

**Ph.D. Preliminary Examination  
Spring 2007**

**Code Number** \_\_\_\_\_

**Instructions:**

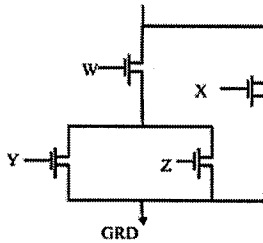
1. Please check to ensure that you have a complete exam booklet. There are 25 numbered problems. **Problem 2 occupies 2 pages.** Including the cover sheet, you should have **27 pages.** There should be no blank pages in the booklet.
2. The examination is closed book and closed notes. No reference material 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 chose 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!

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

**Problem 1 (Core: CompE-ECE2030)**

**Code Number:** \_\_\_\_\_

- a. Using the nFET network given below, draw the corresponding pFET network to complete this complex CMOS logic gate. What function does this circuit implement?



- b. Show the LOGIC schematic for the following Boolean function. Please show the implementation (preferably with mixed logic notation) using NOR gates and INVERTERS only.

$$F = \overline{X} \overline{Y} + \overline{Z} \overline{W} + A$$

- c. Show the TRANSISTOR schematic for a complex CMOS gate that implements the following function with a minimum number of transistors.

$$OUT = \overline{X} \overline{Y} + \overline{Z} \overline{W} + A$$

**Problem 2 (Core: CompE-ECE2030) Code Number: \_\_\_\_\_**

(a) List all the *prime implicants* of the boolean function  $f(w,x,y,z)$  given by the following Karnaugh map:

|    |    |    |    |    |    |
|----|----|----|----|----|----|
|    |    | yz |    |    |    |
|    |    | 00 | 01 | 11 | 10 |
| wx | 00 | 1  | 1  |    | 1  |
|    | 01 |    | 1  | 1  |    |
|    | 11 |    |    | 1  |    |
|    | 10 |    |    | 1  | 1  |

Prime implicants:

(b) List all the *essential prime implicants* of the boolean function  $f()$ , above.

Essential prime implicants:

(c) Give a minimal *sum of products* form expression for the function  $f()$  below:

$f(wxyz) =$

(d) Give a minimal *product of sums* expression for the same function  $f()$  below:

$f(wxyz) =$

- (e) Show an implementation of the function  $f(wxyz) = w\bar{x} + xy + \bar{w}\bar{y}z$  using a *minimum* number of inverters and NAND gates only. You may use two or three input NAND gates in your design.

**Problem 3 (Core: CompE-ECE3055)**

Code Number: \_\_\_\_\_

The following RISC assembly language program is executed on a 32-bit MIPS processor. Fill in the register values that will be present, after execution of this program. A summary of MIPS instructions is included at the bottom of the page – for anyone unfamiliar with the MIPS instruction set. Prior to execution of the program, memory location 0x01000 contains 0x30552031. *Note:* 0x indicates hexadecimal and all answers must be in hexadecimal, default is decimal in the MIPS assembly language source file. A MIPS memory word or register contains 32-bits. Use XXXXXXXX for an undefined value.

```

lw      S3, 0x01000
sll     S4, S3, 4
add     S2, S3, S4
and     S3, S4, S3
lui     S5, 0x3055
ori     S5, S5, 38
sub     S6, S4, S3
bne     S3, S6, LABEL1
addi    S6, S0, -20
LABEL1: sw      S6, 0x01000

```

After execution of the MIPS code sequence above,

R2 = 0x \_\_\_\_\_ ( in hexadecimal)

R3 = 0x \_\_\_\_\_ ( in hexadecimal)

R4 = 0x \_\_\_\_\_ ( in hexadecimal)

R5 = 0x \_\_\_\_\_ ( in hexadecimal)

Memory Location 0x01000 contains: 0x \_\_\_\_\_ ( in hexadecimal)

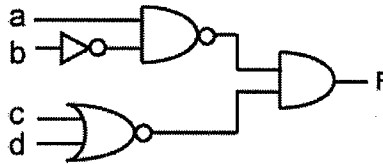
The MIPS processor contains thirty-two 32-bit registers, \$0 through \$31. \$0 always contains a zero. By default, all arithmetic operations use two's complement arithmetic. Assume no branch delay slot is present.

| <u>MIPS Instruction</u>    | <u>Meaning</u>   |
|----------------------------|--|
| ADD Rd, Rs, Rt             | - Rd = Rs + Rt (R – register (\$))                                 |
| AND Rd, Rs, Rt             | - Rd = Rs bitwise logical AND Rt (R – register (\$))               |
| ORI Rd, Rs, <i>Immed</i>   | - Rd = Rs bitwise logical OR <i>Immediate</i> value                |
| LUI Rd, <i>Immed</i>       | - Rd = 16-bit <i>Immediate</i> value high 16-bits, 0's low 16-bits |
| BNE Rs, Rt, <i>address</i> | - Branch to <i>address</i> , only if Rs not equal to Rt            |
| LW Rd, <i>address</i>      | - LOAD - Rd gets contents of memory at <i>address</i>              |
| SLL Rd, Rs, <i>count</i>   | - Shift left logical (use 0 fill) by <i>count</i> bits             |
| SUB Rd, Rs, Rt             | - Rd = Rs - Rt   |
| SW Rd, <i>address</i>      | - STORE - memory at <i>address</i> gets contents of Rd             |
| XOR Rd, Rs, Rt             | - Rd = Rs bitwise logical XOR Rt                                   |

**Problem 4 (Core: CompE-ECE3060)**

**Code Number:** \_\_\_\_\_

Consider the following circuit.



- a) (4pts) Draw a CMOS transistor-level schematic of  $F$  using the minimum number of transistors. Your solution should contain a single pair of pull-down and pull-up networks. Assume that complemented inputs are available.
- b) (3pts) Assuming that the width of all transistors in part a) is  $3w$ , compute the worst-case RC delay in terms of  $\tau$  when  $F$  is driving a load of  $10C_{inv}$ .  $w$  and  $R$  are the width and the resistance of the minimum-size nFET, respectively.  $C_{inv}$  is the input capacitance of the minimum-sized inverter, and  $\tau = R \cdot C_{inv}$ .
- c) (3pts) Determine the width of all transistors in part a) in terms of  $w$  so that the worst-case rise and fall time are matched and the RC delay of driving a minimum-sized inverter becomes  $\tau$ .

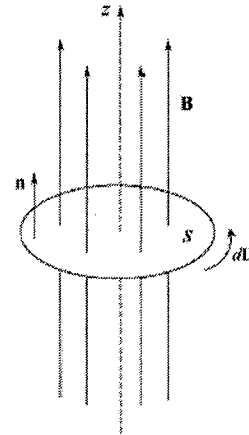
**Problem 5 (Core: E&M-ECE3025)**

Code Number: \_\_\_\_\_

One of Maxwell's equations is Faraday's law of induction, expressed below in point and integral forms: The left-hand integral is taken over a contour,  $C$ , that forms the closed boundary of surface  $S$ . The unit vector,  $\mathbf{n}$ , is normal to that surface. The direction of the contour integral is defined according to the right-hand convention, in which the thumb of the right hand is directed along the normal,  $\mathbf{n}$ , while the fingers of the right hand curl in the direction of the contour integral (or  $d\mathbf{L}$ ).

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\oint_C \mathbf{E} \cdot d\mathbf{L} = -\frac{d}{dt} \iint_S \mathbf{B} \cdot \mathbf{n} \, da$$

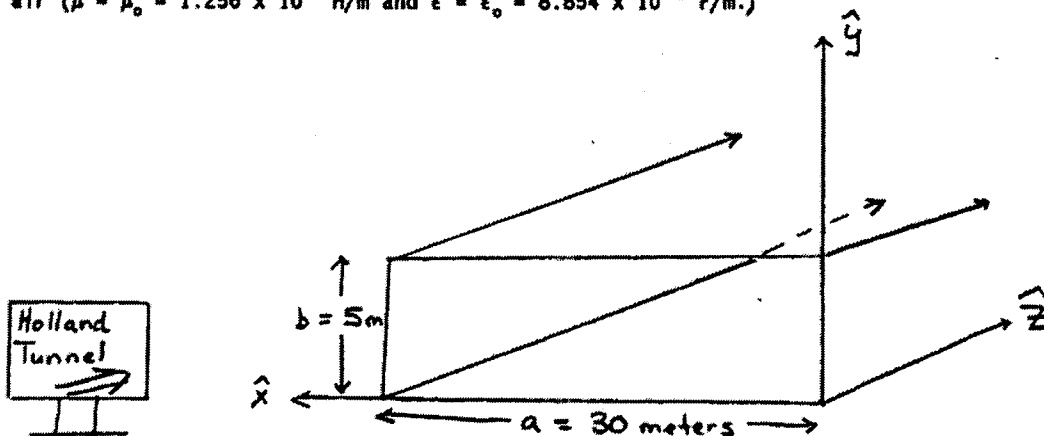


- a. Suppose a spatially-uniform, but time-varying magnetic field,  $\mathbf{B}(t)$ , penetrates a circular surface,  $S$ , in the  $xy$  plane, with the magnetic field oriented in the positive  $z$  direction.  $\mathbf{B}$  is known to *decrease* with time. Obtain the correct orientation of the induced electric field, and express this direction as an appropriate unit vector in cylindrical coordinates.
  
- b. Describe the modifications that could be made to the given  $\mathbf{B}$  field that would lead to the same answer as in part *a*.
  
- c. Under the conditions of part *a*, write an expression for the magnitude of the net induced *voltage* around a circular loop of radius  $a$ , with the loop in the  $xy$  plane. Express your result in terms of  $B(t)$  and other pertinent quantities.
  
- d. Under the conditions of part *a*, write an expression for the magnitude and direction of the induced *electric field* at radius  $a$ . Express your result in terms of  $B(t)$  and other pertinent quantities.

Problem 6 (Core: E&M-ECE3065)

Code Number: \_\_\_\_\_

The Holland Tunnel has a rectangular cross-section with dimensions shown below. Because of the water which permeates the walls of the tunnel, the walls can be considered as nearly perfect conductors, and the tunnel is filled with lossless air ( $\mu = \mu_0 = 1.256 \times 10^{-6}$  H/m and  $\epsilon = \epsilon_0 = 8.854 \times 10^{-12}$  F/m.)



- a) What is the cut-off frequency for the dominant waveguide mode propagating inside the tunnel?

$f_c =$  \_\_\_\_\_ Hz

- b) What waveguide mode will have the next highest cut-off frequency?

\_\_\_\_\_ (name of mode)

- c) Will signals from local AM radio stations (assume  $f = 1000$  kHz =  $10^6$  Hz) propagate inside the tunnel? (Yes or No, and Why?)

Yes      No      (Circle one)

Why? \_\_\_\_\_

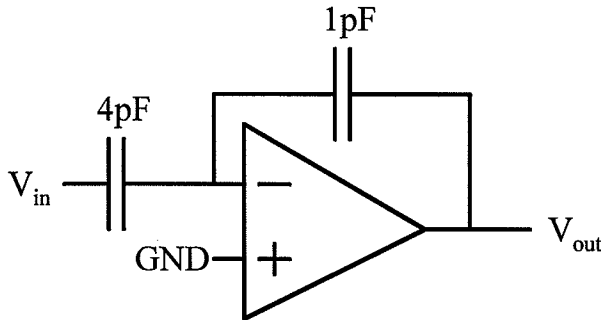
- d) Assuming a 6 MHz ( $6 \times 10^6$  Hz) transmitter is placed at the entrance to the tunnel, what will be the wavelength of propagating waves inside the tunnel?

$\lambda_g =$  \_\_\_\_\_ meters

**Problem 7 (Core: EDA-ECE2040)**

**Code Number:** \_\_\_\_\_

Consider the circuit below Assume the op-amp is an ideal op-amp. You must write your answers in the line (where a line is given) below to receive any credit.



What is the input resistance / impedance looking into the input terminals of an ideal op-amp?

\_\_\_\_\_

For a DC input voltage of 0V applied to the input, the DC output voltage is 2V. What is the cause of

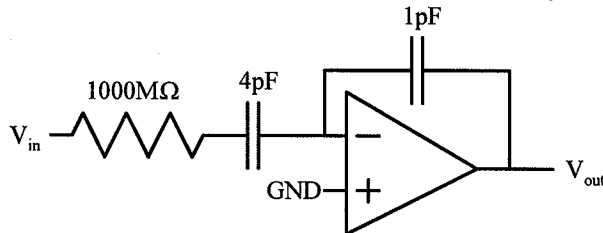
the 2V DC output voltage?

For the rest of the problem, assume the statement to be true for a DC input voltage of 0V applied to the input, the DC output voltage is 2V. Solve for the dc gain and the bandpass gain.

Dc gain = \_\_\_\_\_

Bandpass gain = \_\_\_\_\_

For the circuit below, solve for the dc gain, the bandpass gain, and the corner frequency for the resulting circuit. Assume the op-amp is an ideal op-amp. You must write your answers in the line below to receive any credit. For this circuit, when a dc input of 0V is



applied, the dc output voltage is 0V.

DC gain = \_\_\_\_\_

Bandpass gain = \_\_\_\_\_

Corner frequency = \_\_\_\_\_

**Problem 8 (Core: EDA-ECE3050/3041) Code Number: \_\_\_\_\_**

Assume you have a MOSFET transistor with all four terminals available, where one of the terminals is a gate, one is a source, one is a drain, and one is a well terminal, but none of the terminals were labeled. You know that none of the terminals are tied together. Your job is to determine an experimental procedure to identify all four terminals using typical laboratory benchtop equipment (i.e. voltage sources, voltage meters, current meters), as well as identify whether the device is an nFET or a pFET transistor.

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

A transformer is rated 100 kVA, 11,000:2200 V and 60 Hz. The no-load test on the low voltage winding has the following data: 2200V, 2A, 100 W, and 60 Hz.

- a) Determine the value of the core loss conductance,  $G_c$ , and the magnetizing susceptance,  $B_m$ , for this transformer referred to low voltage winding.
- b) Determine the value of the core loss conductance,  $G_c$ , and the magnetizing susceptance,  $B_m$ , for this transformer referred to high voltage winding.
- c) If this no-load test were performed on the high-voltage winding at rated voltage, determine the current and power that would be measured.
- d) If this same transformer were connected as a 13,200:11,000 V autotransformer, what would be the rating of the autotransformer?

**Problem 10 (Core: Power-ECE3070)****Code Number:** \_\_\_\_\_

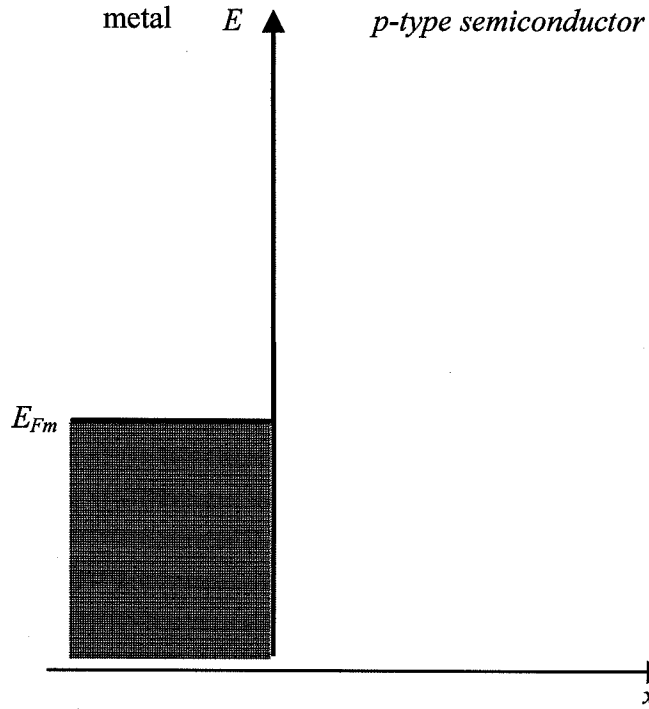
A 3-phase, Y-connected, 220 V (phase to phase), 7.5 Kw, 60 Hz, 6 pole, induction motor has the following resistance and reactance parameters in  $\Omega$ /phase referred to the stator (subscripts "R" and "S" refer to the stator and rotor, respectively):

$$\begin{array}{lll} R_S = 0.294 \Omega & R'_R = 0.144 \Omega & \\ X_S = 0.503 \Omega & X'_S = 0.209 \Omega & X'_m = 13.25 \Omega \end{array}$$

The total friction, windage and core losses may be assumed to be nearly constant (403 W) at all speeds that the machine operates at. For a slip of 2 percent ( $s = 0.02$ ), compute the speed, output torque and power, stator current, power factor and efficiency. Assume that the motor is operated at rated voltage and frequency.

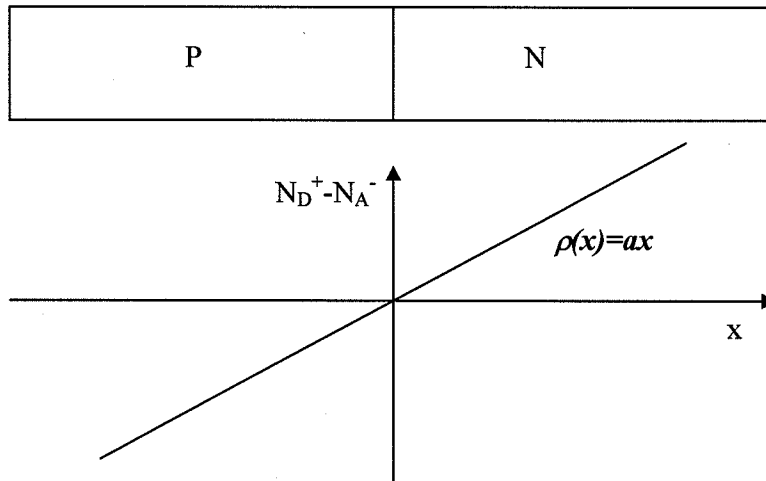
**Problem 11 (Core: Microsystems-ECE3040) Code Number: \_\_\_\_\_**

On the diagram below, sketch the  $E(x)$  vs.  $x$  energy-band diagram for a *Schottky barrier* composed of a *p-type semiconductor—metal junction* under equilibrium conditions and label the quantities  $V_{bi}$ ,  $E_C$ ,  $E_{Fs}$ ,  $E_i$ ,  $E_o$ ,  $\chi$ ,  $\Phi_m$ ,  $\Phi_s$ ,  $E_V$ , and show the direction of the electric field,  $\mathcal{E}$ . What is the relative magnitude of the metal and semiconductor work functions for this case? \_\_\_\_\_



**Problem 12 (Core: Microsystems-ECE3080) Code Number: \_\_\_\_\_**

Using Poisson's equation and appropriate boundary conditions, show that a zero-biased linearly-graded  $p$ - $n$  junction ( $N_D^+ - N_A^- = ax$ , where  $a$  is a constant) has a depletion width ( $W$ ) of  $(\frac{12\epsilon_0\epsilon_s}{qa} V_{bi})^{1/3}$ , where  $V_{bi}$  is the built-in potential of the  $p$ - $n$  junction,  $\epsilon_s$  is the permittivity of the semiconductor,  $\epsilon_0$  is the permittivity of free space, and  $q$  is the electron charge. To simplify this problem, the depletion approximation is applied.



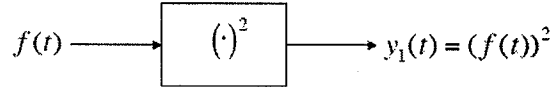
**Problem 13 (Core: DSP-ECE2025)****Code Number:** \_\_\_\_\_

This question has three parts.

In this question,  $f(t)$  is a continuous-time signal that is bandlimited to  $\Omega$ , meaning that its Fourier transform

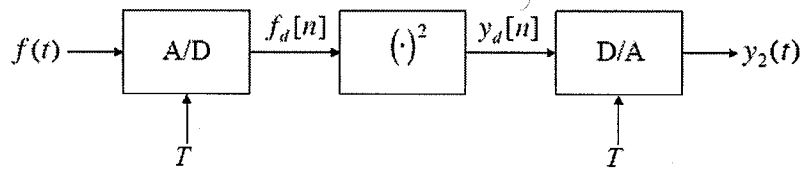
$$\hat{f}(\omega) = \int_{-\infty}^{\infty} f(t)e^{-j\omega t} dt$$

is equal to zero for  $|\omega| > \Omega$ . Consider a system that *squares*  $f(t)$ :



a) (3 points) What is the frequency support of the output  $y_1(t)$ ? In other words, over what range of  $\omega$  is  $\hat{y}_1(\omega) = 0$ ?

Suppose we wish to implement the above system digitally with the following architecture:



where the “A/D” block is an ideal sampler

$$f_d[n] = f(nT),$$

the “ $(\cdot)^2$ ” block squares the discrete-time signal

$$y_d[n] = (f_d[n])^2,$$

and the “D/A” block is an ideal sinc interpolator

$$y(t) = \sum_{n=-\infty}^{\infty} y_d[n] \frac{\sin(\pi(t - nT)/T)}{\pi(t - nT)/T}.$$

b) (3 points) For what range of values for the sampling interval  $T$  is the output of these two systems guaranteed to be equal,  $y_1(t) = y_2(t)$  ?

c) (4 points) Suppose that instead of squaring  $f$ , the input-output relationship is a fixed polynomial

$$y_1(t) = a_N \cdot (f(t))^N + a_{N-1} \cdot (f(t))^{N-1} + \dots + a_1 \cdot f(t)$$

for some  $a_N, \dots, a_1 \in \mathbb{R}$ , and similarly

$$y_d[n] = a_N \cdot (f_d[n])^N + a_{N-1} \cdot (f_d[n])^{N-1} + \dots + a_1 \cdot f_d[n].$$

For what range of  $T$  will we again have  $y_1(t) = y_2(t)$ ?

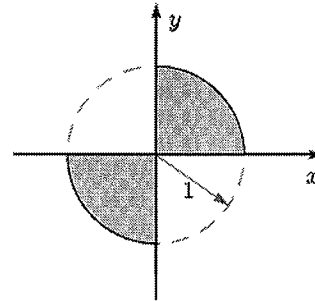
**Problem 14 (Core: DSP-ECE3075)**

Code Number: \_\_\_\_\_

**3075 PROBLEM**

Let  $X$  and  $Y$  be random variables that are uniformly distributed over the shaded region shown to the right, so that the joint pdf for  $X$  and  $Y$  is:

$$f(x, y) = \begin{cases} K, & \text{for } (x, y) \in \text{shaded region} \\ 0, & \text{elsewhere} \end{cases}$$



where  $K$  is an appropriate constant.

- (a) Are  $X$  and  $Y$  independent?  YES  NO

Explain.

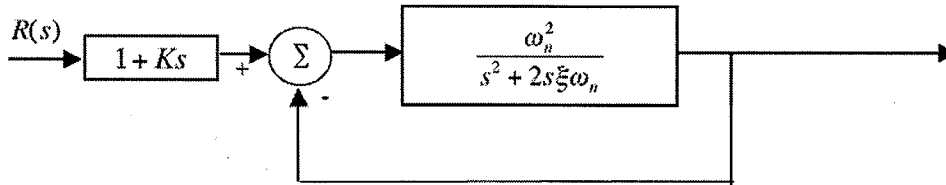
- (b) *Sketch* the conditional pdf  $f(y|x)$ , carefully labeling both axes.

- (c) Define a new random variable  $R = \sqrt{X^2 + Y^2}$ . Find an equation for, and also carefully sketch, its pdf  $f(r)$ .

**Problem 15 (Core: S&C-ECE3085)**

**Code Number:** \_\_\_\_\_

For the system below, the input signal  $R(s)$  is filtered through a PD (proportional-derivative) compensator. What value should  $K$  be to eliminate the steady state value of the error signal  $R(s) - C(s)$  if  $R(s)$  is a unit ramp input?



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

Have a look at the system with transfer function

$$H(s) = \frac{s + 3}{s^2 - s + 1}.$$

Its Nyquist plot is shown (for positive frequencies) in Figure 1. Next to it, in Figure 2, part of a Root Locus (RL) branch is shown.

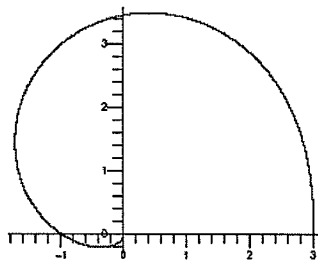


Figure 1: Nyquist plot

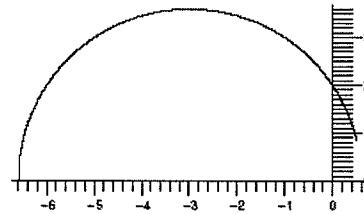


Figure 2: (Partial) Root Locus

Something strange is observed: Look at the point where the Nyquist plot crosses the negative real axis. If you measure the (directed) angle from the Nyquist plot to the real axis, you will see that it is (approximately ?) the same as the angle from the imaginary axis to the RL branch at the point where the RL intersects the imaginary axis. One should wonder if this is a mere coincidence.

To satisfy your suspicion, if not curiosity, your task is to prove the following general result:

Let  $H(s)$  be a rational transfer function. If  $\Omega = \{\omega \mid H(j\omega) \in \mathbb{R}_-\} \neq \emptyset$ , then let  $0 < \omega_0 < \infty$  be a point of  $\Omega$ , and set  $H(j\omega_0) = -N_0 < 0$ .

- o) First, put arrows on both paths above showing the natural direction of the plots.
- i) Show that the Nyquist plot of  $H(s)$  must cross the real axis at  $-N_0 < 0$ .
- ii) Show that at least one branch of the RL of  $H(s)$  must cross the imaginary axis at  $j\omega_0$ .
- iii) If  $\phi_N$  is the (directed) angle from the Nyquist plot to the real axis at  $-N_0$  and  $\phi_{RL}$  is the (directed) angle from the imaginary axis to the RL branch at  $j\omega_0$ , show that  $\phi_N = \phi_{RL}$ .

**Problem 17 (Specialized: Comp Science-CS3210) Code Number: \_\_\_\_\_**

Implement the acquire and release operations of a counting semaphore in the assembly language of your choice, using the following primitives, which are always used in combination:

|                    |   |
|--------------------|---|
| ll reg, loc        | load locked: load the contents of memory location loc into register reg   |
| sc reg1, loc, reg2 | store conditional: if no other write has occurred to memory location loc since its corresponding ll was executed, then write contents of register reg1 to loc, else do not write to loc; if write succeeds, store "1" in reg2, else store "0" in reg2 |

Assume that the semaphore is initialized to an arbitrary integer value.

**Problem 18 (Specialized: Software Sys- ECE3035) Code Number: \_\_\_\_\_**

Below is a snapshot of heap storage in byte addressed memory. Values that are pointers are denoted with a "\$". The heap pointer is \$6112. The heap has been allocated contiguously beginning at \$6000, with no gaps between objects. Objects are word-aligned. Each allocated object has a header word containing the size of the object in bytes. The address of the object points to the word just after the header (i.e., the first word allocated for the object's data). For example, the object pointed to by \$6004 has size 16 bytes, so the next allocated object in the heap is of size 8 bytes and is pointed to by \$6024.

| addr | value  | addr | value  | addr | value  | addr | value  | addr | value |
|------|--------|------|--------|------|--------|------|--------|------|-------|
| 6000 | 16     | 6032 | 12     | 6064 | 8      | 6096 | 12     | 6128 | 0     |
| 6004 | 33     | 6036 | 28     | 6068 | 4      | 6100 | \$6024 | 6132 | 0     |
| 6008 | \$6004 | 6040 | 24     | 6072 | \$6092 | 6104 | 16     | 6136 | 0     |
| 6012 | 16     | 6044 | \$6100 | 6076 | 8      | 6108 | 0      | 6140 | 0     |
| 6016 | 3      | 6048 | 12     | 6080 | \$6068 | 6112 | 0      | 6144 | 0     |
| 6020 | 8      | 6052 | \$6080 | 6084 | 0      | 6116 | 0      | 6148 | 0     |
| 6024 | 25     | 6056 | 16     | 6088 | 4      | 6120 | 0      | 6152 | 0     |
| 6028 | 52     | 6060 | \$6004 | 6092 | \$6068 | 6124 | 0      | 6156 | 0     |

**Part A** Suppose the stack holds a local variable whose value is the memory address \$6052. No registers or static variables currently hold heap memory addresses. List the addresses of all objects in the heap that are *not* garbage.

**Addresses of Non-Garbage Objects:** \_\_\_\_\_

**Part B** If an object of size 15 bytes is allocated, what address will be returned as a pointer to the newly allocated object using a first-fit allocation strategy?

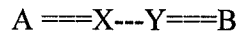
**Address:** \_\_\_\_\_

**Part C** If the local variable whose value is the address \$6052 is popped from the stack, which addresses will be reclaimed by each of the following strategies? If none, write "none."

|                                 |  |
|---------------------------------|--|
| <b>Reference Counting:</b>      |  |
| <b>Mark and Sweep:</b>          |  |
| <b>Old-New Space (copying):</b> |  |

**Problem 19 (Specialized: Telecom-ECE3076) Code Number: \_\_\_\_\_**

Between hosts A in Atlanta and B in Las Vegas there are 2 routers (X,Y). The link between routers (---) is 10 Mbps. The access links (LANs, ===) are 1000 Mbps. The distance from A to B is 2500 km. A starts to send a large file using TCP, sending 1500 byte packets to B. B Asks with 40 byte packets. There is no other traffic on this network.



What is the time required to transmit a 1200 Byte datagram at 10 Mbit/s?  
\_\_\_\_\_ ms

What is the propagation delay for the round trip in milliseconds (ms):  
\_\_\_\_\_ ms

If the router buffers are empty, what is the total round trip transmission delay (neglect processing delay)? \_\_\_\_\_ ms

What is the average transport rate for a 5 kByte Window size and this RTT?  
\_\_\_\_\_

How big a Window size would be needed to reach 10 Mbit/s?  
\_\_\_\_\_

What would happen if the window size was 65 kByte?  
\_\_\_\_\_  
\_\_\_\_\_

Other traffic builds up the average level in X's X-to-Y output buffer to 50 kBytes. What does this queuing delay add to the RTT? \_\_\_\_\_ ms

What is the average transport rate for this new (total) RTT (Window still 5 kByte)?  
\_\_\_\_\_ Mbits/s

What will happen to reduce the rate A sends bits if packets start being lost?  
\_\_\_\_\_

Why is the output buffer delay for router Y not a concern?  
\_\_\_\_\_

**Problem 20 (Specialized: Optics-ECE4500) Code Number: \_\_\_\_\_**

KDP is a birefringent uniaxial crystal with ordinary refractive index  $n_o = 1.507$  and extraordinary  $n_e = 1.467$  for a wave with a wavelength of 633 nm. (The system of units for this problem is SI.)

1) Derive an expression for the electric permittivity tensor (also called dielectric function) in a coordinate system that corresponds to the principal axes of the crystal (one assumes the symmetry axis to be along  $z$ ).

2) Give expressions of the two independent electric permittivity tensor elements and calculate their numerical value (free-space permittivity  $\epsilon_0 = 8.85 \times 10^{-12}$  F/m).

A HeNe laser beam is propagating in KDP and its wave-vector makes an angle  $\theta = 45^\circ$  with respect to the symmetry axis  $z$  of the crystal.

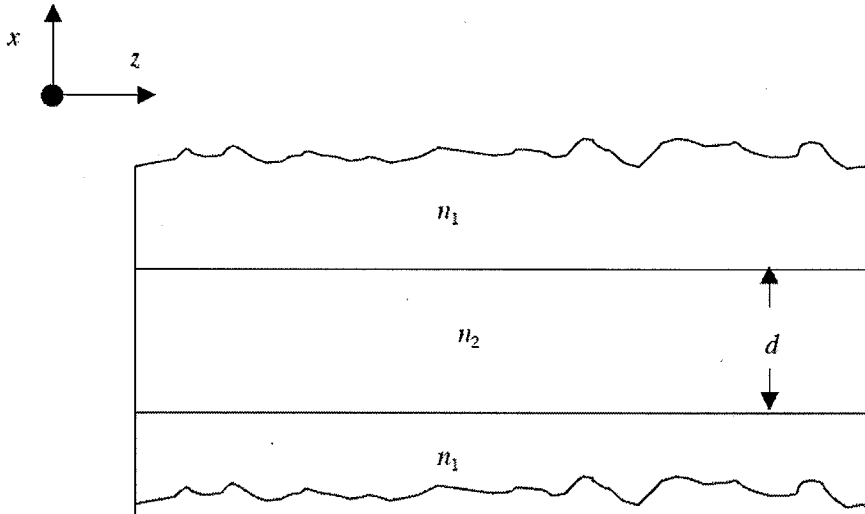
3) Give an expression of the index ellipsoid in the plane  $x = 0$ .

4) Calculate the refractive index if the HeNe laser is s-polarized.

5) Calculate the refractive index if the HeNe is p-polarized.

**Problem 21 (Specialized: Optics-ECE4501) Code Number: \_\_\_\_\_**

Consider a symmetric slab waveguide, as drawn, composed of perfect dielectrics. The core region of thickness  $d$  has refractive index  $n_1$  while the two cladding layers have

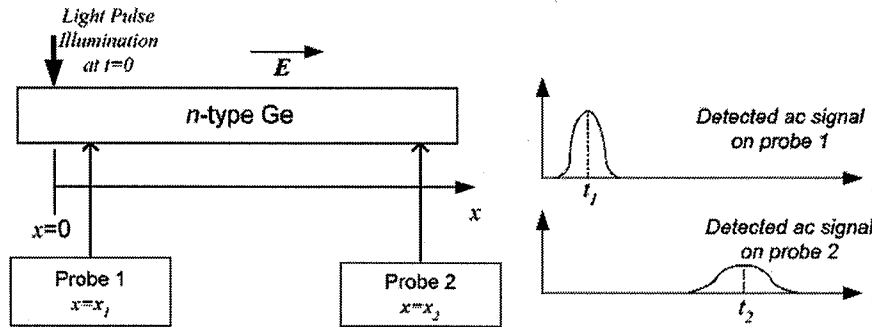


refractive index  $n_2$ . Note that  $n_2 > n_1$ . The  $y$ -direction is into the paper. The waveguide is assumed to extend infinitely in the  $\pm y, z$  directions and the cladding layers extend uniformly in the  $\pm x$ -directions. Recall that TE (TM) modes the electric (magnetic) field points in the  $y$ -direction.

Use the boundary conditions on the electric and magnetic field components to obtain transcendental equations that give the frequency-wavevector relations for TE and TM modes. Show that the  $TE_0$  and  $TM_0$  modes have no cutoff frequency.

**Problem 22 (Specialized: Microsystems-ECE4451) Code Number: \_\_\_\_\_**

The Haynes-Shockley experiment is a famous classic semiconductor experiment. An exemplary schematic drawing of this experiment setup is shown below.



A constant electric field  $E$  ( $E=2$  V/cm) is applied on an  $n$ -type Ge sample. At  $t=0$ , a light pulse is illuminated at  $x=0$  and creates a photocurrent pulse  $I_0$ . Two probes are located at  $x_1=0.5$  mm and  $x_2=4.5$  mm, respectively. After the light pulse, the peak signal is detected at time  $t_1 (=112.5 \mu\text{s})$  from Probe 1, and then at time  $t_2 (=212.5 \mu\text{s})$  from Probe 2. The continuity equations are given below to help your analysis:

$$\frac{\partial n}{\partial t} = \frac{1}{q} \nabla \cdot J_N - \frac{\Delta n}{\tau_n} + G$$

$$\frac{\partial p}{\partial t} = -\frac{1}{q} \nabla \cdot J_P - \frac{\Delta p}{\tau_p} + G$$

Note that  $J_N$  is the electron current,  $J_P$  is the hole current,  $\tau_n$  and  $\tau_p$  are carrier lifetimes, and  $G$  is the generation rate.

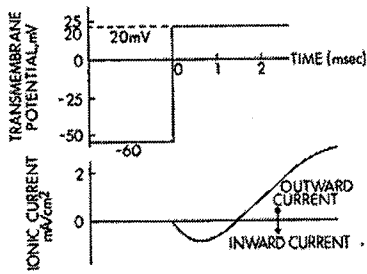
1. (1 pts) What is the minority carrier in this experiment setup?
2. (4 pts) Write a 1-D time-dependent continuity equation for minority carrier as a function of *excess minority carriers* at  $t>0^+$ .
3. (2 pts) Calculate the drift velocity for minority carriers.
4. (3pts) Calculate the minority carrier diffusion coefficient.

**Problem 23 (Specialized: Bio Eng-ECE4781) Code Number: \_\_\_\_\_**

- a)(3 pts) Draw a circuit for an electrode being used in functional neurostimulation. Identify and clarify the physical correlation between each circuit component and the physiological deployment of the electrode.
- b)(3 pts) Sketch the Charge vs. Voltage curve for an electrode. Identify the three regions of operation and describe what happens when one ventures outside of the reversible range.
- c) (2 pts) If you are stimulating a nerve trunk with a point electrical source, which size of fibers are more likely to reach threshold. Explain your answer.
- d) (2 pts) How can one keep the tissue being stimulated from venturing into an irreversible electrochemical region?

**Problem 24 (Specialized: Bio Eng-ECE4781) Code Number: \_\_\_\_\_**

- a) (4 pts) First sketch the full circuit model for the plasma membrane for an electrophysiological cell (e.g. an axon). Explain the physiological origin of each of the components.
- b) (3 pts) Write the differential equation for the total membrane current associated with the model.
- c) (3pts) A voltage clamp experiment is performed and the resulting membrane voltage and membrane current are shown below. Based on your model and looking at the situation described by the figure below, what is not right about the curve for the ionic current?



**Problem 25 (Specialized: Bio Eng-ECE4782) Code Number: \_\_\_\_\_**

- a) (4pts) Describe the proper sequence of firing events for the heart.
- b) (3pts) Sketch the anticipated ECG/EKG in the case where there is an AV block, i.e. the atrial muscle and the AV node lose their electrical connection.
- c) (3pts) Explain, using mathematical arguments why the p wave in the case where the SA node fails to fire will be inverted. Be sure to use the curve for the membrane voltage of the atrial muscle as a function of distance in your answer.