Op-Amps

IDEAL: $R_i \to \infty$, $\therefore I_i \to 0$, $V_2 = V_1$, $A \to \infty$, $R_o \to 0$

$V_o = A(V_2 - V_1)$, $A = \frac{V_o}{V_s}$

INVERTING:

$A = \frac{V_o}{V_s} = \frac{-R_2}{R_1}$

$R_{in} = R_1$

SUMMING (-'ve):

$I_a = \frac{V_a - V_1}{R_a} = \frac{V_a}{R_a}$

$I = \frac{V_1 - V_o}{R} = \frac{-V_o}{R}$

$\Rightarrow V_o = -R\left[\frac{V_a}{R_a} \dots\right]$

NON-INVERTING:

$A = \frac{V_o}{V_s} = 1 + \frac{R_2}{R_1}$

INTEGRATOR:

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

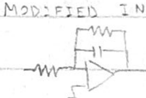
$H(jw) = \frac{-Z_2}{Z_1} = -\frac{1}{jwC \cdot R}$

$|H(jw)| = \frac{w_o}{w}$

$\angle H(jw) = j \cdot \frac{w_o}{w} = 90°$

(poor) LOW PASS FILTER

MODIFIED INTEGRATOR:



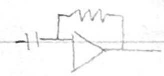
$w_o = \frac{1}{CR_2}$

$H(jw) = \frac{-R_2/R_1}{1 + jwCR_2}$

$|H(jw)| = \left|\frac{K}{1 + jw/w_o}\right|$

$\angle H(jw) = 180° + \angle 1 + jw/w_o$

DIFFERENTIATOR:



$w_o = 1/RC$

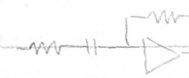
$H(jw) = -jwRC$

$|H(jw)| = w/w_o$

$\angle H(jw) = -90°$

(poor) HPF

MODIFIED DIFFERENTIATOR:

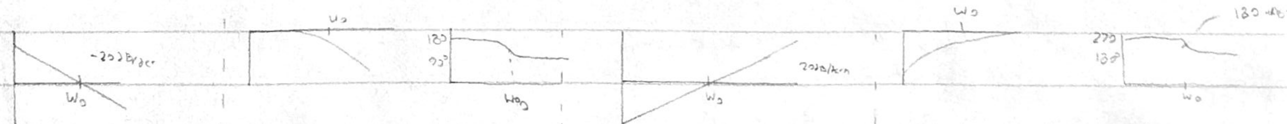


$w_o = \frac{1}{CR_1}$

$H(jw) = -\frac{1}{1 - jw_o/w}$

$|H(jw)| = \left|\frac{1}{1 - jw_o/w}\right|$

$\angle H(jw) = 180° - \angle 1 - jw_o/w$



DIODES

FB → Depletion Region shrinks

RB → Depletion Region Grows

Break down occurs due to - Kinetic energy of minority carrier
- Zener/field effect

$V_D = V_{Do} + I_D r_d$

$V_z = V_{zo} + I_z r_z$

$I_D = I_s(e^{V_D/nV_t} - 1)$ (negligible)

(for physical model)

$r_d = \frac{nV_t}{I_D}$

$V_t = 25\,mV$ @ room temp

$V_{rms} = \frac{V_{pk}}{\sqrt{2}}$

$\frac{I_{D2}}{I_{D1}} = e^{(V_{D2} - V_{D1})/nV_t}$

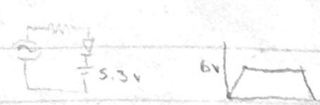
SMALL SIGNAL ANALYSIS:

$|V_z| < |V_{zk}|$
$|I_z| < |I_{zk}|$ } off

DC ANALYSIS: FIND I_D (using specified model)

AC ANALYSIS: $r_d = nV_t/I_D$

CLIPPER:



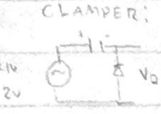
$r_z = 1/slope$

RECTIFICATION:

HWR: $V_{DC} = V_m/\pi$, $PIV = V_m$

FWR: $V_{DC} = 2V_m/\pi$, $PIV = 2V_m$ (center tapped), V_m (Bridge)

CLAMPER:

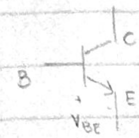


-'ve: $V_D = 0V$, $V_C = -2V$

+'ve: $V_o = V_i - V_c = 4 - (-2) = 6v$

→ KVL for BE side to obtain current

BJT's



	SATURATION	ACTIVE
	EBJ: FB, CBJ: FB	EBJ: FB, CBJ: RB
	$V_{BE} > 0.7V$	$V_{BE} > 0.7$
	$V_{CE} < V_{BE}$	$V_{CE} > V_{BE}$
		$(V_C > V_B > V_E)$

$I_E = I_B + I_C = (\beta+1) I_B$

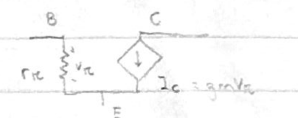
$I_C = \beta I_B = \alpha I_E$

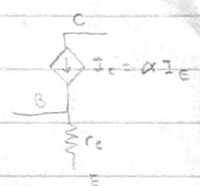
$I_B = (1-\alpha) I_E$

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

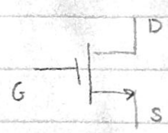
$g_m = \frac{I_C}{V_t} = \frac{\beta}{r_\pi} = \frac{\alpha}{r_e}$ $\quad r_o = \frac{|V_A|}{I_C}$ $\quad r_\pi = \frac{V_t}{I_B} = (\beta+1) r_e$ $\quad r_e = \frac{V_t}{I_E} = \frac{r_\pi}{\beta+1}$ $\quad G = \frac{V_o}{V_\pi} \cdot \frac{V_\pi}{V_s} = A_v$

	CONFIG	R_i	R_o	A_{v1}	A_{v2}	Phase inv
AMP	CE BYPASSED	$R_1 \| R_2 \| r_\pi$ OK	$r_o \| R_C$ OK	$\frac{R_i}{R_i + R_s}$ OK	$-g_m R_L'$ GOOD	✓
AMP	CE UN- "	$R_1 \| R_2 \| (r_\pi + R_1(\beta+1))$ GOOD	R_C OK	$\frac{R_i}{R_i + R_s}$ GOOD	$\frac{-\alpha R_L'}{r_e + R_E} \approx \frac{-R_L'}{R_E}$ BAD	✓
AMP	CB	$R_E \| r_e$ BAD	R_C OK	$\frac{R_i}{R_i + R_s}$ BAD	$\frac{\alpha R_L'}{r_e} = g_m R_L'$ GOOD	×
BUFFER "emitter follower"	CC	$(R_1 \| R_2) \| [r_e + (\beta+1)(R_E \| R_L)]$ GOOD	$R_E \| (r_e + \frac{R_s \| R_1 \| R_2}{\beta+1})$ GOOD	$\frac{R_i}{R_i + R_s}$ ~1	$\frac{R_E \| R_L}{r_e + (R_E \| R_L)}$ ~1	×





MOSFET's



	TRIODE	SATURATION
	$V_{GS} > V_t$	$V_{GS} > V_t$
	$V_{DS} < V_{GS} - V_t$	$V_{DS} \geq V_{GS} - V_t$

$$I_{DS(sat)} = \frac{1}{2} \underbrace{\overbrace{\mu_n C_{ox}}^{K_n'} \frac{W}{L}}_{K_n} (V_{GS} - V_t)^2$$

$$I_{DS}(tri) = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_t) V_{DS}$$

	phase inv		R_i	R_o	A_v
AMP	✓	CS	∞	$r_{o1} \| r_{o2}$	$-g_m R_L' = -g_m(r_{o1} \| r_{o2} \| R_L)$
AMP	×	CG	$\left(\frac{1}{g_{m1} + g_{mb1}}\right)\left(\frac{1 + r_{o2}}{1 + r_{o1}}\right)$ BAD	$r_{o1} \| r_{o2}$	$\frac{r_{o1} r_{o2}\left[\frac{1}{r_{o1}} + g_{m1} + g_{mb1}\right]}{r_{o1} + r_{o2}} \doteq 1 + (g_{m1} + g_{mb1}) r_o$
Buffer "Impedance matching" "source follower"	×	CD	∞	$r_{o1} \| r_{o2} \| \frac{1}{g_m} \| \frac{1}{g_{mb}}$	$\frac{g_{m1} R_L'}{1 + g_{m1} R_L'}$

$g_m = \sqrt{2 \cdot I_{DS} \cdot K_n}$ $\quad g_{mb} = g_m \cdot \gamma$

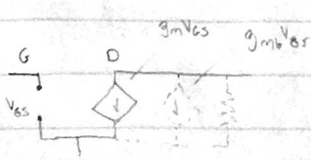
$r_o = \frac{|V_A|}{I_{DS}}$

→ KVL across source and drain to achieve V_{GS} in terms of I_{DS}

→ plug into I_D eqn, solve quadratic

→ solve V_{GS}, pick answer that isn't too small

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



CG: $V_{gs} = V_g - V_s = 0 - V_s = -V_i$

$(g_{m1} + g_{mb1}) V_i + \frac{V_i - V_o}{r_{o1}} = \frac{V_o}{r_{o2}}$

$\Rightarrow V_i[\ ] = V_o[\ ]$

$\Rightarrow A_v = \frac{V_o}{V_i} = \ldots$

CD: $V_{bs1} = V_b - V_s$

$g_{mb1}(-V_o)$

$g_{mb1}(V_o)$