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

$V_c(0^-) = V_c(0^+) = 0$

$V_c(\infty) = V_0$

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

$V_c(0^-) = V_c(0^+) = V_0$

$V_c(\infty) = 0$

$i(t)$ $0^- \to 0$, $0^+ \to V_0/R$, $\infty \to 0$

$V_{c_1}(t)$ $0^- \to V_0$, $0^+ \to V_0$, $\infty \to \frac{V_0 C_1}{C_1+C_2}$

V_{c_2} $0^- \to 0$, $0^+ \to 0$, $\infty \to \frac{V_0 C_1}{C_1+C_2}$

$i(t) = i_0 e^{-t/RC_{eq}}$

$V_{c_1}(t) = \frac{C_1}{C_1+C_2} V_0 + \frac{C_2}{C_1+C_2} V_0 e^{-t/\tau}$

$V_{c_2}(t) = \frac{C_1 V_0}{C_1+C_2}\left(1 - e^{-t/\tau}\right)$

C_1 V_0 $\frac{C_1 V_0}{C_1+C_2}$ 0

C_2 0 $\frac{C_1 V_0}{C_1+C_2}$ 0

$V_{C_2} = \frac{C_1 V_0}{C_1+C_2} e^{-t/RC_{eq}}$

Semiconductors

$n_i = BT^{3/2} e^{-E_g/2kT}$

$k = 1.38 \times 10^{-23}$ J/k

$n_p^2 = n_p$ $E_g = 1.12$ eV

$v_{dp} = \mu_p E$ | $I_p = A p q \mu_p E$

$v_{dn} = -\mu_n E$ | $J_p = \frac{I_p}{A}$

$\sigma_p = \mu_p p q$

$J = (\mu_n n + \mu_p p) q E = (\sigma_n + \sigma_p) E$

$V_T = \frac{kT}{q} = 26$ mV

I_D — diffusion $E = \frac{dv}{l}$

I_S — drift $I_S \propto$ Temp.

$V_0 = V_T \ln \frac{N_A N_D}{n_i^2}$

Reverse bias — $I_D = 0$, I_S ✓

open circuit — $I_S = I_D$

Forward Bias

$I_D = I_S(e^{V_D/V_T} - 1)$

$I_S = \frac{A q n_i^2 D_n}{L_n N_A}$

$I_{S_2} = I_{S_1} 2^{\frac{T_2 - T_1}{10}}$

$10° \uparrow$ — I_S double

$V_{D_2} - V_{D_1} = V_T \ln \frac{I_{S_1}}{I_{S_2}}$

$V_{D(ON)} = 0.8$V

Dynamic Conductance

$g = \frac{\partial I_D}{\partial V_D}$; $r = \frac{1}{g}$

$i_D = I_S\left(e^{V_D/V_T} - 1\right)$

$i_D = f(V_{D_0}) + \frac{d}{dV_D}(I_S e^{V_D/V_T} - 1)(V_D - V_{D_0}) + \frac{d}{2!}\frac{\partial y}{\partial^2 V_D}(V_D - V_{D_0})^2 + \dots$

$i_d = \frac{I_0}{V_T} e^{V_{D_0}/V_T} v_d + \frac{1}{2}\frac{I_0}{V_T^2} e^{V_{D_0}/V_T}(v_d)^2$

$\frac{1}{2V_T} v_d^2 << v_d$

$v_d << 2V_T$

Small v_s:

$V_D = v_d + V_D$

$i_D = i_d + I_D$

$I_D = I_S e^{V_D/nV_T}$

$i_D = I_S e^{(v_d + V_D)/nV_T}$

$= I_S e^{V_D/nV_T} \cdot e^{v_d/nV_T}$

$= I_D \cdot e^{v_d/nV_T}$

$= I_D\left(1 + \frac{v_d}{nV_T}\right)$

$= I_D + i_d$

$i_d = \frac{v_d}{nV_T} I_D$

$g = \frac{I_D}{nV_T}$

Half-wave Rect

Dynamic

$i = \frac{V_{in} - V_0 - 5}{R + R_{on}}$

$V_{out} = \frac{V_{in}}{R+R_{ON}} R_{ON} + \frac{V_0 + 5}{R+R_{on}} R$

$-5 < V_{in} < 5$ Both on

$V_{in} > 5$ D_1 — on, $V_{out} = -5$

D_2 — on

$V_{in} < -5$ D_2 — on, $V_{out} = 5$

D_1 — on.

Low Pass

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

$\frac{V_{out}}{V_{in}} = \frac{1}{1+sCR}$

$\phi = -\tan^{-1}(\omega RC)$

High Pass

V_c $0^- \to 0$, $0^+ \to 0$, $\infty \to V_0$

$V_R = V_0$

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

$\frac{V_0}{V_{in}} = \frac{sCR}{1+sCR}$

$\phi = \pi/2 - \tan^{-1}(\omega RC)$

All pass $\frac{V_0}{V_{in}} = \frac{R_2}{R_1+R_2}$

$R_1 C_1 = R_2 C_2$

Peak rectifier

Clamper

v_{in}

shifts up

shifts down

Voltage Doubler

V_{pin}

D_1 V_{D_1}

$2V_p$

Across D_1

$-V_p$

$-2V_p$

peak detector gives $-2V_p$ to capacitor

Center Tap

$V_0 = V_s - V_D$

$-V_s - V_0$

$PIV = V_0 - (-V_s)$

$= |2V_s - V_0|$

Bridge Wave

$V_0 = V_s - 2V_D$

$-V_D$ D_3 V_0

$PIV = V_0 - (-V_D)$

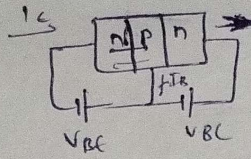
$= V_0 - 2V_D + V_D$

$= |V_s - V_D|$

$-2V_D$ $2V_D$

Scanned with OKEN Scanner

Bipolar Junction Transistor



$I_C = I_S e^{V_{BE}/V_T}$

$i_e = i_B + i_c$

$\beta = \frac{\alpha}{1-\alpha}$

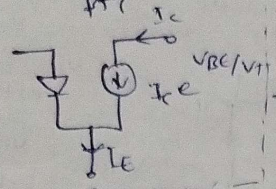
$I_B = \frac{I_C}{\beta}$

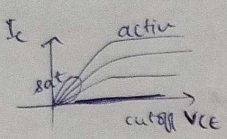
$\alpha = \frac{\beta}{\beta+1}$

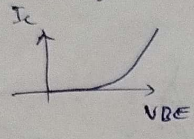
$I_E = (\beta+1) I_B$

$I_C = \left(\frac{\beta}{\beta+1}\right) I_E$

$I_C = \alpha I_E$

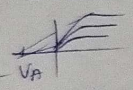






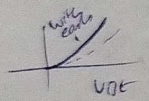
$g_m = \frac{I_C}{V_T} = \frac{dI_C}{dV_{BE}}$

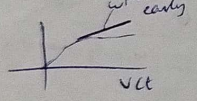
Early Effect :



$r_o = \frac{V_A}{I_B} = \frac{\Delta V_{CE}}{\Delta I_C}$

$I_C = I_S e^{V_{BE}/V_T}\left(1 + \frac{V_{CE}}{V_A}\right)$

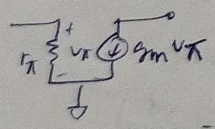




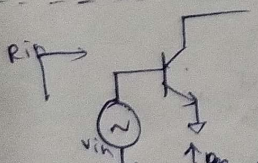
dyn region increases

BJT working on at $V_{CE} > V_{BE}$

$r_\pi = \frac{\beta}{g_m}$



$i_c = g_m v_\pi$



$R_{in} = \frac{\beta}{g_m} = r_\pi$

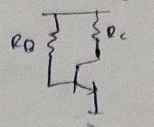
To find Rout inputs = 0.

$R_e = \frac{1}{g_m}$

$r_e = \frac{r_\pi}{1+\beta}$

Biasings

Simple V_{CC}

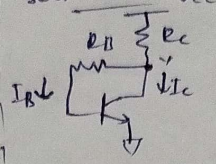


$R_B I_B + V_{BE} = V_{CC}$

$I_C = \beta \frac{V_{CC} - V_{BE}}{R_B}$

$V_{CE} = V_{CC} - R_C I_C$

Self-Biased



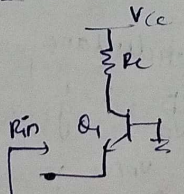
$V_y = V_{CC} - R_C I_C$

$V_y = R_B I_B + V_{BE}$

$I_C = \frac{V_{CC} - V_{BE}}{R_C}$

always in active mode

Emitter stage



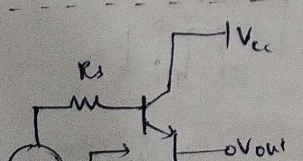
$A_V = \frac{-R_C}{\frac{1}{g_m} + R_E}$

$R_{in} = r_\pi + (\beta+1) R_E$

$R_{out} = R_C$

$R_{in} = \frac{1}{g_m}$

$R_{out} = R_C \| R_D$



$R_{in} = r_\pi + (1+\beta) R_E$

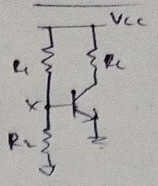
$R_o = \frac{1}{\frac{1}{R_E} + \frac{1+g_m r_\pi}{R_S + r_\pi}} \approx \frac{1}{g_m}$

$\frac{V_{out}}{V_{in}} = \frac{(1+\beta) R_E}{(\beta+1) R_E + R_S + r_\pi}$

— low impedance

$\frac{1}{g_m}$ r_o — high impedance

Resistor Divider



$V_x = \frac{R_2}{R_1+R_2} V_{CC}$

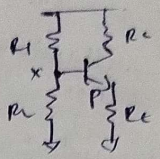
$I_C = I_S \exp(V_x/V_T)$

$V_{TH} = \frac{R_2}{R_1+R_2} V_{CC}$

$R_{Then} = R_1 \| R_2$

$V_x = V_{Then} - I_B R_{Then}$

Emitter Degeneration

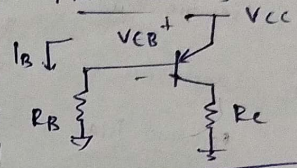


$V_x = V_{CC}(R_2/R_1+R_2)$

$V_p = V_x - V_{BE}$

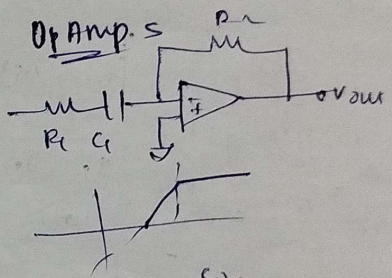
$I_E = \frac{V_p}{R_E} \approx I_C$

PNP Biasing

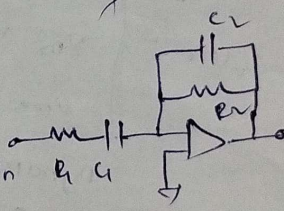


$I_B R_B + V_{EB} = V_{CC}$

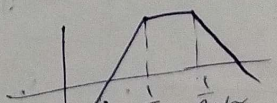
Op Amps



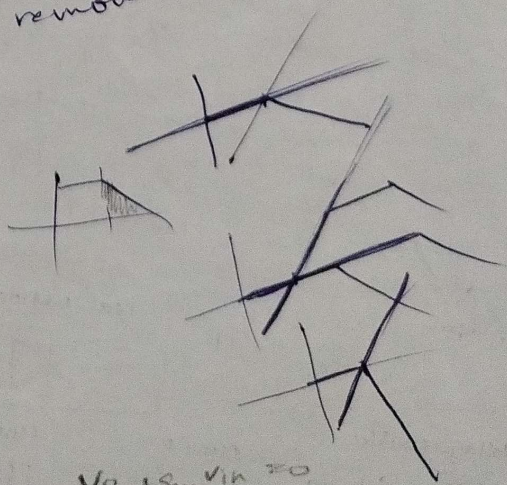
$\frac{V_o}{V_i} = \frac{R_2}{R_1 + \frac{1}{sC_1}} = \frac{sC_1R_2}{1+sC_1R_1} \approx \frac{R_2}{R_1}$



$\frac{V_o}{V_i} = \frac{\frac{R_2}{1+sC_2R_2}}{sC_1R_1+1} = \frac{sC_1R_2}{(1+sC_2R_2)(1+sC_1R_1)}$



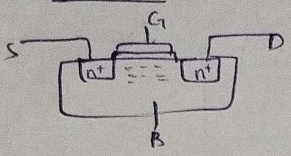
to remove this $R_1C_1 = R_2C_2$



$\frac{V_o}{r_o} + g_m V_{in} = 0$

$\frac{V_o}{V_{in}} = -g_m r_o$

MOSFET



$V_G < 0$ accumulation of hole

$V_G = 0$

$V_G > 0$ depletion Mode of hole

$V_G \geq V_{TH}$ – strong inversion

$V_{Body} = 0$

~~Early~~ DIBL –

$V_T = V_{T0} - \eta V_{DS}$

Body effect

if $V_{BS} > 0$, $V_T \downarrow$ $g_m \uparrow$

$V_{BS} < 0$ $V_T \uparrow$ $g_m \downarrow$

$V_{GS} < 0$; $I_{DS} = 0$ (cutoff)

$(V_{GS} - V_T)$ – overdrive voltage

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

$V_{GS} \geq V_T$; $V_{DS} < V_{GS} - V_T$

$$I_{DS} \approx \mu_n C_{ox} \frac{W}{L}(V_{GS} - V_T)V_{DS} \quad \text{with} \quad V_{DS} << 2(V_{GS} - V_T)$$

$$R = \frac{V_{DS}}{I_{DS}} = \frac{1}{\mu_n C_{ox} \frac{W}{L}(V_{GS} - V_T)}$$ acts as resistor in

$V_G \geq V_{TH}$ – strong inversion

$V_{Body} = 0$

$$I_{DS} = \mu_n C_{ox} \frac{W}{L}(V_{GS} - V_T)^2(1 + \lambda V_{DS})$$; saturation

$V_{GS} \geq V_T$; $V_{DS} \geq V_{GS} - V_T$

pinchoff occur

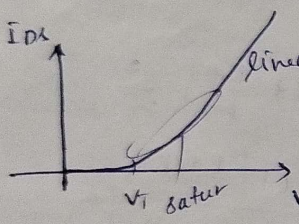
$$\lambda \propto \frac{\Delta L}{L} \propto \frac{1}{V_{DS}}$$

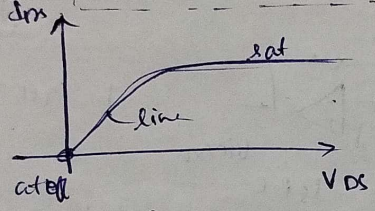
$$r_O = \frac{1}{\lambda I_D}$$

$$g_m = \mu_n C_{ox} \frac{W}{L}(V_{GS} - V_T) = \frac{\partial I_D}{\partial V_{GS}}$$

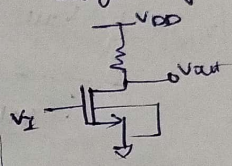
$$= \sqrt{2 I_D \mu_n C_{ox} \frac{W}{L}}$$

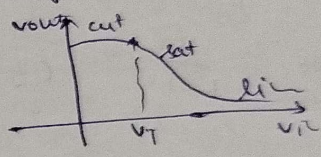
$$= 2 I_D / (V_{GS} - V_T)$$





Large – sig Analysis

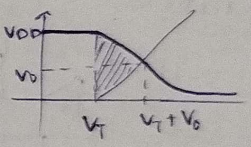




Valid i/p / o/p :

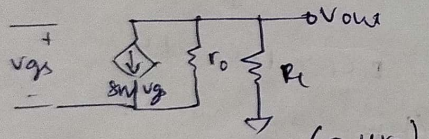
$V_{IN} \geq V_T$

$V_{out} \geq V_{IN} - V_T$

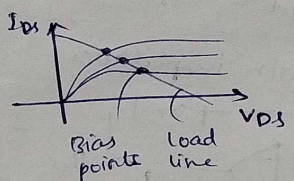


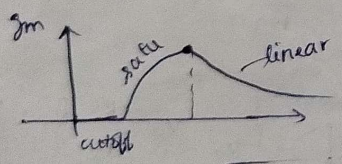
V_{IN} – V_T to $V_T + V_O$

$$V_O = \frac{-1 \pm \sqrt{1 + 2V_{DD}kR_L}}{kR_L}$$



$$\frac{V_{out}}{V_{in}} = -g_m(R_L \| r_O)$$





$R_{out} = r_O$ (High)

diode com $R_{out} = r_O \| \frac{1}{g_m} \approx \frac{1}{g_m}$ (Low)

R_{in} from src $= r_O \| \frac{1}{g_m} \approx \frac{1}{g_m}$ (Low)

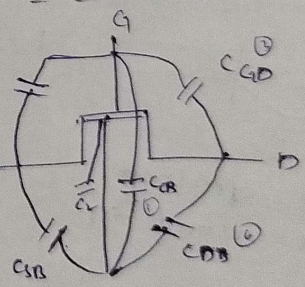
$C_g = WLC_{ox}$ $\left(C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}\right)$

C_s = substrate $= WL\sqrt{\frac{q\varepsilon_{Si}N_{sub}}{4\phi_F}}$

C_3C_4 – overlap cap – WC_{ov}

C_5C_6 – n^+ dep cap $= C_j\left(1 + \frac{V_R}{\phi_0}\right)$

sidewall cap $C_{jsw}(2(L+W))$



Design null converter

$L = 2\lambda$, $PS = 2W + 10\lambda$

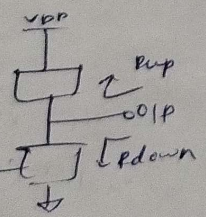
$\frac{AS}{AD} = SWA$

* Mosfet cut off

overlap – $C_{GS} = C_{GD} = WC_{ov}$

* In satur, $C_{GD} = WC_{ov}$ $C_{GS} = WC_{ov} + \frac{1}{3}WLC_{ox}$

* In linear $C_{GS} = C_{GD} = \frac{1}{2}WLC_{ox} + WC_{ov}$



$$\frac{V_O}{V_{in}} = g_m(R_{up} \| R_{down})$$

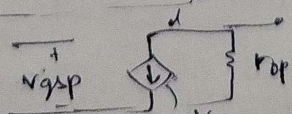
PMOS $V_{THP} < 0$

$V_{GSP} > V_{THP}$ – cutoff

$V_{GSP} \leq V_{THP}$ – ON

$V_{DSP} \geq V_{GSP} - V_{THP}$ – Linear

$$I_D = \mu_p C_{ox} \frac{W}{L}\left[(V_{SGp} - V_{THP})V_{SDp} - \frac{1}{2}V_{SDp}^2\right]$$



$V_{DSp} \leq V_{GSP} - V_{THP}$ – Satn

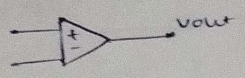
$$I_D = \frac{1}{2}\mu_p C_{ox} \frac{W}{L}(V_{SGp} - V_{THP})^2$$

$$\text{degen} = \frac{-R_D}{\frac{1}{g_m} + R_S}$$

emitter degen to Rout

$R_{out} = R_S + r_O(1 + g_m R_S)$

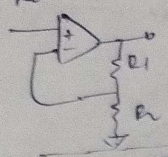
Operational Amplifier



$R_{in} \to \infty$ A_{vo}

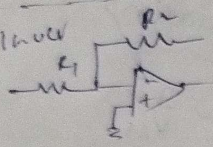
$R_{out} \to 0$ $BW = \infty$

Non-In



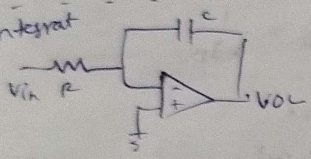
$\frac{V_o}{V_{in}} = 1 + \frac{R_f}{R_1}$

Inver



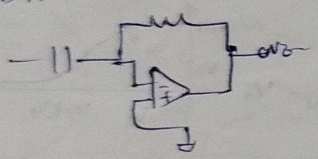
$\frac{V_o}{V_{in}} = -\frac{R_f}{R_1}$

Integrat

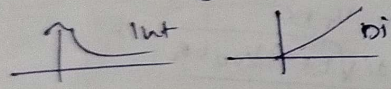


$\frac{V_o}{V_{in}} = \frac{-1}{R_1 C s}$ / $V_o = -\frac{1}{C_1 R_1} \int V_{in}\, dt$

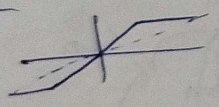
Differ



$\frac{V_o}{V_i} = -R_1 C s$



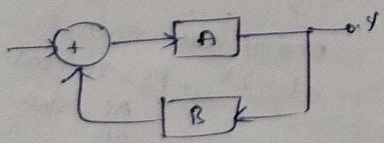
Tra



$k = 1 + \frac{R_1}{R_2}$

A – open loop

G – closed loop



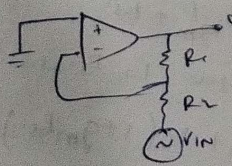
$\frac{y}{x} = \frac{A}{1 + AB}$

Put $V_{in} = 0$

Loop gain $= AB$

$AB >> 1$

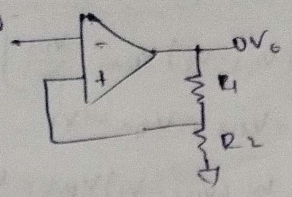
$\frac{y}{x} = \frac{1}{B}$



$\frac{V_o}{V_{in}} = -\frac{R_1}{R_2}$

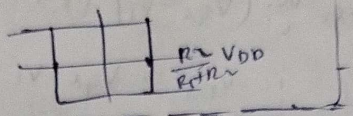
$\frac{V_{out}}{V_i} = R_o / 1 + A$

Hysteresis

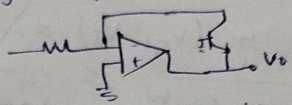


$\frac{V_o}{V_{in}} = -\frac{A}{1 - \frac{AR_2}{R_1 + R_2}}$

$= -\left(1 + \frac{R_1}{R_2}\right)$

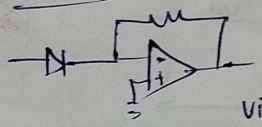


Logarithmic



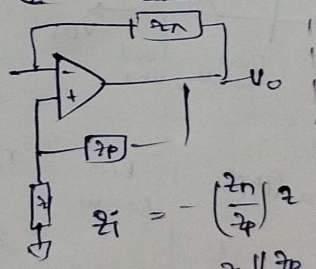
$V_{out} = -V_T \ln \frac{V_{IN}}{I_S R_1}$

Anti-Log



$V_{out} = -I_S R e$

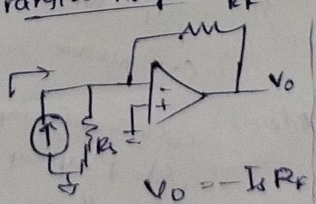
Negative Impedance



$Z_i = -\left(\frac{Z_n}{Z_p}\right) Z$

$Z_{out} = Z_n // Z_p$

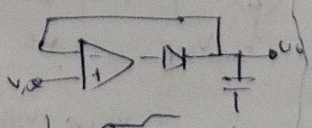
Tranzin Amplifier

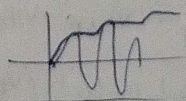


$V_O = -I_S R_F$

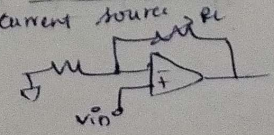
$Z_{in} \to Low$

Peak detect

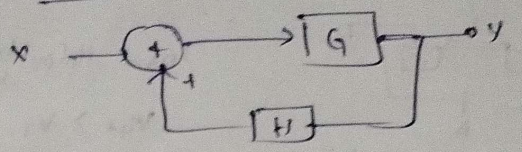




Current source



Oscillator



① → $\frac{y}{x} = \frac{G}{1 - GH}$ $|GH| > 1$ unstable

$|GH| < 1$ ✓

② → $\frac{y}{x} = \frac{G}{1 + GH}$ $|GH| \geq 1$

Loop sus

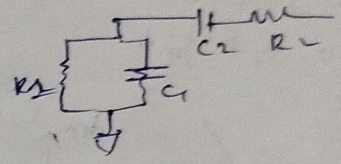
$\phi = 180°$

Bark Hausen Criterion

$|GH| \geq 1$ $\angle GH = 180°$

If G has non-inverting conti

H →



$T = GH = \left(1 + \frac{R_4}{R_3}\right) \frac{Z_1}{Z_1 + Z_2}$

$T(j\omega) = \frac{1 + R_4/R_3}{3 + j\left(RC\omega - \frac{1}{RC\omega}\right)}$

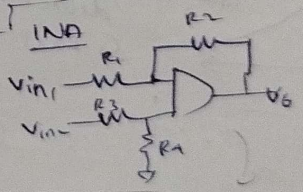
$R_1 C_1 = R_2 C_2 = RC$

$\angle T(j\omega) = 0$ $\omega = 1/RC$

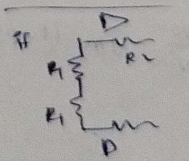
$|GH| = T(j\omega) \geq 1$

$\frac{R_4}{R_3} \geq 2$

INA



$V_o = \frac{R_2}{R_1}(V_2 - V_1)$



$V_{o1} = -\frac{R_4}{R_3}\left(1 + \frac{R_2}{R_1}\right)V_1$

$V_{o2} = \left(1 + \frac{R_4}{R_3}\right)\left(1 + \frac{R_4}{R}\right)V_2$

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

$V_o = \frac{R_4}{R_3}\left(1 + \frac{R_2}{R_1}\right)(V_2 - V_1)$

if $2R_1$

$V_o = \frac{R_4}{R_3}(V_{o2} - V_1)$

$= \frac{R_4}{R_3}\left(1 + \frac{R_2}{R_1}\right) V_{id}$

if single R_1

$V_o = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_1}\right) V_{id}$

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