EECS 140 Final Exam

NAME

SOLUTIONS

Fall 1996

\[ L_n = L_p = 10^{-4} \text{ H} \]
\[ g_n = g_p = 0 \]
\[ \lambda_n = \lambda_p = 0.01 \]
\[ V_{Tn} = V_{Tp} = 1 \text{ V} \]

2.6 Volts

\[ W/L = 100 \]

a) \[ V_{Min} = 1.7 \text{ Volts} \]
\[ V_{Max} = 3.7 \text{ Volts} \]

b) \[ 600 \text{ pf} \]

b) \[ 10 \text{ Volts/Sec} \]

b) \[ 90 \text{ Degrees} \]

9) \[ \frac{40}{\text{Rad/Sec}} \]

10) \[ \frac{20}{\text{Volts/Sec}} \]

b) \[ 90 \text{ Degrees} \]

4) \[ R = 600 \Omega \]

5) \[ C = 1000 \text{ pf} \]

6) \[ I_{Ref} = 25 \text{ mA} \]

7) \[ a) \frac{9.7}{k} \text{ Rad/Sec} \]
\[ b) 9.4 \text{ M Rad/Sec} \]

8) \[ a) \frac{710}{V_{in}} \]
\[ b) \frac{710}{I_{in}} \]
\[ c) R_{in} = 1 \Omega \]
1) All transistors have W/L=50, unless otherwise indicated.

a) What is maximum value at $v_{out}$ in the positive direction which still has all transistors in saturation?

$$v_o = 5 - (V_T + 2V_{d_{SAT}}) = 3.64$$

b) Choose the W/L of M1 to maximize the swing at $v_{out}$ in the negative direction which has all transistors in saturation.

$$V_T + V_{d_{SAT,M1}} = V_T + 2V_{d_{SAT}}$$

$$V_{d_{SAT,M1}} = 0.36V$$

$$\left(\frac{2 \times 40 \times 10^{-6}}{10^{-4} \times \frac{W}{L}}\right)^{1/2} = 0.36$$

$$\frac{W}{L} = 6.2$$
2) What is the range of DC voltages at $V_{out}$ over which the gain is maximum?

$V_{Vin} = V_B - V_T = 1.72\, \text{V}$
$V_{Max} = V_B + V_T = 3.72\, \text{V}$

5) What is that maximum gain? 10$^6$

$R_{o} = \frac{g_m}{2}$

$A_V = g_m R_{o} = \frac{(g_m R_{o})^2}{2} = \frac{2 A_{V_{max}} \mu_0 l D s}{2}$

$= 10^6$
(a) Assume $V_{in}$ is set so the output is at 0 volts. What are the $W/L$'s of $M4$ and $M2$ so that the output resistance, $R_{out}$ = 500Ω.

\[ R_{out} = \frac{V_{out}}{I_{ds}} = 500Ω \]

\[ I_{ds} = 10^{-4} A = 100μA \]

\[ (W/L)_{M1} = 2 \cdot \frac{W}{L} \]

\[ I_{ds} = \frac{2 (V_{gs} - V_{th})}{L} \]

\[ V_{th} = \frac{10^{-3} V}{\frac{W}{L}} \]

\[ V_{th} = 2 \cdot \frac{I_{ds}}{L} \]

\[ V_{in} - 2.93V \leq V_{dsat} \leq V_{in} + 2.93V \]

(b) Assume $W/L$ of $M1$ & $M2 = 50$, then what are the maximum positive and minimum negative voltages (devices can go into linear region) if $V_{in}$ goes between +5V to -5V.

\[ V_{min} = 2.93V \]

\[ V_{max} = 2.93V \]

\[ 5 - V_{in} - V_{dsat} = V_{out} \]

\[ V_{out} = 4 - \left( \frac{2V_{out}}{10^{-3}V} \right) \]

\[ V_{out} = 4 - V_{out} \cdot 0.63 \]

\[ V_{out} \approx 2.93 \]
4) \[ \text{All } V_{ES} = 100 \]

The emitter of Q\(_2\) is 10 times larger than the emitter of Q\(_1\).

What is the value of \( V_{out} = 100 \mu A \) good?

\[ V_t = \frac{V_{out}}{1 + \frac{R}{2Q_{on}}} \]

\[ V_t = ln(10) \frac{I}{R} \]

\[ \frac{V_t}{2} = 0.026 \ln(10) \frac{I}{R} \]

\[ 1 = \frac{I}{10^{-4}} \]

\[ = 6000 \Omega \]
All \( W/L \)'s = 50

(5)

100\( \mu \)A

\( u_{in} \)

\( C_{c} \)

\( U_{out} \)

\[ g_{m} = \left(2 \cdot 10^{-4}, 50 \cdot 10^{-4}\right)^{1/2} \]

\[ f_{0} = 10^{6} \quad = 10^{-3} \]

\[ f_{0} = 10^{6} \]

\[ g_{m} = \frac{1}{g_{mF0C}} \]

\[ C_{c} = \frac{g_{m}}{10^{6}} = 10^{-9} \text{ f} \]

**What is the capacitor, \( C_c \), which will give \( W_{unity} \) at \( f_{0} \) sec?**

\( C_{c} \quad \text{1000 pf} \)

\( W_{unity} = \text{open loop unity gain frequency} \)

\( a_{c} (g_{mF0})^2 \quad \text{10}\text{6} \)

\[ W_{0} = \frac{\left(g_{mF0}\right)^2}{10^{6}} \frac{1}{5(g_{mF0C})} \]
What is the current, $I_{\text{ref}}$, which gives a common mode rejection ratio (CMRR) of 60 dB?

$$\text{CMRR} = \frac{A_{dm}}{A_{cm}} = \frac{\frac{g_m I_{04}}{2}}{\frac{g_m I_{04}}{1 + 2 g_m R_0}}$$

$$R_0 = \frac{R_{04}}{2}$$

$$= \frac{1 + g_m R_{04}}{2} \approx \frac{g_m R_{04}}{2} = 10^3$$

$$\left(2 \frac{L}{W} I_{\text{DS}}\right)^{1/2} \frac{I_{\text{DS}}}{I_{\text{DS}_L}} = 2 \times 10^3$$

$$I_{\text{DS}} = 25 \mu A$$
Problem 7)

\[ \text{5 volts} \]

\[ V_{\text{in}} \rightarrow \text{M1} \rightarrow \text{M2} \rightarrow \text{M3} \rightarrow \text{M4} \rightarrow \text{M5} \rightarrow \text{M6} \rightarrow \text{M7} \rightarrow \text{M8} \rightarrow \text{M9} \]

\[ I_{\text{ref}} = 100 \mu A \]

\[ R_0 = 10^6 \]

\[ V_{\text{out}} \]

\[ \text{All W/L's=50 except for M6} \]

\[ \text{1M}\Omega \]

\[ 10\text{pf} \]

\[ -5\text{ volts} \]

\( e = V_{\text{in}} \)

\( V_{\text{out}} \)

\( e \)

\( V_{\text{in}} \)

\( V_{\text{out}} \)

\( 10\text{pf} \)

\( 1\text{M}\Omega \)

\( 1\text{M}\Omega \)

\( W/L=100 \)

\[ a) \text{ Where is the first pole of } V_{\text{out}}/V_{\text{in}}? \]

\[ \text{Node A} \]

\[ C_A = \left( C_{gs5} + C_{gd5} \frac{g_{m5}^2}{2} + 20\text{pf} \right) \]

\[ = 20.6 \text{pf} \]

\[ \omega_1 = \frac{1}{R_0} C_A = \frac{1}{10^6 \cdot 20.6 \text{pf}} = 97 \times 10^3 \]

\[ b) \text{ Where is the second pole?} \]

\[ \text{Node B} \]

\[ \omega_2 = \frac{1}{R_0} \left( C_{gs2} + C_{gb2} + C_{gd2} \right) = \frac{1}{10^6 \cdot (106 \text{ff})} \]

\[ = 9.4 \text{ Meq/s} \]

\[ \text{Kra0} \text{/sec} \]

\[ 9.4 \text{ Meq/s} \]

\[ \text{/sec} \]
Analyze this circuit considering M1 & M3 as the providing feedback and M2 & M4 as the basic amplifier.

a) What kind of feedback is this? Shunt

b) What is the closed loop gain, \( V_{out} \over V_{in} \)?

c) What is \( R_{in} \)?

\[ g_m = \frac{2 \times 10^{-4} \cdot 100 \cdot 100 \mu A}{g_m} = 1.4 \times 10^{-3} \]

\[ R_{in} = \frac{1}{g_m} = \frac{1}{g_m} \over g_m \frac{f_0}{2} = 2 \over 2 + f_0 \frac{2 \times 10^6}{10^6} = 1 \Omega \]
A) An op amp has the following poles and zeros:

\[
\begin{align*}
W_{P1} &= 10^7 \text{ rad/sec} \\
W_{P2} &= 10^8 \text{ rad/sec} \\
W_{P3} &= 10^9 \text{ rad/sec} \\
W_c &= 2
\end{align*}
\]

And the open loop gain \( G_0 = 10^5 \)

If the op amp is connected as follows:

![Op Amp Diagram]

At what frequency should a compensation pole be added so that the phase margin is 45°? We have \( \frac{\pi}{2} \text{ rad/sec} = 410 \text{ rad/sec} \)

\[
T = 0.5 = 10^5 \cdot (1) = 10^4
\]

Each pole at 10^9 should be 22.5°.

Contribution from \(-1 \frac{W}{10^7} = 22.5°\)

\[
W = 10^7 \tan 22.5° = 4.1 \times 10^6
\]
Problem 10)

\[ V_{\text{out}} = \frac{20}{\Delta t} = \frac{2 \times 10^{-4}}{10^{-11}} = 20 \, \text{V/\mu s} \]

a) What is the minimum slew rate of this circuit?

\[ 20 \, \frac{\text{V}}{\text{\mu s}} \]

b) What is the phase margin of this circuit?

\[ 90^\circ \]

\[ R_{0,\text{f}} = R_0 \left( g_{m1} R_2 \right) \parallel R_0 \left( g_{m2} R_2 \right) \]

\[ 210 \cdot a_0 = \frac{1}{1.2 \times 10^8} \]

\[ w_d = 47 \times 10^7 \, \text{sec}^{-1} \]

\[ w_{0N} \approx \frac{1}{g_m (12.4 f)} \]

\[ w_{0N} = 10^9 \]

\[ R_{0,\text{f}} = 1.4 \times 10^3 \times 4.7 \times 10^9 \]

\[ \approx 6.8 \times 10^5 \]