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

Preliminary Examination - Spring 2018

Friday, February 16, 2018

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. After graduating, you are asked to become the lead computer designer at New Computers Inc. You have invented a scheme that reduces the loads and stores normally associated with procedure calls and returns. The first thing you do is run some experiments with and without this optimization. Your experiments use the same state-of-the-art optimizing compiler that will be used with either version of the computer. These experiments reveal the following information:

- The clock rate of the un-optimized version is 15% higher.
- 45% of the instructions in the un-optimized version are loads and stores.
- The optimized version executes one-third as many loads and stores as the un-optimized version.
- For all other instructions the dynamic execution counts are unchanged.
- All instructions (including load and store) take one clock cycle.

Which is faster? The optimized version or the un-optimized one. Justify your decision quantitatively by computing an improvement factor to validate your answer.

2. The IEEE 754 Floating point number standard format for single precision floating-point numbers can be summarized as follows:

The 32 bits number is divided as shown below:

S	Exponent	Fraction
31	30 … 23	22 … 0

A number is normalized if the Exponent value is between 1 and 254, and is denormalized if the exponent value is 0 and the Fraction value is not 0.

The value of a normalized number is $(-1)^{S}x(1+\text{Fraction}) \times 2^{(\text{Exponent-bias})}$
and the value of a denormalized number is $(-1)^{S}x(0+\text{Fraction}) \times 2^{(1\text{-bias})}$

Where the bias value is 127.

Please answer the following questions:

a. What are the maximum and minimum normalized numbers that can be computed using single precision format?
b. What are the maximum and minimum denormalized numbers that can be computed using single precision format?
c. If we change the Exponent size to be 10 bits instead of 8 and the fraction to be 21 bits instead of 23 bits:
    a. What should the bias value be?
    b. Repeat question 2 for the new format
    c. Repeat question 3 for the new format
d. Represent the following two decimal numbers in Single Precision format:
    a. 0.1
    b. 33554431
e. Take the values you computed in (d) and convert them back into decimal. Did the numbers change? Explain why.

3. For a hypothetical CPU which has 64 bit virtual address and 41 bit physical address with two levels of cache. The L1 cache is virtually indexed and physically tagged. The L1 size is 8KB. The page size is 8KB. The L2 cache is 4MB. The block size is 64 bytes. Please illustrate the translation of virtual address to physical address, as well as the interactions to the TLB and L1/L2 Cache. Indicate how many bits are used for page number, page offset, TLB index, TLB tag, cache index, cache tag, etc.

Section 2

4. Given $\mathbf{A} = \begin{bmatrix} 1 & 2 & 3 & 4 \\ -1 & 1 & 3 & 2 \\ 2 & 2 & 2 & 4 \end{bmatrix}$, $\mathbf{y}_1 = \begin{pmatrix} 2 \\ -2 \\ 4 \end{pmatrix}$, $\mathbf{y}_2 = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}$

a) Find a basis for the range space of $\mathbf{A}$, $R(\mathbf{A})$

b) Find a basis for the null space $\mathbf{A}$, $N(\mathbf{A})$

c) Find the rank and nullity of $\mathbf{A}$

d) For the equation $\mathbf{y}_1 = \mathbf{A}\mathbf{x}_1$, where $\mathbf{x}_1$ is a 4x1 vector, does a solution exist for $\mathbf{x}_1$?

e) For the equation $\mathbf{y}_2 = \mathbf{A}\mathbf{x}_2$, where $\mathbf{x}_2$ is a 4x1 vector, does a solution exist for $\mathbf{x}_2$?

f) If a solution $\mathbf{x}_1$ and/or $\mathbf{x}_2$ exist in parts (d) and (e), find <u>all</u> solutions.

5. For the system $\mathbf{A} = \begin{bmatrix} -1 & -8 \\ 0.5 & -1 \end{bmatrix}$, $\mathbf{b} = \begin{pmatrix} 1 \\ 0.5 \end{pmatrix}$, $\mathbf{c} = \begin{bmatrix} -1 & 1 \end{bmatrix}$

a) Design a state observer;

b) Using the state estimates from part a), find an appropriate state feedback such that the system will have a purely oscillatory response with a natural frequency of oscillation $\omega n = 2 \;\; radians\,/\,second.$

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

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

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

Section 3

7. A binary source generates a sequence of symbols with probabilities p and 1-p, respectively. Given the first symbol in the sequence, the source continues to generate symbols until the opposite symbol is generated. Let X denote the length of the sequence, including the first symbol.

a) Find the probability mass function of X.

b) Find the expected value of X.

8. Messages arriving at a central office switch are exponentially distributed in length, with average length 800 bits and average arrival rate of 16 messages per second. The switch has an infinite buffer and is served by a 64 kilobit per second transmission circuit.

a) Determine the traffic intensity for the switch in Erlangs.

b) Determine the probability distribution of the number of messages in the buffer.

c) Determine the average waiting time of a message in the buffer in seconds.

d) Determine the total average time a message spends in the system, including the waiting time and the service time.

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 magnetic field of a particular mode in a parallel-plate air waveguide with a plate separation of 2.5 cm is given by

$$H_z(x, y) = Ce^{-j640\pi x/3} \cos(160\pi y)$$

where x and y are both in meters.

a) Is this a TE_n or TM_n mode? What is n? Is it a propagating or non-propagating mode?

b) What is the operating frequency?

c) Find the corresponding electric field.

11. An electromagnetic field in free space, $\mu_0 = 4\pi \times 10^{-7}$ henry/meter, $\varepsilon_0 = 8.85 \times 10^{-12}$ farads/meter, is specified as by the vector phasor

$$\underline{E}(\underline{r}) = \underline{E}_0 \varepsilon^{-j\underline{k}g\underline{r}}$$

where $\underline{E}_0 = \hat{x}$ the unit vector in the x direction of a rectangular coordinate system (x, y, z).

$$\underline{r} = x\hat{x} + y\hat{y} + z\hat{z}$$
$$\underline{k} = -j\hat{y} + 2\hat{z}.$$

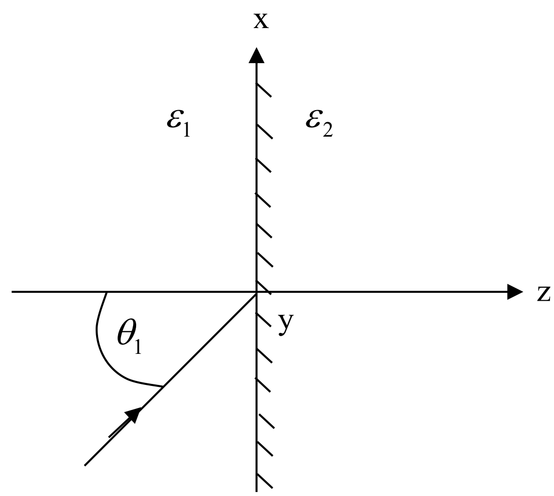
a) What is the frequency f of the electromagnetic field (Hz)?

b) Describe the equi-phase surfaces of the field. Write a general equation for the equi-phase surfaces.

c) Describe the constant magnitude-of-field surfaces. Write a general equation for these equal-magnitude surfaces.

d) Evaluate the average power as a function of position.

12. A plane wave is incident in the interface between two dielectrics ε_1 and $\varepsilon_2, \varepsilon_1 > \varepsilon_2$.



a. Find the angle θ_{1c} such that all waves incident with $\theta_1 > \theta_{1c}$ are "totally reflected".

b. For $\theta_1 > \theta_{1c}$, describe the field (if any) in the region z > 0 in the ε_2 dielectric.

c. If $\underline{E}$ is perpendicular to the plane of the incidence, $\underline{E} = E_y\ \hat{y}$, find the phase of the reflection coefficient.

Section 5

13. In the following:

a) Find the Fourier transform of

$$x(t) = \frac{\sin(\pi 2Bt)}{\pi 2Bt} \cos(2\pi f_c t)$$

where $f_c > 2B > 0$.

b) Find the Hilbert transform $\hat{x}(t)$ of $x(t)$.

c) Find the analytic signal $\psi(t)$ of $x(t)$.

d) Find the complex envelope $\gamma(t)$ of $x(t)$.

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) 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 illustrate your answer.

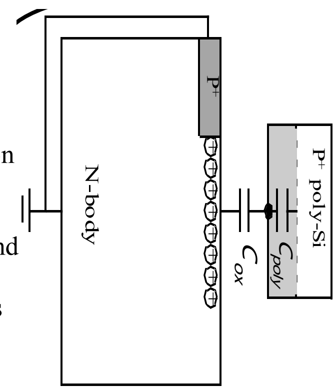
17. MOS Capacitor

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_{Sc}, 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 $N_{poly} = 1\text{x}10^{19}$ 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: $N_a = 8.0\text{x}10^{16}$ cm^{-3} *p*-type and $N_d = 1\text{x}10^{16}$ cm^{-3} *n*-type. For this material, the minority-carrier lifetimes are: $\tau_n = 4\text{x}10^{-6}$ s and $\tau_p = 1\text{x}10^{-6}$ 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.

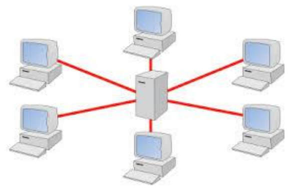
Section 7

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.

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

b) 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?

c) 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 250MVA, 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 230MW 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 7.0 MW. The rated upwind free wind speed is 13 m/s. Determine the length of the rotor blades and the height of the supporting tower 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 = 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.