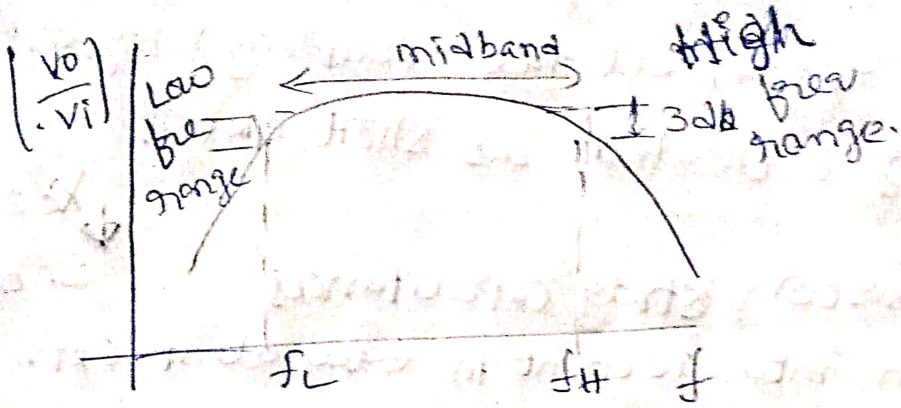
unit - II

Frequency response

*

→ All Amplifier gain factors are functions of signal frequency

→ These include voltage, current, transconductance, and transresistance.



The curve drawn between frequency & gain factor. is called frequency response curve.

= The frequency ranges are divided as:

- low frequency $f < f_L$ — $20Hz < f < 20KHz$
- High frequency $f > f_H$ — $f_H > 20KHz$
- Medium frequency. — f_H

Frequency ranges

$\uparrow X_C = \frac{1}{2\pi f C}$ high capacitancy

low frequency range

→ In this region, coupling and bypass capacitors must be included in the equivalent ckt and in the amplification factor equations

→ The stray and transistor capacitances are treated as open ckts.

→ In Low frequencies range, $f < f_L$, the gain ↓ as fre ↓ because of couplings & bypass capacitor effects.

High frequency Range

→ In this range all the stray & parasitic capacitors are present.

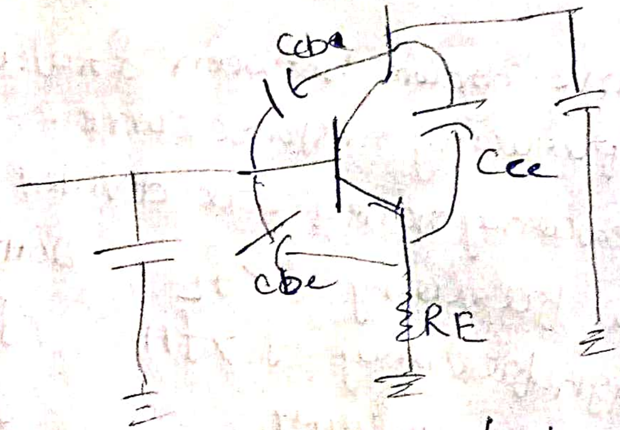
→ due to these capacitances the gain decreases as frequency increase.

→ In this range we use High frequency equivalent ckt.

→ In this region all the coupling & Bypass capacitors are going to treated as short ckts.

$\downarrow X_C = \frac{1}{2\pi f c}\uparrow$
Short ckts.

→ The transistor & stray capacitances are taken into account in equivalent ckt.



→ due to PN Junction (between collector, base and emitter)

→ C_μ & C_π

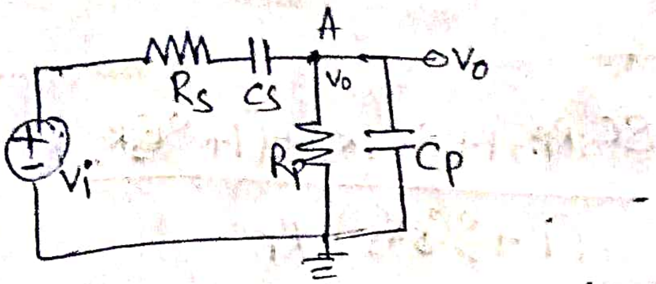
Midband Range :-

→ coupling & bypass capacitors are treated as short ckt

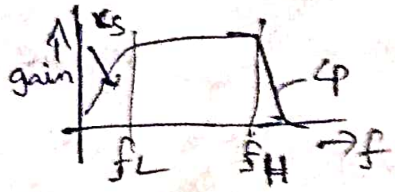
→ stray and transistor capacitances are treated as open ckts.

→ so In this range no capacitances in the equivalent ckt.

short ckt and open ckt Time constant



- CS is the coupling capacitor
- CP is the load capacitor and is in parallel with the output and ground.



- Applying KCL at output node

→ due to CS at low frequencies the gain is going to be reduced

→ due to CP at High frequencies the gain is going to be reduced. at mid fre the stray, paracitic capacitances are appear so, gain maintains constant.

→ Applying KCL at node A ie) output node

$$\frac{V_o - V_i}{R_s + 1/sC_s} + \frac{V_o}{R_P} + \frac{V_o}{1/sC_P} = 0$$

$$\therefore \frac{(V_o - V_i)sC_s}{1 + sC_sR_s} + \frac{V_o}{R_P} + V_o \cdot sC_P = 0$$

separate V_o & V_i terms, to get the transfer function $\frac{V_o}{V_i}$. so, the equation becomes

$$V_o\left[\frac{sC_s}{1+sC_sR_s} + \frac{1}{R_P} + sC_P\right] = \frac{(V_i)sC_s}{1+sC_sR_s}$$

$$\frac{V_o}{V_i} = \frac{sC_s}{1+sC_sR_s\left[\frac{sC_s}{1+sC_sR_s} + \frac{1}{R_P} + sC_P\right]}$$

take LCM

$$\frac{V_o}{V_i} = \frac{S\cancel{C}_s}{1+\cancel{SC_s}R_s\left[\frac{SC_sR_p+1+SC_sR_s+(1+\cancel{SC_sR_s})R_p\,SC_p}{(1+\cancel{SC_sR_s})\,R_p}\right]}$$

$$\cancel{X} = \frac{SC_s\cdot\cancel{R_p}}{1+SC_sR_s\left[\{1+SC_sR_s\}\cancel{R_p}\cdot\frac{C_p}{C_s}+R_p+R_s+1\right.}$$

$$= \frac{\cancel{SC_s}\,R_p}{\cancel{SC_s}\left[\frac{1}{SC_s}+R_s+R_p+(1+SC_sR_s)R_p\frac{C_p}{C_s}\right]}$$

$$= \frac{R_p}{\left[R_s+R_p+\frac{1}{SC_s}+(R_p+SC_sR_pR_s)\cdot\frac{C_p}{C_s}\right]}$$

$$= \left[\frac{R_p}{R_s+R_p}\right]\left[\frac{1}{1+\underbrace{\frac{1}{SC_s(R_p+R_s)}}_{\text{Series combination } ST_s}+\left(\frac{R_p}{R_s+R_p}\right)\frac{C_p}{C_s}+\underbrace{\left(\frac{R_pR_s}{R_s+R_p}\right)\cdot SC_p}_{\text{parallel combination } ST_p}}\right]$$

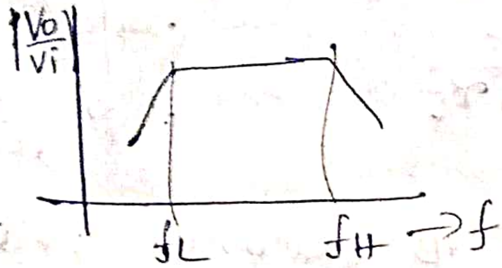
$$\frac{V_o(S)}{V_i(S)} = \left[\frac{R_p}{R_s+R_p}\right]\left[\frac{1}{1+\left(\frac{R_p}{R_s+R_p}\right)\frac{C_p}{C_s}+\frac{1}{ST_s}+ST_p}\right]$$

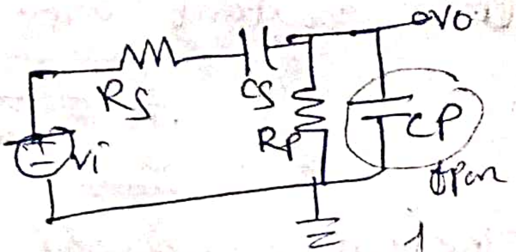
where

$\tau_s = (R_s + R_p) C_s$

$\tau_p = \left(\frac{R_s R_p}{R_s + R_p}\right) C_p$ Time constants

→





Cs - affects the low frequency response

Cp - affects the High frequency response

at low frequencies Cp as an open ckt

if $C_p \ll C_s$

To find the equivalent resistance seen by a capacitor, set all independent sources equal to zero.

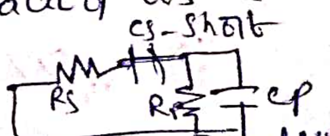
∴ The effective resistance seen by Cs is the series combination of Rs & Rp.

The Time constant of ckt is

$\tau_s = (R_s + R_p) C_s$.

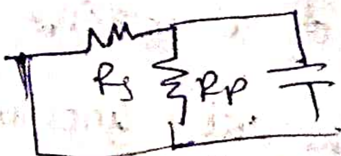
Since Cp was made an open ckt, τ_s is called an "open ckt" time constant.

⇒ At high frequencies, Cs coupling capacitor act as a short ckt.



∴ The effective resistance seen by Cp is the parallel combination of Rs and Rp and the associated time constant is

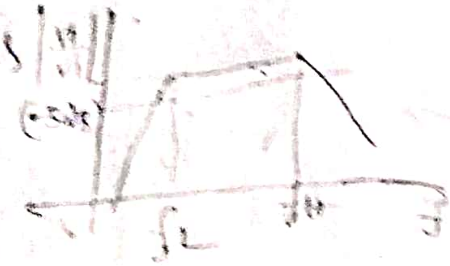
$\tau_p = \left(\frac{R_s R_p}{R_s + R_p}\right) \cdot C_p$



∴ τ_p is called the "short ckt time constant.

let consider
Bode plot of the voltage transfer function magnitude

- The lower corner (or) 3dB frequency, which is at the low end of the frequency scale, is a function of the open ckt time constant and is defined as



$$f_L = \frac{1}{2\pi\tau_s}$$

→ The upper corner (or) 3dB frequency which is at the high end of the frequency scale, is a function of the short ckt time constant and is defined as

$$f_H = \frac{1}{2\pi\tau_P};$$

→ The amplifier gain is constant over a wide frequency range, called the "mid band".

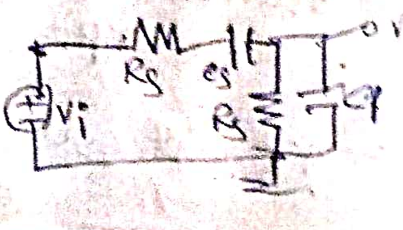
→ In "mid band" frequency range all capacitance effects are negligible (stray and parasitic capacitances)

→ The mid band range (or) bandwidth is defined by the corner frequencies f_L and f_H as

$$BW = f_H - f_L$$

is $f_H >> f_L$ then $\boxed{f_{BW} \cong f_H}$

Determine the corner frequencies and bandwidth of a passive ckt containing two capacitors, consider the ckt shown in figure, with parameters $R_S = 1K\Omega$, $R_P = 10K\Omega$, $C_S = 1\mu F$ and $C_P = 3pF$.



Sol:

$\tau_s = (R_s + R_p)C_s = (10^3 + 10\times10^3)(10^{-6}) = 1.1\times10^{-2}$ s

$\tau_p = \left(\frac{R_s R_p}{R_s + R_p}\right).C_p = \frac{10^3\times10\times10^3}{10^3+10\times10^3}(3\times10^{-12}) = 2.73\times10^{-9}$ s

$f_L = \frac{1}{2\pi\tau_s} = \frac{1}{2\pi\times1.1\times10^{-2}} = 14.5$ Hz

$f_H = \frac{1}{2\pi\tau_p} = \frac{1}{2\pi(2.73\times10^{-9})} = 58.3$ MHz

$f_{BW} = f_H - f_L = 58.3\times10^{-6} - 14.5$ Hz $\quad f_H >> f_L$

$= 58.3$ MHz $\quad \boxed{BW \simeq f_H}$

Time Response :-

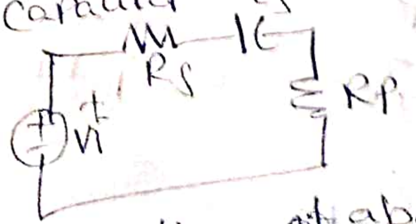
→ upto now we observed steady state sinusoidal frequency response, we for sinusoidal inputs.

→ In some cases, we may need to amplify other than sinusoidal signal also, ie pulse, square, triangular signals. ie digital signals.

→ In these cases, we need to consider the time response of output signals.

series ~~load~~ coupling capacitor

consider ckt



The voltage transfer function of above ckt

$$\frac{V_o(s)}{V_i(s)} = \frac{R_P}{R_s + R_P + \frac{1}{sC_s}}$$

$$= \frac{sC_s R_P}{1 + s(R_s + R_P)C_s}$$

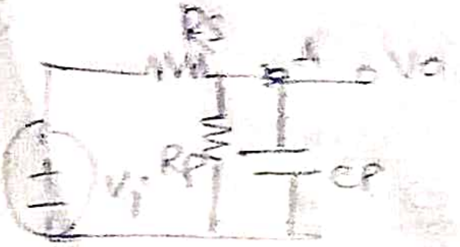
$$\frac{V_o(s)}{V_i(s)} = \left(\frac{R_P}{R_S + R_P}\right) \frac{s(R_S+R_P)C_S}{1+s(R_S+R_P)C_S}$$

$$\left(\frac{V_o}{V_i}\right) = K_2 \frac{s\tau_2}{1+s\tau_2}$$

$$\therefore \tau_2 = (R_S+R_P)C_S$$

$$\therefore K_2 = \frac{R_P}{R_S+R_P}$$

Parallel load capacitor ckt



KCL at output node A

$$\frac{V_o - V_i}{R_S} + \frac{V_o}{R_P} + \frac{V_o}{1/sC_P} = 0$$

$$\frac{V_o}{R_S} + \frac{V_o}{R_P} + \frac{V_o}{1/sC_P} = \frac{V_i}{R_S}$$

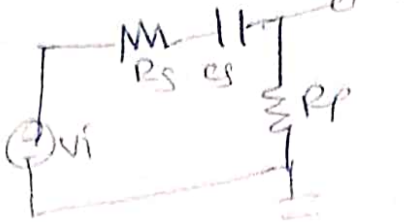
$$\frac{V_o}{V_i} = \left(\frac{R_P}{R_S+R_P}\right) \frac{1}{1+s\left(\frac{R_S R_P}{R_S+R_P}\right)C_P}$$

$$= \left(\frac{R_P}{R_S+R_P}\right)\left(\frac{1}{s\tau_P+1}\right)$$

$$\tau_P = (R_S \parallel R_P)C_P.$$

In the input voltage is a step function $V_i(s) = 1/s$. (8) series coupling capacitor ckt. Then output voltage can be

$V_o(s) =$



$$V_o(s) = K_2\left[\frac{s\tau_2}{1+s\tau_2}\right] =$$

$$= \left(\frac{Rp}{Rs+Rp}\right)\left[\frac{s(Rs+Rp)Cs}{1+s(Rs+Rp)Cs}\right]$$

$$\frac{V_o(s)}{V_i(s)} = K_2\left[\frac{s\tau_2}{1+s\tau_2}\right] \quad \text{if} \quad V_i(s) = 1/s$$

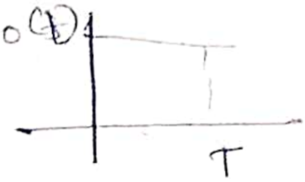
$$= K_2\left[\frac{1}{s+1/\tau_2}\right] \qquad V_o(s) = K_2\left[\frac{s\tau_2}{1+s\tau_2}\right] \times \frac{1}{s}$$

$$= K_2\left[\frac{\tau_2}{1+s\tau_2}\right]$$

$$= K_2\left[\frac{1}{s+1/\tau_2}\right]$$

Taking inverse Laplace transform function, then

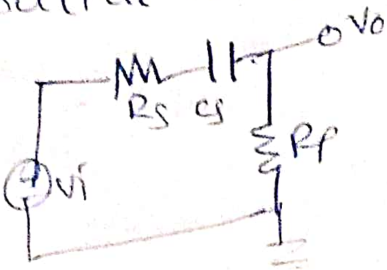
$$V_o(s) = K_2 e^{-t/\tau_2}$$



If we apply pulse input voltage, to above ckt the voltage applied to load ckt is slowly decreases.

—o —o —o —

If the input voltage is a step function $V_i(S) = 1/S$. V_o can be
Series coupling capacitor ckt. Then output voltage
$V_o(S) =$



$$V_o(S) = k_2\left[\frac{S\tau_2}{1+S\tau_2}\right] =$$

$$= \left(\frac{\cancel{x}\,R_p}{R_s+R_p}\right)\left[\frac{S(R_s+R_p)\,C_s}{1+S(R_s+R_p)\,C_s}\right]$$

$$\frac{V_o(S)}{V_i(S)} = k_2\left[\frac{S\tau_2}{1+S\tau_2}\right] \quad \text{if } V_i(S) = 1/S$$

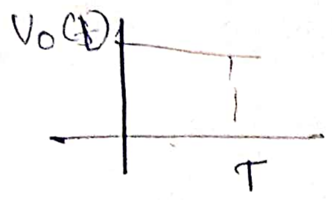
$$= k_2\left[\frac{1}{S+1/\tau_2}\right] \qquad V_o(S) = k_2\left[\frac{S\tau_2}{1+S\tau_2}\right]\times\frac{1}{S}$$

$$= k_2\left[\frac{\tau_2}{1+S\tau_2}\right]$$

$$= k_2\left[\frac{1}{S+1/\tau_2}\right]$$

Taking inverse Laplace transfer function, then

$$V_o(S) = K_2\, e^{-t/\tau_2}$$



If we apply pulse input voltage, to above ckt the voltage applied to load ckt is slowly decreases.