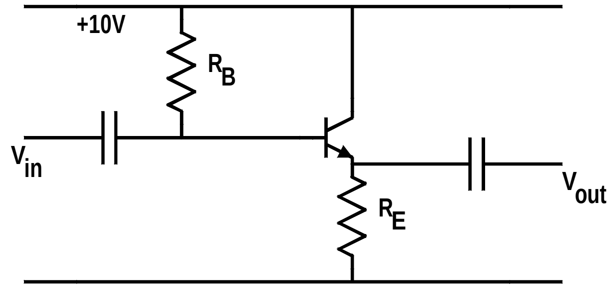

Figure 34.1: Emitter follower.

$$\text{giving} \quad R_{in} = \frac{v_{in}}{i_{in}} = \frac{v_b}{i_b} = \beta\left(\frac{25\,\text{mV}}{I_E} + R_E\right)$$

typically $R_E \approx 1\,\text{k}\Omega \gg \frac{25\,\text{mV}}{I_E}$ and we can see that the input resistance of the emitter follower will easily be of the order of $250 \times 1\,\text{k}\Omega = 250\,\text{k}\Omega$.

This makes the circuit ideal for use as the input stage in situations where we require a high input impedance to minimize the loading on sensors or other electronic pick-up devices.

The emitter follower is also used for output stages where the high current driving capability of the circuit—its current amplification properties—makes it ideal for driving low impedance loads such as loudspeakers ($R_{in} = 8\,\Omega$ typically), small, speed controlled motors and other devices which draw large currents at low voltages.

Push-pull emitter follower. The main problem with the single transistor npn emitter follower is that while the npn responds well to positive going signals, fast, large, negative going signals can give a reverse biased emitter-base junction and a turned off transistor. This occurs especially in situations where there is some capacity associated with the emitter circuit which tends to maintain the emitter voltage constant. There is therefore a good fast response for positive going signals but a poor response for negative going signals. The reverse is true for the pnp version of the emitter follower.

The solution to this asymmetric response problem is to use two transistors, one pnp and the other npn, in series as shown in Figure 34.2 (a). This gives fast response to fast input signals of either polarity but, as is normal, the solution to one problem causes another problem. The circuit in Figure 34.2 (a) has a dead spot in the response, for signals within $\pm 0.7\,\text{V}$ of zero, due to the fact that neither transistor is conducting in this region. This is called crossover distortion and Figure 34.3 shows how such a system distorts a sinusoidal input waveform.

This crossover distortion can be minimized or eliminated by providing some DC forward bias for the transistors even when there is no input signal.

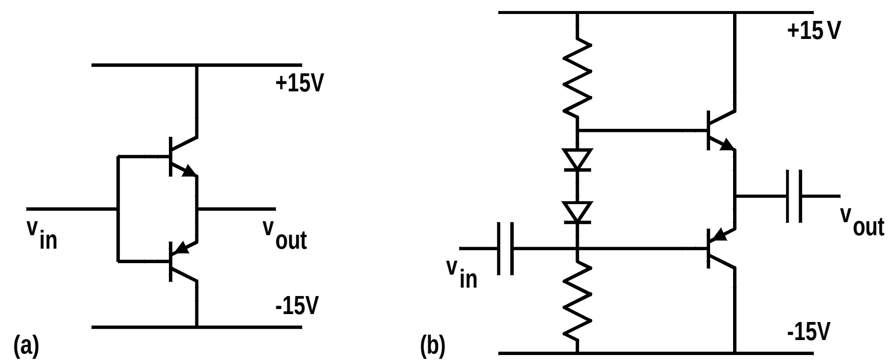

Figure 34.2: Push-pull emitter follower.

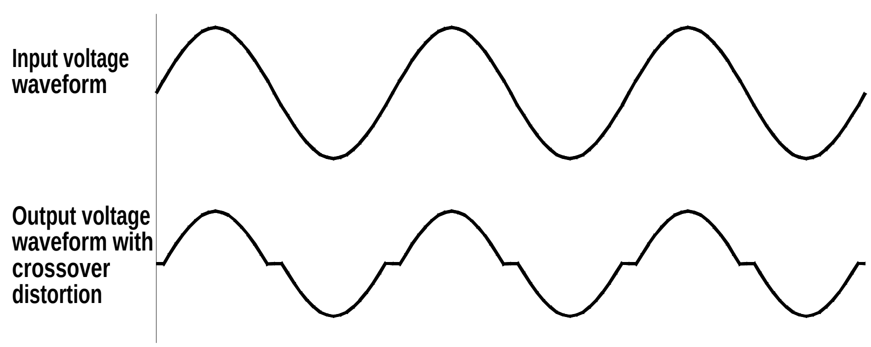

Figure 34.3: Crossover distortion.

The necessary modification is shown in Figure 34.2 (b) where the two diodes are forward biased by the resistor chain and the emitter-base junctions are maintained at $V_{BE} \approx 0.7\,\text{V}$ for each transistor. So we no longer have the problem of both emitter followers being off for small signals and therefore the crossover distortion is eliminated. Diodes are often used to give the 1.4 V between the bases rather than another resistor as the use of two diodes maintains a constant 1.4 V even if different + and − supply voltages are used. This method of minimizing crossover distortion is at the expense of increased quiescent current in the two transistors which can then be a problem in battery powered equipment.

Differential amplifier. Small AC signals can be coupled into a single transistor amplifier through a capacitor without upsetting the DC bias in the transistor. It is not possible to couple in DC signals without affecting the V_{BE} of 0.7 V and therefore it is not possible to construct a single transistor

DC amplifier which operates down to zero volts.

The method used to obtain DC amplification is to use two transistors, balanced against each other, in what is called a differential amplifier configuration. A typical circuit is shown in Figure 34.4 in which representative values are shown for the resistors.

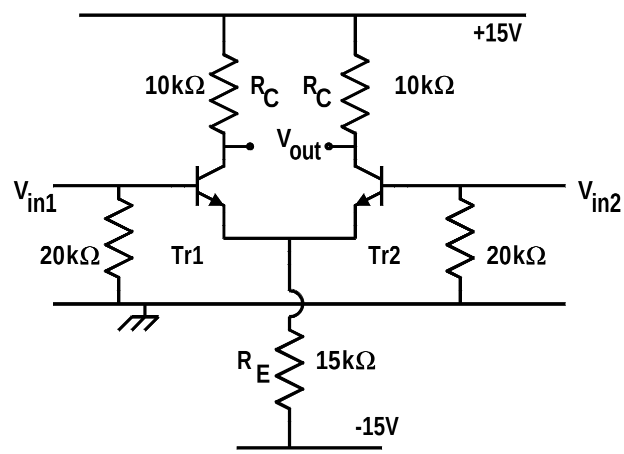

Figure 34.4: Differential amplifier.

The circuit is symmetrical, with a signal applied to the base of each transistor. The essential principle of operation is that the two halves of the circuit are coupled together by the shared emitter resistor, R_E, of 15 kΩ.

When no input signals are present at the inputs, the current in R_E divides equally between the two transistors giving equal voltages at the two collectors and therefore giving a differential output voltage between the two collectors of 0 V.

If a small positive voltage signal is applied to the base of the left hand transistor, Tr1, then this transistor conducts more current. This causes the current in R_E to increase slightly due to emitter follower action and the V_{BE} for the right hand transistor, Tr2, is reduced slightly reducing the current in Tr2. The net effect is that the voltage at the collector of Tr1 decreases and the voltage at the collector of Tr2 increases giving a change in the voltage difference between the two collectors.. The current in R_E remains nearly constant since an increase of current through Tr1 is balanced by a decrease of current through Tr2.

If the signal already being applied to the base of Tr1 is also applied to the base of Tr2 then the balance of the circuit is restored and the voltage difference between the collectors is restored to zero.

We now obtain an expression for the gain of the differential amplifier.

First set up the basic equation (see Unit 31) by calculating the voltage drops along the path from the ground line to the base of Tr1, through the emitter-base junction of Tr1 and then through the R_E to the $-15\,\mathrm{V}$ supply. We then get the basic equation for our circuit:

$$0\,\mathrm{V} - (-15\,\mathrm{V}) = I_B \times 20\,\mathrm{k}\Omega + 0.7\,\mathrm{V} + 2 \times I_E \times 15\,\mathrm{k}\Omega$$

Note the factor of 2 for the current when calculating the voltage drop across R_E. The emitter current of two transistors flows through R_E. If we use $I_E = \beta I_B$ and take a value of $\beta = 300$ we then get:

$$14.3\,\mathrm{V} = (20 \times 10^3 + 2 \times 300 \times 15 \times 10^3) \times I_B = 9.02 \times 10^6 \times I_B$$

and $I_B = 1.58 \times 10^{-6} = 1.58\,\mu\mathrm{A}$ which then readily gives:

$$\begin{aligned} V_B &= -20\,\mathrm{k}\Omega \times 1.58\,\mu\mathrm{A} = -0.032\,\mathrm{V} \\ V_E &= -0.032\,\mathrm{V} - 0.7\,\mathrm{V} = -0.732\,\mathrm{V} \\ I_E &= \frac{15\,\mathrm{V} - 0.732\,\mathrm{V}}{2 \times 15\,\mathrm{k}\Omega} = \frac{0.95\,\mathrm{mA}}{2} = 0.475\,\mathrm{mA} \\ V_C &= 15\,\mathrm{V} - 0.475\,\mathrm{mA} \times 10\,\mathrm{k}\Omega = 15\,\mathrm{V} - 4.75\,\mathrm{V} = 10.25\,\mathrm{V} \end{aligned}$$

The small signal response is analyzed by noting that a small signal, v_{in}, applied to one input with no signal to the other input is equivalent to a small signal of $+\frac{v_{in}}{2}$ applied to one input and a signal of $-\frac{v_{in}}{2}$ applied to the other input because of the coupling action of the shared emitter resistor. The effect of this signal on one half of the circuit is the same as if that signal were applied to a common emitter amplifier for which the amplification is $-R_C \times \frac{I_E}{25\,\mathrm{mV}}$. Thus the change in the voltage at one collector is the effective input signal times the amplification:

$$\Delta V_C = -R_C \times \frac{I_E}{25\,\mathrm{mV}} \times \frac{v_{in}}{2}$$

and the change in the voltage difference between the two collectors is twice this so that the differential voltage amplification for the amplifier is:

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

which is the same as the equation for A_V for the common emitter amplifier.

Current mirror. The current in the base of a transistor is a very sensitive function of the emitter-base voltage and it is not normally possible to control the base current by controlling the base voltage. However, the circuit in Figure 34.5 shows one very important example of how this can be achieved.

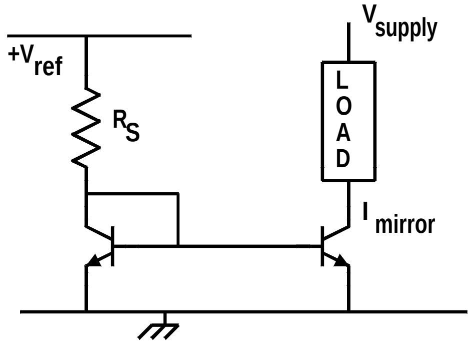

Figure 34.5: Current mirror circuit.

In the left hand transistor the base is connected to the collector to give what is called a diode connected transistor or a transistor which functions as a diode with the voltage drop across the emitter-base junction diode being that appropriate to a current of $\approx \frac{V_{ref}-0.7}{R_S}$. The two transistors are of the same type and in critical applications would be a specially selected matched pair. Since the bases are connected together, the emitter-base voltages are the same and therefore the collector current in the right hand transistor is controlled by the current in R_S in the left hand transistor.

The current in the unknown load driven by the V_{supply} (which may vary) will mirror the current in the left hand transistor. So we have a constant current in the right hand transistor and therefore also in the load. In some circuits the left hand transistor, which is a diode connected transistor, is replaced by a diode or shown on the circuit diagram as a diode but better thermal stability is obtained by using a diode connected transistor.

Tuned amplifier. The gain of a common emitter amplifier is given by $-R_C \times \frac{I_E}{25\,\mathrm{mV}}$ which is essentially independent of frequency. However, coupling capacitors limit the low frequency response and stray capacitances and carrier transit times in the base limit the high frequency response. Between these limits the response of the common emitter amplifier has an essentially flat frequency response curve. In other words, the amplification does not vary with frequency in this central region.

If the R_C is replaced by a resonant circuit, having a maximum impedance at one particular frequency, then the resulting amplifier also has a highly peaked gain versus frequency response curve.

The usual configuration is a parallel LC load such as is shown in Figure 34.6 (a). The Q factor of the LC circuit (see Units 13 and 17) determines the sharpness of the response which is shown in Figure 34.6 (b). The peak

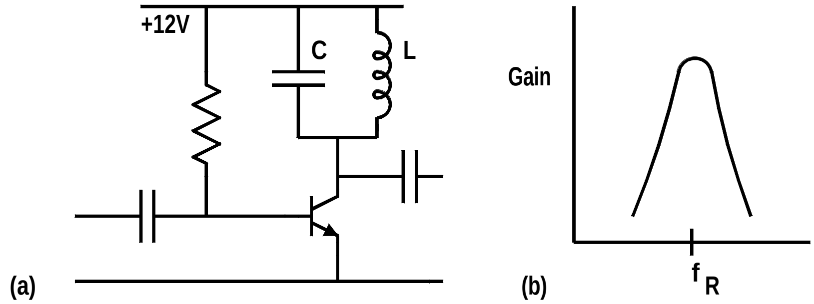

Figure 34.6: Tuned amplifier.

in the gain is at the resonant frequency of:

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

Calculation of the value of the gain at the maximum is not so straightforward as it depends on the resistance of the inductance and also on the input impedance of the next stage or the load. This type of resonant tuned amplifier allows one particular radio frequency signal, picked up from an antenna, to be selectively amplified and converted, either by amplitude or frequency demodulation, to an audio signal in a radio receiver. The selection of the received station is achieved by varying the resonant frequency of the resonant circuit by using a variable capacitor for tuning. Signals at other frequencies from other transmitters are not amplified and thus do not appear at the final output stage. A number of tuned amplifier stages must be used in a practical radio receiver, if good selectivity is to be obtained.

34.1 Problems

34.1 A signal of +19 mV is applied to input 1 and a signal of +34 mV is applied to input 2 of the amplifier in Figure 34.4. Calculate the resulting change in the voltage difference between the collectors.

34.2 The input signals used in Problem 34.1 are replaced by −6 mV and +4 mV. Calculate the new collector voltages.