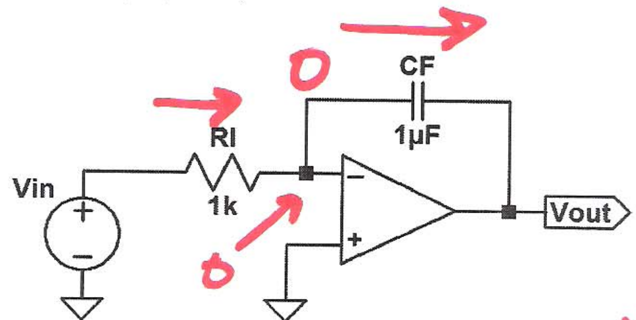
Lecture 19, April 14, 2014

Midterm2 EE 320 Electronics, Spring 2014 Name: ______________________

- Closed notes, open book, **show your work** (hand calculations, including algebra) for credit.
- No scratch paper is allowed.
- Unless otherwise indicated use $KP_N = 120\ \mu A/V^2$, $KP_P = 40\ \mu A/V^2$, $V_{THN} = 800$ mV, $V_{THP} = 900$ mV, W = 10 μm, L = 1 μm, and a $C'_{ox} = 1.75\ fF/\mu m^2$.

1. The input to the integrator seen below is a sinusoid having a peak amplitude of 1 V and a frequency of 318 Hz. Calculate the amplitude and phase shift of the output voltage assuming an ideal op-amp is used. Sketch the circuits' input and output voltage on the same plot in the time domain. (20 points)



SINE(0V 1V 318HZ)

$$\frac{V_{in}}{1K} = \frac{0 - V_{OUT}}{1/j\omega C}$$

$$\frac{V_{OUT}}{V_{IN}} = \frac{-1}{j\omega 10^{-6} \cdot 10^{3}}$$

$$\left|\frac{V_{OUT}}{V_{IN}}\right| = \frac{1}{2\pi \cdot 318 \cdot 10^{-3}}$$

$$\left|\frac{1}{0 + ja}\right| = \frac{1}{\sqrt{0^2 + a^2}}$$

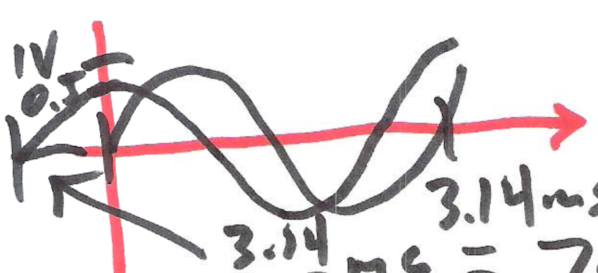
$$\boxed{\frac{V_{OUT}}{V_{IN}} = 0.5}$$

$j \rightarrow 90°$

$$\angle\frac{V_{OUT}}{V_{IN}} = \angle\frac{j}{j} \cdot \frac{-1}{j\omega 10^{-3}} = \frac{j}{2\pi \cdot 318}$$

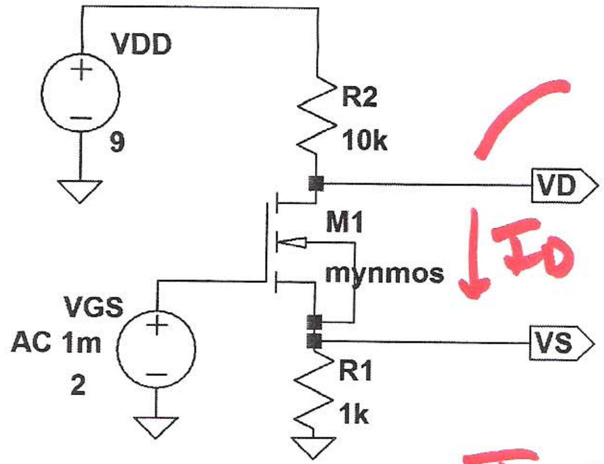
$$\tan^{-1}\frac{2\pi \cdot 318}{0}$$

$$\boxed{\angle\frac{V_{OUT}}{V_{IN}} = +90°}$$



$\frac{3.14}{4}$ ms = .786 ms

2. Calculate the AC and DC voltages on the gate, drain, and source of the NMOS transistor in the following circuit. Show your work for credit. (20 points)



$V_D = 9 - 10K \cdot I_D$

$V_G = 2V$

$V_S = 1K \cdot I_D$

$I_D = \frac{120\mu A/V^2}{2} \cdot \frac{10}{1} \cdot (V_{GS} - .8)^2$

$I_D = 600\mu(2 - I_D \cdot 1K - .8)^2$

$= 600\mu(1.2 - I_D \cdot 1K)^2$

$I_D = 600\mu(1.44 - 2.4K I_D + I_D^2 \cdot 10^6)$

$I_D = 600 I_D^2 - 1.44 I_D + 864\mu$

$0 = I_D^2 + \frac{-2.44}{600} I_D + \frac{864\mu}{600}$

$0 = I_D^2 + (-4.067m) I_D + 1.44\mu$

$$I_D = \frac{4.067m \pm \sqrt{(4.067m)^2 - 4(1.44\mu)\cdot 1}}{2}$$

$$= \frac{4.067m \pm \sqrt{16.5\mu - 5.764}}{2}$$

$$\frac{4.067m \pm 3.28m}{2}$$

$$V_D = 9 - 10K \cdot 393\mu = 5.07V$$

$$V_G = 2V$$

$$V_S = 1K \cdot I_D = 393mV$$

$$I_D = 393\mu$$

$$g_m = KP \cdot \frac{W}{L}(V_{GS} - V_{THN})$$

$$= 120\mu \cdot \frac{10}{1}(2 - .393 - .8)$$

$$g_m = 968\mu A/V$$

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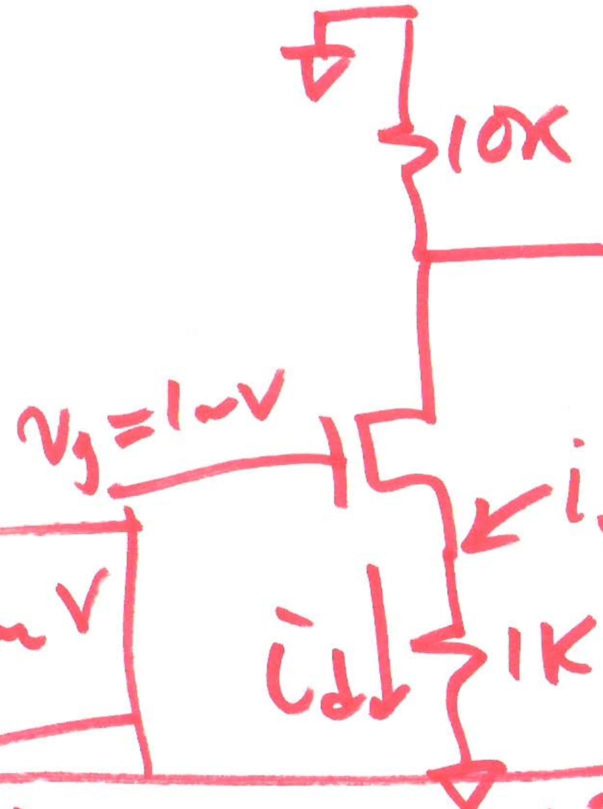
$g_m = 9684\,\mu A/V$



$v_{out} = -i_d \cdot 1M$

$v_g = v_{gs} - i_d \cdot 1K$

$v_{gs} = \frac{i_d}{g_m}$

$v_g = 1mV$

$1mV = i_d\left(\frac{1}{9684} + 1K\right)$

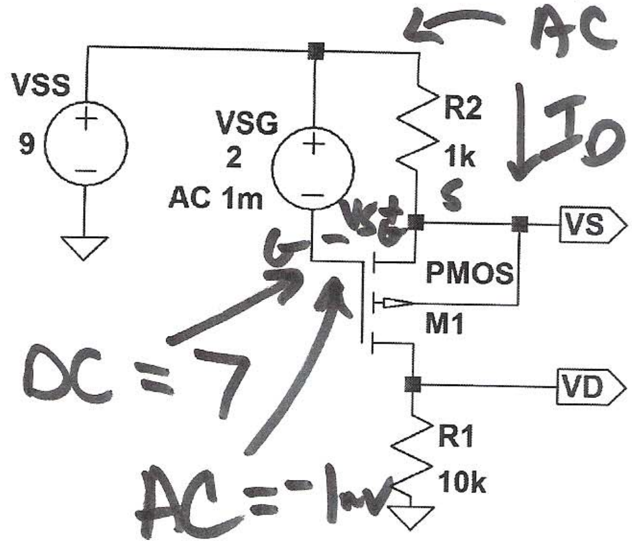
$\frac{1}{9684} \approx 2K$

$i_d \approx 500\,nA$

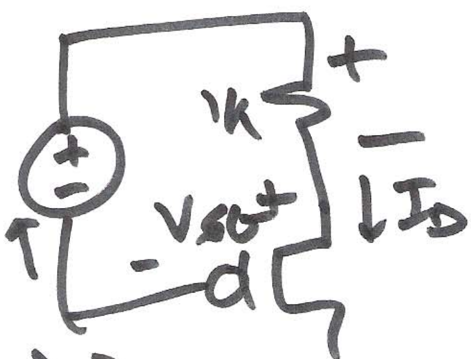
$v_s = i_d \cdot 1K \approx 500\,\mu V$

$v_{out} = -i_d \cdot 10K \approx -5\,mV$

3. Calculate the AC and DC voltages on the gate, drain, and source of the PMOS transistor in the following circuit. Show your work for credit. (20 points)



$$I_D \quad 2 = 1K \cdot I_D + V_{SG}$$



$$I_D = \frac{40m}{2} \cdot \frac{10}{1}\left(V_{SG} - .9\right)^2$$

$$2 = 1K \cdot 200m\left(V_{SG}^2 - 1.8V_{SG} + .81\right) + V_{SG}$$

$$2 = 0.2V_{SG}^2 - .36V_{SG} + .162 + V_{SG}$$

$$0 = 0.2V_{SG}^2 + .64V_{SG} - 1.838$$

$$0 = V_{SG}^2 + 3.2V_{SG} - 9.19$$

$$V_{SG} = \frac{-3.2 \pm \sqrt{10.24 + 36.76}}{2}$$

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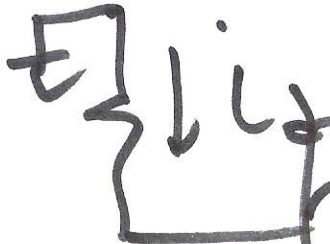


$V_{SG} = \frac{-3.2 \pm 6.85}{2} = \boxed{1.83V}$

$\boxed{v_s = -i_d \cdot 1K = 270\mu}$

$\frac{2 - 1.83}{1K} = I_D = 170\mu A$

$g_m = 40\frac{\mu}{V^2} \cdot \frac{10}{1}(1.83 - .9)V$

$g_m = 400\mu \cdot .93$

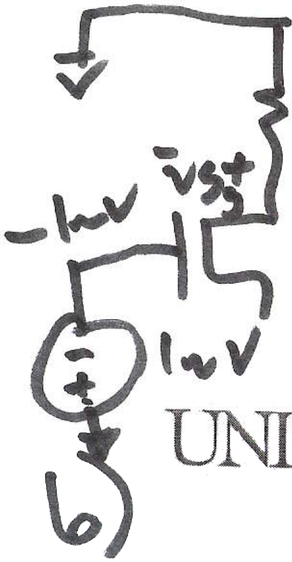
$\boxed{g_m = 372\mu A/V}$

$V_G = 7$

$V_D = I_D \cdot 10K = 1.7V$

$V_S = 9 - 1K \cdot I_D = 8.83V$

$I_D = 170\mu$



$1K i_d + v_{sg} - 1mV = 0$

$1K \cdot i_d + v_{sg} = 1mV$

$v_{sg} = \frac{i_d}{g_m}$

$i_d = \frac{1mV}{1K + \frac{1}{372\mu}} = \boxed{271nA}$

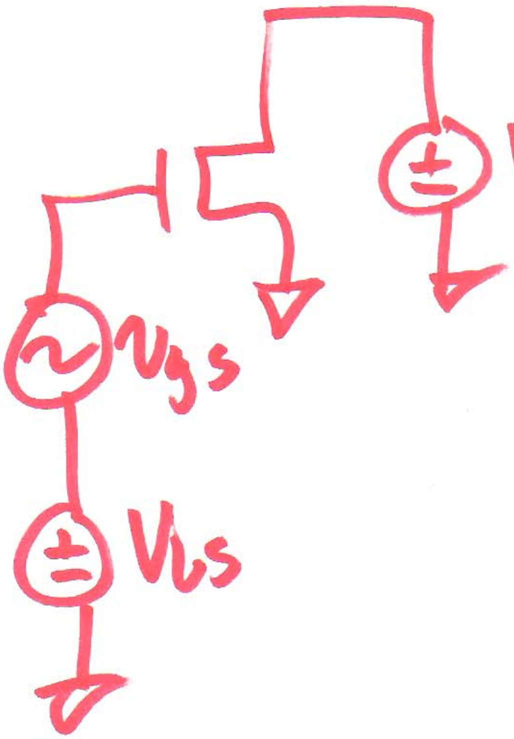
$v_s = -270\mu$

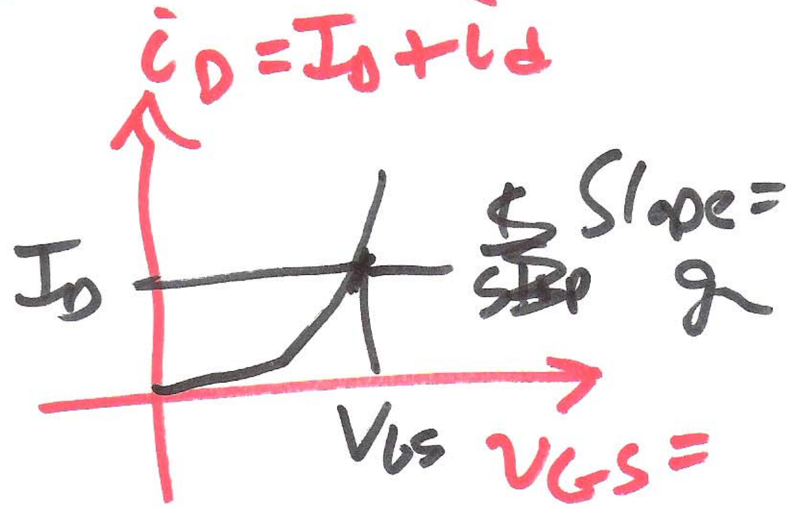
$v_g = -1mV$

$v_d = 2.71mV$

$v_d = 271nA \cdot 1k = \boxed{271\mu V} = 2.71mV$

4. Show, using both figures and equations, how to derive the small-signal transconductance of an NMOS transistor. (20 points)





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

$$g_m = \frac{\partial (I_D + i_d)}{\partial v_{GS}} \Bigg|_{\substack{I_D = CONST \\ V_{GS} = CONST}} = \frac{\partial \frac{KP}{2} \cdot \frac{W}{L}\left(v_{gs} + V_{GS} - V_{THN}\right)^2}{\partial v_{GS}}$$

$V_{GS} >> v_{gs}$

$$g_m = KP \cdot \frac{W}{L} \left(V_{GS} + v_{gs} - V_{THN}\right)$$

$$\boxed{g_m = KP \cdot \frac{W}{2}\left(V_{GS} - V_{THN}\right)}$$

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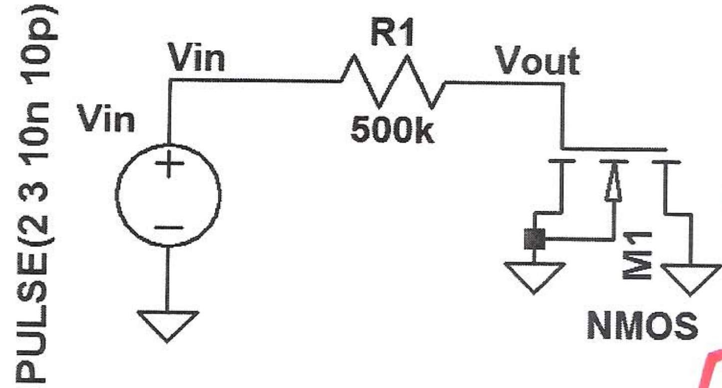
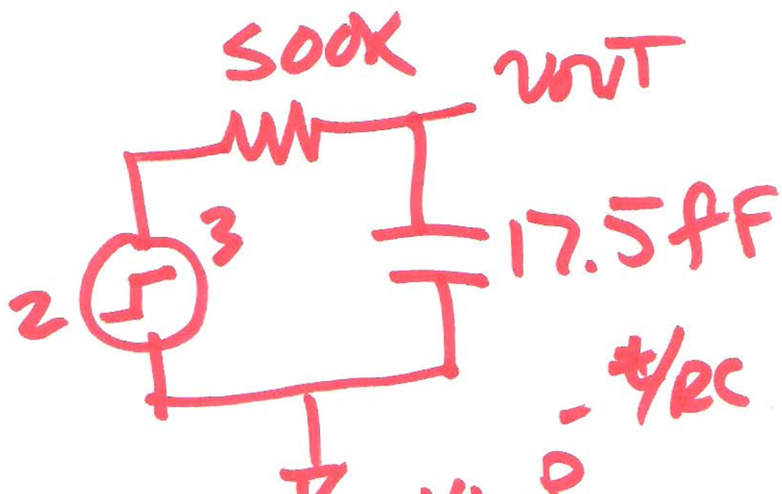
5. Sketch Vin and Vout versus time on the same plot for the following circuit. Note that Vin is a pulse transitioning at 10 ns from 2 to 3 V in 10 ps. (20 points)

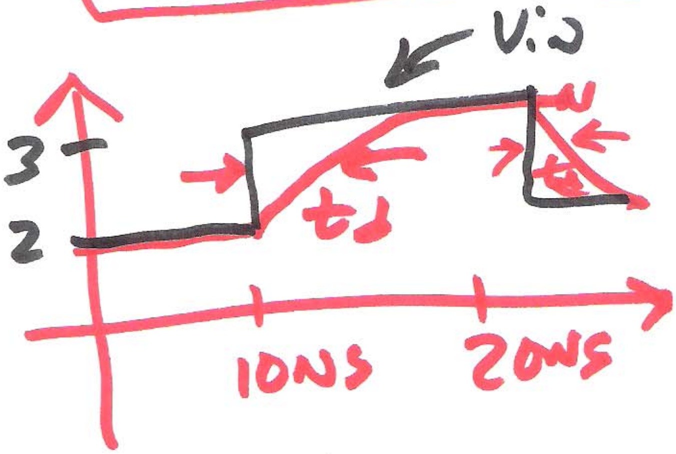


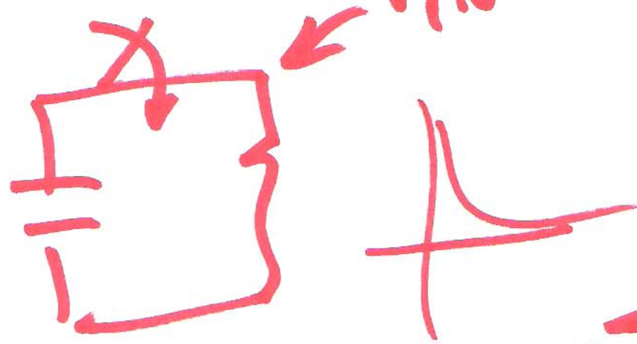
$C_{ox} = 1.75fF \cdot 10 \cdot 1$

$C_{ox} = 17.5fF$



$V_{in} e^{-t/RC}$





$t_d = 0.7RC$

$= 0.7 \cdot 500k \cdot 17.5f$

$t_d = 6.125NS$

$V_{out} = 2 + 1 \cdot (1 - e^{-t/RC})$

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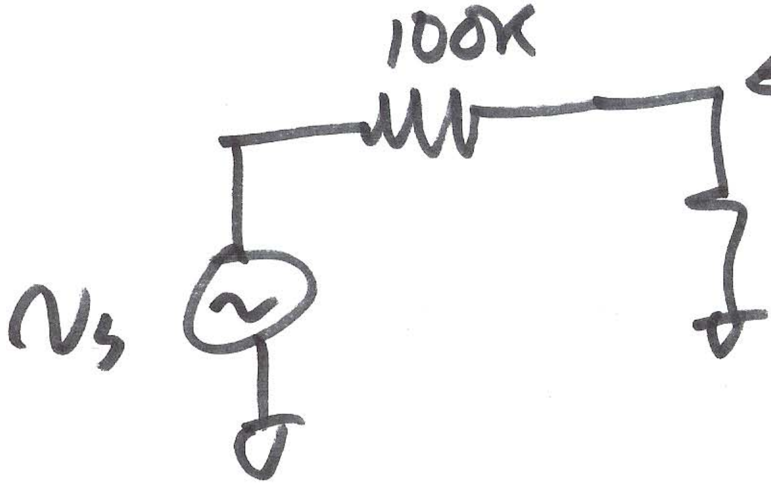
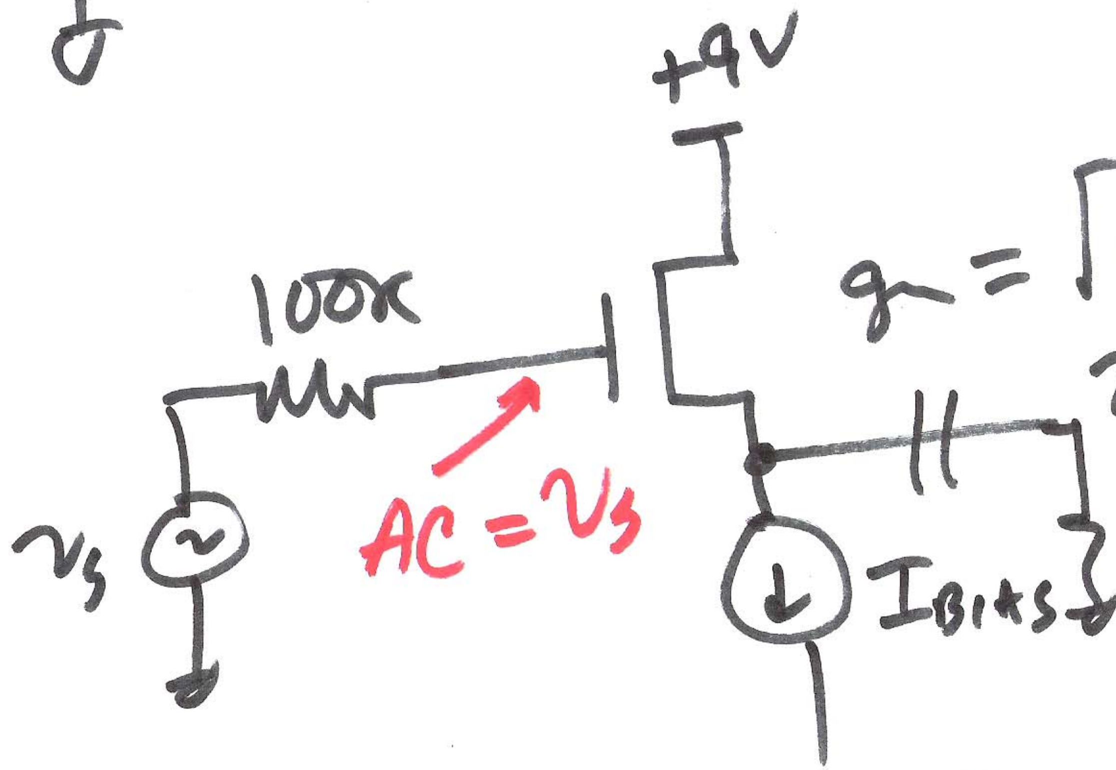


$$v_{inT} = v_s \cdot \frac{1}{101}$$

Source follower



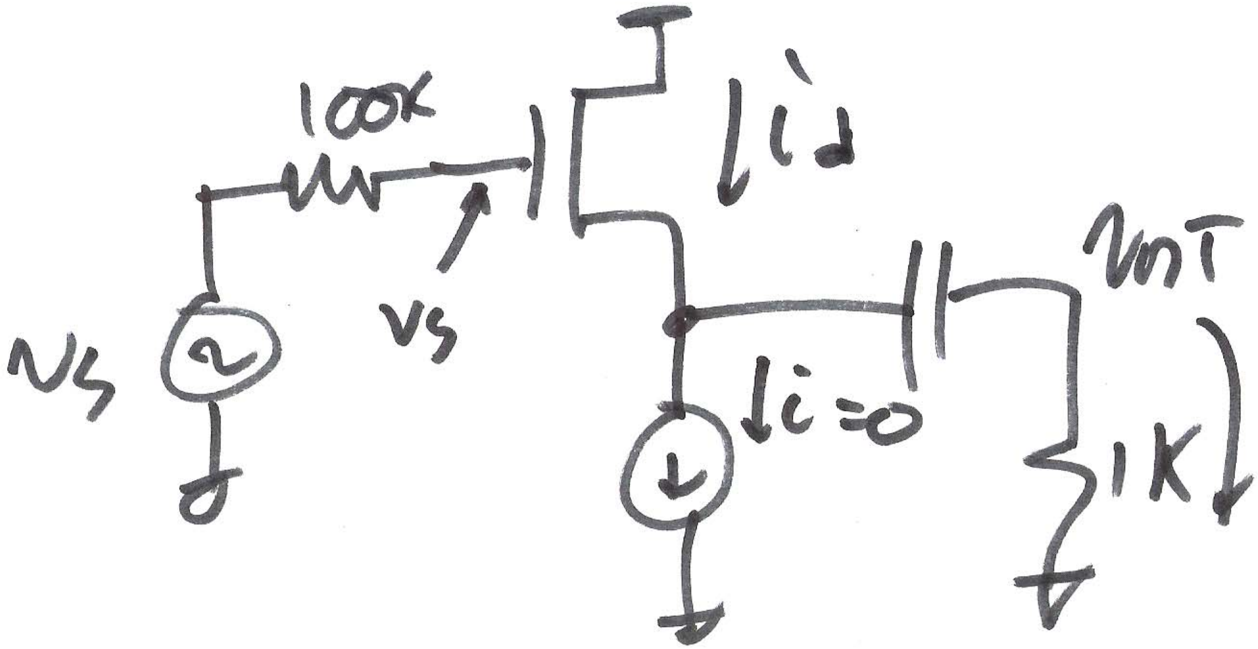
$$g_m = \sqrt{KP \frac{W}{L} I_{BIAS}}$$

$$v_{inT} = v_s$$

$$i_d = g_m v_{sg}$$

$$i_d = 0$$

$$v_{gs} = v_s - v_{inT}$$



$$i_d = \frac{v_{out}}{1K}$$

$$g_m = 1\,mA/V \qquad i_d = \frac{v_{out}}{1K} = g_m \underbrace{(v_s - v_{out})}_{v_{gs}}$$

$$v_{out}\left(\frac{1}{1K} + g_m\right) = g_m v_s$$

$$\frac{v_{out}}{v_s} = \frac{1\,mA/V}{\frac{1\,mA}{V} + \frac{1\,mA}{V}} = \frac{1}{2}$$

$$\frac{v_{out}}{v_s} = \frac{g_m}{\frac{1}{1K} + g_m}$$