Texas A&M University
Department of Electrical and Computer Engineering

ECEN 720 – High-Speed Links

Spring 2023

Exam #1

Instructor: Sam Palermo

- Please write your name in the space provided below
- Please verify that there are **7** pages in your exam
- Good Luck!

Problem	Score	Max Score
1		30
2		20
3		25
4		25
Total		**100**

Name: SAM PALERMO

UIN: ____________________

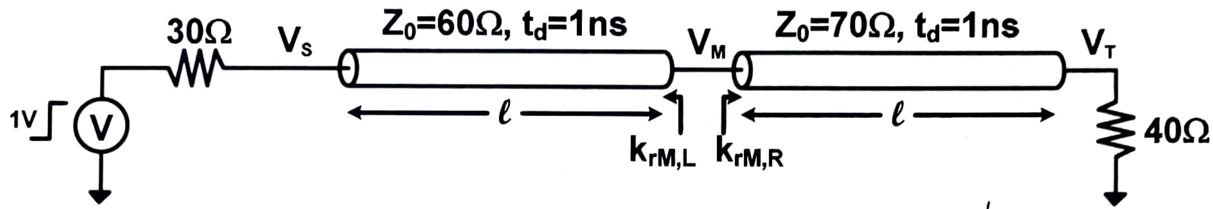
Problem 1 (30 points)

a) A 1V step is launched onto the channel below at t=0ns. (20 points)

i. Calculate the reflection coefficient at the source, k_{rS}, at the middle point for right traveling signals, $k_{rM,R}$, and left traveling signals, $k_{rM,L}$, and the end termination, k_{rT}

ii. Fill in the lattice diagram below until t=4ns.

iii. Also plot the source voltage, V_S, and the termination voltage, V_T until 4ns.



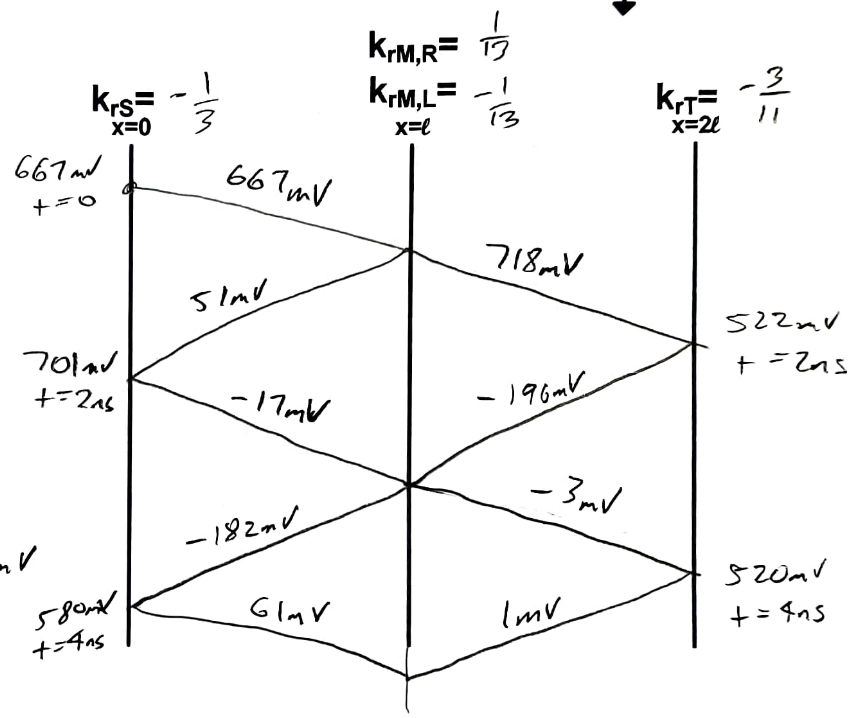
$$K_{rS} = \frac{30-60}{30+60} = -\frac{1}{3}$$

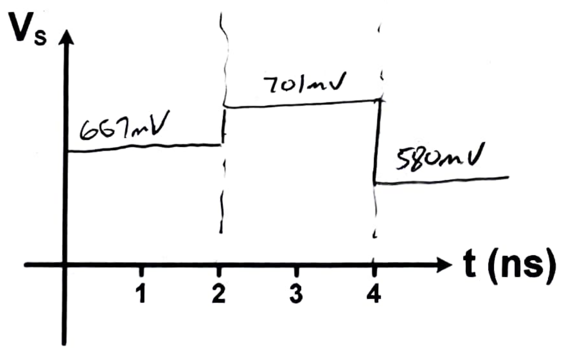
$$K_{rM,L} = \frac{60-70}{60+70} = -\frac{1}{13}$$

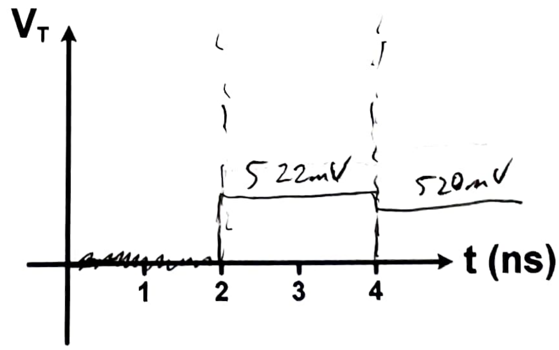
$$K_{rM,R} = \frac{70-60}{70+60} = \frac{1}{13}$$

$$K_{rT} = \frac{40-70}{40+70} = -\frac{3}{11}$$

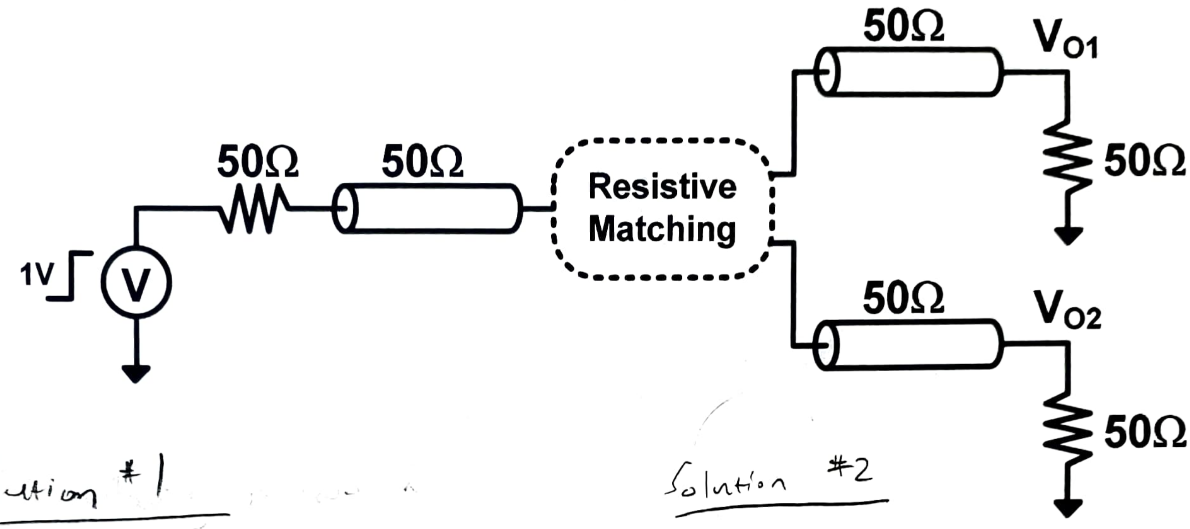
$$\text{Initial Voltage} = \frac{60}{30+60}(1V) = 667mV$$



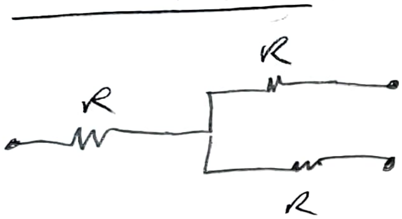




b) For the circuit below, design a three-terminal resistive matching network to eliminate any reflections in any direction and make $V_{O1}=V_{O2}$. If a 1V step is launched onto the network, what is the step value at the two outputs? (10 points)



Solution #1



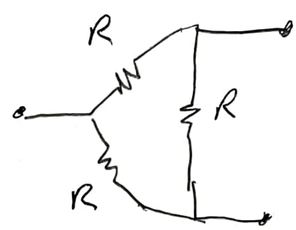
$$R + (R+50)\,||\,(R+50) = 50$$

$$R + \frac{R+50}{2} = 50$$

$$3R = 50$$

$$R = 16.7\,\Omega$$

Solution #2

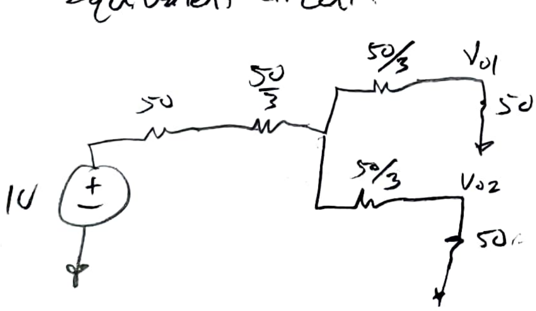


$$(R+50)\,||\,(R+50) = 50$$

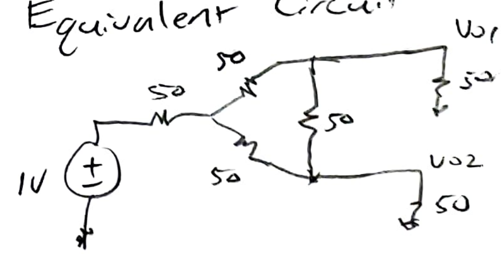
$$\frac{R+50}{2} = 50$$

$$R = 50$$

Equivalent Circuit



Equivalent Circuit



$V_{O1} = V_{O2} =$

$$V_{o1} = V_{o2} = \frac{\left(\frac{50}{50+50/3}\right)\left(\frac{50+50/3}{2}\right)}{50 + \frac{50}{3} + \frac{50+50/3}{2}} = 0.25\,V$$

$$V_{o1} = V_{o2} = \frac{\left(\frac{50}{50+50}\right)\left(\frac{50+50}{2}\right)}{50 + \frac{50+50}{2}} = 0.25\,V$$

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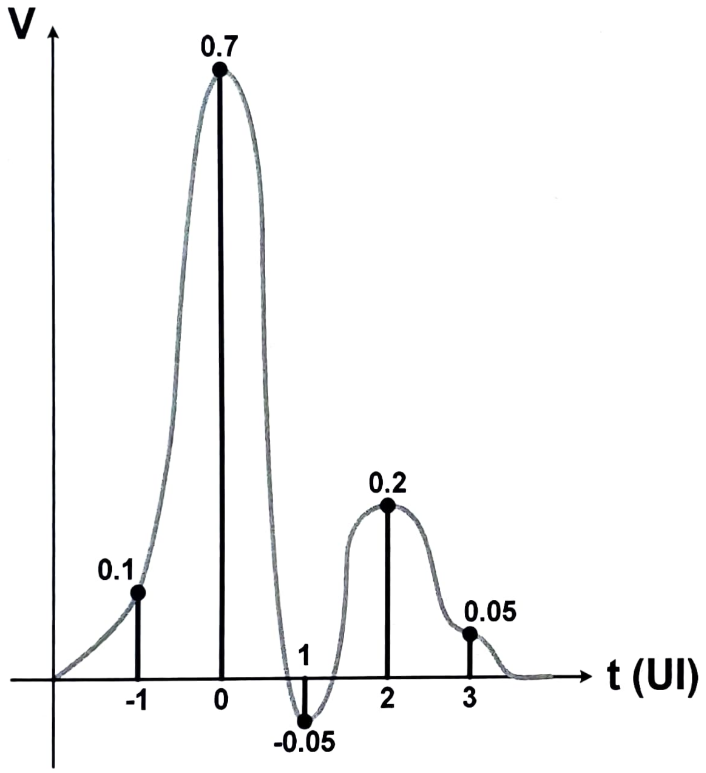
Problem 2 (20 points)

A channel has the pulse response, $y^{(1)}$, below for a "1" bit.

a. Find the channel's worst-case eye height at this bit rate.

b. Give the channel's worst-case bit pattern at this bit rate.

$$y^{(1)} = [0.1 \;\; 0.7 \;\; -0.05 \;\; 0.2 \;\; 0.05]$$



$y_0^{(1)} = 0.7$

$\sum_{k \neq 0} y^{(1)} \Big|_{y<0} = -0.05$

$\sum_{k \neq 0} y^{(1)} \Big|_{y>0} = 0.1 + 0.2 + 0.05 = 0.35$

W.C. Eye Height $= 2(0.7 - 0.05 - 0.35) = 0.6$

To find W.C. Bit Pattern: Flip around cursor and invert all but cursor

$[0.1 \;\; 0.7 \;\; -0.05 \;\; 0.2 \;\; 0.05] \Rightarrow [-0.05 \;\; -0.2 \;\; 0.05 \;\; 0.7 \;\; -0.1]$

Then take sign

$[-0.05 \;\; -0.2 \;\; 0.05 \;\; 0.7 \;\; -0.1] \Rightarrow [-1 \;\; -1 \;\; 1 \;\; 1 \;\; -1]$

Worst-Case Eye Height = 0.6

Cursors

Worst-Case Bit Pattern = $[-1 \;\; -1 \;\; 1 \;\; 1 \;\; -1]$ Worst-case "1"

$[1 \;\; 1 \;\; -1 \;\; -1 \;\; 1]$ Worst-case "-1"

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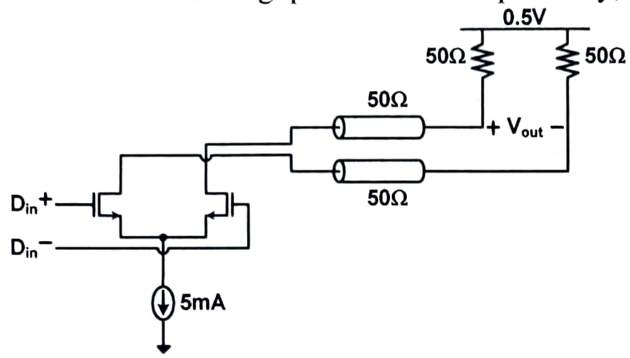
Problem 3 (25 points)

Answer the following questions for the pull-only, differential current-mode driver shown below.



a. What is the peak-to-peak differential output swing, $V_{d,1} - V_{d,0}$?

b. What is the average power consumption of the driver?

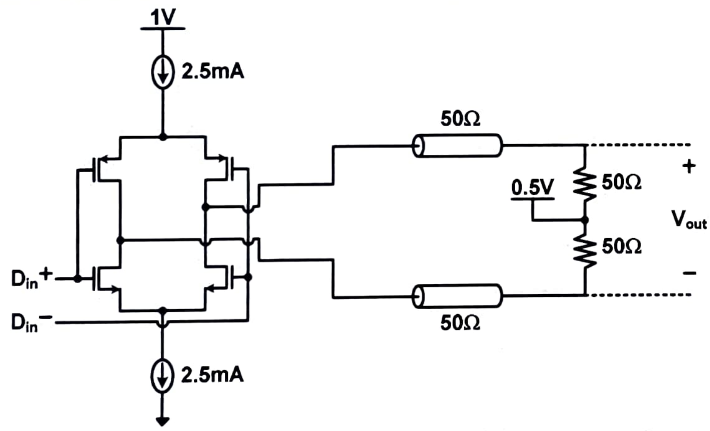
$V_{d,1} - V_{d,0} = IR - (-IR) = 2IR = 2(5mA)(50\Omega) = 500mV$

$V_{out,dpp} = V_{d,1} - V_{d,0} =$ 500mV

$P_{avg} = 5mA(0.5V) = 2.5mW$

Average Power = 2.5mW

Now consider the push-pull differential current-mode driver shown below. **Note that the bias current has been reduced from 5mA to 2.5mA.**



$V_{d,1} - V_{d,0} =$

$2IR - (-2IR) = 4IR$

$= 4(2.5mA)(50\Omega) = 500mV$

c. What is the peak-to-peak differential output swing, $V_{d,1} - V_{d,0}$?

d. What is the average power consumption of the driver?

$P_{avg} = 2.5mA(1V) = 2.5mW$

$V_{out,dpp} = V_{d,1} - V_{d,0} =$ 500mV

Average Power = 2.5mW

e. Why doesn't this push-pull driver dissipate half the power of the pull-only driver, for the same signal swing? In particular, explain the factor that constrains the supply voltage (1V) or the termination voltage (0.5V).

For the push-pull driver, we need both the top (PMOS) and the bottom (NMOS) current sources to stay in saturation.

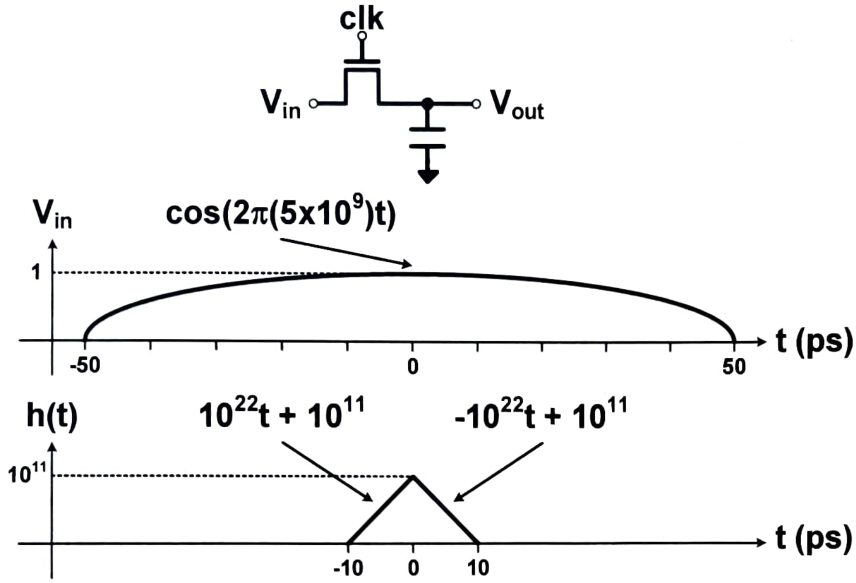
Thus, we need about[5] twice the supply voltage.

Problem 4 (25 points)

The NMOS sampler below is used to sample a 5GHz sinusoidal signal at t=0. Assume that the sampler displays the triangular sampling function, h(t).

i. Setup, **but do not calculate**, the integral expression for the sampled output voltage.

ii. Calculate the sampler aperture time from the sampling function. Assume that the aperture time is defined as the time where 80% of the sampler sensitivity is confined.



i. Sampled $V_{out} = \int_{-\infty}^{\infty} V_{in}(t)\, h(t)\, dt$

$$= \int_{-10ps}^{0} \cos(2\pi(5\times10^9)t)\left[10^{22}t + 10^{11}\right]dt + \int_{0}^{10ps} \cos(2\pi(5\times10^9)t)\left[-10^{22}t + 10^{11}\right]dt$$

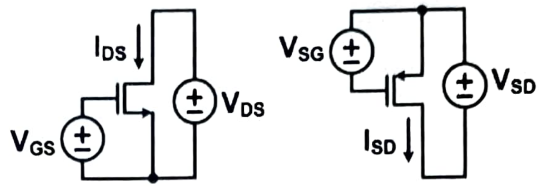
ii. Need to find how much time = 10% of area or 0.1 because $\int_{-\infty}^{\infty} h(t) = 1$

Area = 0.1 $\frac{1}{2}(10^{22}t)(t) = 0.1 \Rightarrow t = 4.47ps$ for 10% area

Aperture time = 20ps − 2(4.47ps)

= 11.1ps

Key MOS Equations & Scratch Paper



$$\text{Saturation: } NMOS\ \ I_{DS} = \frac{1}{2} KP_N \frac{W}{L} (V_{GS} - V_{TN})^2$$

$$\text{Saturation: } PMOS\ \ I_{SD} = \frac{1}{2} KP_P \frac{W}{L} (V_{SG} - |V_{TP}|)^2$$

$$\text{Triode: NMOS } I_{DS} = KP_N \frac{W}{L} \left(V_{GS} - V_{TN} - \frac{V_{DS}}{2} \right) V_{DS}$$

$$\text{Triode: } PMOS\ I_{SD} = KP_P \frac{W}{L} \left(V_{SG} - |V_{TP}| - \frac{V_{SD}}{2} \right) V_{SD}$$

$$NMOS\ g_m = \frac{\partial I_{DS}}{\partial V_{GS}},\ \ PMOS\ g_m = \frac{\partial I_{SD}}{\partial V_{SG}}$$

$$NMOS\ \ g_o = \frac{\partial I_{DS}}{\partial V_{DS}},\ \ PMOS\ \ g_o = \frac{\partial I_{SD}}{\partial V_{SD}}$$