AC

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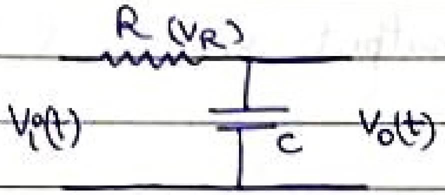
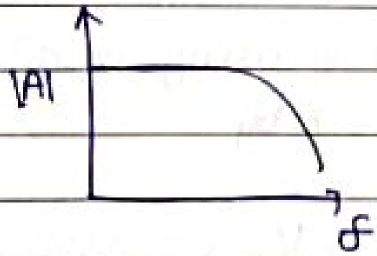
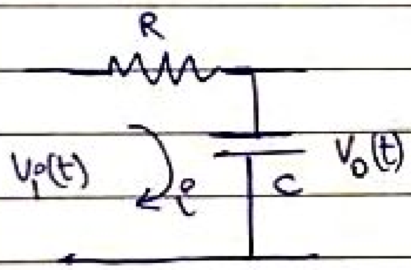
Low Pass RC Ckt :-





$X_c = \frac{1}{\omega C}$ low freq – open ckt $V_o(t) = V_i(t)$
High freq – short ckt $V_o(t) \neq V_i(t) = 0$

① Sinsoidal I/P :-



$V_i(t) = V_m \sin \omega_m t$

$V_i(S) = \left(R + \frac{1}{SC}\right) i(S).$

$i(S) = \frac{V_i(S)}{R + \frac{1}{SC}} = \frac{V_i(S)}{R\left(1 + \frac{1}{RSC}\right)}$

$V_o(S) = \frac{1}{SC} i(S)$, So, Transfer Function is, $\frac{V_o(S)}{V_i(S)}$

$\Rightarrow \frac{1 \cancel{i(S)} \times 1}{SC \times R\left(1 + \frac{1}{RSC}\right) \cancel{i(S)}} \Rightarrow \frac{1}{1 + SCR} \Rightarrow \frac{1}{1 + j2\pi f RC}$

Again transfer func. can be given in complex func in polar form as,

$\frac{V_o(S)}{V_i(S)} = A\angle\theta°$ where A is the gain and θ is output leads input angle

⑥ $A = \frac{1}{\sqrt{1 + \left(\frac{f}{f_2}\right)^2}}$ f_2 = upper cutoff freq

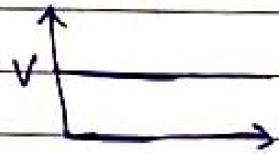
⑥ $\theta = \tan^{-1}\left(\frac{f}{f_2}\right)$ $\left\{ f_2 = \frac{1}{2\pi RC} \text{ upper cuttoff freq} \right\}$

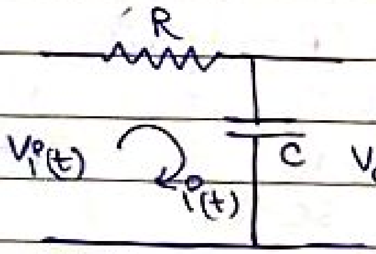
Hence using eq ⑤ & ⑥ output signal $V_o(t)$ is given by

$$V_o(s) = V_i(s) A \angle \theta^0$$
$$= A V_m \sin(\omega t + \theta) \quad -⑧$$

As the phase angle θ is negative hence output $V_o(t)$ lags behind input signal $V_i(t)$ by θ°.

② Step Input :-





$V_i(t) = V_R + V_C$

Consider capacitor charge & discharge exponentially. Applying KVL,

$$V_i(t) = i(t)R + \frac{1}{C}\int i(t)\,dt$$
$$V = i(t)R + \frac{1}{C}\int i(t)\,dt$$

Diff wrt t

$$\frac{dV}{dt} = 0$$

$$\Rightarrow 0 = R\frac{di(t)}{dt} + \frac{1}{C}i(t)$$

$$\frac{di(t)}{dt} + \frac{1}{RC}i(t) = 0$$

_/_/__

Put $\frac{d}{dt} = D$ $\rightarrow$ $(D + \frac{1}{RC})i = 0$. $D = -\frac{1}{RC}$

$$i(t) = c_1 e^{-t/RC}$$

① Put $t = 0$ ② Put $t = 0$

$i^0 = \frac{V}{R}$ $c_1 = \frac{V}{R}$.

$$i(t) = \frac{V}{R} e^{-t/RC}$$

$$V_t = i(t) R$$

$$V_R(t) = \frac{V}{\cancel{R}} e^{-t/RC} \cancel{R} = Ve^{-t/RC}$$

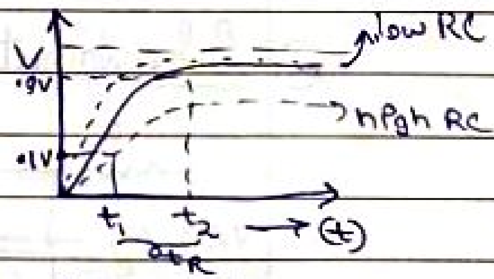
$$\boxed{V_R = Ve^{-t/RC}}$$

$$\boxed{V_C = V - Ve^{-t/RC} = V(1 - e^{-t/RC})}$$

$$V_C = V_0(t) = V(1 - e^{-t/RC})$$

At $t = 0$, $t = \infty$

$V_0(t) = 0$ $V_0(t) = V$



<u>Rise time</u>:- Time taken by capacitor voltage to increase from 10% - 90% of it's final voltage V_0 is called rise time.

$$V_0(t) = V(1 - e^{-t/RC})$$

$t = t_1 =$ $.1\cancel{V} = \cancel{V}(1 - e^{-t/RC})$

$$e^{-t/RC} = .9\cancel{V}$$

$$\frac{-t}{RC} = \log(.9)$$

$t_1 = .105\,RC$

$.9V = V(1 - e^{-t/RC})$

$e^{-t_2/RC} = .1$

$\frac{-t_2}{RC} = \log .1$

$t_2 = 2.303\,RC$

Now Rise time, $t_r = t_2 - t_1$

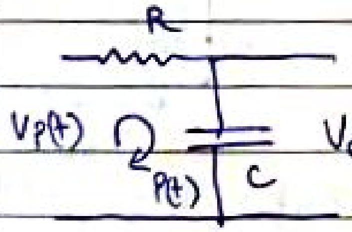
$t_r = 2.2\,RC$

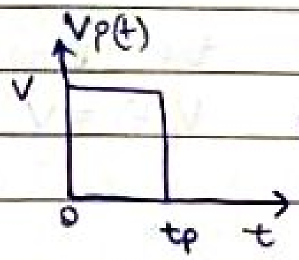
Let f_2 be upper 3db frequency $\left(\frac{1}{2\pi RC}\right)$, so,

$t_r = 2.2\,RC$

$t_r = \frac{2.2}{2\pi f_2} = \boxed{t_r = \frac{.35}{f_2}}$

② Pulse Input :-





$V_P(t) = V_R + V_C$

At $t=0$

$V_P(t) = V$ as $V_C = 0$

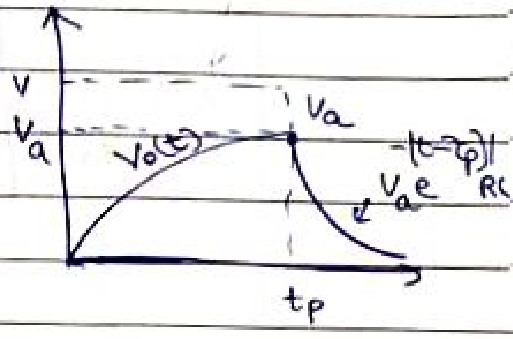
$V_R = V$

At $0 < t < t_p$

$$V_i = V, \quad V_c = V(1-e^{-t/RC})$$

At $t = t_p$

$$V_a = V(1-e^{-t/RC})$$



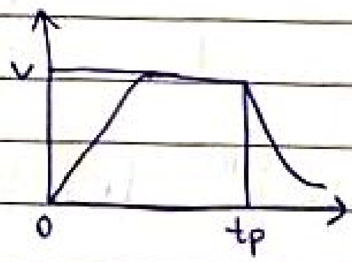
At $t > t_p$

$$V_c(t) = V_a(e^{-(t-t_p)/RC}).$$

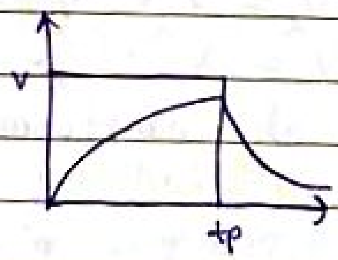
$t_p \to$ time period of pulse

$RC \to$ time constant of ckt

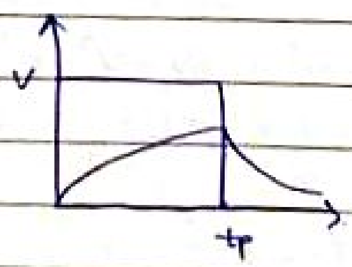
When $t_p >> RC$



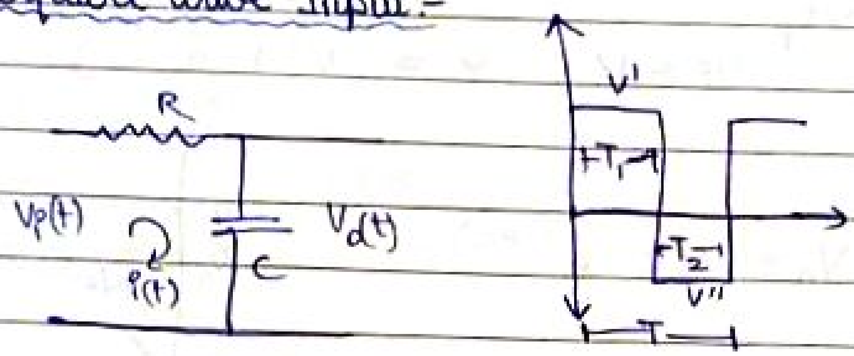
When $t_p = RC$

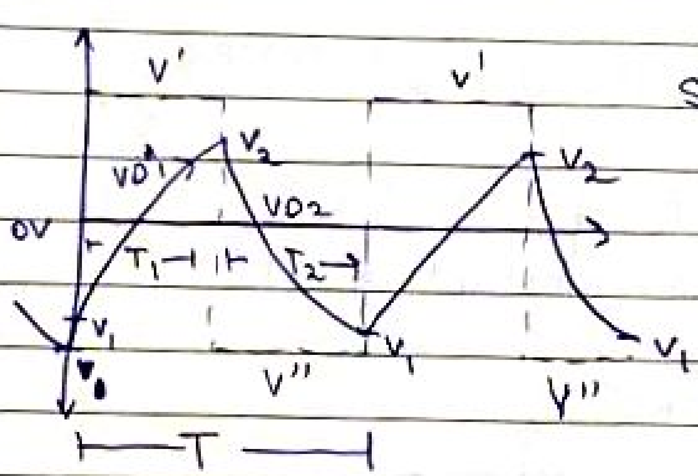


When $t_p << RC$



(1) Square Wave Input:-





Steady State
RC > T

$$V_o(t) = V_f + (V_i - V_f)e^{-t/RC} \quad \boxed{FIF}$$

In accordance to it,

$$V_2 = V' + (V_1 - V')e^{-t/RC}$$
$$V_1 = V'' + (V_2 - V'')e^{-t/RC}$$

considering symmetrical waveform as input we have,

$$V' = -V'' = \frac{V}{2}$$
$$T_1 = T_2 = \frac{T}{2}$$

$$V_2 = -V_1$$

$$V_2 = V' + (V_1 - V')e^{-t_1/RC}$$
$$= \frac{V}{2} + \left(-V_2 - \frac{V}{2}\right)e^{-t/2RC}$$

$$V_2\left(1 + e^{-\frac{t}{2RC}}\right) = \frac{V}{2}\left(1 - e^{-\frac{t}{2RC}}\right)$$

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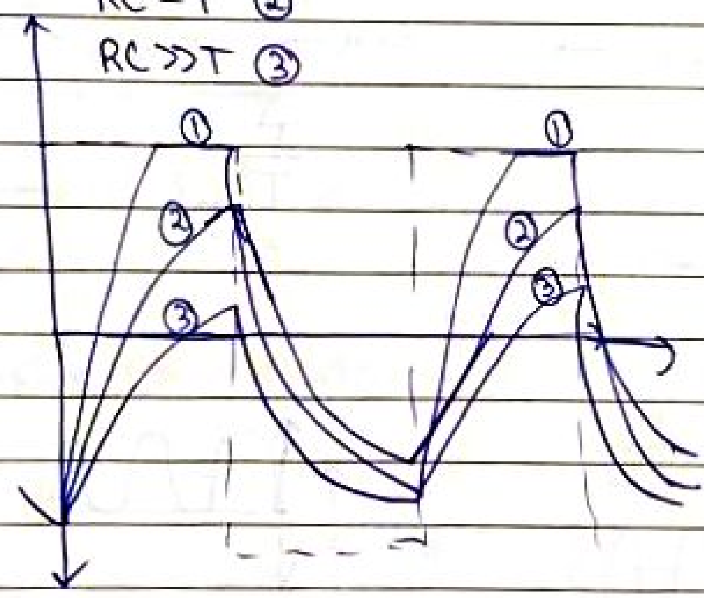
$$V_2 = \frac{V}{2}\frac{(1-e^{-t/2RC})}{(1+e^{-t/2RC})}\frac{(e^{t/4RC})}{(e^{t/4RC})}$$

$$V_2 = \frac{V}{2}\left(\frac{e^{t/4RC} - e^{-t/4RC}}{(e^{t/4RC} + e^{-t/4RC})}\right)$$

$$V_2 = \frac{V}{2}\left(\frac{e^{x} - e^{-x}}{(e^{x} + e^{-x})}\right)$$

$$\boxed{V_2 = \frac{V}{2}\tanh x} \qquad x = \frac{-t}{4RC}$$

When RC << T ①
RC = T ②
RC >> T ③



Q. An ideal 1 microsecond pulse is fed to an amplifier. Calculate & plot the output waveform,
(i) the upper 3dB is 10MHz,
(ii) upper freq is 1MHz

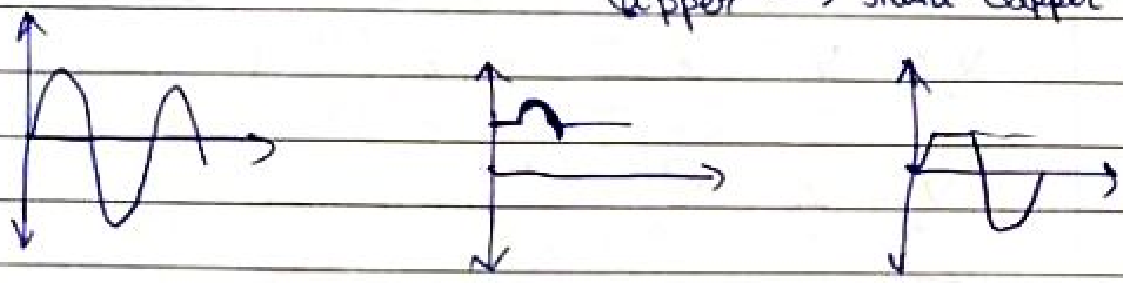
$t_p = 1\times10^{-6}$ secs

$$f_2 = \frac{1}{2\pi RC}$$

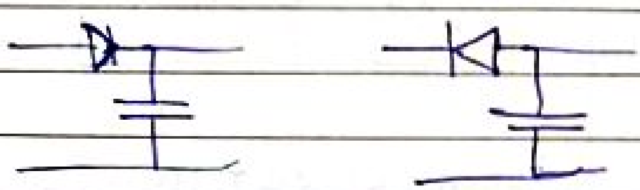
$$RC = \frac{1}{2\pi 10\times10^{6}} \rightarrow \frac{.5\times10^{-5}}{\pi} \rightarrow .159\times10^{-5} \rightarrow 1.59\times10^{-6}$$

Clipper & Clamping :-

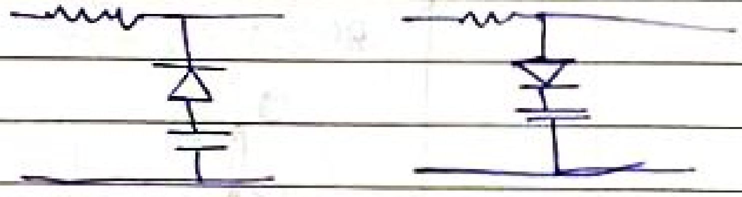
Clipper → Series
Clipper → Shunt clipper



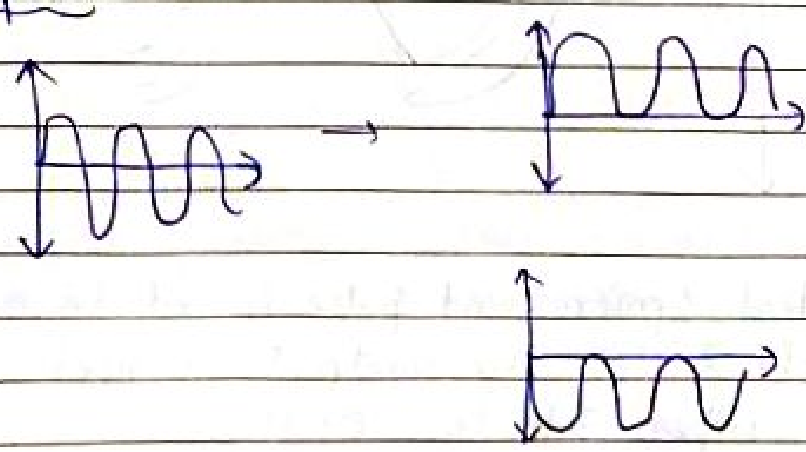
Series clipper →



Shunt clipper →



Clamper :-

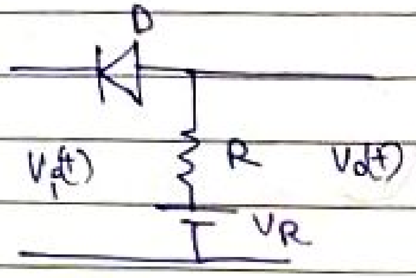


+ve clamp

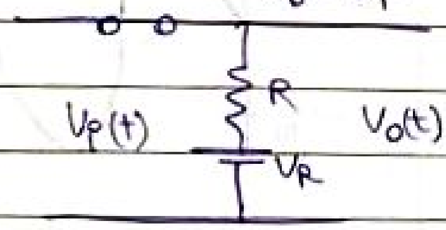
−ve clamp

Series clipper :-

① Clipping above refference voltage :-

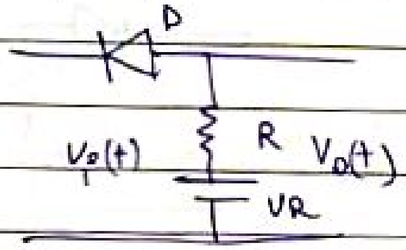


$V_o = V_i$

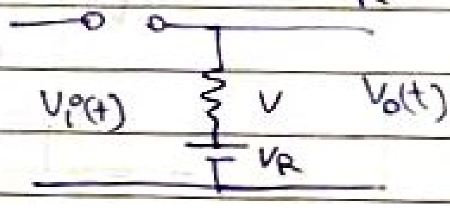


$V_R > V_i$

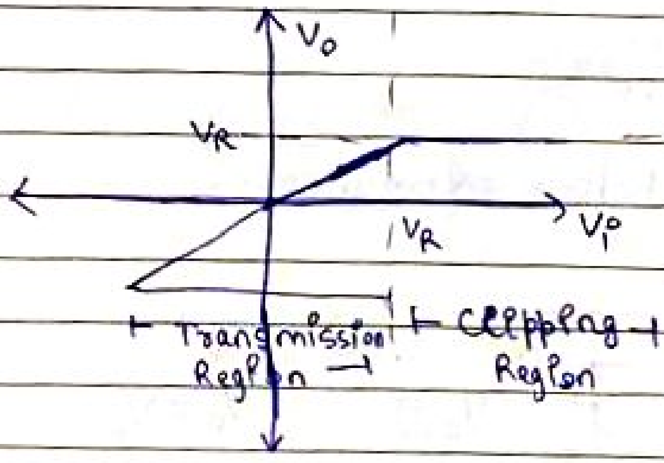
$V_R < V_i$



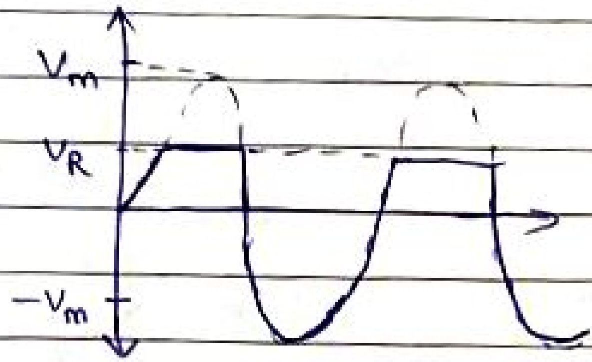
$V_o = V_R$



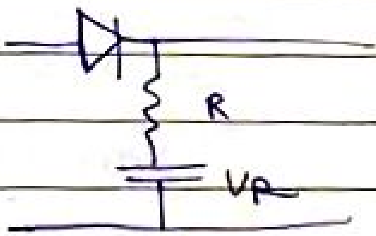
Transfer Characteristics :-



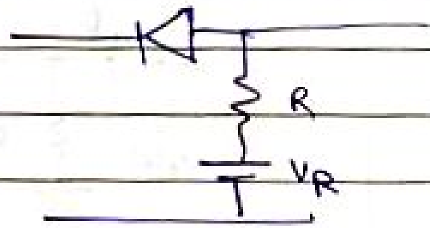
With sinusoidal i/p :-



Clipping below reference :-



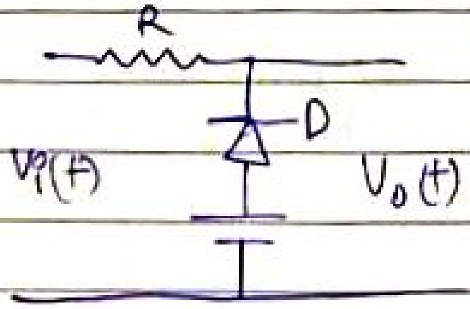
$V_R > V_I$



$V_R < V_I$

Shunt Clipper :-

Clipping below reference :-



$V_o = V_R$

$V_R > V_I$

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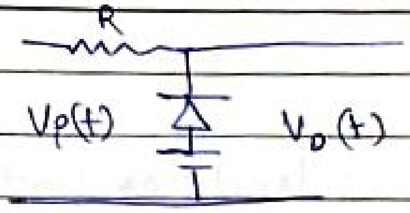


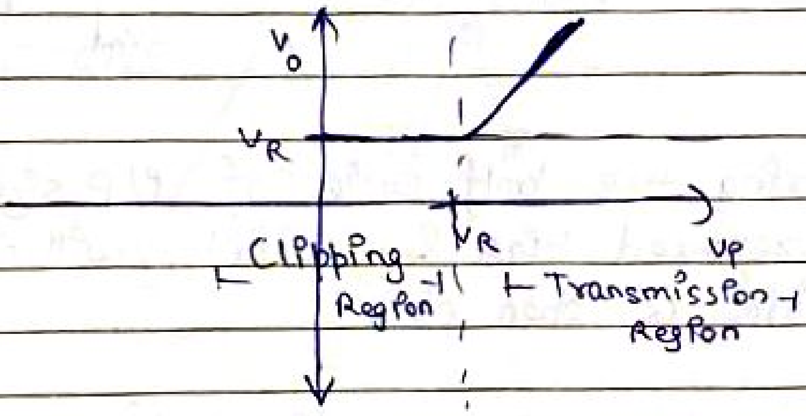
$V_0 = V_i$

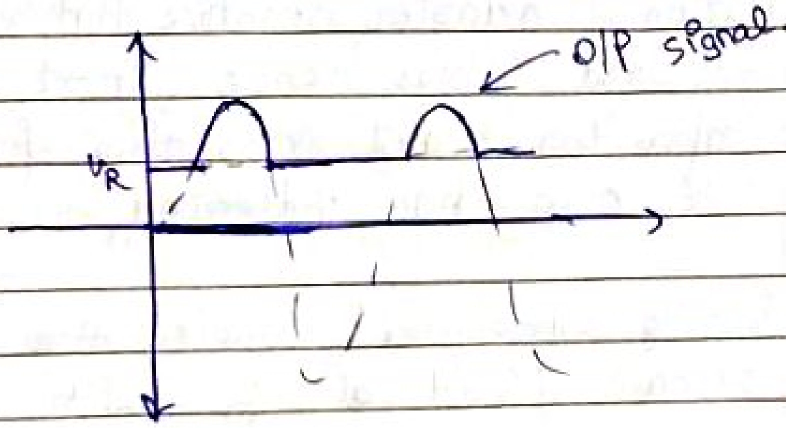
$V_R < V_i$

Transfer Characterstics :-

$V_0 = V_R \quad V_i < V_R$

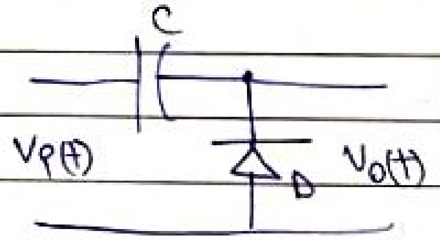
$V_0 = V_i \quad V_i > V_R$

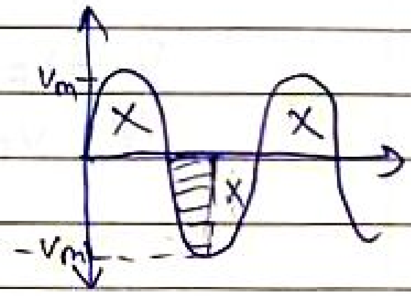




Clamper :-

Positive Clamper - This ckt introduces positive DC value to i/p signal





First open ckt diode
Second short ckt

During +ve half cycle of i/p signal the diode is reversed bias & capacitor will not charge as diode is open ckt

During 1st quarter negative half cycle the diode is forward bias hence short ckt ~~and~~, then capacitor start charging upto $-V_m$ where -ve sign has indicated on capacitor.

During subsequent cycle the capacitor voltage remain fixed at V_m with same polarity.

Under steady state condition,

$$V_o = V_i + V_m$$

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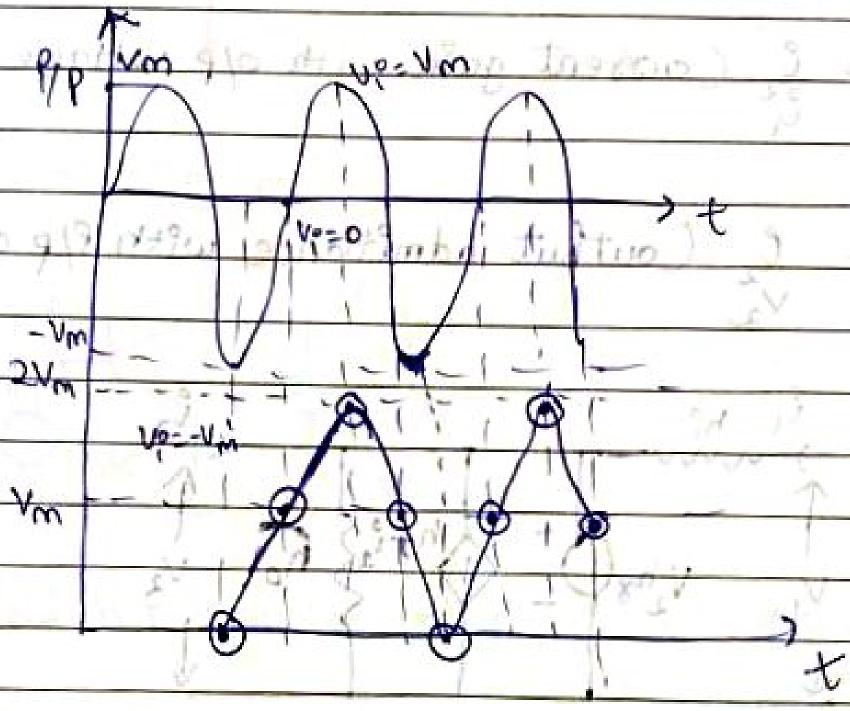
V_i	V_o
0	V_m
$-V_m$	0
V_m	$2V_m$



Hybrid Parameter :-

$$i_c = i_C - I_C = \Delta i_C$$

i_c → Instantaneous value of varying components

i_C → Inst. total value

I_C → Quiescent value

I_{dc} → fixed value b/w two terminal

i/p current & o/p voltage - Independant term
i/p voltage & o/p current - dependant term

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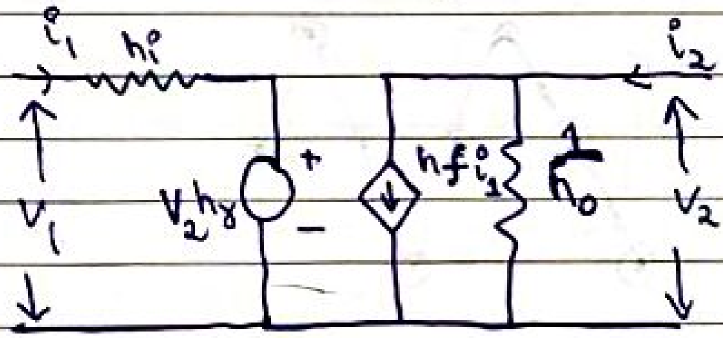
(h_i) $h_{11} = \frac{V_1}{I_1}$ (input impedance with o/p voltage short ckt)

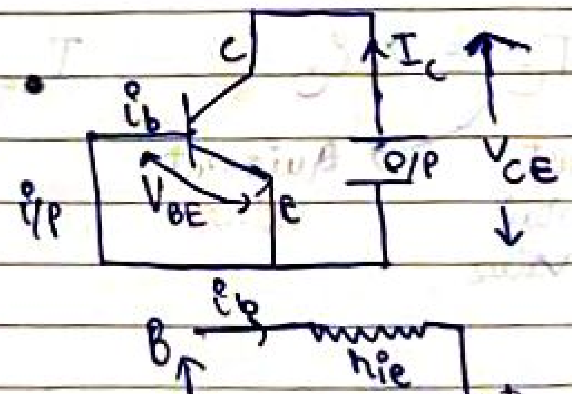
(h_r) $h_{12} = \frac{V_1}{V_2}$ (reverse voltage gain with i/p current open)

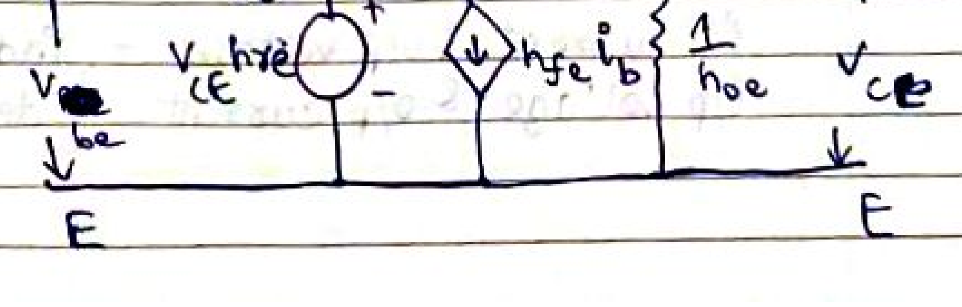
(h_f) $h_{21} = \frac{i_2}{i_1}$ (current gain with o/p voltage short ckt)

(h_o) $h_{22} = \frac{i_2}{V_2}$ (output admittance with i/p current open)

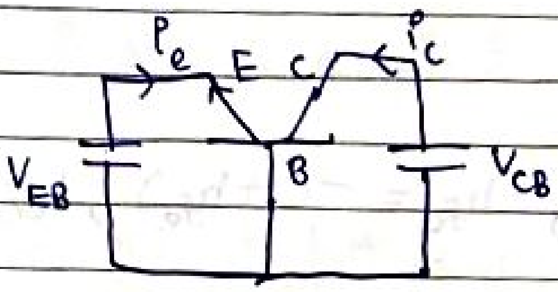


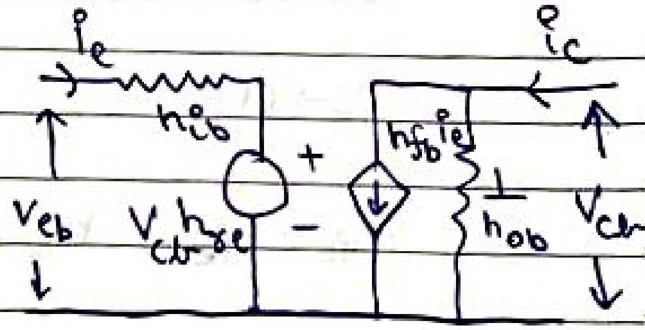
Common Emitter :-



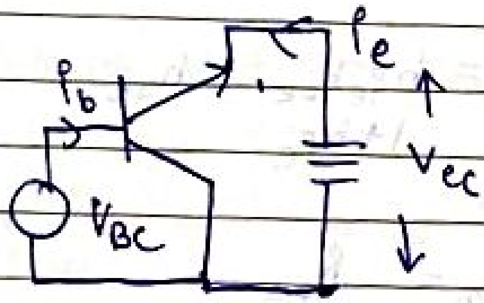


Common Base :-





Common Collector :-



Typical h Parameter value at $I_E = 1.3$ mA

Parameter	CE	CB	CC
h_i	1100 Ω	1100 Ω	21.6 Ω
h_r	25×10^{-4}	1	2.9×10^{-4}
h_f	50	−51	−.98
h_o	24 μ A/V	25 μ A/V	·49μ A/V
$1/h_o$	40 kΩ	40 KΩ	2.04 MΩ

Conversion Formula :-

CC → CE

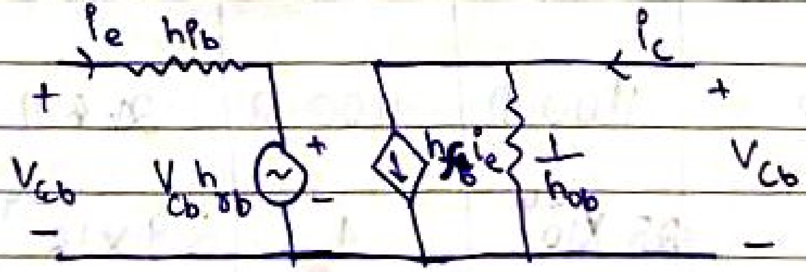
$h_{ic} = h_{ie}$, $h_{rc} = 1$, $h_{fc} = -(1+h_{fe})$, $h_{oc} = h_{oe}$

CB → CE , Same CE → CB ; just replace e with b

$h_{ib} = \frac{h_{ie}}{1+h_{fe}}$, $h_{rb} = \frac{h_{ie}h_{oe}}{1+h_{fe}} - h_{re}$

$h_{fb} = \frac{-h_{fe}}{1+h_{fe}}$, $h_{ob} = \frac{h_{oe}}{1+h_{fe}}$

h_{re} in terms of CB :-



$h_{re} = \frac{V_{be}}{V_{ce}} \Big|_{i_b=0}$

$= \frac{V_{bc} + V_{ce}}{V_{ce}} = \left(1 + \frac{V_{bc}}{V_{ce}}\right) \Big|_{i_b=0}$

Find h_{rb} in terms of CE

__/__/____

If $i_b = 0$, then $i_e = -i_c$

i in h_{ob} is equal to $i = h_{ob} V_{bc}$

$= (1 + h_{fb}) i_e$

Apply KVL to path ebce

$$h_{ib} i_e + V_{cb} h_{rb} + V_{bc} + V_{ce} = 0$$

Combining last 2 eq^n we have,

$$\frac{h_{ib} h_{ob}}{1+h_{fb}} V_{bc} - h_{rb} V_{bc} + V_{bc} + V_{CE} = 0$$

$$\frac{V_{bc}}{V_{ce}} = \frac{-(1+h_{fb})}{h_{ib} h_{ob} + (1-h_{rb})(1+h_{fb})}$$

Hence, $h_{re} = 1 + \frac{V_{bc}}{V_{ce}} \Rightarrow \frac{V_{bc}}{V_{ce}} = h_{re} - 1$

$$h_{re} = 1 - \frac{(1+h_{fb})}{h_{ib} h_{ob} + (1-h_{rb})(1+h_{fb})}$$

$$h_{re} = \frac{h_{ib} h_{ob} - h_{rb}(1+h_{fb})}{h_{ib} h_{ob} + (1-h_{rb})(1+h_{fb})} \rightarrow \text{Exact expressi}$$

As, $h_{rb} << 1$ & $h_{ib} h_{ob} << (1 + h_{fb})$

So, $h_{re} \approx \frac{h_{ib} h_{ob}}{1+h_{fb}} - h_{rb}$ → Simple approx formula

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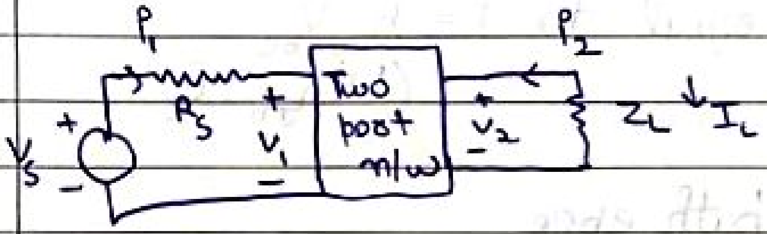
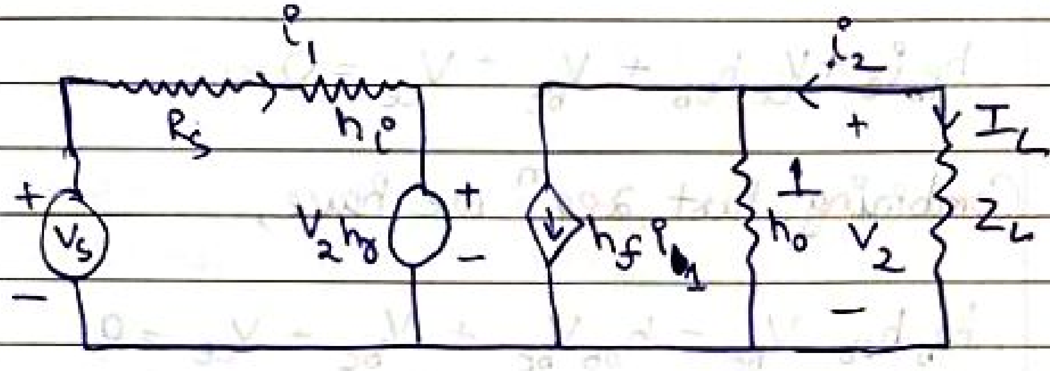
Analysis of Transistor n/w using h - parameter :-





Current gain, $A_I = \frac{-i_2}{i_1} = -\frac{(h_f i_1 + h_o V_2)}{i_1}$

$V_2 = I_L Z_L$
$= -i_2 Z_L$

$A_i = -\frac{(h_f i_1 - h_o i_2 Z_2)}{i_1}$

$\Rightarrow \dfrac{i_2\left(-h_f \frac{i_1}{i_2} + h_o Z_L\right)}{i_1}$

$\Rightarrow \frac{i_2}{i_1} = \frac{-h_f}{1 + h_o Z_L}$

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Input Impedance :-

$$Z_i = \frac{V_1}{I_1} = \frac{h_i i_1 + h_r V_2}{i_1}$$

$$Z_i = h_i + h_r \frac{V_2}{i_1}$$

$$= h_i - h_r \frac{i_2 Z_L}{i_1}$$

$$\frac{Z_i}{Z_L} = (h_i + A_i h_r Z_L)\frac{1}{Z_L}$$

$$\left\{\frac{1}{Z_L} = Y_L\right\}$$

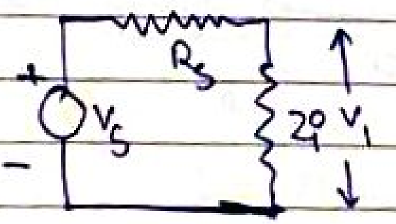
$$\boxed{Z_i \Rightarrow h_i - \frac{h_f h_r}{Y_L + h_o}}$$

voltage gain :-

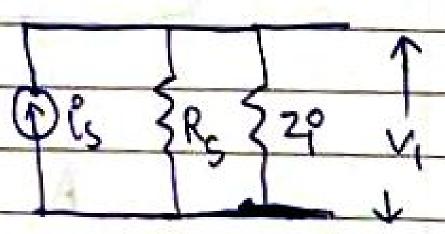
$$A_V = \frac{V_2}{V_1} = \frac{A_i i_1 Z_L}{V_1} \quad \{V_2 = A_i i_1 Z_L\}$$

$$A_V = \frac{A_i Z_L}{Z_i}$$

overall gain :-



Thevenin's Eq.



Norton's Eq.

$$AV_s = \frac{V_2}{V_s} = \frac{V_2}{V_1}\frac{V_1}{V_s} \Rightarrow A_V\frac{V_1}{V_s}$$

$$V_1 = \frac{V_s Z_i}{R_s + Z_i} \quad \text{So,} \quad AV_s = A_V \frac{\cancel{V_s} Z_i}{(R_s+Z_i)\cancel{V_s}}$$

$$\boxed{AV_s = \frac{A_V Z_i}{R_s + Z_i}}$$

$$AV_s = \frac{A_i Z_L}{R_s + Z_i}$$

$$Ai_s = \frac{-i_2}{i_s} = \frac{-i_2}{i_1}\frac{i_1}{i_s}$$

$$= +A_i \frac{i_1}{i_s}$$

$$Ai_s = A_i \frac{i_1}{i_s} \quad \left\{ i_1 = i_s \frac{R_s}{R_s + Z_i} \right\}$$

$$\boxed{Ai_s = A_i \frac{R_s}{R_s + Z_i}}$$

$$R_s = \infty$$

$$Ai_s = A_i$$

Hence A_i is current gain for ideal current source.

$AV_s = AI_s \left(\frac{Z_L}{R_s}\right)$

$\cancel{\frac{AV_s}{AI_s} = \frac{Z_L}{R_s}}$

Output Admittance :-

$$Z_o = \frac{1}{Y_o}$$

$$Y_o = \frac{i_2}{V_2}$$

$$Y_o = h_f \frac{i_1}{V_2} + h_o$$

Put $V_s = 0$, So,

$$R_s i_1 + h_i i_1 + h_r V_2 = 0$$

$$\frac{i_1}{V_2} = \frac{-h_r}{h_i + R_s}$$

$$\boxed{Y_o = h_o - \frac{h_f h_r}{h_i + R_s}}$$

Small signal analysis of a transition :-

$$A_i = \frac{-h_f}{1 + h_o Z_L}$$

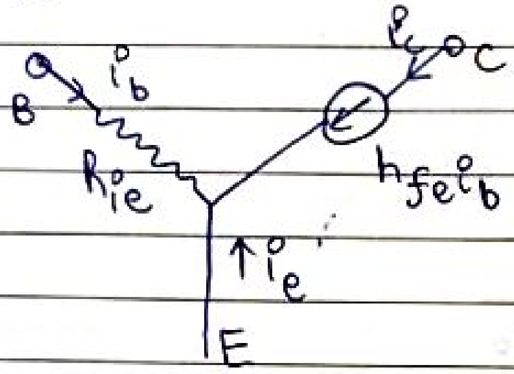
$$Z_i = h_i + h_r A_i Z_L$$

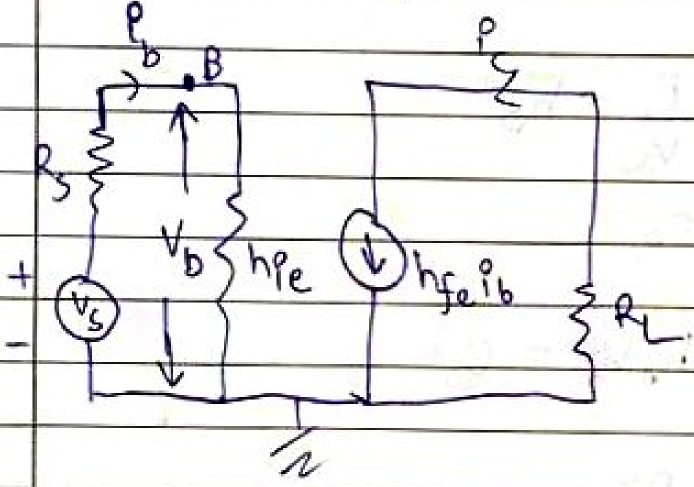
$$Y_o = h_o - \frac{h_f h_r}{h_i + R_i}$$

$$A_v = \frac{A_i Z_L}{Z_i}$$

Simplified Hybrid Model :-

$h_{oe}R_L < .1 \rightarrow$ Condition





Approx model

$$A_I = -h_{fe}$$

$$R_i = h_{ie} + h_{re}A_iR_L$$

$$= h_{ie}\left(1 + \frac{h_{re}A_iR_L}{h_{ie}}\right)$$

$$= h_{ie}\left(1 + \frac{h_{re}\,h_{fe}}{h_{ie}\,h_{oe}}\,\frac{A_i}{h_{fe}}\,h_{oe}R_L\right)$$

$$A_s = \frac{h_{fe}h_{re}}{h_{ie}h_{oe}} \approx .5$$

$R_i = h_{ie}$

$A_v = A_i \frac{R_L}{R_i} = -h_{fe} \frac{R_L}{h_{ie}}$

$R_L = \infty$ if $V_s = 0V$

Summary for approx eq^n $h_{oe}(R_i + R_L) < .1$

	CE	CE with R_i	CC	CB
A_i	$-h_{fe}$	$-h_{fe}$	$1+h_{fe}$	$-h_{fb}$
R_i	h_{ie}	$h_{ie} + (1+h_{fe})R_e$	$h_{ie} + (1+h_{fe})R_L$	h_{ib}
A_v	$\frac{-h_{fe} R_L}{R_i}$	$- \frac{R_L}{R_i}$	$1 - \frac{h_{ie}}{R_i}$	$h_{fe} \frac{R_L}{h_{fe}}$
R_o	∞	∞	$\frac{R_s + h_{ie}}{1+h_{fe}}$	∞
R_o' or $\left(\frac{1}{R_o}\right)$	R_L	R_L	$R_o \| R_L$	R_L

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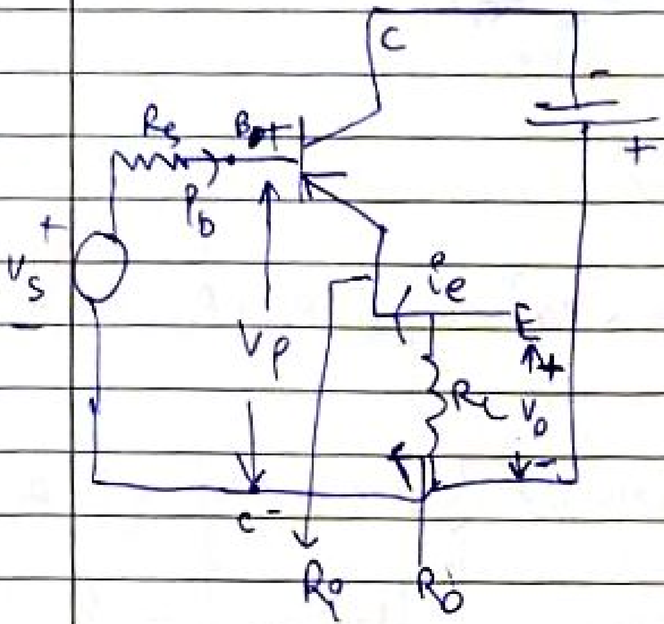
Emitter Follower :-



$A_v \cong 1$

R_i = impedance input

R_o = impedance output

Change in base voltage appears as an equal change across the load. Hence emitter follow i/p signal.

Both A_i & A_v are real & positive

R_i is very high
R_o is very low

It is used as a buffer stage for resistance transformation from high to low resistance over a wide range of freq having voltage gain unity.

It also the power level of signal & no ~~phas~~ phase shift b/w i/p & o/p

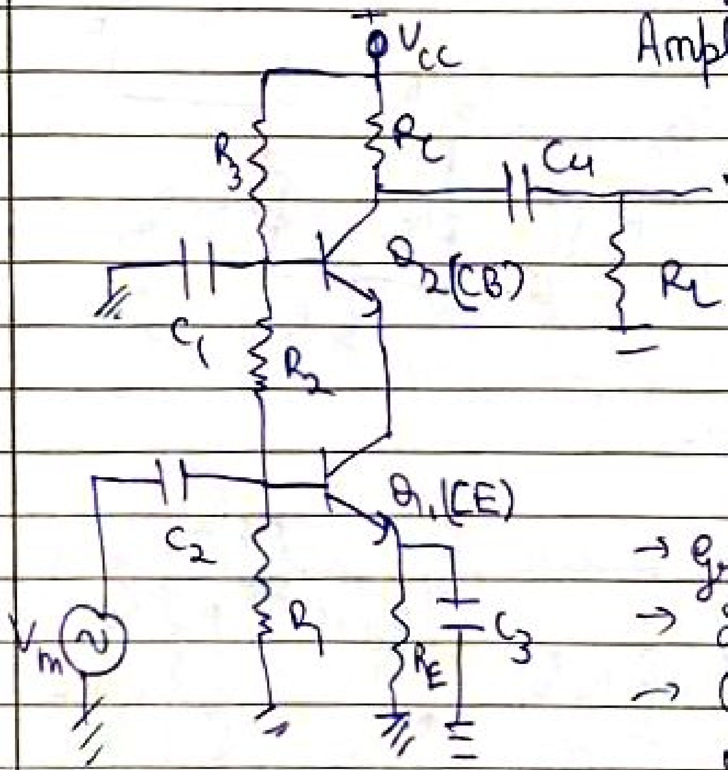
$$A_i = \frac{-I_e}{I_b} = \frac{-h_{fe}}{1+h_{oe}R_L}$$

$$R_i = h_{ic} + h_{rc} A_i R_L = h_{ie} + A_i R_L$$

$$A_V = \frac{A_i R_L}{R_i} = \frac{R_i - h_{ie}}{R_i} = 1 - \frac{h_{ie}}{R_i}$$

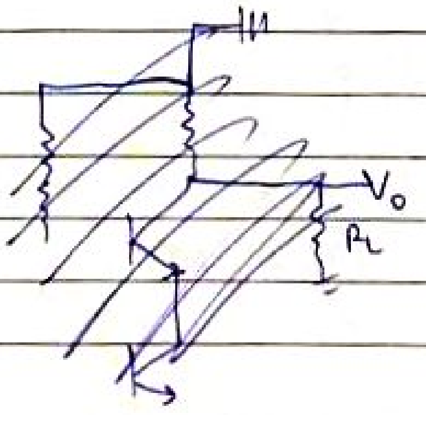
$$Y_o = h_{oc} + \frac{1 + h_{fe}}{h_{ie} + R_s}$$

Cascade Amplifier :- Multistage Amplifier



AC Analysis :-

→ Grd the DC compound
→ Short ckt the capacitor
→ Change the transistor with approx diagram



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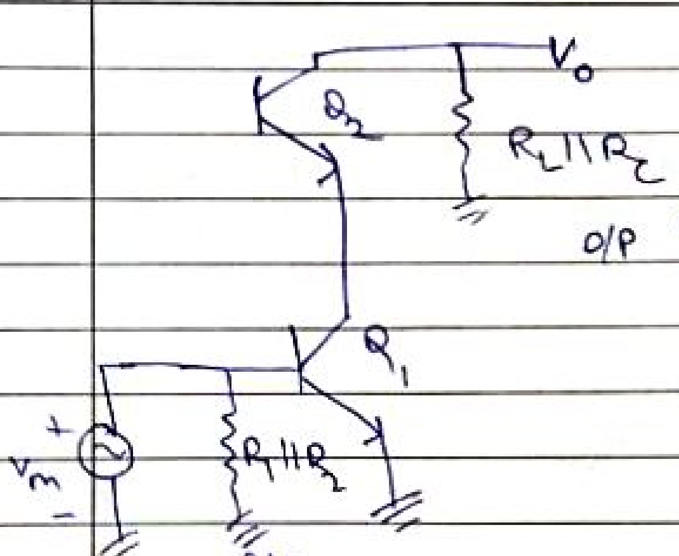
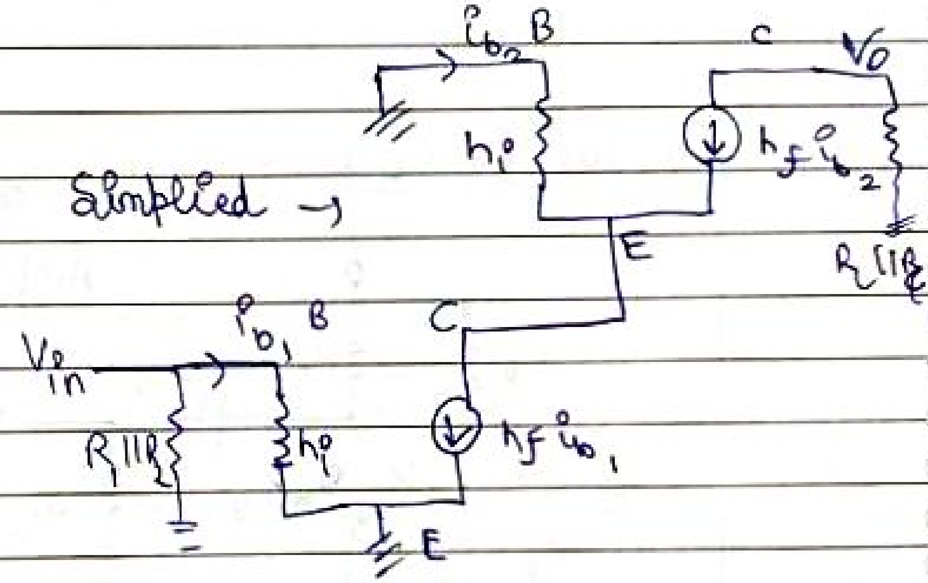


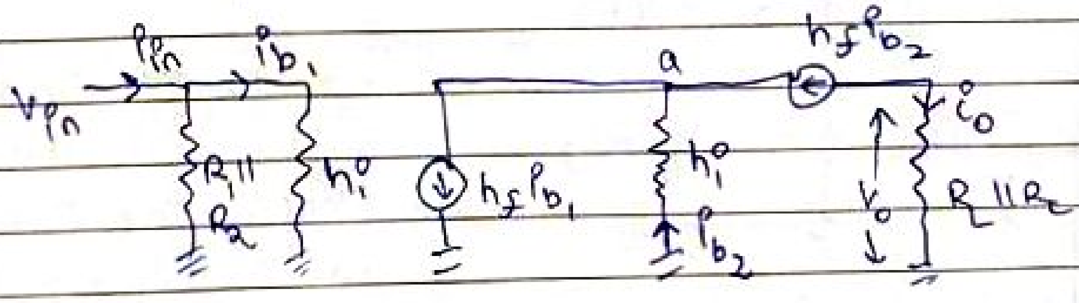
o/p impedance

i/p imp

Simplied →



In same plane :-



$R_i = R_1 \| R_2 \| h_i$

$R_o = R_L \| R_C$

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$i_o = -h_f i_{b_2}$

Apply nodal at a,

$$h_f i_{b_1} = h_f i_{b_2} + i_{b_2}$$

$$h_f i_{b_1} = i_{b_2}(1+h_f)$$

$$i_{b_2} = \frac{h_f i_{b_1}}{(1+h_f)}$$

$$V_o = i_o (R_L \| R_c)$$

$$i_{b_1} = \frac{V_{in}}{h_i} \quad , \quad i_{b_2} = \frac{h_f V_{in}}{h_i(1+h_f)} \; \cancel{= \frac{h_f i_{in}(R_1 \| R_2)}{}}$$

$$i_o = \frac{-h_f(h_f V_{in})}{h_i(1+h_f)} = \frac{-h_f^2 V_{in}}{h_i(1+h_f)}$$

$$V_o = \frac{-h_f^2 V_{in}}{h_i(1+h_f)}(R_L \| R_c)$$

$$\frac{V_o}{V_{in}} = A_v = \frac{-h_f^2 (R_L \| R_c)}{h_i(1+h_f)}$$

$$i_{b_2} = \frac{h_f i_{in}(R_1 \| R_2)}{h_i(1+h_f)}$$

$$i_o = \frac{-h_f h_f i_n (R_1 \| R_2)}{h_i(1+h_f)} \rightarrow \overbrace{\frac{i_o}{i_n}}^{A_i} = \frac{-h_f^2 (R_1 \| R_2)}{h_i(1+h_f)}$$

So final current gain,

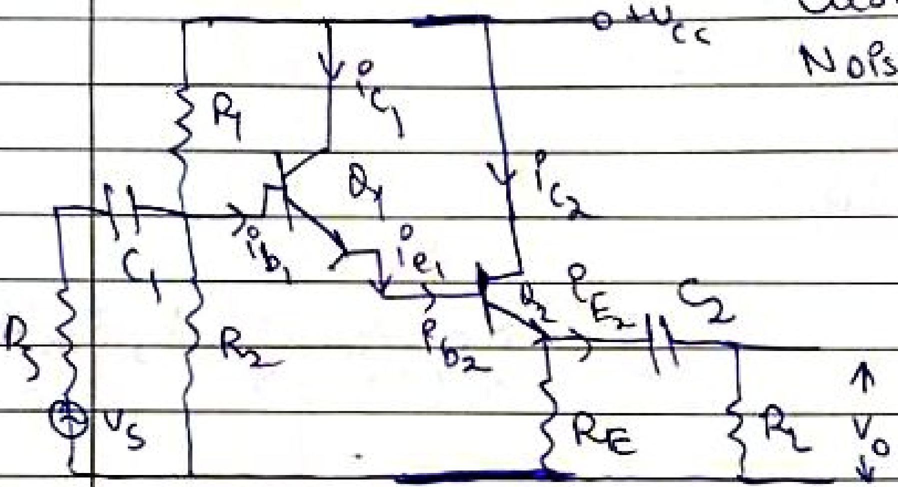
$$A_i = \frac{-h_f^2 (R_1 \| R_2)}{(1+h_f)(R_1 \| R_2 + h_i)}$$

Darlington pair :-

β Multiplier

Current Gain Max

Noisy, Heat dissipation is more



As we know $A_i = \frac{i_{e_2}}{i_{b_1}}$ for Q_1

$i_e = \beta i_b$

$i_{e_1} = i_{b_2}$ So, $A_i = \frac{\beta_2 i_{b_2}}{i_{b_1}} = \beta_2 \frac{i_{e_1}}{i_{b_1}}$

$$A_i = \beta_2 \beta_1 \frac{i_{b_1}}{i_{b_1}} = \beta_2 \beta_1$$

Common emitter with emitter resistance :-

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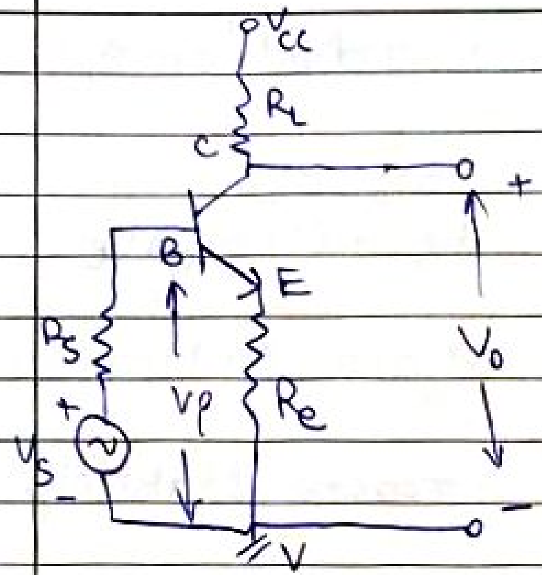
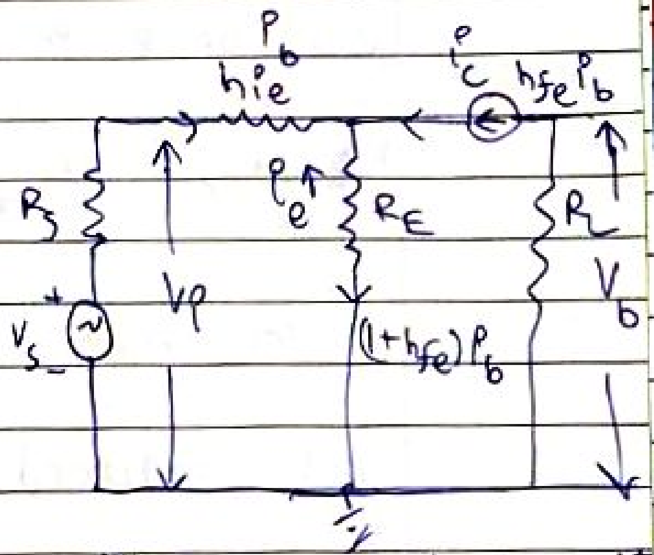


CE ampr with emitter resist.



Approx small signal eq ckt

$$A_i = \frac{-i_c}{i_b} = \frac{-h_{fe}\cancel{i_b}}{\cancel{i_b}} \Rightarrow -h_{fe}$$

~~Res~~ Current gain equal the short ckt value & is unaffected by addition of R_E

$$R_i = \frac{V_i}{i_b} = \frac{i_b h_{ie} + (1+h_{fe}) i_b R_e}{i_b}$$

$$= \frac{\cancel{i_b}(h_{ie} + 1 + h_{fe} R_e)}{\cancel{i_b}}$$

$\rightarrow$ ~~$R_e + h_{fe} R_e + h_{fe}$~~

$\rightarrow$ $R_e + h_{fe} R_e + h_{ie}$

From it can be concluded input

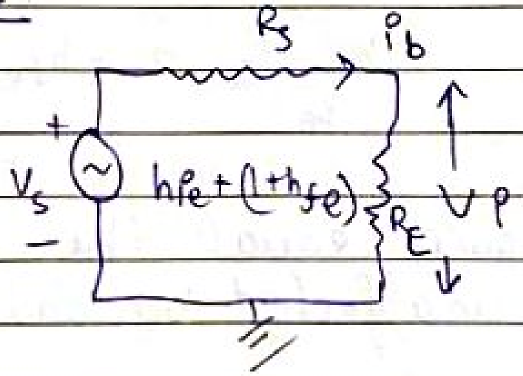
resistance is mostly dependant on R_E.

$$A_V = \frac{A_i R_L}{R_i} = \frac{-h_{fe} R_L}{h_{ie} + (1+h_{fe})R_E}$$

or $A_V \cong -\frac{R_L}{R_E}$. Hence voltage gain got reduced by increases stability also.

Looking into Base & Emitter of Transistor:-

Base:-



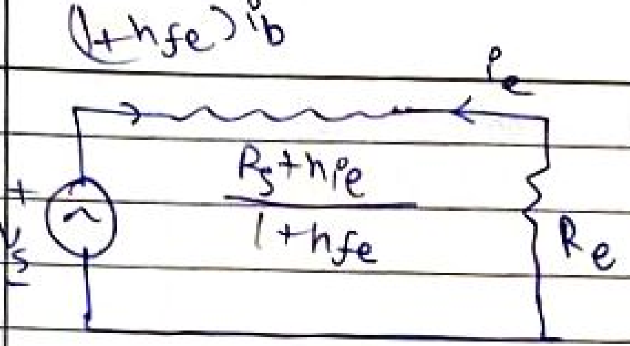
$$i_b = \frac{V_s}{R_s + h_{ie} + (1+h_{fe})R_E}$$

Emitter to Gnd voltage is,

$$V_e = (1+h_{fe})\, i_b R_E$$

$$= \frac{V_s R_E}{(R_s + h_{ie})/(1+h_{fe}) + R_E}$$

Looking from emitter



$$i_e = \frac{-V_e}{R_e}$$

$$i_b = \frac{-i_e}{1+h_{fe}}$$