DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING
OLD DOMINION UNIVERSITY
MS COMPREHENSIVE EXAM
Fall 2022

ODU HONOR PLEDGE

I pledge to support the Honor system of Old Dominion University. I will refrain from any form of academic dishonesty or deception, such as cheating or plagiarism. I am aware that as a member of the academic community, it is my responsibility to turn in all suspected violators of the Honor Code. I will report to a hearing if summoned.

Student Signature: ____

Student Name (BLOCK CAPITALS): _____________________________________

UIN Number: ____

Please turn in this examination document with the pledge above signed and with one answer book for each solved problem.

1. This examination contains 30 problems in the following seven areas:

A.	MATH (At most 2 problems can be answered from the Math area)	A1	A2	A3	A4		
B.	CIRCUITS & ELECTRONICS	B1	B2	B3			
C.	SYSTEMS, SIGNAL AND IMAGE PROCESSING	C1	C2	C3	C4	C5	C6
D.	PHYSICAL ELECTRONICS I	D1	D2	D3			
E.	PHYSICAL ELECTRONICS II	E1	E2	E3			
F.	COMPUTER SYSTEMS	F1	F2	F3	F4	F5	F6
G.	CYBERSECURITY	G1	G2	G3	G4	G5	

2. You must answer five problems (no more than two from the MATH group).
3. Answer in the blue books provided. **Use a separate book for each problem. Put the title and problem number on the front of each book (eg., MATH A-1)**
4. Return all the 30 problems.
5. You will be graded on your answers to five problems only.
6. The examination is “closed-book;” only blue books, exam problems and a scientific calculator are allowed. **No formula sheet is allowed**. Some problems include reference formulas. No material shall be shared without prior permission of the proctor(s).
7. You have four hours to complete this examination.

DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING
OLD DOMINION UNIVERSITY
PH.D. DIAGNOSTIC EXAM
Fall 2022

ODU HONOR PLEDGE

I pledge to support the Honor system of Old Dominion University. I will refrain from any form of academic dishonesty or deception, such as cheating or plagiarism. I am aware that as a member of the academic community, it is my responsibility to turn in all suspected violators of the Honor Code. I will report to a hearing if summoned.

Student Signature: ____

Student Name (BLOCK CAPITALS): _____________________________________

UIN Number: ____

Please turn in this examination document with the pledge above signed and with one answer book for each solved problem.

1. This examination contains 30 problems in the following seven areas:

A.	MATH (At most 3 problems can be answered from the Math area)	A1	A2	A3	A4		
B.	CIRCUITS & ELECTRONICS	B1	B2	B3			
C.	SYSTEMS, SIGNAL AND IMAGE PROCESSING	C1	C2	C3	C4	C5	C6
D.	PHYSICAL ELECTRONICS I	D1	D2	D3			
E.	PHYSICAL ELECTRONICS II	E1	E2	E3			
F.	COMPUTER SYSTEMS	F1	F2	F3	F4	F5	F6
G.	CYBERSECURITY	G1	G2	G3	G4	G5	

2. You must answer <u>eight</u> problems (no more than three from the MATH group).
3. Answer in the blue books provided. **Use a separate book for each problem. Put the title and problem number on the front of each book (eg., MATH A-1)**
4. Return all the 30 problems.
5. You will be graded on your answers to eight problems only**.**
6. The examination is "closed-book;" only blue books, exam problems and a scientific calculator are allowed. **No formula sheet is allowed**. Some problems include reference formulas. No material shall be shared without prior permission of the proctor(s).
7. You have four hours to complete this examination.

PROBLEM A1 – MATH

Solve for the current i shown in the first order nonhomogeneous equation:

$$L\frac{di}{dt} + Ri = V_0 \cos(\omega t)$$

Let's assume the following is true:

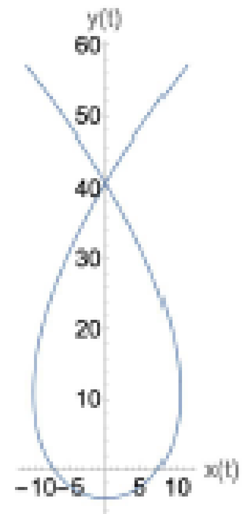
the initial condition for the current is $i\,(0+) = i(0-) = 0$

and L, R, ω and V_0 are constants.

PROBLEM A2 – MATH

The parametric curve shown below is defined by

$$x(t) = t(9 - t^2), \quad y(t) = 5t^2 - 4 \quad , \quad for - 3.5 < t < 3.5$$



Determine the area of the closed droplet (i.e., for $y_{min} = -4$, to $y_{max} = 41$).

PROBLEM A3 – MATH

Linear Algebra

Let $A = \left[a_{ij}\right]_{1 \le i,j \le n}$ be a symmetric matrix with real-valued elements and dimension $n \times n$.

1. Show that all of the eigenvalues of matrix A are real.
2. Show that the determinant of matrix A is equal to the product of its eigenvalues.
3. Show that the quadratic form $\underline{x}^T A \, \underline{x}$, where $\underline{x}$ is a vector with real-valued elements and norm equal to 1, is bounded, and that its lower and upper bounds are $\lambda_{\min}$ and $\lambda_{\max}$, the smallest and largest eigenvalues, respectively, of matrix A.

Note: For full credit formal proofs using a sequence of logical reasoning steps are expected.

PROBLEM A4 – MATH

<u>Probability</u>

A coin with radius *R* lands randomly on a square table with side-length *L*.

A. What is the probability that the coin lies *entirely* on the table?

B. A second coin lands randomly on the table. What is the probability that *both* coins lie entirely on the table?

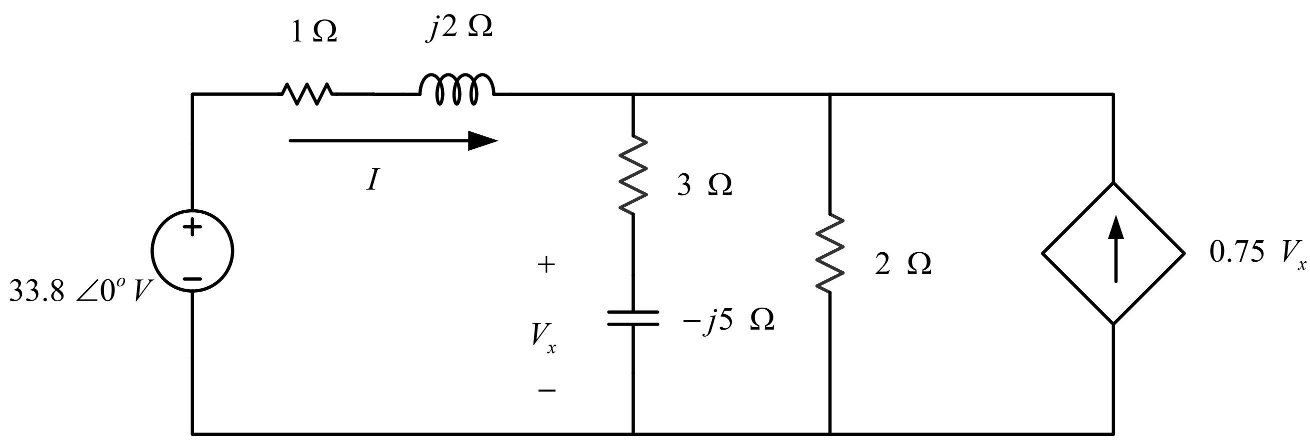
C. Given that the two coins lie entirely on the table, how should *L* and *R* be chosen so that *on average* they are not touching each other?

For each part, clearly justify your answer and explicitly state any required assumptions.

PROBLEM B1 – CIRCUITS AND ELECTRONICS

Sinusoidal Steady State Analysis

Use the **mesh-current method** to find the phasor current **I** in the circuit shown.



PROBLEM B2 – CIRCUITS AND ELECTRONICS

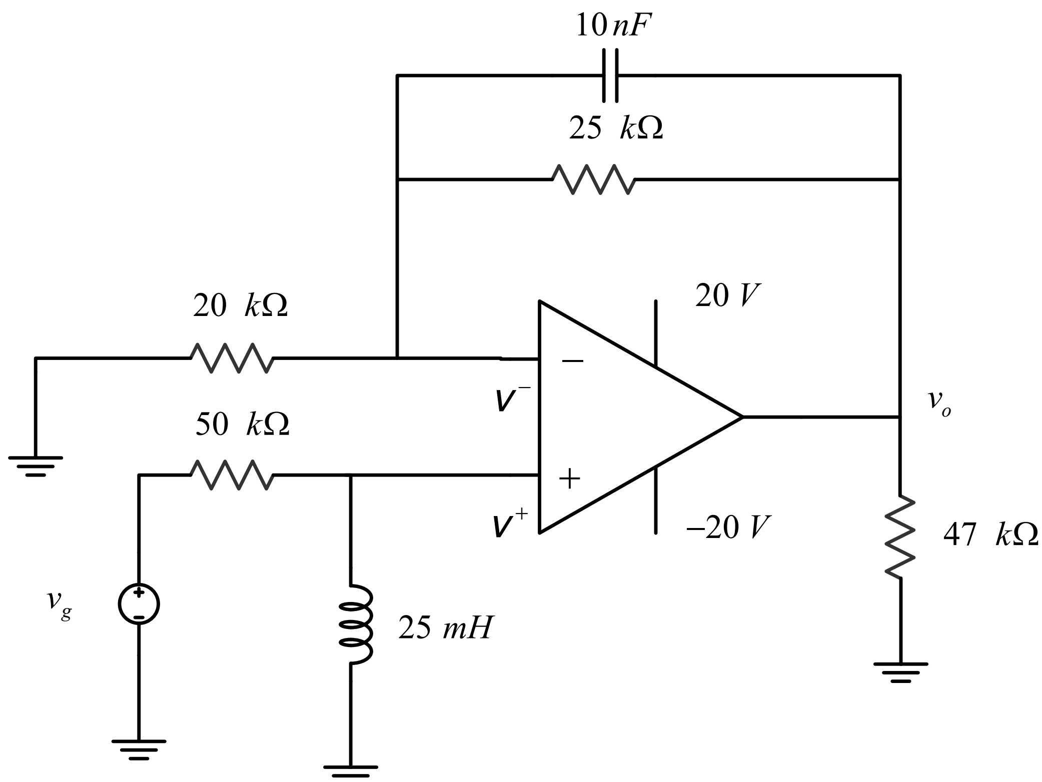
Laplace Application to Circuit Analysis

The op-amp in the circuit shown is ideal.

a. Find the transfer function $\frac{V_o(s)}{V_g(s)}$.

b. Find $v_o(t)$ if $v_g(t) = 10u(t)\ V$.

c. Find the steady state expression for $v_o(t)$ if $v_g(t) = 8\cos(2000t)\ V$.

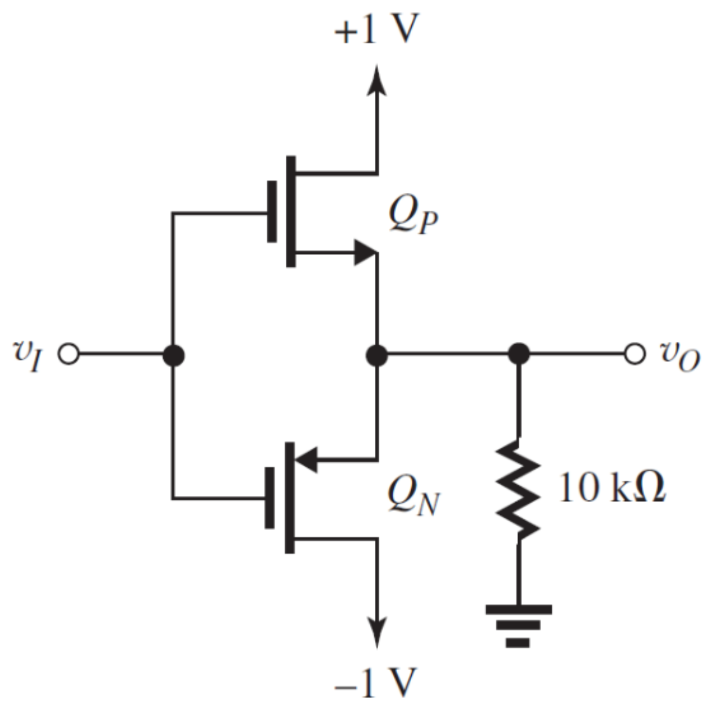


PROBLEM B3 – CIRCUITS AND ELECTRONICS

Electric Circuits

The transistors in the below circuit have $k_n = k_p = 2\text{mA/V}^2$ and $V_{tn} = -\,V_{tp} = 0.4\text{V}$.

Find V_O when V_I=0V and V_I=-2V.



PROBLEM C1 – SYSTEMS, SIGNALS AND IMAGE PROCESSING

Image Processing

1.

a. Use your own words to describe Notch Filtering and why we use Notch Filtering on images with correlated noise.

b. Which of following spectrum power image is the most likely to have a correlated noise? Why?

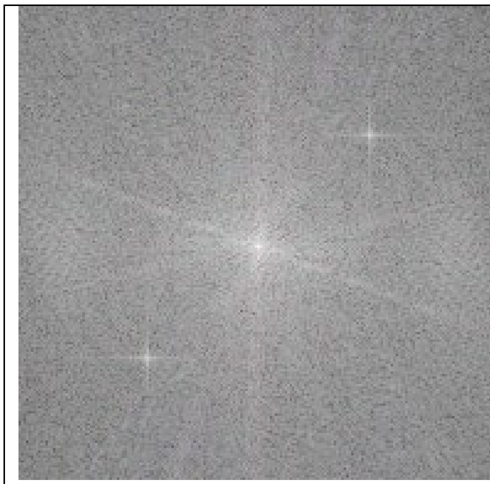
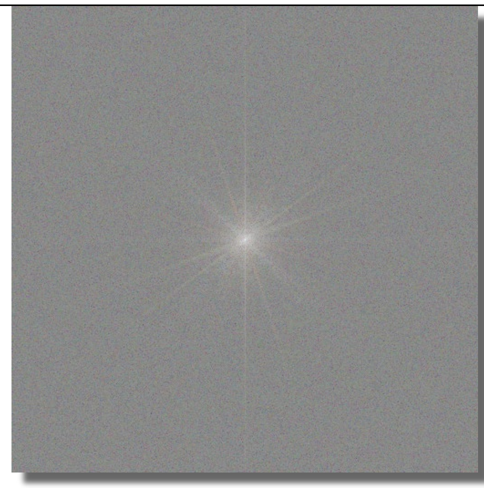
	

Image A	Image B

2.

a. Explain Histogram Equalization.

b. Given the following 3x3 image I (grey image), you need to conduct Histogram Equalization on it and show each step to get the result.

Hint: $\mathbf{J}(r,c,b) = 255 \cdot P_{\mathbf{I}}\left[\mathbf{I}(r,c,b)+1\right].$, where P_I is the cumulative distribution function (CDF) of image, *I*.

100	11	11
100	255	11
50	50	11

Intensity Values for 3x3 Image, *I*

PROBLEM C2 – SYSTEMS, SIGNALS AND IMAGE PROCESSING

Consider the following discrete-time system:

$$y[n] = \sum_{k=0}^{n} x[k]$$

a. Determine the difference equation for the system. (3 points)

b. Determine the impulse response $h[n]$ of the system (2 points)

c. Is the system stable? Is the system casual? Justify your answers. (2 points)

d. Determine the output $y[n]$ for the input $x[n] = (1/8)^n u[n]$. (3 points)

PROBLEM C3 – SYSTEMS, SIGNALS AND IMAGE PROCESSING

a. (3 points) We are using N-point DFT to compute linear convolution for two sequences $x[n]$ and $h[n]$, where the length of $x[n]$ is 13 and the length of $h[n]$ is 16. What is the minimum value for N that can avoid time aliasing?

b. (7 points) Two finite length signals, $x_1[n]$ and $x_2[n]$ are given as:

$$x_1[n] = u[n] - u[n-6]$$

$$x_2[n] = u[n] - u[n-4]$$

Let $x_3[n]$ be the 8-point circular convolution of $x_1[n]$ and $x_2[n]$, determine $x_3[n]$.

PROBLEM C4 – SYSTEMS, SIGNALS AND IMAGE PROCESSING

Control Systems

Assume that the transfer function of the longitudinal dynamics of an aircraft during a particular maneuver is

$$G_2(s) \triangleq \frac{\text{Pitch Rate}}{\text{Elevator Deflection}} = \frac{s\theta(s)}{\delta_e(s)} = \frac{-5}{(s+10)(s-2)(s+5)}.$$

a) If a proportional unity feedback controller K_2 is used to stabilize the plant as shown in the block diagram below, determine

   a. the closed-loop transfer function $\frac{\text{Pitch rate}(s)}{\text{Desired pitch rate}(s)}$,
   b. the closed-loop transfer function $\frac{\text{Elevator Deflection}(s)}{\text{Desired pitch rate}(s)}$,
   c. if the closed-loop is stable, determine the initial and final (steady-state) values of the elevator deflection and pitch rate in the time domain if the desired pitch rate is a unit step,
   d. determine the range of K_2 to maintain stability.

b) Briefly explain the significance of the gain and phase margins.

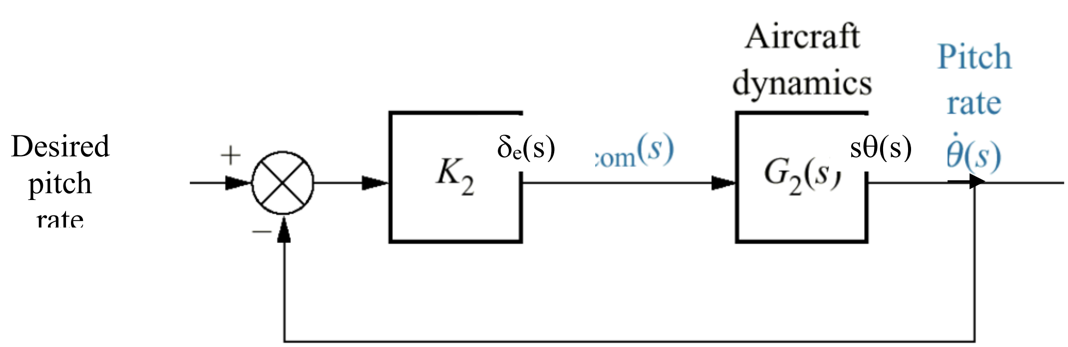


Figure 1. Block diagram a a pitch rate closed loop system. The command input on the left is the desired pitch rate.

c) When K_2 =-22 what are the closed-loop transfer function, and the gain and phase margins? The Nyquist and open-loop Bode plots are given below.

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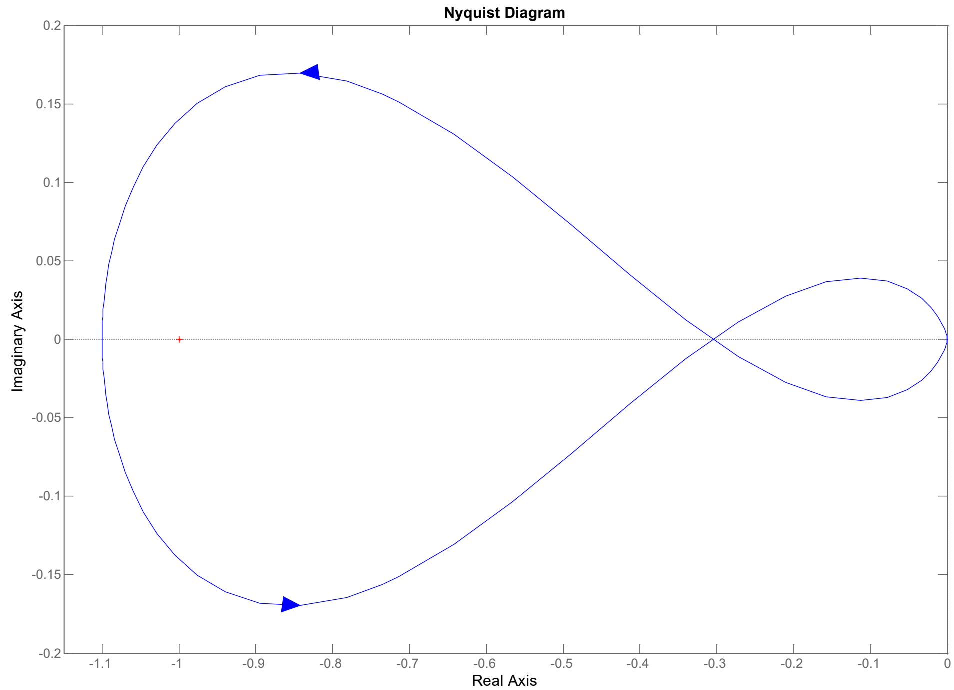

Figure 2. Nyquist plot of -22G_2(s).

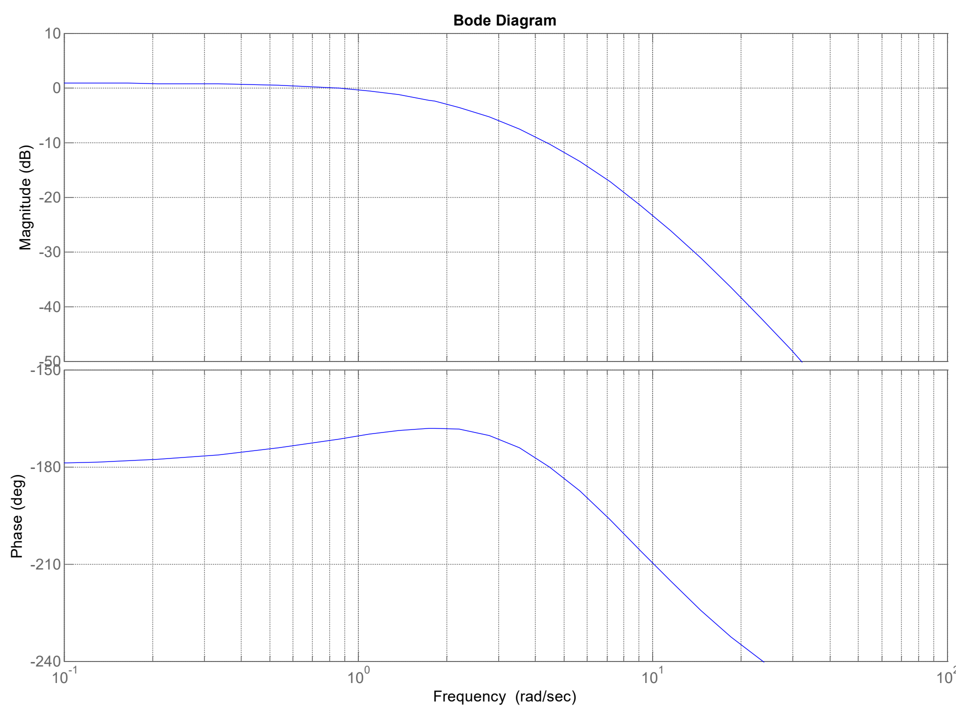

Figure 3. Bode plots of -22G_2(s).

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Laplace's Theorems

Let F(s) be the Laplace transform of f(t) .

- Initial Value Theorem
  - Now, if *F(s)* be a strictly proper rational transfer function (degree denominator > degree numerator), then

$$f\left(0^{+}\right)=\lim_{s\to\infty} sF\left(s\right).$$

- Final Value Theorem
  - If all the poles of *sF(s)* have negative real parts, then

$$\lim_{t\to\infty} f\left(t\right)=\lim_{s\to 0} sF\left(s\right).$$

PROBLEM C5 – SYSTEMS, SIGNALS AND IMAGE PROCESSING

<u>Communications Problem</u>:

Heterodyning is the process of shifting the spectrum of a given signal from one frequency band to a different one. Consider a real-valued bandpass signal $x_1(t)$ with center frequency f_1 and bandwidth B for which heterodyning is used to shift its spectrum to convert it to a new signal $x_2(t)$ with center frequency f_2.

1. Sketch a block diagram outlining how heterodyning is accomplished with clear notations for all blocks and signals involved in the process, and explain the difference between up-conversion and down-conversion of signal $x_1(t)$.

2. Explain using Fourier analysis how heterodyning changes the spectrum of bandpass signal $x_1(t)$ to produce signal $x_2(t)$. State the specific property of the Fourier transform that is relevant to heterodyning.

For full credit the explanations should be given in full sentences with sufficient details, and should include all supporting arguments.

PROBLEM C6 – SYSTEMS, SIGNALS AND IMAGE PROCESSING

<u>Communications Networks</u>

1. (5 pts) The data link layer at the transmitter retransmits a frame if it is not received by the receiver. If the probability of a frame being damaged is p. What is the mean number of transmissions needed to let the receiver successfully receive a frame?

2. (5 pts) A bit string 1101011111111 needs to be transmitted at the data link layer. What is the bit string actually transmitted after bit stuffing?

PROBLEM D1 – PHYSICAL ELECTRONICS I

The E-field measured in air just above a plastic plate, as shown in Fig. D1, is equal to 1 MV/m in magnitude and is directed at 30˚ away from the boundary. The magnitude of the E-field measured just below the boundary is equal to 1.22 MV/m. 1) Find the angle θ for the E-field in the glass just below the boundary. 2) Given the dielectric constant of glass is 1.25 times that of air, determine the critical angle θ_c of an air-glass horizontal interface.

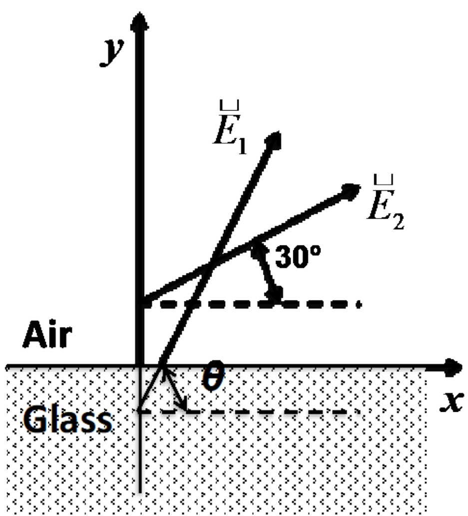
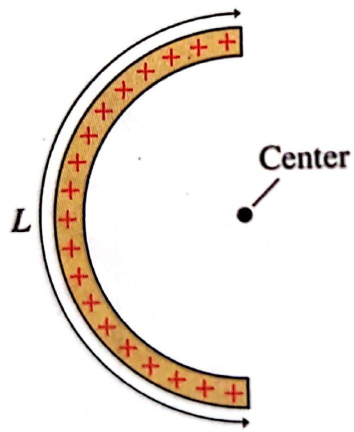


Fig. D1

PROBLEM D2 – PHYSICAL ELECTRONICS I

Electromagnetics

Charge Q is uniformly distributed along a thin, flexible rod of length $\boldsymbol{L}$. The rod is then bent into the semi-circle, as shown below. Find an expression for the electric field E at the center of the semicircle.



PROBLEM D3 – PHYSICAL ELECTRONICS I

Optical Fiber Communication

When a current pulse is applied to a laser diode, the injected carrier pair density n within the recombination region of width d changes with time according to the relationship:

$$\frac{\partial n}{\partial t} = \frac{J}{qd} - \frac{n}{\tau}$$

Assume τ is the average carrier lifetime in the recombination region when the injected carrier pair density is n_{th} near the threshold current J_{th}. That is, in the steady state we have:

$$\frac{\partial n}{\partial t} = 0 \qquad \text{so that} \qquad n_{th} = \frac{\tau J_{th}}{qd}$$

If a current pulse of amplitude I_p is applied to an unbiased laser diode, show that the time needed for the onset of stimulated emission is,

$$t_d = \tau \ln \frac{I_p}{I_p - I_{th}}$$

Assume the drive current $I = JA$, where J is the current density and A is the area of the active region.

PROBLEM E1 - PHYSICAL ELECTRONICS II

Physical Electronics

An abrupt Si P-N Junction with a cross-section of A = 10^{-4} cm^2 has the following properties:

P side	N side
$N_a = 10^{17}$ cm^{-3}	$N_d = 10^{15}$ cm^{-3}
$\tau_n =$ 0.1 μs	$\tau_p =$ 10 μs
$\mu_p = 200$ cm^2/ V-s	$\mu_n = 1300$ cm^2/ V-s
$\mu_n = 700$ cm^2/ V-s	$\mu_p = 450$ cm^2/ V-s

The junction is forward biased by 0.5 V.

a) What is the total forward current for an ideal p-n junction at + 0.5V bias?
(Need to calculate D_p, D_n, L_p, L_n, p_n, n_p)

b) What is the total current at a reverse bias of – 0.5V?

c) Calculate the junction potential also called built-in potential V_{bi}

d) What is the total depletion capacitance (C_j) at -4 V reverse bias?

e) Calculate the depletion widths on the p-side of the junction X_p and on the n-side X_n for the following reverse biases -4 V and -10 V, the sum of which provides the total depletion width W = $X_p + X_n$.

Physical Constants:

Intrinsic carrier concentration in Si : $n_i =$ 1.45 x 10^{10} cm^{-3}

Permittivity in Vacuum ε = 8.8854 x 10^{-14} F/ cm ;

Dielectric constant of S_i $K_{si} = 11.7$

Elementary Charge : q = 1.602 x 10^{-19} C

Boltzman Constant: k = 1.38066 x 10^{-23} J/ K = $8.62*10^{-5} eV/K$

Thermal voltage at 300K: kT/q = 0.0259 V

PROBLEM E2 – PHYSICAL ELECTRONICS II

1. (5 pts) For a silicon abrupt junction with $N_A = 2\ 10^{18}$ cm^{-3}, $\varepsilon_{max} = 2 \times 10^5$ V/cm at reverse bias V_R = 25V (T = 300K), calculate the n- type doping concentration.

2. (5 pts) Calculate the theoretical saturation current, I_S of an ideal silicon p-n junction having following specifications: $N_D=10^{18}$ cm^{-3}, $N_A= 10^{16}$ cm^{-3}, $\tau_p=\tau_n=3 \times 10^{-7}$s, D_p = 11 cm^2/s, D_n = 21 cm^2/s and a device area of 10^{-2} mm^2. Also calculate the forward current at 1 V.

$$J_p = q\mu_p p\left(\frac{1}{q}\frac{dE_i}{dx}\right) - kT\mu_p\frac{dp}{dx} \qquad \frac{d^2\psi}{dx^2} \equiv -\frac{d\mathscr{E}}{dx} = -\frac{\rho_s}{\varepsilon_s} = -\frac{q}{\varepsilon_s}(N_D - N_A + p - n).$$

$$V_{bi} = \psi_n - \psi_p = \frac{kT}{q}\ln\left(\frac{N_A N_D}{n_i^2}\right). \qquad N_A x_p = N_D x_n. \qquad W = x_p + x_n. \qquad \mathscr{E}_m = \frac{qN_D x_n}{\varepsilon_s} = \frac{qN_A x_p}{\varepsilon_s}.$$

$$V_{bi} = \frac{1}{2}\mathscr{E}_m W. \qquad W = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{N_A + N_D}{N_A N_D}\right)V_{bi}}. \qquad \mathscr{E}(x) = -\mathscr{E}_m + \frac{qN_B x}{\varepsilon_s}, \qquad \mathscr{E}_m = \frac{qN_B W}{\varepsilon_s}$$

$$C_j = \frac{\varepsilon_s}{W} = \sqrt{\frac{q\varepsilon_s N_B}{2(V_{bi} - V)}} \qquad V_{bi} = \frac{kT}{q}\ln\frac{p_{po}n_{no}}{n_i^2} = \frac{kT}{q}\ln\frac{n_{no}}{n_{po}}, \qquad n_{no} = n_{po}e^{qV_{bi}/kT}.$$

$$p_{po} = p_{no}e^{qV_{bi}/kT}. \qquad n_n = n_p e^{q(V_{bi}-V)/kT}, \qquad n_p = n_{po}e^{qV/kT}$$

$$J = J_p(x_n) + J_n(-x_p) = J_s\left(e^{qV/kT} - 1\right), \qquad J_s \equiv \frac{qD_p p_{no}}{L_p} + \frac{qD_n n_{po}}{L_n},$$

Silicon (300 K): N_C= 2.86 10^{19} cm^{-3} ; N_V = 2.66 10^{19} cm^{-3} ; n_i = 9.65 10^9 cm^{-3}

m_p =1 m_0; m_n = 0.19 m_0; m_0 = 0.91 10^{-30} kg; k = 1.38 10^{-23} J/K ; q = 1.6 10^{-19} C

ε_s = 105 10^{-14} F/cm

$$k_o = \frac{C_s}{C_l} \qquad k_e = \frac{C_s}{C_l} = \frac{k_o}{k_o + (1-k_o)e^{-v\delta/D}} \qquad C_s = C_0[1-(1-k_e)^{-k_e x/L}]$$

$$C_s = k_o C_o\left(1 - \frac{M}{M_o}\right)^{k_o - 1} \qquad C_s = k_e C_l e^{-k_e x/L}$$

$$F = \frac{DC_0}{x + (D/\kappa)}. \qquad x^2 + Ax = B(t + \tau). \qquad A = 2D/\kappa, B = 2DC_0/C_1$$

$$B/A = \kappa C_0/C_1. \qquad \tau = (d_0^2 + 2Dd_0/\kappa)C_1/2DC_0$$

PROBLEM E3 – PHYSICAL ELECTRONICS II

An electron with an energy of 100 eV is attenuated to half its original flux after passing a distance of 5 cm in a gas. If the gas density is 2×10^{14} cm^{-3}, find:

(a) The electron mean free path (4 points)

(b) The electron collisional frequency (4 points)

(c) What type of collisions do you expect to be dominant? What do these dominant collisions result in? (2 points)

(Note: 1 eV = 1.6×10^{-19} J)

PROBLEM F1 – COMPUTER SYSTEMS

Microprocessors

In robotic applications, a wheel encoder can be used to measure the angular position, angular velocity, and angular acceleration of a wheel. Combined with other robotic information including the dimensions, physical state of the robotic vehicle, and other sensor information, the position/velocity/acceleration of the robotic vehicle can be estimated.

The wheel encoder generates pulses as the wheel rotates. Assume that when the wheel completes a full rotation, 100 pulses are generated. The pulse width is 1ms±5%.

You have been charged with designing a microcontroller based system to report an estimate of the ***linear*** position, velocity, and acceleration with respect to a convenient reference position. For these estimates, assume the wheel is 10cm in diameter. Further, velocity and acceleration estimates based on two successive pulses are too noisy, so your estimates should be based on an average derived from several successive pulses.

Your microcontroller system should use interrupt driven timers to capture timing information. Furthermore, your microcontroller system should use memory mapped I/O to interface to any required peripherals.

Answer the following questions for the information given above. Clearly state any additional assumptions you need to make.

1. (2 points) Give a block diagram of the system. Note also the addresses assigned to peripherals and any details regarding how your timers operate.
2. (4 points) Give the pseudocode or the flow chart for software required to implement this system.
3. (4 points) Give the assembly language program, in a form as complete as possible, for this system. Include all initialization and interrupt handling code. You may use either the assembly language attached or an assembly language you are familiar with (please indicate).

Continued on next page

Category	Instruction				Low power	Meaning
Arithmetic	addi	rB,	rA	imm[1]		rB ← rA + imm_s
	add	rC,	rA,	rB		rC ← rA + rB
	sub	rC,	rA,	rB		rC ← rA − rB
	muli	rC,	rA,	rB		rC ← $(rA \times imm_s)_{31..0}$
	mul	rC,	rA,	rB		rC ← $(rA \times rB)_{31..0}$
	mulxuu	rC,	rA,	rB		rC ← $((unsigned)rA \times (unsigned)rB)_{63..32}$
Logical	and	rC,	rA,	rB		rC ←rA *and* rB
	andi	rB,	rA,	imm	y	rB ←rA *and* imm_u
	or	rC,	rA,	rB		rC ←rA *or* rB
	ori	rB,	rA,	imm	y	rB ←rA *or* imm_u
	xor	rC,	rA,	rB		rC ←rA *xor* rB
	xori	rB,	rA,	imm	y	rB ←rA *xor* imm_u
	nor	rC,	rA,	rB		rC ←rA *nor* rB
Comparator	cmpgei	rB,	rA,	imm		rB ← $(rA \geq imm_s)$? 1 : 0
	cmplti	rB,	rA,	imm		rB ← $(rA < imm_s)$? 1 : 0
	cmpnei	rB,	rA,	imm		rB ← $(rA \neq imm_s)$? 1 : 0
	cmpeqi	rB,	rA,	imm		rB ← $(rA = imm_s)$? 1 : 0
	cmpgeui	rB,	rA,	imm		rB ← $(rA \geq imm_u)$? 1 : 0
	cmpltui	rB,	rA,	imm		rB ← $(rA_u < imm_u)$? 1 : 0
	cmpge	rC,	rA,	rB		rC ← $(rA \geq rB)$? 1 : 0
	cmplt	rC,	rA,	rB		rC ← $(rA < rB)$? 1 : 0
	cmpne	rC,	rA,	rB		rC ← $(rA \neq rB)$? 1 : 0
	cmpeq	rC,	rA,	rB		rC ← $(rA = rB)$? 1 : 0
	cmpgeu	rC,	rA,	rB		rC ← $(rA_u \geq rB_u)$? 1 : 0
	cmpltu	rC,	rA,	rB		rC ← $(rA_u < rB_u)$? 1 : 0
Shifts	sll	rC,	rA,	rB		rC ← rA << $rB_{4..0}$
	slli	rC,	rA,	imm		rC ← rA << $imm_{4..0}$
	srl	rC,	rA,	rB		rC ← rA_u >> $rB_{4..0}$
	srli	rC,	rA,	imm		rC ← rA_u >> $imm_{4..0}$
	sra	rC,	rA,	rB		rC ← rA_s >> $rB_{4..0}$
	srai	rC,	rA,	imm		rC ← rA_s >> $imm_{4..0}$
	rol	rC,	rA,	rB		rC ← rA *rol* $rB_{4..0}$
	ror	rC,	rA,	rB		rC ← rA *ror* $rB_{4..0}$
	roli	rC,	rA,	imm		rC ← rA *rol* $imm_{4..0}$
Memory	ldw	rB,	imm	(rA)	y	rB ← MEM[imm_s+rA]
	stw	rB,	imm	(rA)	y	MEM[imm_s+rA] ← rB
Branch	br	imm			y	PC ← PC+4+imm_s
	bge	rA,	rB,	imm		if$(rA \geq rB)$ PC ← PC+4+imm_s
	blt	rA,	rB,	imm		if$(rA < rB)$ PC ← PC+4+imm_s
	bne	rA,	rB,	imm	y	if$(rA \neq rB)$ PC ← PC+4+imm_s
	beq	rA,	rB,	imm	y	if$(rA = rB)$ PC ← PC+4+imm_s
	bgeu	rA,	rB,	imm		if$(rA_u \geq rB_u)$ PC ← PC+4+imm_s
	bltu	rA,	rB,	imm		if$(rA_u < rB_u)$ PC ← PC+4+imm_s
Jump[2]	call	imm				PC ← imm << 2 ; retAdd←PC+4
	callr	rA				PC ← rA ; retAdd←PC+4
	ret					PC ← retAdd
	jmp	rA				PC ← rA
	jmpi	imm			y	PC ← imm << 2
System	IntEn					Enable interrupt
	IntDs					Disable interrupt

[1]imm=$IR_{15..0}$ unless otherwise noted, imm_s is signed, imm_u is unsigned

[2]for Jump instructions imm=$IR_{27..0}$

PROBLEM F2 – COMPUTER SYSTEMS

<u>Digital Systems</u>

You are designing a Tolerance Monitoring System (TMS), a digital system, that monitors a manufacturing line for widgets. The TMS computes the empirical probability that the number of widgets manufactured is out of tolerance and below a certain threshold. The manufacturing line must be shut down if the probability exceeds the threshold.

When the widget exits the manufacturing line, it is measured and the measured value (*M*) is assessed against the required tolerances. The minimum and maximum acceptable tolerances are $T_{\min}$ and $T_{\max}$, respectively. After the manufacturing line has produced at least *N* widgets, when the empirical probability that the bad widgets exceeds a certain threshold (P_{bad}) a signal (*F*) is asserted indicating that the manufacturing line must be shut down.

Finally, your TMS should be expandable to simultaneously monitor 10 independent manufacturing lines.

Answer the following questions using this information. State any additional assumptions you need to make.

4. (4 point) Give the SM chart for a TMS capable of monitoring one manufacturing line.
5. (4 points) Give the associated datapath for the TMS.
6. (2 points) In your favored hardware description language (either VHDL or Verilog), give the entity or module interface as appropriate. With your entity/module interface give a code efficient (fewest lines of code) for the larger TMS system that monitors 10 independent manufacturing lines.

PROBLEM F3 – COMPUTER SYSTEMS

Computer Architecture

1. Suppose the current program counter (PC) is set to $2000\ 0000_{hex}$. Is it possible to use the jump (j) MIPS instruction to set the PC to the address as $3200\ 0000_{hex}$? Why? (need to elaborate on how you get your answer.

2. If we have hit the power wall (i.e., unable to reduce supply voltage much further or the capacitive load; No new coooling technologies to remove more heat), we have to reduce the power consupmption, but still want to increase the performance of the computer in terms of CPU exeecution time for a program. How can we achive this? Why?

PROBLEM F4 – COMPUTER SYSTEMS

Computer Algorithms

You are composing an algorithm study the properties of prime numbers and one input is the sequence of prime numbers starting with 2 up to the N^{th} prime number.

The specific property you are studying is prime number triples that differ by $2R$, where R is a positive integer and the second input. The prime numbers in the triple do not need to be consecutive. For example, if $R = 1$, an example is 3, 5, 7.

1. (6 point) Assuming the prime number list is input as well as the integer R, give the pseudocode for an algorithm that searches for prime number triples through the N^{th} prime number.
2. (4 points) Give the time and space complexity of your algorithm.

PROBLEM F5 – COMPUTER SYSTEMS

Data Structure

1.

A stack bStack contains the following items

7
8
−3
14
5

What is the output to the screen of the following code?

```
int x;
while (!bStack.isEmpty()){
  bStack.pop(x);
  if (x>0 && !bStack.isEmpty())
    bStack.pop();
  cout << x << endl;
}
```

2.

Please provide pseudo code or diagram (explanations) for following questions

Given the input A (2, 8, 7, 2 0, 1, 1, 6),

2.1 Construct a binary search tree according to the input A sequence.

2.2 Add a node, 5, into this binary search tree?

2.3 Delete a node, 0, from this binary search tree?

PROBLEM F6 – COMPUTER SYSTEMS

Logic Design

A circuit accepts a 4-bit word (A, B, C and D) that gives 1 **iff** it detects a pattern of two-consecutive 1s (11) in the word. (10 points)

(a) (4 pts) Using K-map give the minimal **Sum-of-Product (SOP)** form.

(b) (3 pts) Draw the minimized SOP of F in part a using "NAND" and "NOT" (INV) gates.

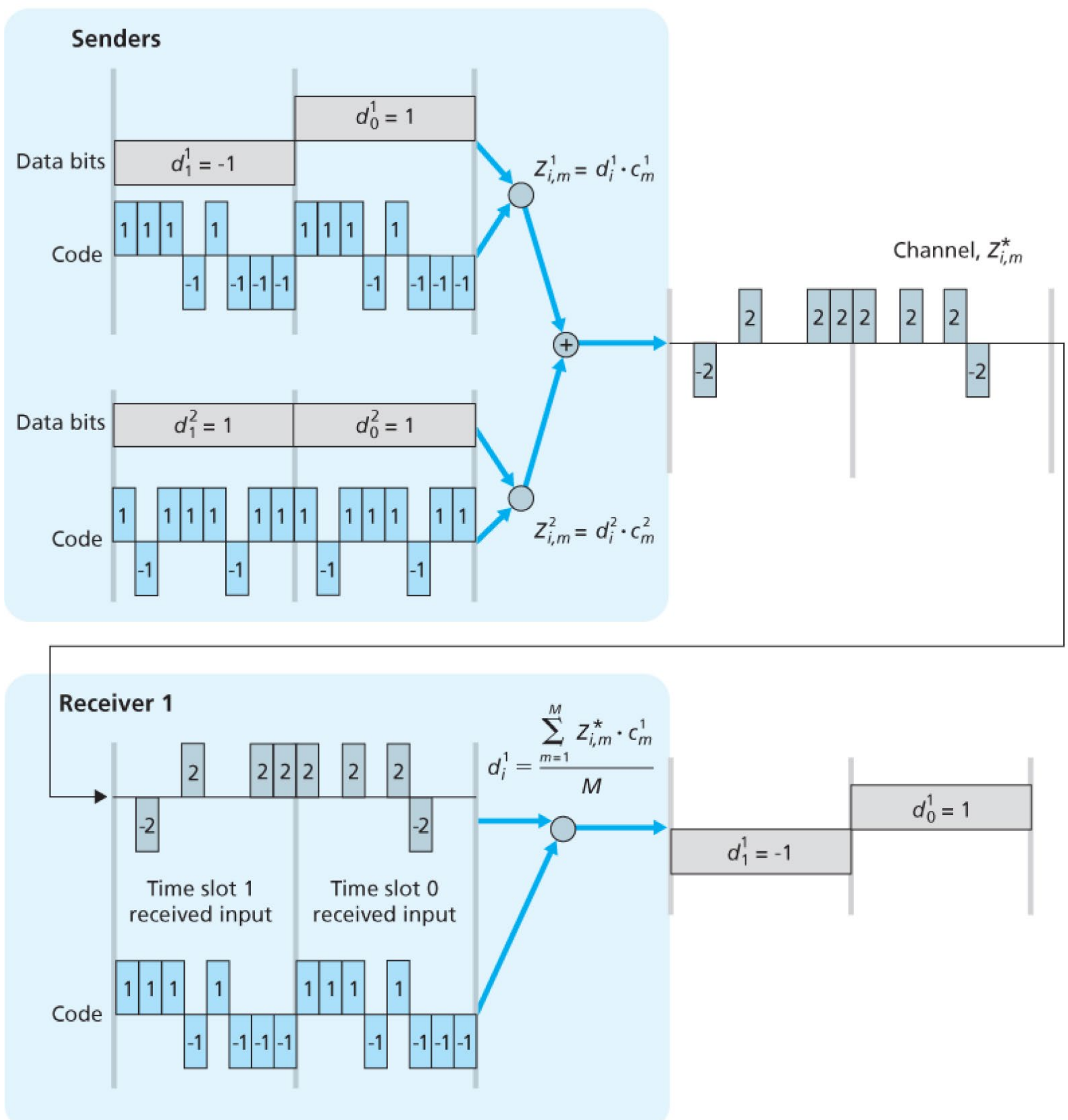
(c) (3 pts) Give the longest path delay and the shortest path delay of the circuit in part b using the gates information in the table

Gate	t_{pd} (ps)	t_{cd} (ps)
NOT	15	10
2-input NAND	20	15
3-input NAND	30	25
2-input NOR	30	25
3-input NOR	45	35
2-input AND	30	25
3-input AND	40	30
2-input OR	40	30
3-input OR	55	45
2-input XOR	60	40

PROBLEM G1 – CYBERSECURITY

<u>Computer Networks and Security</u>

1. Consider sender 2 in Figure below,
   a) What is the sender's output to the channel if the sender's 2 CDMA code were $(1, -1, 1, -1, 1, -1, 1, -1)$ (before it is added to the signal from sender 1), $Z^2_{i,m}$?
   b) Suppose that the receiver in the Figure wanted to receive the data being sent by sender 2. Show (by calculation) that the receiver is indeed able to recover sender 2's data from the aggregate channel signal by using sender 2's code given in part a.



PROBLEM G2 – CYBERSECURITY

Cyber Defense Fundamentals

1. (5 pts) What is the difference between encryption and digital signature?

2. (5 pts) Give one example of public key cryptography algorithm, and describe the mathematics foundation of the algorithm, e.g., what kind of math functions are used by the algorithm.

PROBLEM G3 – CYBERSECURITY

Cyber Physical System Security

1. (5 pts) If passwords are three uppercase alphabetic characters long, how much time would it take to determine a particular password, assuming that testing an individual password requires 5 seconds?

2. (5 pts) What is a distributed denial of service (DDOS) attack?

PROBLEM G4 – CYBERSECURITY

Buffer Overflow

Assume we want to protect a program vulnerable through a buffer overflow attack. The OS is Linux and the memory addresses are 4 bytes long. Assume that the function parse_string called from its main(), whose inputs can be controlled by the attacker. In the function below, the programmer intends to copy a substring of the string str to the buffer buf. The substring starts at position pos1 in str and ends at pos2. The programmer carefully checks the length substring before using malloc to allocate memory for the buffer. Assumes the string is indexed as follows: the leftmost character is at position 0, and so on.

```
int parse_string(char *str, int pos1, int pos2) {
   ⋮
   char buf[1024];

   if(pos2-pos1 > 1024)
      exit(-1);
   strcpy(buf, str);
   ⋮
   return 1;
}
```

a) Explain how there can be a buffer overflow in the above program. (5 pts)

b) How would you fix the above code such that there is no possibility of a buffer overflow? (5pts)

PROBLEM G5 – CYBERSECURITY

Security and Privacy of Embedded Systems

A. Define side-channel attacks in embedded systems and identify three possible side-channel attacks, explain. (4 pts)

B. The sensors in certain embedded systems use a communication protocols where data from various on-board sensors is read as a stream of bytes from a designated port or network socket. The code below illustrates one such scenario. Here, the programmer expects to read at most 16 bytes of sensor data, storing them into array **sensor_data.**

a. Identify the security problem in this code. (3 pts)
b. Suggest a scenario an attacker can distort this code and cause security issue. (3 pts)

```
char sensor_data [16];
int secret-key;
void read_sensor_data () {
   int i  = 0;
      // more_data returns 1 if there is more data, and 0 otherwise
   while (more_data () )    {
    sensor_data [i] = get_next_byte ();
     i++;
     }
     return;
  }
```