DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING
OLD DOMINION UNIVERSITY
MS COMPREHENSIVE EXAM
Spring 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
Spring 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 eight 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 the nonhomogeneous equation

$y'' - 4y' + 3y = 10e^{-2x}$

PROBLEM A2 – MATH

Math Calculus

Consider a two dimensional flow field in the xy-plane with velocity components

$$u_x = 3x + y, \qquad u_y = 2x - 3y \tag{1}$$

Determine the circulation

$$\oint_C \mathbf{u} \cdot d\ell \tag{2}$$

where C is the contour $(x-1)^2 + (y-6)^2 = 4$

Note: $\boldsymbol{d\ell}$ is the vector path length along the contour.

PROBLEM A3 – MATH

Linear Algebra

Consider the matrix

$$A = \begin{bmatrix} 1 & 1 & 2 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}$$

1. Determine the LU factorization of matrix A, that is find matrices P, L, and U such that $PA = LU$, where P is a permutation matrix, L is a lower triangular matrix with all diagonal elements equal to 1, and U is an upper triangular matrix.
2. Determine the QR factorization of matrix A by applying the Gram-Schmidt orthogonalization procedure to determine an orthogonal matrix Q and an upper triangular matrix R such that $A = QR$.
3. Discuss how the LU and QR factorizations are used in the context of solving systems of linear equations.

PROBLEM A4 – MATH

Probability

Consider all the solutions to the equation

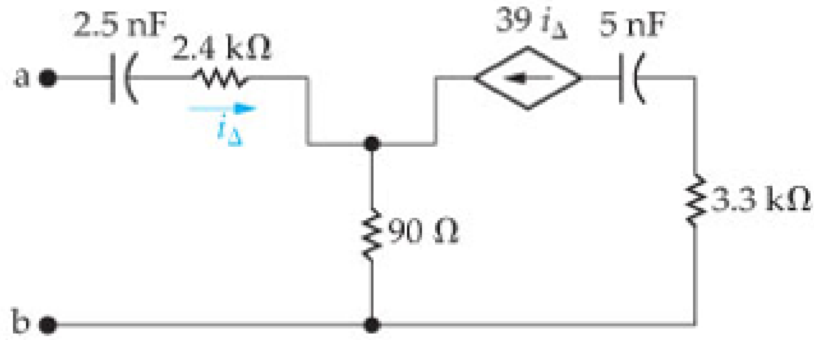
$$x_1 + x_2 + x_3 + x_4 + x_5 = 20,$$

where each x_i is a positive integer. If a solution is selected at random, what is the probability that all the x_i's are the same?

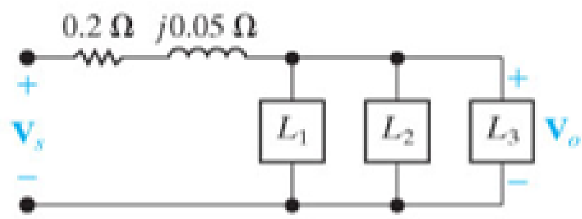
PROBLEM B1 – CIRCUITS AND ELECTRONICS

Sinusoidal Steady State Analysis

A. Find the Thevenin impedance seen looking into the terminals a,b of the circuit in the figure if the frequency of operation is $(25/\pi)$kHz.



B. Three loads are connected in parallel across a $V_o=310\angle 0°$V (rms) line and fed from a line having a series impedance $0.2+j0.05$ Ω, as shown in figure. Load 1 absorbs 3 kW at unity power factor; Load 2 absorbs 5 kVA at 0.8 leading; Load 3 absorbs 5 kWand delivers 6 kVAR



a) Calculate the rms value of the voltage ($\mathbf{V}_S$) at the sending end of the line.
b) Calculate the average power associated with the line impedance. Use positive value if the power is absorbed and negative value if the power is delivered.
c) Calculate the reactive power associated with the line impedance. Use positive value if the reactive power is absorbed and negative value if the reactive power is delivered.
d) Calculate the average power at the sending end of the line associated with the line and the load. Use positive value if the power is absorbed and negative value if the power is delivered.
e) Calculate the reactive power at the sending end of the line associated with the line and the load. Use positive value if the reactive power is absorbed and negative value if the reactive power is delivered.
f) Calculate the efficiency (η) of the line if the efficiency is defined as $\eta=(P\text{load}/P\text{sendingend})\times 100\%$.

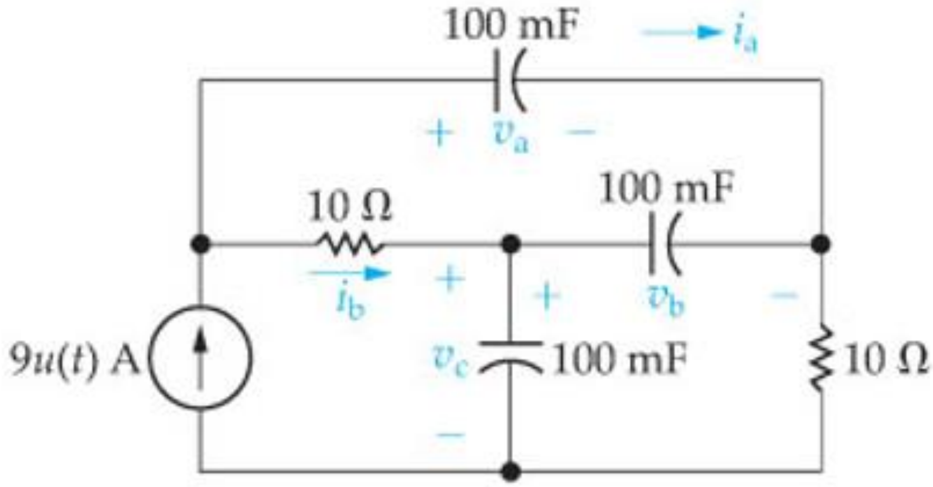
PROBLEM B2 – CIRCUITS AND ELECTRONICS

Laplace Application to Circuit Analysis

A. Given that $F(s) = L\{f(t)\}$, show that

$$(-1)^n \frac{d^n F(s)}{ds^n} = \mathcal{L}(t^n f(t))$$

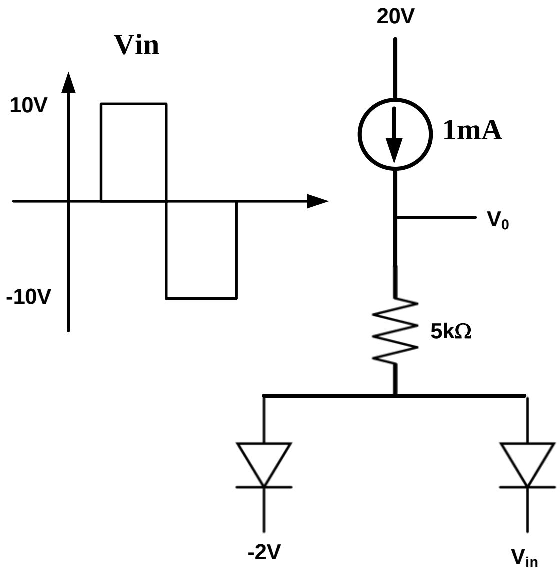
B. There is no energy stored in the circuit in the figure at the time the current source is energized. Draw the circuit in s-domain and solve.



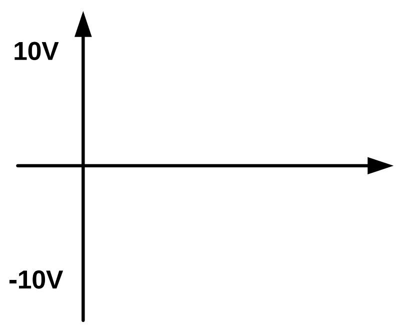
a) Find $I_a(s)$ and $I_b(s)$
b) Find $i_a(t)$ and $i_b(t)$
c) Find $V_a(s)$, $V_b(s)$ and $V_c(s)$
d) Find $v_a(t)$, $v_b(t)$ and $v_c(t)$.

PROBLEM B3 – CIRCUITS AND ELECTRONICS

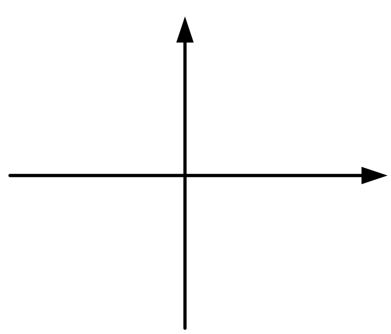
Assume that v_i is a 1 kHz, 10 V peak rectangle wave as shown in below figure and diodes are ideal and have no voltage drop.



(a) Sketch the waveform resulting at v_o and show your work

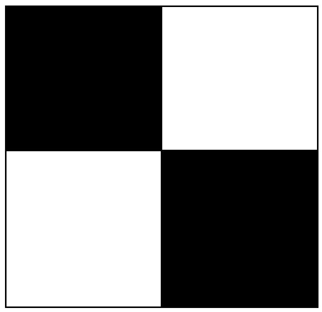


(b) Sketch the transfer characteristic v_o versus v_{in} and show your works



PROBLEM C1 – SYSTEMS, SIGNALS AND IMAGE PROCESSING

<u>Digital Image Processing</u>



(a)

(b)

The two purely black and white images shown above are each 40 x 40 pixels. Each image contains an equal number of black and white pixels, which are represented using 8-bit grayscale intensity levels. The black lines around the boarder signify the image edges and are not pixels. Answer the following questions. Clary label all axes.

a. Sketch the histogram of each image, a and b.

b. Suppose each image is smoothed using a 3x3 uniform filter having coefficients that sum to 1. Disregarding the pixels that are affected by the image boundaries, determine all unique pixel intensity values that will be present in each smoothed image.

c. Roughly sketch the two resulting histograms from part b.

d. Roughly sketch the 2D Discrete Fourier Transform (DFT) of each original image (Prior to smoothing)

PROBLEM C2 – SYSTEMS, SIGNALS AND IMAGE PROCESSING

(a). (2 points) Given $x[n] = u[n] - u[n\text{-}1000]$ and $h[n] = u[n] - u[n\text{-}50]$. If $y[n]$ is the linear convolution of $x[n]$ and $h[n]$ as $y[n] = x[n] * h[n]$, what is the maximum value of $y[n]$?

(b). (2 points) What is the fundamental period of $x[n] = cos(\frac{1}{9}\pi n)$?

(c). (3 points) Let $h[n]$ denote the impulse response of a LTID system

$$h[n] = u[n]$$

what is the zero-state response for the input of $h[n] = (1/3)^n u[n\text{-}2]$?

(d). (3 points) Two finite length signals, $x_1[n]$ and $x_2[n]$ are given as:

$$x_1[n] = 2u[n] - 2u[n\text{-}6]$$
$$x_2[n] = u[n] - u[n\text{-}4]$$

Let $y[n]$ be the **linear convolution** of $x_1[n]$ and $x_2[n]$ Determine $y[n]$.

PROBLEM C3 – SYSTEMS, SIGNALS AND IMAGE PROCESSING

An analog signal, $x(t)$, has a bandwidth of $40k$ Hz. In this problem, you will work as an engineer to design a simple discrete-time signal processing system to process the signal.

a) (2 points) In the first step, you will sample this analog signal. What is the Nyquist rate for $x(t)$?

b) (4 points) Assume that you sampled the analog signal, $x(t)$, using a sampling frequency of $90k$ Hz and obtained a discrete-time signal $x[n]$, what is the highest frequency in $x[n]$?

c) (4 points) If you want to design a discrete-time low-pass filter $h[n]$ to filter out all frequency components beyond $5k$ Hz in $x(t)$, what is the cut-off frequency of $h[n]$?

PROBLEM C4 – SYSTEMS, SIGNALS AND IMAGE PROCESSING

Control Systems

Consider the block diagram of a closed-loop position control system in Figure C2.1 where the transfer function of the plant is

$$G_p(s) = \frac{5}{s(s+5)}.$$

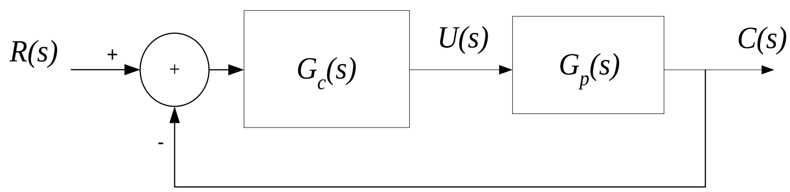


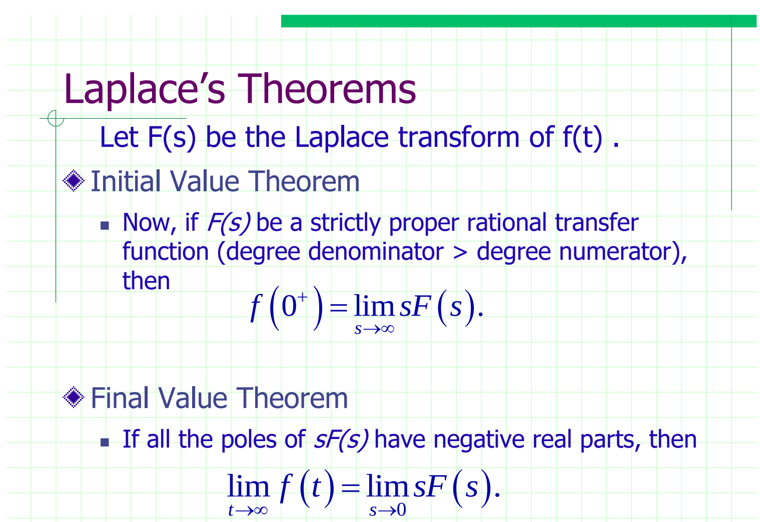
Figure C2.1. Block diagram of a closed-loop system.

a) If a proportional controller is used, that is, $G_c(s) = K$, find the following two transfer functions: $T_{rc}(s) = \dfrac{C(s)}{R(s)}$ and $T_{ru}(s) = \dfrac{U(s)}{R(s)}$. If the closed-loop system is asymptotically stable, find the initial and final values of the unit step responses corresponding to $c(t)$ and $u(t)$.

b) Analytically find the range of values for the gain K that make the closed-loop system asymptotically stable.

c) Find the range of gains K that make the steady-state error to the input $r(t) = 5,\ \ t > 0$ be less than 1%.

d) Design a proportional controller that results in a stable closed-loop system with little if any overshoot to a step response. What is the approximate gain margin of this design? What is the significance of the gain margin?



PROBLEM C5 – SYSTEMS, SIGNALS AND IMAGE PROCESSING

Communications Problem:

Consider a sinusoidal carrier $c(t) = A_c \cos(2\pi f_c t)$ and the information-bearing signal $m(t) = A_m \cos(2\pi f_m t)$ where $f_c >> f_m$.

1. Describe how frequency modulation (FM) of the carrier $c(t)$ with $m(t)$ is accomplished and write the mathematical expression of the resulting FM signal $u(t)$. Argue whether FM is a linear modulation scheme or not.
   Note: you must provide mathematical proof to get credit.
2. Write the expression of the maximum frequency deviation $\Delta f_{\max}$ for the FM signal and define the modulation index β_f for the FM scheme.
3. Write the expressions of the pre-envelope signal $u_+(t)$ and of the complex envelope $\tilde{u}(t)$ corresponding to the FM signal $u(t)$, and determine the in-phase and quadrature components $u_I(t)$ and $u_Q(t)$ of the FM signal $u(t)$.
4. Argue that $\tilde{u}(t)$ is periodic and use its Fourier series representation to evaluate the spectrum of the FM signal $u(t)$.

USEFUL MATHEMATICAL FORMULAS

Trigonometric identities:

$$\sin(x \pm y) = \sin x \cos y \pm \sin y \cos x$$

$$\cos(x \pm y) = \cos x \cos y \mp \sin x \sin y$$

$$\cos(x)\cos(\mathrm{y}) = \frac{\cos(\mathrm{x - y}) + \cos(\mathrm{x + y})}{2}$$

$$\sin(\mathrm{x})\ \sin(\mathrm{y}) = \frac{\cos(\mathrm{x - y}) - \cos(\mathrm{x + y})}{2}$$

$$\sin(x)\cos(\mathrm{y}) = \frac{\sin(\mathrm{x - y}) + \sin(\mathrm{x + y})}{2}$$

Euler's formula

$$e^{jx} = \cos(x) + j\sin(x)$$

Hilbert transform pairs

$$\mathcal{H}\{\cos 2\pi f_c t\} = \sin 2\pi f_c t$$

$$\mathcal{H}\{\sin 2\pi f_c t\} = -\cos 2\pi f_c t$$

Fourier transform pair: $\mathcal{F}\{e^{j2\pi f_0 t}\} = \delta(f - f_0)$

PROBLEM C6 – SYSTEMS, SIGNALS AND IMAGE PROCESSING

<u>Communications Networks</u>

1. (5 pts) We have a character frame from the higher layer: A B FLAG C. Assume the byte stuffing framing method is used at the data link layer, what will be the actual frame to be transmitted? Note the special characters are FLAG and ESC.

2. (5pts) The data link layer retransmits a frame if it is not acknowledged by the receiver. If the probability of a frame being damaged is p, and the probability of an ACK being damaged is q. Suppose the user data contains n frames. What is the mean number of transmissions needed to let the receiver successfully receive all frames?

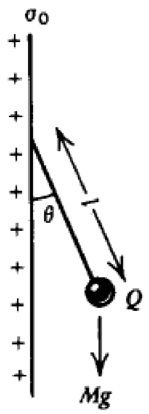
PROBLEM D1 – PHYSICAL ELECTRONICS I

A 60-MHz plane wave traveling in the negative *x*-direction in dry soil with relative permittivity $\varepsilon_r = 4$ has an electric field polarized along the *z*-direction [*i.e.*, $\vec{E} = \hat{z}E(t, x)$]. Dry soil is assumed to be lossless. Given that the magnetic field has a peak value of 10 (mA/m) and that its value was measured to be 7 (mA/m) at $t = 0$ and $x = -0.75$ m, develop complete expressions for the wave's electric $\vec{E}(x, t)$ and magnetic fields $\vec{H}(x, t)$ by calculate the angular frequency, wavenumber, and initial phase. Must indicate the direction of the fields as well as the units.

PROBLEM D2 – PHYSICAL ELECTRONICS I

Electromagnetics

A small sphere of mass M in a gravity field g carrying a charge Q is connected by a massless string to a sheet of surface charge of the same polarity with density σ_0. What is the angle θ between the sheet and charge?



PROBLEM D3 – PHYSICAL ELECTRONICS I

Fiber Optics Communications

Derive the expressions of the numerical aperture, NA, and the acceptance angle, Θ_a, of an optical fiber with a core refractive index n_1 and a cladding refractive index n_2. Show all details of your derivation.

PROBLEM E1 - PHYSICAL ELECTRONICS II

Consider a long n-channel **MOSFET** characterized by the following technical parameters:

N^+ polySi gate (with work function $\mathbf{\Phi_M = \chi_S = 4.04}$ **eV**);
gate oxide thickness $\mathbf{d_{ox} = 15}$ **nm,**
uniform doping $\mathbf{N_A = 10^{17}}$ $\mathbf{cm^{-3}}$; length $\mathbf{L = 1.0}$ **µm,** width $\mathbf{Z = 10.0}$ **µm,**
at a bias given by $\mathbf{V_G = 2.5}$ **V**, and $\mathbf{V_{DS} = 1.0}$**V**, plus back-bias $\mathbf{V_{BS} = 0}$ **V**.
Use $\mathbf{\mu_e = 500}$ $\mathbf{cm^2/}$ **V-s.**

a) Calculate the oxide capacitance $\mathbf{C_{ox}}$ and the factor $\mathbf{K} = (\varepsilon_s\, q\, N_A)^{1/2}/C_{ox}$

b) Calculate the surface potential $\mathbf{\Psi_s}$

c) Calculate the flatband voltage $\mathbf{V_{FB}}$

d) Calculate the threshold voltage $\mathbf{V}_T$

e) Calculate the sheet charge density $\mathbf{Q_i\,(x=0)}$ at the source end of the channel at the indicated bias.

f) Calculate the sheet charge density $\mathbf{Q_i\,(x=L)}$ at the drain end of the channel at the indicated bias. Determine if this MOSFET is actually biased in the linear regime or the saturation regime.

g) Calculate the drain current $\mathbf{I_D}$

If the same MOSFET is now biased with $V_G = 2.5$ V and $V_{DS} = 4$ V,
the transistor is now biased in the saturation regime.

a) Calculate the saturation drain current $\mathbf{I_{Dsat}}$

PROBLEM E2 – PHYSICAL ELECTRONICS II

Physical electronics

1. Draw a (011) plane and a (111) plane for crystalline silicon

2. Using an energy-momentum diagram, explain the difference between a direct bandgap semiconductor and indirect bandgap semiconductor. Give two examples of semiconductor for each type of bandgap, and explain what is the most suited device application for each type of bandgap.

3. An ideal silicon junction has $N_A = 2 \times 10^{19}$ cm^{-3} and $N_D = 4 \times 10^{15}$ cm^{-3}. Calculate the depletion layer width, the maximum field and the junction capacitance at zero volt and at reverse bias of 3V (T = 300K).
   A list of equations and data is provided to you below. Please note that not all equations and data should be used.

$$J_p = q\mu_p p\left(\frac{1}{q}\frac{dE_i}{dx}\right) - kT\mu_p\frac{dp}{dx}$$

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

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

$$\mathscr{E}_m = \frac{qN_D x_n}{\varepsilon_s} = \frac{qN_A x_p}{\varepsilon_s}. \qquad V_{bi} = \frac{1}{2}\mathscr{E}_m W. \qquad W = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{N_A + N_D}{N_A N_D}\right)V_{bi}}.$$

$$\mathscr{E}(x) = -\mathscr{E}_m + \frac{qN_B x}{\varepsilon_s}, \qquad \mathscr{E}_m = \frac{qN_B W}{\varepsilon_s} \qquad C_j = \frac{\varepsilon_s}{W} = \sqrt{\frac{q\varepsilon_s N_B}{2\left(V_{bi} - V\right)}}$$

$$V_{bi} = \frac{kT}{q}\ln\frac{p_{po}n_{no}}{n_i^2} = \frac{kT}{q}\ln\frac{n_{no}}{n_{po}}, \qquad n_{no} = n_{po}e^{qV_{bi}/kT}.$$

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

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

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

PROBLEM E3 – PHYSICAL ELECTRONICS II

(5 points) **(a)** For a Maxwellian electron speed distribution:

$$f(v) = 4\pi v^2 \left(\frac{m}{2\pi kT}\right)^{\frac{3}{2}} e^{-\frac{mv^2}{2kT}}$$

Calculate the most probable speed.

(5 points) **(b)** Calculate the mean speed of the following distribution function of speed?

$f(v) = 3nv^2$ for $0 \leq v \leq 1$ and $f(v) = 0$ otherwise, n is the particle density.

PROBLEM F1 – COMPUTER SYSTEMS

Microprocessors

You are designing and prototyping a safety device for an assisted driving mode that keeps the vehicle in the lane on the highway which will be referred to as lane driving assistant (LDA). Safe operation of the vehicle requires the attention of the driver while the vehicle is in LDA mode. In the event the driver has their hands off the wheel for a designated period of time T_S, the system issues a warning to the driver. In addition, the LDA includes a prototype eye tracking system (not a common feature today) to confirm the driver's attention is on the roadway. If the driver is inattentive for some period of time T_A, the system also issues a warning.

Your microcontroller system should use interrupt driven timers in the above warning system. Furthermore, your microcontroller system should use memory mapped I/O to interface to the required peripherals. Further, you should assume each peripheral generates a simple binary input signal to indicate whether a particular condition is true (hands on steering wheel, appropriately attentive). Finally, assume your microcontroller operates using a 50 MHz clock.

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 initializations and interrupt handling. 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 ≥ imm_s)? 1 : 0
	cmplti	rB,	rA,	imm		rB ← (rA < imm_s)? 1 : 0
	cmpnei	rB,	rA,	imm		rB ← (rA ≠ imm_s)? 1 : 0
	cmpeqi	rB,	rA,	imm		rB ← (rA = imm_s)? 1 : 0
	cmpgeui	rB,	rA,	imm		rB ← (rA ≥ imm_u)? 1 : 0
	cmpltui	rB,	rA,	imm		rB ← (rA_u < imm_u)? 1 : 0
	cmpge	rC,	rA,	rB		rC ← (rA ≥ rB)? 1 : 0
	cmplt	rC,	rA,	rB		rC ← (rA < rB)? 1 : 0
	cmpne	rC,	rA,	rB		rC ← (rA ≠ rB)? 1 : 0
	cmpeq	rC,	rA,	rB		rC ← (rA = rB)? 1 : 0
	cmpgeu	rC,	rA,	rB		rC ← (rA_u ≥ 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 ≥ 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 ≠ 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 ≥ 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

Digital Systems

You are designing a digital system that is a part of a laser range finder. The range finder emits a laser pulse that reflects off an object and the reflected pulse is detected. The duration between when the laser pulse is emitted and when the reflected pulse is detected, the time of flight, can be used to determine the distance between the range finder and the object.

Assume the digital system's clock frequency is 200MHz and the speed of light is 299,705,543 m/s at sea level and standard pressure.

1. (2 points) Give the range measured and percentage error resulting in distances of 1m, 5m, 10m and 50m assuming the time resolution is 5ns. Assume the pulse is emitted on the rising edge of the clock and the reflected pulse is detected on the rising clock edge after arrival at the detector.

2. (4 points) Create a SM chart that includes the salient features to calculate the distance, up to 50m.

3. (3 points) Give the data path you assumed in the previous part.

4. (1 point) If the time the laser pulse is emitted is uncorrelated with respect to the digital system's clock system, the precision can be refined by averaging several consecutive measurements. Briefly summarize how to modify your system to support measurement averaging.

PROBLEM F3 – COMPUTER SYSTEMS

Computer Architecture

1. Given the following MIPS instructions, if we only implement the following hazard detection unit without the forwarding control capacity, (1) please identify what problems it will occur with explanation and (2) How do we fix the problem with explanation.

   Here is the only hazard detection unit we implement:
   if (ID/EX.MemRead and
   ((ID/EX.RegisterRt = IF/ID.RegisterRs) or (ID/EX.RegisterRt = IF/ID.RegisterRt)))
   stall the pipeline

   lw $2, 20($1)
   and $4, $2, $5
   or $8, $2, $6

2. For this question, we assume that individual stages/steps of the data-path have the following latencies:

IF	ID	EXE	MEM	WB
250 ps	350 ps	150 ps	300 ps	200ps

   What is the clock cycle time in this pipelined processor? What is the total latency of a MIPS addition instruction (i.e., add) in this pipelined processor (Supposedly, there is no data, structural, or control hazard for this case)? Need to explain your answers.

PROBLEM F4 – COMPUTER SYSTEMS

Computer Algorithms

You have a process that generates list of partially sorted keys where an input key deviates at most $\Delta << N$ places from its sorted position where N is the length of the input list.

1. (4 points) Give the time and space complexity required if bubble sort is used to sort the input list.

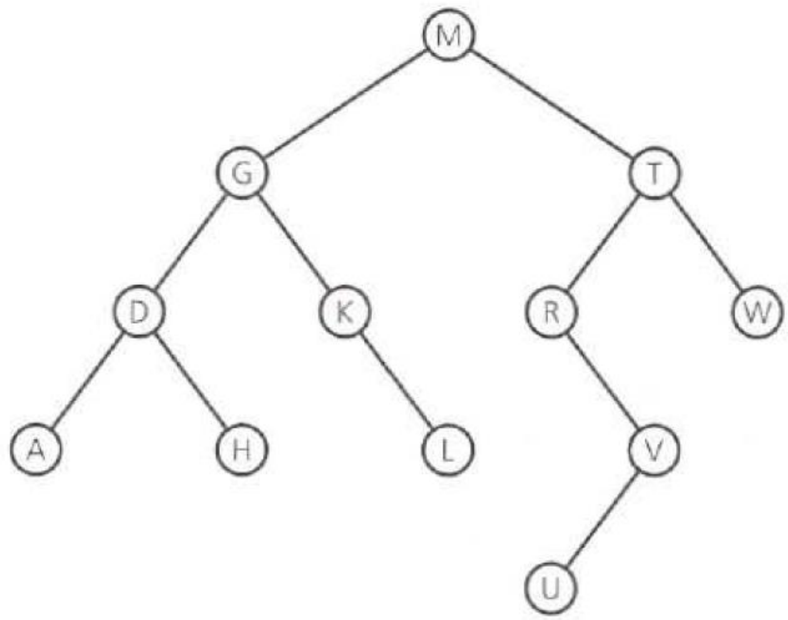
2. (4 points) Give the time and space complexity required if merge sort is used to sort the input list.

3. (2 points) Which algorithm is superior and why? Please be specific.

PROBLEM F5 – COMPUTER SYSTEMS

<u>Data Structures</u>

1. What are the preorder, inorder, and postorder traversals of the following binary tree:



2. What is the order (Time Big-O Complexity) of each of following tasks in the worst case (need to explain how you get your answer to get a full credit)?

   2.1 Displaying all n integers in a sorted linked list.

   2.2 Displaying the last integer in a linked list.

   2.3 Adding an item to a stack of *n* items.

PROBLEM F6 – COMPUTER SYSTEMS

Logic Design

Consider the following Boolean expression where d is don't care

$$F(A,B,C,D) = \sum m\,(0,1,3,7,8) + d(5,10,13,14)$$

(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

Consider the 3-bit block cipher given in Table 1 below. Suppose the plaintext is 100100100.

a) Initially assume that CBC (Cipher Block Chaining) is not used. What is the resulting ciphertext?
b) Suppose James sniffs the ciphertext. Assuming he knows that a 3-bit block cipher without CBC is being employed (but doesn't know the specific cipher), what can she surmise?
c) Now suppose that CBC is used with Initialization Vector, IV=111. What is the resulting ciphertext?

Input	Output
000	110
001	111
010	101
011	100
100	011
101	010
110	000
111	001

Table 1: A specific 3-bit block cipher

PROBLEM G2 – CYBERSECURITY

Suppose your RSA modulus is $n = 35 = 5 \times 7$ and your encryption exponent is $e = 3$. (a) Show how to encrypt a message "abc" and (b) find the decryption modulus *d* and show how to decrypt the ciphertext.

PROBLEM G3 – CYBERSECURITY

Discuss three service models in cloud computing and the security risks in each service model.

PROBLEM G4 – CYBERSECURITY

Problem 1 - (Format String Vulnerability)

What if we want to write a small number such as 0 to a target address using a format-string vulnerability, but due to the %x's that we have to place in the format string, the number of characters printed out by printf() is already nonzero before the pointer reaches the target address. Is it still possible to write 0 to the target address?

Problem 2 – (Buffer Overflow) 5pts

Several students had issue with the buffer overflow attack. Their badfile was constructed properly where shell code is at the end of badfile, but when they try different return addresses, they get the following observations. Can you explain why some addresses work and some do not?

```
buffer address : 0xbffff180
case 1 : long retAddr = 0xbffff250 -> Able to get shell access
case 2 : long retAddr = 0xbffff280 -> Able to get shell access
case 3 : long retAddr = 0xbffff300 -> Cannot get shell access
case 4 : long retAddr = 0xbffff310 -> Able to get shell access
case 5:  long retAddr = 0xbffff400 -> Cannot get shell access
```

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. (5 pts)

B. Medical devices are increasingly software-controlled, personalized, and networked. An example of such a device is a blood glucose meter, used by doctors and patients to monitor a patient's blood glucose level. Consider a hypothetical glucose meter that can take a reading of a patient's glucose level, show it on the device's display, and also transmit it over the network to the patient's hospital. The code is a highly-abstracted version of the software that might perform these tasks

```
int patient_id;      // initialized to the patient's unique identifier

void take_reading () {

  float reading = read_from_sensor();

  display(reading);

  send (network_socket, hospital_server, reading, patient_id);

  return;

}
```

The function ***take reading*** records a single blood glucose reading and stores it in a floating-point variable ***reading***. It then writes this value, suitably formatted, to the device's display. Finally, it transmits the value along with the patient's ID without any encryption over the network to the hospital server for analysis by the patient's doctor.

a. Does this program preserve privacy of the patient's information? (2 pts)

b. The flow of information from ***reading*** to ***network_socket***, which one is visible to the attacker? (3 pts)