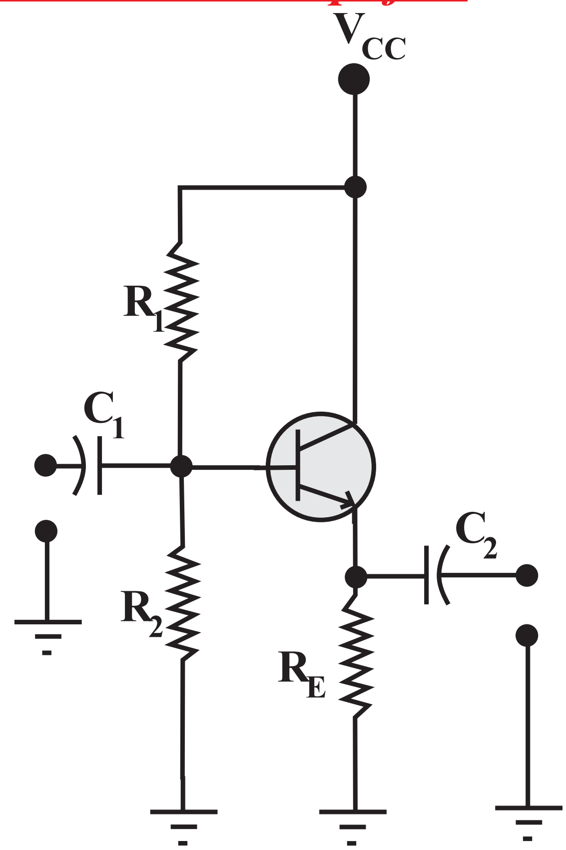
The Emitter Follower -aka -The Common Collector Amplifier



The ***Emitter Follower*** is used to provide ***current gain*** and in ***impedance matching*** applications.

The input to this circuit is applied to the base , while the output is taken from the emitter.

The ***voltage gain is always less than 1*** and the ***output voltage is in phase with the input voltage.***

Since the output "follows" the input, this amplifier is referred to as the emitter follower rather than the common collector amplifier.

Looking at the circuit on the next page we can see that the collector is tied directly to V_{CC} with no collector resistor R_C

Also, there is no emitter bypass capacitor, and that we take our output from the emitter in this circuit.

dc Analysis

DC analysis for the emitter follower is similar to the common emitter amplifier that we have been with.

The base voltage is achieved using a voltage divider as before , and the base voltage is found as:

$$\boxed{V_B = \frac{R_2}{R_1 + R_2} V_{CC}}$$

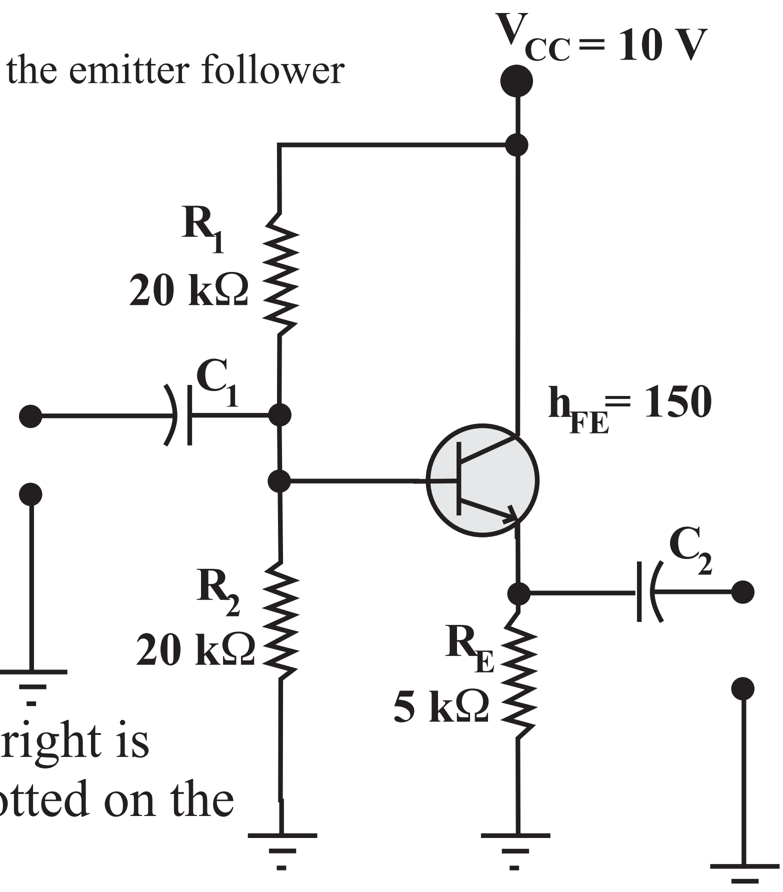
The Emitter Follower 10.1

The emitter voltage is found exactly as before $\boxed{V_E = V_B - 0.7V}$

The emitter current is: $\boxed{I_E = \frac{V_E}{R_E}}$

V_{CEQ} is found as: $\boxed{V_{CEQ} = V_{CC} - V_E}$

Example 10.1 shows the dc analysis of the emitter follower

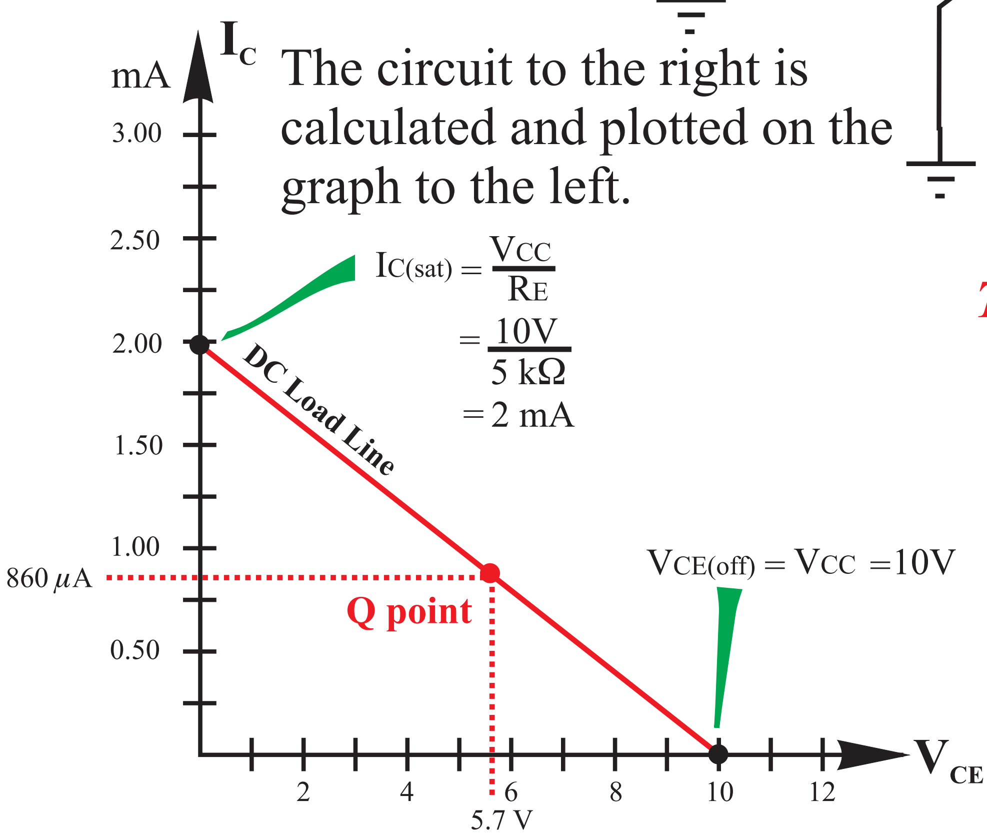


The dc Load Line

The DC load line is found in a similar fashion as before:

Find both ends of the line, plot them, then connect them with a straight line.

The circuit to the right is calculated and plotted on the graph to the left.



The equations are:

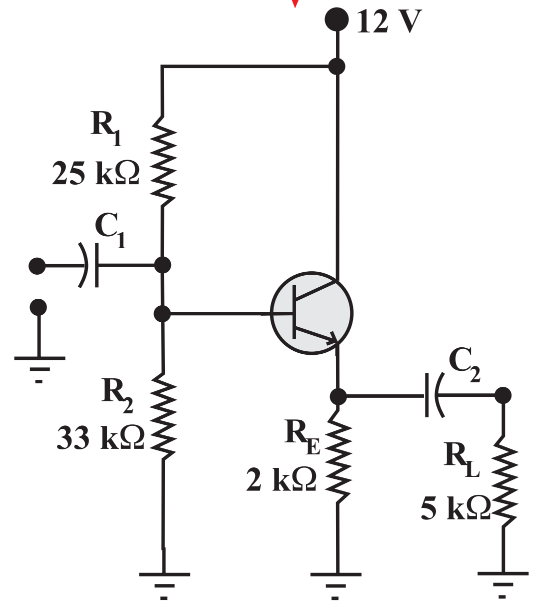
$$\boxed{I_{C(sat)} = \frac{V_{CC}}{R_E}}$$

$$\boxed{V_{CE(off)} = V_{CC}}$$

The Emitter Follower 10.2

ac Analysis

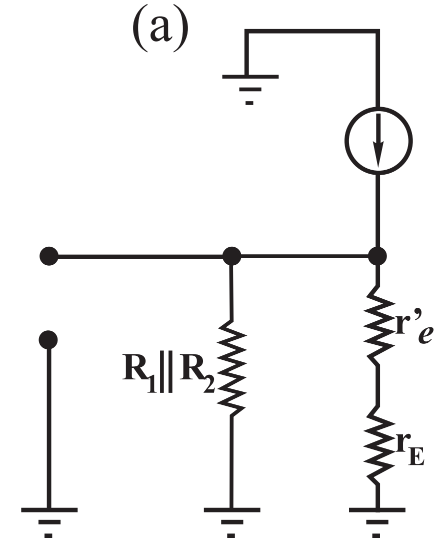
A typical emitter follower is shown in circuit (a). Note that the load is capacitively coupled to the ***emitter***.



(a)

Now look at circuit (b). It is the ac equivalent circuit. Here, the ***total equivalent ac emitter resistance*** is r_E, and is found as:

$$r_E = R_E \,||\, R_L$$



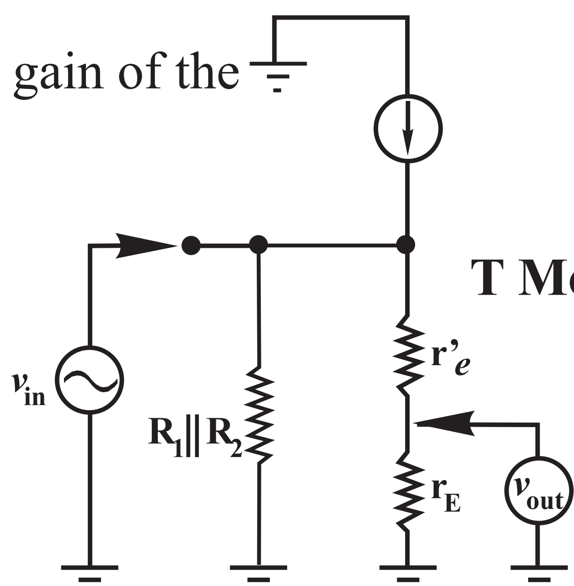
(b)

Look at figure (c). The input signal is applied to both the input circuit ($R_1||R_2$) and the output circuit.

The output circuit, which is made up of r'_e and r_E, divides the input signal. This is why the voltage gain is always less than 1.

We can calculate the voltage gain of the circuit as:

$$A_V = \frac{r_E}{(r'_e + r_E)}$$



T Model

(c)

In most practical cases r'_e is very small when compared to the value of r_E. When this is true, we can approximate the gain as:

$$\boxed{A_V \cong 1 \quad (\text{when } r_E >> r'_e)}$$

Example 10.3 illustrates the calculation of the voltage gain.

Current Gain

The current gain for the emitter follower is found as:

$$\boxed{A_i = h_{fc}\left(\frac{Z_{in}\, r_E}{Z_{base}\, R_L}\right)}$$

The current gain of the emitter follower is significantly lower than the current gain of the transistor.

This relationship is due to the current divisions that occur in both the input and output circuits. This is similar to the low current gain situation with the C.E. amplifier.

Note that in the equation above, we have used h_{fc} in place of h_{fe}. We are assuming that h_{fc} is approximately equal to h_{fe}. The subscript "c" merely indicates that the parameter applies to the emitter follower (common collector) rather than the common emitter amplifier.

The exact equation for h_{fc} is $\boxed{h_{fc} = h_{fe} + 1}$

Since h_{fe} is normally much greater than 1, we normally assume that they are approximately equal.

Power Gain

As with the C.E. amplifier, power gain is the product of current gain and voltage gain. Since the value of A_V is slightly less than 1, the power gain of the emitter follower is always slightly less than the current gain.

This point is shown in example 10.4

$$\boxed{A_p = A_i\, A_v}$$

Input Impedance (Z_{in})

The input impedance of the emitter follower is found as the parallel equivalent resistance of the base resistors and the transistor input impedance.

$$\boxed{Z_{in} = R_1 \,||\, R_2 \,||\, Z_{base}}$$

Example 10.5 finds the input impedance of the emitter follower

The Base Input Impedance (Z_{base})

The base input impedance is:

$$\boxed{Z_{base} = h_{fc}\,(r'_e + r_E)}$$

where: h_{fc} = transistor current gain
r'_e = the ac emitter resistance
r_E = RE||RL

Output Impedance (Z_{out})

The output impedance is the impedance that the circuit presents to its load. When a load is connected to the circuit, the output impedance of the circuit acts as the source impedance for that load.

Since the emitter follower is often used in impedance matching applications, the output impedance becomes important.

One main function of the emitter follower is to match the source impedance to the load impedance to improve power transfer from the source to the load.

Output Impedance (Z_{out}) Continued

The formula for output impedance is given as:

$$\boxed{Z_{out} = R_E \,\|\, \left(r'_e + \frac{R'_{in}}{h_{fc}} \right)}$$

where: Z_{out} = the output impedance of the amplifier
R_{in} = $R_1 \| R_2 \| R_S$
R_S = the output resistance of the input voltage source

Example 10.6 determines the output impedance of the emitter follower

Summary

- **The value of Z_{base} is typically higher than the common emitter amplifier.**

- **The voltage gain is always less than 1**

- **The heavy swamping of the circuit virtually eliminates the effect of r'$_e$ on the voltage gain (low distortion)**

The two main uses of the emitter follower are:

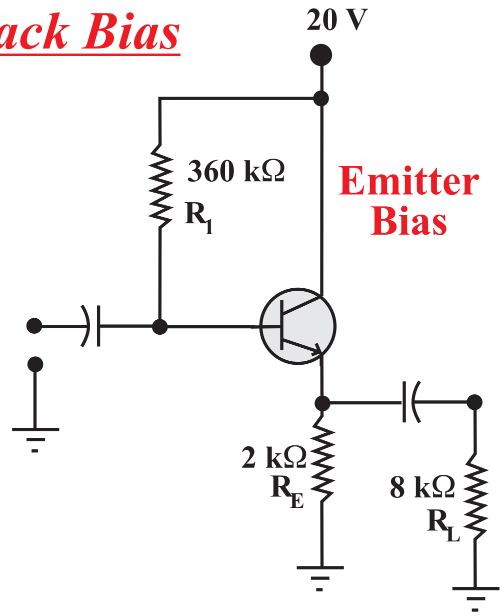
- **To isolate a low impedance load from a C.E. amplifier**
- **To provide current amplification**

If a C.E. amplifier tries to drive a low impedance load directly, it will be overloaded because the ac resistance is too low.

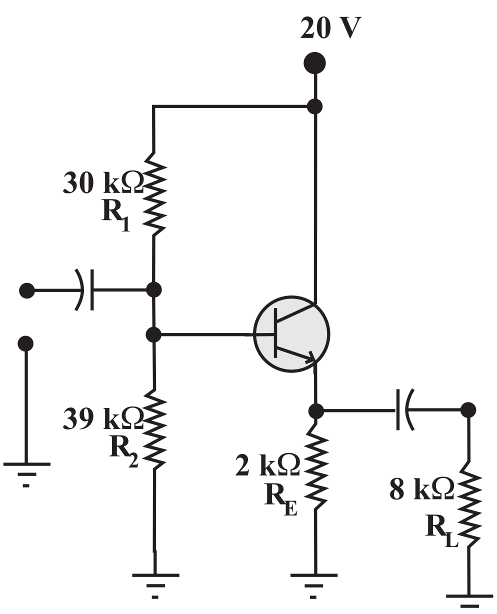
By using an emitter follower between the C.E. amplifier and the low impedance load, overloading can be prevented
.
The emitter follower is basically a circuit that steps up the impedance. (low impedance out and high impedance in)

Practical Considerations -- Emitter Feedback Bias

In some impedance matching considerations, it is important to have an input impedance that is as high as possible.



(a)



(b)

Here, emitter feedback bias is often used. Figure (a) shows an emitter follower using emitter feedback. A comparable circuit using voltage divider bias is shown in figure (b).

Figure (a) will have a much higher input impedance than figure (b) The reason:

For figure (b) $Z_{in} = R_1 \,||\, R_2 \,||\, Z_{base}$

But, for figure (a) $Z_{in} = R_1 \,||\, Z_{base}$

Note that R_1 in (b) is much less than R_1 in (a). This makes a difference in the calculated value of Z_{in}

Example 10.7 illustrates this.

Decoupling Capacitors

See Section 10.3.2 in the text

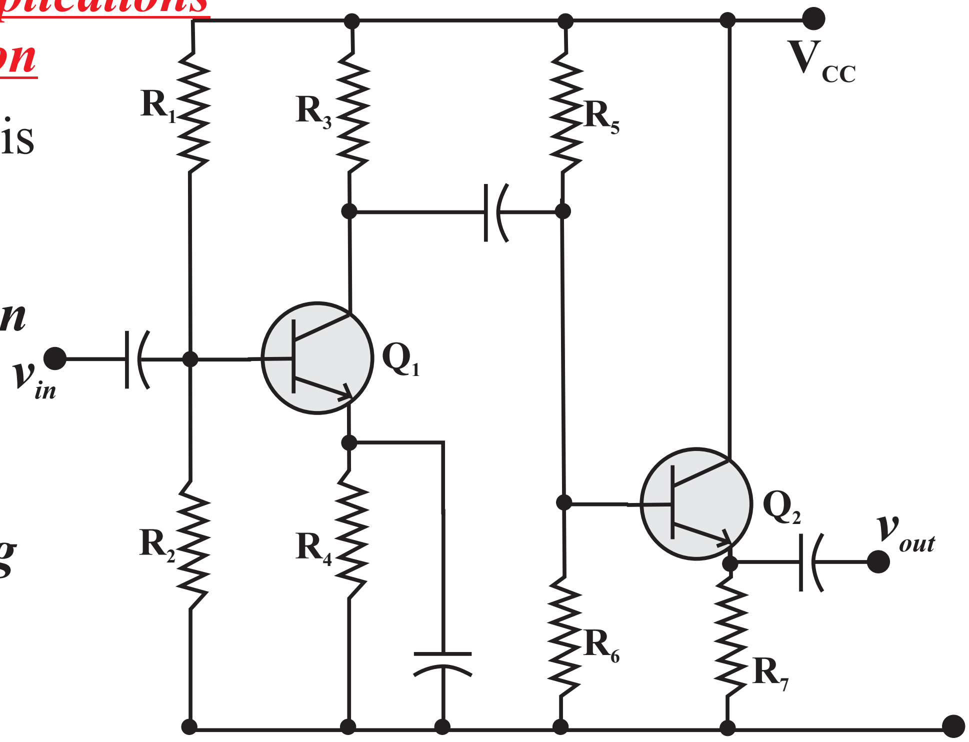
Emitter Follower Applications

Current Amplification

The emitter follower is used when:

current amplification is needed without voltage gain

impedance matching is required.



There can be instances when current gain is required but the voltage level is already sufficient (digital electronics). The emitter follower would be used to provide the additional current gain while not increasing the voltage gain.

In the figure above, the first stage provides specific values of both current gain and voltage gain. The second stage is the emitter follower, and it increases the current gain further without increasing the voltage gain.

Impedance Matching

We know that ***maximum power is transferred to a load when the source and load impedances are equal.***

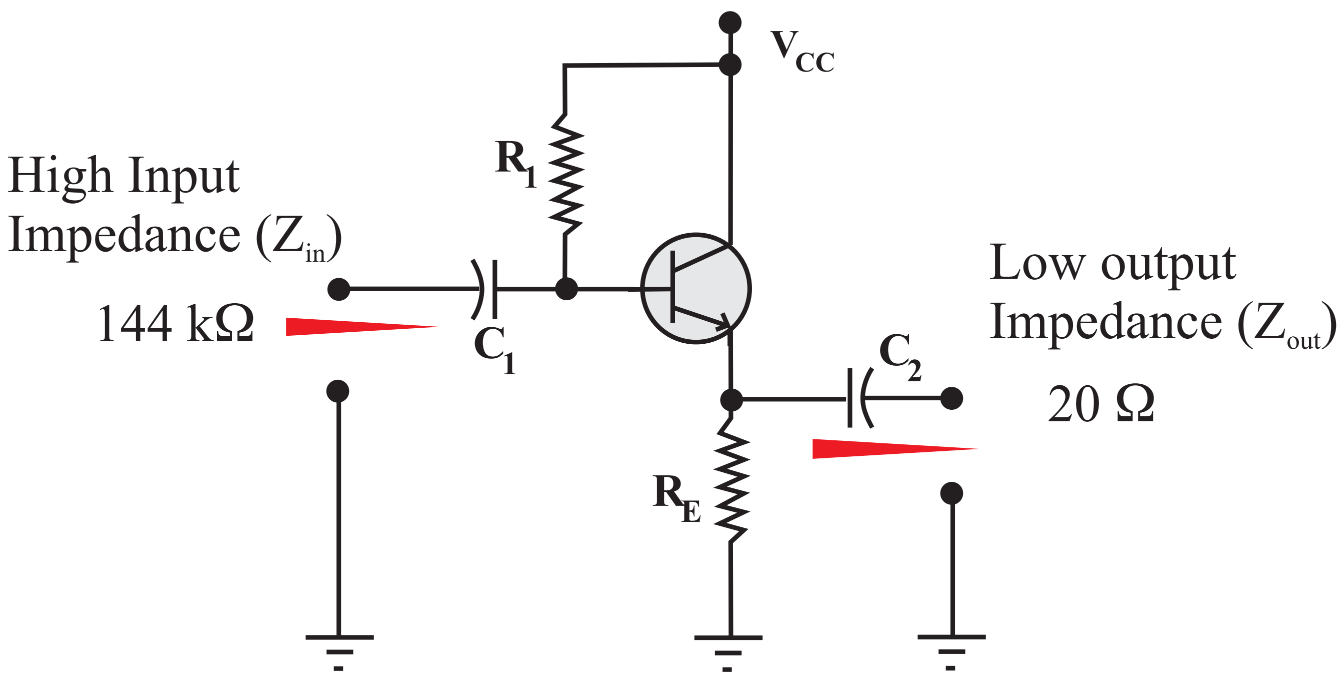
When the two impedances are equal, they are said to be matched.

Impedance Matching *(continued)*

The circuit below is an example of the emitter follower being used as a ***buffer***.

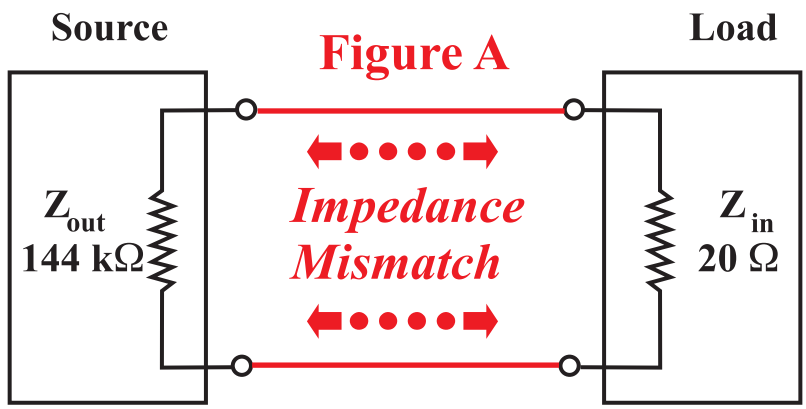
A buffer is a circuit that is used for impedance matching that aids the transfer of power from the source to the load.

In the circuit shown below, note the relatively high input impedance and the relatively low output impedance of the circuit.



Impedance Matching *(continued)*

In the circuit shown, Fig. A shows a source with a 144kΩ internal impedance, connected to a load with a 20Ω internal impedance.



In this case, only a small amount of the source power will be delivered to the load.

Most of the power will be developed across its own internal resistance & will be lost.

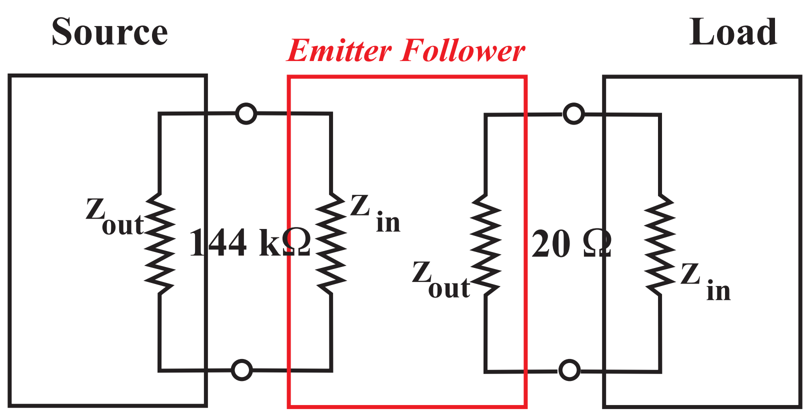


Figure B shows an emitter follower inserted between the same source and load.

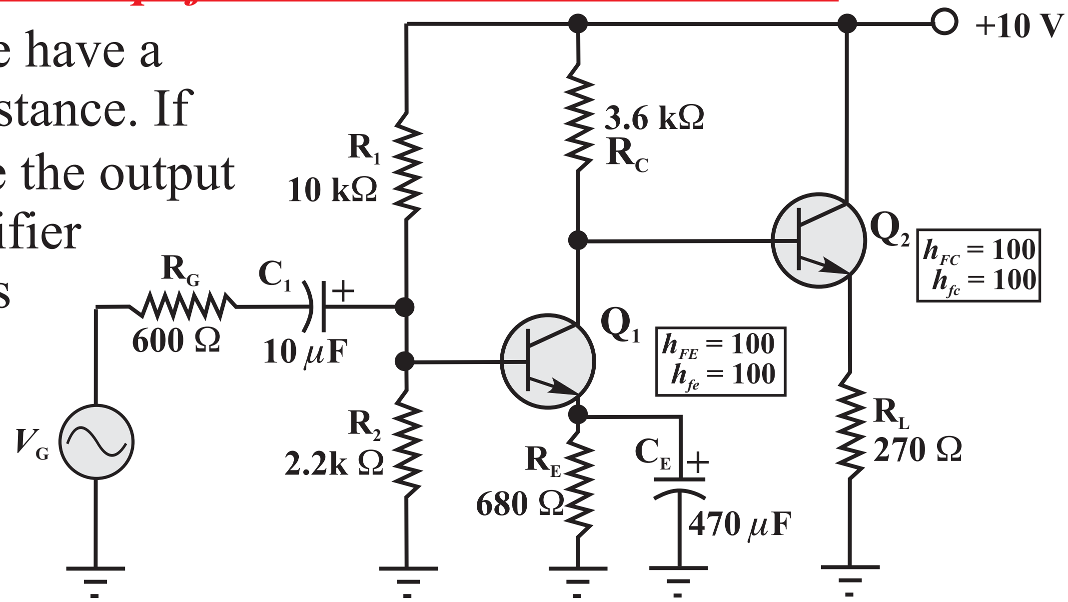
Here, the source impedance closely matches the input impedance of the amplifier, providing an improvement of power transfer from the source to the amplifier.

The same is true at the output, since the output impedance of the amplifier now matches the load.

The end result is that the maximum power has been transferred from the original source to the original load

Note: This section is not in the textbook.

Cascading the CE amplifier and the Emitter Follower



Direct Coupled Output Stage

Suppose that we have a 270 Ω load resistance. If we try to couple the output of our CE amplifier directly into this load resistance, we may overload the amplifier and a substantial drop in gain will occur.

One way to solve this problem is to add an emitter follower between the CE. amplifier and the load resistance.

The circuit above is an example of a typical CE. amplifier that is ***direct coupled*** to an emitter follower.

Direct coupling avoids the need for a coupling capacitor between the collector of Q_1 and the base of $Q_{2.}$ Further, direct coupling eliminates the need for the biasing resistors that would normally be required to bias Q_2. This eliminates some of the parasitic ac signal current loss associated with them.

The base of Q_2 is connected directly to the collector of $Q_{1.}$

This means that the collector voltage at Q_1 is being used to bias the base of $Q_{2.}$

The CE Amp & the Emitter Follower

Note: This section is not in the textbook.

Cascading the CE amplifier and the Emitter Follower

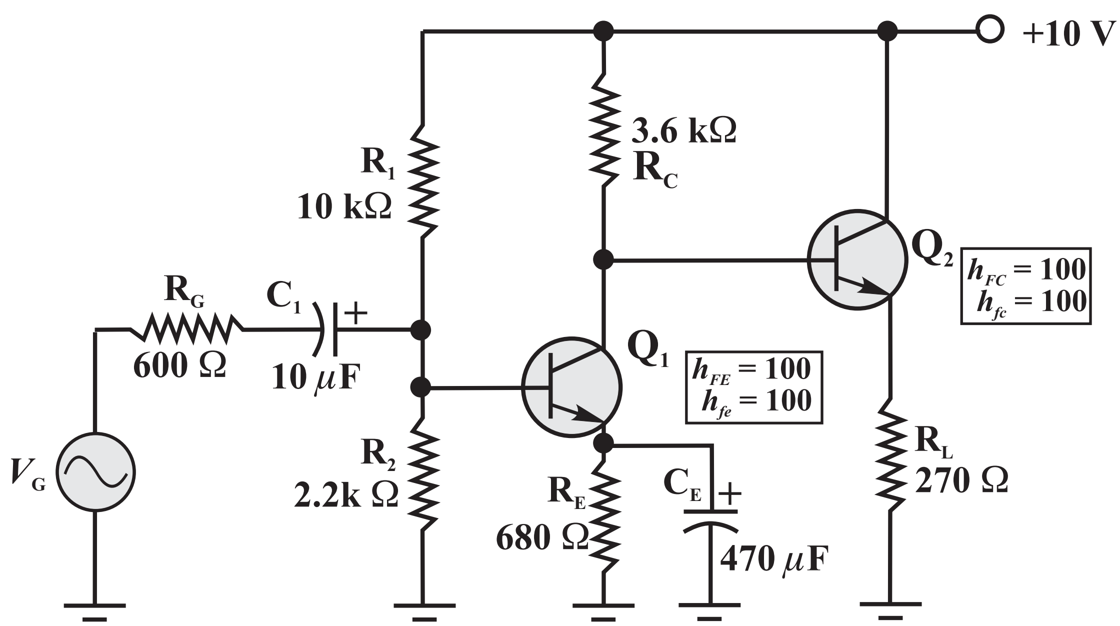
If h_{FC} of Q_2 is 100, then the dc resistance looking into the base of Q_2 is:

$$R_{base} = h_{FC}\,R_E$$
$$= 100(270\ k\Omega) = 27\ k\Omega$$

R_{base} of Q_2 is much higher that the collector resistance R_C.

This means that the collector voltage at Q_1 is hardly disturbed by the fact that it is biasing Q_2.

Without the emitter follower, the 270 Ω load would overload the CE. amp, but with the emitter follower, the impedance effect is increased by a factor of 100 in this example. This means that the 270 Ω load appears like 27 kΩ in both the dc and ac equivalent circuits.



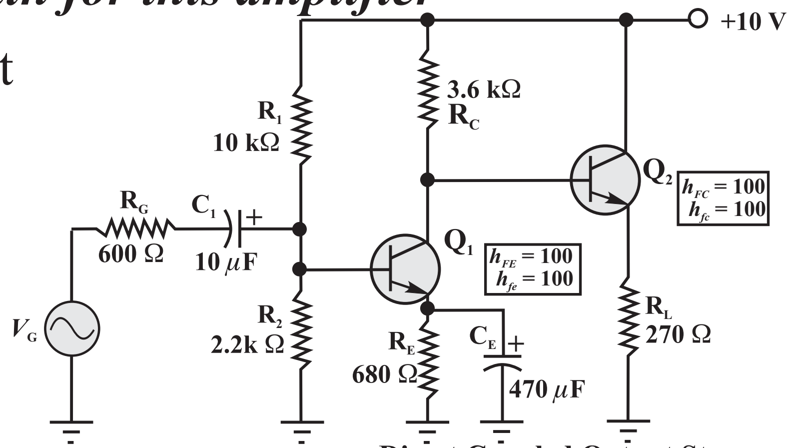
Direct Coupled Output Stage

The CE Amp & the Emitter Follower

Note: This section is not in the textbook.

Cascading the CE amplifier and the Emitter Follower

Example *Find the voltage gain for this amplifier*



Direct Coupled Output Stage

The dc base voltage of the first stage is 1.8 V and the emitter voltage is 1.1 V ,found in the usual way.

① For Q_1

$$I_{E1} = \frac{1.1\ \text{V}}{680\ \Omega} = \boxed{1.61\ \text{mA}}$$

$$r'_e = \frac{25\ \text{mA}}{1.61\ \text{mA}} = \boxed{15.5\ \Omega}$$

$$V_{C1} = 10\ \text{V} - ((1.61\ \text{mA})(3.6\ \text{k}\Omega)) = \boxed{4.2\ \text{V}}$$

② For Q_2

$$V_{C1} = V_{B2} = 4.2\ \text{V}$$

$$V_{E2} = 4.2\ \text{V} - 0.7\ \text{V} = 3.5\ \text{V}$$

$$I_{E2} = \frac{3.5\ \text{V}}{270\ \Omega} = 12.9\ \text{mA}$$

$$r'_{e2} = \frac{25\ \text{mA}}{12.9\ \text{mA}} = 1.95\ \Omega$$

③ Now, calculate Z_{in} of the emitter follower

Since there are no biasing resistors, the value of Z_{in} is simply Z_{base}

③ *continued*

$$Z_{in} = Z_{base}$$

$$Z_{in} = h_{fc}(r'_e + r_E)$$
$$= 100(1.95\ \Omega + 270\ \Omega)$$
$$= 27.2\ \text{k}\Omega$$

④ Direct Coupled Output Stage

Find the ac collector resistance of the CE amplifier

$$r_c = R_C \parallel R_L$$
$$= 3.6\ \text{k}\Omega \parallel 27.2\ \text{k}\Omega$$
$$= 3.18\ \text{k}\Omega$$

⑤ Finally, find the voltage gain of the stage

$$A_V = \frac{r_C}{r'_{e1}} = \frac{3.18\ \text{k}\Omega}{15.5\Omega} = \boxed{205.16}$$

Since the emitter follower has a voltage gain of approximately 1, the total voltage gain at the load is approximately 205.16

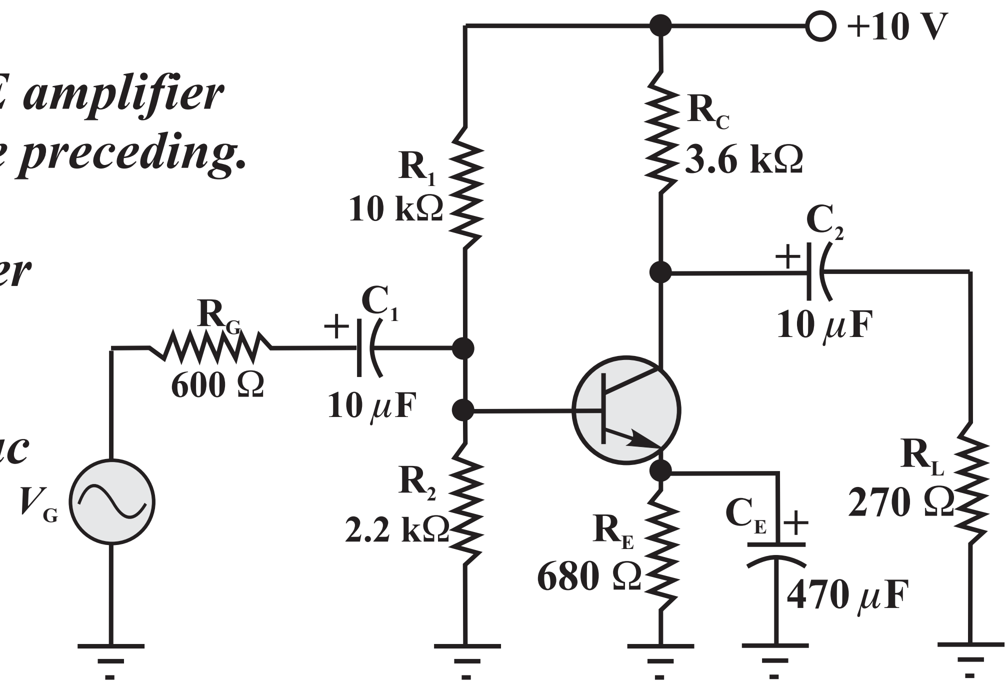
The CE Amp & the Emitter Follower

Note: This section is not in the textbook.

Cascading the CE amplifier and the Emitter Follower Example

This is the same CE amplifier used in the example preceding.

The emitter follower has been removed , and a capacitor is used to couple the ac signal to the 270 Ω load.



Find the voltage gain for this amplifier

All the dc values including r'_e remain the same as before.

The big difference now is the value of the ac collector resistance. It is now much smaller since it is the parallel resistance of 3.6 kΩ and 270 Ω.

$$\begin{aligned} r_C &= R_C \| R_L \\ &= 3.6\ \text{k}\Omega \,\|\, 270\Omega \\ &= 251\ \Omega \end{aligned}$$

This much lower resistance causes the gain to drop to:

$$A_V = \frac{r_C}{r'_e} = \frac{251\ \Omega}{15.5\Omega} = \boxed{16.2}$$

The Darlington Amplifier

This is a special case emitter follower that uses two transistors to increase the overall values of circuit current gain (A_i) and input impedance (Z_{in}).

Note that :

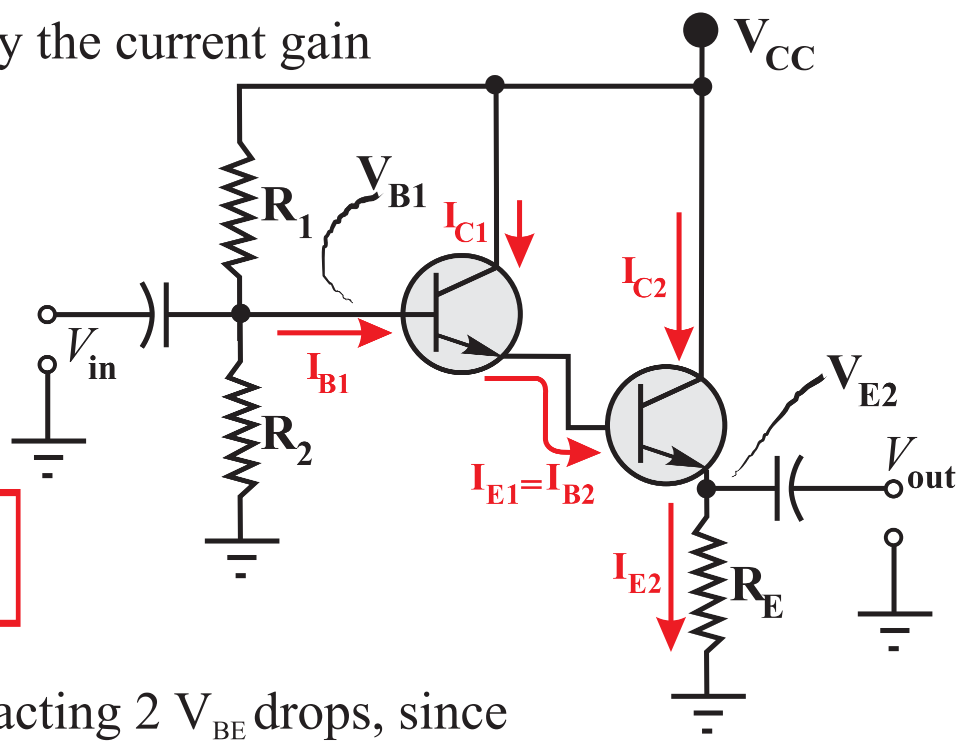
- The emitter of the first transistor is tied to the base of the second.
- The collector terminals are tied together.

The circuit configuration is shown below along with the resulting current paths.

dc Analysis

R_{in} is R_E multiplied by the current gain of both transistors.

$$R_{in} = h_{FC1} h_{FC2} R_E$$



V_{B1} is found in the normal way.

$$V_{B1} = \frac{R_2}{R_1 + R_2} V_{CC}$$

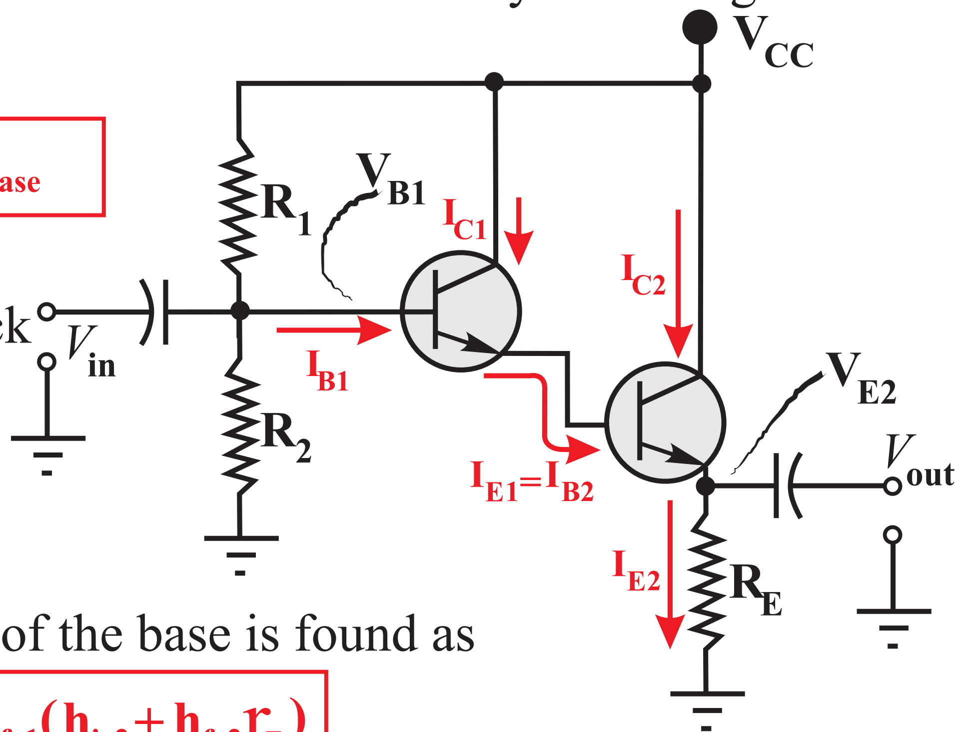
V_{E2} is found by subtracting 2 V_{BE} drops, since there are 2 transistors.

$$V_{E2} = V_{B1} - 1.4\text{ V}$$ and $$I_{E2} = \frac{V_{E2}}{R_E}$$

The Darlington Amplifier 10.4

ac Analysis

The input impedance is found in the usual way for voltage divider bias.



$$Z_{in} = R_1 \,||\, R_2 \,||\, Z_{base}$$

When emitter-feedback bias is used :

$$Z_{in} = R_1 \,||\, Z_{base}$$

The input impedance of the base is found as

$$Z_{in(base)} = h_{ic1} + h_{fc1}(h_{ic2} + h_{fc2} r_E)$$

where h_{ic} = the input impedance of the identified transistor
h_{fc} = the ac current gain of the identified transistor
r_E = the parallel combination of R_E and R_L

The output impedance is found in the same way as with the emitter follower.
The gain of the second transistor must be part of the equation:

$$Z_{out} = R_E \,||\, \left(r'_{e2} + \frac{r'_{e1} + (R'_{in}/h_{fc1})}{h_{fc2}} \right)$$

This equation approximates Z_{out} when R_E is much greater than the rest of the equation.

$$Z_{out} \cong r'_{e2} + \frac{r'_{e1} + (R'_{in}/h_{fc1})}{h_{fc2}}$$

where R'_{in} = the input impedance of the identified transistor
r'_e = the ac emitter resistance of the identified transistor
h_{fc} = the ac current gain of the identified transistor

ac Analysis

The ac current gain of the Darlington pair is the product of the individual gains. This can easily be in the thousands. Even with the losses associated with the input and output circuits, the overall ***current gain*** of the Darlington amplifier is very high.

Note: Even though the Darlington amplifier has a ***high current gain***, the ***voltage gain (A_V) is slightly less than 1.***
Example 10.9 illustrates this.

The "Quick" Analysis

Use these equations when you are interested in ***quickly*** determining ***approximate*** circuit values.

$$\boxed{Z_{base} \cong h_{fc1} h_{fc2} r_E}$$

$$\boxed{A_V \cong 1}$$

$$\boxed{A_i = h_{fc1} h_{fc2} \left(\frac{Z_{in}\, r_E}{Z_{in(base)}\, R_L} \right)}$$

$$\boxed{Z_{out} \cong r'_{e2} + \frac{r'_{e1}}{h_{fc2}}}$$

$$\boxed{A_i = h_{fc1} h_{fc2} \left(\frac{Z_{in}\, r_E}{Z_{in(base)}\, R_L} \right)}$$

Summary

The characteristics of the Darlington amplifier are:

1) **It has a voltage gain of slightly less than 1 ($A_V < 1$).**
2) **It has an extremely high input impedance to the base.**
3) **It has a high current gain.**
4) **It has an extremely low output impedance.**
5) **Input and Output voltages currents are in phase.**

The characteristics of the Darlington amplifier are basically the same as the emitter follower. When a higher input impedance or current gain are required and/or a lower output impedance is needed than the emitter follower can provide, use a Darlington Amplifier.