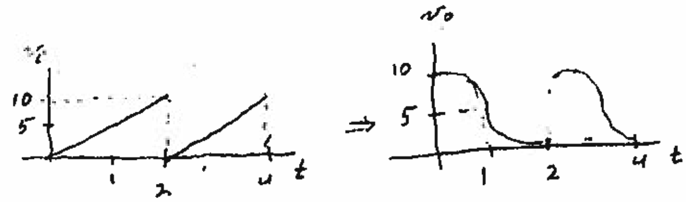
#1. a)



b), @ $t=0$, M_p is ohmic as $V_{SG}=10$, $V_{SD}=0$ while @ $t=1$, $v_i = v_o = 5 \Rightarrow |V_{SG}|-|VTO_p| < |V_{SD}|$ & between $t=0$ & $t=1$, M_p switches from ohmic to saturation, this being when $|V_{SG}|-|VTO_p| = |V_{SD}| \Rightarrow V_{DD}-v_i-|VTO_p| = V_{DD}-v_o$ and so we need v_o some

$$i_{SD_p} = \frac{KP_p}{2}\left(\frac{W}{L}\right)_p (V_{DD}-v_o)^2(1+\lambda[V_{DD}-v_o])$$

$$= i_{DS_n}$$

∴ need regime of M_n at $v_i = v_o - |VTO_p| = v_o - VTO_n$ or $v_i - VTO_n = v_o - 2VTO_n < v_o$

$$\equiv V_{GS_n} - VTO_n < V_{DS_n} \Rightarrow M_n \text{ saturation}$$

$$= \quad i_{DS_n} = \frac{KP_n}{2}\left(\frac{W}{L}\right)_n (v_o - 2VTO_n)^2(1+\lambda v_o)$$

as $\lambda v_o < 10^{-5}$ can ignore, $\Rightarrow i_{SD_p} = i_{DS_n} \Rightarrow (V_{DD}-v_o^2) = (v_o - 2VTO_n)^2$

use $+\sqrt{\ }$ as M_p & M_n are on $\Rightarrow V_{DD}-v_o = v_o - 2VTO_n \Rightarrow 2v_o = V_{DD}+2VTO$

from $v_i = v_o - |VTO_p| \Rightarrow v_i = \frac{(V_{DD}+2VTO)}{2} - VTO = V_{DD}/2$

$$\Rightarrow v_i = 5V$$

#2. as $V_{DS} = V_{GS} > V_{GS} - VTO$ both M_{n_1} & M_{n_2} are in saturation with bias current $I_B \Rightarrow$

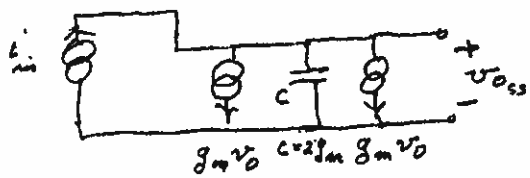
$$I_B = \frac{KP}{2}\cdot\frac{W}{L}(V_{GS}-VTO)^2(1+\lambda V_{DS}) \approx \frac{KP}{2}\frac{W}{L}(V_{GS}-V_{TO})^2$$

$$\Rightarrow \quad V_{GS}-VTO = +\sqrt{\frac{I_B}{\frac{KP}{2}(\frac{W}{L})}} = \sqrt{\frac{6\times10^{-4}}{\frac{3}{2}\times10^{-4}}} = \sqrt{4} = 2V$$

We need $g_m = \frac{\partial i_{DS}}{\partial v_{GS}} = 2\frac{I_B}{(V_{GS}-V_{TO})} = \frac{2\times0.6\times10^{-3}}{2} = 6\times10^{-4}$

Here $g_o = \frac{\partial i_o}{\partial v_{DS}} = \frac{I_B}{\lambda}\cdot\frac{1}{(1+\lambda V_{DS})} \approx 0$

The equivalent circuit for small signal i_{in} is .



By KCL: $i_{in} = 2g_m v_{o_{ss}} + C\frac{dv_{o_{ss}}}{dt} = \left(\frac{dv_{o_{ss}}}{dt} + v_{o_{ss}}\right)2g_m = 2\times10^{-4}\sin t$

$$\Rightarrow \quad \frac{dv_{o_{ss}}}{dt} + v_{o_{ss}} = \frac{2\sin t}{2\times6} = \frac{1}{6}\sin t$$

To solve:

Let $v(t) = A\cos t + B\sin t \Rightarrow \frac{dv}{dt} = -A\sin t + B\cos t$

$\Rightarrow (-A+B)\sin t + (A+B)\cos t = \frac{1}{6}\sin t \Rightarrow$

$A+B=0 \Rightarrow B=-A$ & $-A+B = -2A = \frac{1}{6} \Rightarrow A = -\frac{1}{12}$, $B = \frac{1}{12} = 0.0833$

$\Rightarrow v_{ss}(t) = (-\sin t + \cos t)\frac{1}{12}$

The total $v_o(t)$ includes bias, $V_{o_{bias}} = V_{GS} = 2 + VTO = 3$

$\Rightarrow$

$v_o(t) = 3 + \frac{1}{12}(-\sin t + \cos t)$

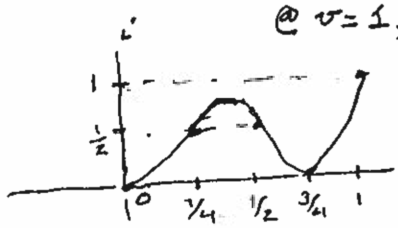
#3.

a). $i = v(1 + \sin 2\pi v)$, an increasing sin with v.

Key values: @ $v = 0$, $i = 0$, @ $v = \frac{1}{4}$, $i = \frac{1}{4}(1+1) = \frac{1}{2}$

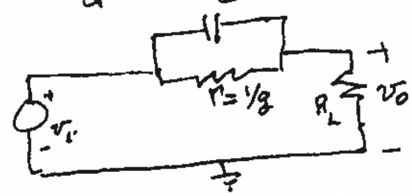
@ $v = \frac{1}{2}$, $i = \frac{1}{2}(1+0) = \frac{1}{2}$, @ $v = \frac{3}{4}$, $i = \frac{3}{4}(1-1) = 0$

@ $v = 1$, $i = 1(1+0) = 1$



b) $g = \left.\frac{\partial i}{\partial v}\right|_Q = (1 + \sin 2\pi v) + v(+2\pi \cos 2\pi v) = 1 + \sin 2\pi v + 2\pi v \cos 2\pi$

c)

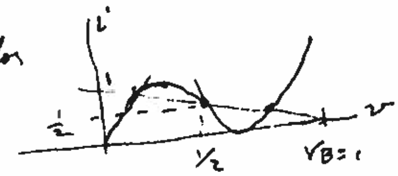


by voltage divider action

$$v_0 = \frac{R_L}{R_L + \frac{1}{g+sC}} v_i = \frac{sC+g}{sC+(g+G_L)} v_i$$

$$\Rightarrow T(s) = \frac{s + g/C}{s + (g+G_L)/C}$$

d) If Q point $v_Q = 1/2 \Rightarrow i_Q = \frac{1}{2} \Rightarrow R_L$ for



$\frac{-1}{R_L} = \text{slope} = \frac{0 - 1\,\text{amp}}{1v - 0v} = -1$

$\Rightarrow R_L = 1\ \Omega$

and $g = 1 + \sin 2\pi \cdot \frac{1}{2} + 2\pi \times \frac{1}{2} \cos 2\pi \frac{1}{2} = 1 - \pi < 0$

$\therefore\ T(s) = \frac{s + (1-\pi)/C}{s + (2-\pi)/C} = \frac{s - 2.14\ldots}{s - 1.14\ldots}$

zero at $s = \pi - 1$
pole at $s = \pi - 2$ $> 0 \Rightarrow$ unstable $\Rightarrow$ will oscillate between equilibria