EE4C10 Analog Circuit Design Fundamentals

Homework Assignment II

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Problem 1

1. Overdrive voltage, V_{gt}, for:

   (a) M1

$$I_{D1} = \frac{\mu_n C_{OX}}{2}(\frac{W}{L})_1(V_{GS_1} - V_{TH_1})^2(1 + \lambda_1 V_{DS_1})$$
$$I_{D1} \approx \frac{\mu_n C_{OX}}{2}(\frac{W}{L})_1(V_{gt_1})^2$$
$$V_{gt_1} \approx \sqrt{\frac{2I_{D_1}}{\mu_n C_{OX}}(\frac{L}{W})_1}$$

$$V_{gt_1} \approx 109.11mV$$

   (b) M2

$$V_{gt_2} \approx \sqrt{\frac{2I_{D_2}}{\mu_p C_{OX}}(\frac{L}{W})_2}$$

$$V_{gt_2} \approx 377.96mV$$

2. Small-signal gain

$$g_{m1}V_{in} = \frac{-V_{out}}{r_{o1}//r_{o2}}$$
$$\frac{V_{out}}{V_{in}} = -g_{m1}(r_{o1}//r_{o2})$$

$$g_{m1} = \mu_n C_{OX}(\frac{W}{L})_1 V_{gt_1}$$
$$= 4.582mS$$

$$r_{o1} = \frac{1}{I_{D1}\lambda_n}$$
$$= 20k\Omega$$

$$r_{o2} = \frac{1}{I_{D2}\lambda_p}$$
$$= 40k\Omega$$

$$\frac{V_{out}}{V_{in}} \approx -61.09$$

3. V_{out} output swing
   For M_1 to be in saturation,
   $$V_{DS1} \geq V_{gt1}$$
   $$V_{out} \geq 0.109V$$
   For M_2 to be in saturation,
   $$V_{DS2} \geq V_{gt2}$$
   $$V_{DD} - V_{out} \geq 0.377V$$
   $$V_{out} \leq 3.3V - 0.377V$$
   $$V_{out} \leq 2.923V$$
   Swing of V_{out},
   $$0.109V < V_{out} < 2.923V$$

   $$V_{out,pp} = 2.923V - 0.109V$$
   $$= 2.814V$$

4.

Problem 2

1. For M1 to be 100mV from triode,
   $$V_{DS1} = V_{GS1} - V_{TH,N} + 100mV$$
   $$X = V_{in} - V_{TH,N} + 100mV$$
   V_{in} for M1 to be in saturation with I_{D1} of 0.35 mA,
   $$I_{D1} = \frac{\mu_n C_{OX}}{2}(\frac{W}{L})_1(V_{GS1} - V_{TH,N})^2$$
   $$I_{D1} = \frac{\mu_n C_{OX}}{2}(\frac{W}{L})_1(V_{in} - V_{TH,N})^2$$
   $$V_{in} = \sqrt{\frac{2I_{D1}}{\mu_n C_{OX}}(\frac{L}{W})_1} + V_{TH,N}$$

   $$X = \sqrt{\frac{2I_{D1}}{\mu_n C_{OX}}(\frac{L}{W})_1} + 100mV$$
   $$\approx 0.253V$$

V_b for M2 to be in saturation with I_{D2} of 0.35 mA,

$$\begin{aligned}
I_{D2} &= \frac{\mu_n C_{OX}}{2}(\frac{W}{L})_2(V_{GS2} - V_{TH,N})^2 \\
I_{D2} &= \frac{\mu_n C_{OX}}{2}(\frac{W}{L})_2(V_b - X - V_{TH,N})^2 \\
V_b &= \sqrt{\frac{2I_{D2}}{\mu_n C_{OX}}(\frac{L}{W})_2} + X + V_{TH,N} \\
&\approx 0.906V
\end{aligned}$$

2. Small-signal gain

$$G_m = \frac{-g_{m1}}{1 + \frac{r_{o2}}{r_{o1}}}$$

$$R_{out} = (r_{o1} + r_{o2})//R_d$$

Small-signal gain,

$$\begin{aligned}
\frac{V_{out}}{V_{in}} &= G_m R_{out} \\
&= \frac{-g_{m1} r_{o1} R_d}{r_{o1} + r_{o2} + R_d}
\end{aligned}$$

$$\begin{aligned}
g_{m1} &= \mu_n C_{OX}(\frac{W}{L})_1(V_{GS1} - V_{TH,N})(1 + \lambda_n V_{DS1}) \\
&= \mu_n C_{OX}(\frac{W}{L})_1(V_{in} - V_{TH,N})(1 + \lambda_n X) \\
&= 4.698mS
\end{aligned}$$

$$\begin{aligned}
r_{o1} &= \frac{1}{I_{D1}\lambda_n} \\
&= 28.571k\Omega
\end{aligned}$$

$$\begin{aligned}
r_{o2} &= \frac{1}{I_{D2}\lambda_p} \\
&= 28.571k\Omega
\end{aligned}$$

$$\frac{V_{out}}{V_{in}} \approx -10.90$$

3. Maximum output swing,