Common emitter BJT amplifier

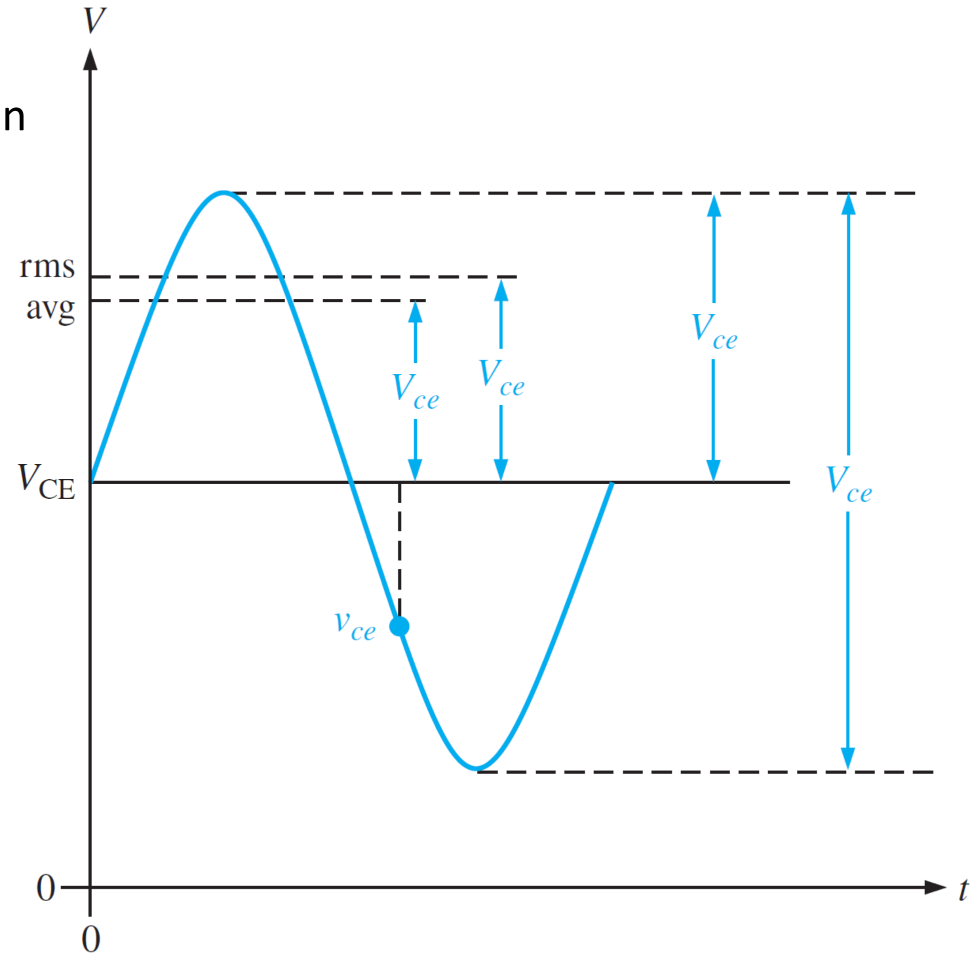
BPT: 401: Electronics and Modern Physics

Tutorial – 14

Small-signal Transistor amplifiers.

The biasing of a transistor is purely a dc operation. The purpose of biasing is to establish a Q-point about which variations in current and voltage can occur in response to an ac input signal. In applications where small signal voltages must be amplified such as from an antenna or a microphone-variations about the Q-point are relatively small. Amplifiers designed to handle these small ac signals are often referred to as **small-signal amplifiers**.

For small-signal transistor amplifiers, an suitable Q-point has been chosen. Then the dc levels can be ignored in the ac analysis network.



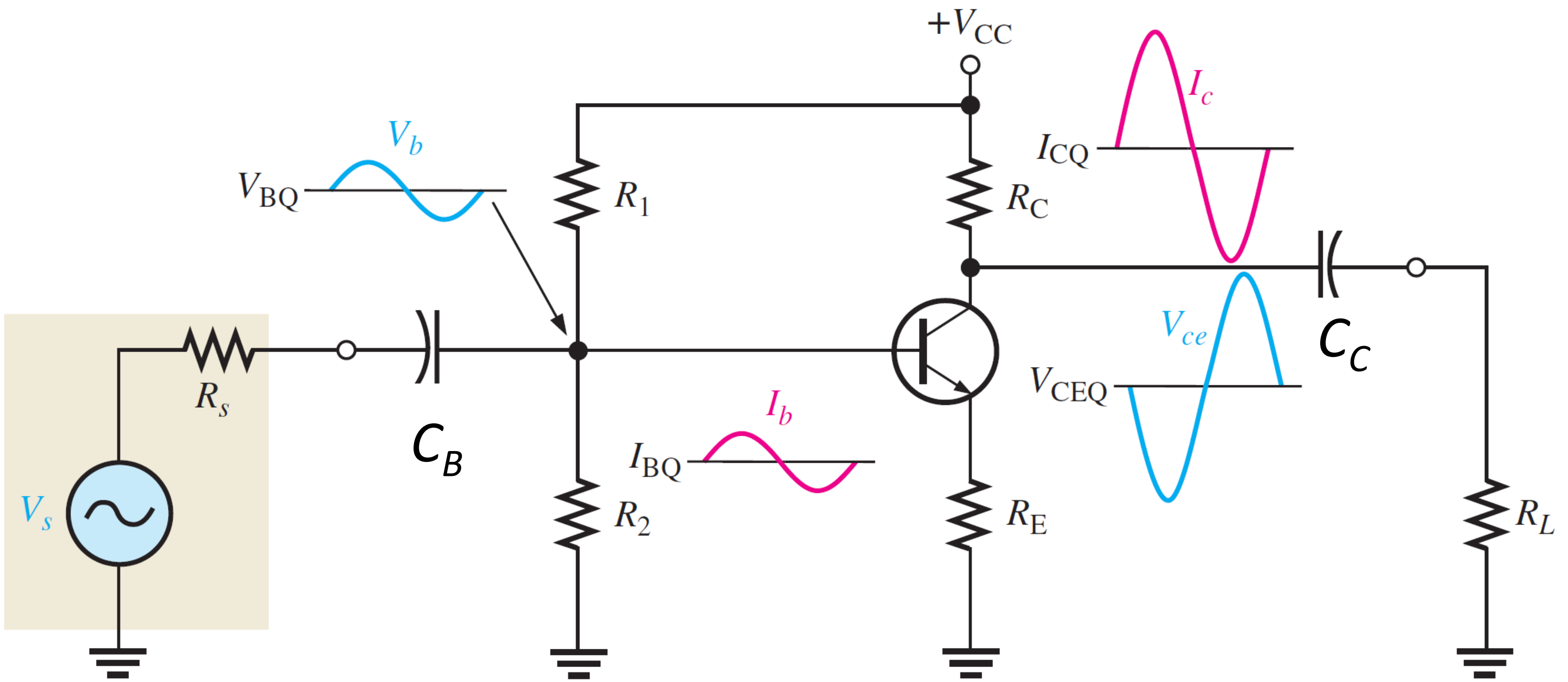
AC Quantities

In the transistor biasing section, dc quantities were identified by uppercase (capital) subscripts such as $I_C, I_E, V_C, and\ V_{CE}$. Lowercase subscripts are used to indicate ac quantities of rms, peak, and peak-to-peak currents and voltages: for example, $I_c, I_e, I_b, V_c, and\ V_{ce}$. Instantaneous quantities are represented by both lowercase letters and lowercase subscripts such as $i_c, i_e, i_b, and\ v_{ce}$. Figure illustrates these quantities for a specific voltage waveform.

In addition to currents and voltages, resistances often have different values when a circuit is analyzed from an ac viewpoint as opposed to a dc viewpoint. Lowercase subscripts are used to identify ac resistance values. For example, R_c is the ac collector resistance, and R_C is the dc collector resistance. Resistance values internal to the transistor use a lowercase to show it is an ac resistance. An example is the internal ac emitter resistance, r'_e.

The Linear Amplifier

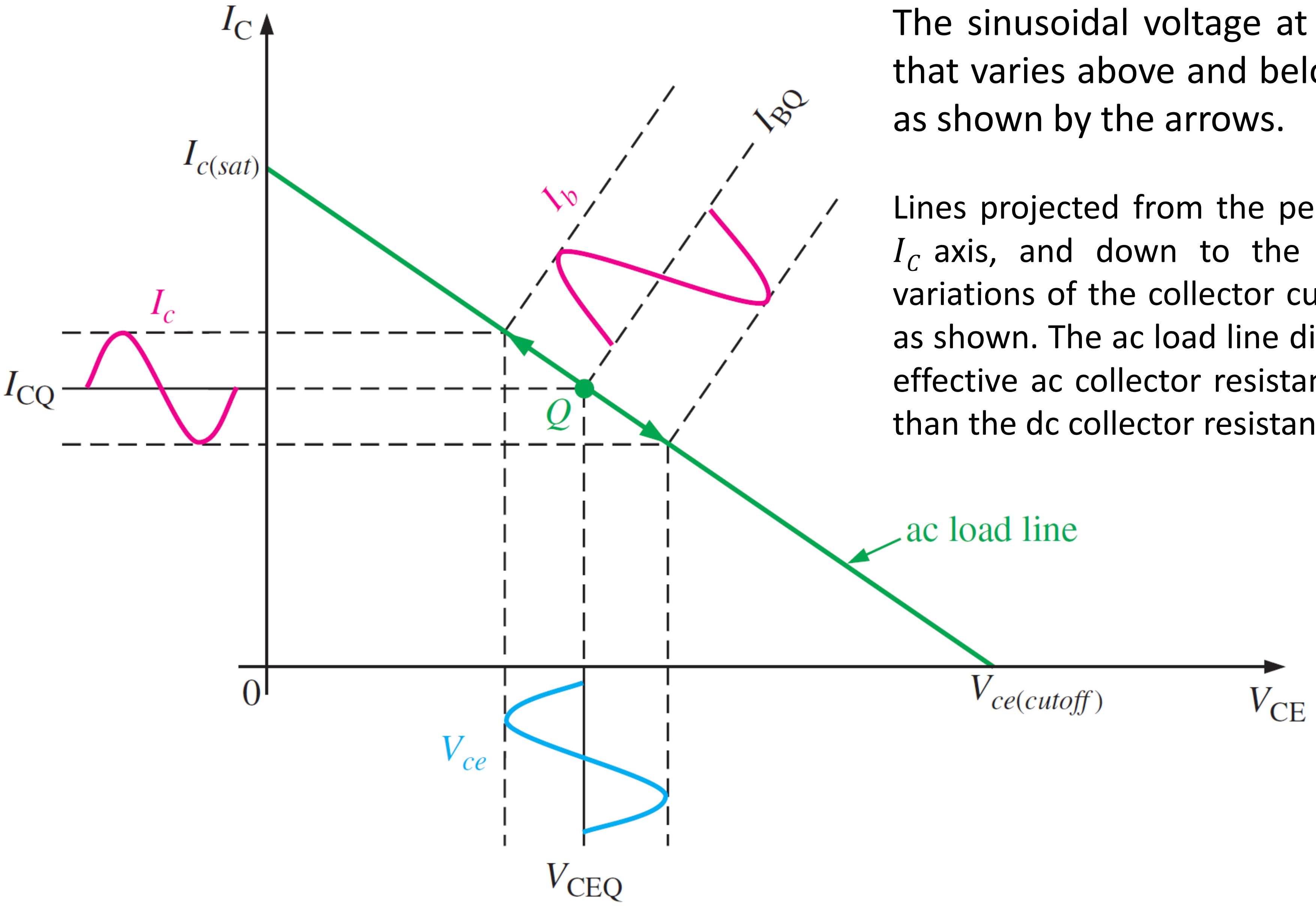
A linear amplifier provides amplification of a signal without any distortion so that the output signal is an exact amplified replica of the input signal. A voltage-divider biased transistor with a sinusoidal ac source capacitively coupled to the base through C_B and a load capacitively coupled to the collector through C_C is shown in Figure. The coupling capacitors block dc and thus prevent the internal source resistance, R_s, and the load resistance, R_L, from changing the dc bias voltages at the base and collector. The capacitors ideally appear as shorts to the signal voltage. The sinusoidal source voltage causes the base voltage to vary sinusoidally above and below its dc bias level, V_{BQ}. The resulting variation in base current produces a larger variation in collector current because of the current gain of the transistor.



As the sinusoidal collector current increases, the collector voltage decreases. The collector current varies above and below its Q-point value, I_{CQ}, in phase with the base current. The sinusoidal collector-to-emitter voltage varies above and below its Q-point value, V_{CEQ}, 180◦ out of phase with the base voltage, as illustrated in Figure.

A transistor always produces a phase inversion between the base voltage and the collector voltage.

Representation of ac output current (I_c) and output voltage (V_{ce}) swing from dc biasing Q-point



The sinusoidal voltage at the base produces a base current that varies above and below the Q-point on the ac load line, as shown by the arrows.

Lines projected from the peaks of the base current, across to the I_C axis, and down to the V_{CE} axis, indicate the peak-to-peak variations of the collector current and collector-to emitter voltage, as shown. The ac load line differs from the dc load line because the effective ac collector resistance is R_L in parallel with R_C and is less than the dc collector resistance R_C alone.

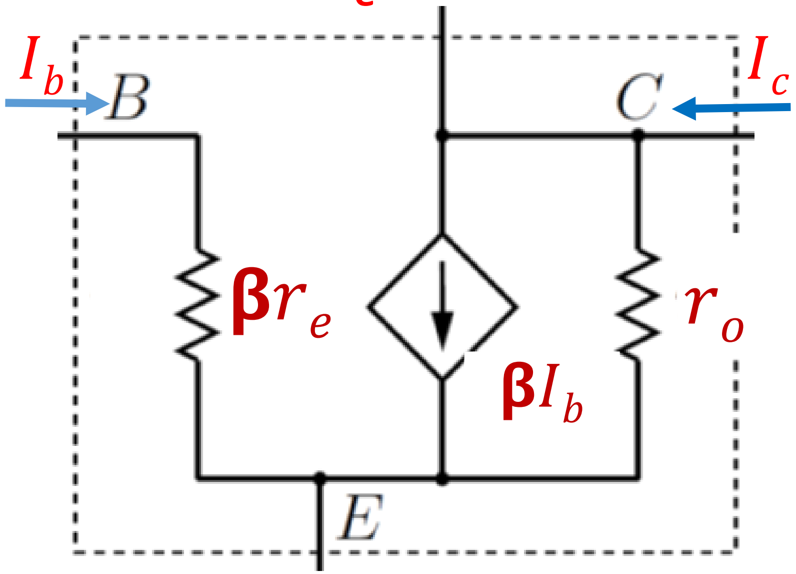
Common Emitter Amplifier

AC equivalent circuit model of CE BJT amplifier

To visualize the operation of a transistor in an amplifier circuit, it is often useful to represent the device by a model circuit.
A transistor model circuit uses various internal transistor parameters to represent its operation. The following are the three AC equivalent circuit model of CE BJT amplifier.

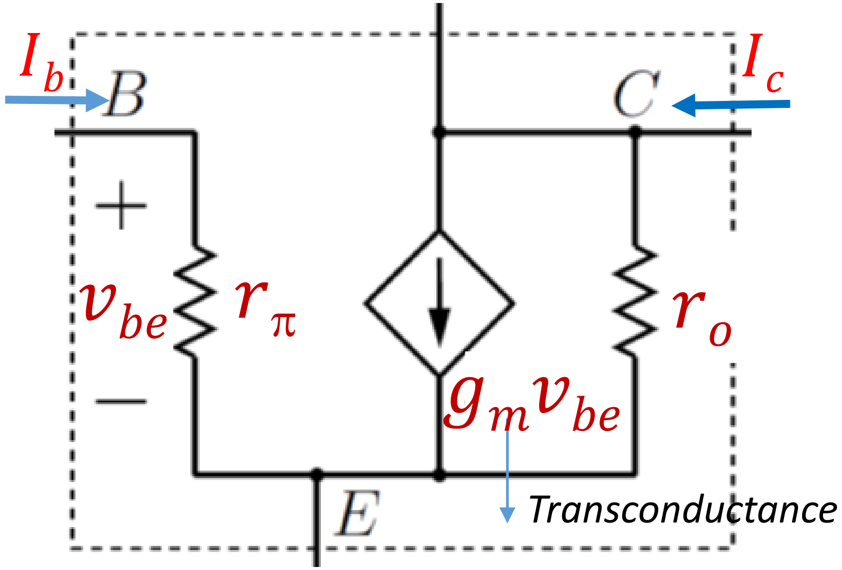
(i) r_e model
(ii) r_π or hybrid-π model
(iii) h-parameter model

r_e model



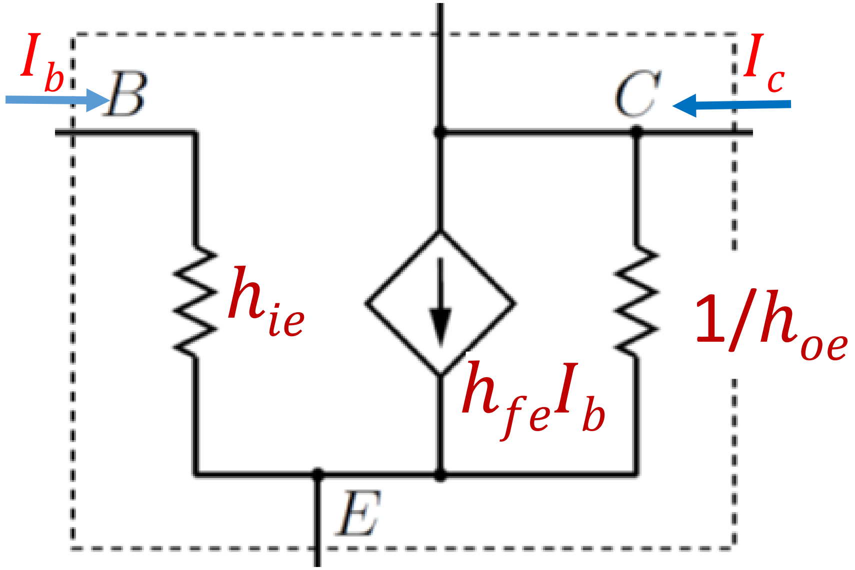
CE Hybrid π model equivalent circuit of BJT amplifier

***Hybrid π* model**



CE Hybrid π model equivalent circuit of BJT amplifier

***h-parameter* model**



CE h-parameter model equivalent circuit of BJT amplifier

$$\boxed{\beta r_e = r_\pi = h_{ie}}$$

$$\boxed{\beta I_b = g_m v_{be} = h_{fe} I_b}$$

$$\boxed{r_o = 1/h_{oe}}$$

Relation between r-parameter and h-parameter

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

h PARAMETER	DESCRIPTION	CONDITION
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	$h_{ic}, h_{rc}, h_{fc}, h_{oc}$

$$r_\pi = \frac{\beta}{g_m}$$

$$g_m = \frac{I_C}{V_T} = \frac{I_C}{25\ mV}$$

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

$$\beta r_e = r_\pi = h_{ie}$$

$$\beta I_b = g_m v_{be} = h_{fe} I_b$$

$$r_o = 1/h_{oe}$$

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

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

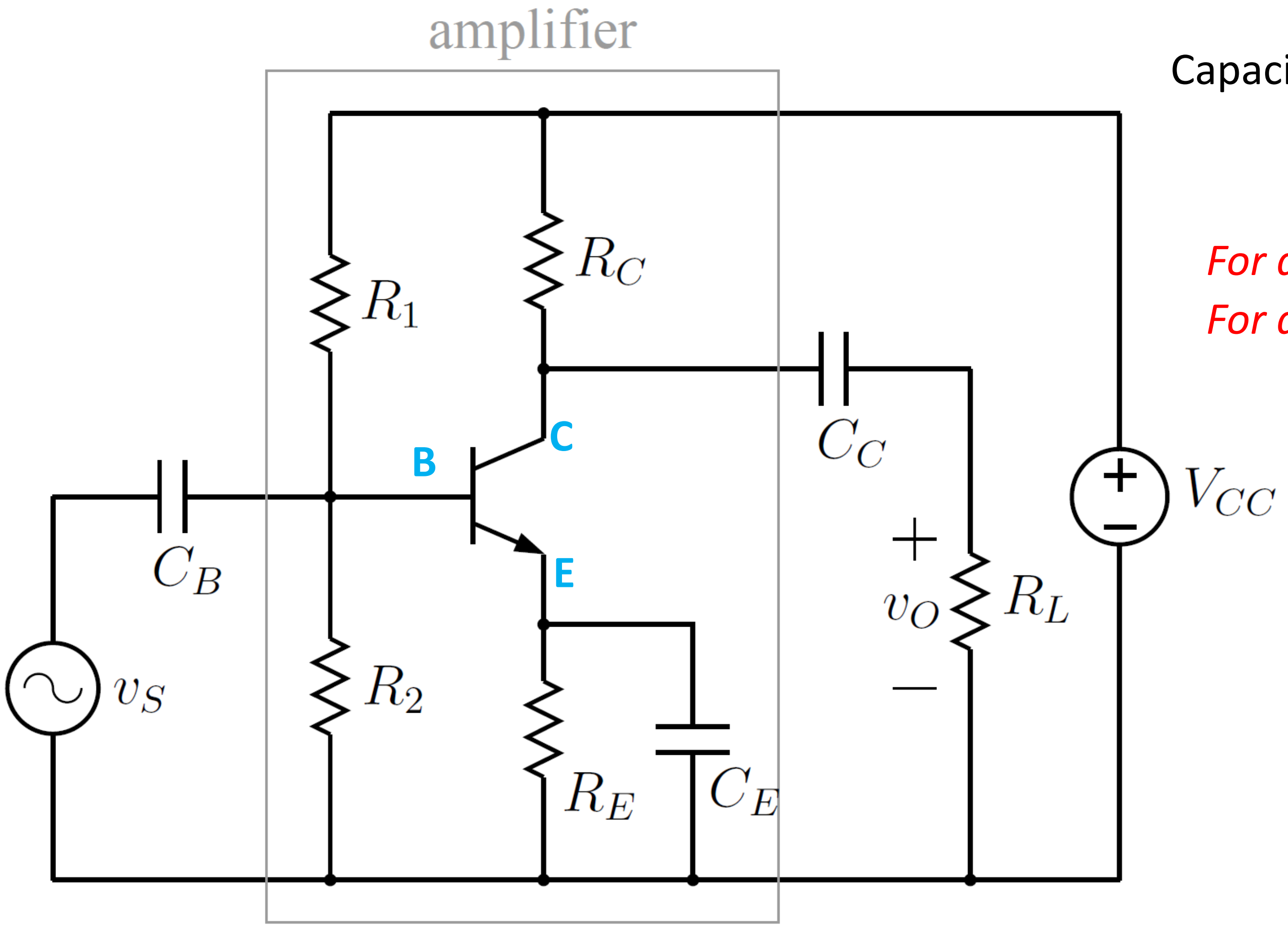
$$r'_b = h_{ie} - \frac{h_{re}}{h_{oe}}(1 + h_{fe})$$

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

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

Common Emitter BJT Amplifier

- The circuit diagram of a common-emitter (CE) amplifier is shown in Figure. The capacitor C_B is used to couple the input signal to the input port of the amplifier, and C_C is used to couple the amplifier output to the load resistor R_L.
- The resistances R_1, R_2, and R_E are used to form the voltage biasing and stabilization circuit. The R_E resistor is used for thermal stability.
- The coupling capacitors C_B and C_C are used to separate the AC signals from the DC biasing voltage. If it is not there, the signal source resistance, Rs will come across R_2, and hence, it will change the bias.



Capacitive reactance, $X_C = 1/2\pi fC$

Where, f – frequency

C - Capacitance

For dc signal, f = 0 → $X_C = \infty$ (open circuit)

For ac signal, f ≠ 0 → $X_C \approx 0$ (closed circuit)

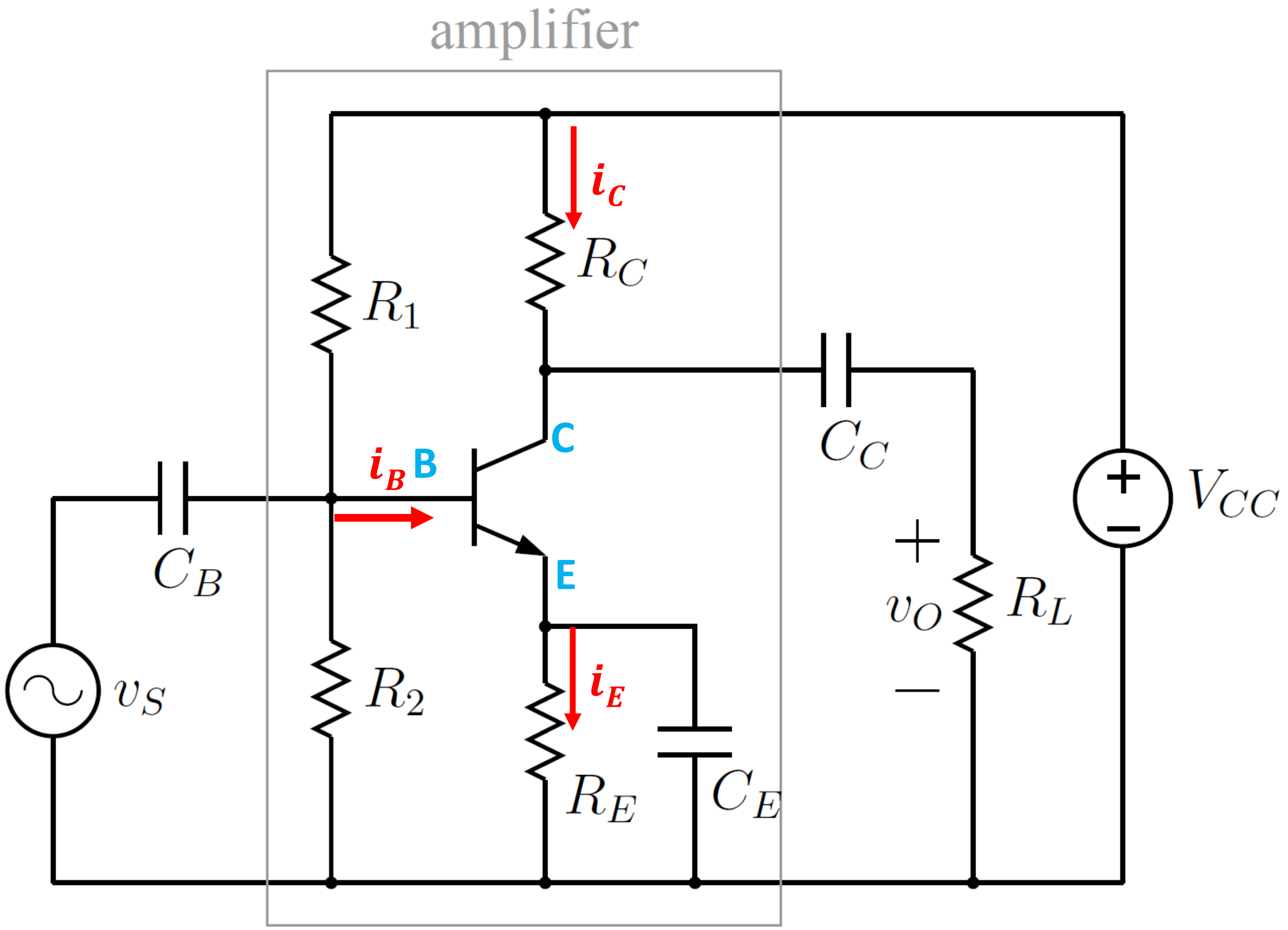
An Emitter bypass capacitor C_E is used parallel with R_E to provide a low reactance path to the amplified AC signal. If it is not used, then the amplified AC signal following through R_E will cause a voltage drop across it, thereby dropping the output voltage.

We are interested in the bias currents and voltages, mid-band gain, and input and output resistances of the amplifier.

Common Emitter Amplifier

Working

Once a weak input AC signal is given toward the base terminal of the transistor, then a small amount of base current will supply, because of this transistor act, high AC. current will flow throughout collector load (R_C), so high voltage can come into view across the collector load as well as the output. Thus, a feeble signal is applied toward the base terminal which appears in the amplified form within the collector circuit. The amplifier's voltage gain like Av is the relation between the amplified input and output voltages.



CE Amplifier Circuit Currents

Base current $(i_B = I_B + i_b)$

where,

I_B = DC base current when no signal is applied.

i_b = AC base when AC signal is applied and

i_B = total base current.

Collector current $(i_C = I_C + i_c)$

where,

i_C = total collector current.

I_C = zero signal (DC) collector current.

i_c = AC collector current when the AC signal is applied.

Emitter Current $(i_E = I_E + i_e)$

where,

I_E = Zero signal (DC) emitter current.

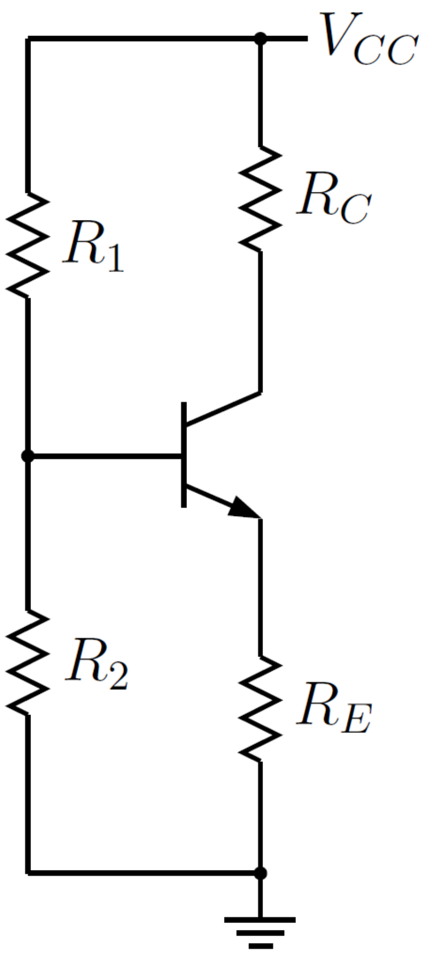
I_e = AC emitter current when AC signal is applied.

i_E = total emitter current.

Common Emitter Amplifier

Bias Computation (DC Circuit Analysis)

The term "bias" refers to the DC conditions (currents and voltages) inside the amplifier circuit. The capacitors C_B, C_E, and C_C are replaced with open circuits under DC conditions, and the circuit reduces to that shown in Figure.



If the transistor is assumed to have large **β** (**β**→ ∞), the base current can be neglected, and the R_1-R_2 network is then simply a voltage divider, giving $V_B = V_{CC}\left(\frac{R_2}{R_1+R_2}\right)$

For the circuit to operate as an amplifier, it is designed such that the BJT operates in its active region, with the B-E junction under forward bias and the B-C junction under reverse bias. The B-E voltage drop ($V_{BE} = V_B - V_E$) is about 0.7V for a silicon BJT, and that gives V_E as

$$V_E = V_{CC}\left(\frac{R_2}{R_1+R_2}\right) - 0.7$$

The emitter current I_E is then obtained as $I_E = V_E/R_E$, and $I_C = \frac{\beta}{(\beta+1)} I_E$

$I_C \approx I_E$ since we have assumed **β** to be large.

The DC collector-emitter voltage is

$$V_{CE} = V_C - V_E = V_{CC} - I_C R_C - I_E R_E \approx V_{CC} - I_C (R_C + R_E)$$

$$V_{Th} = I_B R_{Th} + V_{BE} + (\beta + 1)\, I_B R_E$$

The collector current IC is then given by $I_C = \beta\, I_B = \beta \frac{V_{Th} - V_{BE}}{R_{Th} + (\beta+1) R_E}$

$$R_{Th} = R_1 \| R_2 = \frac{R_1 R_2}{R_1+R_2}$$

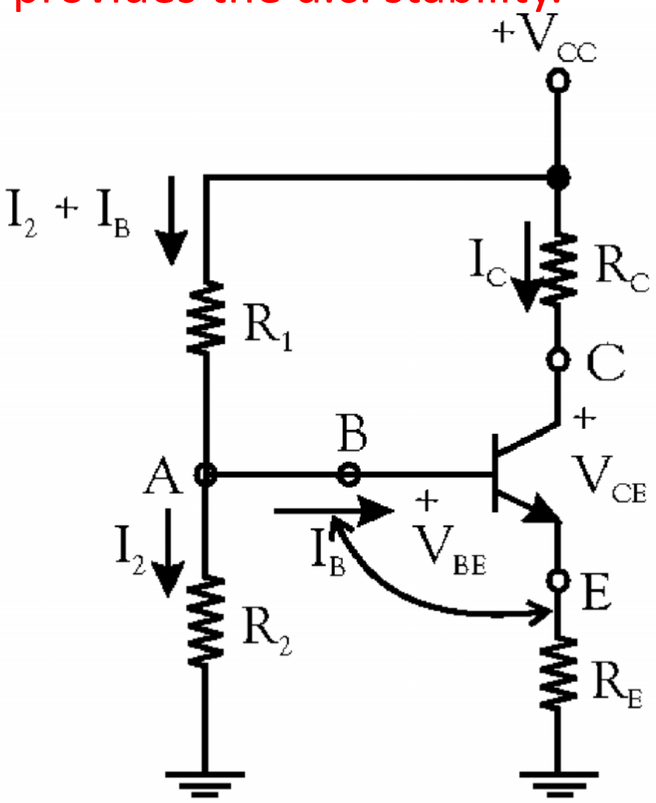
$$V_{Th} = V_{CC}\left(\frac{R_2}{R_1+R_2}\right)$$

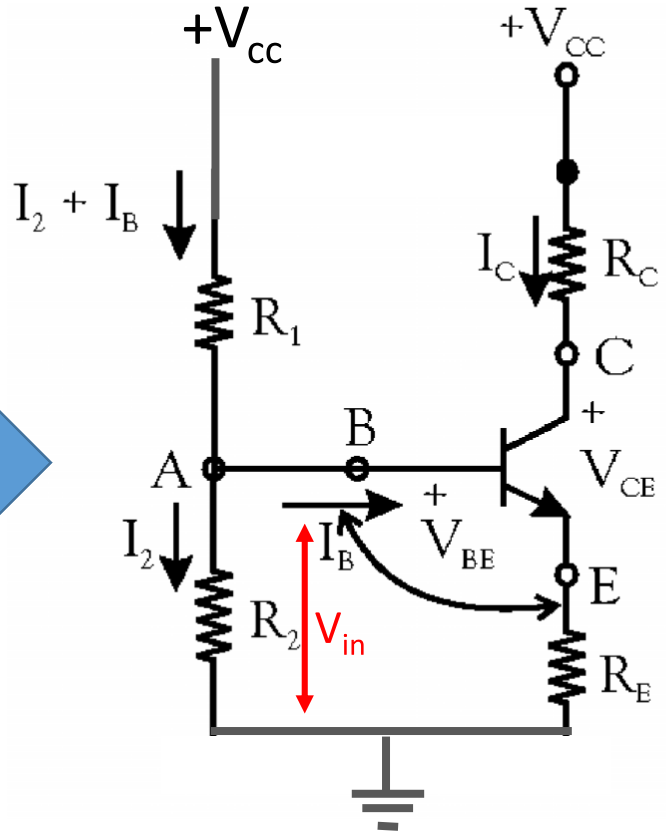
For details about DC Circuit analysis of Common Emitter (EC) configuration BJT transistor amplifier, please refer the next 5 slides. Otherwise skip to the AC equivalent circuit analysis of CE BJT amplifier. The same we have analyzed in biasing and bias stabilization topic.

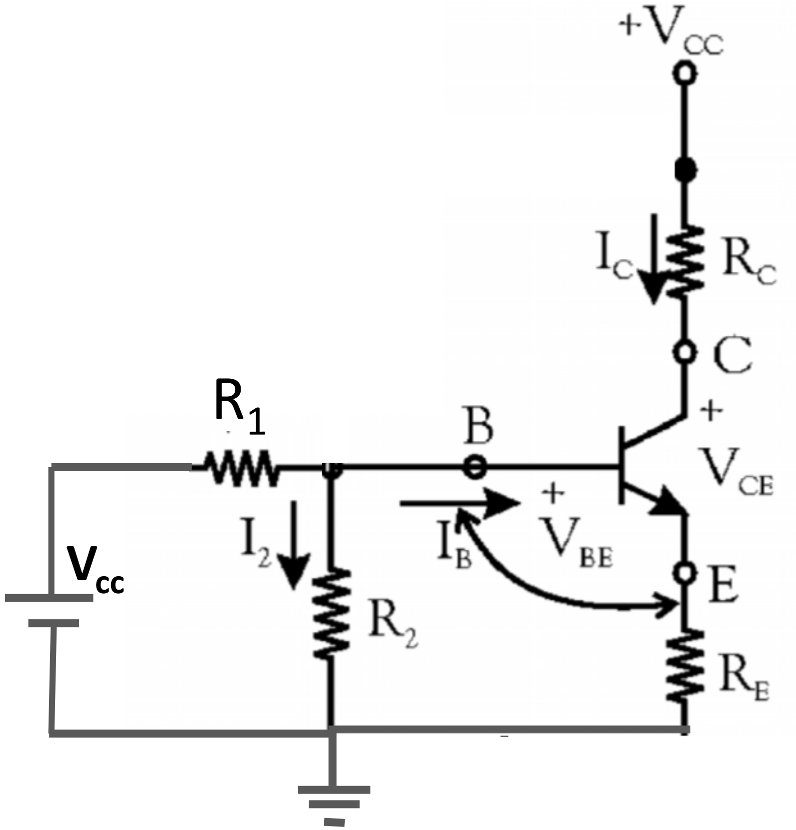
Voltage divider or potential divider bias (self bias)

In base bias and Collector feedback bias, the values of d.c. current (I_C) and voltage (V_{CE}) of the collector depends upon the current gain (**β**) of the transistor. But we know that the value of current gain (**β**) is temperature sensitive. Therefore it would be desirable to provide a d.c. bias circuit which is independent of the transistor current gain (**β**). The d.c. bias circuit shown in Fig meets this condition and is thus a very popular bias circuit. It is commonly known as voltage divider bias or self bias circuit.

The name voltage divider is derived from the fact that resistors R_1 an R_2 form a voltage divider across the V_{CC} supply. The voltage drops across resistor R_2 forward biases the base-emitter junction of a transistor. The emitter resistor (R_E) provides the d.c. stability.







Voltage divider or potential divider bias (self bias)

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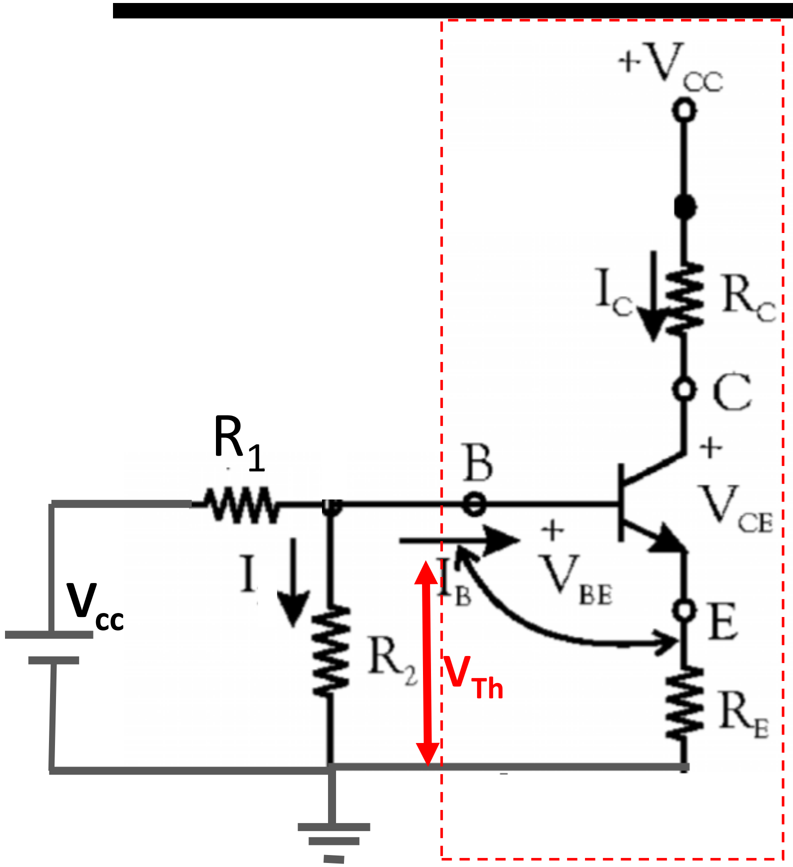
The voltage drops across resistor R_2 forward biases the base-emitter junction of a transistor.



According to Thevenin's theorem

Thevenin's resistance R_{Th} can be determined with open-circuit load and short-circuit V_{CC}

$$R_{Th} = R_1 \parallel R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

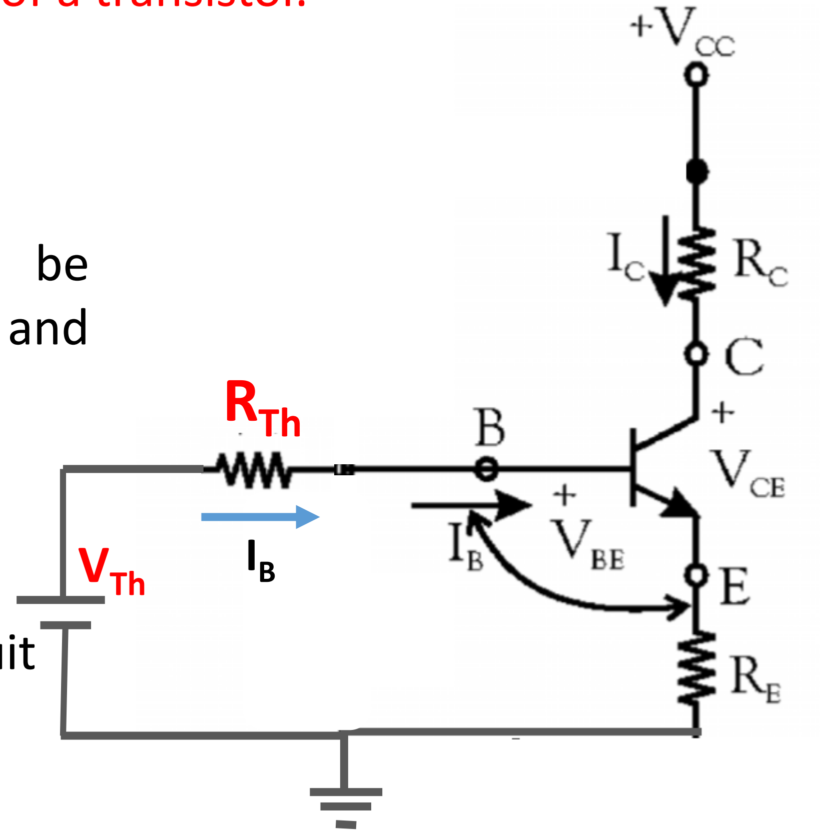
Thevenin's voltage V_{Th} is the open circuit voltage across the resistance R_2

Using KVL,

$$V_{cc} - IR_1 - IR_2 = 0$$

$$I = \frac{V_{cc}}{R_1 + R_2}$$

$$V_{Th} = IR_2 = \frac{V_{cc} R_2}{R_1 + R_2}$$



In voltage divider bias we have to find

(i) $V_B = V_{Th}$

(ii) V_C

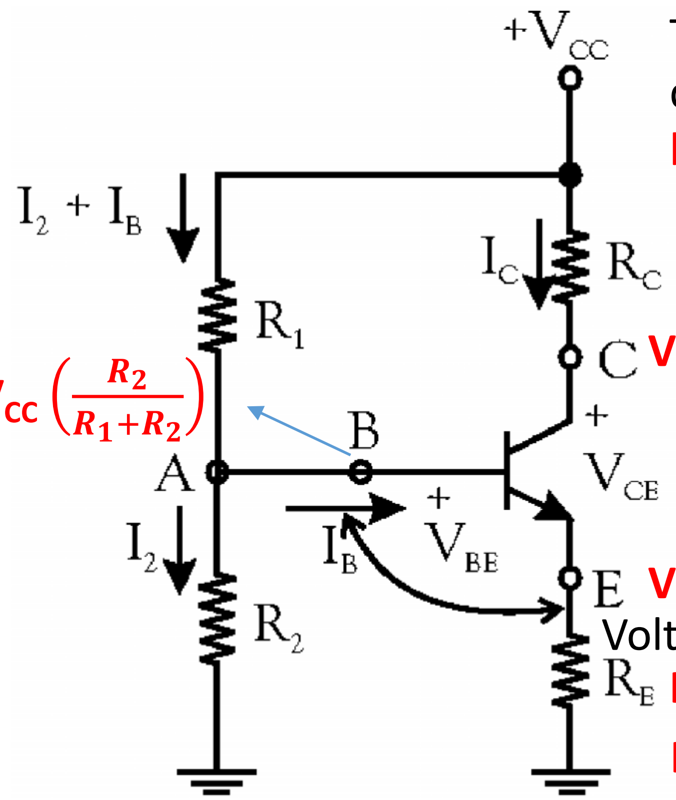
(iii) V_E

(iv) $V_{CE} = V_C - V_E$

(v) $I_C = I_E$

Voltage divider or potential divider bias (self bias)

In base bias and Collector feedback bias, the values of d.c. current (I_C) and voltage (V_{CE}) of the collector depends upon the current gain (**β**) of the transistor. But we know that the value of current gain (**β**) is temperature sensitive. Therefore it would be desirable to provide a d.c. bias circuit which is independent of the transistor current gain (**β**). The d.c. bias circuit shown in Fig meets this condition and is thus a very popular bias circuit. It is commonly known as voltage divider bias or self bias circuit.



$$V_B = V_{CC}\left(\frac{R_2}{R_1+R_2}\right)$$

$V_C = V_{CC} - I_C R_C$

$V_E = V_B - V_{BE}$

Voltage drop across R_E

$I_E R_E = V_E - 0$

$I_E = V_E/R_E$

(a) Voltage divide bias circuit

Using KVL in B-E loop

$$I_2 R_2 - V_{BE} - I_E R_E = 0$$

$$I_E = (I_2 R_2 + V_{BE})/R_E$$

The name voltage divider is derived from the fact that resistors R_1 an R_2 form a voltage divider across the V_{CC} supply. The voltage drops across resistor R_2 forward biases the base-emitter junction of a transistor. The emitter resistor (R_E) provides the d.c. stability.

Circuit Analysis

Base voltage, $V_B = V_{CC}\left(\frac{R_2}{R_1+R_2}\right)$

Emitter current, $I_E = V_E/R_E$ (or)

$$I_E = (I_2 R_2 + V_{BE})/R_E$$

Collector current, $I_C = I_E$

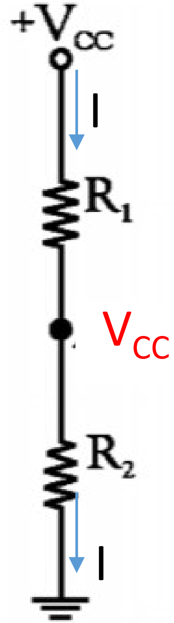
$$I_C = \frac{\beta}{(\beta+1)} I_E$$

$$I_C = (I_2 R_2 + V_{BE})/R_E$$

(or)

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

*In voltage divider bias, I_C is independent of **β**.*



$$V_{CC}\left(\frac{R_2}{R_1+R_2}\right)$$

(b) Voltage divider

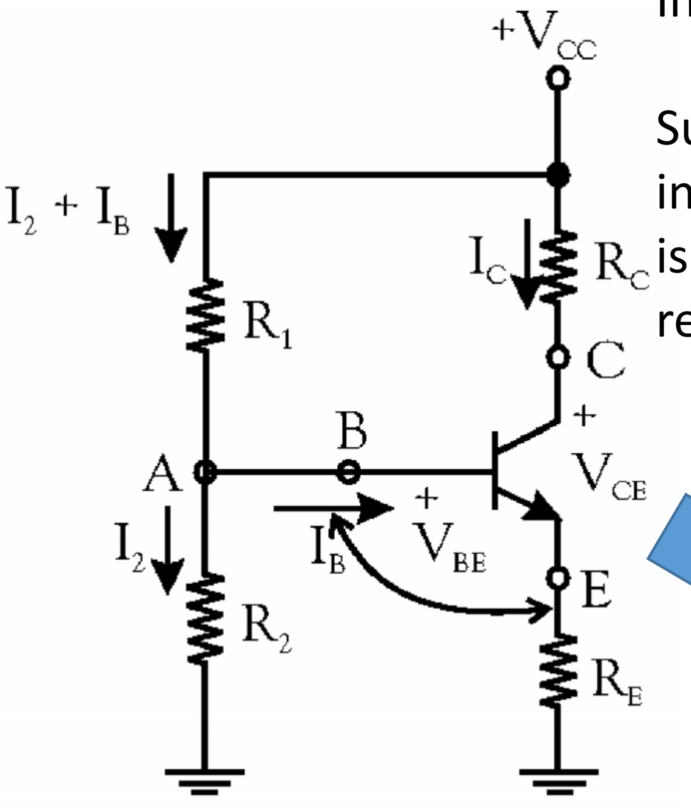
Collector-emitter voltage, $V_{CE} = V_C - V_E$

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E$$

$$V_{CE} = V_{CC} - I_C (R_C + R_E)$$

Since, $I_C = I_E$

Voltage divider bias (self bias)



(a) Voltage divide bias circuit

In this circuit, excellent stabilization is provided by R_E.

$$I_2 R_2 = V_{BE} + I_C R_E$$

Suppose the collector current I_C increases due to rise in temperature. This will increase the voltage drop across emitter resistance R_E. As voltage drop across R_2 (I_2R_2) is independent of I_C, therefore, V_{BE} decreases. This in turn causes I_B to decrease. The reduced value of I_B tends to restore I_C to the original value.

Using KVL in B-E loop

$$I_2 R_2 - V_{BE} - I_E R_E = 0$$

$$I_2 R_2 = V_{BE} + I_E R_E$$

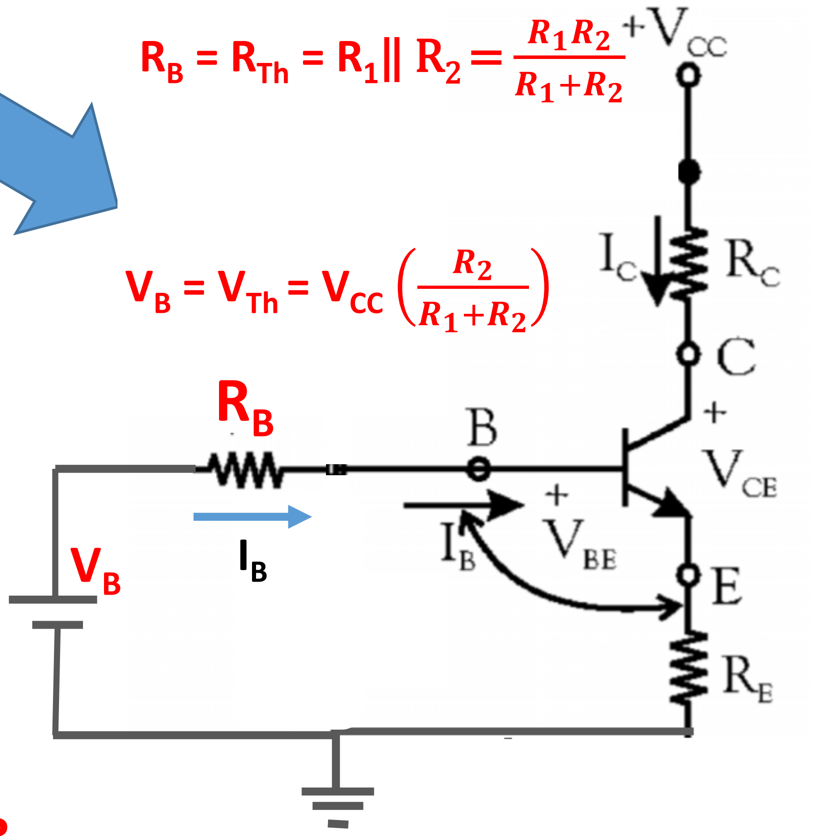
Since, $I_E = I_C$

$$I_2 R_2 = V_{BE} + I_C R_E$$

$$I_C = I_E = (I_2 R_2 + V_{BE})/R_E$$

$$R_B = R_{Th} = R_1 \| R_2 = \frac{R_1 R_2}{R_1+R_2}$$

$$V_B = V_{Th} = V_{CC}\left(\frac{R_2}{R_1+R_2}\right)$$



Using KVL in B-E loop

$$V_B - I_B R_B - V_{BE} - I_E R_E = 0$$

$$V_{Th} - I_B R_{Th} - V_{BE} - (1+\beta) I_B R_E = 0$$

$$I_B = \frac{V_{Th} - V_{BE}}{R_{Th} + (\beta+1) R_E}$$

We know, $I_C = \beta I_B = \beta \dfrac{V_{Th} - V_{BE}}{R_{Th} + (\beta+1) R_E}$

If $R_{Th} << (\beta+1)R_E$

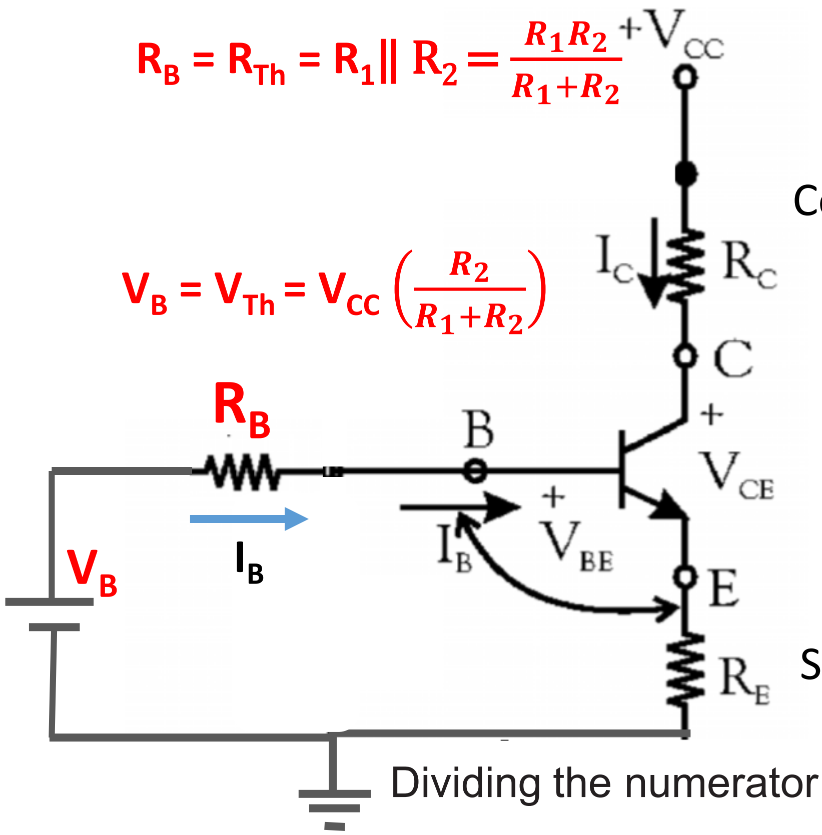
$$I_C = \frac{V_{Th} - V_{BE}}{R_E} \qquad (\beta + 1) \approx \beta$$

Then output current I_C does not depend on β

Stability factor of Voltage divider bias (self bias)

$R_B = R_{Th} = R_1 \| R_2 = \frac{R_1 R_2}{R_1+R_2}$

$V_B = V_{Th} = V_{CC}\left(\frac{R_2}{R_1+R_2}\right)$



Using KVL in B-E loop $V_B - I_B R_B - V_{BE} - I_E R_E = 0$

$V_B = I_B R_B + V_{BE} + (I_B + I_C) R_E$ $\qquad I_E = I_B + I_C$

Considering V_{BE} to be constant and differentiating the above equation w.r.t. I_C,

$$0 = R_B \frac{dI_B}{dI_C} + 0 + R_E \frac{dI_B}{dI_C} + R_E$$

$$-R_E = \frac{dI_B}{dI_C}(R_B + R_E)$$

$$\frac{dI_B}{dI_C} = \frac{-R_E}{(R_B + R_E)}$$

Stability factor, $S = \dfrac{\beta+1}{1-\beta\frac{dI_B}{dI_C}} = \dfrac{\beta+1}{1+\beta\frac{R_E}{(R_B+R_E)}} = \dfrac{(\beta+1)(R_B+R_E)}{R_B+R_E+\beta R_E} = \dfrac{(\beta+1)(R_B+R_E)}{R_B+(\beta+1)R_E}$

Dividing the numerator and denominator of R.H.S. of the above equation by R_E, we have,

$$S = \frac{(\beta+1)(1+R_B/R_E)}{\beta+1+R_B/R_E}$$

For greater thermal stability, the value of S should be small. This can be achieved by making R_B/R_E small. If R_B/R_E is made very small, then it can be neglected as compared to 1. $\quad S = (\beta+1)\frac{1}{(\beta+1)} = 1$

$$R_B = \frac{R_1 R_2}{R_1+R_2}$$

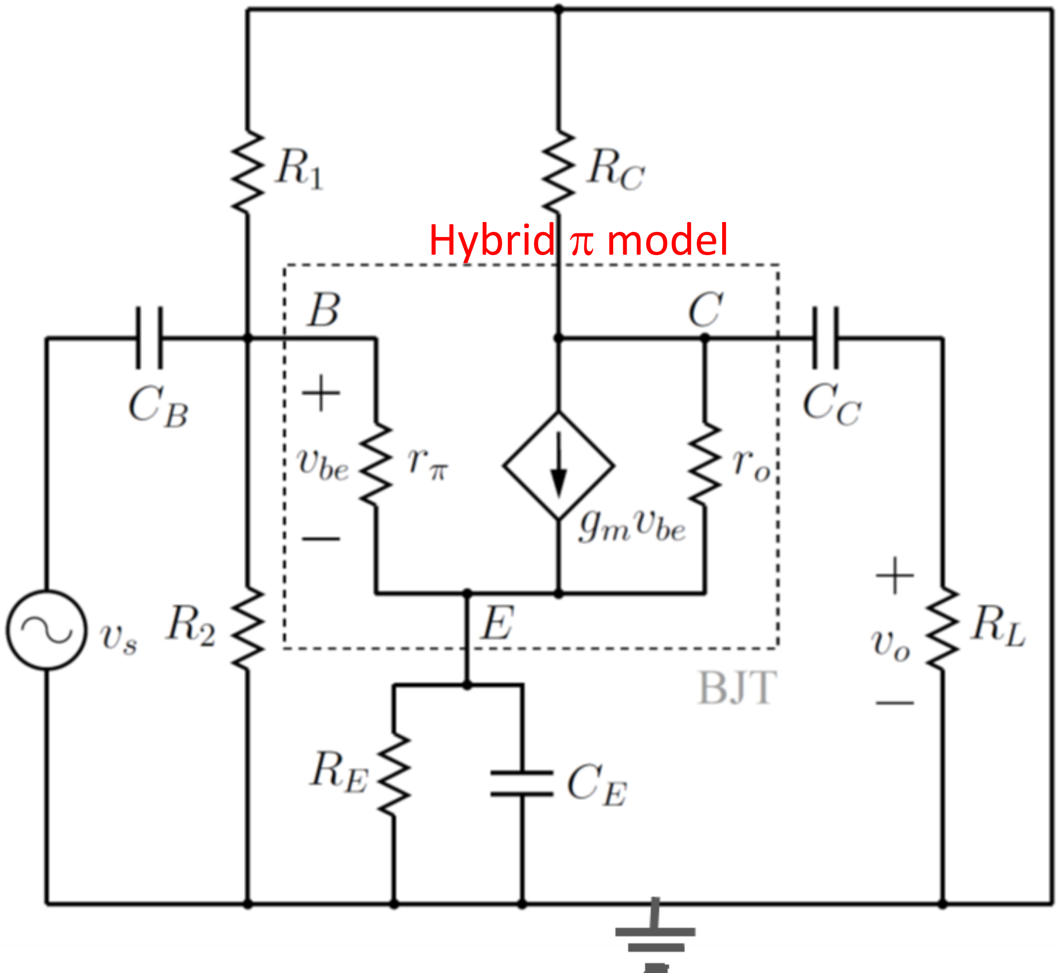
The ratio R_B/R_E can be made very small by decreasing R_B and increasing R_E.

Low R_B can be obtained by making R_2 very small. But with low value of R_2, current drawn from V_{CC} will be large. This puts restriction on the choice of R_B. Increasing the value of R_E requires greater V_{CC} in order to maintain the same zero signal collector current. Due to these limitations, a compromise is made in the selection of the values of R_B and R_E. Generally, these values are so selected that S≈10.

Common Emitter Amplifier

AC equivalent circuit representation of an amplifier

An amplifier can be represented by the AC equivalent circuit (Hybrid π model) enclosed by the box in Figure. Note that the signal source (voltage V_S with a series resistance R_S), R_1, R_2, R_C and the load resistance R_L are external to the amplifier. The coupling capacitors (C_B and C_C) are not shown in the AC equivalent circuit (shown in next slide), since their impedances are negligibly small in the "mid-band" frequency region.



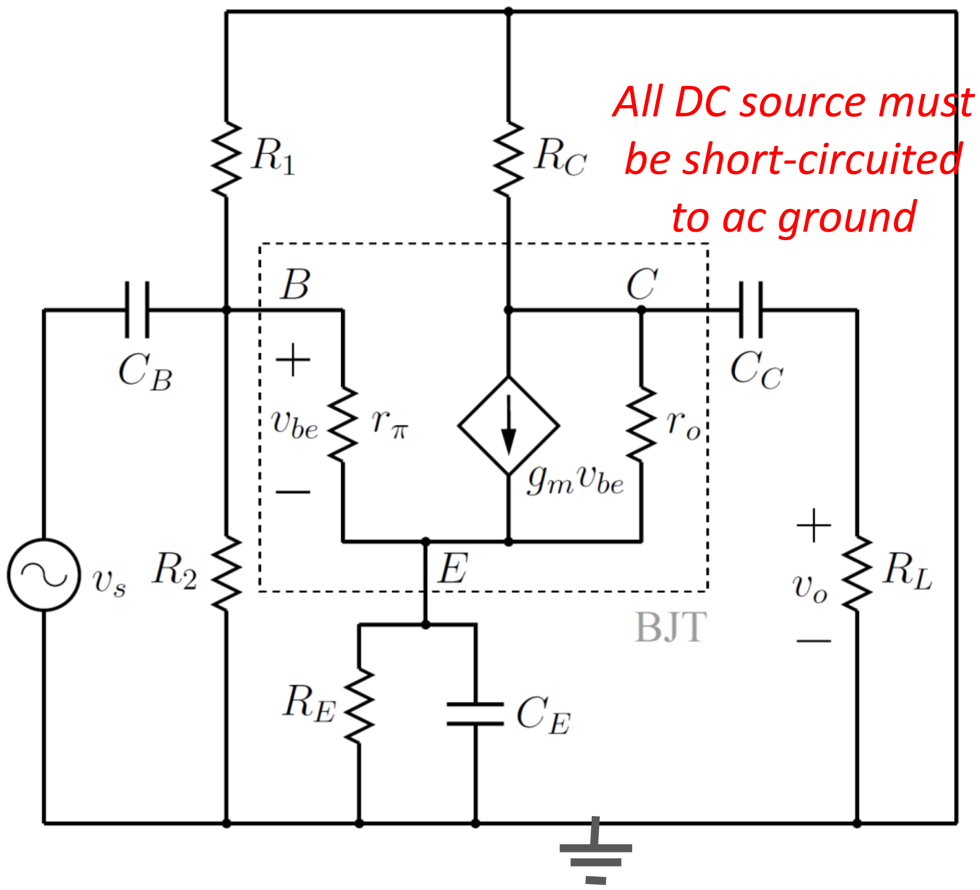
The coupling capacitor C_B, C_C and bypass capacitor C_E are chosen to have a very small reactance. Therefore, they can be replaced by a short circuit. This also results in the "shorting out" of dc biasing resistor R_E.

Steps to obtain ac equivalent circuit:

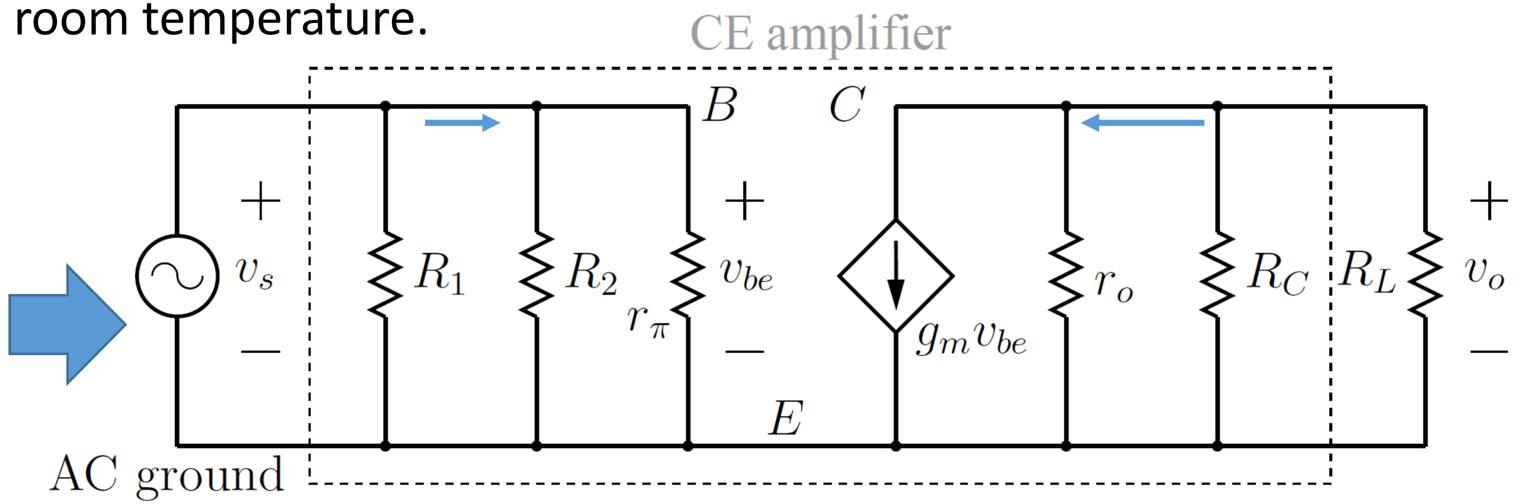
- Replace all dc sources with ground
- Replace all capacitors with short circuits
- Removing elements bypassed by short circuits (example R_E) and rearranging network

Common Emitter Amplifier – r_π or Hybrid-π Model

The BJT small-signal (v_{be} << V_T) equivalent circuit (consisting of the resistances r_π and r_o, and the dependent current source) used in Figure is valid only if the time-varying B-E voltage v_{be} is much smaller than $V_T = kT/q$, the thermal voltage which is about 25mV at room temperature.



Small-signal AC equivalent circuit of a CE amplifier



Simplified circuit after replacing the coupling and bypass capacitors with short circuits.

The parameters r_π and g_m depend on the bias current I_C as

$$g_m = \frac{I_C}{V_T} \qquad r_\pi = \frac{\beta}{g_m}$$

$$v_o = (R_C \parallel R_L \parallel r_o) \times (-g_m v_{be})$$

Since, $v_{be} = v_s$

For large ro, gain with R_L, $A_{VL} = \frac{V_o}{V_S} = -g_m(R_C \parallel R_L) = -\frac{\beta}{r\pi}(R_C \parallel R_L)$

For $R_L \rightarrow \infty$, open-circuit gain $A_{VO} = \frac{V_o}{V_S} = -g_m R_C = -\frac{\beta}{r\pi} R_C$

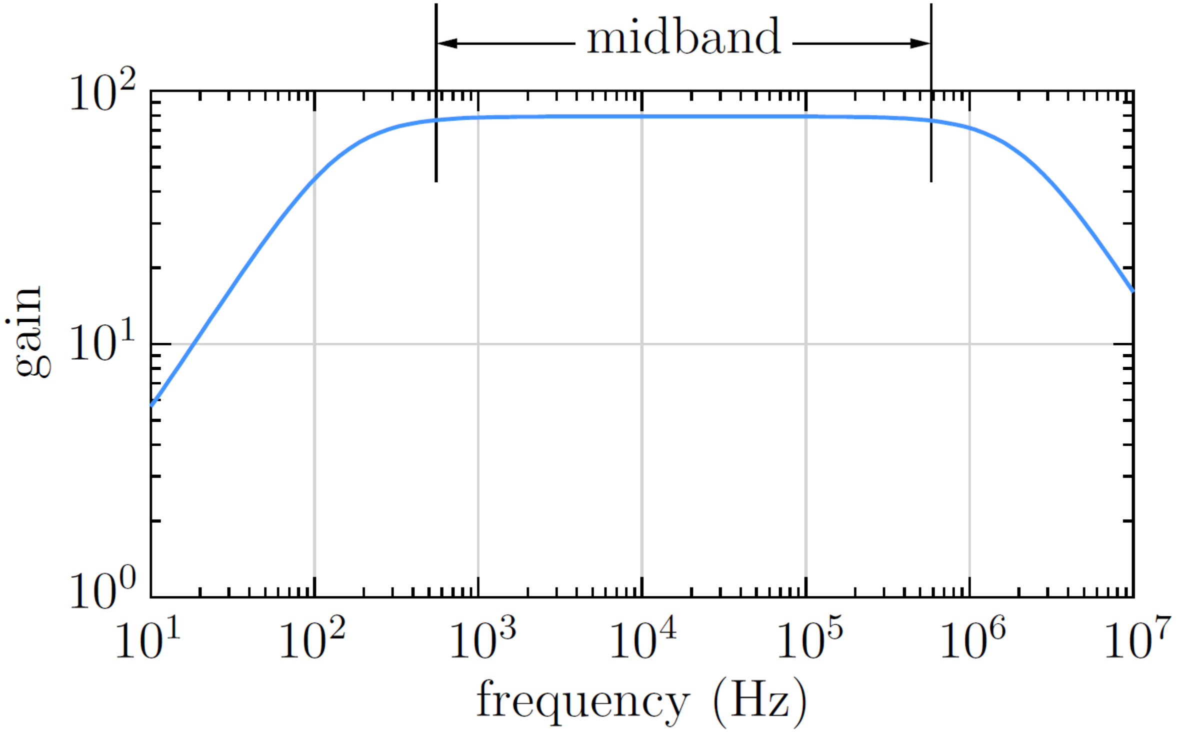
The negative sign indicates 180° phase shift between v_s & v_o

To measure A_{VL} and A_{V0}, we apply a sinusoidal input voltage (v_s) and measure v_o with R_L in place and with $R_L \rightarrow \infty$ (i.e., open circuit), respectively.

Common Emitter Amplifier

Mid-band gain (A_{V0})

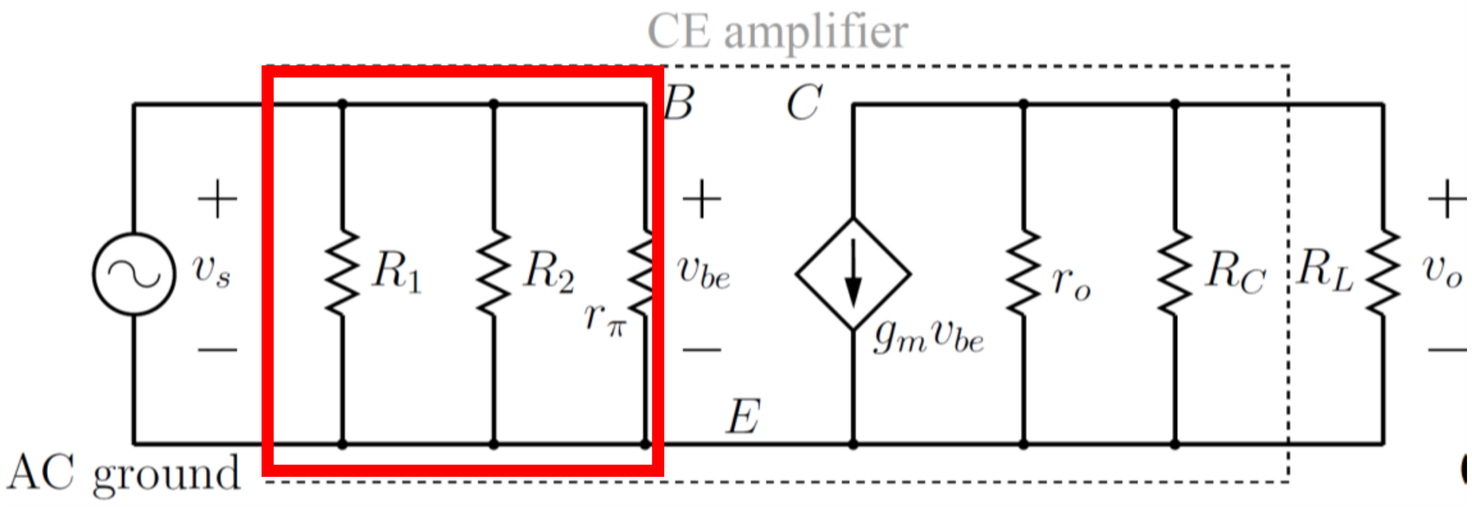
The term "mid-band" refers to the frequency region in which the amplifier gain is constant. In this region, the impedances due to the coupling capacitors (C_B and C_C) and of the bypass capacitor C_E are negligibly small (i.e., they can be replaced with short circuits), and the impedances due to the BJT device capacitances are very large compared to the other components in the circuit (i.e., they can be replaced with open circuits). With these simplifications, the small-signal (AC) equivalent circuit of the CE amplifier



Frequency response of a common-emitter amplifier (representative Bode plot)

Common Emitter Amplifier

Input resistance R_i



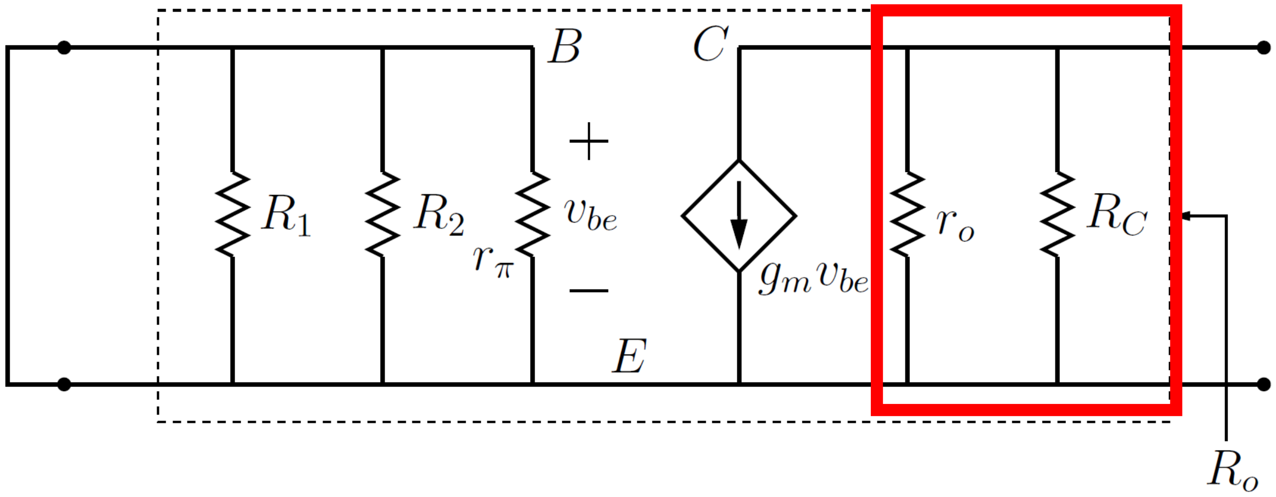
Small-signal AC equivalent circuit of a CE amplifier

From the AC equivalent circuit, we can see that the input resistance of CE amplifier is

$$R_i = (R_1 \parallel R_2 \parallel r_\pi)$$

$$where,\ r_\pi = \frac{\beta}{g_m} = \beta\frac{V_T}{I_C}$$

Output resistance R_O



Small-signal AC equivalent circuit of the CE amplifier with v_s = 0.

The output resistance of CE amplifier is

$$R_o = r_o \parallel R_C \approx R_C$$

Since, r_o of a BJT is typically much larger than R_C.

$$R_o \approx R_C$$

Common Emitter Amplifier

Distortion

An amplifier is expected to produce a faithful or undistorted version of the input voltage (except for the amplification factor) at the output.

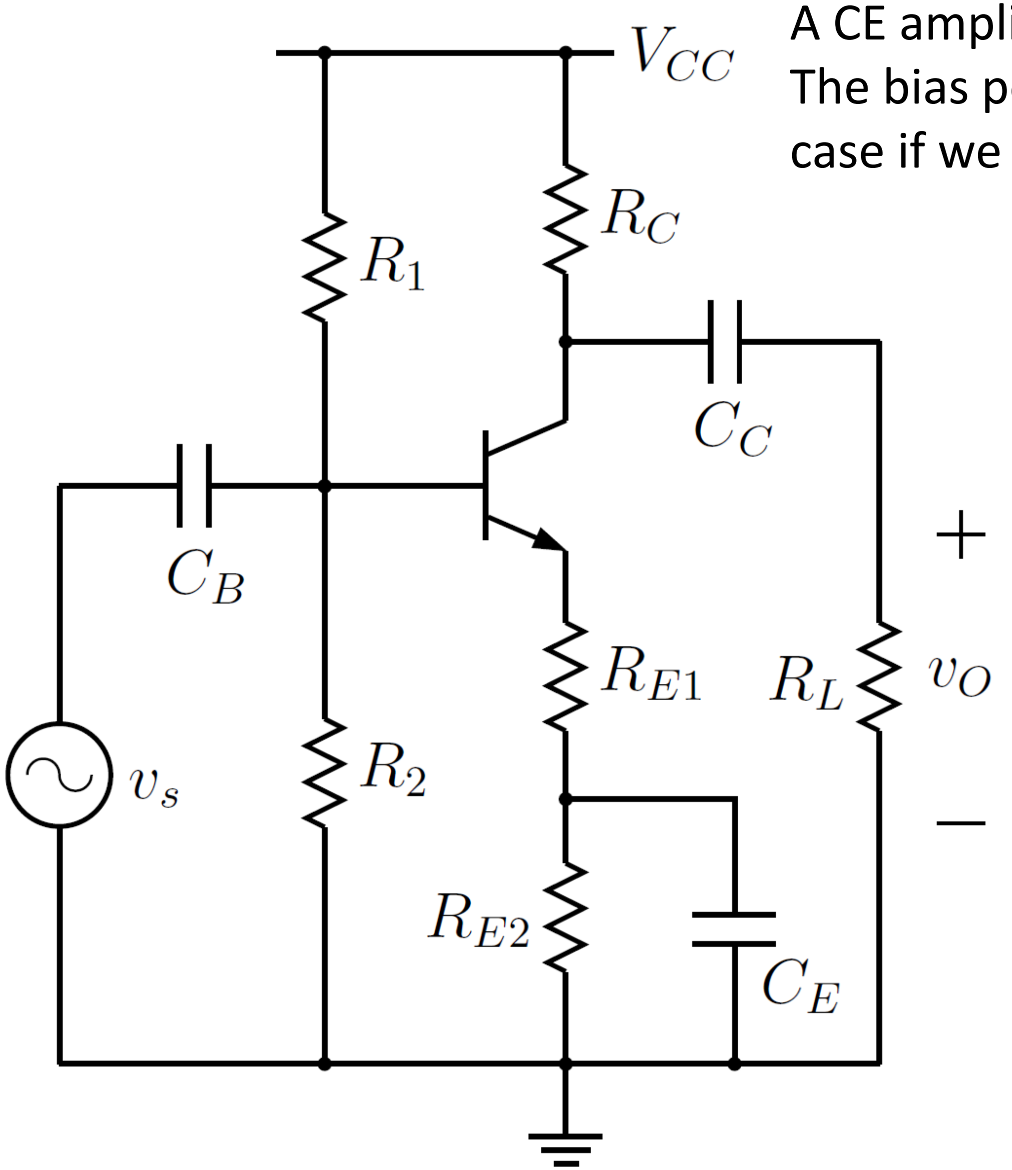
For the CE amplifier, an undistorted output voltage is obtained as long as the small-signal condition $v_{be} \ll VT$ is satisfied.

Since the signal voltage v_s is the same as v_{be} in the CE amplifier, we must have $v_s \ll VT$ to avoid distortion in the output voltage.

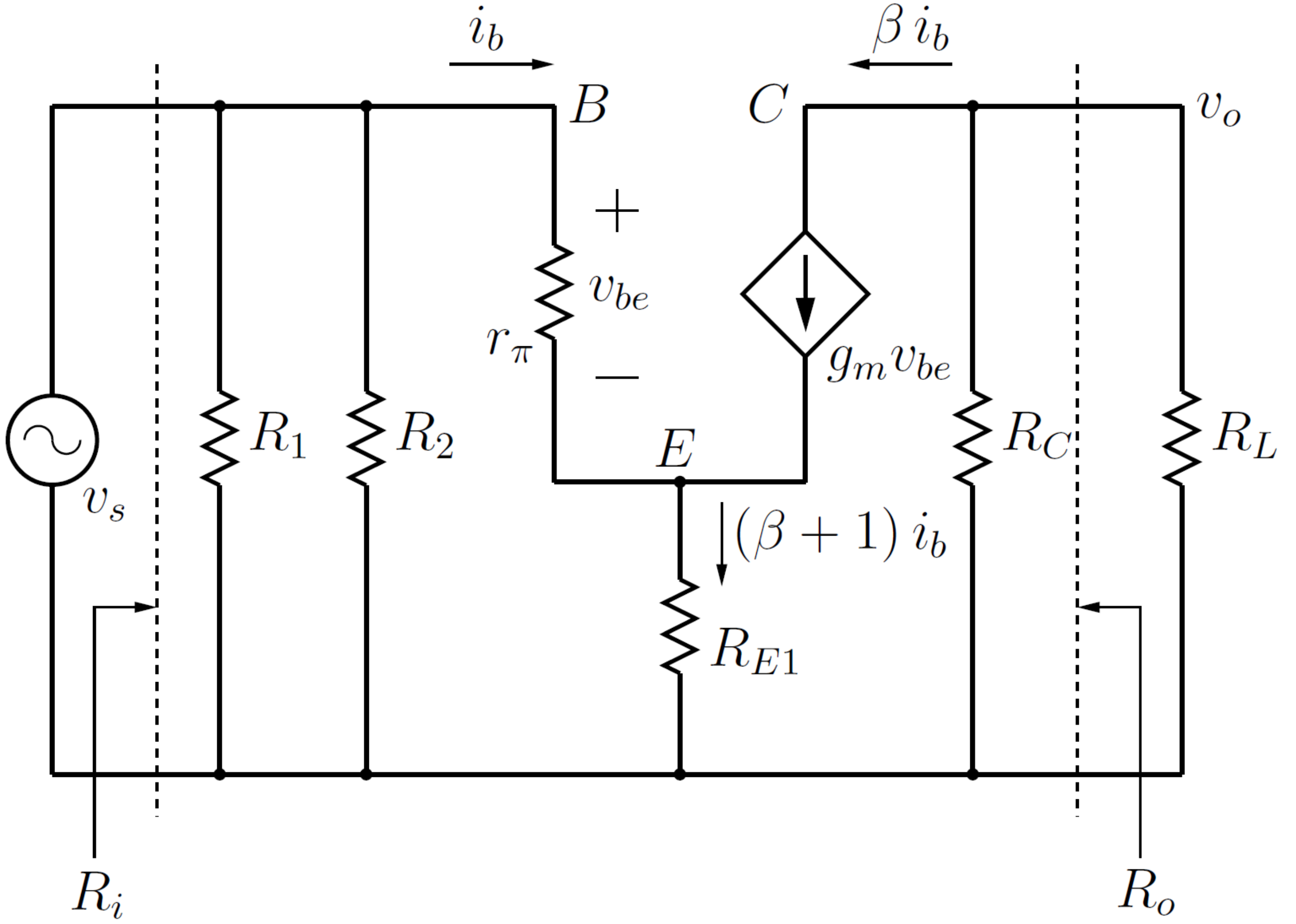
With $V_T \approx 25mV$ at room temperature, the amplitude of v_s should therefore be restricted to about $5mV$.

Common Emitter Amplifier with partial bypass

A CE amplifier with partially bypassed emitter resistance is shown in Figure. The bias point computation of the CE amplifier is valid for the partial bypass case if we replace R_E with $(R_{E1} + R_{E2})$.

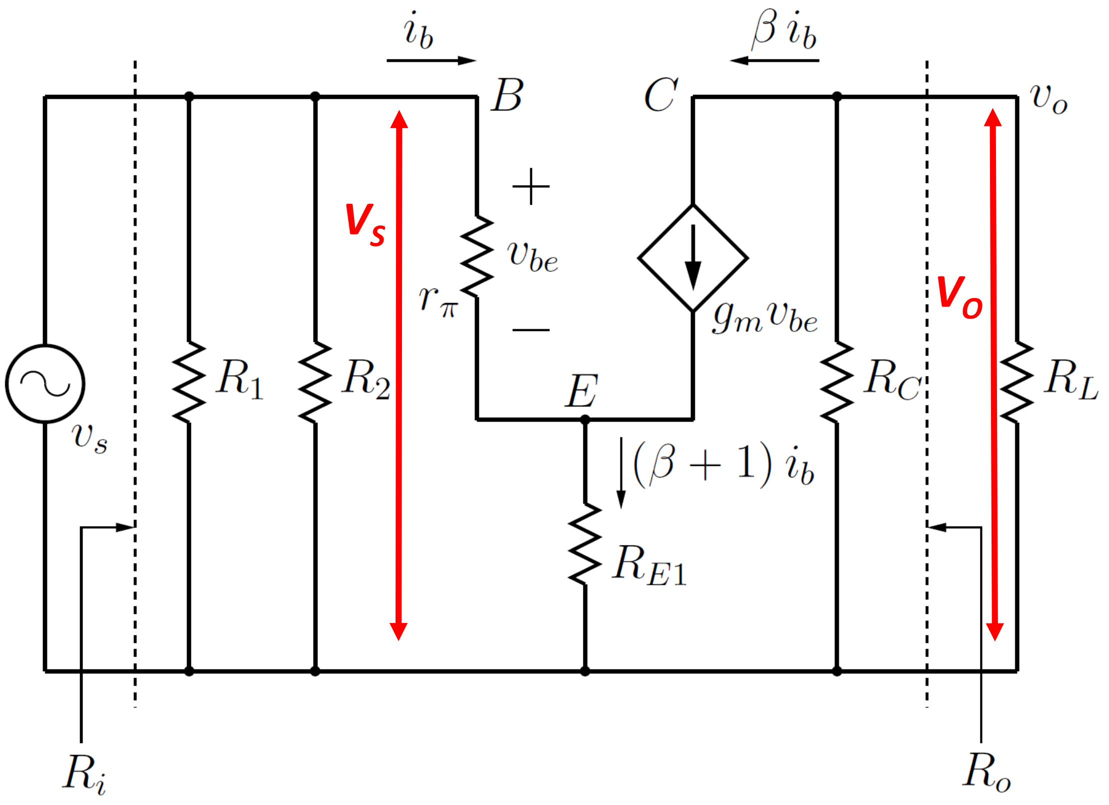


CE amplifier with partially bypassed emitter resistance



AC equivalent circuit of *CE amplifier with partially bypassed emitter resistance*

Common Emitter Amplifier with partial bypass



Since $i_e = (\boldsymbol{\beta} + 1)\, i_b$, the resistance R_{E1} appears as $(\boldsymbol{\beta} + 1)R_{E1}$ as seen from the base, and we can write

The input voltage $v_s = i_b\,[r_\pi + (\boldsymbol{\beta} + 1)R_{E1}]$

The current at point C is $\boldsymbol{\beta} i_b$

The output voltage is $v_o = -\boldsymbol{\beta} i_b \times (R_C \parallel R_L)$

The gain with load R_L is $A_{VL} = \dfrac{V_O}{V_S} = \dfrac{-\boldsymbol{\beta}(R_C \parallel R_L)}{r_\pi + (\boldsymbol{\beta}+1)R_{E1}}$

If $r_\pi \ll (\boldsymbol{\beta} + 1)R_{E1}$ then, $A_{VL} = -\dfrac{(R_C \parallel R_L)}{R_{E1}}$ $\quad (\boldsymbol{\beta} + 1) \approx \boldsymbol{\beta}$

The open-circuit gain ($R_L \rightarrow \infty$), $A_{VO} = -\dfrac{R_C}{R_{E1}}$.

The input resistance

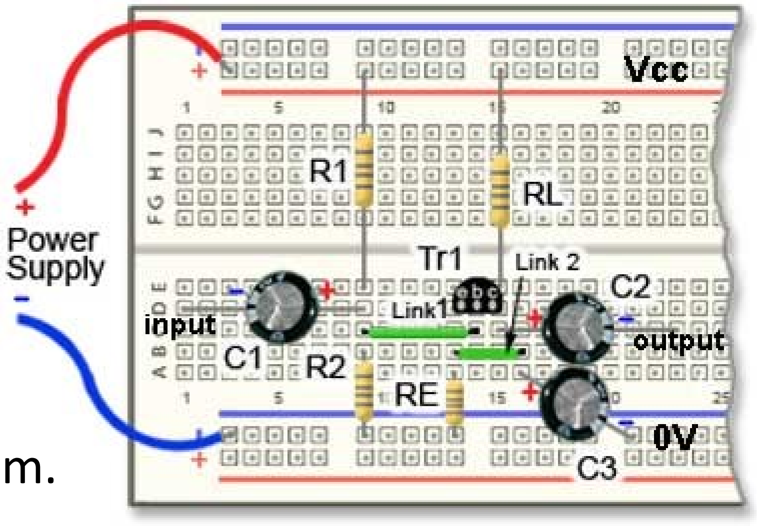
$$R_i = R_1 \parallel R_2 \parallel (r_\pi + (\boldsymbol{\beta} + 1)R_{E1})$$

The output resistance is $Ro \approx RC$, assuming r_o of the BJT to be large.

The gain of the CE amplifier with partial bypass (independent of **β**) is less than that of the CE amplifier. Therefore, higher amplitude V_S can be amplified without distortion in CE amplifier with partial bypass

Characteristics of Common Emitter Amplifier

- The voltage gain of a common emitter amplifier is medium
- The power gain is high in the common emitter amplifier
- There is a phase relationship of 180 degrees in input and output
- In the common emitter amplifier, the input and output resistors are medium.



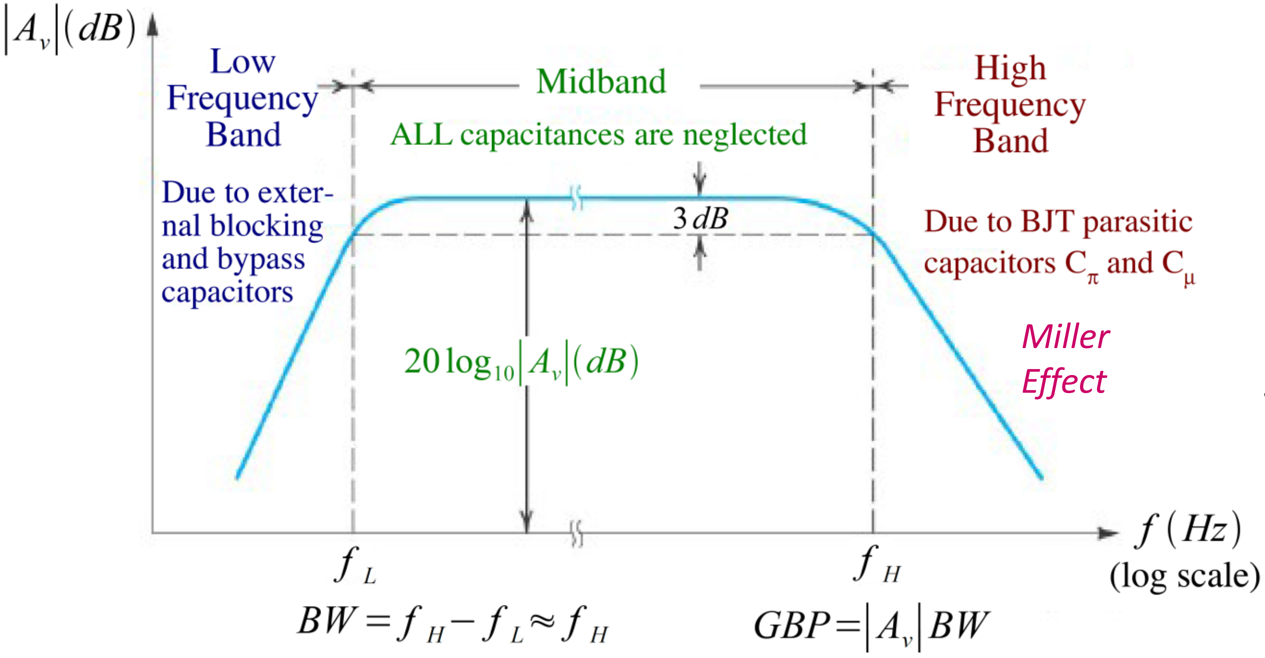
Voltage Gain of Common Emitter Amplifier

The current gain of the common emitter amplifier is defined as the ratio of change in collector current to the change in base current. $\beta = \Delta Ic / \Delta I_b$

The voltage gain is defined as the product of the current gain and the ratio of the output resistance of the collector to the input resistance of the base circuits. $Av = \beta \, Rc/R_b$

CE Amplifier Frequency Response

The voltage gain of a CE amplifier varies with signal frequency. It is because the reactance of the capacitors in the circuit changes with signal frequency and hence affects the output voltage. The curve drawn between voltage gain and the signal frequency of an amplifier is known as ***frequency response***. Frequency Response of an amplifier shows how the gain of the output responds to input signals at different frequencies. The below figure shows the frequency response of a typical CE amplifier.



Bandwidth can be defined as the interval of frequency among low-cut off & upper cut-off frequencies.

$$BW = f_U - f_L$$

The amplifier's voltage gain (Av) for several input frequencies can be measured. Its characteristics can be drawn (frequency on X-axis whereas voltage gain on Y-axis). The gain of amplifier can be decreased at very high and low frequencies, however, it stays stable over an extensive range of mid-frequency area.

The f_L (low cut off frequency) can be defined as when the frequency is below 1. The range of frequency can be decided at which the amplifier gain is double the gain of mid-frequency.

The f_U(upper cut off frequency) can be defined as when the frequency is in the high range at which the amplifier's gain is 1/√2 times the gain of mid-frequency.

CE Amplifier Frequency Response

From frequency response graph of **CE** amplifier, we observe that the voltage gain drops off at low ($< F_L$) and high ($> F_H$) frequencies, whereas it is constant over the mid-frequency range (F_L to F_H).

At Low Frequencies ($< F_L$) The reactance of coupling capacitor C_C is relatively high and hence very small part of the signal will pass from the amplifier stage to the load. Moreover, C_E cannot shunt the R_E effectively because of its large reactance at low frequencies. These two factors cause a drops off of voltage gain at low frequencies.

At High Frequencies ($> F_H$) The reactance of coupling capacitor C_C is very small and it behaves as a short circuit. This increases the loading effect of the amplifier stage and serves to reduce the voltage gain. Moreover, at high frequencies, the capacitive reactance of base-emitters junction is low which increases the base current. This frequency reduces the current amplification factor β. Due to these two reasons, the voltage gain drops off at a high frequency.

At Mid Frequencies (F_L to F_H) The voltage gain of the amplifier is constant. The effect of the coupling capacitor C_C in this frequency range is such as to maintain a constant voltage gain. Thus, as the frequency increases in this range, the reactance of C_C decreases, which tends to increase the gain.