Ph.D. Preliminary Examination **Code Number** ____________
Fall 2010

Instructions:

1. Please check to ensure that you have a complete exam booklet. There are 25 numbered problems. Note that **Problem 1 occupies 2 pages** and **Problem 3 occupies 2 pages**. Including the cover sheet, you should have **28 pages**. There should be no blank pages in the booklet.
2. The examination is closed book and closed notes. No reference material is allowed at your desk. A calculator is permitted.
3. All wireless devices must be turned off for the entire duration of the exam.
4. You may work a problem directly on the problem statement (if there is room) or on blank sheets of paper available from the exam proctor. Do not write on the back side of any sheet.
5. Your examination code number **MUST APPEAR ON EVERY SHEET**. This includes this cover sheet, the problem statement sheets, and any additional work sheets you turn in. **DO NOT** write your name on any of these sheets. Use the preprinted numbers whenever possible, or **WRITE LEGIBLY!!!**
6. Under the rules of the examination, you must choose 8 problems to be handed in for grading. Each problem to be graded should be separated from the rest of the materials, stapled to the associated worksheets, and placed on the top of the appropriate envelope in the front of the exam room. **DO NOT TURN IN ANY SHEETS FOR THE OTHER 17 PROBLEMS!!**
7. The examination lasts 4 hours, from 9:30 AM to 1:30 PM.
8. When you hand in the exam:
   (a) Separate the 8 problems to be graded as explained above.
   (b) Check to see that your Code Number is in **EVERY** sheet you are turning in.
   (c) On the section at the bottom of this page, **CIRCLE** the problem numbers that you are turning in for grading.
   (d) Turn in this cover sheet (containing your code number) and the 8 problems to be graded.
   (e) All other material is to be placed in the discard box at the front of the room. You are not allowed to take any of the exam booklet pages from the room!

1	2	3	4	5	6	7	8	9
10	11	12	13	14	15	16	17	18
19	20	21	22	23	24	25		

Problem 1 (Core: VSDD-ECE2030) **Code Number:_________**

(a) Rewrite the function $F = A \bullet (\overline{B} + (E \bullet (C + \overline{D})))$ using only OR gates and inverters.

F =

(b) Simplify the expression F = $A\overline{B} + ABC + B\overline{C}$ so that F can be implemented with no more than one OR gate (2-input), one AND gate (2-input) and one inverter.

F=

c) Fill in the K-map for the Boolean expression
$F = \overline{A}\,\overline{B}\,\overline{C}\,\overline{D} + A\overline{B}C + ABD + \overline{A}\,\overline{B}C\overline{D} + A\overline{B}\overline{C}D$
below. Give the minimized sum of products form and product of sums form expressions for F from the K-map.

AB \ CD	00	01	11	10
00				
01				
11				
10				

Problem 1 (Core: VSDD-ECE2030) **Code Number:_________**

Sum of products form:
F =

Product of sums form:
F=

Problem 2 (Core: VSDD-ECE2030) Code Number:_________

Complete each design below. Be sure to label all signals.

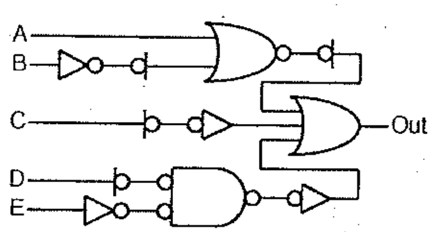
Part A: Implement the following expression using N and P type switches (NFETs and PFETs).

$$Out_X = (\overline{A} \cdot B + \overline{C}) \cdot D$$

Part B: Implement a transparent latch using only basic gates (AND, OR, NAND, NOR, and NOT).

IN	Y	OUT	$\overline{OUT}$
A	0	Q_o	$\overline{Q_o}$
A	1	A	$\overline{A}$

Part C: Determine the appropriate expression for this mixed logic design. How many transistors are required?



Out =

transistors =

Part D: Reimplement the design in Part C using *only* NAND gates. How many transistors are required?

transistors =

Problem 3 (Core: CSS-ECE3055) Code Number:__________

Given a 32-bit MIPS processor consists of five pipeline stages (shown in the next page) is executing the following program. Also given is the MIPS ISA encoding. The corresponding ALUop control signals are provided in Table 1. Currently, the PC of the instruction in the WB stage (addi) is 0x1401BCD8. Please fill the blanks with the resulting values. Assume each data memory byte is loaded with the least significant byte of its own address. For example, a byte at 0xFFFFFF01 contains 0x01. Assume that each register is initialized to the value equal to its own register ID number prior to the execution. Also assume that a "register write" takes place (the first half cycle) prior to a "register read" (the second half) when accessing the same register in the ID stage. Assume there is no branch prediction mechanism and also assume that there is a pipeline flush mechanism (not shown) to turn speculative instructions to NULL.

```
                  xor   $2, $1, $1
0x1401BCD8:       addi  $5, $2, 0x12DC
           L1:    beq   $5, $2, L2
                  lw    $22, 8($5)
                  add   $23, $15, $16
                  add   $22, $23, $22
                  addi  $6, $5, 0x100
                  sw    $22, ($6)
                  j     L1
           L2:    sub   $22, $23, $10
```

Please fill "Hex" for data signals and binary for control signals and 'x' for don't care.

Input value to the "PC" in the IF stage

____

"Read Data 1" in the ID stage

____

Output of the MUX3 in the EX stage

____

Output of the main ALU in the EX stage

____

"PCSrc" in the IF stage

____

EX[3:1] (3 bits) in the EX stage

____

OpMux1[1:0] in the EX stage

____

OpMux2[1:0] in the EX stage

____

M[2:0] in the MEM stage

____

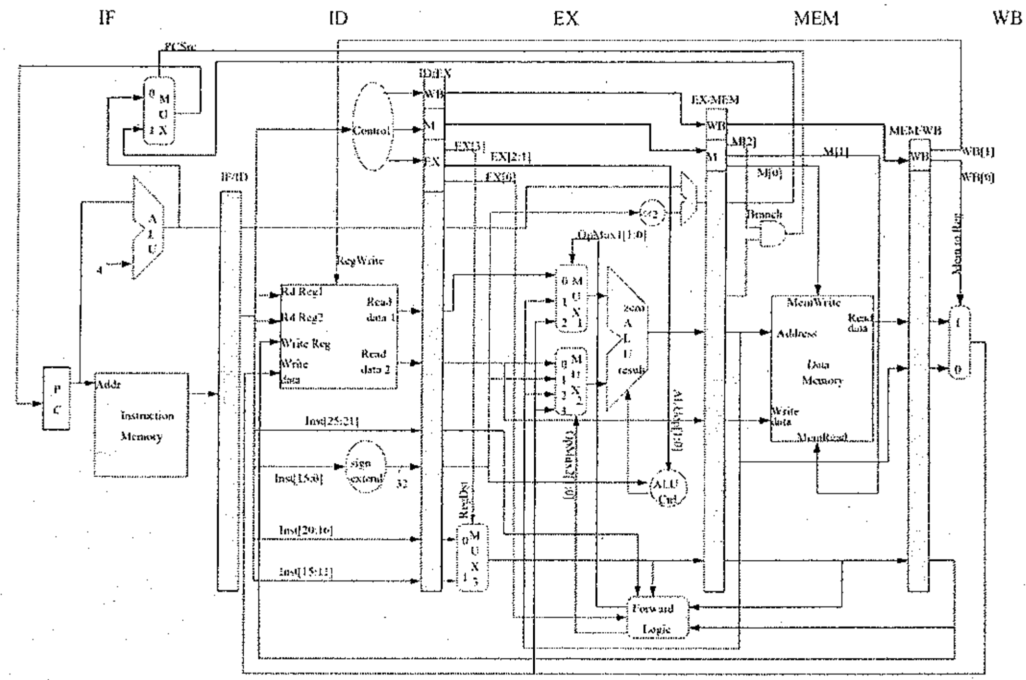
WB[1:0] in the WB stage

____

Instruction	ALUop[1]	ALUop[0]
Arithmetic	1	0
"lw"	0	0
"sw"	0	0
"bne"	1	1

Table 1. ALU Signal Definition

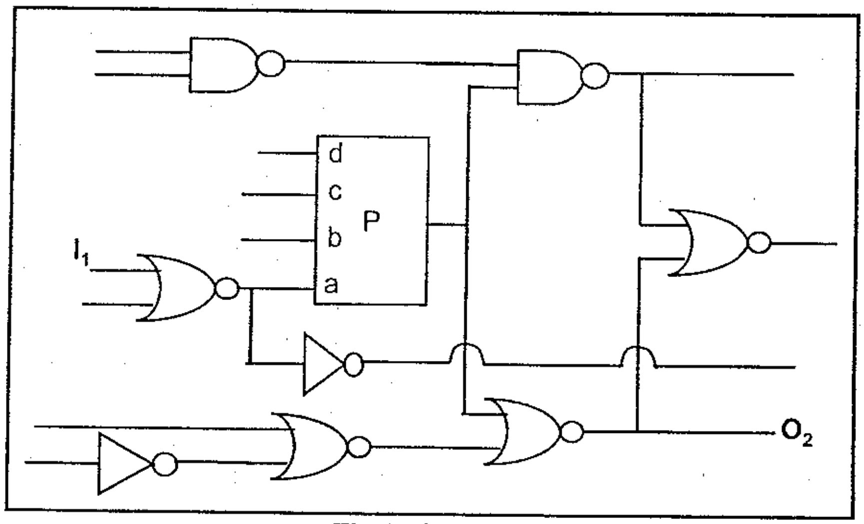
Problem 3 (Core: CSS-ECE3055) Code Number:_________



	31	25	20	15	10	5	
R Format	op	rs	rt	rd	shamt	func	rd = rs op rt
I Format	op	rs	rt	offset			rt = offset(rs) or rt = rs op offset
J Format	op	26-bit address					op address

Problem 4 (Core: VSDD-ECE3060) Code Number:__________

Consider the following Boolean network. Assume that the load at all inputs is C_{inv} and the load at all outputs is $18C_{inv}$ where C_{inv} is the input capacitance of a minimum size inverter. Use fanout for branching factor calculation.



The logic circuit

Consider $P = \overline{a + bc + d}$.

(a) First consider P needs to be implemented as a single CMOS complex gate. Draw the complex gate implementation (CMOS circuit only) and compute the logical effort of input 'a'. You need to size the NMOS and PMOS devices in P so that the output resistance is the same as that of an inverter with an NMOS W/L = 1 and PMOS W/L = 2 (You can put the numbers on the transistor diagram).

(b) Compute the path effort (F) for the path from I1 to O2. Note 'a' input of P is used in the path. Remember the path effort (F) is defined as F=GBH where, G is the path logical effort, B is the path branch effort, and H is the path electrical effort.

(c) You are now allowed to implement P as a network of gates (you can use NOR2, NAND2, and INV gates). Provide a design for P that can reduce the path effort from I1 to O2 as much as possible [compared to the result in part (b)].

Problem 5 (Core: E&M-ECE3025) Code Number:__________

Consider an air-filled coaxial transmission line having inner radius a, outer radius b, and unit length in the z direction. Its capacitance per unit length is $C = 2\pi\epsilon_0/\ln(b/a)$. Compare this to an ideal air-filled parallel-plate transmission line (no fringing fields) having plate width, w, plate separation d, and having unit length in z.

a. Express the ratio b/a in terms of the ratio d/w, such that the two structures will store the same electrostatic energy for a given applied voltage.

b. Suppose that $w >> d$. Find the approximate coaxial conductor spacing, $b - a$, such that the capacitances of the two structures are the same. The approximation $e^x \approx 1 + x$ may be useful here.

c. Suppose that $d = b - a$, and equal voltages are applied to the two structures. In which line will the greater electric field intensity be found? Explain carefully.

Problem 6 (Core: E&M-ECE3065) Code Number:__________

In a nonmagnetic, lossy, dielectric medium, a 300-MHz plane wave is characterized by the magnetic field phasor

$\tilde{\mathbf{H}} = (\hat{\mathbf{x}} - j\,4\,\hat{\mathbf{z}})\, e^{-2y}\, e^{-j9y}$ [A/m]

(a) Assuming that the complex dielectric constant of the medium can be expressed as $\epsilon_c = \epsilon' - j\epsilon'' = \epsilon_o(\epsilon_r' - j\epsilon_r'')$, calculate the parameters ϵ_r' and ϵ_r''

[Use $\mu_o = 4 \times \pi \times 10^{-7}$ [H/m] and $\epsilon_o = 10^{-9} / (36\,\pi)$ [F/m]]

(b) Calculate the complex intrinsic impedance of the medium, η_c.

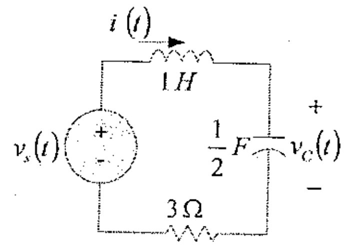
(c) Calculate the phasor expression for the electric field.

(d) Determine the distance at which the magnetic field amplitude has been reduced by 40 dB.

(e) Determine the distance at which the power density has been reduced by 40 dB.

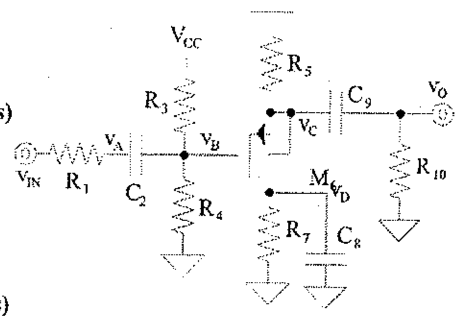
Problem 7 (Core: EDA-ECE2040) **Code Number:__________**

Find $i(t)$ for $t > 0$ in the following circuit when $v_s(t) = 2u(t)$ V, $v_C(0^-) = 1$ V, and $i(0^-) = 0$ A.



Problem 8 (Core: EDA-ECE3050) **Code Number:**__________

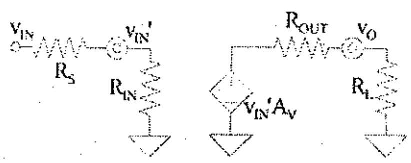
a. In less than six words, state the purpose of C_9. **(1 pts)**



b. (Circle your choice.) C_2 introduces ***a zero / a pole / both a zero and a pole / neither of these*** to ac gain v_b / v_{in}. **(2 pts)**

c. Assuming capacitances are infinitely high, draw the ac-equivalent circuit. (Label all circuit components and replace Q_6 with its ac equivalent.) **(4 pts)**

d. (Circle your choice.) In mapping the circuit to the ac equivalent shown below, the test condition that must be applied to the circuit above to derive R_{OUT} is ***$v_{IN} = 0$ / v_{IN} = open / $v_{IN}' = 0$ / v_{IN}' = open / $v_O = 0$ / v_O = open***. **(1 pts)**



e. Assuming capacitances are infinitely high, derive an expression for small-signal gain v_o / v_b. **(2 pts)**

Problem 9 (Core: Power-ECE3070) **Code Number:__________**

A 3-phase, 60 Hz, Y-connected, 2-pole, 100MVA, 24 kV synchronous generator is synchronized to a 24 kV network, following which its active power output is increased to 75 MW. If no other changes are made, its synchronous reactance is $X = 0.5$ Ohms per phase, and stator resistance is negligible, calculate by what percentage should the rotor current be increased so that the generator operates at unity power factor. Also, calculate what was the reactive power produced prior to the adjustment of the rotor current.

Problem 10 (Core: Power-ECE3070) Code Number:__________

1. A three phase 4160:480 volt wye-wye 60 hertz transformer rated at 300 kVA has the following characteristics:
   - Under short circuit test, rated current flows at 120 volts rms line-line input on the high voltage side. Losses under this condition are 3.6 kW.
   - Under open circuit conditions, with rated voltage connected on the high voltage side, the current drawn is 4 Amperes, and the power loss is 5.4 kW.

a) Develop a detailed equivalent circuit model for the transformer.
b) An induction motor load draws 500 kVA at 0.5 power factor lagging on start-up. What is the minimum value of the output voltage on the transformer secondary winding.

Problem 11 (Core: Microsystems-ECE3040) Code Number:__________

A semiconductor has the following parameters:

Hole Mobility: $\mu_p = 500\ cm^2/VSec$
Electron Mobility: $\mu_n = 1400\ cm^2/VSec$
Substrate relative Dielectric Constant: $\varepsilon_{r\text{-}semiconductor} = K_S = 11.8$
Dielectric Constant of free space: $\varepsilon_0 = 8.854\times10^{-14}$ F/cm
Intrinsic carrier concentration: $n_i = 10^{10}\ cm^{-3}$

The hole concentration in EQUILIBRIUM in the material is maintained at

$p(x) = 10^{16} \cdot x\ cm^{-3}$ (i.e. it linearly increases with x)

at room temperature.

a.) Calculate the required electric field in the material to keep the material in equilibrium.
b.) What is the resistivity of the semiconductor?

You may also need kT = 0.026 eV, $q = 1.6\ 10^{-19}$ C.

Problem 12 (Core: Microsystems-ECE3080) Code Number:__________

Consider these two pieces of Si:

Piece A: N_A-N_D = 10^{15} cm^{-3}
Piece B: N_A-N_D = − 10^{14} cm^{-3}
(N_A and N_D are doping concentrations of acceptor and donor atoms, respectively).

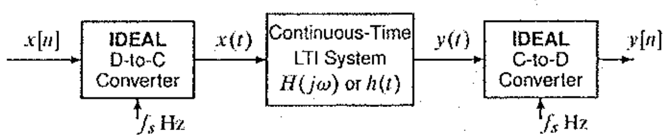
1) Calculate E_F-E_i and draw the band diagram for each piece.
2) Draw the band diagram for a step junction formed by these two pieces of Si at equilibrium and use the diagram to calculate the built-in potential.
3) If the junction width on the n-side is 2.5μm, what would be the junction width on the p-side.
4) Use the Poisson's equation to calculate the maximum electric field.
5) What would be the electron concentration at the boundary of the depletion region on the p side if a reverse voltage of 3V is applied (an approximate answer is enough)?

You may need these parameters for Si:
Intrinsic carrier concentration n_i=$10^{10}$$cm^{-3}$, Bandgap E_g=1.1 eV, and Dielectric Constant K_s=11.6

You may also need to use:
Electron charge q=1.6E-19 C and kT=0.025 eV (@ room temperature)

Problem 13 (Core: DSP-ECE2025) Code Number:__________

Consider the following ideal system[1] for continuous-time (CT) and discrete-time (DT) processing of a signal:



For all parts: $f_s = 3000\,\text{Hz}$

(a) Suppose that the input signal has a z-Transform $X(z) = \dfrac{z^{-4}}{2z-1}$.
Determine the signal $x[n]$ from $X(z)$.

(b) Suppose that the LTI system has a frequency response given by $H(j\omega) = u(\omega + 500\pi) - u(\omega - 500\pi)$, i.e., it is a lowpass filter. When the input $x[n]$ is an impulse, the signal $x(t)$ is a sinc function because the ideal bandlimited interpolation formula (below) has only one nonzero term. Determine the CT output $y(t)$ in this case.

(c) If the input signal is $x[n] = 0.1\cos(5000\pi(n/3000))$, determine a formula for $y[n]$ when the LTI system is a differentiator, i.e., $y(t) = \dfrac{d}{dt}x(t)$.

(d) Determine whether the following statement is TRUE or FALSE: "It is possible to define a ***nonzero*** $H(j\omega)$ so that the output $y[n]$ will ***always*** be identically zero ***for any possible input*** $x[n]$."
Justify your answer, i.e., if TRUE, give a specific filter for $H(j\omega)$, if FALSE, explain your reasoning.

---

[1] The Ideal C-to-D converter is defined by $y[n] = y(nT_s)$, where T_s is the sampling period, i.e., $T_s = 1/f_s$.
The Ideal D-to-C converter is defined by the ideal ***bandlimited*** interpolation formula: $x(t) = \sum_{n=-\infty}^{\infty} x[n] \dfrac{\sin(\pi(t-nT_s)/T_s)}{\pi(t-nT_s)/T_s}$.

Problem 14 (Core: DSP-ECE3075) Code Number:__________

3075 PROBLEM

(a) Consider the joint probability mass function table for a pair of random variables X and Y shown here. Although there are three missing entries there is still enough information to find the conditional mean of Y given that $X = 2$:

$y \backslash x$	0	1	2
0		3/40	2/40
1			6/40

$$E(Y|X = 2) = \boxed{}.$$

(b) YES NO ☐☐ Can you fill in the missing entries so that X and Y are independent?

(c) If YES, do it. If NO, leave table blank and explain.

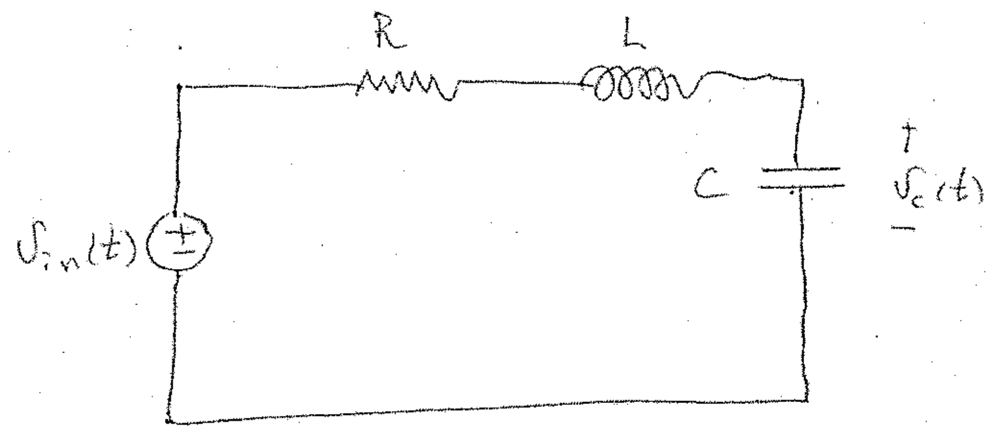
(d) YES NO ☐☐ Here is the same table. Can you fill in the missing entries so that $E(XY) = \frac{2}{3}E(X^2Y)$?

(e) If YES, do it. If NO, leave table blank and explain.

$y \backslash x$	0	1	2
0		3/40	2/40
1			6/40

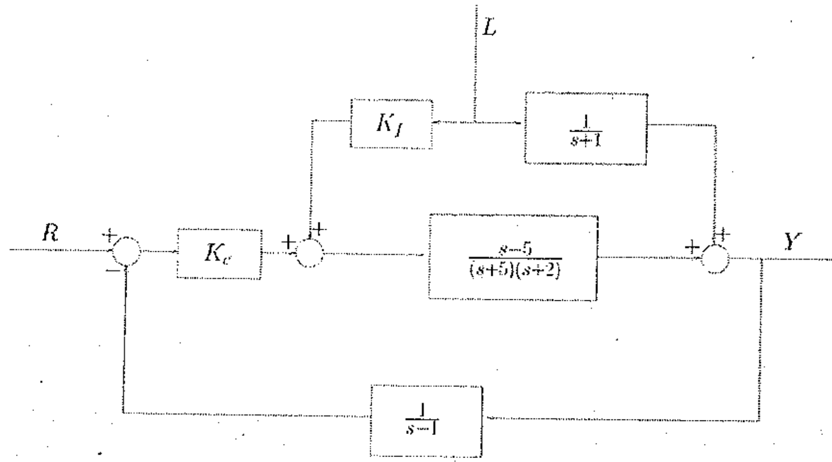
Problem 15 (Core: S&C-ECE3085) Code Number:__________

Consider the circuit shown below. Let $G(s)$ denote the transfer function from v_{in} to v_c. Suppose that the angles of the poles of $G(s)$ are 135 degrees and 225 degrees, respectively. Define $\omega_n := \frac{1}{\sqrt{LC}}$. Suppose that the input voltage is $v_{in}(t) = \sin(\omega_n t)$, and denote by $v_{C,SS}(t)$ the steady-state part of the corresponding response $v_C(t)$. We know that $v_{C,SS}(t) = A\sin(\omega_n t + \varphi)$ for some $A > 0$ and $\varphi \in R$.
Compute A. The answer should be a number.



Problem 16 (Core: S&C-ECE3085) **Code Number:__________**

Consider the following control system: What values of K_c and K_f ensure stability of the system?



Problem 17 (Specialized: CSS-CS3210) Code Number:_____

Priority Inversion with Thread Scheduling

Assume you are developing and running software on an operating system that supports assignment of scheduling priorities for multiple threads in a single process. Further assume you have written an application using three threads, with three different priorities (one low, one medium, one high). Finally assume your application has at least one critical section and at least one *condition wait / condition signal* pair.

1. Explain how the phenomenon called *priority inversion* can occur in this example application.

2. Explain one solution to the *priority inversion* problem. Your solution can either be modifications to your application, or modifications to the way your operating system handles thread scheduling.

Problem 18 (Specialized: CSS - ECE3035) Code Number: ____

Prelim Problem

Computing Mechanisms

Part A: Perform the following standard compiler optimizations on the body of the C subroutine below by writing the optimized version (in C) to the right: strength reduction, loop invariant removal, common subexpression elimination, and dead code elimination. You may add additional local variables if needed.

```
int bar(int x, int y) {

   int i = 0, w = 0;

   int a = 32;

   while (baz(x*y, i)) {      ⇨

      w = foo(w*a);

      i++;

   }}
```

Part B: Consider the following C fragment. Assume a 32-bit integer datapath with a 32-bit memory address space. Assume *int* datatypes are 1 word long and *double* datatypes are 2 words long. In C syntax, "&" is the address operator and "*" is the dereference or indirection operator.

```
double F (double A) {
   int      x = 5;
   double   y = 20.0;
   double *p = &y
   double   Vector[3] = {4.7, 9.3, 16.1};
   y = G(p, x, Vector);
   return y+A;}
```

What is the total number of words of storage allocated in F's activation frame for F's input and output parameters and local variables?

____**words for F's I/O and local variables.**

What is the total number of words of storage allocated in G's activation frame for G's input and output parameters?

____**words for G's I/O parameters.**

Problem 19 (Specialized: Telecom-ECE3076) Code Number:________

1. Consider window-based TCP congestion control algorithm. Let MSS be TCP segment size, and RTT be the round-trip time. Let the window size be measured by the number of segments in a congestion window. Assume all segments are of the same size.

(a) Given that the total 5 windows are needed for the slow-start algorithm to send a message. Given the segment size (MSS) is *1500* bytes. Write an expression for and find the total bytes in the message. Assume there is no loss.

(b) Now assume for simplicity that the Time-Out (TO) and thus the threshold constant window-based TCP congestion control. Assume also that the threshold is 4*MSS between slow-start and congestion avoidance.

- Fine the window size when time-out occurs. Assume at the initial phase of TCP, TCP congestion window goes from slow-start to congestion avoidance when the window size reaches the threshold.
- Sketch the sender congestion window *w* as a function of time which would include all phases of TCP for one cycle.
- Find the time duration of the slow-start phase, and the time duration of additive increase, in terms of RTT.

2. Routing: Consider a network where distance vector (Bellman-Ford) routing algorithm is used.

(a) Write an equation for finding the minimum distance of distance-vector (Bellman-Ford) algorithm. Specify the meaning of the variables you use in the equation.

(b) Consider node *Z*, which has only two neighbors – *X* and *Y*. The link cost from *Z* to *X* is 2 and the link cost from *Z* to *Y* is 3. Suppose *X* and *Y* have the distance tables shown below with unknowns ("?"), which they send to *Z*. For example, "13" in X-table is the distance from node *X* to destination *f* via node s_1.

Dx	s_1	s_2	s_3
f	13	?	4
g	?	7	9

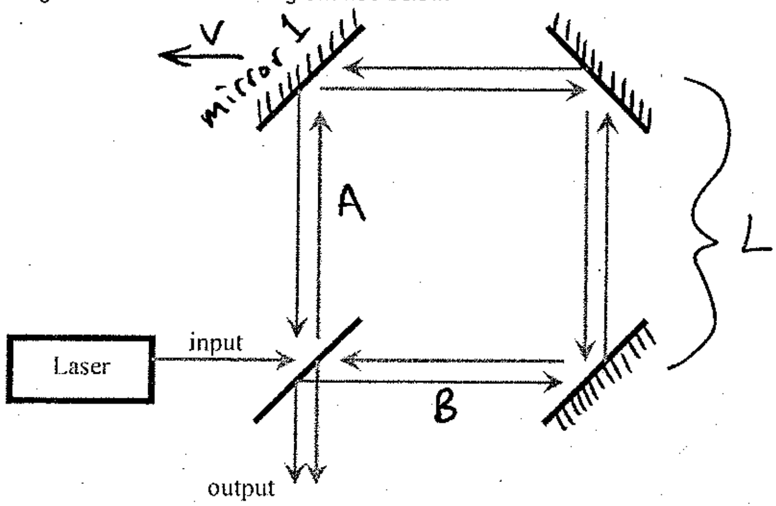
Dy	t_1	t_2	t_3
f	?	6	8
g	7	9	?

Given the distance table for node Z below. Fill the unknowns ("?") in *X* and *Y Tables*.

Dz	X	Y
f	4	8
g	7	6

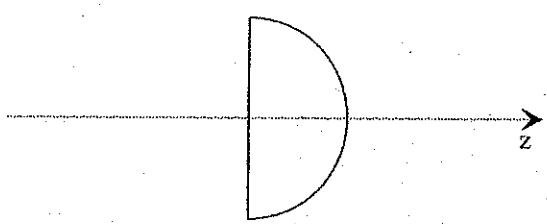
Problem 20 (Specialized: Optics-ECE4500) Code Number:__________

(a) A Sagnac interferometer is diagrammed below.



The interferometer forms a square ring of side length L. Laser light of wavelength λ is split to travel along path A or path B. Path A travels clockwise around the ring, while path B travels counterclockwise. Mirror 1 is moving to the left with velocity v. Find an expression for the minimum value of v which results in destructive interference between the two beams at the output. Neglect beam spreading.

(b) A glass hemisphere of refractive index n = 1.5 is shown below. It is surrounded by air. The radius of the spherical surface is R = 5 cm. Find the output focal length (2nd focal length) of the hemisphere.



Problem 21 (Specialized: Optics-ECE4501) Code Number:__________

Prelim Problem: ECE4501

The dispersion parameter of a single-mode optical fiber can often be expressed as a function of wavelength through:

$$D(\lambda) = D(\lambda_m) + (\lambda - \lambda_m)S(\lambda_m)$$

where $S(\lambda_m) = dD/d\lambda|_{\lambda_m}$ is the dispersion slope. Both $D(\lambda_m)$ and $S(\lambda_m)$ are measured quantities at specified wavelength, λ_m.

Now consider a link consisting of two connected fibers having lengths L_1 and L_2, and dispersions $D_1(\lambda)$ and $D_2(\lambda)$. The second fiber is set up to partially compensate the dispersion of the first fiber. For this link, the path-average dispersion is

$$D_{avg} = \frac{D_1L_1 + D_2L_2}{L_1 + L_2}$$

a. For a pulse of center wavelength λ what two conditions must be met to achieve zero path-average dispersion in the two-segment link?

b. What additional condition must be met to achieve zero path-average dispersion *simultaneously* for two pulses at *different* wavelengths, λ_a and λ_b?

c. You are given the following data:

$D_1(1.55\,\mu m) = 6.6$ ps/nm-km
$D_2(1.55\,\mu m) = -115$ ps/nm-km
$S_1(1.55\,\mu m) = 0.045$ ps/nm^2-km
$S_2(1.55\,\mu m) = -0.78$ ps/nm^2-km.

With $L_1 = 100$ km and $L_2 = 5.6$ km, find D_{avg} at $\lambda_a = 1.56\,\mu m$ and at $\lambda_b = 1.58\,\mu m$.

Problem 22 (Specialized: Microsystems-ECE4752) Code Number:____

Given: 4" (100) silicon wafer with a background phosphorous concentration of 4×10^{15} cm^{-3} with boron thermally diffused into the surface of the wafer to form a junction depth of 5 μm. After the diffusion a four point probe is used to determine the sheet resistance, 52 ohms / square. Electron mobility = 1350 cm^2/V-s, hole mobility = 480 cm^2/V-s, q = 1.6E-19 C, T = 300 K

(A) What is the resistivity of the diffused layer?
(B) What is the average boron concentration?
(C) If the diffused region is used for a resistor with a length of 4.0 cm and a width of 30 μm, what is the resistance of the resistor?

Problem 23 (Specialized: Bio Eng-ECE4784) Code Number:________

a)(3pts)Using the values for channel resting conductance provided for a mammalian axon calculate the sodium and potassium membrane conductance of a section which has a diameter of 0.1mm and a length of 1mm.

Na: channel conductance of 10pS. channel density of 1000 per μm^2.

K: channel conductance of 5pS. channel density of 300 per μm^2.

b) (3pts) Compare and contrast semiconductor pn junctions and electrically active membranes. Be thorough in your comparison, indicating what is remarkably similar and what is not. **Also include in this a description of the physiological make-up of the plasma membrane, i.e. draw a picture.**

c) (4pts)The equation for Johnson noise is $i_n = \sqrt{\frac{4kT\Delta f}{R}}$, where k is the Boltzmann constant, R is the resistance through which the current is flowing and Δf is the bandwidth of interest. At a membrane voltage, V_m, of 70mV and a Nernst potential of 20mV for Na, what will be the membrane current through a single Na channel. In addition calculate the signal to noise ratio of that channel in dB. Make any reasonable assumptions necessary to solve the problem.

Constants: $\mathcal{R} = 8.314\frac{J}{K\,mol}$(from ideal gas law), F =96485 = Faraday Constant, **Avagadro's Number** = 6.02 x 10^{23} atoms/mol

Problem 24 (Specialized: Bio Eng-ECE4782) Code Number:________

Part A) When recording from excitable tissue (cardiac, neural, muscle), it is possible to measure both intracellular and extracellular potentials.

A1) (2 points) What are the typical ranges (order of magnitude) of intracellular and extracellular potential measurements?

A2) (2 points) Explain your answer to A1, and address the role of current flow in your explanation.

A3) (1 point) What aspects of the action potential cannot be quantified by an extracellular measurement but can be quantified by an intracellular measurement? List at least one.

A4) (2 points) You wish to design a micro-machined device that can measure the firing rate of action potentials from isolated cells in response to the application of particular drugs. The goal is a high-throughput device. Would you make intra- or extra-cellular measurements, and why?

Part B) (3 points) An implantable cardiac pacemaker can use bipolar or unipolar electrodes to stimulate cardiac tissue. Draw a simple picture of bipolar and unipolar electrodes and the lines of current flow resulting from each. Provide at least one reason why bipolar stimulation is preferable and more commonly used today.

Problem 25 (Specialized: Bio Eng-ECE4781) Code Number:________

(A) Draw an equivalent circuit for an impedance measurement on a single non excitable biological cell. Label all components of the equivalent circuit and give relative values. Assume that the electrodes are in direct contact with the cell membrane and there is not a leakage current.

(B) Draw an equivalent circuit for an impedance measurement on a single non excitable biological cell. Label all components of the equivalent circuit and give relative values. Assume that the electrodes are NOT in direct contact with the cell membrane.