Integrated circuit amplifiers for general purposes are almost without exception of the differential input, single-ended output, voltage operational type discussed in section 5.9. Grounding one or other input results in a single input, inverting or non-inverting amplifier. Some applications were considered in sections 5.7 and 5.8, the beginning of chapter 6 and in chapter 8. Although straightforward construction of the circuits described will usually produce a working device, providing the frequency compensation is adequate, some attention paid to practical details will yield a better design. In this chapter some important details will be introduced and it will be shown how they influence circuit design.

Ideal operational amplifier properties were discussed in section 5.7. When a differential input is provided, these properties are modified slightly as discussed in section 5.9. The virtual earth concept, useful for approximate analysis, can be applied except that the difference between the input voltages tends to zero rather than the absolute values. In Figure 5.13(b) a good approximation is that $V_x = V_y$.

9.1 Bias currents

Referring back to the bipolar transistor difference amplifiers described in chapter 4 it should be clear that the input voltages are applied directly to the bases of transistors. Since a bipolar transistor base must be supplied with current for collector current to flow, it follows that a symmetrical circuit will require equal small direct bias currents into each terminal. Such currents obviously constitute a common mode signal and vary from 10 μA to about 10 nA but can never be zero (see section 4.11).

Consider figure 5.13(b) which shows a differential amplifier with a resistive feedback circuit. If a load is connected from the output to common then only the bias currents will flow when $V_1 = V_2 = 0$. In this situation it is also required that $V_o = 0$ for most applications, that is, no input, no output. One bias current flows through $R_1$ and $R_f$ and the other through $R_2$ and $R_3$. Thus, when $V_o = V_1 = V_2 = 0$

$$V_x = I_B \left( \frac{R_1 R_f}{R_1 + R_f} \right)$$

$$V_y = I_B \left( \frac{R_2 R_3}{R_2 + R_3} \right)$$

but $V_x = V_y$

$$\therefore R_2//R_3 = R_1//R_f$$

A. G. Martin et al., *Linear Microelectronic Systems*

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More generally, for equal bias currents, the resistances to the common line from the input terminals of the amplifier must be equal or the bias currents will cause a difference signal. Furthermore, the sources must allow direct current to pass so capacitive coupling of a.c. signals can only be achieved if a current path is also added.

For an inverting amplifier, $R_2$ can be omitted and $R_3 = R_1/R_f$. If the source of $V_1$ is capacitively coupled, bias current cannot flow through $R_1$ so $R_3 = R_f$.

For a noninverting amplifier $V_1 = 0$, $R_3$ is redundant and $R_2 = R_1/R_f$. If the source of $V_2$ is capacitively coupled $R_3$ must be included ($R_3 = R_1/R_f$) or the circuit will not function. Often this restriction will result in too low an input impedance since $R_3$ shunts the source. Figure 9.1 shows how the technique of bootstrapping will raise the input impedance. $R_f$ provides one bias current path, $R_f$ and $R_3$ a.c. feedback while $V_X$ is capacitively coupled back to reduce the a.c. voltage across $R_2$ to zero. Note for balanced biasing $R_2 + R_3 = R_f$.

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Figure 9.1 Bootstrap bias circuit

When the source or sources pass d.c. bias current they will rarely do so without providing some resistance. In some cases this may have to be accounted for and, for instance, the value $R_1$ in the inverting amplifier configuration may well consist of the actual resistor plus the source d.c. resistance.

### 9.2 Offsets, drift and equivalent circuit

Usually an IC operational amplifier is not perfectly symmetrical because, as discussed in section 4.11, it is impossible to achieve complete matching of components. It has been seen that this slight asymmetry leads to a small voltage offset at the input when the output voltage is zero. In many cases balancing the resistance at each input will be sufficient though the output voltage will be displaced from zero by a small amount. Output offsets simply reduce the available output swing for a.c. amplifiers.

Referring to the inverting amplifier, made by removing $R_2$ from figure 5.13(b), a simple analysis of the offsets is possible. Defining the input offset voltage as $V_o$, then the output voltage is $V_o = A(V_d - V_e)$ where $V_d$ is the input voltage difference. The input bias currents will normally be different with, say, $I_1$ to the inverting and $I_2$ to the noninverting input. Input offset current can be conveniently defined as