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

Preliminary Examination - Fall 2017

Friday, October 20, 2017

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. A multicore chip has 4 32-bit pipelined processors. Each processor requires, per pipeline cycle of T=40ns, to: i) fetch a 32-bit instruction; ii) fetch 2x32-bit operands, and iii) store a 32-bit result. You are given, however, memory chips with 1.28μsec cycle time. Sketch and explain a solution to satisfy the chip demands, showing any needed calculation.

2. Let us say a 5-stage single-pipeline micro architecture with Fetch, Register Read, Execute, Memory and Commit. Let us say we have 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    R1,  0(R2)
       MUL R1, R1, R5
       SW    R1, 0(R2)
       ADDI R2, R2, -4
       BEZ   R2, Loop
```

3. 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.

SECTION 2

4.

The following are examples of simultaneous linear algebraic equations $\mathbf{y} = \mathbf{A}\mathbf{x}$ with unknown $\mathbf{x}$.

1) $$\begin{bmatrix} 1 & -2 & 4 \\ 2 & -1 & 3 \\ 0 & 2 & -2 \\ -2 & 3 & -7 \\ 1 & 1 & 1 \end{bmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = \begin{pmatrix} -8 \\ -7 \\ 6 \\ 13 \\ 1 \end{pmatrix};$$

2) $$\begin{bmatrix} 1 & 1 & 2 & 0 \\ -1 & 2 & 1 & -3 \\ 2 & 0 & 2 & 6 \end{bmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}$$

For each, find

a. The dimension of the range space of **A** (rank);

b. The dimension of the null space of **A** (nullity);

c. All solutions **X**. for the equations.

5.

Given the system S={**A**, **b**, **c**}, where

$$\mathbf{A} = \begin{bmatrix} 1 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & -1 \end{bmatrix}, \quad \mathbf{b} = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}, \quad c = \begin{bmatrix} 1 & 0 & 1 \end{bmatrix}$$

a. Is the system internally stable?

b. Is the system BIBO stable?

c. It is desired that the response of the system have a time constant $t = 1\ s$ and a natural frequency of oscillation $W_n = 1\ radian / s$. Can you do it using state feedback? If yes, do it and show all your steps. If no, explain in detail why not.

6.

Consider system with a transfer function

G(s) = $\frac{(s-2)(s-5)}{(s+1)(s-3)(s+4)}$

Is it possible, using <u>state feedback</u> to change it to

a) G(s) = $\frac{(s-5)}{(s+1)(s+4)}$?

b) G(s) = $\frac{s-5}{(s+1)(s+3)(s+4)}$?

If yes, do it. Are the resulting systems controllable? observable? If no, explain why not?

SECTION 3

7.

X is a continuous random variable uniformly distributed over the interval 10 - 12.
For $Y = X^2$, find:

The Cumulative Distribution Function
The Probability Density Function
The Expected Value
The Variance
The Standard Deviation

8.

X and Y are independent random variables, each uniformly distributed over the interval 0 – 1. Find the probability of the following events:

a) $X > 0.6$

b) $Y < X$

c) $X + Y \leq 0.3$

d) $\text{Max}\{X,Y\} \geq 1/3$

e) $XY \leq \frac{1}{4}$

9.

Let { X_n: n = 1, 2 . . } be an infinite sequence of independent binary random variables with sample values {0, 1) and

$P\{ X_n = 0 \} = 2/3$

Let $Y_n = \sum_{i=1}^{n} X_i$ be a random process defined by X_n.

a) For n=5, determine all sample functions of the random process

b) Determine the probability mass function of Y_n.

c) Find the expected value and variance of Y_n

d) Find the autocorrelation function of Y_n

$R\{Y(n, n + k)\}= E\{Y_n Y_{n+k}\}$

SECTION 4

10.

The complex phasor (time dependence $\exp(+j\omega t)$) representing the electric field of a plane wave in free space is

$$\boldsymbol{E} = E_0 e^{\frac{j\pi}{2}} \left(\boldsymbol{x} - \boldsymbol{y} \right) e^{-j\left(\frac{\omega}{c}\right)\frac{(x+y)}{\sqrt{2}}}$$

where ω is the angular frequency, c is the free space velocity of light, and E_0 is a real constant.

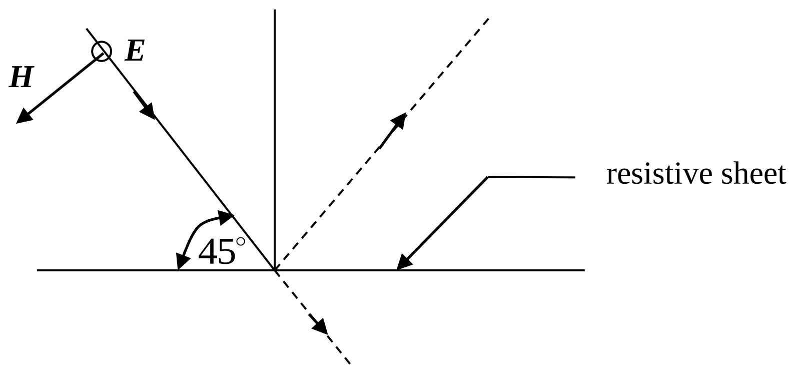
a) What is the direction of propagation of the wave?

b) What is the polarization of the wave?

c) Find $\boldsymbol{H}(x, y, z, t)$.

11.

A plane wave, whose $\boldsymbol{E}$ field is parallel to a resistive sheet and has an amplitude of 1 volt/meter, is incident at 45° onto the resistive sheet shown below.



The sheet is characterized by a linear relationship between the surface current $\mathbf{J_s}$ flowing in it and the tangential electric field of $\boldsymbol{E}_t$:

$$\mathbf{J_s} = G\,\boldsymbol{E}_t$$

Calculate the value of G for which the intensities of the transmitted and reflected waves are equal.

12.

A center-fed half wave dipole antenna of length $\ell \left(\ell = \lambda/2\right)$ where λ is the wavelength has a current distribution of the form

$$I(z) = I_0 \sin\left[k\left(\frac{\ell}{2} - z\right)\right], \quad \frac{\ell}{2} > z \geq 0$$

$$I(z) = I_0 \sin\left[k\left(\frac{\ell}{2} + z\right)\right], \quad -\frac{\ell}{2} < z < 0$$

and $k = 2\pi/\lambda$.

a) Find the electric field in the far zone of the antenna.

b) Determine the magnetic field in the far zone.

c) Find the average power density in the far zone.

SECTION 5

13.

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.

14.

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 $H(z) = 1 - 0.9z^{-1}$.

15.

Solve the differential equation

$$y''(t) + 2y'(t) + y(t) = u(t-1)$$

for $t \geq 0$ using the Laplace transform. $u(t)$ is the unit step function and the initial conditions are $y(0^{-}) = y'(0^{-}) = 1$.

SECTION 6

16.

Provide clear explanations to the following questions:

a) Draw the energy band diagram of a metal-semiconductor junction under the condition that the work-function of the metal layer is larger than the work-function of the semiconductor layer. Does such a material system allow the construction of an Ohmic contact? If so, describe how this can be accomplished employing the band-diagram. If not, why not?

b) Describe how the assumptions and relevance of the depletion region approximation of a *pn*-junction.

c) The electron mobility is a key material parameter that has direct relevance on electronic device performance. Discuss two physical effects that improve mobility.

17.

MOS Capacitor

a) Draw the band diagram of a MOS system where the “metal” work function $_M$ is larger than the silicon work function $_S$. Assume that there are no applied voltages at the p-type substrate (doping N_A) 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) Poly-Silicon Gate Depletion (refer to Figure 1): Assume the voltage V_{ox} = 1V across a 2 nm thin SiO_2 oxide. The P^+ poly gate doping is $N_{poly} = 8x10^{19}$ cm^{-3} and the substrate is n-doped with $N_D = 10^{17}$ cm^{-3}. Find the poly depletion width, W_{dep}.

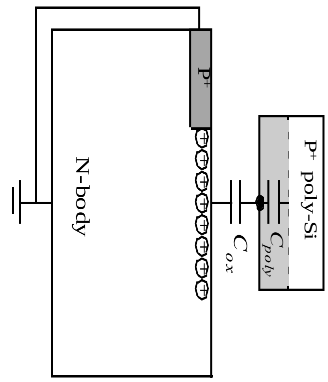


Figure 1. Schematic of the poly depletion capacitances upon gating this MOS capacitor. T=300K. Gate

18.

Basic *pn*-junction operation.

Consider the ideal so-called "long-base" abrupt *pn*-junction silicon diode that has a uniform cross section and constant doping on both sides of the *pn*-junction. The diode is doped as follows: $N_a = 5.0x10^{16}$ cm^{-3} *p*-type and $N_d = 3x10^{16}$ cm^{-3} *n*-type. For this material, the minority-carrier lifetimes are: $\tau_n = 2x10^{-6}$ s and $\tau_p = 1x10^{-6}$ s, respectively. You may assume that the effects within the space-charge region are negligible and that the minority carriers flow only by diffusion in the charge neutral regions.

(a) Draw/sketch the band-diagram for this system. Also, plot the electrostatic potential, the net charge density and the corresponding electric field.

(b) Determine the value of the built-in potential across the pn-junction.

(c) Calculate the density of the minority carriers at the edge of the space-charge region for a forward bias of 0.25V.

(d) Under the above bias condition, calculate and plot the minority and majority carrier currents as a function of distance from the junction.

SECTION 7

19.

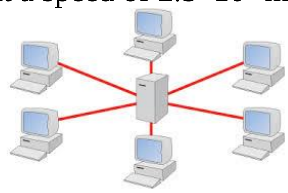
Answer the following questions about LANs (wired and wireless):

a) Describe (through some pseudo code and sufficient explanation) CSMA/CD and Binary Exponential Backoff as used in IEEE 802.3 Ethernet.

b) Describe CSMA/CA (through some pseudo code and sufficient explanation) as used in IEEE 802.11 WiFi.

20.

M terminals are attached by a dedicated pair of lines to a hub in a star topology. The distance from each terminal to the hub is d meters, the speed of the transmission lines is R bits/second, all frames are f length 12,500 Bytes, and the signal propagates on the line at a speed of $2.5*10^8$ meters/second.



For M=6 terminals, d=25 meters and R=10Gbps, what is the maximum network throughput achievable when the hub is implementing slotted ALOHA?

21.

Consider a data link layer with the following parameters: Frame transmission time at the sender is t_f=20 microseconds. ACK or NAK transmission time at the receiver is t_{ack}=10 microseconds. Link propagation delay on both directions is t_{prop}=25 microseconds. Suppose frame processing time at both sender and receiver is negligible, i.e., t_{proc}=0. Finally, overall round-trip probability of frame error on the link is r=0.04.

Assume that for the Stop-and-wait ARQ scheme, the TIMEOUT at the sender is chosen optimally. What is the resulting throughput (frames/second)?

a) In the Go-Back-N ARQ scheme, if the link is error free, what is the minimum window size *N* that is able to keep the link busy?

b) Choose window size in Part b and now consider the link error probability r=0.04. What is the throughput (frames/second) of the Go-Back-N ARQ scheme?

SECTION 8

22.

A three-phase 200MVA, 20kV, 60Hz salient pole synchronous machine has parameters $X_d = 1.1$ pu, $X_q = 0.7$ pu and $R_a \sim 0$. The machine delivers 180MW at 0.80 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 5.0 MW. The rated upwind free wind speed is 12 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 450MVA, 20kV, 60-Hz round-rotor synchronous generator has an Inertia constant H = 2,5s.

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 Line to Line fault when the input torque from the turbine is 1.0 pu as shown in the diagram.