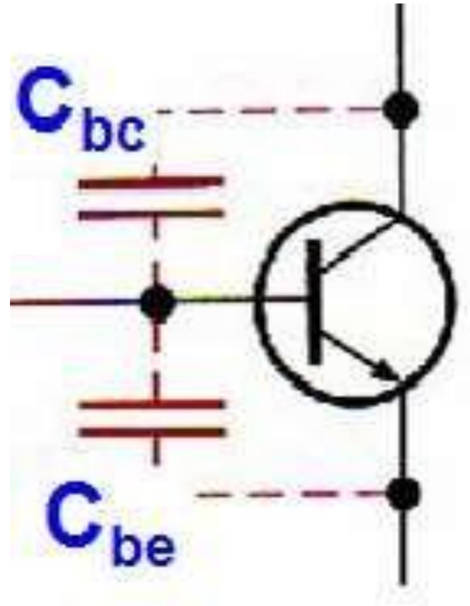
Frequency Response of BJT Amplifiers

High frequency Response of CE Amplifier

➢**At high frequencies, internal transistor junction capacitances do come into play, reducing an amplifier's gain and introducing phase shift as the signal frequency increases.**

In BJT, C_{be} is the B-E junction capacitance, and C_{bc} is the B-C junction capacitance. (output to input capacitance)

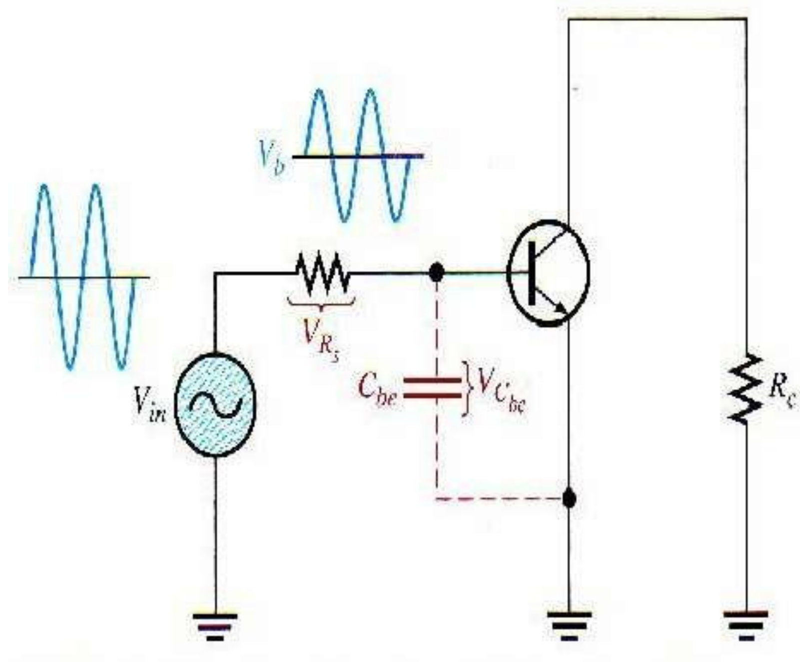


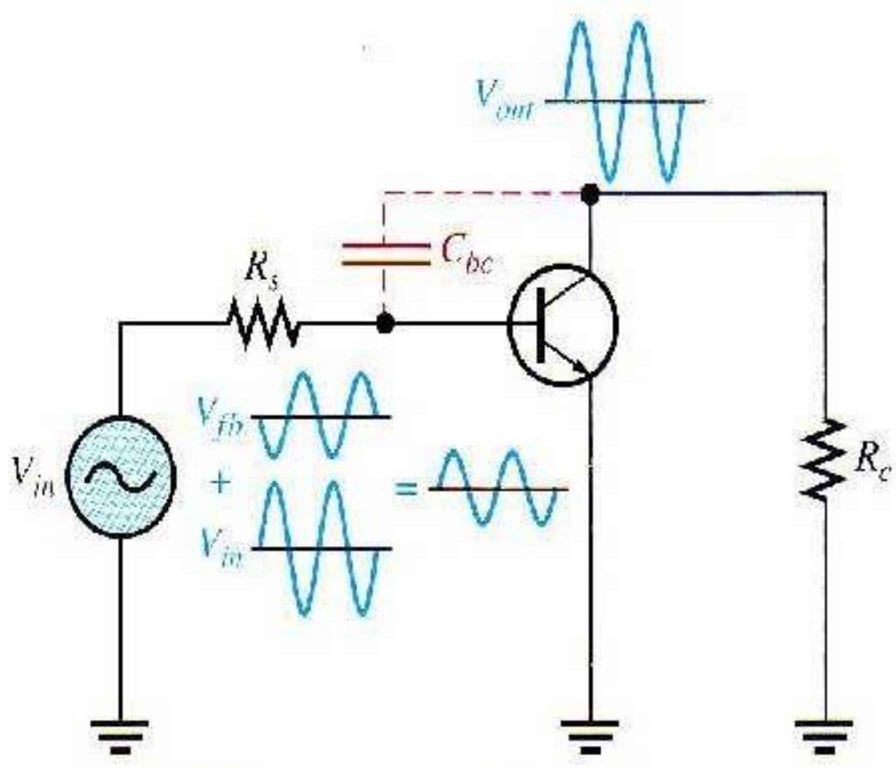
➢**At lower frequencies, the internal capacitances have a very high reactance because of their low capacitance value (usually only a few pf) and the low frequency value. Therefore, they look like opens and have no effect on the transistor's performance.**

➢**As the frequency goes up, the internal capacitive reactance's go down, and at some point they begin to have a significant effect on the transistor's gain.**

High frequency Response of CE Amplifier

➢When the reactance of C_{be} becomes small enough, a significant amount of the signal voltage is lost due to a voltage-divider effect of the source resistance and the reactance of C_{be}.

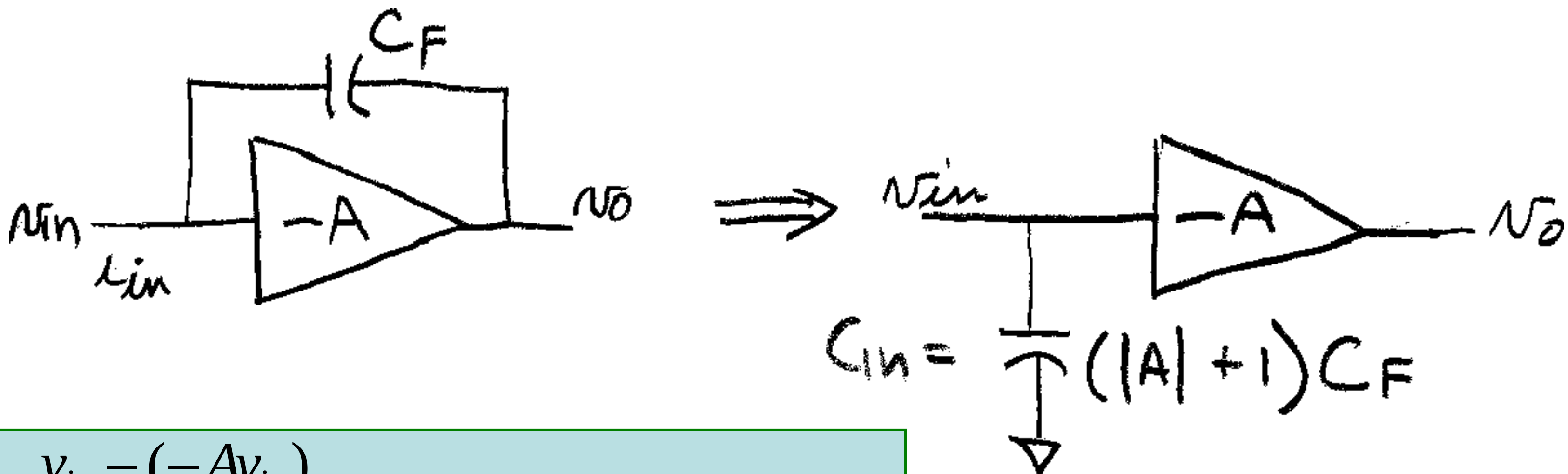




➢When the reactance of C_{bc} becomes small enough, a significant amount of output signal voltage is fed back out of phase with the input (negative feedback), thus effectively reducing the voltage gain.

Millers Theorem

The Miller effect occurs only in inverting amplifiers –it is the inverting gain that magnifies the feedback capacitance.



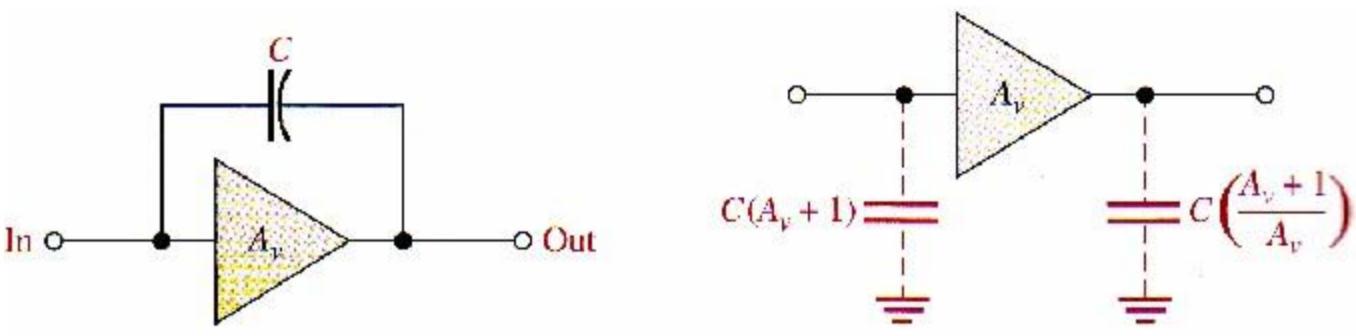
$$i_{in} = \frac{v_{in} - (-Av_{in})}{X_C} = v_{in}(1+A) \times 2\pi \times f \times C_F$$

Here C_F represents C_{bc}

$$Z_{in} = \frac{v_{in}}{i_{in}} = \frac{1}{(1+A) \times 2\pi \times f \times C_F} = \frac{1}{2\pi \times f \times C_{in}}$$

$$C_{in} = (1+A) \times C_F$$

High frequency Response of CE Amp.: Millers Theorem



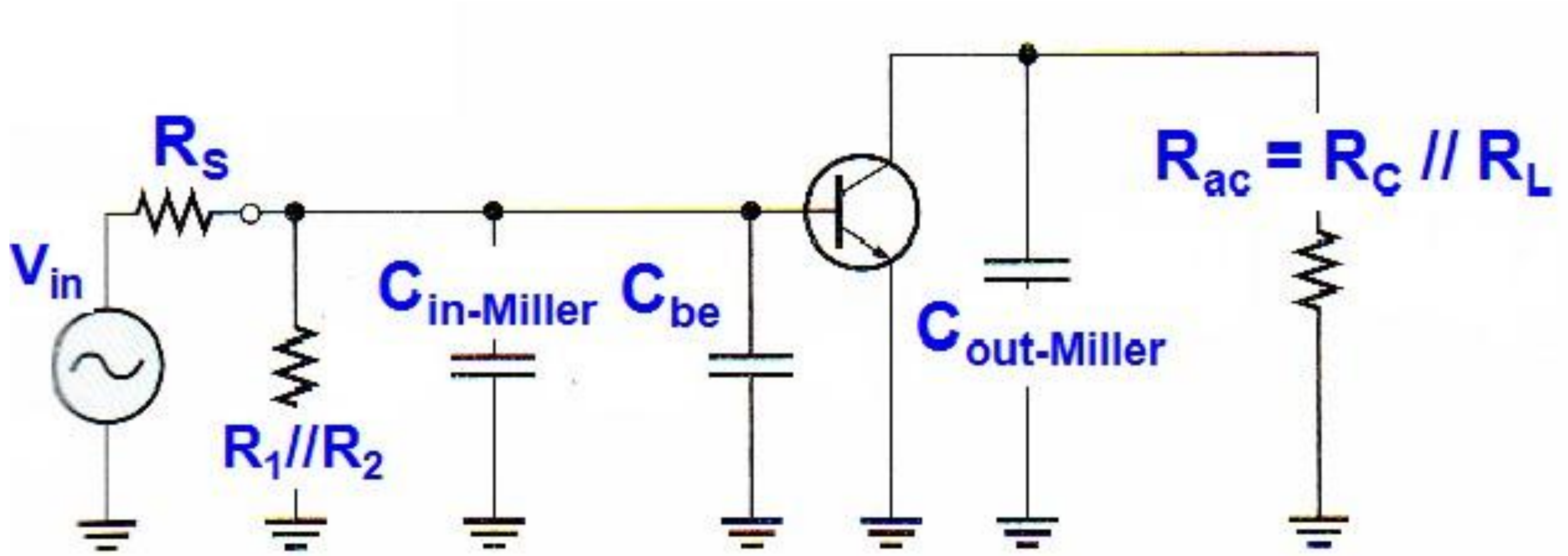
➢**Miller's theorem is used to simplify the analysis of inverting amplifiers at high-frequencies where the internal transistor capacitances are important. A_v is the voltage gain of the amplifier at midrange frequencies, and C represents C_{bc}**

Miller theorems state that C effectively appears as a capacitance from input to ground and can be expressed as follows: $C_{in}(Miller) = C(A_v + 1)$

Miller's theorems also state that C effectively appears as a capacitance from output to ground and can be expressed: $C_{out}(Miller) = C(A_v + 1)/A_v$

➢**This indicates that if the voltage gain is 10 or greater C_{out} (Miller) is approximately equal to C_{bc} because (Av + 1) / Av is equal to 1**

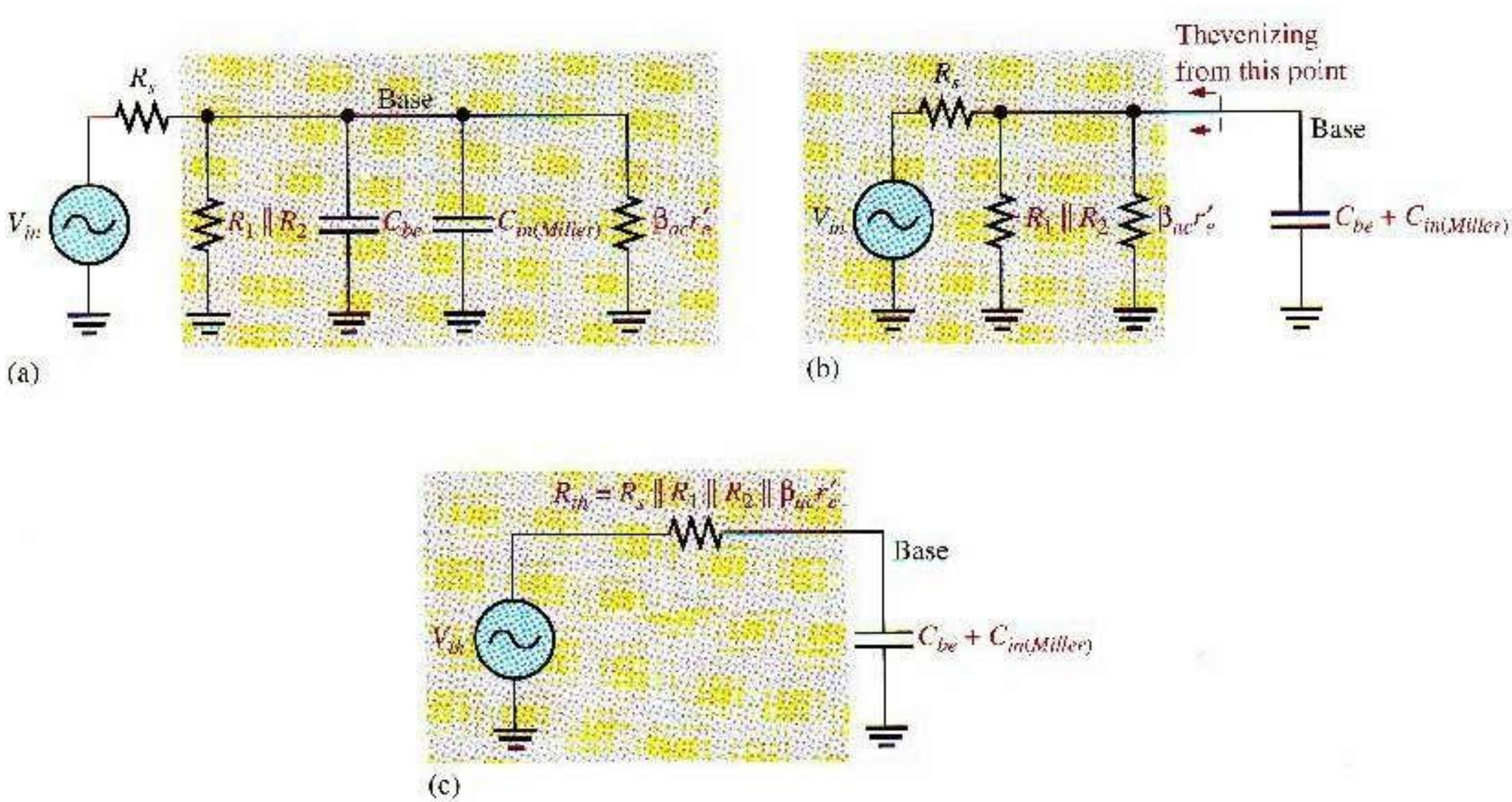
High frequency Response of CE Amp.: Millers Theorem



NOTE: Common base and common collector amplifiers do not suffer from the Miller effect, since in these amplifiers, one side of is connected directly to ground.

When the common base mode is used,the base-collector capacitor does not affect the input since it is grounded at the base end. The input capacitance is equal to C_{be}. (Well,in practise there is a small parasitic capacitance between collector and emitter) Common collector circuit has the collector end grounded (Vcc is ground for AC) , so the input capacitance equals the base-collector capacitance provided the load has no capacitance of its own.

High frequency Response of CE Amp.: Input RC ckt



As the frequency increases, the capacitive reactance becomes smaller. This cause the signal voltage at the base to decrease, so the amplifier's voltage gain decreases. The reason for this is that the capacitance and resistance act as a voltage divider and, as the frequency increases, more voltage is dropped across the resistance and less across the capacitance.

High frequency Response of CE Amp.: Input RC ckt

At the critical frequency, the gain is 3 dB less than its midrange value. Just as with the low frequency response, the critical high frequency, f_c , is the frequency at which the capacitive reactance is equal to the total resistance

$$X_C = \frac{1}{2\pi \times f_c \times C_{total}} = R_s // R_1 // R_2 // \beta_{ac} r_e'$$

$$f_C = \frac{1}{2\pi \times (R_s // R_1 // R_2 // \beta_{ac} r_e') \times C_{total}}$$

$$C_{total} = C_{be} + C_{in-Miller}$$

As the frequency goes above in the input RC circuit causes the gain to roll off at a rate of -20 dB/decade just as with the low-frequency response.

Phase shift for Input RC ckt at high frequency

Because the output voltage of a high-frequency input RC circuit is across the capacitor, the output of the circuit lags the input.

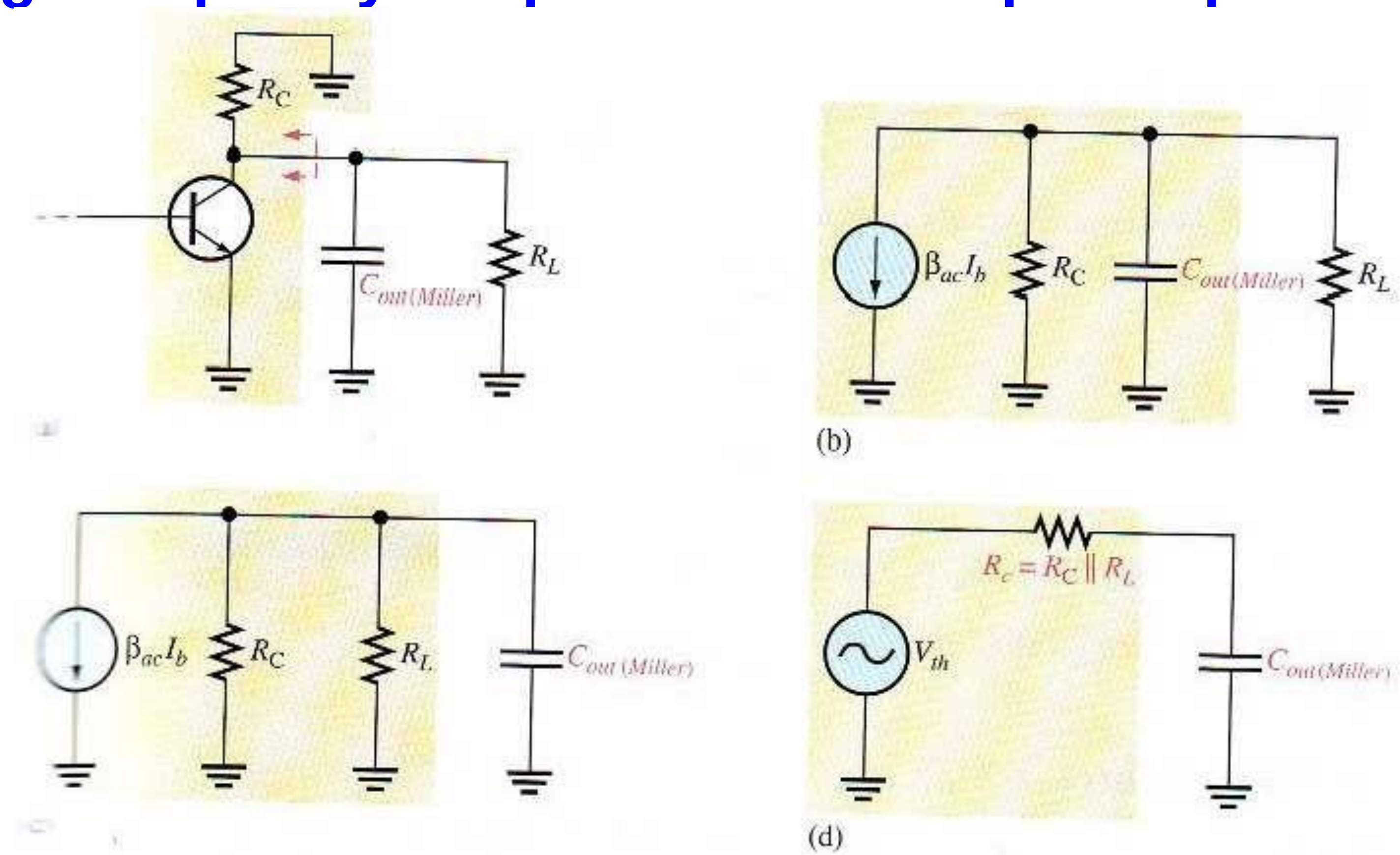
The phase shift in the output RC circuit is

$$\theta = \tan^{-1}\left(\frac{R_s // R_1 // R_2 // \beta_{ac} r_e'}{X_c}\right)$$

As the frequency increases above fc , the phase angle increases above 45° and approaches 90° when the frequency is sufficiently high.

At the critical frequency f_C , the phase shift is 45º with the signal voltage at the base of the transistor lagging the input signal.

High frequency Response of CE Amp.: Output RC ckt



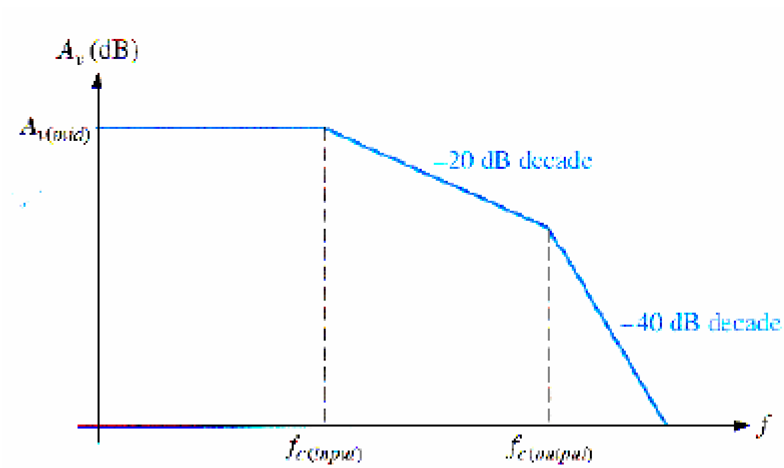
The critical frequency is determine with the following equation, where $R_{ac}=R_C \parallel R_L$

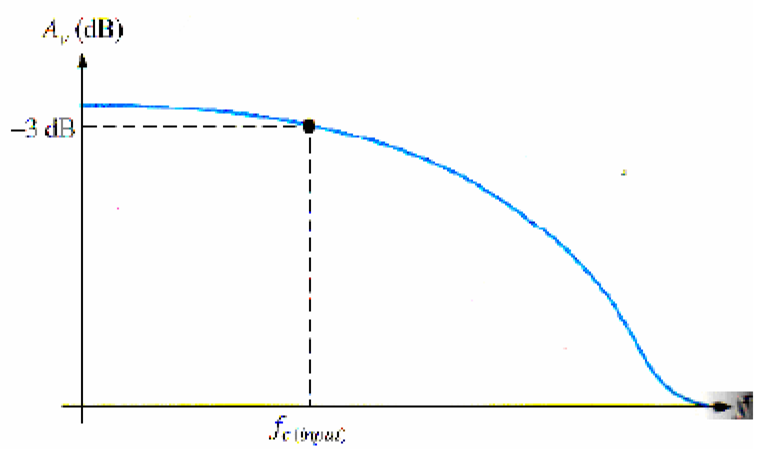
$$f_C = \frac{1}{2\pi \times R_{ac} \times C_{out-Miller}}$$

$$\theta = \tan^{-1}\left(\frac{R_{ac}}{X_{c-out-Miller}}\right)$$

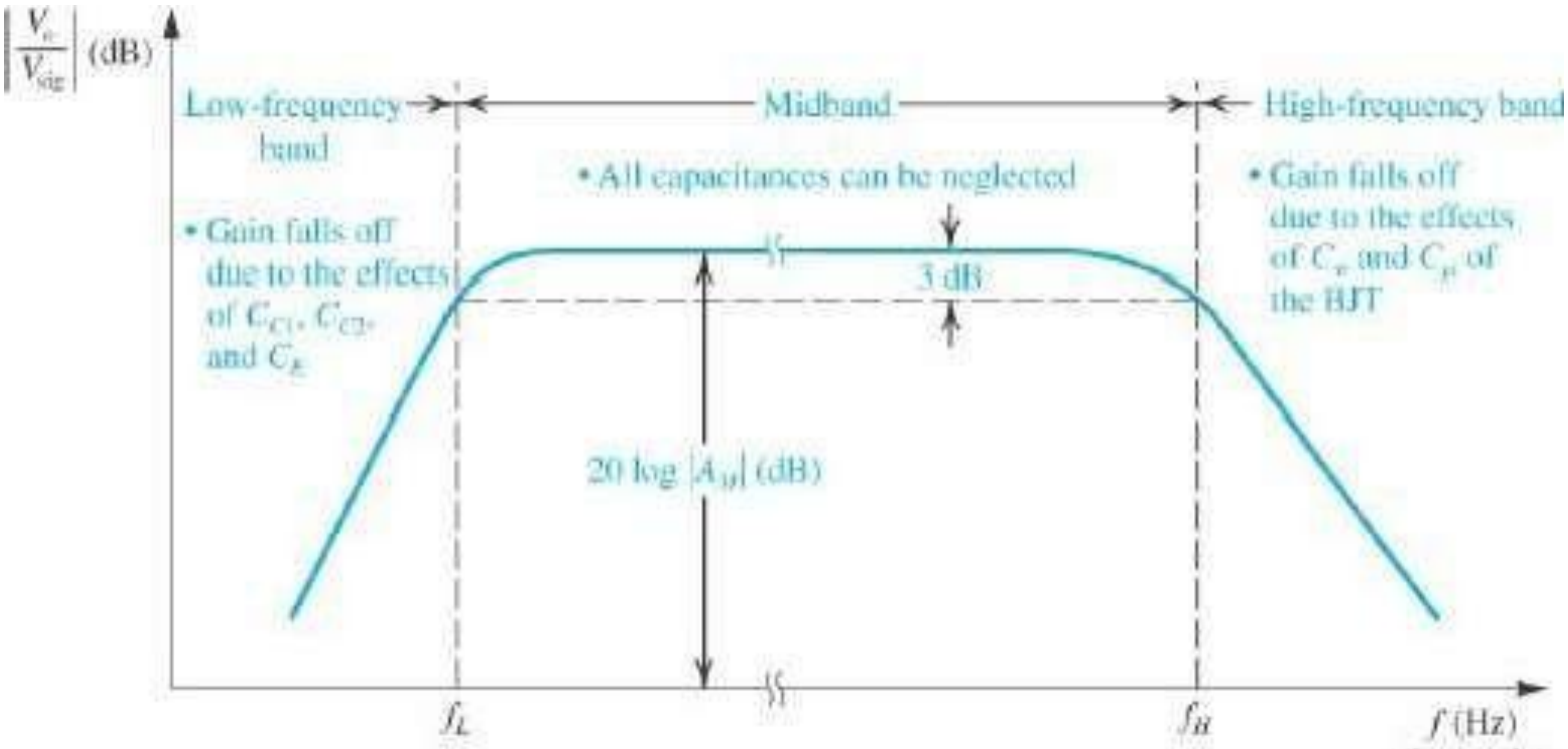
Total High frequency Response of CE Amplifier

The two RC circuits created by the internal transistor capacitances influence the high frequency response of BJT amplifiers. As the frequency increases and reaches the high end of its midrange values, one of the RC will cause the amplifier's gain to begin dropping off. The frequency at which this occurs is the dominant critical frequency; it is the lower of the two critical high frequencies. At fc(input) the voltage gain begins to roll off at -20dB/decade. At fc(output) , the gain begins dropping at -40 dB/decade because each RC circuit is providing a -20 dB/decade roll-off





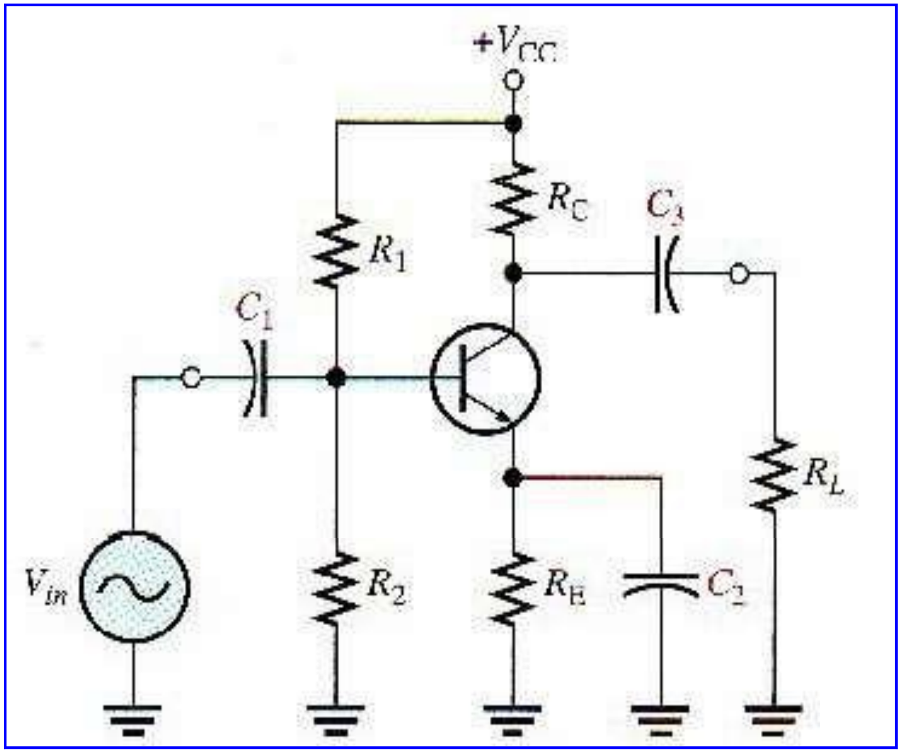
Total frequency Response of CE Amplifier



(b)

Frequency Response of BJT Amplifiers

Frequency Response of CE BJT Amplifier



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

Assuming that the coupling and bypass capacitors are ideal shorts at the midrange signal frequency, the midrange voltage gain can be determined by

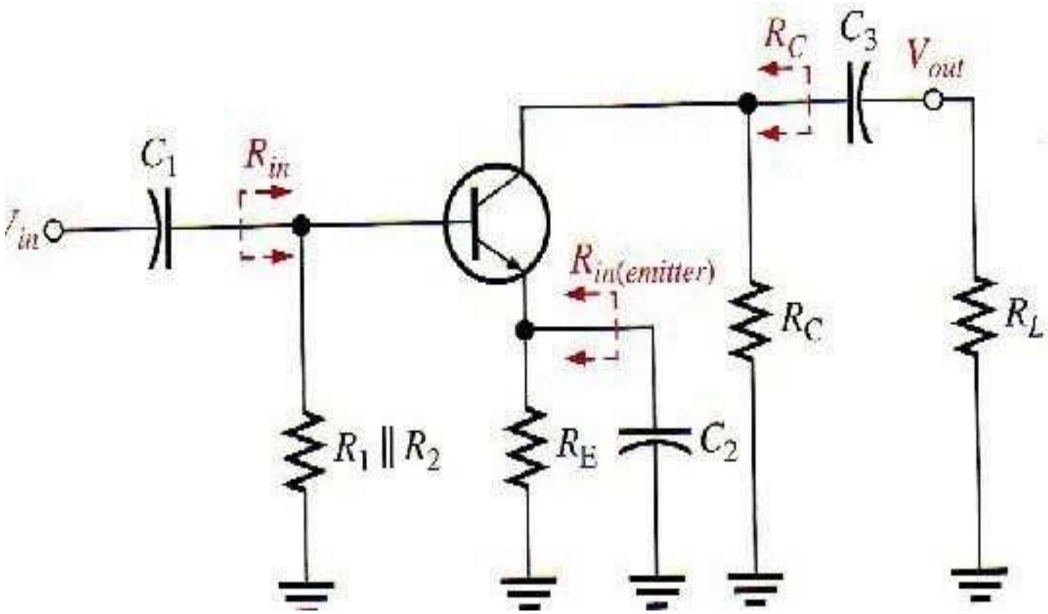
$$A_{v,mid} = \frac{(R_C \setminus\setminus R_L)}{r_e'}$$

➢**In the low frequency range, BJT amplifier *has three high-pass RC circuits, namely input, bypass and output RC circuit, that affect its gain.***

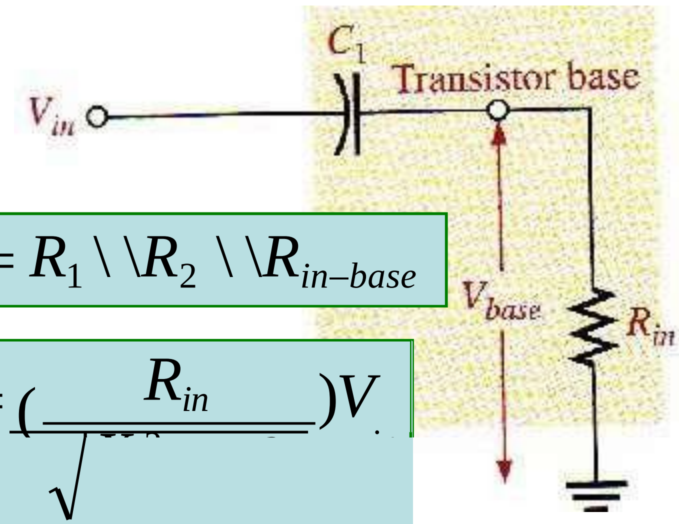
➢**The lower cutoff frequency of a given common emitter amplifier will be given by the highest of the individual RC circuits.**

$$f_{C\text{-low}} = MAX(f_{c\text{-input}}, f_{c\text{-output}}, f_{c\text{-bypass}})$$

Low Frequency Response of Input RC circuit



The input RC Circuit



$$\mathrm{R_{in}} = R_1 \backslash\backslash R_2 \backslash\backslash R_{in-base}$$

$$V_B = \left(\frac{R_{in}}{\sqrt{\;}}\right)V$$

➢***As the signal frequency decreases, X_{C1} increase, This causes less voltage across the input resistance of the amplifier at the base and because of this, the overall voltage gain of the amplifier is reduced.***

Decibel

Bel is a form of gain measurement and is commonly used to express amplifier response.

The Bel is a logarithm measurement of the ratio of one power to another or one voltage to another.

$$\boxed{G = \log_{10}(P_2 / P_1)}$$

$$\boxed{\begin{aligned} G(dB) &= 10\log_{10}(P_2 / P_1) \\ G(dB) &= 20\log_{10}(V_2 / V_1) \end{aligned}}$$

It was found, that the Bel was too large a unit of measurement for practical purposes, so the decibel (dB) was defined such that 1B =10dB

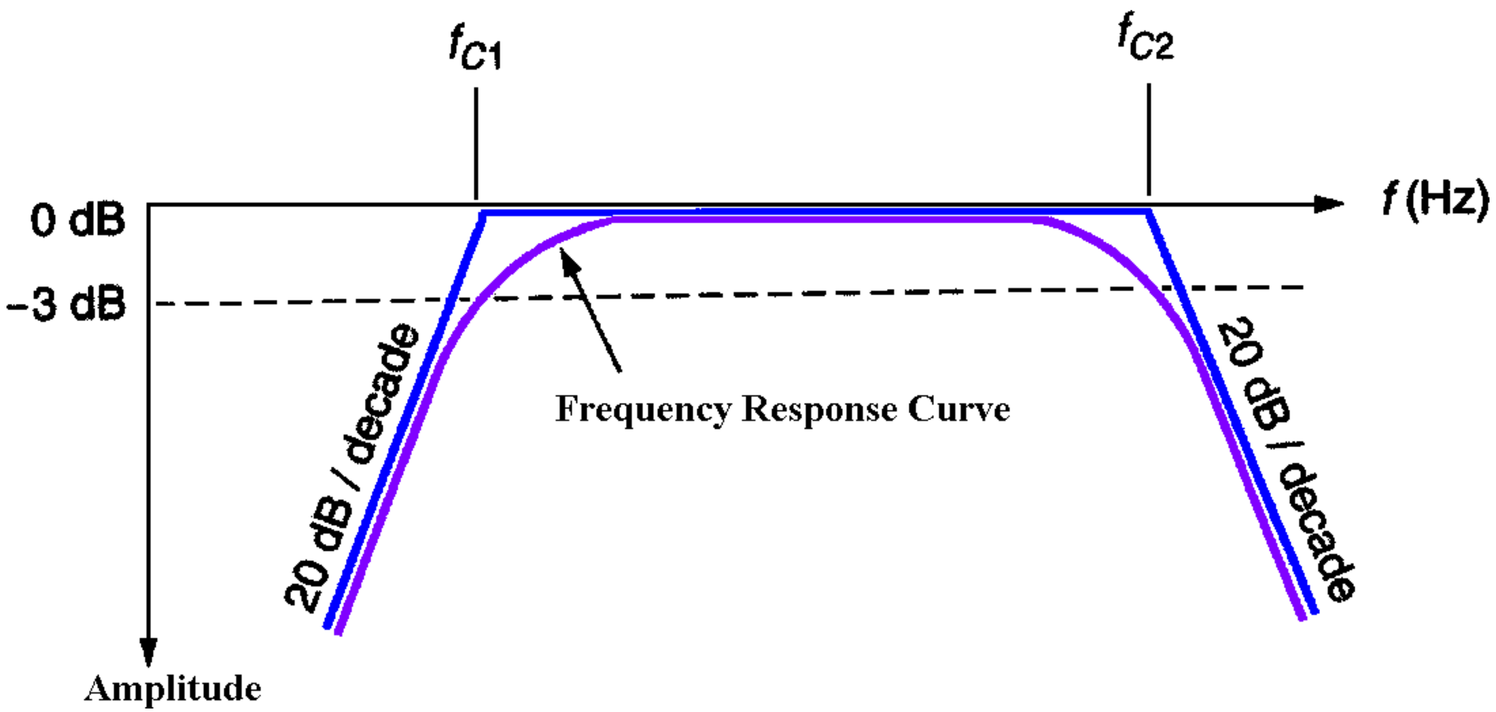
0 dB reference

It is often convenient in amplifiers to assign a certain value of gain as the 0 dB reference This does not mean that the actual voltage gain is 1 (which is 0 dB); it means that the reference gain, is used as a reference with which to compare other values of gain and is therefore assigned a 0 dB value. The maximum gain is called the midrange gain and is assigned a 0 dB value. Any value of gain below midrange can be referenced to 0 dB and expressed as a negative dB value.

Bode Plots

A plot of dB voltage gain versus frequency on semilog graph paper is called a bode plot.

The Bode Plot is a variation of the basic frequency response curve. A Bode plot assumes the amplitude is zero until the cutoff frequency is reached. Then the gain of the amplifier is assumed to drop at a set rate of 20 dB/decade (or one RC time constant).



Low Frequency Response of Input RC ckt

➢ **A critical point in the amplifier's response occurs when the output voltage is 70.7% of its midrange value. This condition occurs in the input RC circuit when $X_{C1} = R_{in}$**

$$\boxed{V_B = \left(\frac{R_{in}}{\sqrt{X_{c1}^{2} + R_{in}^{2}}}\right)V_{in}}$$

In terms of measurement in decibels:

$$\boxed{20\log(V_{out}/V_{in}) = 20\log(0.707) = -3dB}$$

Lower critical frequency

The condition where the gain is down 3 dB is called the -3dB point of the amplifier response; The frequency f_c at which the overall gain is 3dB less than at midrange is called the lower cutoff frequency.

$$X_{C_1} = \frac{1}{2\pi \times f_c \times C_1} = R_{in}$$

$$\boxed{f_C = \frac{1}{2\pi \times (R_s + R_{in}) \times C_1}}$$

Where R_s is the signal internal resistance and $\boxed{\mathrm{R_{in}} = R_1 \backslash\backslash R_2 \backslash\backslash R_{in-base}}$

Voltage Gain Roll Off for input ckt at low frequency

➢**The input RC circuit reduces the overall voltage gain of an amplifier by 3 dB when the frequency is reduced to the critical value f_C.**

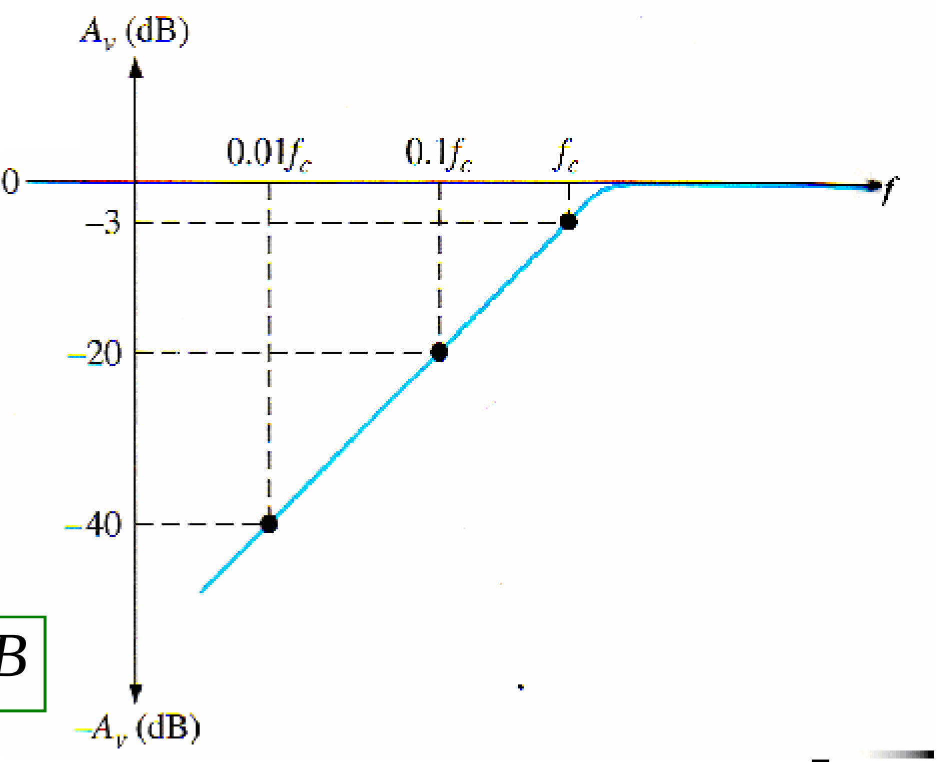
➢**As the frequency continues to decrease below f_C the overall voltage gain also continues to decrease. The decrease in voltage gain with frequency is called roll-off.**

➢**For each ten times reduction in frequency below f_C there is a 20dB reduction in voltage gain.**

At f_c, $X_{C1} = R_{in}$, so $X_{C1} = 10\,R_{in}$ at $0.1f_c$,

$$\frac{V_B}{V_{in}} = \frac{R_{in}}{\sqrt{X_{c1}^{\,2} + R_{in}^2}} = 0.1$$

$$\boxed{20\log(V_B / V_{in}) = 20\log(0.1) = -20dB}$$



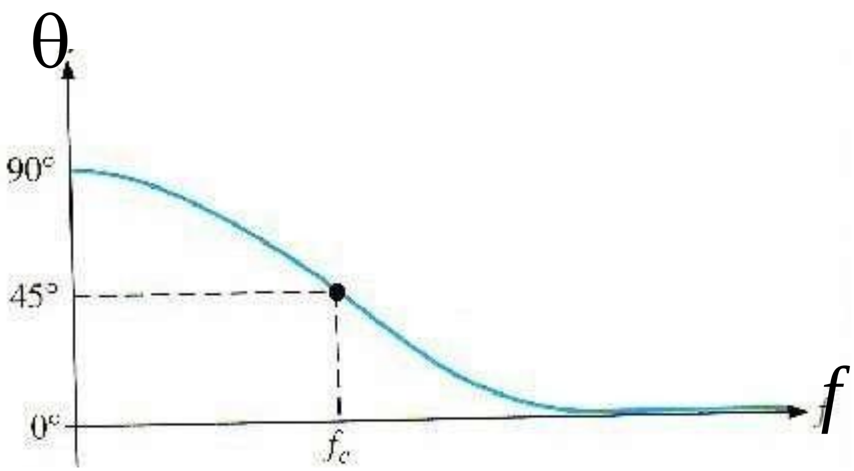
Phase shift for input RC ckt at low frequency

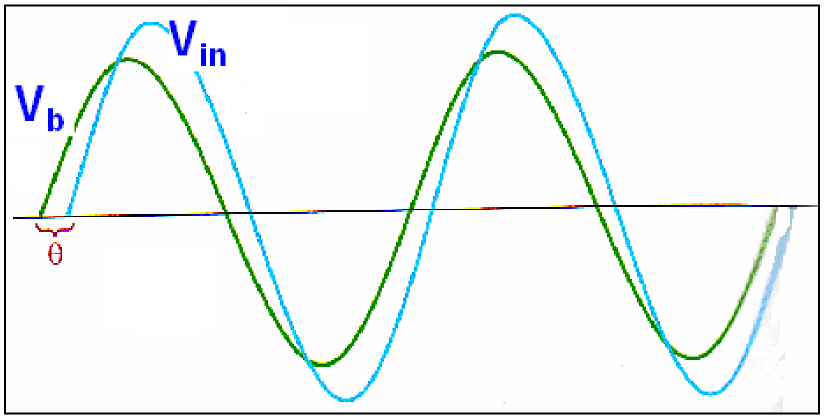
➢ ***At lower frequencies, higher values of X_{C1} cause a phase shift to be introduced, and the output voltage leads the input voltage.***

➢ ***The phase angle in an input RC circuit is expressed as:***

$$\theta = \tan^{-1}\left(\frac{X_{C1}}{R_{in}}\right)$$

➢ **At midrange frequencies the phase shift through the input RC circuit is zero because $X_{C1} \approx 0\Omega$.**

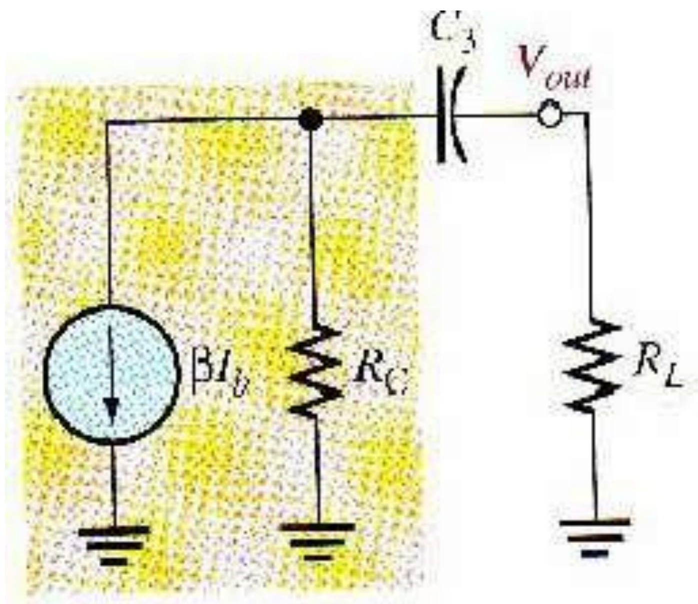


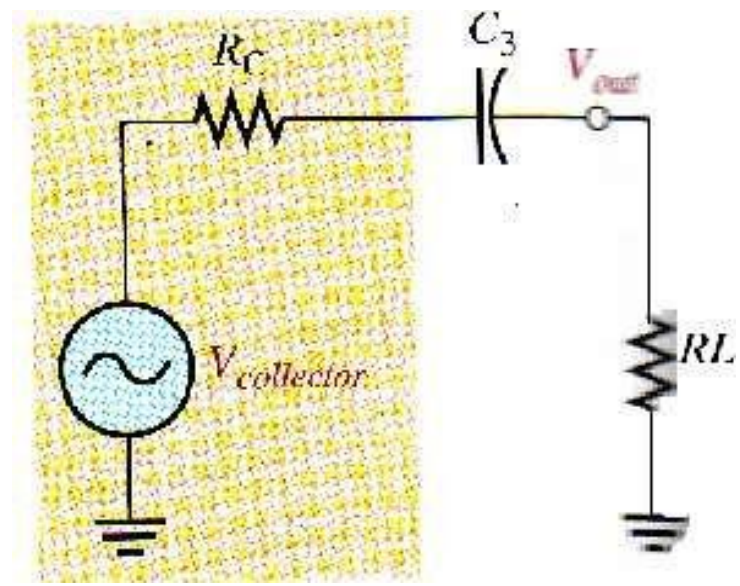


Output RC circuit at low frequency

$$X_{C_3} = \frac{1}{2\pi \times f_c \times C_3} = R_C + R_L$$

$$f_C = \frac{1}{2\pi \times (R_C + R_L) \times C_3}$$





As the signal frequency decreases, X_{C3} increases. This causes less voltage across the load resistance because more voltage is dropped across C_3.

The signal voltage is reduced by a factor of 0.707 when frequency is reduced to the lower critical value, f_C, for the circuit. This corresponds to a 3 dB reduction in voltage gain

Phase shift for Output RC ckt at low frequency

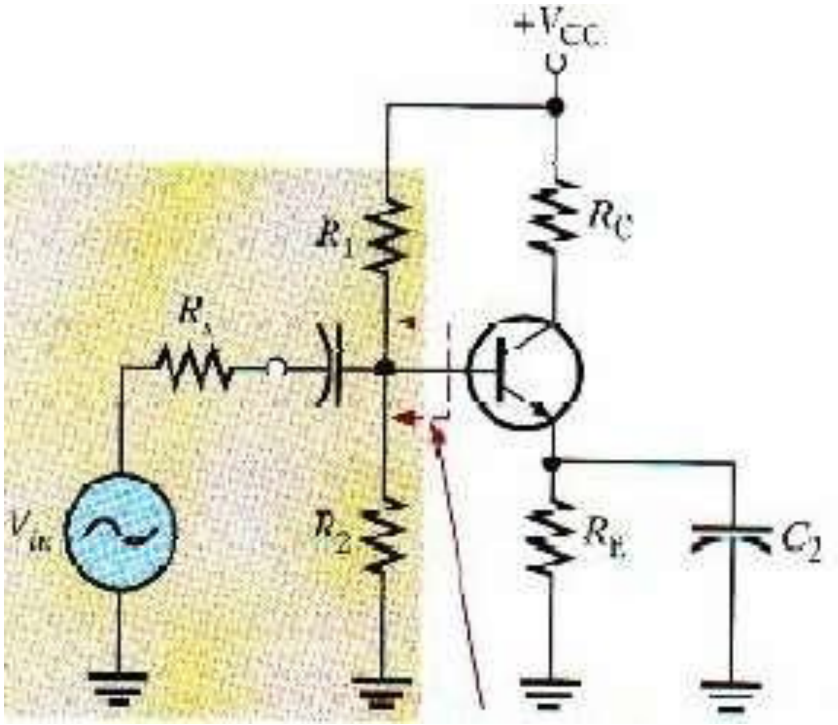
The phase shift in the output RC circuit is

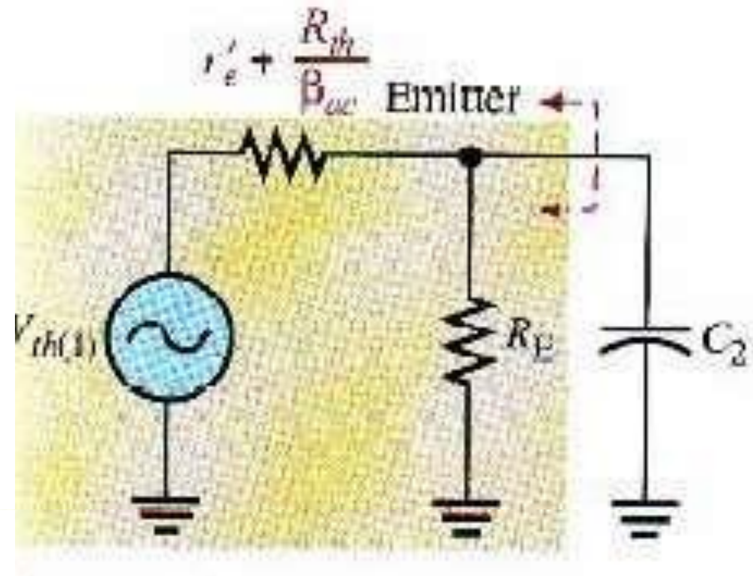
$$\boxed{\theta = \tan^{-1}\left(\frac{X_{C3}}{R_C + R_L}\right)}$$

- **$\theta \approx 0$ for the midrange frequency and approaches 90º as the frequency approaches zero (X_{C3} approaches infinity).**

- **At the critical frequency f_C , the phase shift is 45º**

Emitter-bypass RC ckt at low frequency





$$R_{in-emitter} = \frac{V_e}{I_e} + r_e'$$

$$R_{in-emitter} = \frac{R_{th} I_b}{\beta I_b} + r_e' = \frac{R_{th}}{\beta} + r_e'$$

$$f_C = \frac{1}{2\pi \times [(r_e' + \frac{R_{th}}{\beta_{ac}}) // R_E] \times C_2}$$

Total Low frequency Response of CE Amplifier

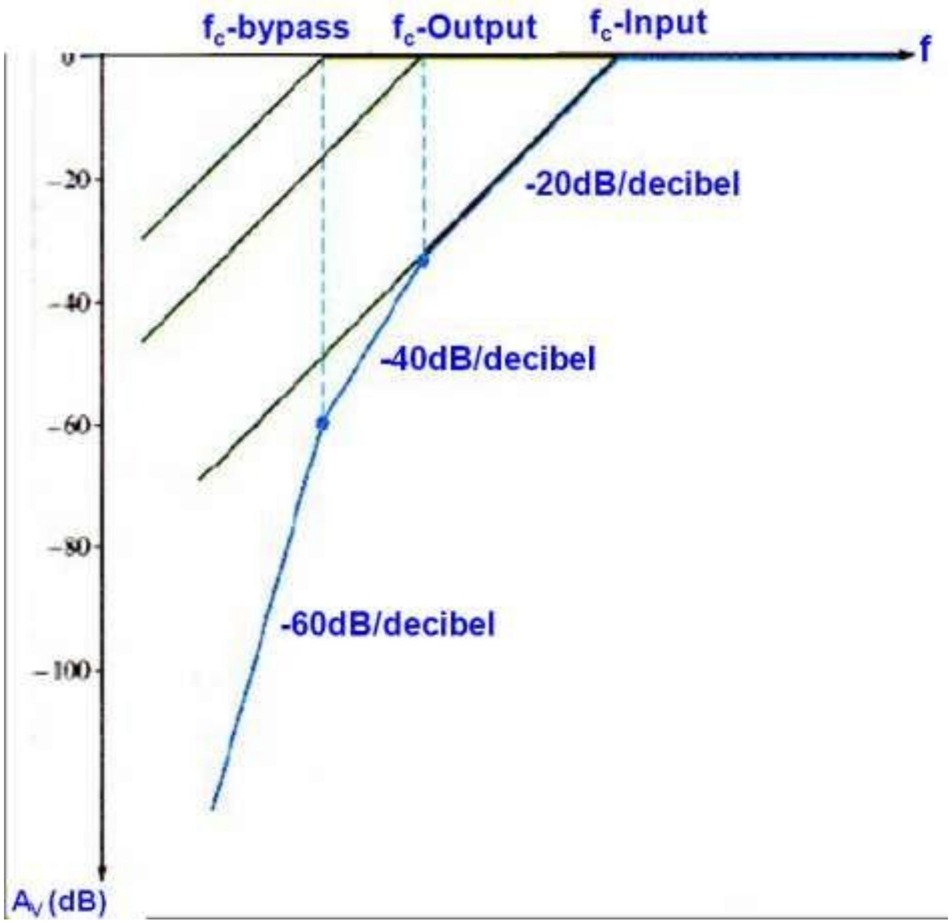
➢The critical frequencies of the three RC circuits are not necessarily all equal. If one of the RC circuits has a critical frequency higher than the other two, then it is dominant RC circuit.

➢As the frequency is reduced from midrange, the first "break point" occurs at the critical frequency of the input RC circuit, f_c(input) , and the gain begins to drop at -20dB/decade.

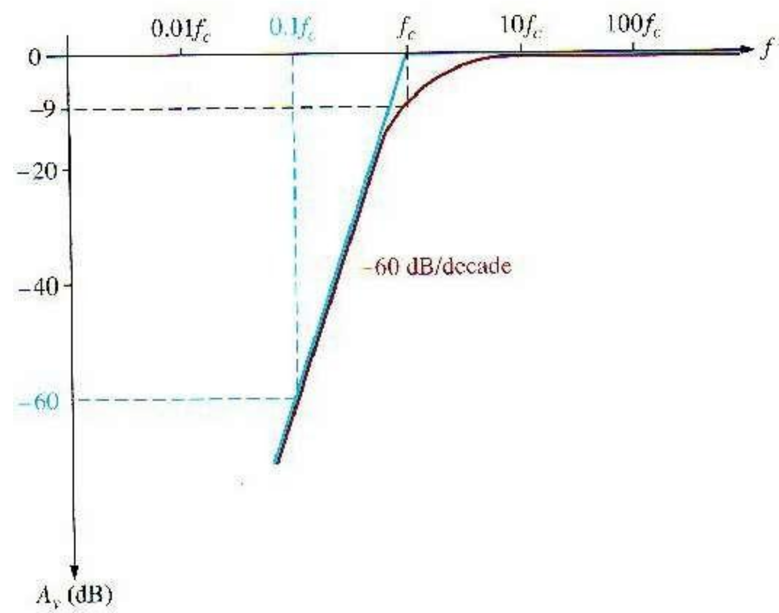
➢This constant roll\off rate continues until the critical frequency of the output RC circuit, f_c(output), is reached. At this break point, the output RC circuit adds another - 20 dB/decade to make a total roll-off of -40 dB/decade.

➢This constant -40 dB/decade roll-off continues until the critical frequency of the bypass RC circuit, f_c(bypass), is reached. At this break point, the bypass RC circuit adds still another -20dB/decade, making the gain roll-off at - 60 dB/decade

If all RC circuits have different critical frequency



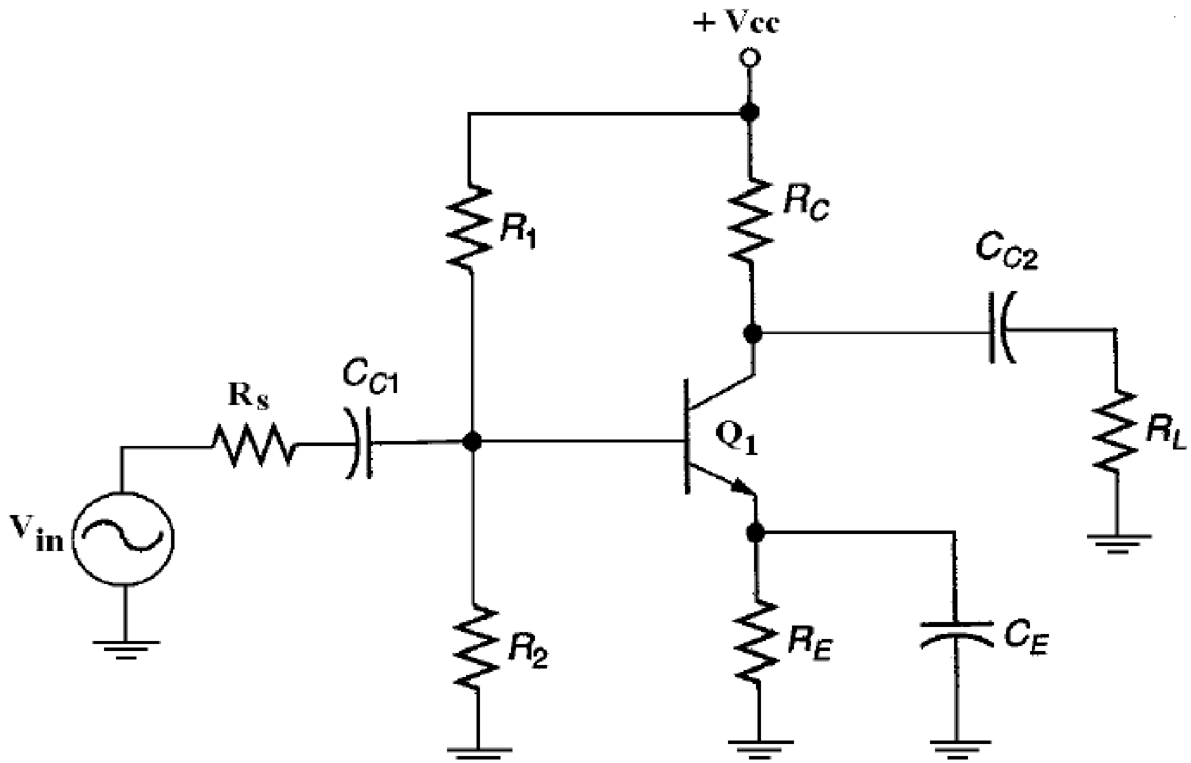
If all RC circuits have the same critical frequency



http://www.uotiq.org/dep-eee/lectures/2nd/Electronics%201/part6.pdf

Low frequency Response of CE Amplifier

Determine the value of the lower cutoff frequency for the following amplifier. Consider the following component values:
$R_S = 600\ \Omega$, $R_1 = 18\ k\Omega$, $R_2 = 4.7\ k\Omega$, $R_C = 1.5\ k\Omega$, $R_E = 1.2\ k\Omega$, $R_L = 5\ k\Omega$, $C_{C1} = 1\ \mu F$, $C_{C2} = 0.22\ \mu F$, $C_E = 10\ \mu F$, $h_{fe} = 200$, $h_{ie} = 4.4\ k\Omega$, $V_{cc} = 10\ V$



$f_{c\text{-input}} = 61.2$ Hz
$f_{c\text{-output}} = 111$ Hz
$f_{c\text{-bypass}} = 650$ Hz

Lower cutoff frequency of the amplifier:

$f_{C\text{-Low}} = \max(61.2, 111, 650)$
$f_{C\text{-Low}} = 650$ Hz