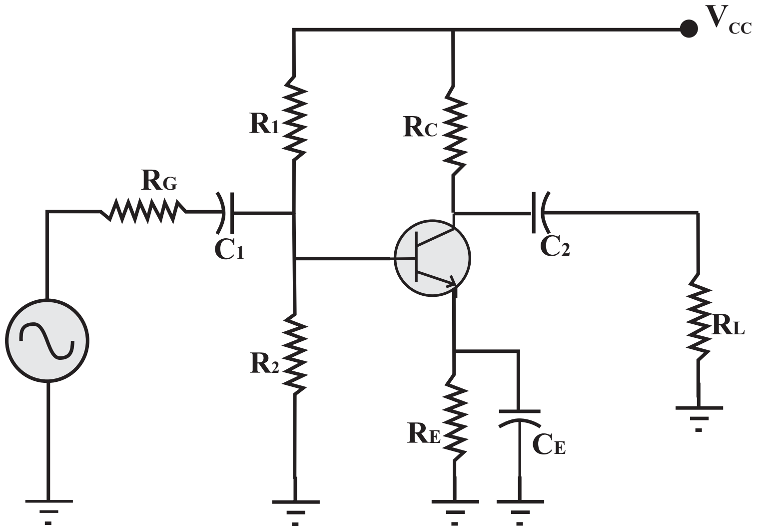
AC Concepts



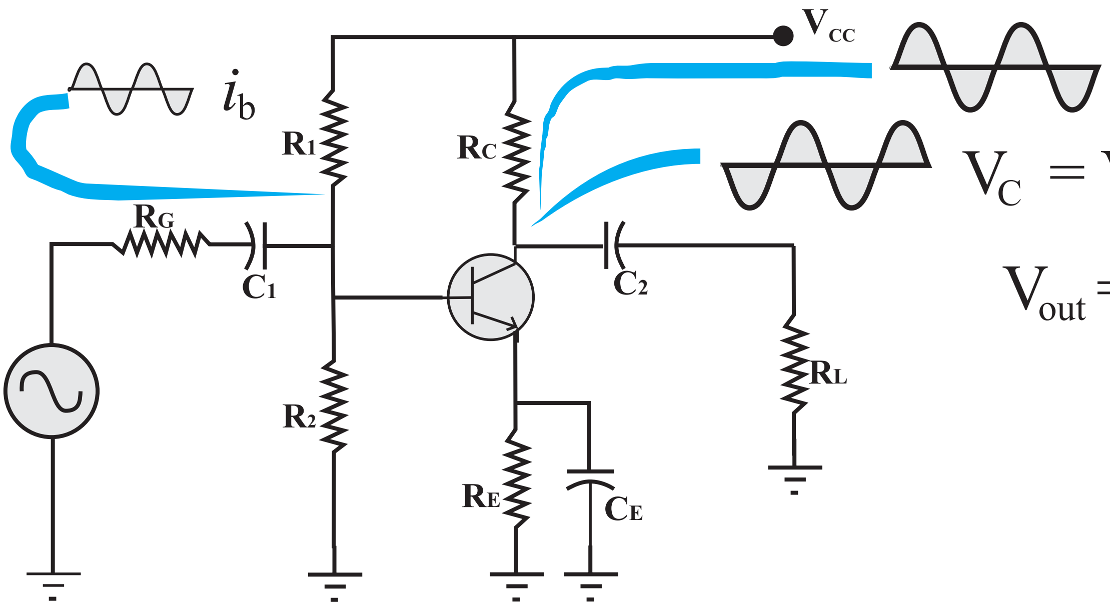
Amplifier Gain

The 3 types of Gain

- ☑ **Current Gain** $A_i = \dfrac{i_{out}}{i_{in}}$
- ☑ **Voltage Gain** $A_v = \dfrac{v_{out}}{v_{in}}$
- ☑ **Power Gain** $A_p = \dfrac{p_{out}}{p_{in}}$

Phasing Relationships

- ☑ **The Input and Output currents are in phase**
- ☑ **The Input and Output voltages are 180^{o} out of phase**



$$i_c = A_i\, i_b$$

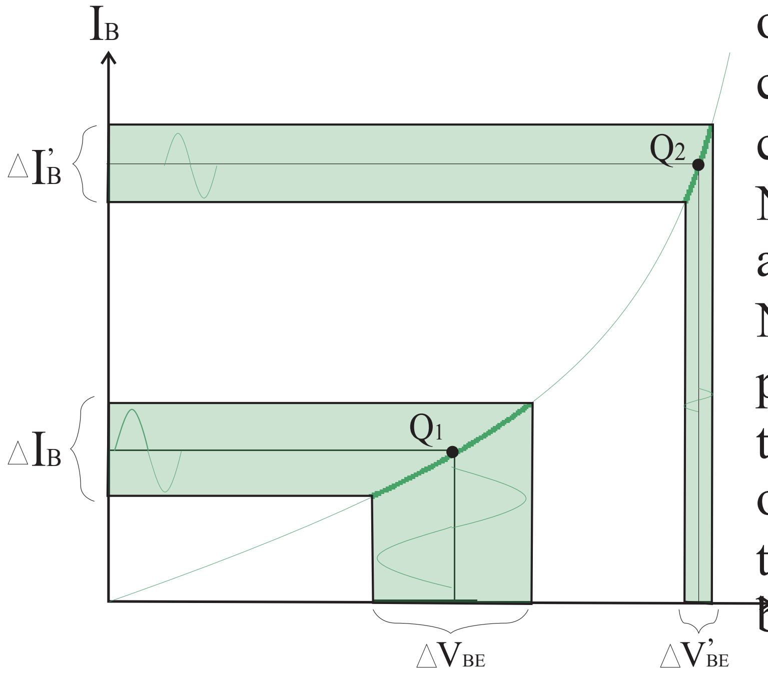
$$V_C = V_{CC} - I_C R_C$$

$$V_{out} = V_C$$

Current and Voltage Relationship

AC Emitter Resistance

$$r'_e = \frac{25\text{ mV}}{I_E} \qquad r'_e = \frac{\Delta V_{BE}}{\Delta I_E}$$

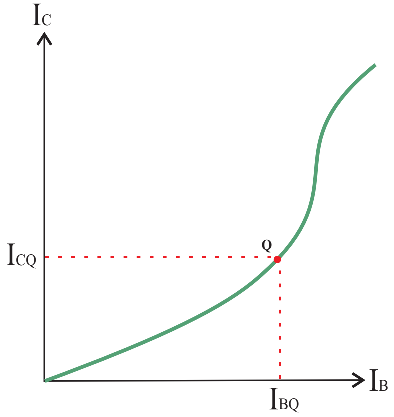


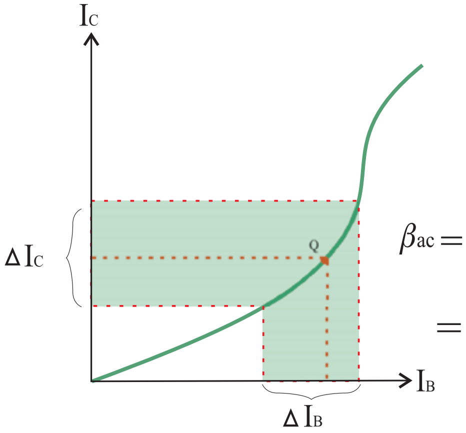
The figure to the right shows the diode curve for the base emitter junction of a transistor. If the transistor is biased at the operating point labeled Q_1, The change in I_B causes the corresponding change in V_{BE}. Note that the changing values are shown as ΔI_B and ΔV_{BE}. Note that the value of ΔV_{BE} produced by ΔI_B decreases if the transistor is biased at the operating point labeled Q_2. Thus the value of r'*e* is affected by the biasing point of the amplifier.

ac Beta -- a.k.a. β_{ac} and h_{fe}

The ac current gain is different than the dc current gain. This has to do with the fact that dc current gain is measured with I_C & I_B being constant. AC current gain is measured with changing ac current values.

The ac beta is the ratio of ac collector current to ac base current.





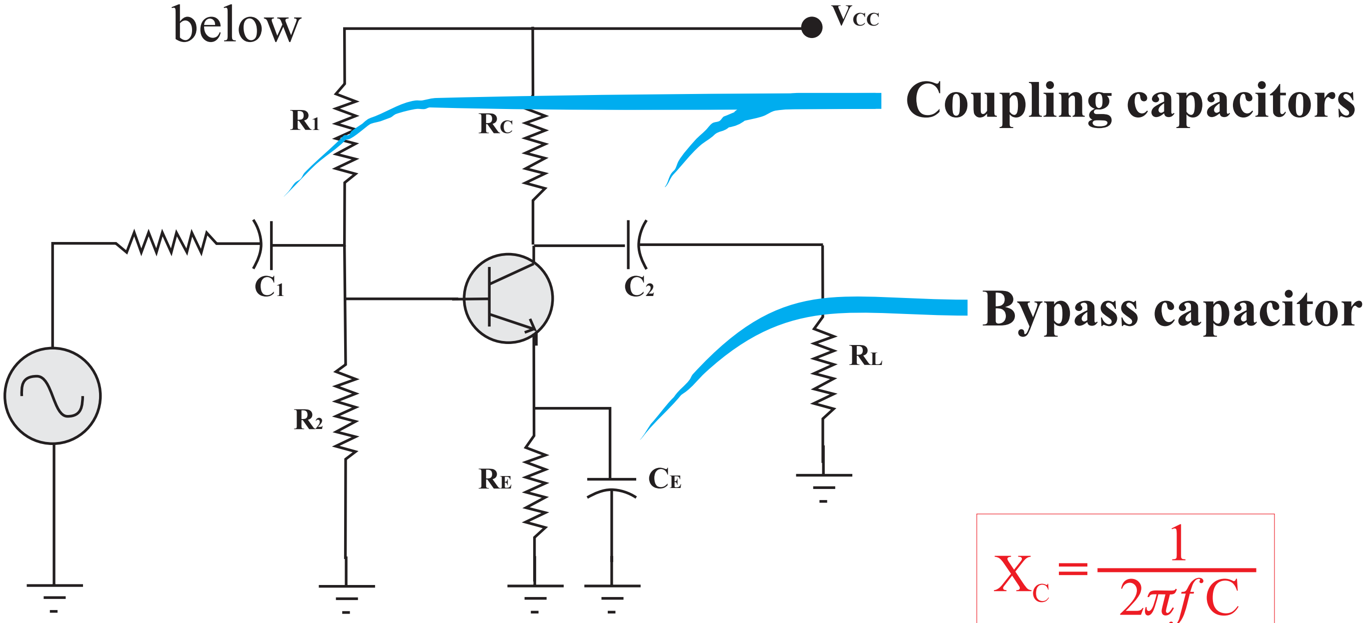
$$\beta_{ac} = \frac{\Delta I_C}{\Delta I_B} = \frac{i_c}{i_b}$$

Example 9-1 is an example of finding ac emitter resistance

The Role of Capacitors in Amplifiers

Capacitors have 2 roles in our common emitter amplifier

- *Coupling Capacitors* allow the ac signal to pass from one amplifier to another, while providing dc isolation between the two.
- Bypass capacitors are used to "short circuit" ac signals to ground while not affecting the dc operation of the circuit.
- Both types depend on the mathematical relationship below



$$X_C = \frac{1}{2\pi f C}$$

Capacitive Reactance

This formula says that the capacitive reactance is inversely proportional to frequency and to capacitance.

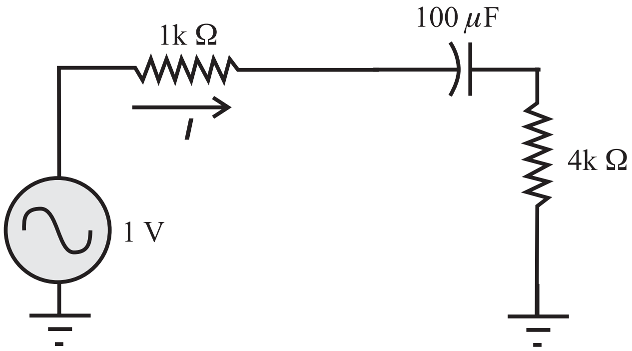
- **If you double the frequency - the reactance drops by half**
- **When the frequency is high enough, the reactance approaches zero**
- **When the frequency decreases to zero, the reactance becomes infinite.**

This means:

- A capacitor is an ***ac short*** at ***high frequencies***
- A capacitor is a ***dc open*** at ***low frequencies***

The Critical Frequency

The critical frequency for the circuit to the right is the frequency that produces a capacitive reactance that is equal to the total resistance in the circuit.



or $\boxed{X_C = R}$

For this condition:

$$\boxed{I = 0.707\ I_{(max)}}$$

This means that at the critical frequency, the rms current decreases to 70.7% of the maximum value.

The High Frequency Border

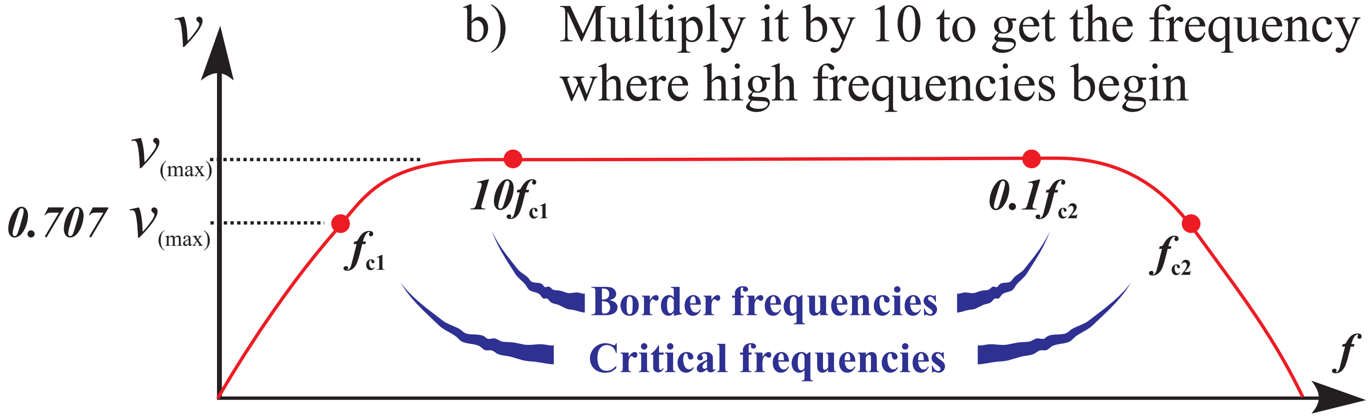
We know that the coupling capacitor acts like a short at ***high frequencies*** but what does "***high***" mean:

High means 10 times as high as the critical frequency

When we say that the reactance has to be at least 10 times smaller than the total resistance, we are saying that the frequency has to be at least 10 times higher than the critical frequency.

$$\boxed{f_h > 10f_C}$$

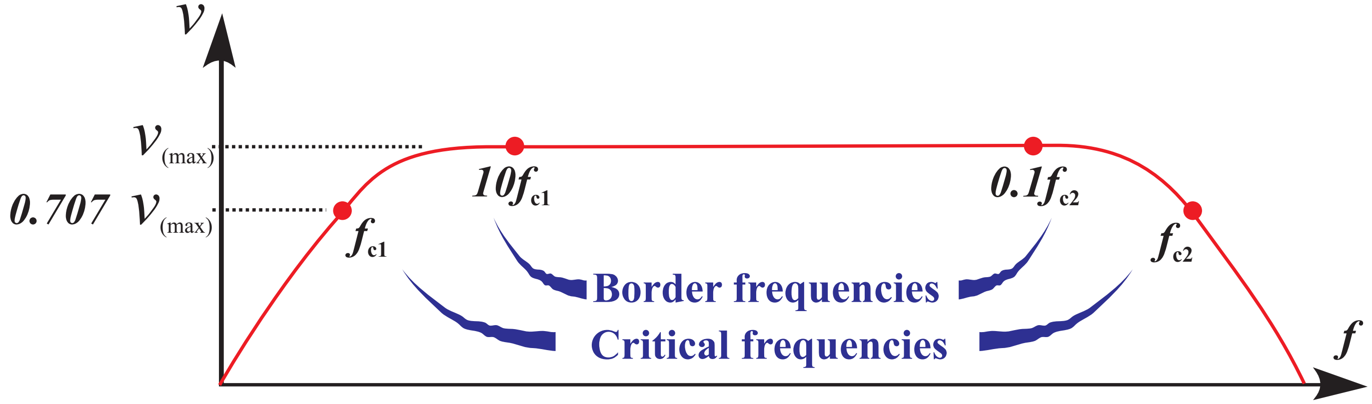
Given an RC circuit
a) Find the critical frequency
b) Multiply it by 10 to get the frequency where high frequencies begin



The High Frequency Border

The high frequency border is where high frequencies begin for the coupling capacitor.

Above the high frequency border, the load current is within 1% of the maximum value.

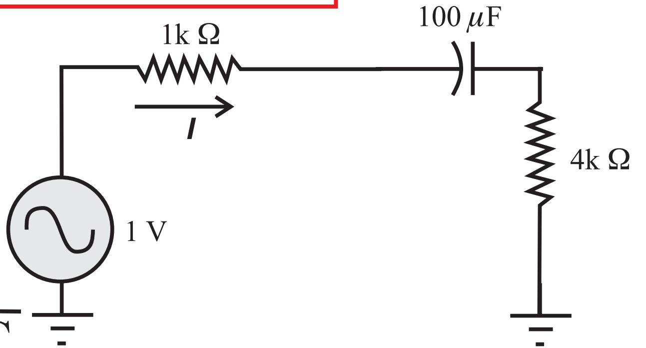


- At the critical frequency X_C and R are equal
- As the frequency goes up , X_C goes down
- At 10 f_C, X_C has dropped to one tenth of its critical frequency value

X_C = 0.1R at the border frequency
Where $R = R_G + R_L$

An Example Calculation

Find the high frequency border
Find the maximum current



$$I_{(max)} = \frac{v_G}{R_G + R_L} = \frac{1\text{V}}{1\text{ k}\Omega + 4\text{k}\Omega} = 200\ \mu\text{A}$$

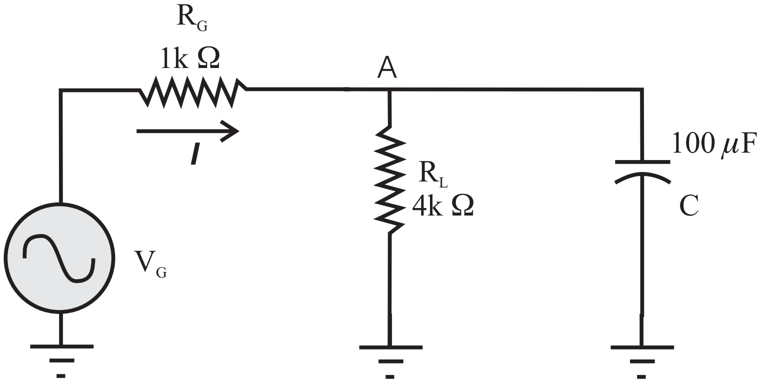
$$f_C = \frac{1}{2\pi RC} = \frac{1}{(6.28)(5\text{ k}\Omega)(100\mu\text{F})} = 0.318\text{ Hz}$$

$$f_H = 10 f_C = 10(0.318) = 3.18\text{ Hz}$$

As long as the generator is above 3.18 Hz, the capacitor acts as an ac short.

The Bypass Capacitor

The Bypass Capacitor



This figure shows a bypass capacitor.

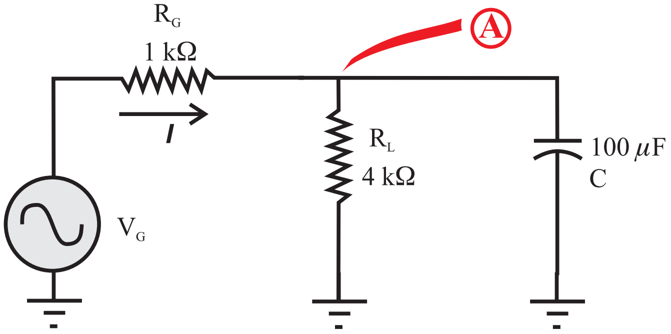
As can be seen, it is connected in parallel across a resistor rather than in series as with the coupling capacitor.

The reason is to shunt or bypass ac current away from the resistor.

When the frequency is high enough, the capacitor appears as an ac short at point A, shorting point A to ground.

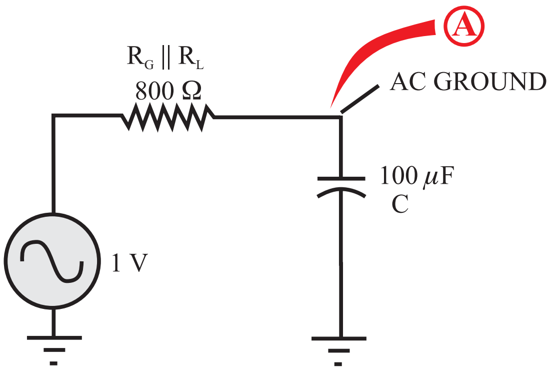
If we were to look at point A with an oscilloscope, we would see nothing at high frequencies because point A is at ground potential.

The Critical Frequency



The critical frequency for this circuit is the same as before.

In this formula, R is the ***Thevenin Resistance*** facing the capacitor.

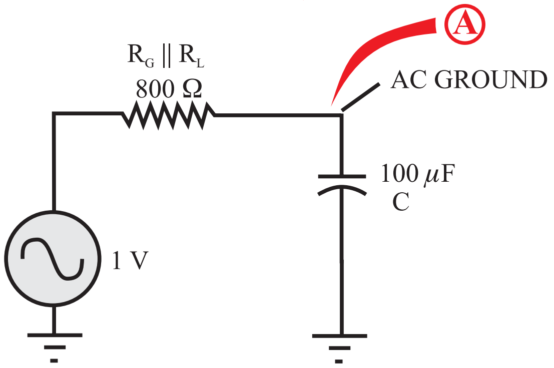


To find it, short out the voltage source and you can see that R_G and R_L are in parallel

$$\mathbf{R = R_G \parallel R_L}$$

The Bypass Capacitor

The High Frequency Border



The high frequency border is the same as before:

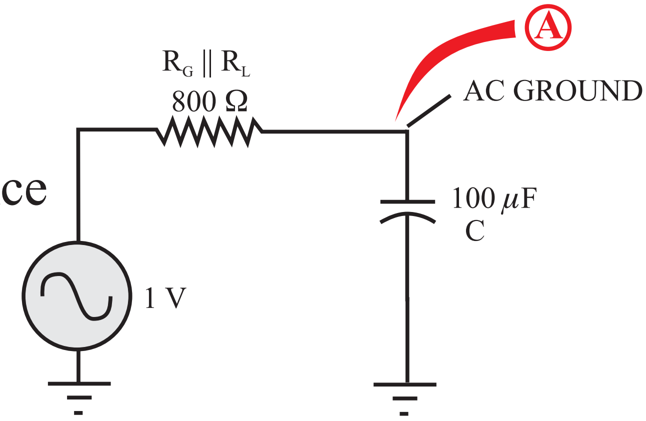
$$f_H = 10f_C$$

When the generator is equal to or greater than this value, the bypass capacitor acts like a short and ***point A is at ac ground.***

If we were to connect an oscilloscope to point A, we would see almost no signal since point A is now at ac ground.

An Example Calculation

For this bypass circuit, calculate the high frequency border.



a) We know the Thevenin resistance facing the capacitor is

$$R_G \| R_L = 800\Omega.$$

Find the critical frequency:

$$f_C = \frac{1}{2\pi RC}$$

$$= \frac{1}{(6.28)(800\ \Omega)(100\mu F)}$$

$$= 1.99\text{ Hz}$$

$$f_H = 10f_C$$

$$= 10(1.99\text{ Hz})$$

$$= 19.9\text{ Hz}$$

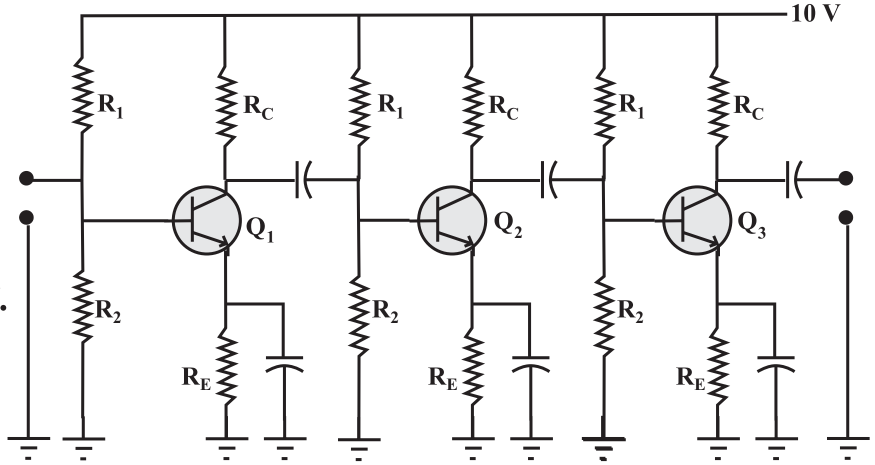
When the generator frequency is equal to or greater than 19.9 Hz, point A is at ac ground.

Equivalent Circuits

Coupling Capacitors

This circuit shows a typical three stage common emitter amplifier.

Note the position of the three coupling capacitors.



Three Stage Amplifier

These should ideally be “transparent” to the ac signal, thus allowing it to pass with no loss from stage to stage.

Bypass Capacitors

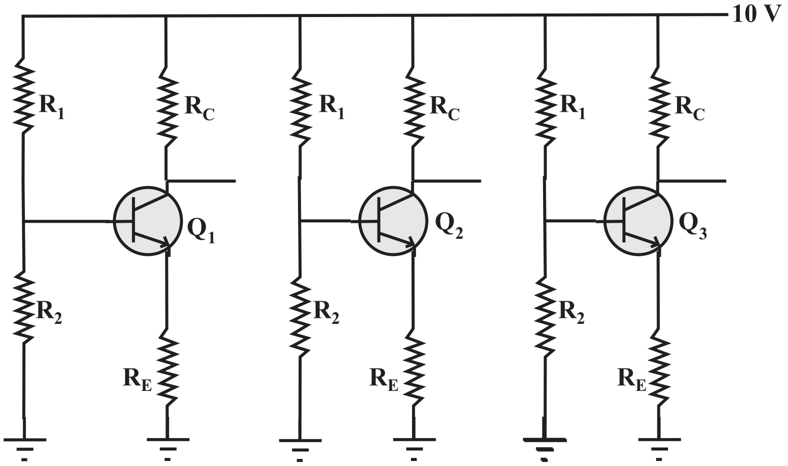
Note the position of the three bypass capacitors.

These are ideally “transparent” to the ac signal also and should hold the emitter of the transistor at ac ground.

The dc Equivalent Circuit

Note that all the capacitors have been replaced with open circuits.

These open circuit represent the capacitor’s infinite opposition to the dc current and voltage levels of the three stages.



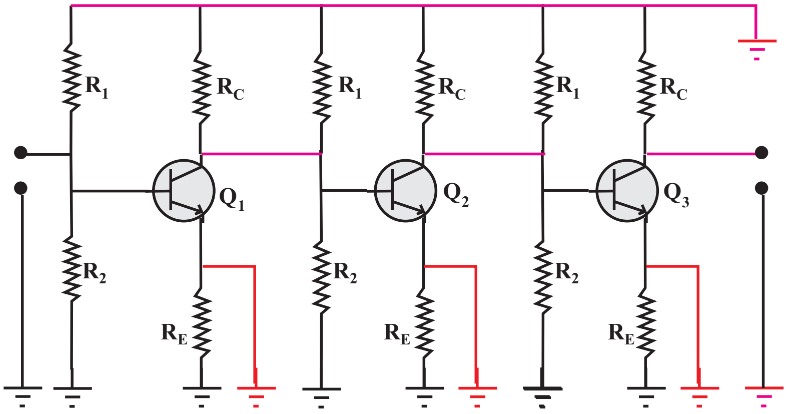
Three Stage Amplifier
The DC Equivalent

This is the circuit that you will use to solve for the dc voltages that are present in the circuit.

The ac Equivalent Circuit

Note that all the capacitors have been replaced with short circuits.

These represent the capacitor's "transparent" quality to the ac signal voltage and allow it to pass unhindered, from stage to stage.



Three Stage Amplifier
The AC Equivalent

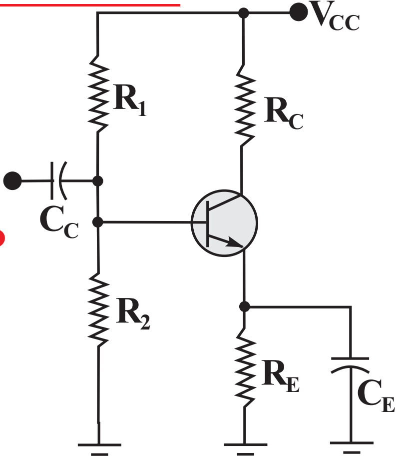
Remember that the dc supply (V_{CC}) has a very low ac resistance value. We must replace the dc source with a ground in the equivalent circuit because the ac signals see V_{CC} as a ground.

AC Analysis -- Simplifying the Circuit -- The Process

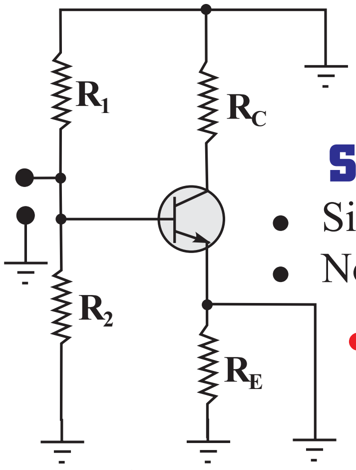
Derive the ac equivalent circuit for the circuit shown

Step 1

- Short out all the capacitors in the circuit
- Replace all the dc sources with a ground
- This gives us circuit (b) below



Before ac Analysis

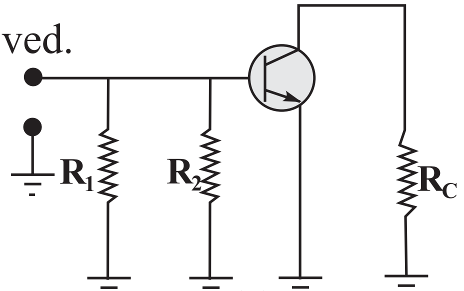


(b)
After step 1

Step 2

- Since R_E is shorted out, it can be removed.
- Note that R_1,R_2,& R_C all are grounded

Redraw the circuit as shown in (C)

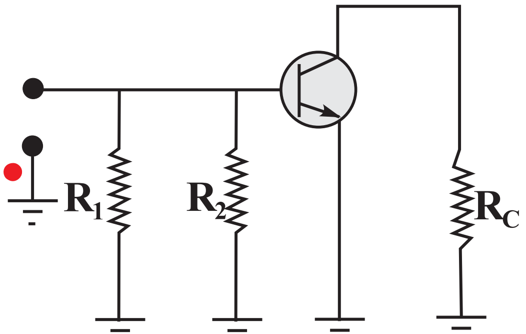


(c)
After Step 2

Coupling & Bypass Capacitors

AC Analysis -- Simplifying the Circuit -- The Process (cont.)

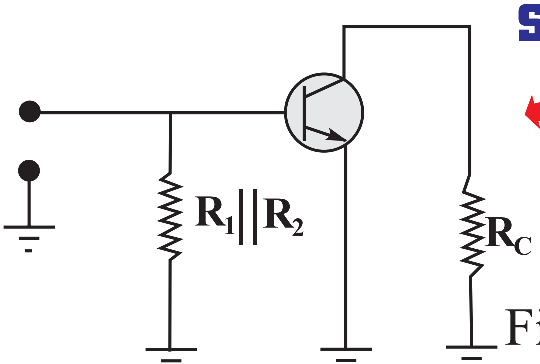
- Note that R_1 is in parallel with R_2
- Redraw the circuit as shown in (d)



(c)

After Step 2

Step 3



(d)

After Step 3

Fig (d) shows the final ac equivalent circuit.

Note: ***The ac equivalent circuit is based on the ac characteristics of the amplifier and does not affect the dc analysis or troubleshooting the amplifier.***

Amplifier Gain 9.4

Remember that there are three types of gain:

- ☑ Voltage Gain
- ☑ Current Gain
- ☑ Power Gain

Remember: - that gain is a ratio
- That gain is a number without units
- That gain is a multiplier that exists between the input and output of an amplifier

Voltage Gain

$$\boxed{A_V = \frac{v_{out}}{v_{in}}}$$

Where: A_V = the voltage gain of the amplifier
v_{out} = the ac output of the amplifier
v_{in} = the ac input of the amplifier

Example 9.3 shows an example calculation

Predicting Voltage Gain

How can we predict the voltage gain of an amplifier when v_{out} and v_{in} are not known?

$$\boxed{A_V = \frac{r_C}{r'_e}}$$

Where: A_V = the voltage gain of the amplifier
r_C = the total ac resistance of the collector circuit
r'_e = the ac emitter resistance of the transistor

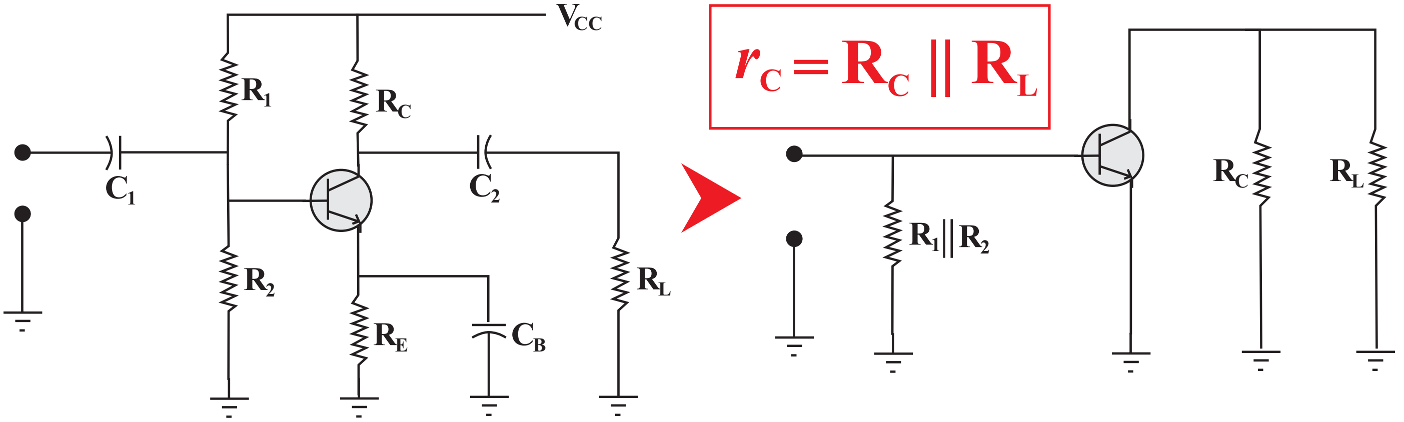
Amplifier Gain 9.4

What is r_C

r_C is the total ac resistance of the collector circuit

Circuit (a) below shows a common emitter amplifier with a load resistor connected.

Circuit (b) shows the resultant circuit with R_C in parallel with R_L



$$r_C = R_C \parallel R_L$$

(a)

(b)

Examples 9.4 & 9.5 shows examples of determining A_V

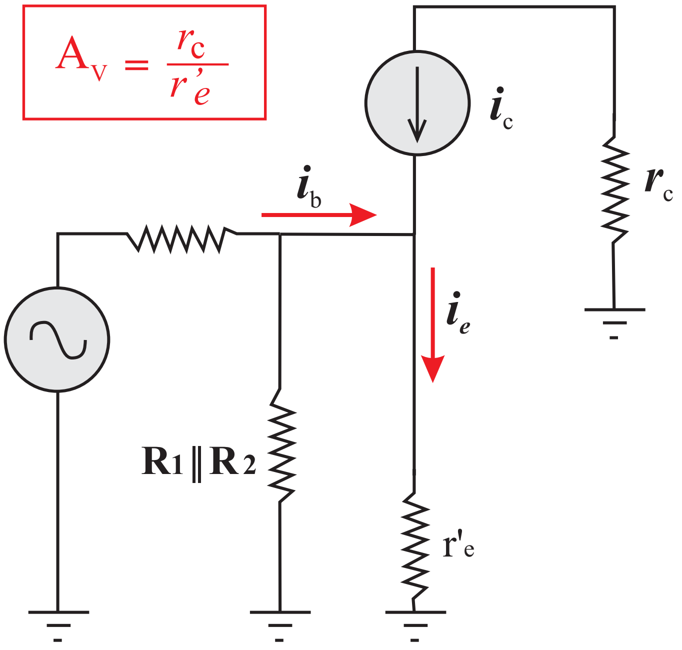
Voltage Gain Instability

This circuit shows us an ac model of our common emitter amplifier.

The voltage gain is equal to the ratio of ac collector resistance to the ac emitter resistance.

Remember that r'_e (ac emitter resistance) is a dynamic value that can change with temperature.

$$A_V = \frac{r_C}{r'_e}$$



AC Equivalent Circuit with the *T Model*

Because of this, the voltage gain of our amplifier, as it exists, can be somewhat unstable. To reduce this effect due to temperature, the swamped amplifier is used.

Calculating v_{out}

Calculating v_{out} is a simple task when the voltage gain is known.

$$\boxed{v_{\text{out}} = A_v v_{\text{in}}}$$

Example 9.6 shows an example of determining v_{out}

Current Gain

Current Gain (A_i) is the factor by which ***ac current increases from the input of an amplifier to the output.***

$$\boxed{A_i = \frac{i_{\text{out}}}{i_{\text{in}}}}$$

where

A_i = the current gain of the amplifier.
i_{out} = the ac output or load current
i_{in} = the ac input or source current

We know that the current gain of the transistor is given on the spec. sheet as h_{fe}

The actual amplifier gain will *always be lower* than the value of h_{fe} for 2 reasons:

1) The ac input current is divided between the transistor and the biasing network.

2) The ac collector current is divided between the collector resistor and the load

Power Gain A_P

Power Gain (A_p) is the factor by which ***ac signal power increases from the input of an amplifier to the output.***

Power gain can be found by multiplying current gain by voltage gain.

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

Amplifier Gain 9.4

Power Gain (continued)

Once the power gain of an amplifier has been determined, you can calculate the output power at the load:

$$\boxed{p_{out} = A_p p_{in}}$$

where

A_p = the power gain of the amplifier.
p_{out} = the amplifier output power
p_{in} = the amplifier input power

Example 9.7 shows an example of determining A_P

The Effects of Loading

- The value of the load has an effect on the voltage gain of the common emitter amplifier.

- The lower the resistance of the load, the lower the voltage gain of the amplifier.

- The opposite is also true; that is the greater the resistance of the load, the greater the voltage gain of the amplifier.

- The greatest value of voltage gain (A_V) occurs, when the load opens

- When the load is open, the ac collector circuit consists of R_C only.

- This is when $r_C = R_C$ Since R_C must always be greater than $R_C||R_L$, an amplifier has its maximum value of A_V when the load resistor is open.

The Effects of Loading With a 12 kΩ Load

The next three figures show the effect of different loading on the output of an amplifier.

In each case, the different load will affect the voltage gain (A_V) of the stage.

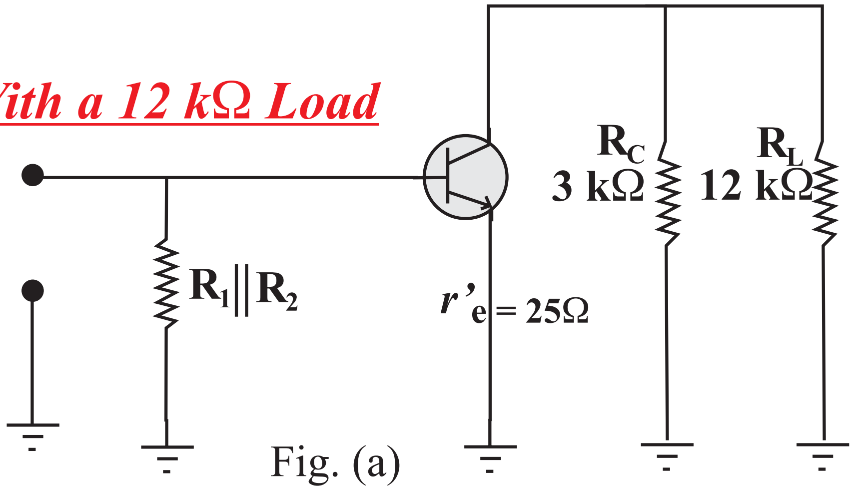


Fig. (a)

Fig. (a) shows an amplifier with a 12 kΩ load resistor.

$$r_c = R_C || R_L = 2.4\ \text{k}\Omega$$

$$A_V = \frac{r_c}{r'_e} = \frac{2.4\ \text{k}\Omega}{25\ \Omega} = 96$$

Note that r_C is 2.4 kΩ and the voltage gain is 96

The Effects of Loading With a 6 kΩ Load

Fig. (b) shows an amplifier with a 6 kΩ load resistor.

Note that r_C is now 2 kΩ and the voltage gain drops from 96 to 80

This shows that as the load resistance decreases, the voltage gain (A_V) decreases.

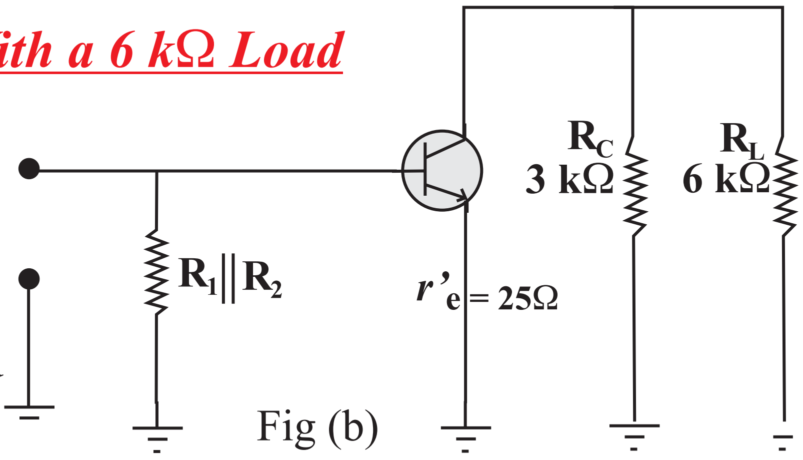


Fig (b)

$$r_c = R_C || R_L = 2\ \text{k}\Omega$$

$$A_V = \frac{r_c}{r'_e} = \frac{2\ \text{k}\Omega}{25\ \Omega} = 80$$

The Effects of Loading With no Load

Fig. (c) shows an amplifier with the load resistor open.

This leaves only R_C in the collector circuit, with no other resistance in parallel with it.

This situation gives us the maximum value of A_V as shown in the calculation.

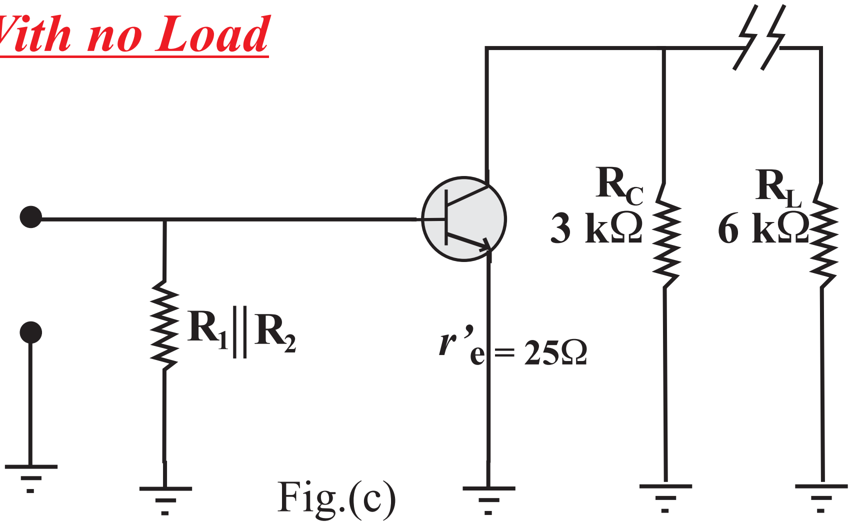


Fig.(c)

$$r_c = R_C = 3\ \text{k}\Omega$$

$$A_{VO} = \frac{r_c}{r'_e} = \frac{3\ \text{k}\Omega}{25\ \Omega} = 120$$

A_{VO} = **The *open load voltage gain* of the circuit**

Input Impedance

The input impedance of an amplifier is determined by the following formula.

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

where Z_{in} = input impedance of the amplifier
Z_{base} = input impedance the transistor base terminal.

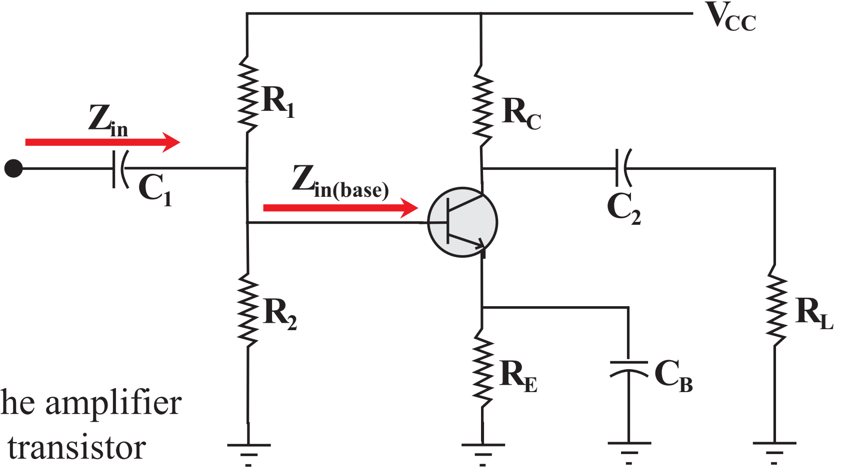


Fig. (a)

Circuit (a) shows a typical C.E. amplifier.
Circuit (b) shows the equivalent circuit.

Note that Z_{base} is the input impedance to the base of the transistor.

Note that Z_{in} is the parallel combination of Z_{base} and the biasing resistors R_1 and R_2

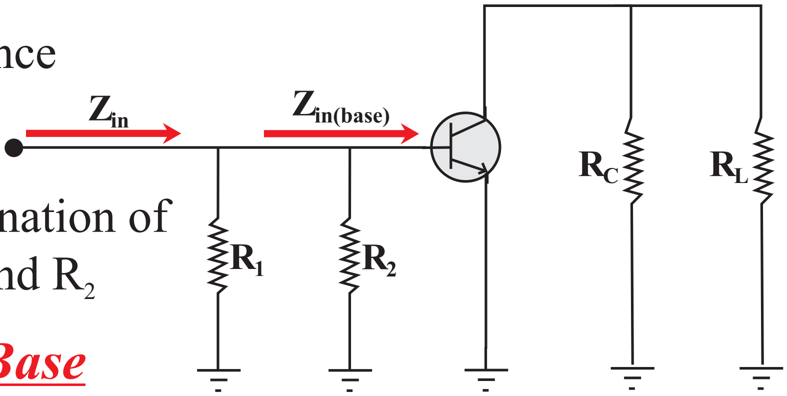


Fig. (b)

The Input Impedance to the Base

Earlier we studied the dc input resistance of the base .

Looking into the base of the transistor, the dc current sees the emitter resistor R_E, magnified by the dc current gain h_{FE}

This gave us the formula $\boxed{R_{base} = h_{FE} R_E}$

The input impedance of the base is an ac quantity that is derived in a similar fashion.

Looking into the base of the transistor, the ac current sees only the ac resistance of the emitter diode magnified by the ac current gain of the transistor.

This gives us the formula $\boxed{Z_{base} = h_{fe}\, r'_e}$

Example 9.9 **shows an example of finding input impedance**

Calculating Current Gain (A_i)

We know that the overall current gain for a C.E. amplifier is always lower than the current gain (h_{fe}) of the transistor.

We know that:

$$\boxed{A_i = \frac{i_{out}}{i_{in}}}$$

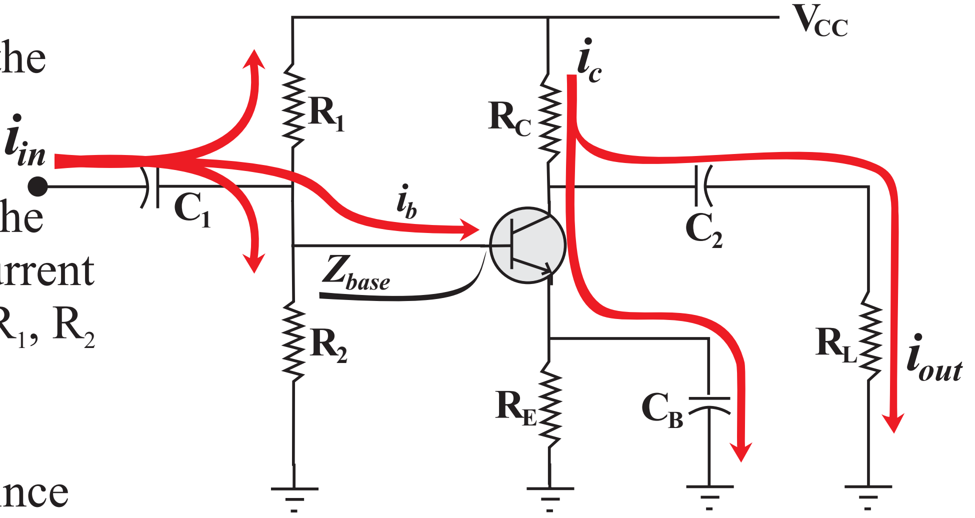
This says that :
The current gain of the amplifier is the ratio of the ac load current (I_{out}) to the ac source current (I_{in})

We also know that:

$$\boxed{h_{fe} = \frac{i_c}{i_b}}$$

This says that:
The current gain of a transistor is the ratio of ac collector current to the ac base current

Refer to the circuit to the right:



ac current distributions

Note that the input to the amplifier contains a current divider consisting of R_1, R_2 and Z_{base}

i_b will be less than i_{in} since some current splits off through R_1 and R_2.

Similarly, i_{out} is less than i_c since some of the collector current splits off through R_L.

These two factors combine to cause the overall current gain of the amplifier to be significantly lower than the current gain of the transistor.

Calculating the current gain (Ai)

The formula that follows takes these factors into account and provides us with figure for current gain of the stage.

$$A_i = h_{fe}\left(\frac{Z_{in}\, r_c}{Z_{base}\, R_L}\right)$$

where: Ai = the current gain of the common emitter amplifier

h_{fe} = the current gain of the transistor

$(Z_{in} r_C)/(Z_{base}) R_L)$ = the reduction factor introduced by the biasing and output components

Example 9.10 illustrates the above

Multistage Amplifier Gain Calculations

How do we determine the overall gain of a multi-stage amplifier ?

1) Determine the appropriate gain values for each individual stage.
2) Determine the overall gain by using one of the equations below

① $A_{vT} = (A_{v1})(A_{v2})(A_{v3})$

② $A_{iT} = (A_{i1})(A_{i2})(A_{i3})$

③ $A_{pT} = (A_{vT})(A_{iT})$

Equations 1 and 2 above indicate that the overall value of A_V or A_i is a product of he individual stage gain values. Simply multiply them together to find the overall value.

Equation 3 indicates that the overall power gain is simply the product of the overall values of A_V and A_i

Multistage Amplifier Gain Calculations

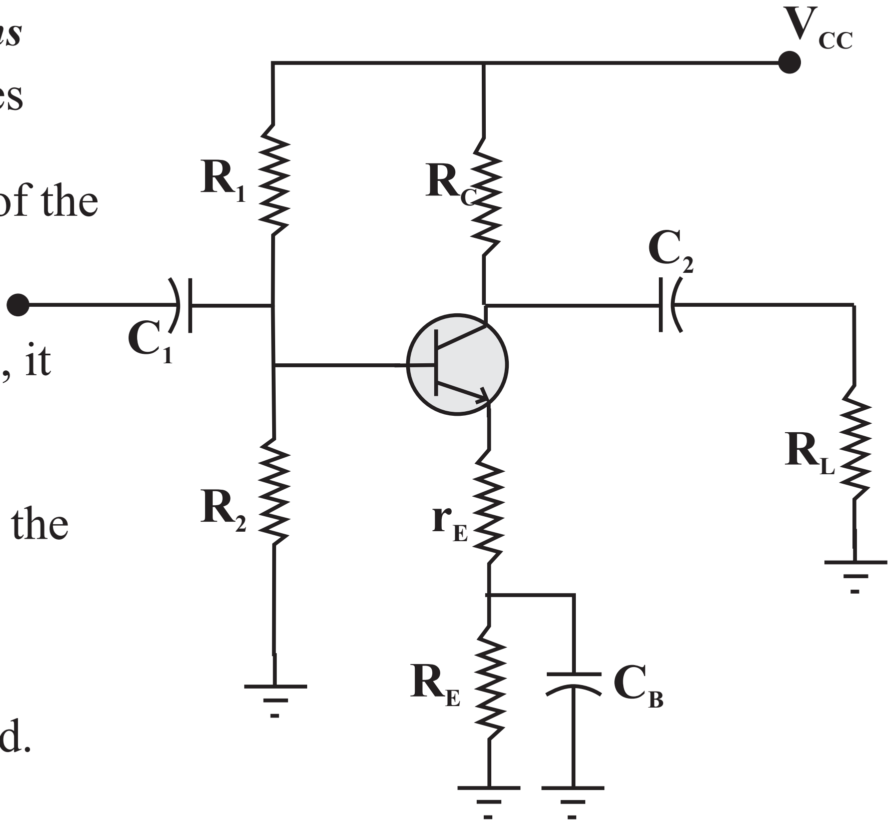
Finding the voltage gain of a two stage amplifier.

- Perform the basic dc analysis on both stages in the usual way
- Find r'*e* for both stages.
- Find the input impedance of the second stage (Z_{in})
- Find the ac collector resistance of the first stage. (r_C)
- Find the voltage gain of the first stage.
- Find the voltage gain of the second stage.
- Find the total gain for both stages.

Examples 9.11 and 9.12 show a complete example of this procedure

The Swamped Amplifier 9.6

Gain & Impedance Calculations



A swamped amplifier reduces variations in voltage gain by increasing the ac resistance of the emitter circuit.

By increasing this resistance, it also increases Z_{base}
This, in turn, reduces the amplifier's loading effect on the previous stage.

Note that only part of the dc emitter resistance is bypassed.

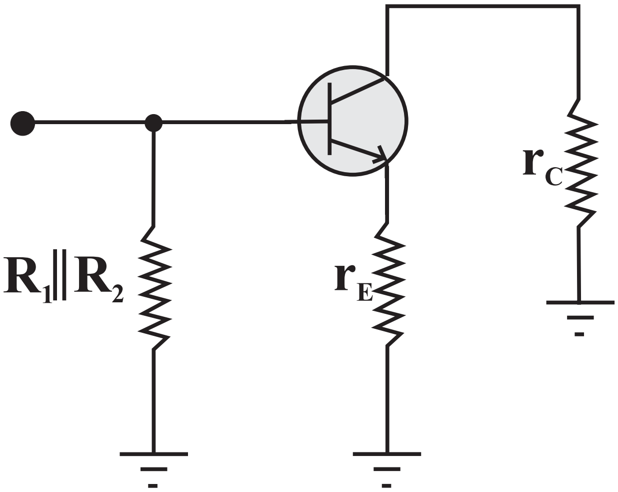
The bypass capacitor eliminates only the value of R_E.

The other emitter resistor r_E, is now part of the ac equivalent circuit as shown on the next page.

The Swamped Amplifier 9.6

Gain & Impedance Calculations

Note in the figure to the right that r_E has now been included in the ac equivalent circuit.



Only part of the total dc emitter resistance has been bypassed.

Since the voltage gain of the amplifier is the ratio of collector resistance to emitter resistance, a new formula for voltage gain.

$$\boxed{A_v = \frac{r_C}{r'_e + r_E}}$$

Example 9.13, 9.14 demonstrates the gain calculation for a swamped amplifier.

The Effects of Swamping on Z_{base}

The input impedance is shown in the equation below.

$$\boxed{Z_{base} = h_{fe}\left(r'_e + r_E\right)}$$

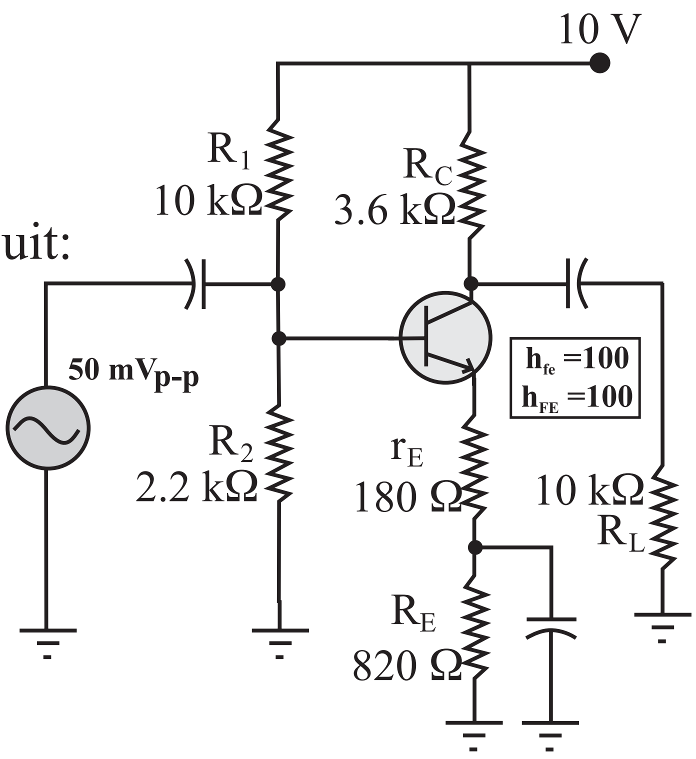
This says that the input impedance of the transistor base is equal to the ac emitter resistance r'_e plus the un-bypassed emitter resistance, all magnified by the ac current gain h_{fe}

Advantages	- more stable against variations r'_e - has a higher input impedance
Disadvantages	- It has a reduced voltage gain compared to a standard CE amplifier

Examples 9.15 ,9.16, 9.17 illustrate Z_{in} and Z_{base}

Example Calculation

1) Find all the dc voltages
2) Find the ac output voltage



For the dc analysis of this circuit:

$$R_E = (R_E + r_E)$$

1) Will R_{in} affect the value of V_B

$$R_{base} = h_{FE} R_E$$
$$= 100(1000)$$
$$= 100\ k\Omega$$

Since R_{base} is greater than 10 times R_2 it can be ignored.

2) Find V_B

$$V_B = \frac{R_2}{R_1 + R_2} V_{CC}$$
$$\boxed{= 1.80\ V}$$

3) Find V_E

$$V_E = V_B - 0.7\ V$$
$$\boxed{= 1.10\ V}$$

4) Find I_E

$$I_E = \frac{V_E}{R_E}$$
$$= \frac{1.10\ V}{1000\ \Omega}$$
$$\boxed{= 1.10\ mA}$$

5) Find V_C

$$V_C = V_{CC} - I_C R_C$$
$$= 10V - (1.10\ mA 3.6k\ \Omega)$$
$$\boxed{= 6.03\ V}$$

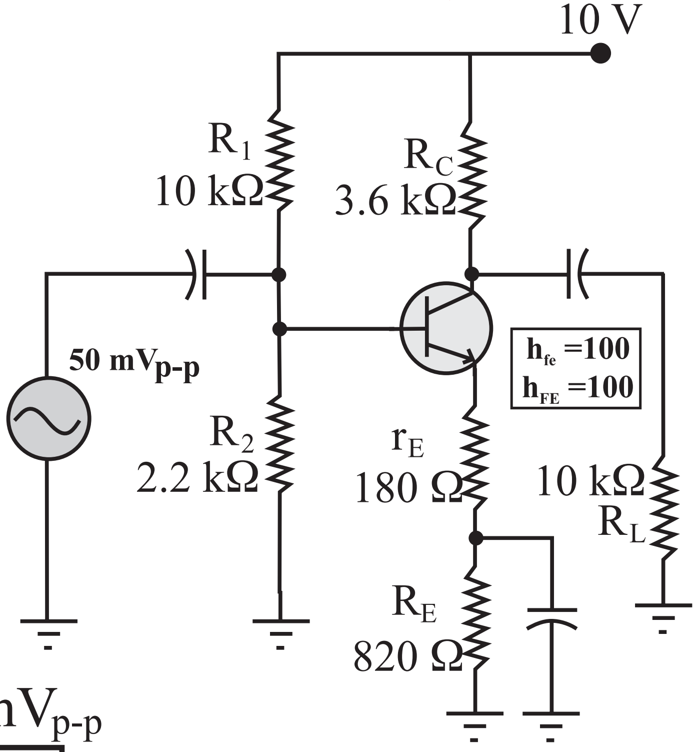
6) Find V_{CE}

$$V_{CE} = V_{CC} - I_C (R_C + R_E)$$
$$= 10V - 1.10\ mA(4.6k\ \Omega)$$
$$\boxed{= 4.92\ V}$$

7) Find r'_e

$$r'_e = \frac{25\ mV}{I_E} = \frac{25\ mV}{1.10\ mA}$$
$$= \boxed{22.66\ \Omega}$$

Example Calculation



8) Find r_C

$$r_C = R_C \parallel R_L$$
$$= 2647.06\ \Omega$$

9) Find A_V

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

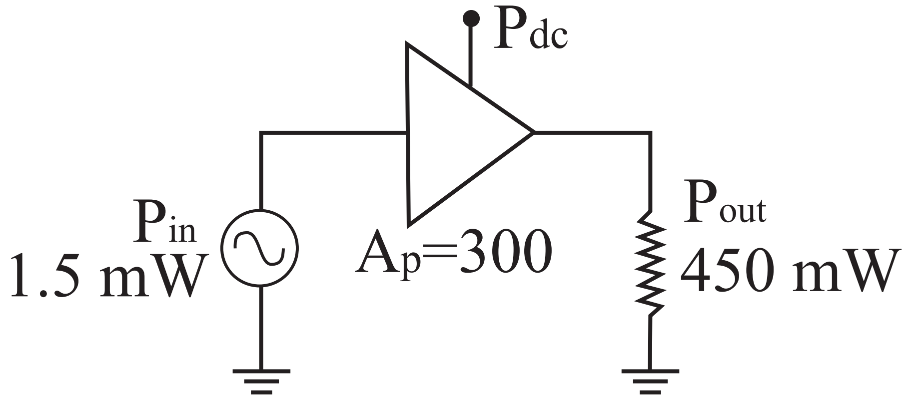
$$= \frac{2647.06\ \Omega}{22.66\ \Omega + 180\ \Omega} = \boxed{13.06}$$

10) Find v_{out}

$$v_{out} = A_V v_{in}$$
$$=(13.06)\ 50\ \text{mV}_{p\text{-}p}$$
$$= \boxed{653\ \text{mV}_{p\text{-}p}}$$

Amplifier Efficiency

Amplifiers actually increase the power level of an ac input by transferring power from the dc power supply to the input signal.

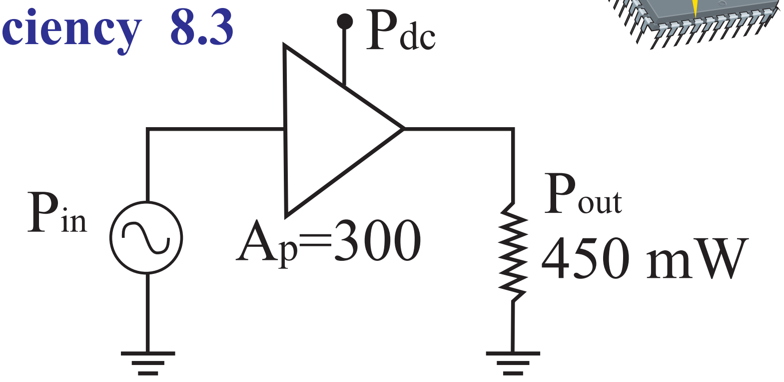


In this example, the input signal has a power rating of 1.5 mW

This gives an output power of 450 mW , if A_p is 300.

The difference between P_{in} & P_{out} is 448.5 mW, and this power was actually transferred from the dc power supply to the load.

Amplifier Efficiency 8.3



Amplifier Efficiency

The ideal amplifier would deliver 100% of the power it draws from the dc power supply to the load.

This does not occur in practice , however , because the components of the amplifier dissipate some of the power.

A figure of merit for any amplifier is its efficiency. The efficiency of an amplifier ***is the amount of power drawn from the supply that is actually delivered to the load.***

Example 8.6 illustrates efficiency rating

$$\boxed{\eta = \frac{P_L}{P_{dc}} \times 100}$$

Where η = the efficiency of the amplifier
P_L = the ac load power
P_{dc} = the dc input power

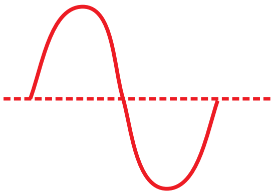
η is the Greek letter *eta*

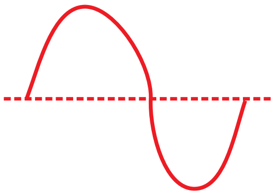
Distortion

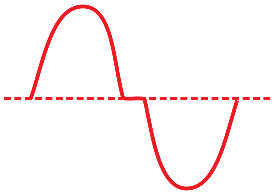
One of the goals in amplification is to produce an output waveform that has the exact same shape as the input waveform.

Distortion is defined as any undesired change in the shape of the waveform.

The waveforms below illustrate several different types of distortion that can be produced by amplifiers


Input Waveform
(pure sinewave)


Non Linear
Distortion


Crossover
Distortion

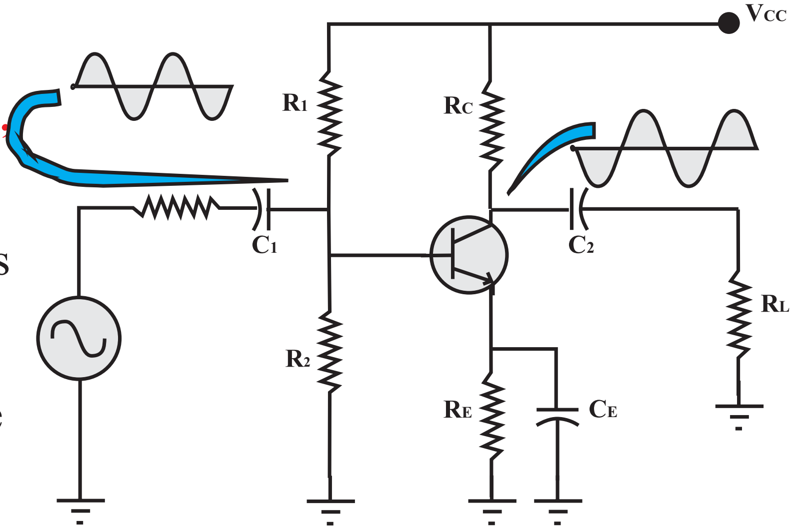
Amplifier Classifications 8.3

Class A

Our mid-point biased C.E. amplifier that we have studied is Class A.

Under normal operating conditions, the Class A amplifier has:

- An active device that conducts during the entire input cycle
- An output that contains little or no distortion
- A maximum theoretical efficiency of 25%.



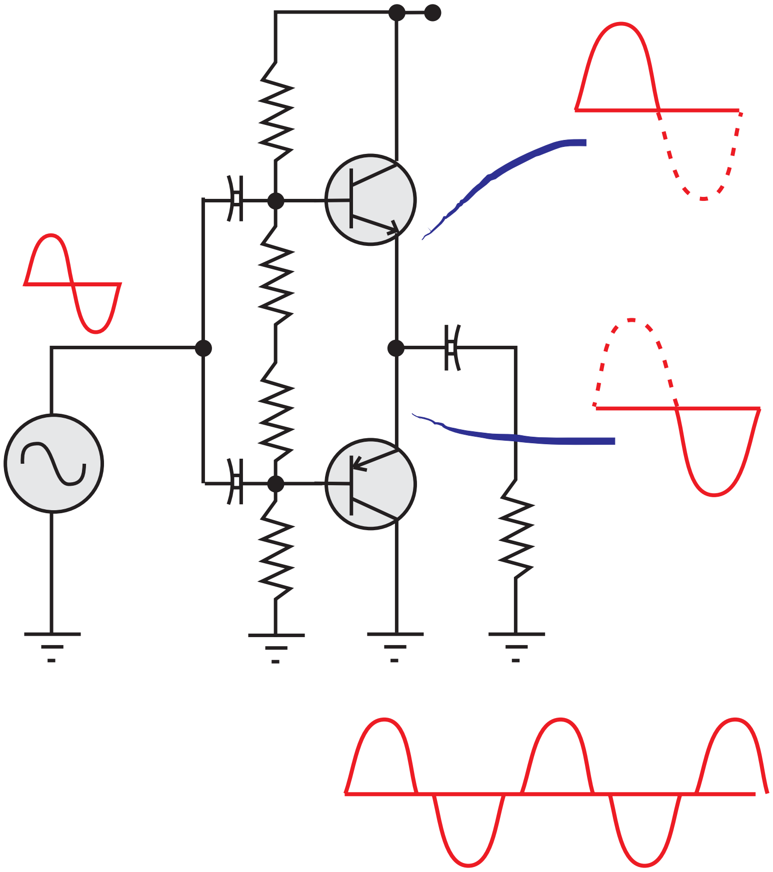
Class A Amplifier

Class B

A typical Class B amplifier will have two transistors that are connected as shown here.

Under normal operating conditions, the Class B amplifier has:

- Two transistors that are biased at cutoff (each conducts during one half of the input cycle.
- An output that contains little or no distortion
- A maximum theoretical efficiency of 78.5%



Typical Class B Amplifier
Push - Pull
Complementary-symmetry

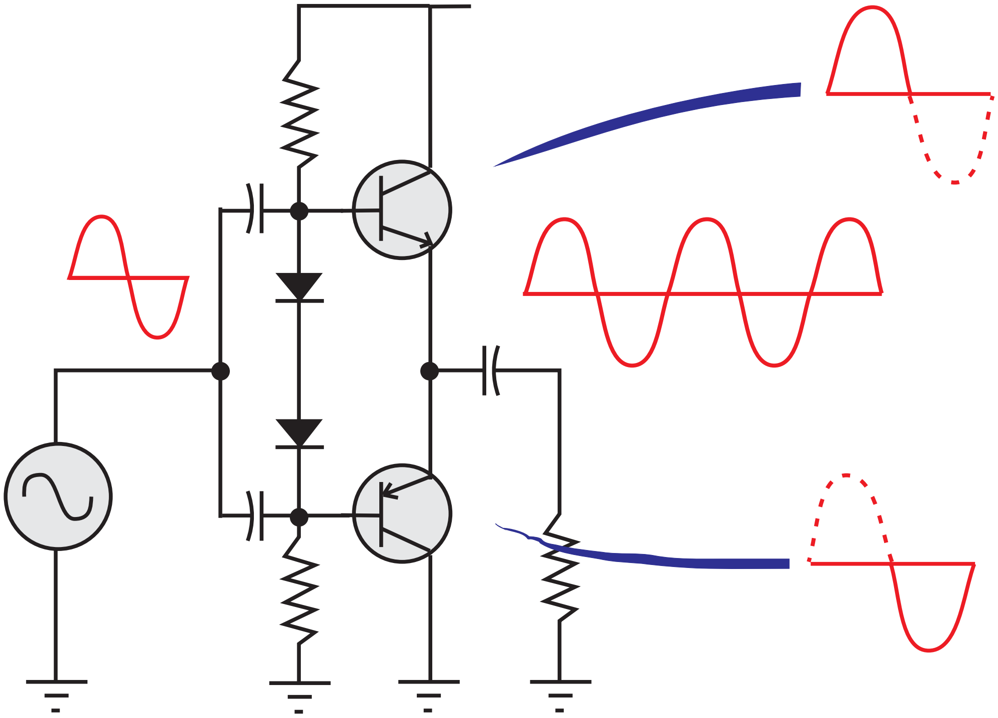
Amplifier Classifications 8.3

In Class B amplifiers, no current flows through the output transistors in the quiescent state.
This creates the relatively high efficiency rating and suits them well for use as power amplifiers

Class AB

Class AB amplifiers conduct for slightly more than 180° of the input cycle

This helps reduce cross-over distortion which will be discussed later



Typical Class AB Amplifier Complementary-symmetry

Class C

The Class C amplifier contains a single transistor that conducts for less than 180° of the ac input cycle.

The transistor is biased deeply into cutoff

The ac input to the transistor causes
it to conduct for only a brief time during the input cycle

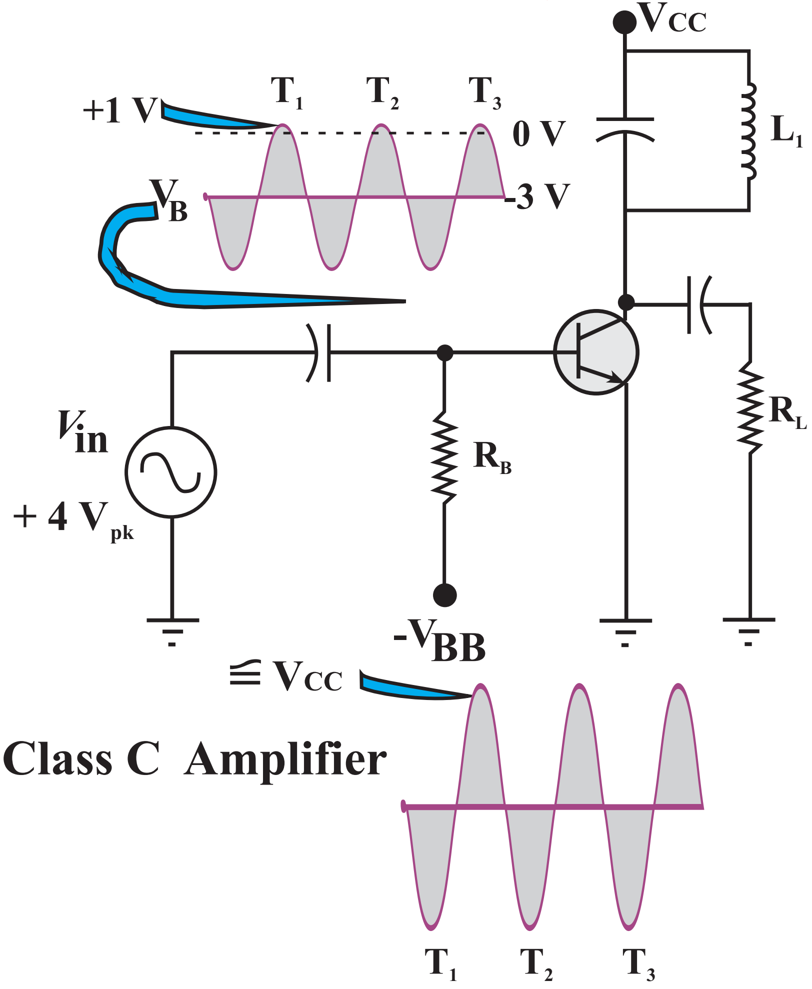
The rest of the output waveform is produced by the LC tank in the collector circuit.

Amplifier Classifications 8.3

Class C

The class C amplifier is, by its design, a tuned amplifier.

A tuned amplifier is one that produces a usable output over a specific range of frequencies.



Class C Amplifier

A Class C Amplifier typically has:

- A single transistor that conducts for less than 180° of the input cycle.
- An output that may contain a significant amount of distortion.
- A maximum theoretical efficiency rating of 99%

All amplifiers may be allocated to one of a number of classes depending on the way the active device is operated

h - Parameters 9.7

Hybrid parameters or h-parameters are transistor specifications that describe the component operating characteristics under special circumstances. Each of the four h-parameters is measured under ***no-load*** or ***full load*** conditions.

These h-parameters are then used in circuit analysis applications.

The four h-parameters for a transistor in a common emitter amplifier are:

h_{ie} = the base input impedance
h_{fe} = the base-to-collector ac current gain
h_{oe} = the output admittance
h_{re} = the reverse voltage feedback ratio.

The Input Impedance of the Base (h_{ie})

The Input Impedance of the Base (h_{ie}) is measured with the output shorted. A shorted output is a full load condition. You can see in Fig (A) that the capacitor is an ac short from collector to emitter. Note that h_{ie} is determined as:

$$\boxed{h_{ie} = \frac{v_{in}}{i_b}}$$

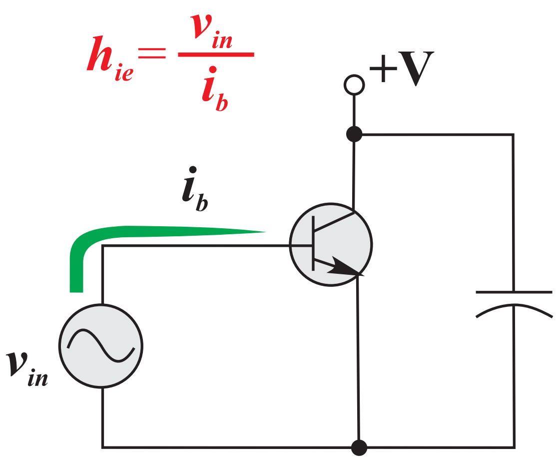


Fig (A) Input Impedance

Why short the output? Take the example of a swamped amplifier, we know that:

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

By shorting the collector and emitter terminals, the measured value of h_{ie} does not reflect any external resistance in the circuit.

ac Current (h_{fe})

The base to collector current gain is also measured with the output shorted. This means that h_{fe} is measured under full load.

$$h_{fe} = \frac{i_c}{i_b}$$

In Fig. (B), the output is shorted, and an ac signal voltage is applied to the base.

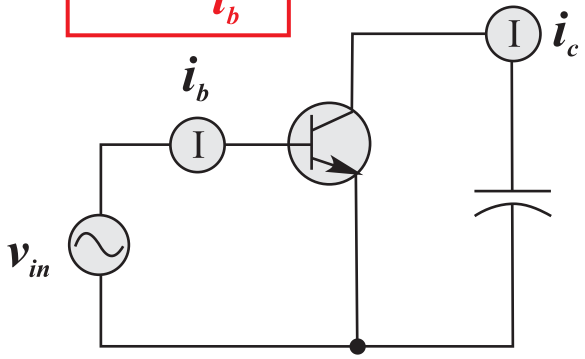
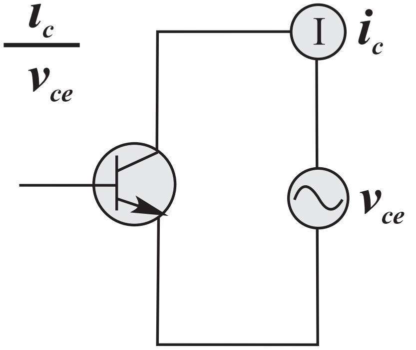


Fig (B) ac Current Gain

Both i_b and i_c are measured under this full load condition and the ratio of them is the ac current gain.

Output Admittance (h_{oe})

$$h_{oe} = \frac{i_c}{v_{ce}}$$



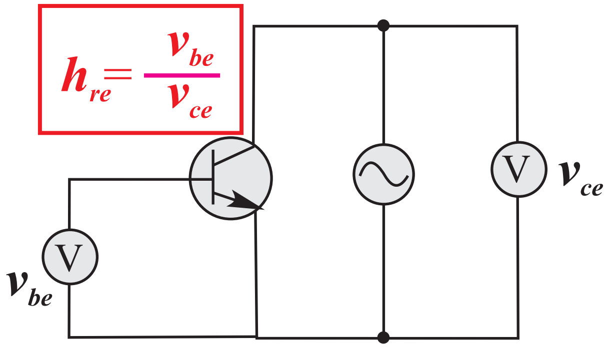
The output admittance is measured with the ***input open***. An ac signal voltage is applied across the collector - emitter terminals and the ac current is measured in the collector circuit. The value of admittance is then calculated as:

$$h_{oe} = \frac{i_c}{v_{ce}}$$

Fig (C) Output Admittance

Reverse Voltage Feedback (h_{re})

$$h_{re} = \frac{v_{be}}{v_{ce}}$$



This is the amount of output voltage that is reflected back to the input. It is measured with the input open. A signal is applied to the collector-emitter terminals. With the input open, the voltage fed back to the base-emitter junction is measured. Since the base-emitter voltage is less than the collector-emitter voltage, h_{re} will always be less than 1.

Fig (D) Reverse Voltage feedback

Circuit Calculations Involving h-parameters

For our purposes, we are interested in these four h-parameter equations.

These equations will give us more accurate results and should be used where ever possible.

$$A_i = h_{fe}\left(\frac{Z_{\mathrm{in}}\,r_c}{h_{ie}\,R_L}\right) \qquad r'_e = \frac{h_{ie}}{h_{fe}}$$

$$Z_{\mathrm{base}} = h_{ie} \qquad A_v = \frac{h_{fe}\,r_c}{h_{ie}}$$