Texas A&M University
Department of Electrical and Computer Engineering

ECEN 620 – Network Theory (Broadband Circuit Design)

Fall 2023

Exam #2

Instructor: Sam Palermo

- Please write your name in the space provided below
- Please verify that there are **4** pages in your exam
- You may use one double-sided page of notes and equations for the exam
- Good Luck!

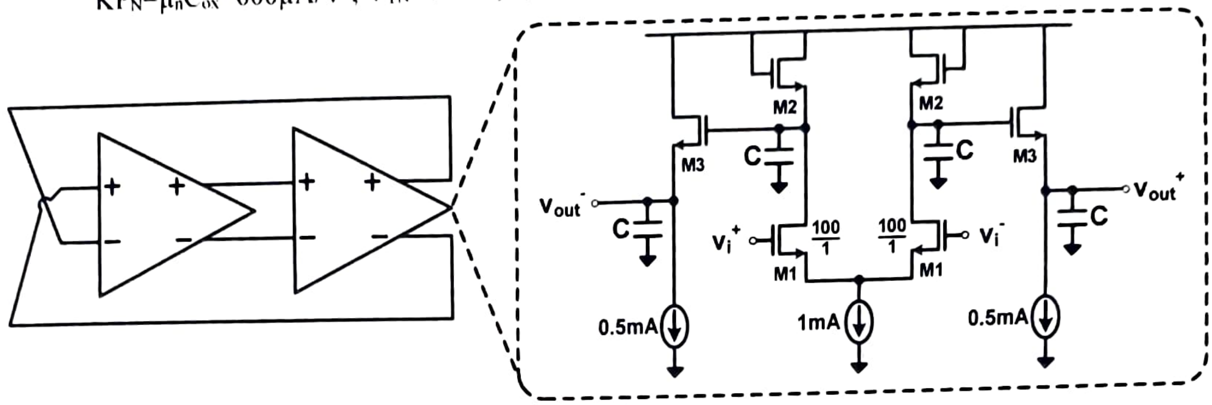
Problem	Score	Max Score
1		50
2		50
Total		**100**

Name: SAM PALERMO

UIN:

Problem 1 (50 points)
A differential ring oscillator is shown below. Assume that all transistors are operating in saturation with $r_o=\infty$ and you can ignore any transistor device capacitors. Assume that C=100fF and use the following NMOS parameters

$$KP_N=\mu_n C_{ox}=600\mu A/V^2,\ V_{TN}=0.35V,\ \lambda_N=0V^{-1}$$



a) Assume that for M2 and M3 that $W_2/L_2 = W_3/L_3$. Determine the sizes (W/L) of M2 and M3 to achieve oscillation.

b) What is the oscillation frequency?

a. Each oscillator cell: $\left[\dfrac{\frac{g_{m1}}{g_{m2}}}{1+\frac{sC}{g_{m2}}}\right]\left[\dfrac{1}{1+\frac{sC}{g_{m3}}}\right]$

$$H(s) = \left[\frac{\frac{g_{m1}}{g_{m2}}}{1+\frac{sC}{g_{m2}}}\right]^2\left[\frac{1}{1+\frac{sC}{g_{m3}}}\right]^2$$

To oscillate each cell should contribute a phase shift of

$$\frac{360^\circ-180^\circ}{2} = 90^\circ$$

Since $\left(\frac{W}{L}\right)_2 = \left(\frac{W}{L}\right)_3$ and $I_2 = I_3 \Rightarrow g_{m2} = g_{m3}$. Thus, each cell has 2 poles that are both at $-\frac{g_{m2}}{C}$

$\Rightarrow$ Circuit will oscillate when each pole gives 45°, which is

$$\omega_{osc} = \omega_p = \frac{g_{m2}}{C}$$

At ω_{osc}, the gain is $\frac{g_{m1}}{g_{m2}}\left(\frac{1}{\sqrt{2}}\right)\left(\frac{1}{\sqrt{2}}\right) = \frac{g_{m1}}{2g_{m2}}$ which needs to equal 1.

$$\frac{g_{m1}}{2g_{m2}} = \frac{\sqrt{KP\left(\frac{W}{L}\right)_1 2I_D}}{2\sqrt{KP\left(\frac{W}{L}\right)_2 2I_D}} = \frac{1}{2}\sqrt{\frac{(W/L)_1}{(W/L)_2}} = 1 \Rightarrow \left(\frac{W}{L}\right)_2 = \frac{(W/L)_1}{4} = \frac{25}{1}$$

b. $\omega_{osc} = \dfrac{g_{m2}}{C}$

$$= \frac{\sqrt{KP\left(\frac{W}{L}\right)_2 2I_D}}{C}$$

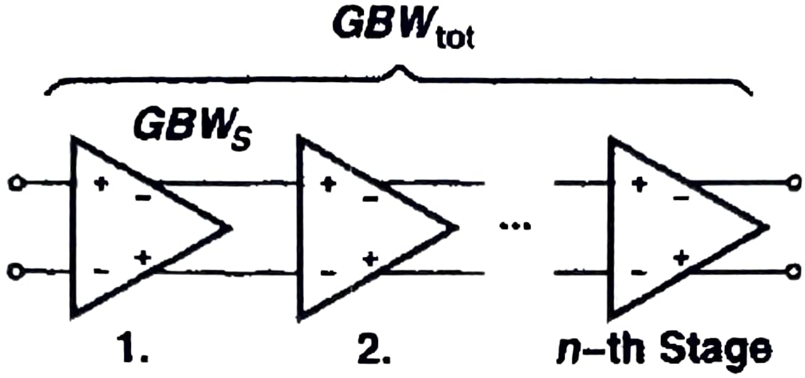
$$= \frac{\sqrt{(600\mu)(25)(2)(0.5mA)}}{100fF}$$

$$= 38.7\,Grad/s = 6.17\,GHz$$

$W_2/L_2 = W_3/L_3 = \dfrac{25}{1}$

$f_{osc} =$ 6.17GHz

Problem 2 (50 points)
Assume that the limiting amplifier below consists of cascaded identical single-pole amplifier stages, with gain A_{vs} and bandwidth ω_{3dBs}.



a) Design the limiting amplifier to achieve a 34dB total gain and 20GHz total bandwidth with the minimum per-stage gain-bandwidth product. Give the stage number and the per-stage gain and bandwidth. Also compute the per-stage gain-bandwidth product.

$n_{opt} = 2\ln(G_{tot}) = 2\ln(50.1) = 7.83 \Rightarrow$ Use 8 stages

W/ $n=8$ $\quad A_{vs} = \sqrt[8]{50.1} = 1.63$

$\omega_{3dBtot} = \omega_{3dBs}\sqrt{2^{1/8}-1} \Rightarrow \omega_{3dBs} = \frac{\omega_{3dBtot}}{\sqrt{2^{1/8}-1}} = \frac{2\pi(20GHz)}{\sqrt{2^{1/8}-1}} = 417\,Grad/s = 66.5\,GHz$

$GBW_s = (1.63)(417\,Grad/s) = 680\,Grad/s = 108\,GHz$

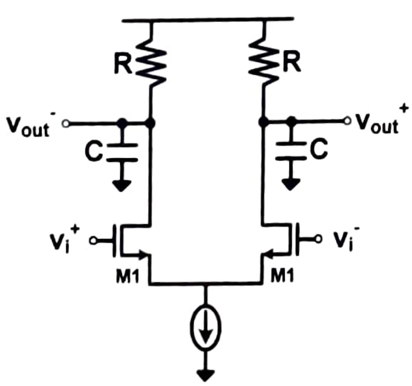
n = 8

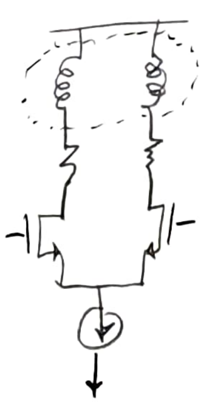
A_{vs} = 1.63

ω_{3dBs} = 417 Grad/s (66.5GHz)

GBW_s = 680 Grad/s (108GHz)

b) Assume that the simple differential amplifier stage shown below can only achieve a maximum GBW_s=70GHz. Propose a change to the stage design below to achieve the required GBW_s from part (a).





$\Rightarrow$ Add shunt peaking inductors

W/ $L = \frac{R^2C}{2.41}$ can increase BW by 72% (GBW to up to 120GHz) w/ no peaking in magnitude response.