- *Class C* is an amplifier biased to amplify only a small portion of the waveform. Most of the transistor's time is spent in cutoff mode. In order for there to be a complete waveform at the output, a resonant tank circuit is often used as a "flywheel" to maintain oscillations for a few cycles after each "kick" from the amplifier. Because the transistor is not conducting most of the time, power efficiencies are high for a class C amplifier.

- *Class D* operation requires an advanced circuit design, and functions on the principle of representing instantaneous input signal amplitude by the duty cycle of a high-frequency squarewave. The output transistor(s) never operate in active mode, only cutoff and saturation. Little heat energy dissipated makes energy efficiency high.

- DC bias voltage on the input signal, necessary for certain classes of operation (especially class A and class C), may be obtained through the use of a voltage divider and *coupling capacitor* rather than a battery connected in series with the AC signal source.

4.10 Biasing calculations

Although transistor switching circuits operate without bias, it is unusual for analog circuits to operate without bias. One of the few examples is "TR One, one transistor radio" (page 427) with an amplified AM (amplitude modulation) detector. Note the lack of a bias resistor at the base in that circuit. In this section we look at a few basic bias circuits which can set a selected emitter current I_E. Given a desired emitter current I_E, what values of bias resistors are required, R_B, R_E, etc?

4.10.1 Base Bias

The simplest biasing applies a *base-bias* resistor between the base and a base battery V_{BB}. It is convenient to use the existing V_{CC} supply instead of a new bias supply. An example of an audio amplifier stage using base-biasing is "Crystal radio with one transistor . . . " (page 427). Note the resistor from the base to the battery terminal. A similar circuit is shown in Figure 4.85.

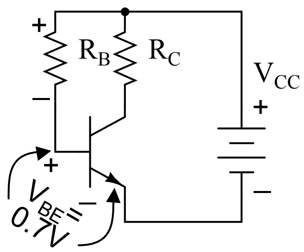
Write a KVL (Krichhoff's voltage law) equation about the loop containing the battery, R_B, and the V_{BE} diode drop on the transistor in Figure 4.85. Note that we use V_{BB} for the base supply, even though it is actually V_{CC}. If β is large we can make the approximation that $I_C = I_E$. For silicon transistors $V_{BE} \cong 0.7$V.

Silicon small signal transistors typically have a β in the range of 100-300. Assuming that we have a β=100 transistor, what value of base-bias resistor is required to yield an emitter current of 1mA?

Solving the IE base-bias equation for R_B and substituting β, V_{BB}, V_{BE}, and I_E yields 930kΩ. The closest standard value is 910kΩ.

$$\beta = 100 \qquad V_{BB} = 10\text{V} \qquad I_C \approx I_E = 1\text{ma}$$

$$R_B = \frac{V_{BB} - V_{BE}}{I_E / \beta} = \frac{10 - 0.7}{1\text{mA} / 100} = 930\text{k}$$



$$V_{BB} - I_B R_B - V_{BE} = 0$$

$$V_{BB} - V_{BE} = I_B R_B \qquad \text{(KVL)}$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

$$I_E = (\beta+1) I_B \approx \beta I_B$$

$$\mathbf{I_E} = \frac{\mathbf{V_{BB} - V_{BE}}}{\mathbf{R_B}/\beta} \qquad \text{(IE base-bias)}$$

Figure 4.85: *Base-bias*

What is the emitter current with a 910kΩ resistor? What is the emitter current if we randomly get a β=300 transistor?

$$\beta = 100 \qquad V_{BB} = 10V \qquad R_B = 910k \qquad V_{BE} = 0.7V$$

$$I_E = \frac{V_{BB} - V_{BE}}{R_B/\beta} = \frac{10 - 0.7}{910k/100} = 1.02mA$$

$$\beta = 300$$

$$I_E = \frac{10 - 0.7}{910k/300} = 3.07mA$$

The emitter current is little changed in using the standard value 910kΩ resistor. However, with a change in β from 100 to 300, the emitter current has tripled. This is not acceptable in a power amplifier if we expect the collector voltage to swing from near V_{CC} to near ground. However, for low level signals from micro-volts to a about a volt, the bias point can be centered for a β of square root of (100·300)=173. The bias point will still drift by a considerable amount . However, low level signals will not be clipped.

Base-bias by its self is not suitable for high emitter currents, as used in power amplifiers. The base-biased emitter current is not temperature stable. *Thermal run away* is the result of high emitter current causing a temperature increase which causes an increase in emitter current, which further increases temperature.

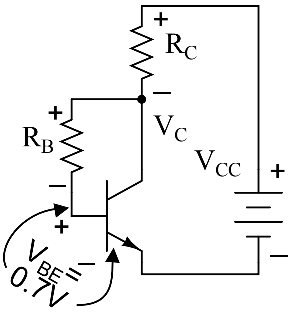
4.10.2 Collector-feedback bias

Subject of EP215 Lab 6

Variations in bias due to temperature and beta may be reduced by moving the V_{BB} end of the base-bias resistor to the collector as in Figure 4.86. If the emitter current were to increase, the voltage drop across R_C increases, decreasing V_C, decreasing I_B fed back to the base. This, in turn, decreases the emitter current, correcting the original increase.

Write a KVL equation about the loop containing the battery, R_C , R_B , and the V_{BE} drop. Substitute $I_C \cong I_E$ and $I_B \cong I_E/\beta$. Solving for I_E yields the IE CFB-bias equation. Solving for I_B yields the IB CFB-bias equation.

Find the required collector feedback bias resistor for an emitter current of 1 mA, a 4.7K collector load resistor, and a transistor with β=100 . Find the collector voltage V_C. It should be



$$I_C = \beta I_B \qquad I_C \approx I_E \qquad I_E \approx \beta I_B$$
$$V_{CC} - I_C R_C - I_B R_B - V_{BE} = 0 \qquad \text{(KVL)}$$
$$V_{CC} - I_E R_C - (I_E/\beta)R_B - V_{BE} = 0$$
$$V_{CC} - V_{BE} = I_E R_C + (I_E/\beta)R_B$$
$$V_{CC} - V_{BE} = I_E((R_B/\beta) + R_C)$$
$$\mathbf{I_E} = \frac{\mathbf{V_{CC} - V_{BE}}}{\mathbf{R_B/\beta + R_C}} \qquad \text{(IE CFB-bias)}$$
$$\mathbf{R_B} = \beta\left[\frac{\mathbf{V_{CC} - V_{BE}}}{\mathbf{I_E}} - \mathbf{R_C}\right] \qquad \text{(RB CFB-bias)}$$

Figure 4.86: *Collector-feedback bias.*

approximately midway between V_{CC} and ground.

$$\beta = 100 \qquad V_{CC} = 10V \qquad I_C \approx I_E = 1ma \qquad R_C = 4.7k$$

$$R_B = \beta\left[\frac{V_{CC} - V_{BE}}{I_E} - R_C\right] = 100\left[\frac{10 - 0.7}{1mA} - 4.7k\right] = 460k$$

$$V_C = V_{CC} - I_C R_C = 10 - (1mA)\cdot(4.7k) = 5.3V$$

The closest standard value to the 460k collector feedback bias resistor is 470k. Find the emitter current I_E with the 470 K resistor. Recalculate the emitter current for a transistor with β=100 and β=300.

$$\beta = 100 \qquad V_{CC} = 10V \qquad R_C = 4.7k \qquad R_B = 470k$$

$$I_E = \frac{V_{CC} - V_{BE}}{R_B/\beta + R_C} = \frac{10 - 0.7}{470k/100 + 4.7k} = 0.989mA$$

$$\beta = 300$$

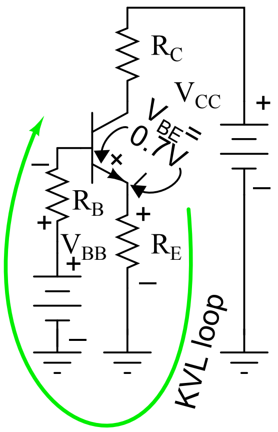
$$I_E = \frac{V_{CC} - V_{BE}}{R_B/\beta + R_C} = \frac{10 - 0.7}{470k/300 + 4.7k} = 1.48mA$$

We see that as beta changes from 100 to 300, the emitter current increases from 0.989mA to 1.48mA. This is an improvement over the previous base-bias circuit which had an increase from 1.02mA to 3.07mA. Collector feedback bias is twice as stable as base-bias with respect to beta variation.

4.10.3 Emitter-bias

Inserting a resistor R_E in the emitter circuit as in Figure 4.87 causes *degeneration*, also known as negative feedback. This opposes a change in emitter current I_E due to temperature changes, resistor tolerances, beta variation, or power supply tolerance. Typical tolerances are as follows:

resistor— 5%, beta— 100-300, power supply— 5%. Why might the emitter resistor stabilize a change in current? The polarity of the voltage drop across R_E is due to the collector battery V_{CC}. The end of the resistor closest to the (-) battery terminal is (-), the end closest to the (+) terminal it (+). Note that the (-) end of R_E is connected via V_{BB} battery and R_B to the base. Any increase in current flow through R_E will increase the magnitude of negative voltage applied to the base circuit, decreasing the base current, decreasing the emitter current. This decreasing emitter current partially compensates the original increase.



$$V_{BB} - I_B R_B - V_{BE} - I_E R_E = 0$$

$$I_E = (\beta+1) I_B \approx \beta I_B$$

$$V_{BB} - (I_E/\beta) R_B - V_{BE} - I_E R_E = 0$$

$$V_{BB} - V_{BE} = I_E\left((R_B/\beta) + R_E \right)$$

$$\mathbf{I_E} = \frac{\mathbf{V_{BB} - V_{BE}}}{\mathbf{R_B/\beta + R_E}} \qquad \text{(IE emitter-bias)}$$

$$R_B/\beta + R_E = \frac{V_{BB} - V_{BE}}{I_E}$$

$$\mathbf{R_B} = \beta \left[\frac{\mathbf{V_{BB} - V_{BE}}}{\mathbf{I_E}} - \mathbf{R_E} \right] \qquad \text{(RB emitter-bias)}$$

Figure 4.87: *Emitter-bias*

Note that base-bias battery V_{BB} is used instead of V_{CC} to bias the base in Figure 4.87. Later we will show that the emitter-bias is more effective with a lower base bias battery. Meanwhile, we write the KVL equation for the loop through the base-emitter circuit, paying attention to the polarities on the components. We substitute $I_B \cong I_E/\beta$ and solve for emitter current I_E. This equation can be solved for R_B , equation: RB emitter-bias, Figure 4.87.

Before applying the equations: RB emitter-bias and IE emitter-bias, Figure 4.87, we need to choose values for R_C and R_E . R_C is related to the collector supply V_{CC} and the desired collector current I_C which we assume is approximately the emitter current I_E. Normally the bias point for V_C is set to half of V_{CC}. Though, it could be set higher to compensate for the voltage drop across the emitter resistor R_E. The collector current is whatever we require or choose. It could range from micro-Amps to Amps depending on the application and transistor rating. We choose I_C = 1mA, typical of a small-signal transistor circuit. We calculate a value for R_C and choose a close standard value. An emitter resistor which is 10-50% of the collector load resistor usually works well.

$$V_C = V_{CC}/2 = 10/2 = 5V$$

$$R_C = Vc/I_C = 5/1mA = 5k \quad (4.7k \text{ standard value})$$

$$R_E = 0.10R_C = 0.10(4.7K) = 470\Omega$$

Our first example sets the base-bias supply to high at $V_{BB} = V_{CC}$ = 10V to show why a lower voltage is desirable. Determine the required value of base-bias resistor R_B. Choose a standard value resistor. Calculate the emitter current for β=100 and β=300. Compare the stabilization of the current to prior bias circuits.

$$\beta = 100 \qquad I_E \approx I_C = 1ma \qquad Vcc = V_{BB} = 10V \qquad R_E = 470\Omega$$

$$R_B = \beta\left[\frac{V_{BB} - V_{BE}}{I_E} - R_E\right] = 100\left[\frac{10 - 0.7}{0.001} - 470\right] = 883k$$

An 883k resistor was calculated for R_B, an 870k chosen. At β=100, I_E is 1.01mA.

$$\beta = 100 \qquad R_B = 870k$$

$$I_E = \frac{V_{BB} - V_{BE}}{R_B/\beta + R_E} = \frac{10 - 0.7}{870K/100 + 470} = 1.01mA$$

$$\beta = 300$$

$$I_E = \frac{V_{BB} - V_{BE}}{R_B/\beta + R_E} = \frac{10 - 0.7}{870K/300 + 470} = 2.76mA$$

For β=300 the emitter currents are shown in Table 4.7.

Table 4.7: *Emitter current comparison for β=100, β=300.*

Bias circuit	**IC β=100**	**IC β=300**
base-bias	1.02mA	3.07mA
collector feedback bias	0.989mA	1.48mA
emitter-bias, V_{BB}=10V	1.01mA	2.76mA

Table 4.7 shows that for V_{BB} = 10V, emitter-bias does not do a very good job of stabilizing the emitter current. The emitter-bias example is better than the previous base-bias example, but, not by much. The key to effective emitter bias is lowering the base supply V_{BB} nearer to the amount of emitter bias.

How much emitter bias do we Have? Rounding, that is emitter current times emitter resistor: $I_E R_E$ = (1mA)(470) = 0.47V. In addition, we need to overcome the V_{BE} = 0.7V. Thus, we need a V_{BB} >(0.47 + 0.7)V or >1.17V. If emitter current deviates, this number will change compared with the fixed base supply V_{BB},causing a correction to base current I_B and emitter current I_E. A good value for V_B >1.17V is 2V.

$$\beta = 100 \qquad I_E \approx I_C = 1ma \qquad Vcc = 10V \qquad V_{BB} = 2V \qquad R_E = 470\Omega$$

$$R_B = \beta\left[\frac{V_{BB} - V_{BE}}{I_E} - R_E\right] = 100\left[\frac{2 - 0.7}{0.001} - 470\right] = 83k$$

The calculated base resistor of 83k is much lower than the previous 883k. We choose 82k from the list of standard values. The emitter currents with the 82k R_B for β=100 and β=300 are:

$$\beta = 100 \quad R_B = 82k$$

$$I_E = \frac{V_{BB} - V_{BE}}{R_B/\beta + R_E} = \frac{2 - 0.7}{82K/100 + 470} = 1.01mA$$

$$\beta = 300$$

$$I_E = \frac{V_{BB} - V_{BE}}{R_B/\beta + R_E} = \frac{2 - 0.7}{82K/300 + 470} = 1.75mA$$

Comparing the emitter currents for emitter-bias with V_{BB} = 2V at β=100 and β=300 to the previous bias circuit examples in Table 4.8, we see considerable improvement at 1.75mA, though, not as good as the 1.48mA of collector feedback.

Table 4.8: *Emitter current comparison for β=100, β=300.*

Bias circuit	**IC β=100**	**IC β=300**
base-bias	1.02mA	3.07mA
collector feedback bias	0.989mA	1.48mA
emitter-bias, V_{BB}=10V	1.01mA	2.76mA
emitter-bias, V_{BB}=2V	1.01mA	1.75mA

How can we improve the performance of emitter-bias? Either increase the emitter resistor R_E or decrease the base-bias supply V_{BB} or both. As an example, we double the emitter resistor to the nearest standard value of 910Ω.

$$\beta = 100 \quad I_E \approx I_C = 1ma \quad Vcc = 10V \quad V_{BB} = 2V \quad R_E = 910\Omega$$

$$R_B = \beta \left[\frac{V_{BB} - V_{BE}}{I_E} - R_E \right] = 100 \left[\frac{2 - 0.7}{0.001} - 910 \right] = 39k$$

The calculated R_B = 39k is a standard value resistor. No need to recalculate I_E for β = 100. For β = 300, it is:

$$\beta = 300 \quad R_B = 39k$$

$$I_E = \frac{V_{BB} - V_{BE}}{R_B/\beta + R_E} = \frac{2 - 0.7}{39K/300 + 910} = 1.25mA$$

The performance of the emitter-bias circuit with a 910¡Onega¿ emitter resistor is much improved. See Table 4.9.

As an exercise, rework the emitter-bias example with the emitter resistor reverted back to 470Ω, and the base-bias supply reduced to 1.5V.

Table 4.9: *Emitter current comparison for β=100, β=300.*

Bias circuit	**IC β=100**	**IC β=300**
base-bias	1.02mA	3.07mA
collector feedback bias	0.989mA	1.48mA
emitter-bias, V_{BB}=10V	1.01mA	2.76mA
emitter-bias, V_{BB}=2V, R_E=470	1.01mA	1.75mA
emitter-bias, V_{BB}=2V, R_E=910	1.00mA	1.25mA

$$\beta = 100 \qquad I_E \approx I_C = 1\text{ma} \qquad Vcc = 10V \qquad V_{BB} = 1.5V \quad R_E = 470\Omega$$

$$R_B = \beta\left[\frac{V_{BB} - V_{BE}}{I_E} - R_E\right] = 100\left[\frac{1.5 - 0.7}{0.001} - 470\right] = 33k$$

The 33k base resistor is a standard value, emitter current at β = 100 is OK. The emitter current at β = 300 is:

$$I_E = \frac{V_{BB} - V_{BE}}{R_B/\beta + R_E} = \frac{1.5 - 0.7}{33K/300 + 470} = 1.38mA$$

Table 4.10 below compares the exercise results 1mA and 1.38mA to the previous examples.

Table 4.10: *Emitter current comparison for β=100, β=300.*

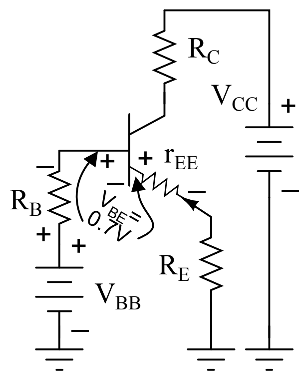
Bias circuit	**IC β=100**	**IC β=300**
base-bias	1.02mA	3.07mA
collector feedback bias	0.989mA	1.48mA
emitter-bias, V_{BB}=10V	1.01mA	2.76mA
emitter-bias, V_{BB}=2V, R_B=470	1.01mA	1.75mA
emitter-bias, V_{BB}=2V, R_B=910	1.00mA	1.25mA
emitter-bias, V_{BB}=1.5V, R_B=470	1.00mA	1.38mA

The emitter-bias equations have been repeated in Figure 4.88 with the internal emitter resistance included for better accuracy. The *internal emitter resistance* is the resistance in the emitter circuit contained within the transistor package. This internal resistance r_{EE} is significant when the (external) emitter resistor R_E is small, or even zero. The value of internal resistance R_{EE} is a function of emitter current I_E, Table 4.11.

Table 4.11: *Derivation of r_{EE}*

r_{EE} = KT/I_Em
where:
    K=1.38×10^{-23} watt-sec/^{o}C, Boltzman's constant
    T= temperature in Kelvins $\cong$300.
    I_E = emitter current
    m = varies from 1 to 2 for Silicon
$r_{EE} \cong$ 0.026V/I_E = 26mV/I_E

For reference the 26mV approximation is listed as equation rEE in Figure 4.88.



$$V_{BB} - I_B R_B - V_{BE} - I_E r_{EE} - I_E R_E = 0 \qquad \text{(KVL)}$$

$$I_E = (\beta+1)I_B \approx \beta I_B$$

$$V_{BB} - (I_E/\beta)R_B - V_{BE} - I_E r_{EE} - I_E R_E = 0$$

$$V_{BB} - V_{BE} = (I_E(R_B/\beta) + I_E r_{EE} + I_E R_E)$$

$$\mathbf{I_E} = \frac{\mathbf{V_{BB} - V_{BE}}}{\mathbf{R_B/\beta + r_{EE} + R_E}} \qquad \text{(IE EB)}$$

$$R_B/\beta + R_{EE} + R_E = \frac{V_{BB} - V_{BE}}{I_E}$$

$$\mathbf{R_B} = \beta\left[\frac{\mathbf{V_{BB} - V_{BE}}}{\mathbf{I_E}} - \mathbf{r_{EE}} - \mathbf{R_E}\right] \qquad \text{(RB EB)}$$

$$\mathbf{r_{EE} = 26mV/I_E} \qquad \text{(rEE)}$$

Figure 4.88: *Emitter-bias equations with internal emitter resistance r_{EE} included..*

The more accurate emitter-bias equations in Figure 4.88 may be derived by writing a KVL equation. Alternatively, start with equations IE emitter-bias and R_B emitter-bias in Figure 4.87, substituting R_E with r_{EE}+R_E. The result is equations IE EB and RB EB, respectively in Figure 4.88.

Redo the R_B calculation in the previous example (page 241) with the inclusion of r_{EE} and compare the results.

$\beta = 100 \qquad I_E \approx I_C = 1ma \qquad Vcc = 10V \qquad V_{BB} = 2V \qquad R_E = 470\Omega$

$r_{EE} = 26mV/1mA = 26\Omega$

$$R_B = \beta\left[\frac{Vcc - V_{BE}}{I_E} - r_{EE} - R_E\right] = 100\left[\frac{2.0 - 0.7}{0.001} - 26 - 470\right] = 80.4k$$

The inclusion of r_{EE} in the calculation results in a lower value of the base resistor R_B a shown in Table 4.12. It falls below the standard value 82k resistor instead of above it.

Table 4.12: *Effect of inclusion of r_{EE} on calculated R_B*

r_{EE}?	**r_{EE} Value**
Without r_{EE}	83k
With r_{EE}	80.4k

Bypass Capacitor for R_E

One problem with emitter bias is that a considerable part of the output signal is dropped across the emitter resistor R_E (Figure 4.89). This voltage drop across the emitter resistor is in series with the base and of opposite polarity compared with the input signal. (This is similar to a common collector configuration having <1 gain.) This degeneration severely reduces the gain from base to collector. The solution for AC signal amplifiers is to bypass the emitter resistor with a capacitor. This restores the AC gain since the capacitor is a short for AC signals. The DC emitter current still experiences degeneration in the emitter resistor, thus, stabilizing the DC current.

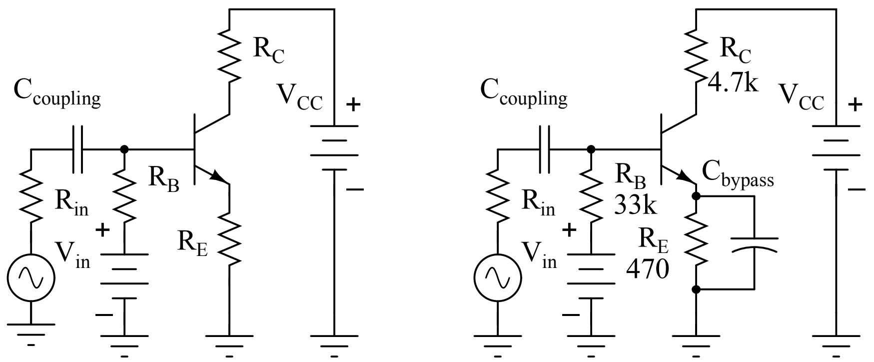


Figure 4.89: *Cbypass is required to prevent AC gain reduction.*

What value should the bypass capacitor be? That depends on the lowest frequency to be amplified. For radio frequencies Cbpass would be small. For an audio amplifier extending down to 20Hz it will be large. A "rule of thumb" for the bypass capacitor is that the reactance should be 1/10 of the emitter resistance or less. The capacitor should be designed to accommodate the lowest frequency being amplified. The capacitor for an audio amplifier covering 20Hz to 20kHz would be:

$$X_C = \frac{1}{2\pi fC}$$

$$C = \frac{1}{2\pi fX_C}$$

$$C = \frac{1}{2\pi 20(470/10)} = 169\mu F$$

Note that the internal emitter resistance r_{EE} is not bypassed by the bypass capacitor.

4.10.4 Voltage divider bias

Stable emitter bias requires a low voltage base bias supply, Figure 4.90. The alternative to a base supply V_{BB} is a voltage divider based on the collector supply V_{CC}.

The design technique is to first work out an emitter-bias design, Then convert it to the voltage divider bias configuration by using Thevenin's Theorem. [4] The steps are shown graphically in Figure 4.91. Draw the voltage divider without assigning values. Break the divider

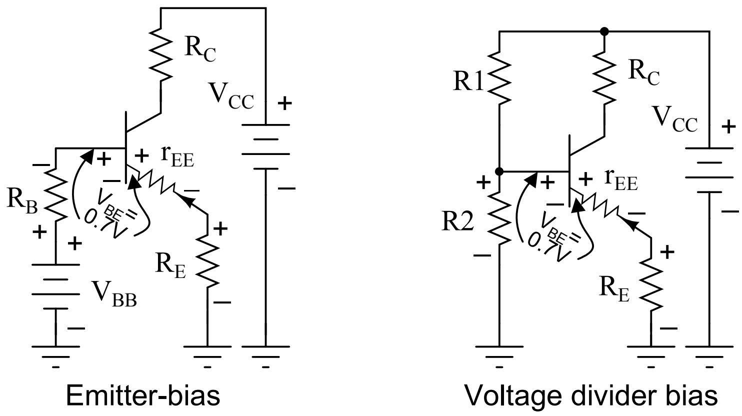


Figure 4.90: *Voltage Divider bias replaces base battery with voltage divider.*

loose from the base. (The base of the transistor is the load.) Apply Thevenin's Theorem to yield a single Thevenin equivalent resistance Rth and voltage source Vth.

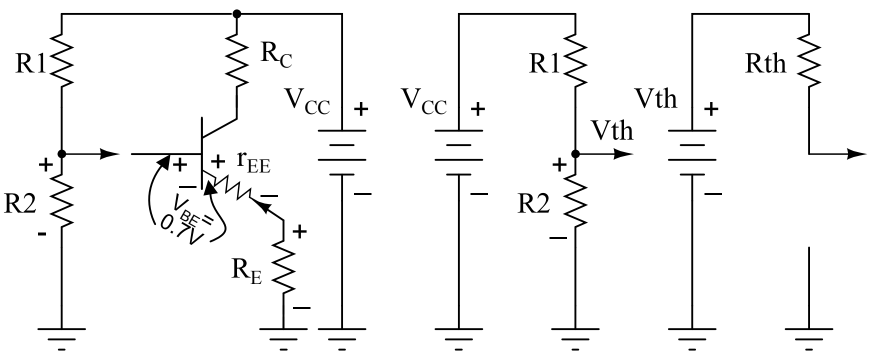


Figure 4.91: *Thevenin's Theorem converts voltage divider to single supply Vth and resistance Rth.*

The Thevenin equivalent resistance is the resistance from load point (arrow) with the battery (V_{CC}) reduced to 0 (ground). In other words, R1||R2.The Thevenin equivalent voltage is the open circuit voltage (load removed). This calculation is by the voltage divider ratio method. R1 is obtained by eliminating R2 from the pair of equations for Rth and Vth. The equation of R1 is in terms of known quantities Rth, Vth, Vcc. Note that Rth is R_B , the bias resistor from the emitter-bias design. The equation for R2 is in terms of R1 and Rth.

$$\mathrm{Rth} = \mathrm{R1} \parallel \mathrm{R2} \qquad \mathrm{Vth} = V_{CC}\left[\frac{\mathrm{R2}}{\mathrm{R1}+\mathrm{R2}}\right]$$

$$\frac{1}{\mathrm{Rth}} = \frac{1}{\mathrm{R1}} + \frac{1}{\mathrm{R2}} \qquad f = \frac{\mathrm{Vth}}{V_{CC}} = \left[\frac{\mathrm{R2}}{\mathrm{R1}+\mathrm{R2}}\right]$$

$$\frac{1}{\mathrm{Rth}} = \frac{\mathrm{R2}+\mathrm{R1}}{\mathrm{R1}\cdot\mathrm{R2}} = \frac{1}{\mathrm{R1}}\left[\frac{\mathrm{R2}+\mathrm{R1}}{\mathrm{R2}}\right] = \frac{1}{\mathrm{R1}}\cdot\frac{1}{f}$$

We built this in Lab 5: See Fig 4.89 why an emitter bypass capacitor is also required

$$\mathrm{R1} = \frac{\mathrm{Rth}}{f} = \mathrm{Rth}\frac{V_{CC}}{\mathrm{Vth}} \qquad \frac{1}{\mathrm{R2}} = \frac{1}{\mathrm{Rth}} - \frac{1}{\mathrm{R1}}$$

Convert this previous emitter-bias example to voltage divider bias.

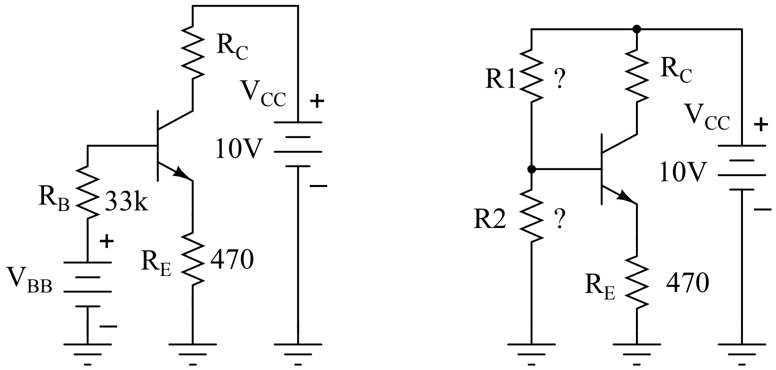


Figure 4.92: *Emitter-bias example converted to voltage divider bias.*

These values were previously selected or calculated for an emitter-bias example

$\beta = 100 \quad I_E \approx I_C = 1\mathrm{ma} \quad \mathrm{Vcc} = 10\mathrm{V} \quad V_{BB} = 1.5\mathrm{V} \quad R_E = 470\Omega$

$$R_B = \beta\left[\frac{V_{BB} - V_{BE}}{I_E} - R_E\right] = 100\left[\frac{1.5 - 0.7}{0.001} - 470\right] = 33\mathrm{k}$$

Substituting V_{CC} , V_{BB} , R_B yields R1 and R2 for the voltage divider bias configuration.

$$V_{BB} = \mathrm{Vth} = 1.5\mathrm{V} \qquad \frac{1}{\mathrm{R2}} = \frac{1}{\mathrm{Rth}} - \frac{1}{\mathrm{R1}}$$

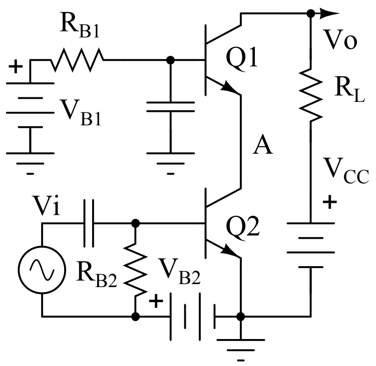
$$R_B = \mathrm{Rth} = 33\mathrm{k}$$

$$\mathrm{R1} = \mathrm{Rth}\frac{V_{CC}}{\mathrm{Vth}} \qquad \frac{1}{\mathrm{R2}} = \frac{1}{33\mathrm{k}} - \frac{1}{220\mathrm{k}}$$

$$\mathrm{R1} = 33\mathrm{k}\,\frac{10}{1.5} = 220\mathrm{k} \qquad \mathrm{R2} = 38.8\mathrm{k}$$

R1 is a standard value of 220K. The closest standard value for R2 corresponding to 38.8k is 39k. This does not change I_E enough for us to calculate it.

Problem: Calculate the bias resistors for the cascode amplifier in Figure 4.93. V_{B2} is the bias voltage for the common emitter stage. V_{B1} is a fairly high voltage at 11.5 because we want the common-base stage to hold the emitter at 11.5-0.7=10.8V, about 11V. (It will be 10V after accounting for the voltage drop across R_{B1} .) That is, the common-base stage is the load, substitute for a resistor, for the common-emitter stage's collector. We desire a 1mA emitter current.



Cascode

$$V_{CC} = 20V \quad I_E = 1mA \quad \beta = 100 \quad V_A = 10V \quad R_L = 4.7k$$

$$V_{BB1} = 11.5V \quad V_{BB2} = 1.5V$$

$$I_E = \frac{V_{BB} - V_{BE}}{R_B/\beta}$$ (IE base-bias)

$$R_{B1} = \frac{V_{BB} - V_{BE}}{I_E/\beta} = \frac{(V_{BB1} - V_A) - V_{BE}}{I_E/\beta} = \frac{(11.5\text{-}10) - 0.7}{1mA/100} = 80k$$

$$R_{B2} = \frac{V_{BB2} - V_{BE}}{I_E/\beta} = \frac{(1.5) - 0.7}{1mA/100} = 80k$$

Figure 4.93: *Bias for a cascode amplifier.*

Problem: Convert the base bias resistors for the cascode amplifier to voltage divider bias resistors driven by the V_{CC} of 20V.

$R_{BB1} = 80k \quad V_{CC} = Vth = 20V$

$V_{BB1} = 11.5V$

$V_{BB} = Vth = 11.5V$

$R_B = Rth = 80k$

$$R1 = Rth\frac{V_{CC}}{Vth}$$

$$R1 = 80k\,\frac{20}{11.5} = 139.1k$$

$$\frac{1}{R2} = \frac{1}{Rth} - \frac{1}{R1}$$

$$\frac{1}{R2} = \frac{1}{80k} - \frac{1}{139.1k}$$

$R2 = 210k$

$R_{BB2} = 80k$

$V_{BB2} = 1.5V$

$V_{BB} = Vth = 1.5V$

$R_B = Rth = 80k$

$$R3 = Rth\frac{V_{CC}}{Vth}$$

$$R3 = 80k\,\frac{20}{1.5} = 1.067Meg$$

$$\frac{1}{R4} = \frac{1}{Rth} - \frac{1}{R3}$$

$$\frac{1}{R4} = \frac{1}{80k} - \frac{1}{1067k}$$

$R4 = 86.5k$

The final circuit diagram is shown in the "Practical Analog Circuits" chapter, "Class A cascode amplifier . . . " (page 433).

- **REVIEW:**
- See Figure 4.94.
- Select bias circuit configuration
- Select R_C and I_E for the intended application. The values for R_C and I_E should normally set collector voltage V_C to 1/2 of V_{CC}.
- Calculate base resistor R_B to achieve desired emitter current.
- Recalculate emitter current I_E for standard value resistors if necessary.
- For voltage divider bias, perform emitter-bias calculations first, then determine R1 and R2.
- For AC amplifiers, a bypass capacitor in parallel with R_E improves AC gain. Set $X_C \leq 0.10 R_E$ for lowest frequency.

4.11 Input and output coupling

To overcome the challenge of creating necessary DC bias voltage for an amplifier's input signal without resorting to the insertion of a battery in series with the AC signal source, we used a voltage divider connected across the DC power source. To make this work in conjunction with an AC input signal, we "coupled" the signal source to the divider through a capacitor, which acted as a high-pass filter. With that filtering in place, the low impedance of the AC signal source couldn't "short out" the DC voltage dropped across the bottom resistor of the voltage divider. A simple solution, but not without any disadvantages.

Most obvious is the fact that using a high-pass filter capacitor to couple the signal source to the amplifier means that the amplifier can only amplify AC signals. A steady, DC voltage applied to the input would be blocked by the coupling capacitor just as much as the voltage divider bias voltage is blocked from the input source. Furthermore, since capacitive reactance is frequency-dependent, lower-frequency AC signals will not be amplified as much as higher-frequency signals. Non-sinusoidal signals will tend to be distorted, as the capacitor responds differently to each of the signal's constituent harmonics. An extreme example of this would be a low-frequency square-wave signal in Figure 4.95.

Incidentally, this same problem occurs when oscilloscope inputs are set to the "AC coupling" mode as in Figure 4.97. In this mode, a coupling capacitor is inserted in series with the measured voltage signal to eliminate any vertical offset of the displayed waveform due to DC voltage combined with the signal. This works fine when the AC component of the measured signal is of a fairly high frequency, and the capacitor offers little impedance to the signal. However, if the signal is of a low frequency, or contains considerable levels of harmonics over a wide frequency range, the oscilloscope's display of the waveform will not be accurate. (Figure 4.97) Low frequency signals may be viewed by setting the oscilloscope to "DC coupling" in Figure 4.96.