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

Preliminary Examination - Spring 2017

Friday, February 24, 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.

Assume a five stage single pipeline microarchitecture. All ops are one cycle except LW and SW, which are 1+2 cycles, and braches, which are 1+1 cycles. There is no forwarding. Given the following code,

```
Loop:  LW    R3, 0(R0)
       LW    R1, 0(R3)
       ADDI  R1, R1, #1
       SUB   R4, R3, R2
       SW    R1, 0(R3)
       BNZ   R4, Loop
```

For one iteration of the loop, show the phases of each instruction per clock cycle. Considering three cases: a) entering the loop the first time; b) in the loop; and c) exiting the loop.

1) How many clock cycles per loop iteration are attributed to branch overhead?
2) Assume a 1-bit static branch predictor, capable of recognizing a backwards branch in the Decode stage. Now how many clock cycles are wasted on branch overhead?
3) Assume a dynamic branch predictor. How many cycles are lost on a correct prediction? How many on an incorrect prediction?

2.

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:  LD    R12, -12(R10)
       ADD R12, R12, R5
       SD    R12, -12(R10)
       ADDI R10, R10, -4
       BNEZ   R10, Loop
```

3.

A pipeline for adding floating point numbers is constructed with stages for alignment of exponents, addition of mantissas, and normalization. The prorogation delay through these stages is 15, 25, and 15 nanoseconds, respectively. A latch that requires 5 nano seconds of latch time is used in front of each stage. While the pipeline allows brining in two operands at a time, there are two feedback paths from the output of the pipe to present that output to each of the two inputs with arbitrary number of delays [From 0 up to 3 pipeline clocks] to enable accumulating numbers in a variety of ways. It is desired to add the elements of a vector of floating point numbers of length 256. A) Sketch a timing diagram representing an efficient schedule for this computation. B) Derive and evaluate an exact expression for the speed up of the pipeline over that of an equivalent non-pipelined adder. C) Derive and evaluate exact expressions for the efficiency and the throughput (in additions/second).

SECTION 2

4.

Do the following systems of equations have a solution? If so, find all solutions.

$$\text{a)}\quad \begin{aligned} 1 &= x_1 + 2x_3 + 2x_4 \\ 0 &= 2x_1 + x_2 - 3x_3 - 2x_4 \\ 0 &= 3x_1 + 2x_2 + 3x_3 + 2x_4 \end{aligned}$$

$$\text{b)}\quad \begin{aligned} 1 &= x_1 - x_2 + x_3 + x_4 \\ -2 &= -2x_1 + 5x_2 - x_3 - x_4 \\ 3 &= x_1 + 3x_2 + 6x_3 - 9x_4 \end{aligned}$$

5.

Given the system $S=\{\mathbf{A},\mathbf{b},\mathbf{c}\}$, where

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

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 $\tau = 1\,s$ and a natural frequency of oscillation $\omega_n = 1\,radian/s$. Can you do it using state feedback? If, yes, do it and show all your steps. If no, explain in detail why not.

6.

Solve the linear time-invariant nonhomogeneous vector differential equation for $x(t)$

$$\dot{\mathbf{x}} = \begin{bmatrix} 0 & 0 & 1 \\ -1 & 1 & 1 \\ -1 & 0 & 2 \end{bmatrix} \mathbf{x} + \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} t$$

SECTION 3

7.

A sequence of n binary digits is transmitted over a channel in which the probability of an error is p and errors occur independently from digit to digit.

a) Find the probability that no more than j digits are received in error

An error correcting code is applied to the n data digits to produce a codeword of $m > n$ digits. The code can correct any one error among the m digits but cannot correct any error pattern of two or more errors.

b) Find the probability that the code can correct the actually occurring error pattern among the m transmitted digits

The code can be used in error detection mode and detect any pattern of two or fewer errors.

c) Find the probability that the code can detect the actually occurring error pattern among the m transmitted digits.

8.

Let X(t) be a zero mean wide sense stationary continuous time random process with autocorrelation function $R(\tau) = \mu \exp(-\lambda|\tau|)$ for $-\infty < \tau < \infty$. Let X(t) be the input to a linear time-invariant filter with impulse response h(t).

Find the expected value of the instantaneous power in the output process at time t.

9.

Let N = (0, 1, 2, …) be the random variable equal to the total number of messages in two M/M/1 queuing systems, each of which operates independently with Poisson input rates λ_1 and λ_2 and exponential service rates μ_1 and μ_2, respectively.

a) Determine the steady-state probability of n messages in the system as a whole, for n = 0, 1, 2, ….

b) Determine the expected value E{N} of the number of messages in the system as a whole.

SECTION 4

10.

A Hertzian dipole situated at the origin and oriented along the x-axis carries a current of $I_1 = I_0 \cos \omega t.$ A second Hertzian dipole having current $I_2 = I_0 \sin \omega t$ is also situated at the origin but oriented along the z-axis. Find the radiated electric field (far field) at

a) a point on the x-axis,

b) a point on the z-axis,

c) a point on the y-axis, and

d) a point on the line $x = y,\ z = 0.$

11.

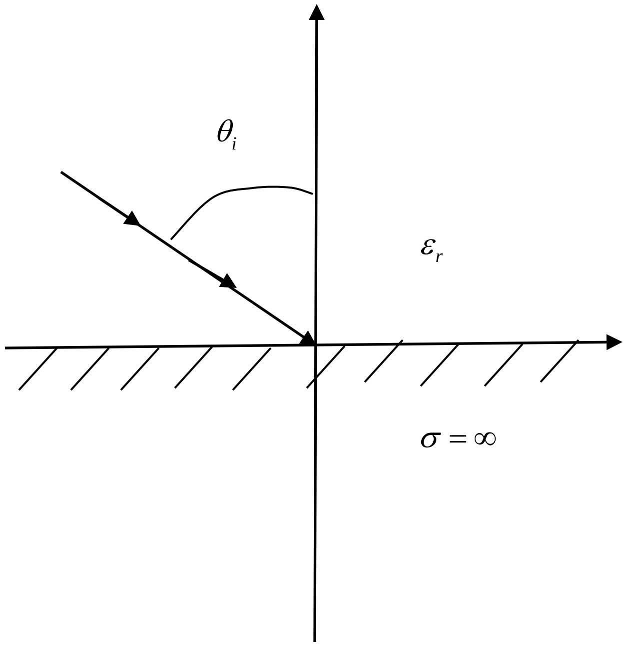


Figure 1

A dielectric medium $(\mu = \mu_0)$ lies above a perfectly conducting plane as shown in Figure 1. A plane wave having the electric field

$$\mathbf{E}(x,z) = \left(3E_0\mathbf{x} + \frac{9E_0}{4}\mathbf{z}\right)e^{-j3k_0x + j4k_0z}$$

is incident upon a perfectly conducting plane. Here E_0 is a constant and k_0 is the free space wavenumber $\left(k_0 = \sqrt{\mu_0\varepsilon_0}\right)$.

a) What is the angle of incidence θ_i?

b) What is the dielectric constant ε_r of the medium?

c) Find the z component of the reflected electric field.

12.

A right-hand circularly polarized uniform plane wave traveling in air is incident normally on a flat and smooth water surface with $\varepsilon_r = 81$ and $\sigma = 0.1$ S/m. Assuming a frequency of 1 GHz and an incident electric field of

$$\mathbf{E}' = \left(\mathbf{y} + \mathbf{z}e^{j\psi}\right) E_0 e^{j\beta_0 x}$$

Do the following.

a) Determine the value of ψ.

b) Write an expression for the corresponding incident magnetic field.

c) Write expressions for the reflected electric and magnetic fields.

d) Determine the polarization (including sense of rotation) of the reflected wave.

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

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

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 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 the assumptions made of the depletion region approximation of a *PN*-junction, and their relevance for the operation of the *PN* junction, such as depletion width, IV curve etc.
c) The electron mobility is a key material parameter that has direct relevance on electronic device performance. Discuss at least two physical effects that can improve the mobility.

17.

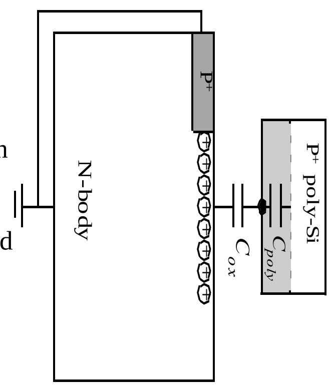
MOS Capacitor

a) Draw the band diagram of a MOS system where the “metal” work function Φ_M is larger than the silicon work function Φ_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 χ , 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 t_{ox}, the potential drop in the oxide ϕ_{ox}, and the potential drop in the semiconductor $\phi(x)$.

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

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 $N_{poly} = 8\times10^{19}$ 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 and body are Silicon. The gate oxide is SiO_2, t_{ox}=2nm.



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: $\tau_n = 4x10^{-6}$ 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 0.3V.

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.

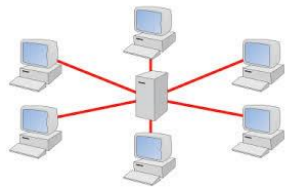
Answer the following questions about LANs (wired and wireless):

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, $X_q = 0.6$ pu and $R_a \sim 0$. The machine delivers 180MW at 0.85 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 3.0 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 450MVA, 20kV, 60-Hz round-rotor synchronous generator has an Inertia constant H = 3s.

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