Complementary CC Amplifier

Figure 1 shows a complementary common-collector stage. This is commonly used as the final output stage in op amps and audio power amplifiers. Compared to a non-complementary CC amplifier, it can supply large positive and negative load currents with low power dissipation in the absence of a signal. The npn BJT supplies positive load current while the pnp BJT supplies negative load current.

Let us first examine the performance of the circuit with $V_B = 0$. For $v_I = 0$, both transistors are cut off. In order to obtain a positive output voltage, $v_I$ must be increased until $Q_1$ turns on. Denote the turn-on voltage for $Q_1$ by $V_\gamma$. Similarly, denote the turn-on voltage for $Q_2$ by $-V_\gamma$. When $-V_\gamma < v_I < V_\gamma$, both transistors are off and there is very little output voltage. For $v_I > V_\gamma$, $Q_1$ turns on and $v_O$ goes positive. For $v_I < -V_\gamma$, $Q_2$ turns on and $v_O$ goes negative. The plot of $v_O$ versus $v_I$ would resemble curve a in Fig. 2. A sine wave applied to the circuit would exhibit distortion in the crossover range for $-V_\gamma < v_I < V_\gamma$ as is illustrated by curve a in Fig. 3. The distortion in the waveform is called crossover distortion or center clipping.

For $V_B > 0$, a positive bias voltage is applied to the base of $Q_1$ and a negative bias voltage is applied to the base of $Q_2$. As $V_B$ is increased, both transistors turn on and emitter currents flow that are given by

$$I_{E1} = I_{E2} = \frac{2V_B - V_{BE1} - V_{BE2}}{R_{E1} + R_{E2}}$$

The bias voltage causes the portion of curve a in Fig. 2 for $v_I > 0$ to be shifted to the left and the portion for $v_I < 0$ to be shifted to the right. The effective sum curve changes into approximately a straight line as shown in curve b in Fig. 2. This eliminates the crossover distortion in the output waveform in shown by curve b in Fig. 3.

Once the transistors are turned on, the emitter currents are extremely sensitive to the value of $V_B$. To reduce this sensitivity, resistors are often used in series with the emitters as shown in Fig. 1. If an excessive emitter current flows, the voltage drops across $R_{E1}$ and $R_{E2}$ cause $V_{BE1}$ and $V_{BE2}$ to decrease, causing the current to decrease. For minimum power dissipation in these resistors, their value must be much smaller than that of $R_L$. In the design of op amps, the emitter resistors are usually omitted. In this case, the value...
Figure 2: Plots of $v_O$ versus $v_I$. Curve a - $V_B = 0$. Curve b - $V_B$ adjusted to eliminate the deadband region.

Figure 3: Sine wave (a) with and (b) without crossover distortion.
of $V_B$ is chosen to bias the transistors just below cutoff. Although a small amount of crossover remains, it is minimized by the negative feedback that is used in the application of the op amps.

The circuit that is commonly used to bias a common-collector stage is the $V_{BE}$ multiplier. Fig. 4 shows a simple $V_{BE}$ multiplier consisting of transistor $Q_3$ connected between the bases of $Q_1$ and $Q_2$. The voltage across the multiplier is given by

$$V_B = I_1 R_1 + V_{BE3}$$

If the base current in $Q_3$ is small compared to $I_1$, we can write $I_1 = V_{BE3}/R_2$. When this is substituted into the equation for $V_B$, we obtain

$$V_B = \frac{V_{BE3}}{R_2} R_1 + V_{BE3} = V_{BE3} \left(1 + \frac{R_1}{R_2}\right)$$

It follows that the voltage $V_B$ can be set by proper choice of the ratio $R_1/R_2$.

![Figure 4: Complementary common-collector amplifier with a $V_{BE}$ multiplier bias circuit.](image)

The exact equation for $V_B$ can be obtained by writing a node equation at the base node of $Q_3$. The equation is

$$\frac{V_B - V_{BE}}{R_1} = \frac{V_{BE}}{R_2} + \frac{1}{\beta} \left(I - \frac{V_B - V_{BE}}{R_1}\right)$$

This can be solved for $V_B$ to obtain

$$V_B = V_{BE} \left(\alpha + \frac{R_1}{R_2}\right) + \frac{IR_1}{1 + \beta}$$

where $\alpha = \beta/(1 + \beta)$ has been used. This agrees with the approximate solution above if $\beta$ is large and $IR_1 \ll 1 + \beta$. 

3