# DEPARTMENT OF ELECTRICAL \& COMPUTER ENGINEERING <br> OLD DOMINION UNIVERSITY <br> MS COMPREHENSIVE EXAM <br> Spring 2023 

## 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: $\qquad$
Student Name (BLOCK CAPITALS): $\qquad$
UIN Number: $\qquad$
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 <br> 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 <br> PH.D. DIAGNOSTIC EXAM <br> Spring 2023 

## ODU HONOR PLEDGE

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Student Signature: $\qquad$
Student Name (BLOCK CAPITALS): $\qquad$
UIN Number: $\qquad$
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:

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

An $2^{\text {nd }}$ order inhomogeneous differential equation is given
$y^{\prime \prime}+4 y^{\prime}+3 y=2 x+1$
we know the initial conditions are:
$y^{\prime}(x=0)=0$, and $y(x=0)=0$
Solve for y as a function of x

## PROBLEM A2 - MATH

Consider the parametric curve

$$
\begin{equation*}
x(t)=3 \cos 4 t, \quad y(t)=6 \sin 8 t, \quad \text { for } \quad 0<t<\frac{\pi}{8} \tag{1}
\end{equation*}
$$

(a) Determine any turning points of the curve $\mathrm{y}(\mathrm{x})$,
(b) Determine the area under this parametric curve

## PROBLEM A3 - MATH

## Linear Algebra

Let $A=\left[a_{i j}\right]_{1 \leq i, j \leq n}$ 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 $\lambda_{\text {min }}$ and $\lambda_{\text {max }}$, 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

## A4 MATH: Probability

Consider a discrete-time random process

$$
\boldsymbol{x}(n)=2 \cos \left(\frac{\pi n}{8}+\boldsymbol{\theta}\right)
$$

where $n$ is an integer, and $\boldsymbol{\theta}$ is a uniform random variable on the interval $[0,2 \pi]$.
(a) Compute the mean function, $\mu(n)$.
(b) Compute the autocorrelation function, $R(m, n)$.
(c) Is this process wide-sense stationary? Explain.

## PROBLEM B1 - CIRCUITS AND ELECTRONICS

## Sinusoidal Steady State Response

The sinusoidal voltage source in the circuit shown is generating the voltage vg = 1.2 cos 100 tV . The op-amp is ideal. What is the expression output voltage $\mathrm{v}_{\mathrm{o}}(\mathrm{t})$ if $\mathrm{C}=1 \mathrm{uF}$.

The variable capacitor $C$ is adjusted until the output voltage leads the input voltage by $120^{\circ}$.
a. Find the value of $C$ in microfarads.
b. Write the steady state expression for the output voltage $\mathrm{v}_{\mathrm{o}}(\mathrm{t})$ when C has the value found in (a).


## PROBLEM B2 - CIRCUITS AND ELECTRONICS

## Laplace Application to Circuit Analysis

a. Find the s-domain expression for the voltage $\mathrm{V}_{0}$ in the circuit shown.
b. Use the s-domain expression derived in (a) to predict the initial and final values of $\mathrm{v}_{\mathrm{o}}$.
c. Find the time domain expression for $\mathrm{v}_{\mathrm{o}}$.


PROBLEM B3 - CIRCUITS AND ELECTRONICS

The below circuit is designed with $\mathrm{V}_{0}=3 \mathrm{~V}$ when $\mathrm{I}_{\mathrm{L}}=0$ and $\mathrm{V}_{0}$ changes by 25 mV per 1 mA of load current.
(a) Use the small signal model of the diode, find total small signal resistance of the four diodes
(b) Use the small signal model of the diode, find the value of $\mathrm{I}_{\mathrm{D}}$ and R ? (assume $\mathrm{V}_{\mathrm{T}}=25 \mathrm{mV}$ )
(c) Specify the value of $\mathrm{I}_{\mathrm{S}}$ of each of the diodes using $\mathrm{i}_{\mathrm{D}}=\mathrm{I}_{\mathrm{S}} \mathrm{e}^{\mathrm{V}_{\mathrm{D}} / \mathrm{V}_{\mathrm{T}}}$ where $\mathrm{V}_{\mathrm{T}}=25 \mathrm{mV}$
(d) When a current $\mathrm{I}_{\mathrm{L}}=1 \mathrm{~mA}$ is drawn from the regulator, find the actual change in $\mathrm{V}_{0}$


## PROBLEM C1 - SYSTEMS, SIGNALS AND IMAGE PROCESSING

## Digital Image Processing



The two purely black and white images shown above are each $40 \times 40$ 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 $3 \times 3$ 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

Consider a causal LTI system described by the following difference equation:

$$
y[n+2]-5 / 6 y[n+1]+1 / 6 y[n]=x[n+2]
$$

(a). Determine the system function $\mathrm{H}[\mathrm{z}]$ for the system. (2 points)
(b). Find the impulse response $h[n]$ for the system. Is the system stable? ( 2 points)
(c). Determine the output $y[n]$ for the input $x[n]=(1 / 5)^{n} u[n]$. (2 points)
(e). Find the response of the system for the input (4 points)

$$
x(n)=1+\sin \left(\pi n+\frac{\pi}{3}\right), \text { for all } n
$$

## PROBLEM C3 - SYSTEMS, SIGNALS AND IMAGE PROCESSING

An analog signal, $x(t)$, has a bandwidth of $20 k \mathrm{~Hz}$. In this problem, you will work as an engineer to design a simple discrete-time signal processing system to process the signal.
a) In the first step, you will sample this analog signal. What are the Nyquist rate and Nyquist interval for $x(t)$, respectively? ( 2 points, 1 point for each)
b) Assume that you sampled the analog signal, $x(t)$, using a sampling frequency of 40 kHz and obtained a discrete-time sequence $x[n]$, what is the highest frequency in $x[n]$ ? (4 points)
c) If you want to design a discrete-time low-pass filter $h[n]$ to filter out all frequency components beyond $10 k \mathrm{~Hz}$ in $x(t)$, what is the cut-off frequency of $h[n]$ ? (4 points) (Attention: $h[n]$ is in discrete-time domain)

## PROBLEM C4 - SYSTEMS, SIGNALS AND IMAGE PROCESSING

## Control Systems

There are many industrial applications of automatic control such as in the design of automated guided vehicles that are used to autonomously transfer materials in a factory. For this problem, consider the simplified block diagram of one loop of the navigation system as shown below.


Figure 1. Simplified block diagram of the bearing angle control system of an automated guided vehicle with a proportional compensator.
i) What is the closed-loop transfer function?
ii) What values can the proportional controller take to maintain closed-loop stability?
iii) If $K=1$, what is the gain margin in dB ? Explain what is the gain margin of a system. Hint: The answer for this part can be determined from your answer to part (ii).
iv) Make a rough sketch of a possible root locus for $K>0$. There is no need to find the break-away and break-in points or to determine the angle of departure.
v) Let the proportional compensator gain be $K=2$.
a. What is the steady-state error to a unit step input?
b. What is the steady-state error to a unit ramp input?
c. If the percent overshoot of the unit step response is $11.1 \%$, will the percent overshoot increase, decrease or remain the same if the gain is increased to $K=3$ ? Explain why.

## Continued on next page

## REVIEW

For a prototype second order open-loop transfer function $\mathrm{G}(\mathrm{s})=\omega_{\mathrm{n}}{ }^{2} /\left(\mathrm{s}^{2}+2 \zeta \omega_{\mathrm{n}} \mathrm{s}+\omega_{\mathrm{n}}{ }^{2}\right)$ the following unit step response relations are useful:

- percent overshoot $=100 \exp \left(-\varsigma \pi / \operatorname{sqrt}\left(1-\zeta^{2}\right)\right)$
- $2 \%$ settling time $\approx 4 /\left(\varsigma \omega_{n}\right)$

Suppose that the loop gain of the closed-loop system can be written as $K G(s)$ with

$$
G(s)=K_{G} \frac{\prod_{i=1}^{m}\left(s-z_{i}\right)}{\prod_{j=1}^{n}\left(s-p_{j}\right)} \text {, where } K \text { is the gain of the controller that needs to be determined, }
$$

$G(s)$ represents the loop gain when $K=1$, and the loop gain has $m$ zeros at $z_{i}$ and $n$ poles at $p_{j}$. The magnitude condition of root locus states that

$$
|K|=\frac{\prod_{j=1}^{n}\left|s-p_{j}\right|}{K_{G}\left(\prod_{i=1}^{m}\left|s-z_{i}\right|\right)}, \quad \text { whenever } s \text { a closed-loop pole. }
$$

## 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

$$
f\left(0^{+}\right)=\lim _{s \rightarrow \infty} s F(s)
$$

## - Final Value Theorem

- If all the poles of $s F(s)$ have negative real parts, then

$$
\lim _{t \rightarrow \infty} f(t)=\lim _{s \rightarrow 0} s F(s)
$$



Figure 3. Graphical definitions of the gain and phase margins using part of a Nyquist diagram . (C2000, John Wiley \& Sons, Inc. Nise/Control Systems Engineering, 3/e)


Figure 4. Graphical definitions of the gain and phase margins using part of the Bode diagrams of a minimum phase system.(©2000, John Wiley \& Sons, Inc. Nise/Control Systems Engineering, 3/e)

## PROBLEM C5 - SYSTEMS, SIGNALS AND IMAGE PROCESSING

## Communications Problem:

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 $\mathrm{x}_{2}(\mathrm{t})$ with center frequency $\mathrm{f}_{2}$.

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 upconversion and down-conversion of signal $\mathrm{x}_{1}(\mathrm{t})$.
2. Explain using Fourier analysis how heterodyning changes the spectrum of bandpass signal $\mathrm{x}_{1}(\mathrm{t})$ to produce signal $\mathrm{x}_{2}(\mathrm{t})$. 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

## Communications Networks:

1. ( 5 pts) We have a character frame from the higher layer: A ESC FLAG B 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. ( 5 pts ) 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 $q$. What is the mean number of transmissions needed for the receiver to successfully receive a frame?

## PROBLEM D1 - PHYSICAL ELECTRONICS I

A microwave oven typically operates at 2.45 GHz . A bottom round steak has a relative permittivity of 40 (or $\varepsilon^{\prime}=40 \varepsilon_{0}, \varepsilon_{0}=8.8542 \times 10^{-12} \mathrm{~F} / \mathrm{m}, \mu=\mu_{0}=4 \pi \times 10^{-7} \mathrm{H} / \mathrm{m}$ ) and a loss tangent $\tan \delta=0.5$ at the operating frequency.
(a) Find the propagation velocity of the wave in steak.
(b) Calculate the complex wavenumber $\underline{k}$.
(c) Calculate the penetration depth $d_{p}$ in steak.
(d) Calculate the intrinsic impedance $\underline{\eta}$.

## PROBLEM D2 - PHYSICAL ELECTRONICS I

## Electromagnetics

A uniformly charged circular contours of radius of and total charge Q rotates in free space about its axis with a uniform angular velocity $w=w \hat{z}$ as shown in below figure. A charged particle of $\boldsymbol{q}$ moves with a uniform velocity $\boldsymbol{v}=\boldsymbol{v} \hat{\boldsymbol{y}}$ along a path that belongs to the plane $\boldsymbol{z}=\boldsymbol{a}$ and is parallel to the y -axis. Find the Lorentz force $\boldsymbol{F}=\boldsymbol{q}(\boldsymbol{E}+\boldsymbol{v} \widehat{\boldsymbol{y}} \times \boldsymbol{B})$ on the particle at an instant when it is at the point $P(0,0, a)$ above the center of the contour.


## PROBLEM D3 - PHYSICAL ELECTRONICS I

## Optical Fiber Communications

The intensity of radiation in a laser diode at a photon energy of (hv) is given by:

$$
I(z)=I(0) \operatorname{Exp}\{[g(h v)-\alpha(h v)]\} \cdot z
$$

where $g(h v)$ is the gain of the cavity, $\alpha(h v)$ is the absorption coefficient along the optical path, and $z$ is the axial distance.
Given a cavity of length $L$ and the Fresnel reflection coefficients of the cavity two mirrors are $\mathrm{R}_{1}$ and $R_{2}$, derive the expression of the threshold gain ( $\mathrm{g}_{\text {th }}$ ) above which lasing occurs.


## PROBLEM E1 - PHYSICAL ELECTRONICS II

## Physical Electronics

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

$$
\begin{array}{ll}
\text { P side } & \text { N side } \\
\mathrm{N}_{\mathrm{a}}=10^{17} \mathrm{~cm}^{-3} & \mathrm{~N}_{\mathrm{d}}=10^{15} \mathrm{~cm}^{-3} \\
\tau_{\mathrm{n}}=0.1 \mu \mathrm{~s} & \tau_{\mathrm{p}}=10 \mu \mathrm{~s} \\
\mu_{\mathrm{p}}=200 \mathrm{~cm}^{2} / \mathrm{V}-\mathrm{s} & \mu_{\mathrm{n}}=1300 \mathrm{~cm}^{2} / \mathrm{V}-\mathrm{s} \\
\mu_{\mathrm{n}}=700 \mathrm{~cm}^{2} / \mathrm{V}-\mathrm{s} & \mu_{\mathrm{p}}=450 \mathrm{~cm}^{2} / \mathrm{V}-\mathrm{s}
\end{array}
$$

The junction is forward biased by 0.5 V .
a) What is the total forward current for an ideal p-n junction at +0.5 V bias? (Need to calculate $D_{p}, D_{n}, L_{p}, L_{n}, D_{n}, n_{p}$ )
b) What is the total current at a reverse bias of -0.5 V ?
c) Calculate the junction potential also called built-in potential $V_{b i}$
d) What is the total depletion capacitance $\left(C_{j}\right)$ 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 $\mathrm{W}=X_{p}+X_{n}$.

## Physical Constants:

Intrinsic carrier concentration in $\mathrm{Si}: \mathrm{n}_{\mathrm{i}}=1.45 \times 10^{10} \mathrm{~cm}^{-3}$
Permittivity in Vacuum $\varepsilon=8.8854 \times 10^{-14} \mathrm{~F} / \mathrm{cm}$;
Dielectric constant of $S_{i} \quad K_{s i}=11.7$
Elementary Charge: $\quad \mathrm{q}=1.602 \times 10^{-19} \mathrm{C}$
Boltzman Constant: $\quad \mathrm{k}=1.38066 \times 10^{-23} \mathrm{~J} / \mathrm{K}=8.62 * 10^{-5} \mathrm{eV} / \mathrm{K}$
Thermal voltage at $300 \mathrm{~K}: \quad \mathrm{kT} / \mathrm{q}=0.0259 \mathrm{~V}$

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

$$
\begin{aligned}
& J_{p}=q \mu_{p} p\left(\frac{1}{q} \frac{d E_{i}}{d x}\right)-k T \mu_{p} \frac{d p}{d x} \quad \frac{d^{2} \psi}{d x^{2}} \equiv-\frac{d \mathscr{E}}{d x}=-\frac{\rho_{s}}{\varepsilon_{s}}=-\frac{q}{\varepsilon_{s}}\left(N_{D}-N_{A}+p-n\right) . \\
& V_{b i}=\psi_{n}-\psi_{p}=\frac{k T}{q} \ln \left(\frac{N_{A} N_{D}}{n_{i}{ }^{2}}\right) \cdot \quad N_{A} x_{p}=N_{D^{x}} x_{n} . \quad W=x_{p}+x_{n} . \quad \mathscr{E}_{m}=\frac{q N_{D} x_{n}}{\varepsilon_{s}}=\frac{q N_{A} x_{p}}{\varepsilon_{s}} . \\
& V_{b i}=\frac{1}{2} \mathscr{E}_{m} W . \quad W=\sqrt{\frac{2 \varepsilon_{s}}{q}\left(\frac{N_{A}+N_{D}}{N_{A} N_{D}}\right) V_{b i}} . \quad \mathscr{E}(x)=-\mathscr{E}_{m}+\frac{q N_{B} x}{\varepsilon_{s}}, \quad \mathscr{E}_{m}=\frac{q N_{B} W}{\varepsilon_{s}} \\
& C_{j}=\frac{\varepsilon_{s}}{W}=\sqrt{\frac{q \varepsilon_{s} N_{B}}{2\left(V_{b i}-V\right)}} \quad V_{b i}=\frac{k T}{q} \ln \frac{p_{p o} n_{n o}}{n_{i}^{2}}=\frac{k T}{q} \ln \frac{n_{n o}}{n_{p o}}, \quad n_{n o}=n_{p o} e^{q V_{b i} / k T} . \\
& p_{p o}=p_{n o} e^{q V_{b i} / k T} . \quad n_{n}=n_{p} e^{q\left(V_{b i}-V\right) / k T}, \quad n_{p}=n_{p o} e^{q V / k T} \\
& J=J_{p}\left(x_{n}\right)+J_{n}\left(-x_{p}\right)=J_{s}\left(e^{q V / k T}-1\right), \quad J_{s} \equiv \frac{q D_{p} p_{n o}}{L_{p}}+\frac{q D_{n} n_{p o}}{L_{n}},
\end{aligned}
$$

Silicon (300 K): $\mathbf{N C}=2.8610^{19} \mathrm{~cm}^{-3} ; \mathrm{Nv}=2.6610^{19} \mathrm{~cm}^{-3} ; \mathrm{n}_{\mathrm{i}}=9.6510^{9} \mathrm{~cm}^{-3}$
$m_{p}=1 \mathrm{~m}_{0} ; \mathrm{m}_{\mathrm{n}}=0.19 \mathrm{~m}_{0} ; \mathrm{m}_{0}=0.91 \mathbf{1 0}^{-30} \mathrm{~kg} ; \mathrm{k}=1.3810^{-23} \mathrm{~J} / \mathrm{K} ; q=1.610^{-19} \mathrm{C}$

## PROBLEM E3 - PHYSICAL ELECTRONICS II

(a) (5 points) For a homogeneous (i.e., spatially uniform) plasma in the afterglow with the charge-particles only electrons and singly-charged positive ions, the continuity equation is

$$
\frac{\partial n_{e}}{\partial t}=-k_{r} n_{e} n_{i}
$$

where $k_{r}$ is the rate coefficient for recombination, $n_{e}$ is electron density, and $n_{i}$ is ion density. The density of electrons at time $t=0$ is $n_{0}$. Calculate $n_{e}$ for $t>0$.Assume that the plasma is quasi-neutral.
(b) (3 points) If this plasma is bounded by two parallel large electrodes (assumed each located on the x -axis), add the diffusion term to the continuity equation for the decay of $n_{e}$.
(c) (2 points) For a capacitively-coupled discharge used for plasma deposition or etching, which term (recombination or diffusion) do you expect to be dominant and why?

## PROBLEM F1 - COMPUTER SYSTEMS

## Microprocessors

1. (2 points) Give an original example of a simple embedded system that has two interrupt based inputs. For your system, if both interrupts arrived at the same time, would one have priority over the other and why?
2. (4 points) You have two interrupts and one has a higher priority than the other. Give a code example showing how you can prioritize one over the other. Provide any reasonable assumptions you make.
3. (3 points) Give a code example showing how to prioritize one input over another using polling.
4. (1 point) From the perspective of interrupt priority, compare/contrast polled input versus interrupt driven input.

## Continued on next page



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## PROBLEM F2 - COMPUTER SYSTEMS

## Digital Systems

You are designing a two input ( X and Y ), one output ( Z ) finite state machine that detects a sequence on X consisting of two 1 's followed by zero or more 0 's followed by two 1 's. When the sequence is detected, it should output a ' 1 ' when the last input of the sequence is input. In addition, overlaps are permitted. The second input, Y , is the "ignore" the input. When $\mathrm{Y}=\mathrm{I}^{\prime} 1^{\prime}, \mathrm{X}$ inputs are ignored, and resumes detecting the sequence when $Y$ returns to ' 0 '.

Here are a couple of input/output examples:

| Example 1 | Example 2 | Example 3 | Example 4 | Example 5 |
| :---: | :---: | :---: | :---: | :---: |
| $\mathrm{X}=1111$ | $\mathrm{X}=11011$ | $\mathrm{X}=110011011$ | $\mathrm{X}=1101011011$ | $\mathrm{X}=1101011011$ |
| $\mathrm{Y}=0000$ | $\mathrm{Y}=00000$ | $\mathrm{Y}=000000000$ | $\mathrm{Y}=0000000000$ | $\mathrm{Y}=0011100000$ |
| $\mathrm{Z}=0001$ | $\mathrm{Z}=00001$ | $\mathrm{Z}=000001001$ | $\mathrm{Z}=0000000001$ | $\mathrm{Z}=0000001001$ |

1. (4 points) Give the state machine (SM) Chart for this sequence detector.
2. (4 points) Give the circuit for a one-hot finite state machine that implements this state machine.
3. (2 points) If the state machine were reformulated to be suitable for a microcoded controller, would the state machine be able to detect any and all required sequences? Why or why not?

## 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)
ADD \$4, \$2, \$5
SUB \$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 | 200 ps |

What is the clock cycle time in this pipelined processor? What is the total latency of 100 MIPS addition instructions (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

## Algorithms

You are comparing two candidate algorithms for a particular workload.
Time complexity of Algorithm 1 :

$$
\begin{equation*}
F(n)=n^{3} \tag{1}
\end{equation*}
$$

Time complexity of Algorithm 2:

$$
\begin{equation*}
F(n)=15 n \log _{3} n \tag{2}
\end{equation*}
$$

1. (4 points) Independent of any outside constraints or usage behavior, state the circumstances under which you would select one algorithm over the other. Please be sure to clearly state any assumptions you make.
2. (4 points) If the job length, $n$, follows an exponential distribution, give the formula for the aggregate expected time complexity for each algorithm if the statistics of $n$ are defined by

$$
\begin{equation*}
f_{n}(n \mid \lambda)=\lambda e^{-\lambda(n-1)} \tag{3}
\end{equation*}
$$

Note that in (3), $n$ is discrete and greater than zero, and $\lambda$ is the distribution rate for the exponential distribution. Assume $\lambda=1 / 15$.
3. (2 points) Assuming the distribution of jobs determined in the previous part, if you were to only implement one algorithm, which would you select? You are welcome to make any reasonable approximations or assumptions in your determination.

## PROBLEM F5 - COMPUTER SYSTEMS

## Data Structures

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

Design a circuit that accepts 4 bits (ABCD) constitutes 2 2-bit numbers, N1 (AB) and $\mathrm{N} 2(\mathrm{CD})$ with a single output F.
The circuit performs on the multiplication of N1 and N2 (N1 X N2) as follows:

1. If $\mathrm{N} 1 \times \mathrm{N} 2=0$, then $F=0$
2. if $0<(N 1 \times N 2)<4$ then $F=1$
3. Else, if ( $\mathrm{N} 1 \times \mathrm{X} 2$ ) $\geq 4, F=d$ (don't care)
a) Construct the truth table of the circuit
b) Using K-map, please give the simplest SOP of F .
c) Implement F in part (b) using NAND and NOT.
d) Use the table below to give the longest path and shortest path delay values.

| Gate | $\boldsymbol{t}_{p d}(\mathrm{ps})$ | $\boldsymbol{t}_{c d}(\mathrm{ps})$ |
| :--- | :---: | :---: |
| 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 | $\mathbf{6 0}$ | 40 |

## PROBLEM G1 - CYBERSECURITY

Consider using RSA encryption algorithm,
(a) choose $\mathrm{p}=3$ and $\mathrm{q}=11$, and encode the word "dog" by encrypting each letter separately. Apply the decryption algorithm to the encrypted version to recover the original plaintext message.
(b) Repeat part (a) but now encrypt "dog" as one message m.

## PROBLEM G2 - CYBERSECURITY

## Cyber Defense Fundamentals

1. (5 pts) Describe how the Diffie-Hellman algorithm enables Alice and Bob to establish a private shared key.
2. ( 5 pts ) Explain why an eavesdropper, Eve, cannot find the private key of Alice and Bob in the Diffie-Hellman system, even if Eve hears all communications between Alice and Bob.

## PROBLEM G3 - CYBERSECURITY

## Cyber Physical System Security

1. ( 5 pts ) Explain how a firewall protects an internal network.
2. ( 5 pts ) What is the buffer overflow attack?

## PROBLEM G4 - CYBERSECURITY

a) Problem 1 - (Format String Vulnerability) Compilers can give a warning if it detects that the number of arguments in printf() does not match with the number of format specifiers. Please comment on the limitation of this countermeasure.
b) Problem 2 - (Race Condition)

Explain the race condition vulnerability in the below program. Provide an example how the vulnerability can be exploited.

```
#include <stdio.h>
#include <unistd.h>
int main()
{
char * fn = "/tmp/XYZ";
char buffer[60];
FILE *fp;
/* get user input */
scanf("%50s", buffer );
if(!access(fn, W_OK))
{
    fp = fopen(fn, "a+");
    fwrite("\n", sizeof(char), 1, fp);
    fwrite(buffer, sizeof(char), strlen(buffer), fp);
    fclose(fp);
}
else printf("No permission \n");
}
```


## PROBLEM G5 - CYBERSECURITY

## Security and Privacy of Embedded Systems

Consider the finite-state machine below with one input $x$ and one output $z$, both taking values in $\{0,1\}$. Both $x$ and $z$ are considered public ("low") signals from a security viewpoint. However, the state of the FSM (i.e., "A" or "B") is considered secret ("high").


TRUE or FALSE: There is an input sequence an attacker can supply that tells him whether the state machine begins execution in A or in B .


[^0]:    $1_{\text {imm }}=I_{15 . .0}$ unless otherwise noted, imms is signed, immu is unsigned
    ${ }^{2}$ for Jump instructions imm=IR27..0

