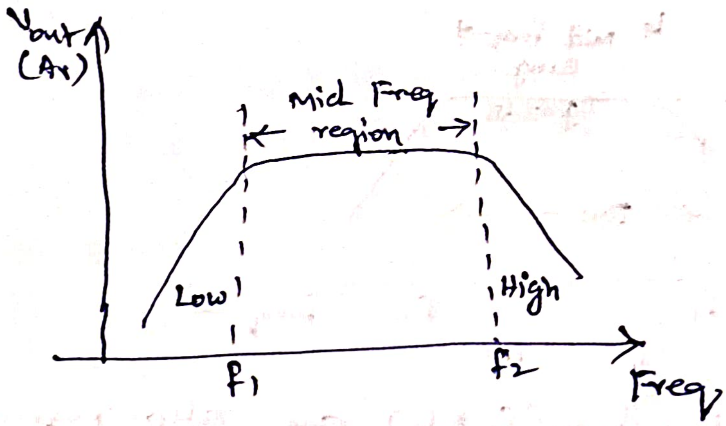
Unit-II

Frequency Response

Low Freq Response of the CS and CE amplifiers, Internal capacitive Effect and the High-Freq. Model of the MOSFET and the BJT, High Freq. Response of the CS, follower, CE, CG and cascode Amplifier.

Introduction:-

* The frequency Response curve is a plot of the voltage gain of an amplifier against the freq of I/p signal.



* I/p volt is kept constant & freq of I/p signal is continously varied.

* The o/p volt at each freq of I/p signal is noted and the gain of the amplifier is calculated.

* The o/p volt. or gain is then plotted againt frequency.

* Note : AF amplifier freq Range is 20 Hz to 20 KHz.

* The Freq response is ideal over a wide range of Mid-freq.

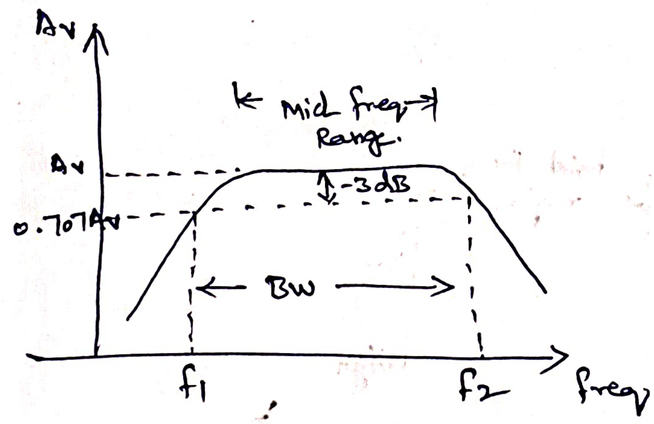
* At low & high freq ends, the gain deviated from Ideal Characteristics.

* The decrease in Voltage gain with freq is called roll-off.

* Bandwidth of the amplifier is defined as the difference b/w f_2 and f_1. (ie; $BW = f_2 - f_1$)

where, f_2 - high freq. Region

f_1 - Low freq Region.

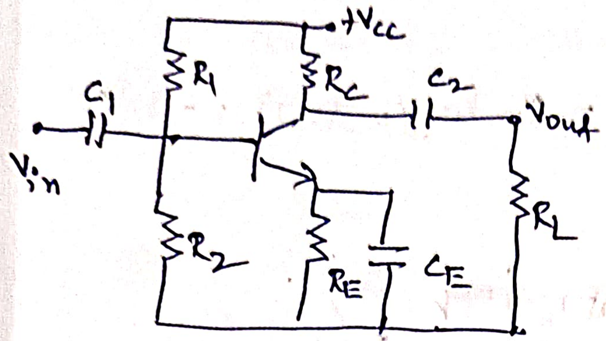


* These two freq (f_1 & f_2) are also referred to as half-power freq since gain or o/p volt. drop to 70.7% of maxi value and this represents a power level of ~~non~~ one-half the power at the reference freq in mid-freq. region.

* Volt. gain in dB = 20 log A_v

power gain in dB = 10 log A_p.

Low Freq Response of CE Amplifier:-



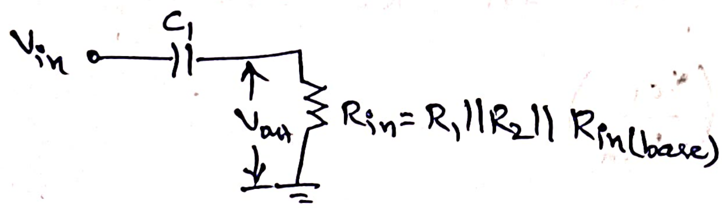
* RC N/w that affect its gain as the freq is reduced below midrange. These are,

① RC N/w formed by the C_1 and I/p impe. of amplifier.

② RC N/w formed by o/p C_2 and an collector Resistance and R_L.

③ RC N/w formed by C_E and R_E.

• I/p RC N/w!



- As per volt. divider theorem,

$$V_{out} = \left(\frac{R_{in}}{\sqrt{R_{in}^2 + X_{C_1}^2}}\right) V_{in}$$

Where, X_{C_1} – capacitance

- A critical point in the amplifier response is generally accepted to occur when the o/p volt is 70.7 % of the I/p.

ie;
$$\frac{R_{in}}{\sqrt{R_{in}^2 + X_{C_1}^2}} = 0.707 = \frac{1}{\sqrt{2}}$$

At this condition, $R_{in} = X_{C_1}$

* overall gain reduced due to the Attenuation provided by the I/p RC N/w.

$$A_V = 20 \log\left(\frac{V_{out}}{V_{in}}\right) = 20 \log(0.707) = -3\,dB$$

* Lower Critical (cut-off) freq is,

$$f_c = \frac{1}{2\pi R_{in} C_1} = \frac{1}{2\pi (R_1 \| R_2 \| h_{ie}) C_1}$$

with Source Resistance,

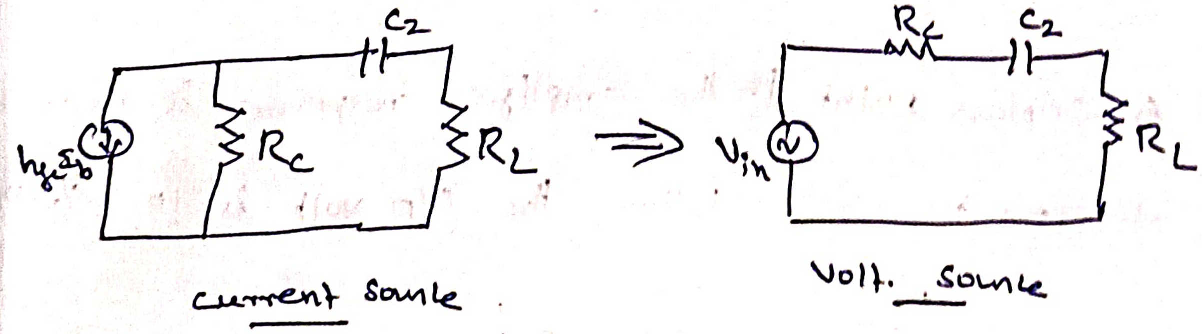
$$f_c = \frac{1}{2\pi (R_s + R_{in}) C_1}$$

* phase angle in an I/P RC ckt is,

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

2. output RC Network:-

- O/p RC N/w formed by C_2, resistance looking in at the collector and the load Resistance.

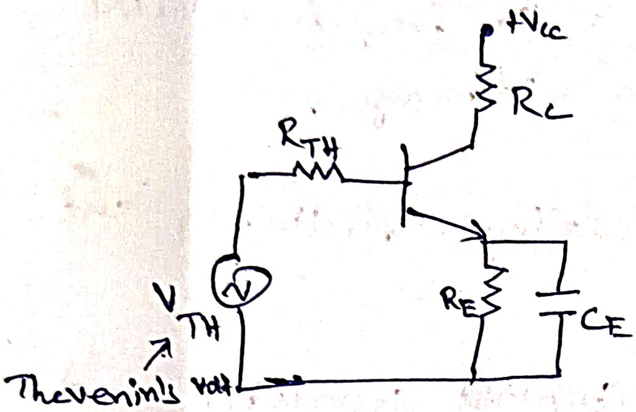


* critical freq, $f_c = \dfrac{1}{2\pi (R_C + R_L) C_2}$

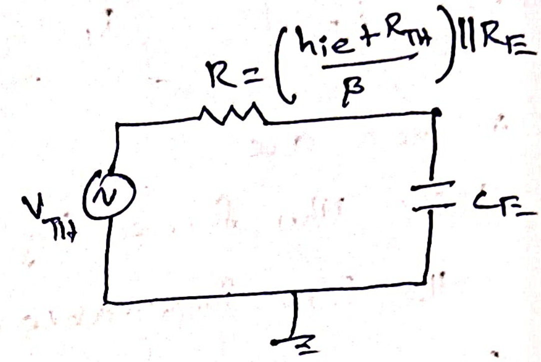
* phase angle, $\theta = \tan^{-1}\left(\dfrac{X_{C2}}{R_C + R_L}\right)$

③ Bypass N/w

Sto RC N/w formed by the emitter bypass capacitor C_E and the resistance looking in at the emitter.



$\Rightarrow$



* Here, $\frac{h_{ie}+R_{TH}}{\beta}$ is the resistance looking in at the emitter.

It is derived as follows,

$$R = \frac{V_e}{I_e} + \frac{h_{ie}}{\beta} \approx \frac{V_b}{\beta I_b} + \frac{h_{ie}}{\beta} = \frac{I_b h_{ie}}{\beta I_b} + \frac{h_{ie}}{\beta} = \frac{R_{TH}+h_{ie}}{\beta}$$

[where, $V_e = V_b$
$I_c = \beta I_b$; $I_E = I_c$

* Critical freq,

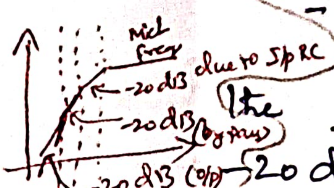
$$f_c = \frac{1}{2\pi R C_E} = \frac{1}{2\pi \left[\left(\frac{h_{ie}+R_{TH}}{\beta}\right) \| R_E\right] C_E}$$

Note:-

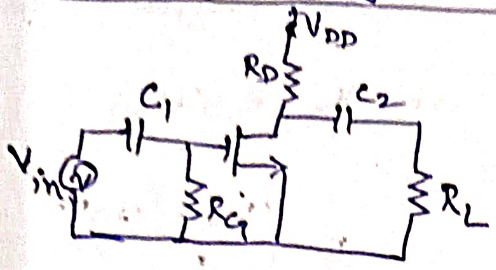
- Each N/w has a critical freq. It is not necessary that all these freq should be equal.

- The N/w which has higher critical freq than other two N/w is called dominant N/w.

- The dominant N/w determines the freq at which the overall gain of the amplifier begin to drop at -20 dB/ decade.



Low Frequency Analysis of CS Amplifier:-



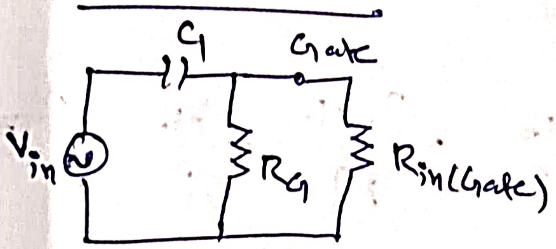
* Two RC N/w that affect its gain as the freq is reduced below midrange.

* There are,

① RC N/w formed by the I/p coupling capacitor C_1 and the I/p impedance.

② RC N/w formed by the O/p coupling capacitor and the output impedance looking in at the drain.

1. I/p RC N/w:-



* RC N/w formed by C_1 and I/p impe of the amplifier.

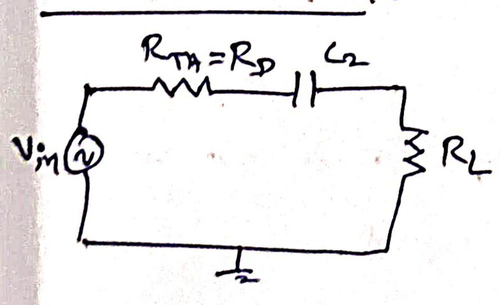
* Critical freq, $f_c = \dfrac{1}{2\pi R_{in} C_1}$

where $R_{in} = R_G \| R_{in(gate)}$

$R_{in(gate)} = \left| \dfrac{V_{GS}}{I_{GSS}} \right|$ where, I_{GSS} is gate ct

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

2. O/p RC N/w



* O/p RC N/w formed by C_2 and o/p impe. in at the drain

* Critical freq, $f_c = \dfrac{1}{2\pi(R_D + R_L)C_2}$

* $\theta = \tan^{-1}\left(\dfrac{X_{C2}}{R_D + R_L}\right)$

Note: which N/w having high critical freq is called dominant N/w.

Internal Capacitances of MOSFET and High Freq. Model:-

* High freq response of MOSFET affects due to internal Capacitances.

* Two types of Internal Capacitances in the MOSFET:

① Gate Capacitance: It is a parallel-plate capacitance formed by a gate electrode with the channel (C_{ox})

-oxide Layer act as a Capacitor dielectric

② Junction capacitance: (source-body, drain body depletion Layer capacitances).

These capacitances are due to reverse biased pn Junction by the n^+ source region and p-type substrate and n^+ drain region and p-type substrate.

① Gate Capacitance:-

There are gate Capacitance: C_{gs}, C_{gd} and C_{gb}

* Value of gate Capacitances:

- In triode region, the Channel has uniform depth

$$C_{gs} = C_{gd} = \frac{1}{2} W L C_{ox}$$

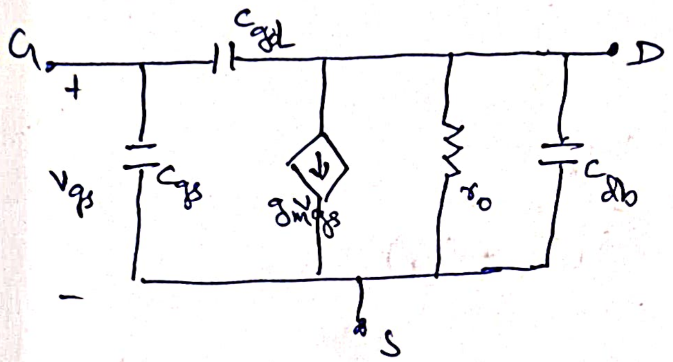
- In saturation region.

$$C_{gs} = \frac{2}{3} W L C_{ox}$$

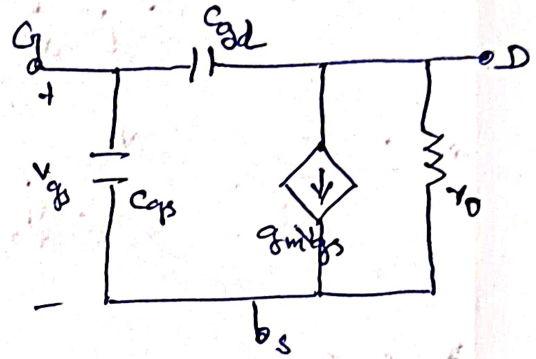
$$C_{gd} = 0$$

High-Frequency MOSFET Model :-

* Fig. shows the high freq equ ckt model of MOSFET. In this model, capacitance C_{db} can be ~~negele~~ neglected to simplify the analysis.



(a) High Freq equ. ckt Model.

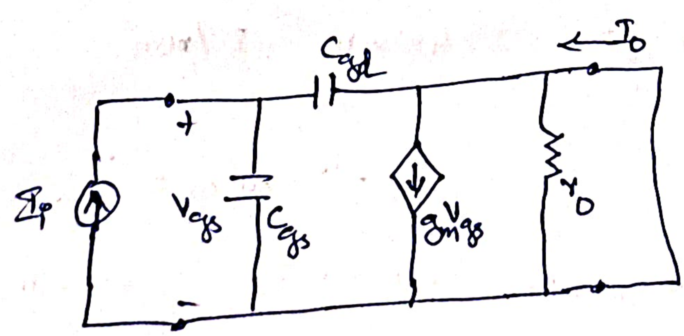


(b) High Freq equ. ckt neglecting C_{db}

Unity Gain Freq :- (f_T)

* The f_T is the freq, at which the SC - ct gain (Short ckt) of the CS MOSFET amplifier ~~gain ac~~ because unity.

* modified high-freq equ ckt to determine SC-ct gain.
  - I/p is fed with a ct-source 'I_i' and o/p is SC.



High Freq model to determine SC- ct gain.

- In cut-off Region, the Channel disappears, thus,

$$C_{gs} = C_{gd} = 0 \text{ (cut-off)}$$

However, gate-body model capacitance is,

$$C_{gb} = W L_{ov} C_{ox} \text{ (cut-off)}$$

- overlap capacitance (C_{gb} known as overlap capacitance).

$$C_{ov} = W L_{ov} C_{ox}$$

where, L_{ov} - overlap length ($0.05L$ to $0.1L$)

② Junction Capacitance :-

* Source diffusion Capacitance is,

$$C_{sb} = \frac{C_{sbo}}{\sqrt{1 + \frac{V_{SB}}{V_0}}}$$

where, C_{sbo} - Zero body-source bias,

V_{SB} - Reverse bias volt.

V_0 - Junction built in volt (0.6 to 0.8V)

* similarly, drain diffusion capacitance,

$$C_{db} = \frac{C_{dbo}}{\sqrt{1 + \frac{V_{DB}}{V_0}}}$$

* The sc-ct I_o is,

$$I_o = g_m V_{gs} - s C_{gd} V_{gs}$$

$$I_o = g_m V_{gs}$$ where, $sC_{gd}V_{gs}$ - small, so neglected.

* V_{gs} in terms of I_i is,

$$V_{gs} = \frac{I_i}{s(C_{gd} V_{gd})}$$

* $\therefore \frac{I_o}{I_i} = \frac{g_m V_{gs}}{g_m s(C_{gd} V_{gd})} = \frac{g_m}{s(C_{gs}+C_{gd})}$

* $s = jm$, then mag. of ct becomes unity at the freq.

* $\omega_T = \frac{g_m}{C_{gs}+C_{gd}} \Rightarrow f_T = \frac{g_m}{2\pi(C_{gs}+C_{gd})}$

$\therefore$ f_T propotional to g_m and Inversely proportional to Internal Capacitan

→ For n-channel MOSFET, $L = 1.0\ \mu m$, $L_{ov} = 0.05$, $W = 10\ \mu m$, $C_{ox} = 3.45 \times 10^{-3}\ F/m^2$, $I_D = 200\ \mu A$ and $k_n = 150\ \mu A/V^2$. Find f_T if MOSFET is operating in triode region.

Sol

① $C_{ox} = 3.45 \times 10^{-3}\ F/m^2 = 3.45 \times 10^{-15}\ F/\mu m^2$

② $C_{gd} = C_{gs} = \frac{1}{2} WL C_{ox} + C_{ov} = \frac{1}{2} WL C_{ox} + W L_{ov} C_{ox}$

$= \left(\frac{1}{2} 10 \times 1 \times 3.45 \times 10^{-15}\right) + 10 \times 0.05 \times 3.45 \times 10^{-15}$

$= 17.25 \times 10^{-15} + 1.725 \times 10^{-15} = 18.975 \times 10^{-15}\ F = 18.975\ fF$

③ $g_m = \sqrt{2k_n'}\sqrt{W/L}\sqrt{I_D} = \sqrt{2 \times 150 \times 10^{-6}}\sqrt{10}\sqrt{1}\sqrt{200 \times 10^{-6}} = 0.7746\ mA/V$

④ $f_T = g_m / (2\pi(C_{gs}+C_{gd})) = 0.7746 \times 10^{-3} / (2\pi \times (18.975 + 18.975) \times 10^{-15}) = 3.24\ GHz$