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XMUT204 Electronic Design

Lecture 3e - BJT AC Analysis

Overview

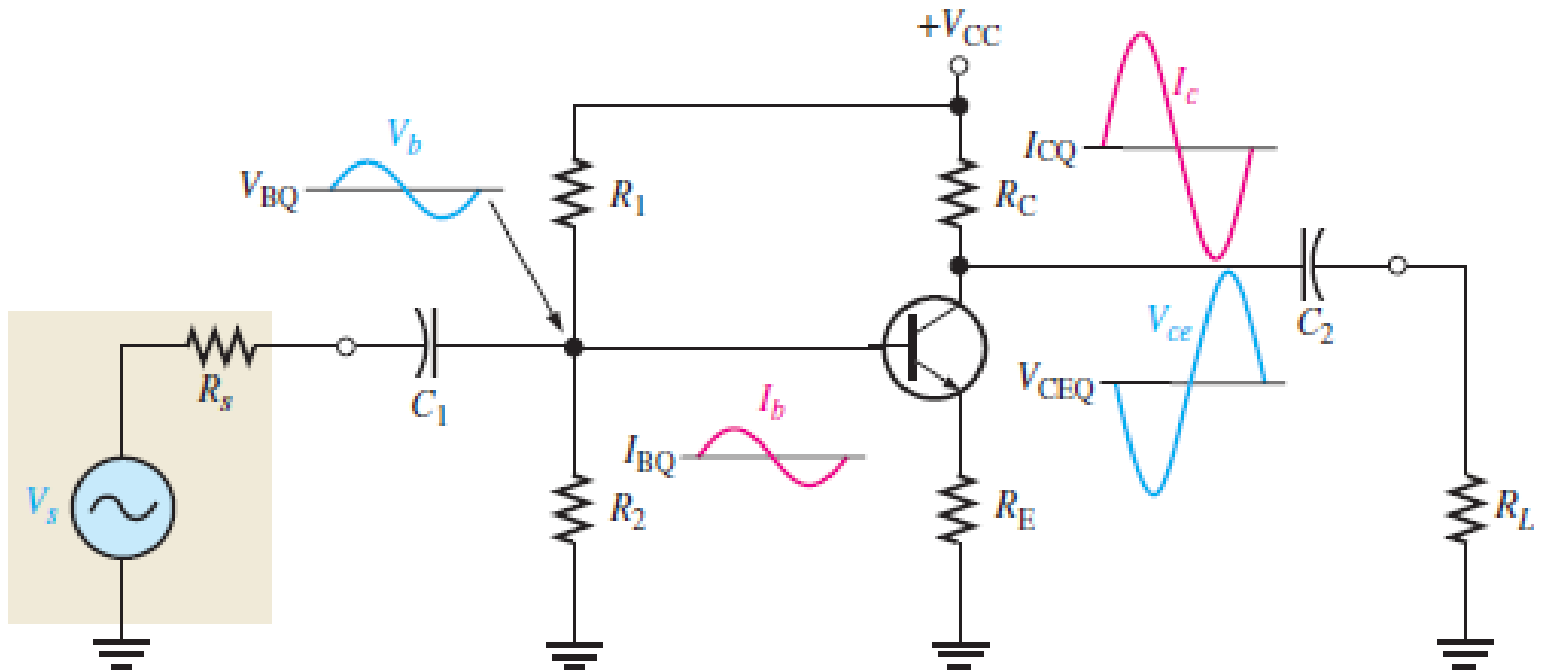
1. BJT Amplifier AC Analysis.
2. Transistor AC Model.
3. Common-Emitter Amplifier.
4. DC Analysis of Amplifier.
5. AC Analysis of Amplifier.
6. Emitter-Bypass Capacitor.
7. Frequency-Response Analysis.
8. Small-Signal Model of Common-Emitter Amplifier.

1. BJT Amplifier AC Analysis

- In previous topic, we looked at the design of a DC bias circuit to provide the correct operating point for the amplifier.
- We will now look at the small-signal component (the AC part) of the signal.
- We will look at the results of so-called small-signal analysis of the transistor, and the use these results in our analysis of the transistor amplifier action.
- Remember notation: as previously defined.

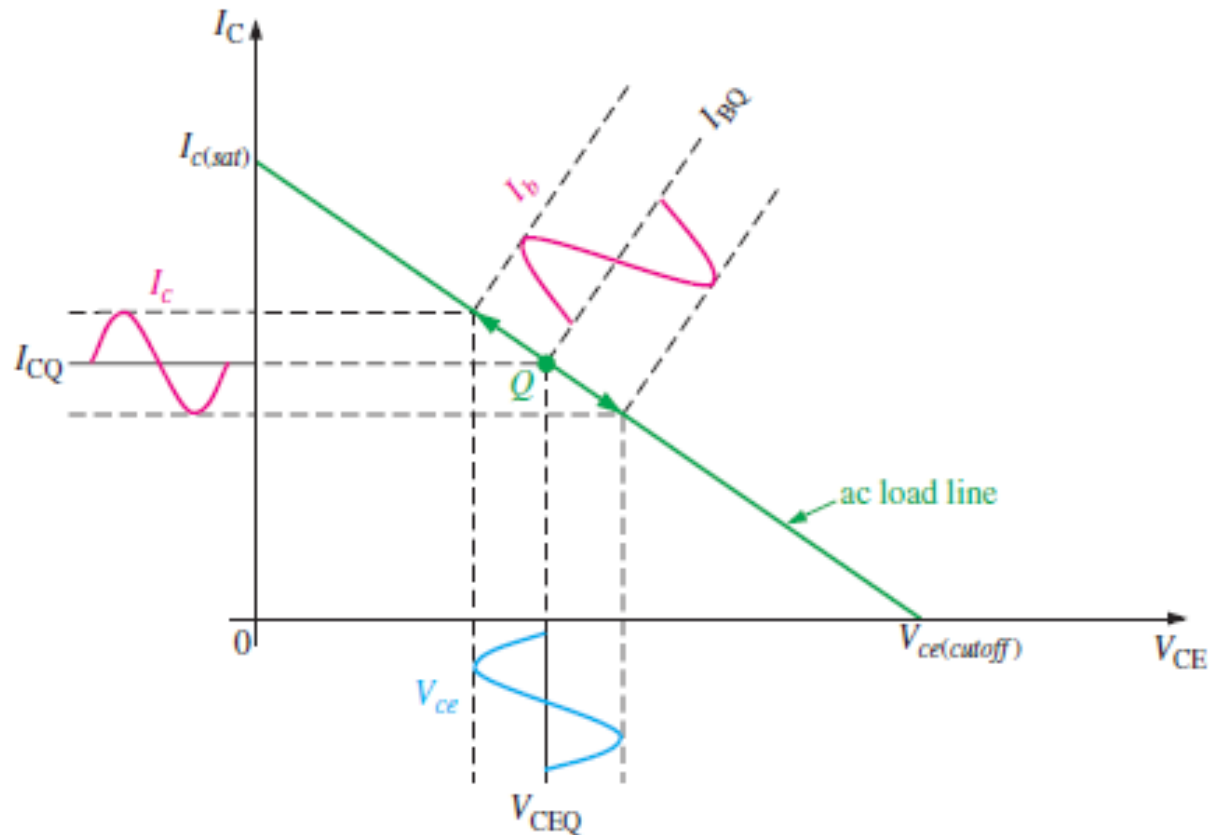
1. Amplifier Circuit and Signals

- For a given BJT amplifier, the goal of its design is to ensure that for a given input voltage and current signals that we obtain the amplified output voltage and current signals.



1. Amplifier Circuit and Signals

- The aim of Q-point determination in the design of BJT amplifier is to ensure output signal without saturation and clipping signals for a given input signal to the amplifier.



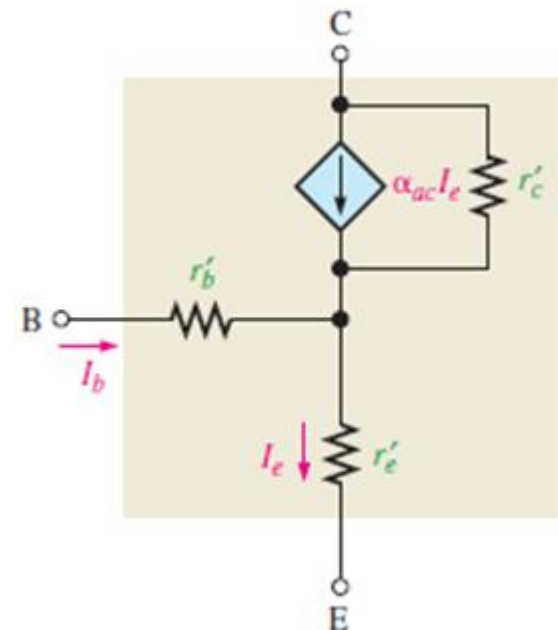
2. Transistor AC Models

- The AC operation of a transistor can be described in terms of a so-called small signal or AC model.
- These models are beyond the discussions of the course, but we will use some of the results from these models to help us with our amplifier designs and calculations.
- We will look at the results of the so-called r -parameter model (i.e. not the only model available out there).

2. The r -Parameter Model

- The r -parameter model analysis of the AC behaviour of the transistor in terms of the r -parameters, i.e. the internal resistances of the transistor.
- For given BJT transistor, five r -parameters are normally used in the model.

r -parameter	Description
α_{ac}	AC alpha (I_c/I_e)
β_{ac}	AC beta (I_c/I_b)
r'_e	AC emitter resistance
r'_b	AC base resistance
r'_c	AC collector resistance



2. The h -Parameter Model

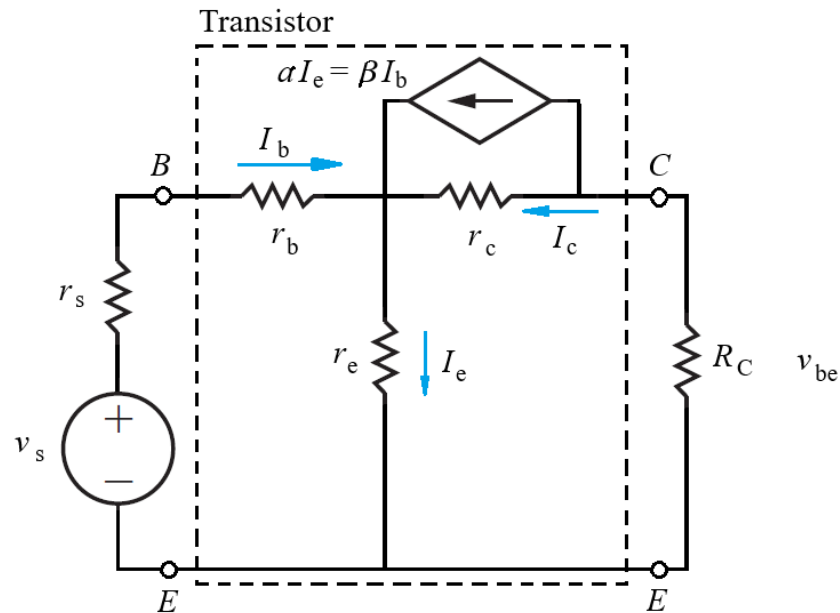
- The manufacturer's datasheet typically specifies h (hybrid) parameters (i.e. h_i , h_r , h_f , and h_o) because they are relatively easy to measure.

h -parameter	Description	Conditions
h_i	Input impedance (resistance)	Output shorted
h_r	Voltage feedback ratio	Input open
h_f	Forward current gain	Output shorted
h_o	Output admittance (conductance)	Input open

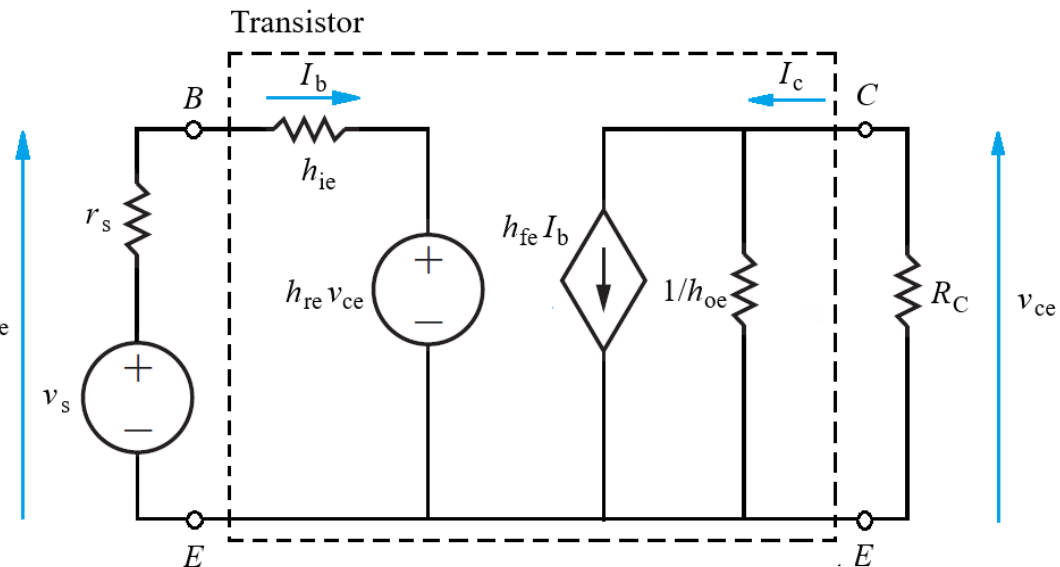
Configuration	h -parameters
Common-emitter	$h_{ie}, h_{re}, h_{fe}, h_{oe}$
Common-base	$h_{ib}, h_{rb}, h_{fb}, h_{ob}$
Common-collector	$h_{ic}, h_{rc}, h_{fc}, h_{oc}$

2. The r -and h -Parameter Models

- The r -parameters and h -parameter equivalent circuits.
- Notice that both circuits refer to the common-emitter BJT amplifier circuit configuration.



(a) CE r -parameter equivalent circuit



(b) CE h -parameter equivalent circuit

2. The Relationship Between r -and h -Parameters Models

- The AC current ratios:

$$\alpha_{ac} = h_{fb}$$

$$\beta_{ac} = h_{fe}$$

- The conversion between h -parameters to r -parameters:

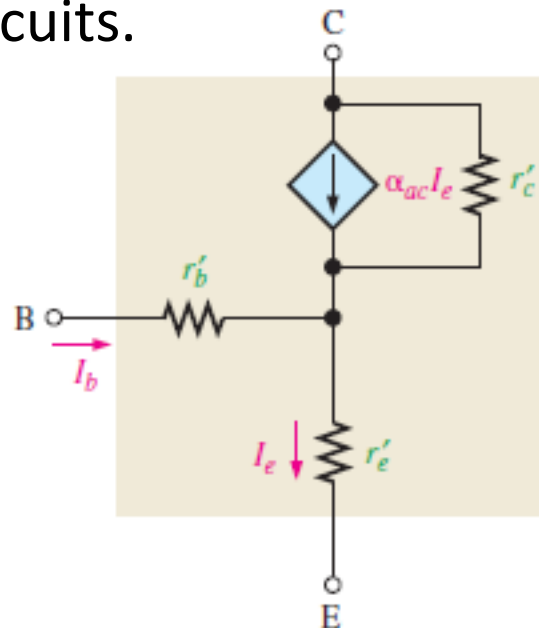
$$r'_e = \frac{h_{re}}{h_{oe}}$$

$$r'_c = \frac{h_{re} + 1}{h_{oe}}$$

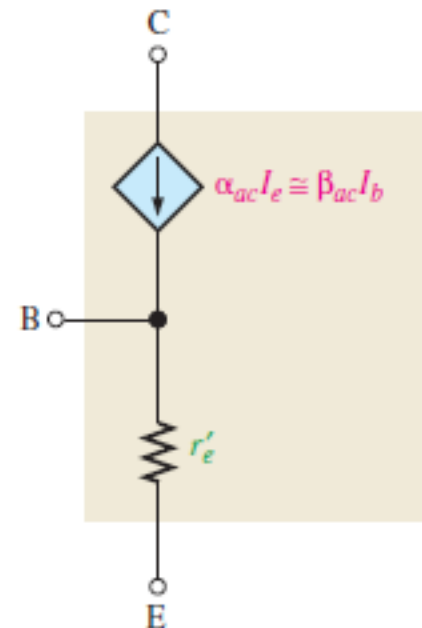
$$r'_b = h_{ie} - \frac{h_{re}}{h_{oe}} (1 + h_{fe})$$

2. Use of r -Parameter Model in BJT Circuit Analysis

- This model is commonly employed for determining the AC behaviour of the BJT amplifier.
- Approximated as simplified r -parameter equivalent circuit.
- The AC base resistance (r'_b) and collector resistance (r'_c) are usually small enough to neglect, so it can be replaced by short circuits.



(a) Generalized r -parameter model for a BJT



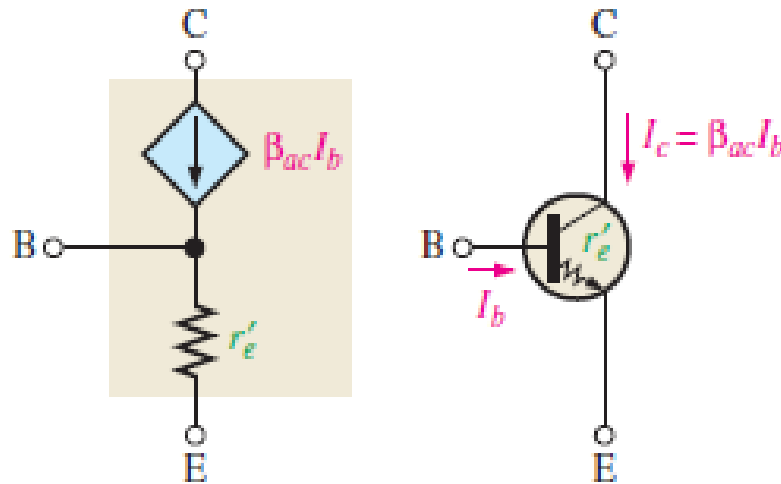
(b) Simplified r -parameter model for a BJT

2. The r -Parameter Model

- The most important result from this model is an estimate of the value of the emitter-internal resistance, r'_e .

$$r'_e = \frac{25 \text{ mV}}{I_E}$$

Where: I_E is the DC emitter current.



2. Determination of r_e -and h -Parameters

- The value of internal emitter resistance of the BJT, r_e is determined from V_{BE} vs. I_E graph.
- It is taken as the slope of the curve in the V_{BE} vs. I_E :

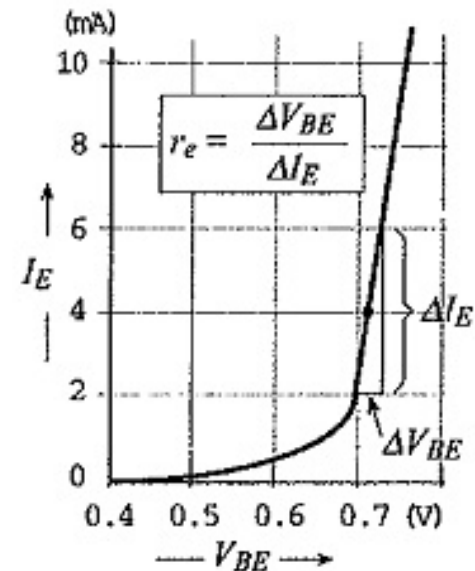
$$r_e = \frac{\Delta V_{BE}}{\Delta I_E}$$

- For $T = 25$ C, r_e can be calculated:

$$r_e = \frac{26 \text{ mV}}{I_E}$$

- At any temperature, r_e is:

$$r_e = \frac{26 \text{ mV}}{I_E} \left(\frac{T + 273^\circ \text{ C}}{298^\circ \text{ C}} \right)$$

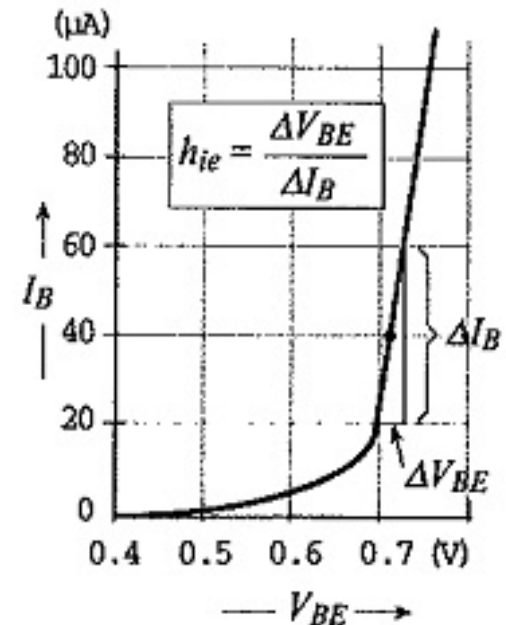
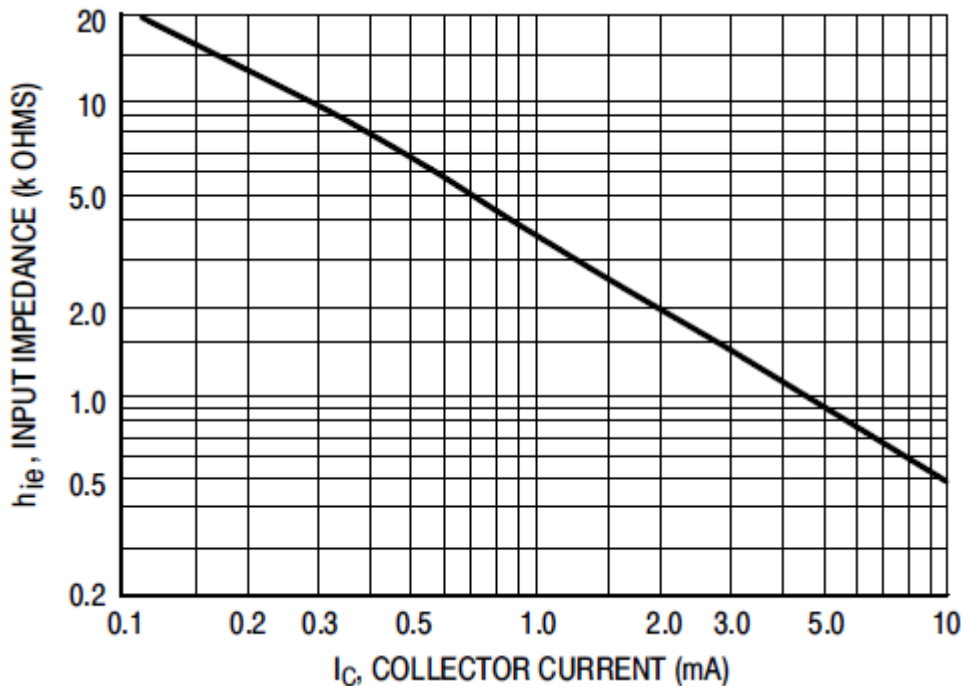


V_{BE} vs. I_E of BJT for determining r_e

2. Determination of r -and h -Parameters (cont.)

- The value, h_{ie} of the BJT is determined from V_{BE} vs. I_B graph.
- The value of h_{ie} is taken as the slope in the V_{BE} vs. I_B :

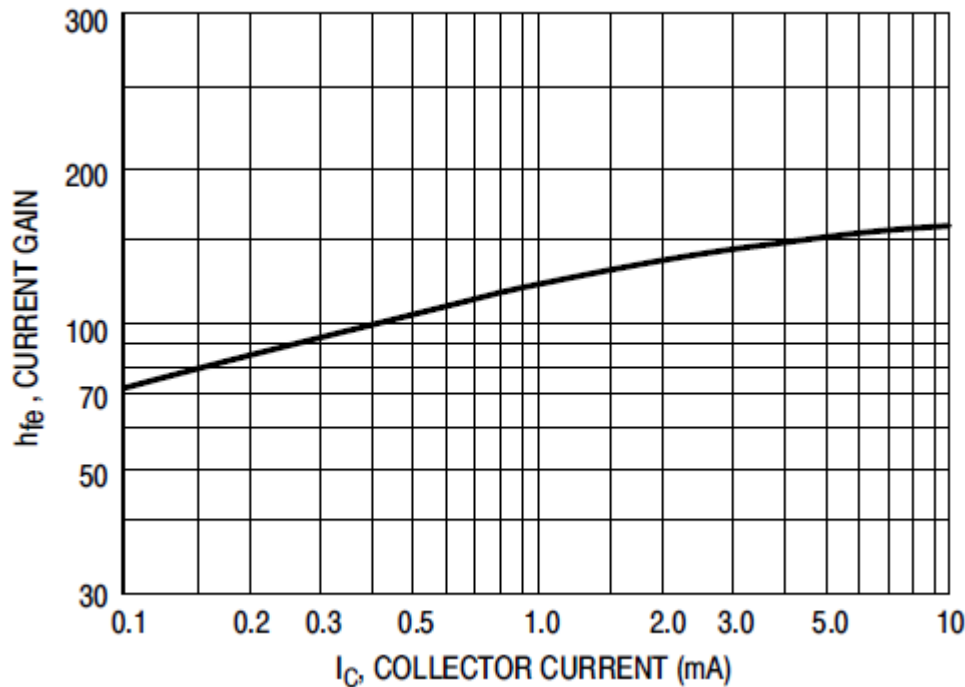
$$h_{ie} = \frac{\Delta V_{BE}}{\Delta I_B}$$



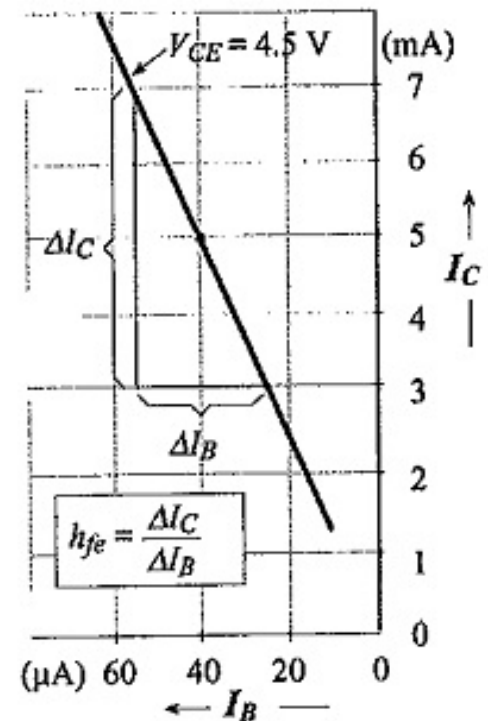
V_{BE} vs. I_B of BJT for determining h_{ie}

2. Determination of r -and h -Parameters (cont.)

- The value, h_{fe} of the BJT is determined from I_C vs. I_B graph.
- The value of h_{fe} is taken as the slope in the I_C vs. I_B :



$$h_{fe} = \frac{\Delta I_C}{\Delta I_B}$$

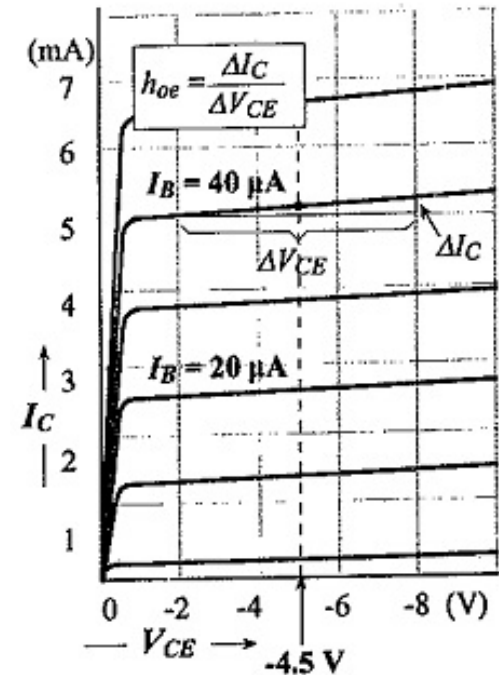
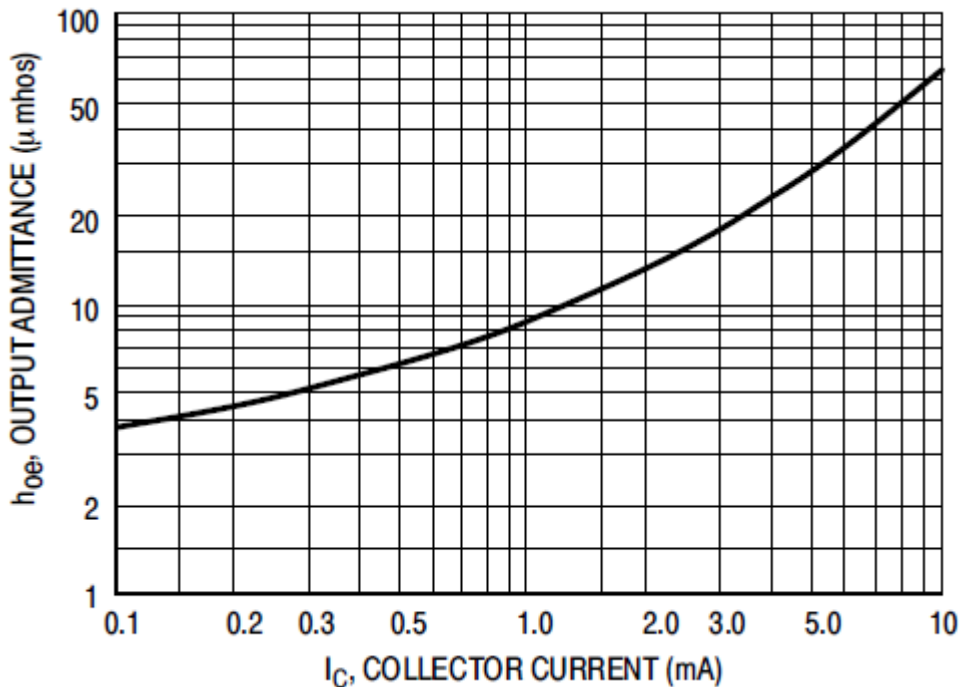


I_C vs. I_B of BJT for determining h_{fe}

2. Determination of r -and h -Parameters (cont.)

- The value, h_{oe} of the BJT is determined from V_{BE} vs. I_C graph.
- The value of h_{oe} is taken as the slope in the I_C vs. V_{CE} :

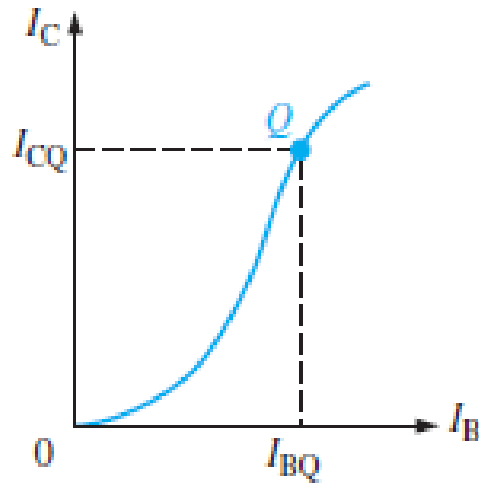
$$h_{oe} = \frac{\Delta I_C}{\Delta V_{CE}}$$



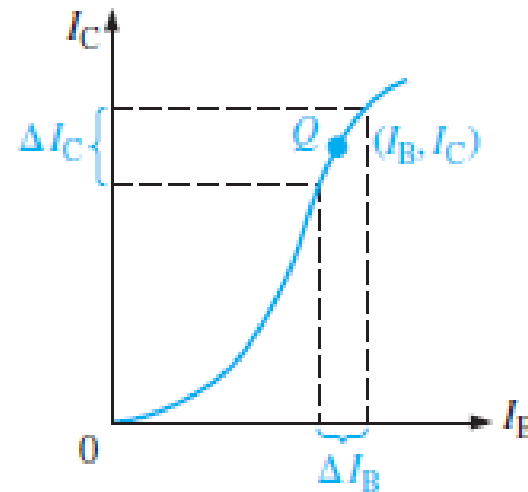
I_C vs. V_{CE} of BJT for determining h_{oe}

2. Comparison Between β_{DC} and β_{AC}

- There are slight difference between β_{DC} and β_{AC} .
- Since $\beta_{DC} = I_C/I_B$ and $\beta_{ac} = \Delta I_C/\Delta I_B$, the values of these two quantities can differ slightly.
- Notice also the graph of I_C vs. I_B is also non-linear.



(a) $\beta_{DC} = I_C/I_B$ at Q-point



(b) $\beta_{ac} = \Delta I_C/\Delta I_B$

Example 1 – r -parameters of BJT

Given in the table below is a partial manufacturer datasheet of 2N3946/2N3947 BJT.

Electrical Characteristics ($T_A = 25^\circ\text{C}$ unless otherwise noted.)

Characteristic		Symbol	Min	Max	Unit
Input capacitance ($V_{EB} = 1.0\text{ V dc}, I_C = 0, f = 1.0\text{ MHz}$)		C_{ibo}	–	8.0	pF
Input impedance ($I_C = 1.0\text{ mA}, V_{CE} = 10\text{ V}, f = 1.0\text{ kHz}$)	2N3946 2N3947	h_{ie}	0.5 2.0	6.0 12	kohms
Voltage feedback ratio ($I_C = 1.0\text{ mA}, V_{CE} = 10\text{ V}, f = 1.0\text{ kHz}$)	2N3946 2N3947	h_{re}	– –	10 20	$\times 10^{-4}$
Small-signal current gain ($I_C = 1.0\text{ mA}, V_{CE} = 10\text{ V}, f = 1.0\text{ kHz}$)	2N3946 2N3947	h_{fe}	50 100	250 700	–
Output admittance ($I_C = 1.0\text{ mA}, V_{CE} = 10\text{ V}, f = 1.0\text{ kHz}$)	2N3946 2N3947	h_{oe}	1.0 5.0	30 50	μmhos
Collector base time constant ($I_C = 10\text{ mA}, V_{CE} = 20\text{ V}, f = 31.8\text{ MHz}$)		$rb'C_c$	–	200	ps
Noise figure ($I_C = 100\ \mu\text{A}, V_{CE} = 5.0\text{ V}, R_G = 1.0\text{ k}\Omega,$ $f = 1.0\text{ kHz}$)		NF	–	5.0	dB

Switching Characteristics

Delay time	$V_{CC} = 3.0\text{ V dc}, V_{OB} = 0.5\text{ V dc},$ $I_C = 10\text{ mA dc}, I_{B1} = 1.0\text{ mA}$	2N3946 2N3947	t_d	–	35	ns
Rise time			t_r	–	35	ns
Storage time	$V_{CC} = 3.0\text{ V}, I_C = 10\text{ mA},$ $I_{B1} = I_{B2} = 1.0\text{ mA dc}$	2N3946 2N3947	t_s	– –	300 375	ns
Fall time			t_f	–	75	ns

(1) Pulse test: $PW \leq 300\ \mu\text{s}$, Duty Cycle $\leq 2\%$.

- a. Refer to the 2N3946/2N3947 partial datasheet given in the table above. Determine the minimum value for each of the following r parameters:
- i. AC gain, β_{AC} . [2 marks]
 - ii. Internal emitter resistance, r_e' . [2 marks]
 - iii. Internal collector resistance, r_c' . [2 marks]
- b. Repeat part (a) for maximum values. [6 marks]
- c. Should you use a 2N3946 or a 2N3947 transistor in a certain application if the design criterion is maximum current gain? [2 marks]

Answer

- Based on the given manufacturer datasheet, for a 2N3947, the parameters of the BJT are:

Symbol	Min	Max	Unit
C_{ibo}	–	8.0	pF
h_{ie}	0.5 2.0	6.0 12	kohms
h_{re}	– –	10 20	$\times 10^{-4}$
h_{fe}	50 100	250 700	–
h_{oe}	1.0 5.0	30 50	μmhos

- $\beta_{AC}(\text{min}) =$
 $h_{fe}(\text{min}) = 100,$

- $r_e'(\text{min})$ cannot be determined since $h_{re}(\text{min})$ is not given, and

- $r_c'(\text{min})$ also cannot be determined since $h_{re}(\text{min})$ is not given.

- b. From the datasheet, for a 2N3947 BJT, $\beta_{AC}(\text{max}) = 700$ and the max. values of r_e' and r_c' parameters are:

$$r_e'(\text{max}) = h_{re}h_{oe} = (20 \times 10^{-4})(50 \mu\text{S}) = 40 \Omega$$

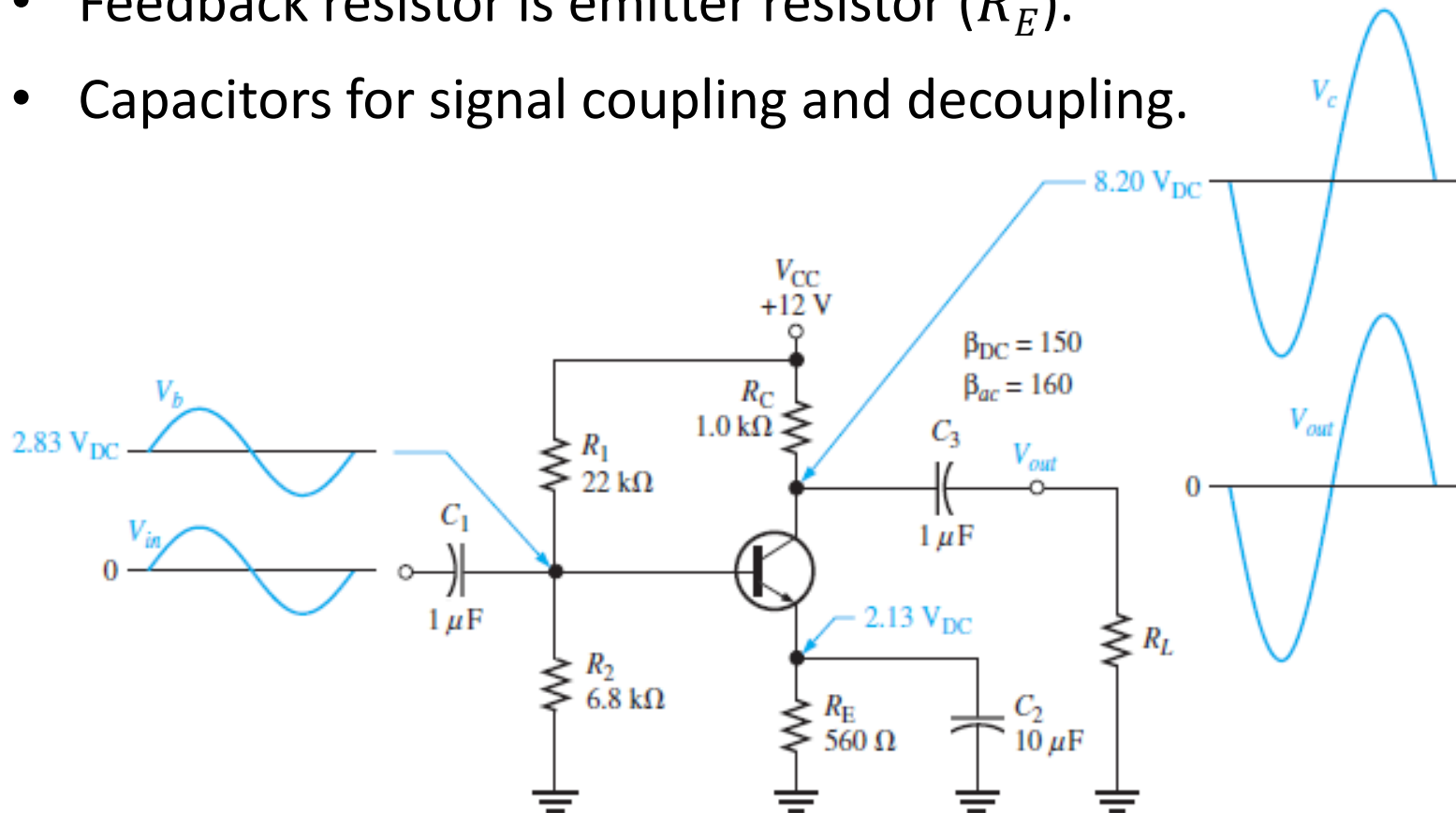
And

$$r_c'(\text{max}) = \frac{h_{re} + 1}{h_{oe}} = \frac{(20 \times 10^{-4} + 1)}{50 \mu\text{S}} = 20 \text{ k}\Omega$$

- c. For maximum current gain, a 2N3947 BJT should be used.

3. The Common-Emitter (with Feedback Resistor) Amplifier

- This type of design model is very popular.
- Voltage divider resistors for biasing purposes.
- Feedback resistor is emitter resistor (R_E).
- Capacitors for signal coupling and decoupling.

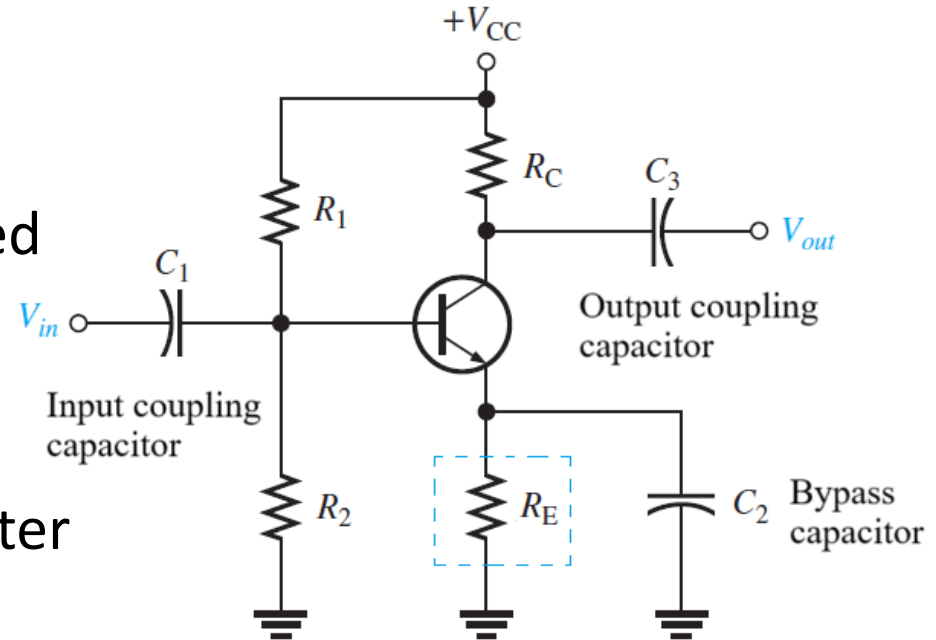


3.1. Emitter Feedback Resistor

- It is included to stabilise the amplifier's bias voltage.
- Emitter is no longer grounded or at zero-volt potential:

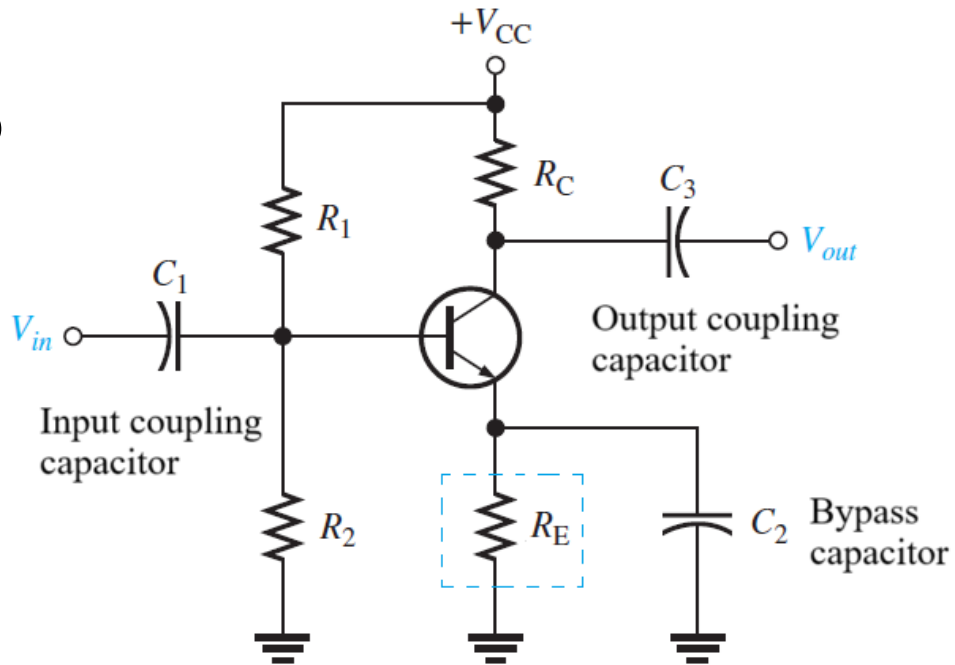
$$V_E = I_E R_E$$

Where: I_E is the actual emitter current.



- The emitter resistor R_E controls the base biasing using negative feedback, which negates any attempted change in I_C with an opposing change in the base bias voltage e.g. the circuit tends to be stabilised at a fixed level.

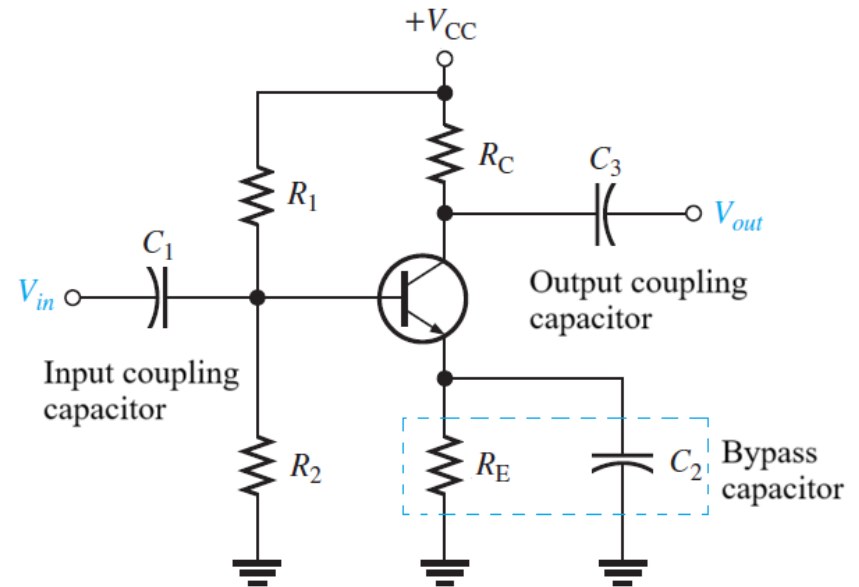
- If V_{CC} increases, then I_C also increases for a given load resistance.
- If I_C increases, I_E must also increase causing the voltage drop across R_E to increase.



- This action results in a proportional increase in V_B as $V_B = V_E + V_{BE}$.
- Since the V_B is held constant by the divider resistors R_1 and R_2 , the DC voltage on V_{BE} is lowered by a proportional amount e.g. reducing the I_B drive and keeping I_C from increasing further.
- A similar action occurs if V_{CC} and I_C decrease in value.

3.2. Basic Characteristics of Common-Emitter Design

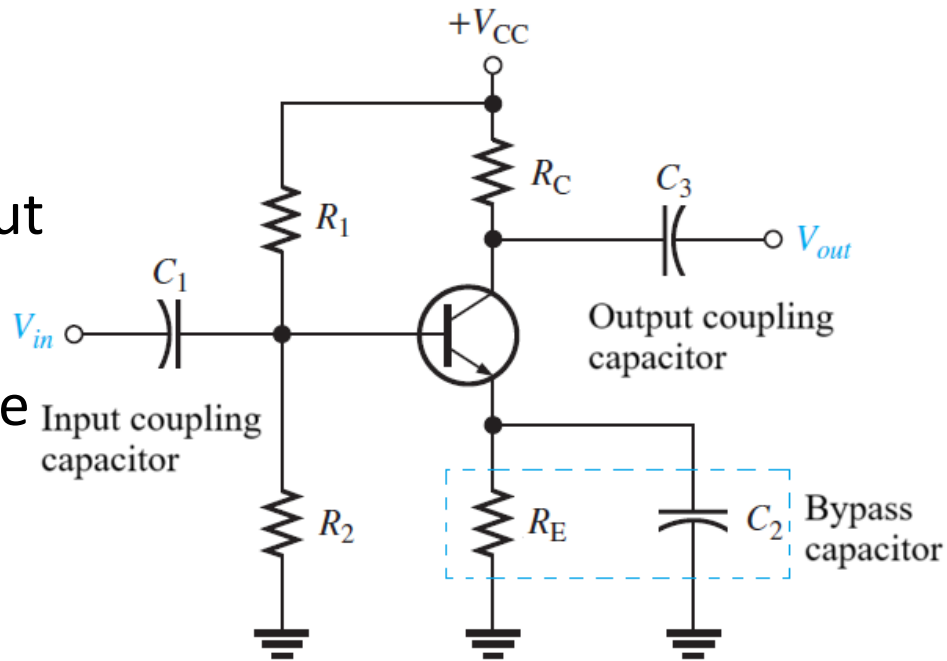
- Use of three capacitors:
 - C_1 to couple the input.
 - C_2 to couple the output.
 - C_3 a bypass capacitor to ground.



- Input signal V_{in} is capacitive-coupled to the base terminal.
- Output signal V_{out} is capacitive coupled between the collector and load.
- No AC signal at the emitter as the bypass capacitor effectively shorts the AC signal at the emitter to ground.

3.2. Basic Characteristics of Common-Emitter Design (cont.)

- AC input and AC output use the emitter as a common point (which is also at ground for AC).
- Refer to this as a common-emitter configuration but for AC analysis only.
- Output signal will be 180° out-of-phase with the input signal.
- Output signal is the inverse of the input signal.
- It is an example of an inverting amplifier.



3.3. Gain of Common-Emitter with Emitter Feedback

- Gain of common-emitter BJT amplifier circuit with emitter feedback resistor is:

$$\frac{v_o}{v_i} = -\frac{R_C}{R_E + r'_e} \approx -\frac{R_C}{R_E} \quad \text{as} \quad r'_e \ll R_E$$

- It is smaller than the gain without feedback in the CE configuration, where the gain was given by:

$$\frac{v_o}{v_i} = -\frac{R_C}{r_e}$$

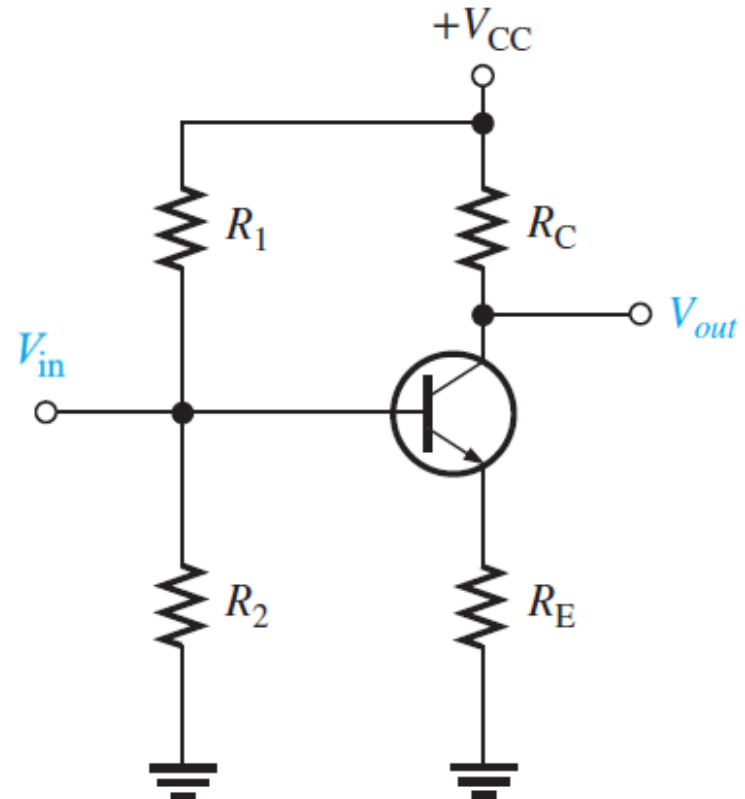
Where: $r_e = 1/g_m$ with g_m is the transconductance (i.e. ratio of I_C/V_{BE}).

3.3. Gain of Common-Emitter with Emitter Feedback (cont.)

- Thus, we can increase the gain, simply by increasing this ratio of R_C/R_E . This can only be done to a limited extent in practice.
- The resistor R_E cannot be too small, as we need a significant amount of feedback to make the circuit work.
- On the other hand, the resistor R_C cannot be too large to limit the current that flows.
- We have thus traded off the increased stability for a loss of high gain.
- This circuit can be further improved using a voltage divider pair to bias the base – provides improved bias stability.

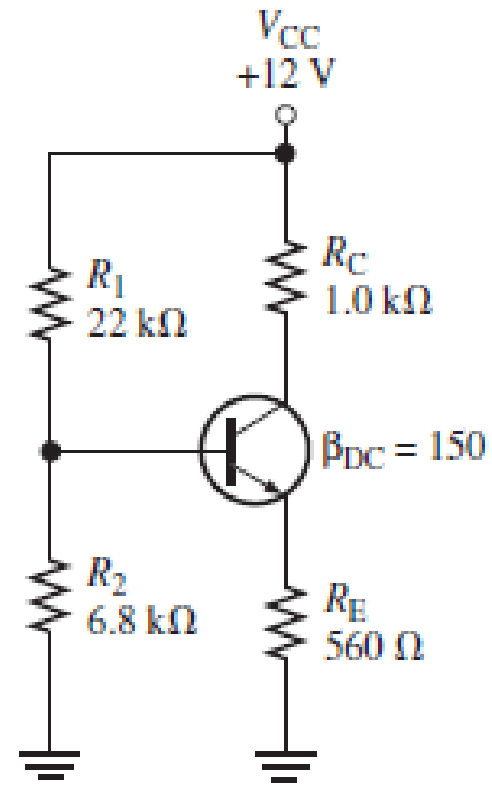
4. DC Analysis of the Amplifier

- DC equivalent circuit determined by removing coupling and bypass capacitors because they appear open as far as the DC is concerned.
- Then, analyse using the method given in the previous biasing topic for voltage divider biasing of the BJT transistor.
- Determining the design parameters of the biasing circuit will lead to the values of the components in the potential divider biasing circuit.



Example 2 - DC Analysis of BJT Amplifier

- Given a potential divider biasing circuit for a BJT amplifier circuit.
- Perform DC analysis of the amplifier circuit by calculating circuit parameters (e.g. voltages V_B , V_E , and V_C , currents I_E and I_C , and V_{CE}) in the circuit given below.
- Assume no base current loading.



Answer

Calculate circuit parameters assuming no base current loading*:

- Voltage at the base of the amplifier circuit is:

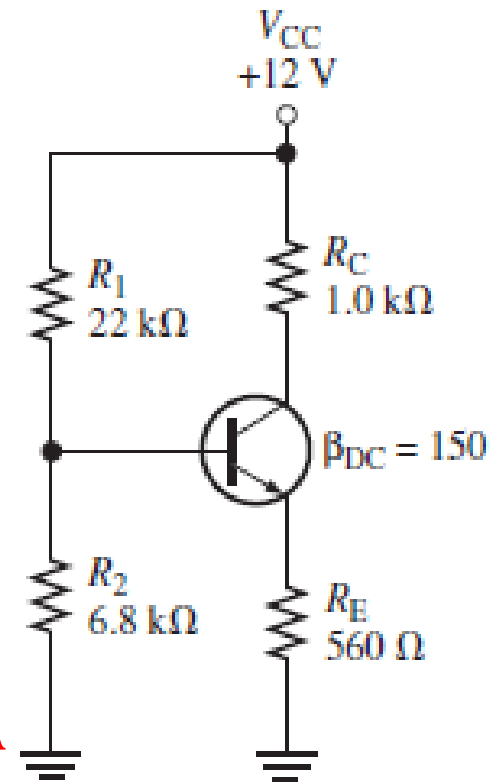
$$V_B = \left(\frac{R_2}{R_1 + R_2} \right) V_{CC}$$
$$= \left[\frac{6.8 \text{ k}\Omega}{6.8 \text{ k}\Omega + 22 \text{ k}\Omega} \right] 12 \text{ V} = 2.83 \text{ V}$$

- Voltage at the emitter of BJT is:

$$V_E = V_{IN} - V_{BE} = 2.83 \text{ V} - 0.7 \text{ V} = 2.13 \text{ V}$$

- Current that flows in the emitter of BJT is:

$$I_E = \frac{V_{IN} - V_{BE}}{R_E} = \frac{2.83 \text{ V} - 0.7 \text{ V}}{560 \Omega} = 3.8 \text{ mA}$$



- The current that flows in the collector is equal to current that flows in the emitter:

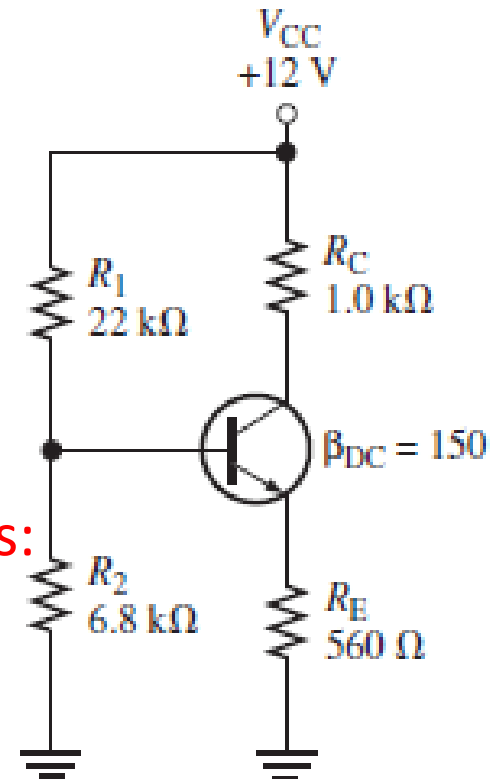
$$I_C \approx I_E = 3.8 \text{ mA}$$

- The voltage at the collector of BJT is:

$$\begin{aligned} V_C &= V_{CC} - I_C R_C \\ &= 12 \text{ V} - (3.8 \text{ mA})(1 \text{ k}\Omega) = 8.2 \text{ V} \end{aligned}$$

- The voltage across the collector-to-emitter is:

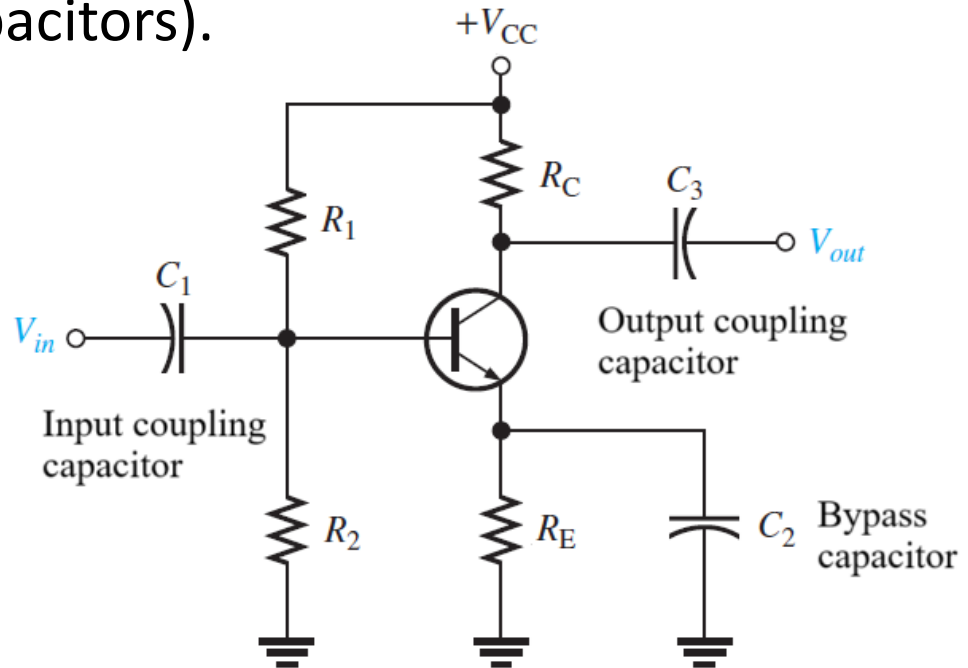
$$\begin{aligned} V_{CE} &= V_C - V_E \\ &= 8.2 \text{ V} - 2.1 \text{ V} = 6.1 \text{ V} \end{aligned}$$



* A slightly more complex method can be used to take any base current loading into consideration – give better approximations of the DC parameters than our estimates.

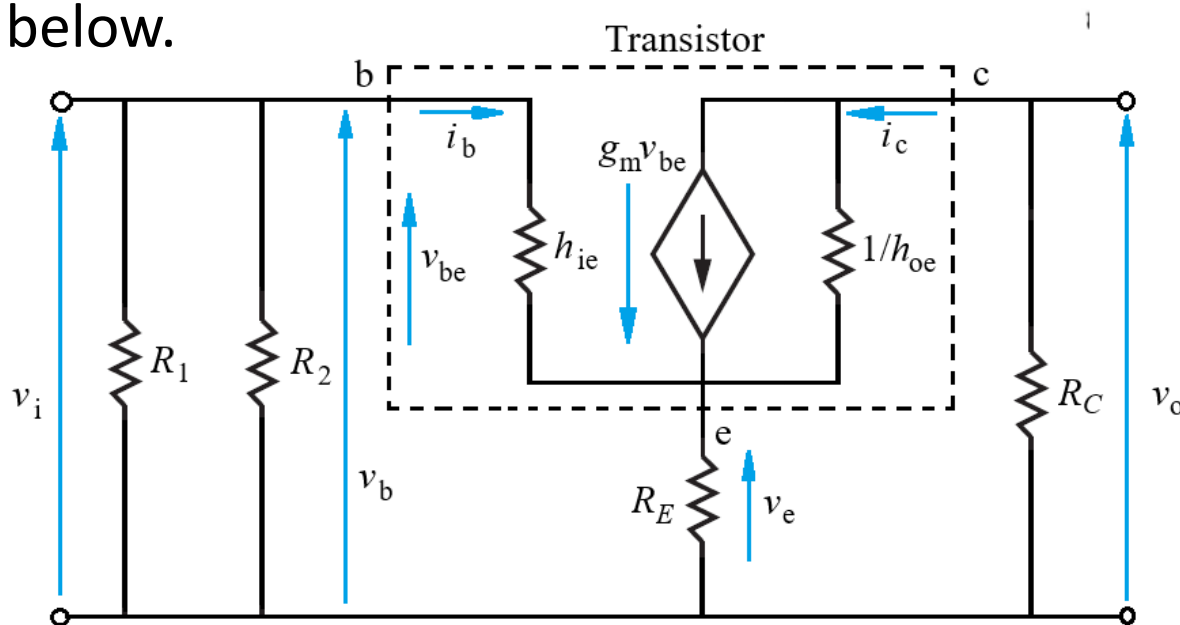
5. Small-Signal Model for Common-Emitter BJT Amplifier

- Voltage divider resistors (R_1 and R_2) for biasing purpose.
- R_C and R_E for active region with required Q-point.
- Feedback resistor is emitter resistor (R_E).
- Capacitors for signal coupling and bypass purposes (input, output and bypass capacitors).
- This circuit is improved using a voltage divider pair to bias the base – provides improved bias stability.



5.1. The Use of Small-Signal Models

- Detail on circuit parameters can be obtained by considering the so-called small-signal equivalent model of the transistor as shown below.



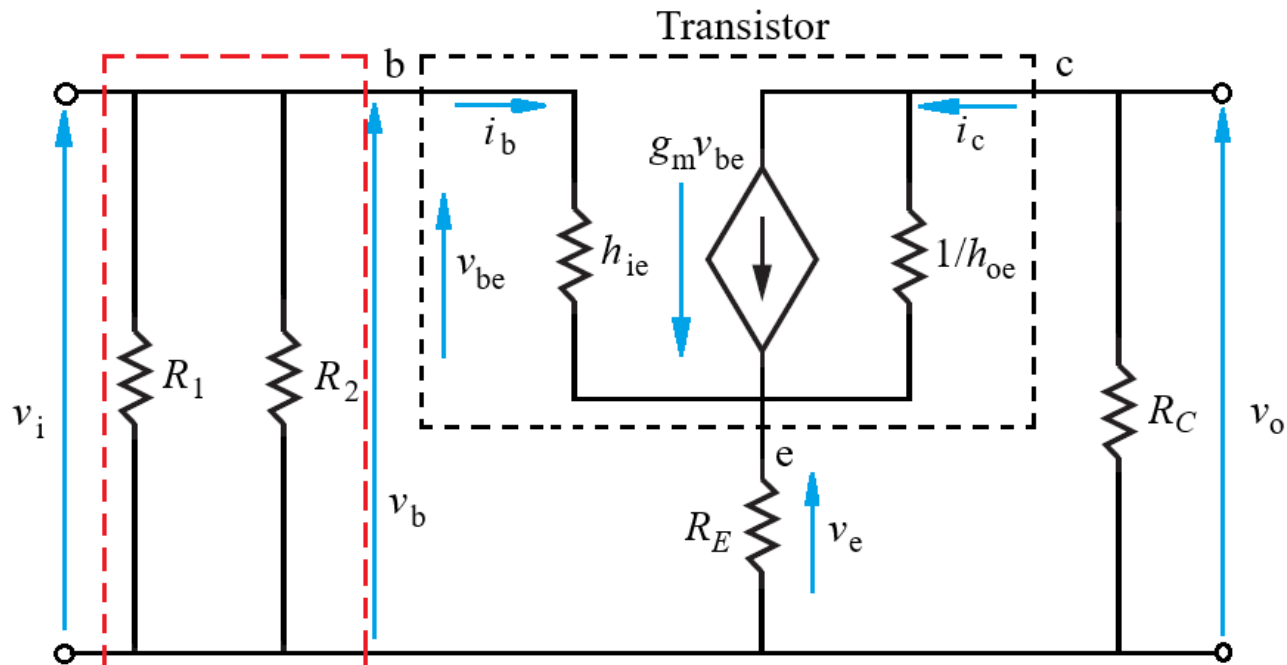
- However, this model will not be considered in any more detail in this course, but we will only look at a few significant results: biasing resistors, input/output resistors and capacitors, emitter feedback resistor and capacitor.

5.1. The Use of Small-Signal Models (Input Resistance)

- The **input resistance** into the amplifier is approximately:

$$r_i \approx R_1 \parallel R_2$$

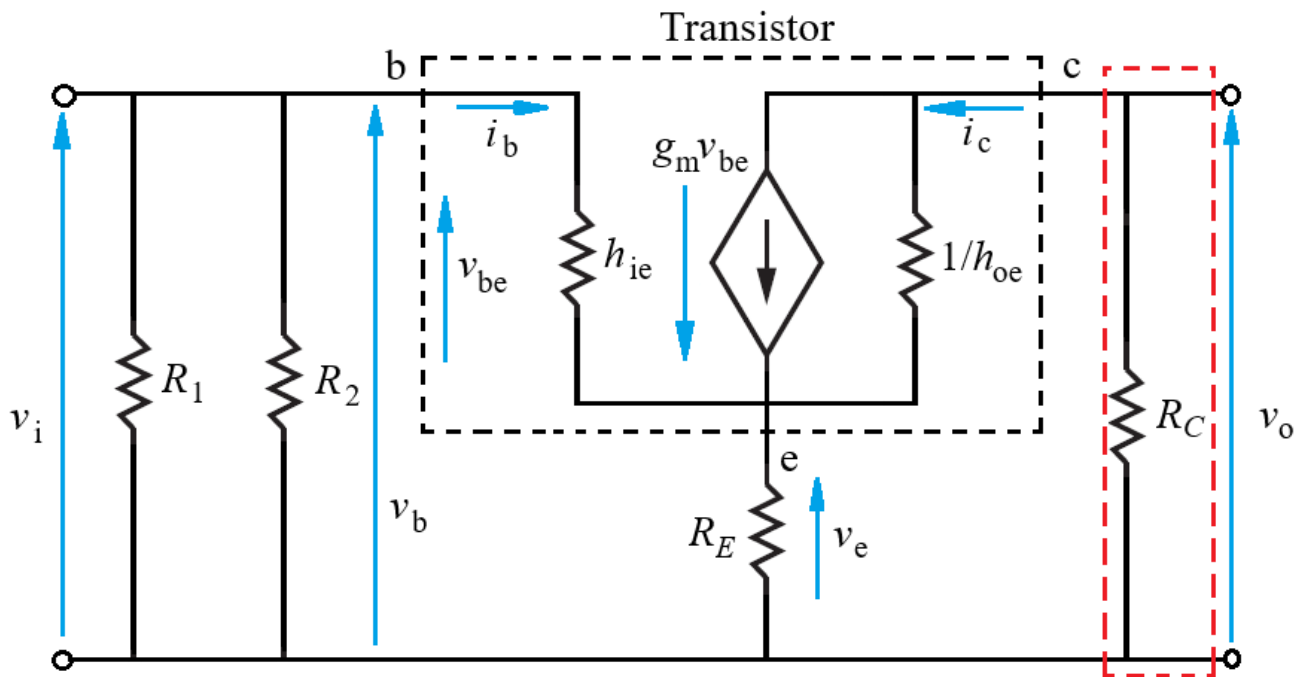
- For a high input resistance, need R_1 and R_2 as high as possible.
- But we need to keep current in R_1 and $R_2 \gg$ current via I_B .
- Design guide: choose R_2 approximately $10R_E$.



5.1. The Use of Small-Signal Models (Output Resistance)

- The **output resistance** in the small-signal model to be approximately:

$$r_o \approx R_C$$



5.1. The Use of Small-Signal Models (Output Resistance)

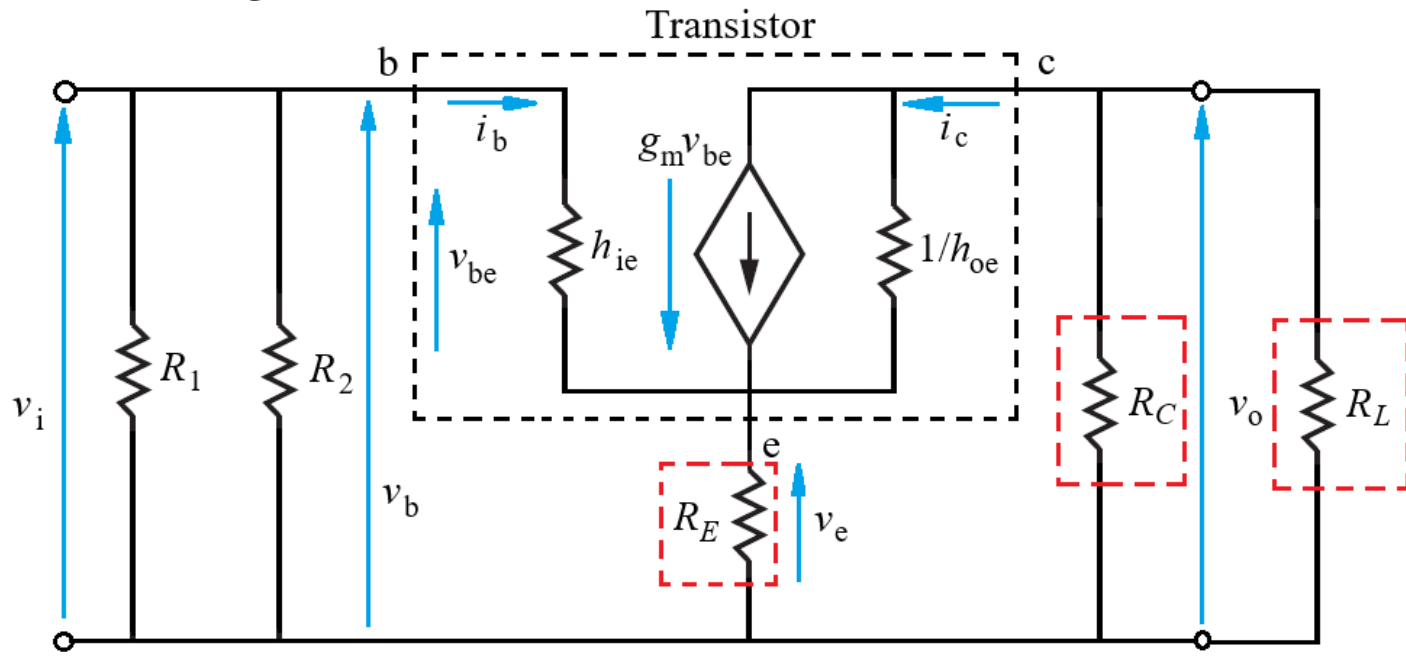
- The effect of the load resistance R_L - reduce the gain from:

$$A_v = -R_C/R_E$$

to

$$A_v = -(R_C \parallel R_L)/R_E$$

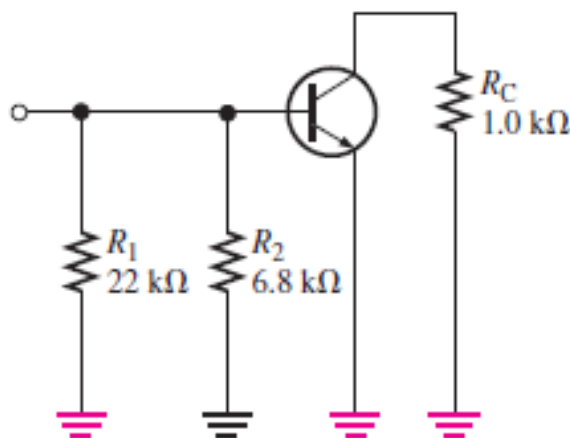
- It is a parallel combination of R_C and R_L .
- If $R_L \gg R_C$, the loading effects on the amplifier will be small.



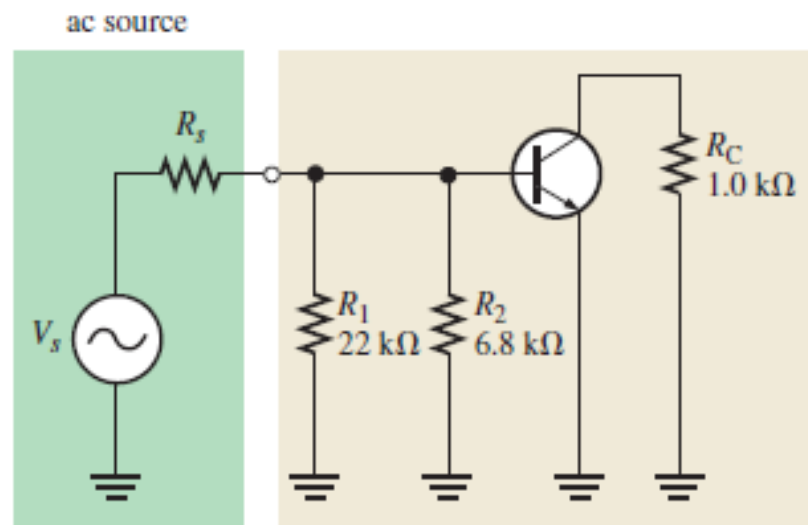
5.2. Method of AC Analysis of the Amplifier

To develop a circuit for the AC analysis, we:

- Replace the capacitors C_1, C_2, C_3 as shorts e.g. these capacitors are selected so that their impedances (X_C) are negligible at signal frequency, so the impedance can be zero.
- The DC source is replaced by ground.
- From this model, several derivations can be done for various circuit parameters.



(a) Without an input signal voltage
(AC ground is shown in red.)



(b) With an input signal voltage

5.2. Method of AC Analysis of the Amplifier (cont.)

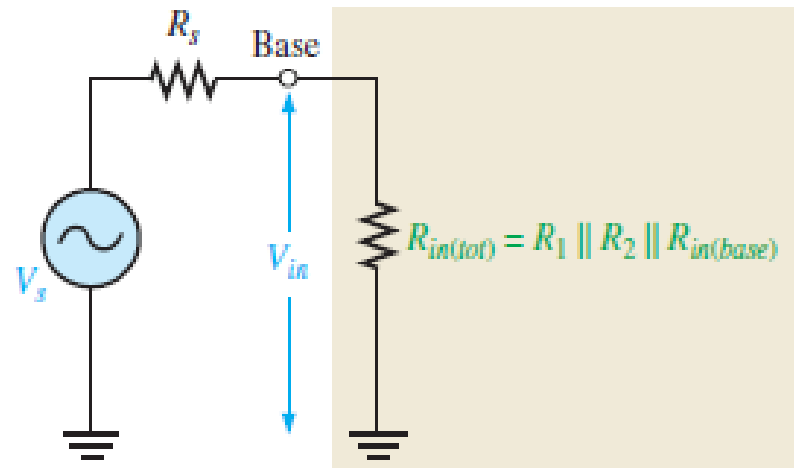
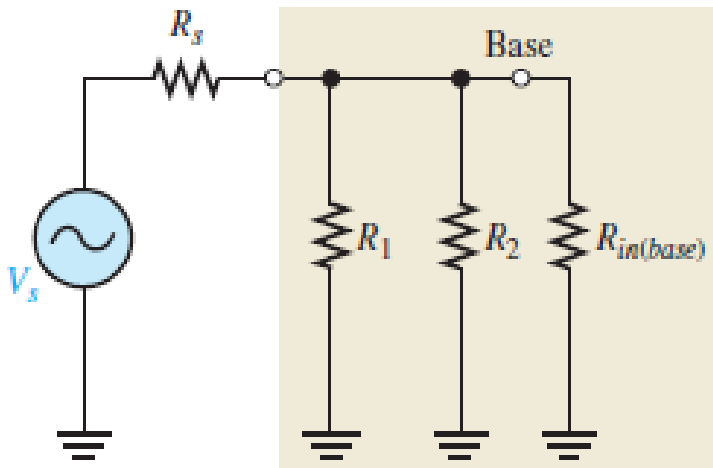
- The total input resistance into the transistor is given by:

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

Where: $R_{in(base)}$ is the AC input resistance at the base of transistor.

- We should consider also the source resistor (R_s).

$$R_{in(tot)} = [R_1 \parallel R_2 \parallel R_{in(base)}] + R_s$$



5.2. Method of AC Analysis of the Amplifier (cont.)

- It can be proven that $R_{in(base)} = \beta_{ac} r'_e$.
- The input resistance looking in at the base is:

$$R_{in(base)} = \frac{V_{in}}{I_{in}} = \frac{V_b}{I_b}$$

- The base voltage is:

$$V_b = I_e r'_e$$

- Since $I_e \cong I_c$:

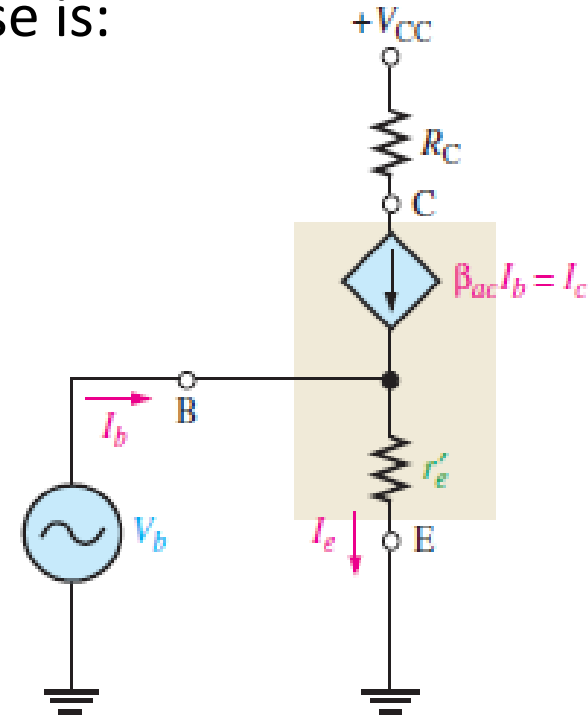
$$I_b \cong \frac{I_e}{\beta_{ac}}$$

- Substituting for V_b and I_b :

$$R_{in(base)} = \frac{V_b}{I_b} = \frac{I_e r'_e}{I_e / \beta_{ac}}$$

- Cancelling I_e :

$$R_{in(base)} = \beta_{ac} r'_e$$

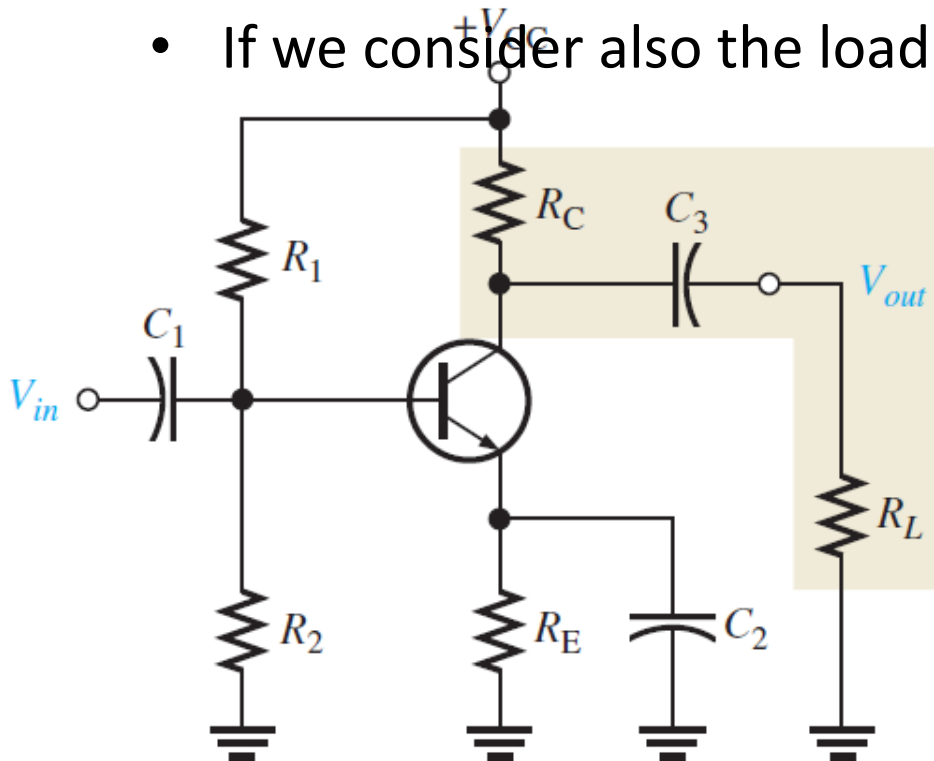


5.2. Method of AC Analysis of the Amplifier (cont.)

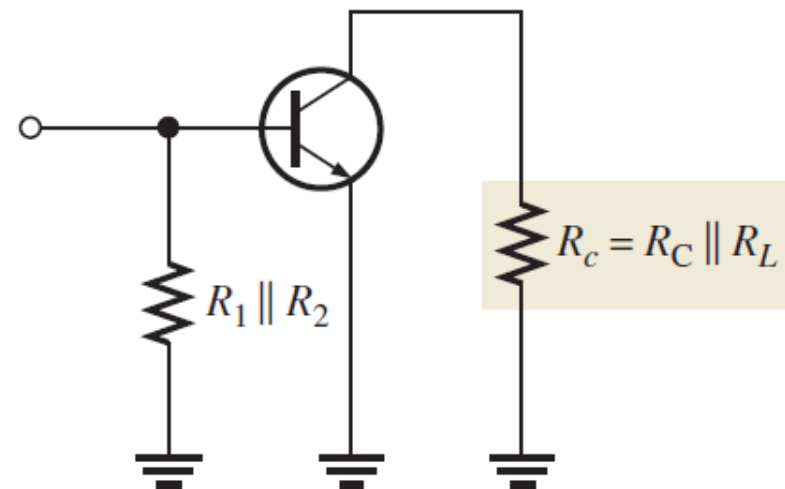
- The output resistance is the resistance looking at the collector and is given by: $R_{out(tot)} = R_C \parallel r'_c$
- But since internal AC resistance of transistor at collector (r'_c) is typically much larger than R_C , it is now:

$$R_{out(tot)} \approx R_C$$

- If we consider also the load resistor (R_L).



$$R_{out(tot)} \approx R_C \parallel R_L$$



5.2. Method of AC Analysis of the Amplifier (cont.)

- The voltage gain is given by $A_v = R_C/r'_e$ as proven below.

$$A_v = \frac{V_{out}}{V_{in}} = \frac{V_C}{V_b}$$

- Knowing $I_c = \alpha_{ac}I_e$ and $\alpha_{ac} \approx 1$, notice that:

$$V_C = \alpha_{ac}I_eR_C \cong I_eR_C \quad \text{and} \quad V_b = I_e r'_e$$

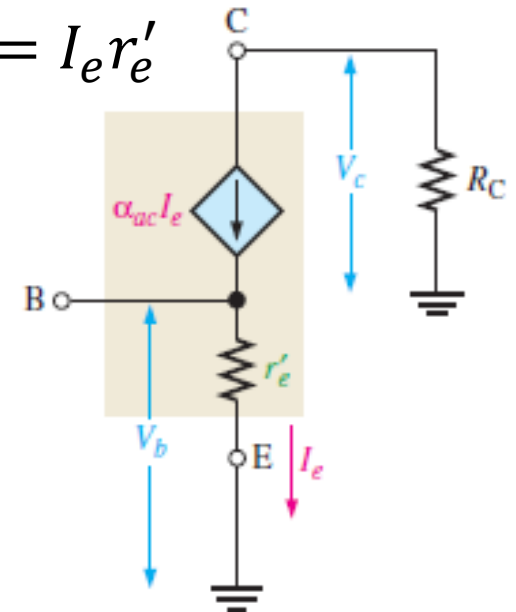
- Therefore:

$$A_v = \frac{I_eR_C}{I_e r'_e}$$

- The I_e term cancel, so:

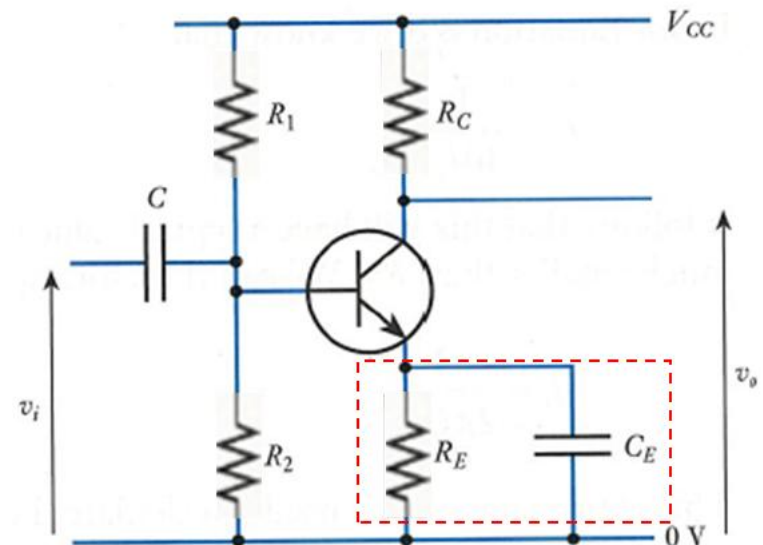
$$A_v = \frac{R_C}{r'_e}$$

- This voltage gain will only be obtained with the bypass capacitor in place as this will short the AC signal to ground.



6. Use of An Emitter-Bypass Capacitor

- It was shown that the use of R_E produces negative feedback to stabilise the transistor, but at the cost of reduced gain.
- This loss in gain can be reduced using a bypass capacitor in parallel with R_E that the amount of AC feedback is reduced, but the DC feedback remains unchanged.
- The bypass capacitor shorts the AC signal around the emitter resistor R_E to increase signal voltage gain.

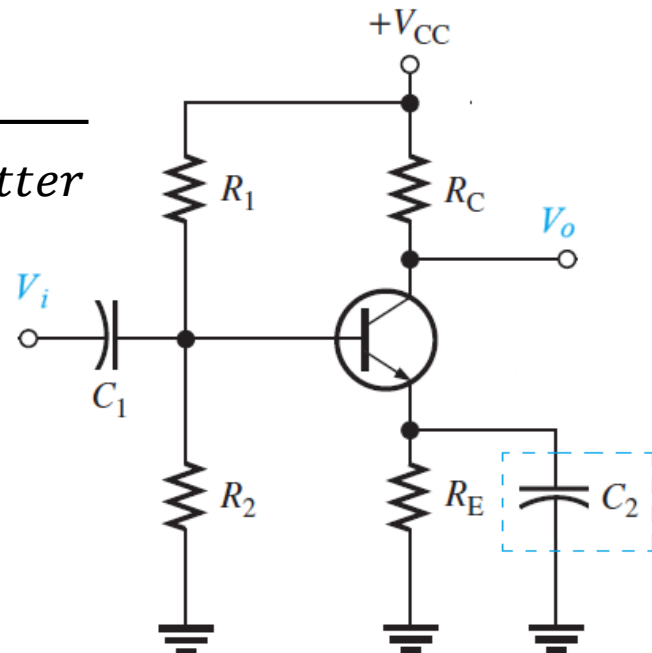


6. Use of An Emitter-Bypass Capacitor (cont.)

- As the emitter is effectively at ground for small-signal inputs, the amplifier can now be correctly described as a common-emitter amplifier again.
- Capacitor chosen so that at frequencies of interest it has very little impedance, however at lower frequencies the impedance may be significant, and the gain will eventually fall.

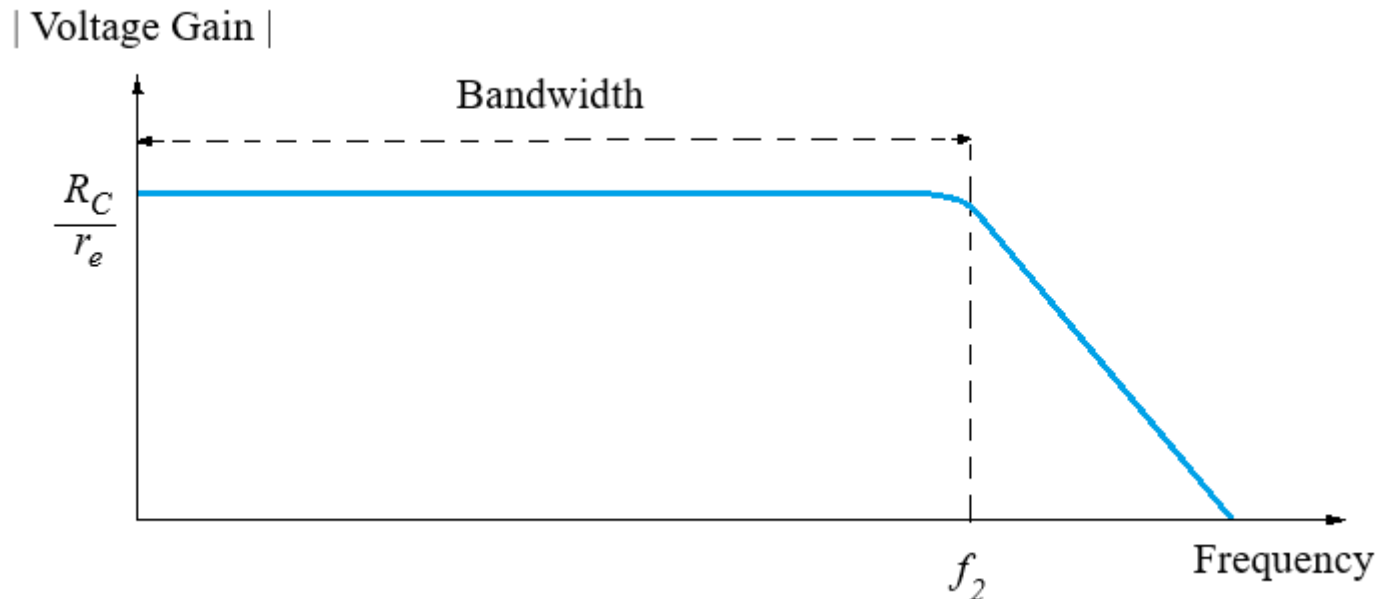
$$f_{c(bypass)} = \frac{1}{2\pi C_{bypass} R_{emitter}}$$

- Furthermore, the gain of this circuit will have a certain frequency range or bandwidth.



7. 1. Frequency Response of the Amplifier

- The frequency response of the different configurations we have considered will also differ.



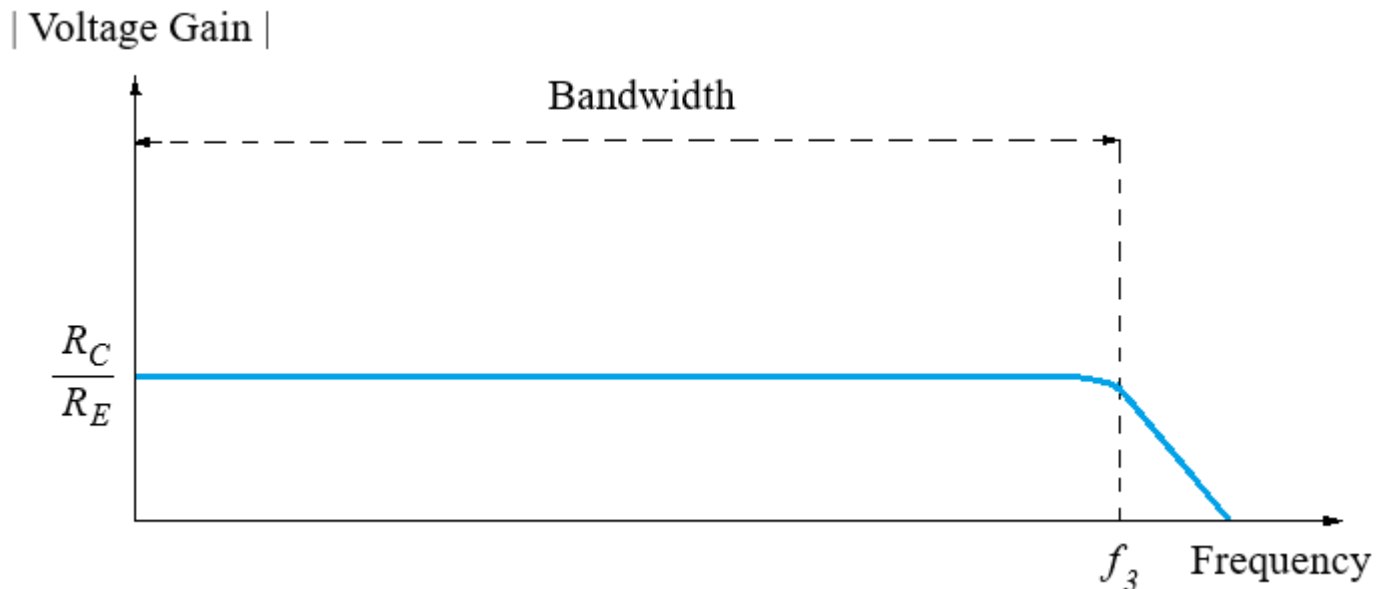
- Without emitter resistor and capacitor, the voltage gain and cut-off frequency e.g. $A_v = R_C/r_e$ and f_2 will be determined by the characteristics of the transistor.
- For the common emitter amplifier without an emitter resistor, the gain rolls off at -20 dB/decade at the cut-off frequency (f_2).

7. Frequency Response of the Amplifier (cont.)

- When an emitter resistor is in place, the voltage gain will drop from:

$$A_v = R_C/r_e \quad \text{to} \quad A_v = R_C/R_E$$

- The cut-off frequency is shifted from f_2 to f_3 .
- Notice an increase of the bandwidth.

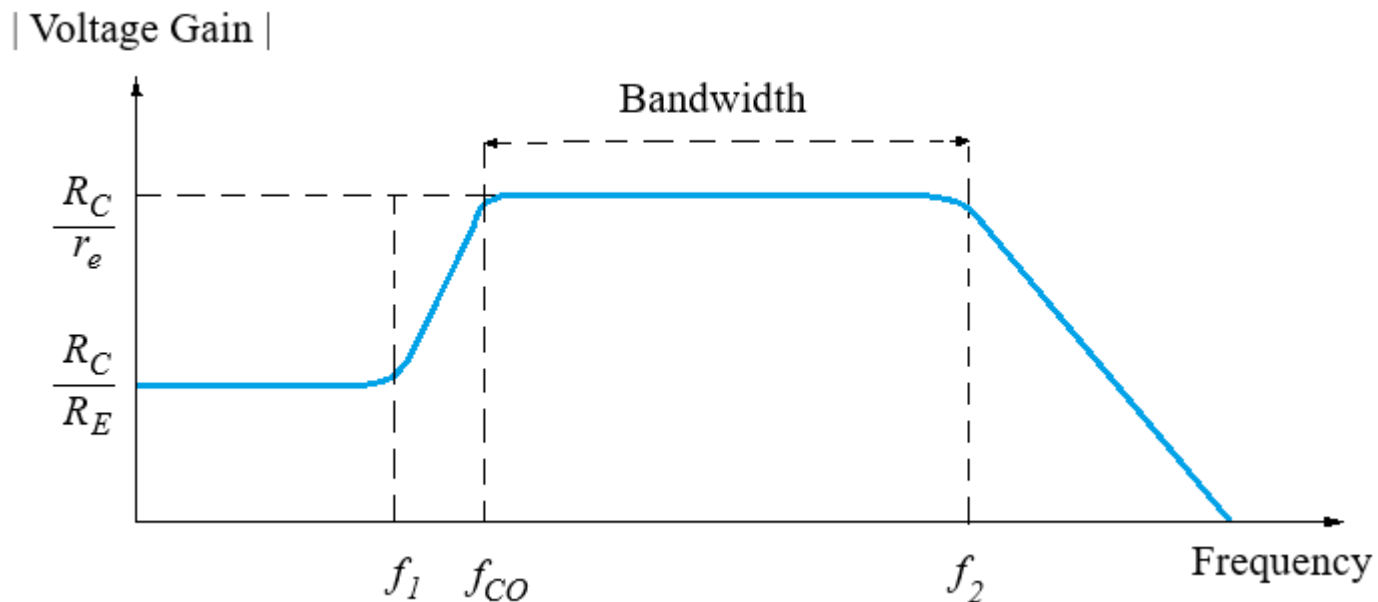


7. Frequency Response of the Amplifier (cont.)

- With a capacitor over the emitter resistor, the voltage gain will be increased in the mid-range (from f_1 to f_{CO}) from :

$$A_v = R_C/R_E \quad \text{to} \quad A_v = R_C/r_e$$

- We have several low cut-off frequencies at this region e.g. f_1 and f_{CO} , but we still have the high cut-off frequency at f_2 .

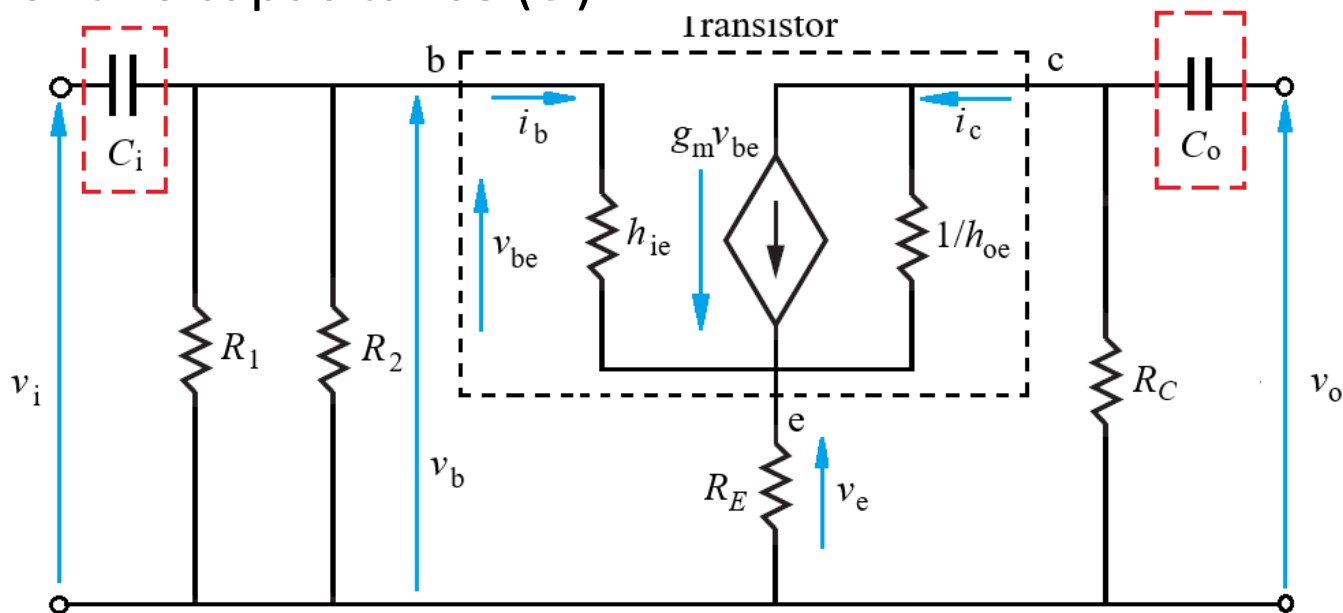


7.2. The Use of Small-Signal Models (Coupling Capacitors)

- The **coupling capacitors** at the input and output is designed to have negligible effect at the frequency of interest i.e. their low-frequency cut-off (f_c) must be well below it.

$$f_c = \frac{1}{2\pi CR}$$

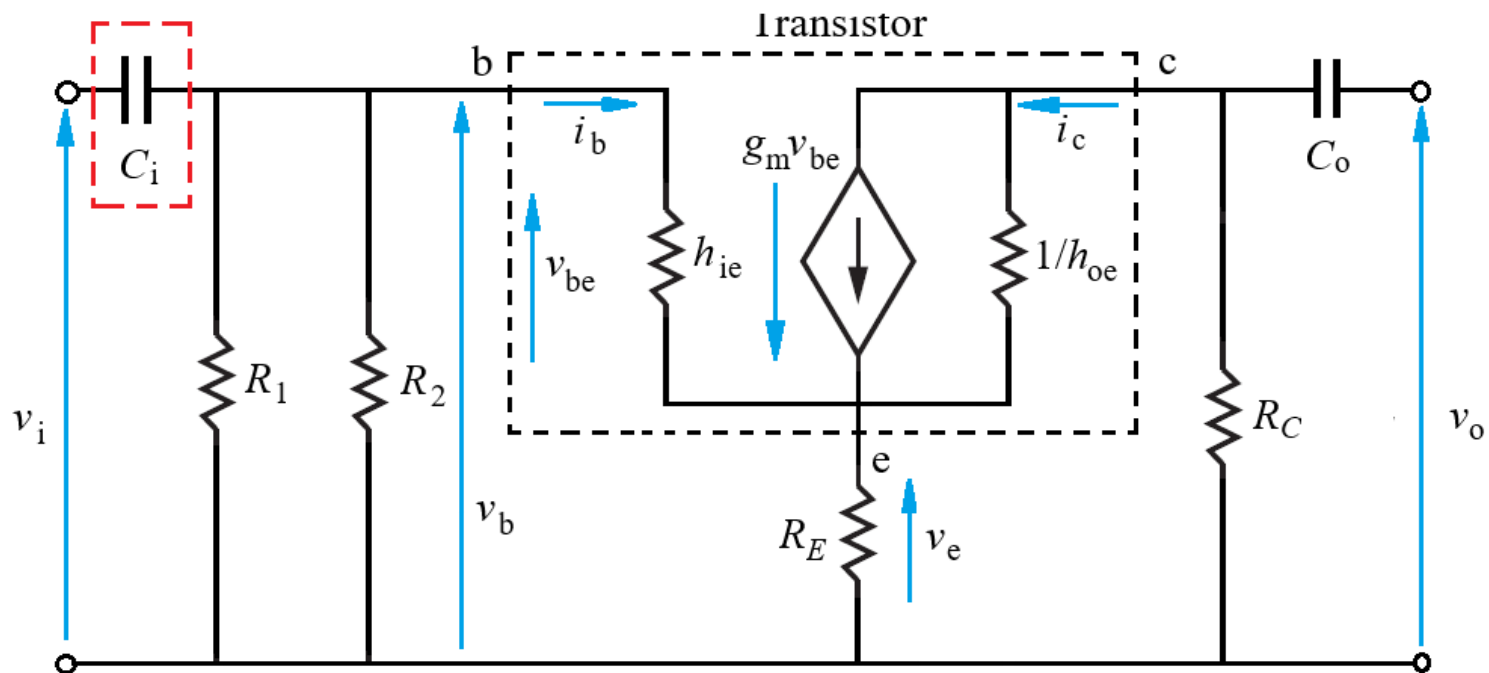
Where: R is the resistance at input or output in series with the value of this capacitance (C).



5. The Use of Small-Signal Models (Coupling Capacitors) (cont.)

- For an input capacitor - the sum of the input resistance of the amplifier and the source resistance.

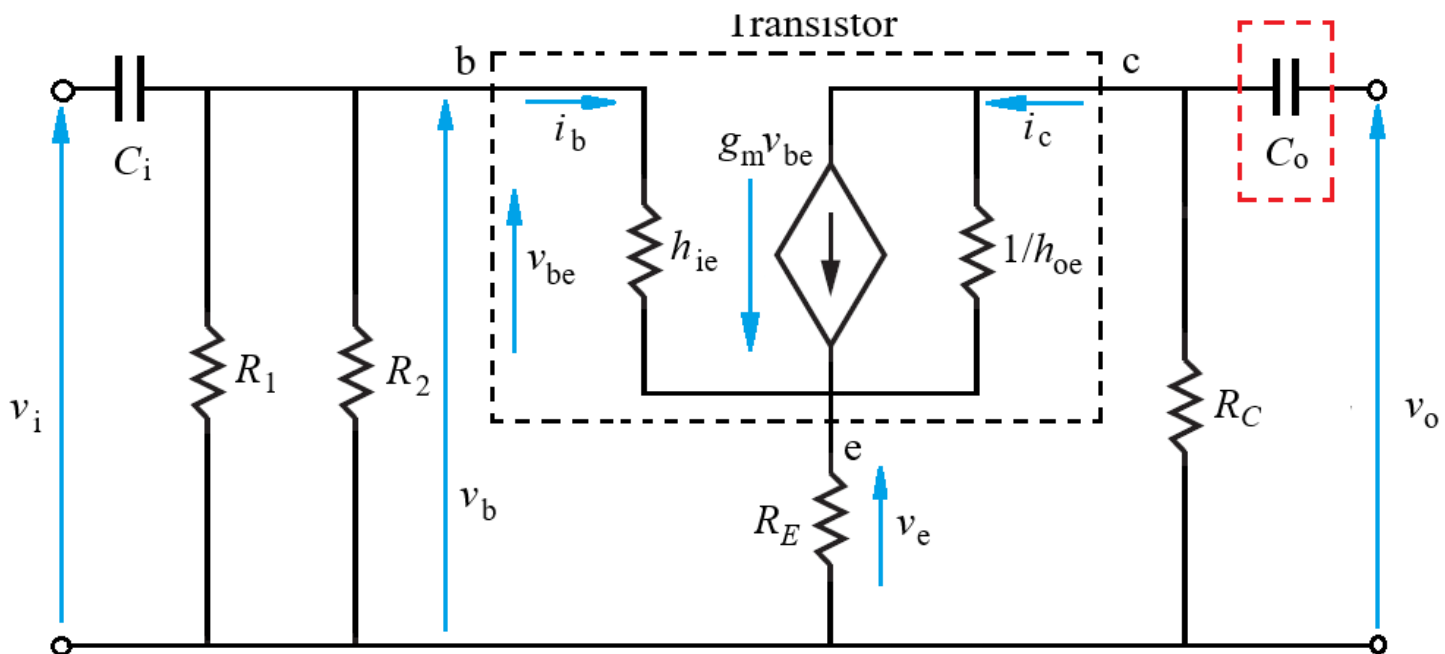
$$f_{c(in)} = \frac{1}{2\pi C_{in} R_{in}}$$



5. The Use of Small-Signal Models (Coupling Capacitors) (cont.)

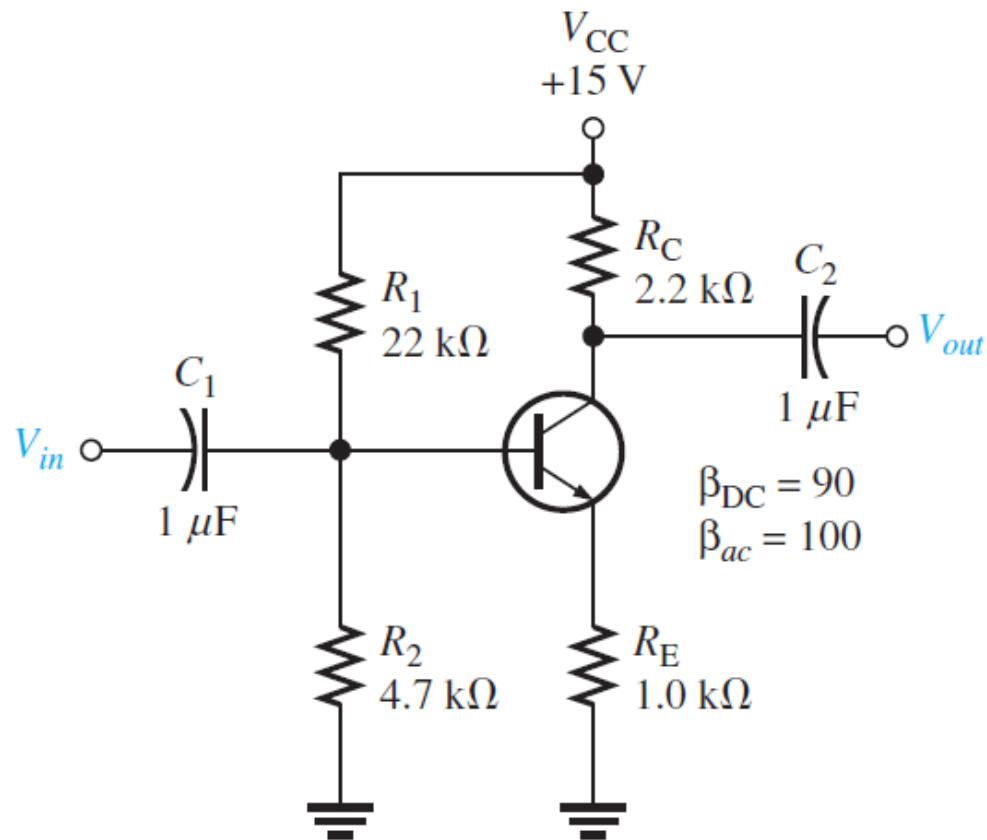
- For the output capacitor - the sum of the output resistance of the amplifier and the load resistance.

$$f_{c(out)} = \frac{1}{2\pi C_{out} R_{out}}$$



Example 3 – AC Analysis of CE BJT Amplifier

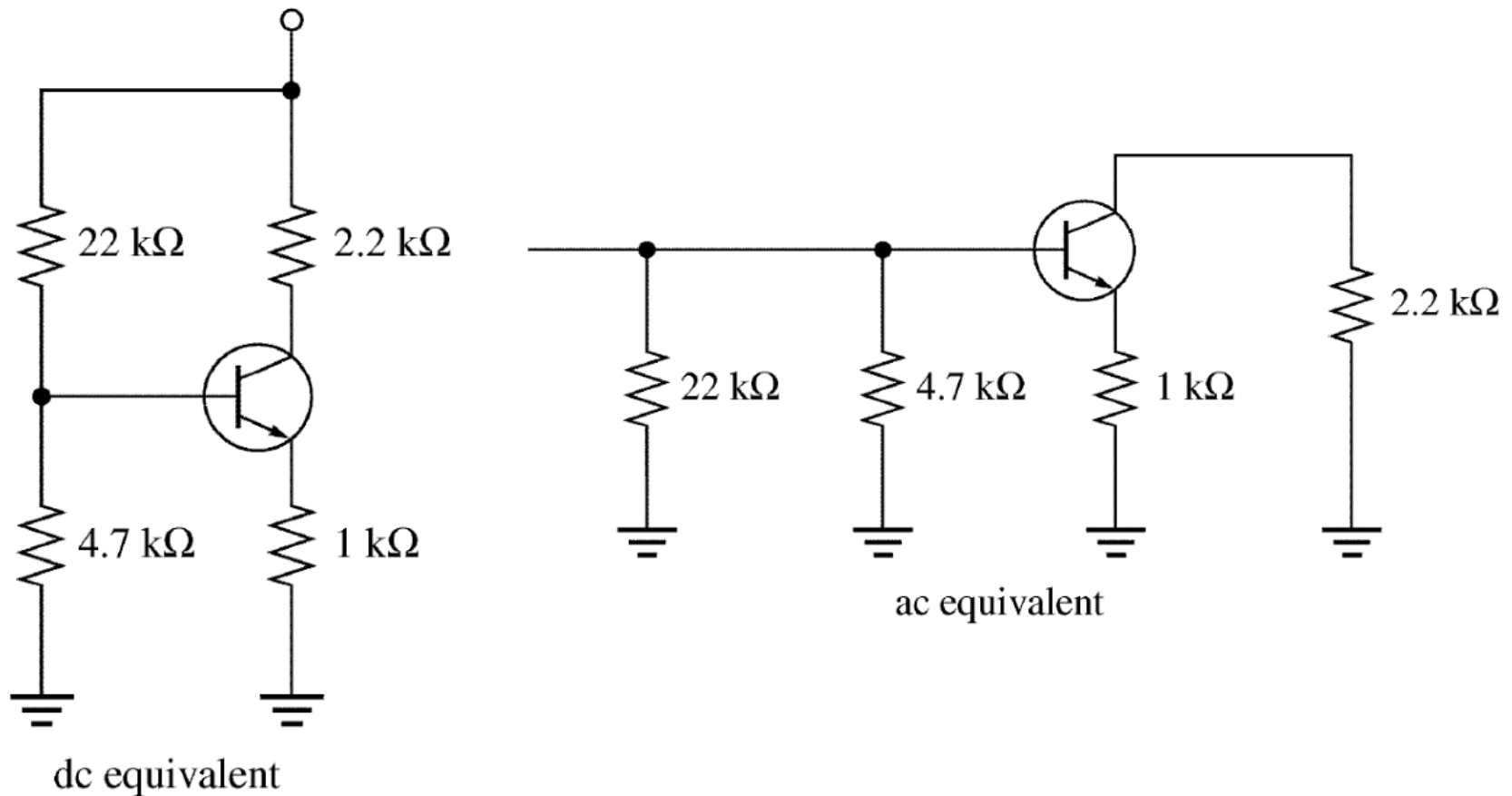
Given the following diagram is a common-emitter BJT amplifier circuit.



- a. Draw the DC equivalent circuit and the AC equivalent circuit for the unloaded amplifier. [10 marks]
- b. Determine the following DC values for the amplifier. [20 marks]
- (i) V_B (ii) V_E (iii) I_E (iv) I_C (v) V_C
- c. Calculate biasing (quiescent) power dissipation. [6 marks]
- d. Determine the following values for the amplifier. [12 marks]
- (i) $R_{in}(\text{base})$ (ii) $R_{in}(\text{tot})$ (iii) A_v
- e. Connect a bypass capacitor across R_E and repeat part (d). [12 marks]
- f. Connect a 10 k Ω load resistor to the output and repeat part (e). [12 marks]

Answer

- a. The DC and AC equivalent circuits of the common-emitter BJT amplifier circuit is as shown in the figure below.



b. The DC parameters of the common-emitter BJT amplifier circuit are determined as follows:

- The base voltage is:

$$V_B = \left(\frac{R_2}{R_1 + R_2} \right) V_{CC} = \left(\frac{4.7 \text{ k}\Omega}{22 \text{ k}\Omega + 4.7 \text{ k}\Omega} \right) 15 \text{ V} = 2.64 \text{ V}$$

- The emitter voltage is:

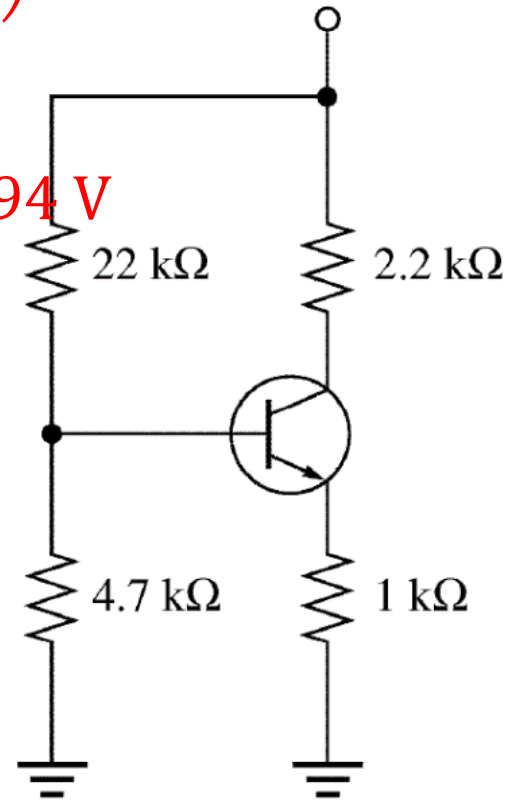
$$V_E = V_B - V_{BE} = 2.64 \text{ V} - 0.7 \text{ V} = 1.94 \text{ V}$$

- The emitter current is:

$$I_E = \frac{V_E}{R_E} = \frac{1.94 \text{ V}}{1 \text{ k}\Omega} = 1.94 \text{ mA}$$

- The collector current is:

$$I_C \cong I_E = 1.94 \text{ mA}$$



- The collector voltage is:

$$V_C = V_{CC} - I_C R_C = 15 \text{ V} - (1.94 \text{ mA})(2.2 \text{ k}\Omega) = 11.6 \text{ V}$$

- c. The bias current at the input is:

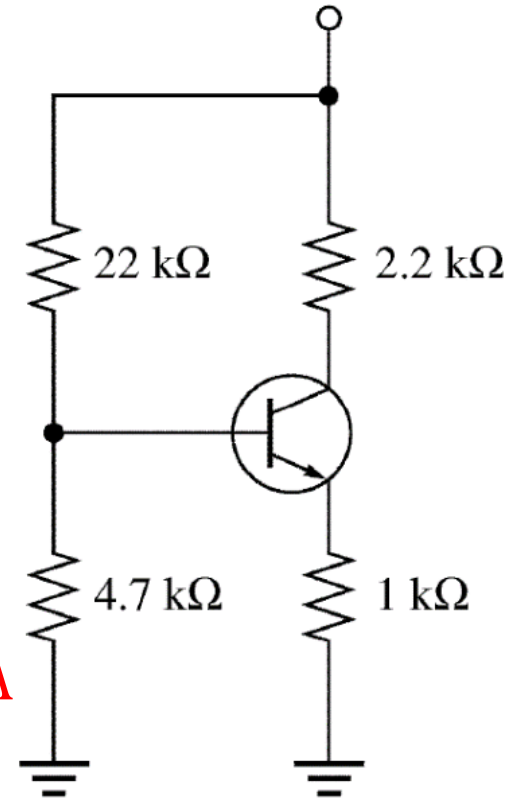
$$I_{bias(in)} = \frac{V_B}{R_2} = \frac{2.64 \text{ V}}{4.7 \text{ k}\Omega} = 562 \mu\text{A}$$

Knowing $I_{bias(out)} = I_C$, the total bias current (i.e. at the input and output) is:

$$\begin{aligned} I_{bias(tot)} &= I_{bias(in)} + I_{bias(out)} \\ &= 562 \mu\text{A} + 1.94 \text{ mA} = 2.50 \text{ mA} \end{aligned}$$

The power dissipated for biasing is:

$$\begin{aligned} P_{bias(tot)} &= I_{bias(tot)} V_{CC} \\ &= (2.5 \text{ mA})(15 \text{ V}) = 37.5 \text{ mW} \end{aligned}$$



d. With emitter feedback resistor added, the AC parameters of the common-emitter BJT amplifier circuit are determined as follows:

- The base voltage is:

$$V_B = \left(\frac{R_2}{R_1 + R_2} \right) V_{CC} = \left(\frac{4.7 \text{ k}\Omega}{22 \text{ k}\Omega + 4.7 \text{ k}\Omega} \right) 15 \text{ V} = 2.64 \text{ V}$$

The emitter voltage is:

$$V_E = V_B - V_{BE} = 2.64 \text{ V} - 0.7 \text{ V} = 1.94 \text{ V}$$

The emitter current is:

$$I_E = \frac{V_E}{R_E} = \frac{1.94 \text{ V}}{1 \text{ k}\Omega} = 1.94 \text{ mA}$$

The AC emitter internal resistance of the BJT is:

$$r'_e = \frac{25 \text{ mV}}{I_E} = \frac{25 \text{ mV}}{1.94 \text{ mA}} = 12.9 \Omega$$

The base resistance is:

$$R_{in(base)} = \beta(r'_e + R_E) = 100(12.9 + 1000) = 101 \text{ k}\Omega$$

- The input resistance of the common-emitter BJT amplifier circuit is:

$$\begin{aligned} R_{in} &= R_1 \parallel R_2 \parallel R_{in(base)} \\ &= 22 \text{ k}\Omega \parallel 4.7 \text{ k}\Omega \parallel 101 \text{ k}\Omega = 3.73 \text{ k}\Omega \end{aligned}$$

- The voltage gain of the common-emitter BJT amplifier circuit is:

$$A_v = \frac{R_C}{R_E + r'_e} = \frac{2.2}{12.02} = 2.17$$

e. With emitter feedback resistor and bypass capacitor included, the AC parameters of the common-emitter BJT amplifier circuit are determined as follows:

- The base resistance is:

$$R_{in(base)} = \beta r'_e = 100(12.9) = 1.29 \text{ k}\Omega$$

- The input resistance of the common-emitter BJT amplifier circuit is:

$$\begin{aligned} R_{in} &= R_1 \parallel R_2 \parallel R_{in(base)} = 22 \text{ k}\Omega \parallel 4.7 \text{ k}\Omega \parallel 1.29 \text{ k}\Omega \\ &= 968 \Omega \end{aligned}$$

- The voltage gain of the common-emitter BJT amplifier circuit is:

$$A_v = \frac{R_C}{r'_e} = \frac{2.2 \text{ k}\Omega}{12.9 \Omega} = 171$$

f. With load resistor added, the AC parameters of the common-emitter BJT amplifier circuit are determined as follows:

- The base resistance is:

$$R_{in(base)} = \beta r'_e = 100(12.9) = 1.29 \text{ k}\Omega$$

- The input resistance of the common-emitter BJT amplifier circuit is:

$$\begin{aligned} R_{in} &= R_1 \parallel R_2 \parallel R_{in(base)} = 22 \text{ k}\Omega \parallel 4.7 \text{ k}\Omega \parallel 1.29 \text{ k}\Omega \\ &= 968 \Omega \end{aligned}$$

- The voltage gain of the common-emitter BJT amplifier circuit is:

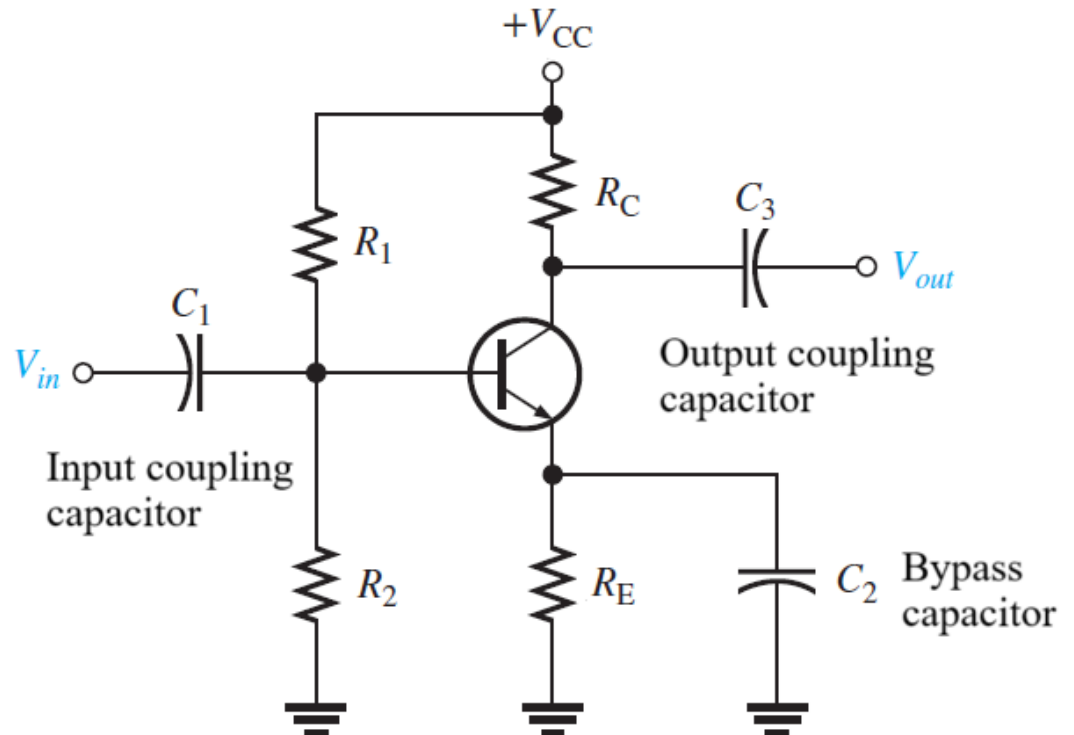
$$A_v = \frac{R_C}{r'_e} = \frac{2.2 \text{ k}\Omega \parallel 10 \text{ k}\Omega}{12.9 \Omega} = 140$$

Design Note:

Need to select components for the following functions:

1. Capacitor C_1 is to capacitive couple the AC input signal to the base. Blocks DC component of this signal to the base.
2. Capacitor C_2 is to block any DC component of the output signal.

Only amplified
AC component
will then appear
at V_{out} .



3. Resistors R_1 and R_2 provide a voltage dividing network on the input to ensure that BE junction is forward biased at a stable voltage.
4. Resistors R_C and R_E provide a voltage dividing network on the output side to ensure the transistor is operating in the active region with the correct Q point. R_E acts as a negative feedback to stabilise the gain to variations in β and R .
5. Capacitor C_E is a bypass capacitor to short the AC signal around the emitter resistor and increase voltage gain.

