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A.G.M RURAL COLLEGE OF ENGINEERING AND TECHNOLOGY, VARUR, HUBLI

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

NOTES

Subject with code: Electronic Principles and Circuits (BEC303)

Module 1

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Syllabus :

Transistor Biasing: Voltage Divider Bias, VDB Analysis, VDB Load line and Q point, Two supply Emitter Bias, Other types of Bias.

BJT AC models: Base Biased Amplifier, Emitter Biased Amplifier, Small Signal Operation, AC Beta, AC Resistance of the emitter diode, Two transistor models, Analyzing an amplifier, H parameters, Relations between R and H parameters.

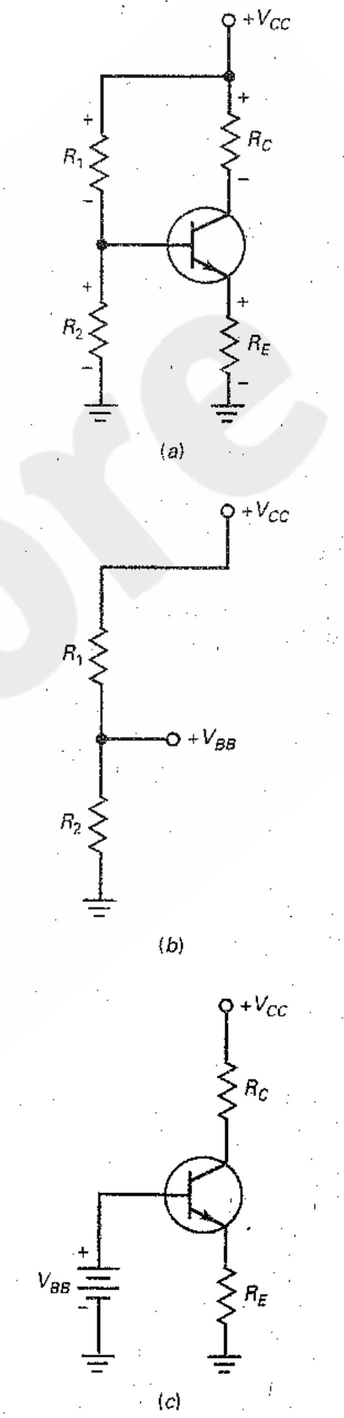
Voltage Amplifiers: Voltage gain, Loading effect of Input Impedance.

CC Amplifiers: CC Amplifier, Output Impedance.

Transistor Biasing

Voltage Divider Biasing

Figure 8-1 Voltage-divider bias. (a) Circuit; (b) voltage divider; (c) simplified circuit.



The figure 8.1a shows the voltage divider biasing circuit. Notice that the base circuit contains a voltage divider (R1 and R2) because of this circuit is called voltage divider bias (VDB).

VDB Analysis

In any well designed VDB circuit the base current is very negligible compared to current through voltage divider circuit and hence equivalent circuit at base is shown in figure 8.1b.

To analyse VDB circuit we need follow the steps given below.

1. Calculate the base voltage V_{BB} out of voltage divider bias which is given by

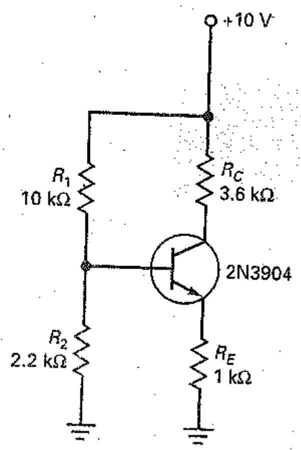
$$V_{BB} = \frac{R_2}{R_1 + R_2} V_{CC}$$

With V_{BB} as a dc source the equivalent circuit for figure 8.1a is given in figure 8.1c.

2. Subtract 0.7V to get the emitter voltage.
   $V_E = V_{BB} - V_{BE}$
3. Divide the V_E by R_E to get emitter current.
   $I_E = V_E / R_E$
4. Assume the collect current is equal to emitter current.
   $I_C \approx I_E$
5. Calculate collector voltage using following equation.
   $V_C = V_{CC} - I_C R_C$
6. Then calculate collector emitter voltage (V_{CE}) by subtracting emitter voltage from collector voltage.
   $V_{CE} = V_C - V_E$

Example 8-1

Figure 8-2 Example.



MultiSim

What is the collector-emitter voltage in Fig. 8-2?

SOLUTION The voltage divider produces an unloaded output voltage of:

$$V_{BB} = \frac{2.2\ \text{k}\Omega}{10\ \text{k}\Omega + 2.2\ \text{k}\Omega}\,10\ \text{V} = 1.8\ \text{V}$$

Subtract 0.7 V from this to get:

$$V_E = 1.8\ \text{V} - 0.7\ \text{V} = 1.1\ \text{V}$$

The emitter current is:

$$I_E = \frac{1.1\ \text{V}}{1\ \text{k}\Omega} = 1.1\ \text{mA}$$

Since the collector current almost equals the emitter current, we can calculate the collector-to-ground voltage like this:

$$V_C = 10\ \text{V} - (1.1\ \text{mA})(3.6\ \text{k}\Omega) = 6.04\ \text{V}$$

The collector-emitter voltage is:

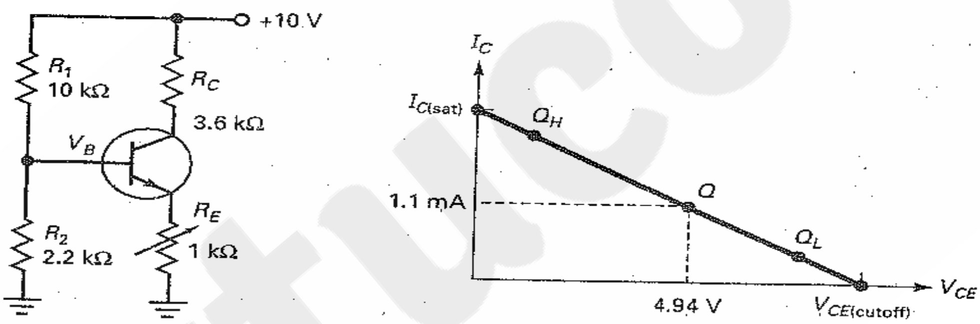
$$V_{CE} = 6.04 - 1.1\ \text{V} = 4.94\ \text{V}$$

Here is an important point. Th...

VDB load line and Q point

The Q point

Figure 8-6 Calculating the Q point.



From the example 8.1 the Q point is calculated which is at the collector current of 1.1mA and a collector emitter voltage of 4.94 V. These values are plotted to get the Q point shown in Figure 8.6. S0ince the voltage divider bias is derived from emitter bias, one way to move the Q point of figure 8.6 is by varying the emitter resistor.

For instance, if the emitter resistance is changed to 2.2 kΩ, the collector current decreases to:

$$I_E = \frac{1.1\ \text{V}}{2.2\ \text{k}\Omega} = 0.5\ \text{mA}$$

The voltages change as follows:

$$V_C = 10\ \text{V} - (0.5\ \text{mA})(3.6\ \text{k}\Omega) = 8.2\ \text{V}$$

and

$$V_{CE} = 8.2\ \text{V} - 1.1\ \text{V} = 7.1\ \text{V}$$

Therefore, the new Q point will be Q_L and will have coordinates of 0.5 mA and 7.1 V.

On the other hand, if we decrease the emitter resistance to 510 Ω, the emitter current increases to:

$$I_E = \frac{1.1\ \text{V}}{510\ \Omega} = 2.15\ \text{mA}$$

and the voltages change to:

$$V_C = 10\text{ V} - (2.15\text{ mA})(3.6\text{ k}\Omega) = 2.26\text{ V}$$

and

$$V_{CE} = 2.26\text{ V} - 1.1\text{ V} = 1.16\text{ V}$$

In this case, the Q point shifts to a new position at Q_H with coordinates of 2.15 mA and 1.16 V.

Two Supply Emitter Bias

Two supply emitter bias of figure 8.8 shows a transistor circuit with two power supplies +10V and -2V. The negative supply forward biases the emitter diode. The positive supply reverse biases the collector diode. This circuit is derived from the emitter bias. Hence we refer this as two supply bias(TSEB).

Figure 8–8 Two-supply emitter bias.

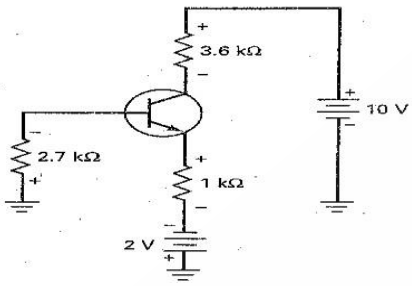
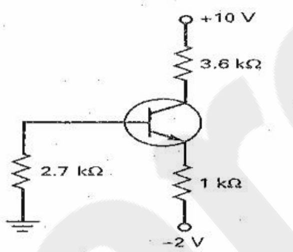


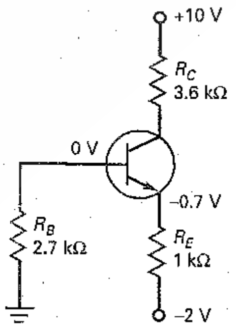
Figure 8–9 Redrawn TSEB circuit.



The circuit in figure 8.8 is redrawn in figure 8.9 for simplicity. The steps for analysing circuit above as follows

1. If this circuit is correctly designed the base current I_B is very small and hence considered as approximately zero. Voltage V_B is approximately zero
   $V_B = 0$
2. Calculate the V_E which is obtained by analysing the circuit at emitter
   $V_E = V_B - V_{BE}$
3. Find the emitter current I_E
   $I_E = (V_E - (-V_{EE})) / R_E$
4. Assume the collect current is equal to emitter current.
   $I_C \approx I_E$
5. Calculate collector voltage using following equation.
   $V_C = V_{CC} - I_C R_C$
6. Then calculate collector emitter voltage (V_{CE}) by subtracting emitter voltage from collector voltage.
   $V_{CE} = V_C - V_E$

Figure 8-10 Base voltage is ideally zero.



$$V_{RE} = -0.7\text{ V} - (-2\text{ V}) = 1.3\text{ V}$$

Once you have found the voltage across the emitter resistor, calculate the emitter current with Ohm's law:

$$I_E = \frac{1.3\text{ V}}{1\text{ k}\Omega} = 1.3\text{ mA}$$

This current flows through the 3.6 kΩ and produces a voltage drop that we subtract from +10 V as follows:

$$V_C = 10\text{ V} - (1.3\text{ mA})(3.6\text{ k}\Omega) = 5.32\text{ V}$$

The collector-emitter voltage is the difference between the collector voltage and the emitter voltage:

$$V_{CE} = 5.32\text{ V} - (-0.7\text{ V}) = 6.02\text{ V}$$

Other types of Bias

Emitter feedback bias

In base bias circuit of figure 8.12a the Q point is varies all over the load line due to replacement of transistor and change in temperature. Hence to stabilize Q point the emitter feedback bias of circuit shown in figure 8.12b used. Noticed that the emitter resistor is added at the circuit to stabilize the Q point.

Here are the equations for analysing the Q point

$$I_E = \frac{V_{CC} - V_{BE}}{R_E + R_B/\beta_{dc}}$$

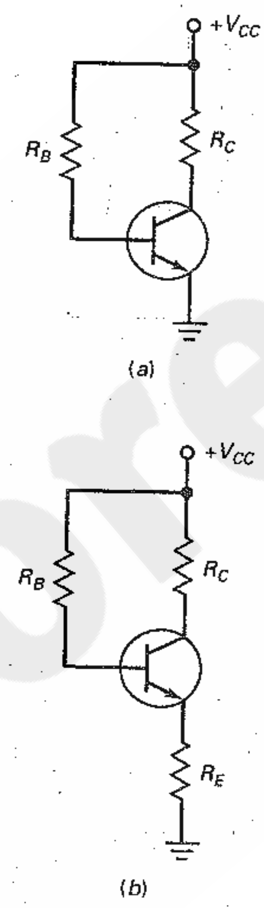
$$V_E = I_E R_E$$

$$V_B = V_E + 0.7\ \text{V}$$

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

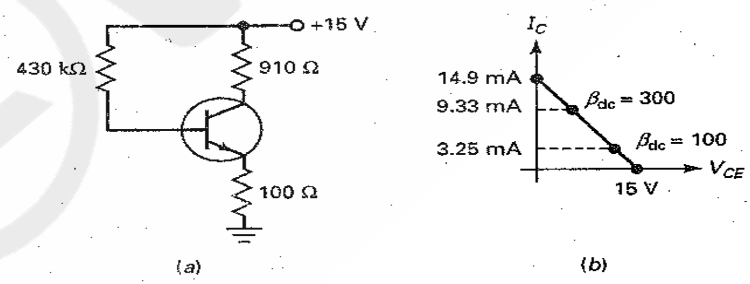
VCE = V_C - V_E

Figure 8-12 (a) Base bias; (b) emitter-feedback bias.



Looking at equations above it is clear that when IC increases, VE increases causing VB to increase. Which gives more VB hence less voltage across RB reduces base current IB which opposes original increase in IC. In this way change in IC due to variation in temperature will be opposes by emitter feedback bias circuit. It is called feedback because of change in emitter voltage is being feedback to the base circuit.

Figure 8-13 (a) Example of emitter-feedback bias; (b) Q point is sensitive to changes in current gain.



Collector – Feedback Bias

The figure 8.14a shows the collector feedback bias also called self-bias. Here feedback the voltage to the base from the collector to neutralize any change in collector current. For a instance suppose the collector current increases. This decreases the collector voltage VC which decreases the voltage across the base resistor. In trun, this decreases the base current, which opposes the original increase in collector current IC.

Here are the equations for analysing collector feedback bias.

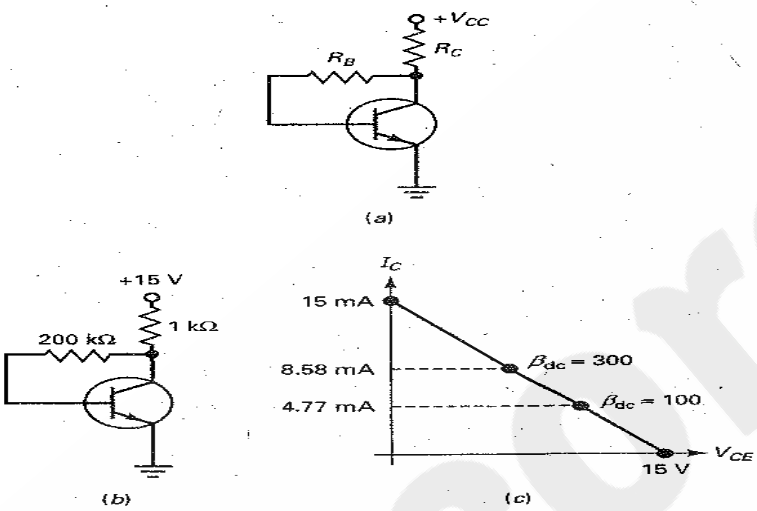
$$I_E = \frac{V_{CC} - V_{BE}}{R_C + R_B/\beta_{dc}}$$

$$V_B = 0.7\ \text{V}$$

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

$V_{CE} = V_C$

Figure 8-14 (a) Collector-feedback bias; (b) example; (c) Q point is less sensitive to changes in current gain.



The Q point is set near the middle of load line by using base resistance of

$$R_B = \beta_{dc} R_C$$

Collector and Emitter Feedback bias

Collector and emitter feedback bias used to set more stable bias for transistor circuits. The figure 8.15 shows the collector – emitter feedback bias. Combining both types of feedback in one circuit helps to stabilize Q point but still production.

Here are the equations for analysing it

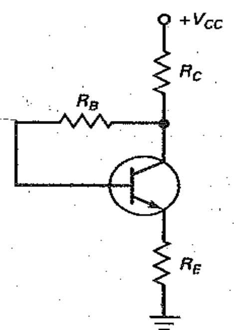
$$I_E = \frac{V_{CC} - V_{BE}}{R_C + R_E + R_B/\beta_{dc}}$$

$$V_E = I_E R_E$$

$$V_B = V_E + 0.7\ \text{V}$$

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

Figure 8-15 Collector-emitter feedback bias.



Base Biased Amplifier

DC biasing circuit

Figure 9.4 shows a base biased circuit, looking the circuit.
$I_B = (30v-0.7)/1M = 30\mu A$
With current gain ·=100
$I_C = I_B \times 100 = 3mA$
And the collector voltage
$V_c = V_{CC} - I_C \times R_C = 30 - (3m)(5K) = 15v$
Hence the Q point is located at 3mA and 15V of IC and VC respectively

Amplifying circuit

Figure 9.4 shows base bias amplifier circuit with an ac source voltage is 100uV. Since the input coupling capacitor is an ac short, all the ac of source voltage appears between the base and the ground. For coupling capacitor work properly, its reactance must be 10 times less than input resistance of amplifier at the lowest frequency of the ac source ($X_c < 0.1R$). The ac voltage produces an ac base current that is added to the existing dc base current. Figure 9.3 a illustrates the ac component is super imposed on the dc component of 30uA. The ac base current produces an amplified variation in collector current because of the current gain. In figure 9.3 b shows the amplified the ac collector current superimposed on dc collector of 3mA

Since this amplified collector current flows through the collector resistor, it produces a varying voltage across the collector resistor. Which is subtracted from the supply voltage we get the collector voltage shown in figure 9.3c.

Voltage waveforms

The voltage gain of an amplifier is defined as the ac output voltage divided by the ac input voltage.

Figure 9-4 Base-biased amplifier with waveforms.

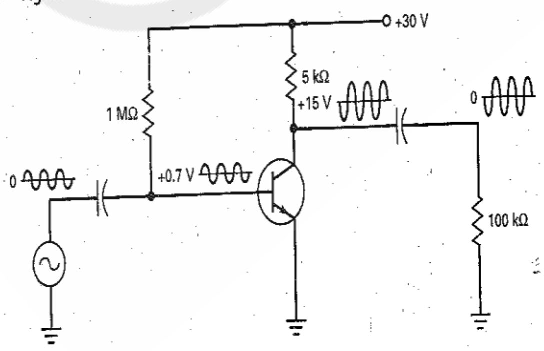
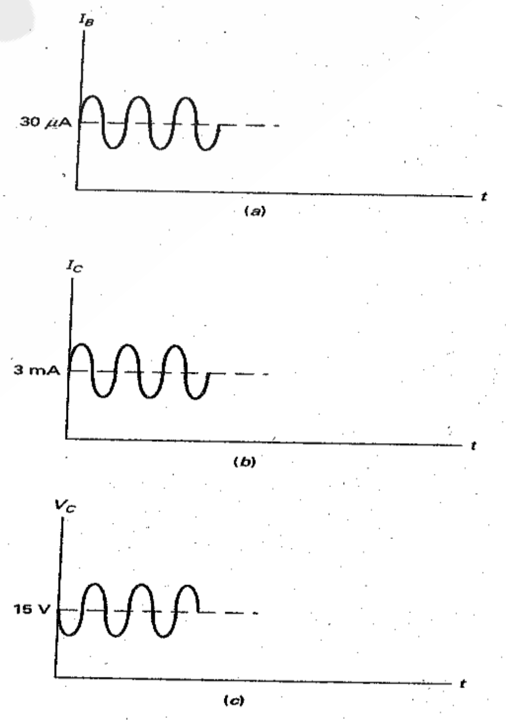


Figure 9-3 DC and ac components. (a) Base current; (b) collector current; (c) collector voltage.



(a)

Figure 9.4 shows the waveforms for a base biased amplifier. The ac source voltage is small sinusoidal voltage. This is coupled into the base, where it is superimposed on the dc component of +0.7V. The variation in base voltage produces sinusoidal variation in base current, collector current and collector voltage. The total collector voltage is an inverted sine wave superimposed on the dc collector voltage of

+15v. The coupling capacitor at the load blocks all dc component and hence the load voltage is pure ac signal.

Emitter Biased Amplifier

VDB(Voltage divider bias) Amplifier

Figure 9-8 VDB amplifier with waveforms.

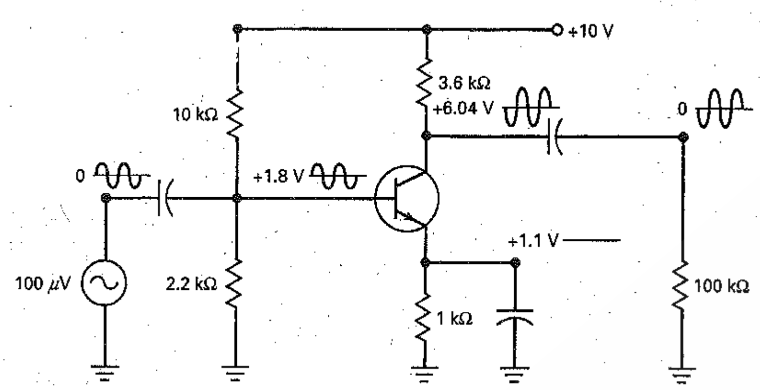


Figure 9.8 shows a voltage divider biased (VDB) amplifier. To calculate the dc voltages and currents, mentally open all capacitors. The quiescent or dc values for this circuit are

VB= 10 x 2.2k/12.2k = 1.8V,
VE =VB-VBE= 1.8 – 0.7 = 1.1V,

IC=IE = VE/RE = 1.1/1K = 1.1mA,
VC=VCC – IC x RC= 10-1.1m x 3.6k= 6.04V,

With coupling capacitors it is also use a bypass capacitor between the emitter and ground without this capacitor the ac base current would be much smaller. With this capacitor we get a much larger voltage gain. To work bypass capacitor properly its reactance must be minimum 10 times less than the resistance at lowest frequency of ac signal (Xc<0.1R).

VDB Waveforms

Notice the voltage waveforms in figure 9.8. The ac source voltage is a small sinusoidal voltage with an average value of zero. The base voltage is an ac voltage superimposed on a dc voltage 1.8 V. The collector voltage is an amplified and inverted ac voltage superimposed on the dc collector voltage of +6.04V. The load voltage is the same as the collector voltage except that it has an average value of zero. It is also note that voltage at emitter is pure dc of +1.1V because of bypass capacitor.

Two- supply emitter bias (TSEB) amplifier

Figure 9.9 shows TSEB amplifier, The dc analysation of this circuit shown in figure 8.10.

Figure 9-9 TSEB amplifier with waveforms.

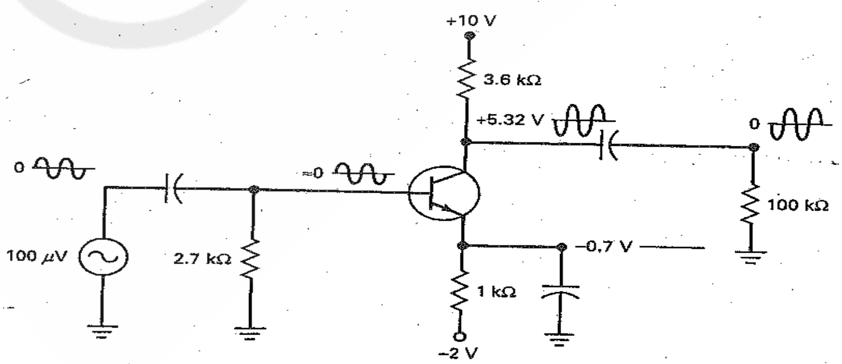


Figure shows a two supply emitter bias (TSEB) amplifier. By analysing the dc part of the cirucit and calculate these quiescent voltages

VB= 0V , VE = VB-VBE = -0.7V,

IC = IE =VE-(-2)/RE = -0.7-(-2)/1k = 1.3mA,

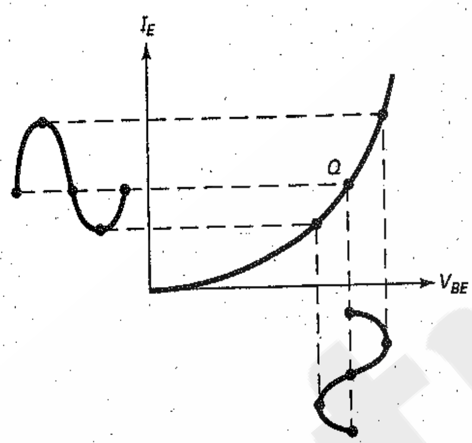
VC = VCC-IC x RC= 10-1.3m x 306k= 5.32 V

Figure 9.9 shows two coupling capacitors to block ac at input and output side and a bypass capacitor to bypass ac component through emitter resistor RE so that it does not disturbe the operating point.

Notice waveform that the ac source voltage is a small sinusodial voltage. The base voltage has a small ac component riding on a dc component of approximately 0v. The total collector voltage is inverted sine wave riding on the dc the dc collector voltage of +5.32V. The load voltage is the same amplified signal with no dc component.

1. Small Signal Operation

Figure 9-10 Distortion when signal is too large.



When an ac voltage is coupled into the base of a transistor, an ac voltage appears across the base emitter diode.This produces the sinusodial variation in VBE shown in figure 9.10. When the voltage increases to its positive peak, the instantaneous operating point moves from Q to the upper point. On the other hand when the sine wave decreases to its negative peak, the operating point moves from Q to the lower point.

Distortion & Reducing distortion

The ac emitter current is not a perfect replica of the ac base voltage.Since the graph is curved upward, the positive half cycle of ac emitter current is stretched and the negative half cycle is compressed. This stretching and compressing is called distortion.

One way to reduce this distortion is by keeping the ac base voltage small. When you reduce the peak value of base voltage, you reduce the movement of the instantaneuos operating point. Using 10 percent rule to minimize the distortion, the peak to peak ac value of i_e must be small comparted to I_{EQ} i.e (i_e(pp) < $0.1I_{EQ}$). Where i_e is ac emiiter current and I_{EQ} is dc emitter current.

AC Beta

The dc current gain (dc beta) is

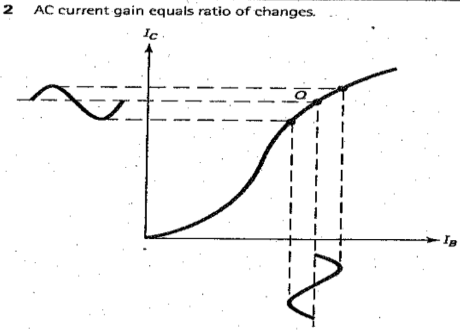
$\beta dc = I_C / I_B$

Where ac current gain is (ac beta) equal the ac collectr current divided by the ac base current.

$\beta = i_c/i_b$

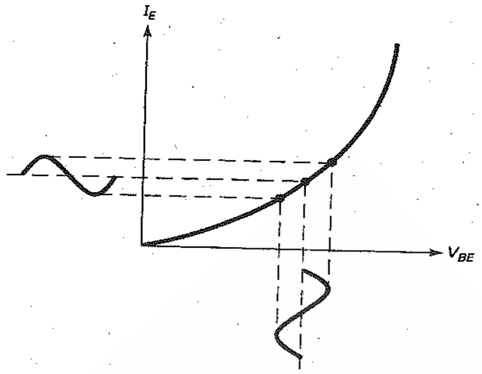
Graphically, β equals the slope the curve at point Q

Figure 9-12 AC current gain equals ratio of changes.



AC Resistance of the Emitter Diode

Figure 9-13 AC resistance of emitter diode.



When a small ac voltage vbe change at the emitter and base junction produces the ac emitter current as shown in figure 9.13

The ac emitter resistance of the emitter diode is the ac base emitter voltage divided by the ac emitter current.

re’ = vbe/ie

The ac emitter resistance is also 25mV divided by dc emitter current IE

re’ = 25 mV / IE

Two Transistor Models

To analyse the ac operation of a transistor amplifier, we need an ac equivalent circuit(ac model) for a transistor that simulates how it behaves when an ac signal is present.

The T Model

The T model also called Ebers-Moll model shown in figure 9.16. Here the emitter diode of a transistor acts like an ac resistance re’ and the collector diode acts like a current source ic. Since it looks like T shape so it is called T model.

When an ac input signal is applied this gives an ac base emitter vbe across emitter base and produces ac base current i_b as shown in figure 9.17a. Hence Looking at base the input impedance Zin(base) as shown in figure 9.17b is

$$z_{in(base)} = \frac{v_{be}}{i_b} \qquad \textbf{(9-11)}$$

Figure 9–16 T model of a transistor.

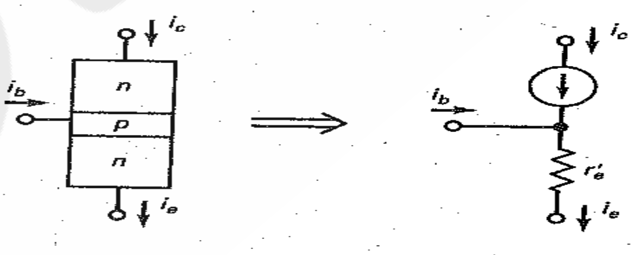
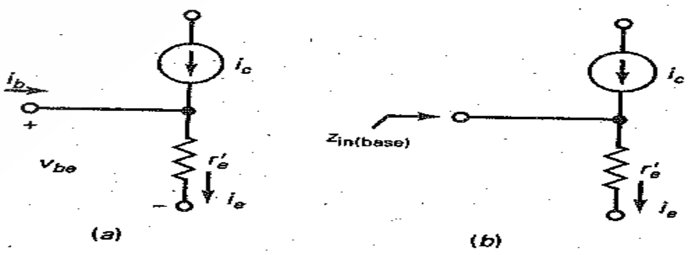


Figure 9–17 Defining the input impedance of the base.



The π Model

Figure 9.18a shows the π model of transistor. This model is easier to use than the T model shown in figure 9.18b beacause the input impdance is not bovious in T model.

Applying ohm's law to the emitter diode of fig. 9.17a, we can write.

$$v_{be} = i_e r'_e$$

Equating vbe = $i_b$re' into equation 9.11 will give

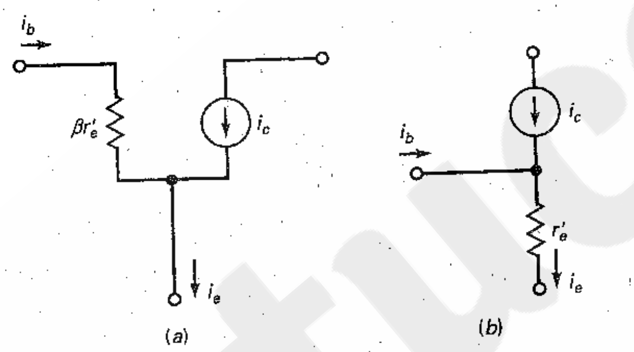
$$z_{in(base)} = \frac{v_{be}}{i_b} = \frac{i_e r'_e}{i_b}$$

Since $i_e \approx i_c$, the foregoing equation simplifies to:

$$z_{in(base)} = \beta r'_e$$

Hence π model shown in figure 9.18a having input impendance of βre'

Figure 9-18 π model of a transistor.



Analysing an Amplifier

The simplest way to analyse an amplifier_is to split the analsis into two parts, 1) dc analysis b) ac analysis

In dc analysis we calculate the dc voltages and currents to do this we need to open all capacitors. The circuit that remains is dc equavalent circuit.

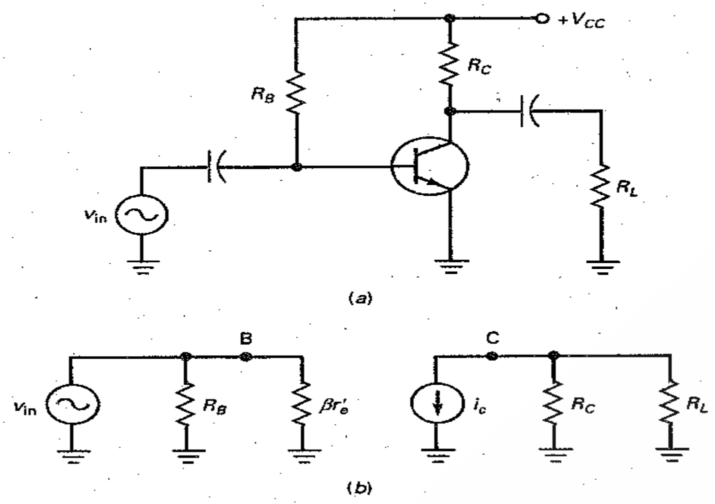
In ac analysis short all capacitors and dc voltage sources and then trasistor can be replaced by either the π model or the T model.

Analysis of Base bias amplifier

Figure 9.20a shows base biased amplifier. For dc analysation open all capacitors and analyse the dc equavalent cicuit which means calculate the operating point values I_C and V_{CE}.

For ac analysation the figure 9.20b shows the ac equivalent circuit. Which we got after shorting all capacitors and dc source +VCC and then repalce the transitor with its π model. As you can see in the base circuit, the ac input voltage appears across RB in parllel with βre'. In the collector circuit, the current source pumps an ac current of ic through R_C in parllel with R_L

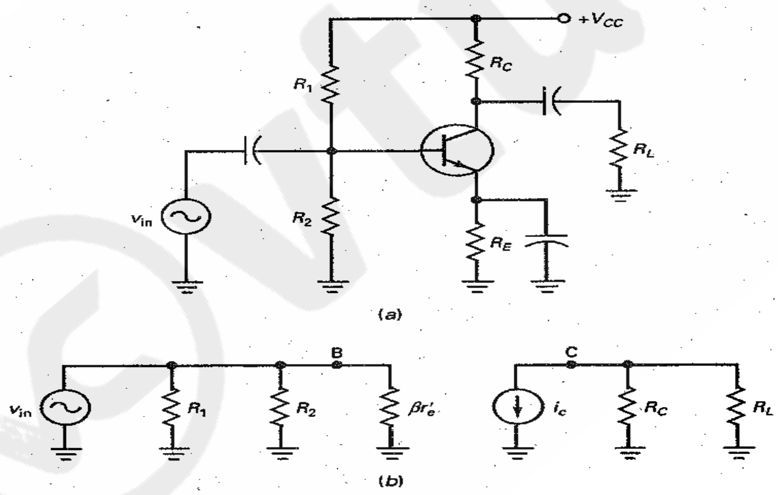
Figure 9-20 (a) Base-biased amplifier; (b) ac equivalent circuit.



Analysis of Voltage divider bias amplifier

Figure 9.21a is VDB amplifier and figure 9.21b is its ac equavalent cicuit. As you can see. All capacitors have been shorted, the dc supply point has become an ac ground and the trasnsistor has been replaced with R_2 in parllel with βre. In the collector cicuit, the current source pumps an ac current of ic through R_C in parllel with R_L

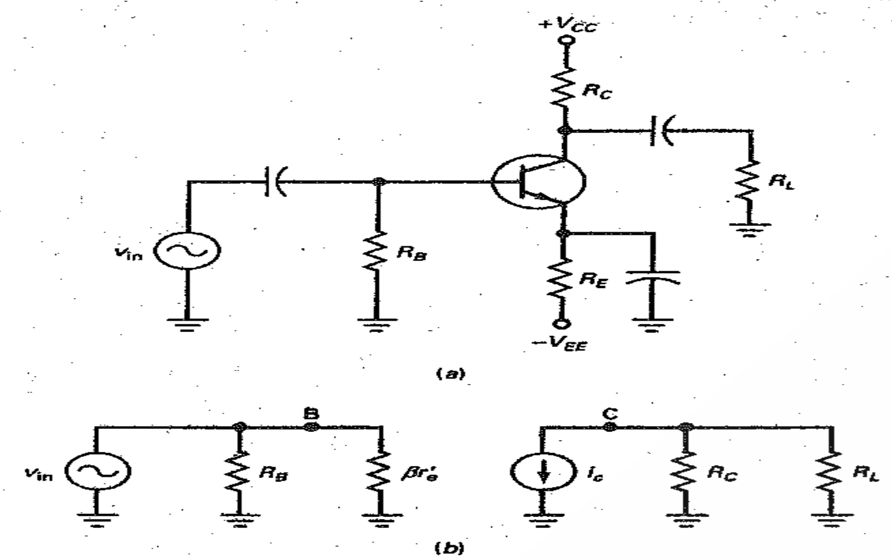
Figure 9-21 (a) VDB amplifier; (b) ac equivalent circuit.



Analysis of Two supply emitter bias amplifier

The two supply emitter biasing is shown in figure 9.22a. The equivalent for TSEB is shown in figure 9.22b to get it again all capcitors and dc voltage source are shorted and the trasisitor is replaced by its π model. In the base circuit, the ac input voltage appears across RB in parllel with Bre'. In the collector circuit, the current source pumps an ac current of ic through Rc in parallel with R_L

Figure 9-22 (a) TSEB amplifier; (b) ac equivalent circuit.



H parameters

When trasistor was first invented, an approach used to analyse and design the trasistor circuit is known as h parameters. The more practical approach is the one using π model which is called r, parameter method, which uses the quantity like β and re' but h parameters are sill survived on data sheet. There are h parameters which gives very usefull information are h_{fe}, h_{ie}, h_{re} and h_{oe}

Relation between R and H parameters

1. The h_{fe} in H parameter is nothing but a current gain β in R parameters
   $\beta = h_{fe}$
2. Similarly the quantity h_{ie} in H parmeter equaivalent to the input impedance which is relate to R parameter's re' like this
   $$r'_e = \frac{h_{ie}}{h_{fe}}$$
3. The another two parameters h_{re} and h_{oe} are not needed for troubleshooting and basic design

Voltage Amplifiers

Voltage gain

Figure 10.1a shows a voltage divider biased amplifier. Here voltage gain was defined as the ac output voltage divided by the ac input voltage. Let us derive the voltage gain equation using both T and π model

Derived from the π Model

Figure 10-1*b* shows the ac equivalent circuit using the π model of the transistor. The ac base current i_b flows through the input impedance of the base ($\beta r'_e$). With Ohm's law, we can write:

$$v_{in} = i_b \beta r'_e$$

In the collector circuit, the current source pumps an ac current i_c through the parallel connection of R_C and R_L. Therefore, the ac output voltage equals:

$$v_{out} = i_c(R_C \parallel R_L) = \beta i_b(R_C \parallel R_L)$$

Now, we can divide v_{out} by v_{in} to get:

$$A_V = \frac{v_{out}}{v_{in}} = \frac{\beta i_b(R_C \parallel R_L)}{i_b \beta r'_e}$$

which simplifies to:

$$A_V = \frac{(R_C \parallel R_L)}{r'_e}$$

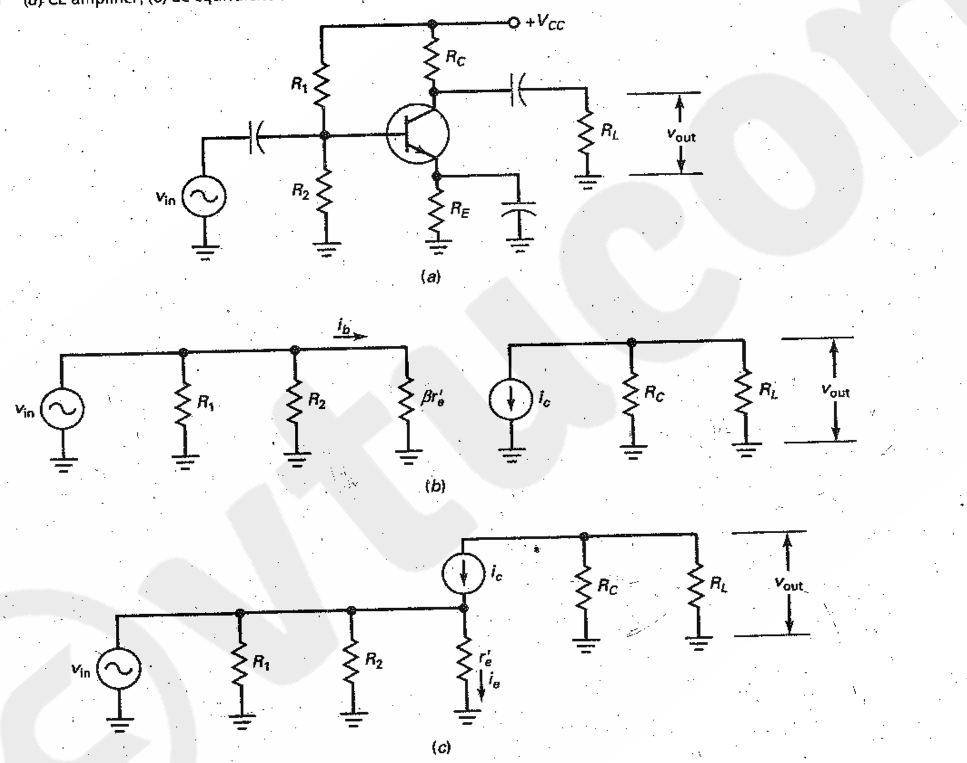
From the figure 10.1b The total load resistance seen by the collector is parallel combination of R_C and R_L. This is called the ac collector resistance r_c.

$$r_c = R_C \parallel R_L$$

Now, we can rewrite Eq. (10-1) as:

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

Figure 10-1 (a) CE amplifier; (b) ac equivalent circuit with π model; (c) ac equivalent circuit with T model.



<u>Derived from the T model</u>

The figure 10.c shows the ac equavalent circuit using the T model of the transistor. The input voltage vin appears acros r_e'. With Ohm's law we can write:

$$v_{in} = i_e r'_e$$

In the collector circuit, the current source pumps an ac current i_c through the ac collector resistance. Therefore, the ac output voltage equals:

$$v_{out} = i_c r_c$$

Now, we can divide v_{out} by v_{in} to get:

$$A_V = \frac{v_{out}}{v_{in}} = \frac{i_c r_c}{i_e r'_e}$$

Since $i_c \approx i_e$, we can simplify the equation to get:

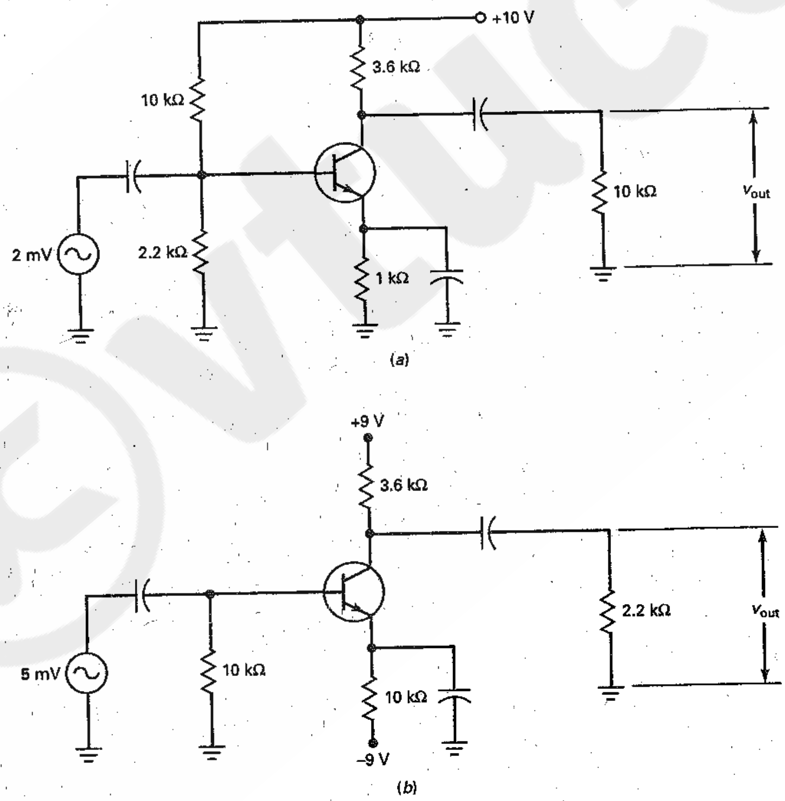
$$A_V = \frac{r_c}{r'_e}$$

Example 10-1

MultiSim

What is the voltage gain in Fig. 10-2*a*? The output voltage across the load resistor?

Figure 10-2 (*a*) Example of VDB amplifier; (*b*) example of TSEB amplifier.



SOLUTION The ac collector resistance is:

$$r_c = R_C \parallel R_L = (3.6\ \text{k}\Omega \parallel 10\ \text{k}\Omega) = 2.65\ \text{k}\Omega$$

In Example 9-2, we calculated an r'_e of 22.7 Ω. So, the voltage gain is:

$$A_V = \frac{r_c}{r'_e} = \frac{2.65\ \text{k}\Omega}{22.7\ \Omega} = 117$$

The output voltage is:

$$v_{out} = A_V v_{in} = (117)(2\ \text{mV}) = 234\ \text{mV}$$

Example 10-2

What is the voltage gain in Fig. 10-2*b*? The output voltage across the load resistor?

SOLUTION The ac collector resistance is:

$$r_c = R_C \parallel R_L = (3.6\ \text{k}\Omega \parallel 2.2\ \text{k}\Omega) = 1.37\ \text{k}\Omega$$

The dc emitter current is approximately:

$$I_E = \frac{9\ \text{V} - 0.7\ \text{V}}{10\ \text{k}\Omega} = 0.83\ \text{mA}$$

The ac resistance of the emitter diode is:

$$r'_e = \frac{25\ \text{mV}}{0.83\ \text{mA}} = 30\ \Omega$$

The voltage gain is:

$$A_V = \frac{r_c}{r'_e} = \frac{1.37\ \text{k}\Omega}{30\ \Omega} = 45.7$$

The output voltage is:

$$v_{out} = A_V v_{in} = (45.7)(5\ \text{mV}) = 228\ \text{mV}$$

The loading effect of input impedance

Input impedance :

In figure 10.30a, an ac voltage source vg has an internal resistance RG. Some of the ac source voltage is dropped across its internal resistance. As a result, the ac voltage between the base and ground is less than ideal.

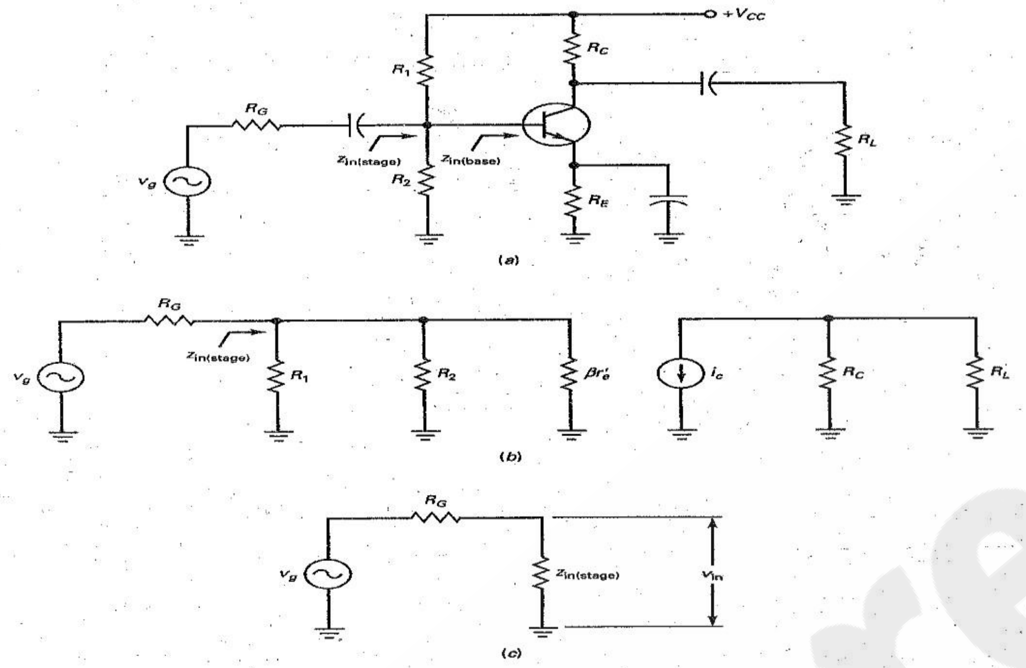
The ac generator has to drive the input impedance of the stage Zin(stage). Ac equaivalent circuit of figure 10.3a shown in figure 10.3b. Looking from the input circuit of fig 10.3b input impedance Zin(stage) is given by.

$$z_{in(stage)} = R_1 \parallel R_2 \parallel \beta r'_e$$

Therefore equation for input voltage Vin looking at figure 10.3c will be

$$v_{in} = \frac{z_{in(stage)}}{R_G + z_{in(stage)}} v_g$$

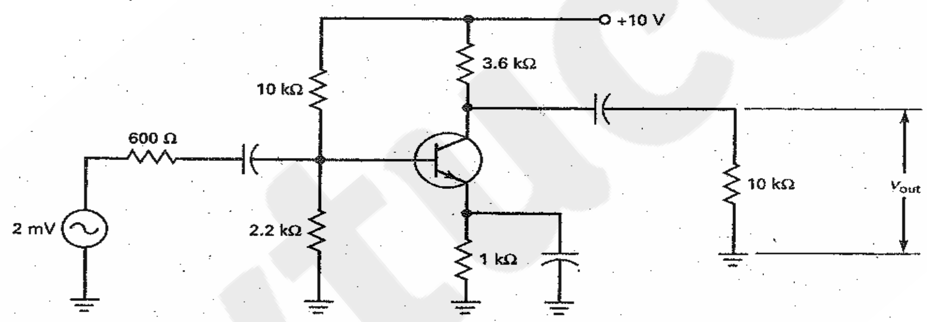
Figure 10–3 CE amplifier. (*a*) Circuit; (*b*) ac equivalent circuit; (*c*) effect of input impedance.



Example 10–3

In Fig. 10-4, the ac generator has an internal resistance of 600 Ω. What is the output voltage in Fig. 10-4 if $\beta = 300$?

Figure 10–4 Example.



SOLUTION Here are two quantities calculated in earlier examples: $r'_e = 22.7\ \Omega$ and $A_V = 117$. We will use these values in solving the problem.

When $\beta = 300$, the input impedance of the base is:

$$z_{in(base)} = (300)(22.7\ \Omega) = 6.8\ k\Omega$$

The input impedance of the stage is:

$$z_{in(stage)} = 10\ k\Omega \parallel 2.2\ k\Omega \parallel 6.8\ k\Omega = 1.42\ k\Omega$$

With Eq. (10-4), we can calculate the input voltage:

$$v_{in} = \frac{1.42\ k\Omega}{600\ \Omega + 1.42\ k\Omega} 2\ mV = 1.41\ mV$$

This is the ac voltage that appears at the base of the transistor, equivalent to the ac voltage across the emitter diode. The amplified output voltage equals:

$$v_{out} = A_V v_{in} = (117)(1.41\ mV) = 165\ mV$$

Example 10–4

Repeat the preceding example for $\beta = 50$.

SOLUTION When $\beta = 50$, the input impedance of the base decreases to:

$$z_{in(base)} = (50)(22.7\ \Omega) = 1.14\ k\Omega$$

The input impedance of the stage decreases to:

$$z_{in(stage)} = 10\ k\Omega \parallel 2.2\ k\Omega \parallel 1.14\ k\Omega = 698\ \Omega$$

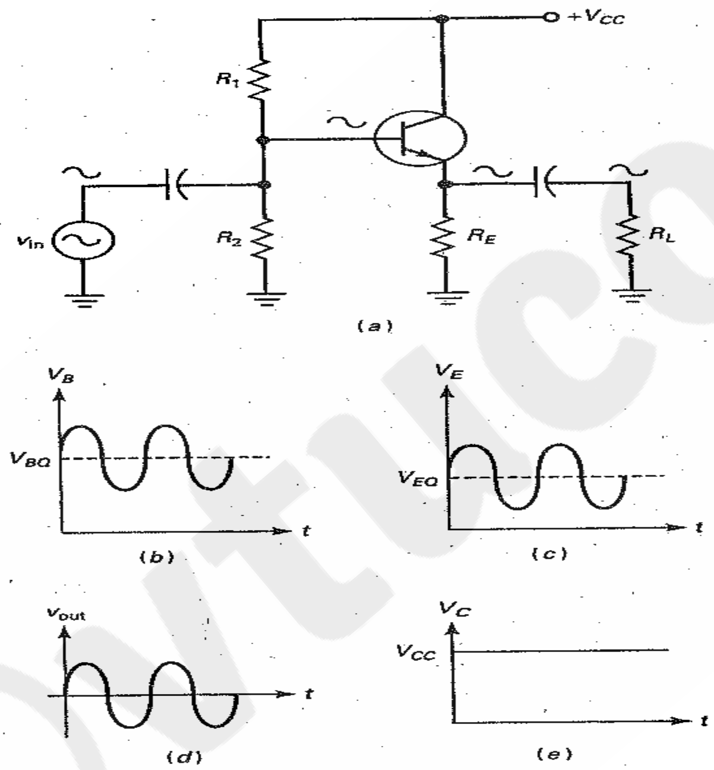
With Eq. (10-4), we can calculate the input voltage:

$$v_{in} = \frac{698\ \Omega}{600\ \Omega + 698\ \Omega} 2\ mV = 1.08\ mV$$

CC (Common Collector Amplifier)

The emitter follower is also called a common collector (CC) amplifier. Figure 11.1a shows an emitter follower at which input voltage is coupled to the base and output produces at the emitter. The figure 11.1b shows the total voltage between base and ground. It has a dc component quiescent voltage V_{BQ} and an input voltage ac component rides on V_{BQ}. Similarly figure 11.1c shows the voltage between the emitter and ground. This time, the ac input voltage is entered on a quiescent emitter voltage V_{EQ}. The ac emitter outpu voltage coupled to the load resistor as shown in figure 11.1d. This output voltage is approximatly equal to the input voltage. Because the output voltage follows the input voltage this circuit is called emitter follower.

Figure 11-1 Emitter follower and waveforms.



Voltage gain of CC amplifier:

As shown the figure 11.1a the total ac emitter resistance is

$$r_e = R_E \| R_L \tag{11-1}$$

Figure 11-2*a* shows the ac equivalent with the T model. Using Ohm's law, we can write these two equations:

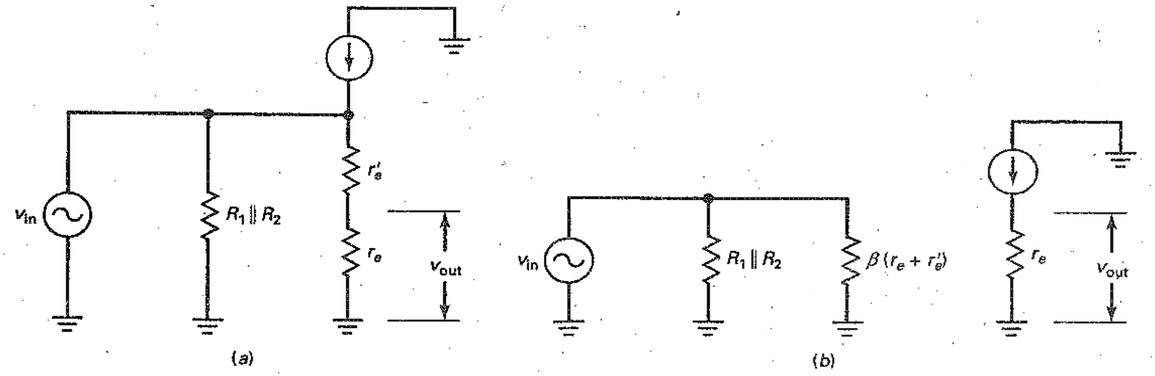
$$v_{out} = i_e r_e$$

$$v_{in} = i_e(r_e + r'_e)$$

Divide the first equation by the second, and you get the voltage gain of the emitter follower:

$$A_V = \frac{r_e}{r_e + r'_e} \tag{11-2}$$

Figure 11-2 AC equivalent circuits for emitter follower.



Input impedance of the CC amplifier :

The figure 11.2b shows the ac equavalent circuit of CC amplifier looking in this figure input impedance of the base is

$$z_{in(base)} = \beta(r_e + r'_e) \tag{11-3}$$

Hence the total input impedance of the input stage looking from the source Vin in figure 11.2b is

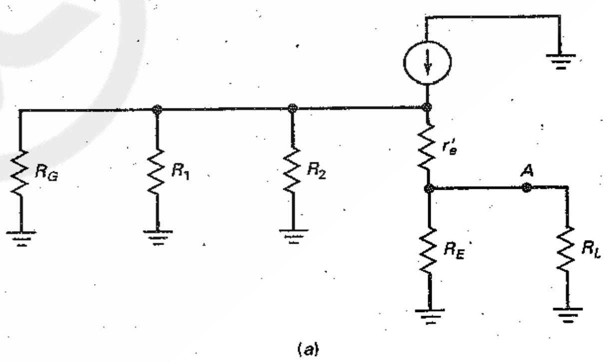
$$z_{in(stage)} = R_1 \| R_2 \| \beta(r_e + r'_e) \tag{11-4}$$

Output impedance of the CC amplifier

Figure 11.8 shows ac equivalent circuit for emitter follower. Looking from the output load resistor R_L and by considering the emitter current ie is flowing through the total resistor RG||R1||R2 at the input side, we have output impendace Zout is

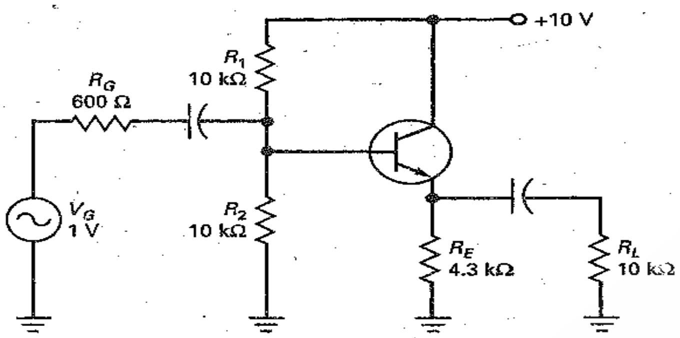
$$z_{out} = R_E \| \left(r'_e + \frac{R_G \| R_1 \| R_2}{\beta} \right) \tag{11-5}$$

Figure 11-8 Output impedance of emitter follower.



What is the input impedance of the base in Fig. 11-3 if $\beta = 200$? What is the input impedance of the stage?

Figure 11–3 Example.



SOLUTION Because each resistance in the voltage divider is 10 kΩ, the dc base voltage is half the supply voltage, or 5 V. The dc emitter voltage is 0.7 V less, or 4.3 V. The dc emitter voltage is 4.3 V divided by 4.3 kΩ, or 1 mA. Therefore, the ac resistance of the emitter diode is:

$$r'_e = \frac{25\text{ mV}}{1\text{ mA}} = 25\ \Omega$$

The external ac emitter resistance is the parallel equivalent of R_E and R_L, which is:

$$r_e = 4.3\text{ k}\Omega \parallel 10\text{ k}\Omega = 3\text{ k}\Omega$$

Since the transistor has an ac current gain of 200, the input impedance of the base is:

$$z_{in(base)} = 200(3\text{ k}\Omega + 25\ \Omega) = 605\text{ k}\Omega$$

The input impedance of the base appears in parallel with the two biasing resistors. The input impedance of the stage is:

$$z_{in(stage)} = 10\text{ k}\Omega \parallel 10\text{ k}\Omega \parallel 605\text{ k}\Omega = 4.96\text{ k}\Omega$$

Because the 605 kΩ is much larger than 5 kΩ, troubleshooters usually approximate the input impedance of the stage as the parallel of the biasing resistors only:

$$z_{in(stage)} = 10\text{ k}\Omega \parallel 10\text{ k}\Omega = 5\text{ k}\Omega$$

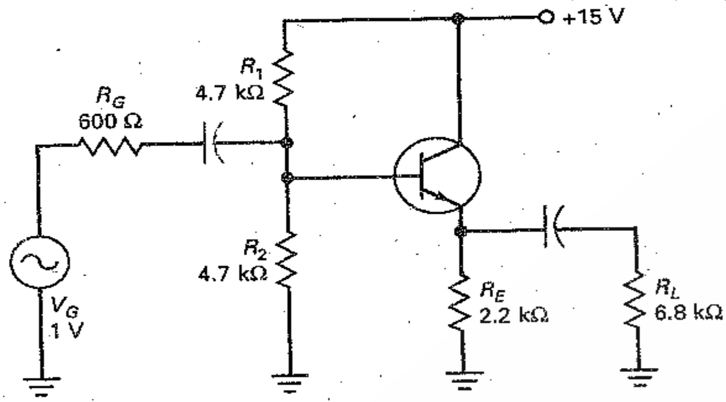
PRACTICE PROBLEM 11–1 Find the input impedance of the base and the stage, using Fig. 11-3, if β changes to 100.

Example 11-3

MultiSim

What is the voltage gain of the emitter follower in Fig. 11-5? If $\beta = 150$, what is the ac load voltage?

Figure 11-5 Example.



SOLUTION The dc base voltage is half the supply voltage:

$$V_B = 7.5 \text{ V}$$

The dc emitter current is:

$$I_E = \frac{6.8 \text{ V}}{2.2 \text{ k}\Omega} = 3.09 \text{ mA}$$

and the ac resistance of the emitter diode is:

$$r'_e = \frac{25 \text{ mV}}{3.09 \text{ mA}} = 8.09 \ \Omega$$

The external ac emitter resistance is:

$$r_e = 2.2 \text{ k}\Omega \parallel 6.8 \text{ k}\Omega = 1.66 \text{ k}\Omega$$

The voltage gain equals:

$$A_V = \frac{1.66 \text{ k}\Omega}{1.66 \text{ k}\Omega + 8.09 \ \Omega} = 0.995$$

The input impedance of the base is:

$$z_{in(base)} = 150(1.66 \text{ k}\Omega + 8.09 \ \Omega) = 250 \text{ k}\Omega$$

This is much larger than the biasing resistors. Therefore, to a close approximation, the input impedance of the emitter follower is:

$$z_{in(stage)} = 4.7 \text{ k}\Omega \parallel 4.7 \text{ k}\Omega = 2.35 \text{ k}\Omega$$

The ac input voltage is:

$$v_{in} = \frac{2.35 \text{ k}\Omega}{600 \ \Omega + 2.35 \text{ k}\Omega} 1 \text{ V} = 0.797 \text{ V}$$

The ac output voltage is:

$$v_{out} = 0.995(0.797 \text{ V}) = 0.793 \text{ V}$$