Unit 35 Combining circuit blocks

- A current mirror block can be used as a collector resistor active load in a common emitter amplifier to give a large effective R_C and high gain.
- A current mirror block can be used as the shared emitter resistor in a differential amplifier to give a constant current.
- A common emitter amplifier with a feedback capacitor connected from the collector to the base acts as a low pass filter with a corner frequency proportional to $\frac{1}{C_F}$.

There are only a limited number of basic circuit building blocks which are used in analog electronics and we have analyzed the more important of these in the last three units.

The problem solving power of analog electronics results from combining a small number of well understood circuit blocks to make complex systems. In analyzing a complicated circuit diagram you should always try to split the circuit up into smaller blocks which have well known characteristics. In this unit we will show how the one and two transistor blocks which we have analyzed can be combined to synthesize an operational amplifier and how these blocks then facilitate the fabrication of operational amplifiers as integrated circuits containing about 40 transistors on a single integrated circuit.

We have already analyzed the operation of the common emitter amplifier and found the gain to be given by $-R_C \times \frac{I_E}{25\,\text{mV}}$. This gives a small signal gain of about -200 in a typical common emitter amplifier. If R_C is increased in value, while maintaining I_E constant, the gain is then increased in proportion but the supply voltage must also increase to keep $V_{sup} - I_C \times R_C > 0$. The ideal situation would be an R_C which is large for small signals but which is small for purposes of calculating the DC currents and voltages. This can be achieved by using what is called an active load.

Consider the transistor output characteristic shown in Figure 35.1. The characteristic curves are not horizontal but have a small upward slope.

The curve for $I_B = 10\,\mu A$ increases by $0.2\,\text{mA}$ for a change of $20\,\text{V}$ in V_{CE} to give a dynamic resistance of $100\,\text{k}\Omega$. Therefore a current mirror constructed from transistors having these characteristics is not perfect but

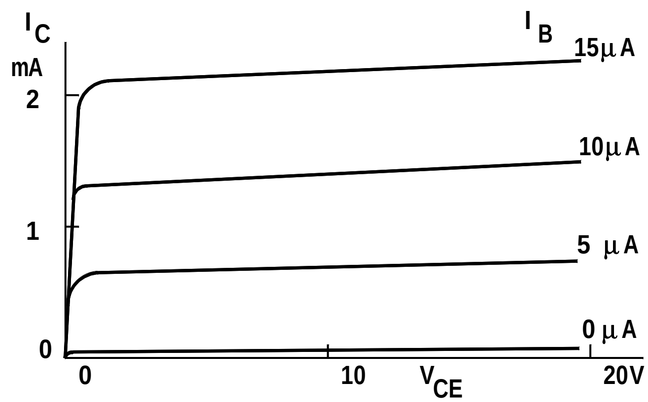

Figure 35.1: Slope of output characteristic gives a high resistance.

does show some small dependence on the V_{CE}. We take advantage of this large dynamic resistance of the current mirror and use it as a collector load resistor in a common emitter amplifier. Effectively we obtain a large R_C for small signal amplification without the need for a larger supply voltage to maintain the I_E in $-R_C \times \frac{I_E}{25\,\mathrm{mV}}$. This is achieved in practice by using a pnp transistor current mirror as a collector resistor in an npn common emitter amplifier so as to obtain a very high gain for small signals. The common emitter amplifier circuit is shown in Figure 35.2 (a).

The common emitter amplifier with the R_C replaced by the current mirror circuit is shown in Figure 35.2 (b).

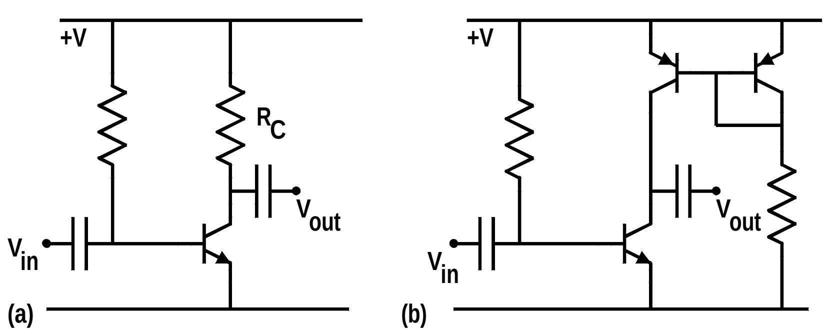

Figure 35.2: Use of a pnp current mirror in place of the collector resistor.

In the differential amplifier discussed in Unit 34, the voltage across the shared emitter resistor, R_E, is nearly constant. This ensures that an increase in current in one transistor of the differential amplifier is balanced by a reduction of the current in the other transistor. This is the circuit which is shown in Figure 35.3 (a). The balancing is improved if the R_E is replaced by a current mirror as shown in Figure 35.3 (b) which gives a more constant current which is to be divided between the two transistors. The total current

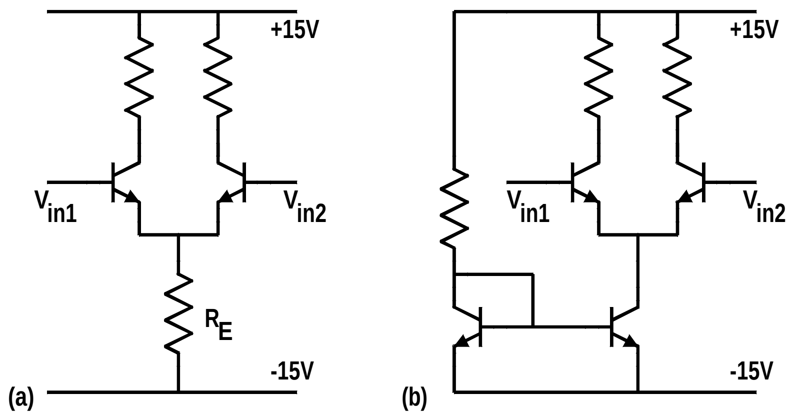

Figure 35.3: Current mirror used as emitter resistor in differential amplifier.

is now also much less dependent on any common mode signal applied to both bases of the transistors together. The circuit is also much less dependent on the value of the negative voltage supply.

If a capacitor is connected from the collector to the base in a common emitter amplifier, as shown in Figure 35.4, the amplified signal at the collector is fed back through the C_F to the base. This amplified and inverted signal

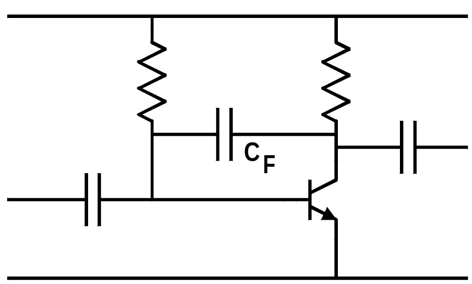

Figure 35.4: Use of collector-base capacitance to reduce high frequency gain.

is added to the input signal and gives a reduced net signal at the base and therefore a reduced output signal. Effectively the gain of the amplifier is reduced. The higher the signal frequency the lower will be the impedance of the capacitance through which the signal is fed back and the smaller will be the amplifier gain. Thus we expect the curve of gain as a function of frequency to show a decrease in gain as the frequency increases.

Even if there is no capacitor connected, there is always some stray capacitance between the collector and the base and so there will always be a decrease in the gain of a common emitter amplifier at high frequencies. Even though the stray capacitance is small its value has to be multiplied by a factor of $(1 + A)$ since it is the amplified signal which appears across the capacitance. This is called the Miller effect and it is a disadvantage if we are trying to make an amplifier which works up to high frequencies. On the other hand, if we want to limit the gain at high frequencies, we increase the effect by connecting a capacitor between the collector and the base to form an effective low pass filter with a corner frequency which depends on C_F and on the input resistance of the common emitter amplifier.

35.1 Problem

35.1 The circuit shown in Figure 35.5 is a schematic version of the circuit which is used in a 741 integrated circuit operational amplifier. Identify each of the circuit block types which are used in the circuit and draw boxes to show which components constitute each circuit block. You should be able to identify five current mirrors, one differential amplifier, one common emitter amplifier, one low pass filter, one emitter follower and one push-pull emitter follower.

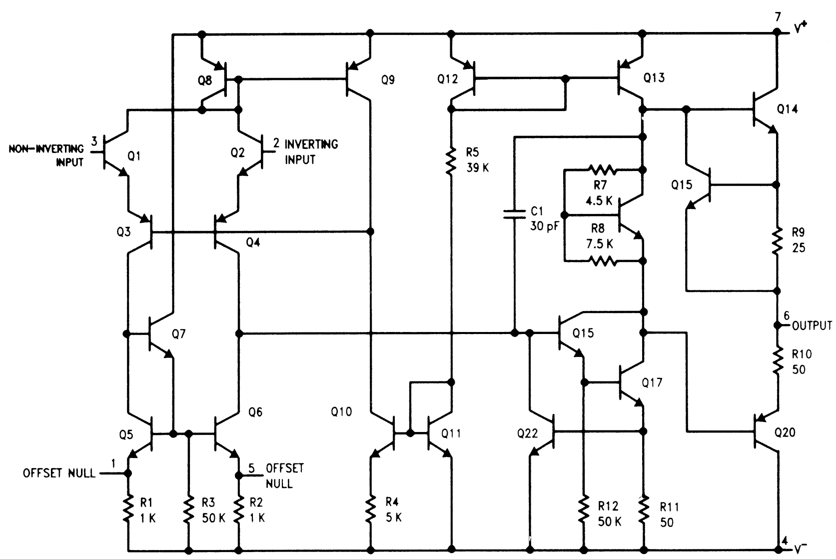

Figure 35.5: Schematic of the internal circuitry of a 741 operational amplifier. Courtesy of National Semiconductors.