Example 8-4

For the circuit shown in Fig. 8-7, design the resistor values to meet these specifications:

$V_{CC} = 10$ V V_{CE} @ midpoint

$I_C = 10$ mA 2N3904's $\beta_{dc} = 100–300$

SOLUTION First, establish the emitter voltage by:

$$V_E = 0.1\ V_{CC}$$

$$V_E = (0.1)\ (10\ V) = 1\ V$$

The emitter resistor is found by:

$$R_E = \frac{V_E}{I_E}$$

$$R_E = \frac{1\ V}{10\ mA} = 100\ \Omega$$

The collector resistor is:

$$R_C = 4\ R_E$$

$$R_C = (4)\ (100\ \Omega) = 400\ \Omega\ (\text{use } 390\ \Omega)$$

Next, choose either a stiff or firm voltage divider. A stiff value of R_2 is found by:

$$R_2 \leq 0.01\ \beta_{dc}\ R_E$$

$$R_2 \leq (0.01)\ (100)\ (100\ \Omega) = 100\ \Omega$$

Now, the value of R_1 is:

$$R_1 = \frac{V_1}{V_2} R_2$$

$$V_2 = V_E + 0.7\ V = 1\ V + 0.7\ V = 1.7\ V$$

$$V_1 = V_{CC} - V_2 = 10\ V - 1.7\ V = 8.3\ V$$

$$R_1 = \left(\frac{8.3\ V}{1.7\ V}\right)(100\ \Omega) = 488\ \Omega\ (\text{use } 490\ \Omega)$$

PRACTICE PROBLEM 8-4 Using the given VDB design guidelines, design the VDB circuit of Fig. 8-7 to meet these specifications:

$V_{CC} = 10$ V V_{CE} @ midpoint stiff voltage divider

$I_C = 1$ mA $\beta_{dc} = 70\text{-}200$

8-4 Two-Supply Emitter Bias

Some electronic equipment has a power supply that produces both positive and negative supply voltages. For instance, Fig. 8-8 shows a transistor circuit with two power supplies: +10 and −2 V. The negative supply forward biases the emitter

Figure 8-8 Two-supply emitter bias.

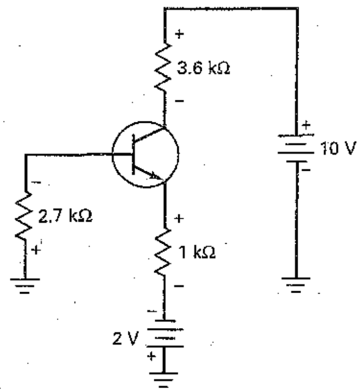
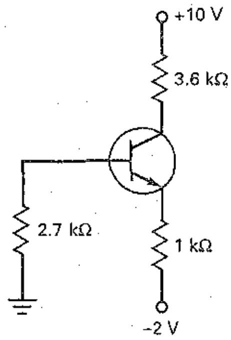


Figure 8-9 Redrawn TSEB circuit.



diode. The positive supply reverse biases the collector diode. This circuit is derived from emitter bias. For this reason, we refer to it as **two-supply emitter bias (TSEB).**

Analysis

The first thing to do is to redraw the circuit as it usually appears on schematic diagrams. This means deleting the battery symbols, as shown in Fig. 8-9. This is necessary on schematic diagrams because there usually is no room for battery symbols on complicated diagrams. All the information is still on the diagram, except that it is in condensed form. That is, a negative supply voltage of −2 V is applied to the bottom of the 1 kΩ, and a positive supply voltage of +10 V is applied to the top of the 3.6-kΩ resistor.

When this type of circuit is correctly designed, the base current will be small enough to ignore. This is equivalent to saying that the base voltage is approximately 0 V, as shown in Fig. 8-10.

GOOD TO KNOW

When transistors are biased using well-designed voltage-divider or emitter-bias configurations, they are classified as beta-independent circuits because the values of I_C and V_{CE} are unaffected by changes in the transistor's beta.

The voltage across the emitter diode is 0.7 V, which is why −0.7 V is shown on the emitter node. If this is not clear, stop and think about it. There is a plus-to-minus drop of 0.7 V in going from the base to the emitter. If the base voltage is 0 V, the emitter voltage must be −0.7 V.

In Fig. 8-10, the emitter resistor again plays the key role in setting up the emitter current. To find this current, apply Ohm's law to the emitter resistor as follows: The top of the emitter resistor has a voltage of −0.7 V, and the bottom has a voltage of −2 V. Therefore, the voltage across the emitter resistor equals the difference between the two voltages. To get the right answer, subtract the more negative value from the more positive value. In this case, the more negative value is −2 V, so:

$$V_{RE} = -0.7\text{ V} - (-2\text{ V}) = 1.3\text{ V}$$

Once you have found the voltage across the emitter resistor, calculate the emitter current with Ohm's law:

$$I_E = \frac{1.3\text{ V}}{1\text{ k}\Omega} = 1.3\text{ mA}$$

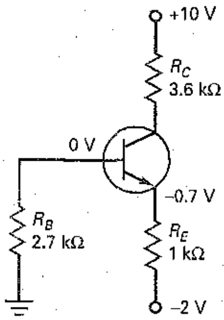
This current flows through the 3.6 kΩ and produces a voltage drop that we subtract from +10 V as follows:

$$V_C = 10\text{ V} - (1.3\text{ mA})(3.6\text{ k}\Omega) = 5.32\text{ V}$$

The collector-emitter voltage is the difference between the collector voltage and the emitter voltage:

$$V_{CE} = 5.32\text{ V} - (-0.7\text{ V}) = 6.02\text{ V}$$

Figure 8-10 Base voltage is ideally zero.



When two-supply emitter bias is well designed, it is similar to voltage-divider bias and satisfies this 100 : 1 rule:

$$R_B < 0.01\beta_{dc}R_E \tag{8-12}$$

In this case, the simplified equations for analysis are:

$$V_B \approx 0 \tag{8-13}$$

$$I_E = \frac{V_{EE} - 0.7\text{ V}}{R_E} \tag{8-14}$$

$$V_C = V_{CC} - I_C R_C \tag{8-15}$$

$$V_{CE} = V_C + 0.7\text{ V} \tag{8-16}$$

Base Voltage

One source of error in the simplified method is the small voltage across the base resistor of Fig. 8-10. Since a small base current flows through this resistance, a negative voltage exists between the base and ground. In a well-designed circuit, this base voltage is less than −0.1 V. If a designer has to compromise by using a larger base resistance, the voltage may be more negative than −0.1 V. If you are troubleshooting a circuit like this, the voltage between the base and ground should produce a low reading; otherwise, something is wrong with the circuit.

Example 8-5

MultiSim

What is the collector voltage in Fig. 8-10 if the emitter resistor is increased to 1.8 kΩ?

SOLUTION The voltage across the emitter resistor is still 1.3 V. The emitter current is:

$$I_E = \frac{1.3\text{ V}}{1.8\text{ k}\Omega} = 0.722\text{ mA}$$

The collector voltage is:

$$V_C = 10\text{ V} - (0.722\text{ mA})(3.6\text{ k}\Omega) = 7.4\text{ V}$$

PRACTICE PROBLEM 8-5 Change the emitter resistor of Fig. 8-10 to 2 kΩ and solve for V_{CE}.

Example 8-6

A **stage** is a transistor and the passive components connected to it. Figure 8-11 shows a three-stage circuit using two-supply emitter bias. What are the collector-to-ground voltages for each stage in Fig. 8-11?

SOLUTION To begin with, ignore the capacitors because they appear as open circuits to dc voltage and currents. Then, we are left with three isolated transistors, each using two-supply emitter bias.

The first stage has an emitter current of:

$$I_E = \frac{15\text{ V} - 0.7\text{ V}}{20\text{ k}\Omega} = \frac{14.3\text{ V}}{20\text{ k}\Omega} = 0.715\text{ mA}$$

and a collector voltage of:

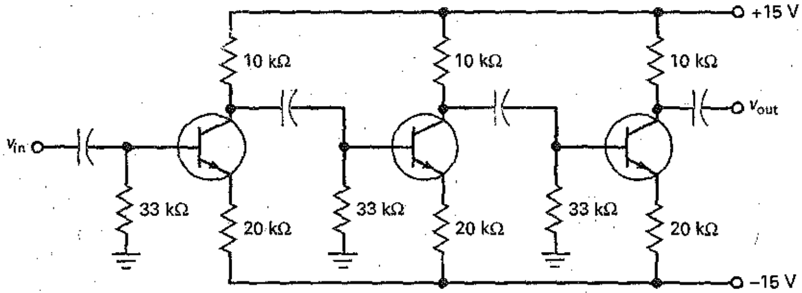
$$V_C = 15\text{ V} - (0.715\text{ mA})(10\text{ k}\Omega) = 7.85\text{ V}$$

Since the other stages have the same circuit values, each has a collector-to-ground voltage of approximately 7.85 V.

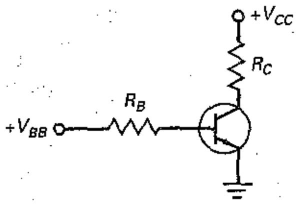
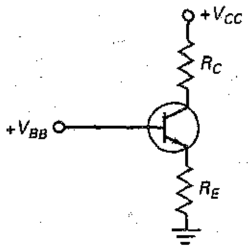
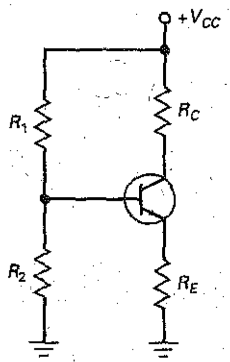
Summary Table 8-1 illustrates the four main types of bias circuits.

PRACTICE PROBLEM 8-6 Change the supply voltages of Fig. 8-11 to +12 V and −12 V. Then, calculate V_{CE} for each transistor.

Figure 8-11 Three-stage circuit.



Summary Table 8-1 | Main Bias Circuits

Type	Circuit	Calculations	Characteristics	Where used
Base bias		$I_B = \frac{V_{BB} - 0.7\text{ V}}{R_B}$ $I_C = \beta I_B$ $V_{CE} = V_{CC} - I_C R_C$	Few parts; β dependent; fixed base current	Switch; digital
Emitter bias		$V_E = V_{BB} - 0.7\text{ V}$ $I_E = \frac{V_E}{R_E}$ $V_C = V_C - I_C R_C$ $V_{CE} = V_C - V_E$	Fixed emitter current; β independent	I_C driver; amplifier
Voltage divider bias		$V_B = \frac{R_2}{R_1 + R_2} V_{CC}$ $V_E = V_B - 0.7\text{ V}$ $I_E = \frac{V_E}{R_E}$ $V_C = V_{CC} - I_C R_C$ $V_{CE} = V_C - V_E$	Needs more resistors; β independent; needs only one power supply	Amplifier