* Linear time-invariant

Time response $\xleftrightarrow[\text{Transform}]{}$ Frequency Response

Fourier Transform

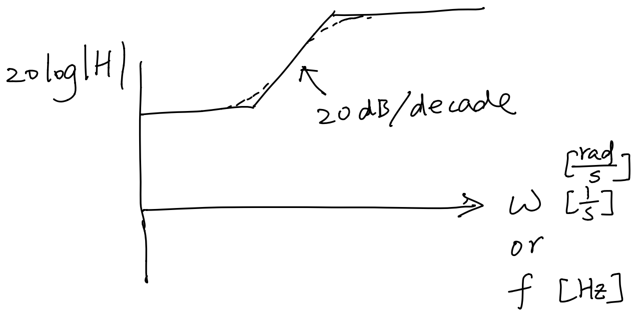
Phasor $i_D \rightarrow I_D e^{j\phi}$ $\quad (= I_D e^{j\omega t + j\phi})$

* **Bode Plot**

$$H(j\omega) = \frac{A\,(1 + j\omega\tau_1)}{B\,(1 + j\omega\tau_2)}$$

Pole $\omega_p = \frac{1}{\tau_2}$

Zero $\omega_z = \frac{1}{\tau_1}$



$\omega \rightarrow 0 \;.\; |H| \rightarrow \left|\frac{A}{B}\right|$ $\qquad \omega = 2\pi f$

e.g. $\omega_z > \omega_p$

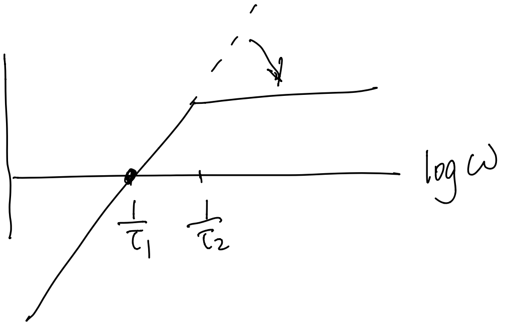
$\omega_z < \omega < \omega_p \,,\; |H| \rightarrow \left|\frac{A}{B}\right| \left|\frac{j\omega\tau_1}{1}\right|$

$\omega_p < \omega \qquad |H| \rightarrow \left|\frac{A}{B}\right| \left|\frac{j\omega\tau_1}{j\omega\tau_2}\right|$

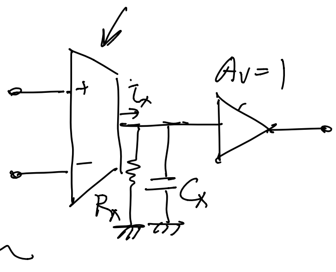
$= \left|\frac{A}{B}\right| \left|\frac{\tau_1}{\tau_2}\right|$

$$H(j\omega) = \frac{(j\omega\tau_1)}{(1 + j\omega\tau_2)}$$

$\omega \rightarrow 0 \;.\; H \rightarrow j\omega\tau_1$



$i_x = G_m(v_+ - v_-)$



* Ideal Op-amp

* Non-ideal Op-amp

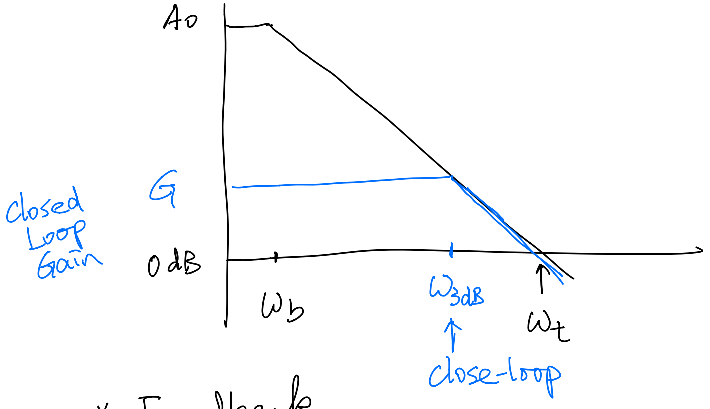
$A_0 < \infty$ Open-loop gain

ω_b Open-loop 3dB bandwidth

$\omega_t = A_0\omega_b$ unity gain frequency

$\omega_b = \frac{1}{R_x C_x}$

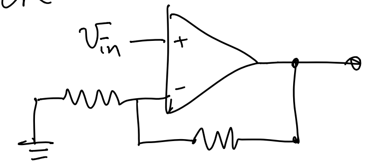
Bode Plot



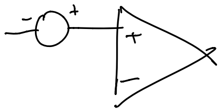
$$A(j\omega) = \frac{A_o}{(1+j\frac{\omega}{\omega_b})}$$

$$G\cdot\omega_{3dB} = A_o\omega_b$$

* Feedback



* Offset voltage : Pay attention to polarity



$A_o(v_+ - v_-)$

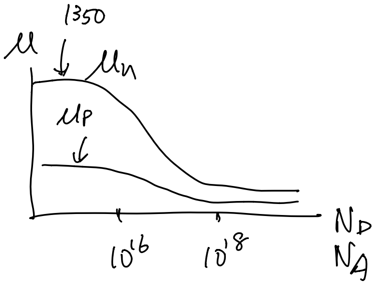
* Slew rate V/μs

$v = \mu E$

$$\frac{cm}{s} \Big/ \frac{V}{cm} = \frac{cm^2}{s\cdot V}$$

* Semiconductor : electron, hole

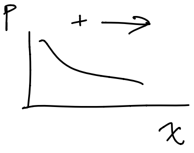
Drift current
$\sigma = nq\mu_n$ for n-type
$\sigma = pq\mu_p$ p-type



Diffusion current

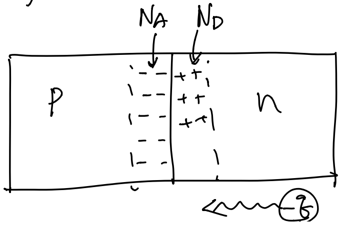
$$J_p = -qD_p\frac{dp}{dx}$$

$$J_n = qD_n\frac{dn}{dx}$$



$\frac{dp}{dx} < 0$

* p-n junction → Diode



$\longleftarrow E \quad \textcircled{-q} \longrightarrow$

$J_{p,drift} \longleftarrow$ } cancel out at equilibrium, i.e. $V_{Bias} = 0$
$J_{p,diff} \longrightarrow$

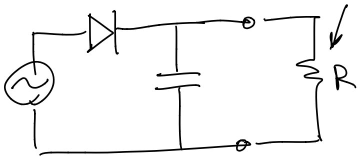
$J_{n,drift} \longleftarrow$ } cancel
$J_{n,diff} \longrightarrow$

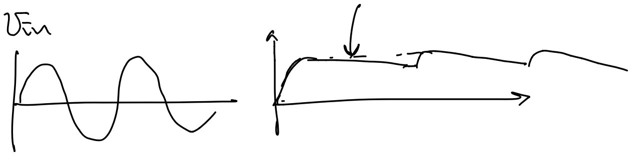
Apply v_D

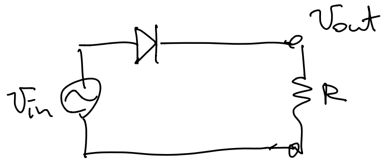
$$i_D = I_S \left(e^{\frac{v_D}{V_T}} - 1\right) \uparrow \quad : \text{Large-signal model}$$

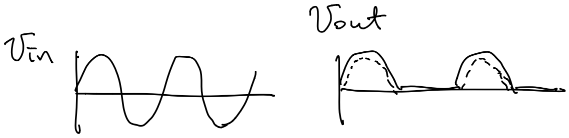
* Rectifying circuit

$\propto \left(1 - e^{-\frac{t}{RC}}\right)$









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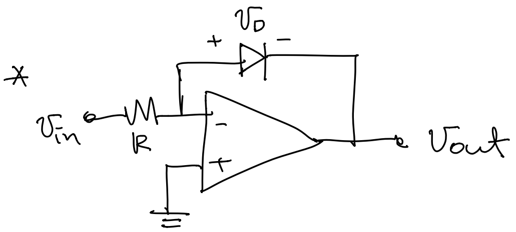
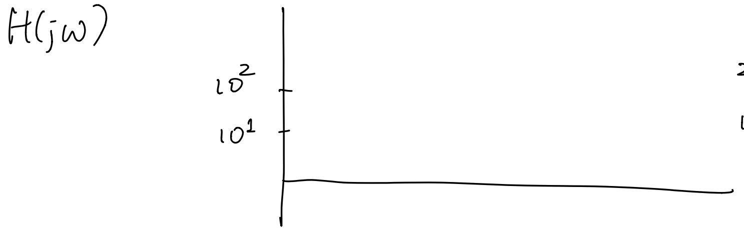


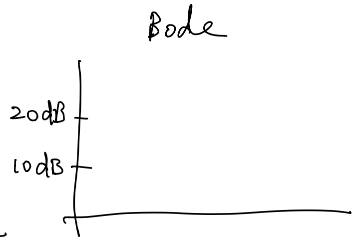
$$v_{out} = \underset{\substack{\shortparallel \\ v_+ \\ \shortparallel \\ 0}}{v_-} - v_D = 0 - v_D = -v_D$$

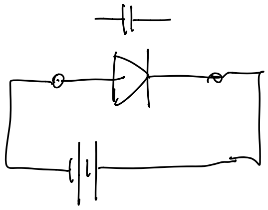
$$i_D = I_S e^{\frac{v_D}{V_T}} = \frac{v_{in} - v_-}{R} = \frac{v_{in}}{R}$$

$$v_D = V_T \cdot \ln \frac{v_{in}}{I_S R}$$

$$v_{out} = -v_D = -V_T \ln \frac{v_{in}}{I_S R}$$



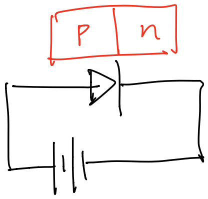




Reverse bias

$i_D \to -I_S$

$C_{dep} = \frac{\epsilon_{Si} \cdot A}{W} = \frac{C_0}{\sqrt{1+\frac{|V_R|}{V_{bi}}}}$ ✓



Forward bias

$i_D = I_S e^{\frac{v_D}{V_T}}$

2 capacitance

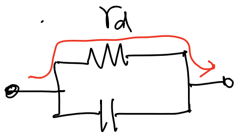
Cdep

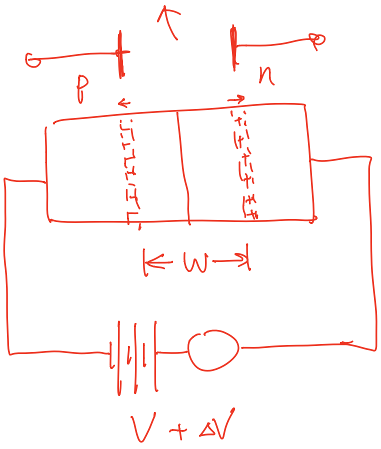
$\boxed{C_{diff}}$ (did not discuss)

↑ diffusion cap

= stored minority carriers

Equivalent





$C_{dep} = \frac{\epsilon_{Si} \cdot A}{W}$

* Closed Book

2 pages

Calculator → × 3 decimal

a few %

0.7

0.72

$i \sim 1.1\ \text{mA}$

$1\ \text{mA}$

$1 + \frac{R_2}{R_1}$ $\quad$ $\frac{R_2}{R_1} = 100$ $\quad$ $\underset{\uparrow\uparrow\ \uparrow}{1.0875}$

$e^{\frac{v_D}{V_T}}$