# Lecture 17: BJT Biasing. Current Mirror.

It is important for the biasing of a transistor amplifier that it remains largely invariant to fairly large changes in $\beta$ and temperature.

Proper biasing doesn't happen by chance. For example, the *npn* and *pnp* inverter circuits in Laboratory #3 are highly sensitive to variations in $\beta$. That is usually a poor design (but was done on purpose for the lab, of course).

In this lecture, we will study four BJT biasing methods:

1. Single power supply
2. Dual power supply
3. Alternate method for common emitter amplifiers
4. Current source.

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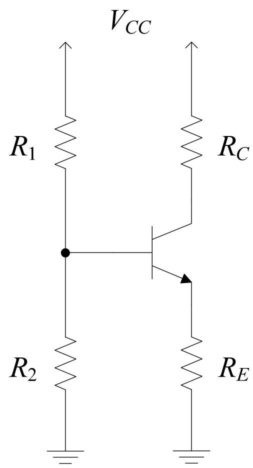
## Single Power Supply Biasing Method

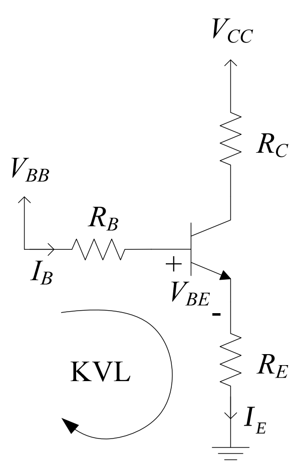
Perhaps the most common method for biasing BJT amplifier circuits with a single power supply is shown in Fig. 5.44:




(Fig. 5.44a)

$R_E$ is part of this biasing method as well. When used as an amplifier, the input signal would be capacitively coupled to the base of the BJT while the output would be taken (through capacitive coupling) at the collector or emitter of the transistor, depending on the specific requirements for the amplifier.

We analyzed a specific example of this type of circuit in Lecture 12 employing Thévenin's theorem to simplify the analysis:




(Fig. 5.44b)

where $V_{BB}$ and $R_B$ are given in (5.68) and (5.69) in the text.

Using KVL in the loop shown above

$$V_{BB} = I_B R_B + V_{BE} + I_E R_E \tag{1}$$

With $I_B = I_E / (\beta + 1)$ then (1) becomes

$$V_{BB} = V_{BE} + \frac{R_B}{\beta+1} I_E + R_E I_E = V_{BE} + \left( \frac{R_B}{\beta+1} + R_E \right) I_E \tag{2}$$

Consequently,

$$I_E = \frac{V_{BB} - V_{BE}}{R_E + \dfrac{R_B}{\beta+1}} \qquad (5.70),(3)$$

We can use (3) to design the biasing circuit so that it is <u>largely insensitive to variations in $\beta$</u>. The question is then how do we make $I_E$ (and hence $I_C$) largely insensitive to $\beta$ variations? Examining (3), we deduce that the answer is to choose

$$R_E \gg \frac{R_B}{\beta+1} \qquad (5.72),(4)$$

Furthermore, we can design this biasing circuit so that it is largely <u>insensitive to variations in temperature</u>. The effects of temperature enter this circuit because $V_{BE}$ is a relatively strong function of temperature having a temperature coefficient of -2 mV/°C. (We saw this same behavior with diodes.)

From (3) we can see that if we choose

$$V_{BB} \gg V_{BE} \qquad (5.71),(5)$$

then we'll have a biasing circuit design that is largely insensitive to variations in temperature.

So physically how do these conditions (4) and (5) make a good biasing circuit?

- Eqn. (4) makes the base voltage largely independent of $\beta$ and determined almost solely by $R_1$ and $R_2$. How? Because the current in the divider is much greater than the base current. The rule of thumb for "much greater" is that the divider current should be on the order of $I_E$ to $I_E/10$.
- Eqn. (5) ensures that small variations in $V_{BE}$ (from its nominal 0.7 V) due to temperature changes are much smaller than $V_{BB}$.

Additionally, there is an upper limit to $V_{BB}$ because a higher $V_{BB}$ lowers $V_{CB}$ and affects the small values of the positive signal swing. The rule of thumb here is that $V_{BB} \approx V_{CC}/3$ and $V_{CB}$ (or $V_{CE}$) $\approx V_{CC}/3$, and $I_C R_C \approx V_{CC}/3$.

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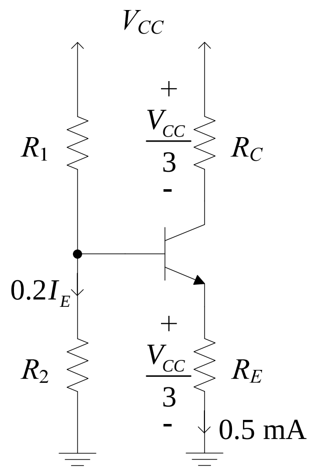
**Example N17.1**. Design the bias circuit below for $V_{CC} = 9$ V to provide $V_{CC}/3$ V across $R_E$ and $R_C$, $I_E = 0.5$ mA, and the voltage divider current of $0.2I_E$, as shown. Design the circuit for a large $\beta$, then find the actual value obtained for $I_E$ with a BJT having $\beta = 100$.




For the resistors $R_E$ and $R_C$, $I_E R_E = V_{CC}/3 = 3$ V. For $I_E$ = 0.5 mA, then $R_E$ = 6 kΩ. For large $\beta$, then $I_C \approx I_E$. For $I_C R_C = V_{CC}/3 = 3$ V, then $R_C$ = 6 kΩ.

For the voltage divider, if this BJT is in the active mode then $V_{BE} \approx 0.7$ V. Hence,

$$V_B = V_{BE} + V_E = 0.7 + 3 = 3.7 \text{ V}$$

such that

$$R_2 = \frac{V_B}{0.2I_E} = \frac{3.7}{0.2 \cdot 0.5 \text{ mA}} = 37 \text{ k}\Omega$$

A large $\beta$ for a BJT in the active mode implies $I_B \approx 0$. By Ohm's law

$$\frac{V_{CC}}{R_1 + R_2} = 0.2I_E \quad \text{or} \quad R_1 + R_2 = 90 \text{ k}\Omega$$

Hence,

$$R_1 = 90 \text{ k}\Omega - R_2 = 53 \text{ k}\Omega$$

For the design with $\beta = 100$ it can be shown that $I_E = 0.48$ mA. (This is only a -4% change from 0.5 mA with $\beta = \infty$.)

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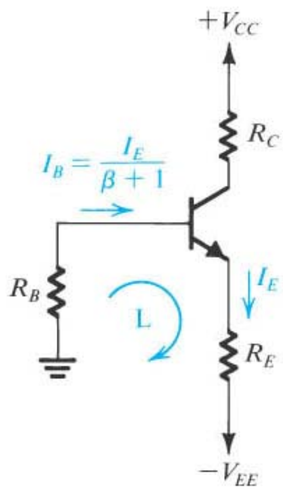
## Dual Power Supply Biasing Method

When two power supplies are available, a possible biasing method is




(Fig. 5.45)

Using KVL around the loop L gives

$$\frac{I_E}{\beta+1} R_B + V_{BE} + I_E R_E = +V_{EE} \tag{6}$$

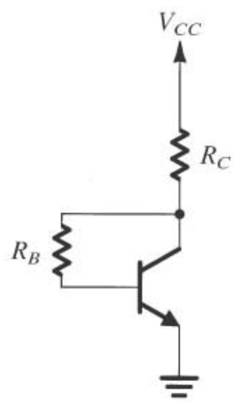
or

$$I_E = \frac{V_{EE} - V_{BE}}{R_E + \dfrac{R_B}{\beta+1}} \tag{5.73),(7}$$

This is the same result as (3), but with $V_{BB}$ replaced by $V_{EE}$. Consequently, the $\beta$- and temperature-invariant design equations for this circuit are the same as those given earlier in (4) and (5) with $V_{BB}$ replaced by $V_{EE}$.

## Alternative Biasing for Common Emitter Amplifiers

This biasing method has a resistor tied from the collector to the base as




(Fig. 5.46a)

As shown in the text, for $I_E$ to be insensitive to $\beta$ variations, choose

$$R_C \gg \frac{R_B}{\beta+1} \qquad (8)$$

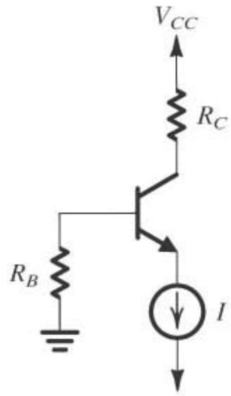
and for $V_{BE}$ to be insensitive to temperature variations, choose

$$V_{CC} \gg V_{BE} \qquad (9)$$

This latter requirement is most often very easy to meet!

## Biasing with a Current Source

The last BJT amplifier biasing method we'll consider is one using a current source.



(Fig. 5.47a)

In this circuit, $I_E = I$. If we are using a "good" current source, then $I_E$ will not depend on $\beta$. Very nice.

However, what we've done in this approach is to push the technical problem to the design of a good current source.

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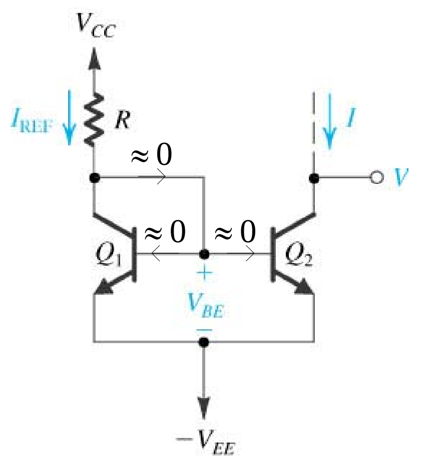
## Current Mirror

Simple biasing methods often fail to provide constant collector currents if the supply voltage or ambient temperature change. This is a problem with mobile telephones, for example, where the battery voltage changes with use and the device operates in a range of temperatures.

There are sophisticated circuits consisting of tens of devices that can produce "golden currents" that are supply voltage and temperature independent. These golden currents are replicated throughout a device using a current mirror:




(Fig. 5.47b)

There are better and more sophisticated approaches than this, of course. This is just a simple example.

In this current mirror, $Q_1$ is called a diode-connected BJT because the collector and base terminals are connected together. For proper operation of this circuit, it is very important that the BJTs be "matched," meaning they having the same $\beta$, characteristic curves, etc. Usually this means that the BJTs must be fabricated at the same time on the same substrate.

For the analysis of this circuit, we assume that $\beta$ is very large and that $Q_1$ and $Q_2$ operate in the active mode. Because of this, we ignore the base currents in $Q_1$ and $Q_2$.

Therefore, the collector (and emitter) current through $Q_1$ is approximately equal to $I_{\text{REF}}$. By KVL,

$$V_{CC} = I_{\text{REF}} R + V_{BE} - V_{EE}$$

or

$$I_{\text{REF}} = \frac{1}{R}\left(V_{CC} - V_{BE} + V_{EE}\right) \qquad (5.76),(10)$$

Now, since $Q_1$ and $Q_2$ are matched and they have the same $V_{BE}$, then the collector currents must be the same. This implies that

$$I = I_{\text{REF}} = \frac{V_{CC} + V_{EE} - V_{BE}}{R} \qquad (5.77),(11)$$

This current mirror circuit will supply this current $I$ as long as $Q_2$ operates in the active region:

$$V > V_{BE} - V_{EE}$$

Notice that the diode-connected $Q_1$ cannot saturate since the base and collector terminals are shorted together. Hence, $Q_1$ operates in the active mode or is simply cutoff.