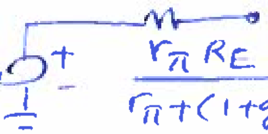
215A Diagnostic Test Solutions

(1) $$\frac{v_{out}}{v_{in}} = -g_m R_L$$

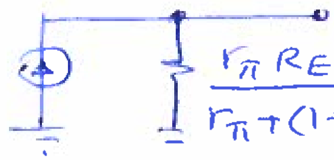
(2) $$\frac{v_{out}}{v_{in}} = \frac{(1+g_m r_\pi)R_E}{r_\pi + (1+g_m r_\pi)R_E}$$

(3) $$\frac{(1+g_m r_\pi)R_E}{r_\pi+(1+g_m r_\pi)R_E} v_{in}$$



$$\frac{r_\pi R_E}{r_\pi+(1+g_m r_\pi)R_E}$$

(4) $$\left(\frac{1}{r_\pi}+g_m\right)v_{in}$$



$$\frac{r_\pi R_E}{r_\pi+(1+g_m r_\pi)R_E}$$

(5) $I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2$ If $V_{TH}\uparrow$; $I_D\downarrow$.

(6) At low V_{DS}, the transistor is in the triode region. In this plot, the device is in the <u>deep</u> triode region because I_D is a linear function of V_D:

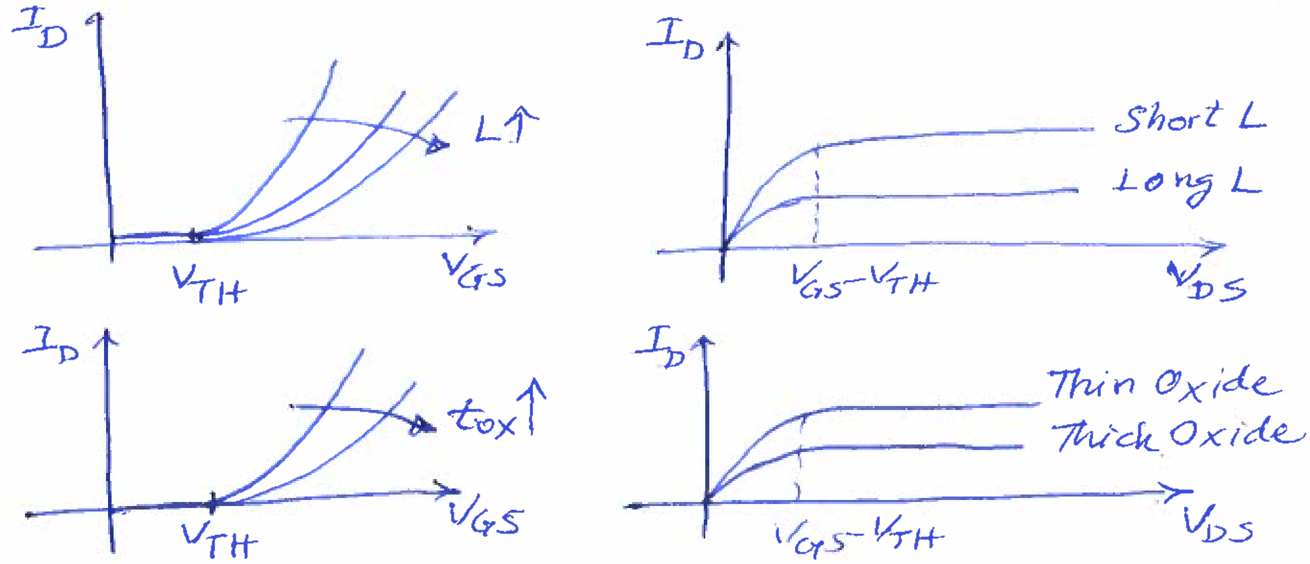
$$I_D = \mu_n C_{ox}\frac{W}{L}\left[(V_{GS}-V_{TH})V_{DS} - \frac{V_{DS}^2}{2}\right]$$

$$\approx \mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})V_{DS}$$

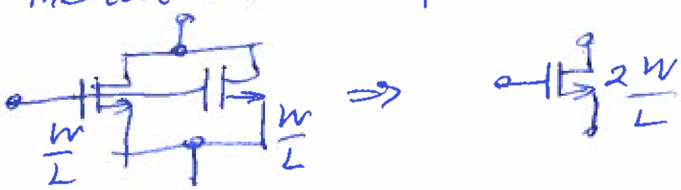
$$\Rightarrow \frac{V_{DS}}{I_D} = R_{on} = \frac{1}{\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})}$$

(7) The device turns on in saturation because V_{GS} begins to cross V_{TH} and hence $V_{GS}-V_{TH}$ is <u>small</u>. That is, $V_{DS} > V_{GS}-V_{TH}$.

(8)



(9) Yes, the two can be lumped into one with twice the width:



(10) $\lambda = 0$ because I_D is independent of V_{DS} in the saturation region.

(11) We guess that M_1 is in saturation and check at the end.

$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(1\,V - 0.4\,V)^2 = 200\,\mu A.$

$V_{DS} = V_{DD} - R_D I_D = 0.8\,V \Rightarrow$ saturated.

If V_{GS} changes by 10 mV, the drain current changes by

$g_m \times (10\,mV) = \mu_n C_{ox}\frac{W}{L}(1\,V - 0.4\,V) \times (10\,mV) = 6.7\,\mu A$, yielding

an output voltage change of $g_m \times (10\,mV) \times R_D = 33\,mV$.

(12) At the edge, $V_{DS} = V_{GS} - V_{TH} = 0.6\,V \Rightarrow V_{DD} - R_D I_D = 0.6\,V$

$\Rightarrow I_D = 0.24\,mA = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(0.6\,V)^2 \Rightarrow \frac{W}{L} = 13.3$

(13) $V_{GS} = V_{DD} - I_D R_D + V_{TH} = V_{DD} + V_{TH} - \frac{R_D}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2.$

$\Rightarrow V_{GS}$ can be found from the quadratic.

(14) $g_m = \sqrt{2\mu_n C_{ox}\frac{W}{L} I_D} \Rightarrow g_m$ doubles. $I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2$

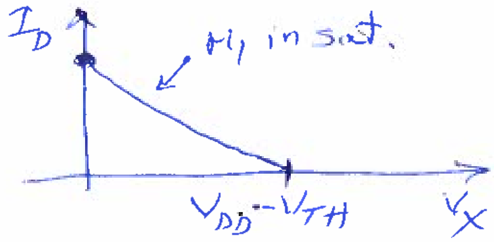
$\Rightarrow V_{GS} - V_{TH}$ const.

(15) $r_o \approx \dfrac{1}{\lambda I_D} = 10\,k\Omega$, $\Delta I_D = \dfrac{\Delta V_{DS}}{r_o} \approx 50\,\mu A$

(16) If L is doubled, λ is halved $\Rightarrow r_o \approx 20\,k\Omega \Rightarrow \Delta I_D \approx 25\,\mu A$.

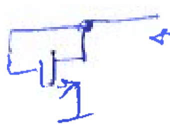
(17) Both are right. When using $g_m = \dfrac{2 I_D}{V_{GS} - V_{TH}}$, we assume that I_D is constant and, inevitably, W/L is variable. For $g_m = \mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH})$, on the other hand, we assume W/L is constant and I_D is variable.

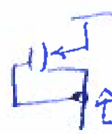
(18)



(19) If $V_{DD} - |V_{TH}| < V_1 < V_{DD} \Rightarrow M_1$ is off.
If V_1 falls below $V_{DD} - |V_{TH}|$, M_1 turns on in saturation.
As V_1 falls to $1V - |V_{TH}|$, M_1 reaches the edge of triode region.

(20)

 $R_X = \dfrac{1}{g_m} \| r_o$

 $R_Y = \dfrac{1}{g_m} \| r_o$

Due to the <u>low</u> resistance, these (diode-connected) devices cannot act as current sources.

(21) General procedure: (1) determine which terminal is the source (the one with a lower potential), (2) see if the device is on ($V_{GS} \lessgtr V_{TH}$), and (3) find the region of operation (triode or sat.)

(a) off (b) off (c) triode (d) sat.

(22) (a) off (b) sat. (c) triode (d) triode (e) triode (f) off (g) sat. (h) sat. (i) sat.

(23) (a) off (b) off (c) sat. (d) off

(24) (a) sat. (b) triode (c) edge of triode (d) triode

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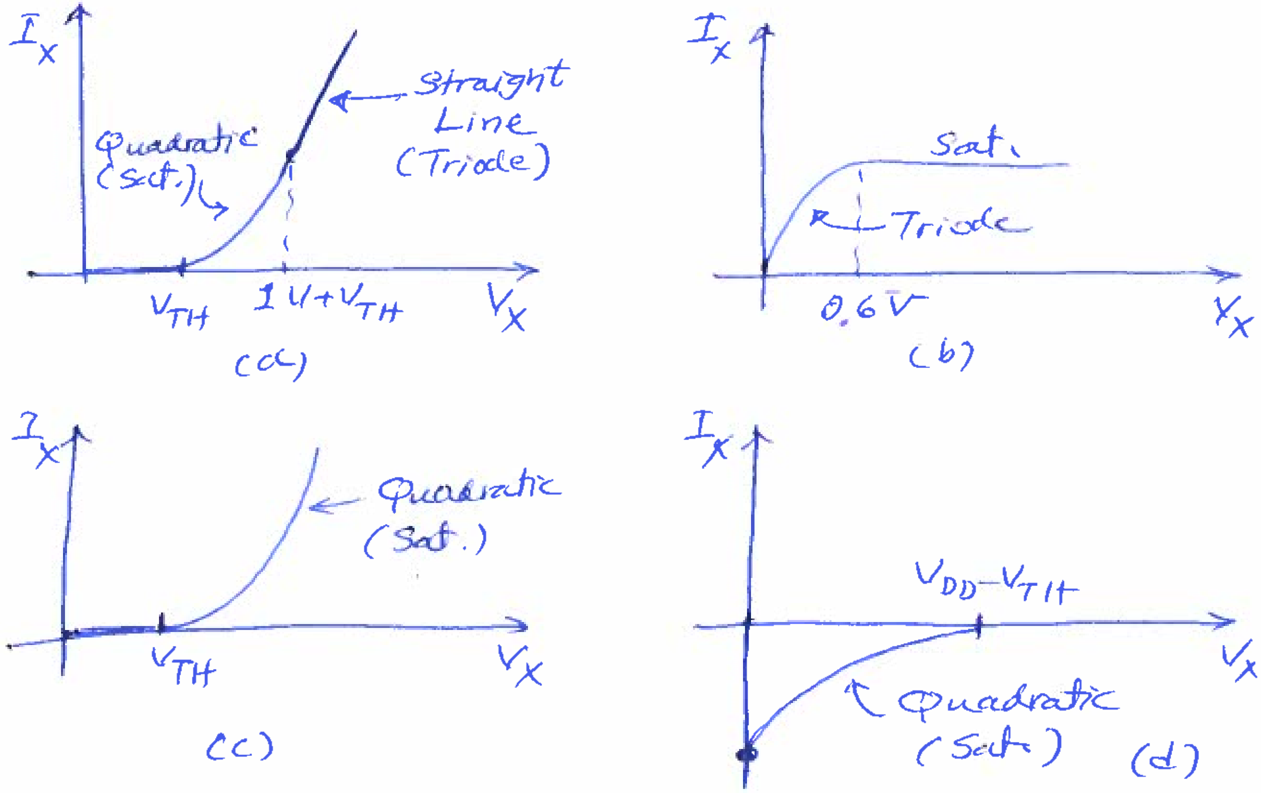

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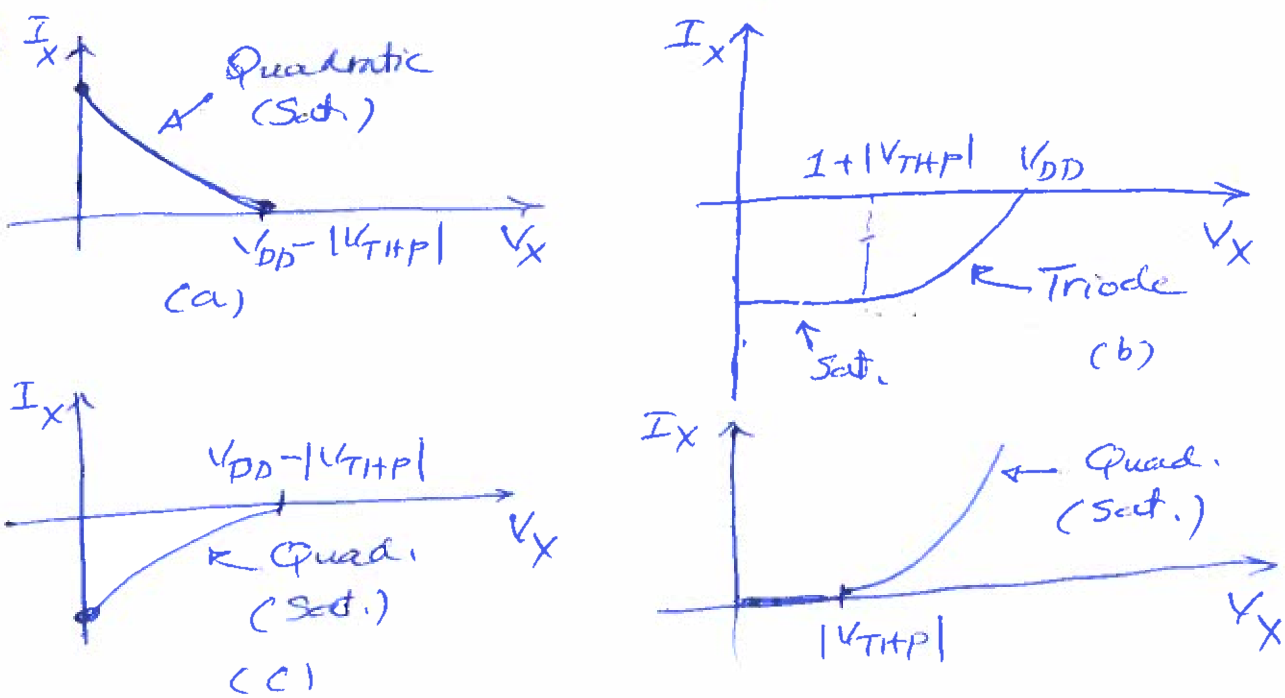

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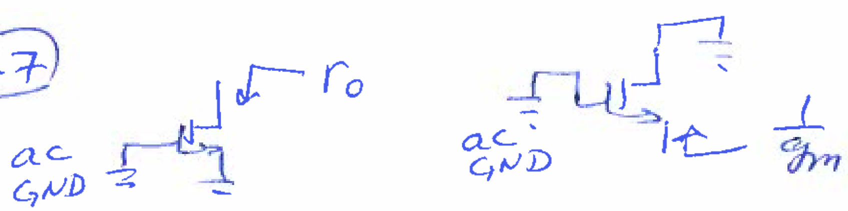

28 The two on the right cannot act as a current source because they exhibit a low output resistance $(\approx \frac{1}{g_m})$.

(29) In a CS stage, the input is applied to the gate and the output is sensed at the drain.

(30) $A_v = -g_m r_o$ if the current source is ideal.

(31) $A_v = -g_{m1}(r_{o1} \| r_{o2})$

(32) $A_v = \dfrac{-R_D}{\frac{1}{g_m} + R_S}$

(33) $A_v = \dfrac{-R_D}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}}$

(34) $R_{out} = (1 + g_m r_o)R_S + r_o$

(35) $R_{out} = (1 + g_{m1} r_{o1}) r_{o2} + r_{o1}$

(36) In a CG stage, the input is applied to the source and the output is sensed at the drain.

(37) $R_{in} = \dfrac{1}{g_m}$, $R_{out} = R_D$

(38) $A_v = -g_{m1}\left(r_{o1} \| r_{o2} \| \frac{1}{g_{m3}} \| r_{o3}\right)$

(39) If $\lambda = 0$ for all transistors, $A_v \to \infty$.
If $r_{o2} < \infty$, $A_v = \dfrac{-r_{o2}}{\frac{1}{g_{m1}} + \frac{1}{g_{m3}}}$

(40) $\dfrac{V_{out2}}{V_{in}} = \dfrac{-\frac{1}{g_{m3}}}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}}$ $\qquad \dfrac{V_{out1}}{V_{in}} = \dfrac{\frac{1}{g_{m2}}}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}}$