Frequency response of an amplifier:

- Consider a sinusoidal signal of angular frequency ω represented by $AV_m \sin(\omega t + \phi)$ If the voltage gain of amplifier has a magnitude A and the signal suffer a phase change θ. Then the output will be.

$$AV_m \sin(\omega t + \phi + \theta) = AV_m \sin\left[\omega\left(t + \frac{\theta}{\omega}\right) + \phi\right]$$

- If the amplification A is independent of frequency and if the phase shift θ is proportional to frequency, then the amplifier will followed the input signal although the signal will be shifted in time by $\frac{\theta}{\omega}$. It means both amplitude and time delay responses are sensitive indicator of frequency distortion.

- For an amplifier stage the frequency characteristic may be divided into three regions.

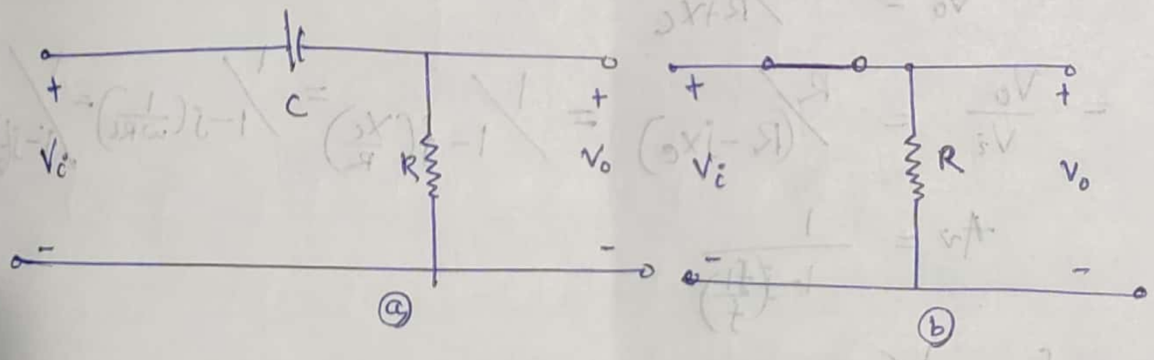
i. Mid-band Frequency: the region of frequency where the amplification and decay is reasonably constant i.e. gain is nearly equal to one.

ii. Below mid-band Frequency: in this region, the active circuit may behaves as simple high pass circuit. The response decrease with decreasing frequency and output approaches to zero

iii. Above mid-band frequency: in above mid band frequency, the circuit behaves like a low pass circuit and the response decrease with increase in frequency.

Low Frequency response:

In the low-frequency region of the single-stage BJT or FET amplifier. It is the R-C combinations formed by the network capacitors C_c, C_E and C_s and the network resistive parameters that determine the cutoff frequencies. In fact, an R-C network similar to the below can be established for each capacitive element and the frequency at which the output voltage drops to 0.707 of its maximum value determined. Once the cutoff frequency due to each capacitor are determined, they can be compared to establish which will determine the low-cutoff frequency for the system.



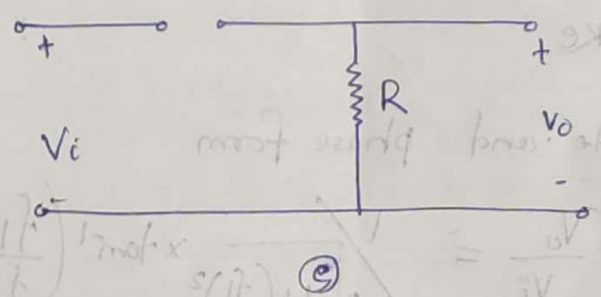


Fig (a) R-C Combination that will define a low cutoff frequency

(b) R-C Circuit at very high frequency

(c) R-C circuit at low frequency i.e. $f=0$

The output and input voltages are related by voltage divider rule in the following manner:

$$V_o = \frac{RV_i}{R+X_c}$$

maximum value determined. Once the cutoff frequencies due to each capacitor are determined, they can be compared to establish which will determine the low-cutoff frequency for the system.

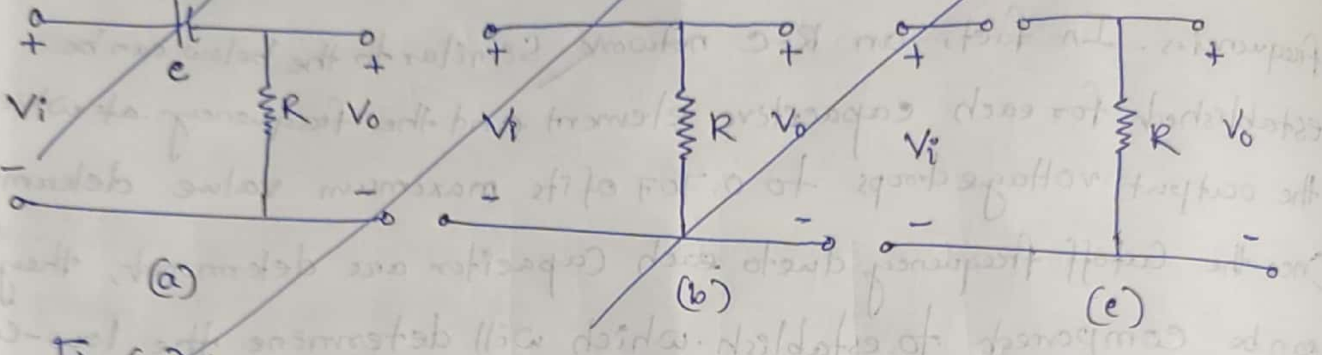


Fig (a):

$$V_o = \frac{RV_1}{R+X_C}$$

$$A_v = \frac{V_o}{V_i} = \frac{R}{(R - jX_C)} = \frac{1}{1 - j\left(\frac{X_C}{R}\right)} = \frac{1}{1 - j\left(\frac{1}{\omega RC}\right)} = \frac{1}{1 - j\frac{1}{2\pi f C}}$$

$$A_v = \frac{1}{1 - j\left(\frac{f_1}{f}\right)}$$

When $f_1 = \frac{1}{2\pi RC}$

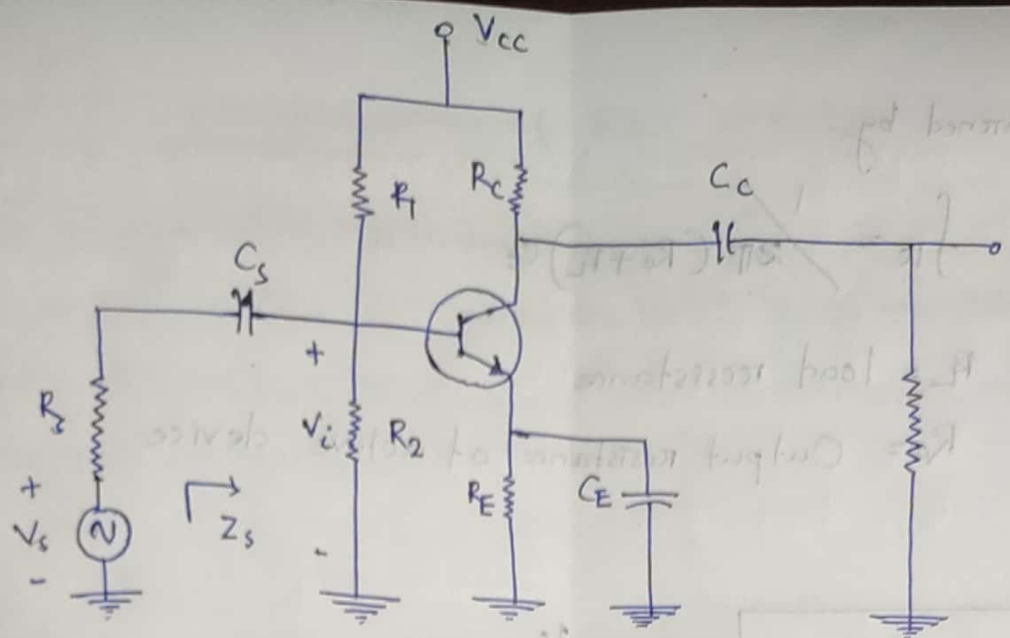
In the magnitude and phase form.

$$A_v = \frac{V_o}{V_i} = \frac{1}{\sqrt{1 + \left(\frac{f_1}{f}\right)^2}} \times \tan^{-1}\left(\frac{f_1}{f}\right)$$

At $f = f_1$, $|A_v| = \frac{1}{\sqrt{2}} = 0.707 \rightarrow -3\,dB$

Low frequency response of BJT amplifier:

For any BJT configuration, it will simply be necessary to find the appropriate equivalent resistance for the R-C combination and capacitance C_C, C_E and C_S will determine the low frequency response of the network.

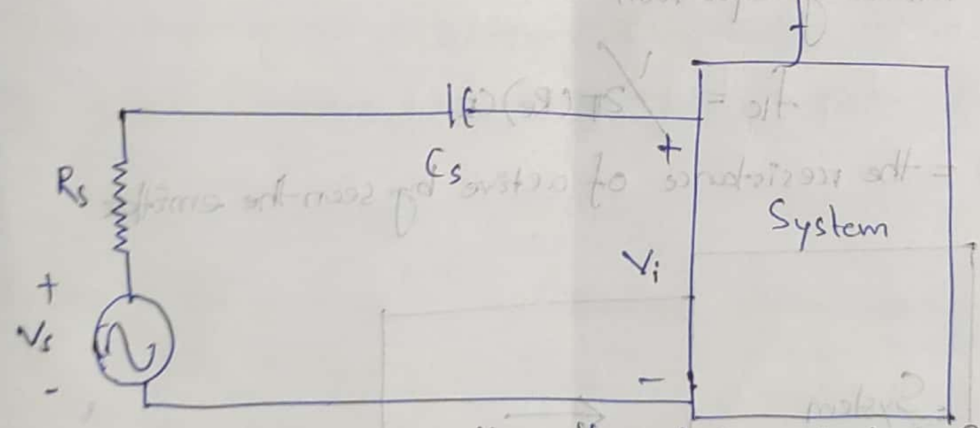


C_s: It is normally connected between the applied source and the active device, the general form of R-C configuration is established by the network. The total resistance is now $R_s + R_E$ and the Cutoff frequency is

$$f_{LS} = \frac{1}{2\pi (R_s + R_i) C_s}$$

Where R_s Source resistance

R_i = input resistance of the active device.



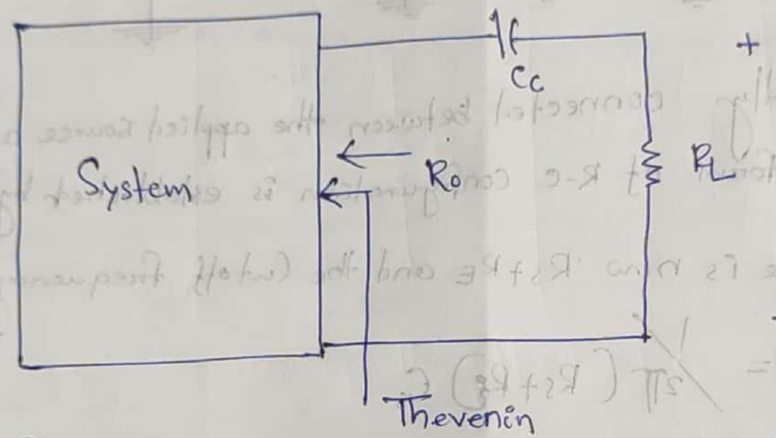
Determining the effect of C_s on the low frequency response.

C_c: The coupling capacitor is normally connected betn the output of the active device and the applied load, the R-C configuration that determines the low cutoff frequency due to C_c appears and the total series resistance is now $R_L + R_o$ and the Cut off frequency due to is determined by

$$f_{lc} = \frac{1}{2\pi (R_o + R_L) C_c}$$

Where R_L = load resistance

R_o = Output resistance of active device

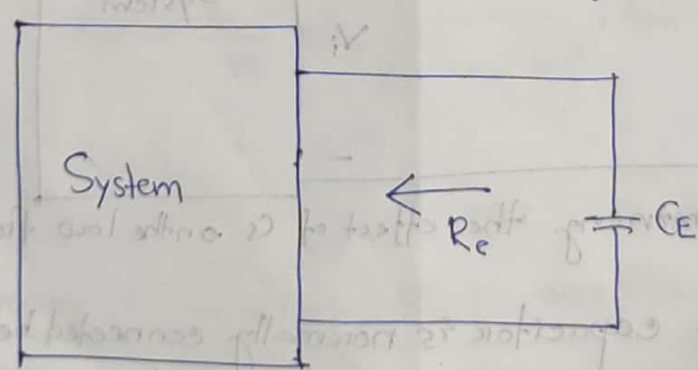


Determining the effect of C_E on the low frequency response

C_E : The cutoff frequency due to C_E can be determined using the following equation

$$f_{lc} = \frac{1}{2\pi (R_e) C_E}$$

Where R_e = the resistance of active by seen the emitter

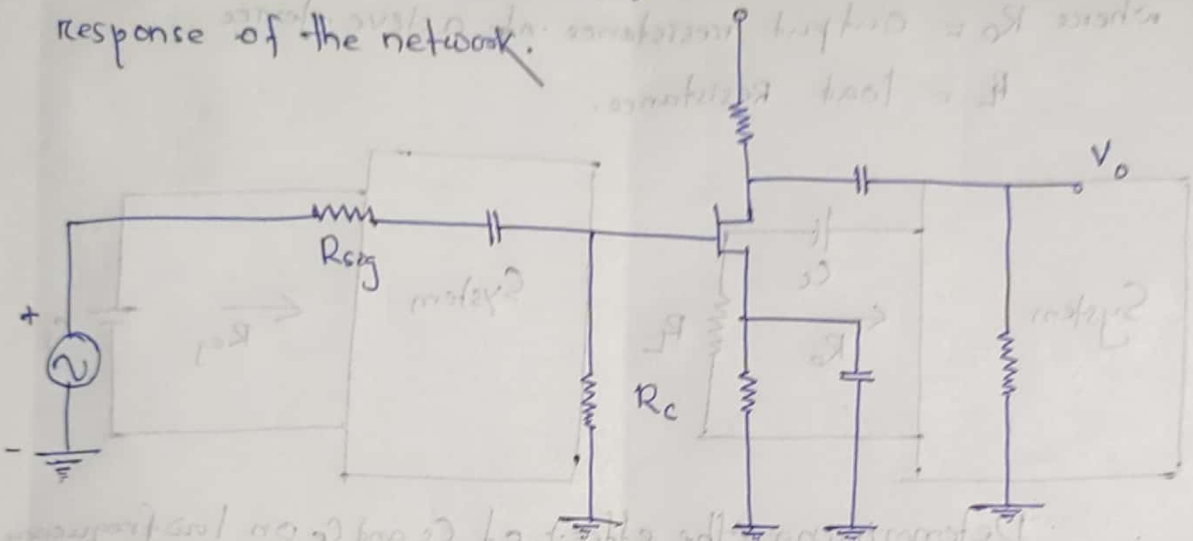


Determining the effect of C_E on the low frequency response

The highest low-frequency cutoff determined by C_c, C_E and C_s will have the greatest impact since it will be the last encountered before the mid-band level.

Low-frequency response of FET amplifier:

The analysis of the FET amplifier in the low-frequency region will be quite similar to that of the BJT amplifier. There are again three capacitors C_G, C_C and C_S will determine the low frequency response of the network.



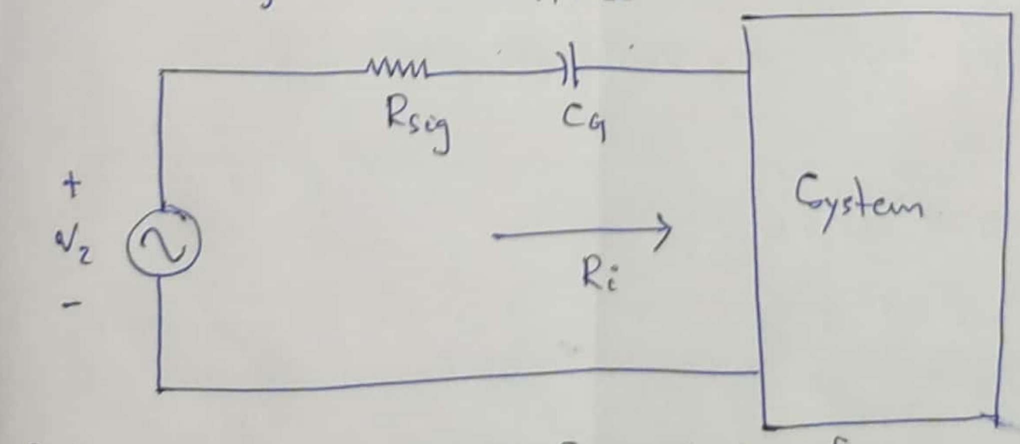
Capacitive elements that affect the low frequency response of JFET amplifier.

C_G: The coupling capacitor between the source and the active device, the ac equivalent network will appear as shown in below figure. The cutoff frequency determined by C_G will then be

$$f_{LG} = \frac{1}{2\pi C R} \Big) C_G$$

Where, R_i — input resistance of active device i.e. in FET R_i-R_G

R_{sig} — source resistance



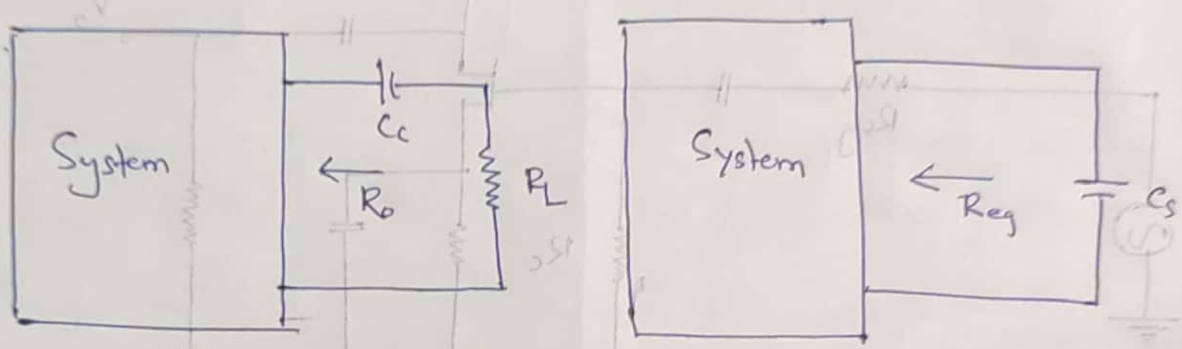
Determining the effect of C_G on the low frequency response

C_c – The coupling capacitor between the active device and the load the network. The resulting cutoff frequency is

$$f_{lC} = \frac{1}{2\pi (R_o + R_L) C_c}$$

where R_o = Output resistance of active device

R_L = load Resistance.



Determining the effect of C_s and C_e on low frequency response.

C_s : It is the Source capacitance and the resulting cut-off frequency is

$$f_{lC} = \frac{1}{2\pi (R_{eq}) C_c}$$

Where $R_{eq} = R_s \parallel \frac{1}{g_m}$ when $r_d \cong \infty$

High Frequency response:

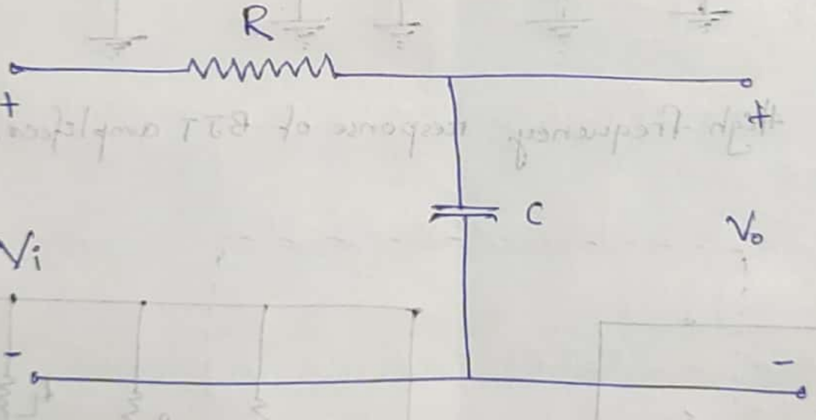
At the high-frequency end, there are two factors that will define the 3-dB point. the network capacitance C (parasitic and introduced) and the frequency dependence of $h_{fe}(\beta)$.

In the high-frequency region, the RC network of concern has the configuration appearing in the below figure. The gain of the following RC network is given by

$$A_v = \frac{1}{1+j\left(\frac{f}{f_2}\right)}$$

Where f_2 = Cutoff frequency of a device

At $f = f_2$. $|A_v| = \frac{1}{\sqrt{2}} = 0.707 \rightarrow -3dB$

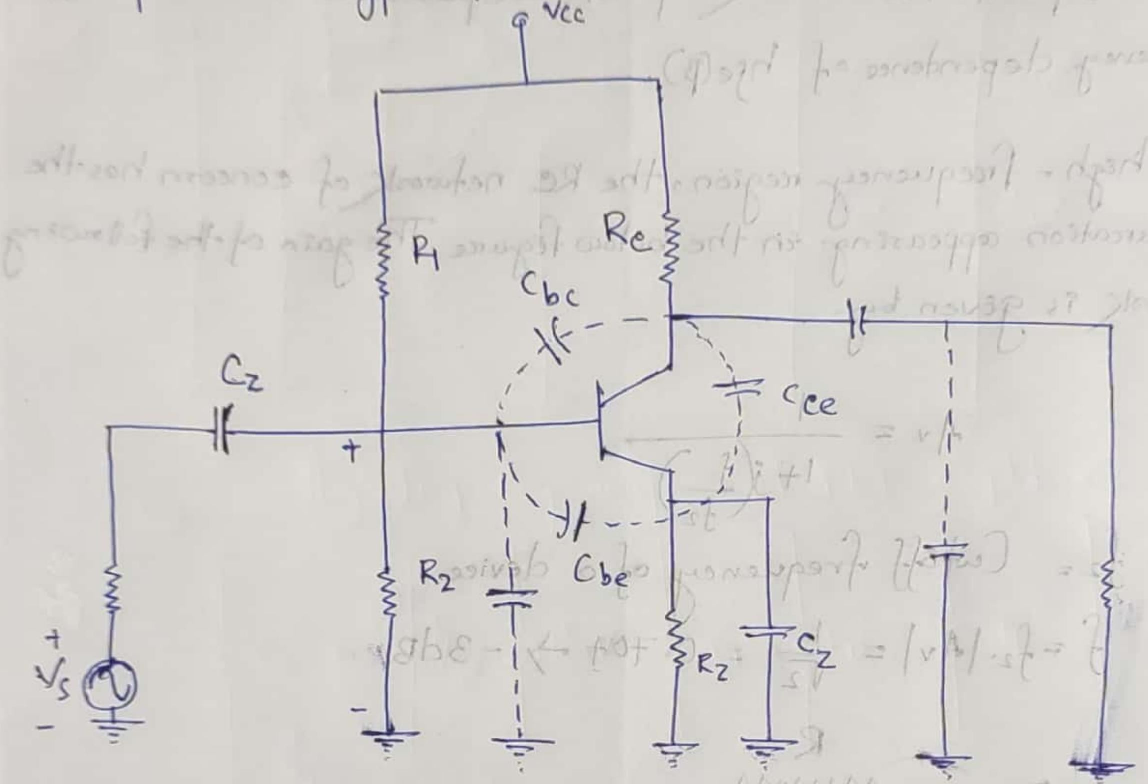


R.C combination that will define a high Cut off frequency

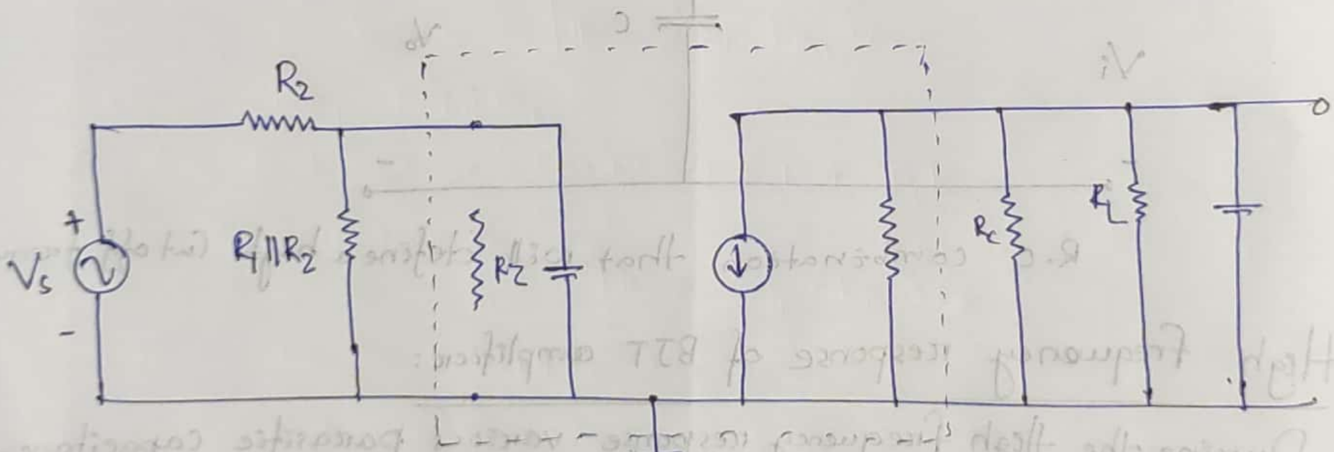
High frequency response of BJT amplifier:

During the High frequency response various parasitic capacitances (C_{be}, C_{ce} and C_{bc}) of the transistor have been included with wiring capacitances. (C_{wi}, C_{wo}) introduced in the network. The capacitance C_i includes the input wiring capacitance C_{wi}. the transistor Capacitance C_{be} and the Miller Capacitance C_{Mi} the Capacitance C_o includes the Output wiring capacitance C_{wo}. the capasitic Capacitances, with C_e

the smallest. In fact the most significantly the network consists of C_{be} and C_{bc} and do not include C_{ce} unless it will affect the response of a particular type of transistor in a specific area of application.



High frequency response of BJT amplifiers.



High frequency ac equivalent model of BJT amplifier.

The Thevenin equivalent circuit for the input and output networks of the above network is given below. For the input network the 3dB frequency is defined by

$$f_{H1} = \frac{1}{2\pi (R_{Th_1}) C_i}$$

where $R_{Th_1} = R_Z \parallel R_1 \parallel R_2 \parallel R_L$

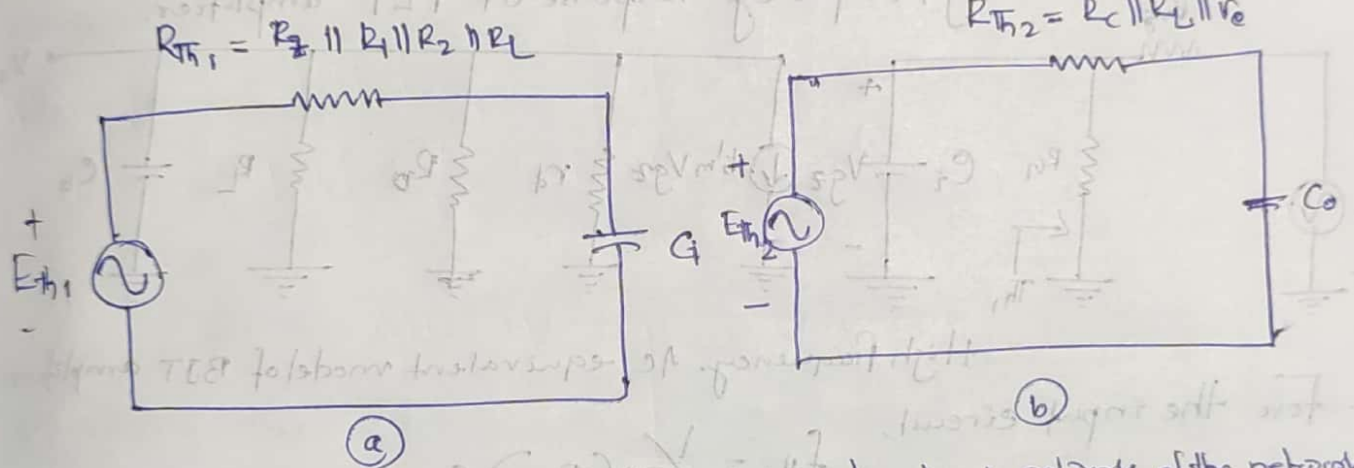
$$C_i = C_{M_i} + C_{W_i} + C_{bn} = C_{w_i} + C_{bw} + (1 - A_v) C_{bc}$$

Similarly, for output network, the 3-dB frequency is defined by

$$f_{Ho} = \frac{1}{2\pi (R_{th_2}) C_o}$$

Where $R_{th_2} = R_C \parallel R_L \parallel r_e$

$$C_o = C_{M_o} + C_{W_o} + C_{be}$$



Thevenin circuit of the input and output network of the network.

High frequency response of FET amplifier:

The analysis of the high frequency response of the FET amplifier will proceed in a very similar manner to that encountered for the BJT amplifier. There are interelectrode and wiring capacitances that will determine the high frequency characteristics of the amplifier. The capacitor C_{gs} and C_{gd} typically vary from 1 to 10 pF, while the capacitance C_{ds} is usually quite a bit smaller ranging from 0.1 to 1 pF.

The cutoff frequencies defined by the input and output circuits can be obtained by first finding the Thevenin equivalent circuits for each section.

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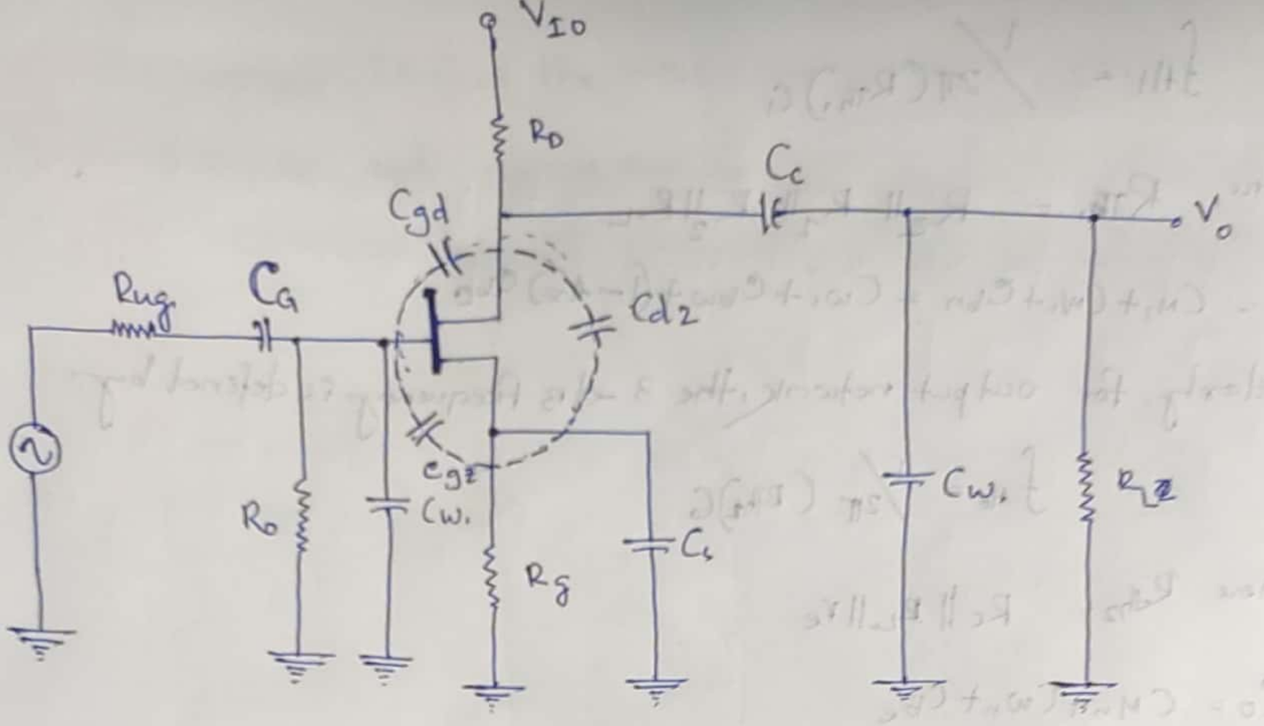
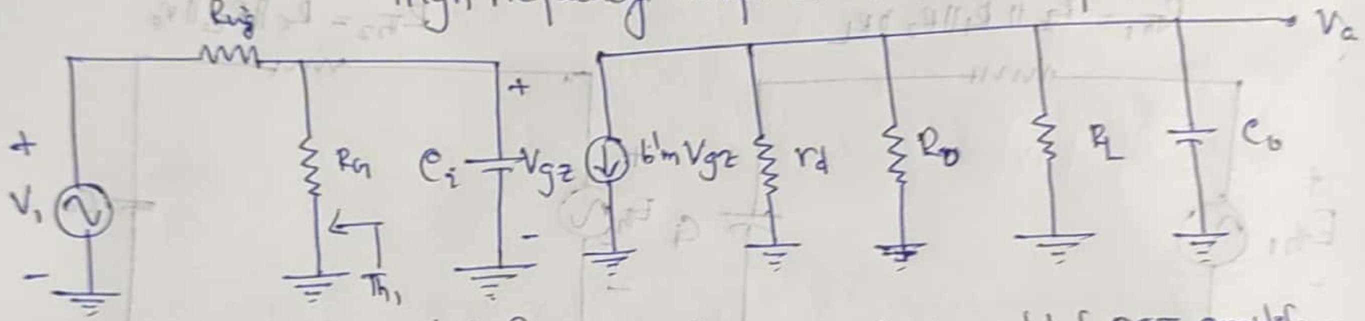


High frequency response of FET amplifier.



High frequency AC equivalent model of BJT amplifier.

For the input circuit, $f_{H_1} = 1/2\pi(R_{Th_1})C_i$

Where $R_{Th_1} = R_{sig} \| R_G$

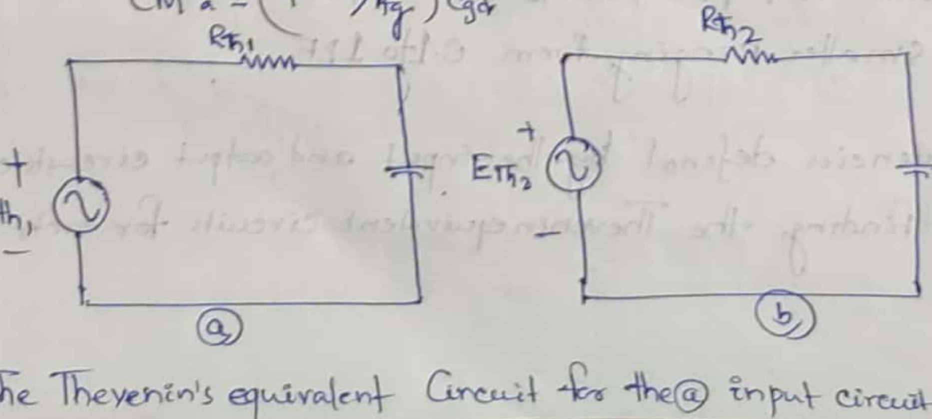
$C_i = C_{M_i} + C_{W_1} + C_{gv} = C_{W_1} + C_{be} + (1 - A_v)C_{gd}$

For the output circuit, $f_{H_o} = 1/2\pi(R_{Th_2})C_o$

Where $R_{Th_2} = R_D \| R_L \| r_d$

$C_o = C_{M_o} + C_{W_o} + C_{ds}$

$C_{M_o} = \left(1 - 1/A_v\right) C_{gd}$



The Thevenin's equivalent Circuit for the (a) input circuit (b) Output circuit