# 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!

| Problem | Score | Max Score |
|---|---|---|
| 1 | | 35 |
| 2 | | 35 |
| 3 | | 30 |
| **Total** | | **100** |

Name: SAM PALERMO

UIN:

Problem 1 (35 points)

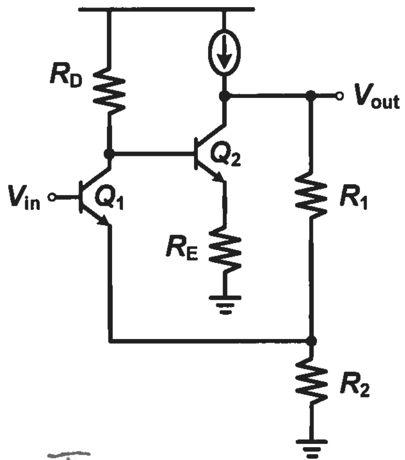
For the circuit shown below, assume that all transistors are operating in the active region and that $V_A=\infty$.

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.

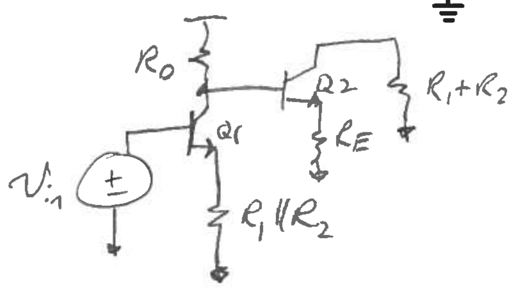
c. What is the feedback factor, $K$?

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




a. Voltage (Sensing) - Voltage (Return) Feedback or Series (FB) - Shunt (Sensing)

b. Breaking Loop



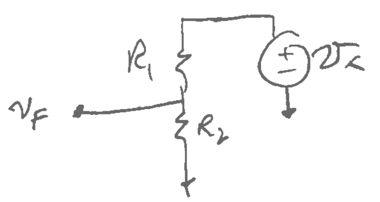

$$A_{OL} = \left(\frac{-\alpha\left(R_D \| \left(r_{\pi_2} + (\beta+1)R_E\right)\right)}{r_{e_1} + R_1 \| R_2}\right)\left(\frac{-\alpha\left(R_1+R_2\right)}{r_{e2} + R_E}\right)$$

$$\simeq \left(\frac{g_{m_1}\left(R_D \| \left(r_{\pi_2} + (\beta+1)R_E\right)\right)}{1 + g_{m_1}(R_1 \| R_2)}\right)\left(\frac{g_{m2}\left(R_1+R_2\right)}{1 + g_{m2} R_E}\right)$$

$$R_{in,OL} = r_{\pi_1} + (\beta+1)(R_1 \| R_2)$$

$$R_{out,OL} = R_1 + R_2$$

For K:




c. $$K = \frac{R_2}{R_1+R_2}$$

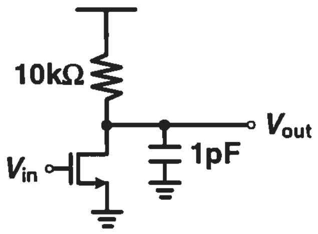
d. $$A_{CL} = \frac{A_{OL}}{1+KA_{OL}}$$

$$R_{in,CL} = R_{in,OL}(1+KA_{OL})$$

$$R_{out,CL} = \frac{R_{out,OL}}{1+KA_{OL}}$$

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 **$g_m$=1mA/V** and **λ=0**. Only consider the explicitly drawn capacitors, i.e. no transistor capacitors.

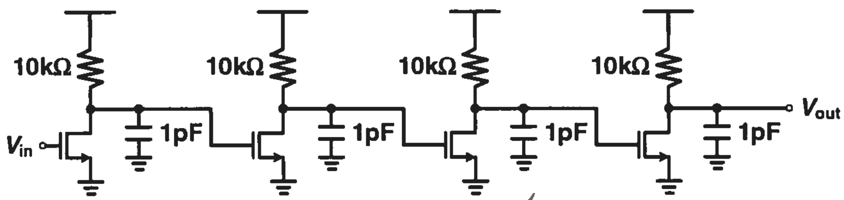



$A_{DC} = -g_m R_D = -(1\,mA/V)(10k\Omega) = -10\,V/V$

$|\omega_p| = \frac{1}{R_D C} = \frac{1}{(10k\Omega)(1pF)} = 100\,Mrad/s$

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

b. Now this single-stage amplifier is used in a 4-stage amplifier. Again, assume all transistors operate in saturation with **$g_m$=1mA/V** and **λ=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° ($\omega_{PX}$).




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

$\tan^{-1}\left(\frac{\omega_{px}}{10^8}\right) = 45°$

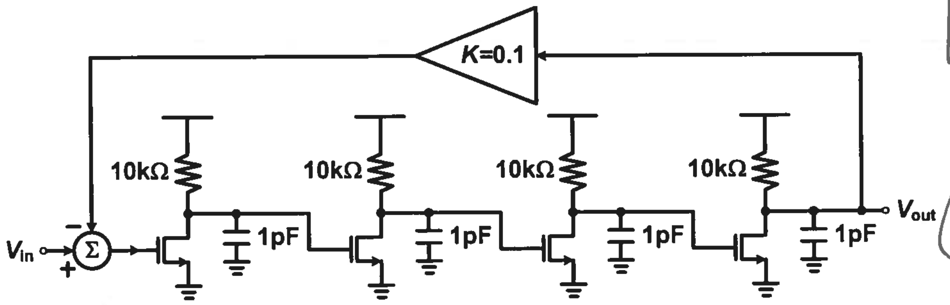
$\omega_{px} = 10^8\,rad/s$

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

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

$\omega_{PX}$ = 100 Mrad/s

c. Now this 4-stage amplifier is place in feedback with ***K*=0.1**. Give the frequency at which the feedback system |*KH*(s)|=1 ($\omega_{GX}$). Is the system stable?




$$|KH(s)| = 1$$

$$\frac{(0.1)(10^4)}{\left(\sqrt{1+\frac{\omega_{Gx}^2}{10^{16}}}\right)^4} = 1$$

$$\left(1+\frac{\omega_{Gx}^2}{10^{16}}\right)^2 = 10^3$$

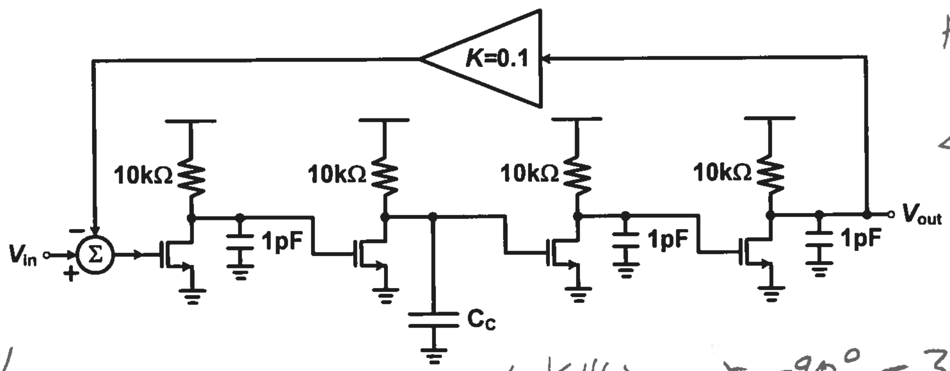
$$1+\frac{\omega_{Gx}^2}{10^{16}} = 10^{1.5}$$

$$\omega_{Gx} = 10^8\sqrt{10^{1.5}-1} = 553M$$

$\omega_{GX}$ = 553M rad/s

System Stable? (Yes or No) No ($\omega_{Gx} > \omega_{px}$)

d. Now only the second stage is modified with a large compensation capacitor Cc to establish a single dominant pole system. Assume that this dominant pole contributes -90° at the new $\omega_{GX}$. 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°?




For PM = 45°

$$\angle KH(j\omega_{Gx_{new}}) = -135°$$

w/ one dominant pole $\angle KH(j\omega_{Gx_{new}}) = -90° - 3\tan^{-1}\left(\frac{\omega_{Gx_{new}}}{10^8}\right) = -135$

$$\tan^{-1}\left(\frac{\omega_{Gx_{new}}}{10^8}\right) = 15°$$

$$\omega_{Gx_{new}} = 26.8M\,\text{rad/s}$$

To place $\omega_{Gx_{new}}$ at 26.8M rad/s

$$\omega_{p1}' = \frac{\omega_{Gx_{new}}}{|KH|} = \frac{26.8M\,\text{rad/s}}{10^3} = 26.8K\,\text{rad/s}$$

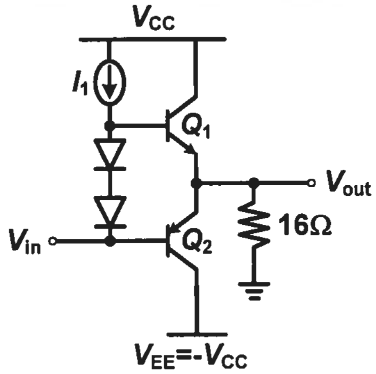
$$\omega_{p1}' = \frac{1}{R_D C_c}$$

Cc (PM=45°) = 3.73nF

$$C_c = \frac{1}{(10k\Omega)(26.8K\,\text{rad/s})} = 3.73n$$

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 16Ω load?




The maximum average power of the transistors

$$P_{Q1,max} = \frac{V_{CC}^2}{\pi^2 R_L} \quad \text{with} \quad V_P = \frac{2V_{CC}}{\pi}$$

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

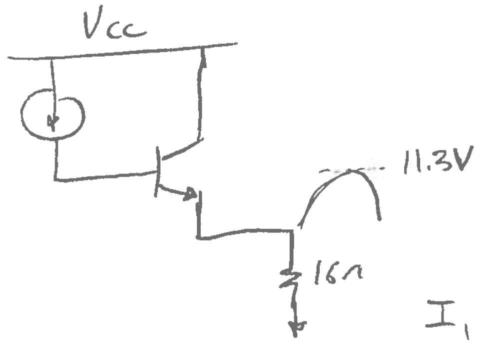
$$P_{Q_1,max} = \frac{\left(\frac{\pi V_P}{2}\right)^2}{\pi^2 R_L} \Rightarrow V_P = 2\sqrt{P_{Q_1} R_L} = 2\sqrt{2W(16\Omega)} = 11.3V$$

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

$P_{RL,max}$ = 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 β=40.

Equivalent circuit during positive peak




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

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

$I_1$ = 17.2m

## Scratch Paper