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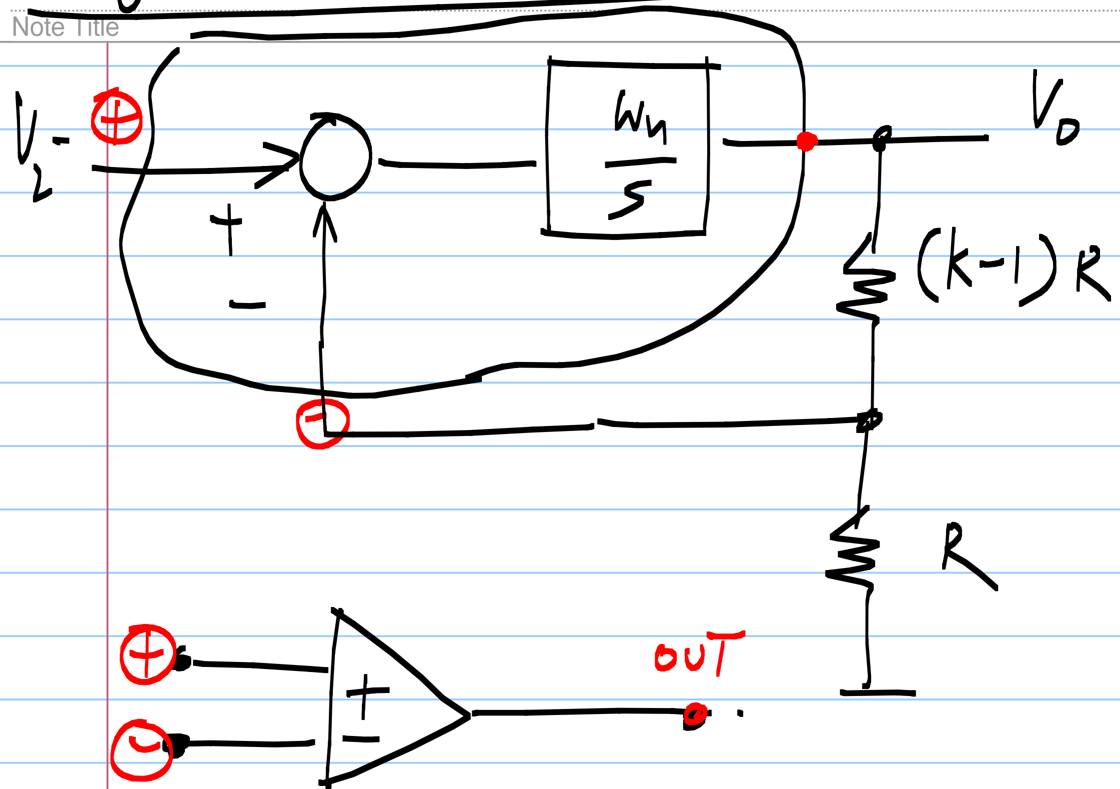
Negative feedback amplifier implementation:



R, L, C

integration

$$v_c = \frac{1}{C}\int i_c \cdot dt$$

$$i_L = \frac{1}{L}\int v_L \cdot dt$$

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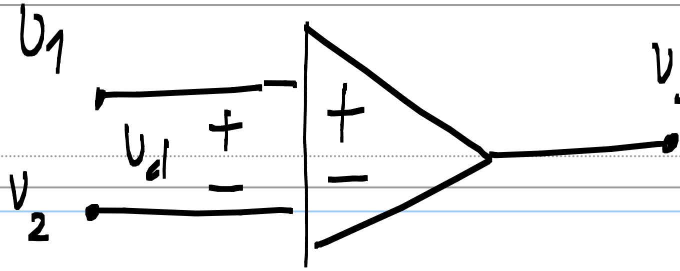
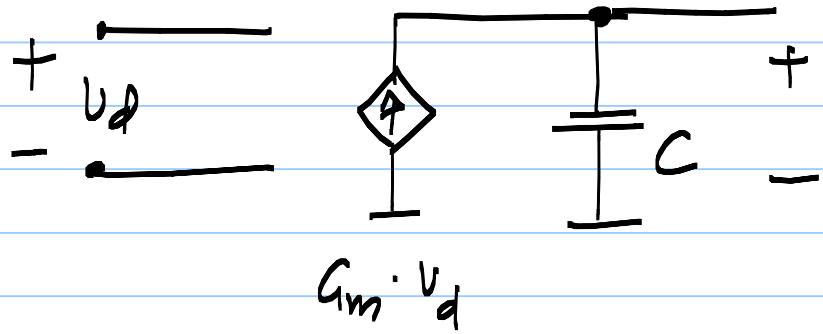


$$v_o = \omega_u \int v_d \cdot dt$$

$$v_c = \frac{1}{C} \int i_c \cdot dt$$

$$\boxed{\omega_u = G_m / C}$$



$$\frac{1}{C} \int G_m \cdot v_d \cdot dt$$

$$= \frac{G_m}{C} \int v_d \cdot dt$$

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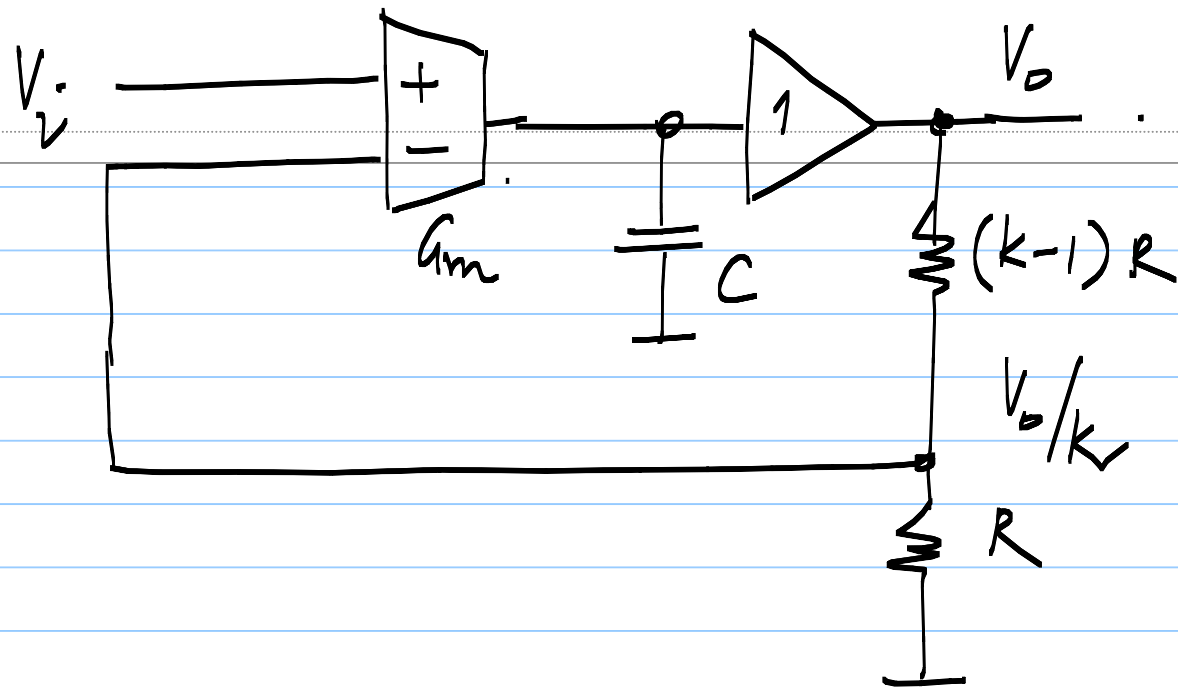
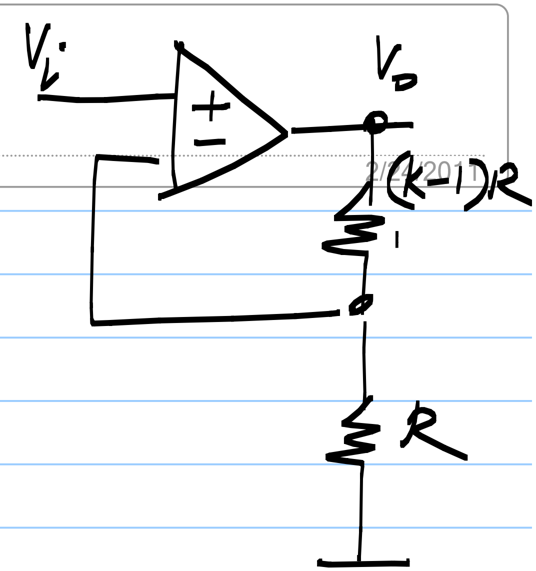
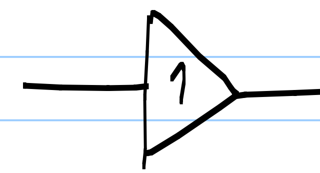
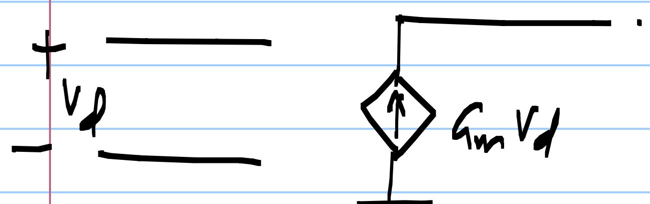
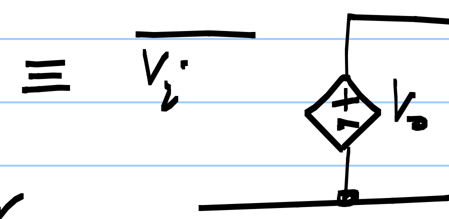


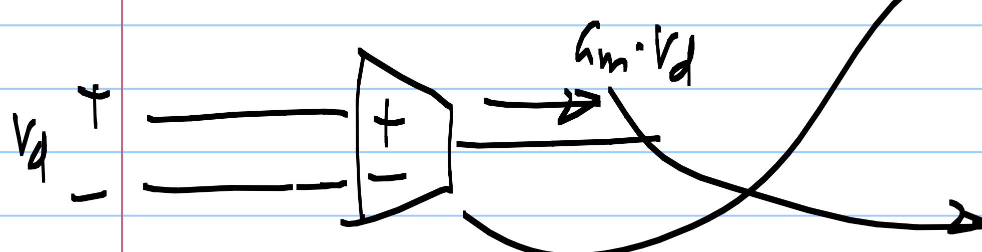






VCCS





Transconductor

Transconductance

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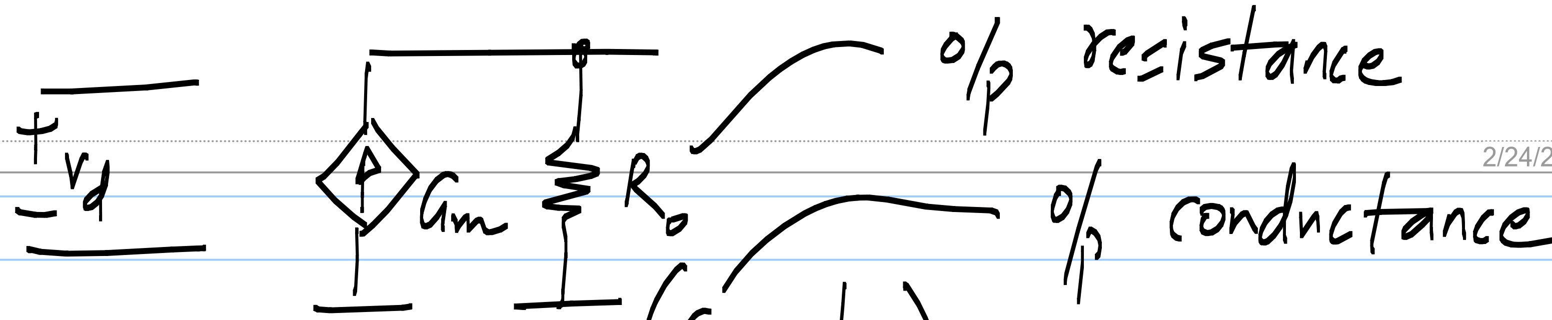

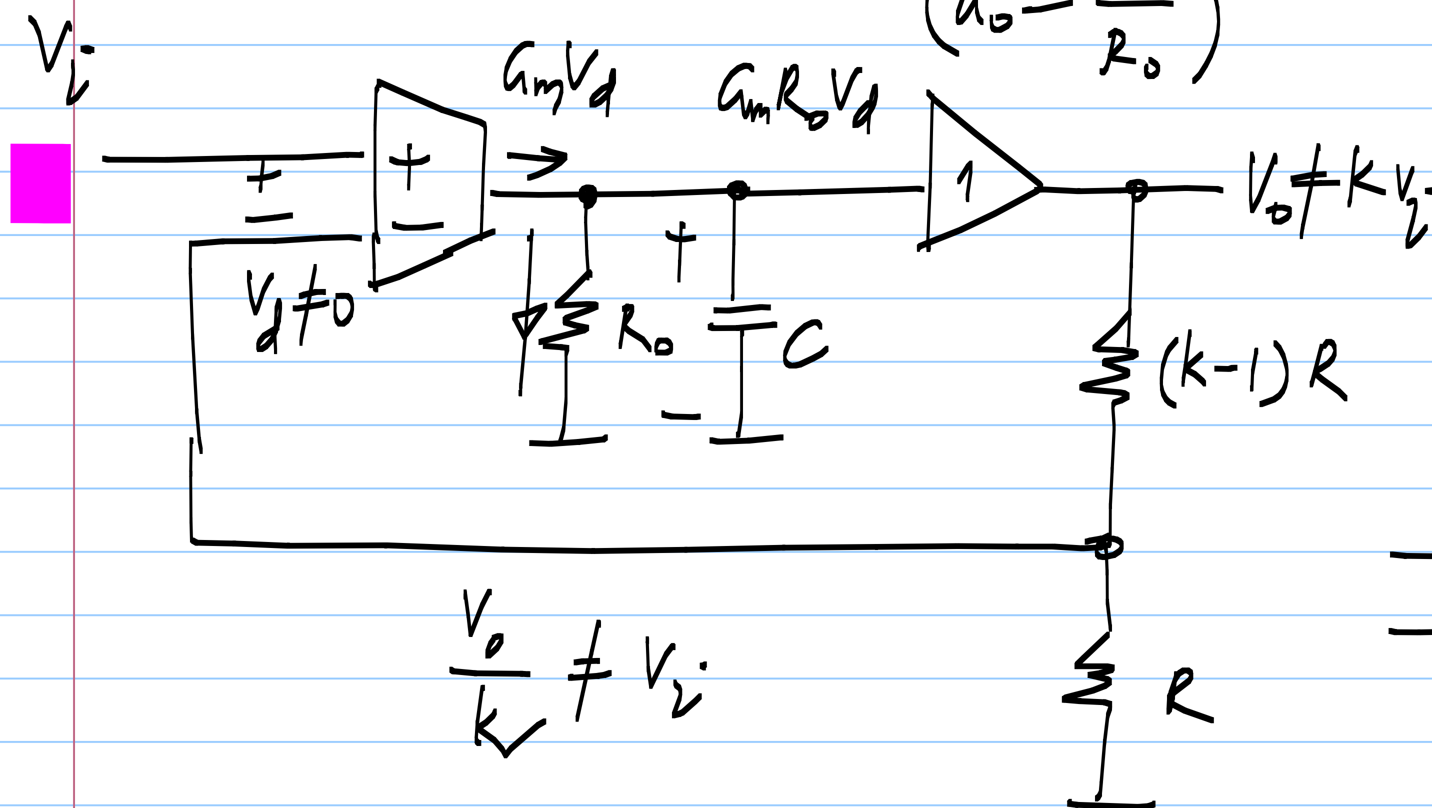

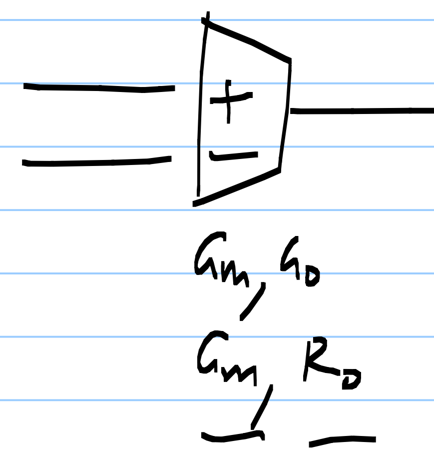

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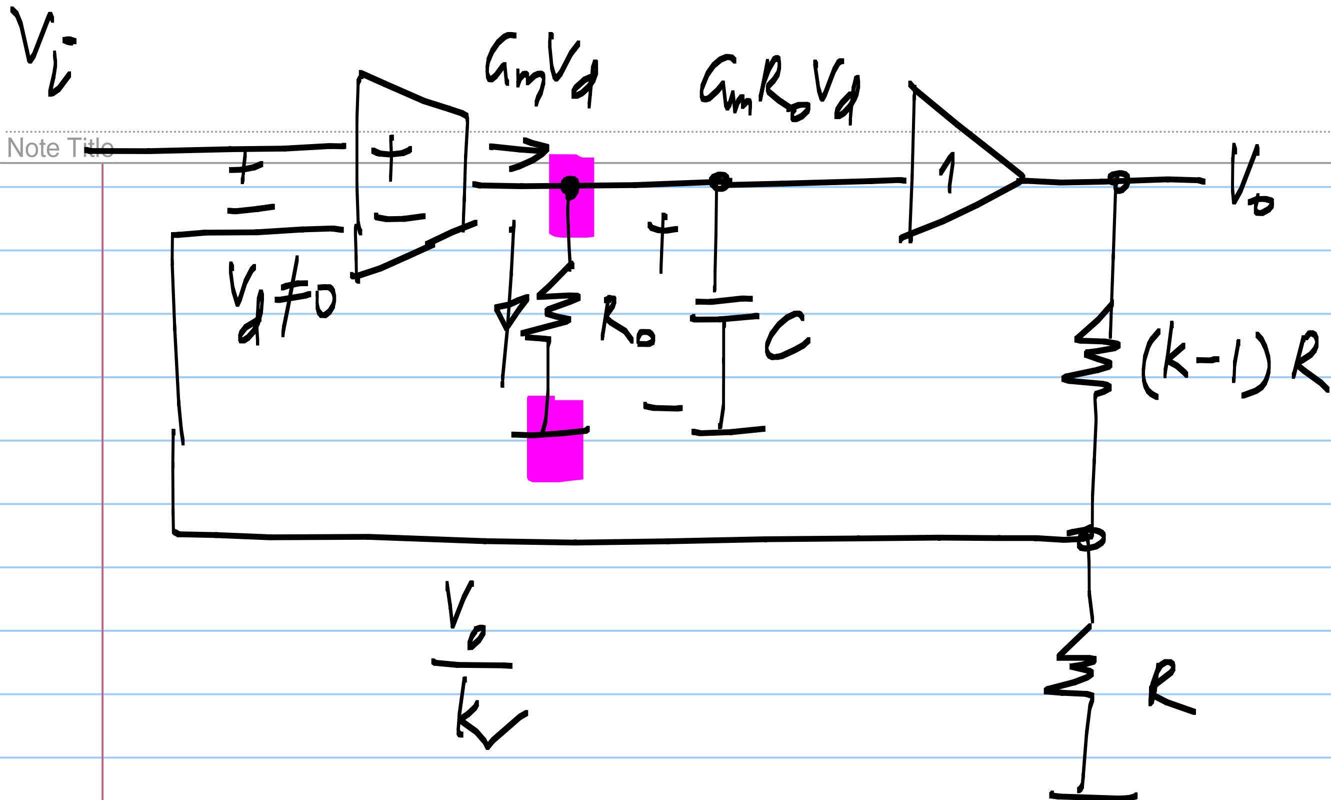
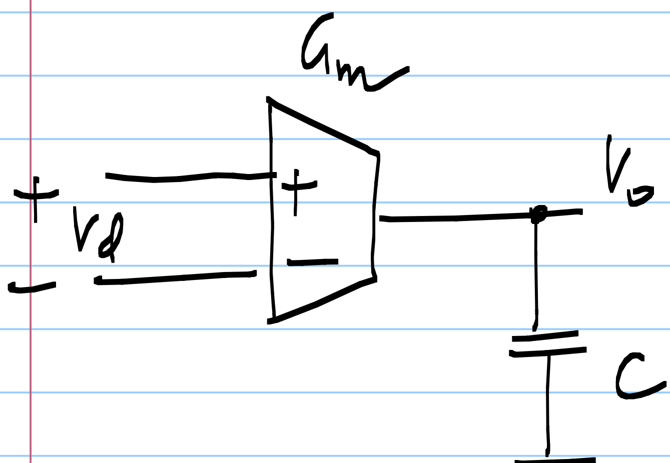
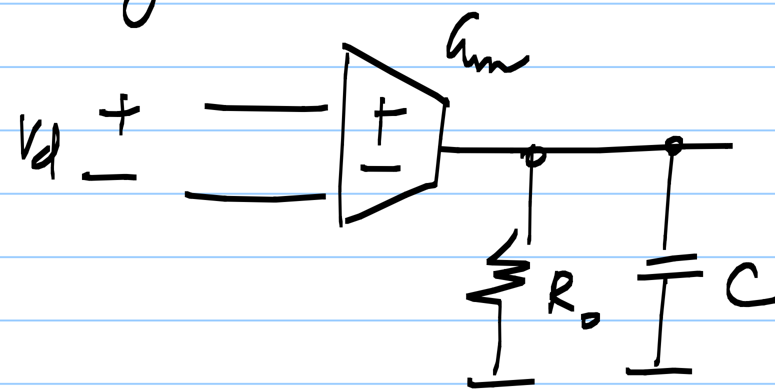


$$\left(V_i - V_o/k\right) G_m R_o = V_o \quad (\text{constant } V_i)$$

$$V_o = \frac{G_m R_o}{1 + \left(G_m R_o/k\right)} \cdot V_i = k V_i \quad \Big| \; R_o = \infty$$

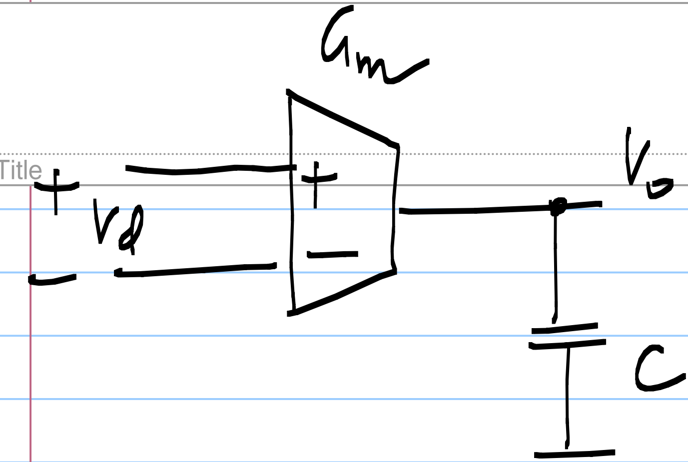
$$V_o = \frac{G_m R_o}{1 + \frac{G_m R_o}{k}} V_i = \underbrace{k}_{\text{ideal gain}} \cdot \underbrace{\frac{1}{1 + \frac{k}{G_m R_o}}}_{\text{error}} \cdot V_i$$

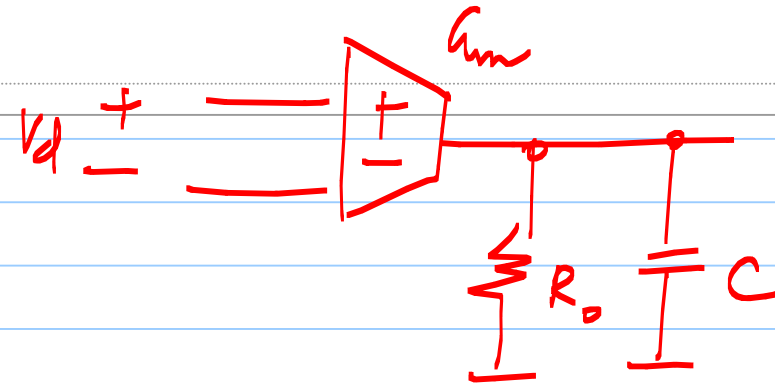




$$\frac{V_o}{V_d} = \frac{G_m}{sC}$$

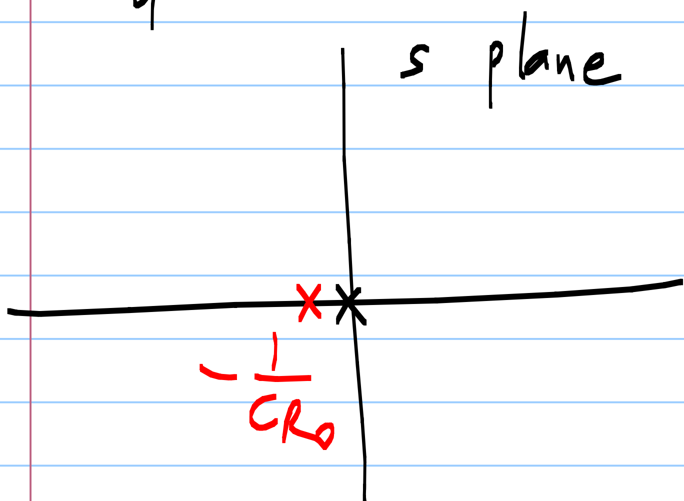
$$\frac{V_o}{V_d} = \frac{G_m}{\frac{1}{R_o} + sC}$$





$$\frac{V_o}{V_d} = \frac{G_m}{sC}$$

$$\frac{V_o}{V_d} = \frac{G_m}{\frac{1}{R_o} + sC} = \frac{G_m R_o}{1 + sCR_o}$$



Pole : $-\frac{1}{CR_o}$

Note Title 2/24/2011

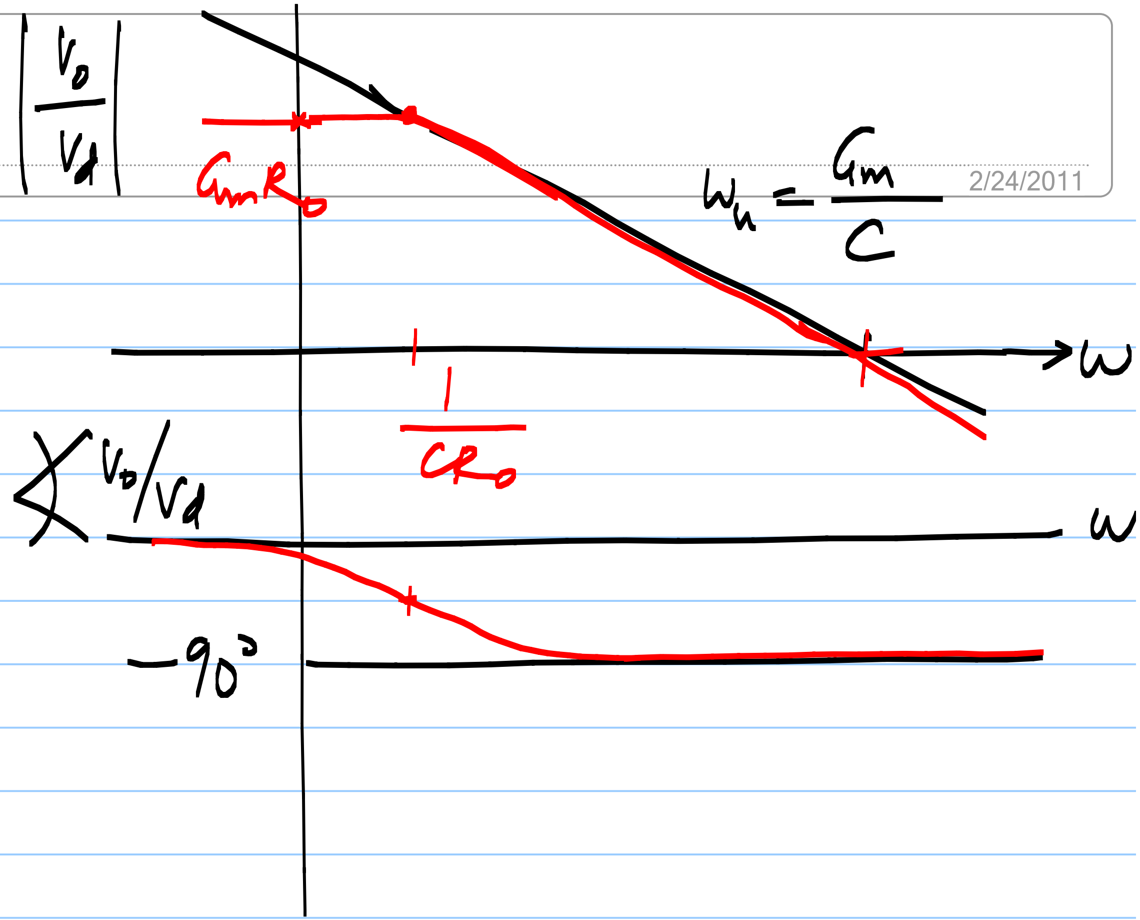
$$\frac{V_o}{V_d} = \left.\frac{G_m}{sC}\right]$$

$$\frac{V_o}{V_d} = \left.\frac{G_m}{sC + 1/R_o}\right]$$

$$= \frac{G_m}{sC + G_o}$$

$$= \frac{G_m R_o}{1 + sCR_o}$$

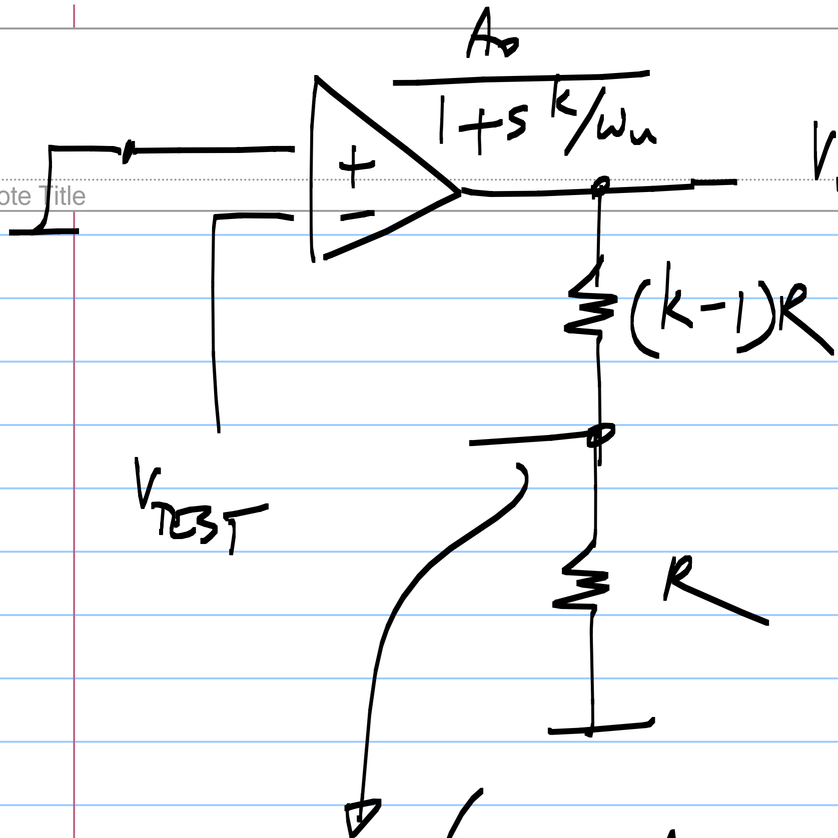
$$\left| \frac{G_m}{j\omega C + 1/R_o} \right| = 1$$



$$G_m^2 = \omega^2 C^2 + \frac{1}{R_o^2}$$

$$\omega^2 = \frac{G_m^2}{C^2} - \left(\frac{1}{C^2 R_o^2}\right)$$

Note Title



$$V_{RETURN} = -\underbrace{\left(\frac{1}{k}\,\frac{A_o}{1+s A_o/\omega_u}\right)}_{\text{Loop gain}}$$

$$\frac{\omega_u/k}{s}$$

$$\frac{G_m R_o}{1+sCR_o} = \frac{A_o}{1+s\left(\frac{A_o}{\omega_u}\right)}$$

$$= \frac{G_m}{sC+\frac{1}{R_o}}$$

$$= \frac{1}{s\frac{C}{G_m}+\frac{1}{G_m R_o}} = \frac{1}{\frac{s}{\omega_u}+\frac{1}{A_o}}$$

$$G_m R_o = A_o$$

$$\omega_u = \frac{G_m}{C}$$

pole: $-\left(\frac{\omega_u}{A_o}\right)$

Note Title 2/24/2011

$$\text{Loop gain} = \frac{A_o/k}{1 + s/\omega_u} \qquad \left(\text{used to be } \frac{\omega_u/k}{s}\right)$$

$$\text{dc loop gain} = \frac{A_o}{k} \qquad \left(\text{'' } \quad \infty\right)$$

$$\text{Closed loop gain} = k \cdot \underbrace{\frac{1}{1 + \frac{k}{G_m R_o}}} \qquad \left(\text{'' } \quad k\right)$$

$$\text{relative error} = \left(\frac{k/G_m R_o}{1 + \cancel{\frac{k}{G_m R_o}}}\right)$$

$$\approx \underline{k/G_m R_o} = \left(k/A_o\right)$$

reciprocal

Note Title 2/24/2011

Opamp (integrator):

* VCCS & a capacitor
  - use a buffer @ the output
* VCCS has a finite R_o
  - steady state (dc) error in the output
  - opamp has a finite dc gain $G_m R_o$ (A_o)
  - pole moves from the origin to $-\frac{1}{CR_o}$ $\left(-\frac{\omega_u}{A_o}\right)$
* Finite dc loop gain $\frac{A_o}{k}$
  - rel. error in the dc gain $= \left(\frac{k}{A_o}\right)$

Note Title 2/24/2011

Need to implement $k = 10$

$$9.9 < k < 10.1$$

$$9.99 < k < 10.01$$

relative error $= 1\% = \dfrac{k}{A_o}$

$\therefore \dfrac{A_o}{k} = \dfrac{1}{0.01} = 100$

$G_m R_o = A_o = 1000$

$\dfrac{A_o}{k} = \dfrac{1}{0.001} = 1000 \Rightarrow A_o = 10000$

rel. error

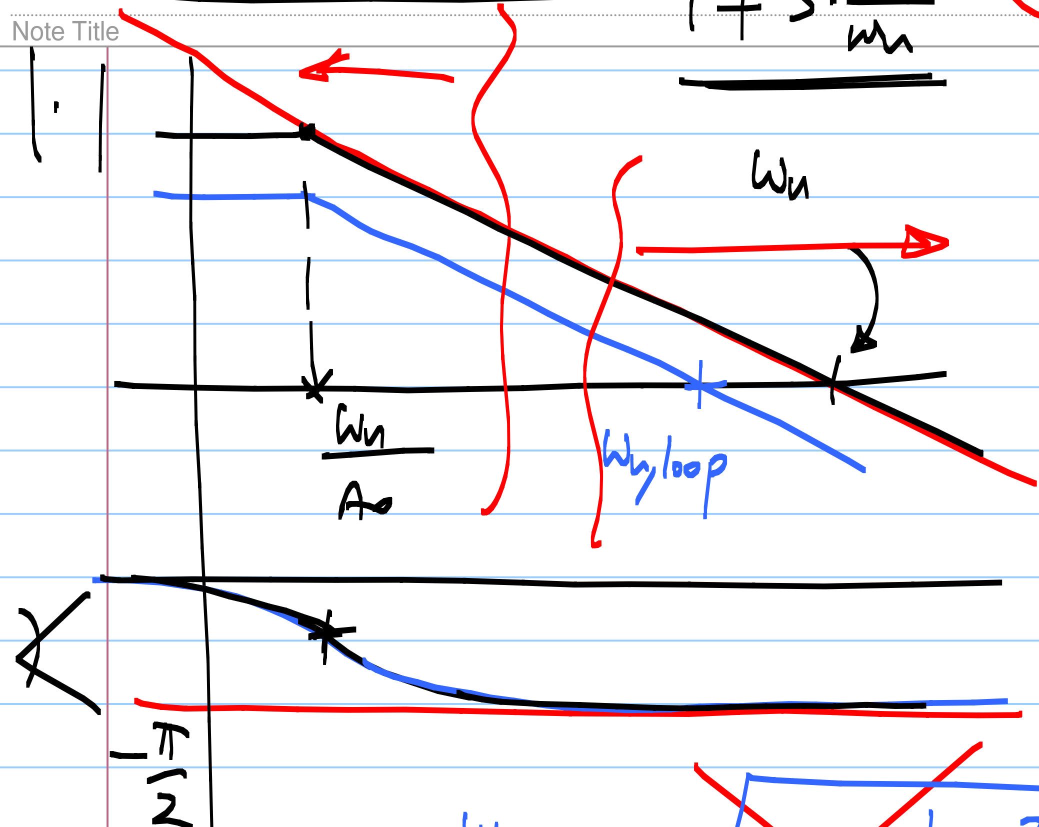
$$\frac{10 - 9.9}{10} = 0.01 \;(1\%)$$

$$\frac{10 - 9.99}{10} = 0.001 = 0.1\%$$

Note Title 2/24/2011

opamp gain: $\dfrac{A_0}{1+s\cdot\dfrac{A_0}{\omega_u}}$ $\quad \dfrac{\omega_u}{s}$

Loop gain: $\dfrac{A_0/k}{1+s\cdot\dfrac{A_0}{\omega_u}}$



$\omega_{u,loop}$: $\left|\dfrac{A_0/k}{1+s\cdot\dfrac{A_0}{\omega_u}}\right| = 1$

$$\left(\frac{A_0}{k}\right)^2 = 1 + \omega^2\left(\frac{A_0^2}{\omega_u^2}\right)$$

$$\omega^2 = \frac{\omega_u^2}{A_0^2}\left(\left(\frac{A_0}{k}\right)^2 - 1\right)$$

$$\omega = \frac{\omega_u}{k}\cdot\sqrt{1-\left(\frac{k}{A_0}\right)^2}$$

$(\omega_{u,loop})$

$$\omega = \omega_u\sqrt{\left(\frac{1}{k}\right)^2-\left(\frac{1}{A_0}\right)^2}$$