XMUT204 Electronic Design

Note 3e: BJT AC Analysis

1. BJT Amplifier AC Analysis

In the previous lecture, 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 the notation as previously defined, for a given BJT amplifier, the goal of its design is to ensure that for a given input voltage and current signal that we obtain amplified output voltage and current signals.

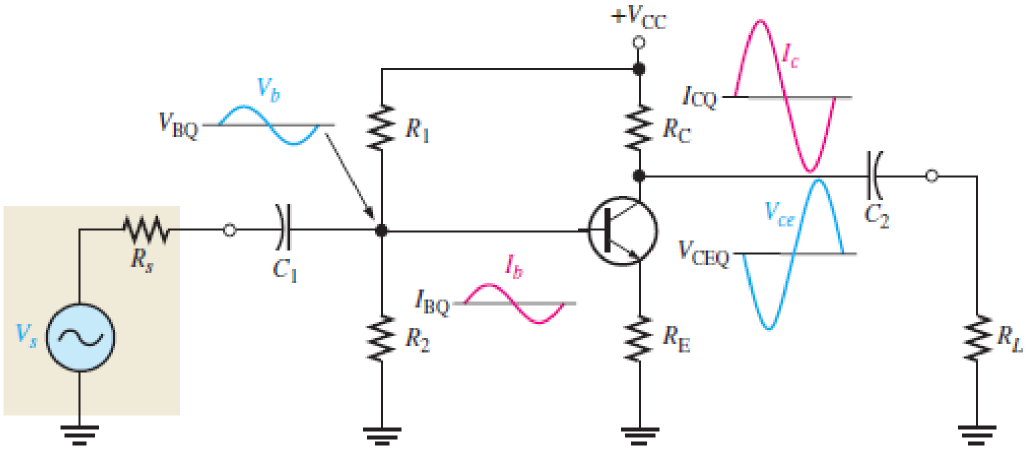


Figure 1: BJT circuit AC analysis

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.

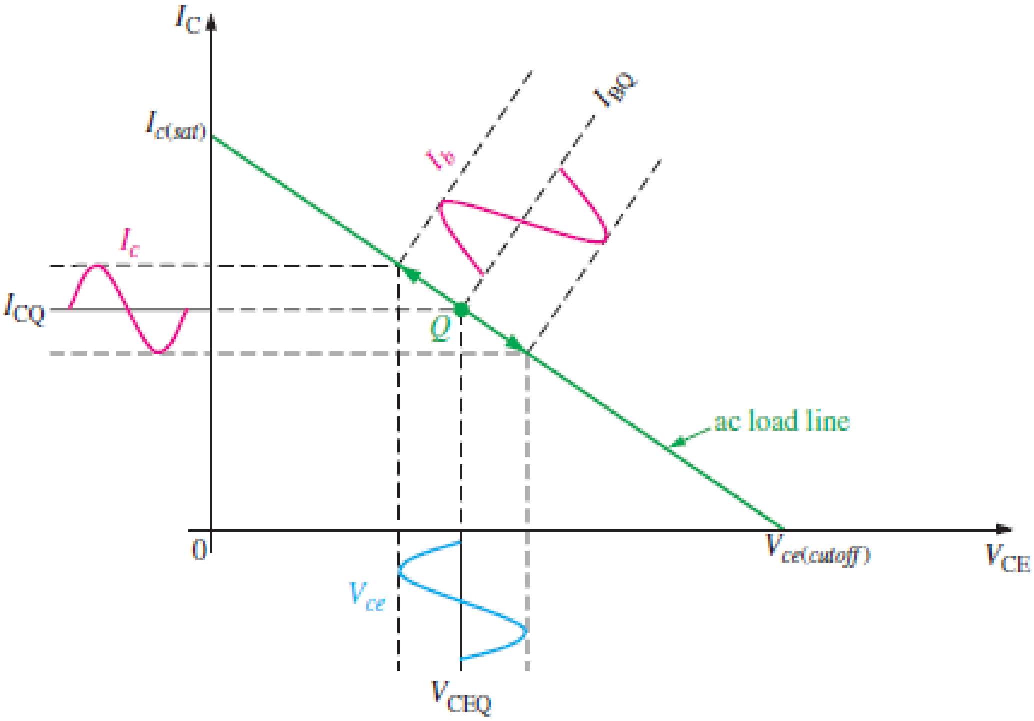


Figure 2: Q-point determination from load line plot

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 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).

2.1. The r-Parameter Model

The r-parameter model analysis of the AC behaviour of the transistor in terms of the r-parameters, e.g. these parameters are the internal resistances of the transistor.

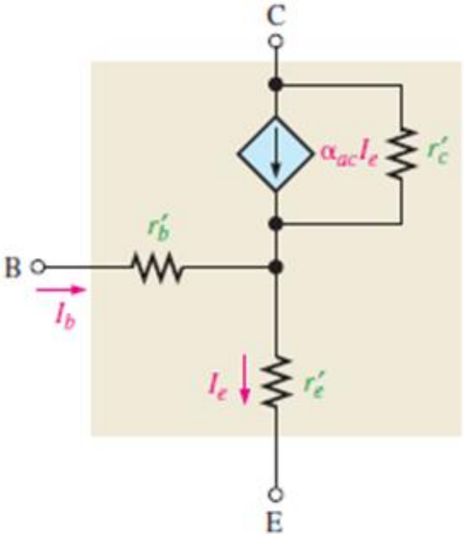


Figure 3: r-Parameters of BJT

Five r-parameters are normally used and their details are shown in the table given below.

$\boldsymbol{r}$-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

Table 1: r-parameter determination for BJT

2.2. The $\boldsymbol{h}$-Parameters Model

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

$\boldsymbol{h}$-parameter	Description	Conditions
h_i	Input impedance (resistance)	Output shorted

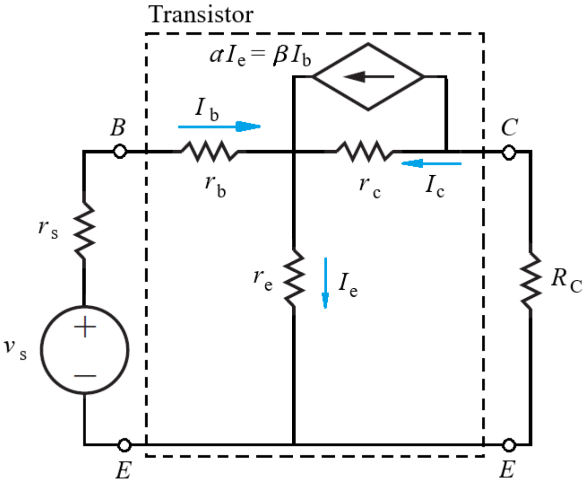
h_{r}	Voltage feedback ratio	Input open
h_f	Forward current gain	Output shorted
h_0	Output admittance (conductance)	Input open

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	$h_{ic}, h_{rc}, h_{fc}, h_{oc}$

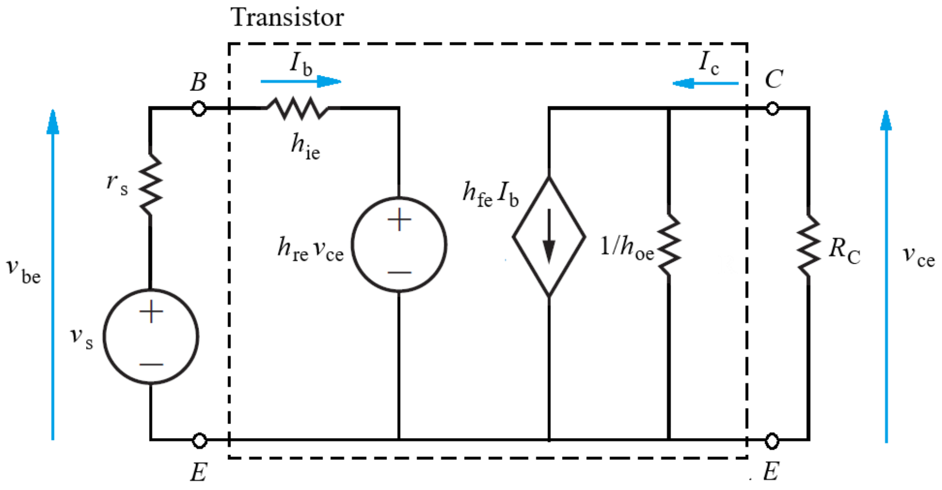
Table 2: h-parameters determination of BJT

2.3. The r-and h-Parameters Models

The following figure shows 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 r-parameter equivalent circuit

Figure 4: The r-parameters and h-parameter equivalent circuits in CE BJT amplifier circuit

The relationship between r-and h-parameters models is outlined as follows.

The AC current ratios:

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

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

The conversion between h-parameters to r-parameters:

$$r_e' = \frac{h_{re}}{h_{oe}}$$

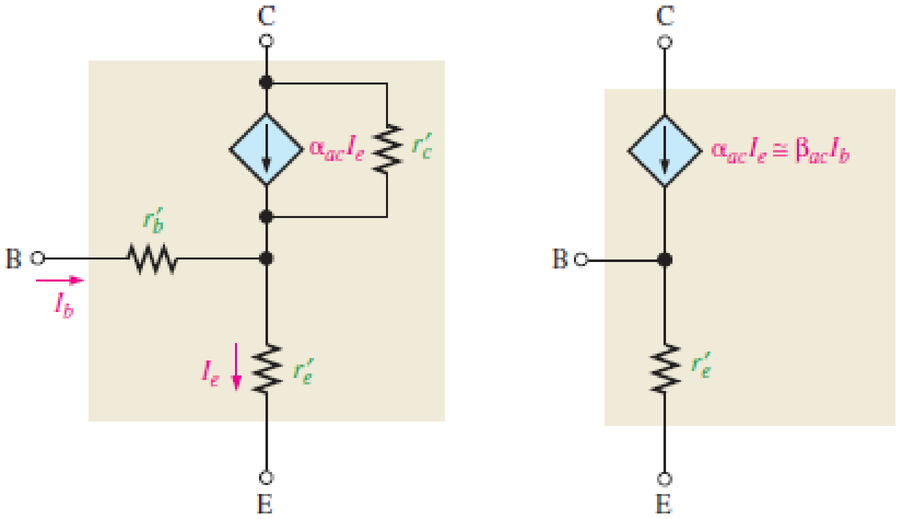
$$r_c' = \frac{h_{re} + 1}{h_{oe}}$$

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

2.4. The Use of r-Parameters in BJT Circuit Analysis

The r-model is commonly employed for determining the AC behaviour of the BJT amplifier. The model is approximated as the 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 shorts.



(a) Generalized *r*-parameter model for a BJT

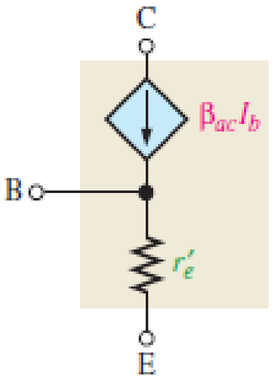
(b) Simplified *r*-parameter model for a BJT

Figure 5: r-parameter model of BJT amplifier

The most important result from this model is an estimate of the value of the emitter resistance r_e'.

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

Where: I_E is the DC emitter current.



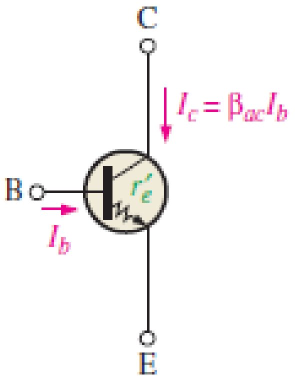


Figure 6: Model and configuration of BJT

2.5. Determination of r-Parameters 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 graph and is calculated from:

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

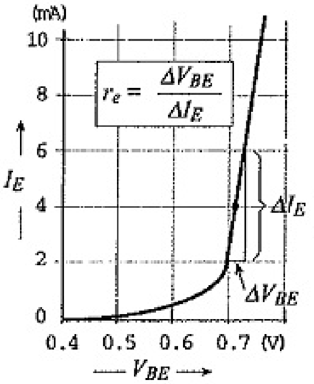


Figure 7: The V_{BE} vs. I_E graph of BJT for determining r_e

For T = 25 C, r_e can be calculated:

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

At any temperature, r_e is:

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

The value of h_{ie} is taken as the slope in the V_{BE} vs. I_B graph and calculated from:

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

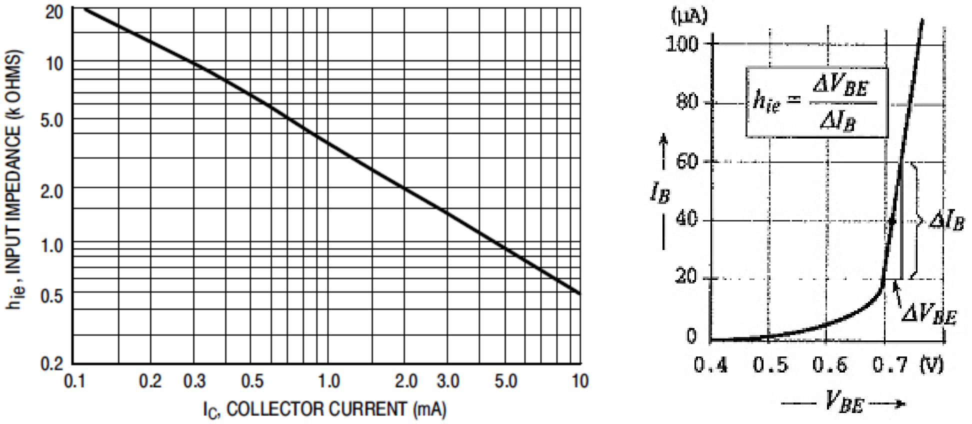


Figure 8: Graph of h_{ie} and the V_{BE} vs. I_B graph of BJT for determining h_{ie}

The value of h_{fe} is taken as the slope in the I_C vs. I_B graph and calculated from:

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

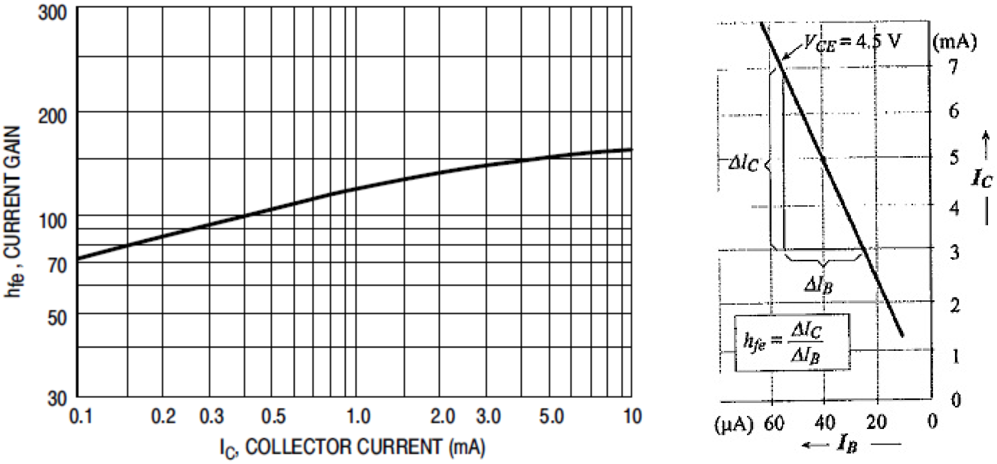


Figure 9: Graph of h_{fe} and the I_C vs. I_B graph of BJT for determining h_{fe}

The value of h_{oe} is taken as the slope in the I_C vs. V_{CE} graph and calculated from:

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

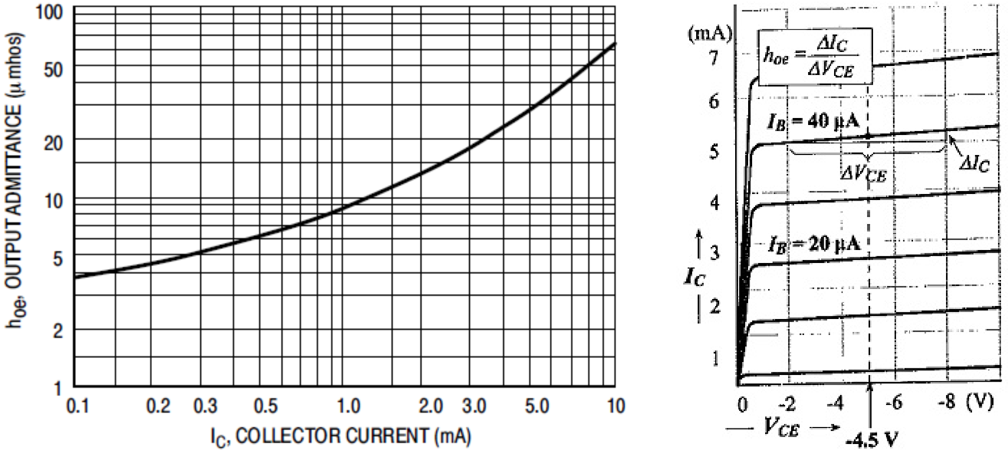
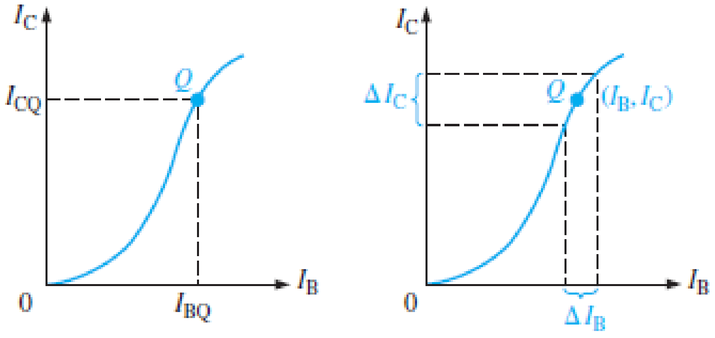


Figure 10: Graph of h_{oe} and the I_C vs. V_{CE} graph of BJT for determining h_{oe}

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

There are slight differences between β_{DC} and β_{AC}. DC gain, $\beta_{DC} = I_C/I_B$ at Q-point and AC gain, $\beta_{AC} = \Delta I_C/\Delta I_B$. 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. Also notice the graph of I_C vs. I_B is also non-linear.

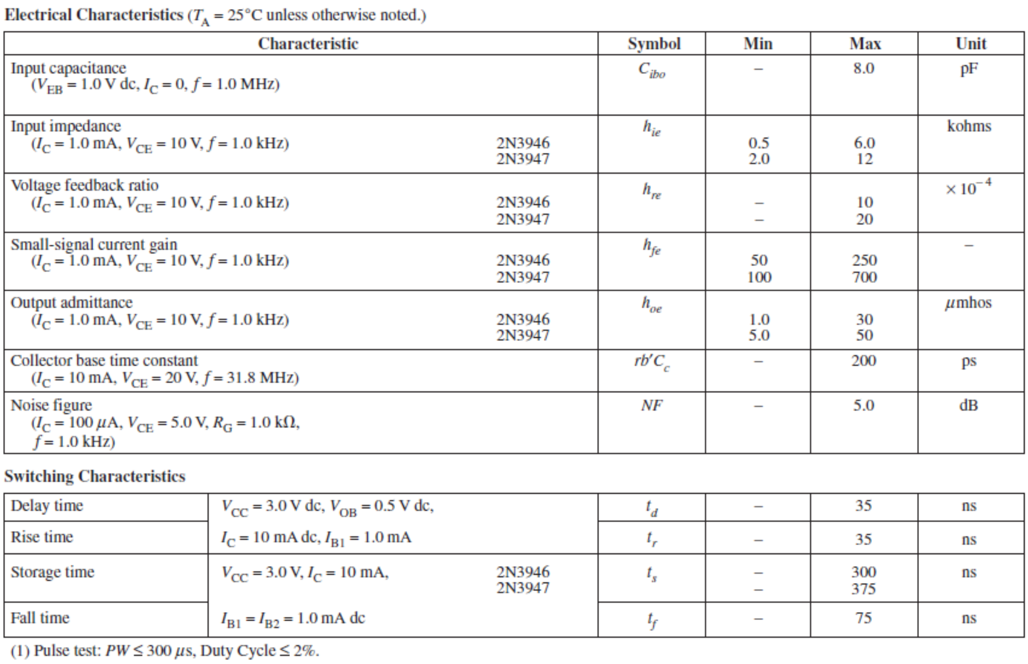


(a) $\beta_{DC} = I_C/I_B$ at Q-point (b) $\beta_{ac} = \Delta I_C/\Delta I_B$

Figure 11: Difference between β_{DC} and β_{AC} in BJT amplifier

Example 1 – r-Parameters of BJT

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



Electrical Characteristics ($T_A = 25°C$ unless otherwise noted.)

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

Switching Characteristics

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

(1) Pulse test: $PW \leq 300\ \mu$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

a. From the given manufacturer datasheet, for a 2N3947 BJT, we found:

- $\beta_{AC}(\min) = h_{fe}(\min) = 100$,
- $r_e'(\min)$ cannot be determined since $h_{re}(\min)$ is not given, and
- $r_c'(\min)$ also, cannot be determined since $h_{re}(\min)$ is not given.

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

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

And

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

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

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

This type of design model is very popular. In addition to the voltage divider resistors for biasing purpose, the feedback resistor is emitter resistor (R_E) and with a couple of capacitors for signal coupling and decoupling purposes.

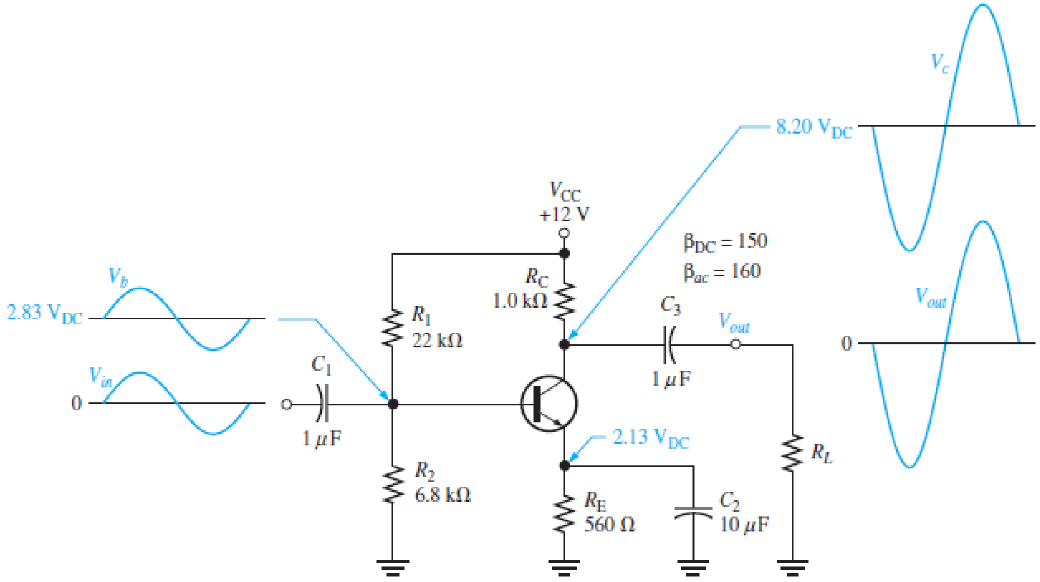


Figure 12: Common emitter amplifier design with input signal and output signal

3.1. Emitter Feedback Resistor

The amplifiers bias voltage can be stabilised by placing a single resistor in the transistors emitter circuit as shown. This resistance is known as the emitter feedback resistance, R_E.

The addition of this emitter resistor means that the transistors emitter terminal is no longer grounded or at zero-volt potential but sits at a small potential above it given by the Ohms Law equation of:

$$V_E = I_E R_E$$

Where: I_E is the actual emitter current.

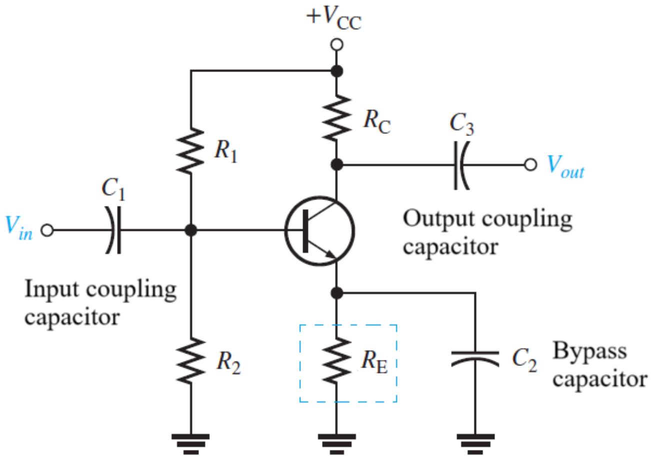


Figure 13: Emitter-feedback resistor in common-emitter amplifier

Now, if the supply voltage V_{CC} increases, the transistors collector current I_C also increases for a given load resistance. If the collector current increases, the corresponding emitter current must also increase causing the voltage drop across R_E to increase. This action results in a proportional increase in base voltage because $V_B = V_E + V_{BE}$.

Since the base voltage is held constant by the divider resistors R_1 and R_2, the DC voltage on the base relative to the emitter V_{be} is lowered by a proportional amount, thus reducing the base current drive and keeping the collector current from increasing further. A similar action occurs if the supply voltage and collector current try to decrease in value.

In other words, the addition of this emitter terminal resistance helps control the transistors base biasing using negative feedback, which negates any attempted change in collector current with an opposing change in the base bias voltage and, so the circuit tends to be stabilised at a fixed level.

Also, since part of the supply is dropped across R_E, its value should be as small as possible so that the largest possible voltage can be developed across the load resistance, R_L and therefore the output. However, its value cannot be too small or once again, the instability of the circuit will suffer.

Then, the current flowing through the emitter resistor is calculated as:

$$I_E = \frac{V_E}{R_E} = \frac{V_B - V_{BE}}{R_E}$$

As a rule of thumb, the voltage drop across this emitter resistance is generally taken to be:

- $V_E = V_B - V_{BE}$, or typically about one-tenth (1/10th) of the value of the supply voltage, V_{CC}.
- A common figure for the emitter resistor voltage is between 1 to 2 volts, whichever is the lower.

3.2. Basic Characteristics of Common-Emitter Design

We use of three capacitors: C_1 to couple the AC signal at the input, C_2 to couple the AC signal at the output and C_3 a bypass capacitor to ground the emitter. Input signal V_{in} is capacitive coupled to the base terminal and the output signal V_{out} is capacitive coupled between collector and load. Thus, no AC signal at the emitter as the bypass capacitor effectively shorts the AC signal at the emitter to ground.

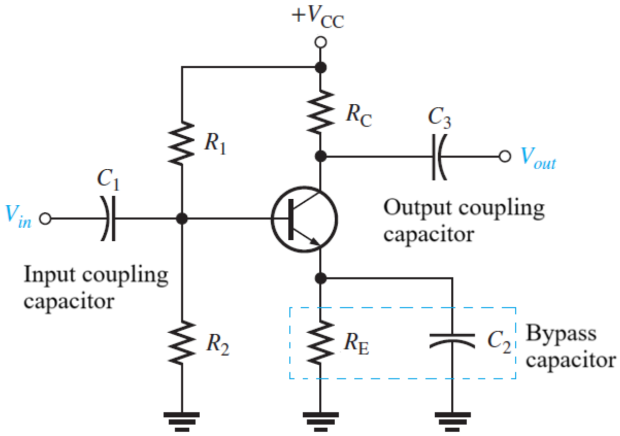


Figure 14: Common-emitter BJT amplifier with emitter feedback resistor and bypass capacitor

The AC input and AC output thus use the emitter as a common point (which is also at ground for AC). So, we can again refer to this as a common-emitter configuration, but for AC analysis only. The output signal will be 180° out of phase with the input signal i.e. inverting amplifier.

3.3. Gain of Common-Emitter BJT Amplifier with Emitter Feedback Resistor

For a common-emitter BJT amplifier circuit with emitter feedback resistor, we have an expression for the voltage gain given by:

$$\frac{v_o}{v_i} = -\left(\frac{R_C}{R_E + r_e}\right) \approx -\left(\frac{R_C}{R_E}\right) \qquad \text{as} \qquad r_e \ll R_E$$

This considerably smaller than the gain without feedback in the CE configuration, where the gain was given by:

$$\frac{v_o}{v_i} = -\left(\frac{R_E}{r_e}\right)$$

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

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 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 is determined by removing coupling and bypass capacitors because they appear open as far as DC is concerned.

Then, we analyse using DC analysis of the common emitter BJT amplifier method using potential divider as covered in previous section.

Determining the design parameters of the biasing circuit will lead toward the values of the components in potential divider biasing circuit.

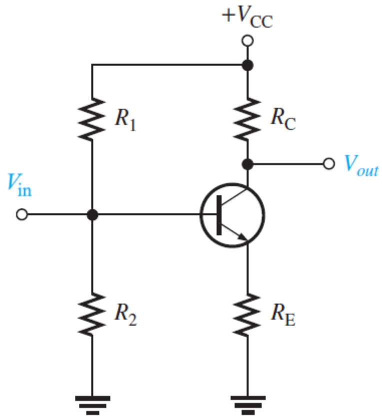
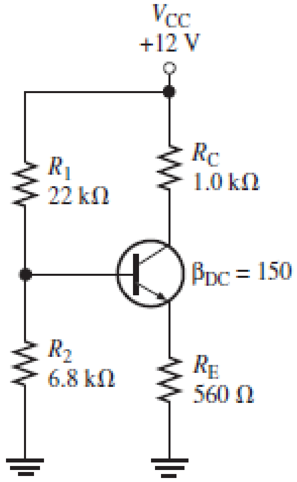


Figure 15: Voltage divider application for BJT amplifier

Example 2 - DC Analysis of BJT amplifier

For a given potential divider biasing circuit for the common emitter amplifier circuit below, determine the circuit parameters: voltages V_B, V_E, and V_C, currents I_E and I_c, and collector-emitter junction voltage V_{CE}. Assume no base current loading.



Answer

For the given amplifier circuit, calculate the V_{CE} assuming no base current loading.

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

The base voltage is calculated from:

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

The voltage at the emitter is determined from:

V_E = $V_B - V_{BE}$ = 2.83 V - 0.7 V = 2.13 V

As a result, the current that flows in the emitter is calculated from:

$$I_E = \frac{V_E}{R_E} = \frac{2.13\ \text{V}}{560\ \Omega} = 3.8\ \text{mA}$$

The current that flows in the collector is:

$I_C \approx I_E$ = 3.8 mA

Thus, the voltage at the collector is:

$V_C = V_{CC} - I_C R_C$ = 12 V – (3.8 mA) (1 kΩ) = 8.2 V

Finally, the voltage across the collector-emitter junction of the BJT is:

$V_{CE} = V_C - V_E$ = 8.2 V – 2.1 V = 6.1 V

5. AC Analysis of the Amplifier

For the DC analysis of the amplifier circuit, the voltage divider resistors (R_1 and R_2) are added for biasing purpose. The application of a voltage divider pair enhances the performance of the circuit and to bias the base – furthermore this provides improved biasing stability.

Resistors R_C and R_E are set for active region with required Q-point that is determined from the load line analysis of the amplifier circuit.

Then, for AC analysis, we improve the stability of the output of the circuit by adding a feedback resistor i.e. emitter resistor (R_E). Then, we have several capacitors for signal coupling and bypass purposes (input, output, and bypass capacitors).

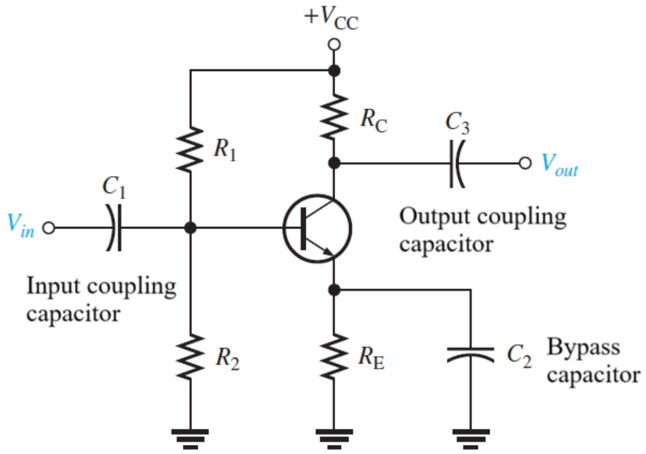


Figure 16: AC Analysis of BJT Amplifier

5.1. Small-Signal Model of BJT Amplifier

Much more detail on circuit parameters of the amplifier circuit for AC analysis can be obtained by considering the so-called small-signal equivalent model of the transistor as shown in the figure below.

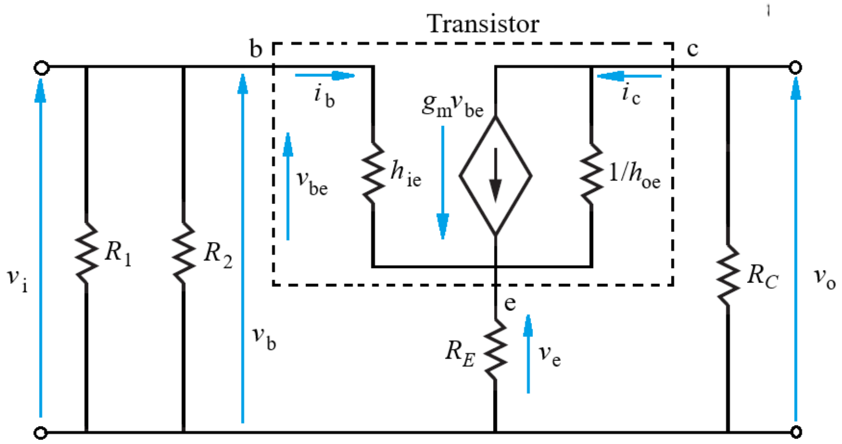


Figure 17: Small-signal model of BJT amplifier

However, this model will not be considered in any more detail in this course, but we will only look at a few significant results.

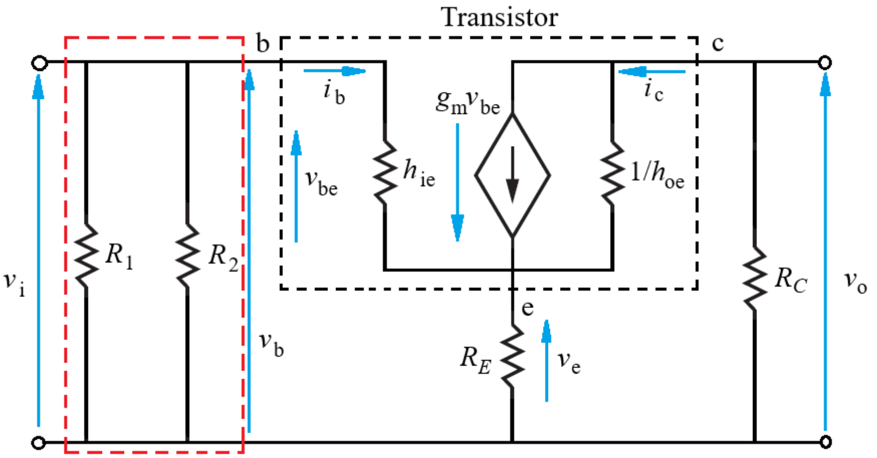


Figure 18: Input resistance in small-signal modal of BJT amplifier

The **input resistance** into the amplifier is approximately determined by:

$$r_i \approx R_1 \parallel R_2$$

To get a high input resistance, we need R_1 and R_2 as high as possible – conflicts with the fact that we need to keep current through R_1 and $R_2 \gg$ current through I_B. Design guide: Choose R_2 approximately $10R_E$.

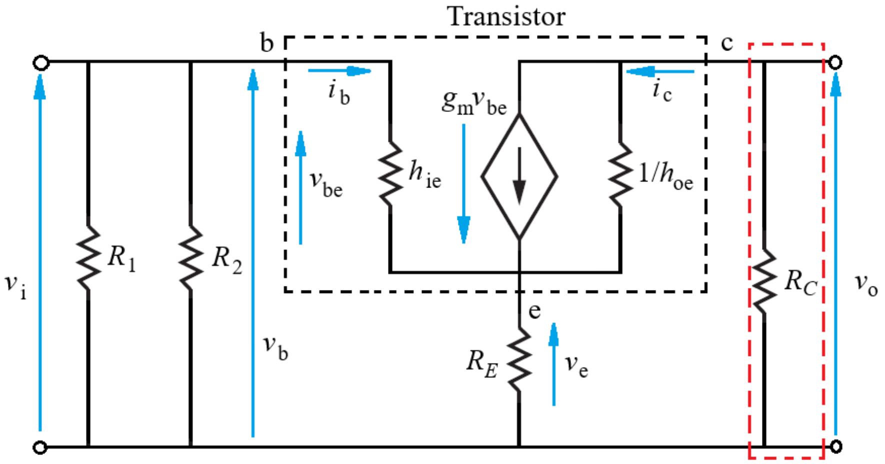


Figure 19: Output resistance in small-signal model of BJT amplifier

The **output resistance** can be shown by the small-signal model to be approximately as:

$$r_o \approx R_C$$

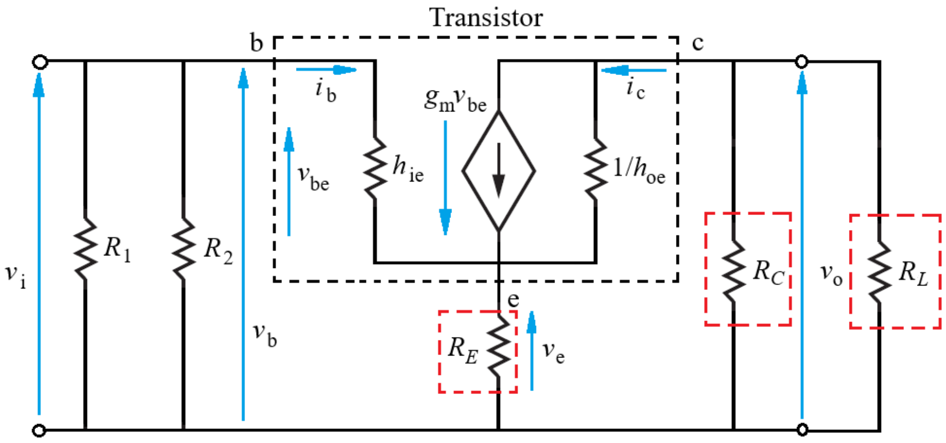


Figure 20: Load resistor with output resistance of small-signal model of BJT amplifier

The **effect of the load resistance R_L** on the amplifier will be to reduce the gain from:

$$A_v = -\frac{R_C}{R_E}$$

into:

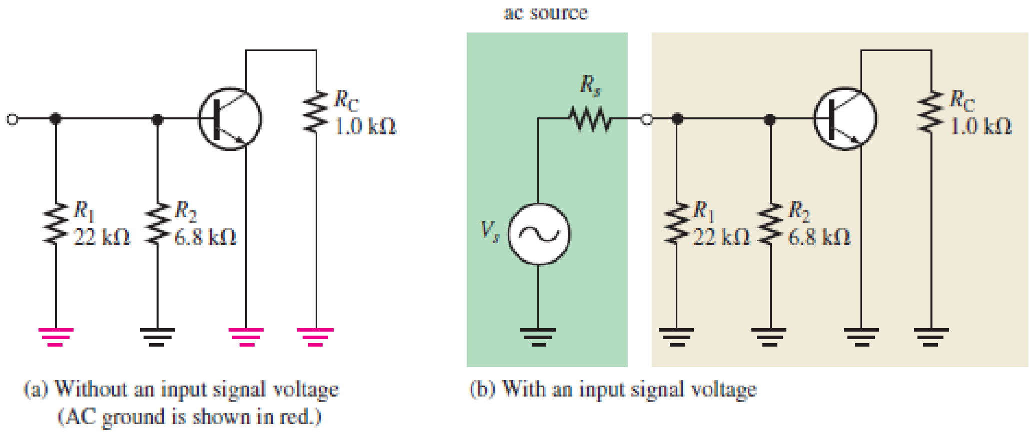
$$A_v = -\frac{(R_C \parallel R_L)}{R_E}$$

Note: sign ‖ is a parallel combination of R_C and R_L. Thus, if R_L is large compared to R_C, the loading effects on the amplifier will be small.

5.2. Method of AC Analysis of CE BJT Amplifier

To develop a circuit for the AC analysis, we replace the capacitors C_1, C_2, C_3 are shorts – these capacitors are selected so that their impedances (X_C) is negligible at signal frequency so impedance can be zero.

Furthermore, DC source is replaced by ground. From this model as shown below, several derivations can be done for various circuit parameters for AC analysis.



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

(b) With an input signal voltage

Figure 21: AC analysis of common emitter BJT amplifier

5.2.1. Equivalent Input Resistance

As shown in the figure below, the total input resistance into the transistor is given by:

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

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

Also, we should consider the source resistor (R_s) at the input if the input source has source resistance as well.

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

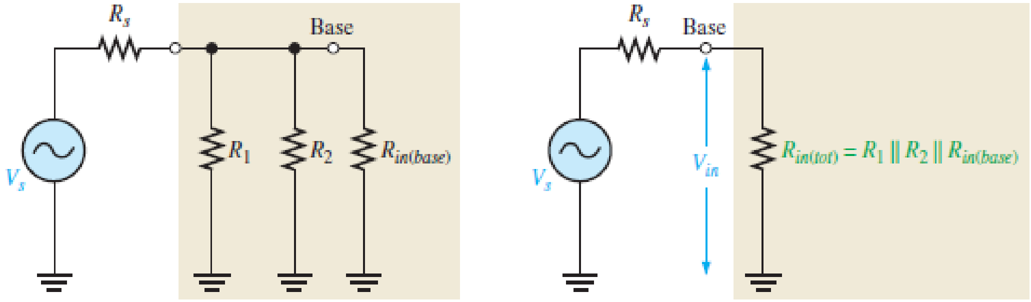


Figure 22: Input resistances in the small signal model of BJT CE amplifier

5.2.2. Equivalent Input Resistance at the Base

As illustrated in the figure below, it can be proven that $R_{in(\mathrm{base})} = \beta_{ac} r_e'$.

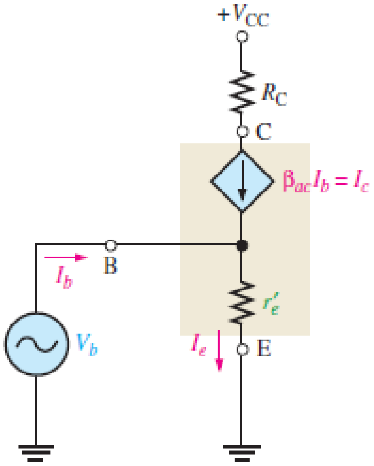


Figure 23: The small-signal model of BJT amplifier for input resistance analysis

The input resistance looking in at the base of the amplifier circuit is:

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

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:

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

Cancelling I_e:

$$R_{in(\mathrm{base})} = \beta_{ac} r_e'$$

5.2.3. Equivalent Output Resistance

As shown in the figure below, the output resistance is the resistance looking at the collector and is given by:

$$R_{out} = R_C \parallel r_c'$$

But since internal AC resistance of transistor at collector (r_c') is typically much larger than R_C, it is now:

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

In the end, we should also consider the impact of the load resistor (R_L) if it is connected to the amplifier at the output.

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

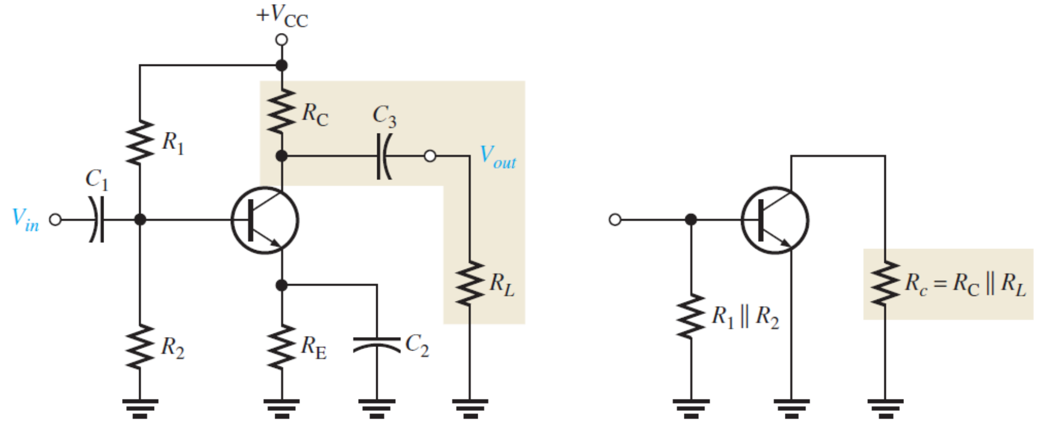


Figure 24: Output resistances in the small signal model of BJT CE amplifier

5.2.4. Voltage Gain of Amplifier

The voltage gain of the amplifier is given by $A_v = R_C/r_e'$ that is proven as follows. Start with:

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

As shown below, knowing $I_c = \alpha_{ac} I_e$ and $\alpha_{ac} \approx 1$, notice in the figure that:

$$V_c = \alpha_{ac} I_e R_c \cong I_e R_c$$

And

$$V_b = I_e r_e'$$

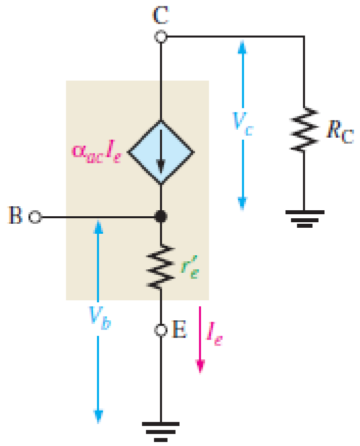


Figure 25: The small-signal model of BJT amplifier for voltage gain analysis

Therefore, substitute V_c and V_b:

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

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 circuit 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.

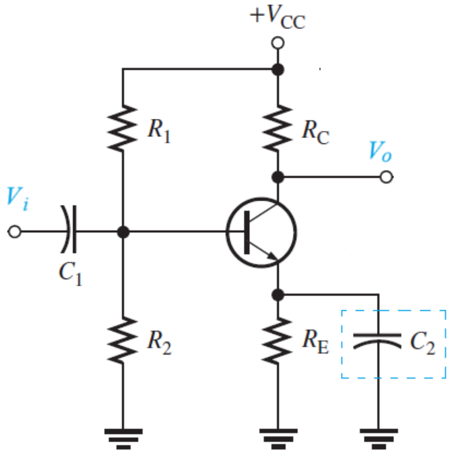


Figure 26: AC analysis with emitter bypass capacitor

The bypass capacitor short circuits the AC signal around the emitter resistor R_E to increase signal voltage gain. As the emitter is effectively at ground for small-signal inputs, the amplifier can now be correctly described as a common-emitter amplifier again.

Bypass capacitor is 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 fall. Furthermore, the gain of this circuit will have a certain frequency range or bandwidth.

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

7. Frequency Response of the Amplifier

The frequency response of the amplifier circuit could provide insight into its characteristic and performance. Typically, the voltage gain and cut-off frequency of the amplifier circuit would determine the nature of frequency response the amplifier circuit.

7.1. Frequency Response of Common-Emitter BJT Amplifier

The diagram shown below illustrates the case for the common-emitter amplifier without an emitter resistor and capacitor. As shown in the graph, the gain is constant at $A_v = R_C/r_e$ and rolls off at -20 dB/decade after the cut-off frequency (f_2).

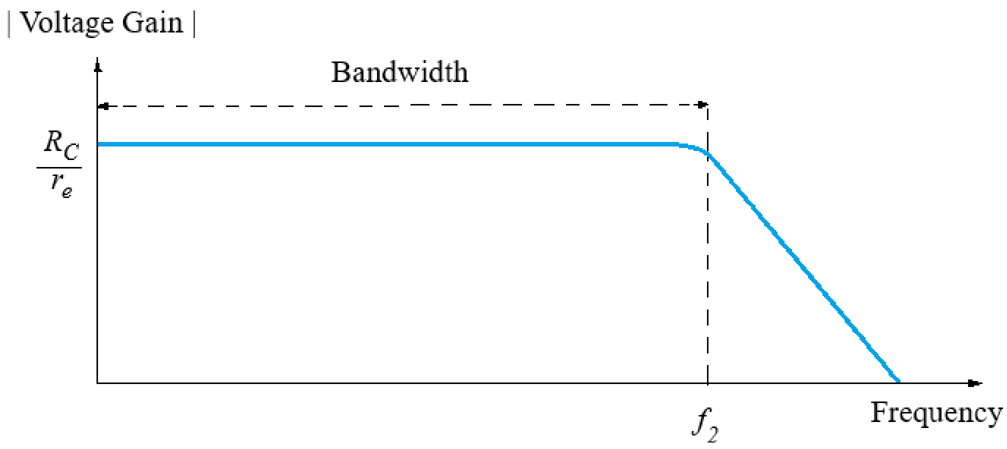


Figure 27: Frequency response of a common-emitter BJT amplifier (without emitter resistor in place)

When an emitter resistor is in place, the constant voltage gain of the BJT amplifier will drop from $A_v = R_C/r_e$ to $A_v = R_C/R_E$ and as a consequence, its cut-off frequency is shifted from f_2 to f_3. Notice also an increase of the bandwidth because of the cut-off frequency shifting.

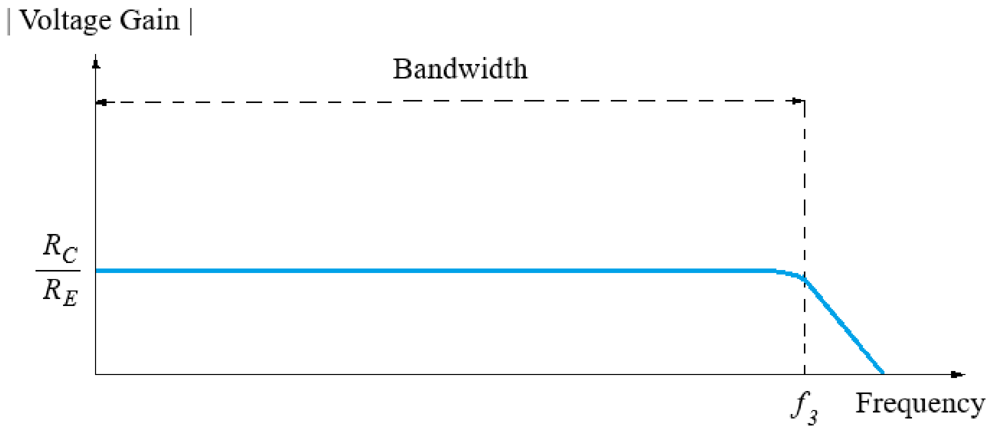


Figure 28: Frequency response of a common-emitter BJT amplifier (with an emitter resistor in place)

With a capacitor over the emitter resistor, the gain will be increased from $A_v = R_C/R_E$ to $A_v = R_C/r_e$ in the mid-range (e.g. from f_1 to f_{CO}). As a result, 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.

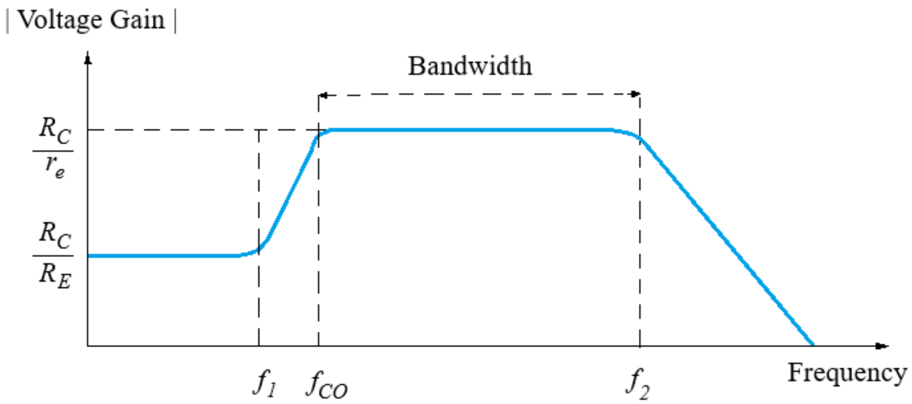


Figure 29: Frequency response of a common-emitter BJT amplifier (with an emitter resistor and a bypass capacitor in place)

7.2. Input and Output Coupling Capacitors

The **choice of coupling capacitors** at the input and output of the amplifier circuit is such that their values are chosen to have negligible effect at the frequency of interest.

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

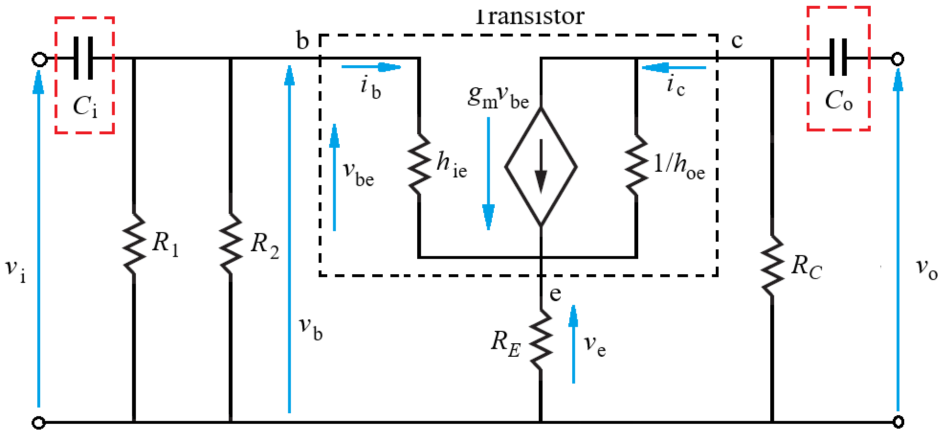


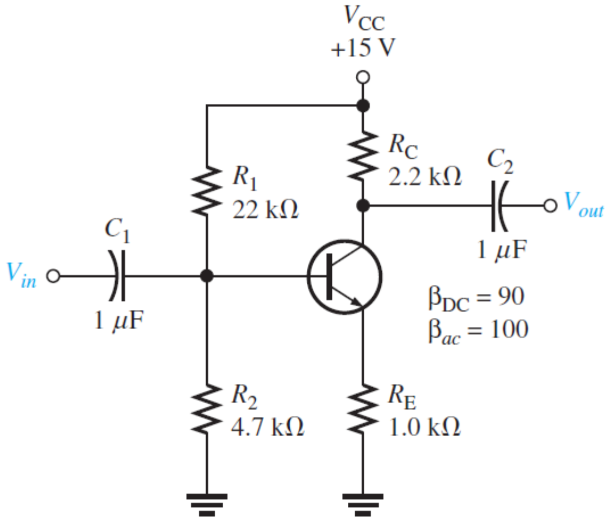
Figure 30: Input and output capacitors in the small-signal model of CE BJT amplifier

Their low frequency cut-off f_c must be well below the frequency of interest, where R is the equivalent resistance at input or output in series with this capacitance at input or output of the amplifier.

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

Example 3 – AC Analysis of 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]

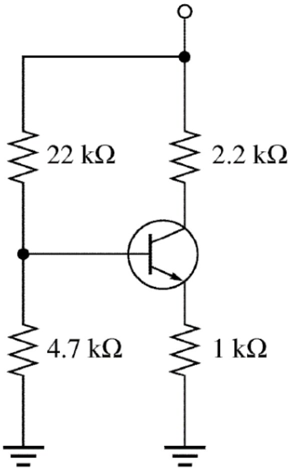
(i) $R_{in}(\text{base})$ (ii) $R_{in}(\text{tot})$ (iii) A_v

e. Connect a bypass capacitor across R_E and repeat part (d). [12 marks]

f. Connect a 10 kΩ load resistor to the output and repeat part (e). [12 marks]

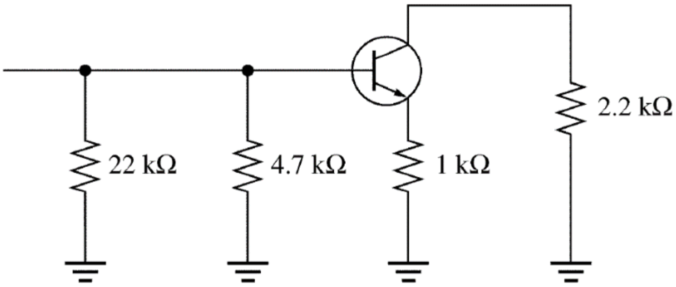
Answer

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



dc equivalent

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



ac equivalent

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

i. The base voltage is:

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

ii. The emitter voltage is:

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

iii. The emitter current is:

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

iv. The collector current is:

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

v. The collector voltage is:

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

c. The bias current at the input is:

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

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

$$I_{bias(\mathrm{tot})} = I_{bias(\mathrm{in})} + I_{bias(\mathrm{out})} = 562\ \mathrm{\mu A} + 1.94\ \mathrm{mA} = 2.50\ \mathrm{mA}$$

The power is dissipated for biasing is:

$$P_{bias(\mathrm{tot})} = I_{bias(\mathrm{tot})} V_{CC} = (2.5\ \mathrm{mA})(15\ \mathrm{V}) = 37.5\ \mathrm{mW}$$

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

i. The base voltage is:

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

The emitter voltage is:

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

The emitter current is:

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

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:

$$R_{in(\text{base})} = \beta(r_e' + R_E) = 100(12.9\ \Omega + 1\ \text{k}\Omega) = 101\ \text{k}\Omega$$

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

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

iii. 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:

i. The base resistance is:

$$R_{in(\text{base})} = \beta_{DC} r_e' = 100(12.9\ \Omega) = 1.29\ \text{k}\Omega$$

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

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

iii. 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:

i. The base resistance is:

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

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

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

iii. 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 Notes:

For a given common-emitter BJT amplifier as shown in the figure below.

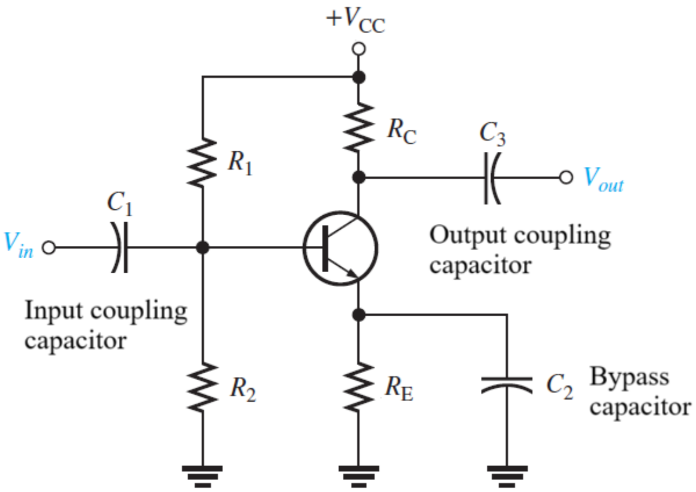


Figure 31: Common-emitter BJT amplifier with emitter capacitor and resistor

Need to select the following components/parts.

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 the 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.