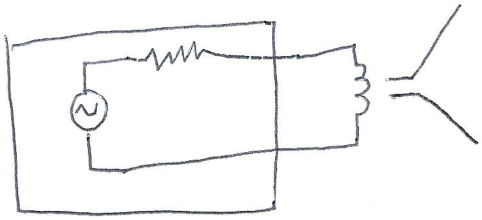
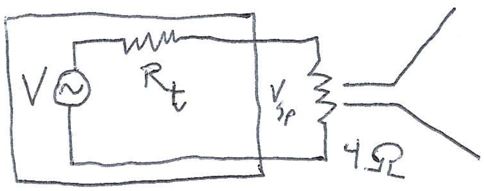
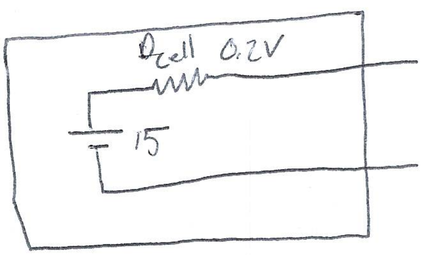
Phys 111A 29 Aug 19

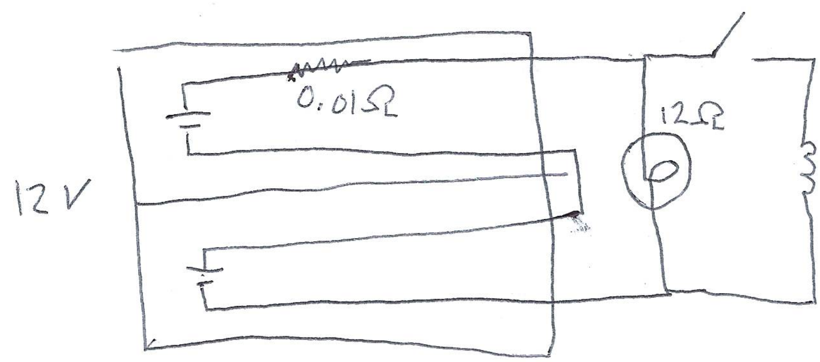




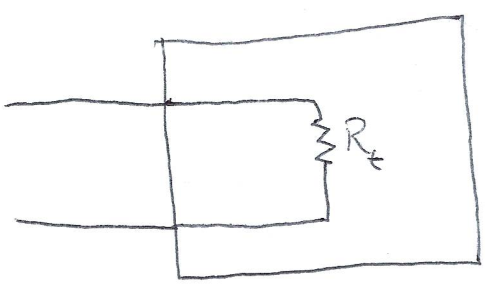
$$V_{sp} = \frac{4}{R_t + 4} V \qquad R_t \to 0 \text{ for loudest speaker}$$

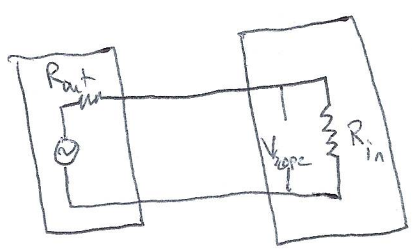
R_t = Output Impedance





Low output impedances are good

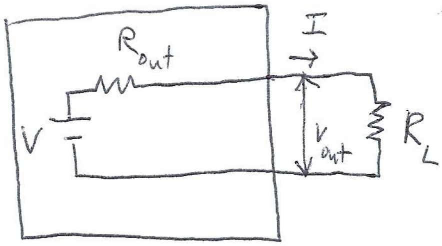




R_t = input impedance = R_{in}

Large ~~output~~ input impedances are good

$$V_{scope} = \frac{R_{in}}{R_{in} + R_{out}} V_s$$



$R_L \to \infty \quad I = 0 \quad V_{out} = V$

As $R_L \downarrow \quad I \uparrow \quad V_{out} \downarrow$

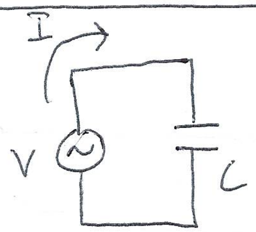
$\Delta I \quad \Delta V$

$\cancel{\Delta V = V} \qquad \Delta V = -R_{out} \Delta I$

$$R_{out} = -\frac{\Delta V}{\Delta I} \qquad V_{out} = V - R_{out} I$$

$$= -\frac{dV}{dI}$$

Frequency Dependent Devices



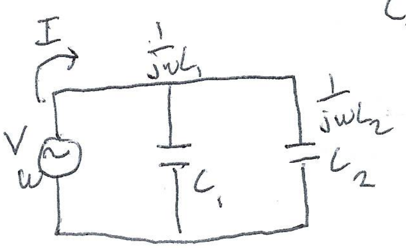
$V = A\cos\omega t \qquad Q = CV \qquad I = \frac{dQ}{dt} = C\frac{dV}{dt}$

$$\frac{dV}{dt} = -A\omega\sin\omega t$$

$$Z = \frac{V}{I} \qquad \frac{A\cos\omega t}{-A\omega\sin\omega t\, C} = \frac{-1}{C\omega}\cot\omega t = Z$$

$V = e^{j\omega t} \qquad I = j\omega e^{j\omega t}$

$$Z = \frac{V}{I} = \frac{+e^{j\omega t}}{Cj\omega e^{j\omega t}} = \frac{+1}{j\omega C}$$ Recovered Ohm's Law

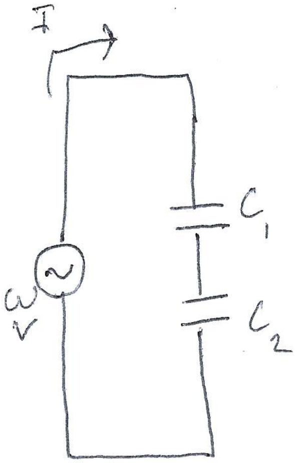


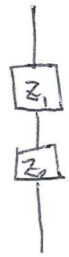
$$\cancel{Z} \quad C_{tot} = \frac{Z_1 Z_2}{Z_1 + Z_2} = \frac{\frac{1}{j\omega C_1}\frac{1}{j\omega C_2}}{\frac{1}{j\omega C_1} + \frac{1}{j\omega C_2}} = \frac{1}{j\omega C_2 + j\omega C_1}$$

$$= \frac{1}{j\omega(C_1 + C_2)}$$

$$C_{tot} = C_1 + C_2$$

$$\frac{V}{Z_{tot}} = \frac{V}{\frac{1}{j\omega C_{tot}}} = j\omega C_{tot} V$$





$$Z_{tot} = Z_1 + Z_2 = \frac{1}{j\omega C_1} + \frac{1}{j\omega C_2}$$

$$= \frac{1}{j\omega}\left(\frac{1}{C_1} + \frac{1}{C_2}\right) = \frac{1}{j\omega}\left(\frac{C_1 + C_2}{C_1 C_2}\right)$$

$$= \frac{1}{j\omega C_{tot}}$$

$$C_{tot} = \frac{C_1 C_2}{C_1 + C_2} \qquad C = \frac{\epsilon_0 A}{d}$$

$$I_{lab} = Re(I)$$

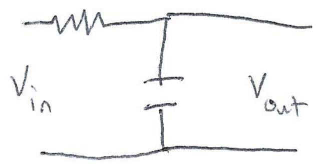
$$Im[I]$$

$$Z_R = R$$

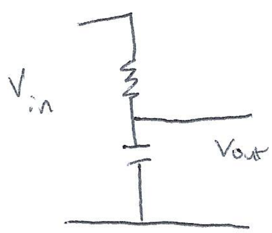
$$Z = Z_R + Z_C = R + \frac{1}{j\omega C}$$

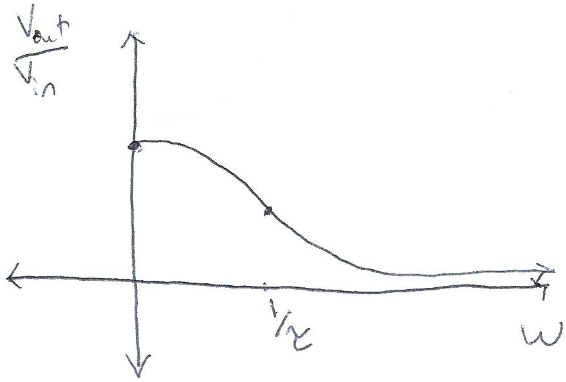
$Re[Z]$ = resistance

$Im[Z]$ = reactance



$$V_{out} = \frac{Z_C V_{in}}{Z_C + Z_R} \qquad Z_R = R, \quad Z_C = \frac{1}{j\omega C}$$





$$\frac{Z_C}{Z_R} = \frac{\frac{1}{j\omega C}}{R} = \frac{1}{j\omega CR}$$

$$\frac{1}{\omega CR} = 1 \qquad \omega = \frac{1}{RC}$$

$$\tau = RC$$

a) $\omega = 0$ $\quad V_{out}/V_{in} = 1$

b) $\omega = \infty$ $\quad V_{out}/V_{in} \Rightarrow 0$

c) construct dimensionless parameter

d) breakpoint

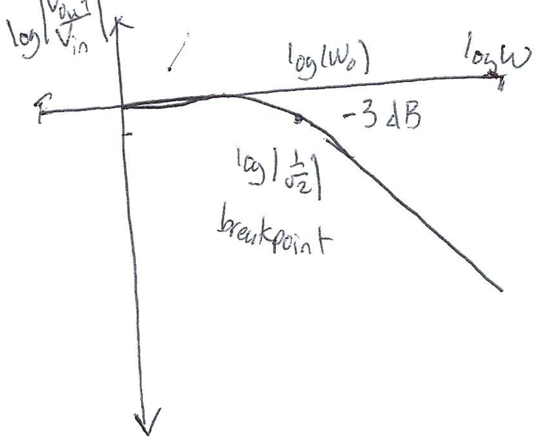
$$\frac{V_{out}}{V_{in}} = \frac{\frac{1}{j\omega C}}{\frac{1}{j\omega C} + R} = \frac{1}{jRC\omega + 1} = \frac{1}{1 + j\omega\tau}$$

$$\omega_0 = \frac{1}{\tau}$$

$$\frac{V_{out}}{V_{in}} = \frac{1}{1 + j\omega/\omega_0}$$

$$\left|\frac{V_{out}}{V_{in}}\right| = \left(\frac{1}{1+\left(\frac{\omega}{\omega_0}\right)^2}\right)^{1/2}$$

Bode plot



$$T = 20\log_{10}\left|\frac{V_{out}}{V_{in}}\right|$$

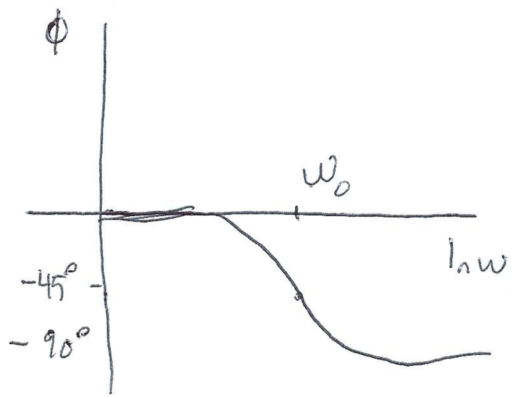
decibels

$$\frac{V_{out}}{V_{in}} = \frac{1}{10} = -20\,dB$$

$P \propto V^2$

$P \propto \frac{1}{100}$ for $-20\,dB$

$$\phi = \tan^{-1}\frac{Im(V_{out})}{Re(V_{out})}$$



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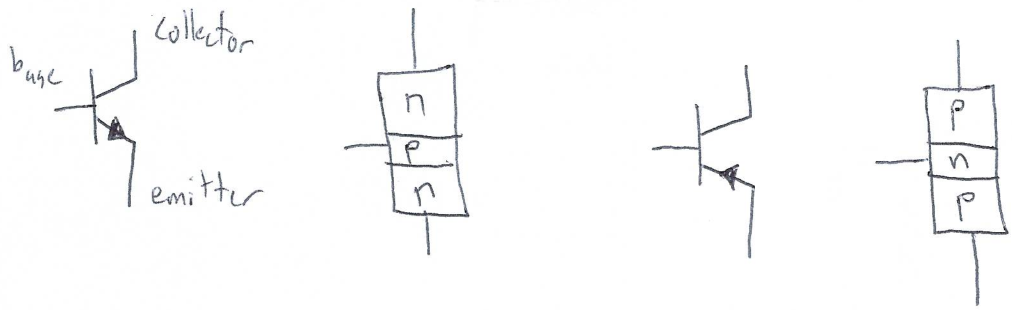
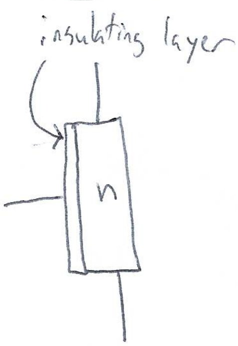
Bipolar Transistor

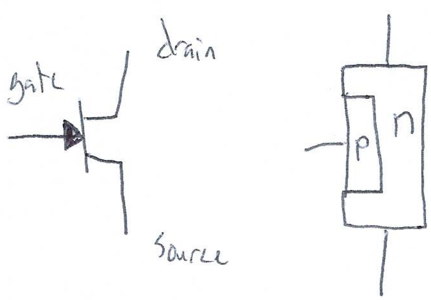


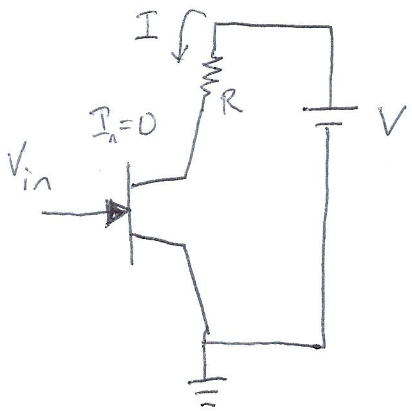
Mosfet / MOSFET



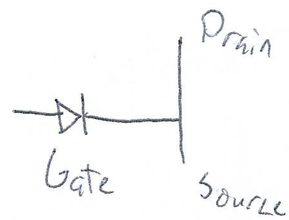
Old Ones
Burn out easily

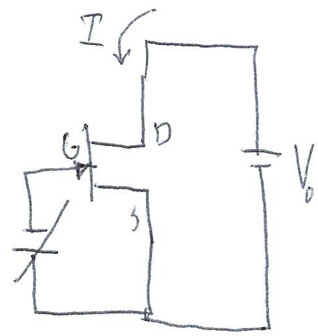
JFET Junction Field Effect Transistor

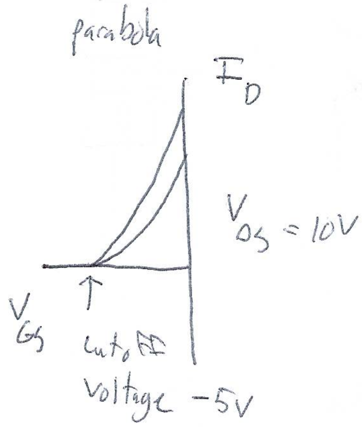


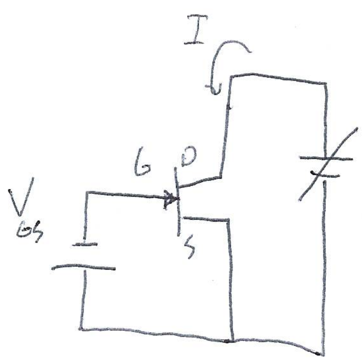


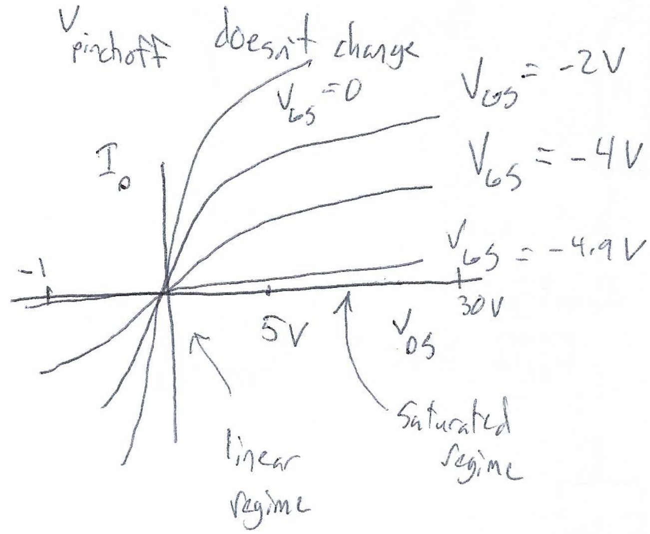
Burn it out by flowing current through gate



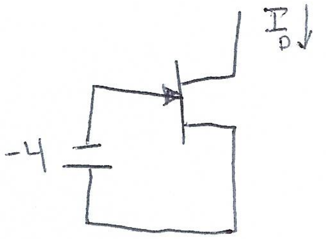


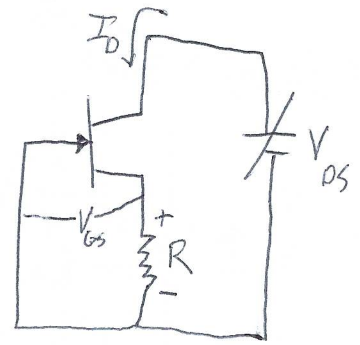






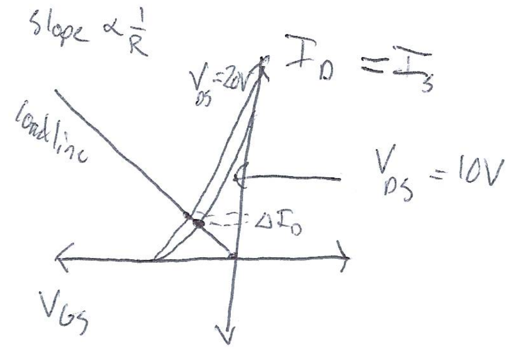
Goal: $\Delta I_D = 0$ for any $V_{DS} > 5V$

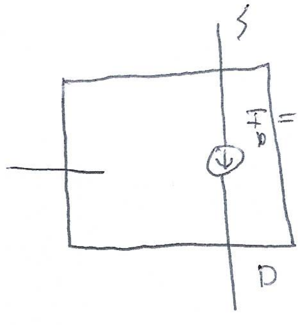




~~$I_D = 0$ $V_{GS} \overset{?}{=} 0$~~ not possible condition

~~$I_D = \text{large}$ $V_{GS} \overset{?}{=} -\text{large}$~~ not possible condition

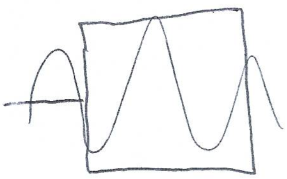




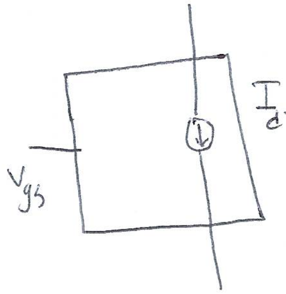
$I_D = I_D(V_{GS}, V_{DS})$

$V_{GS} = V_{GS_0} + v_{gs}$

$I_D = I_{D_0} + I_d$

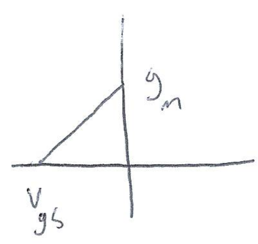


g_m = transconductance

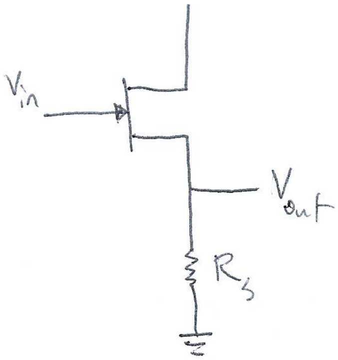


$I_d = -g_m v_{gs}$

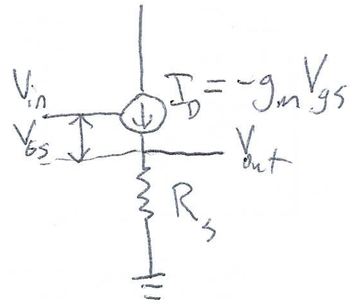
$g_m = \left.\dfrac{\partial I_D}{\partial V_{GS}}\right|_{I_{DS}}$



Follower Circuit



Taylor series model



$$V_{out} = I_D R_s = -g_m V_{gs} R_s$$

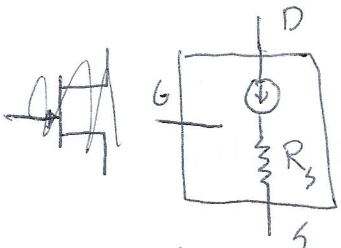
$$V_{gs} = V_{in} - V_{out}$$

$$V_{out} = -g_m R_s (V_{in} - V_{out})$$

$$V_{out}(1 + g_m R_s) = -g_m R_s V_{in}$$

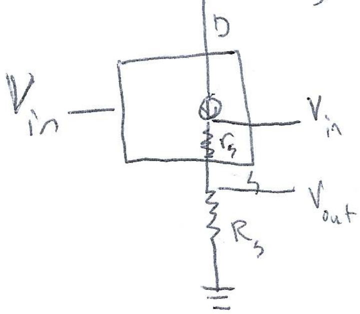
$$V_{out} = \frac{+g_m R_s}{1 + g_m R_s} V_{in} = \frac{+1}{1 + \frac{1}{g_m R_s}} V_{in} \qquad g_m R_s >> 1$$

$$V_{out} \simeq V_{in}$$



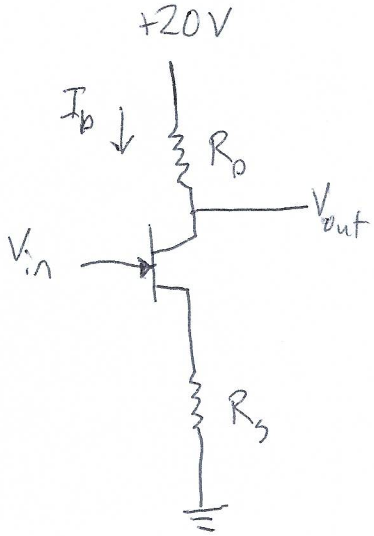
figment of imagination

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



$$V_{out} = \frac{R_s}{r_s + R_s} V_{in} = \cancel{\frac{1}{r_s + R_s}}$$

$$= \frac{1}{1 + \frac{r_s}{R_s}} V_{in} = \frac{V_{in}}{1 + \frac{1}{g_m R_s}}$$



$\cancel{I_D =}$

$$I_d = \frac{V_{outprev}}{R_s} = \cancel{V_{outprev}}$$

$$= \left(\frac{V_{in}}{1 + r_s/R_s}\right)\frac{1}{R_s} = \frac{V_{in}}{R_s}$$

$$V_{out} = \cancel{20V} - R_D I_d$$

$$V_{out} = -\frac{R_D}{R_s} V_{in}$$

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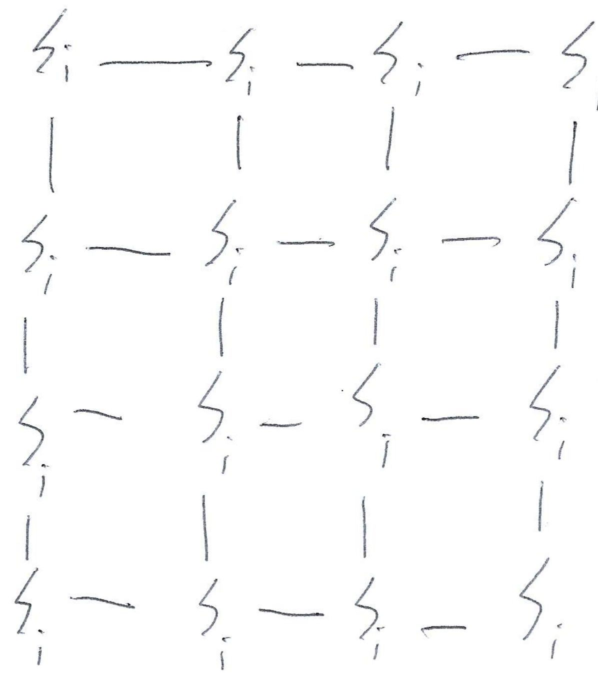
intrinsic

$np = 10^{20} \frac{1}{cm^2}$ @ 300K



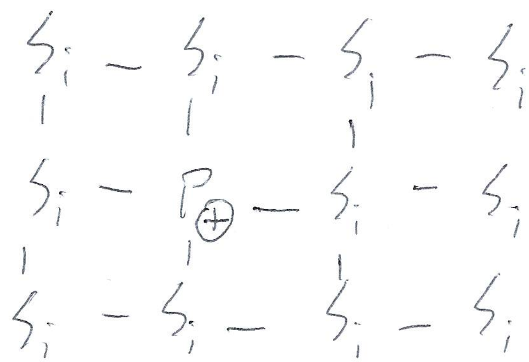
Thermal excitations cause bond breakage and loose electron is born

This creates moving hole

Carriers electrons $n = 10^{10} \frac{1}{cm^3}$

hole $p = 10^{10} \frac{1}{cm^3}$

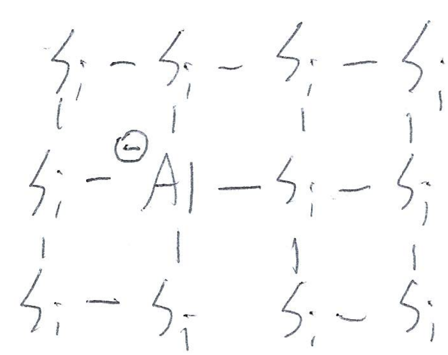
n-type



$n = 10^{15}$

$p = 10^{5}$

p-type

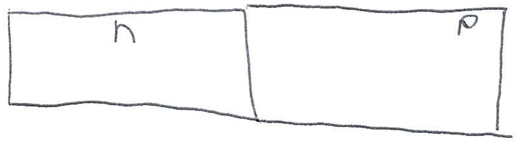


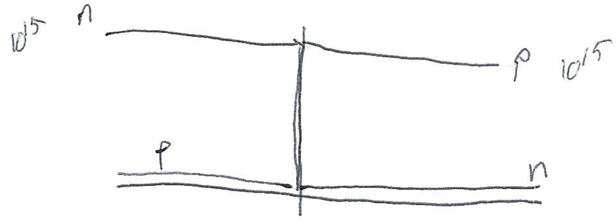
$n = 10^{5}$

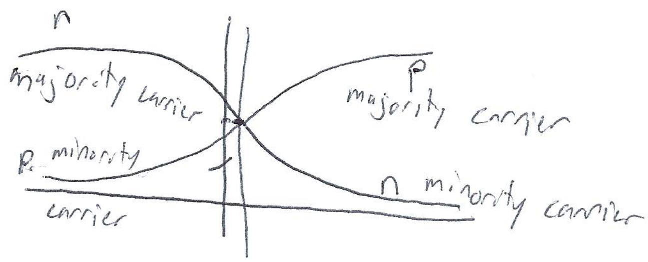
$p = 10^{15}$

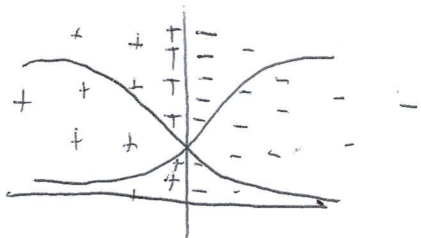
Diffusion

$$\Gamma = -D\nabla n + \mu E$$



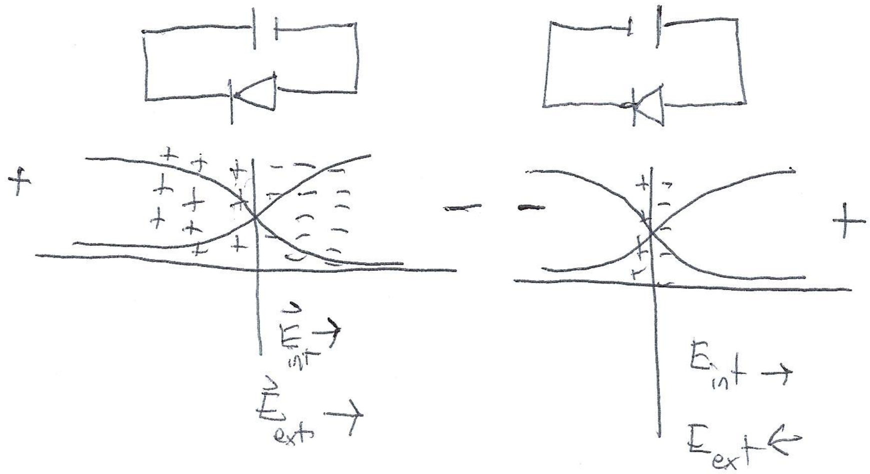




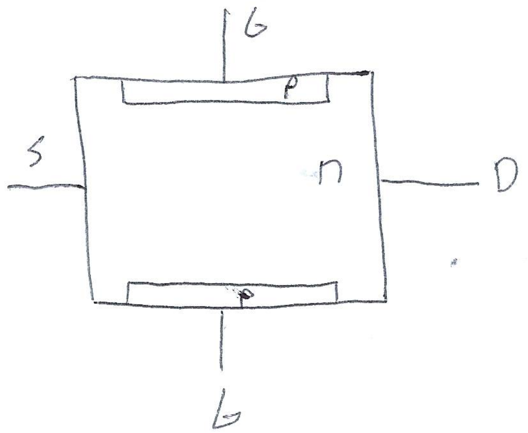


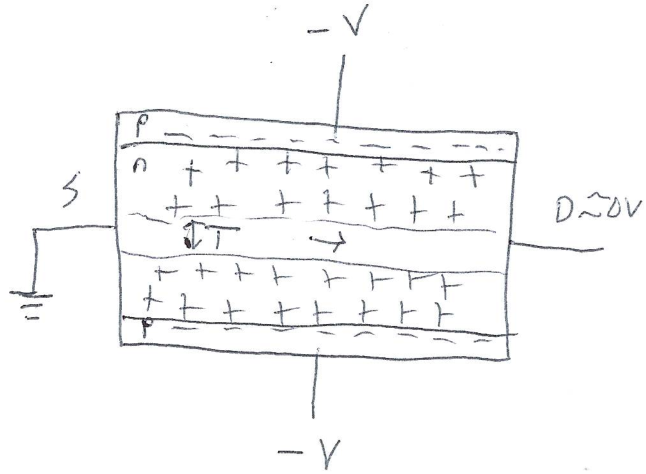
$\vec{E} \rightarrow$

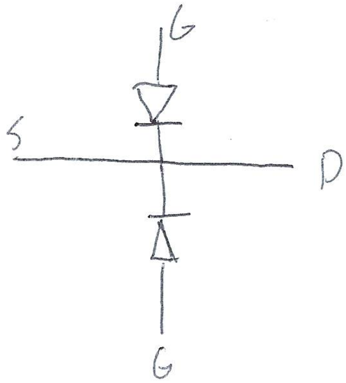
acts against Diffusion
which sets up equilibrium

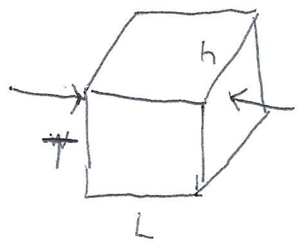


JFET



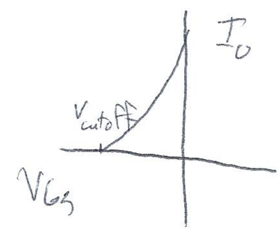


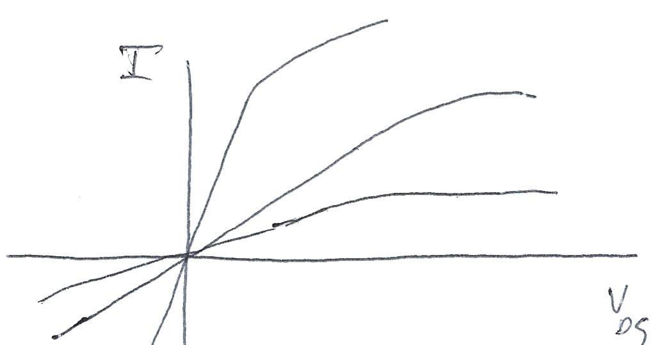


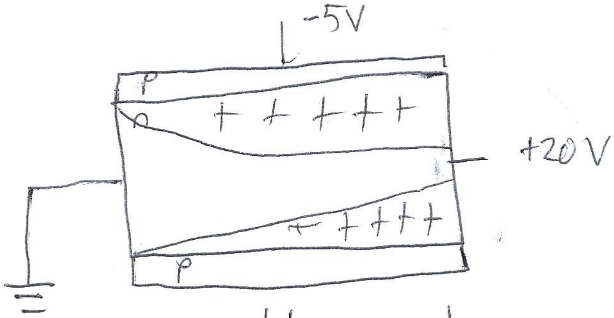


$\cancel{R=\rho\frac{L}{C}}$

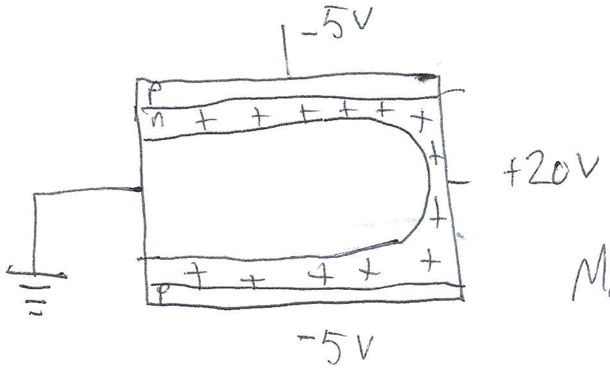
$$R = \rho \frac{L}{hT}$$







Not correct



Most resistance is at the end!

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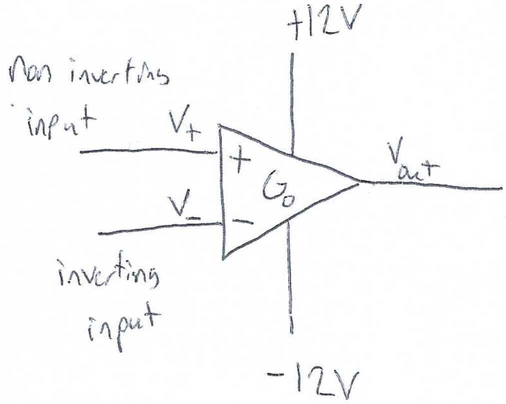


$$V_{out} = G_0 (V_+ - V_-)$$

$G_0 = 10^5 - 10^7$

it is huge!

Positive Feedback

reinforcing Feedback

"Sucks" "useless"

"unstable"

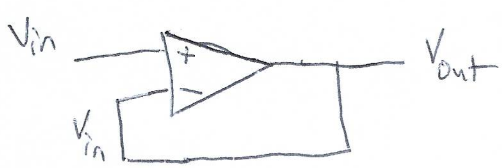
Negative Feedback

Golden Rules

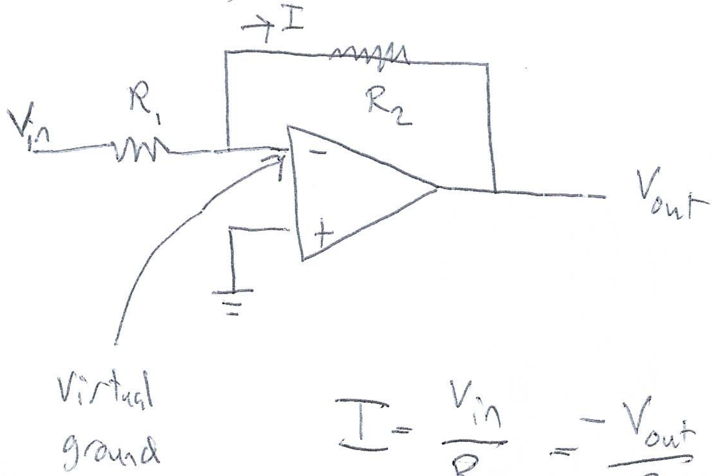
A) Inputs draw no current

B) Op-Amp will do whatever it takes to make $V_+ = V_-$

Follower



Inverting Amplifier

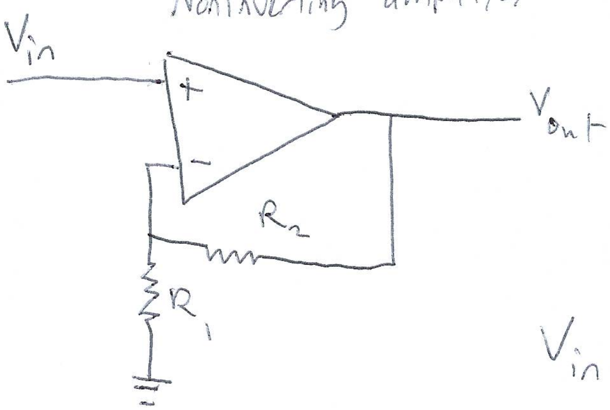


$$V_{out} = \frac{-R_2}{R_1} V_{in}$$

$$I = \frac{V_{in}}{R_1} = \frac{-V_{out}}{R_2}$$

$$G = \frac{-R_2}{R_1}$$

Noninverting amplifier

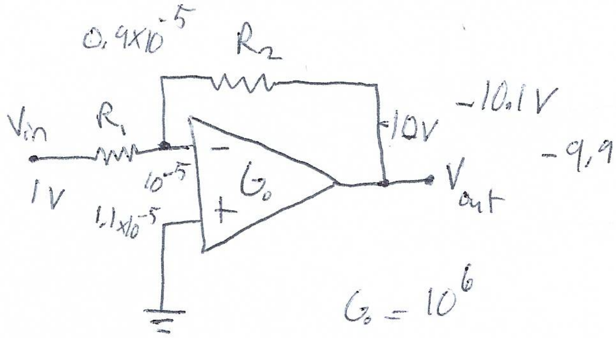


$$V_{out} = G V_{in}$$

$$V_{in} = V_- = \frac{R_1}{R_1 + R_2} V_{out}$$

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

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



$$V_{out} = -G_0 V_- \qquad V_- = V_{in} + \frac{R_1}{R_1+R_2}(V_{out} - V_{in})$$

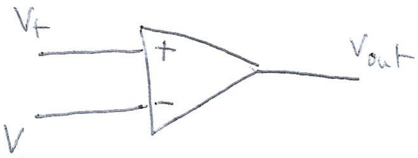
$$-\frac{V_{out}}{G_0} = V_{in} + \frac{R_1}{R_1+R_2}(V_{out} - V_{in})$$

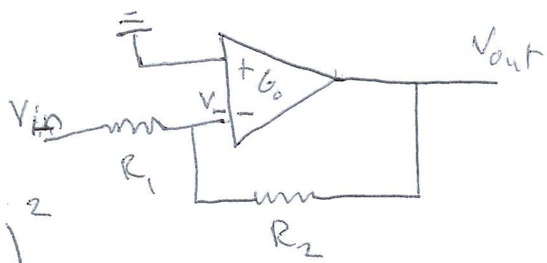
$$-R_1 V_{out} - \frac{V_{out}(R_1+R_2)}{G_0} = (R_1+R_2)V_{in} - R_1 V_{in}$$

$$-R_1 V_{out}\left(1 + \frac{R_1+R_2}{R_1 G_0}\right) = R_2 V_{in}$$

$$V_{out} = -\frac{R_2}{R_1}\left(\frac{1}{1+\frac{\cancel{R_2/R_1}}{G_0}}\right)V_{in} \qquad \frac{1+\frac{R_2}{R_1}}{G_0}$$

$$G = +\frac{R_2}{R_1} \qquad V_{out} = \frac{-G V_{in}}{1+\frac{1+G}{G_0}} = -G V_{in}$$





$$V_{out} = -G_0 (V_+ - V_-)^2$$

$$V_{out} = -G_0 (V_-)^2$$

$$V_- = \pm\sqrt{\frac{-V_{out}}{G_0}}$$

$$V_- = V_{in} + \frac{R_1}{R_1+R_2}(V_{out} - V_{in})$$

$$\pm\sqrt{\frac{-V_{out}}{G_0}} = V_{in} + \frac{R_1}{R_1+R_2}(V_{out} - V_{in})$$

$$\pm\frac{R_1+R_2}{R_1}\sqrt{\frac{-V_{out}}{G_0}} = \frac{R_1+R_2}{R_1}V_{in} + V_{out} - V_{in} = \frac{R_2}{R_1}V_{in} + V_{out}$$

$$-V_{out} = \frac{R_2}{R_1}V_{in} \mp \left(1+\frac{R_2}{R_1}\right)\sqrt{\frac{-V_{out}}{G_0}} \qquad G = \frac{R_2}{R_1}$$

$$V_{out} = -G V_{in} \pm (1+G)\sqrt{\frac{-V_{out}}{G_0}}$$

$$= -GV_{in}\left(1 \mp \frac{(1+G)}{GV_{in}}\sqrt{\frac{-V_{out}}{G_0}}\right) = -GV_{in}\left(1 \mp \left(1+\frac{1}{G}\right)\sqrt{\frac{-V_{out}}{G_0 V_{in}^2}}\right)$$

Assume $V_{out} = -GV_{in}$

$$V_{out} = -GV_{in}\left(1 \mp \left(1+\frac{1}{G}\right)\sqrt{\frac{G\cancel{V_{in}}}{G_0 V_{in}}}\right) \qquad G_0 \gg G/V_{in}$$

$$V_{out} = -GV_{in}(1+0) = -GV_{in}$$

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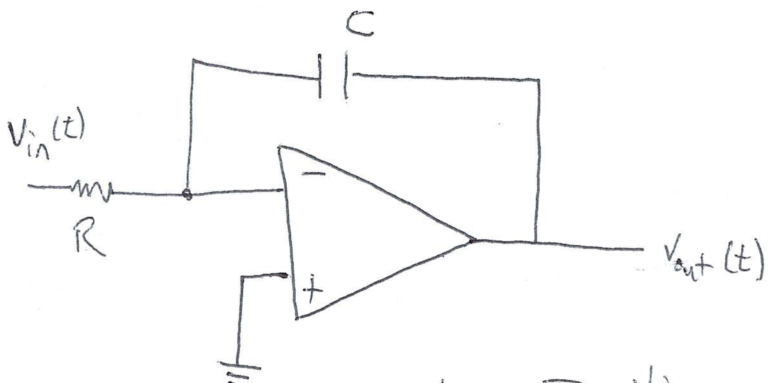
Golden Rules

1) Inputs draw no current

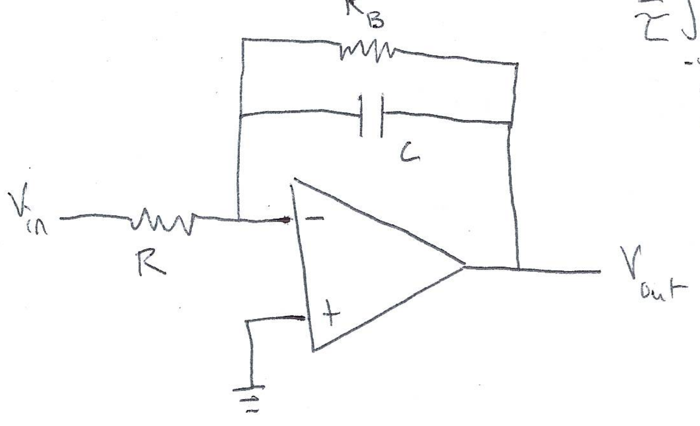
2) Op Amp will do whatever it takes to make $V_+ = V_-$

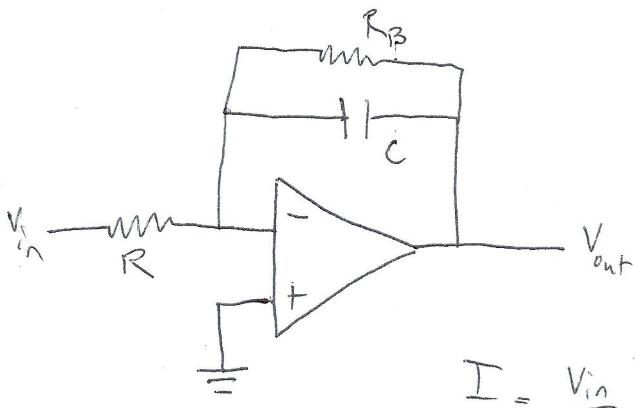


$$I = \frac{V_{in}}{R} = -C\frac{dV_{out}}{dt}$$

$$\frac{dV_{out}}{dt} = \frac{-V_{in}}{\tau} \qquad \tau = RC$$

$$V_{out} = -\frac{1}{\tau}\int_{-\infty \text{ or } 0}^{t} d\tilde{t}\; V_{in}(t)$$





$$I = \frac{V_{in}}{R} = -C\frac{dV_{out}}{dt} - \frac{V_{out}}{R_B}$$

$$\frac{dV_{out}}{dt} + \frac{V_{out}}{\tau_B} = -\frac{V_{in}(t)}{\tau} \qquad \tau_B = R_B C$$

$$\frac{dV_{out}}{dt} + \frac{V_{out}}{\tau_B} = 0 \Rightarrow e^{-t/\tau_B} = V_{out}$$

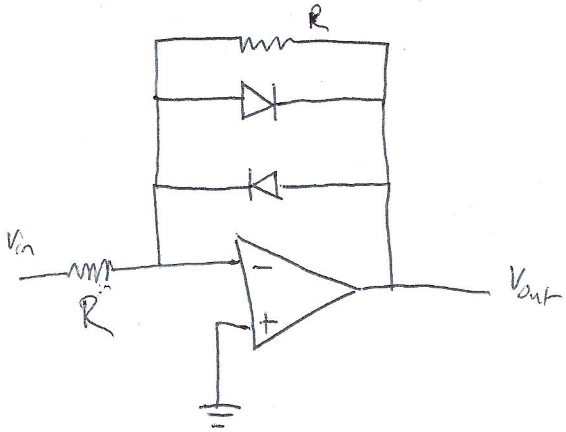
$$V_{out}(t) = f(t)e^{-t/\tau_B}$$

$$+\frac{1}{\tau_B}e^{-t/\tau_B}f(t) \; \cancel{-\frac{1}{t}} \; -\frac{1}{\tau_B}e^{-t/\tau_B}f(t) + e^{-t/\tau_B}\frac{df}{dt} = \frac{dV_{out}}{dt}$$

$$\frac{df}{dt} = e^{t/\tau}V_{in}(t) \qquad f(t) = \frac{1}{\tau}\int_{-\infty}^{t} d\tilde{t}\, e^{+\tilde{t}/\tau_B} V_{in}(\tilde{t})$$

$$V_{out} = \frac{e^{-t/\tau_B}}{\tau}\int_{-\infty}^{t} d\tilde{t}\, e^{\tilde{t}/\tau_B} \overset{V_{in}(\tilde{t})}{f(\tilde{t})} = \frac{1}{\tau}\int_{-\infty}^{t} d\tilde{t}\, e^{-(t-\tilde{t})/\tau_B} \overset{V_{in}(\tilde{t})}{\cancel{f}(\tilde{t})}$$

Convolution integral

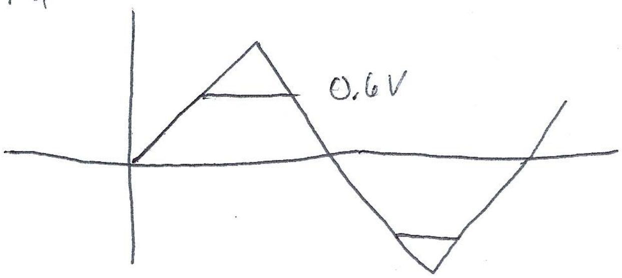


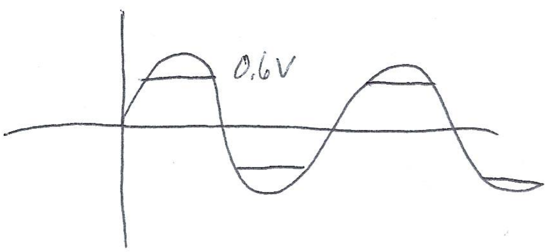
$\cancel{V_{out}} =$

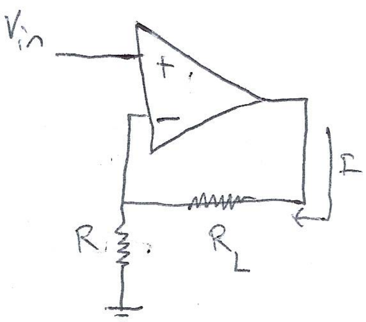
$I = \frac{V}{R}$ $\cancel{V_{out}} =$

Clips signal

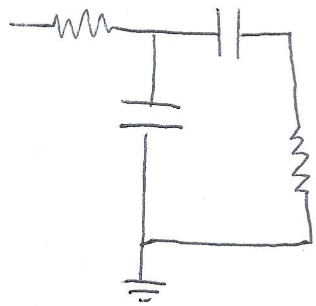
input



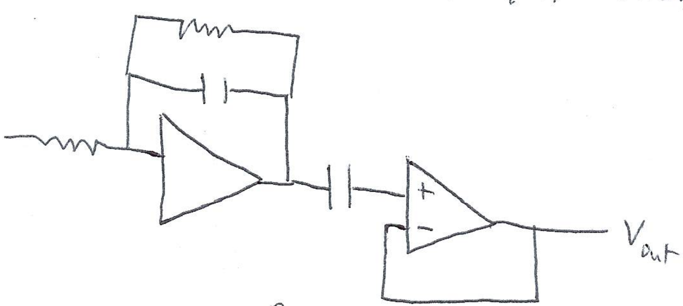


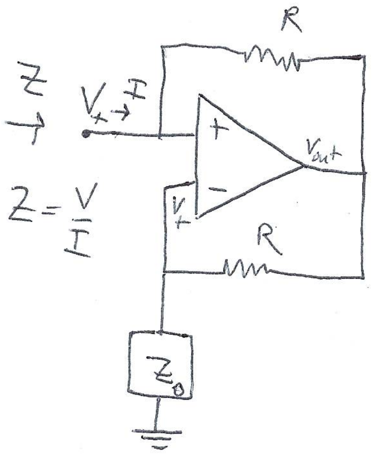


$I = \cancel{\frac{V_{out}}{R_L}}$ $I = \frac{V_{in}}{R}$



Bandpass filters





$$V_+ = V_- = \frac{Z V_{out}}{R + Z_0} \Rightarrow V_{out} = \frac{R + Z_0}{Z_0} V_+ = \left(\frac{R}{Z_0} + 1\right) V_+$$

$$I = \frac{V_+ - V_{out}}{R} = \frac{V_+ - \left(\frac{R}{Z_0} + 1\right) V_+}{R} = \frac{-V_+}{Z_0}$$

$$Z = -Z_0$$

NIC
Negative Impedance Converter

2 NICs → gyrator

$Z_0 = \frac{1}{j\omega C}$ capacitor

$Z = j\omega C R^2$ inductor

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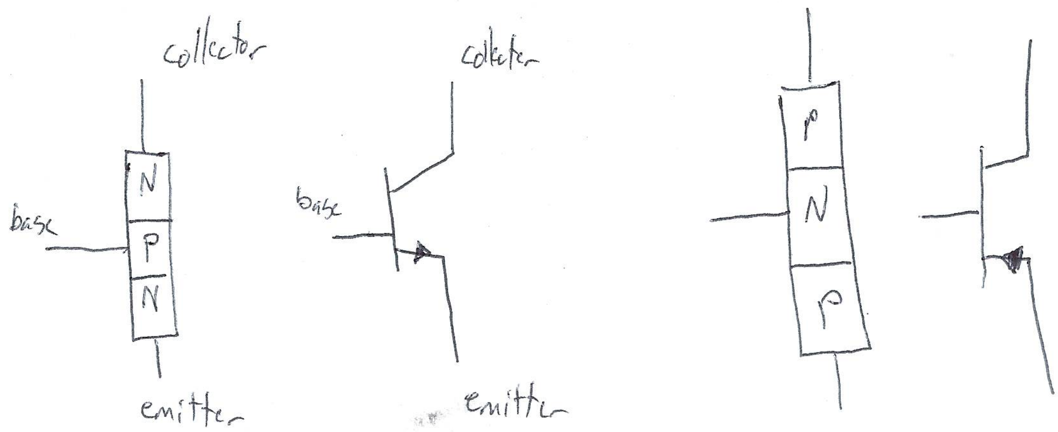
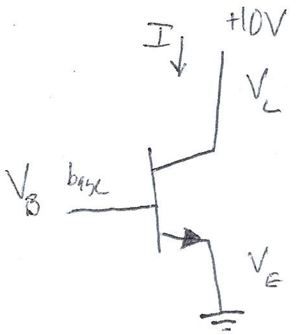
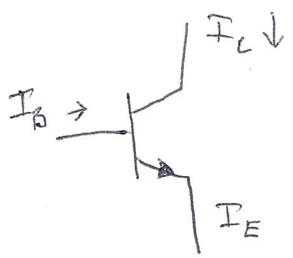




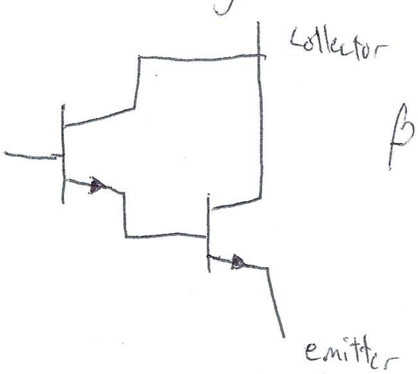
$V_B > 0.65V$ current flows



$$I_C + I_B = I_E$$

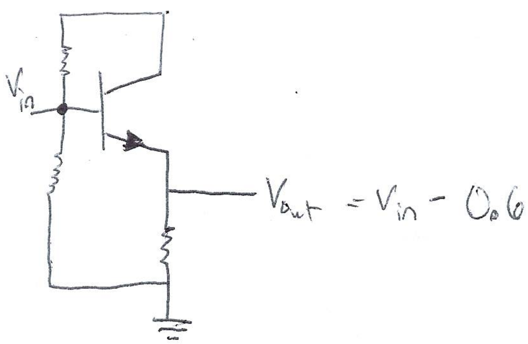
$$I_C = \beta I_B = h_{fe} I_B$$

Darwinton Configuration

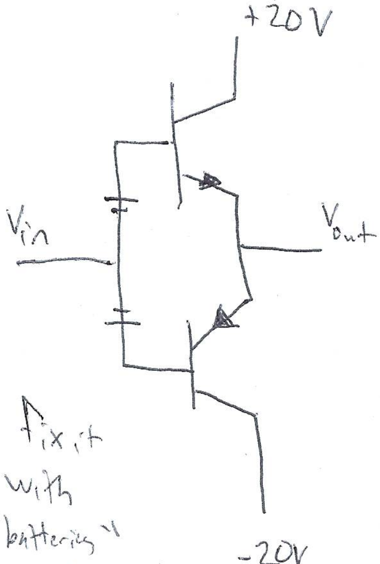


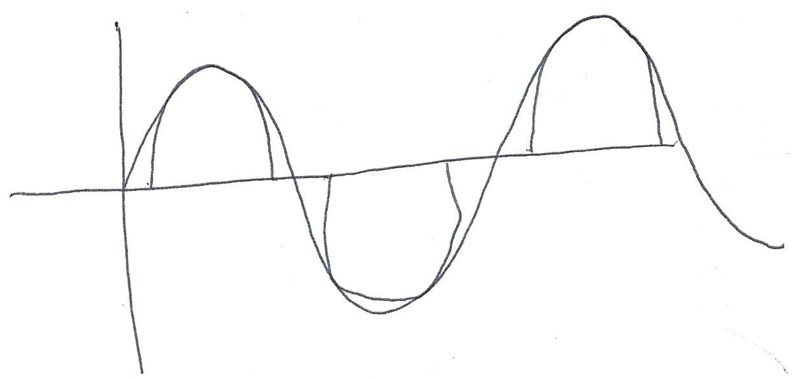
$$\beta = \beta_1 \beta_2$$

follower



Push-pull circuit

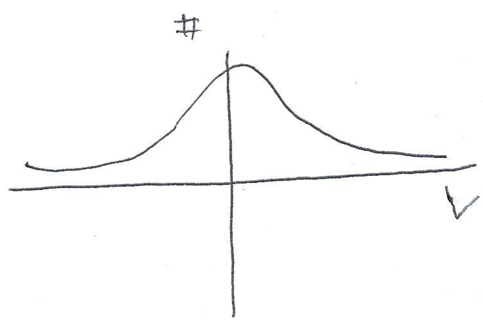




fix it with "batteries" to fill the 0.6V hole

Noise

white noise



Two independent processes

$A \to x \qquad B \to y$

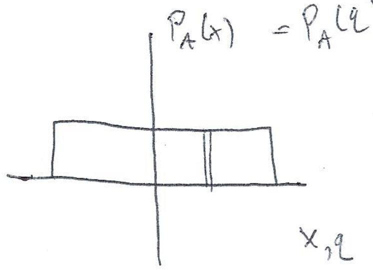
$P_A(x) \qquad P_B(y)$

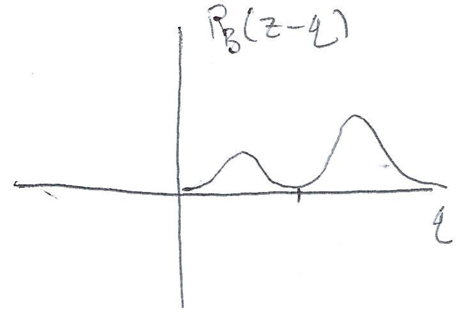
$z = x + y$

$P_A(x=0) \times P_B(y=z) \qquad P_A(x=\frac{z}{2}) \times P_B(y=\frac{z}{2})$

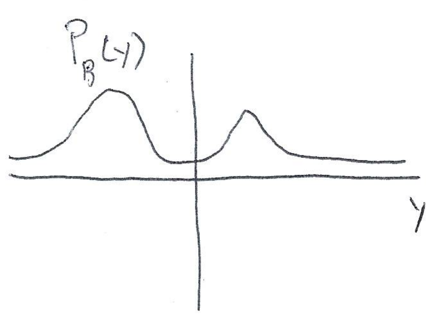
$P_A(x=z) \times P_B(y=0)$

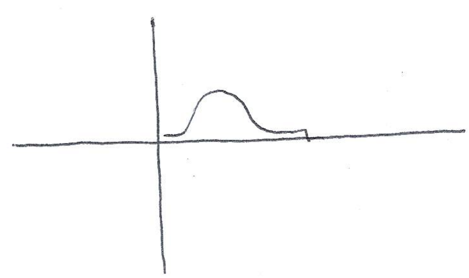
$$P_{A+B}(z) = \int_{-\infty}^{\infty} dq \, P_A(q) \, P_B(z-q)$$ Convolution Integral

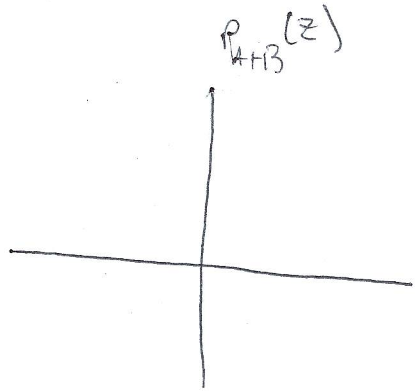


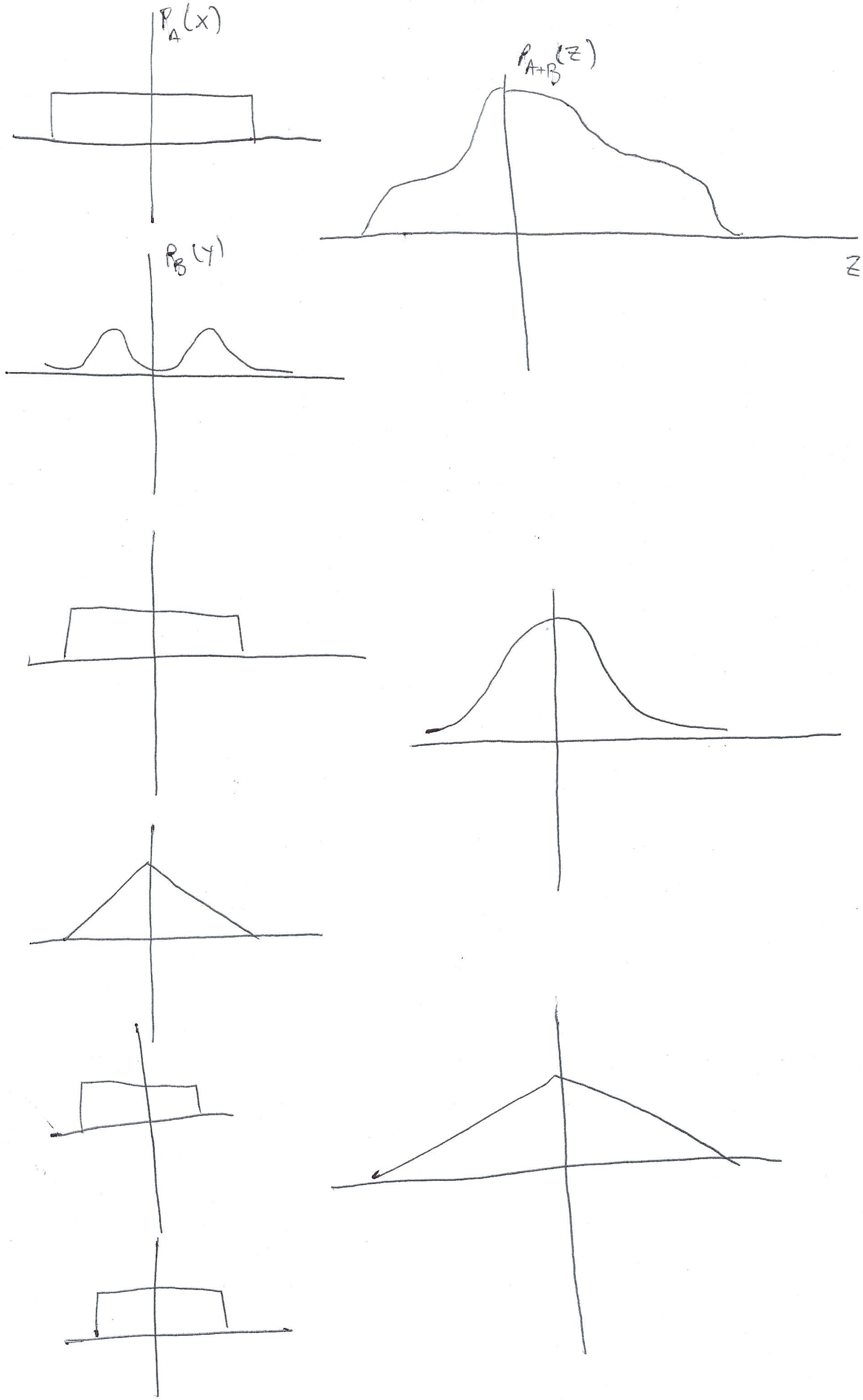


$z = 5$

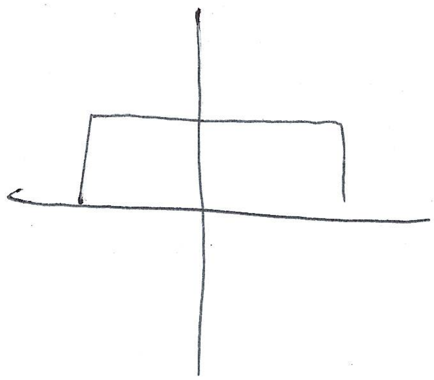


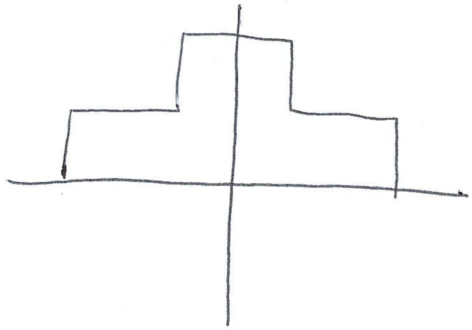


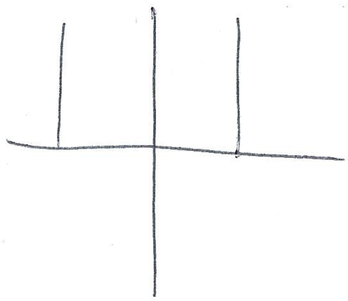




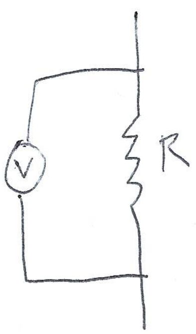
$P_A(x)$
$P_B(y)$
$P_{A+B}(z)$
z







Central Limit Theorem



Thermal noise

Johnson noise

Nyquist noise

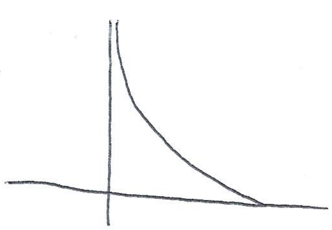
$$P = \frac{V^2}{R}$$

$$E = k_B T$$

$$P = Ef = k_B T f$$

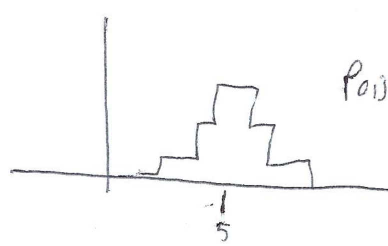
$$\frac{V^2}{R} = k_B T f \rightarrow V = \sqrt{4 R k_B T B}$$

B = bandwidth



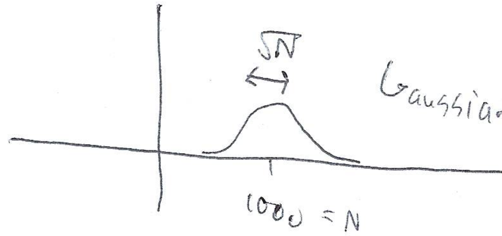
$$P(t) = \frac{1}{\tau} e^{-t/\tau}$$

Poisson Process

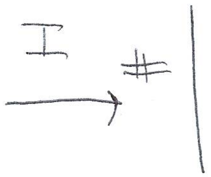


Poisson distribution

→ binomial distribution



Gaussian



$\frac{1}{f}$ noise

$$\frac{1pA}{1C} - \frac{10^{-12}}{10^{-19}} = 10^{7}$$