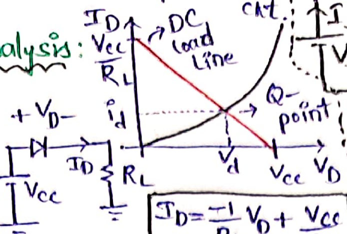
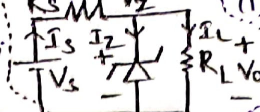
①. Diode Applications : Tests for multiple Diode ckt

OC Test : | SC Test : | DC Analysis :
1. Open ckt all diodes | 1. SC all diodes
2. Find voltage across each diode V_D. | 2. Find all currents through diodes.
3. Highest V_D Diode ON. | $I_A>0 \Rightarrow$ D-ON ; $I_A<0 \Rightarrow$ D-OFF
4. Replace diode with V_γ and repeat the steps.



$$\boxed{I_D = \frac{-1}{R_L}V_D + \frac{V_{cc}}{R_L}}$$

Q-point [Quescent point / Bias point]
Intersection of DC line & VI characteristics
temp ↑↑ − Q point moves Downward on DC Line.



$I_S = \frac{V_S - V_O}{R_S}$

$I_Z = \frac{V_O - V_Z}{R_Z}$

$\boxed{I_S = I_Z + I_L}$

(i). $V_S\uparrow$, R_L-const $(R_L)_{max} \to (I_L)_{min}$

$\boxed{I_S = I_Z + (I_L)_{const}}$ $(R_L)_{min} \to (I_L)_{max}$

$\boxed{(I_S)_{max} = (I_Z)_{max} + (I_L)_{const}}$

$\boxed{(I_S)_{min} = (I_Z)_{min} + (I_L)_{const}}$

ii). V_S-const, $R_L\uparrow$ $\boxed{(I_S)_{const} = I_Z + I_L}$

$\boxed{(I_S)_{const} = (I_Z)_{max} + (I_L)_{min}}$ R_{Lmax}

$\boxed{(I_S)_{const} = (I_Z)_{min} + (I_L)_{max}}$ R_{Lmin}

iii). $V_S\uparrow$ $R_L\uparrow$

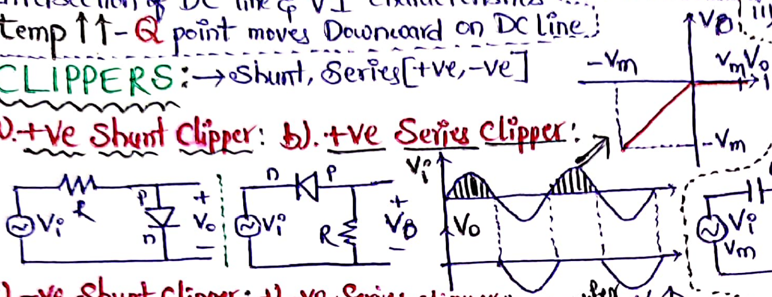
$\boxed{(I_S)_{min} = (I_Z)_{min} + (I_L)_{max}} \Rightarrow R_{Lmin}$

$\boxed{(I_S)_{max} = (I_Z)_{max} + (I_L)_{min}} \Rightarrow R_{Lmax}$

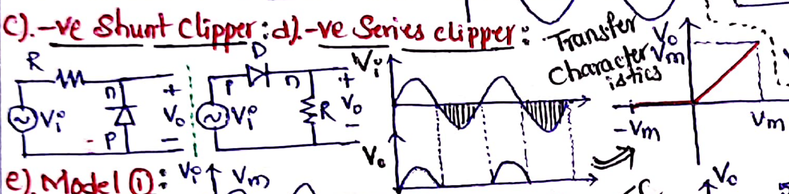
IIT Bombay

CLIPPERS :→ Shunt, Series [+ve, −ve]

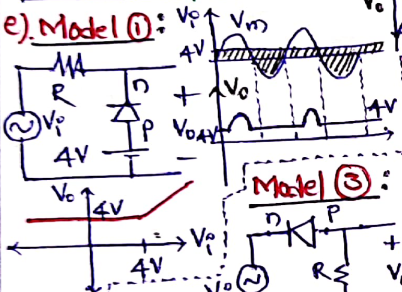
a). +ve Shunt Clipper : b). +ve Series Clipper :



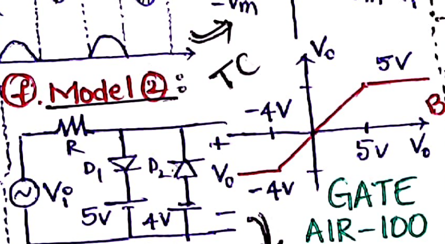
c). −ve Shunt Clipper : d). −ve Series clipper : Transfer Characteristics



e). Model ① :

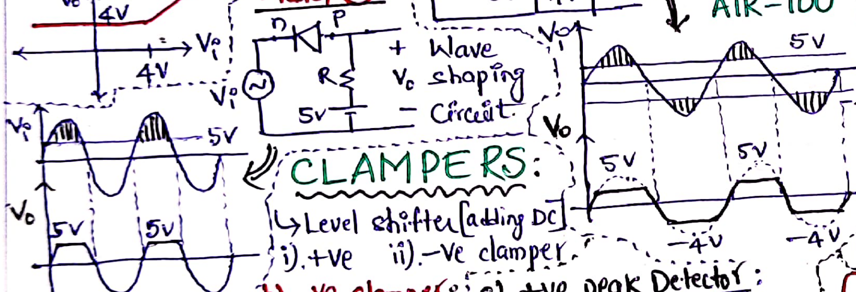


f). Model ② : TC

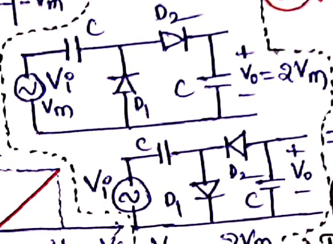


GATE AIR-100

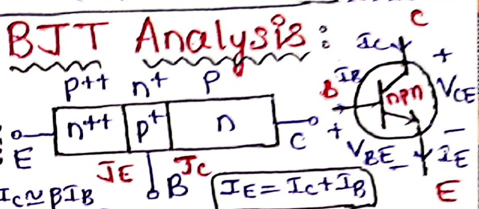
Model ③ : Wave shaping Circuit.



Voltage Multiplier :



②. BJT Analysis :



$\boxed{I_E = I_C + I_B}$

$I_C \approx \beta I_B$
$I_C \propto \alpha I_E$

$\boxed{I_C = \alpha I_E + I_{CBO} = \beta I_B + (1+\beta) I_{CBO}}$

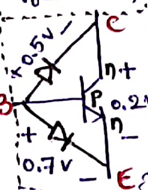
⇒ Identify Operating Mode : $\boxed{\alpha = \frac{\beta}{1+\beta}}$ $\boxed{\beta = \frac{\alpha}{1-\alpha}}$

$\boxed{V_{CE} > 0.2V \Rightarrow \text{Active Mode}}$

$\boxed{V_{CE} \le 0.2V \Rightarrow \text{Saturation}}$

$\boxed{V_{BE} < 0.7V \Rightarrow \text{Cut OFF}}$

$\boxed{I_C = \beta I_B = \alpha I_E}$ → only in Active

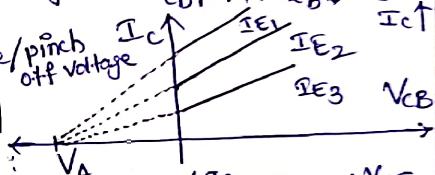


in CB configuration $V_{CB}\uparrow - W\uparrow - x_B\downarrow - I_B\downarrow - I_C\uparrow$

Early Effect :

V_A − Early voltage / pinch off voltage

$\boxed{\text{at } V_A \Rightarrow x_B = 0}$



CB : slop $= \frac{\Delta I_C}{\Delta V_{BE}}$

$\approx \frac{\Delta I_E}{\Delta V_{BE}} = \frac{1}{r_e} = g_m$

CE : slop $= \frac{\Delta I_B}{\Delta V_{BE}} \Rightarrow R_E = \frac{\Delta V_{BE}}{\Delta I_B}$

$\boxed{R_E = r_e(1+\beta)} = \frac{\Delta V_{BE}}{\Delta I_E} \times \frac{\Delta I_E}{\Delta I_B}$

$\boxed{I_C = \alpha I_E + I_{CBO}}$

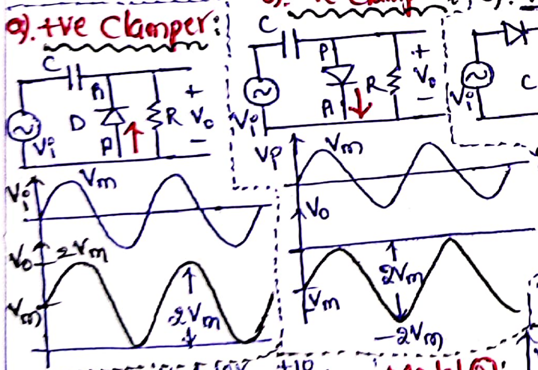
$\boxed{I_C = \beta I_B + (1+\beta) I_{CBO}}$ I_{CEO}

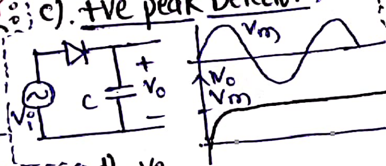
$\boxed{I_E = I_{ES}[e^{V_{BE}/\eta V_T} - 1]}$

CLAMPERS :

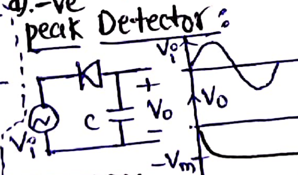
↳ Level shifter [adding DC]
i). +ve ii). −ve clamper.

a). +ve Clamper : b). −ve Clamper : c). +ve peak Detector :





d). −ve peak Detector :



parameter	CB	CE	CC
R_i	Low	High	Low
R_o	V. High	High	Low
A_I	Low	Moderate	High
A_V	High	Moderate	Low
A_P	Low	High	Moderate
P.S	0°	180°	0°

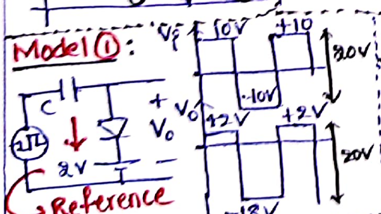
Q-point Stability / Sensitivity :

Q-point $[V_{CE}, I_C]$

$\boxed{P_T = V_{CE} I_C}$ → to have P_T max

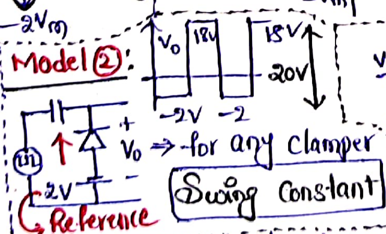
Q-point in middle of the DC load line

Model ① :



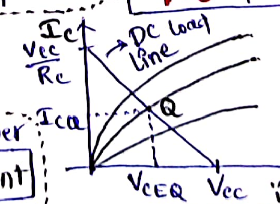
↳ Reference

Model ② :



↳ Reference

Vo → for any clamper $\boxed{\text{Swing Constant}}$



$I_{CQ} = \frac{V_{cc}}{2R_C} \to P_T\ (max)$

$\boxed{I_C = \beta I_B + (1+\beta) I_{CBO}}$

i). $S = \frac{\partial I_C}{\partial I_{CBO}}$ must be minimum

$$\boxed{S = \frac{\partial I_C}{\partial I_{CBO}} = \left[\frac{(1+\beta)}{1-\beta\left(\frac{\partial I_B}{\partial I_C}\right)}\right]}$$

ii). $\boxed{S = \frac{\partial I_C}{\partial V_{BE}}}$ iii). $\boxed{S = \frac{\partial I_C}{\partial \beta}}$

temp ↑↑ − $I_{CBO}\uparrow - V_{BE}\downarrow - \beta\uparrow$

$\boxed{S = \frac{\partial I_C}{\partial I_{CBO}} \ggg \frac{\partial I_C}{\partial V_{BE}}, \frac{\partial I_C}{\partial \beta}}$

Rectifier	f_o	V_{avg}	V_{or}	FF	RF	PIV	TUF	η
HWR	f	V_m/π	$\frac{V_m}{2}$	$\frac{\pi}{2}$	1.21	V_m	0.28	40.5
FWR (Mid point)	2f	$\frac{2V_m}{\pi}$	$\frac{V_m}{\sqrt{2}}$	$\frac{\pi}{2\sqrt{2}}$	0.48	$2V_m$	0.693	81.2
FWR (Bridge)	2f	$\frac{2V_m}{\pi}$	$\frac{V_m}{\sqrt{2}}$	$\frac{\pi}{2\sqrt{2}}$	0.48	V_m	0.812	81.2

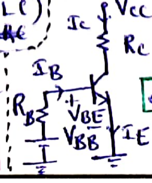
Filters : C, L, LC, CLC, CRC

$RF \propto \frac{1}{f}$ (L, C)

$RF \propto \frac{1}{f^2}$ (LC, CRC)

$RF \propto \frac{1}{f^3}$ (CLC, CRC)

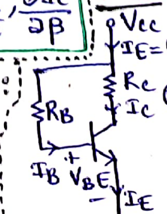
CE Configuration :



$\frac{\partial I_B}{\partial I_C} = 0$

$\boxed{S = (1+\beta)}$ V. High

Fixed Bias Configuration :



① $V_{cc} - I_C R_C - V_{CE} = 0$

② $V_{cc} - I_B R_B - V_{BE} = 0$

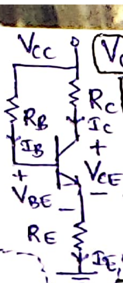
$I_B = \frac{V_{cc} - V_{BE}}{R_B} \Rightarrow \frac{\partial I_B}{\partial I_C} = 0$

$\boxed{S = (1+\beta)} \Rightarrow$ V. High

KVL ②. $V_{cc} - I_B R_B - V_{BE} = 0$

✱ Zener Diode → Heavily doped diode → Reverse Bias operated → Voltage Regulator

A —▷|— K → FB : Normal Diode $\boxed{(P_Z)_{min} = V_Z (I_Z)_{max}}$



$V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0$

$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$

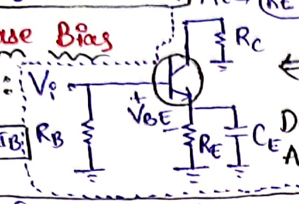
$S = \left[\frac{(1+\beta)}{1+\beta\left(\frac{R_E}{R_E+R_B}\right)}\right] < (1+\beta)$

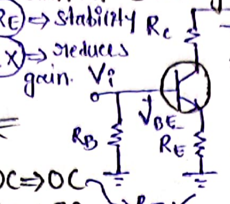
Due to R_E value: → stability of 'Q' ↓ (Good) ↳ Gain reduced. Drawback of Emitter Biasing

I_E; DC ⇒ R_E ✓ AC ⇒ R_E ✗

DC ⇒ (R_E) ⇒ stability

AC ⇒ (R_E ✗) ⇒ reduces gain.

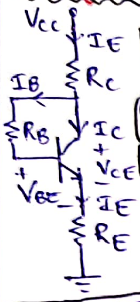




DC ⇒ OC ↳ R_E ✓

AC ⇒ SC ↳ R_E ✗

Collector to Base Bias Configuration:



$I_C = \beta I_B$

① $V_{CC} - I_E R_C - I_B R_B - V_{BE} - I_E R_E = 0$ $\quad (V_{CE})_{sat} = 0.2V$

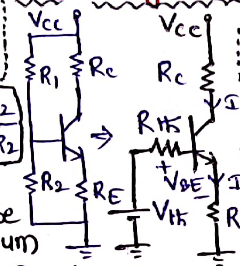
② $V_{CC} - I_E R_C - V_{CE} - I_E R_E = 0$

$S = \left[\frac{(1+\beta)}{1+\beta\left(\frac{R_E+R_C}{R_E+R_C+R_B}\right)}\right]$

$I_E = (1+\beta) I_B$

Stability Factor/ Sensitivity

Voltage Divider Bias Configuration:



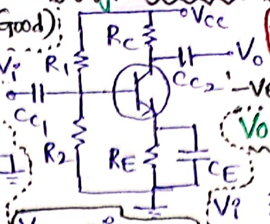
$R_{th} = R_1 \| R_2 \quad V_{th} = \frac{V_{CC} R_2}{R_1 + R_2}$

$S = \left[\frac{(1+\beta)}{1+\beta\left(\frac{R_E}{R_E+R_{th}}\right)}\right] \simeq \left(\frac{R_E + R_{th}}{R_E}\right)$ ⇒ 'S' must be minimum

$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$

$V_{th} - I_B R_{th} - V_{BE} - I_E R_E = 0$

Voltage Divider Bias with C_E:



$Z_{out} = r_o \| R_C$

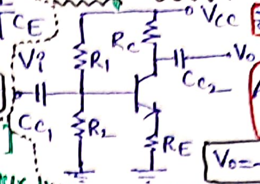
$Z_{in} = R_1 \| R_2 \| \beta r_e$

$A_v = \frac{V_o}{V_i} = \frac{-\beta(r_o \| R_C)}{(1+\beta) r_e}$

'-ve' sign ⇒ 180° P.S.

$V_o = -\beta i_b Z_{out}$

Voltage Divider Bias without C_E:

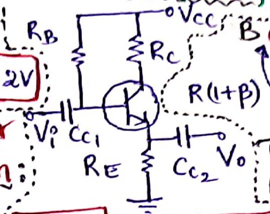


$Z_{in} = R_1 \| R_2 \| \beta(r_e + R_E)$

$A_v = \frac{V_o}{V_i} = \frac{-R_C}{r_e + R_E}$ $\quad Z_{out} = R_C$

$V_o = -\beta i_b R_C$ "-ve" → 180° P.S.

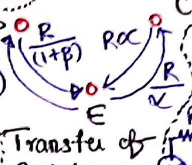
Emitter [CC] Follower Configuration:



$Z_{in} = R_B \| \beta(r_e + R_E)$

$Z_{out} = R_E \quad r_o = \frac{V_A}{I_C}$

$A_v = \frac{V_o}{V_i} = \frac{R_E}{R_E + r_e}$



Transfer of Resistance from B↔E, C↔E

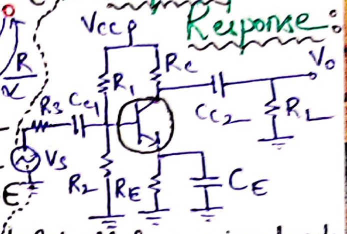
C_T, C_D, C_{sh} ⇒ $C_D >> C_T$

↳ parasitic Capacitors

C_D – FB, C_T – RB width

$\uparrow C_D = \frac{\epsilon A}{d\downarrow} \quad C_T\downarrow = \frac{\epsilon A}{d\uparrow}$ d – depletion

★ Frequency Response:



↳ Cut off frequencies due to

$(f_c)_{C_{C_1}} = \frac{1}{2\pi C_{C_1}[R_s + (R_1 \| R_2 \| h_i)]}$

$(f_c)_{C_{C_2}} = \frac{1}{2\pi C_{C_2}[R_C + R_L]}$

AIR 100

$(f_c)_{C_E} = \frac{1}{2\pi C_E\left[R_E \| \left(\frac{h_i + (R_1 \| R_2 \| R_s)}{1 + h_f}\right)\right]}$

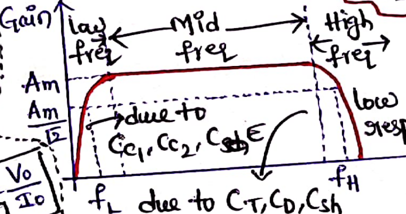
With C_E: $Z_{in} = R_1 \| R_2 \| \beta r_e$ $\quad Z_{out} = r_o \| R_C \| R_L$

$A_v = \frac{V_o}{V_i} = -g_m (r_o \| R_C \| R_L)$

CB → Current Buffer ($A_I = 1$)

CC → Voltage Buffer ($A_V = 1$)

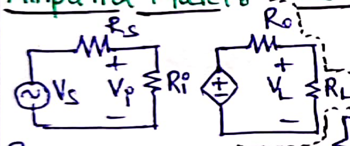
CE → power Amplifier (A_P ↑)

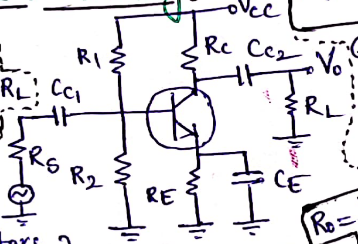


f_L due to C_T, C_D, C_{sh}

AC Analysis of BJT:

Amplifier Model: BJT Modelling:





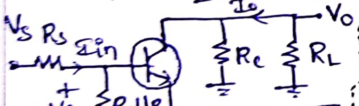
$R_i = \infty$ (OC), $R_o = 0$ (SC) } Ideal case

$R_o = \frac{V_o}{I_o}$

C_{C_1}, C_{C_2} → Coupling Capacitors

C_E → Emitter Bypass Capacitor } AC [SC], DC [OC]

⇒ AC Eq ckt [kill DC Sources] $\quad A_v = \frac{V_o}{V_i} \quad A_I = \frac{I_o}{I_{in}} \quad R_{in} = \frac{V_{in}}{I_{in}}$



$V_o = -I_o R_L$

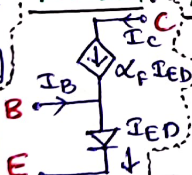
C	Low freq (10 Hz)	Mid freq (10 KHz)	High freq (10 MHz)
C_{C_1}, C_{C_2}, C_E	✓	SC	SC
C_D C_T C_{sh}	OC	OC	✓

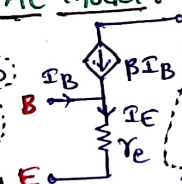
	R_{in}	R_o	Application
VCVS	∞	0	op Amp (V)
CCCS	0	∞	BJT (A)
CCVS	0	0	(R)
VCCS	∞	∞	MOSFET (G)

I/p: ∞ ⇒ Series, 0 ⇒ parallel

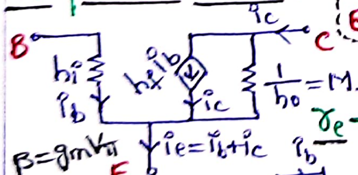
O/p ⇒ opposite

T-Model: AC Model:





h-parameter Model:



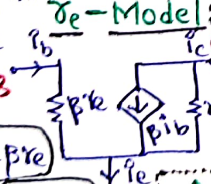
$\frac{1}{h_o} = M\Omega$

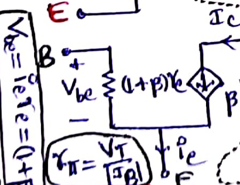
$\beta = g_m V_\pi$ $\quad i_e = i_b + i_c$

$h_i = \beta r_e$ $\quad h_f = \beta$

$1/h_o = r_o$ $\quad (1+\beta) r_e \simeq \beta r_e$

r_e – Model:



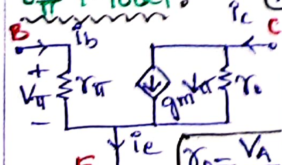


$V_{be} = i_e r_e = (1+\beta) i_b r_e$

$r_\pi = \frac{V_T}{I_B}$

$i_c = \alpha i_e = \beta i_b = g_m v_{be} = g_m v_\pi$

r_π Model:



$h_i = r_\pi$

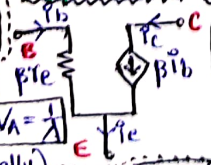
$\beta i_b = g_m V_\pi$

$\beta = g_m r_\pi$

$\alpha = g_m r_e$ $\quad V_A = \frac{1}{\lambda}$

$r_o = \frac{V_A}{I_C}$ = ∞ (practically) = ∞

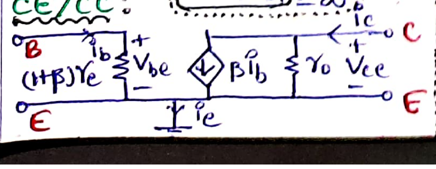
Approximate Model:



$r_e = \frac{V_T}{I_E}$

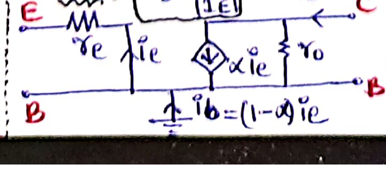
$g_m = \frac{I_C}{V_T} = \frac{\alpha}{r_e}$

CE/CC:



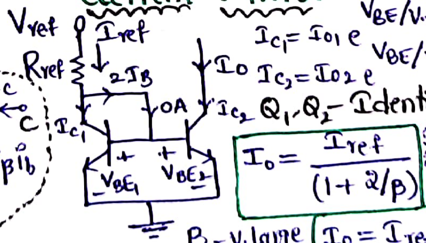
CB:

$r_e = \frac{V_T}{I_E}$



$i_b = (1-\alpha) i_e$

Current Mirror:



$I_{C_1} = I_{o1} e^{V_{BE}/V_T}$

$I_{C_2} = I_{o2} e^{V_{BE}/V_T}$

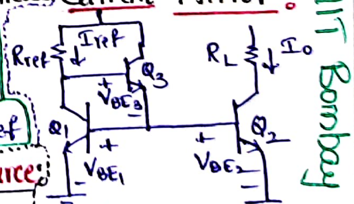
$\frac{I_{C_2}}{I_{C_1}} = \frac{I_{o2}}{I_{o1}}$

Q_1, Q_2 – Identical

$I_o = \frac{I_{ref}}{(1 + 2/\beta)}$

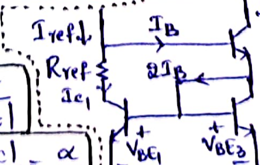
β - v. large $I_o = I_{ref}$

Modified Current Mirror:



$I_o = \frac{I_{ref}}{\left[1 + \frac{2}{\beta(1+\beta)}\right]}$ GATE

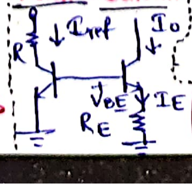
Wilson Current Source:



Q_1, Q_2, Q_3 – Same

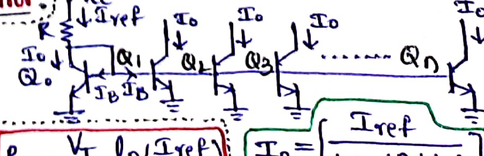
$I_o = \left[\frac{I_{ref}}{\frac{1}{\beta} + \left(\frac{1+\beta}{2+\beta}\right)}\right]$

Widlar Current Mirror:



$R_E = \frac{V_T}{I_E} \ln\left(\frac{I_{ref}}{I_o}\right)$

Current Mirror with Multiple Sources:



$I_o = \left[\frac{I_{ref}}{1 + \left(\frac{n+1}{\beta}\right)}\right]$

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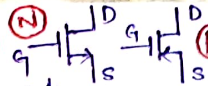
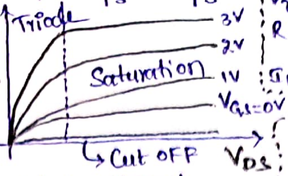
3). MOSFET ANALYSIS

Ⓝ Ⓟ


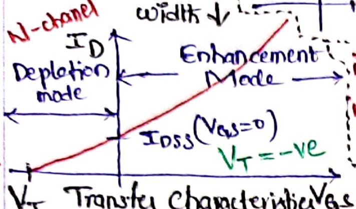
Depletion Type MOSFET
(Channel exist by default)

- $V_{GS}=V_T \rightarrow$ pinch off
- $V_{GS} \geq V_T \rightarrow$ Conducts
- $V_{GS}<0 \rightarrow$ channel width ↓

Enhancement MOSFET
(No channel by default)
No channel

O/P Characteristics


Transfer Characteristics
$g_m=\frac{\partial I_D}{\partial V_{GS}}$
V_{GS} $V_{GS}\uparrow$ - channel width ↑ - $I_D\uparrow$
V_T $V_T=+ve$



Regions of Operation

i). Cut OFF: $V_{GS}<V_T$ $\boxed{I_D=0}$

ii). Triode/Linear $\Rightarrow I_D>0$
$V_{GS}>V_T,\ V_{DS}<(V_{GS}-V_T)$

$\boxed{I_D=\mu_n C_{ox}\left(\frac{W}{L}\right)\left[(V_{GS}-V_T)V_{DS}-\frac{V_{DS}^2}{2}\right]}$

$\boxed{K=\frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)}$ $\boxed{I_D=2K\left[(V_{GS}-V_T)V_{DS}-\frac{V_{DS}^2}{2}\right]}$ $\boxed{K_n'=\mu_n C_{ox}}$ $\boxed{r_{ds}=\left[\frac{\partial I_D}{\partial V_{DS}}\right]^{-1}}$

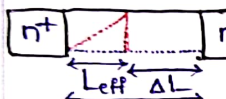
if $V_{DS}<<(V_{GS}-V_T) \Rightarrow \boxed{I_D=2K[(V_{GS}-V_T)V_{DS}]}$

$\boxed{r_{ds}=r_o=\left(\frac{\partial I_D}{\partial V_{DS}}\right)^{-1}=\frac{1}{2K(V_{GS}-V_T)}}$

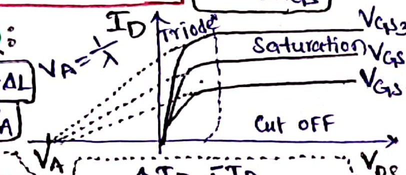
iii) Saturation: $V_{GS}\geq V_T,\ V_{DS}\geq(V_{GS}-V_T)$

$\boxed{I_D=\frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS}-V_T)^2=K(V_{GS}-V_T)^2}$ $\boxed{g_m=\frac{\Delta I_D}{\Delta V_{GS}}}$

Channel Length Modulation:

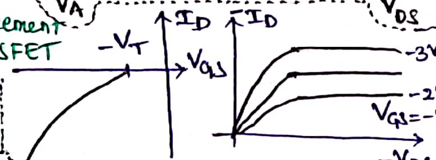


$\boxed{L_{eff}=L-\Delta L}$
$\boxed{\lambda=1/V_A}$
$V_A=\frac{1}{\lambda}$



$\boxed{I_D'=I_D[1+\lambda V_{DS}]}$

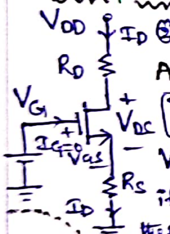
$\boxed{r_{ds}=r_o=\left(\frac{\partial I_D}{\partial V_{DS}}\right)^{-1}=\frac{1}{\lambda I_D}=\frac{V_A}{I_D}}$

Enhancement P-MOSFET


$V_{GS}>V_T \Rightarrow$ Cut OFF
$V_{GS}<V_T,\ V_{DS}>(V_{GS}-V_T)$: Triode
$V_{GS}<V_T,\ V_{DS}<(V_{GS}-V_T)$: saturation

DC Analysis of MOSFET

1). Fixed Bias: ① $V_G-V_{GS}-I_DR_S=0$
② $V_{DD}-I_DR_D-V_{DS}-I_DR_S=0$

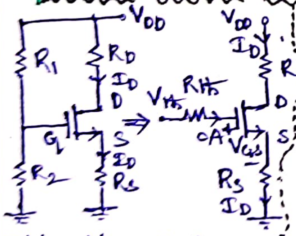


Assume in Sat
$\boxed{I_D=K(V_{GS}-V_T)^2}$
- $V_{DS}>(V_{GS}-V_T)$ ✓
- if not satisfied then triode region

2). Drain to Gate Bias: [Always in Saturation]

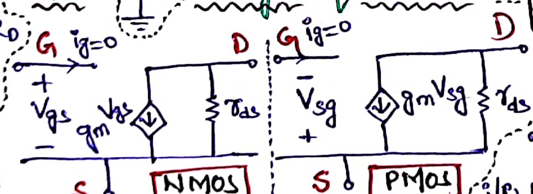
$V_{GS}=V_{DS}\,[V_{DS}>(V_{GS}-V_T)]$
$V_{DD}-I_DR_D-V_{DS}-I_DR_S=0$
$\boxed{I_D=K(V_{GS}-V_T)^2}$

3) Potential Divider Bias:



① $V_{Th}-V_{GS}-I_DR_S=0$
② $V_{DD}-I_DR_D-V_{DS}-I_DR_S=0$
Assume Sat region & solve

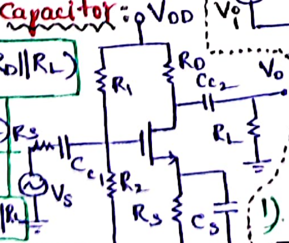
AC Analysis of MOSFET



$\boxed{g_m=\frac{I_D}{V_{gs}}}$

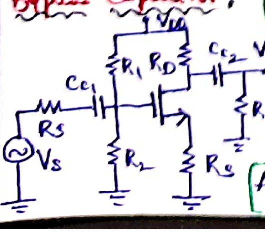
$\frac{1}{h_o}=r_o=r_{ds}=\frac{V_A}{I_D}\ \left(\lambda=\frac{1}{V_A}\right)$
No Channel Length Modulation
$\lambda=0,\ V_A=\infty,\ r_o=\infty$

RC Coupled Amplifier with Bypass Capacitor:



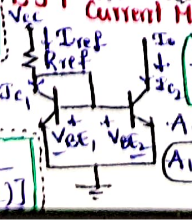
$\boxed{A_V=\frac{V_o}{V_i}=-g_m(R_D\|R_L)}$
$\boxed{A_I=-g_m(R_1\|R_2)}$
$\boxed{R_{in}=R_s+(R_1\|R_2)}$
$\boxed{R_{out}=R_D\|R_L}$

RC Coupled Amplifier without Bypass Capacitor:



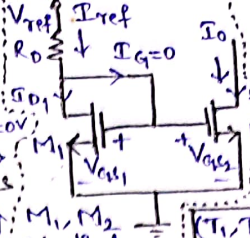
$\boxed{A_V=\frac{V_o}{V_i}=\frac{-g_m(R_D\|R_L)}{(1+g_mR_S)}}$
$\boxed{R_{in}=R_s+(R_1\|R_2)}$
$\boxed{R_{out}=R_D\|R_L}$
$\boxed{A_I=\frac{I_o}{I_S}=\frac{-g_mV_{gs}}{V_S[R_S+(R_1\|R_2)]}}$

BJT Current Mirror



$\boxed{\frac{I_o}{I_{ref}}=\frac{I_{o2}}{I_{o1}}=\frac{A_2}{A_1}}$
A_1, A_2 - Areas (Emitter)
$\boxed{A_1=A_2}$ $\boxed{I_o=I_{ref}}$

Current Mirror:

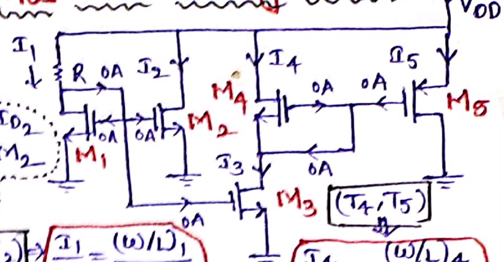


M_1, M_2 Identical

$\boxed{\frac{I_{ref}}{I_o}=\frac{(W/L)_1}{(W/L)_2}}$

$\left(\frac{W}{L}\right)_1=\left(\frac{W}{L}\right)_2 \Rightarrow \boxed{I_o=I_{ref}}$

MOS Current Steering Circuit:

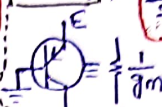


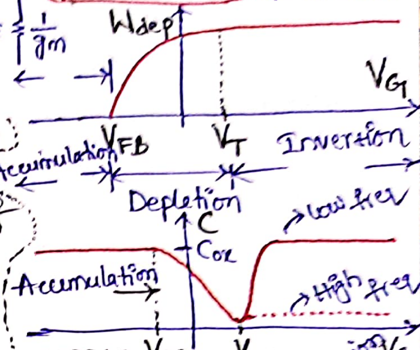
$(I_1, I_2) \rightarrow \boxed{\frac{I_1}{I_2}=\frac{(W/L)_1}{(W/L)_2}}$

$(I_4, I_5) \rightarrow \boxed{\frac{I_4}{I_5}=\frac{(W/L)_4}{(W/L)_5}}$

$(I_1, I_3) \rightarrow \boxed{\frac{I_1}{I_3}=\frac{(W/L)_1}{(W/L)_3}}$

V_{FB} - Flat Band
V_T - Threshold





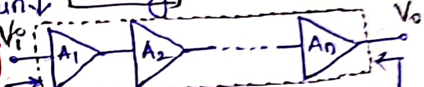
4). Multi Stage Amplifiers:

To increase Gain
⇒ Drawback of Cascading is $\boxed{\text{Loading Effect}}$

Solution: $\boxed{\text{Impedance}}$ $\boxed{\text{Matching}}$

$(R_o)_{eff}=(R_{o1}\|R_{o2})\downarrow$ - Gain ↓

Multistage/Cascading



$\boxed{R_{in}=(R_{in})_{1st}}$
$\boxed{R_o=(R_o)_{n^{th}}}$

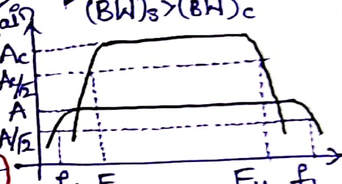
② Types
1. Ⓝ Identical Amplifiers ②. Ⓝ - Non identical.

i). Cascading of Ⓝ Identical Single stage Amplifiers:

$\boxed{A_c=(A)^N}$ $\boxed{F_L=\frac{f_l}{\sqrt{2^{1/N}-1}}}$

$\boxed{F_H=f_h\sqrt{2^{1/N}-1}}$ $\boxed{\text{Gain}\times\text{BW}=\text{const}}$

$(BW)_s>(BW)_c$



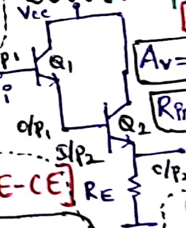
2). Cascading of Ⓝ non-Identical Single Stage Amplifiers:

$\boxed{A_V=A_1A_2A_3\ldots A_N}$ $\boxed{BW=F_H-F_L}$

$\boxed{F_L=\max\{f_{l1}, f_{l2}, \ldots f_{lN}\}}$

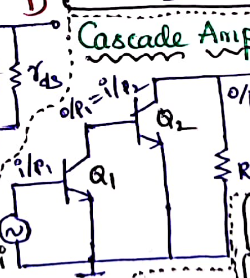
$\boxed{F_H=\min\{f_{h1}, f_{h2}, \ldots f_{hN}\}}$

Darlington pair Configuration [CC-CC]



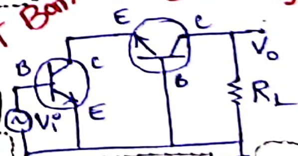
$\boxed{A_V=1}$ $\boxed{A_I=\beta^2}$
$\boxed{R_{in}=\beta^2R_E}$
$\boxed{R_o=r_e}$

Cascade Amplifier: [CE-CE]



$\boxed{A_V=\frac{R_L}{r_e}=g_mR_L}$
$\boxed{R_{in}=\beta r_e}$ $\boxed{R_o=R_L}$

Cascode Amplifier: [CE-CB]



$\boxed{A_V=\frac{-R_C\|R_L}{r_e}}$
$\boxed{A_V=-g_m(R_C\|R_L)}$

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BW of n-stage Amplifier $\boxed{BW'=BW\sqrt{2^{1/n}-1}}$

Feedback Ampliers

Gain sensitivity $\boxed{S_g=\left[\frac{\partial A_F/A_F}{\partial A/A}\right]}$

1). -ve FB: $\boxed{V_o=\left(\frac{A}{1+A\beta}\right)V_S+\frac{V_N}{(1+A\beta)}+\frac{V_D}{(1+A\beta)}}$ $\boxed{S_g=\left(\frac{1}{1+A\beta}\right)}$ → more

$\boxed{A_F=\frac{A}{1+A\beta}}$ V_N, V_D - Noise & Distortion Voltages without FB.

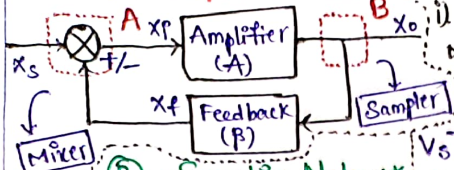
Gain ↓ - BW ↑ $D_g=\frac{1}{S_g}=(1+A\beta)$

2). +ve FB

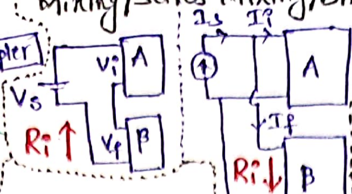
$\boxed{V_o=\left(\frac{A}{1-A\beta}\right)V_S+\frac{V_N}{(1-A\beta)}+\frac{V_D}{(1-A\beta)}}$

$\boxed{A_F=\frac{A}{1-A\beta}}$ Gain ↑ - BW ↓ - Noise ↓ - Distortion ↓

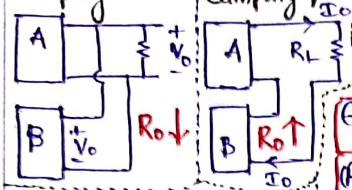
FeedBack Amplifier:



(A) – Mixer Network
i) Voltage Mixing / Series
ii) Current Mixing / Shunt



(B) – Sampling Network
i). Voltage / shunt Sampling
ii). Current / series Sampling



① Series–Shunt / Voltage–Series
i/p(V) o/p(V) o/p i/p(V)
VCVS / Voltage Amplifier:

$\boxed{Gain = \left(\frac{A_{VS}}{1+A_{VS}\beta}\right)}$ $\boxed{BW' = BW(1+A_{VS}\beta)}$

$\boxed{(R_i)_F = R_i(1+A\beta)}$ $\boxed{R_{oF} = R_o/(1+A\beta)}$

② Shunt–Series / Current–Shunt
i/p (I) i/p(I) o/p i/p(I)
CCCS / Current Amplifier:

$\boxed{A_{IF} = \left(\frac{A_{IS}}{1+\beta A_{IS}}\right)}$ $\boxed{BW_F = BW/(1+A_I\beta)}$

$\boxed{R_{iF} = R_i/(1+A_I\beta)}$ $\boxed{R_{oF} = R_o(1+A_I\beta)}$

③ Shunt–shunt / voltage–shunt
i/p(I) o/p(V) o/p i/p(I)
CCVS / Transresistance Amp.:

$\boxed{Gain = \left(\frac{R_{MS}}{1+\beta R_{MS}}\right)}$ $\boxed{BW_F = B/(1+\beta R_M)}$

$\boxed{R_{iF} = R_i/(1+R_M\beta)}$ $\boxed{R_{oF} = R_o/(1+R_M\beta)}$

④ Series–Series / Current–series
i/p (V) o/p(I) o/p i/p(V)
VCCS / Transconductance Amp:

$\boxed{Gain = \left(\frac{G_{MS}}{1+\beta G_{MS}}\right)}$ $\boxed{BW_F = B(1+\beta G_M)}$

$\boxed{R_{iF} = R_i(1+\beta G_M)}$ $\boxed{R_{oF} = R_o(1+\beta G_M)}$

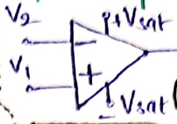
2). Dual i/p Balanced o/p: $\boxed{A_c = 0}$ $\boxed{A_d = \frac{-R_c}{r_e}}$ $\boxed{R_{in1} = R_{in2} = 2\beta r_e}$

$\boxed{R_{o1} = R_{o2} = R_c}$ $\boxed{CMRR = \infty}$ $\boxed{V_o = A_d V_d}$ $R_{in1} = R_{in2} = 2\beta r_e$

3) Single i/p Unbalanced o/p: → $\boxed{A_d = \frac{-R_c}{2r_e}}$ $R_{o1} = R_{o2} = R_c$

4). Single i/p Balanced o/p: $\boxed{A_d = \frac{-R_c}{r_e}}$ $R_{in1} = R_{in2} = 2\beta r_e$ $\boxed{R_{o1} = R_{o2} = R_c}$

Open Loop Configuration:



$V_o = A_{OL} V_d$

$\boxed{V_o = A_{OL}(V_1 - V_2)}$ $\boxed{V_o = A_d V_d + A_c V_c}$ $\boxed{V_d = V_1 - V_2}$

$\boxed{V_o = A_1 V_1 + A_2 V_2}$ Wanted Unwanted

$\boxed{V_d = (V_1 - V_2)}$ $V_1 \neq 0, V_2 = 0 \rightarrow V_{o1} = A_1 V_1$

$\boxed{V_c = \frac{V_1+V_2}{2}}$ $V_1 = 0, V_2 \neq 0 \rightarrow V_{o2} = A_2 V_2$

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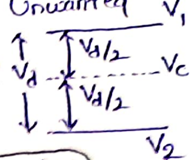


$\boxed{A_c = A_1 + A_2}$ $\boxed{A_d = \frac{A_1 - A_2}{2}}$

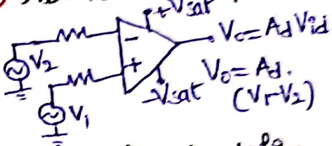
$\boxed{A_1 = A_c + \frac{A_d}{2}}$ $\boxed{CMRR = \left|\frac{A_d}{A_c}\right|}$ $\boxed{CMRR_{dB} = 20\log_{10}\left|\frac{A_d}{A_c}\right|}$

$\boxed{A_2 = -A_c + \frac{A_d}{2}}$ ↳ Figure of Merit $\boxed{CMRR_{dB} = (A_d)_{dB} - (A_c)_{dB}}$

$\boxed{\%Error = \frac{A_c V_c}{A_d V_d} \times 100 = \frac{1}{CMRR}\frac{V_c}{V_d} \times 100}$

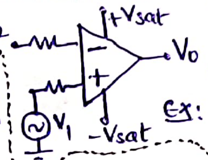
Applications of Open Loop config: $V_o = A_d V_{id}$, $V_{id} = V_1 - V_2$

1) Differential Amplifier:

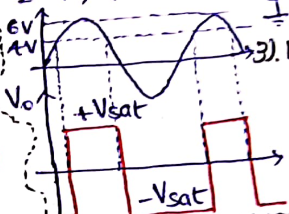


$V_o = A_d V_{id}$
$V_o = A_d \cdot (V_1 - V_2)$

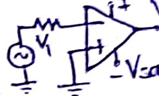
4). Comparator: $V_o = A_d(V_1 - V_2)$



$V_1 > V_2 \Rightarrow V_o = +V_{sat}$
$V_1 < V_2 \Rightarrow V_o = -V_{sat}$
Ex: $V_2 = 4V$, $V_1 = 6\sin\omega t$

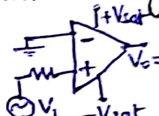


2). Inverting Amplifier



$V_o = -A_d V_1$ 180° PS

3). Non-Inverting Amp:

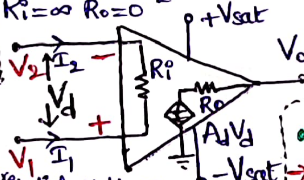


$V_o = A_d V_1$ 0° PS

5). Operational Amplifiers:

Op Amp ↳ VCVS [series–shunt]

$R_i = \infty$ $R_o = 0$



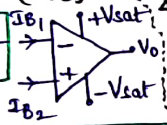
$R_i = \infty \Rightarrow \boxed{I_1 = I_2 = 0}$ $V_{in} = V_1 - V_2$

$\boxed{V_o = A_d V_{id}}$ $\boxed{V_{id} = V^+ - V^-}$ ↳ Differential Voltage

Closed Loop Configuration of Op-Amp
→ To apply Virtual Ground

1). I/p Bias Current (I_{IB}):

$\boxed{I_{IB} = \frac{I_{B1} + I_{B2}}{2}}$



2). I/p Offset Current (I_{IO}): $\boxed{I_{IO} = |I_{B1} - I_{B2}|}$

3). power Supply Rejection Ratio:

$\boxed{PSRR = \frac{\Delta V_{IO}}{\Delta V_S}}$ V_{IO} – I/p offset voltage, V_S – Supply voltage

4). Slew Rate (SR) $V_i = V_m \sin\omega t$, $V_o = AV_m \sin\omega t$

$\boxed{SR = \left.\frac{dV_o}{dt}\right|_{max} = |AV_m\omega_m \cos(\omega_m t)|}$ ↳ A_{CL}

$\boxed{SR = AV_m\omega_m < (SR)_{op-amp}}$

$\boxed{\omega_m = \frac{SR}{AV_m}}$ $\boxed{f_m = \frac{SR}{2\pi AV_m}}$

5). Common Mode Rejection Ratio:

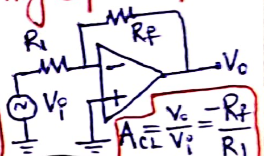
$\boxed{CMRR = \left|\frac{A_d}{A_c}\right|}$ → differential gain, → common mode gain

Ideally $\boxed{A_c = 0}$ $\boxed{CMRR = \infty}$

i). Ideal Op-Amp $\boxed{A = \infty}$

ii). -ve FB ⇒ $\boxed{V^+ = V^-}$

1). Inverting Op-Amp

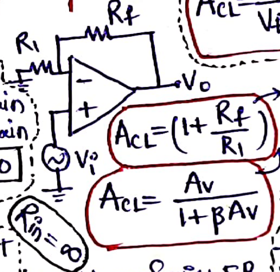


$\boxed{R_{in} = R_1}$ ↳ Voltage shunt FB

$\boxed{A_{CL} = \frac{V_o}{V_i} = \frac{-A\nu\beta}{1+A\nu\beta}\frac{R_f}{R_1}}$ $\boxed{A_{CL} = \frac{V_o}{V_i} = \frac{-R_f}{R_1}}$

↳ practical $\boxed{\beta = \frac{R_1}{R_1 + R_f}}$ ↓ Ideal

2). Non-Inverting op-Amp:



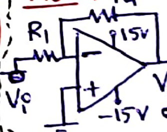
$\boxed{A_{CL} = \left(1 + \frac{R_f}{R_1}\right)}$ ↳ Ideal

$\boxed{A_{CL} = \frac{A\nu}{1+\beta A\nu}}$ ↳ practical

↳ Voltage Series FB.
↳ Increase Gain
↳ Neglects Loading effect.

-ve FB + ∞ Gain : $V_i = 1V$

Note: if $R_f = 31K\Omega$, $R_1 = 1K\Omega$



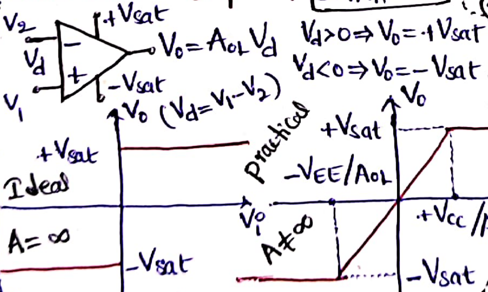
$V_o = \frac{-31}{1}(1) = -31V$
But Max allowed o/p voltage is $\pm V_{sat}$
i.e, $V_o = -15V$. $\boxed{V^+ \neq V^-}$
In this type of ckt VG not valid.

$\boxed{\text{O/p Saturates b/w } \pm V_{sat} \equiv \text{Virtual Ground Not Valid}}$

⇒ properties of Op-Amp:

property	Ideal	practical
R_{in}	∞	few MΩ
R_{out}	0	~100 Ω
Gain(A_V)	∞	~ 10^6
BW	∞	~5MHz
CMRR	∞	~ 10^6
offset	0	nA, nV
SR	∞	5 V/μsec
I_i	0	few Amp

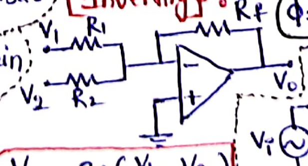
Transfer characteristics of Op-Amp



$V_d > 0 \Rightarrow V_o = +V_{sat}$
$V_d < 0 \Rightarrow V_o = -V_{sat}$

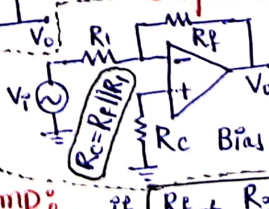
Summing Amplifier [Inverting]:

$\boxed{V_o = \frac{-R_f}{R}(V_1 + V_2)}$ $[\because R_1 = R_2 = R]$ $\boxed{\phi = 180°}$



$\boxed{V_o = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right)}$

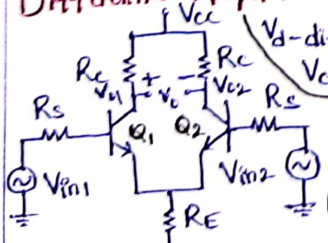
Compensating Resistor:



R_c – compensating Resistor to reduce I/p Bias Current $\boxed{R_c = R_f \| R_1}$

Differential Amplifier $\boxed{V_o = A_d V_d + A_c V_c}$ A_d – differential Gain,

V_d – differential i/p; A_c – common mode Gain.
V_c – common mode i/p and Amplify 'V_d'.
→ Aim: Reject 'V_c'



$\boxed{A_d = \left.\frac{V_o}{V_d}\right|_{V_c=0}}$ $\boxed{A_c = \left.\frac{V_o}{V_c}\right|_{V_d=0}}$

$\boxed{V_d = V_{in1} - V_{in2}}$ $\boxed{V_c = \frac{V_{in1} + V_{in2}}{2}}$

Unbalanced o/p → V_{o1} (or) V_{o2}
Balanced o/p → Both V_{o1} & V_{o2}

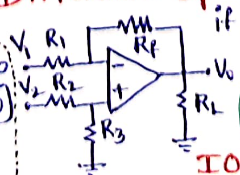
$\boxed{R_{in1} = R_{in2} = 2\beta r_e}$

1). Dual I/p Unbalanced o/p:

$\boxed{A_d = \frac{-R_c}{2r_e}}$ $\boxed{A_c = \frac{-R_c}{2R_E}}$ → $R_E = \infty$ ∴ $\boxed{A_c = 0}$

$|A_c| << |A_d|$ $\boxed{R_{o1} = R_{o2} = R_c}$

Differential Op-Amp:



if $\boxed{\frac{R_f}{R_1} = \frac{R_3}{R_2}}$ $\boxed{V_o = \frac{R_f}{R_1}(V_2 - V_1)}$

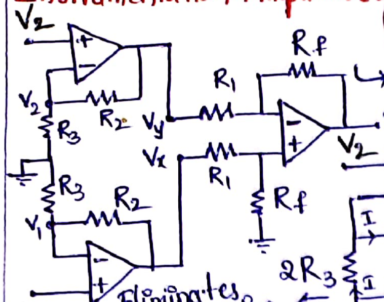
if $\boxed{\frac{R_f}{R_1} \neq \frac{R_3}{R_2}}$ $\boxed{V_o = \left(1 + \frac{R_f}{R_1}\right)\left(\frac{R_3}{R_2 + R_3}\right)V_2 - \frac{R_f}{R_1}V_1}$

$\boxed{V_o = \left(1 + \frac{R_f}{R_1}\right)\left(\frac{R_3}{R_2 + R_3}\right)V_2 - \frac{R_f}{R_1}V_1}$

IOCL

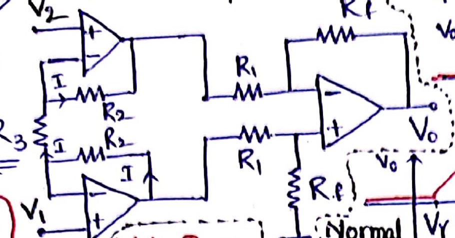
Instrumentation Amplifier:

$$V_o = \frac{R_f}{R_1}\left(1+\frac{R_2}{R_3}\right)(V_1 - V_2)$$



→ Noise amplified by $(1 + R_2/R_3)$

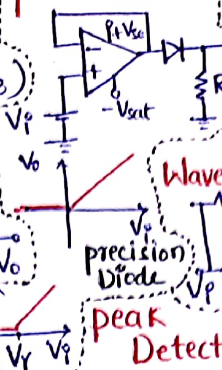
Modified Version:



Eliminates Noise ⇐

$$V_o = \left(\frac{R_f}{R_1}\right)\left(1+\frac{2R_2}{R_3}\right)(V_1 - V_2)$$

precision Diode

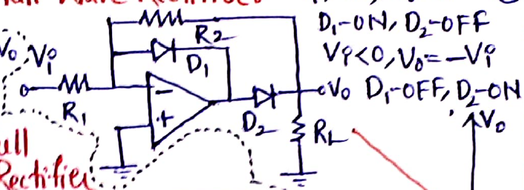


Normal Diode.

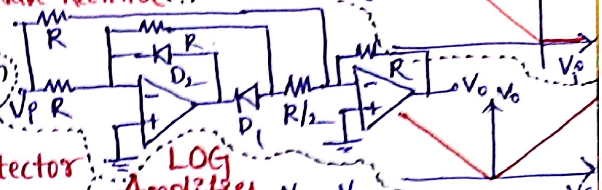
Half Wave Rectifier:

$V_i > 0 \Rightarrow V_o = 0$; D_1-ON, D_2-OFF

$V_i < 0$, $V_o = -V_i$; D_1-OFF, D_2-ON

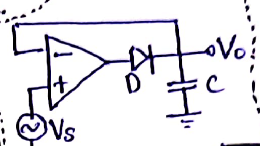


Full Wave Rectifier:



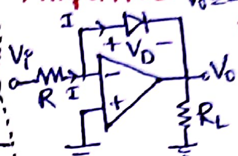
precision Diode

Peak Detector



LOG Amplifier

$V_o = -V_D$

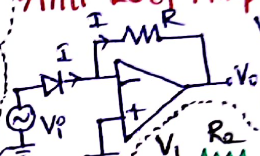


$$V_o = \eta V_T \ln\left(\frac{IR}{V_s}\right)$$

$$V_o \propto -\ln\left(\frac{V_s}{IR}\right)$$

Anti LOG Amplifier

$V_o = -IRe^{V_i/\eta V_T}$

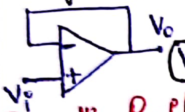


$$V_o \propto e^{V_i/\eta V_T}$$

Voltage Buffer/Voltage Follower

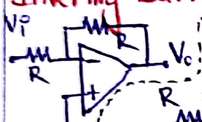
(or) Non-Inverting Buffer (or) Unity Gain Amp (or) Isolation Amp

NFB → VG $(V^+ = V^-)$

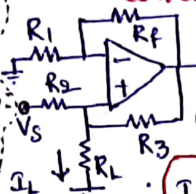


$V_o = V_i$; $A_{CL} = \frac{V_o}{V_i} = 1$

Inverting Buffer: $V_o = -V_i$

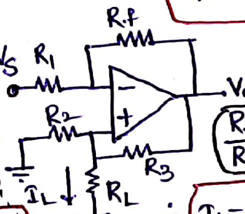


V to I Converter



$$\frac{R_f}{R_1} = \frac{R_3}{R_2}$$

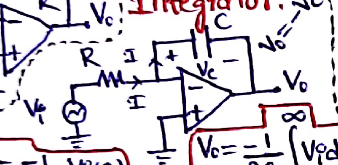
$$\therefore I_L = \frac{V_s}{R_2}$$



$$\frac{R_f}{R_1} = \frac{R_3}{R_2}$$

$$\therefore I_L = \frac{-V_s}{R_2}$$

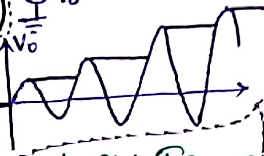
Integrator:



$$V_o = \frac{-1}{RC}\int_0^{\infty} V_i\,dt$$

$$V_o(s) = \frac{-1}{sCR}V_i(s)$$

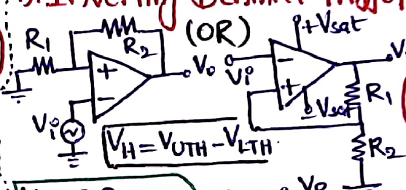
Schmitt Trigger



Bistable Multivibrator

$$V_x = \frac{V_1R_1 + V_2R_2}{(R_1+R_2)}$$

i). Inverting Schmitt Trigger:



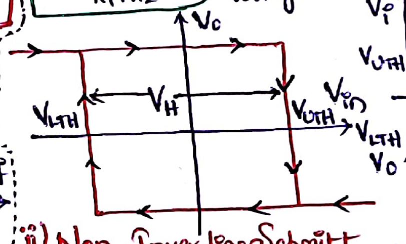
(OR)

$V_H = V_{UTH} - V_{LTH}$

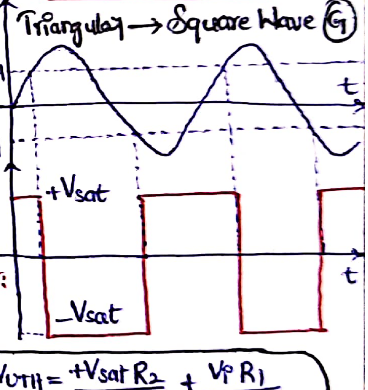
$$V_{UTH} = \frac{+V_{sat}R_2}{R_1+R_2} + \frac{V_R R_1}{R_1+R_2}$$

$$V_{LTH} = \frac{-V_{sat}R_2}{R_1+R_2} + \frac{V_R R_1}{R_1+R_2}$$

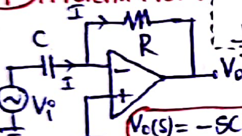
$$V_H = \frac{2R_2 V_{sat}}{R_1+R_2}$$ → Hysteris Voltage



Triangular → Square Wave (G)



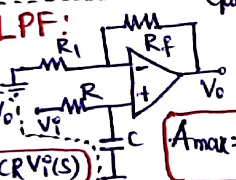
Differentiator:



$$V_o(s) = -SCRV_i(s)$$

$$V_o = -RC\frac{dV_i}{dt}$$

LPF:



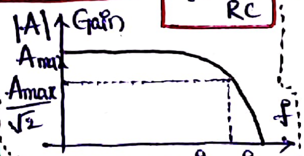
Gain $A = \frac{A_{max}}{[1+j(f/f_c)]}$

$$A_{max} = \left(1+\frac{R_f}{R_1}\right)$$

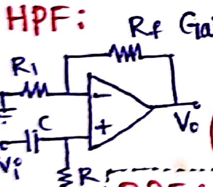
$$f_c = \frac{1}{2\pi RC}$$

$$W_c = \frac{1}{RC}$$

$|A| = A_{max}$ ($f=0$); $|A| = 0$ ($f=\infty$)



HPF:

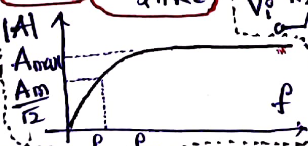


Gain $A = \frac{A_{max}}{\left[1-j\left(\frac{W_c}{W}\right)\right]}$

$$A_{max} = \left(1+\frac{R_f}{R_1}\right)$$

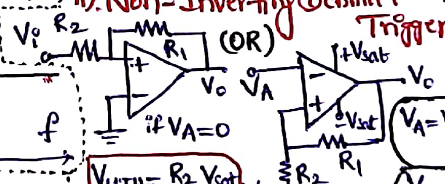
$$W_c = \frac{1}{RC}$$ $$f_c = \frac{1}{2\pi RC}$$

$f_c = f_h$



$f_L = f_c$

ii). Non-Inverting Schmitt Trigger:



(OR)

if $V_A = 0$

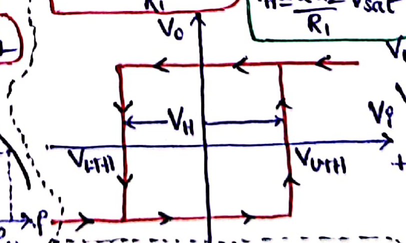
$$V_{UTH} = \frac{R_2}{R_1}V_{sat}$$

$$V_{LTH} = \frac{-R_2}{R_1}V_{sat}$$

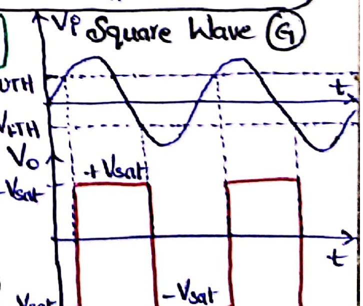
$$V_A = V_{UTH} = \frac{+V_{sat}R_2}{R_1+R_2} + \frac{V_iR_1}{R_1+R_2}$$

$$V_A = V_{LTH} = \frac{-V_{sat}R_2}{R_1+R_2} + \frac{V_iR_1}{R_1+R_2}$$

$$V_H = \frac{2R_2}{R_1}V_{sat}$$

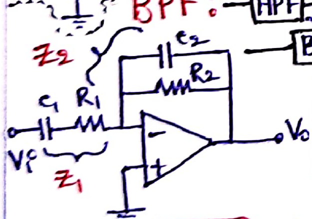


Square Wave (G)



BPF:

HPF → LPF → BPF



$$\frac{V_o}{V_i} = \underbrace{\left(\frac{-R_2}{1+SC_2R_2}\right)}_{LPF}\underbrace{\left(\frac{SC_1}{1+SC_1R_1}\right)}_{HPF}$$

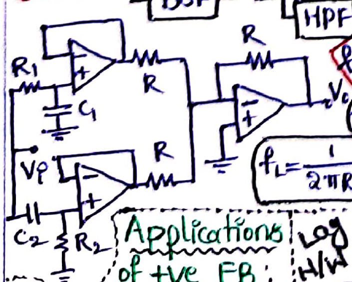
R_1, R_2, C_1, C_2 must be selected such that $f_H > f_L$

$$LPF \Rightarrow f_H = \frac{1}{2\pi R_2C_2}$$

$$HPF \Rightarrow f_L = \frac{1}{2\pi R_1C_1}$$

BSF:

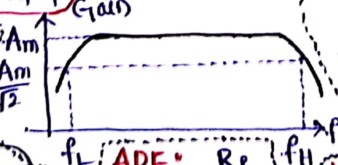
BSF: LPF, HPF



$f_H < f_L$

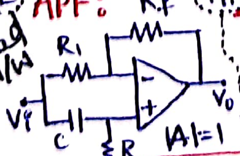
$$f_H = \frac{1}{2\pi R_1C_1}$$

$$f_L = \frac{1}{2\pi R_2C_2}$$



APF:

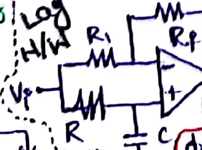
Lead N/W



$|A| = 1$

$\phi = 0°$ to π

Log N/W



$|A| = 1$

$\phi = -\pi$ to $0°$

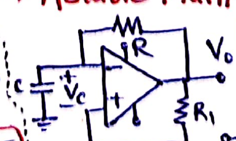
Applications of +ve FB:

Oscillator

Harmonic Osc [Sinusoidal signal (G)]: Audio Freq Osc, Video Freq Osc

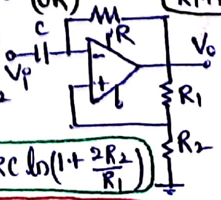
Relaxation Osc [Non-Sinusoidal (G)] → Multivibrator: Astable, Monostable, Bistable → Schmitt Trigger; IC 555 Timer

Astable Multivibrator:



$$V_c(t) = \pm V_{sat}\frac{R_2}{R_1+R_2} = \pm\beta V_{sat}; \quad \beta = \frac{R_2}{(R_1+R_2)}$$

(OR)



Transient time of 'V_c'

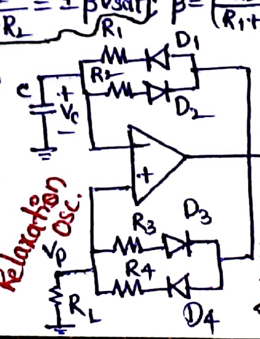
$$t_1 = RC\ln\left(1+\frac{R_2}{R_1}\right)$$

$$T = 2RC\ln\left(1+\frac{2R_2}{R_1}\right)$$

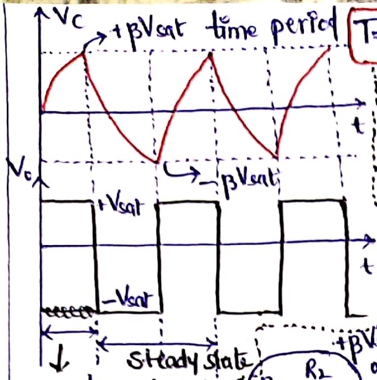
$$T_{charg} = T_{discharge} = RC\ln\left(1+\frac{2R_2}{R_1}\right)$$

$T = T_{ON} + T_{OFF}$

Relaxation Osc.



Astable Multivibrator

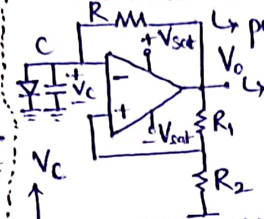


$$T = T_{charge} + T_{discharge} = 2RC\ln\left(1+\frac{2R_2}{R_1}\right)$$

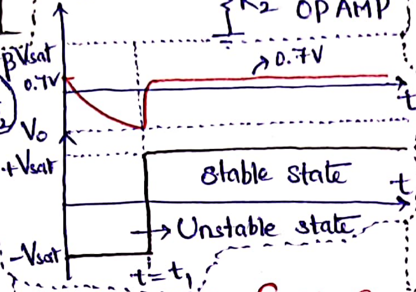
$$\beta = \frac{R_2}{R_1+R_2}$$

Discharging time / Transient time $t_1 = RC\ln\left(\frac{1}{\beta-1}\right)$

→ Monostable Multivibrator:



↳ pulse stretcher ckt
↳ Delay ckt.
BJT
MOSFET
OP AMP

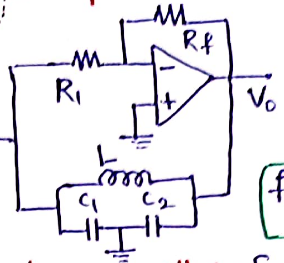


2). Colpitts Oscillator:

Feedback → 180°
Op-Amp → 180°
Total PS := 360°

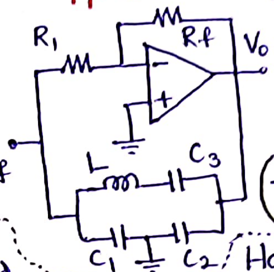
$A = \frac{-R_f}{R_1}$ $\beta = \frac{-C_2}{C_1}$

$\boxed{\frac{R_f}{R_1} = \frac{C_1}{C_2}}$ $|A\beta| = 1$



$\boxed{f_o = \frac{1}{2\pi\sqrt{LC_{eq}}}}$ $\boxed{C_{eq} = \frac{C_1C_2}{C_1+C_2}}$

3). Clapp Oscillator [Modified version of Colpitts]



$A = \frac{-R_f}{R_1}$, $\beta = \frac{-C_2}{C_1}$; $A\beta = 1$ $\boxed{\frac{R_f}{R_1} = \frac{C_1}{C_2}}$

$\boxed{\omega_o = \frac{1}{\sqrt{LC_{eq}}}}$ $\boxed{f_o = \frac{1}{2\pi\sqrt{LC_{eq}}}}$

$\boxed{\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$ IOCL

Hartley → High freq
Wein Bridge → Low freq
Crystal osc → Stable freq

BJT - CCCS
MOSFET - VCCS
Op Amp - VCVS

6). Oscillators:

- Harmonic Oscillator
  - Audio Freq Oscillator
    - Wein Bridge
    - RC phase shift
  - Radio Freq Oscillator
    - Crystal
    - LC
      - Hartley
      - Colpitts
      - Clapp
- Relaxation Oscillator
  - Multi vibrator
  - IC 555

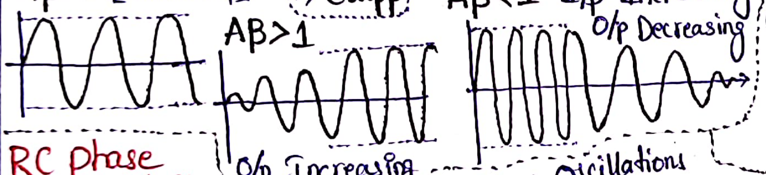
Barkhausan's Criterian for Oscillator:

1). $\boxed{|A\beta| \geq 1}$ → Sustained / Undamped Oscillations

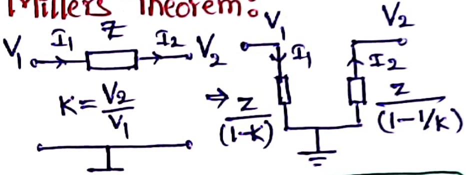
2). $\boxed{\angle A\beta = 0°, \pm 2n\pi}$

Note :- for Oscillation building, $|A\beta|$ will be slightly greater than one $\boxed{1.06}$

$\boxed{+ve \text{ Feedback}}$



Millers Theorem:

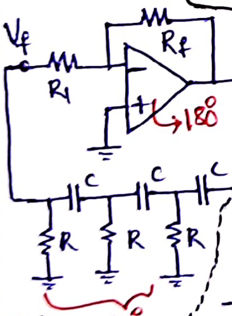


↳ for R, L Same $\boxed{Z_1 = \left(\frac{Z}{1-K}\right)}$ $\boxed{Z_2 = \left(\frac{Z}{1-1/K}\right)}$

↳ for C $\boxed{C_1 = C(1-K)}$ $\boxed{C_2 = C(1-1/K)}$

RC phase shift Oscillator:

$\boxed{A = \frac{V_o}{V_f} = \frac{-R_f}{R_1}}$ for $\boxed{\beta\text{-Real}}$ $\boxed{\omega_o = \frac{1}{RC\sqrt{6}}}$ $\boxed{f_o = \frac{1}{2\pi RC\sqrt{6}}}$



Vo ↳ for 'n' stage Oscillator $\boxed{f_o = \frac{1}{2\pi RC\sqrt{2n}}}$

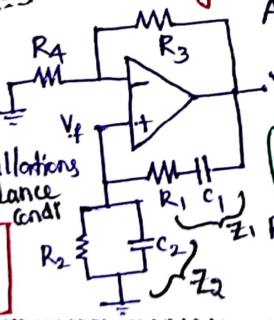
$\boxed{|A| \geq 29}$ $\boxed{R_f \geq 29R_1}$

↳ for Sustained Oscillations $|A\beta| \geq 1$ → Bridge balance condⁿ

$$\boxed{\frac{R_3}{R_4} \geq \frac{R_1}{R_2} + \frac{C_2}{C_1}}$$

Wein Bridge Oscillator:

$A = \left(1 + \frac{R_3}{R_4}\right)$



$\boxed{\omega_o = \frac{1}{\sqrt{R_1R_2C_1C_2}}}$

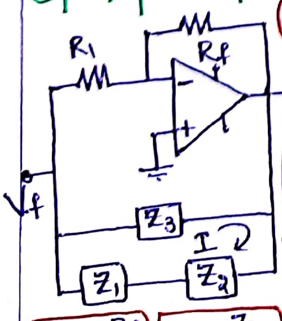
$\boxed{f_o = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}}$

$R_1 = R_2 = R$; $C_1 = C_2 = C$

$\boxed{f_o = \frac{1}{2\pi RC}}$

Op Amp Based LC Oscillator:

$\boxed{Z_1 + Z_2 + Z_3 = 0}$ Vo for freq of oscillations



$\boxed{f_o = \frac{1}{2\pi\sqrt{L_{eq}C_{eq}}}}$

	Z_1	Z_2	Z_3
Hartley →	L	L	C
Colpitts →	C	C	L
Clapp →	C	C	L & C

↳ modified version of Colpitts.

$\boxed{A = \frac{-R_f}{R_1}}$ $\boxed{\beta = \frac{-Z_1}{Z_2}}$

1). Hartley Oscillator

$A = \frac{-R_f}{R_1}$, $\beta = \frac{-L_1}{L_2}$

$A\beta = 1 \Rightarrow \boxed{\frac{R_f}{R_1} = \frac{L_2}{L_1}}$

$\boxed{f_o = \frac{1}{2\pi\sqrt{(L_1+L_2)C}}}$