

**Texas A&M University  
Department of Electrical and Computer Engineering**

**ECEN 620 – Network Theory (Broadband Circuit Design)**

**Fall 2021**

**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!

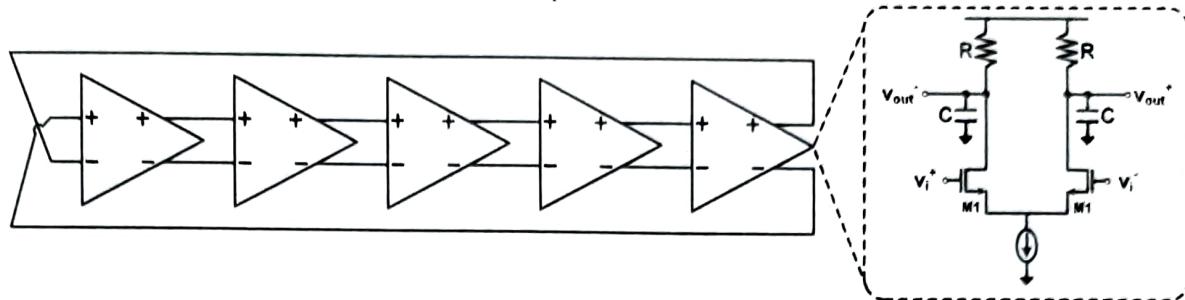
Problem	Score	Max Score
1		50
2		50
<b>Total</b>		<b>100</b>

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.



- Find the frequency of oscillation if  $R=500\Omega$  and  $C=50fF$ .
- What is the minimum transconductance ( $g_{m1}$ ) required for oscillation assuming that all stages are identical?

Each oscillator cell:  $\frac{A_o}{1 + \frac{s}{\omega_p^5}}$  where  $A_o = g_m R$   
 $\omega_p = \frac{1}{RC}$

$$H(s) = \frac{-A_o^5}{(1 + \frac{s}{\omega_p})^5}$$

a. To oscillate each cell should contribute a phase shift of

$$\frac{360^\circ - 180^\circ}{5} = 36^\circ$$

$$\Rightarrow \tan^{-1} \left( \frac{\omega_{osc}}{\omega_p} \right) = 36^\circ \Rightarrow \omega_{osc} = \omega_p \tan(36^\circ) = \frac{0.727}{(500\Omega)(50fF)} = 29.1 \text{ rad/s} = 4.63 \text{ GHz}$$

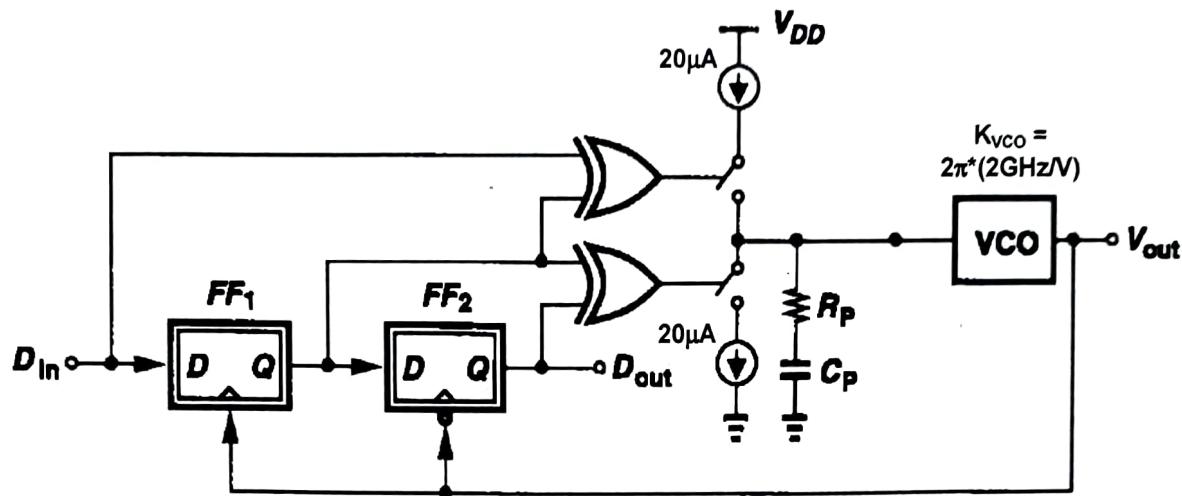
b.  $|H(j\omega_{osc})| = 1 \Rightarrow \frac{(g_m R)^5}{(\sqrt{1 + (0.727)^2})^5} = 1$

$$\left( \frac{g_m R}{1.24} \right)^5 = 1 \Rightarrow g_m \approx \frac{1.24}{R} = \frac{1.24}{500\Omega} = 2.47 \text{ mA/V} \quad f_{osc} = 4.63 \text{ GHz}$$

$$\text{Min } g_{m1} = 2.47 \text{ mA/V}$$

## Problem 2 (50 points)

For the CDR shown below, assume that the incoming data has a **transition density**  $TD = 0.3$ . Assume that the only source of noise in the CDR below is from the VCO, which has  $\kappa = 4 \times 10^{-9} \sqrt{s}$ .



- a) What is the necessary CDR loop bandwidth to satisfy a self-referenced jitter generation of  $\sigma_{\Delta T} = 2 ps_{rms}$ ?

The VCO will accumulate jitter equal to a value of

$$\overline{\sigma_{\Delta T}} = K \sqrt{\frac{1}{\omega_{3dB}}}$$

$$\omega_{3dB} = \frac{\kappa^2}{\overline{\sigma_{\Delta T}}^2} = \frac{(4 \times 10^{-9} \sqrt{s})^2}{(2 ps)^2} = 4 M \text{ rad/s}$$

$$\omega_{3dB} = 4 M \text{ rad/s}$$

- b) Design the loop filter components to yield a  $\zeta = 1$ . Note, for  $\zeta = 1$ ,  $\omega_{3dB} = 2.48\omega_n$ .

$$\frac{\omega}{\omega_n} = 1 \Rightarrow \omega_{3dB} = 2.48\omega_n \Rightarrow \omega_n = \frac{\omega_{3dB}}{2.48} = \frac{4\text{Mrad/s}}{2.48} = 1.61\text{ Mrad/s}$$

$$\omega_n = \sqrt{\frac{K_{PD} I_{CP} K_{VCO}}{C_P}} \Rightarrow C_P = \frac{K_{PD} I_{CP} K_{VCO}}{\omega_n^2}$$

$$\text{Hedge } PD: K_{PD} = \frac{1}{\pi} (TD) = \frac{0.3}{\pi}$$

$$C_P = \frac{(0.3)(20\mu A)(2\pi \cdot 2.6\text{Hz})}{(\pi)(1.61\text{ Mrad/s})^2} = 9.26\text{nF}$$

$$R_P = \frac{2h}{\omega_n C_P} = \frac{2(1)}{(1.61\text{ Mrad/s})(9.26\text{nF})} = 134\Omega$$

$$R = 134\Omega$$

$$C = 9.26\text{nF}$$

**Scratch Paper**