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

Preliminary Examination - Fall 2018

Friday, October 19, 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**

____
Focus Area in which Registered

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. 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:

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 4 and convert them back into decimal. Did the numbers change? Explain why.

2. Consider a system with three processors. Each processor has a non-blocking cache (i.e., a processor does not stop upon encountering a cache miss; while the missing cache line is brought in from memory, the processor continues to execute instructions that are not data or control dependent upon a missing load).

The memory locations x and y are originally 0. The processors execute the following sequence:
P1: W(x,1); R(y,0);
P2: W(y,1); R(y,1); R(x,1);
P3: R(y,1); R(x,0);

Explain whether the underlying system is able to achieve sequential consistency memory model.

3. Answer the questions below.

a) A certain two way set associative cache has an access time of 40ns, compared to a miss time of 90ns. Without the cache, the main memory access time was 70ns. Running a set of benchmarks with and without the cache indicated a speedup of 1.4. What is the hit rate of the cache?

b) Assume a three level cache system, and assume that h1, h2 and h3 are the hit ratio (hit rate) of cache level one, two and three respectively. Also assume that t1, t2, t3 and tm are the access time to cache level one, two, and three and to main memory respectively. What is the Average Memory Access Time (AMAT) of this memory system using the hit rates and access times given above?

c) The computer spends 82% of the time computing and 18% waiting for the disk. The instruction mix and the Clock Cycles for each type is:

Type	Instruction	Clock Cycles
Int	40%	1
FP	30%	5
Other	30%	2

Consider 3 modifications to the computer

(1) Compute the speedup for each.

a. The processor is replaced with a new one that reduces the total computation time by 35%.

b. The disk is replaced with a solid state device that reduces the disk waiting time by 85%.

c. The processor is replaced with a new one that has improved floating point performance. The average floating point Clock cycles is reduced to 3; all other aspects are unchanged.

(2) Which modification gives the best speedup?

Section 2

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

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

b)
$$\begin{aligned} 1 &= x_1 - 2x_2 + x_3 + x_4 \\ -2 &= -2x_1 + 5x_2 - x_3 - 4x_4 \\ 3 &= x_1 + 3x_2 + 6x_3 - 9x_4 \end{aligned}$$

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

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

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

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

Section 3

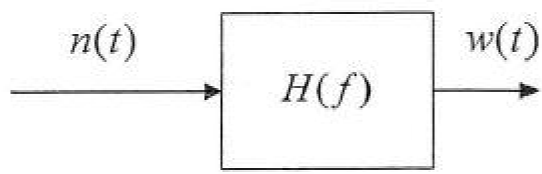
7. Consider the linear system shown in Figure 1 with input noise process n(t) defined by the following autocorrelation function: $R_n(\tau) = \frac{N_0}{2}\delta(\tau)$.

a) Find the power spectral density of noise n(t).

b) Find the power spectral density of output noise w(t).

c) What is the noise power at the output of the filter?

d) Find the autocorrelation function of output noise w(t).



$$H(f) = \begin{cases} 2, & -W \le f \le W \\ 0, & \text{elsewhere} \end{cases}$$

8. A communication channel accepts an arbitrary voltage input v and outputs a voltage $Y = v + N$, where N is a Gaussian random variable with mean 0 and variance σ^2. Suppose that when a 1 is transmitted, $v = V$ and when a 0 is transmitted, $v = -V$. The receiver decides a 0 was sent if Y is negative and a 1 otherwise. Find the probability of the receiver making an error if a 0 was sent; if a 1 was sent. Evaluate for $V = 2$ and $\sigma^2 = 4$.

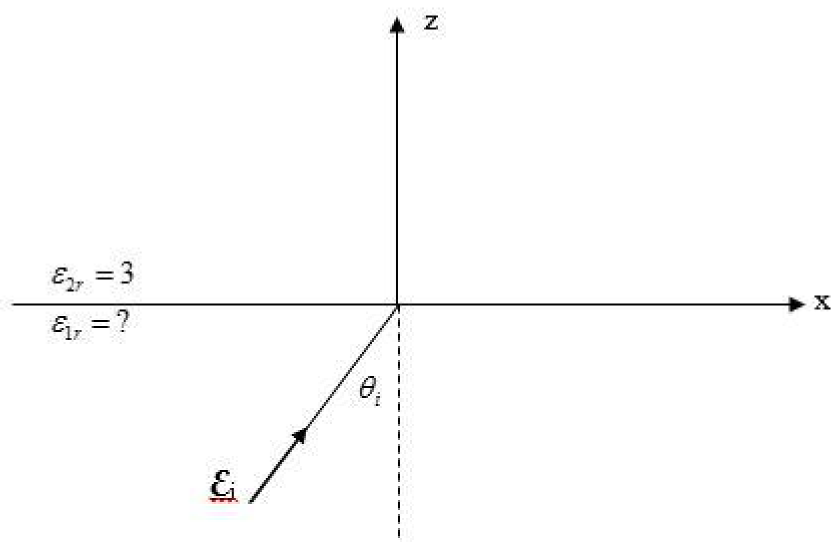
9. The random process $X(t) = \exp(at)$ consists of a family of exponential sample functions determined by the value of the continuous random variable a. In terms of the density function $f(a)$ of a, determine the expected value of $X(t)$, its autocorrelation function $R(t1, t2)$ and its first order density function $f(x, t)$.

Section 4

10. A uniform plane wave is obliquely incident at an angle θ_i at the interface between two nonmagnetic $(\mu_1 = \mu_2 = \mu_0)$ dielectric media as shown in the figure below. The relative permittivity of the second medium is known to be $\varepsilon_{2r} = 3$, and the electric field of the incident wave is given by

$$\boldsymbol{\mathcal{E}}_i(x,z,t) = \hat{\mathbf{y}} E_0 \cos\left[12\times10^9 t - 40\sqrt{3}\,(x+z)\right]$$

a) Calculate the relative dielectric constant ε_{1r} and the angle of incidence θ_i.
b) Write the corresponding expression for the magnetic field of the incident wave (i.e., $\overline{\boldsymbol{\mathcal{H}}}_i(x,z,t)$).
c) Determine the percentage of the incident power that will be transmitted across the interface.



11. Two electric dipoles are excited by prescribed equal currents alternating sinusoidally in time at frequency f. The dipoles are each located on and oriented parallel to the z axis of a Cartesian coordinate system. Their centers are a distance $\lambda = c/f$ apart. Find the radiation pattern of the two dipoles. Here c is the free space velocity of light.

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?

12. 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?

Section 5

13. Answer the questions below.

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. 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 $y(0^-) = y'(0^-) = 1$.

15. Answer the questions below.

a) Using the Gram-Schmidt orthogonalization procedure find set of orthonormal basis functions to represent the three signals $s_1(t)$, $s_2(t)$, and $s_3(t)$ shown in Figure 1. Sketch the orthonormal basis functions.

b) Express each of these signals in terms of the set of basis functions found in part a.

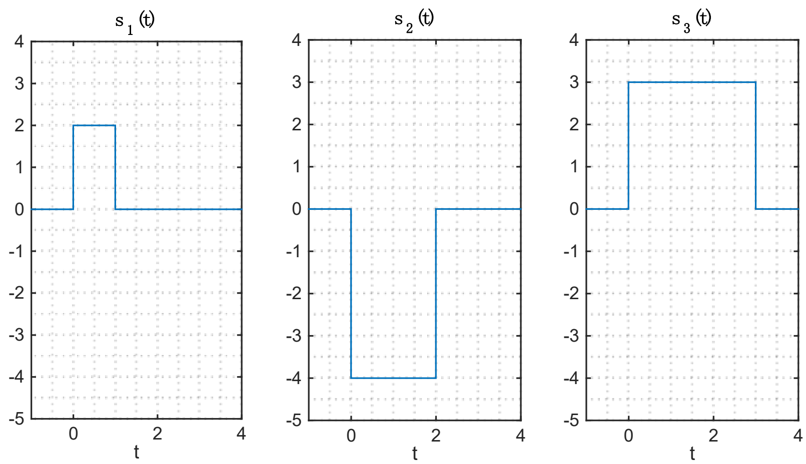


Figure 1: Three signals

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) Derive the Einstein Equations that relate the diffusivity to the mobility of a semiconductor.

c) State at least two possibilities to decrease the power consumption = ½ CV^2 of an electronic device (C = capacitor, V = bias voltage). Explain what parameter should be changed. C, and V are a given, so you need to find other parameters that impact V and C, and discuss those.

17. Mobility

a) State the definition of electron mobility, and its commonly used units

b) We (typically) want a high mobility in a device. Show at least two options how we can improve the mobility?

c) How is effective mass and mobility related? i.e. if you could change the effective mass (i.e. via straining the semiconductor) how could you improve the mobility?

18. MOS Capacitor

a) Derive or state the gate-voltage relationship of the MOS capacity.

b) In inversion we find two charge types on the semiconductor side, describe their origin. Which ones are fixed, which ones are mobile? Draw the band-diagram, and Charge-vs.-device cross-section. Draw qualitatively the amount and location (within the band-diagram) of these charges.

c) Is the threshold voltage (Vt) above or below zero for an N-type silicon MOS capacitor? State at least 2 mechanisms how the Vt can be altered.

Section 7

19. Suppose that a group of 32 stations is serviced by a token-ring LAN. For the following cases, calculate the time it takes to transfer a frame using the three token reinsertion strategies: after completion of transmission, after return of token, and after return of frame.

a) 1000-bit frame; 10 Mbps speed, 2.5-bit latency/adapter, 50 meters between stations.

b) Same as (a) except 100 Mbps speed and 8-bit latency/adapter.

20. Assume that there are N routers in the network and that every router has exactly m neighbors.

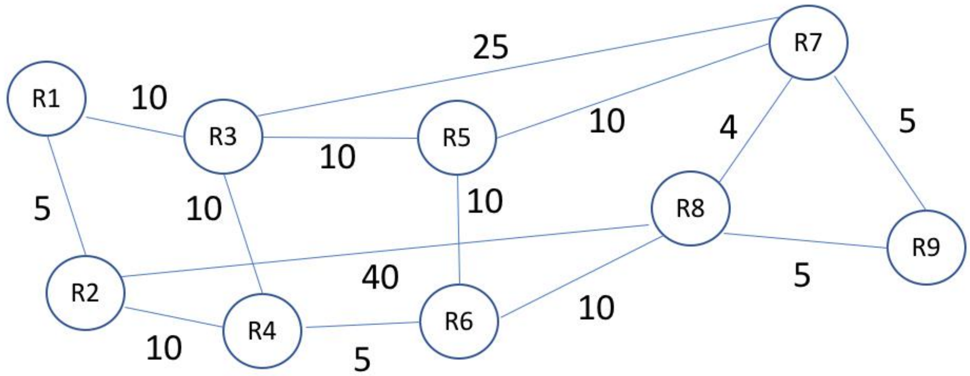
a) Estimate the amount of memory required to store the information used by the distance-vector routing.

b) Estimate the amount of memory required to store the information by the link-state algorithm.

c) If the network uses distance-vector routing, what happens if a router sends a distance vector with all 0's?

d) If the network uses link-state algorithm, what happens if the router fails to claim a link that is attached to it? What if the router claims to have a link that does not exist?

21. In the following network, assume all links are bidirectional and the cost is the same for both directions.



a) Use the Bellman Ford algorithm to find the lowest cost paths to R1 for all the nodes. For each step before convergence, show the current lowest cost to reach R1 and the next hop router to get there for each node.

b) After the minimum cost spanning tree is formed, the link between R4 and R6 fails. For each step before re-convergence, and for each node, show the current lowest cost to reach R1 and the next hop router to get there.

Section 8

22. A three-phase 250MVA, 20kV, 60Hz salient pole synchronous machine has parameters $X_d = 1.0$ pu, $X_q = 0.7$ pu and $R_a \sim 0$. The machine delivers 250MW at 0.88 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 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 7.5 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.