**Problem: CM1** **Area: Computers and Architecture** **Code #_________**

Design a 4-bit carry lookahead adder which can be used for addition and subtraction operation. In addition to input words and output word, your design should have a carryout bit and one select bit to select either addition operation or subtraction operation. You are allowed to use full adder and logic gates to design it.

**Problem: CM2** **Area: Computers and Architecture** **Code #_________**

Suppose we have two implementations (Machine A and machine B, namely) of the same instruction set architecture. For some program which has 1 million instructions,

Machine A has a clock cycle time of 100ps and an average CPI of 4.0.

Machine B has a clock cycle time of 130ps and an average CPI of 3.0.

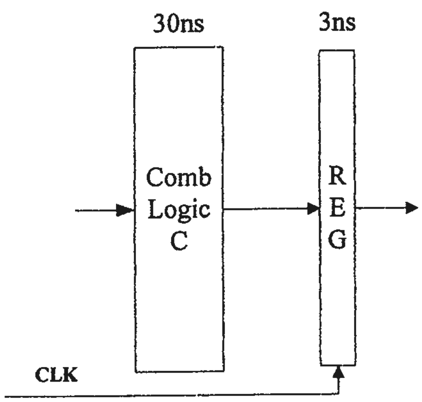
a. What machine is faster for this program, and by how much?

b. If underclocking (i.e., driving the given machine with slower clock speed) of the faster machine is possible, what clock rate should be used to execute the given program to achieve the same execution time of the slower machine?

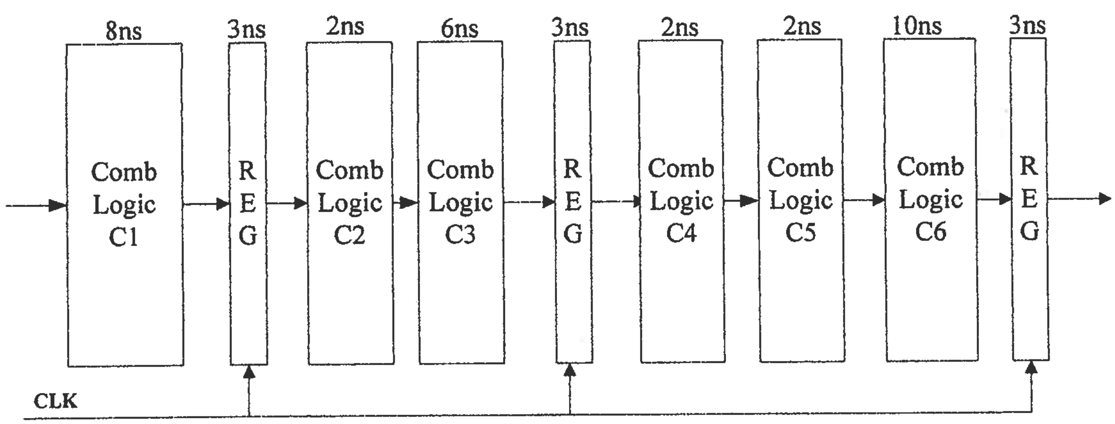
**Problem: CM3** **Area: Computers and Architecture** **Code #________**

The delay is the time between the start of a process and its completion, and throughput is amount of work done per unit time.

1) Calculate the delay and throughput of the system shown as follows :




2) In order to increase the throughput, we design the following 3-stage pipeline system. Please calculate its delay and throughput.




3) Try to rearrange the above structure in section 2) to further optimize the performance, and calculate the delay and throughput of your improved design.

**Problem: CM4** **Area: Computers and Architecture** **Code #________**

Suppose you want to perform two sums: one is a sum of 10 scalar variables, and one is a matrix sum of a pair of two-dimensional arrays, with dimensions 10 by 10.

1. What speed-up do you get with 10 versus 100 parallel processors? Assume performance is a function of the time for an addition operation, t. For example, the total time for a single processor is 10t for scalar additions plus 100t for matrix additions, which is 110t.

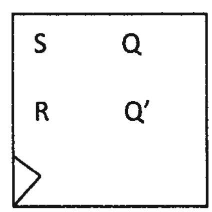
2. Calculate the speed-up again assuming the matrices grow to 100 by 100.

**Problem: CM5** **Area: Integrated Circuits and Logic Design** **Code #_________**

Make a D flip-flop out of the SR flip-flop below. Show all your work and draw the resulting circuit.

| D | Qt | Qt+1 | S | R |
|---|---|---|---|---|
| 0 | 0 | | | |
| 0 | 1 | | | |
| 1 | 0 | | | |
| 1 | 1 | | | |

Qt denotes the current output of the SR flip-flop, and Qt+1 denotes the output of the SR flip-flop after the rising edge clock transition.



**Problem: CM6** **Area: Integrated Circuits and Logic Design** **Code #________**

Given the state table below with the state variables X and Y, externally applied input t, and output f. Answer the questions below.

| Present Input | Present State | | Present Output | Next State | | JK Flip Flop Inputs | | SR Flip Flop Inputs | |
|---|---|---|---|---|---|---|---|---|---|
| t | X | Y | f | X* | Y* | $J_X$ | $K_X$ | $S_Y$ | $R_Y$ |
| 0 | 0 | 0 | 0 | | | 0 | 0 | 1 | 0 |
| 0 | 0 | 1 | 0 | | | 0 | 1 | 0 | 1 |
| 0 | 1 | 0 | 1 | | | 1 | 1 | 1 | 0 |
| 0 | 1 | 1 | 0 | | | 1 | 1 | 0 | 0 |
| 1 | 0 | 0 | 1 | | | 1 | 0 | 1 | 0 |
| 1 | 0 | 1 | 1 | | | 1 | 0 | 0 | 1 |
| 1 | 1 | 0 | 0 | | | 0 | 1 | 0 | 0 |
| 1 | 1 | 1 | 0 | | | 1 | 0 | 0 | 1 |

a) Fill in the missing values for the state table.
b) Draw the state transition diagram based on the state table.

**Problem: CM7** **Area: Integrated Circuits and Logic Design** **Code #________**

Given the function: $F(w,x,y,z) = \Sigma m(0,1,2,3,4,6,7,8,10,13)+dc(9,11,14)$

Answer the following questions.

a) Write the <u>minimal</u> POS expression for F.

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

b) Write the <u>minimal</u> SOP expression for F.

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

c) Determine the implementation for F that uses the fewest number of logic gates (AND, OR, INVERTERS, NAND, NOR up to 3 inputs).

**Problem: CM8** **Area: Integrated Circuits and Logic Design** **Code #__________**

Design and implement a state machine (circuit) which outputs the sequence 0125601256... Implement this machine using D flip flops. Take advantage of any don't cares that come up. ***For full credit, show the derivation of all logic expressions used for implementing this counter.***

**Problem: CM9** **Area: Embedded Computer Systems** **Code #_________**

Answer the following questions for parts a-d below.

(a) Describe the addressing modes used by the 8051 instruction set.

(b) Which addressing mode is most appropriate for accessing external memory?

(c) Which addressing mode is most appropriate for accessing elements of an array stored in internal data memory?

(d) Discuss why it is important to have different addressing modes available in the 8051 instruction set. Give an example which illustrates the need to have different addressing modes.

**Problem: CM10** **Area: Embedded Computer Systems** **Code #_________**

Assume you are given an 16-bit timer. If 12MHz crystal clock frequency is used to drive the given timer and one timer tick is equivalent to 12 crystal clock periods, what would be an appropriate timer initialization value (i.e., 8-bit binary word) to achieve 1ms delay? Show your work clearly.

**Problem: CM11** **Area: Embedded Computer Systems** **Code #________**

Write a C-program which does the same as the following assembly code for the 8051 microcontroller.
Assume instructions are written in the format:
<instruction> <destination>, <source>

```
mydata segment data
                x: DS 2  ; be sure to declare this variable in C program
                y: DS 1  ; be sure to declare this variable in C program
CSEG AT 0000H
                MOV x, #42D
                MOV A, #32D
                CLR C
                RLC A
                MOV R0,#0AH
LOOP:           ADD A, R0
                DJNZ R0, LOOP
                MOV y, A
                END
```

**Problem: CM12** **Area: Embedded Computer Systems** **Code #________**

Answer the following:

a) What does the baud rate measure in serial communication?

b) Explain (a) what interrupts are and (b) what advantage they give us when designing a digital system.

c) A common function used in embedded systems programming is the DELAY subroutine. Calculate the number of machine cycles the following function consumes. Include overhead. (Note: MOV and NOP consume 1 cycle while the other instructions all consume 2. The DJNZ instruction will decrement the register and, if the register is not zero, jump to the indicated label.)

```
DELAY:    MOV R3, #50
OUT:      MOV R2, #100
IN:       NOP
          DJNZ R2, IN
          DJNZ R3, OUT
          RET
```

Answer = ________________

## Problem A12 Area: Waves, Devices, and Optics Code: Solution

An incident uniform electromagnetic plane wave propagates through free space ($\epsilon = \epsilon_0 = 8.854 \times 10^{-12}$ F/m, $\mu = \mu_0 = 4\pi \times 10^{-7}$ H/m, $\sigma = 0$). The electric field phasor associated with this electromagnetic wave is

$$\mathbf{E}(\mathbf{r}) = [\hat{\mathbf{x}} + 3\hat{\mathbf{y}} - \hat{\mathbf{z}}] \exp[-j(x + y + 4z)]$$

The incident electromagnetic wave encounters a dielectric boundary. The boundary is described geometrically by a plane satisfying

$$x + \frac{1}{2}y + z = 0$$

a Find the angular frequency ($\omega$) of the incident plane wave.

b Find the **magnetic field (magnitude AND direction)** of the parallel polarized part of the incident electromagnetic plane wave. Your answer should be written in a form similar to the expression given above for $\mathbf{E}(\mathbf{r})$. Parallel polarization refers to an electromagnetic wave for which the electric field is parallel to the plane of incidence.

---

**Solution**

a

$$\begin{aligned}
\beta &= \omega\sqrt{\mu_0\epsilon_0} = \sqrt{1^2 + 1^2 + 4^2} = \sqrt{18} \\
\omega &= \sqrt{\frac{18}{\mu_0\epsilon_0}} = \sqrt{\frac{18}{(4\pi \times 10^{-7})(8.854 \times 10^{-12})}} = \boxed{1.2719 \times 10^9 \text{ rad/sec}}
\end{aligned}$$

b Letting $\hat{\mathbf{n}}$ and $\hat{\mathbf{s}}$ represent the boundary normal direction and the propagation direction unit vectors, respectively

$$\hat{\mathbf{n}} = \frac{\hat{\mathbf{x}} + \frac{1}{2}\hat{\mathbf{y}} + \hat{\mathbf{z}}}{\sqrt{2.25}} \text{ and } \hat{\mathbf{s}} = \frac{\hat{\mathbf{x}} + \hat{\mathbf{y}} + 4\hat{\mathbf{z}}}{\sqrt{18}}$$

A vector perpendicular to the plane of incidence can be constructed as

$$\mathbf{u} = \begin{vmatrix} \hat{\mathbf{x}} & \hat{\mathbf{y}} & \hat{\mathbf{z}} \\ 2 & 1 & 2 \\ 1 & 1 & 4 \end{vmatrix} = 2\hat{\mathbf{x}} - 6\hat{\mathbf{y}} + \hat{\mathbf{z}}$$

Making this into a unit vector

$$\hat{\mathbf{u}} = \frac{2\hat{\mathbf{x}} - 6\hat{\mathbf{y}} + \hat{\mathbf{z}}}{\sqrt{41}}$$

The electric field component perpendicular to the plane of incidence is

$$\mathbf{E}_\perp = \mathbf{E} \cdot (\hat{\mathbf{u}}\hat{\mathbf{u}})$$

The electric field component parallel to the plane of incidence is

$$\mathbf{E}_\| = \mathbf{E} \cdot (\mathbf{I} - \hat{\mathbf{u}}\hat{\mathbf{u}})$$

$$\begin{aligned}
\mathbf{E}_\| &= \left\{(\hat{\mathbf{x}} + 3\hat{\mathbf{y}} - \hat{\mathbf{z}}) - \frac{(\hat{\mathbf{x}} + 3\hat{\mathbf{y}} - \hat{\mathbf{z}}) \cdot (2\hat{\mathbf{x}} - 6\hat{\mathbf{y}} + \hat{\mathbf{z}})}{\sqrt{41}} \frac{(2\hat{\mathbf{x}} - 6\hat{\mathbf{y}} + \hat{\mathbf{z}})}{\sqrt{41}}\right\} \exp[-j(x + y + 4z)] \\
&= \left\{(\hat{\mathbf{x}} + 3\hat{\mathbf{y}} - \hat{\mathbf{z}}) - \frac{2 - 18 - 1}{\sqrt{41}\sqrt{41}}(2\hat{\mathbf{x}} - 6\hat{\mathbf{y}} + \hat{\mathbf{z}})\right\} \exp[-j(x + y + 4z)] \\
&= \{(\hat{\mathbf{x}} + 3\hat{\mathbf{y}} - \hat{\mathbf{z}}) + 0.41463(2\hat{\mathbf{x}} - 6\hat{\mathbf{y}} + \hat{\mathbf{z}})\} \exp[-j(x + y + 4z)] \\
&= \{(1 + 0.41463 \times 2)\hat{\mathbf{x}} + (3 - 0.41463 \times 6)\hat{\mathbf{y}} + (-1 + 0.41463)\hat{\mathbf{z}}\} \exp[-j(x + y + 4z)] \\
&= \{(1.8293)\hat{\mathbf{x}} + (0.51222)\hat{\mathbf{y}} + (-0.58537)\hat{\mathbf{z}}\} \exp[-j(x + y + 4z)]
\end{aligned}$$

The corresponding magnetic field is

$$
\begin{aligned}
\mathbf{H}_{\|} &= \frac{-1}{j\omega\mu}\nabla\times\mathbf{E}_{\|} \\
&= \left(\frac{-1}{j\omega\mu}\right)\begin{vmatrix} \hat{\mathbf{x}} & \hat{\mathbf{y}} & \hat{\mathbf{z}} \\ -j & -j & -4j \\ 1.8293 & 0.51222 & -0.58537 \end{vmatrix}\exp\left[-j\left(x+y+4z\right)\right] \\
&= \frac{1}{1.2719\times10^{9}\times4\pi\times10^{-7}}\begin{vmatrix} \hat{\mathbf{x}} & \hat{\mathbf{y}} & \hat{\mathbf{z}} \\ 1 & 1 & 4 \\ 1.8293 & 0.51222 & -0.58537 \end{vmatrix}\exp\left[-j\left(x+y+4z\right)\right] \\
&= 6.2566\times10^{-4}\begin{vmatrix} \hat{\mathbf{x}} & \hat{\mathbf{y}} & \hat{\mathbf{z}} \\ 1 & 1 & 4 \\ 1.8293 & 0.51222 & -0.58537 \end{vmatrix}\exp\left[-j\left(x+y+4z\right)\right] \\
&= 6.2566\times10^{-4}\left[7.9026\hat{\mathbf{y}}-1.3171\hat{\mathbf{z}}-2.6343\hat{\mathbf{x}}\right]\exp\left[-j\left(x+y+4z\right)\right] \\
&= 10^{-4}\times6.2566\left(7.9026\hat{\mathbf{y}}-1.3171\hat{\mathbf{z}}-2.6343\hat{\mathbf{x}}\right)\exp\left[-j\left(x+y+4z\right)\right] \\
&= \boxed{10^{-4}\times\left(-16.482\hat{\mathbf{x}}+49.443\hat{\mathbf{y}}-8.2406\hat{\mathbf{z}}\right)\exp\left[-j\left(x+y+4z\right)\right]\ \text{A/m}}
\end{aligned}
$$

A9

Answer:

a- In the far-field, where the direction of propagation is in the $r$-direction (as shown), the radial electric field component is negligible compared to the other field components, and one expects a nearly TEM wave in this region. Thus, the only two components that can potentially remain will be in $\theta$ and $\phi$ directions (i.e., $E_\theta$ and $E_\phi$), as shown.

b- This antenna is elliptically polarized since: a) there are two electric field components associated with its total electric field and they are spatially normal to one another (i.e., $E_\theta$ and $E_\phi$), b) the two field components have a time phase difference of 90° (i.e., $j$), and c) in general the magnitudes of the two components are not equal, since the relationship between $S$ and $D$ are not given. These three conditions make for an elliptically-polarized antenna.

c- For the antenna to be circularly polarized, the magnitude of the two electric field components must be equal, resulting in the following relationship:

$$S = \pi k\left(\frac{D}{2}\right)^2 = \frac{2\pi^2}{\lambda}\left(\frac{D}{2}\right)^2 \quad or \quad D = \frac{\sqrt{2s\lambda}}{\pi}$$

d- If $D$ or $S$ is very small, then the helix approaches a dipole or a loop antenna, respectively, both of which are linearly polarized.

**Problem #M11 Area: Waves & Devices Code #**

Consider a silicon (Si: a Col. IV material)) abrupt-junction pn diode. One side is doped with aluminum (Al: a Col. III materials) and the other side is doped with phosphorous (P: a Col. V material). The contact potential is $V_o = 0.66$ V. T = 300 K. Important physical constants are:

| | | | |
|---|---|---|---|
| Boltzmann's constant: | $k = 1.38 \times 10^{-23}$ J/K $= 8.62 \times 10^{-5}$ eV/K | | |
| Planck's constant: | $h = 4.14 \times 10^{-15}$ eV-s | Electronic charge: | $q = 1.60 \times 10^{-19}$ C |
| Carrier Mobilities | $\mu_n = 1350$ cm$^2$/V-s | $\mu_p = 480$ cm$^2$/V-s | |
| Bandgap Energy of Si | $E_g = 1.11$ eV | | |
| Intrinsic Carrier Concentration | $n_i = 1.50 \times 10^{10}$ cm$^{-3}$ at 300 K | | |

(a) Specify which material is the dopant for the respective sides of the diode. Justify.

n-side of diode: **P** p-side of diode: **Al**

Justification:

**Al has fewer valence electrons than Si hence it produces p-type material.**
**P has more valence electrons than Si hence it produces n-type material.**

(b) Calculate the doping concentrations for the p and n sides if the doping concentrations on each side are equal.

$$V_O = (kT/q)\ \ln\,[(N_{d(n)}^{+} - N_{a(n)}^{-})(N_{a(p)}^{-} - N_{d(p)}^{+})/\ n_i^2] = (kT/q)\ \ln\,[(N_{d(n)}^{+} - 0)(N_{a(p)}^{-} - 0)/\ n_i^2]$$

$$V_O = (kT/q)\ \ln\,[(N)(N)/\ n_i^2] \quad \text{or} \quad N^2 = n_i^2 \exp(qV_o/kT)$$

$$N = n_i \exp(qV_o/2kT) = (1.5 \times 10^{10})\exp(0.66/2\text{x}0.025854) = (5.24\text{x}10^{15})\ \text{cm}^{-3}$$

(c) Calculate the Fermi levels on each side of the junction in eV relative the intrinsic levels.

For the p side

$$(E_F - E_{ip}) = -\ kT\ \text{In}(p_o/n_i)$$
$$(E_F - E_{ip}) = -\ (0.025854\ \text{eV})\ \ln[(5.24\text{x}10^{15})/(1.5 \times 10^{10})] = -\ 0.330\ \text{eV}$$

For the n side

$$(E_F - E_{in}) = kT\ \text{In}(_o/n_i)$$
$$(E_F - E_{in}) = (0.025854\ \text{eV})\ \ln[(5.24\text{x}10^{15})/(1.5 \times 10^{10})] = 0.330\ \text{eV}$$

(d) Calculate the ratio $x_{n0}/x_{p0}$, i.e. the ratio of how far the depletion region extends into each side of the junction. The diode has uniform cross-sectional area.

**The charge density relationship is**

$$|Q_-| = |Q_+|\ ; \quad (N_{ap}^{-} - N_{dp}^{+})\ Ax_{p0} = (N_{dn}^{+} - N_{an}^{-})\ Ax_{n0}\ ;$$

$$\text{or} \quad (N_{ap}^{-})_{Eff}\ x_{p0} = (N_{dn}^{+})_{Eff}\ x_{n0}\ ;$$

$$x_{n0}/x_{p0} = (N_{ap}^{-})_{Eff} / (N_{dn}^{+})_{Eff} = (5.24\text{x}10^{15} - 0)/(\ 5.24\text{x}10^{15} - 0) = 1$$

(d) Answer the following multiple-choice questions. Circle the one best answer.

For reverse bias, the dominant current type is ???

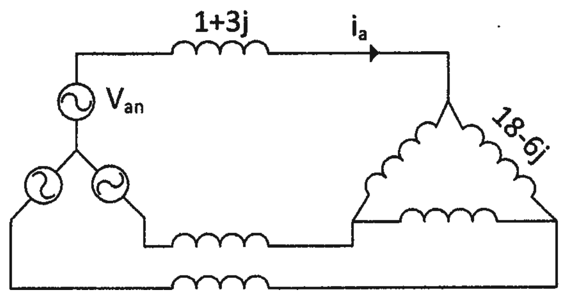
**Drift current** **Diffusion Current** **Neither (Drift = Diffusion)**

For forward bias, the dominant current type is ???

**Drift current** **Diffusion Current** **Neither (Drift = Diffusion)**

**Problem M3** **Power/Machinery** **Code #_________**

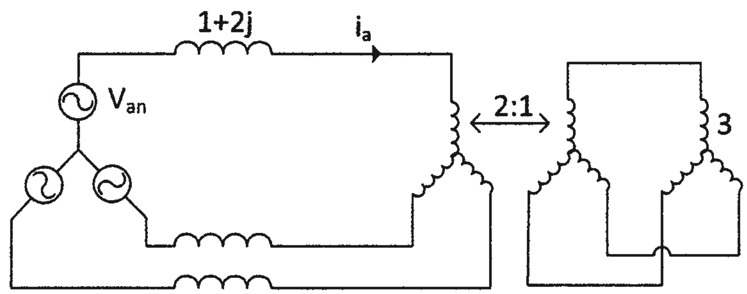
Calculate the power delivered by the 3-phase source for the following system (sources, lines, and loads are balanced): $V_{an} = 200 \angle (0.5 \text{ radian})$ V. The impedances are in Ohms.



**Problem M4** **Power/Machinery** **Code #_________**

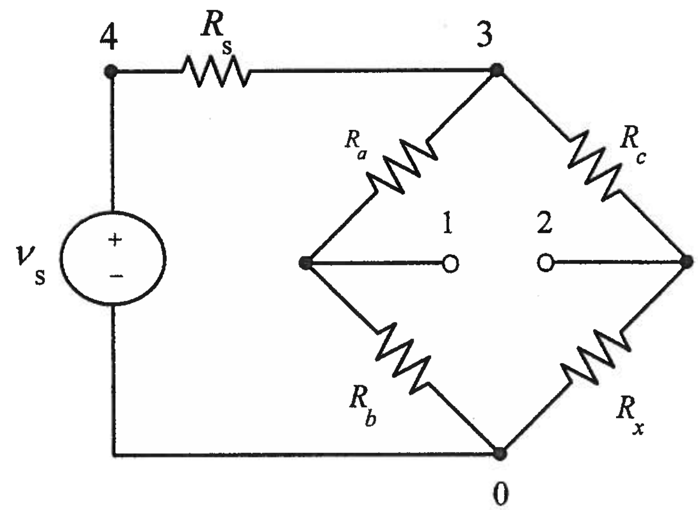
Calculate the current of the source ($i_a$) in the following circuit. The ratio of the 3-phase Y-Y transformer is 2:1. Loads, lines, and sources are balanced. The Y load is 3 ohms per-phase.

$V_{an} = 110 \angle (0.2 \text{ radian})$ V



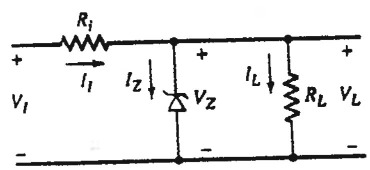
**Problem: M5** **Circuits/Electronics** **Code #_______**

An unknown resistance $R_x$ can be measured in terms of known resistances $R_a, R_b$ and $R_c$ if $v_{12}$ is "balanced" at zero voltage. This is known as a Wheatstone bridge. Find $R_x$ in terms of the known resistances in the circuit shown when the bridge is under such a balanced condition.



Problem : M7 Circuits/Electronics Student Code____

In the voltage regulator circuit shown below, if $V_I = 6.3\ V$, $R_i = 12\ \Omega$, $V_z = 4.8\ V$ and if the Zener diode current, $I_z$ is to be limited to the range $10 \leq I_z \leq 100\ mA$, determine the power rating required for the load resistor, $P_L = V_L I_L(max)$

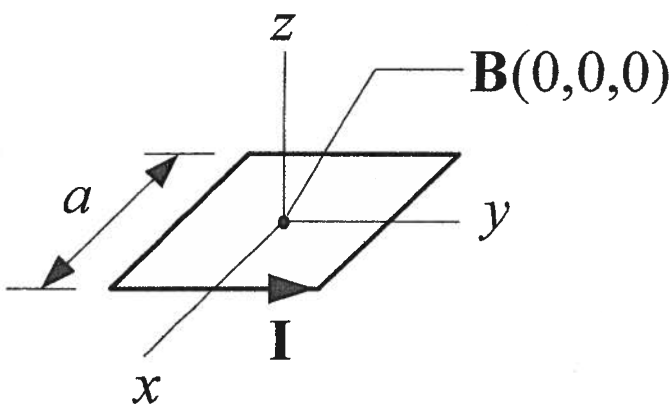



Answer:

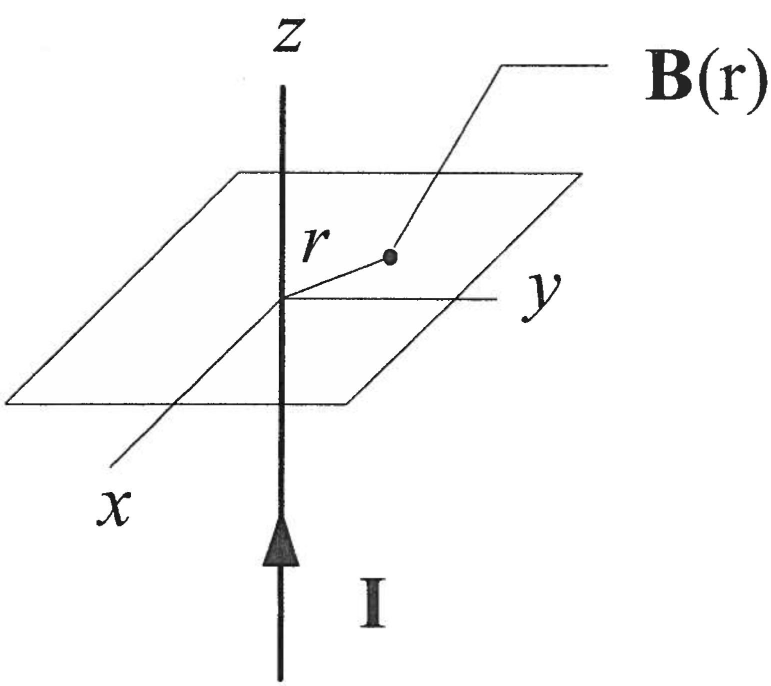
$P_L =$

Problem M9 Field and Waves Code #________

(1) Using Biot-Savart law, evaluate the magnetic field B of a square metal loop of width a and current I at the center of the loop, (0,0,0). The current loop is on x-y plane of width a.




(2) Using Ampere's law to evaluate the magnetic field B at a perpendicular distance r to an infinite line current of I (amp) in z-direction as shown in the right figure. Where is the closed loop used in the evaluation? ( Sketch that closed loop on the figure below)



**Problem #M11** **Area: Waves & Devices Code #** ____________

Consider a silicon (Si: a Col. IV material)) abrupt-junction pn diode. One side is doped with aluminum (Al: a Col. III materials) and the other side is doped with phosphorous (P: a Col. V material). The contact potential is $V_o = 0.66$ V. T = 300 K. Important physical constants are:

| | | | |
|---|---|---|---|
| Boltzmann's constant: | $k = 1.38 \times 10^{-23}$ J/K $= 8.62 \times 10^{-5}$ eV/K | | |
| Planck's constant: | $h = 4.14 \times 10^{-15}$ eV-s | Electronic charge: | $q = 1.60 \times 10^{-19}$ C |
| Carrier Mobilities | $\mu_n = 1350$ cm$^2$/V-s | $\mu_p = 480$ cm$^2$/V-s | |
| Bandgap Energy of Si | $E_g = 1.11$ eV | | |

Intrinsic Carrier Concentration $n_i = 1.50 \times 10^{10}$ cm$^{-3}$ at 300 K

(a) Specify which material is the dopant for the respective sides of the diode. Justify.

n-side of diode: __________ p-side of diode: __________

Justification:

(b) Calculate the doping concentrations for the p and n sides if the doping concentrations on each side are equal.

(c) Calculate the Fermi levels on each side of the junction in eV relative the intrinsic levels.

For the p side

For the n side

(d) Calculate the ratio $x_{n0} / x_{p0}$, i.e. the ratio of how far the depletion region extends into each side of the junction. The diode has uniform cross-sectional area.

(d) Answer the following multiple-choice questions. Circle the one best answer.

For reverse bias, the dominant current type is ???

**Drift current** **Diffusion Current** **Neither (Drift = Diffusion)**

For forward bias, the dominant current type is ???

**Drift current** **Diffusion Current** **Neither (Drift = Diffusion)**

Problem: M12 Area: Waves, Devices, & Optics Code #: ____________

Consider a uniform electromagnetic plane wave in a homogeneous dielectric medium. Its electrical and magnetic field phasors are given as

$$\vec{E}(y) = 2.5e^{j100\pi y}\hat{x} \text{ (V/m) and } \vec{H}(y) = \frac{1}{24\pi}e^{j100\pi y}\hat{z} \text{ (A/m)}$$

where $\hat{z}$ is the unit vector at the z direction. Assume the phasors have a time dependence of $e^{j\omega t}$.

1) What is the propagation direction of the wave?

1) Find the relative dielectric constant of the medium $\varepsilon_r$, assuming $\mu_r = 1$.

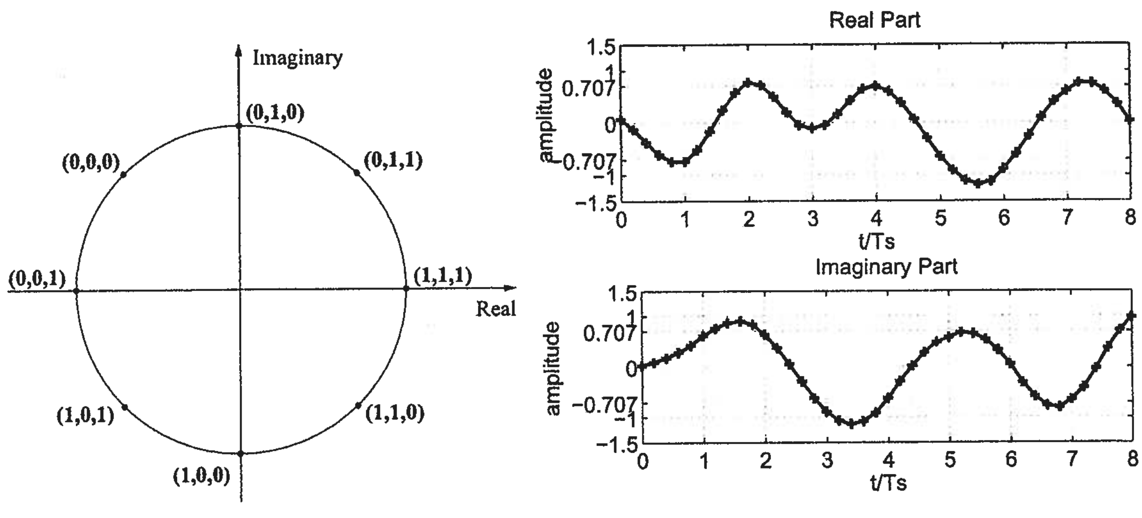
   ($\varepsilon_0 = \frac{1}{36\pi}\times 10^{-9}$ F/m and $\mu_0 = 4\pi\times 10^{-7}$ H/m).

2) Find the frequency and wavelength of the wave.

3) Find the time-average Poynting vector $\vec{S}_{av}$.

A communication system employs the Gray code and 8-PSK passband modulation scheme. The constellation of the modulated signals and their corresponding Gray codes are shown in Figure 2(a). To achieve better bandwidth efficiency, the system also employs square-root raised cosine filter with a roll-off factor of 0.30 as the transmit pulse shaping filter and receive matched filter. The received signal is coherently demodulated and the matched filter output is a complex signal $s(t)$, as shown in Figure 2(b). Answer the questions according to the figures.

1. What does PSK stand for? How many orthonormal base functions does PSK employ and what are they?
2. What is the Maximum Likelihood (ML) decision rule? Explain and show the decision regions on the constellation plot (Figure 2(a)) using one symbol as an example.
3. What are the values of the complex symbols $s(k)$ for $k = t/T_s = 3, 4, 5, 6$ (symbols). Show your reasoning by indicating them in Figure 2(b).
4. Decode the symbols for $k = 3, 4, 5, 6$ to binary bit stream using the ML rule and the Gray Code constellation plot Fig. 2(a).




(a) Gray code and 8-PSK modulation.

(b) The output of the receive matched filter: $s(t)$.

Figure 2: Figures for Problem IV