**THE GEORGE WASHINGTON UNIVERSITY**
**School of Engineering and Applied Science**
**Department of Electrical and Computer Engineering**

# Preliminary Examination - Spring 2016

## Friday, February 19, 2016

## General Instructions. Read carefully before starting.

**Solve 5 problems in all; at most 2 questions may be selected from the same section.**

Candidates registered in the following focus areas must answer two of their five questions from the relevant section as follows:

| | |
|---|---|
| Computer Architecture and High-Performance Computing: | Section 1 |
| Communications & Networks: | Section 3 |
| Electrical Power & Energy: | Section 8 |
| Electromagnetics, Radiation Systems & Microwave Engineering: | Section 4 |
| Electronics, Photonics & MEMS: | Section 6 |
| Signal & Image Processing, Systems & Controls: | Section 3 |

Please write your name and student number below:

_______________________________________ ____________________

**Student Name** **Student Number**

Solve each problem in a **separate** blue book. Write the section number, problem number, and your student number **on the front of each blue book**. **DO NOT WRITE YOUR NAME ON THE BLUE BOOK.**

Submit solutions to **only** five (5) problems. Use only **ONE** blue book per problem.

For each problem, make a special effort to give the answers in a clear form.

The exam will begin at 10:00 a.m. and end promptly at 3:00 p.m.

**Only Calculators provided by the department at the examination will be allowed. Personal items including cell phones and other electrical devices must be relinquished prior to the start of the examination.**

**This is a CLOSED BOOK, CLOSED NOTES EXAMINATION**

# Section 1

1.

Assume a five-stage single-pipeline micro architecture with Fetch, Decode/Register Read, Execute, Memory Access and Register Writeback and Result forwarding support between the pipeline stages. The operand value should be available to the instruction before the Execute stage. Using a multicycle pipeline diagram, demonstrate the progress of each instruction on every clock cycle until the last instruction of the first iteration of the following loop. Calculate the total number of cycles

```
Loop:  LW    R6, -10(R2)
       ADD   R6, R6, R2
       SW    R6, -12(R2)
       BNEZ  R6, Loop
```

2.

Machine X has 64 bit virtual address and 40 bit physical address. The page size is 16KB. The L1 cache is directed mapped 16KB, and L2 is four-way set associative 4MB. Virtually indexed and physically tagged cache. 2-way associative TLB with 256 entries. Please draw a diagram to clearly explain the translation from a virtual address to a physical address, and the interactions to the TLB and L1/L2 Cache.  Indicates how many bits are used for each component.

3.

Part A

Match each of the phrases:

1. Sequential Logic
2. Combinational Logic
3. Flip FLOP
4. Mealy Machine
5. Uses no-clock
6. More Machine
7. Multiplexer
8. Decoder
9. Tri-State
10. Priority Encoder

To the best phrase that fits it:

a. The input will be transmitted to the output line that matches the value on the select lines
b. The output is a function of the input sequence
c. The output that matches the value on the select lines will be set to true
d. Hi-Z
e. The output will be the binary combination equivalent to the highest TRUE input
f. The output values are determined both by the current state and the current input
g. The output values are determined solely by the current state
h. The output is a function of the current inputs
i. Asynchronous
j. 1-bit memory

Part B

Use an 8-input multiplexer to realize the following logic function: Y= AB+A’BC

# Section 2

4.

A laboratory experiment has recorded the following data that is thought to be related by a function $y = f(x)$.

| | | | | | | |
|---|---|---|---|---|---|---|
| $i =$ | 1 | 2 | 3 | 4 | 5 | 6 |
| $x_i =$ | 0 | 1 | 2 | 2.5 | 3 | 4 |
| $y_i =$ | 0.1 | 0.9 | 5 | 6 | 9 | 20 |

If the function is $y = a + bx + cX^2$, find the constant coefficients a, b, and c that fits all the recorded data with minimum total squared error $J = \sum_{i=1}^{6} (y_i - x_i)^2$. In short, find the least squared fit of the function to the data.

5.

A linear system with zero input is described by the equation

$$\dot{x} = \begin{bmatrix} 0 & 1 & 2 \\ 1 & 0 & 1 \\ 2 & 1 & 4 \end{bmatrix} x \quad , \quad x(t_o = 0) = x^{\circ}$$

a) Find the poles of the system.

b) Find the eigenvectors of the system.

c) Find the modes of the system.

d) Determine the stability of the system.

e) Find the transfer function of the system.

f) Find the solution of the system if the initial state is
$x(0) = \begin{bmatrix} x_1(0) & x_2(0) & x_3(0) \end{bmatrix}^T$.

g) What is the maximum angle, in degrees, between any two eigenvectors? What is the minimum angle?

6.

The dynamic behavior of a linear system is described by the equations

$$\dot{x} = \begin{bmatrix} 1 & -1 & 2 \\ 0 & 0 & 0 \\ 1 & -1 & 2 \end{bmatrix} x + \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 1 & -1 \end{bmatrix} u \quad , \quad x(t_o = 0) = x^\circ$$

$$y = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} x$$

a) Is the system state controllable?

b) Is the system state observable?

c) Find the transfer function matrix of the system.

d) Is the system BIBO stable?

# Section 3

**7.**

A coin is tossed n times. Let the random variable Y equal the absolute value of the difference between the number of heads and the number of tails.

a) Describe the sample space of Y.

b) Specify the event Y=0

c) Specify the event $Y \leq k$ for a positive integer k

8.

Assume X(t) is a stationary white noise process with autocorrelation function

$$R_X(\tau) = q\delta(\tau)$$

X(t) is applied to a linear system with impulse response function

$$h(t) = e^{-ct} \text{ for } t \geq 0 \text{ and } c > 0$$

Find the autocorrelation function of the output Y(t) of the system.

9.

The random variables X and Y have a joint density function given in terms of the value of c by

$$f(x,y) = c(2x + y) \text{ for } 2<x<6,\ 0<y<5$$

Find the following:

a) the value of c.

b) the marginal cumulative distribution functions of X and Y

c) the marginal density functions of X and Y

d) the joint cumulative distribution function of X and Y

e) $P(X+Y›0)$

f) are X and Y independent? Explain.

# Section 4

10.

A certain air filled parallel-plate waveguide is 10 cm wide in the $\hat{x}$ direction and has a plate separation of d = 0.5 cm.

a) List the five lowest frequencies modes ($TE_m$, $TM_m$) that can propagate on this line and compute their cut-off frequencies.

b) What are the phase and group velocities ($v_p$ and $v_g$) for the $TM_2$ mode at a frequency equal to 1.6 times the $TM_2$ cut off frequency?

11.

The complex electric field of a uniform plane wave traveling in an unbounded nonmagnetic dielectric medium is given by

$$\tilde{\vec{E}} = \hat{y}\, 4\, e^{-j4\pi z} \qquad \text{(V/m)}$$

where z is measured in meters. Assuming that the frequency of operating is 200 MHz, find the

a. phase velocity of the wave,

b. dielectric constant of the medium,

c. wavelength,

d. time-average power density, and

e. time-average energy density.

12.

a. What is the directivity of the antenna (in dB scale) whose normalized radiation intensity is given by

$$U = \begin{cases} 1 & 0 \le \theta \le \pi/6 \\ 0.5 & \pi/6 \le \theta \le \pi/2 \\ (1 - \cos\theta)/2 & \pi/2 \le \theta \le \pi \end{cases}$$

for $0 \le \phi \le 2\pi$.

b. Assume this antenna is connected to a source having 2 V peak voltage and 50+75j ohms input impedance. What should be the resistance and reactance of the antenna for the maximum power delivery? For the maximum power delivery condition, find the power supplied by the generator dissipated in the generator delivered to the antenna radiation by the antenna.

# Section 5

13.

The Wigner time-frequency distribution for a signal $s(t)$ is defined as

$$\mathrm{W}_s(t, f) = \int_{-\infty}^{+\infty} s^*(t - \frac{\tau}{2}) s(t + \frac{\tau}{2}) \,\mathrm{e}^{-j2\pi f \tau}\,\mathrm{d}\,\tau$$

where $s^*(t)$ is complex conjugated $s(t)$ and $j = \sqrt{-1}$.

(a) Show that

$$\int_{-\infty}^{+\infty} \mathrm{W}_s(t, f)\,\mathrm{d}\,f = | s(t) |^2 .$$

(b) Show that

$$\int_{-\infty}^{+\infty} \mathrm{W}_s(t, f)\,\mathrm{d}\,t = | S(f) |^2$$

where $S(f)$ is the Fourier transform of $s(t)$.

(c) Show that

$$\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \mathrm{W}_s(t, f)\,\mathrm{d}\,t\,\mathrm{d}\,f = E_s$$

where $E_s$ is the signal energy, i.e., $E_s = \int_{-\infty}^{+\infty} | s(t) |^2 \,\mathrm{d}\,t$.

(d) Let $g(t) = s(t - t_0)$, show that

$$\mathrm{W}_g(t, f) = \mathrm{W}_s(t - t_0, f) .$$

(e) Let $h(t) = s(t)\,\mathrm{e}^{j2\pi f_0 t}$, show that

$$\mathrm{W}_h(t, f) = \mathrm{W}_s(t, f - f_0) .$$

14.

The signal

$$s(t) = t - \frac{1}{2}$$

should be approximated on interval $[0,1)$ by a sum of three functions $g(t)$, $\sqrt{2}g(2t)$ and $\sqrt{2}g(2t-1)$ where

$$g(t) = \begin{cases} +1, & 0 \le t < \frac{1}{2} \\ -1, & \frac{1}{2} \le t < 1. \end{cases}$$

a) Find the coefficients multiplying the functions in the sum such that they provide the least mean square error approximation $\hat{s}(t)$ of $s(t)$.

b) Write the expression for the approximation $\hat{s}(t)$ obtained in part (a). Sketch the approximation.

15.

Assume that $x[n]$ is a real-valued discrete-time signal and $h[n]$ is a real-valued impulse response of linear time-invariant discrete-time system. Let $y_1[n] = x[n] \star h[n]$ represent filtering the signal in the forward direction, where $\star$ stands for convolution. Now filter $y_1[n]$ backward to obtain $y_2[n] = y_1[-n] \star h[n]$. The output is then given by reversing $y_2[n]$ to obtain $y[n] = y_2[-n]$.

(a) Show that this set of operation is equivalently represented by a filter with impulse response $h_o[n]$ as $y[n] = x[n] \star h_o[n]$ and express $h_o[n]$ in terms of $h[n]$.

(b) Show that $h_o[n]$ is an even signal and find the phase response of a system having impulse response $h_o[n]$. Is the system causal?

(c) Let $H(z)$ and $H_o(z)$ be $z$-transforms of $h[n]$ and $h_o[n]$, respectively, and that $h[n]$ is causal. If $H(z) = 1/(1 - 0.9z^{-1})$ find $H_o(z)$ , the region of convergence of $H_o(z)$, and $h_o[n]$.

(d) Repeat (c) if $H(z) = 1 - 0.9z^{-1}$.

# Section 6

16.

Provide brief explanations and justifications to the following statements:

a) Using band-theory and energy-related arguments, explain why a metal conducts, an insulator blocks current, and a semiconductor conducts current only under certain situations.

b) A PN junction is used as a photodetector. Assume that light is shining on all parts of the diode equally. Which part of the photodiode is most critical for photo detection and why? In this application, should the devices be under forward or reverse bias?

c) After repeated operations of a PMOS MOSFET, hole-type interface traps are formed in the Si-SiO2 interface, does this process increase or decrease the threshold voltage? Draw the band-diagram and the sub-threshold IV curve to illustrated your answer.

17.

MOS Band Diagram

a) Draw the band diagram of a MOS system where the “metal” work function $_{M}$ is smaller than the silicon work function $_{S}$. Assume that there are no applied voltages at the n-type substrate (doping $N_D$) and the gate. ON the diagram clearly label the following parameters and functions: electron affinity in the semiconductor x, the Fermi level $E_f$, the conduction and valance band edges $E_c$ and $E_v$, the band-gap $E_g$, the mid-gap $E_i$, the thickness of the oxide d, the potential drop in the oxide $_{ox}$, and the potential drop in the semiconductor (x).

b) For this device, what is the most likely outcome when no voltages are applied: inversion or accumulation?

c) If the substrate is grounded, what voltage must be applied to the gate to reach flat-band conditions?

18.

Mobility and Effective Mass

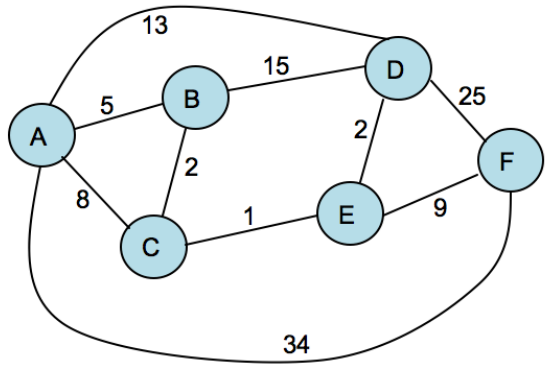
a) State the defining equation for the material mobility of a semiconductor. Name two physical mechanisms that effect the mobility. State their temperature dependency. Sketch (qualitatively) the mobility for silicon as a function of doping level for both the acceptor and donor doped silicon, and briefly explain the trend curves.

b) Derive an equation for the effective mass of a semiconductor. Comment on its relationship to energy band structure. Thus explain, what band structure shape would lead to a high mobility.

# Section 7

19.

Consider the following network with nodes A through F.




(a) If Dijkstra's algorithm is employed for routing on this network, find the path that a packet travels from F to A.

(b) Does Dijkstra's algorithm work if some of the link costs are negative? Why?

(c) Name one problem that would arise if all routing in the Internet was done using Dijkstra's algorithm.

20.

Consider a network link with a link rate of 100 Kb/s and a queue length of 500 packets. Suppose that an audio application sends audio data using RTP and UDP over the network link with an overhead of 50 bytes per packet. The audio is encoded at 32 Kb/s and we want audio packets to be large enough so that the overhead is at most 20% of the total.

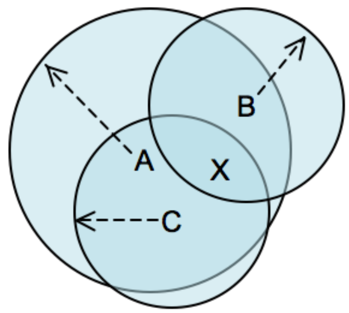
(a) How long does it take to acquire the audio data needed to “fill” a packet?

(b) What is the queuing delay at the network link?

(c)What is the delay if the link rate reduces to 10Kb/s?

21.

The diagram below shows a WIFI network with an access point, X and three hosts, A, B and C. The large circles indicate the coverage areas of the three hosts (i.e., the areas in which their signals can be detected, respectively). The coverage area for X is not shown, but you may assume that it includes all three hosts.




Suppose X is transmitting a packet at time 0µs and finishes sending it at time 100µs. Also,

- A gets a packet to send at time 50µs. The packet takes 100µs to send. A is assigned a backoff timer of 100µs.
- B gets a packet to send at time 70µs. The packet takes 200µs to send. B is assigned a backoff timer of 50µs.
- C gets a packet to send at time 90µs. The packet takes 150µs to send. C is assigned a backoff timer of 150µs.

You may ignore the inter-frame spacing, propagation time, and the time required for ACKs in this question.

(a) Assume 1-Persistent CSMA is used without CD or TS/CTS. For each of the three hosts, what time do they start sending their packets?

(b) Of the three packets sent in Part (), which are successfully delivered on the first attempt and when are they delivered? For each packet that is not successfully delivered on the first attempt, approximately when does the sending host learn that the packet was lost and must be sent again?

# Section 8

22.

A three-phase 200MVA, 20kV, 60Hz salient pole synchronous machine has parameters Xd = 1.1 pu, Xq = 0.6 pu and Ra~0. The machine delivers 180MW at 0.9 lagging power factor to an infinite busbar.

Calculate the excitation voltage and the power angle. Draw the phasor diagram.
(Hint: use per unit values and give your answers in pu)

23.

A wind turbine is to be designed with an electrical power output of 2.0 MW.
The rated upwind free wind speed is 13 m/s. Determine the length of the rotor blades in meters and the rotational speed of the rotor in rev/min if the tip-speed ratio whose value as 7.0 determines the maximum Power Coefficient of 0.45. Use the density of air as 1.225 kg/m$^3$

24. A 200MVA, 20kV, 60-Hz round-rotor synchronous generator has an Inertia constant H = 5s.

Displayed on the axes below are Torque/Angle characteristics for various faults occurring on a double circuit transmission line when connected between a synchronous generator and an infinite busbar. Using the Equal Area Criterion, determine the critical switching times for both a 3φ fault and a L-L fault when the input torque from the turbine is 1.0 pu as shown in the diagram.