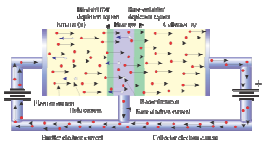
Electronic Devices

Ninth Edition

Floyd

Chapter 6: BJT Amplifiers

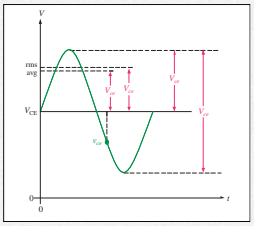


Summary

AC Quantities

AC quantities are indicated with a italic subscript; rms values are assumed unless otherwise stated.

The figure shows an example of a specific waveform for the collector-emitter voltage. Notice the DC component is V_{CE} and the ac component is V_{ce}.

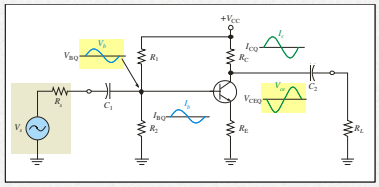


Resistance is also identified with a lower case subscript when analyzed from an ac standpoint.

Summary

Linear Amplifier

A linear amplifier produces an replica of the input signal at the output.



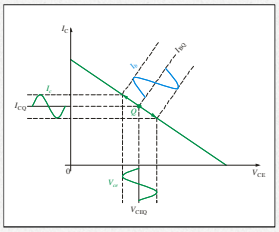
For the amplifier shown, notice that the voltage waveform is inverted between the input and output but has the same shape.

Summary

AC Load Line

Operation of the linear amplifier can be illustrated using an ac load line.

The ac load line is different than the dc load line because a capacitor looks open to dc but effectively acts as a short to ac. Thus the collector resistor appears to be in parallel with the load resistor.



Summary

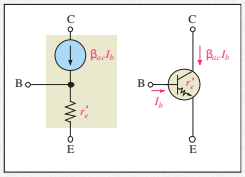
Transistor AC Model

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.

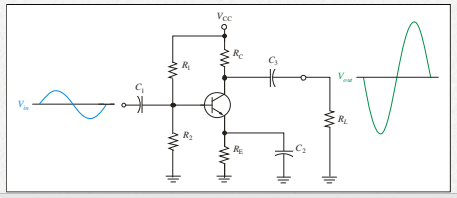
$$r_e' = \frac{25\text{ mV}}{I_E}$$



Summary

The Common-Emitter Amplifier

In the common-emitter (CE) amplifier, the input signal is applied to the base and the inverted output is taken from the collector. The emitter is *common* to ac signals.



Summary

The Common-Emitter Amplifier

Example:

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

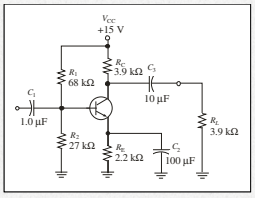
Solution:

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

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

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

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



Summary

The Common-Emitter Amplifier

Follow-up:

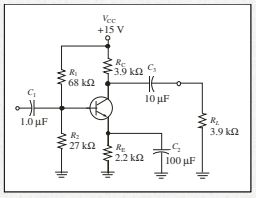
Notice that the ac resistance of the collector circuit is $R_C \| R_L$. What is the gain of the amplifier?

Solution:

$$A_v = \frac{V_{out}}{V_{in}} = \frac{R_c}{r_e'} = \frac{R_C \| R_L}{r_e'}$$

$$A_v = \frac{3.9\ \text{k}\Omega \| 3.9\ \text{k}\Omega}{15.4\ \Omega} = 127$$

The gain will be a little lower if the input loading effect is accounted for.



Summary

The Common-Emitter Amplifier

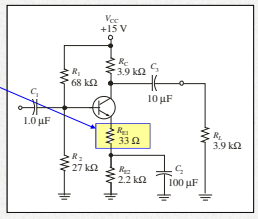
Greater gain stability can be achieved by adding a swamping resistor to the emitter circuit of the CE amplifier. The gain will be lower as a result.

Question:

What is the gain with the addition of the swamping resistor? (Ignore the small effect on r_e'.)

$$A_v = \frac{V_{out}}{V_{in}} = \frac{R_c}{r_e' + R_{E1}} = \frac{R_C \| R_L}{r_e' + R_{E1}}$$

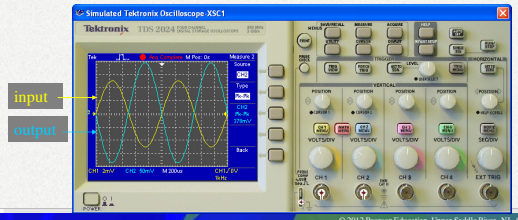
$$A_v = \frac{3.9\ \text{k}\Omega \| 3.9\ \text{k}\Omega}{15.4\ \Omega + 33\ \Omega} = 38.2$$



Summary

The Common-Emitter Amplifier

Multisim is a good way to check your calculation. For an input of 10 mV_{pp}, the output is 378 mV_{pp} as shown on the oscilloscope display for the swamped CE amplifier.



Summary

The Common-Emitter Amplifier

In addition to gain stability, swamping has the advantage of increasing the ac input resistance of the amplifier. For this amplifier, $R_{in(tot)}$ is given by $R_{in(tot)} = R_1 \| R_2 \| \beta_{ac}(r_e' + R_{E1})$

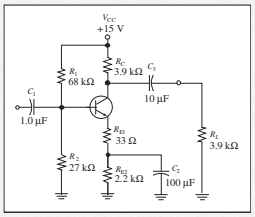
Question:

What is $R_{in(tot)}$ for the amplifier if $\beta_{ac} = 200$?

$$R_{in(tot)} = R_1 \| R_2 \| \beta_{ac}(r_e' + R_{E1})$$

$$= 68\ \text{k}\Omega \| 27\ \text{k}\Omega \| 200(15.4\ \Omega + 33\ \Omega)$$

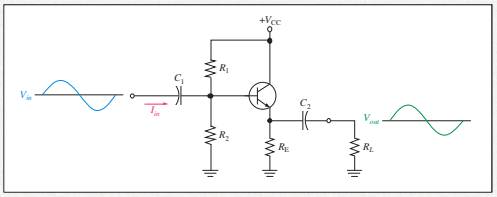
$$= 6.45\ \text{k}\Omega$$



Summary

The Common-Collector Amplifier

The common-collector amplifier (emitter-follower) has a voltage gain of approximately 1, but can have high input resistance and current gain. The input is applied to the base and taken from the emitter.



Summary

The Common-Collector Amplifier

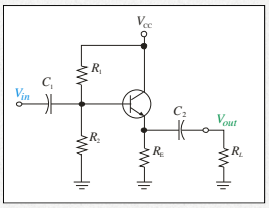
The **power gain** is the ratio of the power delivered to the input resistance divided by the power dissipated in the load. This is approximately equal to the current gain. That is, $A_p \approx A_i$.

You can also write power gain as a ratio of resistances:

$$A_p = \frac{P_L}{P_{in}} = \frac{V_L^2 / R_L}{V_{in}^2 / R_{in(tot)}} = A_v^2 \frac{R_{in(tot)}}{R_L}$$

$$\cong 1\left(\frac{R_{in(tot)}}{R_L}\right) = \frac{R_{in(tot)}}{R_L}$$

The next slide is an example…



Summary

The Common-Collector Amplifier

Example:

Calculate the power gain to the load for the CC amplifier using a ratio of resistances. Assume $A_v = 1$ and $\beta_{ac} = 200$. Use $r_e' = 2\ \Omega$.

Solution:

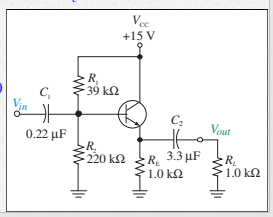
$R_{in(tot)} = R_1 \| R_2 \| \beta_{ac}(r_e' + R_E \| R_L)$

$= 39\ \text{k}\Omega \| 220\ \text{k}\Omega \| 200(2\ \Omega + 500\ \Omega)$

$= 24.9\ \text{k}\Omega$

$R_L = 1.0\ \text{k}\Omega$

$$A_p = \frac{R_{in(tot)}}{R_L} = \frac{24.9\ \text{k}\Omega}{1.0\ \text{k}\Omega} = 24.9$$



Summary

The Common-Collector Amplifier

The input voltage-divider in the previous example is not "rock-solid" but the overall power gain is good. A "rock solid" stiff voltage-divider is not always the best design. Can you spot the problem illustrated here?

$R_{in(tot)} = R_1 \| R_2 \| \beta_{ac}(r_e' + R_E \| R_L)$

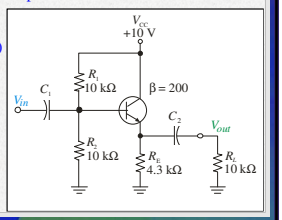
$= 10\ \text{k}\Omega \| 10\ \text{k}\Omega \| 200(25\ \Omega + 3.0\ \text{k}\Omega)$

$= 4.96\ \text{k}\Omega$

$R_L = 10\ \text{k}\Omega$

$$A_p = \frac{R_{in(tot)}}{R_L} = \frac{4.96\ \text{k}\Omega}{10\ \text{k}\Omega} = 0.496!$$

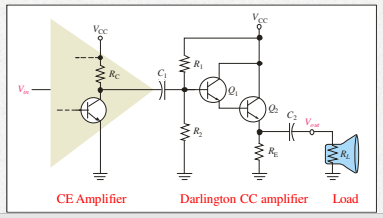
The problem is the power gain is less than 1!



Summary

The Darlington Pair

A Darlington pair is two transistors connected as shown. The two transistors act as one "super β" transistor. Darlington transistors are available in a single package. Notice there are two diode drops from base to emitter.



Summary

The Sziklai Pair

Another high β pair is the Sziklai pair (sometimes called a complementary Darlington), in which a *pnp* and *npn* transistor are connected as shown. This configuration has the advantage of only one diode drop between base and emitter.

Question:

What is the relation between I_{E2} and I_{B1}?

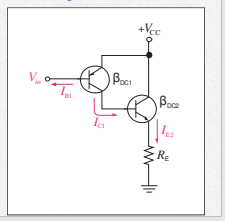
Answer:

The DC currents are:

I_{C1} is β_{DC1} x I_{B1} and is equal to I_{B2}

I_{E2} is approximately equal to β_{DC2} x I_{B2}

Therefore, $I_{E2} \approx \beta_{DC1}\beta_{DC2}I_{B1}$



Summary

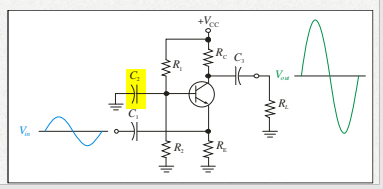
The CB Amplifier

The common-base (CB) amplifier is used in applications where a low input impedance is acceptable. It does not invert the signal, an advantage for higher frequencies as you will see later when you study the Miller effect.

Question: What is the purpose of C_2?

Answer:

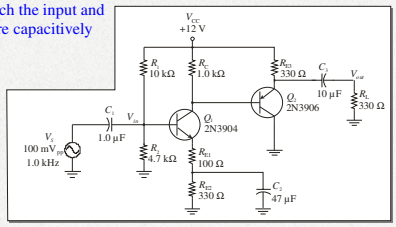
C_2 forces the base to be at ac ground.



Summary

Multistage Amplifiers

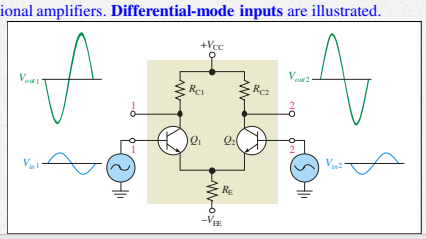
To improve amplifier performance, stages are often cascaded where the output of one drives another. This an example of a two-stage direct-coupled amplifier in which the input and output signals are capacitively coupled.



Summary

Differential Amplifiers

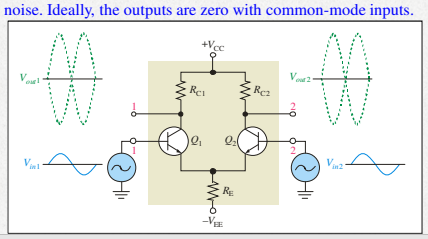
A differential amplifier (diff-amp) has two inputs. It amplifies the difference in the two input voltages. This circuit is widely used as the input stage to operational amplifiers. **Differential-mode inputs** are illustrated.



Summary

Differential Amplifiers

The same amplifier as in the last slide now is shown with **common-mode inputs**. Diff-amps tend to reject common-mode signals, which are usually due to noise. Ideally, the outputs are zero with common-mode inputs.



Selected Key Terms

r-parameter One of a set of BJT characteristic parameters that include α_{ac}, β_{ac}, r_e', r_b', and r_c'.

Common-emitter A BJT configuration in which the emitter is the common terminal to an ac signal.

ac ground A point in a circuit that appears as a ground to ac signals only.

Input resistance The resistance seen by an ac source connected to the amplifier input.

Selected Key Terms

Output resistance The ac resistance looking in at the amplifier output.

Common-collector A BJT configuration in which the emitter is the common terminal to an ac signal.

Differential amplifier An amplifier in which the output is a function of the difference between two input voltages.

Common-mode A condition where two signals applied to differential inputs are of the same phase, frequency and amplitude.

Quiz

1. The equation for finding the ac emitter resistance of a BJT is

a. $r_e' = \dfrac{25\text{ mV}}{I_B}$

b. $r_e' = \dfrac{25\text{ mV}}{I_E}$

c. $r_e' = \dfrac{0.7\text{ V}}{I_B}$

d. $r_e' = \dfrac{0.7\text{ V}}{I_E}$

Quiz

2. For a CE amplifier, a swamping resistor will

a. increase the input resistance

b. increase the gain

c. both of the above

d. none of the above

Quiz

3. A well-designed CC amplifier has

a. voltage gain > 1

b. current gain > 1

c. both of the above

d. none of the above

Quiz

4. In a CC amplifier, the power gain is approximately

a. one

b. equal to the voltage gain

c. equal to the current gain

d. none of the above

Quiz

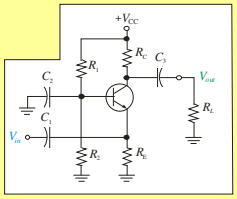
5. The amplifier shown is a

a. differential amplifier

b. CE amplifier

c. CC amplifier

d. CB amplifier



Quiz

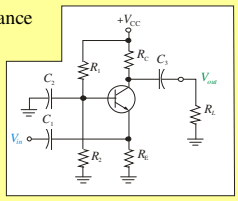
6. An advantage to this amplifier is that it

a. has high current gain

b. has high input resistance

c. is non-inverting

d. all of the above



Quiz

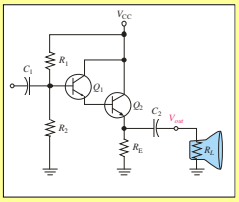
7. Together, Q_1 and Q_2 form a

a. Swamped amplifier

b. Differential pair

c. Sziklai pair

d. none of the above



Quiz

8. A CC amplifier with a power gain less than 1 is

a. a buffer

b. an inverting amplifier

c. unstable

d. an example of poor design

Quiz

9. An *npn* and a *pnp* transistor acting together as a single high β transistor is a

a. Darlington pair

b. Sziklai pair

c. Differential pair

d. cascaded amplifier

Quiz

10. If identical signals are applied to both inputs of a differential amplifier, ideally the output will be

a. zero

b. equal to one of the signals

c. equal to the sum of the two signals

d. very large

Quiz

Answers:

1. b	6. c
2. a	7. d
3. b	8. d
4. c	9. b
5. d	10. a