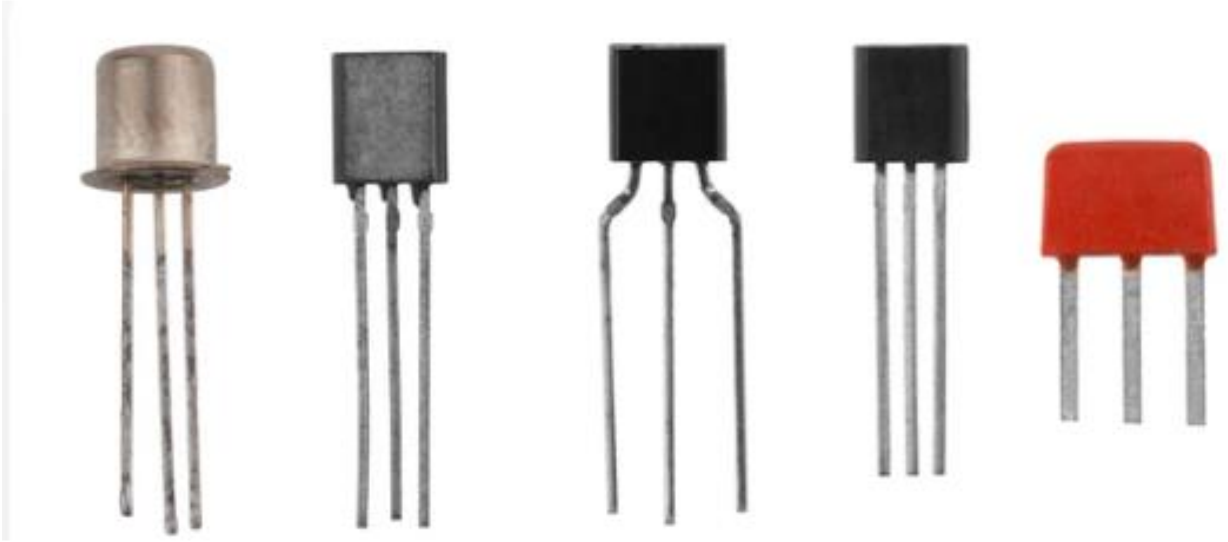
Electronic Circuits (1) EEC2103



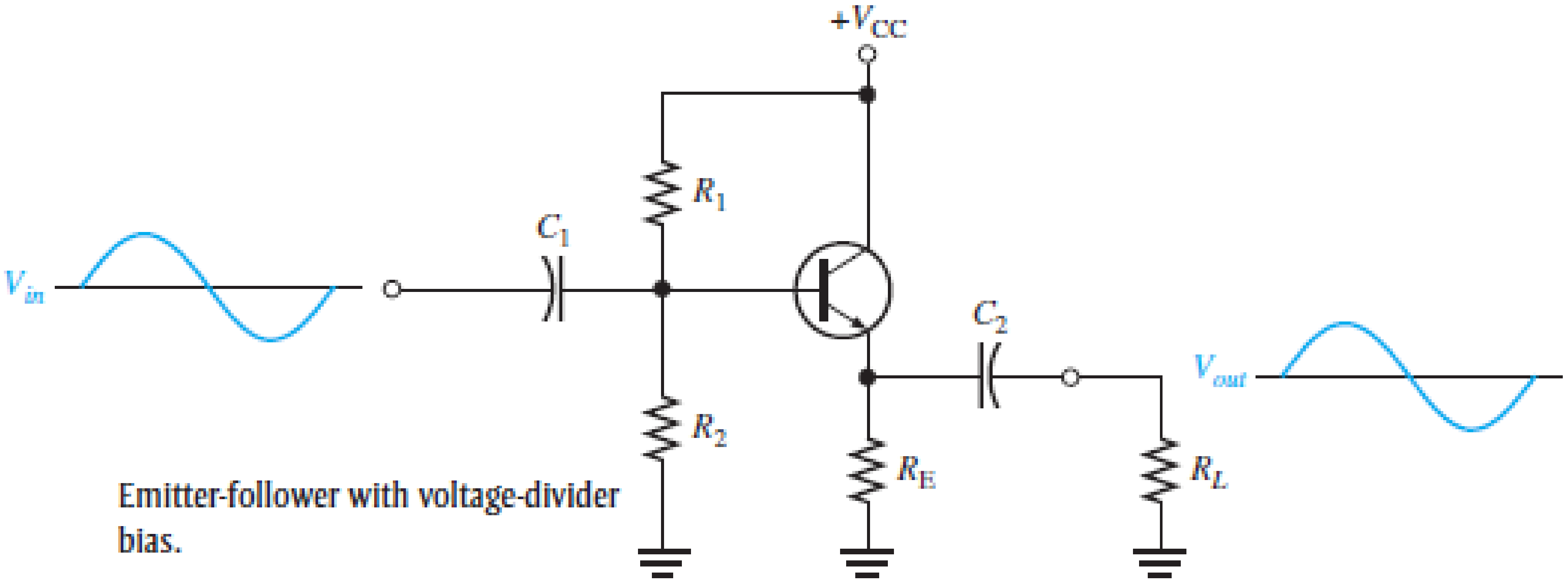
LEC (3) BJT Part 3

AC Analysis - Multistage

Dr. Nancy Alshaer

The Common Collector Amplifier \ AC Analysis

- What are the features, the connection, and the famous name of the CC?



Emitter-follower with voltage-divider bias.

Find the expressions for, A_v, A_i, A_p, $R_{in(tot)}$, R_o.

The Common Collector Amplifier \ AC Analysis

Voltage Gain

As in all amplifiers, the voltage gain is $A_v = V_{out}/V_{in}$. The capacitive reactances are assumed to be negligible at the frequency of operation. For the emitter-follower, as shown in the ac model in Figure 6–26,

$$V_{out} = I_e R_e$$

and

$$V_{in} = I_e(r'_e + R_e)$$

Therefore, the voltage gain is

$$A_v = \frac{I_e R_e}{I_e(r'_e + R_e)}$$

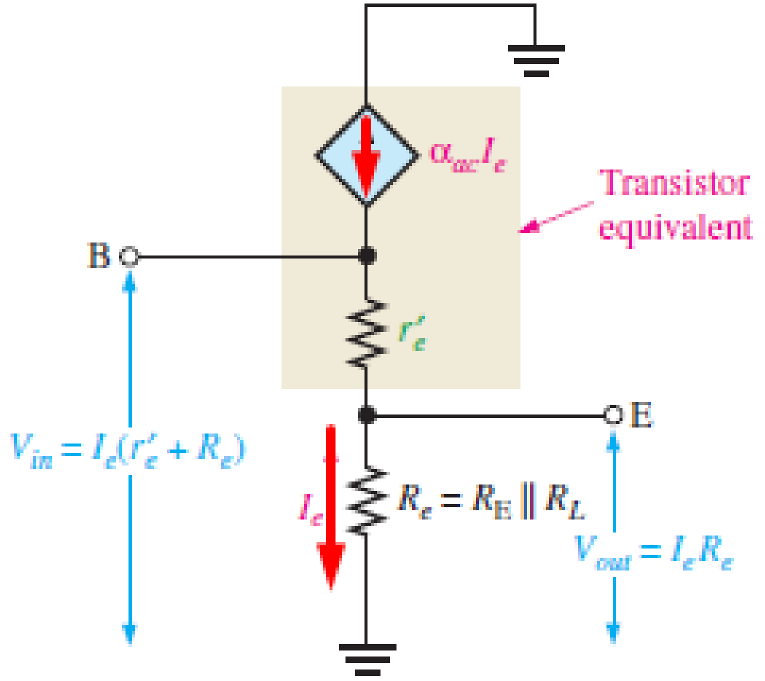
The I_e current terms cancel, and the base-to-emitter voltage gain expression simplifies to

$$A_v = \frac{R_e}{r'_e + R_e}$$

where R_e is the parallel combination of R_E and R_L. If there is no load, then $R_e = R_E$. Notice that the gain is always less than 1. If $R_e \gg r'_e$, then a good approximation is

$$A_v \cong 1$$

Since the output voltage is at the emitter, it is in phase with the base voltage, so there is no inversion from input to output. Because there is no inversion and because the voltage gain is approximately 1, the output voltage closely follows the input voltage in both phase and amplitude; thus the term *emitter-follower*.



The Common Collector Amplifier \ AC Analysis

Input Resistance

The emitter-follower is characterized by a high input resistance; this is what makes it a useful circuit. Because of the high input resistance, it can be used as a buffer to minimize loading effects when a circuit is driving a low-resistance load. The derivation of the input resistance, looking in at the base of the common-collector amplifier, is similar to that for the common-emitter amplifier. In a common-collector circuit, however, the emitter resistor is *never* bypassed because the output is taken across R_e, which is R_E in parallel with R_L.

$$R_{in(base)} = \frac{V_{in}}{I_{in}} = \frac{V_b}{I_b} = \frac{I_e(r'_e + R_e)}{I_b}$$

Since $I_e \cong I_c = \beta_{ac} I_b$,

$$R_{in(base)} \cong \frac{\beta_{ac} I_b(r'_e + R_e)}{I_b}$$

The I_b terms cancel; therefore,

$$R_{in(base)} \cong \beta_{ac}(r'_e + R_e)$$

If $R_e \gg r'_e$, then the input resistance at the base is simplified to

$$\boldsymbol{R_{in(base)} \cong \beta_{ac} R_e}$$

The bias resistors in Figure 6–25 appear in parallel with $R_{in(base)}$, looking from the input source; and just as in the common-emitter circuit, the total input resistance is

$$R_{in(tot)} = R_1 \parallel R_2 \parallel R_{in(base)}$$

The Common Collector Amplifier \ AC Analysis

Output Resistance

With the load removed, the output resistance, looking into the emitter of the emitter-follower, is approximated as follows:

$$R_{out} \cong \left(\frac{R_s}{\beta_{ac}}\right) \parallel R_E$$

R_s is the resistance of the input source. The derivation of Equation 6–14, found in "Derivations of Selected Equations" at www.pearsonhighered.com/floyd, is relatively involved and several assumptions have been made. The output resistance is very low, making the emitter-follower useful for driving low-resistance loads.

The Common Collector Amplifier \ AC Analysis

Current Gain

The current gain for the emitter-follower in Figure 6–25 is

$$A_i = \frac{I_e}{I_{in}}$$

Ib

where $I_{in} = V_{in}/R_{in(tot)}$.

Power Gain

The common-collector power gain is the product of the voltage gain and the current gain. For the emitter-follower, the power gain is approximately equal to the current gain because the voltage gain is approximately 1.

$$A_p = A_v A_i$$

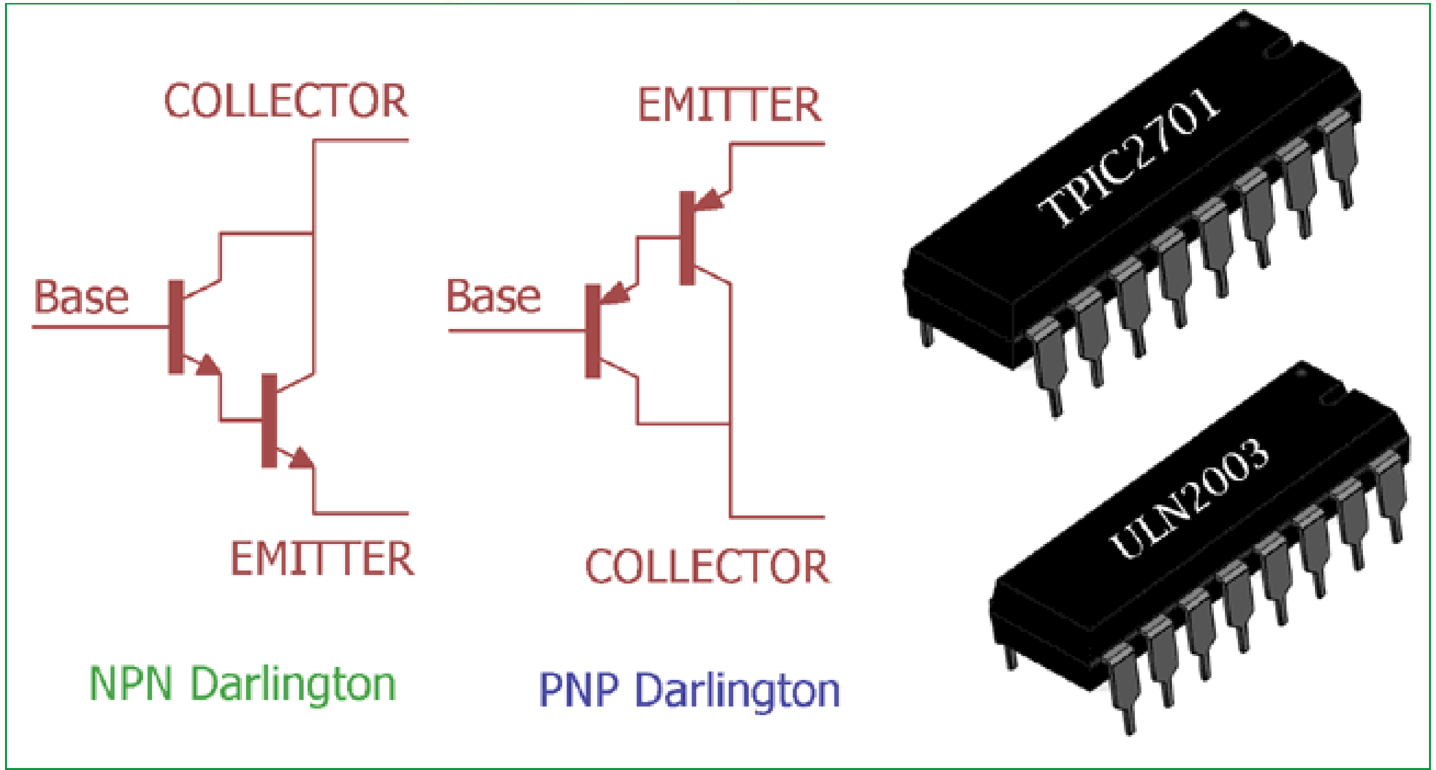
Since $A_v \cong 1$, the power gain is

$$A_p \cong A_i$$

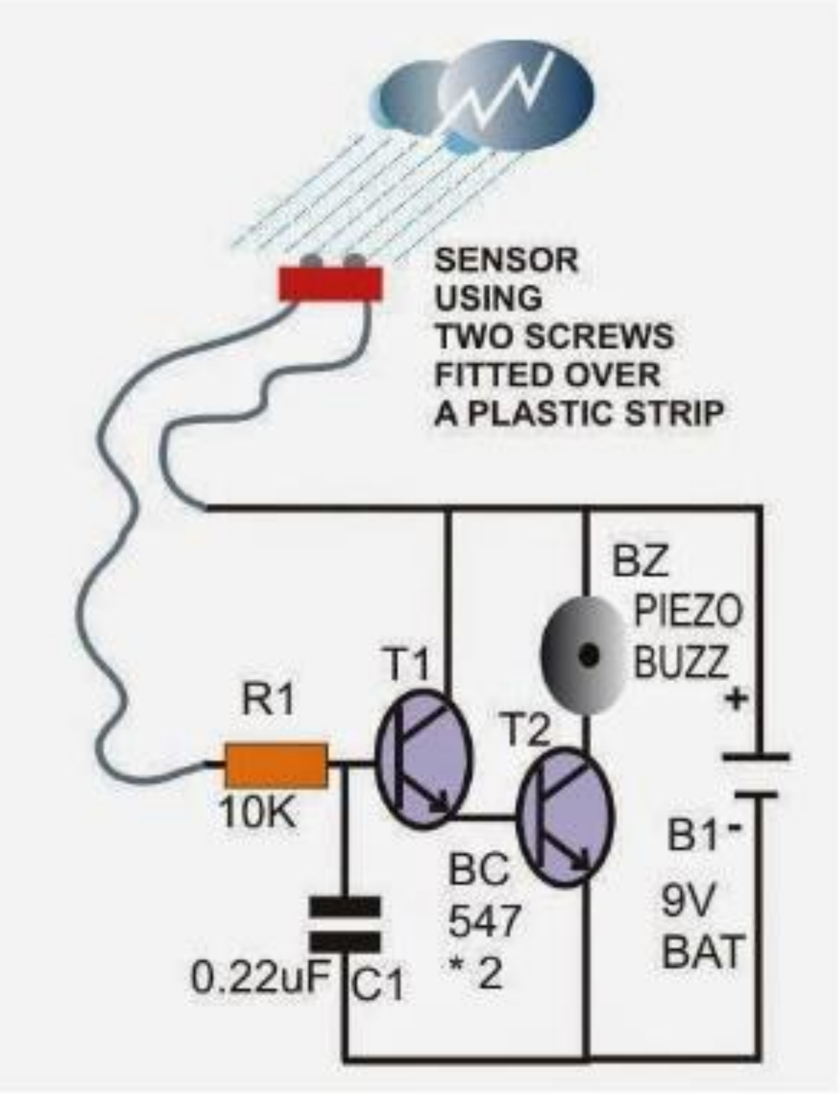
Study Example 6-9

Darlington Connection

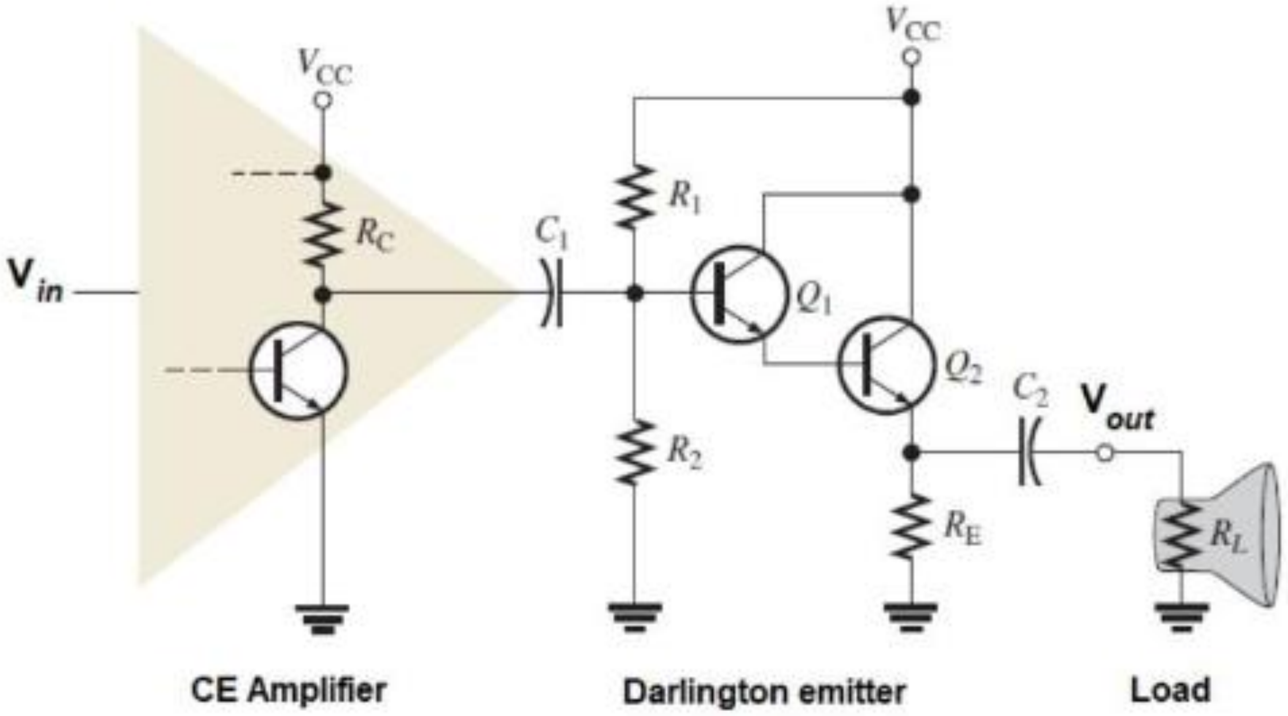
A very popular connection of two bipolar junction transistors for operation as one "super-beta" transistor is the Darlington connection shown in Figure . The main feature of the Darlington connection is that the composite transistor acts as a single unit with a current gain that is the product of the current gains of the individual transistors. If the connection is made using two separate transistors having current gains of β_1 and β_2, the Darlington connection provides a current gain of $\boxed{\beta_D = \beta_1\beta_2}$



Darlington Connection / Applications



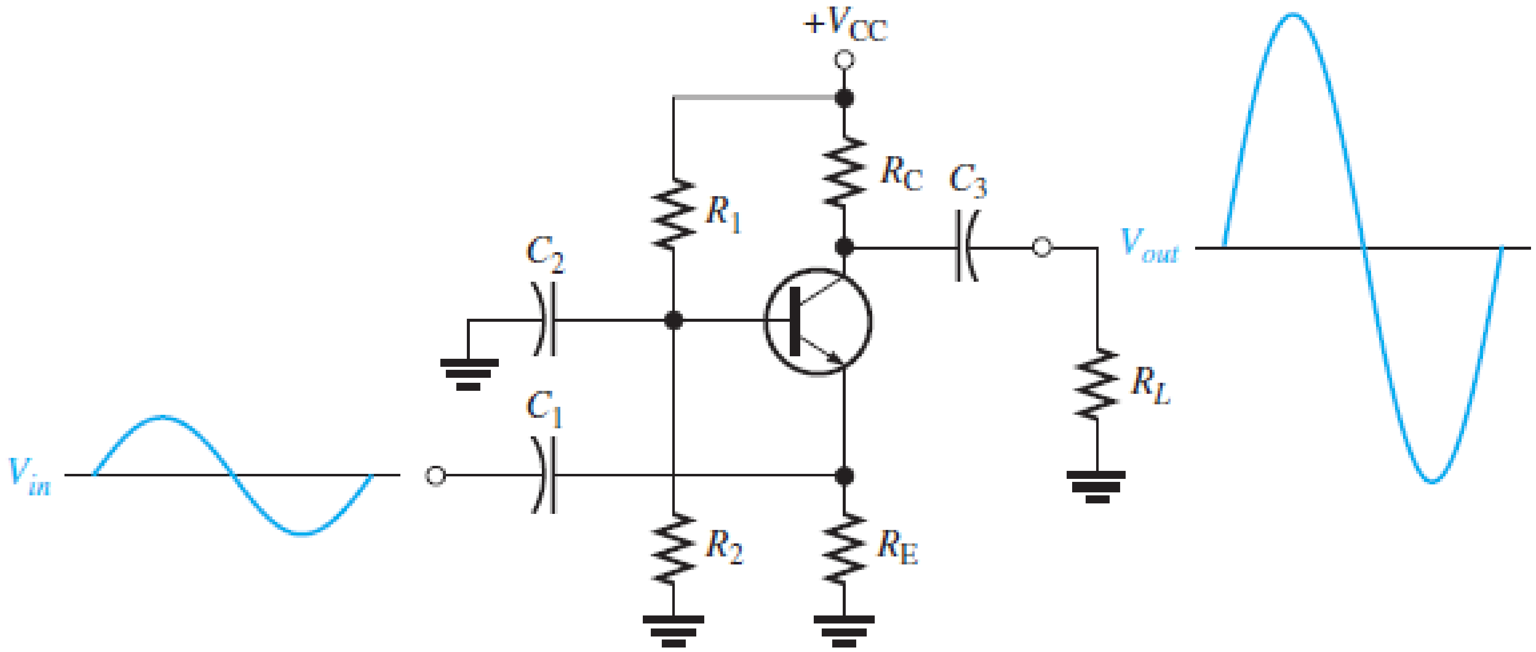
Darlington transistor-pair based rain alarm



A Darlington emitter follower used as a buffer between a common emitter amplifier And a low-resistance load

The Common Base Amplifier \ AC Analysis

- What are the features, the connection, and the most appropriate Applications?



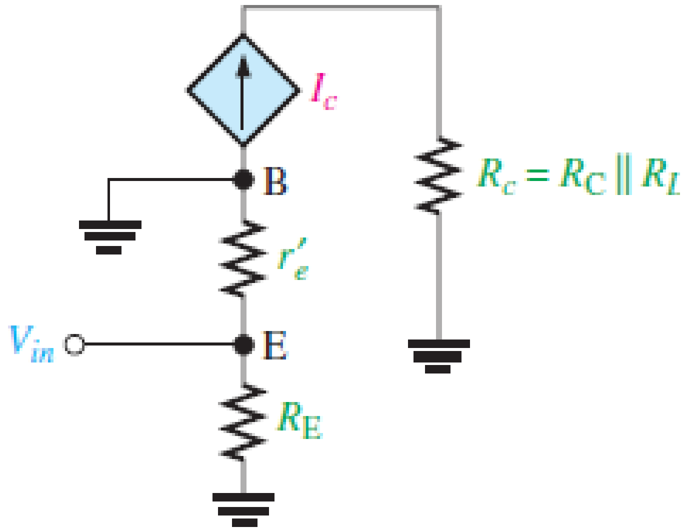
Find the expressions for, A_v, A_i, A_p, $R_{in(tot)}$, R_o.

The Common Base Amplifier \ AC Analysis

Voltage Gain

The voltage gain from emitter to collector is developed as follows ($V_{in} = V_e$, $V_{out} = V_c$).

$$A_v = \frac{V_{out}}{V_{in}} = \frac{V_c}{V_e} = \frac{I_c R_c}{I_e(r'_e \parallel R_E)} \cong \frac{I_e R_c}{I_e(r'_e \parallel R_E)}$$



(b) AC equivalent model

If $R_E \gg r'_e$, then

$$A_v \cong \frac{R_c}{r'_e}$$

where $R_c = R_C \parallel R_L$. Notice that the gain expression is the same as for the common-emitter amplifier. However, there is no phase inversion from emitter to collector.

The Common Base Amplifier \ AC Analysis

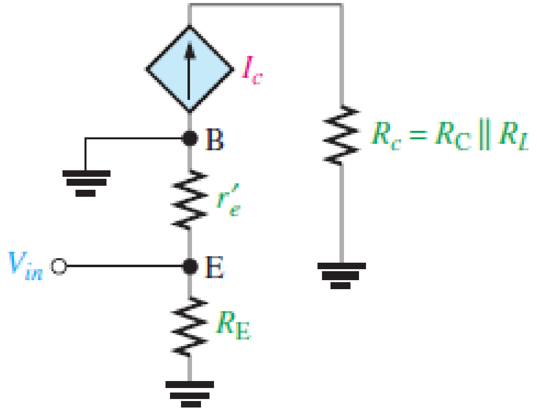
Input Resistance

The resistance, looking in at the emitter, is

$$R_{in(emitter)} = \frac{V_{in}}{I_{in}} = \frac{V_e}{I_e} = \frac{I_e(r'_e \parallel R_E)}{I_e}$$

If $R_E \gg r'_e$, then

$$R_{in(emitter)} \cong r'_e$$



(b) AC equivalent model

R_E is typically much greater than r'_e, so the assumption that $r'_e \parallel R_E \cong r'_e$ is usually valid. The input resistance can be set to a desired value by using a swamping resistor.

Output Resistance

Looking into the collector, the ac collector resistance, r'_c, appears in parallel with R_C. As you have previously seen in connection with the CE amplifier, r'_c is typically much larger than R_C, so a good approximation for the output resistance is

$$R_{out} \cong R_C$$

The Common Base Amplifier \ AC Analysis

Current Gain

The current gain is the output current divided by the input current. I_c is the ac output current, and I_e is the ac input current. Since $I_c \cong I_e$, the current gain is approximately 1.

$$A_i \cong 1$$

Power Gain

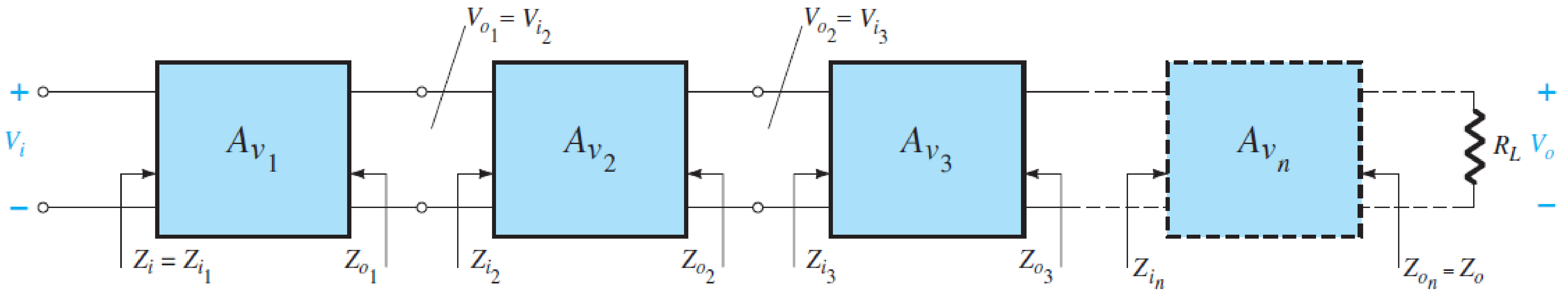
Since the current gain is approximately 1 for the common-base amplifier and $A_p = A_v A_i$, the power gain is approximately equal to the voltage gain.

$$A_p \cong A_v$$

Study Example 6-11

Multistage (Cascaded) Amplifiers

- Two or more amplifiers can be connected in a **cascaded** arrangement with the output of one amplifier driving the input of the next.
- Each amplifier in a cascaded arrangement is known as a **stage.**
- **The basic purpose of a multistage arrangement is to <u>increase the overall voltage gain.</u>**
- A_{v1}, A_{v2}, A_{v3}, and so on, are the voltage gains of each stage *under loaded conditions*.
- That is, A_{v1} is determined with the *input impedance to* A_{v2} *acting as the load on* A_{v1}.
- For A_{v2}, A_{v1} will determine the signal strength and source impedance at the input to A_{v2}.



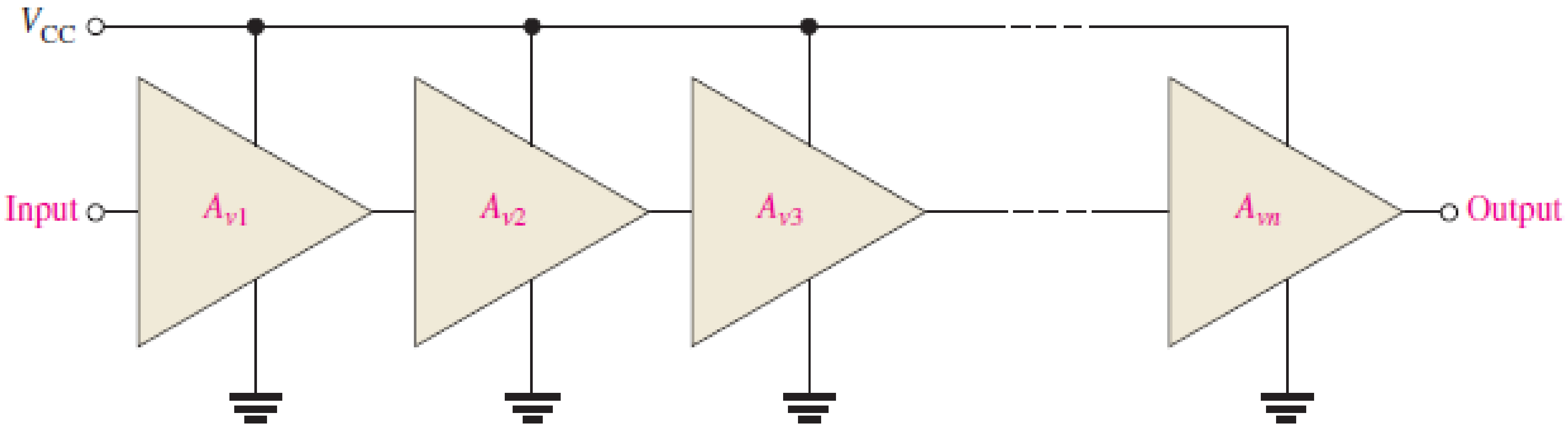
Multistage (Cascaded) Amplifiers

Multistage Voltage Gain

The overall voltage gain, A'_v, of cascaded amplifiers, as shown in Figure 6–33, is the product of the individual voltage gains.

$$A'_v = A_{v1}A_{v2}A_{v3} \ldots A_{vn}$$

where n is the number of stages.



▲ FIGURE 6–33

Cascaded amplifiers. Each triangular symbol represents a separate amplifier.

Multistage (Cascaded) Amplifiers

Amplifier voltage gain is often expressed in **decibels** (dB) as follows:

$$A_{v(\mathrm{dB})} = 20 \log A_v$$

This is particularly useful in **multistage** systems because the overall voltage gain in dB is the *sum* of the individual voltage gains in dB.

$$A'_{v(\mathrm{dB})} = A_{v1(\mathrm{dB})} + A_{v2(\mathrm{dB})} + \cdots + A_{vn(\mathrm{dB})}$$

Study Example 6-12

How to connect multistage transistor amplifiers ?

- In Multi-stage amplifiers, the output of first stage is coupled to the input of next stage using a coupling device (capacitor or transformer).

This process of joining two amplifier stages using a coupling device can be called as **Cascading.**

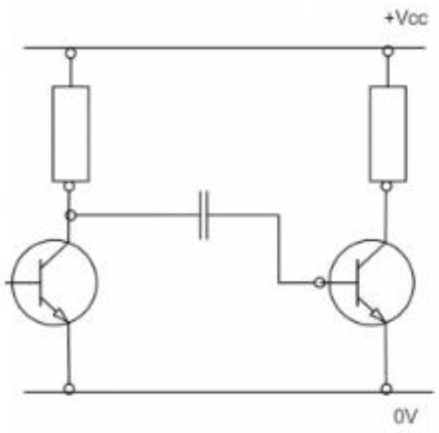
What is the purpose of coupling device?

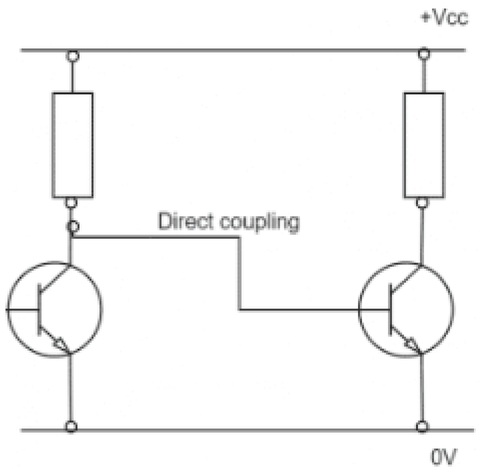
The basic purposes of a coupling device are

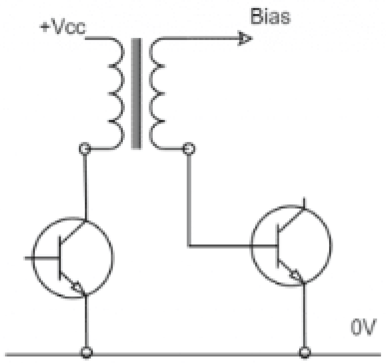
- To transfer the AC from the output of one stage to the input of next stage.
- To block the DC to pass from the output of one stage to the input of next stage, which means to isolate the DC conditions.

- **What are the types of coupling?**

1) Capacitor coupling
2) Direct coupling
3) Transformer coupling





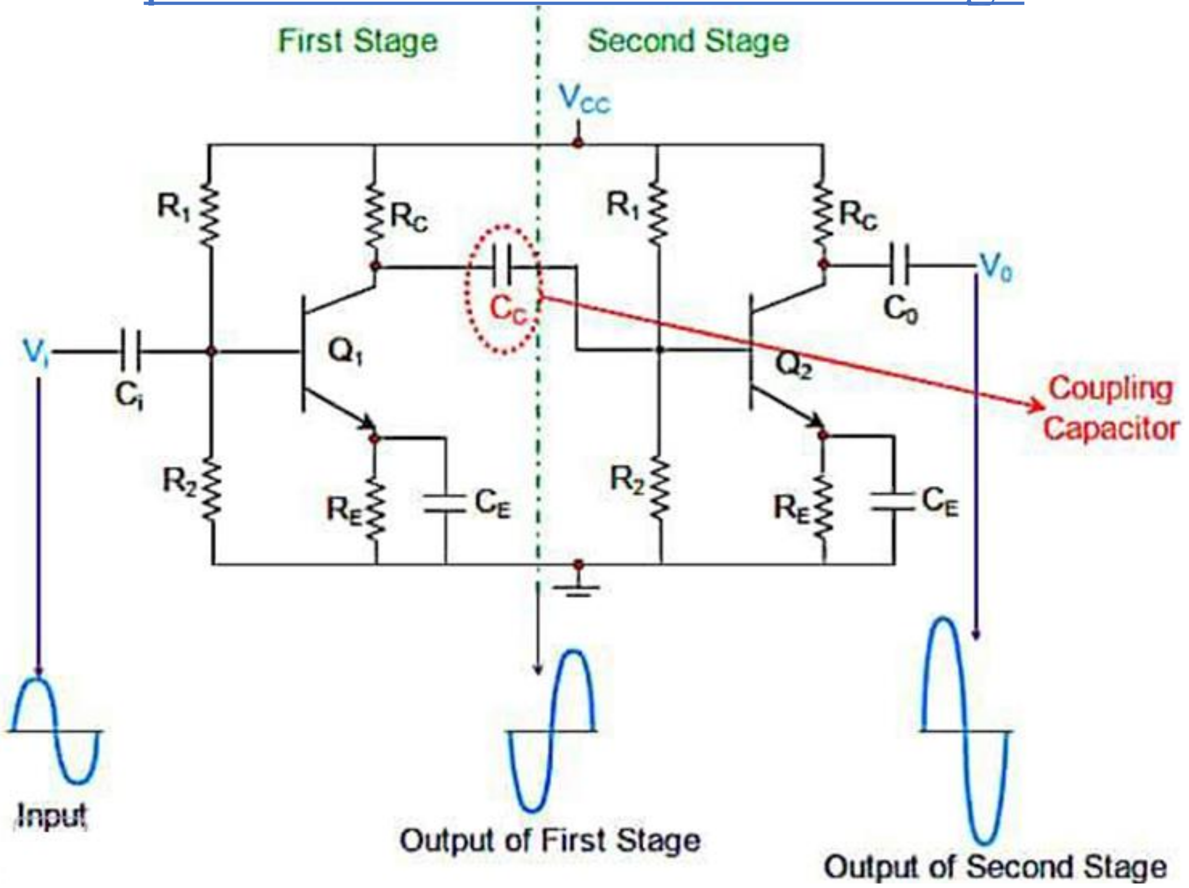


Multistage Amplifiers/ Capacitor Coupling

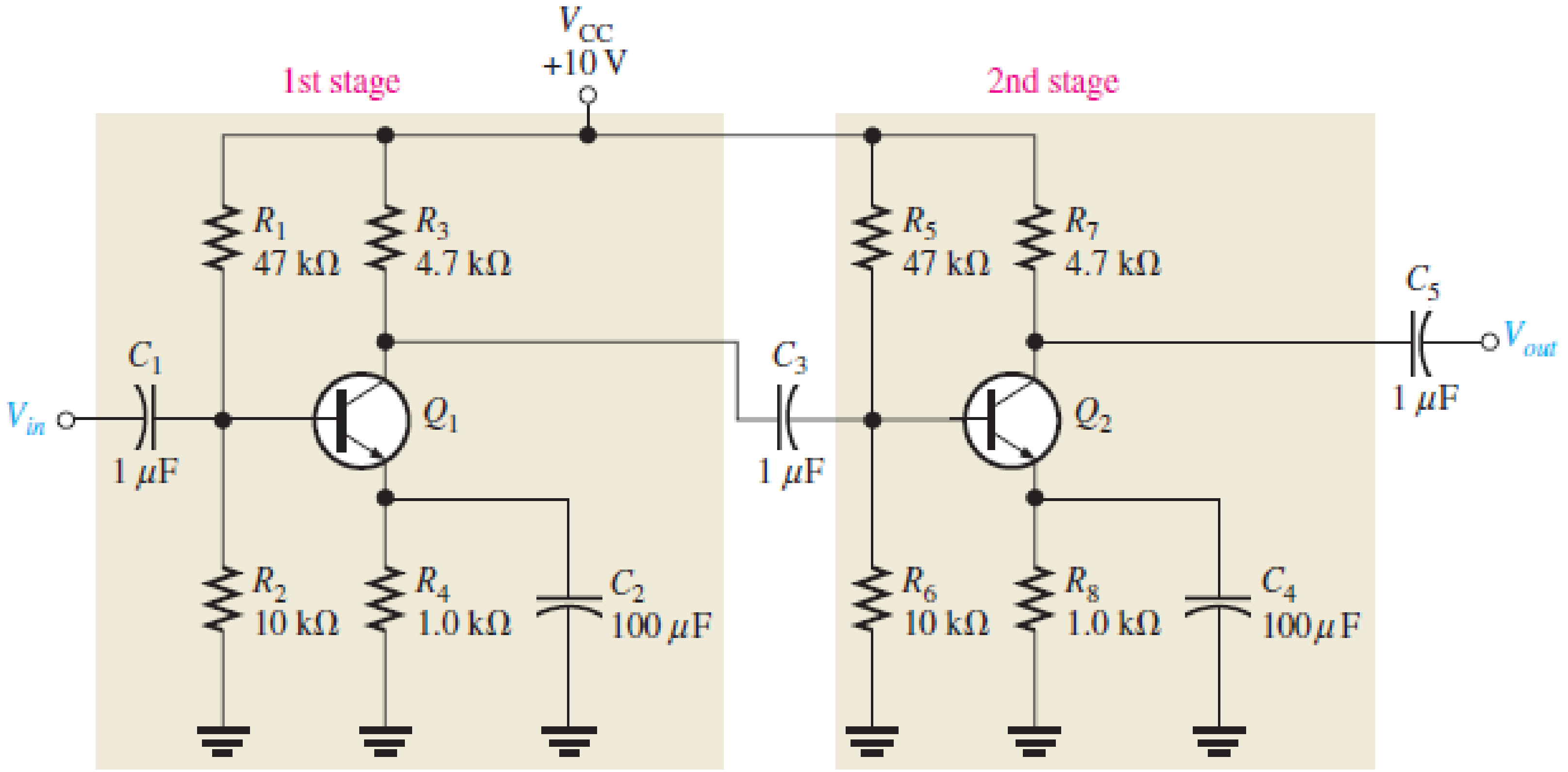
- Capacitor coupling is **the most widely used method of coupling in multistage amplifiers**.
- The coupling capacitor,

  1) Isolates the two stages from a dc viewpoint prevents the dc bias of one stage from affecting that of the other

  2) Allows the ac signal to pass without attenuation because $X_C \cong 0$ at the frequency of operation.



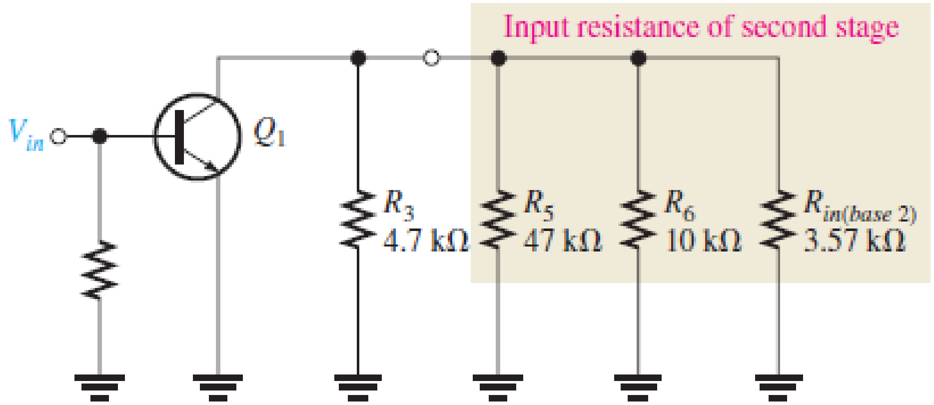
Multistage Amplifiers/ Capacitor Coupling



$\beta_{DC} = \beta_{ac} = 150$ for Q_1 and Q_2

Calculate the overall voltage gain

Multistage Amplifiers/ Capacitor Coupling



Voltage Gain of the First Stage The ac collector resistance of the first stage is

$$R_{c1} = R_3 \| R_5 \| R_6 \| R_{in(base2)}$$

Remember that lowercase italic subscripts denote ac quantities such as for R_c.

You can verify that $I_E = 1.05$ mA, $r'_e = 23.8\,\Omega$, and $R_{in(base2)} = 3.57$ kΩ. The effective ac collector resistance of the first stage is as follows:

$$R_{c1} = 4.7\text{ k}\Omega \| 47\text{ k}\Omega \| 10\text{ k}\Omega \| 3.57\text{ k}\Omega = 1.63\text{ k}\Omega$$

Therefore, the base-to-collector voltage gain of the first stage is

$$A_{v1} = \frac{R_{c1}}{r'_e} = \frac{1.63\text{ k}\Omega}{23.8\ \Omega} = 68.5$$

Multistage Amplifiers/ Capacitor Coupling

Voltage Gain of the Second Stage The second stage has no load resistor, so the ac collector resistance is R_7, and the gain is

$$A_{v2} = \frac{R_7}{r'_e} = \frac{4.7\ \text{k}\Omega}{23.8\ \Omega} = 197$$

Compare this to the gain of the first stage, and notice how much the loading from the second stage reduced the gain.

Overall Voltage Gain The overall amplifier gain with no load on the output is

$$A'_v = A_{v1}A_{v2} = (68.5)(197) \cong 13{,}495$$

If an input signal of 100 μV, for example, is applied to the first stage and if there is no attenuation in the input base circuit due to the source resistance, an output from the second stage of (100 μV)(13,495) $\cong$ 1.35 V will result. The overall voltage gain can be expressed in dB as follows:

$$A'_{v(\text{dB})} = 20 \log (13{,}495) = 82.6\ \text{dB}$$

Multistage Amplifiers/ Direct Coupling

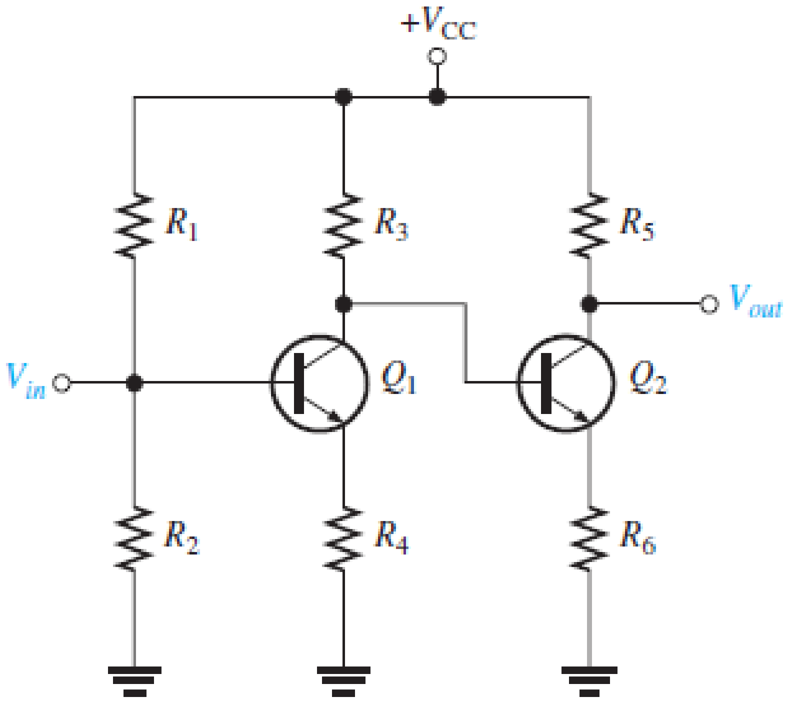
1) There are no coupling or bypass capacitors in this circuit.
2) The dc collector voltage of the first stage provides the base-bias voltage for the second stage.
3) This type of amplifier has **a better low-frequency response than the capacitively coupled type** in which:

The reactance of coupling and bypass capacitors at very low frequencies may become excessive.

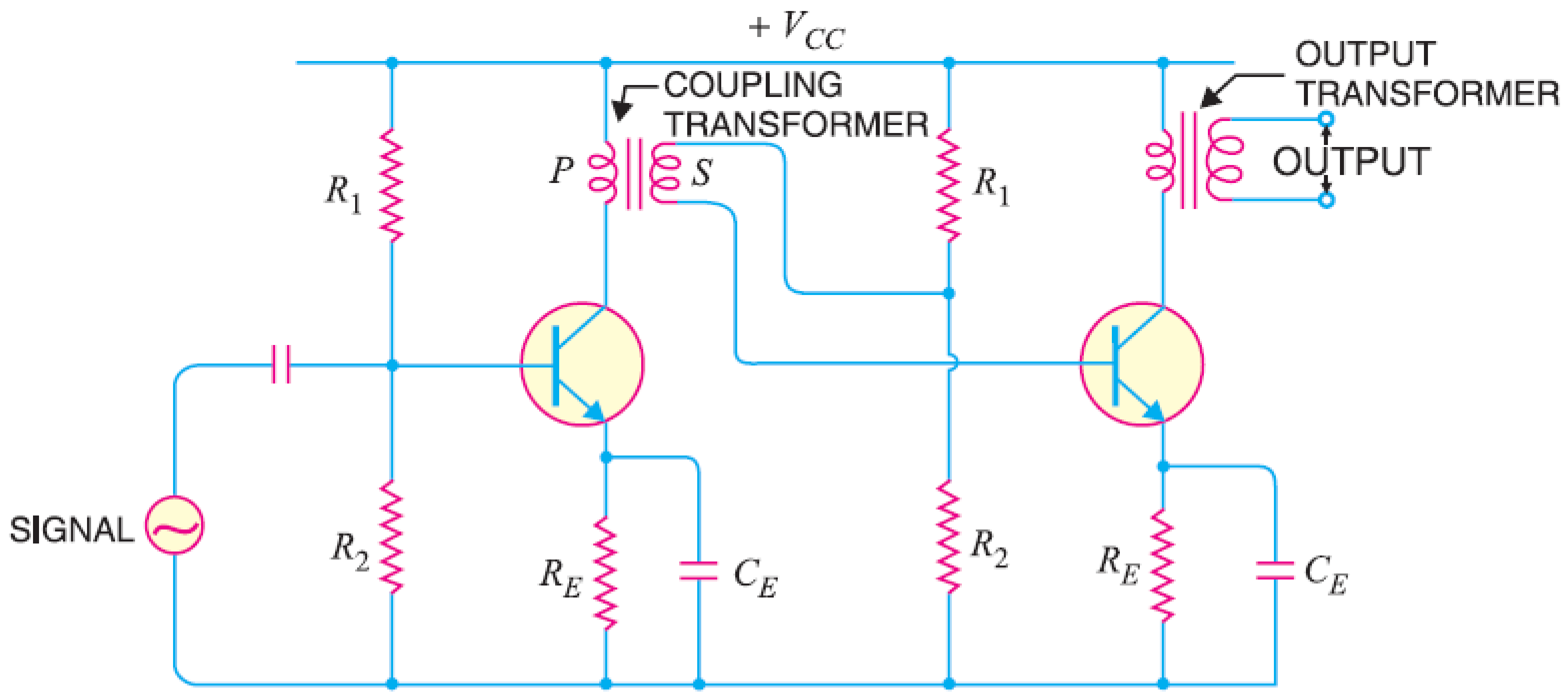
The increased reactance of capacitors at lower frequencies produces gain reduction in capacitively coupled amplifiers.

4) The disadvantage:

Small changes in the dc bias voltages from temperature effects are amplified by the succeeding stages, which can result in a significant drift in the dc levels throughout the circuit.



Multistage Amplifiers/ Transformer Coupling



- There is no capacitor used in this method of coupling because the transformer itself conveys the AC component directly to the base of second stage.

- DC biasing of individual stages will remain unchanged even after cascading.

Multistage Amplifiers/ Transformer Coupling

➢ Advantages:

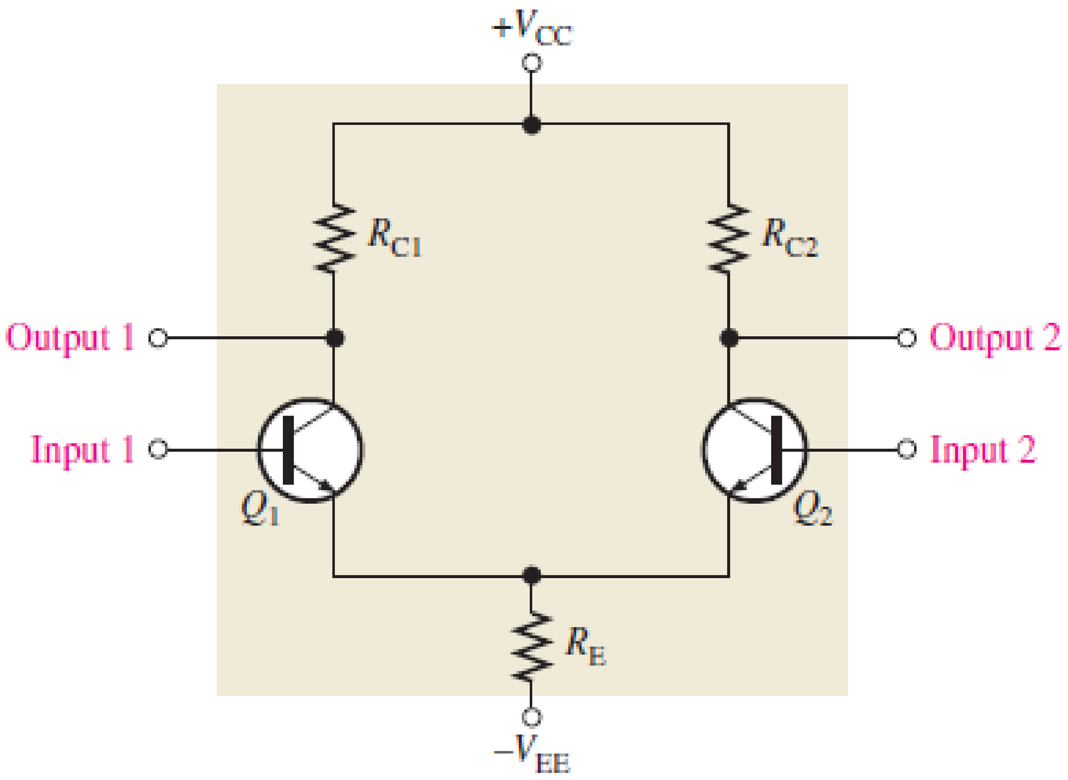
1) Impedance matching.
2) Electrical Isolation.
3) Higher voltage gain than capacitor coupled amplifiers.
4) No loss in collector resistor (replaced by primary winding with low resistance).

➢ Disadvantages:

1) Coupling transformers are expensive and bulky.
2) Though the gain is high, it varies considerably with frequency.
3) Hence a poor frequency response (frequency response is not perfectly flat).

The Differential Amplifier

- A **differential amplifier** is an amplifier that produces outputs that are a function of the difference between two input voltages.
- The differential amplifier has two basic modes of operation:
  - Differential (in which the two inputs are different)
  - Common mode (in which the two inputs are the same).



The Differential Amplifiers \ **Basic Operation**

$$I_{E1} = I_{E2}$$

Since both emitter currents combine through R_E,

$$I_{E1} = I_{E2} = \frac{I_{R_E}}{2}$$

where

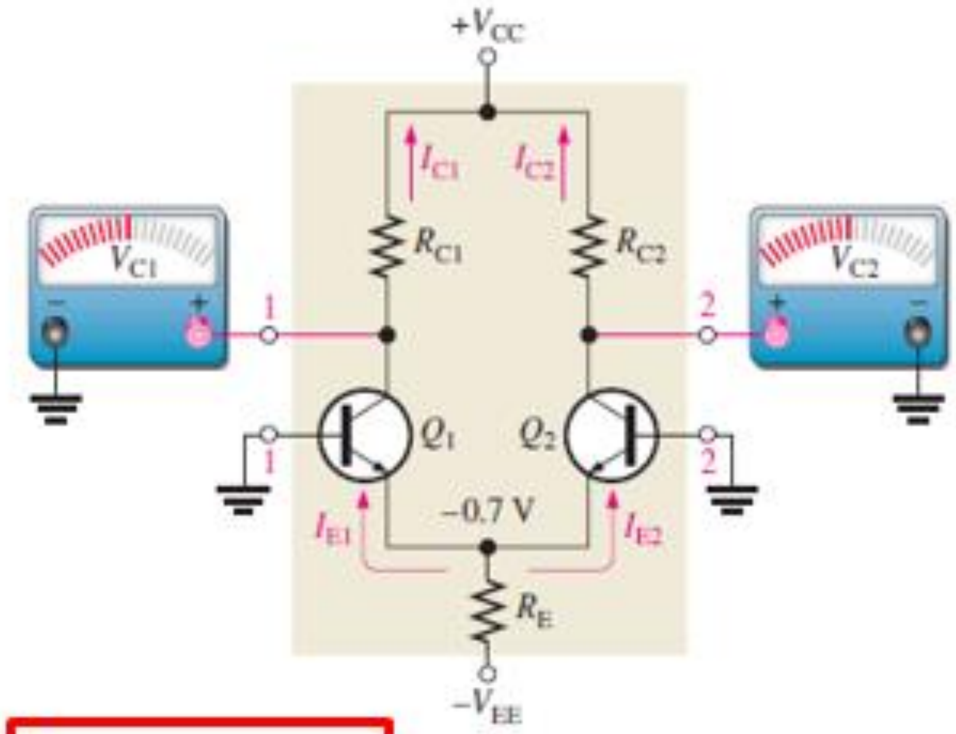
$$I_{R_E} = \frac{V_E - V_{EE}}{R_E}$$

Based on the approximation that $I_C \cong I_E$,

$$I_{C1} = I_{C2} \cong \frac{I_{R_E}}{2}$$

Since both collector currents and both collector resistors are equal (when the input voltage is zero),

$$V_{C1} = V_{C2} = V_{CC} - I_{C1}R_{C1}$$



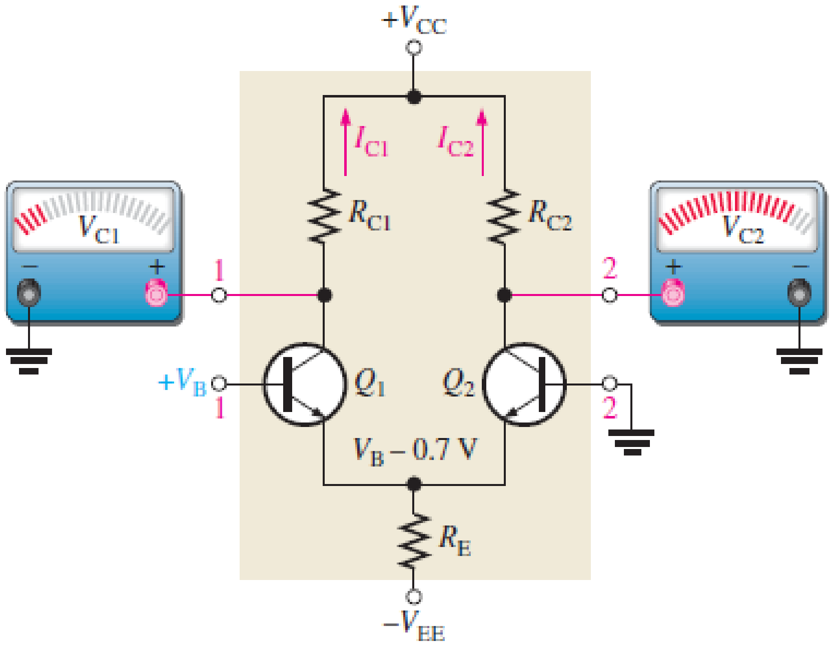
(a) Both inputs grounded

The Differential Amplifiers \ **Basic Operation**

Next, input 2 is left grounded, and a positive bias voltage is applied to input 1, as shown in Figure 6–38(b). The positive voltage on the base of Q_1 increases I_{C1} and raises the emitter voltage to

$$V_E = V_B - 0.7\text{ V}$$

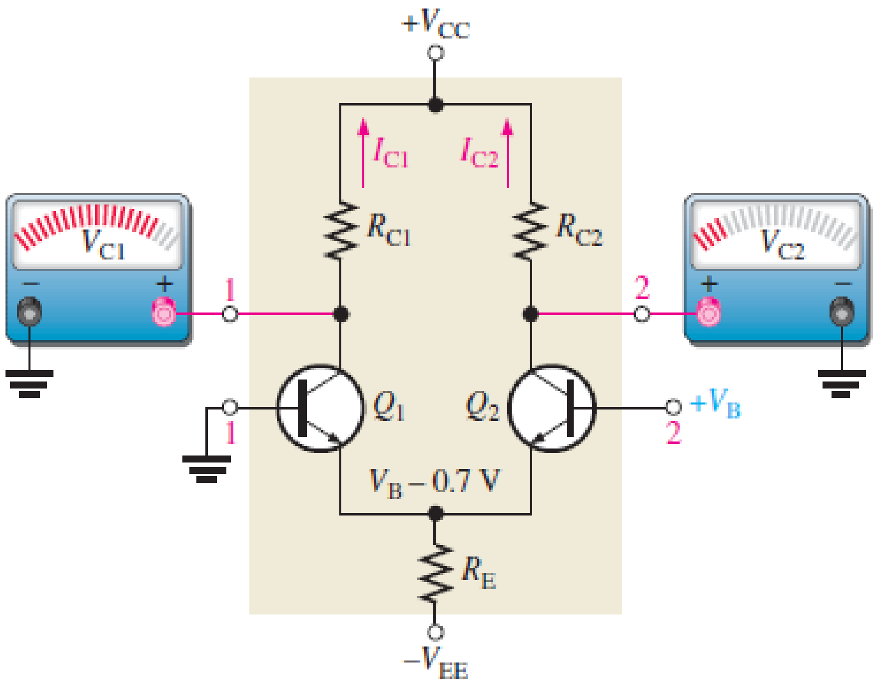
This action reduces the forward bias (V_{BE}) of Q_2 because its base is held at 0 V (ground), thus causing I_{C2} to decrease. The net result is that the increase in I_{C1} causes a decrease in V_{C1}, and the decrease in I_{C2} causes an increase in V_{C2}, as shown.



(b) Bias voltage on input 1 with input 2 grounded

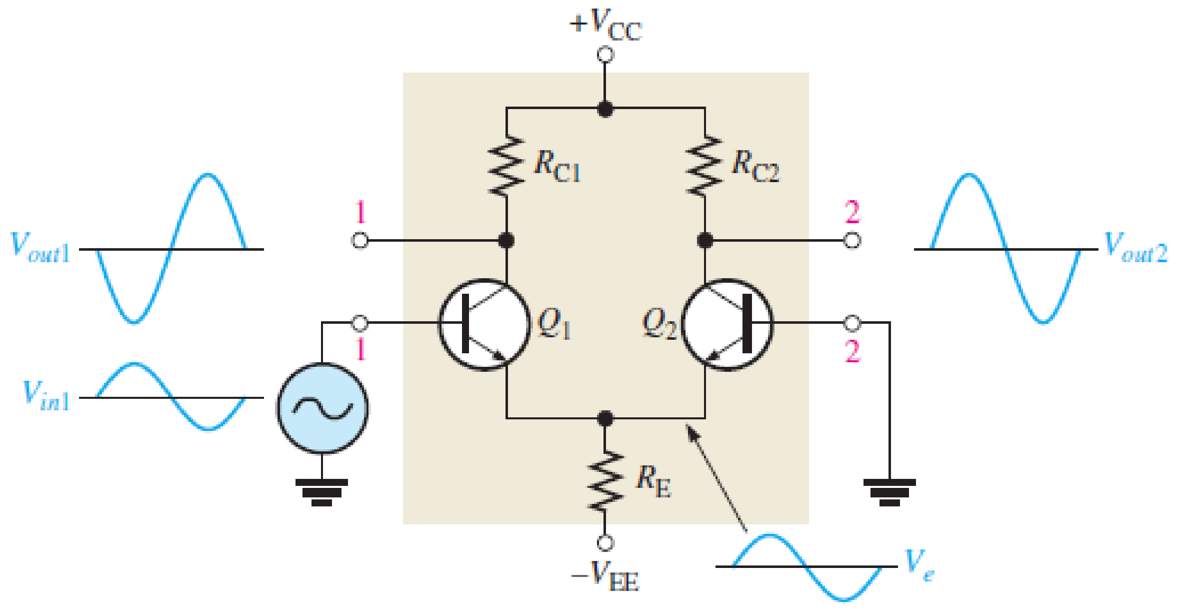
The Differential Amplifiers \ **Basic Operation**

Finally, input 1 is grounded and a positive bias voltage is applied to input 2, as shown in Figure 6–38(c). The positive bias voltage causes Q_2 to conduct more, thus increasing I_{C2}. Also, the emitter voltage is raised. This reduces the forward bias of Q_1, since its base is held at ground, and causes I_{C1} to decrease. The result is that the increase in I_{C2} produces a decrease in V_{C2}, and the decrease in I_{C1} causes V_{C1} to increase, as shown.



(c) Bias voltage on input 2 with input 1 grounded

The Differential Amplifiers \ Modes of Operation

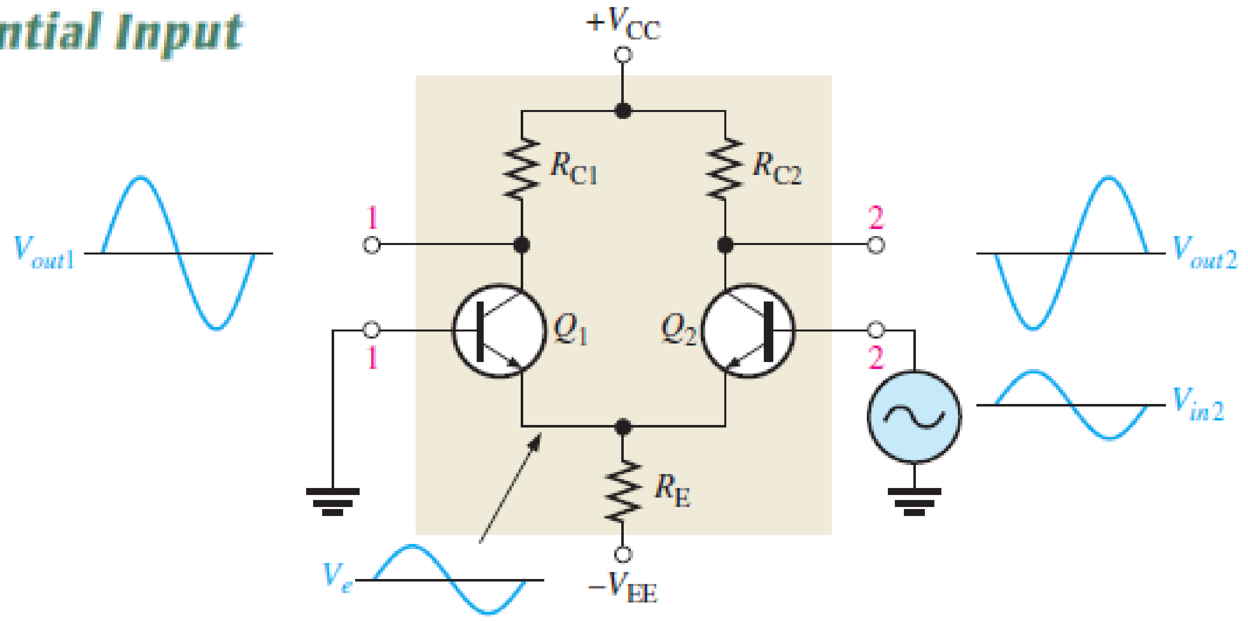


(a)

Single-Ended Differential Input When a diff-amp is operated with this input configuration, one input is grounded and the signal voltage is applied only to the other input, as shown in Figure 6–39. In the case where the signal voltage is applied to input 1 as in part (a), an inverted, amplified signal voltage appears at output 1 as shown. Also, a signal voltage appears in phase at the emitter of Q_1. Since the emitters of Q_1 and Q_2 are common, the emitter signal becomes an input to Q_2, which functions as a common-base amplifier. The signal is amplified by Q_2 and appears, noninverted, at output 2. This action is illustrated in part (a).

The Differential Amplifiers \ Modes of Operation

Single-Ended Differential Input



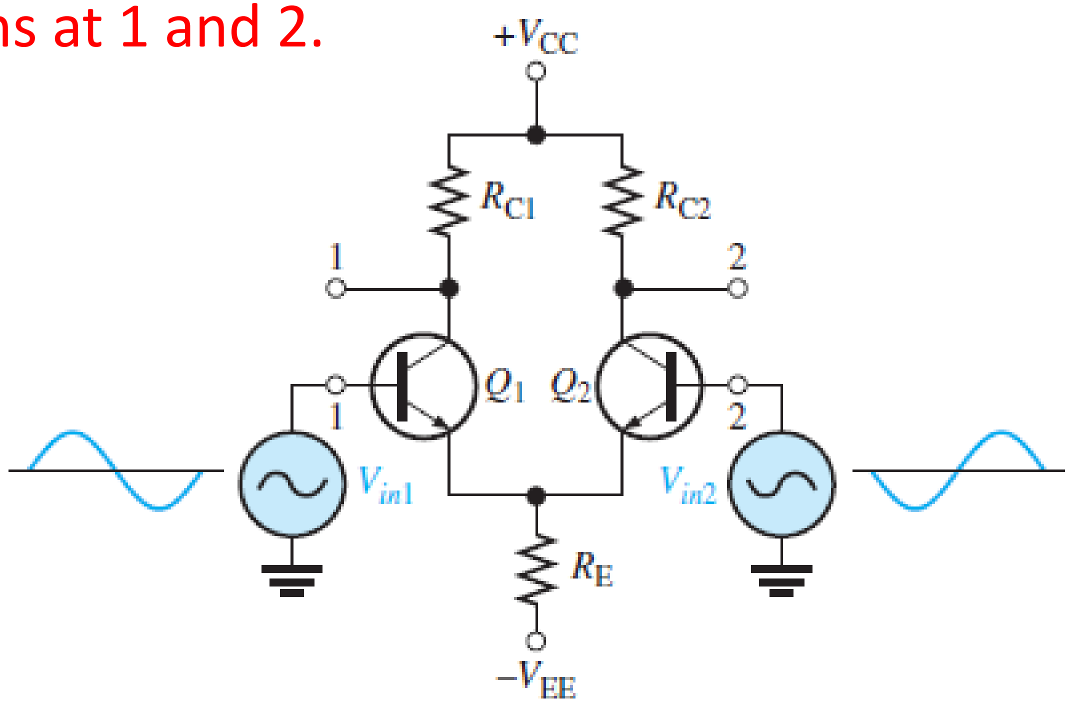
(b)

In the case where the signal is applied to input 2 with input 1 grounded, as in Figure 6–39(b), an inverted, amplified signal voltage appears at output 2. In this situation, Q_1 acts as a common-base amplifier, and a noninverted, amplified signal appears at output 1.

The Differential Amplifiers \ Modes of Operation

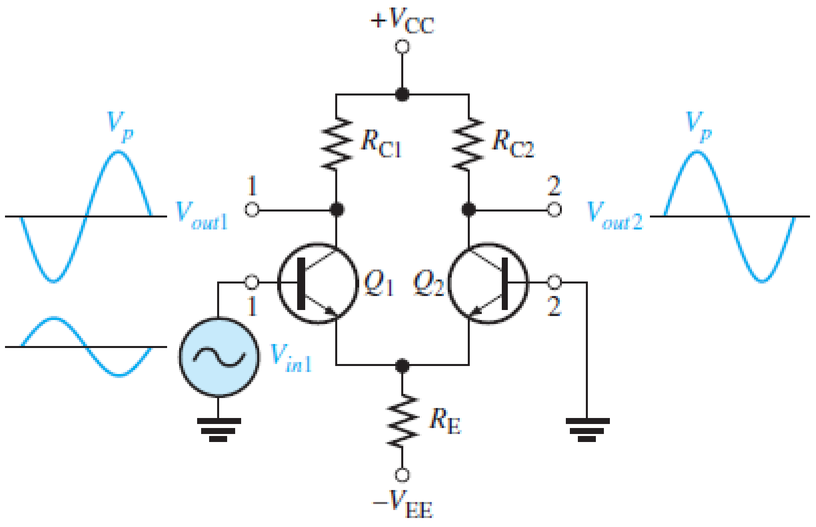
Double-Ended Differential Inputs In this input configuration, two opposite-polarity (out-of-phase) signals are applied to the inputs, as shown in Figure 6–40(a). Each input affects the outputs, as you will see in the following discussion.

Draw the output waveforms at 1 and 2.

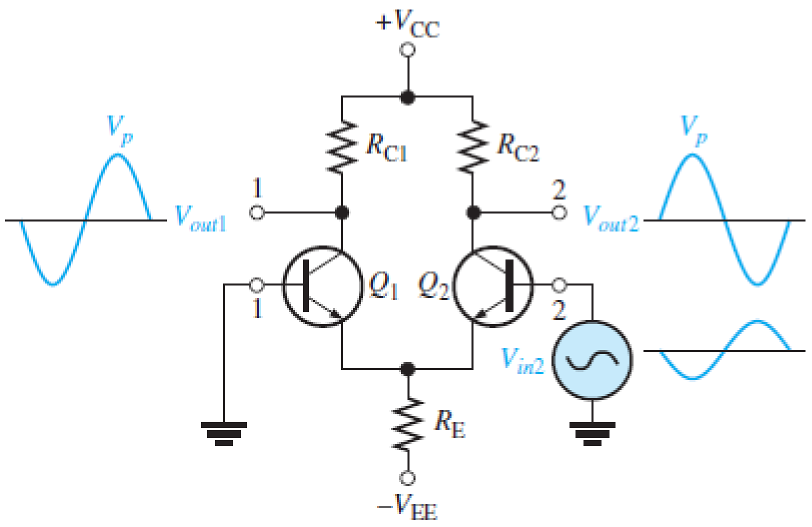


(a) Differential inputs (180° out of phase)

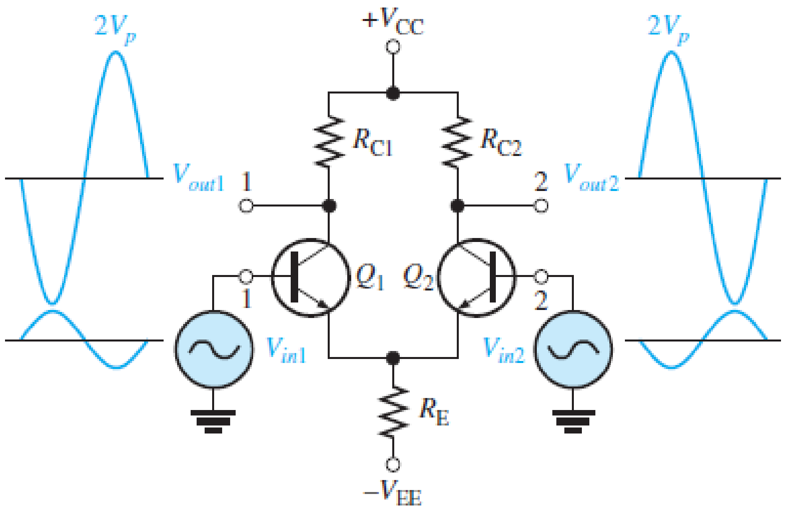
The Differential Amplifiers \ **Modes of Operation**



(b) Outputs due to V_{in1}



(c) Outputs due to V_{in2}

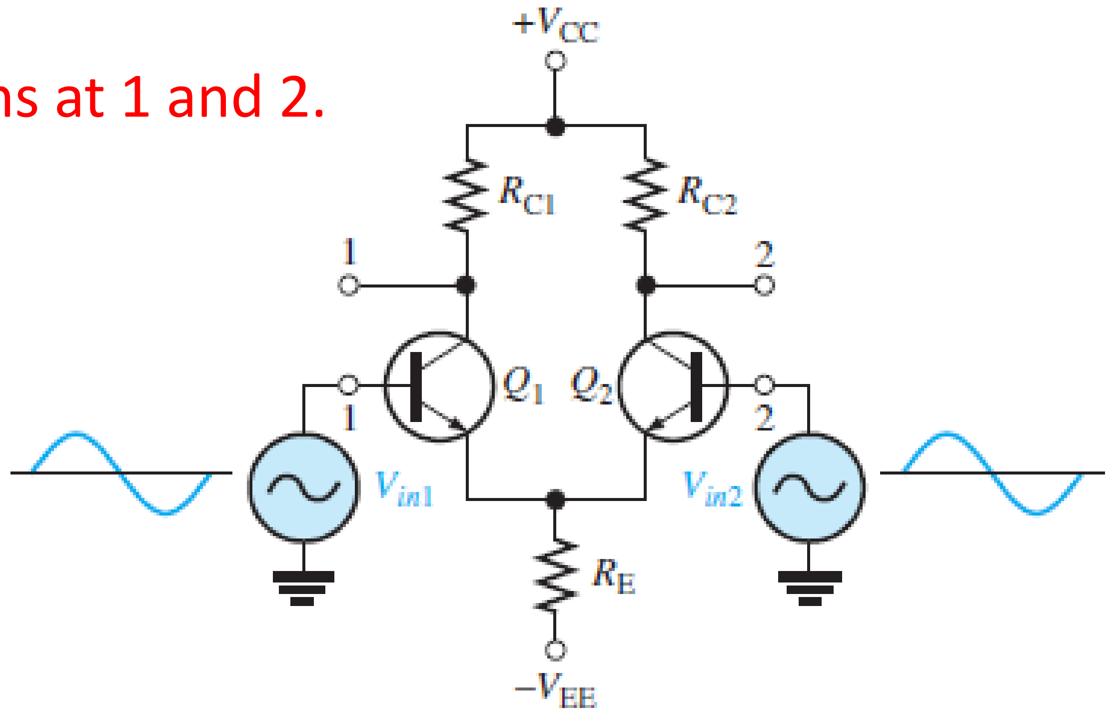


(d) Total outputs

The Differential Amplifiers \ Modes of Operation

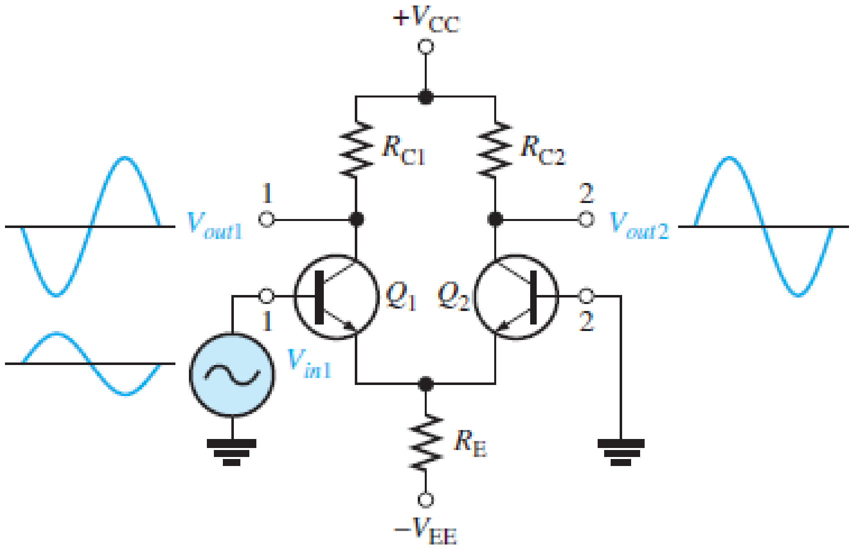
Common-Mode Inputs One of the most important aspects of the operation of a diff-amp can be seen by considering the **common-mode** condition where two signal voltages of the same phase, frequency, and amplitude are applied to the two inputs, as shown in Figure 6–41(a). Again, by considering each input signal as acting alone, you can understand the basic operation.

Draw the output waveforms at 1 and 2.

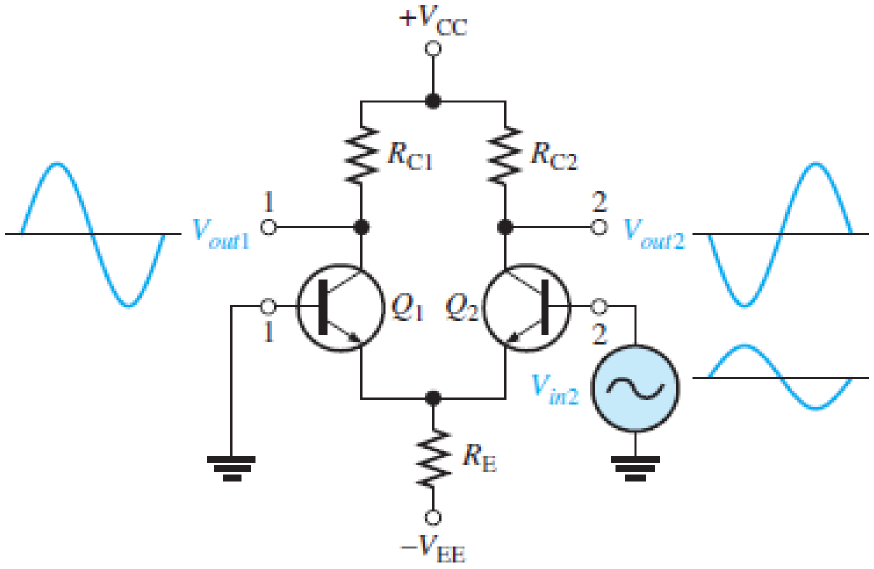


(a) Common-mode inputs (in phase)

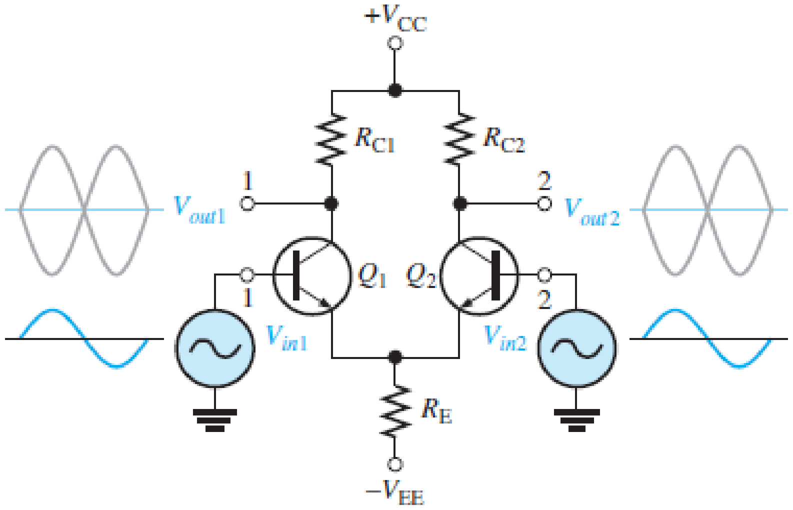
The Differential Amplifiers \ Modes of Operation



(b) Outputs due to V_{in1}



(c) Outputs due to V_{in2}



(d) Outputs due to V_{in1} and V_{in2} cancel because they are equal in amplitude but opposite in phase. The resulting outputs are 0 V ac.

The Differential Amplifiers \ **Modes of Operation**

➢ What is the importance of the Common mode operation?

- This action, in the previous slide, is called ***common-mode rejection***.
- Its importance lies in the situation where an unwanted signal appears commonly on both diff-amp inputs.
- **Common-mode rejection means that** this unwanted signal will not appear on the outputs and distort the desired signal.
- Common-mode signals (noise) generally are the result of the pick-up of radiated energy on the input lines from adjacent lines, the 60 Hz power line, or other sources.

The Differential Amplifiers \ Modes of Operation

- **Common-Mode Rejection Ratio (CMRR)**

- **Desired signals** appear on only one input or with opposite polarities on both input lines.
- These desired signals are amplified and appear on the outputs .
- **Unwanted signals (noise)** appearing with the same polarity on both input lines.
- Unwanted signals are essentially cancelled by the diff-amp and do not appear on the outputs.
- **CMRR:** The measure of an amplifier's ability to reject common-mode signals.
- **Ideally**, a diff-amp provides **a very high gain for desired signals** (single-ended or differential) and **zero gain for common-mode signals**.
- **Practical** diff-amps, however, do exhibit **a very small common-mode gain (usually much less than 1**), while providing **a high differential voltage gain (usually several thousand).**

$$\mathrm{CMRR} = \frac{A_{v(d)}}{A_{cm}} \qquad \mathrm{CMRR} = 20\log\left(\frac{A_{v(d)}}{A_{cm}}\right)$$

- $A_{v(d)}$ is the differential voltage gain and A_{cm} is the common-mode gain.
- The higher the CMRR, the better.