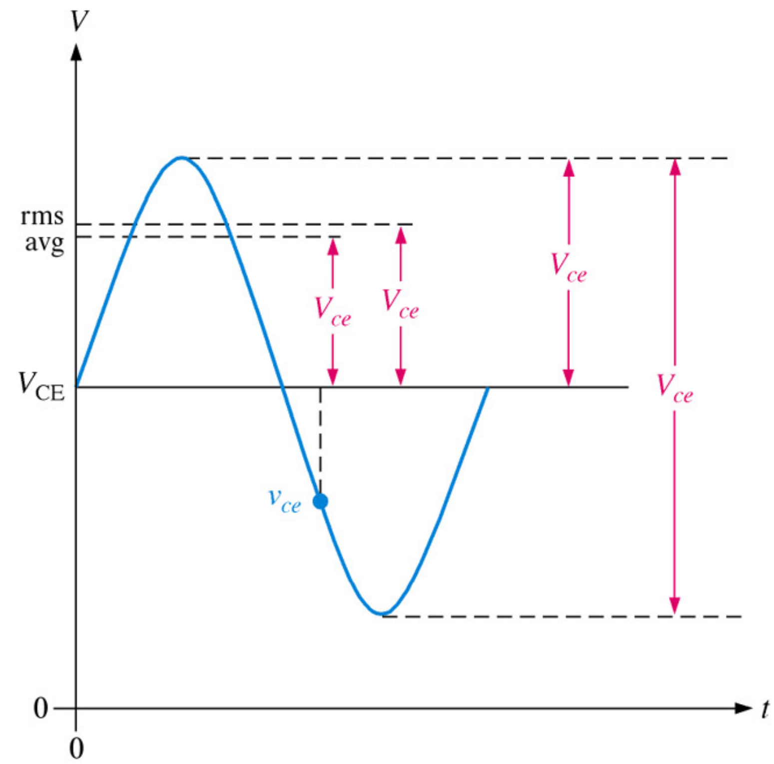
BJT Amplifier

One of the primary uses of a transistor is to amplify ac signals. This could be an audio signal or perhaps some high frequency radio signal. It has to be able to do this without distorting the original input.

For the analysis of transistor circuits from both dc and ac perspectives, the ac subscripts are lower case and italicized. Instantaneous values use both italicized lower case letters and subscripts.

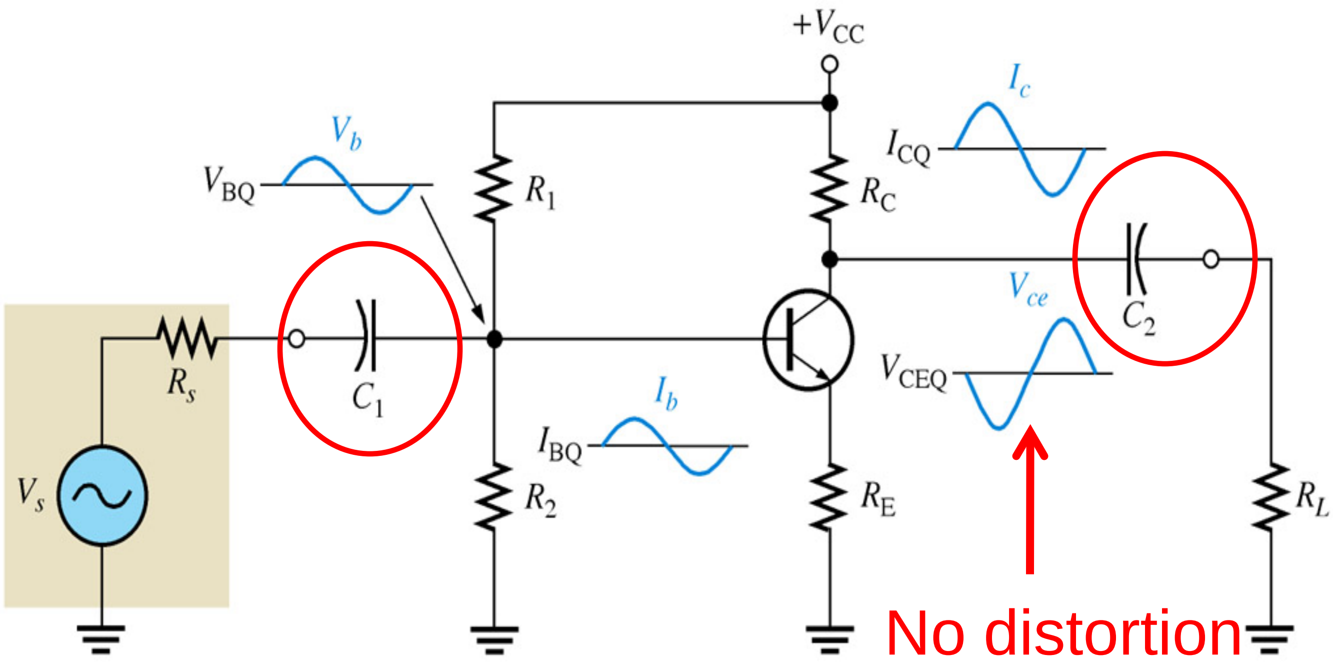


Linear Amplifier

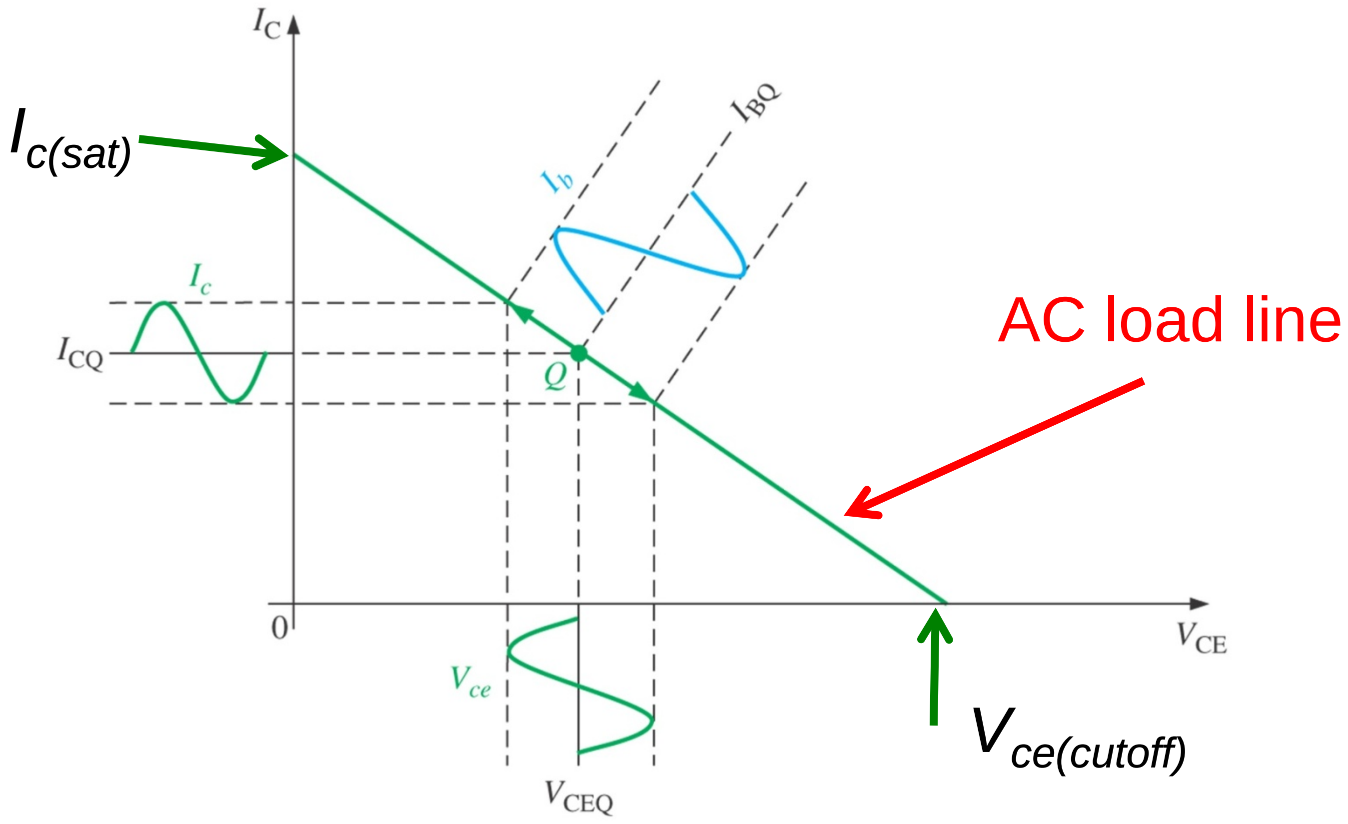
Recall from the previous chapter that the purpose of dc biasing was to establish the Q-point for operation. The collector curves and load lines help us to relate the Q-point and its proximity to cutoff and saturation. The Q-point is best established where the signal variations do not cause the transistor to go into saturation or cutoff.

What we are most interested in is the ac signal itself. Since the dc part of the overall signal is filtered out in most cases, we can view a transistor circuit in terms of just its ac component.

The boundary between cutoff and saturation is called the **linear region**. A transistor which operates in the linear region is called *a linear amplifier*. Note that *only the ac component reaches the load because of the capacitive coupling and that the output is 180º out of phase with input.*



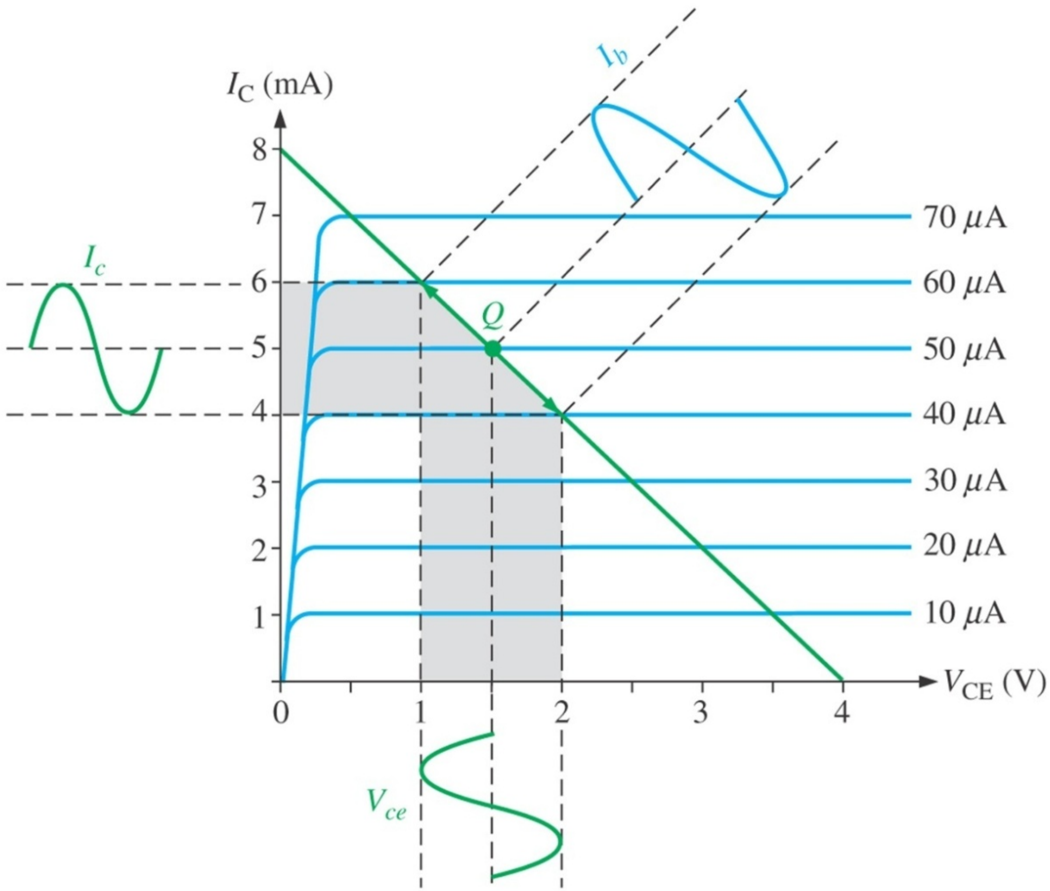
Note. Subscript Q represents Q-point



Graphical operation of the amplifier showing the variation of the base current, collector current, and collector-to-emitter voltage about their dc Q-point values. I_b and I_c are on different scales.

Example

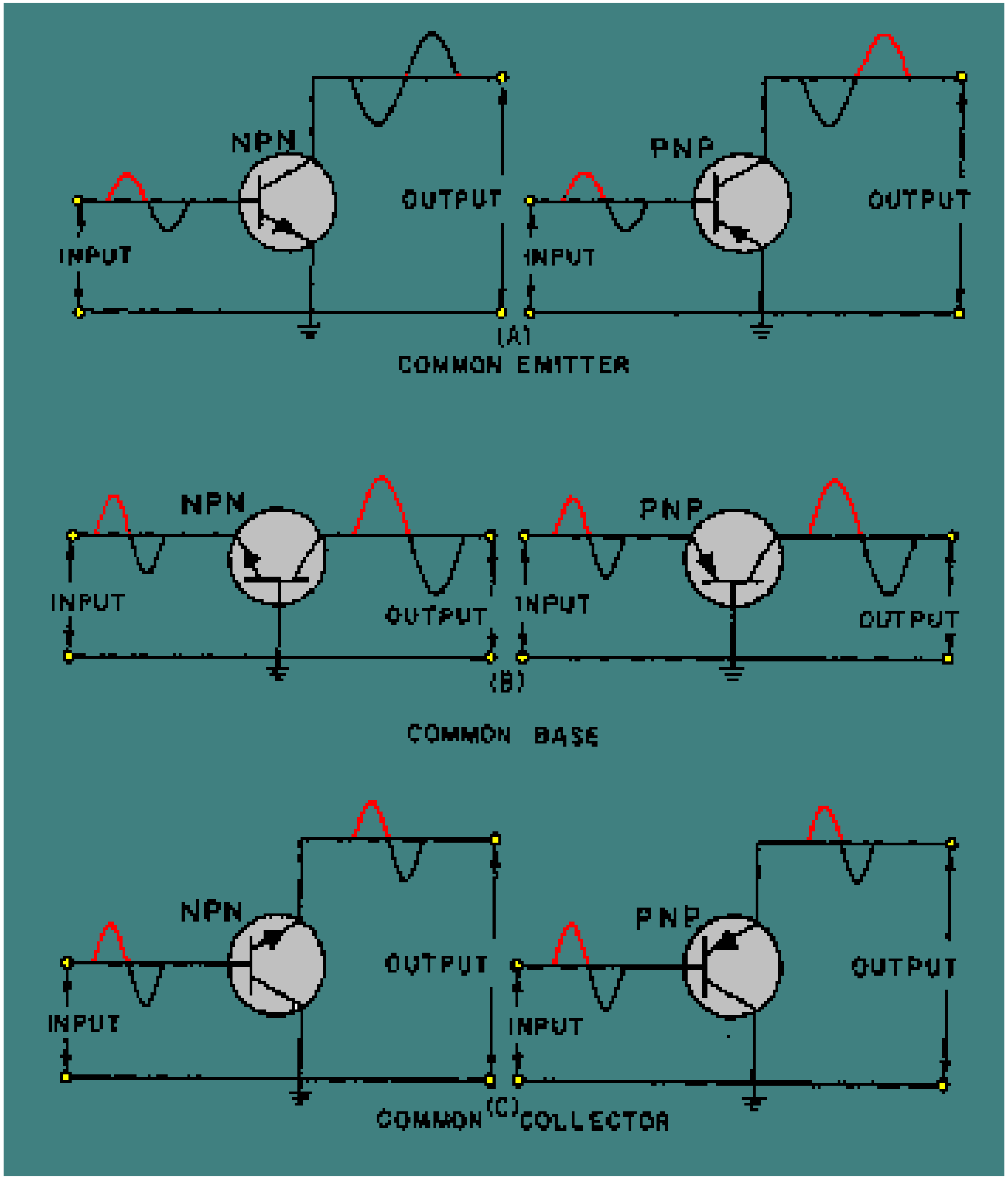
The ac load line of a certain amplifier extends 10µA above and below Q-point base current value of 50µA as shown. Determine the resulting peak-peak value of I_c and V_{ce}.



Amplifier Configuration

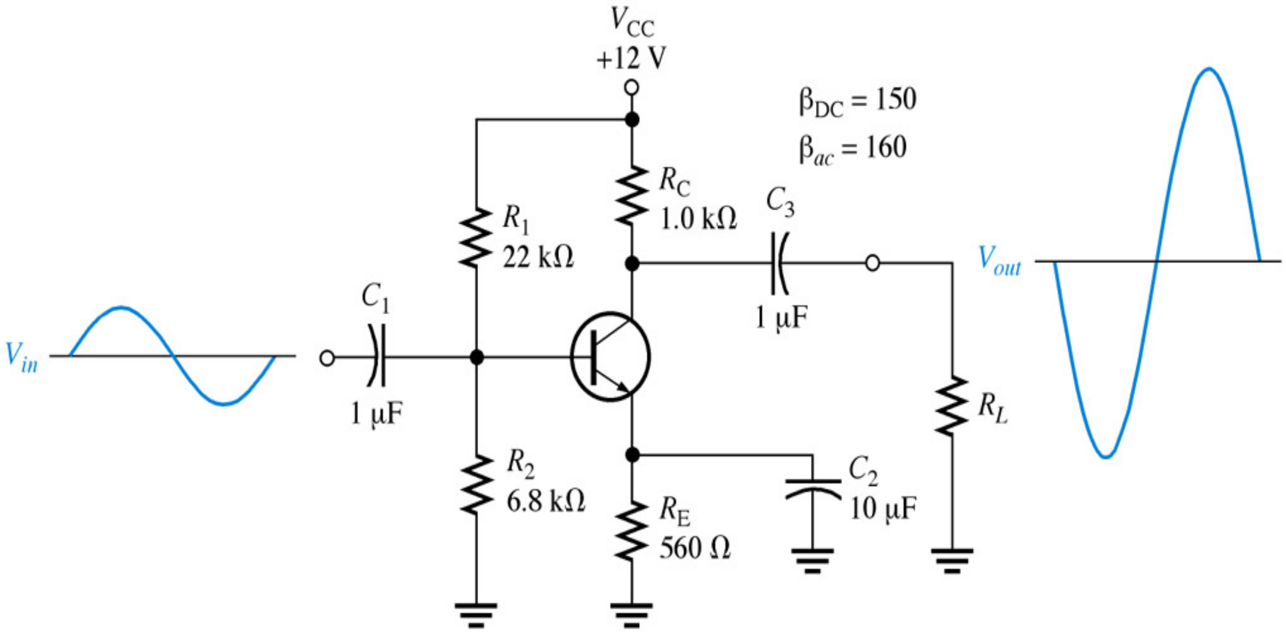
- Common-Emitter(CE) or Grounded Emitter
- Common-Collector(CC) or Grounded Collector
- Common-Base(CB) or Grounded Base

The term **common** is used to denote the element that is common to both input and output circuits, often **grounded**.


NPN
INPUT
OUTPUT
PNP
INPUT
OUTPUT
(A)
COMMON EMITTER
NPN
INPUT
OUTPUT
PNP
INPUT
OUTPUT
(B)
COMMON BASE
NPN
INPUT
OUTPUT
PNP
INPUT
OUTPUT
(C)
COMMON COLLECTOR

Common-Emitter Amplifier

The CE configuration has the emitter as the common terminal, or ground, to an ac signal.



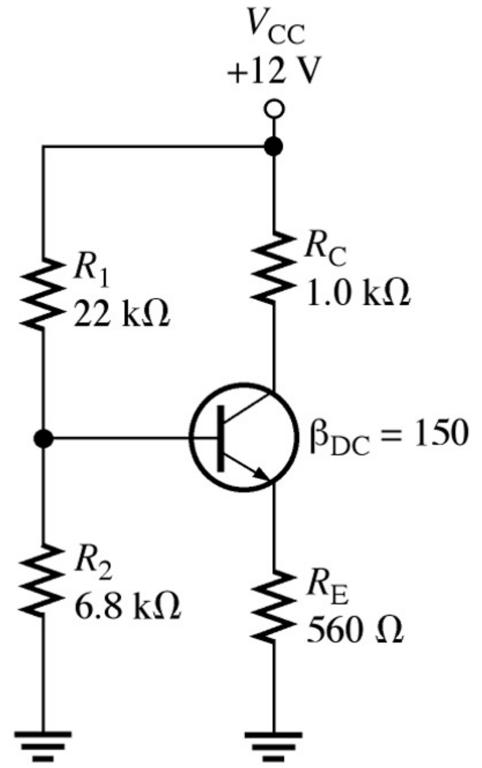
The common-emitter amplifier exhibits **high voltage and current gain**. The output signal is 180º out of phase with the input.

Note. The circuit analysis can be done by dc and ac analysis

CE Amplifier DC Analysis

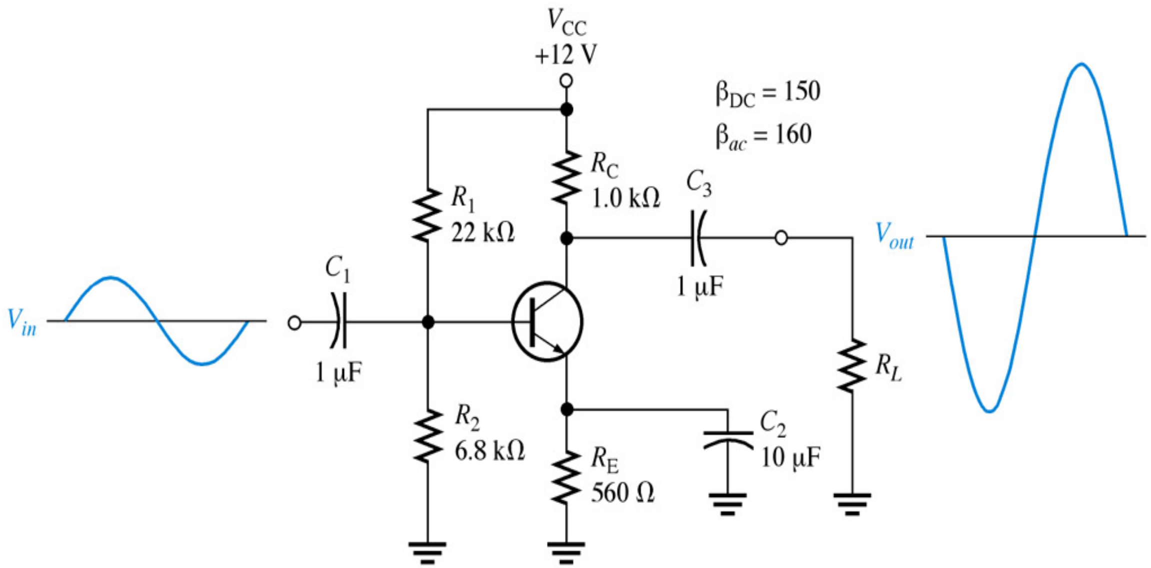
The dc component of the circuit "sees" only the part of the circuit that is within the boundaries of C_1, C_2, and C_3 as the dc will not pass through these components. The equivalent circuit for dc analysis is shown.

The methods for dc analysis are just are the same as dealing with *a voltage-divider circuit.*



Stiff voltage divider or not? [$R_{IN(BASE)} > 10R_2$]

Example



- Draw waveforms of V_B, V_E, I_E, V_{CE}

Transistor AC Model

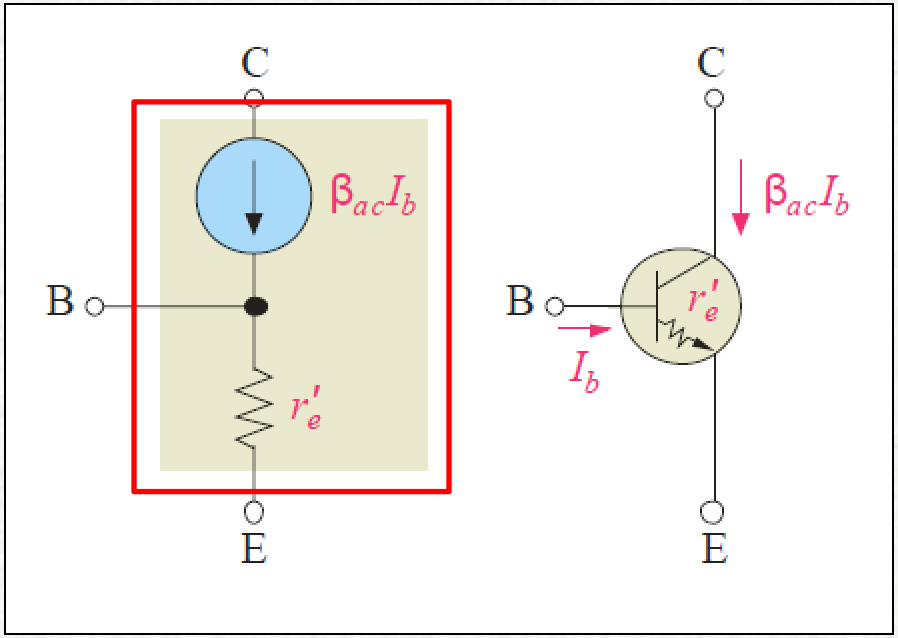
The five resistance parameters (r-parameters) can be used for detailed analysis of a BJT circuit. For most analysis work, the simplified r-parameters give good results.

The simplified r-parameters are shown in relation to the transistor model.

An important r-parameter is r_e'. It appears as a small ac resistance between the base and emitter.

$$r_e' = \frac{25\text{ mV}}{I_E}$$

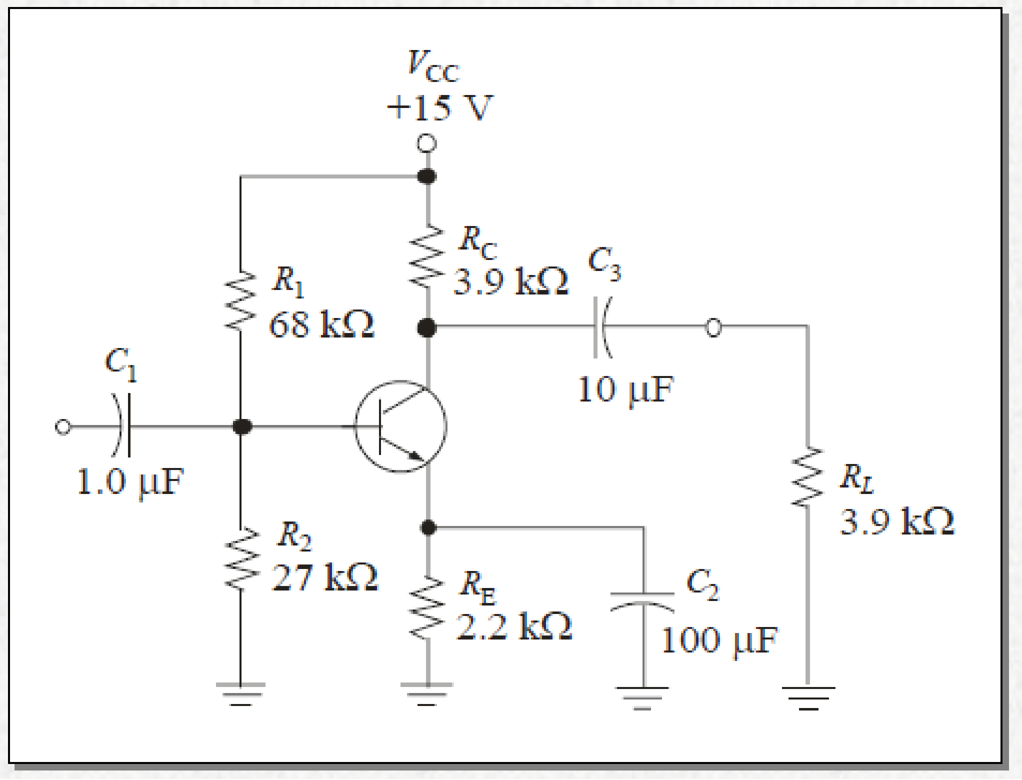
ac emitter resistance*



Note. * Approximate equation from p-n junction at 20 degree Celcius

Example

- What is r_e' for CE amplifier? Assume stiff voltage-divider bias.



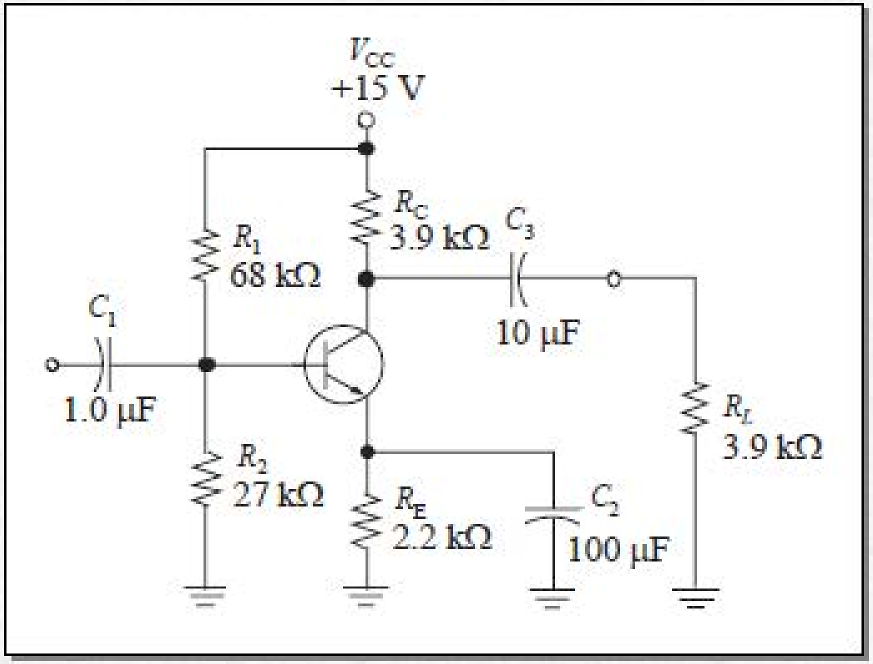
Solution:

$$V_B = \left(\frac{27\ \text{k}\Omega}{68\ \text{k}\Omega + 27\ \text{k}\Omega}\right) 15\ \text{V} = 4.26\ \text{V}$$

$$V_E = 4.26\ \text{V} - 0.7\ \text{V} = 3.56\ \text{V}$$

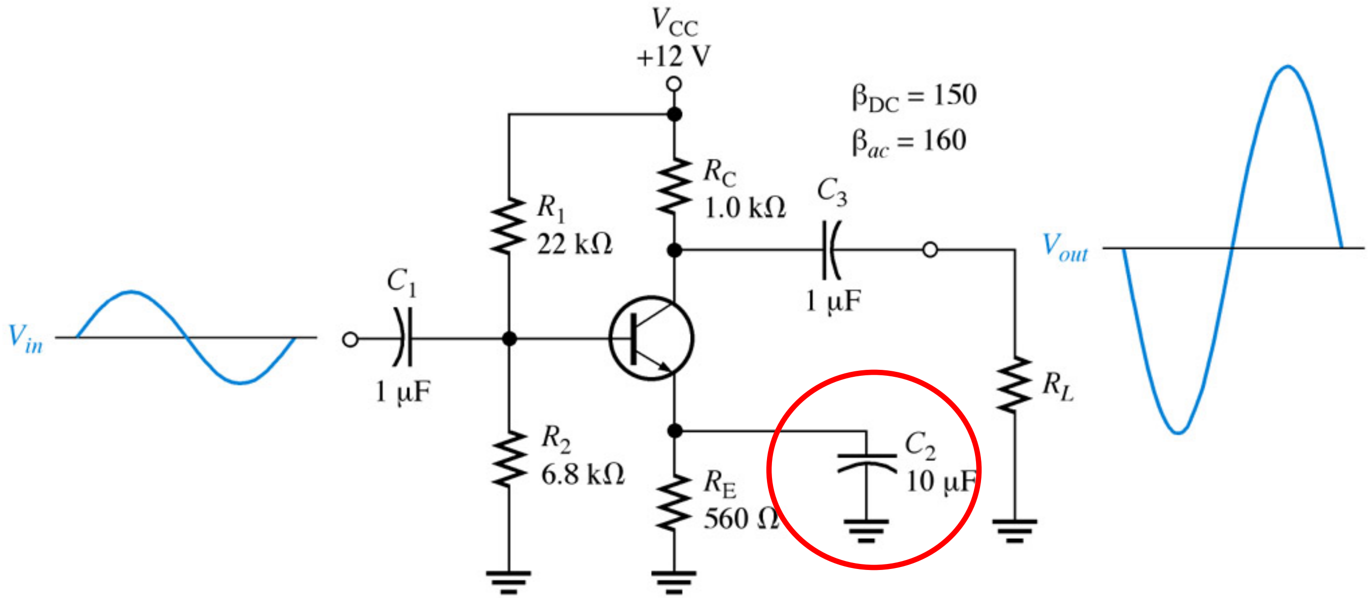
$$I_E = \frac{V_E}{R_E} = \frac{3.56\ \text{V}}{2.2\ \text{k}\Omega} = 1.62\ \text{mA}$$

$$r'_e = \frac{25\ \text{mV}}{I_E} = \frac{25\ \text{mV}}{1.62\ \text{mA}} = 15.4\ \Omega$$



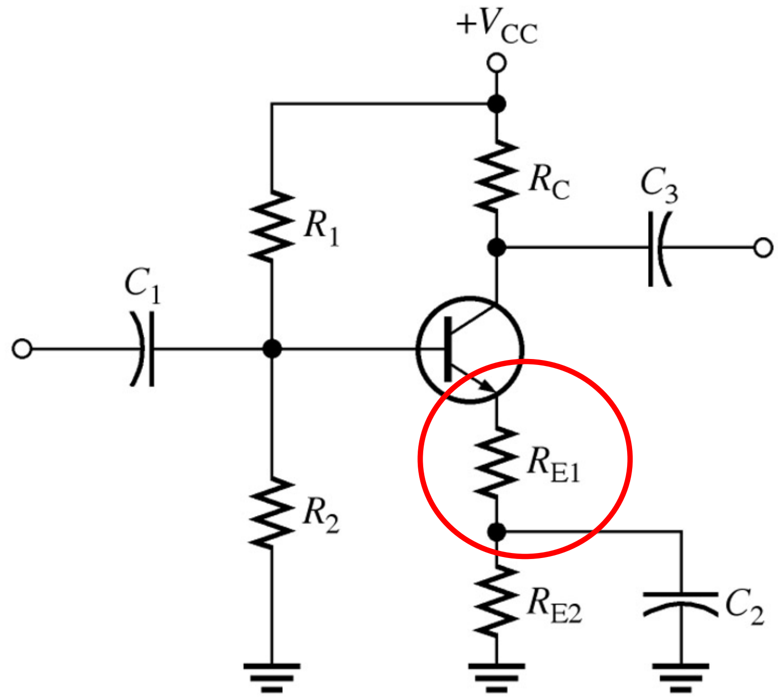
The emitter bypass capacitor helps increase the gain by allowing the ac signal to pass more easily.

The $X_{C(bypass)}$ should be about ten times less than R_E.



The bypass capacitor makes the gain unstable since transistor amplifier becomes more dependent on I_E. This effect can be swamped or somewhat alleviated by adding another emitter resistor(R_{E1}) to lower the voltage gain.

Stability is a measure of how well an amplifier maintain its design value over changes in temperature or for a transistor with a different β

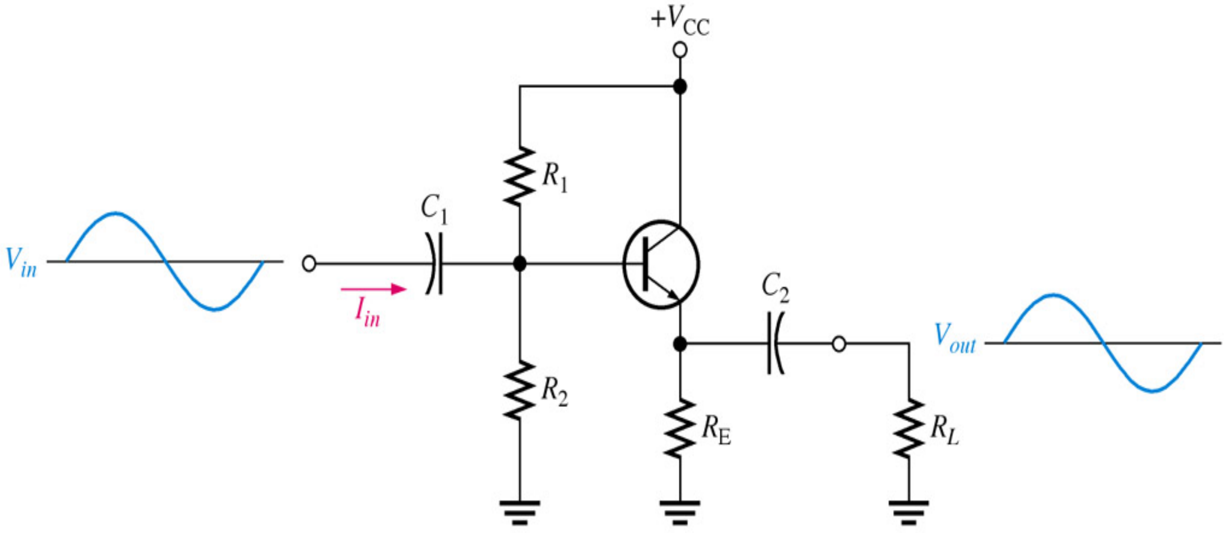


Applications

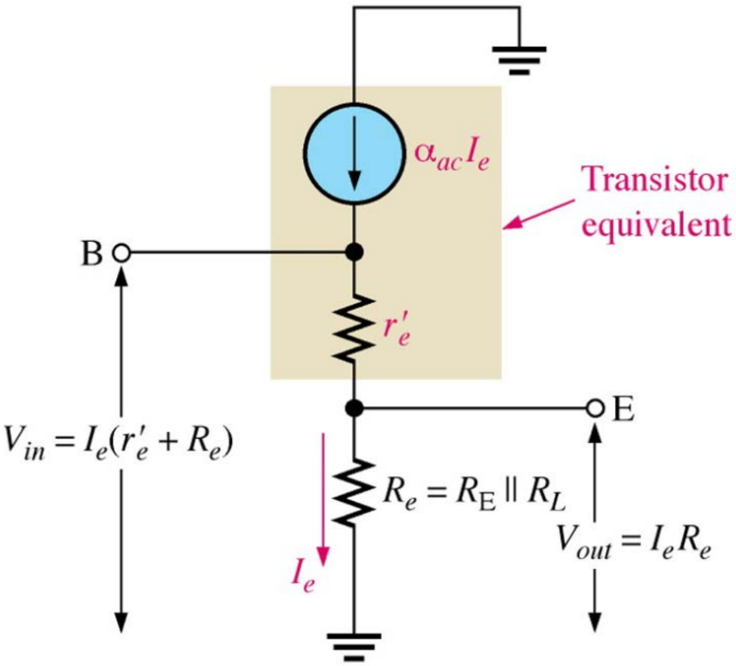
- Most frequently used in practical amplifier
  [Good voltage, current, and power gain]
- Best combination between voltage and current gain

Common-Collector Amplifier

The **common-collector** amplifier is usually referred to as **the emitter follower** (sometimes is called a buffer) because the output developed on the emitter follows the input the input signal applied to the base and there is no phase inversion or voltage gain. The output is taken from the emitter. The common-collector amplifier’s main advantages are its **high current gain and high input resistance with a voltage gain approximately 1.**



Because of its high input resistance the common-collector amplifier used as a buffer to reduce the loading effect of low impedance loads. The input resistance can be determined by the simplified formula below.



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

Summary

The output resistance is very low. This makes it useful for driving low impedance loads.

The current gain(A_i) is approximately $\boldsymbol{\beta_{ac}}$.

The voltage gain(A_v) is approximately 1.

The power gain is approximately equal to the current gain(A_i).

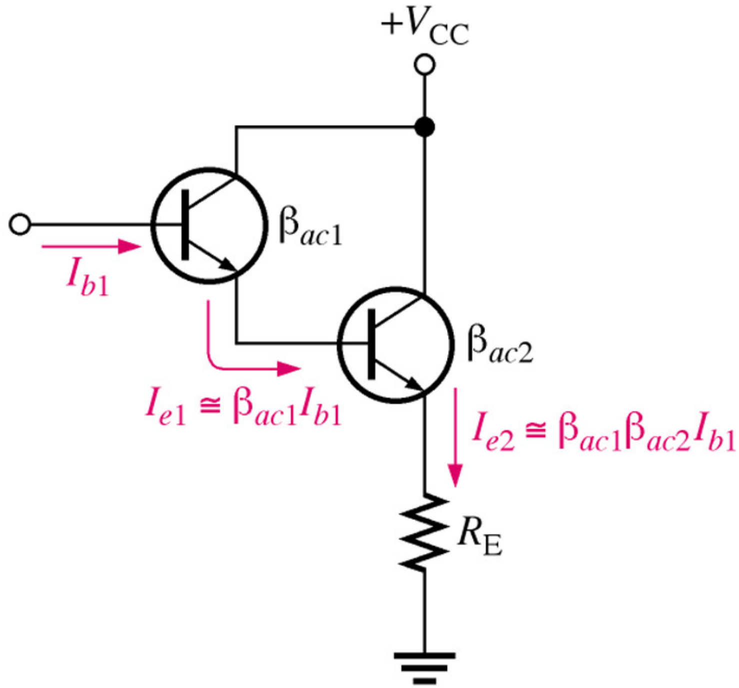
Applications

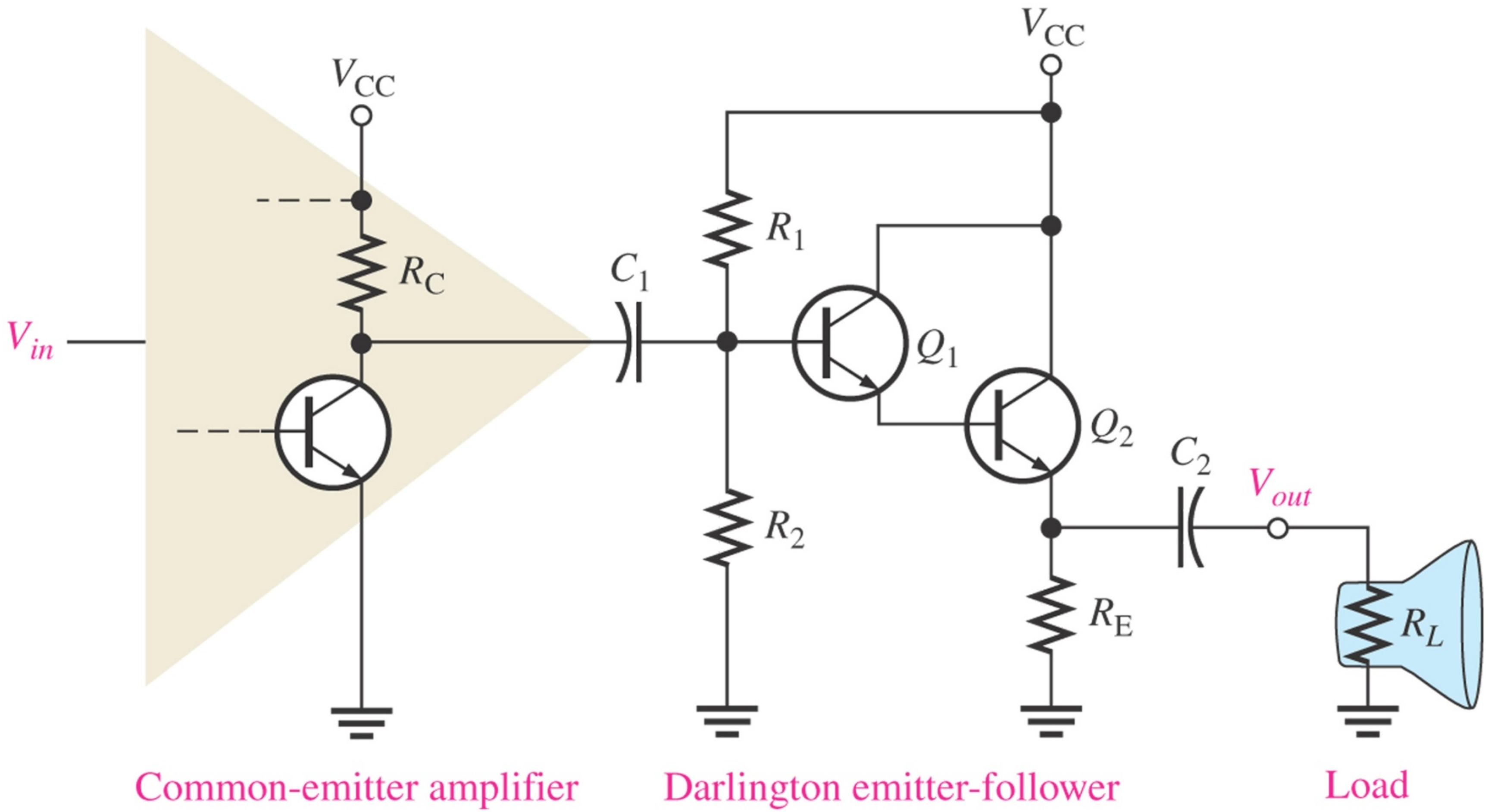
- Impedance matching
- Buffer
- Current driver

Darlington Amplifier

The **darlington pair** is used to boost the input impedance to reduce loading of high output impedance circuits. The collectors are joined together and the emitter of the input transistor is connected to the base of the output transistor. The input impedance can be determined the formula below.

$$R_{in} = \beta_{ac1}\beta_{ac2}R_e$$

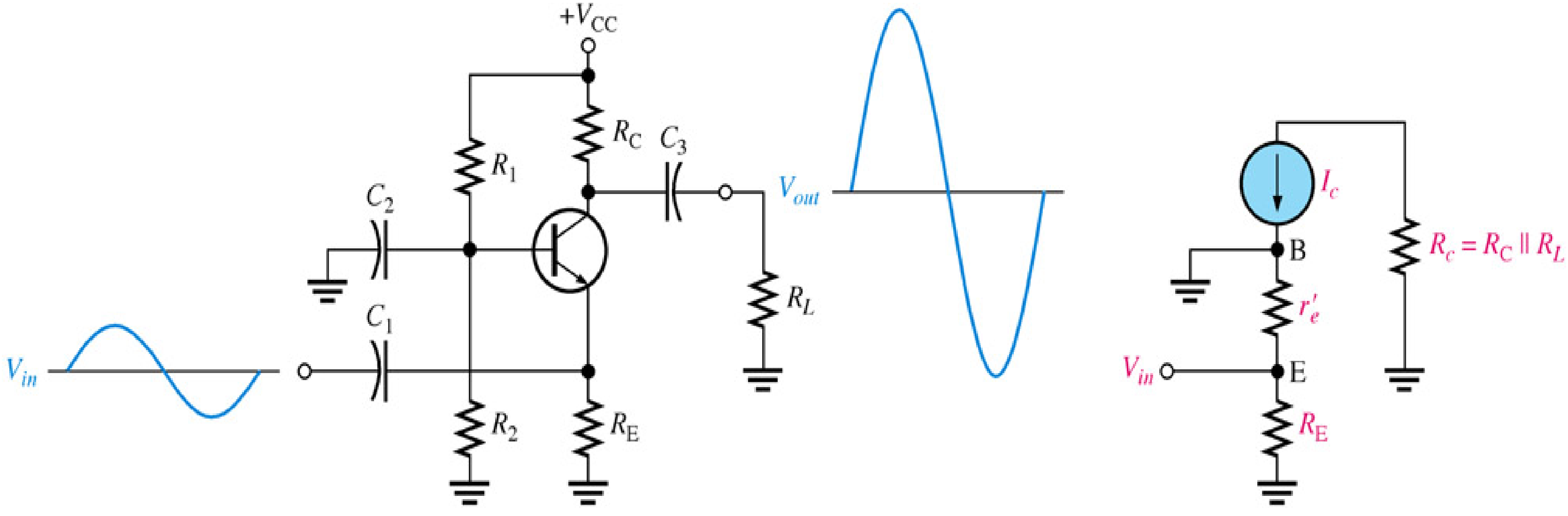




A darlington emitter-follower used as a buffer between a common-emitter amplifier and a low-resistance load such as a speaker.

Common-Base Amplifier

The **common-base amplifier** has **high voltage gain with a current gain no higher than 1**. It has a low input resistance making it ideal for low impedance input sources. The ac signal is applied to the emitter and the output is taken from the collector.



(a) Complete circuit with load

(b) AC equivalent model

Summary

The common-base voltage gain(A_v) is approximately equal to R_c/r'_e

The current gain is approximately 1.

The power gain is approximately equal to the voltage gain.

The input resistance is approximately equal to r'_e.

The output resistance is approximately equal to R_C.

Applications

- Certain applications
- Low input resistance and voltage amplification
- Impedance matching in high frequency circuit
- Current buffer

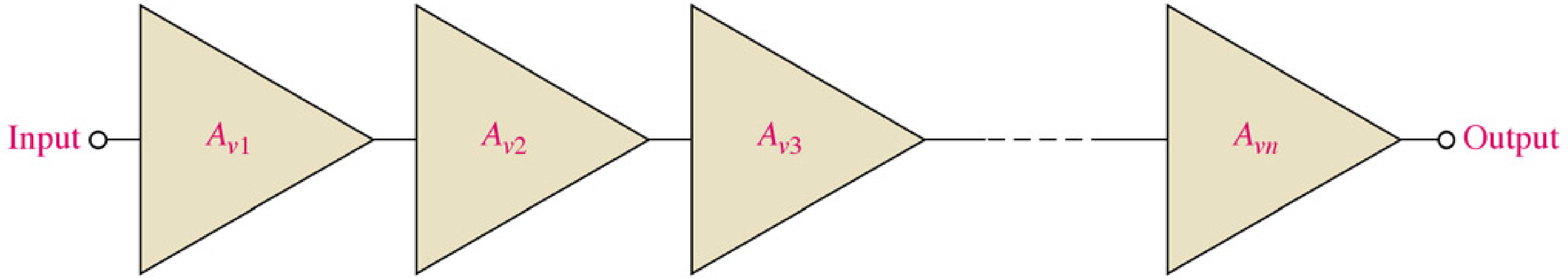
Comparison Table

AMPLIFIER TYPE	COMMON BASE	COMMON EMITTER	COMMON COLLECTOR
INPUT/OUTPUT PHASE RELATIONSHIP	0°	180°	0°
VOLTAGE GAIN	HIGH	MEDIUM	LOW
CURRENT GAIN	LOW (α)	MEDIUM (β)	HIGH (γ)
POWER GAIN	LOW	HIGH	MEDIUM
INPUT RESISTANCE	LOW	MEDIUM	HIGH
OUTPUT RESISTANCE	HIGH	MEDIUM	LOW

Multistage Amplifier

Two or more amplifiers can be connected to increase the gain of an ac signal. The overall gain can be calculated by simply multiplying each gain together.

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



Reminder: The term *GAIN* is used to describe the amplification capability.

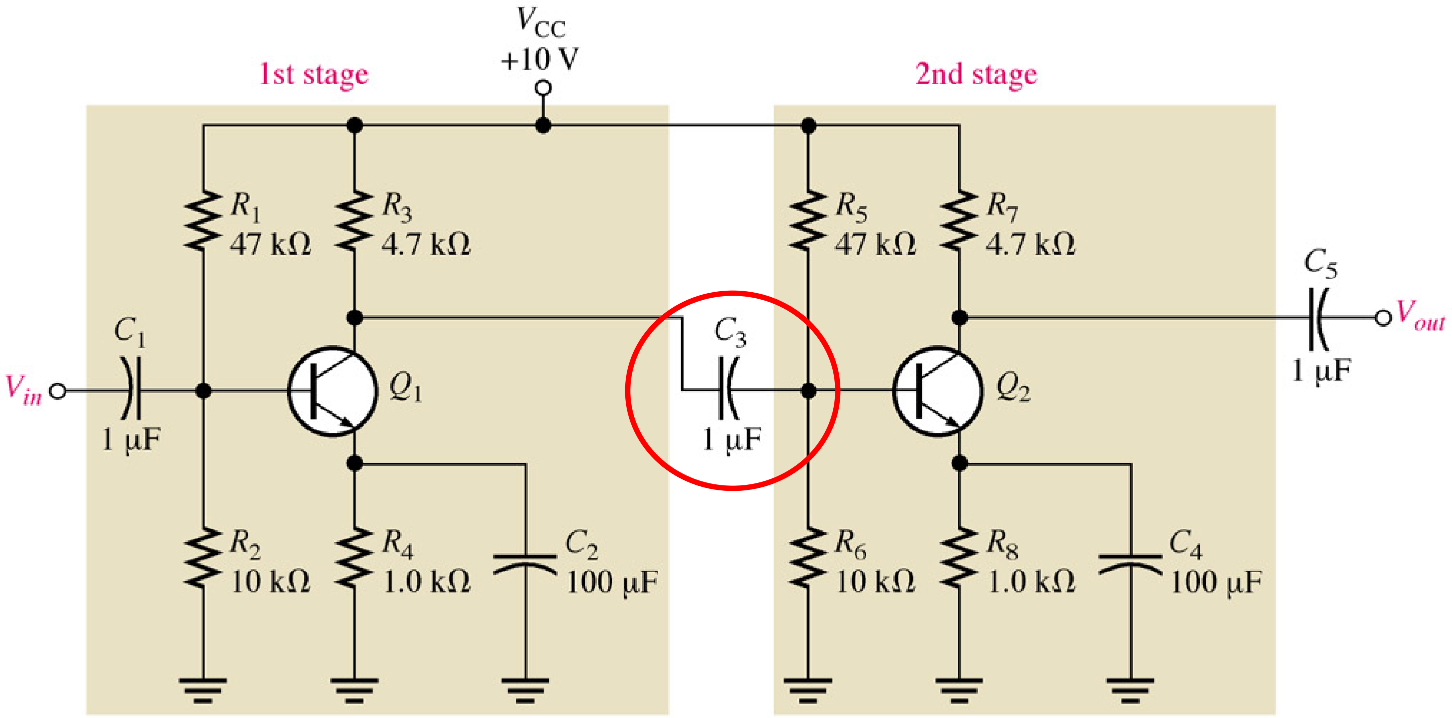
Decibels

- Amplifier voltage gain is often expressed in **decibels**(dB)

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

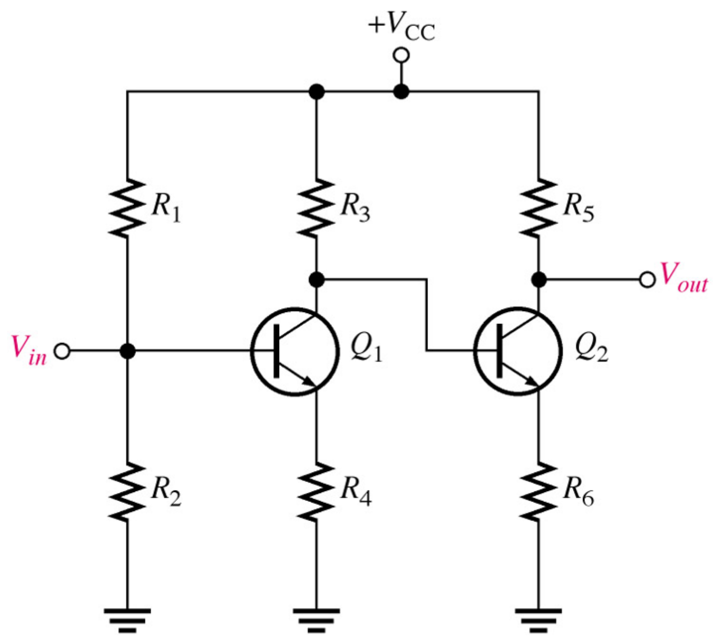
Each stage's gain can now can be simply added together for the total.

The capacitive coupling keeps dc bias voltages separate but allows the ac to pass through to the next stage.



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

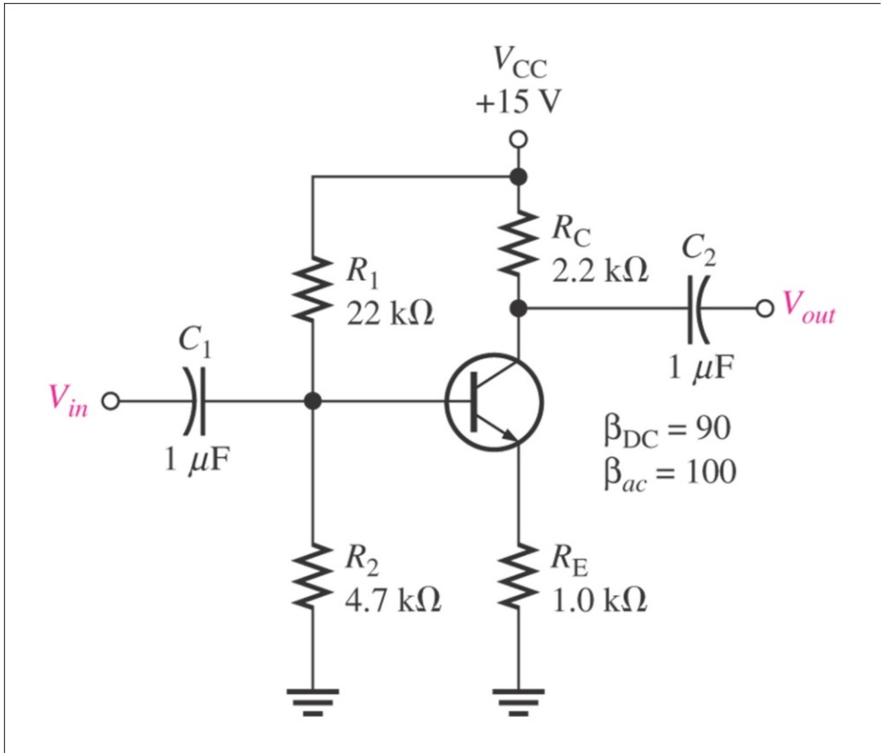
Direct coupling(no coupling or by pass capacitor) between stage improves low frequency gain. The disadvantage is that small changes in dc bias from temperature changes or supply variations becomes more pronounced.



Application: Low frequency or dc(0 Hz) amplifier

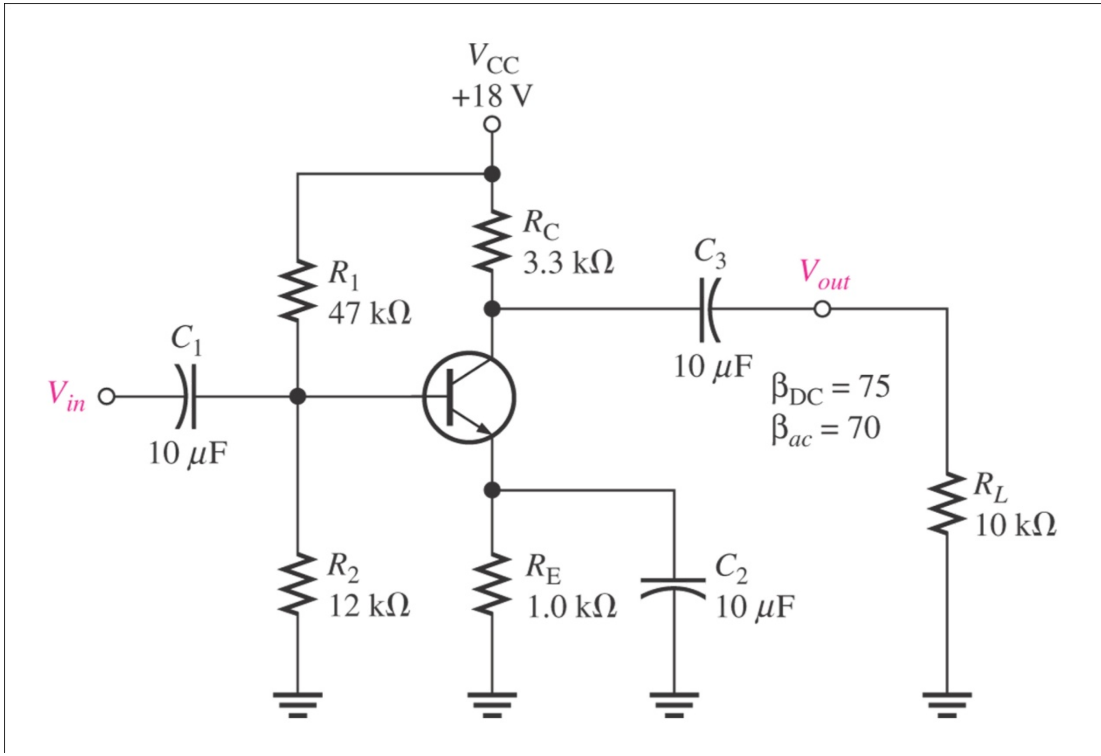
Example

1. Whether or not this voltage-divider is stiff ?
2. Determine V_B V_E I_E I_C and V_C



Example

1. Whether or not this voltage-divider is stiff ?
2. Determine V_B V_E I_E I_C V_C and V_{CE}

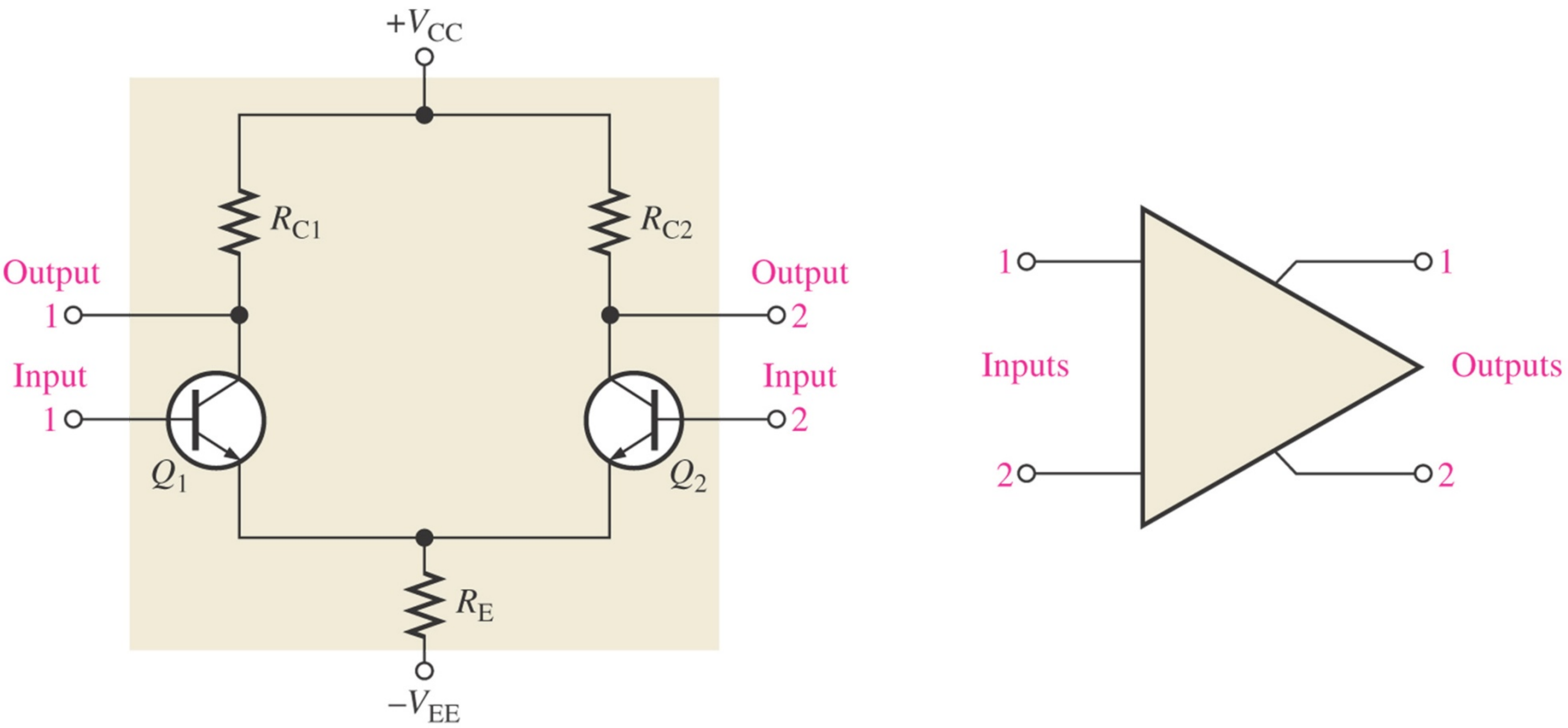


Differential Amplifier

- Outputs are a function of the difference between two inputs
- 2 operational modes:

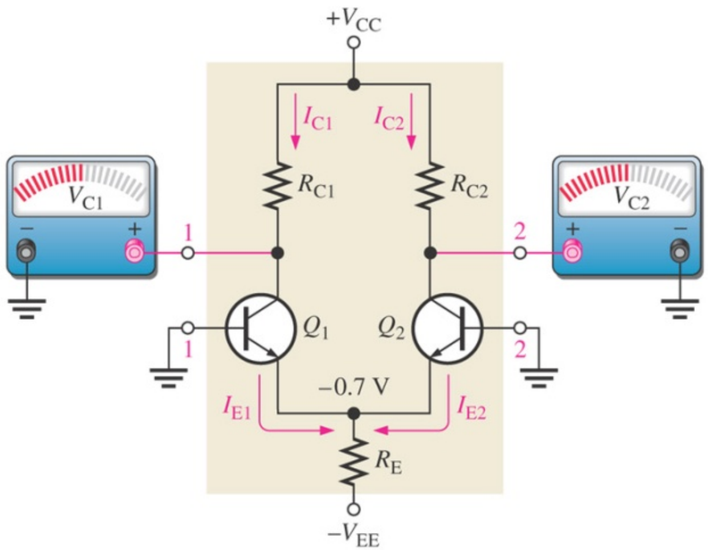
  differential mode and common mode
- It is important as a basic of operational amplifiers.(OP-AMP)

Basic Differential Amp

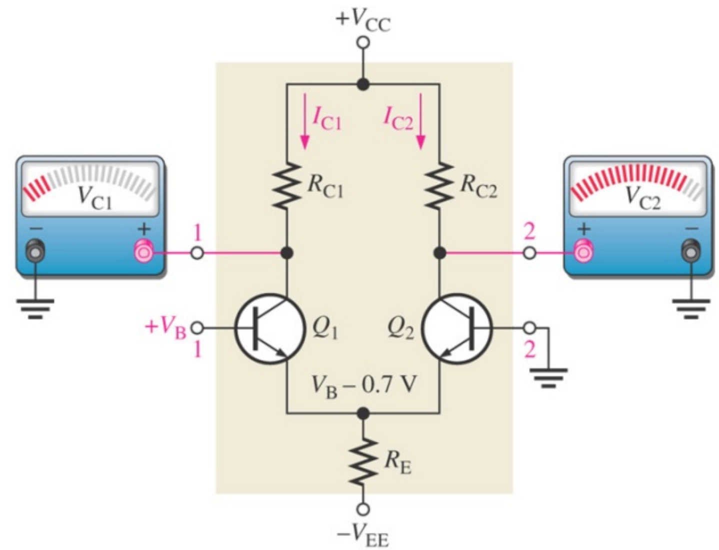


(a) Circuit

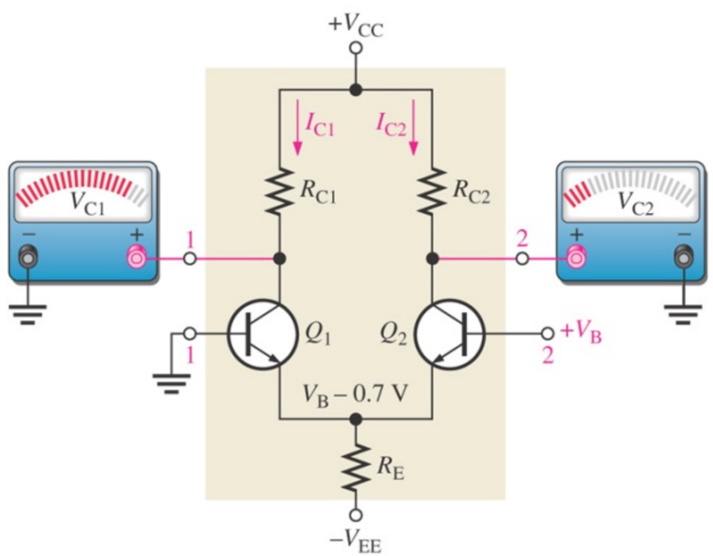
(b) Symbol



(a) Both inputs grounded

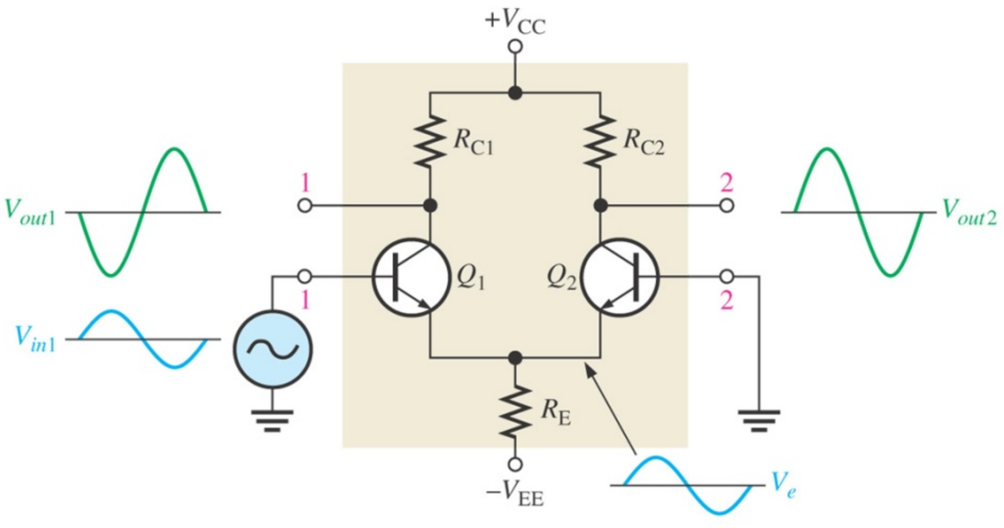


(b) Bias voltage on input 1 with input 2 grounded

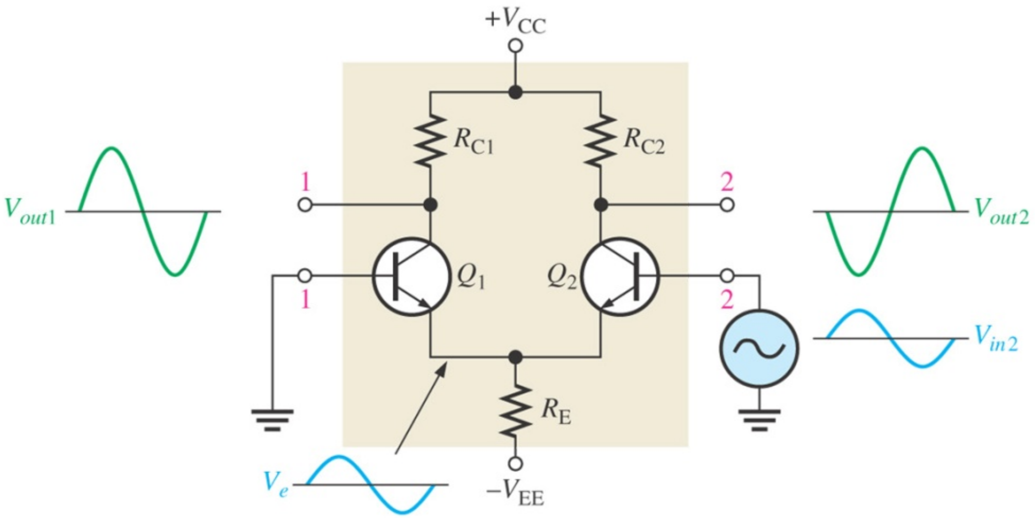


(c) Bias voltage on input 2 with input 1 grounded

Single-ended input operation of differential amplifier

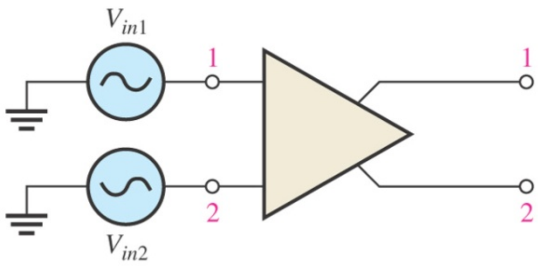


(a)

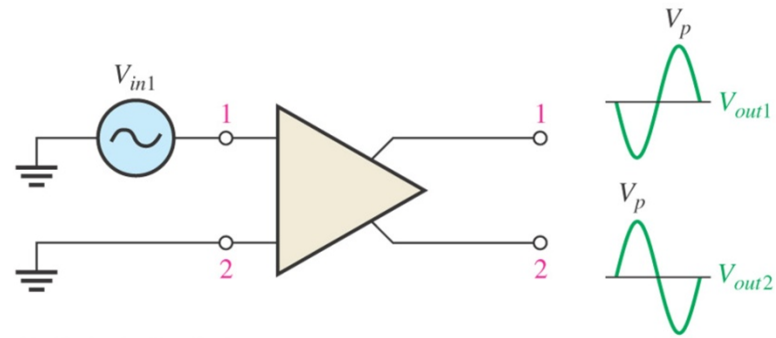


(b)

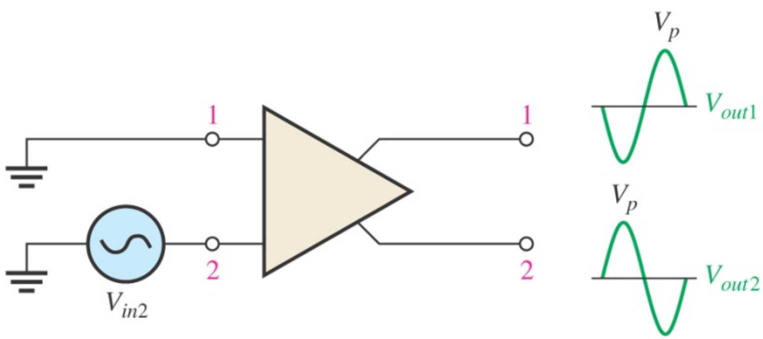
Double-ended input operation of differential amplifier



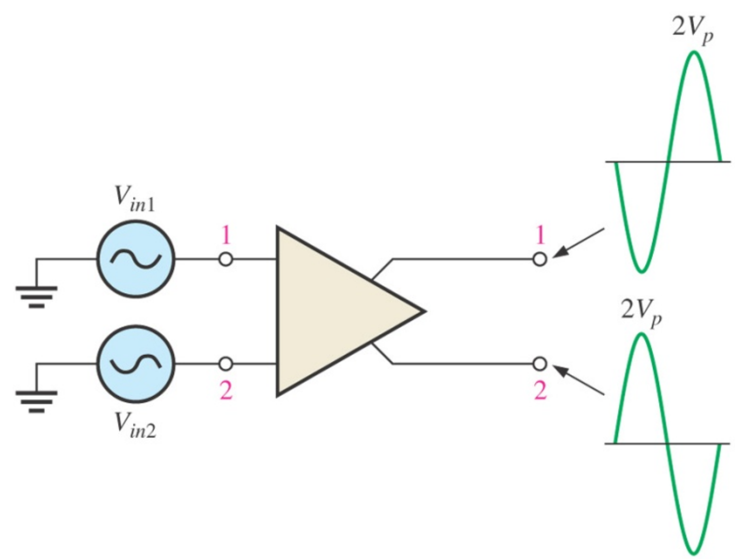
(a) Differential inputs



(b) Outputs due to V_{in1}

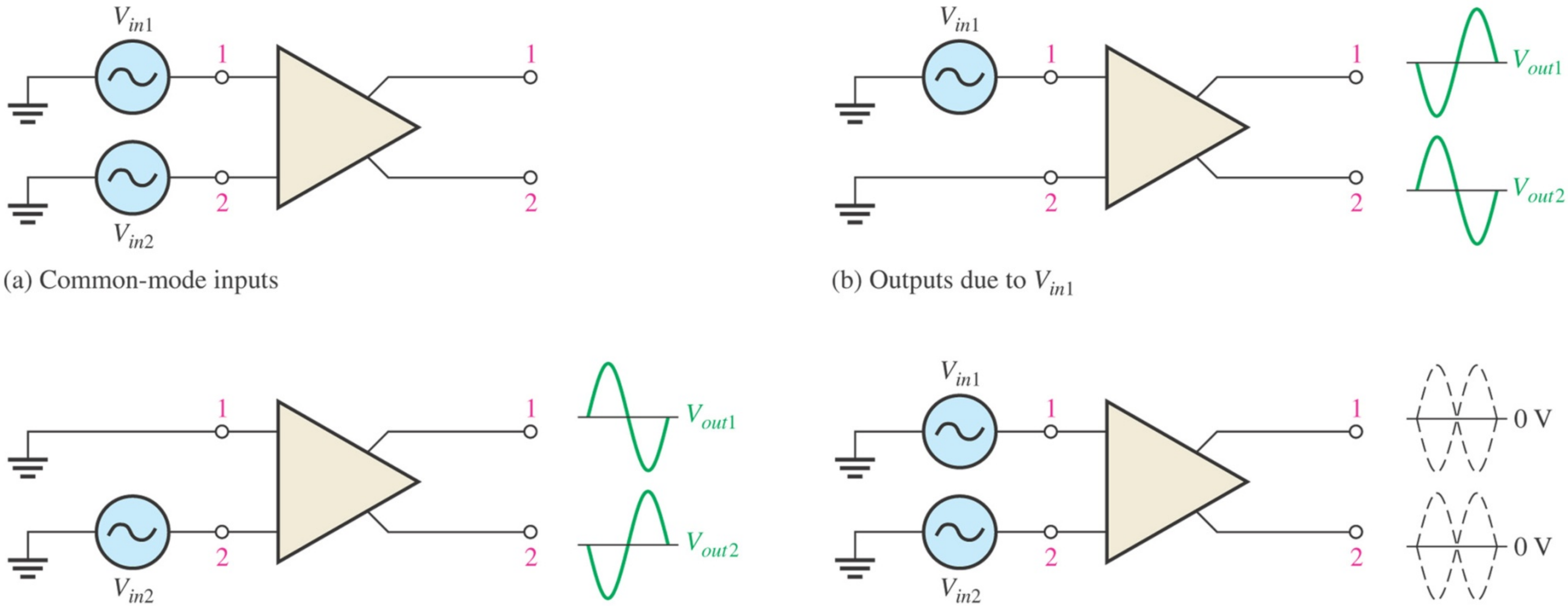


(c) Outputs due to V_{in2}



(d) Total outputs due to differential inputs

Common-mode operation of differential amplifier



(a) Common-mode inputs

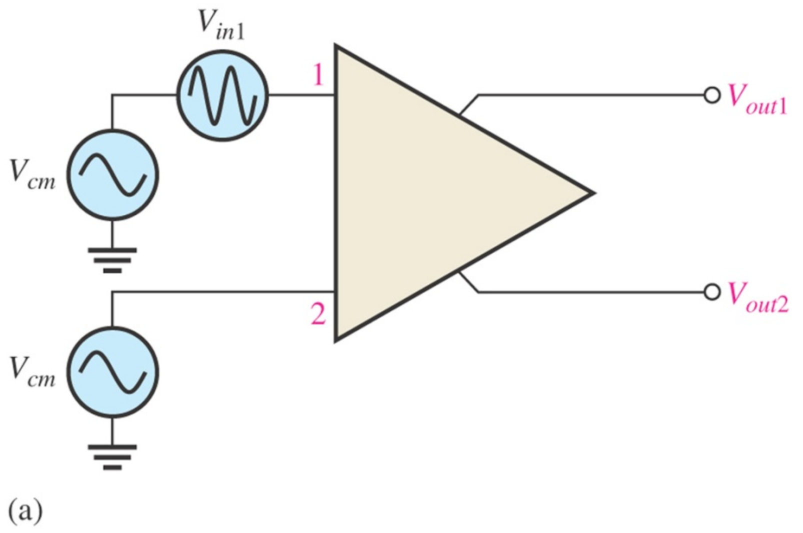
(b) Outputs due to V_{in1}

(c) Outputs due to V_{in2}

(d) Outputs cancel when common-mode signals are applied. Output signals of equal amplitude but opposite phase cancel, ideally producing 0 V on each output.

Example

Draw the waveforms of Vout1 and Vout2



CMRR

- Common-mode rejection ratio(CMRR) is the measure of an amplifier's ability to reject common-mode signal. It is defined as a ratio of differential voltage gain and common-mode gain.
- The higher CMRR, the better.

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

(in decibel)

Summary

➢ Most transistors amplifiers are designed to operate in the linear region.

➢ Transistor circuits can be view in terms of its ac equivalent for better understanding.

➢ The common-emitter amplifier has high voltage and current gain.

➢ The common-collector has a high current gain and voltage gain of 1. It has a high input impedance and low output impedance.

➢ The common-base has a high voltage gain and a current gain of 1. It has a low input impedance and high output impedance

➢ Multistage amplifiers are amplifier circuits cascaded to increased gain. We can express gain in decibels (dB).