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

Preliminary Examination

Spring 2011

Friday, February 18, 2011

General Instructions

Read carefully before starting.

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

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 at 3:00 p.m.

Only Calculators provided by the department at the examination will be allowed.

Section 1

1.

r2, r4 originally contains memory addresses A and B, respectively

```
      xor   r3 <- r3, r3
      xor   r6 <- r6, r6
      addi  r7 <- r0, 64
L:    ld    r1 <- 0(r2)
      ld    r5 <- 0(r4)
      mul   r1 <- r1, r5
      add   r6 <- r1, r6
      addi  r2 <- r2, 4
      addi  r4 <- r4, 4
      blt   r3, r7, L
      addi  r3 <- r3, 1
E:    ...
```

Assume this segment of code is run on a 32-bit MIPS 5-stage pipeline.

(a) How many instructions would have been executed from the very beginning to label E?

(b) Assume that all instructions take 1 cycle in all pipeline stages and data forwarding circuits are available from the end of EX and MEM to the beginning of EX. How many cycles would pass between the time before the first instance of the first load is fetched and the time after "addi r4…" finishes the WB stage? (Hint: Beware of data hazards) If you found bubble(s)/stall(s) among these instructions, suggest a way to rid of it (them)?

(c) Because the multiply instruction takes a lot of time to execute, the processor is now enhanced with buffers to let independent instructions to pass through. If a dependent instruction reaches EX, that and other younger instructions are stalled.
With this new enhancement, it is highly beneficial to separate the multiply instruction and its dependent instruction as far apart as possible.
(c-i) Which instruction is dependent on the mul instruction?
(c-ii) Which other instruction should be swapped with this instruction to take advantage of this new feature?

(d) Memory data at addresses A and B are NOT available in the processor cache before this code segment. Assume there is only one level of cache with 32-byte cache lines. What are the minimum and maximum number of cache misses suffered by this code?

(e) Suggest one technique for minimizing cache misses for this code segment and explain how it works.

2.

For a machine with 4 GB virtual memory, 1 GB physical memory, 8 KB page size, 64 KB L1 cache size, 32 byte line size, 8 way associative, virtually indexed and physically tagged cache, and 2-way associative TLB with 128 entries, draw a diagram to show the translation from a virtual address to a physical address, and the interactions to the TLB and Cache. You are required to **clearly identify and explain** the number of bits in each component (e.g., index, offset, tag, etc.). Failure to do so will lead to no points.

3.

a) In the following table, each of the rows corresponds to an I/O technique, while each of the columns represents a possible feature of that technique. For each of the three techniques indicate all applicable features by placing x in the corresponding cell(s).

	Processor is tied in I/O	Transfer rate depends on CPU speed	Processor Periodically Checks whether I/O device ready	Processor Must relinquish control of the bus	When I/O is complete, processor receives an interrupt
Interrupt Driven I/O					
Programmed I/O					
DMA					

b) Consider a disk system with 480 512-byte sectors per track where the disk rotates at 1800 rpm. A processor reads one sector from the disk using interrupt-driven I/O with one interrupt per byte. If it takes 2.5 microseconds to process each interrupt, what percentage of time will the processor spend handling I/O, if you ignore seek time.

c) Repeat b, with all of its parameters, if a DMA controller is used instead, and each DMA operation transfers an entire sector.

Section 2

4.

An information source is generating a sequence of independent and identically distributed (i.i.d.) random variables $\{x_n\}_{n\epsilon\mathbb{Z}}$, where $x_n\,\epsilon\{-1,+1\}$ and the probability of $x_n = -1$ is equal to the probability of $x_n = +1$. The sequence is transmitted through the discrete-time channel whose output y_n is given as

$$y_n = x_n + 0.5x_{n-1} + v_n$$

where $\{v_n\}_{n\epsilon\mathbb{Z}}$ is white zero-mean wide-sense stationary noise with variance $\sigma^2 = 0.1$ and independent of $\{x_n\}_{n\epsilon\mathbb{Z}}$.

a) Find the autocorrelation function of y_n and the crosscorrelation function of y_n and x_n.

b) In the receiver, y_n is applied to the input of the equalizer whose output is given as

$$z_n = w_0 y_n + w_1 y_{n-1} + w_2 y_{n-2}$$

The equalization error is defined as $z_n - x_n$. Find w_0, w_1 and w_2 such that the mean square equalization error is minimized. Calculate the minimum mean square equalization error.

5.

The random process $Z(t)$ is defined by

$$Z(t) = Xt + Y$$

where X and Y are a pair of random variables with means $m_X = 1$ and $m_Y = 2$, variances $\sigma_X^2 = 1, \sigma_Y^2 = 4$, and correlation coefficient $\rho_{XY} = 0.5$.

a) Find the mean and autocovariance of $Z(t)$.

b) Find the probability density function of $Z(t)$ if X and Y are jointly Gaussian random variables.

c) Is $Z(t)$ a wide-sense stationary random process? Explain your answer.

(Note: The general form of the Gaussian probability density function is

$$f_V(v) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(v-m)^2}{2\sigma^2}}$$

where m is the mean and σ^2 is the variance of a Gaussian random variable V.)

6.

Consider zero-mean Gaussian random variables x and y, each with variance σ^2.

a) Derive the probability density function of $z = \sqrt{x^2 + y^2}$.

b) Calculate $E(z)$ and $E(z^2)$.

c) What is the probability that z is smaller than $\sqrt{E(z^2)}$?

Section 3

7.

The magnetic field of a 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.
d) Find the lowest order mode of the same type (TE or TM) that does not propagate at this operating frequency.

8.

A time harmonic plane wave with electric field

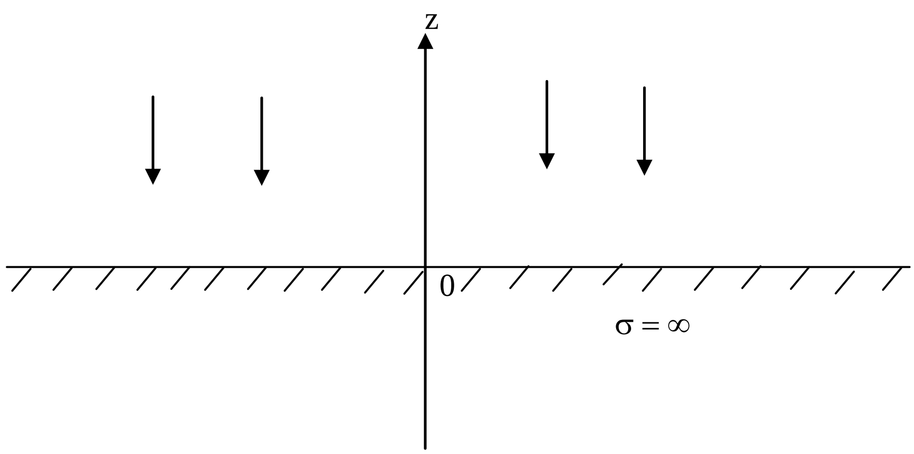
$$\underline{E}_i(z) = E_0\left(x - jy\right)e^{+jk_0z}$$

is normally incident on a perfectly conducting half space. Here E_0 is a real constant and k_0 is the free space wavenumber.

a) What is the polarization of the incident wave?

b) Find the reflected electric field.

c) What is the polarization of the reflected electric field?

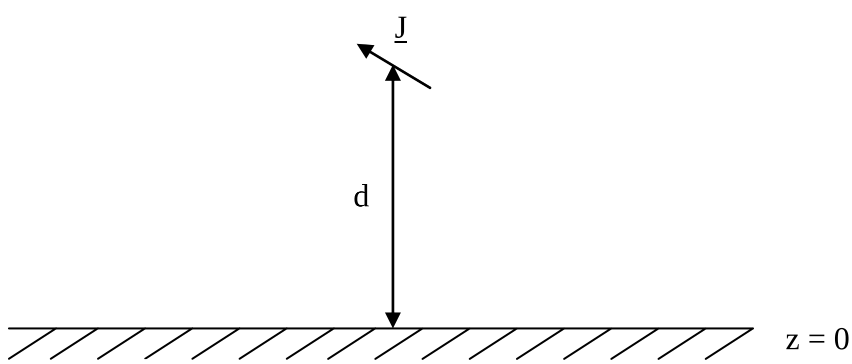


9.

A short dipole of strength J is located above a perfectly conducting plane z = 0. The dipole strength is

$$\underline{\mathrm{J}} = J_0\left(\hat{x}+\hat{z}\right)$$

where $\hat{x}$ and $\hat{z}$ are unit vectors in the x and z directions and J_0 is a constant.. The distance of the dipole from the conductor is “d”.



$\sigma = \infty$

a) Find the location, direction and magnitude of the image.
b) Find the radiation pattern.

Section 4

10.

For the 8×6 matrix $\mathbf{A}$ **,**

$$\mathbf{A} = [\mathbf{a_1}\ \mathbf{a_1}\ \mathbf{a_2}\ \mathbf{a_2}\ \mathbf{a_3}\ \mathbf{a_3}]$$

where $\mathbf{a_1}$, $\mathbf{a}_2$ and $\mathbf{a}_3$ are orthonormal column vectors,

a) Find the vector $\mathbf{x}$ that minimizes ε,

$$\varepsilon = \|\mathbf{Ax} - \mathbf{y}\|^2$$

where

$$\mathbf{y}^T = [1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1]$$

(Note: T denotes the transpose)

b) Find ε

11.

The inverse of the double -sided Laplace transform

$$F_{II}(s) = \frac{1}{(s+2)^3(s^2+4)s}$$

can represent several time functions, depending on the choice of the integration path in the inversion formula. Find and sketch the time functions. Identify the function for which $F_{II}(s)$ represents the single-sided Laplace transform. Find the corresponding Fourier transform.

12.

A linear system is defined by the differential equation (DE)

$$\frac{d^2y}{dt^2}+2\frac{dy}{dt}+y=x(t)$$

a) Find the output $y(t)$ when the input $x(t)$ is $\cos(2t+\pi/8)$

b) Find the impulse response

c) Using Fourier Transforms solve the DE for $t\geq -2$ with initial conditions

$y(-2)=1, y'(-2)=1$ and $x(t)=\begin{cases}1; t>0\\0; t<0\end{cases}$

Section 5

13.

Show that Schwartz's inequality holds for the product of

$$\begin{bmatrix} 2 & 1 \\ 1 & 3 \end{bmatrix} \text{ and } \begin{bmatrix} 5 & 3 \\ 2 & 6 \end{bmatrix}$$

14.

Find the best solution of

$$x + y = 3$$
$$x - y = 1$$
$$y - 2 = 0$$

15.

a) Find the Hermitian transpose of

$$A = \begin{bmatrix} 2 & j & 3 \\ j & 1 & 4 \\ 0 & 3 & 5 \end{bmatrix}$$

where $j = \sqrt{-1}$.

b) Find a matrix that diagonalizes A.

Section 6

16.

Consider a semiconductor device in which the drift-diffusion model is employed to describe current transport. Show that the electrostatic potential ϕ can be related to the Fermi energy as follows: $\phi = (1/q)\ (E_f - E_i)$, under thermal equilibrium. Here, q is the electronic charge, E_i is the mid-gap energy and E_f is the Fermi energy. You may assume that the Fermi energy is within the band gap, i.e., non-degenerate semiconductor. In your derivation and explanations, state any necessary assumptions and define all symbols used.

17.

Derive an expression for the threshold voltage of an n-channel MOSFET. Your derivation needs to include the following physical mechanisms and parameters:

(i) The metal-semiconductor work function difference $\boldsymbol{\Phi_{MS}}$.
(ii) The gate insulator thickness $\boldsymbol{t_{OX}}$ and dielectric constant $\boldsymbol{\varepsilon_{OX}}$.
(iii) The silicon dielectric constant $\boldsymbol{\varepsilon_{Si}}$ and substrate doping $\boldsymbol{N_a}$.
(iv) The fixed oxide charge $\boldsymbol{Q_f}$ and Si-insulator interface charge $\boldsymbol{Q_{it}}$.
(v) The source to substrate potential $\boldsymbol{V_{BS}}$.

In your derivation, state all necessary assumptions and derive all necessary expressions. Comment on possible changes to the threshold voltage when the channel length is in the order of the source and drain depletion region widths, as would commonly be the case.

18.

Consider a *pn*-junction with uniform acceptor and donor densities N_a and N_d, respectively. Show that the built-in potential difference across the junction is $V_T \ln(N_a N_d / n_i^2)$, where, V_T denotes the thermal voltage and $\boldsymbol{n_i}$ denotes the intrinsic carrier density. If this *p-n* diode can be probed via Ω-contacts, can this potential be measured by a voltmeter? Justify your answer.

Section 7

19.

A source generates messages according to a Poisson distribution. Each message contains a geometrically distributed number of bytes.

a) Determine the moment generating function of the message arrival process.

b) Determine the moment generating function of the message length in bytes.

c) Determine the average number of bytes generated in T seconds.

d) Determine the variance of the number of bytes generated in T seconds.

20.

In a packet switching system messages arrive at Poisson rate and are divided into packets of size 1000 bits. The number of packets in a message is geometrically distributed, with average 5 packets per message. Assume the channel bit rate is 50 kilobits per second and the packet error rate on the channel is 0.01. Each packet is transmitted according to the stop-and-wait protocol. The roundtrip propagation delay is 10 milliseconds, processing time is negligible, Ack's or Nak's are 50 bits long and arrive error free.

a) What is the average time required to receive an error-free packet?

b) What is the average time required to transmit a message?

c) What is the system throughput in bits per second?

21.

Stations A and B simultaneously start to exchange data with each other in full duplex mode. Each station transmits frames of 48 data bits over a 4800 bits per second line, using the Normal Response Mode of HDLC. The one-way propagation delay is 50 milliseconds. On the sixth transmission from A to B an error occurs.

a) Assuming no other difficulties, specify the protocol control sequence for the first 10 frames for both A and B.

b) Assume station A ends its transmission after the 10th frame, while station B continues to transmit. If an error occurs during the transmission of the 15th frame from station B, specify the protocol control sequence for the next 10 transmissions, for both A and B.

c) Assume that B ends its transmissions after the 20th frame, whereupon A responds with 2 error-free frames. Specify the protocol control sequence for both A and B.

Section 8

22.

a) Describe the process of respiration as related to pulmonary ventilation and gas exchange.

b) Show the graph of respiratory volumes and capacities (including approximate values).

c) Explain the structure and function of alveoli.

23.

a) List and briefly explain all functions of blood.

b) Explain mechanisms of regulation of blood pressure and blood flow.

c) Show forces acting across capillary walls and discuss capillary exchange.

24.

a) Discuss the structure and function of the vestibular complex.

b) Show relevant drawings of the components of the vestibular complex.