**DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING**
**OLD DOMINION UNIVERSITY**
**PH.D. DIAGNOSTIC EXAM**
**Spring 2014**

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 26 problems from the following six 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 | D4 | | | |
| E. | PHYSICAL ELECTRONICS II | E1 | E2 | E3 | | | | |
| F. | COMPUTER SYSTEMS | F1 | F2 | F3 | F4 | F5 | F6 | |

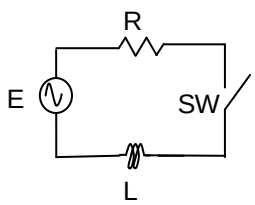
2. You must answer Eight problems, but no more than three from the MATH group.
3. Answer in the blue books provided. **Use a separate book for each problem. Put the title and problem number on the front of each book (eg., MATH A-1)**
4. Return all the 26 problems.
5. You will be graded on your answers 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

## Complex Variables and Differential Equations

In a resistor-inductor circuit, the power source has a voltage dependence $E=E_m sin(\omega t)$, where $E_m$ and $\omega$ are constant. R and L are also constant. After the switch (SW) is turned on, what is the time-dependent expression for the current $i(t)$? Assuming the current is zero before the switch is turned on, i.e., i(t=0)=0.

Hint: You solve the current equation: $\frac{di}{dt} + R\frac{i}{L} = \frac{E}{L}$



# PROBLEM A2 – MATH

**Vector Calculus**

Consider an infinitely long, thin wire running along the *x*-axis in 3D space. If an electric current $I$ passes through the wire, it induces a magnetic field **B** that is a function of space:

$\boldsymbol{B}(\boldsymbol{r}) = \frac{\mu_0 I}{2\pi|r|}\hat{\boldsymbol{r}} \times \hat{\boldsymbol{e}}_{\boldsymbol{x}}$,

where $\mu_0 = 4\pi \cdot 10^{-7}\,\frac{T \cdot A}{m}$ is the vacuum permeability and $\hat{\boldsymbol{e}}_{\boldsymbol{x}}$ is the unit vector in $x$-direction.

a) Sketch $\boldsymbol{B}(\boldsymbol{r})$ in the $yz$-plane.

b) Compute the contour integral of $\boldsymbol{B}$ over the circle $y^2 + z^2 = 1\text{m}^2$ in counter-clockwise direction.

c) Compute curl(**B**).

# PROBLEM A3 – MATH

**Linear Algebra**

Consider two real-valued N-dimensional column vectors $\bar{x} = \begin{bmatrix} x_1 \\ \vdots \\ x_N \end{bmatrix}$ and $\bar{y} = \begin{bmatrix} y_1 \\ \vdots \\ y_N \end{bmatrix}$.

1. Write the expression for the dot product $\bar{x} \bullet \bar{y}$ (also referred to as the inner product) of the two vectors.
2. Define the Euclidian norm for vector $\|\bar{x}\|$ and write it in terms of the dot product.
3. Write the expression of the distance between the two vectors $\bar{x}$ and $\bar{y}$.
4. Write the expression for the cosine of the angle $\theta$ between two vectors $\bar{x}$ and $\bar{y}$.
5. Consider now a matrix with dimensions $m \times n : A = [a_{ij}], 1 \le i \le m, 1 \le j \le n$. Define the norm-2 for matrix $A$ and show that $\|A\|_2$ is equal to the maximum singular value of the matrix $A$.

# PROBLEM A4 – MATH

**Probability**

(1). Let X and Y be continuous random variables with JPDF: $f_{XY}(x,y) = c$ for $0 \leq x \leq y \leq 1$, where "c" is a constant. Determine: $f_X(x)$ and $P[X \leq 0.5]$.

(2). Find the PDF of W = X + Y when X and Y have the joint PDF:

$f_{X,Y}(x,y) = 2$ , for $0 \leq x \leq y \leq 1$; and $f_{X,Y}(x,y) = 0$ otherwise.

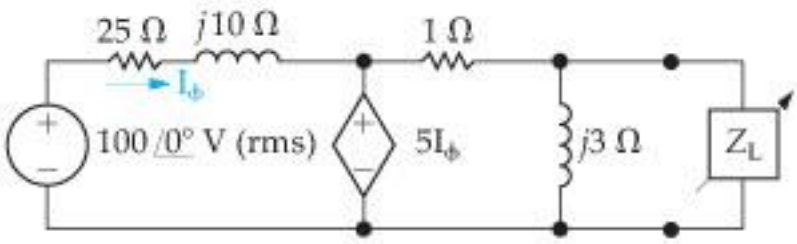
# PROBLEM B1 – CIRCUITS AND ELECTRONICS

## Circuits

### Sinusoidal Steady State Power

The load impedance $Z_L$ for the circuit shown in the figure is adjusted until maximum average power is delivered to $Z_L$.

a) Find the maximum average power delivered to $Z_L$.
b) What percentage of the total power developed in the circuit is delivered to $Z_L$?

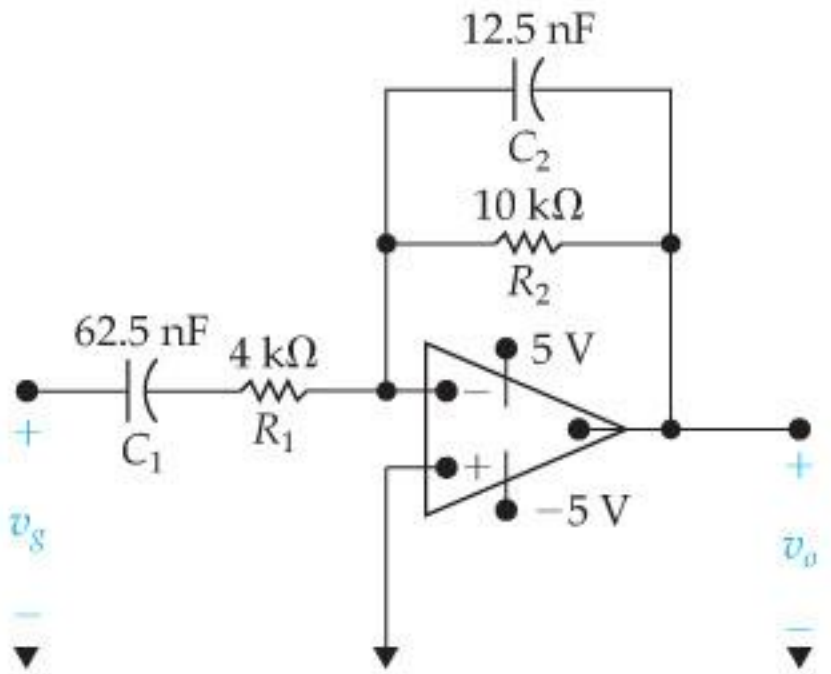


# PROBLEM B2 – CIRCUITS AND ELECTRONICS

**<u>Circuits</u>**
**Laplace Application to Circuit Analysis**

The op amp shown in the circuit is ideal. There is no energy stored in the circuit at the time it is energized. If $v_g = 16{,}000\, u(t)\, V$, find

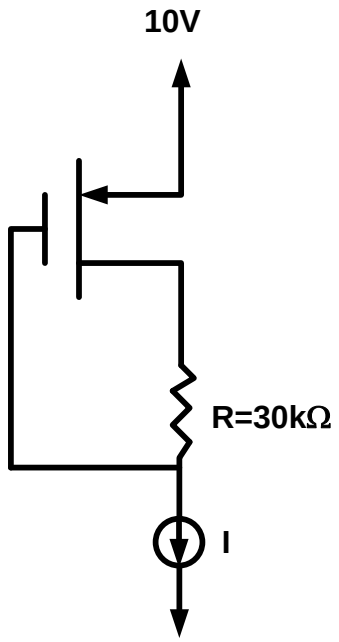
a. Find $V_o(s)$.
b. Find $v_o(t)$.
c. How long does it take to saturate the operational amplifier?
d. How small the rate of increase in $v_g$ must be to prevent saturation?



# PROBLEM B3 – CIRCUITS AND ELECTRONICS

## Electronics

For the PMOS transistor in the circuit with $\mu C=8\mu A/V^2$, W/L=25, and $|V_{tp}|=1V$, the circuit operates with R= 30kΩ for I=100μA.




(a) Does PMOS transistor operate in saturation or triode mode? Explain why?

(b) Calculate the voltages of $V_{SD}$ and $V_{SG}$

# PROBLEM C1 – SYSTEMS, SIGNALS AND IMAGE PROCESSING

## Image Processing

| | | | | |
|---|---|---|---|---|
| **0** | **1** | **5** | **3** | **7** |
| **1** | **2** | **6** | **0** | **5** |
| **9** | **1** | **0** | **5** | **4** |
| **2** | **2** | **8** | **6** | **5** |
| **7** | **6** | **2** | **2** | **9** |

| | | |
|---|---|---|
| **0** | **2** | **0** |
| **-1** | **?** | **-1** |
| **0** | **2** | **0** |

Given the above 5 X 5 grayscale digital image **f(x,y)** and the incomplete 3 X 3 digital filter mask **h(x,y)**, answer the following questions.

a) Given a fixed-bit representation, determine the minimum number of bits per pixel required to represent the image intensities in **f(x,y)**. Based on this value, also determine the number of fixed bits required for storing **f(x,y). (4 pts)**

b) Determine **F(0,0)**, where **F(u,v)** is the centered 5 X 5 two-dimensional Discrete Fourier Transform (DFT) of **f(x,y)**. **(4 pts)**

c) Determine **h(0,0)** and **H(0,0)** such that the **average intensity** of the filtered image will not change, neglecting boundary effects**.** **H(u,v)** represents the centered 3 X 3 DFT of **h(x,y)**. **(4 pts)**

d) Fill in the empty pixel intensities that result when **f(x,y)** is filtered using **h(x,y)** determined in (c). State any assumptions. **(4 pts)**

| | | | | |
|---|---|---|---|---|
| | | **X** | **X** | **X** |
| | | **X** | **X** | **X** |
| | | **X** | **X** | **X** |
| **X** | **X** | **X** | **X** | **X** |
| **X** | **X** | **X** | **X** | **X** |

e) Sketch and clearly label the histogram that results from applying the following intensity transform below to ***f(x,y)***. **(4 pts)**

$$g(x,y) = \begin{cases} 0 & if \;\; f(x,y) = 2 \\ f(x,y) - 1 & if \;\; f(x,y) \geq 5 \\ f(x,y) & otherwise \end{cases}$$

# PROBLEM C2 – SYSTEMS, SIGNALS AND IMAGE PROCESSING

## Digital Signal Processing

A causal LTI system is characterized by the following difference equation:

$$y[n+2] - \frac{5}{6}\, y[n+1] + \frac{1}{6}\, y[n] = x[n+2]$$

(a). Determine the system function H(z) for the system (3 points)
(b). Determine the impulse response $h[n]$ for the LTI system (3 points).
(c). If $x[n] = (1/4)^n u[n]$, what is $y[n]$ (4 points)?

# PROBLEM C3 – SYSTEMS, SIGNALS AND IMAGE PROCESSING

## Digital Signal Processing

(a). If the discrete-time signal $x[n]$ is down-sampled by 4, what is the cutoff frequency for the ideal low pass filter to avoid aliasing? (3 points)

(b). If the discrete-time signal $x[n]$ is up-sampled by 2, what is the cutoff frequency for the ideal low pass interpolation filter? (3 points)

(c). Let $X(e^{j\omega})$ denote the Fourier transform of the signal

$$x[n] = u[n] - u[n\text{-}111]$$

What are the values of $X(e^{j\omega})|_{\omega=0}$ and $X(e^{j\omega})|_{\omega=\pi}$ ? (4 points)

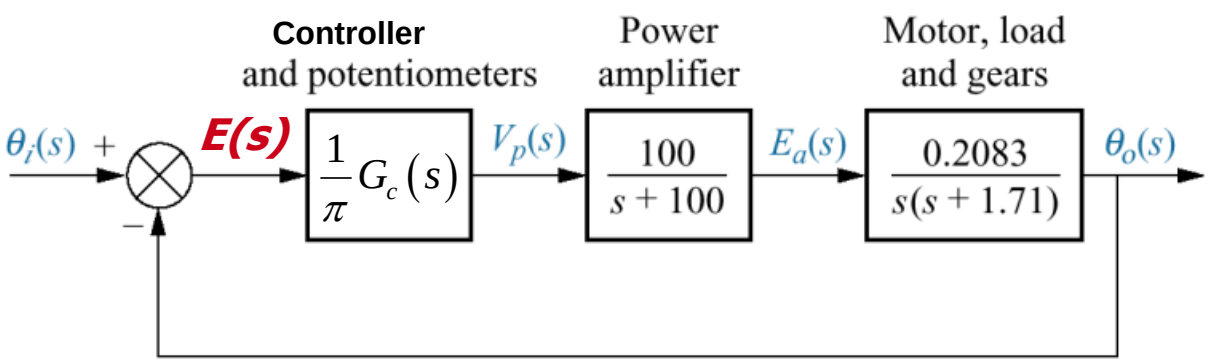
# PROBLEM C4 – SYSTEMS, SIGNALS AND IMAGE PROCESSING

## Control Systems

**Problem.** Consider the block diagram of an antenna azimuth position control system depicted in the figure below.

(i) Find a proportional or PD controller $G_c(s)$ so that the closed-loop system meets the following specification: Settling time ≤ 0.5 sec. Your solution should include at least an approximate root locus sketch.

(ii) If $\theta_i(s) = \frac{1}{s}$, what is the steady-state error for your designed closed-loop system? The error in the time domain is $e(t) = \theta_i(t) - \theta_o(t)$.




## REVIEW

For a prototype second order open-loop transfer function $G(s) = \omega_n^2/(s^2 + 2\zeta\omega_n s + \omega_n^2)$ the following unit step response relations are useful:

- percent overshoot = 100 exp(-ζ / sqrt(1 - $\zeta^2$) )
- 2% settling time ≈4 / ($\zeta\omega_n$)

If the loop gain of a closed-loop system can be written as follows: $K_c G(s) = K_c K_G \frac{\prod_{i=1}^{m}(s - z_i)}{\prod_{j=1}^{n}(s - p_j)}$

where $K_c$ is the gain of the controller that needs to be determined and $G(s)$ represents the transfer function of the plant and the designed portion of the controller with $m$ zeros at $z_i$ and $n$ poles at $p_j$, then the magnitude condition of root locus is:

$$|K_c| = \frac{\prod_{j=1}^{n}|s-p_j|}{K_G\left(\prod_{i=1}^{m}|s-z_i|\right)}, \quad \text{if } s \text{ a closed-loop pole}.$$

# PROBLEM C5 – SYSTEMS, SIGNALS AND IMAGE PROCESSING

## Communication systems

Consider the message signal $m(t) = a\cos(2\pi f_m t)$ that is used to modulated the carrier signal $c(t) = A_c \cos(2\pi f_c t)$, where $f_c >> f_m$.

1. Write the expression of the modulated signal $u(t)$ corresponding to double sideband suppressed carrier amplitude modulation (DSB-SC AM) scheme and identify the lower and upper sideband components of $u(t)$. Argue whether DSB-SC AM is a linear modulation scheme or not.
2. Write the expressions of the pre-envelope signal $u_+(t)$ and of the complex envelope $\tilde{u}(t)$ for the DSB-SC AM signal $u(t)$, and determine its corresponding in-phase and quadrature components $u_I(t)$ and $u_Q(t)$.
3. 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.
4. For the FM signal in Part 3 write the expression of the maximum frequency deviation $\Delta f_{\max}$ and define the modulation index $\beta_f$ for the FM scheme.
5. Write the expressions of the pre-envelope signal $u_+(t)$ and of the complex envelope $\tilde{u}(t)$ for the FM signal $u(t)$, and determine its corresponding in-phase and quadrature components $u_I(t)$ and $u_Q(t)$.

## USEFUL TRIONOMETRIC IDENTITIES

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

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

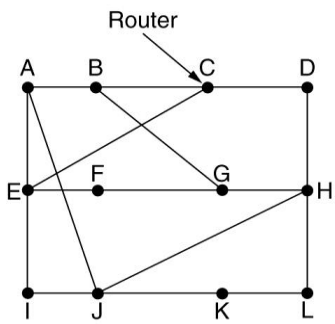
$$\sin(x)\cos(y) = \frac{\sin(x-y)+\sin(x+y)}{2}$$

$$\cos(x) = \frac{e^{jx}+e^{-jx}}{2} \qquad \sin(x) = \frac{e^{jx}-e^{-jx}}{2j}$$

# PROBLEM C6 – SYSTEMS, SIGNALS AND IMAGE PROCESSING

## Communication Networks

1. (7 points) Figure (a) shows a subnet. The four columns of figure (b) show the delay vectors received from the neighbors of router J as well as the estimated delays from J to its four neighbors. please compute the new routing table for J using the Distance Vector Routing protocol.




(a)

| To | A | I | H | K |
|---|---|---|---|---|
| A | 0 | 24 | 20 | 21 |
| B | 12 | 36 | 31 | 28 |
| C | 25 | 18 | 19 | 36 |
| D | 40 | 27 | 8 | 24 |
| E | 14 | 7 | 30 | 22 |
| F | 23 | 20 | 19 | 40 |
| G | 18 | 31 | 6 | 31 |
| H | 17 | 20 | 0 | 19 |
| I | 21 | 0 | 14 | 22 |
| J | 9 | 11 | 7 | 10 |
| K | 24 | 22 | 22 | 0 |
| L | 29 | 33 | 9 | 9 |
| | JA delay is 8 | JI delay is 10 | JH delay is 12 | JK delay is 6 |

Vectors received from J's four neighbors

(b)

2. (3 points) For a channel with 10 MHz bandwidth, if the signal to noise ratio is 20 dB, what is the maximum data rate that can be achieved on this channel?

# PROBLEM D1 – PHYSICAL ELECTRONICS I

## Electromagnetics

(1). The E-field measured in air just above a glass plate is equal to 2 V/m in magnitude and is directed at 45˚ away from the boundary. The magnitude of the E-field measured just below the boundary is equal to 3 V/m. Find the angle θ for the E-field in the glass just below the boundary.

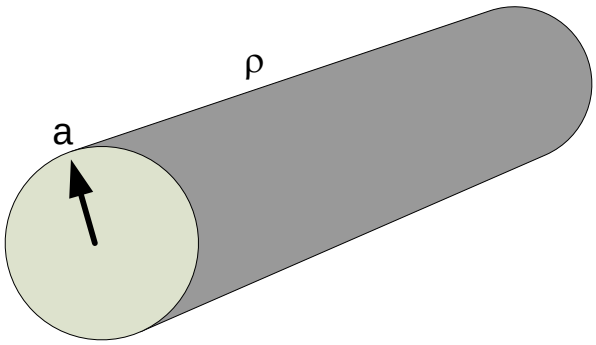
(2). The H-field in air just above a perfect conductor is given by: $\mathbf{H} = 3\,\mathbf{a_x} + 4\,\mathbf{a_z}$ Amps/m. Find the surface current $\mathbf{J_s}$ on the surface of the perfect conductor, given that the conductor occupies the space $y < 0$.

# PROBLEM D2 – PHYSICAL ELECTRONICS I

## Electromagnetics

Assume that a long cylindrical electron beam moving in air has a charge density of ρ coulombs per meter. The radius of the beam is *a* and the charge is distributed uniformly as below. ( Assume that the beam is infinitely long)
Calculate electric field as function of radius *r*?

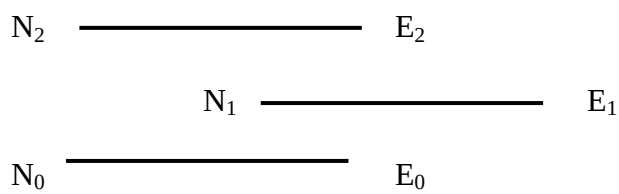
E= (r≤ a)
E= (r>a)



# PROBLEM D3 – PHYSICAL ELECTRONICS I

## Lasers

1) Write the rate equation for each energy level of the three-level laser below.




Assume: The only processes are radiant processes (spontaneous and stimulated), the incident light is monochromatic, and no significant sustained stimulated occurs between the pump level and the upper lasing level.

$E_2 - E_0 = h\nu_p, \quad E_1 - E_0 = h\nu$

Define: $B_{nm}$ is the Einstein $B$ coefficient for the $E_n$, $E_m$ transitions (e.g., $B_{10}$ is the Einstein $B$ coefficient for the $E_0$, $E_1$ transition). Also, note that $B_{nm} = B_{mn}$.
$A_{nm}$ is the Einstein $A$ coefficient for the $E_n$, $E_m$ transitions.
$N_0$, $N_1$, and $N_2$ population density for $E_0$, $E_1$, and $E_2$ energy levels, respectively.
$g(\nu_p)$ is the line shape function of the incident pump light at $\nu_p$.
$g(\nu)$ is the line shape function of the laser light inside the cavity $\nu$
$I_p$ is the irradiance of the incident pump light.
$I$ is the irradiance of the stimulated emission light between $E_1$, and $E_0$.
$c$ is the speed of light.

| | | | |
|---|---|---|---|
| Mass of electron = | $9.10938*10^{-31}$ kg | Gas constant = | 8.3145 J/(mol K) |
| Mass of hydrogen atom = | $1.67372*10^{-27}$ kg | Planck's constant = | $6.62607*10^{-34}$ Js |
| Charge of electron = | $-1.6021766*10^{-19}$ Coulombs | Permittivity of free space = | $8.854*10^{-12}$ F/m |
| Avagadro's number = | $6.022141*10^{23}$ | Permeability of free space = | $1.257*10^{-6}$ H/m |
| Boltzamann's constant = | $1.38065*10^{-23}$ J/K | Velocity of light in free space = | $3*10^{8}$ m/s |

1 atm = 760 torr = $1.013 \times 10^{5}$ N/m$^2$; 1 Å = $10^{-10}$ cm

eV electron volt $1.6 \times 10^{-19}$ J

1 eV of temperature KT 11,600°K

$$\int_0^\infty e^{-x^2}\,dx = \frac{\pi^{1/2}}{2}$$

$$\int_0^\infty x^{1/2} e^{-ax}\,dx = \frac{(\pi/a)^{1/2}}{2a}$$

$$\int_0^\infty x^n e^{-ax^2}\,dx = \begin{cases} \dfrac{(1)(3)(5)\cdots(n-1)}{2(2a)^{n/2}}\left(\dfrac{\pi}{a}\right)^{1/2} & \text{for even } n \geq 2 \\ \dfrac{[(n-1)/2]!}{2a^{(n+1)/2}} & \text{for odd } n \geq 1 \end{cases}$$

$$\int_{-\infty}^\infty x^n e^{-ax^2}\,dx = \begin{cases} 2\int_0^\infty x^n e^{-ax^2}\,dx & \text{for even } n \\ 0 & \text{for odd } n \end{cases}$$

$$\frac{2}{\pi^{1/2}}\int_0^z e^{-x^2}\,dx = \text{erf}(z)$$

# PROBLEM D4 – PHYSICAL ELECTRONICS I

## Optical Fiber Communications

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

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

Assume τ is the average carrier lifetime in the recombination region when the injected carrier pair density is $n_{th}$ near the threshold current $J_{th}$. That is, in the steady state we have $\frac{\partial n}{\partial t} = 0$ so that $n_{th} = \frac{\tau J_{th}}{qd}$

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

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

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

# PROBLEM E1 - PHYSICAL ELECTRONICS II

**Solid State Electronics**

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

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

The junction is forward biased by 0.5 V.

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

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

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

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

e) Calculate the depletion widths on the p-side of the junction $X_p$ and on the n-side $X_n$ for the following reverse biases -4 V and -10 V

**Equations:**

Ideal diode: I = qA $\left(\frac{D_p}{L_p}P_n + \frac{D_n}{L_n}n_p\right)\left(e^{qV/kT} - 1\right) = I_0(e^{qV/kT} - 1)$

$D_p = \frac{kT}{q}\mu_p \quad L_p = \sqrt{D_p\tau_p}$

$D_n = \frac{kT}{q}\mu_n \quad L_n = \sqrt{D_n\tau_n}$

$$X_p = \sqrt{\frac{2\varepsilon_{si}}{q}(V_{bi} - V)\frac{N_d}{N_a(N_a + N_d)}}$$

$$\varepsilon_{si} = \varepsilon * K_{si}$$

$$X_n = \sqrt{\frac{2\varepsilon_{si}}{q}(V_{bi} - V)\frac{N_a}{N_d(N_a + N_d)}}$$

Total depletion width

$$W = X_p + X_n = \sqrt{\frac{2\varepsilon_{si}}{q}(V_{bi} - V)\frac{(N_a + N_d)}{N_a - N_d}}$$

Depletion Capacitance:

$$C_j = \sqrt{\varepsilon} A \left[\frac{q}{2(V_{bi} - V)}\frac{N_d N_a}{N_d + N_a}\right]^{1/2}$$

**Physical Constants :**

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

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

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

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

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

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

# PROBLEM E2 – PHYSICAL ELECTRONICS II

**Physical Electronics**

1. Explain, using appropriate diagram, the main difference between GaAs and Germanium.
2. Based on your answer to question 1, explain and justify which material should be used for fabricating (1) transistor; (2) solar cell; (3) LED. Note that the answer might be none, both or one material.

# PROBLEM E3 – PHYSICAL ELECTRONICS II

**Plasma Science and Discharges**

A cylindrical plasma tube with a diameter of 2 cm and length of 1m is driven by a DC power source. The electric field in the plasma is E = 20 volts/meter, the electron number density is $n_e = 10^{17}\ m^{-3}$, the electron kinetic temperature is $T_e = 1$ eV, and the current density across the tube is $J = 250\ mA/cm^2$ .

a./ Calculate the mean thermal velocity of the electrons.

b./ Calculate the average drift velocity, $v_d$, of the electrons.

c./ Calculate the mobility of the electrons in the plasma. Assume a plasma resistivity of 0.8 Ω.cm

d./ Calculate collision frequency for momentum transfer of the electrons.

# PROBLEM F1 - Computer Systems

## Microprocessors

Microprocessors

Write a subroutine that removes duplicate entries in a byte array for a **Motorola 6811 microprocessor based system**. The byte array has a base address of **$2000** and the size (in bytes) of the initial array is stored in memory location **$1000**. At the termination of your subroutine, the array should have any duplicate entries removed and the updated size of the array stored in location **$1000**. You may assume that the initial array is unsorted and the array at termination can also be unsorted. Your code must be commented and you may include pseudocode or a flow chart to help explain the functionality of the code.

You may safely use memory locations **$0001** to **$00FF** for storage of any temporary variables.

Details: Style - Write your code in a three column format, i.e.:

| | **LABEL:*** | **MNEMONIC** | **OPERAND*** | (* use only when required / needed) |
|---|---|---|---|---|
| ***Example:*** | ***LOOP:*** | ***BRA*** | ***LOOP*** | |

**Symbols:** The use of a # sign before an operand designates immediate addressing mode, $ - hexadecimal, % - binary.

**Example**: LDAA #$F0 – The value F0 hexadecimal is loaded into AccA.

**Addressing modes:** Immediate example: LDAA #$F0 (A← $F0)
Direct example: LDAA $F0 (A← M[$00F0])
Extended example: LDAA $00F0 (A← M[$00F0])
Indexed example: LDAA 0, X (A ← M[X+0])

**Available instructions:**

**LDAA / STAA** : Load / Store Accumulator A (one byte)
**LDAB / STAB** : Load / Store Accumulator B (one byte)
**LDD/STD** : Load / Store Accumulator D (A + B, double byte)
**LDX / STX** : Load / Store index register X (double byte)
**LDY / STY** : Load / Store index register Y (double byte)
**LDS/STS** : Load/Store Stack Pointer (double byte)
**TSX / TXS** : Transfer SP in X / Transfer X in SP

**ABA :** Add Accumulators A + B → A
**ABX/ABY :** Add B to X/Y, IX/IY + 00:B → IX/IY
**ADCA/ADCB :** Add with Carry to A/B, A/B + M + C → A/B
**ADDA/ADDB :** Add Memory to A/B, A/B + M → A/B

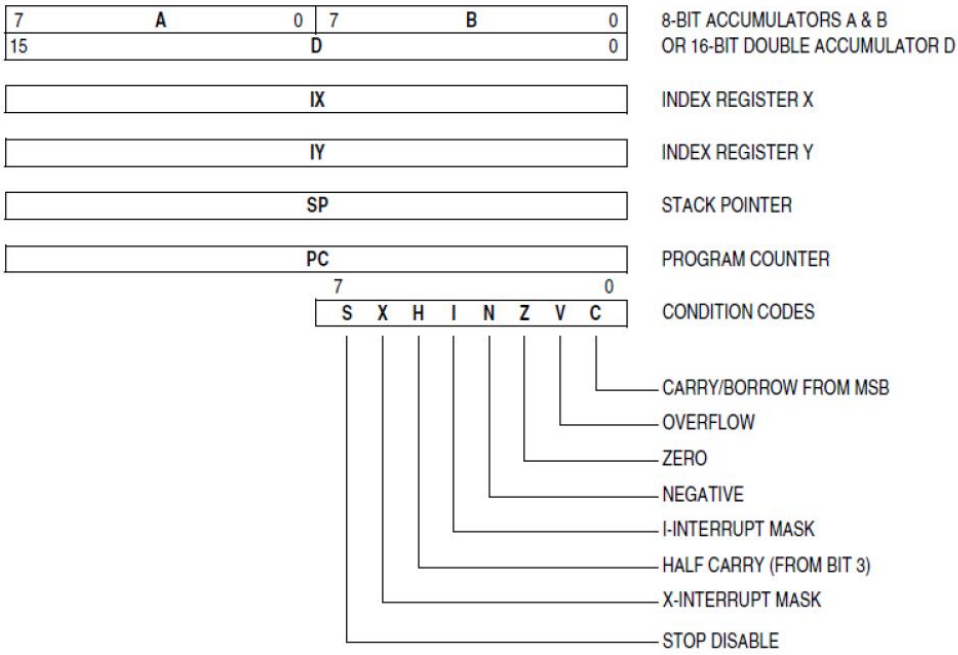
**PSHA / PULA** : Push / Pull Acc. A on / from the stack
**PSHB / PULB** : Push / Pull Acc. B on / from the stack
**PSHX / PULX** : Push / Pull index register X on / from the stack
**PSHY / PULY** : Push / Pull index register Y on / from the stack

**INCA / DECA** : Increment / Decrement AccA – Inherent addressing
**INCB / DECB** : Increment / Decrement AccB
**INC / DEC** : Increment / Decrement memory location contents
**INX / DEX** : Increment / Decrement index register X
**INY / DEY** : Increment / Decrement index register Y
**INS / DES** : Increment / Decrement stack pointer

**BRA** : Branch always - Relative addressing
**BEQ** : Branch if equal to zero
**BNE** : Branch if not equal to zero
**BGT** : Branch if greater than zero
**BLT** : Branch if less than zero
**BGE** : Branch if greater than or equal to zero
**BLE** : Branch if less than or equal to zero
**BMI** : Branch if minus
**BPL** : Branch is plus
**JMP** : Jump to the given address – Absolute addressing
**RTS** : Return from subroutine

**CLRA** : Clear contents of AccA (A ← $00)
**CLRB** : Clear contents of AccB (B ← $00)
**CLR** : Clear memory location contents (M ←$00)

**CMPA** : Compare AccA to memory (A – M)
**CMPB** : Compare AccB to memory (B – M)
**CBA** : Compare AccB to AccA (A-B)
**CPX** : Compare index register X to memory (X – MM)
**CPY** : Compare index register Y to memory (Y – MM)


7 A 0
7 B 0
15 D 0
8-BIT ACCUMULATORS A & B
OR 16-BIT DOUBLE ACCUMULATOR D
IX
INDEX REGISTER X
IY
INDEX REGISTER Y
SP
STACK POINTER
PC
PROGRAM COUNTER
7 0
S X H I N Z V C
CONDITION CODES
CARRY/BORROW FROM MSB
OVERFLOW
ZERO
NEGATIVE
I-INTERRUPT MASK
HALF CARRY (FROM BIT 3)
X-INTERRUPT MASK
STOP DISABLE

# PROBLEM F2 – COMPUTER SYSTEMS

## Digital System Design

**Problem Description:**

1. (5 points) Devise an SM Chart for a sequencer capable of detecting a sequence that begins with `"01"` is followed by one or more `'0'`s, further followed by one or more `'1'`s, ending with `"01"`. Your sequencer does not have to account for overlaps. A couple of examples of sequences that should be detected are shown:

```
"010101"
"010000000101"
"01011111111101"
"010000000111101"
```

2. (5 points) Sketch out the VHDL model for the sequencer for Part 1.

# PROBLEM F3 – COMPUTER SYSTEMS

## Computer Architecture

1. (7 points) Suppose the following code segment is going to be executed in the 5-stage pipeline of the SRC processor.

```
add r1, r2, r10
sub r10, r2, r1
sub r7, r10, r1
st    r7, addr2
```

(a) (3 points) Find out all RAW hazards in the code segment.
(b) (2 points) How many cycles are needed to complete the execution if data forwarding is used? Explain how all the RAW hazards are resolved.
(c) (2 points) How many cycles are needed to complete the execution if data forwarding is **not** used? If an instruction needs to be stalled, list the number of cycles that this instruction has to be stalled.

2. (3 points) Please describe what is the difference between the RISC and the CISC architectures? What are advantages and disadvantages of each architecture?

# PROBLEM F4 – COMPUTER SYSTEMS

## Algorithms

Part 1 (6 points) You are given a connected undirected acyclic graph. Assuming the weight of each link is 1, find the most efficient algorithm to determine the diameter of the graph, where the diameter is the longest path possible between any two nodes in the graph.

Part 2 (4 points) Assuming the weight between two nodes is $W_{ij}$ , find the diameter of the tree in terms of the weights between links.

In solving these problem, be sure to clearly state any assumptions you have had to make.

# PROBLEM F5 – COMPUTER SYSTEMS

## Data Structures

Recall the array-based implementation of class template `Stack` has the following data members:

```
template <class T>
class Stack{
  // public function declarations here ...
 private:
  static const int MAX_STACK = 10;
  T items[MAX_STACK];
  int top;  /* array index of top element of the stack;
               is -1 when stack is empty
            */
};
```

(a)

Write a member function

```
template <class T>
bool Stack<T>::operator== (const Stack<T>& rhsStack) const
```

which checks to see if two stacks are equal (in other words, they have the same number of items, and all these items, from the top to the bottom, are equal).

(b)

A stack of integers `aStack` has the following private data:

```
top: 4
items: 8 0 0 4 7 10 -34323 0 67823 -78999
```

What is the output of the following code?

```
int x;
while (!aStack.isEmpty()){
  aStack.pop(x);
  cout << x << " ";
}
```

Hint: Recall that `top` is the *array index* of the top of the stack.

# PROBLEM F6 – COMPUTER SYSTEMS

## Data Structures

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

Given the input A (-1, 11, 9, 4, 0, 0, 3, 6),

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

2.2 Add a node, 3, into this binary search tree?

2.3 Delete a node, 11, from this binary search tree?

2.4 Given another binary search tree with the input B sequence (4, 5, 7), how to join two trees (Input A and B) into one tree?