A typical analog integrated circuit is composed of several pieces of circuitry, each of which performs a specific circuit function contributing to the overall operation of the circuit. These basic circuit building blocks are common to a large variety of analog circuits and it is convenient to consider them individually. Figure 2-1 shows a two-stage operational amplifier circuit (Op-Amp) and illustrates the individual building blocks that make up the circuit.

In this chapter, many of the circuit blocks commonly found in analog integrated circuits are discussed: current sources, dc level-shift stages, gain stages, and output stages.

![Figure 2-1 A two-stage operational amplifier circuit illustrating its component circuit blocks.](image)
2.1 Current Sources

Current sources provide currents that are relatively constant and independent of device parameters and voltage; they can also be made relatively independent of temperature and power-supply variations as well. In analog circuits, current sources are used for dc biasing and as load elements in amplifier stages. In a current-source circuit, a reference current in one branch is reproduced or mirrored in another branch; hence, these circuits are also called *current mirrors*.

**Basic Current Mirror**

Figure 2-2(a) shows the basic current mirror fashioned with bipolar transistors. In the circuit, both transistors have the same base-emitter voltage. Thus, if the transistors are identical and the output transistor $Q_2$ is operating in the forward-active region, then the collector currents of the two transistors will be equal (neglecting Early effect) and the output current $I_2$ will be approximately equal to the reference current $I_{ref}$. For each transistor, operating in forward active, we have from Eq. (1-36)

$$I_C = I_s e^{qV_{BE}/kT} (1 + V_{CE}/V_A)$$  \hspace{1cm} (2-1)

The transistor saturation current $I_s$ is proportional to emitter area [see Eq. (1-7)]. In an integrated-circuit process, the two transistors (and others) are fabricated simultaneously and, hence, will have identical values of $I_s$, except as scaled by their respective emitter areas (designer specified); they will also have other closely matched device parameters, such as current gain $\beta_T$ and Early voltage $V_A$. In the current mirror, we have for $Q_1$ and $Q_2$ at equal $V_{BE}$,

$$\frac{I_{C1}}{A_1(1 + V_{BE}/V_A)} = \frac{I_{C2}}{A_2(1 + V_{CE2}/V_A)}$$  \hspace{1cm} (2-2)