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

<table>
<thead>
<tr>
<th>D</th>
<th>Q&lt;sub&gt;t&lt;/sub&gt;</th>
<th>Q&lt;sub&gt;t+1&lt;/sub&gt;</th>
<th>S</th>
<th>R</th>
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Qt denotes the current output of the SR flip-flop, and Q<sub>t+1</sub> denotes the output of the SR flip-flop after the rising edge clock transition.
Given the state table below with the state variables X and Y, externally applied input t, and output f. Answer the questions below.

<table>
<thead>
<tr>
<th>Present Input</th>
<th>Present State</th>
<th>Present Output</th>
<th>Next State</th>
<th>JK Flip Flop Inputs</th>
<th>SR Flip Flop Inputs</th>
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</thead>
<tbody>
<tr>
<td>t</td>
<td>X</td>
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<td>f</td>
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a) Fill in the missing values for the state table.
b) Draw the state transition diagram based on the state table.
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 minimal POS expression for \( F \).

\[
\begin{array}{c|cccc}
wx'y' & 00 & 01 & 11 & 10 \\
\hline
00 & & & & \\
01 & & & & \\
11 & & & & \\
10 & & & & \\
\end{array}
\]

b) Write the minimal SOP expression for \( F \).

\[
\begin{array}{c|cccc}
wx'y' & 00 & 01 & 11 & 10 \\
\hline
00 & & & & \\
01 & & & & \\
11 & & & & \\
10 & & & & \\
\end{array}
\]

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

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.
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.
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 \((\epsilon = \varepsilon_0 = 8.854 \times 10^{-12} \text{ F/m, } \mu = \mu_0 = 4\pi \times 10^{-7} \text{ H/m, } \sigma = 0)\). The electric field phasor associated with this electromagnetic wave is

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

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.

\[\Solution\]

\[\beta = \frac{\omega}{\sqrt{\mu_0 \varepsilon_0}} = \sqrt{12 + 12 + 4^2} = \sqrt{18} \]

\[\omega = \frac{18}{\sqrt{\mu_0 \varepsilon_0}} = \sqrt{\frac{18}{(4\pi \times 10^{-7}) (8.854 \times 10^{-12})}} = 1.2719 \times 10^9 \text{ rad/sec}\]

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

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

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

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

Making this into a unit vector

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

The electric field component perpendicular to the plane of incidence is

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

The electric field component parallel to the plane of incidence is

\[\mathbf{E}_\parallel = \mathbf{E} \cdot (\mathbf{1} - \mathbf{\hat{u}})\]

\[\mathbf{E}_\parallel = \left\{(\hat{x} + 3\hat{y} - \hat{z}) - \frac{(\hat{x} + 3\hat{y} - \hat{z}) \cdot (2\hat{x} - 6\hat{y} + \hat{z}) (2\hat{x} - 6\hat{y} + \hat{z})}{\sqrt{41}} \right\} \exp[-j(x + y + 4z)]\]

\[= \left\{(\hat{x} + 3\hat{y} - \hat{z}) - \frac{2 - 18 - 1}{\sqrt{41}} (2\hat{x} - 6\hat{y} + \hat{z}) \right\} \exp[-j(x + y + 4z)]\]

\[= \left\{(\hat{x} + 3\hat{y} - \hat{z}) + 0.41463 (2\hat{x} - 6\hat{y} + \hat{z}) \right\} \exp[-j(x + y + 4z)]\]

\[= \left\{((1 + 0.41463 \times 2)\hat{x} + (3 - 0.41463 \times 6)\hat{y} + (-1 + 0.41463)\hat{z}) \exp[-j(x + y + 4z)]\right\}\]

\[= \left\{((1.8293)\hat{x} + (0.51222)\hat{y} + (-0.58537)\hat{z}) \exp[-j(x + y + 4z)]\right\}\]
The corresponding magnetic field is

\[ H_\parallel = \frac{-1}{j\omega \mu} \nabla \times E_\parallel \]

\[ = \left( \frac{-1}{j\omega \mu} \right) \begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ -j & -j & -4j \\ 1.8293 & 0.51222 & -0.58537 \end{vmatrix} \exp[-j(x+y+4z)] \]

\[ = \frac{1}{1.2719 \times 10^9 \times 4\pi \times 10^{-7}} \begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ 1 & 1 & 4 \\ 1.8293 & 0.51222 & -0.58537 \end{vmatrix} \exp[-j(x+y+4z)] \]

\[ = 6.2566 \times 10^{-4} \begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ 1 & 1 & 4 \\ 1.8293 & 0.51222 & -0.58537 \end{vmatrix} \exp[-j(x+y+4z)] \]

\[ = 6.2566 \times 10^{-4} \left[ 7.9026\hat{y} - 1.317 \hat{z} - 2.6343\hat{x} \right] \exp[-j(x+y+4z)] \]

\[ = 10^{-4} \times 6.2566 \left( 7.9026\hat{y} - 1.317 \hat{z} - 2.6343\hat{x} \right) \exp[-j(x+y+4z)] \]

\[ = 10^{-4} \times \left( -16.482\hat{x} + 49.443\hat{y} - 8.24062 \right) \exp[-j(x+y+4z)] \text{ A/m} \]
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., \( \pi \)), 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:

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

\[D\] 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 phosphorus (P: a Col. V material). The contact potential is $V_0 = 0.66$ 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: $\textbf{P}$
- p-side of diode: $\textbf{Al}$

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.

- $V_0 = (kT/q) \ln \left[ \frac{(N_{a(p)}^- - N_{a(p)}^+)(N_{a(p)}^- - N_{a(p)}^+)/n_i^2}{n_i} \right] = (kT/q) \ln \left[ (N_{d(p)}^- - 0)(N_{a(p)}^+ - 0)/n_i^2 \right]$
- $V_0 = (kT/q) \ln \left[ (N)(N)/n_i^2 \right]$ or $N^2 = n_i^2 \exp(qV_0/kT)$
- $N = n_i \exp(qV_0/2kT) = (1.5 \times 10^{10}) \exp(0.66/2 \times 0.025854) = (5.24 \times 10^{15}) \text{ cm}^{-3}$

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

For the p side
- $(E_F - E_{fp}) = - kT \ln(p_i/n_i)$
- $(E_F - E_{ip}) = - (0.025854 \text{ eV}) \ln[(5.24 \times 10^{15})/(1.5 \times 10^{10})] = - 0.330 \text{ eV}$

For the n side
- $(E_F - E_{fn}) = kT \ln(n_i/n_i)$
- $(E_F - E_{in}) = (0.025854 \text{ eV}) \ln[(5.24 \times 10^{15})/(1.5 \times 10^{10})] = 0.330 \text{ eV}$

(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

- $|Q_1| = |Q_s| \quad (N_{d(p)}^- - N_{d(p)}^+) Ax_{p0} = (N_{d(n)}^+ - N_{a(n)}^-) Ax_{n0} ;$
  \quad or $(N_{d(p)}^-)_{\text{Eff}} x_{p0} = (N_{d(n)}^+)_{\text{Eff}} x_{n0} ;$

- $x_{n0}/x_{p0} = (N_{a(p)}^-)_{\text{Eff}} / (N_{a(p)}^+)_{\text{Eff}} = (5.24 \times 10^{15} - 0)/(5.24 \times 10^{15} - 0) = 1$

(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)