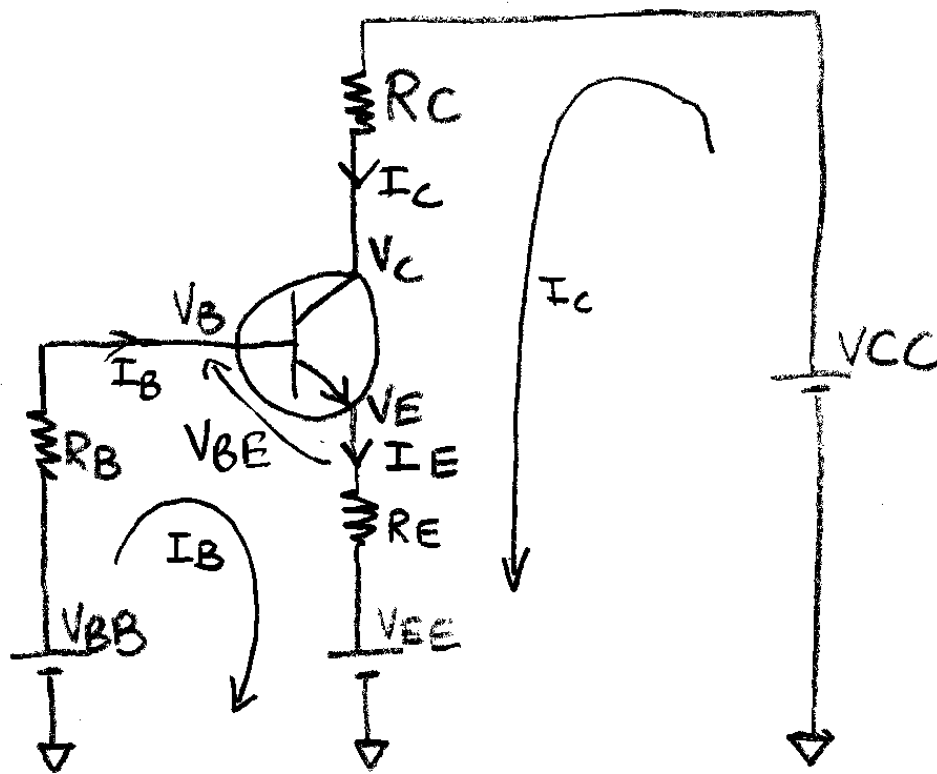


# BJT Bias Analysis

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## Introduction

The purpose of this paper is to illustrate a general method for performing bias analysis on an existing bipolar junction transistor (BJT) circuit where the bias conditions are established without feedback. The use of negative feedback to stabilize bias conditions provides a number of performance improvements, but is beyond the scope of a first course in electronics. The discussion will be about NPN transistors. The last section of this paper discusses the simple changes to make to analyze PNP transistor amplifiers.



## GENERAL BJT BIAS ANALYSIS

$V_B$ ,  $V_C$ , AND  $V_E$  ARE MEASURED WITH RESPECT  
TO GROUND

Figure 1: Circuit for general BJT bias analysis

# BJT Bias Analysis

## The General Circuit

The most general transistor bias network possible is shown in Figure 1. Actual bias networks rarely have three separate voltage sources. A typical bias network has only a single actual voltage source but often has a second source derived by a voltage divider. Instead of performing a special case analysis of the bias network on all of the possible circuits that can exist, the solution to the general circuit will be derived. By simple circuit transformations, any of the other possible circuits can be transformed to the general circuit. Thus, we only need one solution. With this one solution, a standard procedure for bias analysis can be established. Figure 2 at the end of this article shows some typical circuits and the transformations to the general form.

## The General Analysis

The first goal of bias analysis is to determine the emitter current of the transistor. All other bias conditions are easily calculated once the emitter current is known. Since the base-emitter junction is forward biased, then there is a current loop formed by  $V_{BB}$ ,  $R_B$ ,  $V_{BE}$ ,  $R_E$ , and  $V_{EE}$ . The voltage drops around this loop must sum to zero. The emitter current is simply the voltage across  $R_E$  divided by  $R_E$ . The voltage on the emitter side of  $R_E$  is:

$$V_E = V_{BB} - (I_B * R_B) - V_{BE} \quad \text{Eq. 1}$$

Thus, the voltage across  $R_E$  is:

$$V_E - V_{EE} = V_{BB} - I_B * R_B - V_{BE} - V_{EE} \quad \text{Eq. 2}$$

Then, the emitter current is:

$$I_E = \frac{V_{BB} - I_B * R_B - V_{BE} - V_{EE}}{R_E} \quad \text{Eq. 3}$$

Since the base current,  $I_B$ , can be expressed as  $I_E/(B + 1)$ , then we can write:

$$I_E = \frac{V_{BB} - [I_E/(B + 1)] * R_B - V_{BE} - V_{EE}}{R_E} \quad \text{Eq. 4}$$

Completing the solution of Equation 4 gives:

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$$I_E = \frac{V_{BB} - V_{EE} - V_{BE}}{R_E + R_B/(B + 1)} \quad \text{Eq. 5}$$

Note that  $V_{CC}$  and  $R_C$  do not appear in Equation 5. It is assumed right now that the numerical values for these components are such that the emitter current we calculate is correct. But, if we are analyzing a circuit that does not work then that will not be the case and the emitter current calculated will be wrong. So, how do we know whether the calculated emitter current is correct? A simple reality test performed after all bias calculations are completed will reveal whether the calculations are true.

It must be noted that the mathematics developed here was based on a working circuit, not a non-working circuit. It is possible to develop mathematics to analyze the bias conditions of a non-working circuit but one has to ask why. As an example, the physics of the operation of a pneumatic tire are well established. But these physics do not address the situation when the tire has a hole in it. Physics can be developed for this but why? A pneumatic tire is by definition a tire that does not have a hole in it. What good is a pneumatic tire with a hole in it? What good is an electronic circuit that does not work?

Looking ahead to the time when we will consider design, an alternate way to write Equation 5 that illustrates a significant relationship between  $R_B$  and  $R_E$  is:

$$I_E = \frac{V_{BB} - V_{EE} - V_{BE}}{R_E * [1 + (R_B/R_E)/(B + 1)]} \quad \text{Eq. 6}$$

Equation 6 suggests that it would be desirable for the ratio  $(R_B/R_E)$  to be small compared to beta so that wide beta variations from transistor to transistor would have little effect on the emitter current. The discussion on design will determine a specifically good value for this ratio. Since  $V_{BE}$  is a function of temperature, then it seems obvious that by making the difference between  $V_{BB}$  and  $V_{EE}$  sufficiently large compared to  $V_{BE}$ , then temperature will have little effect on bias conditions. The discussion on design will determine specifically just what is sufficiently large.

### Procedure for bias analysis

Step 1: Transform circuit to be analyzed to the general circuit in Figure 1. The result of this will be that the equivalent value for  $R_C$ ,  $R_B$ ,  $R_E$ ,  $V_{CC}$ ,  $V_{BB}$ , and  $V_{EE}$  in the general circuit are known. Many of the transformations are trivial. A few require computing an equivalent Thevenin voltage and resistance.

Step 2: Decide what values will be used for beta and  $V_{BE}$ . For general calculations, beta is often chosen as 100 and  $V_{BE}$  as 0.65 Volts as these are representative of typical. But when it is important to know the bias conditions over a range of beta and  $V_{BE}$

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then specific values are used. For example, the bias conditions might be calculated for a low beta of 50 and a high beta of 250 to see the effect of this wide beta variation. If the circuit must work over a wide temperature range then several calculations with different values of  $V_{BE}$  might be performed to see the temperature effect. At low temperatures,  $V_{BE}$  might be over 0.7 volts and at high temperatures,  $V_{BE}$  might be less than 0.55 Volts.

Step 3: Calculate the following. Note that after  $I_E$  is calculated, the remaining terminal currents are calculated using basic transistor relationships and then the terminal voltages are calculated using Kirchoff's voltage law. The emitter current must always be calculated first. Different sequences for the other terms can be used. The following is just one example.

$$I_E = \frac{V_{BB} - V_{EE} - V_{BE}}{R_E + R_B/(B + 1)} \quad \text{Eq. 5}$$

$$I_C = I_E * [B/(B + 1)] \quad \text{Eq. 7}$$

$$I_B = I_E / (B + 1) \quad \text{Eq. 8}$$

$$V_B = V_{BB} - I_B * R_B \quad \text{Eq. 9}$$

$$V_E = V_{EE} + I_E * R_E \quad \text{Eq. 10}$$

$$V_C = V_{CC} - I_C * R_C \quad \text{Eq. 11}$$

For some problems it is convenient to calculate the collector current in one step. All that is required is a simple combination of Equations 5 and 7.

$$I_C = \frac{(V_{BB} - V_{EE} - V_{BE}) * [B/(B + 1)]}{R_E + R_B/(B + 1)} \quad \text{Eq. 12}$$

Step 4: Apply a reality test to see if analysis is valid. The key reality is that for the transistor to be operating as an amplifier, the base-collector junction must be reversed biased and the base-emitter junction must be forward biased. This can be expressed mathematically as:

Analysis valid if (1)  $V_C > V_B$ , and (2)  $V_B > V_E$ .

It is generally desirable for  $V_C$  to be greater than  $V_B$  by at least 2 volts although the amplifier can work with less than this. But, some more advanced thought may be required to determine if the amplifier is working well enough. Also, if the

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amplifier is working, then  $V_{BE}$  should compute to be exactly the chosen  $V_{BE}$  above  $V_E$ . Be very suspicious of any calculation that does not have this result.

Step 5: The DC analysis is now complete. If the amplifier was determined to be working then AC analysis can be performed. Otherwise there is no point in continuing.

### Bias analysis with PNP transistors

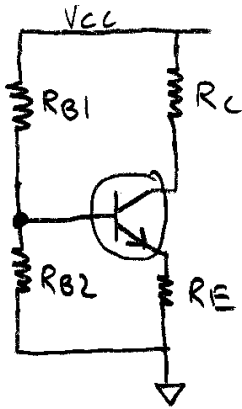
The only difference between analysis for NPN and PNP transistors is that all currents are in the opposite direction and  $V_{BE}$  for PNP transistors is nominally -0.65 Volts. Beta is always a positive number and is not a function of whether the transistor is NPN or PNP. All equations in this note are used normally but the numerator term will always be a negative quantity if the circuit is working. The analysis is valid if:

- (1)  $V_C < V_B$ , and
- (2)  $V_B < V_E$ .

### Typical transistor circuits

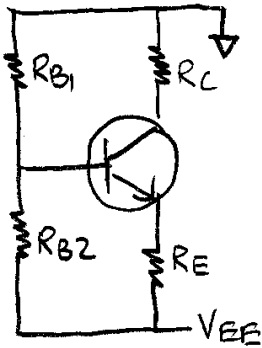
It is rare for an actual transistor amplifier circuit to exactly be the circuit as analyzed in this note. That is not a problem. The circuit analyzed here is very general and any common circuit that does not include negative feedback for bias stability can be analyzed by applying simple transformations to convert it to general form. Figure 2 shows some common transistor amplifier circuits with the transformations to convert each circuit to the general form discussed in this note. Note that in most of the components directly map into general form. The student should practice transforming these circuits to general form as proficiency is required in order to analyze circuits that will be on the tests. The first circuit is one of the most common ones seen. Note the result of the second circuit – students often make a mistake on this one – be sure to understand it. The third circuit requires superposition. The fourth circuit is contrived to be about as hard as possible but the steps are really simple.

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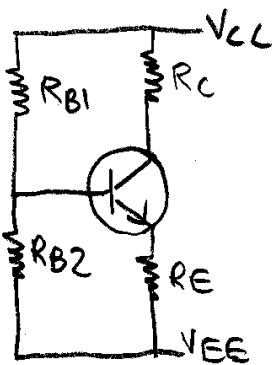
$$R_B = R_{B1} \parallel R_{B2}$$

$$V_{BB} = \frac{V_{CC} * R_{B2}}{R_{B1} + R_{B2}}$$



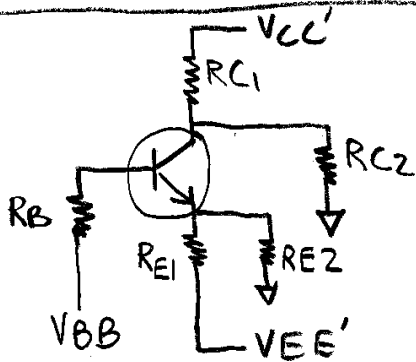
$$R_B = R_{B1} \parallel R_{B2}$$

$$V_{BB} = \frac{V_{EE} * R_{B1}}{R_{B1} + R_{B2}}$$



$$R_B = R_{B1} \parallel R_{B2}$$

$$V_{BB} = \frac{V_{CC} * R_{B2} + V_{EE} * R_{B1}}{R_{B1} + R_{B2}}$$



$$R_C = R_{C1} \parallel R_{C2}$$

$$V_{CC} = \frac{V_{CC'} * R_{C2}}{R_{C1} + R_{C2}}$$

$$R_E = R_{E1} \parallel R_{E2}$$

$$V_{EE} = \frac{V_{EE'} * R_{E2}}{R_{E1} + R_{E2}}$$

Figure 2: Various transistor circuits with conversions to general form