Texas A&M University
Department of Electrical and Computer Engineering

ECEN 620 – Network Theory (Broadband Circuit Design)

Fall 2023

Exam #1

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 <u>one</u> 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

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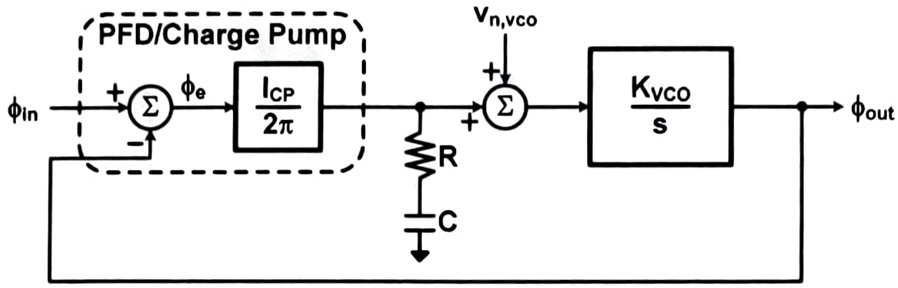
Problem 1 (50 points)
This problem investigates how voltage noise on the VCO control voltage impacts the output phase noise. Assume that the VCO input noise is modeled as an additive voltage noise term, as shown in the model below.



a) Find the expression for the input VCO voltage noise induced phase noise transfer function, $T(s)=\phi_{out}(s)/v_{n,vco}(s)$.

$$T(s) = \frac{\phi_{out}(s)}{V_{n,vco}(s)} = \frac{K_{VCO}\, s}{s^2 + 2\zeta\omega_n s + \omega_n^2} = \frac{K_{VCO}\, s}{s^2 + \frac{I_{cp}K_{VCO}R}{2\pi} s + \frac{I_{cp}K_{VCO}}{2\pi C}}$$

$$\text{where } \omega_n = \sqrt{\frac{I_{cp}K_{VCO}}{2\pi C}} \text{ and } \zeta = \frac{\omega_n}{2} RC$$

$T(s)=\phi_{out}(s)/v_{n,vco}(s) =$

b) Assume that the PLL has been designed for ω_n=1Mrad/s and ζ=0.7. Also, assume that ω_{VCO}=10Grad/s and $K_{VCO}=2\pi*1$GHz/V. If the VCO input voltage noise has sinusoidal modulation
$v_{n,vco}(t) = V_{amp}\, sin(10^8 t)\ \ (V)$
What is the maximum voltage amplitude, V_{amp}, for an output jitter amplitude of 0.5ps?

$$\frac{\Phi_{OUT}}{V_{n,VCO}}(j10^8) = \frac{(2\pi \cdot 1GHz/V)(j10^8\ rad/s)}{-10^{16}(rad/s)^2 + 2(0.7)(10^6\ rad/s)(j10^8\ rad/s) + 10^{12}(rad/s)^2}$$

$$\left|\frac{\Phi_{out}}{V_{n,VCO}}(j10^8)\right| \simeq \frac{(2\pi \cdot 1GHz/V)(10^8\ rad/s)}{10^{16}(rad/s)^2} = 62.8\ rad/V$$

$$V_{amp}(62.8\ rad/V)\left(\frac{2\pi\ 100ps}{2\pi\ rad}\right) = 0.5ps$$

$$V_{amp} = 79.6\mu V$$

V_{amp} = $79.6\mu V$

c) Assuming 10^4 rad/s sinusoidal noise with a 10mV amplitude, what is the output jitter amplitude in ps?

$$\left|\frac{\Phi_{OUT}}{V_{n,VCO}}(j10^4)\right| \cong \frac{(2\pi \cdot 1GHz/V)(10^4\ rad/s)}{10^{12}(rad/s)^2} = 62.8\ rad/V$$

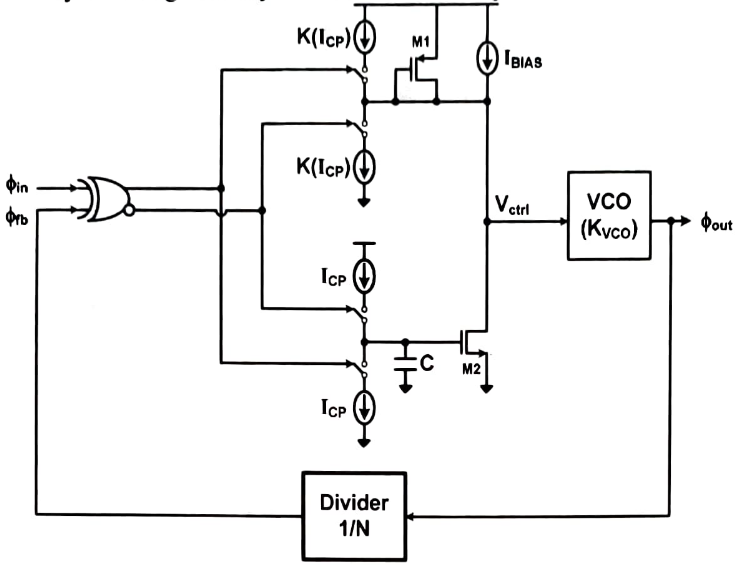
$$(62.8\ rad/V)(10mV) = 0.628\ rad$$

$$(0.628\ rad)\left(\frac{2\pi(100ps)}{2\pi\ rad}\right) = 62.8ps$$

Output Jitter Amplitude (ps) = 62.8ps

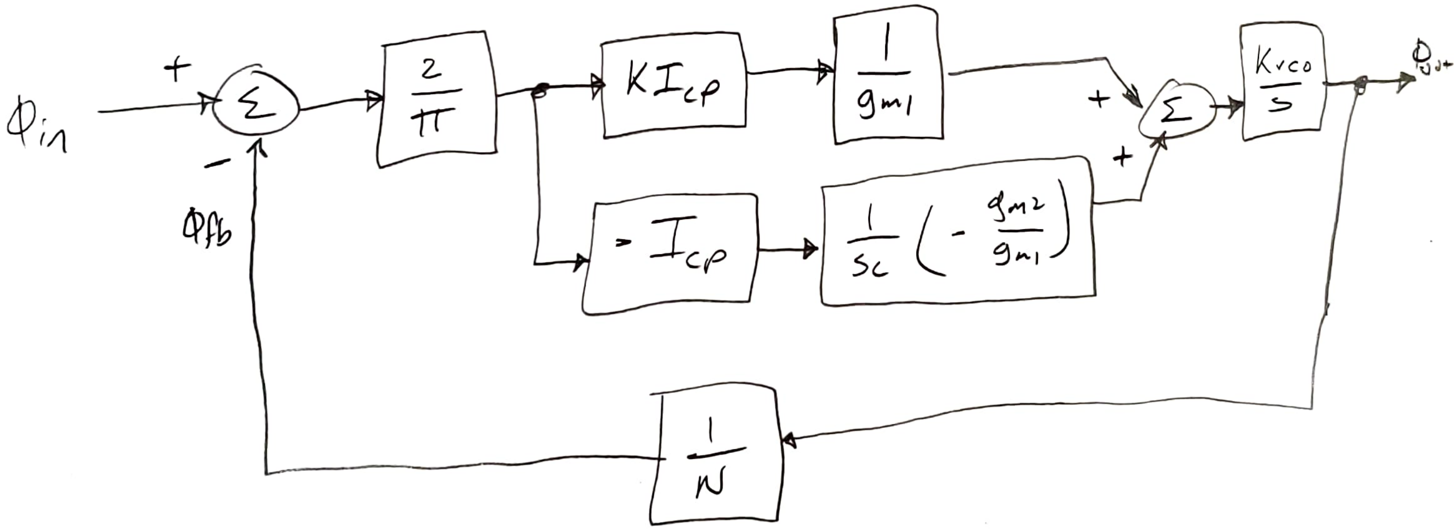
Problem 2 (50 points)

For the PLL shown below, assume that the VCO gain is K_{VCO} is positive, all transistors are operating in saturation with $r_o=\infty$ and you can ignore any transistor device capacitors.



a) Draw the phase domain small signal model of the loop.

b) Find the expressions for the loop gain, LG(s), and determine the pole-zero locations of LG(s).



$$LG(s) = \left(\frac{2}{\pi}\right)\left(\frac{KI_{cp}}{g_{m1}} + \frac{I_{cp}g_{m2}}{sC\,g_{m1}}\right)\left(\frac{K_{vco}}{s}\right)\left(\frac{1}{N}\right)$$

$$\boxed{LG(s) = \frac{\left(\frac{2kI_{cp}K_{vco}}{\pi g_{m1}}\right)\left[s + \frac{g_{m2}}{kC}\right]}{Ns^2}}$$

2 poles at $\emptyset$

1 zero at $-\frac{g_{m2}}{KC}$

c) Assume that K=5, C=200pF, $g_{m1}=g_{m2}=2mA/V$, $K_{VCO}=2\pi*(1GHz/V)$, N=64. Calculate the unit charge pump current, I_{CP}, for a phase margin of 45°.

$$LG(s) = \frac{\left(\frac{2KI_{cp}K_{vco}}{\pi g_{m1}}\right)\left[s + \frac{g_{m2}}{KC}\right]}{Ns^2}$$

① Find ω_u for PM = 45°

$$PM = 180^\circ + \angle LG(j\omega_u)$$

$$= 180^\circ + \tan^{-1}\left(\frac{\omega_u KC}{g_{m2}}\right) - 180^\circ = \tan^{-1}\left(\frac{\omega_u KC}{g_{m2}}\right)$$

$$\tan^{-1}\left(\frac{\omega_u KC}{g_{m2}}\right) = 45^\circ$$

$$\omega_u = \frac{g_{m2}}{KC} = \frac{2mA/V}{5(200pF)} = 2\times10^6 \ rad/s$$

② Set I_{cp} to achieve ω_u

$$|LG(\omega_u)| = 1$$

$$\frac{\frac{2(5)(I_{cp})(2\pi\cdot 1G)}{\pi(2m)}\sqrt{(2\times10^6)^2 + (2\times10^6)^2}}{64(2\times10^6)^2} = 1$$

$$I_{cp} = \frac{64(2\times10^6)(2m)}{2(5)(2\cdot 1G)\sqrt{2}} = 9.05\mu A$$

I_{CP} for 45° Phase Margin = $9.05\mu A$

d) What is the phase relationship between ϕ_{in} and ϕ_{fb} when is PLL locked?

Due to the XOR Phase Detector, the loop will lock with a 90° phase difference.

$\phi_{in} - \phi_{fb} = 90^\circ$