Texas A&M University
Department of Electrical and Computer Engineering

ECEN 326 – Electronic Circuits

Fall 2017

Exam #3

Instructor: Sam Palermo

- Please write your name in the space provided below
- Please verify that there are 6 pages in your exam
- You may use one double-sided page of notes and equations for the exam
- Good Luck!

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Name:  

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Problem 1 (35 points)
For the circuit shown below, assume that all transistors are operating in the active region and that \( V_A = \infty \).

a. What type of feedback is present in the circuit?

b. Give expressions for the open-loop gain \((V_{out}/V_{in})\), input resistance, and output resistance. Make sure to include feedback loading effects.

c. What is the feedback factor, \( K \)?

d. Give expressions for the closed-loop gain \((V_{out}/V_{in})\), input resistance, and output resistance.

\[
\begin{align*}
A_{CL} &= \frac{A_{OL}}{1 + KA_{OL}} \\
R_{in,CL} &= \frac{R_{in,OL}(1 + KA_{OL})}{R_{out,OL}} \\
R_{out,CL} &= \frac{R_{out,OL}}{1 + KA_{OL}}
\end{align*}
\]
Problem 2 (35 points)
a. Give the transfer function (w/ numbers) of the single-stage amplifier shown below. Assume the transistor operates in saturation with $g_m=1\text{mA/V}$ and $\lambda=0$. Only consider the explicitly drawn capacitors, i.e. no transistor capacitors.

$$A_{dc} = -g_m R_C = -(1\text{mA})(10\text{kΩ}) = -10 \frac{\text{V}}{\text{V}}$$

$$|W_R| = \frac{1}{R_C} = \frac{1}{(0\text{kΩ})(1\text{μF})} = 100\text{M rad/s}$$

$$H_1(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{-10}{1 + \frac{s}{10^8}}$$

b. Now this single-stage amplifier is used in a 4-stage amplifier. Again, assume all transistors operate in saturation with $g_m=1\text{mA/V}$ and $\lambda=0$ and only consider the explicitly drawn capacitors, i.e no transistor capacitors. Give the 4-stage amplifier transfer function and the frequency at which the amplifier’s phase equals $-180^\circ$ ($\omega_{px}$).

$$H(s) = \left(H_1(s)\right)^4 = \frac{10^4}{\left(1 + \frac{s}{10^8}\right)^4}$$

$$\angle H(j\omega) = -4 + \tan^{-1}\left(\frac{\omega_{px}}{10^8}\right) = -180^\circ$$

$$H(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{10^4}{\left(1 + \frac{s}{10^8}\right)^4}$$

$$\omega_{px} = 100\text{M rad/s}$$
c. Now this 4-stage amplifier is placed in feedback with $K=0.1$. Give the frequency at which the feedback system $|KH(s)|=1$ ($\omega_{X}$). Is the system stable?

\[
|KH(s)| = 1 \\
\frac{(0.1 \times 10^4)}{1 + \frac{\omega_X^2}{10^6}} = 1 \\
\left(1 + \frac{\omega_X^2}{10^6}\right)^2 = 10 \\
1 + \frac{\omega_X^2}{10^6} = 10^{0.5} \\
\omega_X = 10^8 \times 10^{0.5} - 1 = 553 M \text{ rad/s}
\]

System Stable? (Yes or No) \(\text{No} (\omega_{X} > \omega_{P})\)

d. Now only the second stage is modified with a large compensation capacitor $C_C$ to establish a single dominant pole system. Assume that this dominant pole contributes $-90^\circ$ at the new $\omega_{X}$. Considering the other poles in the system, what is the capacitor value necessary for the feedback system ($KH$) to have a phase margin of $45^\circ$?

For $PM = 45^\circ$

\[\angle KH(j\omega_{X_{new}}) = -90^\circ - 3 \tan^{-1}\left(\frac{\omega_{X_{new}}}{10^8}\right) = -135^\circ\]

With one dominant pole

\[\angle KH(j\omega_{X_{new}}) = -90^\circ - 3 \tan^{-1}\left(\frac{\omega_{X_{new}}}{10^8}\right) = -135^\circ\]

\[+\tan^{-1}\left(\frac{\omega_{X_{new}}}{10^8}\right) = 15^\circ\]

\[\omega_{X_{new}} = 26.8 M \text{ rad/s}\]

\[\omega_{P_2} = \frac{\omega_{X_{new}}}{|KH|} = \frac{26.8 \text{ rad/s}}{10^3} = 26.8 \text{ rad/s}\]

\[C_C(\text{PM}=45^\circ) = 3.73 \text{ nF}\]

\[P_2 = \frac{1}{R_C C_C}\]

\[C_C = \frac{1}{(10k\Omega)(26.8 \text{ rad/s})} = 3.73 \text{ nF}\]
Problem 3 (30 points)
The transistors used in the circuit below have a maximum average power rating of 2W.  

a. What is the largest power that the circuit can deliver to a $16\Omega$ load?

The maximum average power of the transistors is

$$P_{Q1\text{,max}} = \frac{V_{cc}^2}{\pi^2 R_L}$$

with

$$V_P = \frac{2V_{cc}}{\pi}$$

$$\Rightarrow V_{cc} = \frac{\pi V_P}{2}$$

$$P_{Q1\text{,max}} = \left(\frac{\pi V_P}{2}\right)^2 = \frac{V_P^2}{2} \Rightarrow V_P = 2\sqrt{P_{Q1} R_L} = 2\sqrt{2W(16\Omega) = 11.3V}$$

$$P_{RL\text{,max}} = \frac{V_P^2}{2R_L} = 2P_{Q1} = 2(2W) = 4W$$

b. When the circuit is delivering this maximum power to the load, determine the necessary $I_1$ to support the required output swing with minimal distortion. Assume both transistors have $\beta=40$.

During the max positive amplitude, $I_1$ must support the necessary base current.

$$I_1 = \frac{I_E}{\beta + 1} = \frac{V_P}{R_L(\beta + 1)} = \frac{11.3V}{16(40 + 1)} = 17.2mA$$

$$I_1 = 17.2mA$$

$P_{RL\text{,max}} = 4W$