CH-5 Frequency Response of BJT and FET.

INTRODUCTION

The analysis so far has been limited to a particular range of frequencies by ignoring the effects of the capacitive elements and reducing the analysis to only resistive elements and sources of independent & controlled variety.

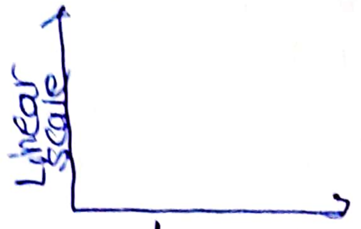
* In this chapter we will investigate the frequency effects introduced by
  1. the capacitive elements of the network (C_C, C_E & C_S) at low frequencies and
  2. the smaller capacitive elements of the active device at high frequencies.

* The frequency response analysis of amplifiers extend over a wide range of frequencies, a logarithmic scale will be defined & used through out the analysis.

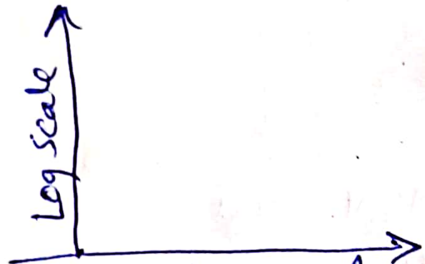
LOGARITHM:- The use of logarithmic scale makes it comfortable plotting the frequency response of Amplifiers b/n wide limits.

Advantages:-
1. The frequency response plot is compressed w/o loss of information
   Ex A frequency of 10,000 Hz in linear scale becomes $\log_{10} 10^4 = 4$ in logarithmic scale. Thus, the frequency plot is compressed
2. The problem of dealing with huge numbers is overcome.

- The use of log scales can significantly expand the range of variation of a particular variable on the graph.
- Most graph paper available is of the semilog or double-log variety



a) Semi-log graph



b) Double log graph

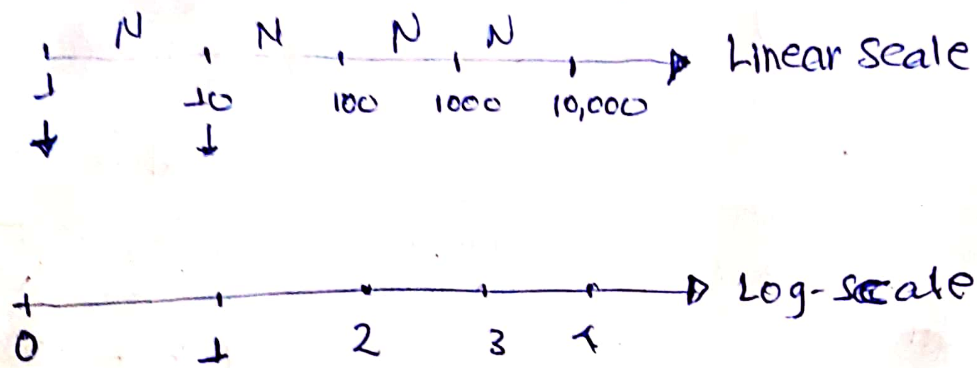


Fig: Conversion of linear scale to log scale

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Decibels :- Decibel is used to compare two power levels on a logarithmic basis.

- The unit "bel" (B) is defined relating two power levels P_1 and P_2 as

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

* As "bel" was found to be a large unit of measurement, the "decibel" (dB) is defined where 10 decibels = 1 bel
* Hence

$$G_{dB} = 10 \log_{10}(P_2/P_1) \text{ dB}$$

* $G_{dB} \rightarrow$ Is a measure of difference in magnitude b/n two power levels, say o/p power level & input power level

Quite often the o/p power level (P_1) is taken as a reference power level ($P_1 = 1mW$, at $R_1 = 600\Omega$) in electronics

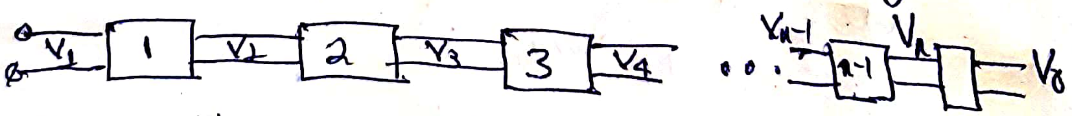
$$G_{dBm} = 10 \log_{10} \frac{P_2}{1mW} \text{ dBm}$$

In terms of voltage

$$G_{dB} = 10 \log_{10} P_2/P_1 = 10 \log_{10} \frac{V_2^2/R_i}{V_1^2/R_i}$$

$$= 20 \log \frac{V_2}{V_1} \text{ dB}, \quad \text{where } R_i - \text{o/p resistance}$$

The advantage of logarithmic r/ship is that the overall gain of a cascade s/s is simply the sum of individual gains.



The overall gain for "n" stage s/s is given by

$$G = G_1 \times G_2 \times G_3 \times \cdots \times G_{n-1} \times G_n$$

or

$$A_V = A_{V1} \times A_{V2} \times A_{V3} \times \cdots \times A_{V_{n-1}} \times A_{V_n}$$

$$\frac{V_o}{V_1} = \frac{V_2}{V_1} \times \frac{V_3}{V_2} \times \frac{V_4}{V_3} \times \cdots \times \frac{V_n}{V_{n-1}} \times \frac{V_o}{V_n}$$

In logarithmic r/ship

$$G_{dB} = 20 \log \frac{V_o}{V_1} = 20 \log \frac{V_2}{V_1} + 20 \log \frac{V_3}{V_2} + \cdots + 20 \log \frac{V_o}{V_n}$$

where

$G_{dB} = G_{V_1} + G_{V_2} + G_{V_3} + \dots + G_{V_n}$ dB

Ex

Voltage gain V_o/V_I	dB-level
0.5	-6
0.707	-3
1	0
2	6
10	20
40	32
100	40
1000	60
10,000	80

Ex Find the magnitude gain corresponding to a voltage gain of

a) 100 dB

b) 200 dB

Soln (a) $G_{dB} = 20 \log V_2/V_1 \Rightarrow 100 = 20 \log V_2/V_1$

$\log \frac{V_2}{V_1} = \frac{100}{20} = 5$

$\Rightarrow \frac{V_2}{V_1} = 10^5$

(b) $20 \log V_2/V_1 = 200$

$\log V_2/V_1 = 10$

$V_2/V_1 = 10^{10}$

Ex A three-stage Amplifier has a first-stage-voltage gain of 30; a second stage voltage gain of 200 & third stage gain of 400. Find the total voltage gain in dB

Soln 1st-stage: $G_1 = 20 \log 30 = 29.54$ dB

2nd-stage: $G_2 = 20 \log 200 = 46$ dB

3rd-stage: $G_3 = 20 \log 400 = 52$ dB

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Over gain

$$G_{dB} = G_1 + G_2 + G_3 = 29.54 + 46 + 52 = 127.54 \, dB$$

Ex The Input power to a device is 10,000W at a voltage of 1000V. The o/p power is 500W, while the o/p impedance is 20Ω.

a) Find the power gain in dB
b) Find the Voltage gain in dB
c) Explain why parts (a) & (b) agree or disagree

Soln

a) $G_{dB} = 10 \log \frac{P_o}{P_i} = 10 \log \frac{500W}{10{,}000W} = 10 \log \frac{1}{20}$

$= -10 \log 20 = -10(1.301) = -13.01 \, dB$

b) $G_V = 20 \log V_2/V_1 = 20 \log \frac{\sqrt{P_o R_o}}{V_1} = 20 \log \frac{\sqrt{500 \times 20}}{1000}$

$= 20 \log \frac{100}{1000} = -20 \log 10 = -20 dB$

c) $R_i = \frac{V_i^2}{P_i} = \frac{(1kV)^2}{10 kW} = \frac{10^6}{10^4} = 100\Omega \neq R_o = 20\Omega$

Ex Determine GdBm for an o/p power level of 25W

Soln $G_{dB} = 10 \log \frac{25W}{1mW} = 10 \log 25 \times 10^3$

$= 10 \log 25 + 30 = 13.98 + 30 = 43.98 \, dBm$

Ex (a) The total dB gain of a 3-stage s/s is 120dB. Determine the dB gain of each stage if the 2nd stage has twice the dB gain of the 1st & the third stage has 2.7 times the dB gain of the 1st.

(b) Determine the Voltage gain of each stage

Soln (a) $G_{dB} = G_1 + G_2 + G_3 = G_1 + 2G_1 + 2.7G_1 = 5.7G_1$

$\Rightarrow 5.7 G_1 = 120 \Rightarrow G_1 = 21.05 dB$

$G_2 = 2 \times 21.05 = 42.1 dB$

$G_3 = 2.7 \times 21.05 = 56.835 \, dB$

b) Stage-1

$$\frac{V_{o1}}{V_1} = \frac{V_2}{V_1} = 10^{\frac{A_V}{20}} = 10^{\frac{21.05}{20}} = 10^{1.0526}$$

$$= 11.288$$

Stage-2

$$\frac{V_{o2}}{V_{i2}} = \frac{V_3}{V_2} = 10^{\frac{42.1}{20}} = 127.35$$

Stage-3 $$\frac{V_{o3}}{V_{i3}} = \frac{V_o}{V_3} = 10^{\frac{56.835}{20}} = 694.624$$

Ex. An Amplifier has a voltage gain of 15 dB. If the o/p signal voltage is 0.8V, determine the o/p voltage

Soln $$G_V = 20 \log \frac{V_o}{V_I}$$

$$15\,dB = 20 \log \frac{V_o}{V_I}$$

$$\frac{V_o}{V_I} = 10^{15/20} = 10^{0.75}$$

$$V_o = V_I\, 10^{0.75}$$

$$= 0.8 \times 10^{0.75} = 4.5V$$

General Frequency considerations

All amplifier gain factors are functions of signal frequency. Up to this point, the analysis has been for the MID-band frequency spectrum. That is, we have assumed that the signal frequency is high enough that coupling & bypass capacitors can be treated as short ccts & at the same time, we have assumed that the signal frequency is low enough that parasitic capacitances can be treated as open ccts.

* In general, an amplifier gain factor versus frequency will resemble that shown below

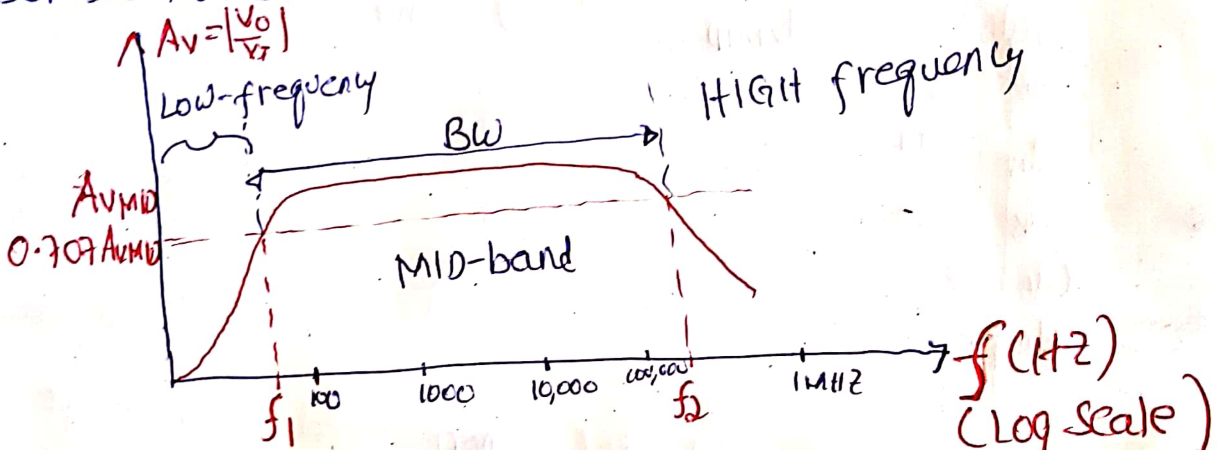


Fig: Gain Vs Frequency

* The frequencies f_1 & f_2 are generally called corner frequency cut-off, band, break or half power frequencies.

$$P_{O MID} = \frac{|V_O^2|}{R_O} = \frac{|A_{VMID} V_I|^2}{R_O}$$

and at half power frequencies

$$P_{O HPF} = \frac{|0.707 A_{VMID} V_I|^2}{R_O} = 0.5 \frac{|A_{VMID} V_I|^2}{R_O}$$

$$P_{O HPF} = 0.5 P_{O MID}$$

* The Bandwidth is given by

$$BW = f_2 - f_1$$

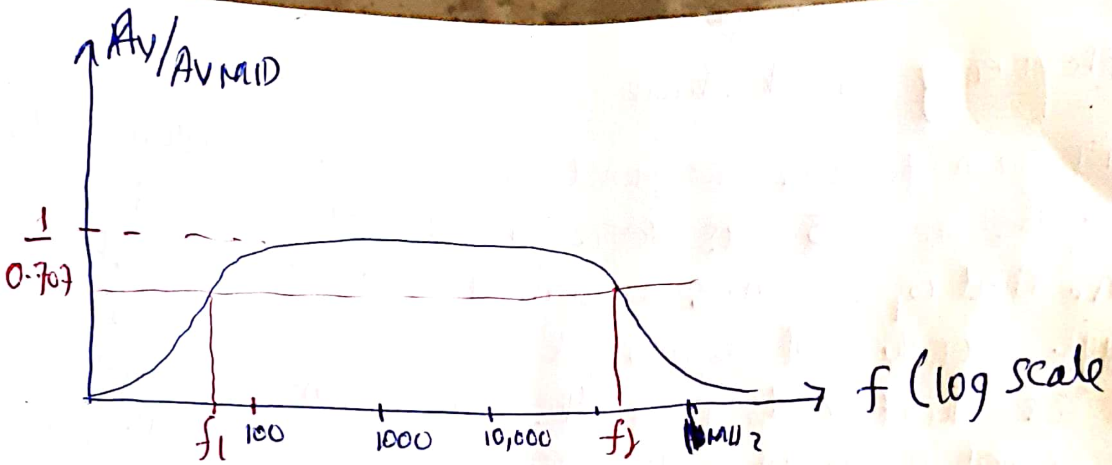


Fig: Normalized gain Vs frequency

* A decibel plot can be obtained as

$$\frac{A_V}{A_{VMID}} = 20 \log \left(\frac{A_V}{A_{VMID}} \right)$$

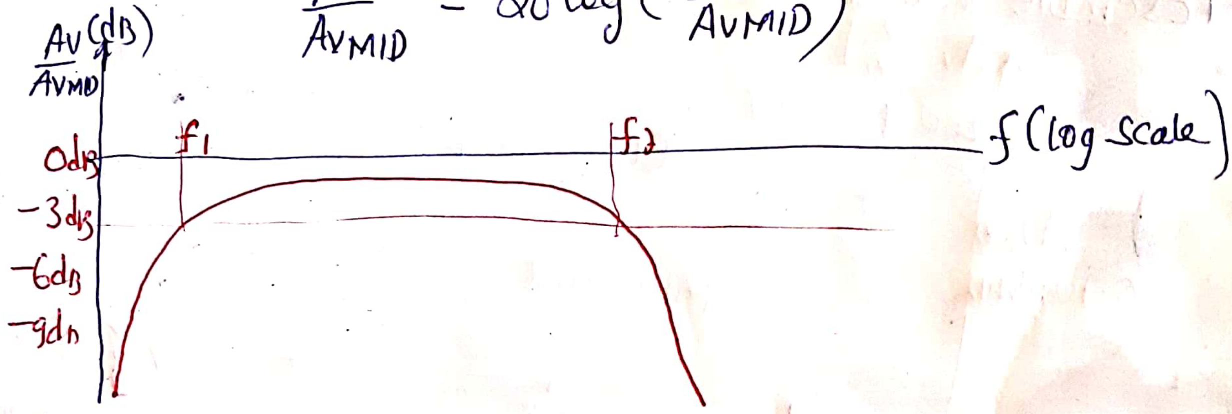


Fig: Decibel plot of normalized gain Vs frequency

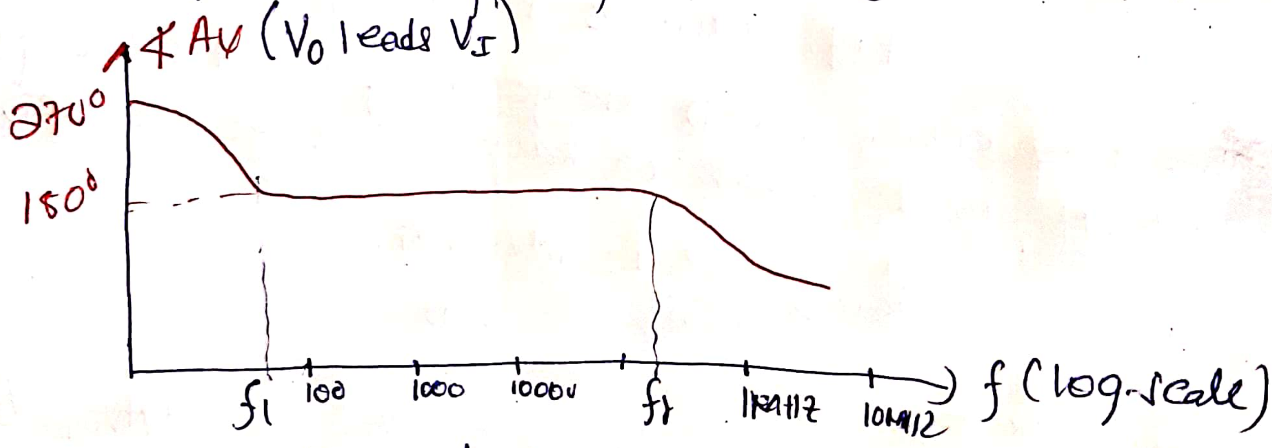


Fig: phase plot

Equivalent ccts

MIDBAND RANGE

* Coupling & bypass capacitors are treated as short cct
* Stray & transistor capacitors are treated as open cct

Low-frequency Range

* Coupling and Bypass capacitors must be included in the Equivalent cct
* The stray and transistor capacitance are treated as open cct

HIGH-Frequency Range

* Coupling & By pass capacitors are treated as short cct
* The stray and transistor capacitance must be included in the analysis.

Low-Frequency Analysis

* In this region, it is the R-C Combination formed by C_c, C_E and C_S and the n/w resistive parameters that determine the cut-off frequencies.
* The Amp cct behaves as a simple High pass cct as shown below

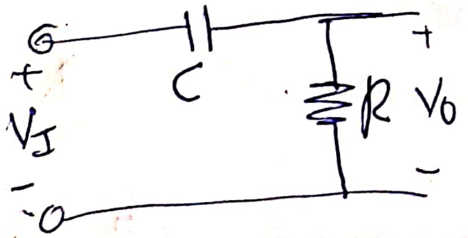
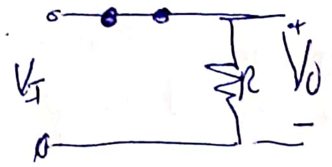


Fig: Equivalent cct for lower cut-off frequencies

* The capacitor behaves as short cct for very high frequency & open for a very low frequency

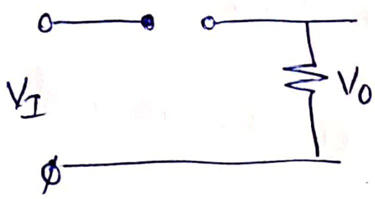
* For HIGH Frequency



$\Rightarrow V_o = V_I$

$$X_c = \frac{1}{2\pi f c} = 0\,\Omega$$

For $f = 0$

* 

$\Rightarrow V_o = 0V$

$$X_c = \frac{1}{2\pi f c} = \infty\,\Omega$$

* A typical frequency response b/n the two extremes is as shown below

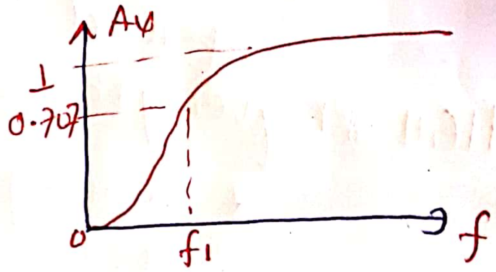


Fig: Low-frequency response

* The o/p voltage is given by

$$V_o = \frac{R V_I}{R \pm jX_c} = \frac{R V_I}{R - jX_c}$$

* The magnitude of Vout is given by

$$|V_{out}| = \frac{R\,V_{in}}{\sqrt{R^2 + X_c^2}}$$

For the special case, when $X_c = R$

$$|V_{out}| = \frac{1}{\sqrt{2}}|V_{in}|$$

$$A_V = \left|\frac{V_o}{V_{in}}\right| = 0.707 \text{ at } X_c = R$$

$\Rightarrow$

$$f_1 = \frac{1}{2\pi RC} \rightarrow \text{corner frequency.}$$

In terms of logs,

$$G_V = 20 \log A_V = 20 \log \frac{1}{\sqrt{2}} = -3\,dB$$

* The Voltage gain, A_V, can be written as

$$A_V = \frac{V_o}{V_I} = \frac{R}{R - jX_C} = \frac{R}{R - j\frac{1}{\omega C}} = \frac{1}{1 - j\frac{1}{2\pi f C R}}$$

$$= \frac{1}{1 - j(f_1/f)}$$

* The magnitude and phase of A_V are

$$A_V = \underbrace{\frac{1}{\sqrt{1+(\frac{f_1}{f})^2}}}_{\text{magnitude}} \quad \underbrace{\angle \tan^{-1} f_1/f}_{\text{phase \& by which } V_o \text{ leads } V_I}$$

* In decibel the gain is given by

$$A_{V_{dB}} = 20 \log \frac{1}{\sqrt{1+(f_1/f)^2}}$$

$$= -10 \log 1+(f_1/f)^2$$

* For $f \ll f_1$

$$A_{V_{dB}} \simeq -20 \log f_1/f$$

at $f = \frac{1}{2} f_1 \Rightarrow A_V = -6\,dB$ at $f = f_1$, $A_V = 0\,dB$

$f = \frac{1}{4} f_1 \Rightarrow A_V = -12\,dB$

$f = \frac{1}{10} f_1 \Rightarrow A_V = -20\,dB$

* The plot is shown below

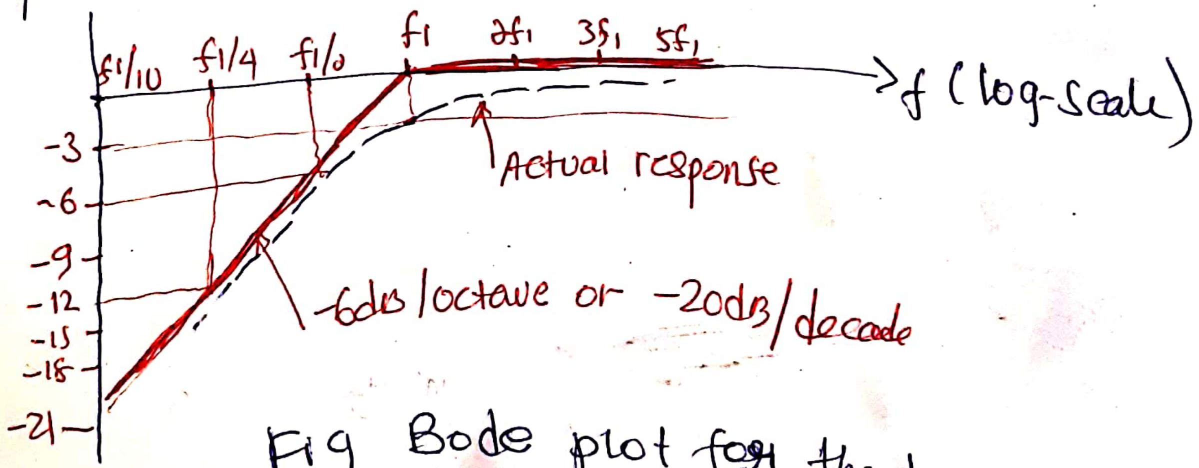


Fig Bode plot for the low-frequency region

* The piece-wise linear plot is called Bode plot of the magnitude Vs frequency

Remarks

① A change in frequency by a factor of 2, Equivalent to 1 octave, results in a 6-dB change in the ratio

② For a 10 : 1 change in frequency, Equivalent to 1 decade, there is a 20dB change in the ratio

The phase angle is determined by

$$\theta = \tan^{-1} f_1/f$$

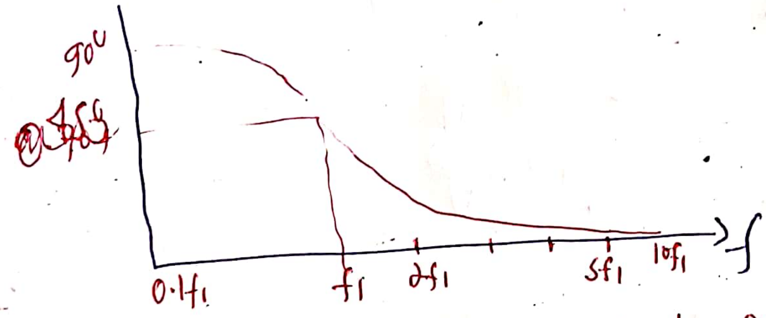
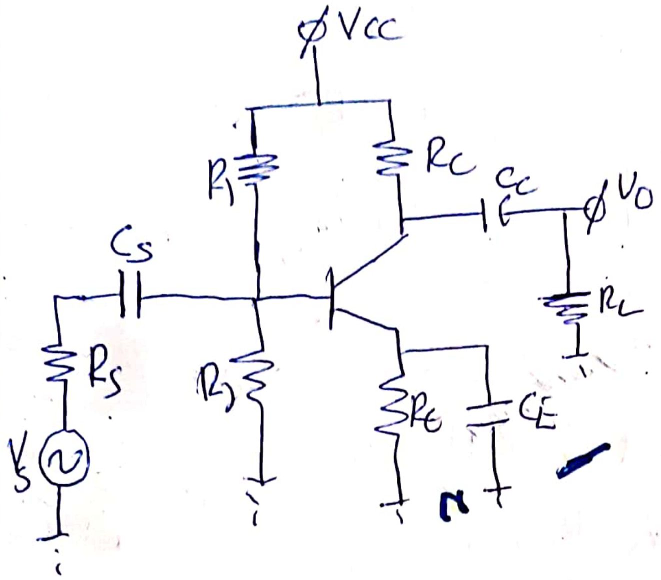


Fig :- phase plot Vs frequency

Low Frequency Response of BJT Amplifier

Consider the voltage-divider BJT bias configuration



Remark

* The analysis can be extended to any BJT configuration
* C_S, C_E, C_C will no longer be considered as short cct for low frequency analysis.
* parasitic capacitance of the device can be considered as open cct.

Analysis :- The effect of each capacitors is treated separately by considering the other two capacitors as a short circuit.

C_S :- C_C & C_E are considered as short circuit

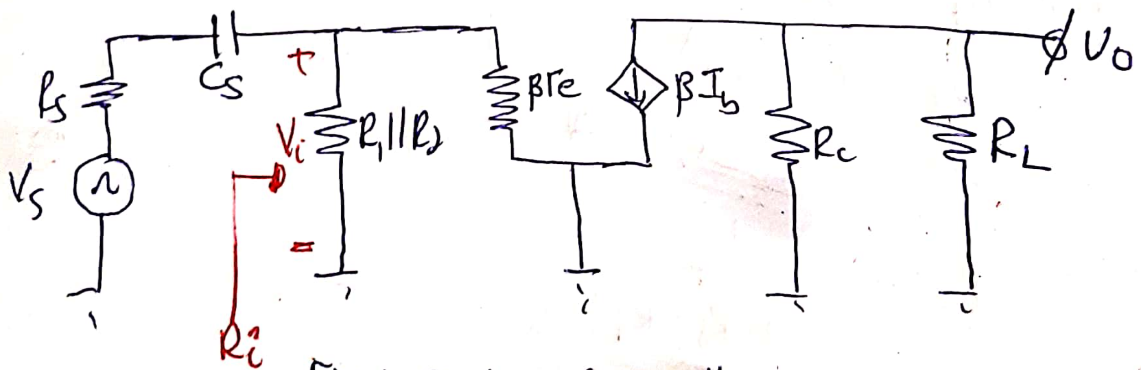


Fig: Determining the effect of C_S

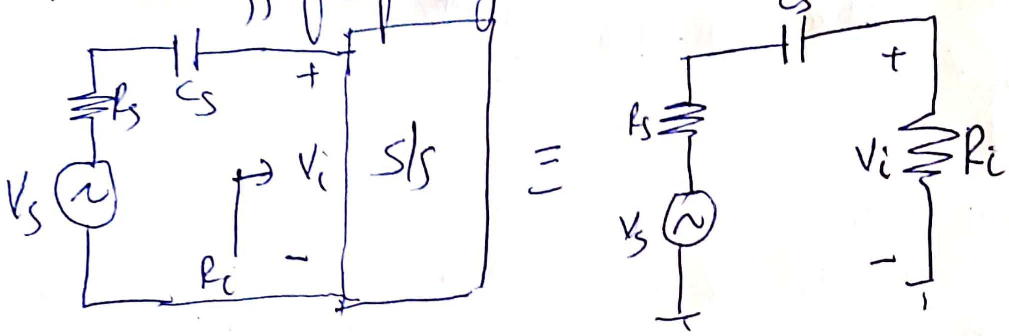
$$R_i = (R_1 \| R_2) \| (\beta r_e)$$

and the i/p voltage, V_i, is given by

$$V_i = \frac{R_i V_S}{R_S + R_i - jX_{C_S}}$$

CamScanner

The cut-off frequency due to C_s can be obtained as



$$\frac{V_i}{V_s} = \frac{R_i}{R_s + R_i + \frac{1}{sC_s}} = \frac{R_i \{ sC_s \}}{1 + s(R_s+R_i)C_s}$$

$$= \left(\frac{R_i}{R_s+R_i}\right)\left(\frac{s(R_s+R_i)C_s}{1 + s(R_s+R_i)C_s}\right)$$

$$= \left(\frac{R_i}{R_s+R_i}\right)\left(\frac{1}{1 + \frac{1}{s(R_s+R_i)C_s}}\right)$$

The frequency response is given by

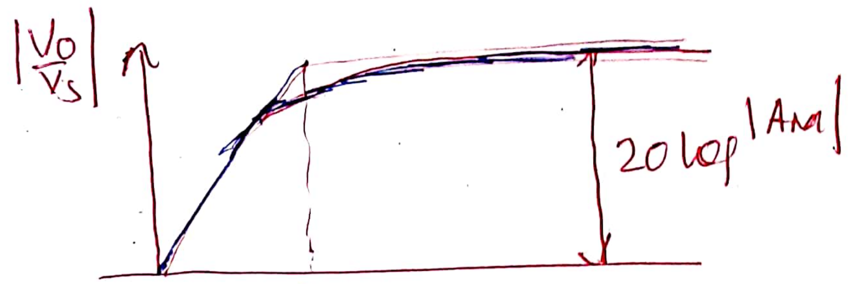
$$\frac{V_I}{V_s} = \left(\frac{R_i}{R_s+R_i}\right)\left(\frac{1}{1 - j\left(\frac{f_o}{f}\right)}\right)$$

Where $$f_o = \frac{1}{2\pi(R_s+R_i)C_s}$$

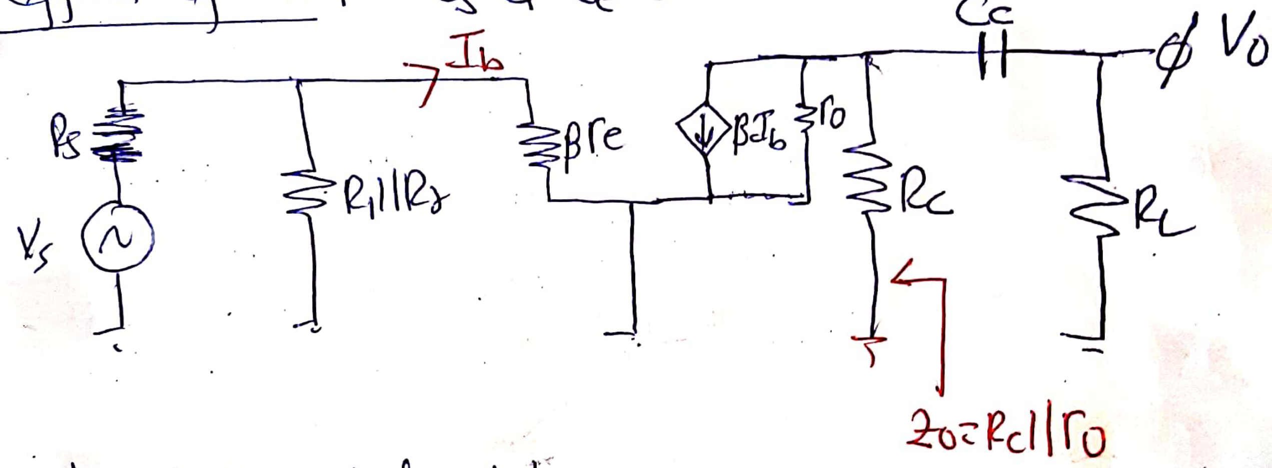
The overall frequency response is given by

$$\frac{V_o}{V_s} = \underbrace{-\left(\frac{R_c \| R_L}{r_e}\right)}_{\text{Mid band gain}} \underbrace{\left(\frac{R_i}{R_s+R_i}\right)\left(\frac{1}{1 + \frac{1}{s(R_s+R_i)C_s}}\right)}_{\text{the effect of } C_s}$$

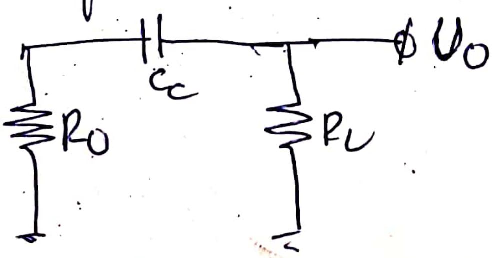
$$f_{LS} = \frac{1}{2\pi(R_S + R_i)C_S}$$



The effect of C_C :- C_S & C_E are assumed as short ccted



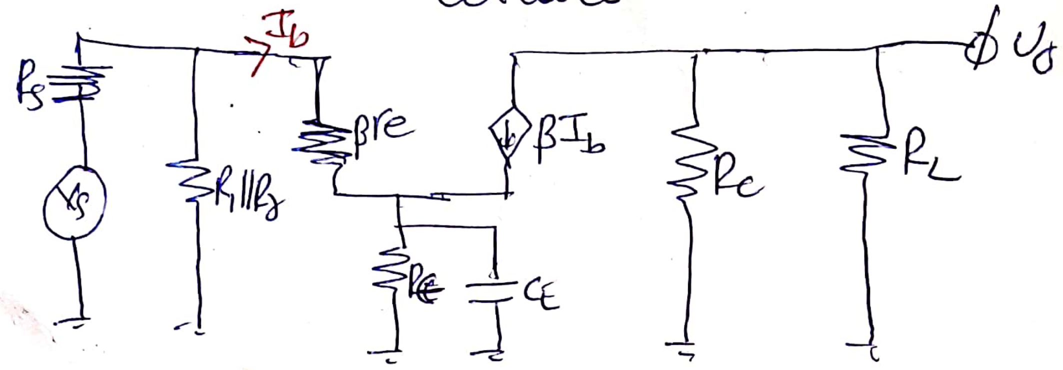
The reduced equivalent cct becomes



The required cut-off frequency is given by

$$f_{LC} = \frac{1}{2\pi(R_o + R_L)C_C}$$

The effect of CE :- C_s & C_c are considered as short circuit.



$$f_{LE} = \frac{1}{2\pi R_e C_E}$$

where $R_e = R_E \| \left(\frac{R_s'}{\beta} + r_e \right)$

$$R_s' = R_s \| R_1 \| R_2$$

Ex Determine the cut-off frequencies for the network shown using the following parameters

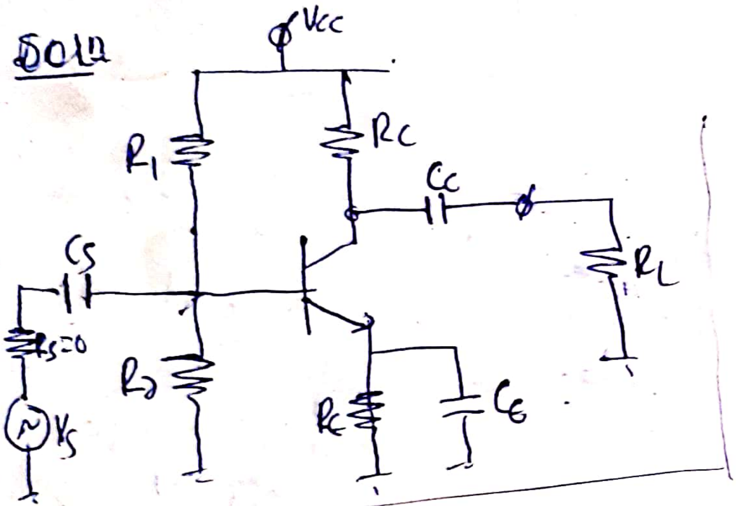
$C_S = 10\mu F$, $C_E = 20\mu F$ $C_C = 1\mu F$ $R_C = 4k\Omega$

$R_1 = 40k\Omega$ $R_2 = 10k\Omega$ $R_E = 2k\Omega$

$R_L = 2.2k\Omega$

$\beta = 100$ $r_o = \infty\Omega$ $V_{CC} = 20V$

Soln



Soln

Test condition

$\beta R_E = 100 \times 2k\Omega = 200k\Omega$

$10R_2 = 100k\Omega$

$\beta R_E >> 10R_2$ ✓ condition met

* we use approximate method

$$V_B = \frac{R_2}{R_1+R_2}V_{CC} = \frac{10k\Omega \times 20V}{10k\Omega + 40k\Omega} = 4V$$

$$V_E = V_B - V_{BE} = 4V - 0.7V = 3.3V$$

$$I_E = \frac{V_E}{R_E} = \frac{3.3V}{2k\Omega} = 1.65mA$$

$$r_e = \frac{V_T}{I_E} = \frac{26mV}{1.65mA} = \cancel{17.76\Omega} = \underline{15.76\Omega}$$

$$\beta r_e = 100 \times 15.76\Omega = 1.576k\Omega$$

Midband gain, $A_M = \frac{V_o}{V_i} = \frac{-R_C \| R_L}{r_e} = \frac{(4k\Omega)\|(2.2k\Omega)}{15.76\Omega} \cong -90$

$\underline{C_S}$ $R_i = R_1 \| R_2 \| \beta r_e = 40k\Omega \| 10k\Omega \| 1.576k\Omega \cong 1.32k\Omega$

$$f_{LS} = \frac{1}{2\pi R_i C_S} = \frac{1}{2\pi \times 1.32\times10^3 \times 10\times10^{-6}}$$

$$= 12.06\,Hz$$

C_C $\quad R_o = R_C || r_o \cong R_C = 4k\Omega$

$$f_{LC} = \frac{1}{2\pi(R_o + R_L)C_C} = \frac{1}{6.28(4k\Omega + 2.2k\Omega)1\mu F}$$

$$= 25.68\ Hz$$

C_E $\quad R_e = R_E || \left(\frac{R_1||R_2}{\beta} + r_e\right)$

$$= 2k\Omega || \left(\frac{8k\Omega}{100} + 15.76\Omega\right)$$

$$= 91.38\Omega$$

$$f_{LE} = \frac{1}{2\pi R_e C_E} = \frac{1}{6.28 \times 91.38 \times 20\mu F} = 87.13\ Hz$$

Since $f_{LE} >> f_{LC}$ or f_{LS}, the bypass capacitor C_E determines the lower cut-off frequency of the Amplifier.

Ex: Repeat the above Example with a source resistance $R_S = 1k\Omega$

(b) Sketch the frequency response using a bode plot

Soln a) The dc-condition remains the same

$r_e = 15.76\Omega$

$\beta r_e = 1.576\ k\Omega$

Mid band gain, $A_M = \frac{V_o}{V_s} = \frac{-R_C||R_L}{r_e} = -90$

$R_i = R_1 || R_2 || \beta r_e = 1.32\ k\Omega$

Overall gain $= A_V = A_M * \frac{R_i}{R_S + R_i}$

$$= -90 * \frac{1.32k\Omega}{2.32k\Omega} = -51.21$$

C_S : $\quad f_{LS} = \frac{1}{2\pi(R_S + R_i)C_S} = \frac{1}{2\pi(2.32k\Omega) \times 10\mu F}$

$$= \frac{10.0}{6.28 \times 2.32} \cong 6.86\ Hz$$

C_C : $f_{LC} = \dfrac{1}{2\pi(R_C+R_L)C_C} = \dfrac{1}{6.28(6.2k\Omega)\times10^{-6}F}$

$= 25.68 Hz$ as before

C_E : $R_e = R_E \| \left(\dfrac{R_S \| R_1 \| R_2}{\beta} + r_e \right)$

$= 2k\Omega \| \left(\dfrac{0.889k\Omega}{100} + 15.76\Omega \right)$

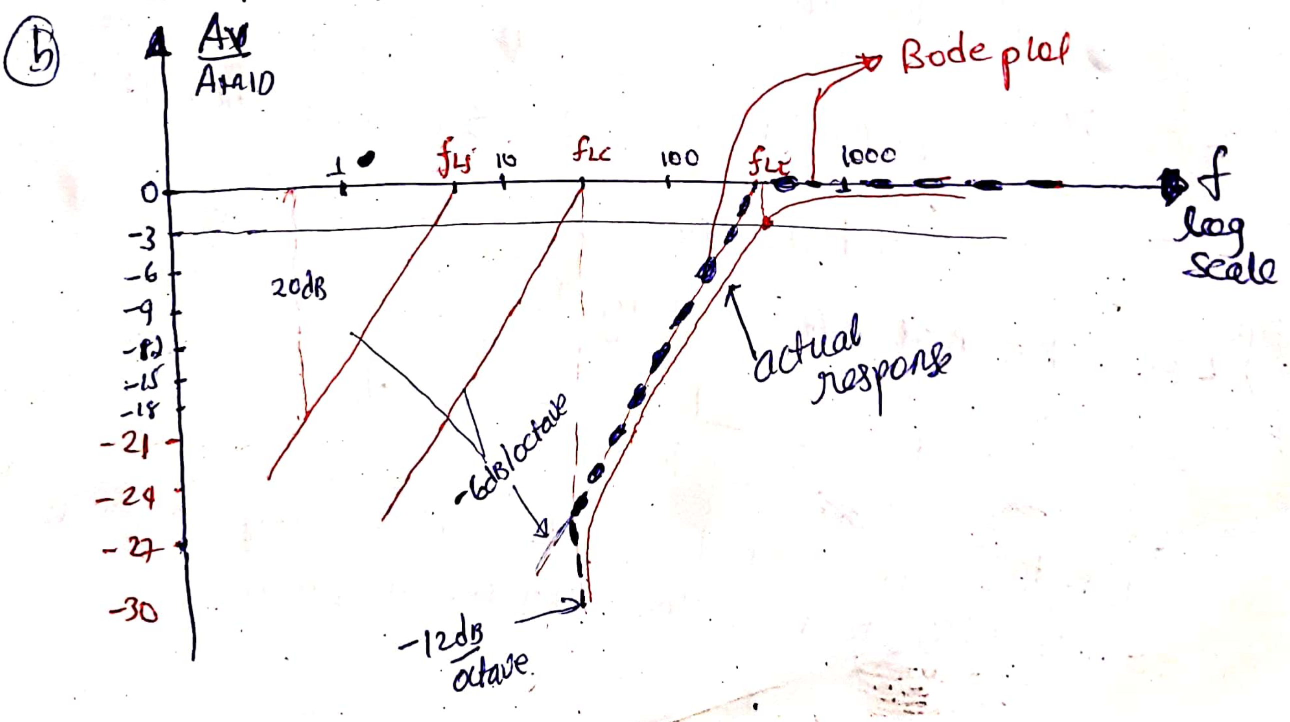
$= 24.35\Omega$

$f_{LE} = \dfrac{1}{2\pi R_e C_E} = \dfrac{1}{6.28 * 24.35 * 20\times10^{-6}}$

$\approxeq 327 Hz$ Vs $87.13 Hz$ w/o R_S

The result is a severe reduction in overall gain, but a corresponding reduction in the lower cut-off frequency.

(b)



Ex: Repeat the analysis of the above example with $r_o = 40k\Omega$.

Soln $r_e = 15.76\Omega$

$$Av_{MID} = \frac{-R_C \| R_L \| r_o}{r_e} = -\frac{4k\Omega \| 2.2k\Omega \| 40k\Omega}{15.76\Omega}$$

$$= -86.97$$

C_S: f_{LS}: r_o donot affect R_i

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

$$f_{LS} = \frac{1}{2\pi(2.32k\Omega)10\mu F} = 6.86 Hz$$

C_C: Now $R_o = R_C \| r_o = 4k\Omega \| 40k\Omega = 3.636 k\Omega$

$$f_{LC} = \frac{1}{2\pi(R_o + R_L)C_C} = \frac{1}{2\pi(3.636k\Omega + 2.2k\Omega)1\mu F}$$

$$= 27.28 Hz$$

f_{LE}: R_e not affected by r_o

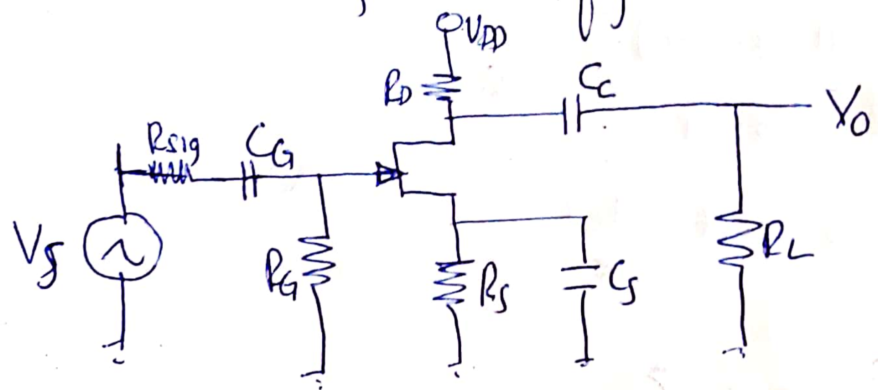
$$f_{LE} = \frac{1}{2\pi R_e C_E} = 327 Hz$$

In total the effect of r_o on the frequency response is to slightly reduce the mid band gain.

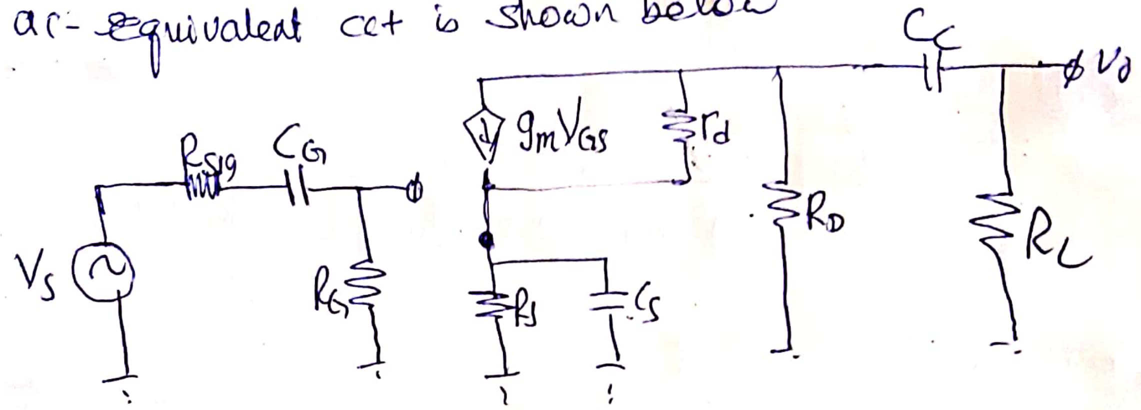
2e

Low-frequency Response – FET Amplifier

Consider the self bias configuration



The ac-equivalent cct is shown below



C_G :- C_s & C_c are considered short-cct

$$f_{LG} = \frac{1}{2\pi (R_{sig} + R_i) C_G}$$

where $R_i = R_G$

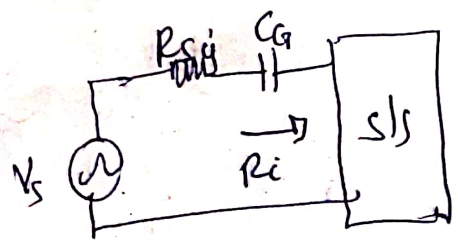
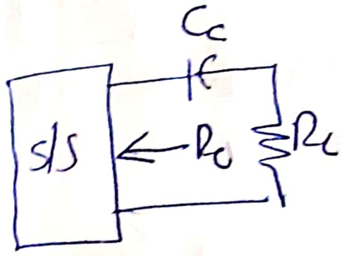


Fig: Determining the effect of C_G

C_C :- C_G & C_S are short ccted



$$f_{L_C} = \frac{1}{2\pi (R_o + R_L) C_C}$$

where $R_o = R_D \| r_d$

C_S :- C_C & C_G are short ccted

$$f_{LS} = \frac{1}{2\pi R_{eq} C_S}$$

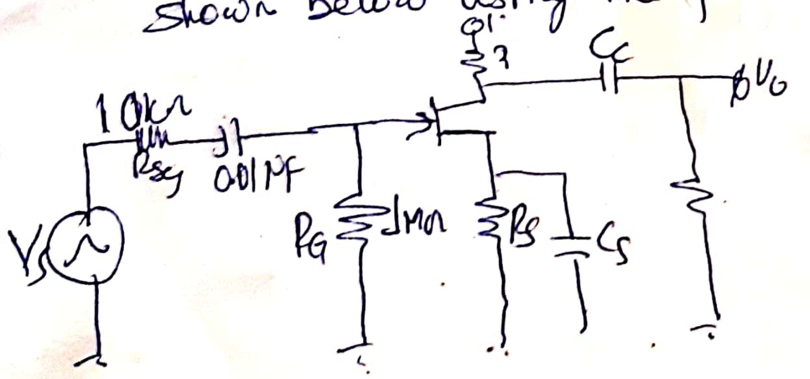
where

$$R_{eq} = \frac{R_S}{1 + R_S(1 + g_m r_d)/(r_d + R_D \| R_L)}$$

for $r_d = \infty \Omega$, R_{eq} becomes

$$R_{eq} = R_S \| \frac{1}{g_m}$$

Ex a) Determine the lower cut-off frequency for the n/w shown below using the following parameters



$C_G = 0.01 \mu F$
$C_S = 2 \mu F$
$C_C = 0.5 \mu F$
$R_{sg} = 10 k\Omega$
$R_G = 1 M\Omega$
$R_D = 4.7 k\Omega$
$R_S = 1 k\Omega$
$R_L = 2.2 k\Omega$
$I_{DSS} = 8 mA$
$V_P = -4V$
$V_{DD} = 20V$
$r_d = \infty$

b) Sketch the frequency response using Bode-plot

$2\pi R_{eq} C_S$ $\quad 2\pi(333.33\Omega) 2\mu F$
$= 238.73 Hz$

Soln DC - Analysis

$$I_D = I_{DSS}(1 - V_{GS}/V_p)^2 = 8(1 + V_{GS}/4)^2$$

$$V_{GS} = -I_D R_S = -I_D$$

$$I_D = 8\left(1 - \frac{I_D}{4}\right)^2 = 8\left(1 - \frac{I_D}{2} + \frac{I_D^2}{16}\right)$$

$$I_D = 8 - 4I_D + \frac{I_D^2}{2}$$

Solving the quadratic equation

$$V_{GSQ} = -2V \quad \& \quad I_{DQ} = 2mA$$

$$g_{mo} = \frac{2 I_{DSS}}{|V_p|} = \frac{2 \times 8mA}{4V} = 4m\mho$$

$$g_m = g_{mo}\left(1 - \frac{V_{GSQ}}{V_p}\right) = 4m\mho\left(1 - \frac{2}{4}\right) = 2m\mho$$

C_G

$$f_{LG} = \frac{1}{2\pi(R_{sig} + R_i)C_G} = \frac{1}{2\pi(10k\Omega + 1M\Omega)(0.01\mu F)}$$

$$= 15.8\,Hz$$

C_C

$$f_{LC} = \frac{1}{2\pi(R_o + R_L)C_C} = \frac{1}{2\pi(4.7k\Omega + 2.2k\Omega)(0.5\mu F)}$$

$$= 46.13\,Hz$$

C_S -

$$R_{eq} = R_S \,||\, \frac{1}{g_m} = 1k\Omega \,||\, \frac{1}{2m\mho} = 1k\Omega \,||\, 0.5k\Omega$$

$$= 333.33\,\Omega$$

$$f_{LS} = \frac{1}{2\pi R_{eq} C_S} = \frac{1}{2\pi(333.33\Omega)2\mu F}$$

$$= 238.73\,Hz$$

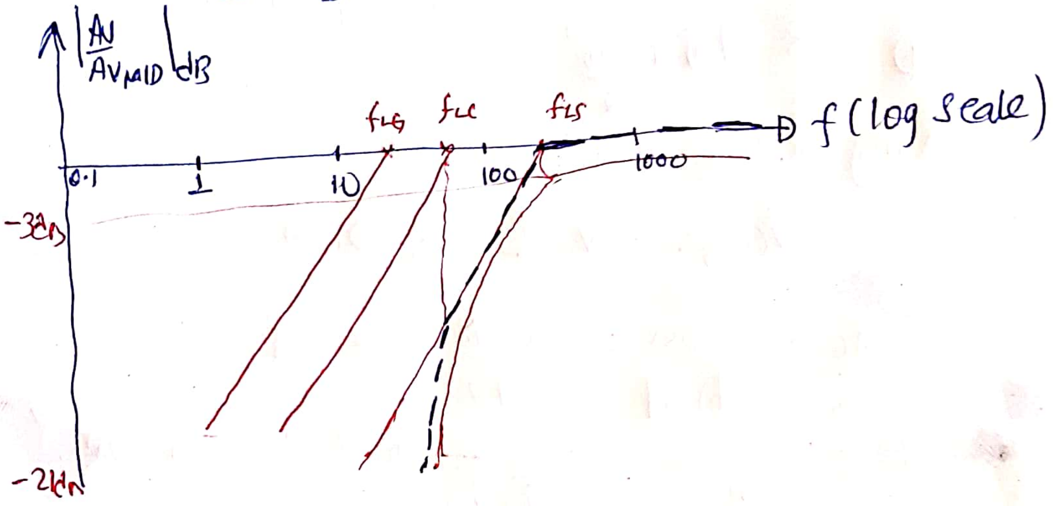
b) The mid band gain

$$A_{V_{MID}} = -g_m(R_D \| R_L)$$

$$= -2mS(4.7k\Omega \| 2.2k\Omega)$$

$$= -2mS \times 1.499k\Omega$$

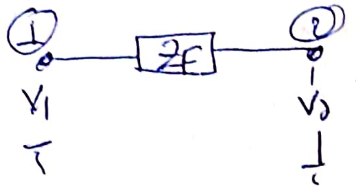
$$\cong -3$$



capacitor

MILLER EFFECT CAPACITANCE

* Consider the general cct shown in the figure, where the floating impedance, Z_F, appears b/n node 1 & 2. We wish transform Z_F to two grounded impedances on the i/p & output sides, while ensuring all the currents and voltages in the cct remains unchanged.

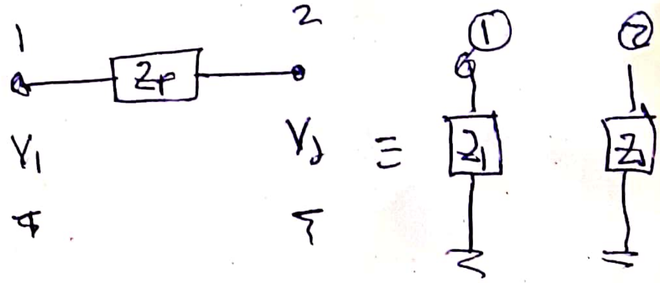


* To determine Z_1 & Z_2, we make two observations.
  1) The current drawn by Z_F from node 1 must be Equal to that drawn by Z_1
  2) The current injected to node 2 must be Equal to that Injected by Z_2

The requirements are

$$\frac{V_1 - V_2}{Z_F} = \frac{V_1}{Z_1}$$

$$\frac{V_1 - V_2}{Z_F} = \frac{-V_2}{Z_2}$$



* Denoting the voltage gain from node 1 to node 2 by A_o, we obtain

$$Z_1 = \frac{Z_F}{1 - A_o} \quad \& \quad Z_2 = \frac{A_o Z_F}{A_o - 1} = \frac{Z_F}{1 - \frac{1}{A_o}}$$

Called Miller's theorem.

* Now consider Z_F is a single capacitor, C_F, tied b/n the i/p & o/p of an inverting Amplifier as shown below

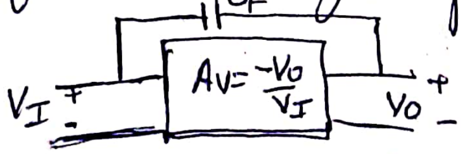


Fig: Inverting Amplifier with floating capacitor

Miller's theorem :- It states that if an impedance Z is connected b/n the i/p and o/p terminals of a n/w which provides a voltage gain of A, an equivalent cct that gives the same effect can be drawn by removing Z & connecting an impedance $Z_i = \frac{Z}{1-A}$ across the input & $Z_0 = \frac{ZA}{A-1}$ across the o/p as shown below

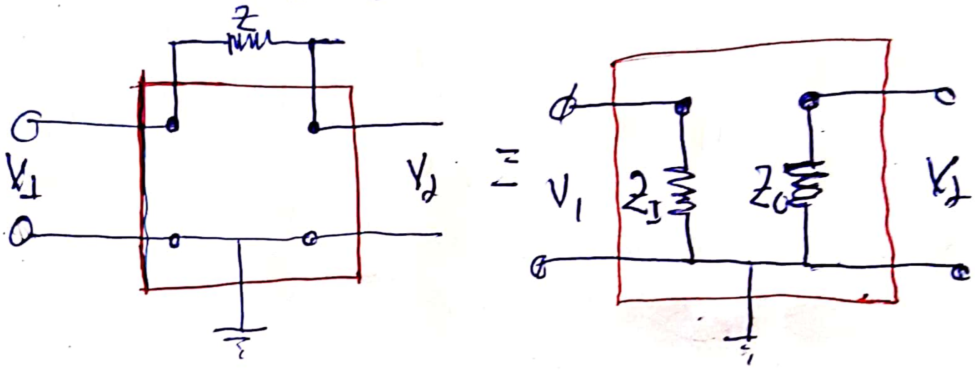


Fig Millers theorem

$$Z_1 = \frac{Z_F}{1 - A_0} = \frac{Z_F}{1 - A_V} = \frac{1}{(1 - A_V) C_F S}$$

⇒ The o/p has a capacitor of value $(1 - A_V) C_F$, as if "C_F" is Amplified by a factor of $(1 - A_V)$

- The effect of C_F at the o/p can be obtained as

$$Z_2 = \frac{Z_F}{1 - \frac{1}{A_0}} = \frac{Z_F}{1 - \frac{1}{A_V}} = \frac{1}{\left(1 - \frac{1}{A_V}\right) C_F S}$$

⇒ The o/p has a capacitator of value $\left(1 - \frac{1}{A_V}\right) C_F$

* In general, the Miller effect input capacitance is defined by

$$C_{Mi} = (1 - A_V) C_f$$

& the Miller output capacitance is defined by

$$C_{Mo} = \left(1 - \frac{1}{A_V}\right) C_f$$

Fig Bode plot for the

HIGH - Frequency Analysis

- In this region, it is the R-C combination formed by the various parasitic capacitances of the transistor (C_{be}, C_{bc}, C_{ce}) and wiring capacitances (C_{Wi}, C_{Wo}) and the n/w resistive parameters that determine the cut-off frequencies
- The Amplifier circuit behaves as a simple Low pass cct as shown below

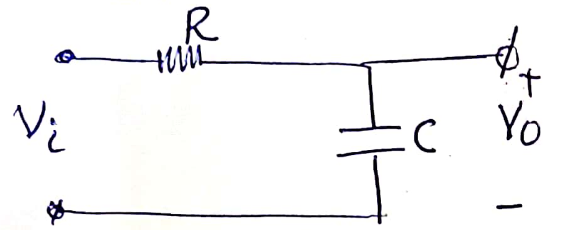


Fig:- RC-combination that will define a high-cut-off frequency.

* The voltage gain, Av, can be written as

$$A_V = \frac{V_o}{V_I} = \frac{\frac{1}{jwC}}{R+\frac{1}{jwC}} = \frac{1}{1+jwRC}$$

$$= \frac{1}{1+j(f/f_2)} \quad ; \text{ where } f_2 = \frac{1}{2\pi RC}$$

* The magnitude, $|A_V|$:

$$|A_V| = \frac{1}{\sqrt{1+w^2R^2C^2}} = \frac{1}{\sqrt{1+(f/f_2)^2}}$$

$$|A_V|_{dB} = -10 \log 1+(f/f_2)^2$$

The bode-plot of $|A_V|_{dB}$ is shown below

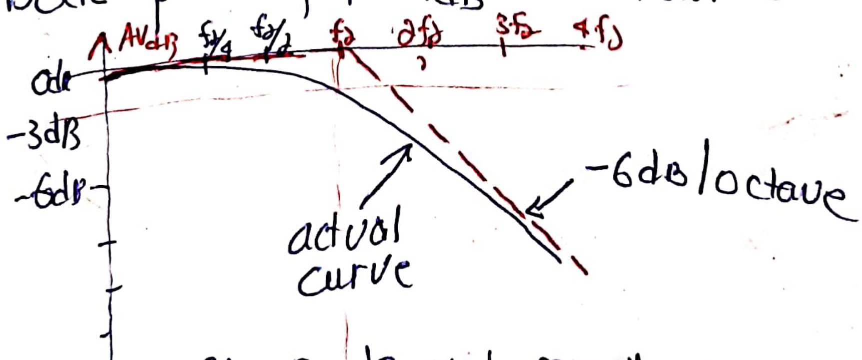
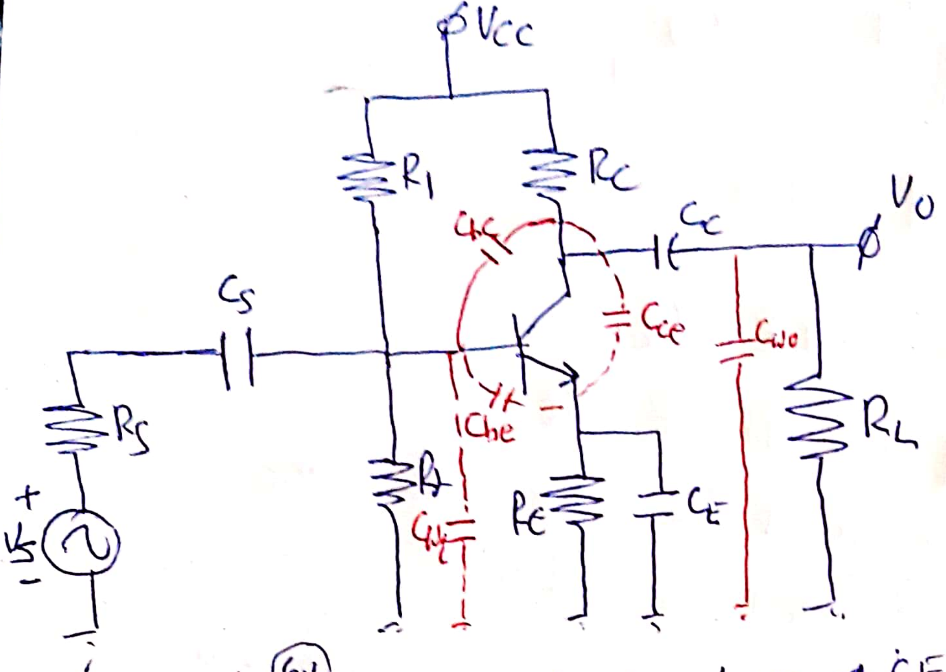


Fig Bode plot for the high frequency region

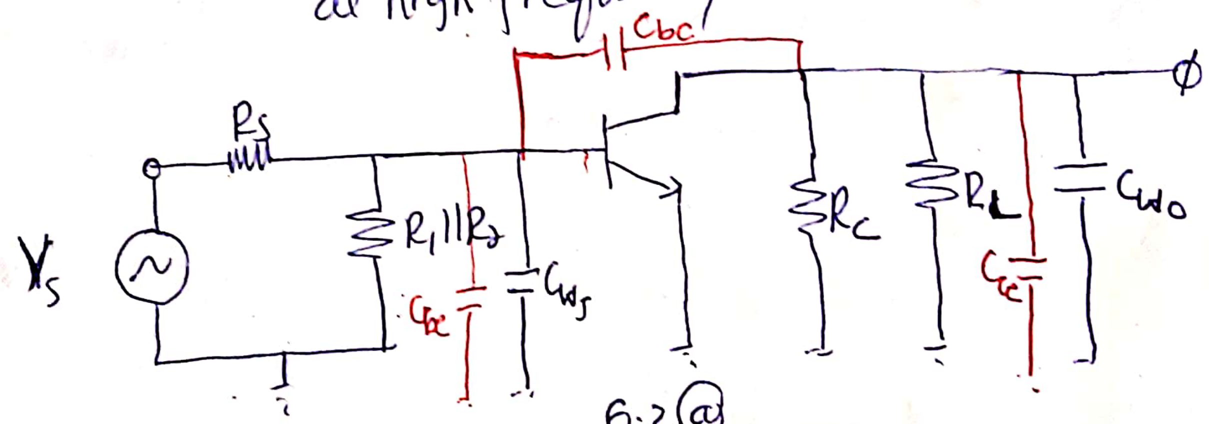
HIGH FREQUENCY RESPONSE OF BJT

A high frequency ac equivalent model for the network of Fig 6.1 appears in Fig 6.2 a & b

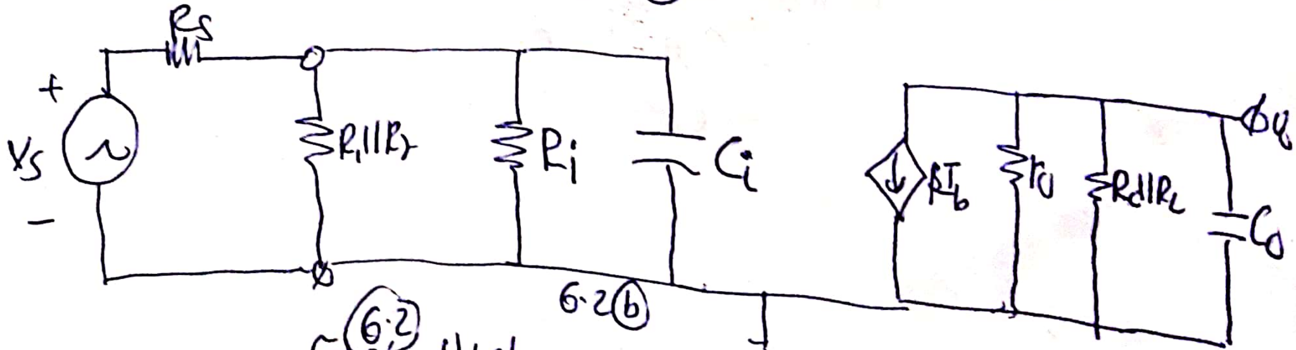


* parasitic capacitance
  C_{be}, C_{bc}, C_{ce}
* wiring capacitances
  C_{wi} − i/p side
  C_{wo} − o/p side

Fig 6.1: Voltage-dividing bias at CE-configuration at high frequency



6.2 (a)

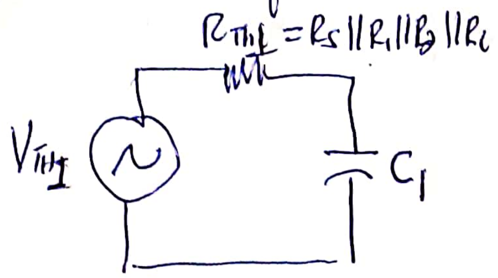


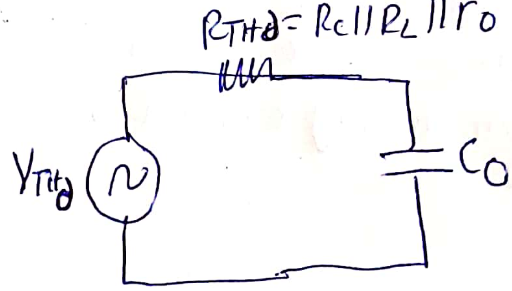
6.2 (b)

Fig 6.2: High frequency ac-equivalent model

$C_i = C_{W_i} + C_{be} + C_{Mi}$ $\qquad C_o = C_{Wo} + C_{ce} + C_{MO}$

The Thevenin Equivalent cct is shown below





The 3dB cut-off frequency is defined by

$$f_{H1} = \frac{1}{2\pi R_{THi} C_i}$$

with

$$R_{TH1} = R_s \| R_1 \| R_2 \| \beta r_e$$

$$C_i = C_{wi} + C_{be} + C_{Mi} = \cancel{C_{wi} + C_{be}}$$

$$= C_{wi} + C_{be} + (1 - A_v) C_{bc}$$

The effect of C_i is

* to reduce the total impedance of the parallel combination of R_1, R_2, R_i

** The result is a reduced level of voltage across C_i and a reduction in I_b, & a gain for the s/s

For the o/p network

$$f_{Ho} = \frac{1}{2\pi R_{TH2} C_o}$$

with

$$R_{TH2} = R_C \| R_L \| r_o$$

$$C_o = C_{wo} + C_{ce} + C_{MO}$$

$$= C_{wo} + C_{ce} + \left(1 - \frac{1}{A_v}\right) C_{bc}$$

Ex For the n/w shown with parameters

$R_S = 1k\Omega$, $R_1 = 40k\Omega$, $R_2 = 10k\Omega$, $R_E = 2k\Omega$ $R_C = 4k\Omega$

$R_L = 2.2k\Omega$, $C_S = 10\mu F$, $C_C = 1\mu F$, $C_E = 20\mu F$

$\beta = 100$, $r_o = \infty\Omega$, $V_{CC} = 20V$

with $C_{be} = 36pF$, $C_{bc} = 4pF$, $C_{ce} = 1pF$, $C_{wi} = 6pF$, $C_{wo} = 8pF$

a) Determine f_{Hi} & f_{Ho}

b) Find f_β & f_T

c) Sketch the frequency response for the high-frequency region using a Bode plot & determine the cut-off frequency

d) ~~what~~ Sketch the overall frequency response

Soln using Approximate method ($\beta R_E >> 10 R_2$)

DC- Analysis

$$V_B = \frac{R_2}{R_1+R_2} V_{CC} = 4V$$

$$V_E = V_B - V_{BE} = 4V - 0.7V = 3.3V$$

$$I_E = \frac{V_E}{R_E} = \frac{3.3V}{2k\Omega} = 1.65mA$$

$$r_e = \frac{V_T}{I_E} = \frac{26mV}{1.65mA}$$

$$r_e = 15.76\Omega$$

$$\beta r_e = 100 \times 15.76 = 1.576k\Omega$$

$$R_i = R_1 \| R_2 \| \beta r_e = 1.32k\Omega$$

MID-BAND GAIN (A_{MID})

$$A_{MID} = \frac{V_o}{V_i} = \frac{-R_C \| R_L}{r_e} = -90$$

AC- Analysis

$1.576k\Omega$

$$R_{TH_i} = R_S \| R_1 \| R_2 \| R_i = 1k\Omega \| 40k\Omega \| 10k\Omega \| \cancel{1.32k\Omega}$$

$1.576k\Omega$

$$= 0.531k\Omega \quad \cancel{590k\Omega}$$

$$C_i = C_{wi} + C_{be} + (1 - A_v) C_{be}$$

$$= 6pF + 36pF + (1 + 90) 4pF$$

$$= 406pF$$

$$f_{HS} = \frac{1}{2\pi R_{TH_i} C_i} = \frac{1}{2\pi (0.531k\Omega)(406pF)}$$

$$= 738.24kHz$$

$R_{TH2} = R_C \| R_L = 4k\Omega \| 2.2k\Omega = 1.419k\Omega$

$C_o = C_{wo} + C_{ce} + C_{Mo}$

$= 8pF + 1pF + (1 + \frac{1}{90}) 4pF$

$= 13.04pF$

$f_{Ho} = \frac{1}{2\pi R_{TH2} C_o} = \frac{1}{2\pi \times 1.419k\Omega \times 13.04pF}$

$= \underline{8.6MHz}$

b) $f_\beta = \frac{1}{2\pi \beta_{mid} r_e (C_{be} + C_{bc})}$

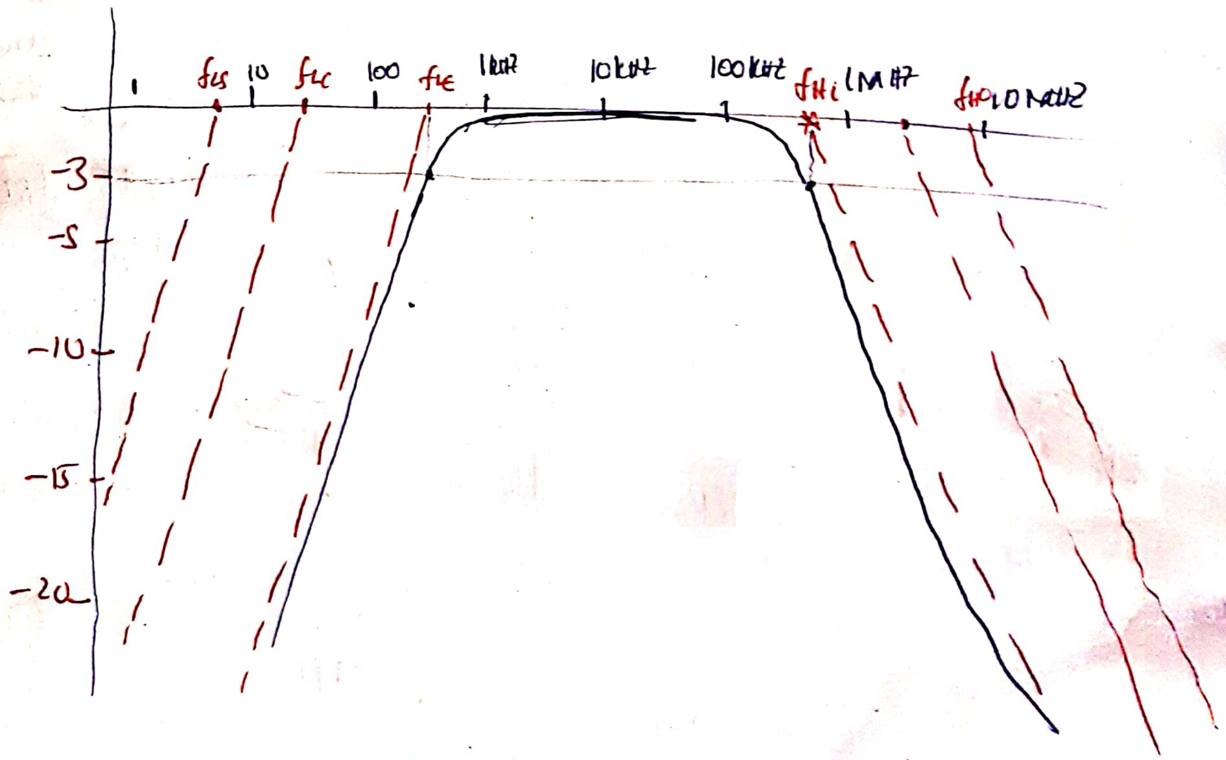
$= \frac{1}{2\pi \times 100 \times 15.76 \times (36pF + 4pF)}$

$\cong 2.52 MHz$

$f_T = \beta_{mid} f_\beta = 100 \times 2.52 MHz$

$= \underline{252MHz}$

c)



HIGH-Frequency Response - FET Amplifier

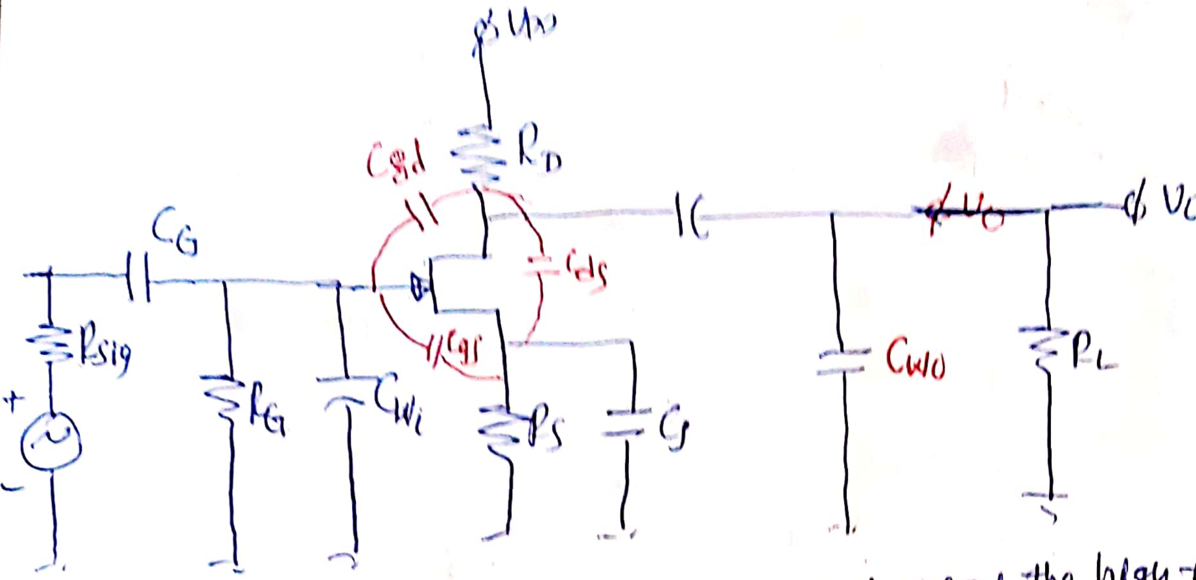


Fig: Capacitive elements that affect the high-frequency response of JFET Amplifier

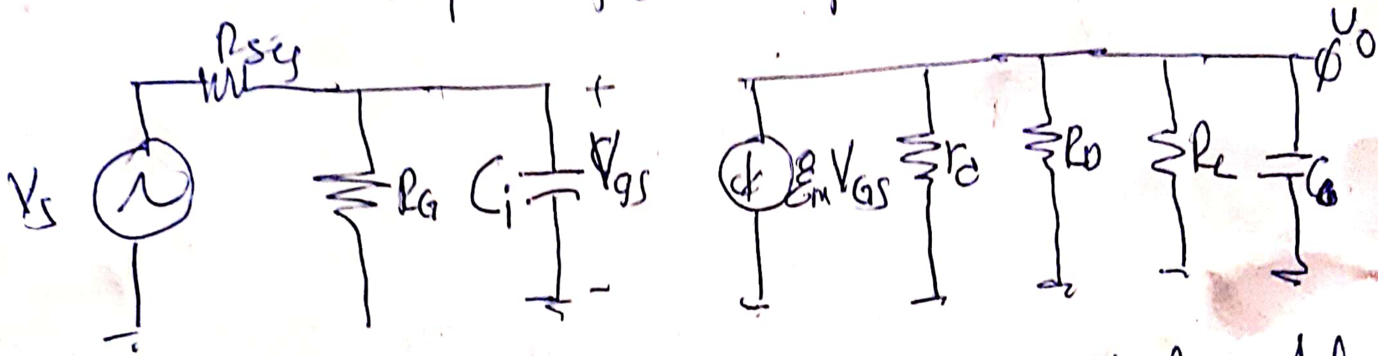


Fig: High frequency ac-Equivalent model

$$f_{Hi} = \frac{1}{2\pi R_{THi} C_i}$$

$$R_{THi} = R_{SIG} \| R_G$$

$$C_i = C_{Wi} + C_{gs} + C_{Mi}$$
$$= C_{Wi} + C_{gs} + (1 - A_v) C_{gd}$$

$$f_{Ho} = \frac{1}{2\pi R_{TH_2} C_o}$$

$$R_{TH2} = R_D \| R_L \| r_d$$

$$C_o = C_{WO} + C_{ds} + C_{MO}$$
$$= C_{WO} + C_{ds} + \left(1 - \frac{1}{A_v}\right) C_{gd}$$

Ex ⓐ Determine the high cutoff frequencies of Ex-2 using the same parameters

$C_G = 0.01\,\mu F$, $C_C = 0.5\,\mu F$, $C_S = 2\,\mu F$

$R_{sig} = 10\,k\Omega$, $R_G = 1\,M\Omega$, $R_D = 4.7\,k\Omega$, $R_S = 1\,k\Omega$

$R_L = 2.2\,k\Omega$, $I_{DSS} = 8\,mA$, $V_P = -4V$, $r_d = \infty\,\Omega$

$V_{DD} = 20V$

$C_{gd} = 2pf$, $C_{gs} = 4pf$, $C_{ds} = 0.5pF$, $C_{wi} = 5pF$

$C_{wo} = 6pF$

ⓑ Sketch the Bode plot

Sol^n $R_{TH1} = R_{sig} \parallel R_G = 10k\Omega \parallel 1M\Omega = 9.9\,k\Omega$

$A_V = -3$

$C_i = C_{wi} + C_{gs} + (1 - A_V)\,C_{gd}$

$= 5pf + 4pf + (1+3)\,2pf$

$= 17pf$

$$f_{HI} = \frac{1}{2\pi R_{TH1}\, C_i} = \frac{1}{2\pi \times 9.9k\Omega \times 17pF}$$

$= 945.67\,KHZ$

$R_{TH2} = R_D \parallel R_L = 4.7k\Omega \parallel 2.2k\Omega$

$= 1.5\,k\Omega$

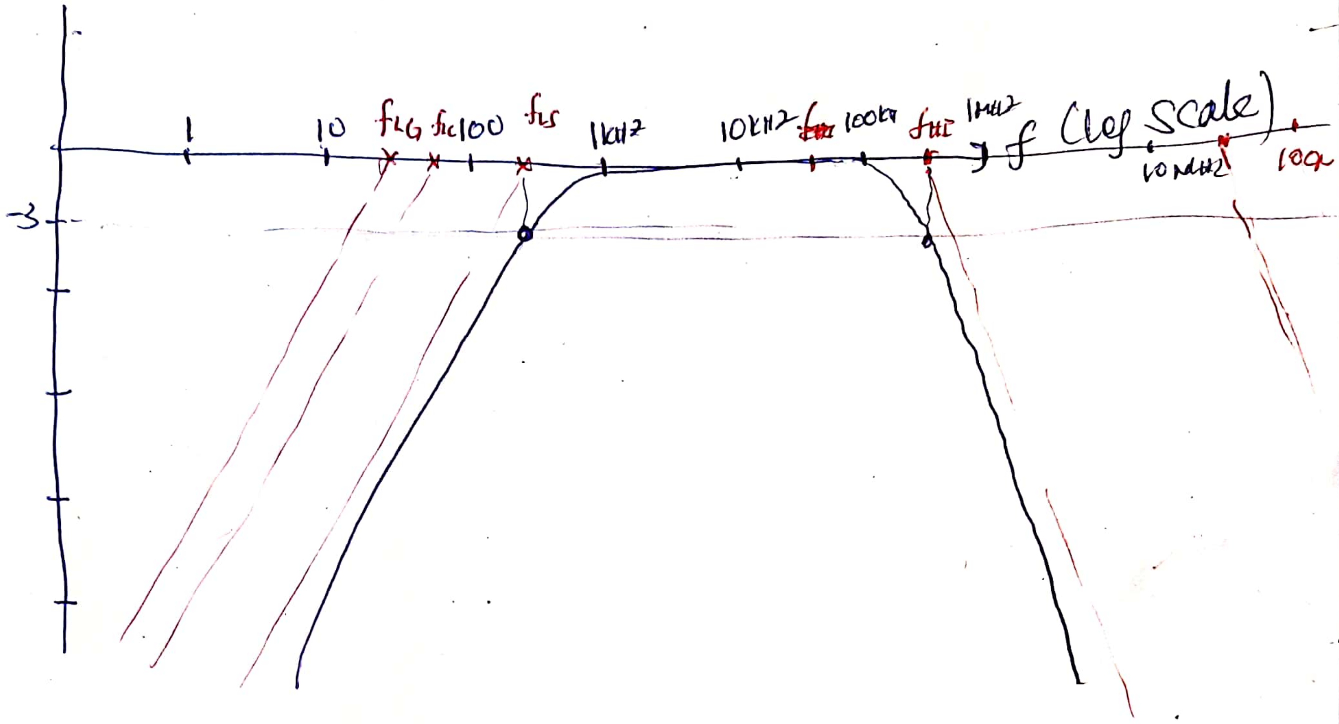
$C_o = C_{wo} + C_{ds} + C_{Mo}$

$= 6pF + 0.5pF + (1 - \frac{1}{-3})\,2pF$

$= 9.17\,pF$

$$f_{Ho} = \frac{1}{2\pi (1.5k\Omega)(9.17pF)} = 11.57\,MHZ$$

(b)



-3
1
10
f_{LG}
f_{LC}
100
f_{LS}
1kHz
10kHz
100kHz
f_{HI}
1MHz
f (log scale)
10MHz
100