Ph.D. Preliminary Examination Solution
Fall 2008

Instructions:

1. Please check to ensure that you have a complete exam booklet. There are 25 numbered problems. Note that **problem 20 has 2 pages.** Including the cover sheet, you should have **27 pages**. There should be no blank pages in the booklet.
2. The examination is closed book and closed notes. No reference material is allowed at your desk. A calculator is permitted.
3. All wireless devices must be turned off for the entire duration of the exam.
4. You may work a problem directly on the problem statement (if there is room) or on blank sheets of paper available from the exam proctor. Do not write on the back side of any sheet.
5. Your examination code number **MUST APPEAR ON EVERY SHEET**. This includes this cover sheet, the problem statement sheets, and any additional work sheets you turn in. **DO NOT** write your name on any of these sheets. Use the preprinted numbers whenever possible, or **WRITE LEGIBLY!!!**
6. Under the rules of the examination, you must choose 8 problems to be handed in for grading. Each problem to be graded should be separated from the rest of the materials, stapled to the associated worksheets, and placed on the top of the appropriate envelope in the front of the exam room. **DO NOT TURN IN ANY SHEETS FOR THE OTHER 17 PROBLEMS!!**
7. The examination lasts 4 hours, from 9:30 AM to 1:30 PM.
8. When you hand in the exam:
   (a) Separate the 8 problems to be graded as explained above.
   (b) Check to see that your Code Number is in **EVERY** sheet you are turning in.
   (c) On the section at the bottom of this page, **CIRCLE** the problem numbers that you are turning in for grading.
   (d) Turn in this cover sheet (containing your code number) and the 8 problems to be graded.
   (e) All other material is to be placed in the discard box at the front of the room. You are not allowed to take any of the exam booklet pages from the room!

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
10	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
19	**20**	**21**	**22**	**23**	**24**	**25**		

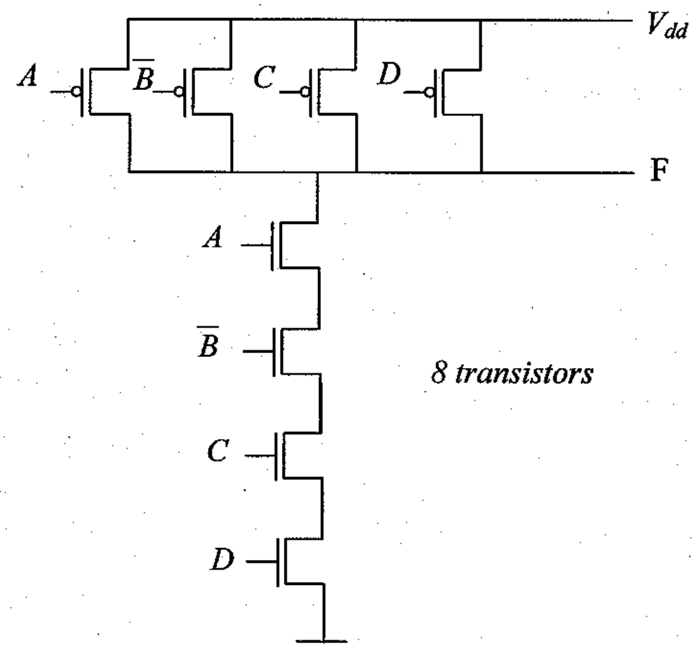
Problem 1 (Core: CompE-ECE2030) **Code Number:__________**

You are initially given the following Boolean expression.

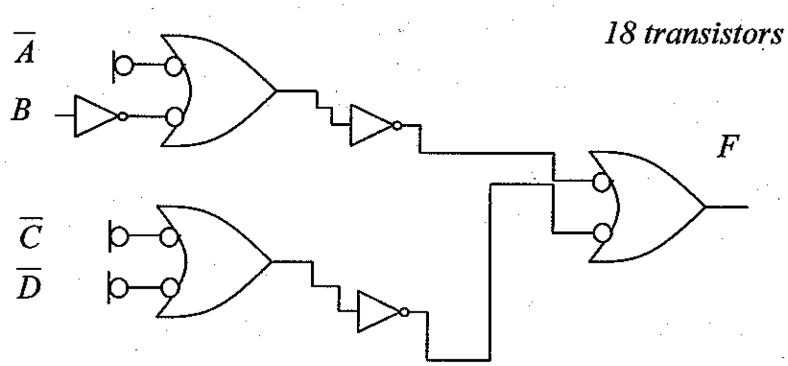
$$F = \overline{(C(\overline{\overline{A}+B}))} + \overline{(\overline{B}D)}$$

a) Provide a CMOS implementation of the expression using p-type and n-type transistors.

$$F = \overline{(C(\overline{\overline{A}+B}))} + \overline{(\overline{B}D)} = \overline{C} + (\overline{\overline{\overline{A}+B}}) + \overline{\overline{B}} + \overline{D} = \overline{A} + B + \overline{C} + \overline{D}$$



b) Provide an implementation using only 2 input NAND gates and inverters (preferably specified in mixed logic notation). Indicate the total number of transistors required and compare to part a).

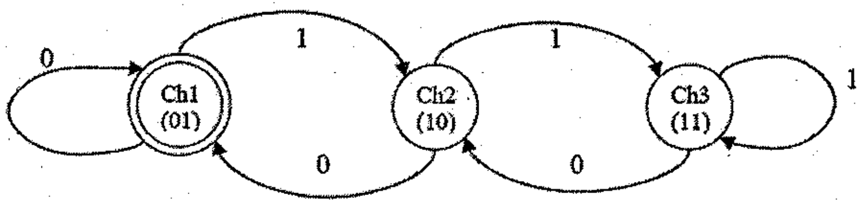


Problem 2 (Core: CompE-ECE2030) Code Number:__________

Design a remote control logic circuit for a 3-channel TV using the finite state machine (FSM) method. The controller contains 2 buttons: Up (1) and Down (0) encoded as a single bit input in the circuit. The state itself indicates the current channel, e.g., state '10' (in binary) is Ch2. When holding the button, the channel will continue to change for each input clock edge. When in the terminal channels, Ch3 (or Ch1), pressing Up (or Down) will not change the channel. First, complete the state diagram shown below for all state transitions and derive the state table based on your state diagram. Then use Karnaugh map to minimize your logic, you must take don't care states into account. Finally, implement your FSM with D flip-flop's and basic logic gates.

Solution provided by Hsien-Hsin S. Lee

State Diagram



Input			Output	
I	S1	S0	NS1	NS0
X	0	0	X	X
0	0	1	0	1
1	0	1	1	0
0	1	0	0	1
1	1	0	1	1
0	1	1	1	0
1	1	1	1	1

NS1

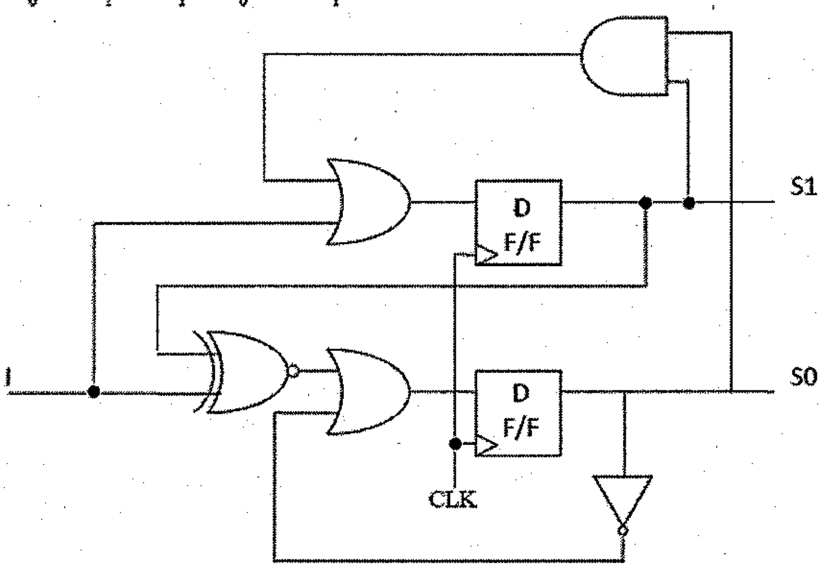
I \ S_1S_0	00	01	11	10
0	x	0	1	0
1	x	1	1	1

NS0

I \ S_1S_0	00	01	11	10
0	x	1	0	1
1	x	0	1	1

$$NS1 = I + S_1S_0$$

$$NS0 = \overline{S_0} + I \cdot S_1 + \overline{I} \cdot \overline{S_1} = \overline{S_0} + \overline{I \oplus S_1}$$



Problem 3 (Core: CompE-ECE3055) Code Number:__________

Virtual Memory.
The hardware design for this system uses a 2K page size (2048 bytes) and the same frame size. A sample direct-mapped page table is given below. The entries in the page table are *Frame Numbers*, not frame addresses. For each logical memory address specified below, give the corresponding physical memory address. Write *Page Fault* if the logical memory address is invalid. The logical addresses are *byte* addresses. **ALL NUMBERS GIVEN ARE IN HEXADECIMAL. GIVE ALL ANSWERS IN HEX.** Show work for partial credit.

Page Table

Page Number	Physical Page Frame Number
0	1234
1	9f9
2	98ba
3	ff
4	67abf
5	4321
6	1ff
7	abc
8	986a7
9	ab878
a	654a
b	100
c	8bbb
d	1
e	fffff
f	def

Logical Address : `12ff` Physical Address :

Logical Address : `0` Physical Address :

Logical Address : `f12` Physical Address :

Logical Address : `6800` Physical Address :

Problem 3 (Core: CompE-ECE3055) Code Number:__________

ANSWER KEY

Virtual Memory.
The hardware design for this system uses a 2K page size (2048 bytes) and the same frame size. A sample direct–mapped page table is given below. The entries in the page table are *Frame Numbers*, not frame addresses. For each logical memory address specified below, give the corresponding physical memory address. Write *Page Fault* if the logical memory address is invalid. The logical addresses are *byte* addresses. **ALL NUMBERS GIVEN ARE IN HEXADECIMAL. GIVE ALL ANSWERS IN HEX.** Show work for partial credit.

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9	ab878
a	654a
b	100
c	8bbb
d	1
e	fffff
f	def

Logical Address : 12ff Physical Address : 4c5d2ff

Logical Address : 0 Physical Address : 91a000

Logical Address : f12 Physical Address : 4fcf12

Logical Address : 6800 Physical Address : 0800

Problem 3 (Core: CompE-ECE3055) Code Number:__________

Prelim Problem Solution **Computing Mechanisms**

Part A: Perform the following standard compiler optimizations on the body of the C subroutine below by writing the optimized version (in C) to the right: strength reduction, loop invariant removal, common subexpression elimination. You may add additional local variables if needed.

```
int foo(int x, int y) {
  int i, d, z = 0;
  for (i=0; i < 5000; i++) {
    z = z + x * i;
    d = x/y + (z+y)*(z+y);
  }
  return z+d;}
```

⇨

```
int foo(int x, int y) {
  int a, b=0, i, d, z = 0;
  int r = x/y;
  for (i=0; i < 5000; i++) {
    z = z + b;
    b = b + x;
    a = z+y;
    d = r + a*a;
  }
  return z+d;}
```

Part B: Consider the following C fragment. Assume a 32-bit integer datapath with a 32-bit memory address space. Assume *int* datatypes are 1 word long and *double* datatypes are 2 words long. In C syntax, "&" is the address operator and "*" is the dereference or indirection operator.

```
int F (int A) {
   int    x = 5;
   double y = 20.0;
   int    *p = &x
   int    Vector[3] = {4, 9, 16};
   double G(int, *double, int V[]);
   y = G(*p, &y, Vector);
   return x+A;}
```

What is the total number of words of storage allocated in F's activation frame for F's input and output parameters and local variables?

__________ 9 __________ **words for F's I/O and local variables.**

What is the total number of words of storage allocated in G's activation frame for G's input and output parameters?

__________ 5 __________ **words for G's I/O parameters.**

Problem 4 (Core: CompE-ECE3060) **Code Number:__________**

1. (2pts) (Circle the correct term in each set of square brackets.) In a pMOS transistor, we tie the n-well to [Vdd / Gnd] and apply a [negative / positive] gate-to-source voltage. This draws [electrons / holes] into the region below the gate, which in turn results in the channel changing to [p-type / n-type].

2. (2pts) (Circle the correct term in each set of square brackets.) The RC delay of an inverter (INV1) driving another inverter (INV2) increases if the width of transistors in INV1 [increases / decreases], the length of transistors in INV1 [increases / decreases], the width of transistors in INV2 [increases / decreases], and the length of transistors in INV2 [increases / decreases].

3. (3pts) Design a half adder using two 2x1 MUXs (and INVs if necessary). Use one of the two operands of the addition as the MUX selection input.

4. (3pts) Draw the CMOS stick diagram of your solution in problem 3 using the minimum number of transistors. Assume that complemented inputs are not available.

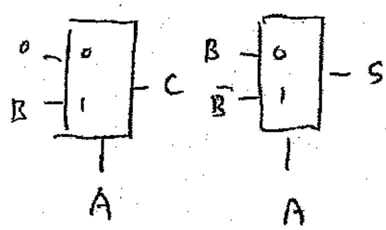
ECE3060 Prelim Problem, Fall 2008 (Solutions)

1. (2pts) In a pMOS transistor, we tie the n-well to [**Vdd** / Gnd] and apply a [**negative** / positive] gate-to-source voltage. This draws [electrons / **holes**] into the region below the gate, which in turn results in the channel changing to [**p-type** / n-type].

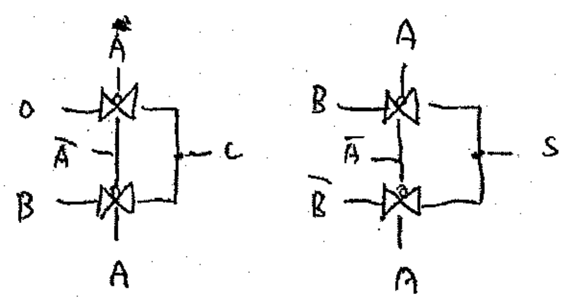
2. (2pts) The RC delay of an inverter (INV1) driving another inverter (INV2) increases if the width of transistors in INV1 [increases / **decreases**], the length of transistors in INV1 [**increases** / decreases], the width of transistors in INV2 [**increases** / decreases], and the length of transistors in INV2 [**increases** / decreases].

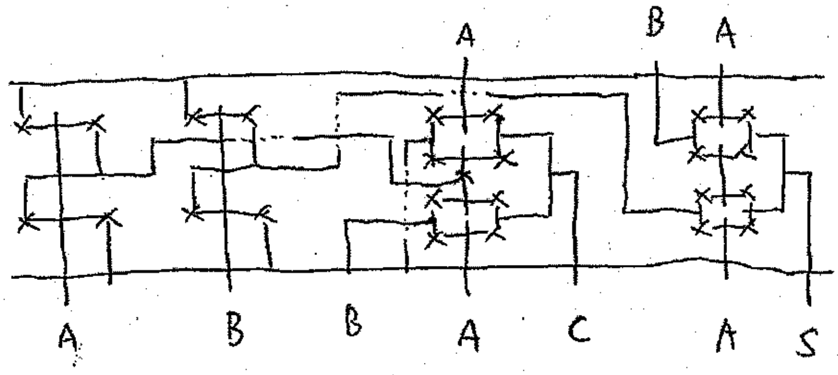
3. (3pts) Design a half adder using two 2x1 MUXs (and INVs if necessary). Use one of the two operands of the addition as the MUX selection input.

A	B	C	S
0	0	0	0
0	1	0	1
1	0	0	1
1	1	1	0



4. (3pts) Draw the CMOS stick diagram of your solution in problem 3 using the minimum number of transistors. Assume that complemented inputs are not available.





Problem 5 (Core: E&M-ECE3025) **Code Number:__________**

Two parallel infinite uniform line charge densities of charge per unit length ρ_1 are separated by distance d. What is the electrostatic force per unit length between the line charges?

Solution:

Call the two line charges 1 and 2. The electric field distance d from line charge 1 due to line charge 1 is

$\mathbf{E}(d,\phi,z) = \lambda/(2\pi\varepsilon_0 d)\ \boldsymbol{\rho}$

In cylindrical coordinates where $\boldsymbol{\rho}$ is a unit vector in the ρ direction. Thus, the force acting on a short length Δz of line charge 2 is

$\lambda\Delta z\ \mathbf{E}(d,\phi,z)$,

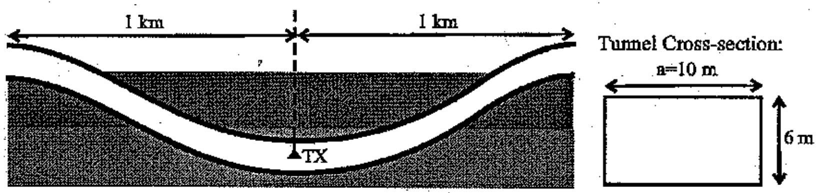
so that the force per unit length acting on line charge 2 is

$\lambda\ \mathbf{E}(d,\phi,z) = \lambda^2/(2\pi\varepsilon_0 d)\ \boldsymbol{\rho}$.

Note that the unit vector $\boldsymbol{\rho}$ points from line charge 1 in direction of line charge 2.

Problem 6 (Core: E&M-ECE3065) Code Number:________

Problem: A section of the Chesapeake bay-bridge tunnel is 2 kilometers long with a width of 10 meters and a height of 6 meters. In the middle of this tunnel is a small 850 MHz cellular base station that provides coverage for mobile users in the tunnel. This station is low-powered and uses the tunnel like a rectangular waveguide to communicate with motorists. Answer the following questions based on this scenario, which is illustrated below:



1. Find the highest value for x such that the TE_{x0} mode still propagates through this tunnel. **(3 points)**

2. For a cell phone user operating at the end the tunnel, what is the dispersion (difference in delay) in nanoseconds between the power carried by the dominant TE_{10} mode and the TM_{77} mode? You may approximate the tunnel to be a straight (horizontal) two kilometers. **(5 points)**

3. What assumption are you making about the material properties of the tunnel in this problem? **(2 points)**

$$v_g = \frac{1}{\sqrt{\epsilon\mu}}\sqrt{1-\left(\frac{f_c}{f}\right)^2} \quad \lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}} \quad (f_c)_{mn} = \frac{1}{2\sqrt{\mu\epsilon}}\sqrt{\left(\frac{m}{a}\right)^2+\left(\frac{n}{b}\right)^2} \quad \begin{array}{c}\epsilon_0 = 8.85\times10^{-12}\ \text{F/m}\\ \mu_0 = 4\pi\times10^{-7}\text{H/m}\end{array}$$

Problem 6 (Core: E&M-ECE3065)   Code Number:__________

Solution:

1. Below is the cut-off equation with the tunnel parameters substituted in:

$$(f_c)_{x0} = \frac{1}{2\sqrt{\mu_0\epsilon_0}}\sqrt{\left(\frac{x}{a}\right)^2 + \left(\frac{0}{b}\right)^2} = x\frac{1.5 \times 10^8 \text{ m/s}}{10 \text{ m}} = 850 \text{ MHz}$$

The value of x that satisfies this relationship exactly is 56.67. Since x represents a modal number, it must be an integer. Thus, the maximum value is 56 (57 would be cut-off).

2. First, let us calculate the cut-off frequencies for the TE_{10} and TM_{77} modes:

$$(f_c)_{10} = \frac{1}{2\sqrt{\mu_0\epsilon_0}}\sqrt{\left(\frac{1}{10 \text{ m}}\right)^2 + \left(\frac{0}{6 \text{ m}}\right)^2} = 15 \text{ MHz}$$

$$(f_c)_{77} = \frac{1}{2\sqrt{\mu_0\epsilon_0}}\sqrt{\left(\frac{7}{10 \text{ m}}\right)^2 + \left(\frac{7}{6 \text{ m}}\right)^2} = 204 \text{ MHz}$$

We know that the group velocity for these modes will be given by:

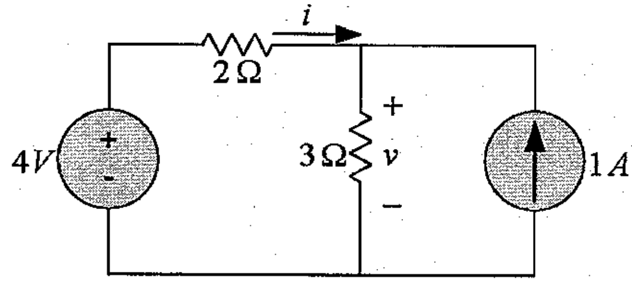
$$v_g = \frac{1}{\sqrt{\mu_0\epsilon_0}}\sqrt{1 - \left(\frac{f_c}{f}\right)^2}$$

which produces a group velocity of 3.00×10^8 m/s for the TE_{10} mode and 2.91×10^8 the TM_{77} mode. After traveling the maximum distance of 1 kilometer (from the base station in the center of the tunnel to a user at the end), this will result in a transit time of 3.33 μs for the TE_{10} mode and a transit time of 3.43 μs for the TM_{77} mode. The difference, 100 ns, is the dispersion between the two modes.

3. You are assuming that the walls of the tunnel approximate a perfect electric conductor (PEC).

Problem 7 (Core: EDA-ECE2040) **Code Number:__________**

Problem: Determine the values of the current, i, and the voltage, v, in the following circuit.



Solution: (3 simple ways)

(a) Superposition principle

If there is only the voltage source,

$$i_1 = \frac{4}{2+3} = 0.8\,\text{A}, v_1 = \frac{3}{2+3} \times 4 = 2.4\,\text{V}$$

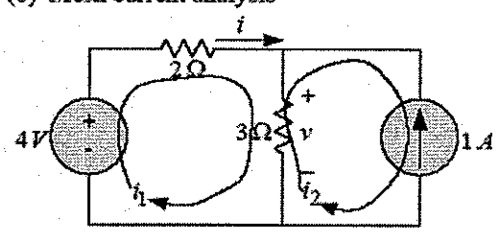
If there is only the current source,

$$i_2 = \frac{3}{2+3} \times (-1) = -0.6\,\text{A}, v_2 = \frac{2\times 3}{2+3} \times 1 = 1.2\,\text{V}$$

If there are both sources,

$$i = i_1 + i_2 = 0.2\,\text{A}, \text{v} = v_1 + v_2 = 3.6\,\text{V}$$

(b) Mesh current analysis



$$2i_1 + 3(i_1 - i_2) - 4 = 0, i_2 = -1$$

$$\Downarrow$$

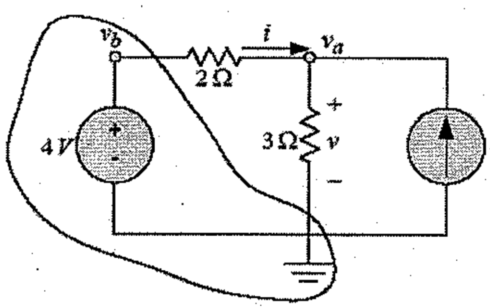
$$i_1 = 0.2, i_2 = -1$$

$$\Downarrow$$

$$i = i_1 = 0.2A$$

$$v = 3(i_1 - i_2) = 3.6V$$

(c) Node voltage analysis



$$\left(\frac{1}{2}+\frac{1}{3}\right)v_a - \frac{1}{2}v_b = 1, v_b = 4$$

$$\Downarrow$$

$$v_a = 3.6, v_b = 4$$

$$\Downarrow$$

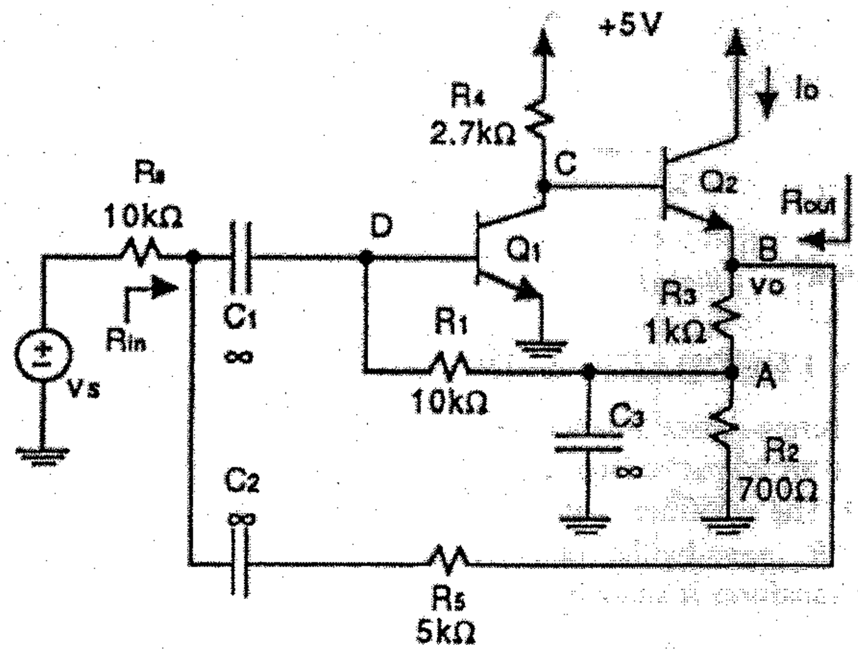
$$i = \frac{v_b - v_a}{2} = 0.2A$$

$$v = v_a = 3.6V$$

Problem 8 (Core: EDA-ECE3050) **Code Number:__________**

The following circuit combines two feedbacks.

(Early voltage) $V_A = \infty$, $\beta_0 = 100$, $V_{BE} = 0.7$ V, $V_{th} = 26$ mV.



a) One feedback involving R_1, R_2, and R_3 only operates at DC but not at high frequency. Why? What type of feedback topology is this?

b) The other feedback, involving R_5, only operates at high frequency (HF), and not at DC. Why? What type of feedback topology is this?

c) The job of the DC feedback is to set the DC potential at node A to be $\sim V_{BE1}$. With this information, find the DC bias points (I_C, V_{CE}) for Q_1 and Q_2.

d) Draw the midband small signal equivalent circuit of the entire circuit (no capacitive effect).

e) For the HF feedback, indicate the feedback network and its loading effect at the input and output of the feed forward path.

f) Draw the small signal equivalent circuit of the loaded (augmented) feed forward amplifier.

g) Find the open loop gain A. (considering the type of HF feedback in part b)

h) For the HF feedback, find the loop-gain $A\beta$.

i) For the HF feedback, find the closed-loop gain of this circuit.

j) For the HF feedback, find the voltage gain of this circuit.

k) Find R_{in} for the closed-loop circuit.

l) Find R_{out} for the closed-loop circuit.

Problem 2 :

a) Bacause at HF, C_3 is shorted to gnd and therefore breaks the feedback loop.
This could be considered a Shunt - Series fB.

b) At DC, C_2 is open and there is no connection. But at HF, C_2 shorts and R_5 forms a feedback loop.
If we consider V_o as the output, this is Shunt_Shunt.
If we consider I_o as the output, then R_3 and R_5 will form the feedback and it will be a Shunt-Series fB.
However the Shunt-Shunt could be more accurate.

c) $V_A = 0.7^v \longrightarrow I_{R_2} = \frac{0.7^v}{0.7k\Omega} = 1\,mA$

Since $V_D \simeq V_A = 0.7^v$ the current through R1 can be neglected.

$\Downarrow$

$I_{R3} = I_{R_2} = 1\,mA = I_{E_2} \simeq I_{C_2}$

$V_B = V_A + R_3 I_{R_2} = 0.7 + 1^v = 1.7^v \Longleftarrow$

$V_{CE_2} = 5^v - 1.7^v = 3.3^v$

$V_C = V_B + V_{BE_2} = 1.7 + 0.7 = 2.4^v$

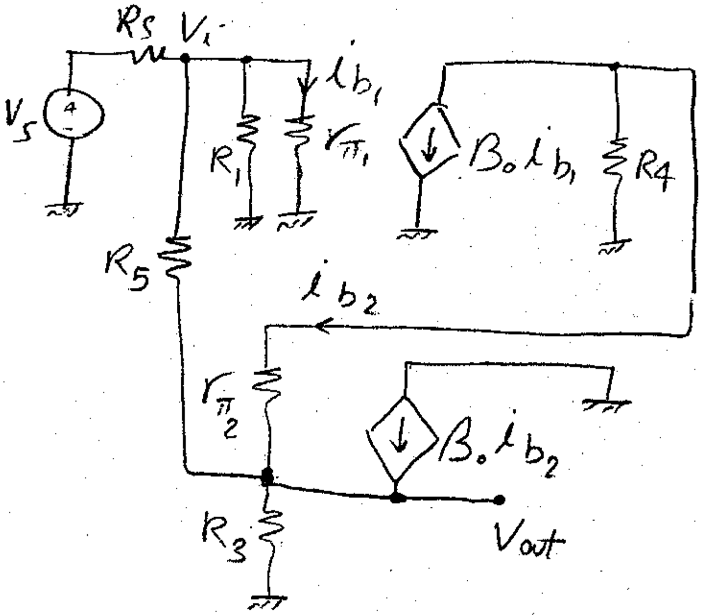
$I_{R4} = \frac{V_{CC} - V_C}{R_4} = \frac{5-2.4}{2.7K\Omega} = 0.96\,mA$

$V_{CE_1} = V_C = 2.4\,V$

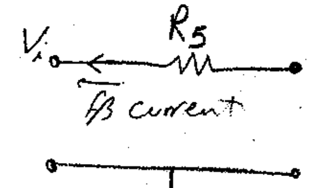
$Q_1\,(0.96\,mA,\ 2.4\,V)$

$Q_2\,(1\,mA,\ 3.3\,V)$

d)



e)



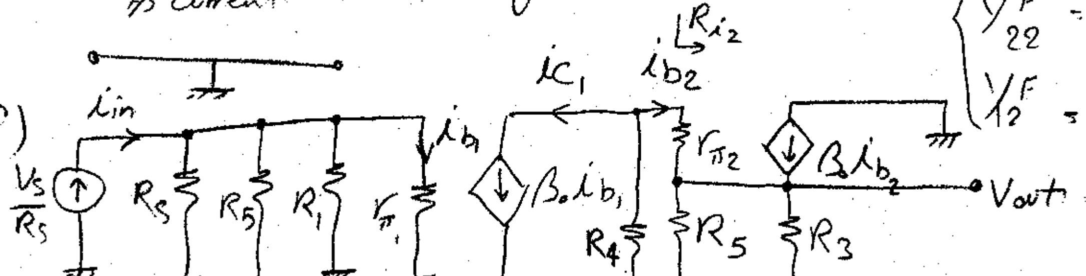
using "Y" Parameters.

$Y_{11}^F = \frac{1}{R_5} = \frac{1}{5k\Omega} = 0.2\,mS$

$Y_{22}^F = \frac{1}{R_5} = 0.2\,mS$

$Y_{12}^F = -\frac{1}{R_5} = -0.2\,mS$

f)



g) $A = \frac{V_{out}}{i_{in}} = \frac{i_{b1}}{i_{in}} * \frac{i_{c1}}{i_{b1}} * \frac{i_{b2}}{i_{c1}} * \frac{i_{e1}}{i_{b2}} * \frac{V_{out}}{i_{e1}}$

$\frac{i_{b1}}{i_{in}} \rightarrow \frac{R_1 \| R_5 \| R_S}{R_1 \| R_5 \| R_S + r_{\pi 1}}$, $\frac{i_{c1}}{i_{b1}} \rightarrow \beta_o$, $\frac{i_{b2}}{i_{c1}} \rightarrow \frac{-R_4}{R_4 + (r_{\pi 2} + \beta_o (R_5 \| R_3))}$, $\frac{i_{e1}}{i_{b2}} \rightarrow (\beta_o + 1)$, $\frac{V_{out}}{i_{e1}} \rightarrow (R_5 \| R_3)$

$\Rightarrow A = -\frac{\beta_o (R_1 \| R_5 \| R_S)(\beta_o + 1) R_4 (R_5 \| R_3)}{(r_{\pi 1} + R_1 \| R_5 \| R_S)(R_4 + (r_{\pi 2} + \beta_o (R_5 \| R_3)))}$

$r_{\pi 1} = 2.7^K$ $\quad r_{\pi 2} = 2.6^K$

Plug in the numbers! $\rightarrow -122.81 K\Omega$

h) $A\beta = + \frac{\beta_o (\beta_o + 1)(R_1 \| R_5 \| R_S) R_4 (R_5 \| R_3)}{R_5 (r_\pi + R_1 \| R_5 \| R_S)(R_4 + (r_{\pi 2} + \beta_o (R_5 \| R_3)))} = \frac{122.81^K}{5^K} = \boxed{24.56}$

i) $A_{CL} = \frac{V_{out}}{i_{in}} = \frac{A}{1 + A\beta} = \frac{-122.81K}{1 + 24.56} = \boxed{-4.8 K\Omega}$

j) $i_{in} = \frac{V_S}{R_S} \longrightarrow \frac{V_{out}}{V_S} = \frac{A_{CL}}{R_S} = \frac{-4.8 K\Omega}{10 K\Omega} = -0.48$

K) $R_{in_{OL}} = R_S \| R_5 \| R_1 \| r_{\pi 1} = 2.5^K \| 2.7^K = 1.3^K$

Since it is Shunt Shunt, $R_{in_{CL}} = \frac{R_{in_{OL}}}{1 + A\beta} = \frac{1.3^K}{25.56} = \boxed{50.8 \Omega}$

l) $R_{out_{OL}} = R_3 \| R_5 \| \left(\frac{r_{\pi 2} + r_4}{\beta_o}\right) = 1^K \| 5^K \| \frac{2.6^K + 2.7^K}{100} \approx 53^\Omega$

$\rightarrow R_{out_{CL}} = \frac{R_{out_{OL}}}{1 + A\beta} = \frac{53^\Omega}{25.56} = \boxed{2.073 \Omega}$

Problem 9 (Core: Power-ECE3070) **Code Number:__________**

A synchronous machine has the following ratings: 3-phase, Y-connected, 60 Hz, 8-pole, 4,000 V, synchronous reactance is 2.5 Ohms per phase. The machine is synchronized to a 4 kV network. Following synchronization, and without any other action, its excitation current was adjusted so that the machine produces 1 MVAr of reactive power. Calculate the needed percent increase of excitation current compared to the value at synchronization.

SOLUTION

Active power P = 0

Reactive power produced by the machine will be:

$$Q = \frac{3EV}{X_s}\cos\delta - \frac{3V^2}{X_s} = \frac{3(1+x)\left(\frac{4,000}{\sqrt{3}}\right)^2}{2.5} - \frac{3\left(\frac{4,000}{\sqrt{3}}\right)^2}{2.5} = 10^6 \quad VAr$$

From which we calculate the necessary increase of excitation current x

$$1+x = \frac{10^6 + \frac{4,000^2}{2.5}}{\frac{4,000^2}{2.5}} = 1.1563$$

which means that the excitation current should be increased by $x = 0.1563$, or 15.63 percent.

Problem 10 (Core: Power-ECE3070) Code Number:________

A 460 volt (L-L) three phase 25 hp, 60 Hz, four pole Y-connected stator induction motor has the following impedances in ohms per phase, ALL referred to the stator circuit.

$R_s = 0.641$ $R_r = 0.332$

$X_s = 1.106$ $X_r = 0.464$

The no-load current is negligibly small.

For a rotor slip of 2.2 % when the stator is supplied by the rated 460 volts (L-L) and 60 Hz, calculate the

(a) Rotor speed in rpm
(b) Stator current per phase
(c) Power factor at the stator terminals
(d) The total three phase power flowing into the stator winding.

SOLUTION

(a) Synchronous speed = 120(60)/4 = 1800 rpm
Shaft speed = (1-slip)1800 = (1-0.022)1800 = 1760 rpm

(b) $Z_r = (R_r /s + jX_r) = (0.332/0.022) + j0.464 = 15.09 + j0.464$ ohm

Therefore the total impedance $Z = Z_s + Z_r = (0.641 + j1.106) + (15.09 + j0.464)$ ohm
$= 15.731 + j1.57$
$= 15.809 \angle 5.7^\circ$

Stator current phasor $I = V_{supply} / Z = (266\angle 0^\circ)/(15.809\angle 5.7^\circ) = 16.83\angle -5.7^\circ$

(c) Power factor = $\cos(5.7^\circ) = 0.995$ lagging

(d) Stator input power = $\sqrt{3}(460)16.83(0.995) = 13{,}343$ watts

Problem 11 (Core: Microsystems-ECE3040) Code Number:__________

PN Junction: Reverse-Bias Junction Capacity

The reverse-bias junction capacity of a silicon n^+p step junction has been measured for two applied voltages. The result is 43.4 nF/cm^2 at V_A = -3 V and 27.6 nF/cm^2 at V_A = -10 V

(a) Calculate the built-in potential V_{bi}.

(b) Calculate the substrate doping N_B.

Given are the elementary charge $q = 1.6 \cdot 10^{-19}$ C and the dielectric constant for silicon $\varepsilon = K_S\, \varepsilon_0 = 11.9 \cdot 8.85 \cdot 10^{-14}$ F/cm.

Also given is the depletion layer width of a step junction as a function of the applied bias:

$$W = \sqrt{\frac{2K_s\varepsilon_0}{q}\frac{N_A + N_D}{N_A N_D}\left(V_{bi} - V_A\right)}$$

Problem 11 (Core: Microsystems-ECE3040) Code Number:__________

Solution:

C-V Relationship:

$$\frac{1}{(C_j/A)^2} = \frac{2}{qN_BK_S\varepsilon_0}(V_{bi} - V_A)$$

i.e. plotting $1/(C_j/A)^2$ vs. V_A gives a straight line with a slope proportional to N_B^{-1} and an intersection with the V-axis at V_A=V_{bi}.

Given are 2 points on this straight line:

Point 1: C_j/A = 43.4 nF/cm^2 V_A = - 3 V

Point 2: C_j/A = 27.6 nF/cm^2 V_A = - 10 V

N_B and V_{bi} can be calculated from the resulting two linear equations:

$$y_1 = m(x_0 - x_1)$$
$$y_2 = m(x_0 - x_2) \qquad (1)$$

with x_1 = - 3 V, x_2 = - 10 V, y_1 = 1/(43.4 10^{-9}) cm^4/F^2, and y_2 = 1/(27.6 10^{-9}) cm^4/F^2

Substracting the two linear equations yields

$$m \equiv \frac{2}{qN_BK_S\varepsilon_0} = \frac{y_1 - y_2}{x_2 - x_1} \qquad (2)$$

Inserting (2) in (1) yields

$$x_0 \equiv V_{bi} = x_1 + y_1/m \qquad (3)$$

Using the two given points, one obtains from (2) and (3):

$$m = 1.117\,10^{14}\,\frac{cm^4}{F^2V}$$

$$x_0 = 1.75\,V$$

and the built-in voltage V_{bi} and the doping N_B (using the constants given in the problem):

$$V_{bi} = 1.75\,V$$

$$N_B = 1.06\,10^{17}\,cm^{-3}$$

Problem 12 (Core: Microsystems-ECE3080) Code Number:__________

A silicon wafer has been doped with a donor concentration $N_D = 10^{16}$ cm^{-3}. While maintaining room temperature, the wafer is first illuminated with light for a long time that generates $G_L = 10^{12}$ carriers cm^{-3} per sec uniformly throughout the wafer. At time t = 0 the light is switched off.

(a) If the minority carrier lifetime is $\tau_p = 1\mu$sec, derive an expression for the minority carrier concentration in the wafer as a function of time. Calculate values for all constants in the expression. State all your assumptions.

(b) Qualitatively describe what is happening to the minority and majority carriers during the process described in the problem statement.

The continuity equations for carriers are listed below.

$$\frac{\partial n}{\partial t} = \frac{1}{q} \bullet \frac{\partial J_N}{\partial x} + \left.\frac{\partial n}{\partial t}\right|_{thermal} + \left.\frac{\partial n}{\partial t}\right|_{\substack{other\\processes}}$$

$$\frac{\partial p}{\partial t} = \frac{1}{q} \bullet \frac{\partial J_P}{\partial x} + \left.\frac{\partial p}{\partial t}\right|_{thermal} + \left.\frac{\partial p}{\partial t}\right|_{\substack{other\\processes}}$$

You may assume that:

$$\left.\frac{\partial n}{\partial t}\right|_{thermal} = -\frac{\Delta n}{\tau_n}$$

$$\left.\frac{\partial p}{\partial t}\right|_{thermal} = -\frac{\Delta p}{\tau_p}$$

Problem 12 (Core: Microsystems-ECE3080) Code Number:__________

Solution:

(a) We begin with the continuity equation for holes (minority carriers in n-type wafer):

$$\frac{\partial p}{\partial t} = -\frac{1}{q}\bullet\nabla J_P + \left.\frac{\partial p}{\partial t}\right|_{thermal} + \left.\frac{\partial p}{\partial t}\right|_{\substack{other\\processes}}$$

We can reduce the equation by making the following set of assumptions:

1. The system is one-dimensional.
2. We restrict the analysis to minority carriers.
3. The electric field in the semiconductor is ~ zero.
4. The equilibrium minority carrier concentrations are not a function of position.
5. Low-level injection occurs.
6. The only other process is photogeneration.

Thus:

$$-\frac{1}{q}\bullet\nabla J_P \rightarrow -\frac{1}{q}\frac{\partial J_P}{\partial x}$$

$$J_P = q\mu_p pE - qD_P\frac{\partial p}{\partial x} \approx -qD_P\frac{\partial p}{\partial x}$$

and since: $p = p_0 + \Delta p \rightarrow \frac{\partial p}{\partial x} = \frac{\partial \Delta p}{\partial x}$

We can combine the results to yield:

$$-\frac{1}{q}\bullet\nabla J_P \rightarrow D_P\frac{\partial^2 \Delta p}{\partial x^2}$$

Since we consider low-level injection and we are limited to considering minority carriers, the rate for thermal R-G is approximately:

$$\left.\frac{\partial p}{\partial t}\right|_{thermal} = -\frac{\Delta p}{\tau_p}$$

Since the only other process is photogeneration:

Problem 12 (Core: Microsystems-ECE3080) Code Number:__________

$$\left.\frac{\partial p}{\partial t}\right|_{light} = G_L$$

And finally, since the equilibrium carrier concentration is never a function of time:

$$\frac{\partial p}{\partial t} = \frac{\partial p_0}{\partial t} + \frac{\partial \Delta p}{\partial t} = \frac{\partial \Delta p}{\partial t}$$

As a result, and recalling that the material is n-type, we have the minority carrier diffusion equation:

$$\frac{\partial \Delta p_n}{\partial t} = D_p \frac{\partial^2 \Delta p_n}{\partial x^2} - \frac{\Delta p_n}{\tau_p} + G_L$$

Now consider the two main sets of conditions:

For time t < 0, the wafer is uniformly illuminated and reaches steady-state. Therefore:

$$\frac{\partial \Delta p_n}{\partial t} = 0$$

Since there is no positional variation with minority carrier concentration:

$$D_p \frac{\partial^2 \Delta p_n}{\partial x^2} = 0$$

The final relationship is of the form:

$$0 = -\frac{\Delta p_n}{\tau_p} + G_L$$

Just before the light is turned off, the excess minority carrier concentration is:

$$\Delta p_n = G_L \bullet \tau_p$$

Now, when the light is turned off, the silicon will try to relax to equilibrium conditions and the excess minority carrier concentration equation reduces to a function of time only:

$$\frac{d\Delta p_n}{dt} = -\frac{\Delta p_n}{\tau_p} \quad \rightarrow \quad \Delta p_n(t) = \Delta p_n(t=0) \bullet e^{-t/\tau_p}$$

Problem 12 (Core: Microsystems-ECE3080) Code Number:__________

Using the excess hole concentration just before the light is turned off as the initial condition, and since the problem asks for the total carrier concentration as a function of time we have:

$$p_n(t) = G_L \bullet \tau_p \bullet e^{-t/\tau_p} + p_{n0}$$

Solving for the constants:

$$p_{n0} = \frac{n_i^2}{N_D} = \frac{1x10^{20}}{1x10^{16}} = 1x10^4 \frac{holes}{cm^3}$$

$$\Delta p_n = G_L \bullet \tau_p = 1x10^{12} \bullet 1x10^{-6} = 1x10^6 \frac{holes}{cm^3}$$

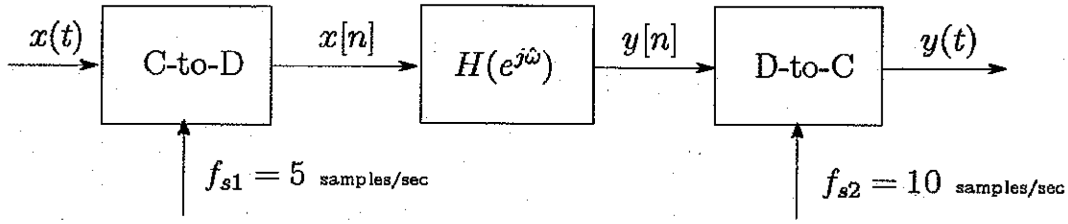
Thus, the final expression is:

$$p_n(t) = 1x10^6 \bullet e^{-t/1x10^{-6}} + 1x10^4 \frac{holes}{cm^3}$$

(b) Light causes the liberation of electron-hole pairs that thermally recombine. Thus the silicon reaches steady-state (not equilibrium) where the excess minority carrier concentration is: $\Delta p_n = G_L \bullet \tau_p$. Once the light is turned-off, the material will attempt to return to equilibrium conditions through the e-h thermal recombination process.

Problem 13 (Core: DSP-ECE2025) **Code Number:**__________

(Note, this problem does not necessarily represent a real-time system.)



As shown in the figure above, a continuous-time signal $x(t) = 8\cos^3(2\pi t)$ is sampled through an ideal continuous-to-discrete converter (labelled as C-to-D in the figure) operating at a rate of 5 samples/second. The resulting discrete-time signal $x[n]$ goes through a linear time invariant (LTI) system. The frequency response of the LTI system is given as

$$H(e^{j\hat{\omega}}) = 1 - \frac{1}{\pi}|\hat{\omega}| \quad \text{for } [-\pi, \pi], \text{ and periodic with period of } 2\pi.$$

The output of the LTI system is denoted by $y[n]$. $y[n]$ then goes through an ideal discrete-to-continuous converter (labelled as D-to-C in the figure) that uses a sampling rate of 10 samples/second, resulting in $y(t)$.

a) [2 pts]- Plot the frequency spectrum of $x(t)$. Label all axis carefully.

b) [2 pts]- Plot the frequency spectrum of $x[n]$. Label all axis carefully.

c) [2 pts]- Plot the frequency spectrum of $y[n]$. Label all axis carefully.

d) [2 pts]- Plot the frequency spectrum of $y(t)$. Label all axis carefully.

e) [2 pts]- Write down $y(t)$ in terms of sum of cosines.

Problem 13 (Core: DSP-ECE2025) **Code Number:**__________

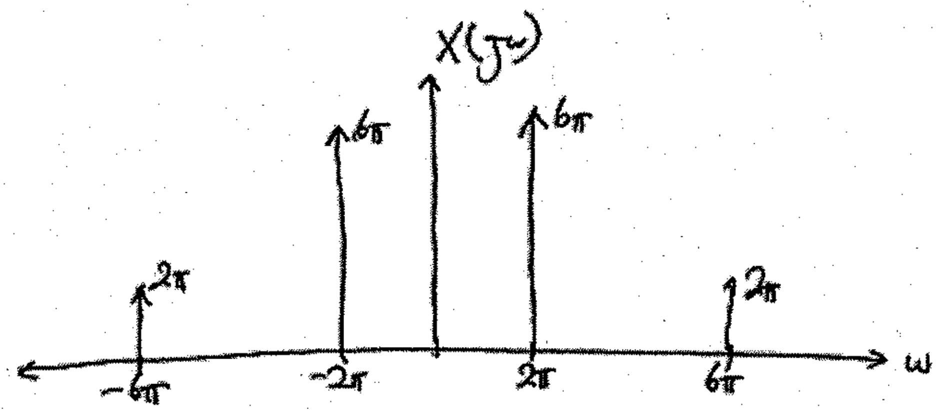
Page #1

Solution:

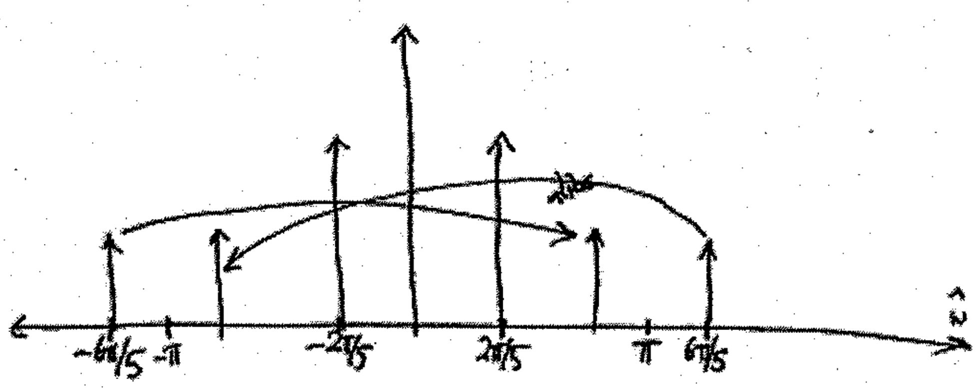
$$8\cos^3(2\pi t) = 8\left(\frac{e^{j2\pi t} + e^{-j2\pi t}}{2}\right)^3$$

$$= e^{j6\pi t} + 3e^{j2\pi t} + 3e^{-j2\pi t} + e^{-j6\pi t}$$

a)

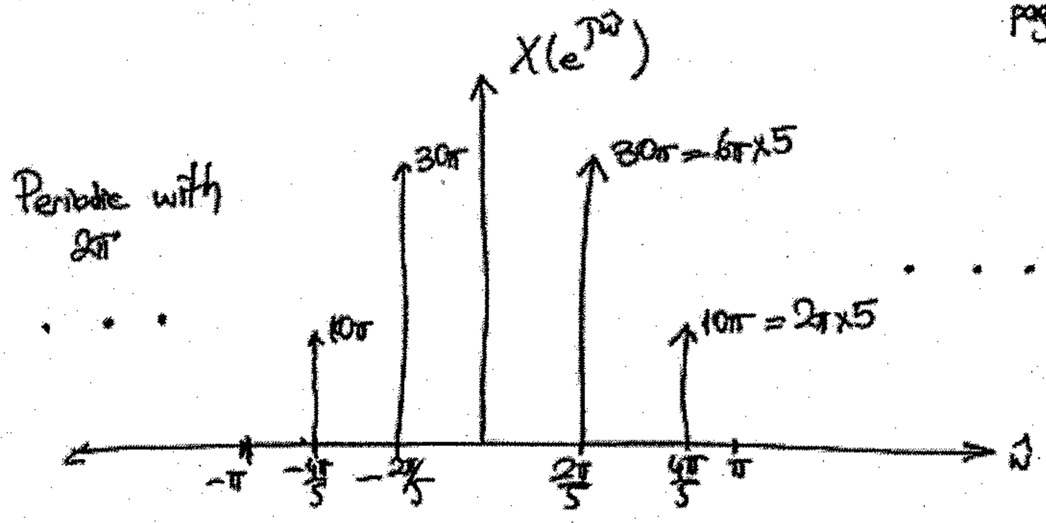


b).



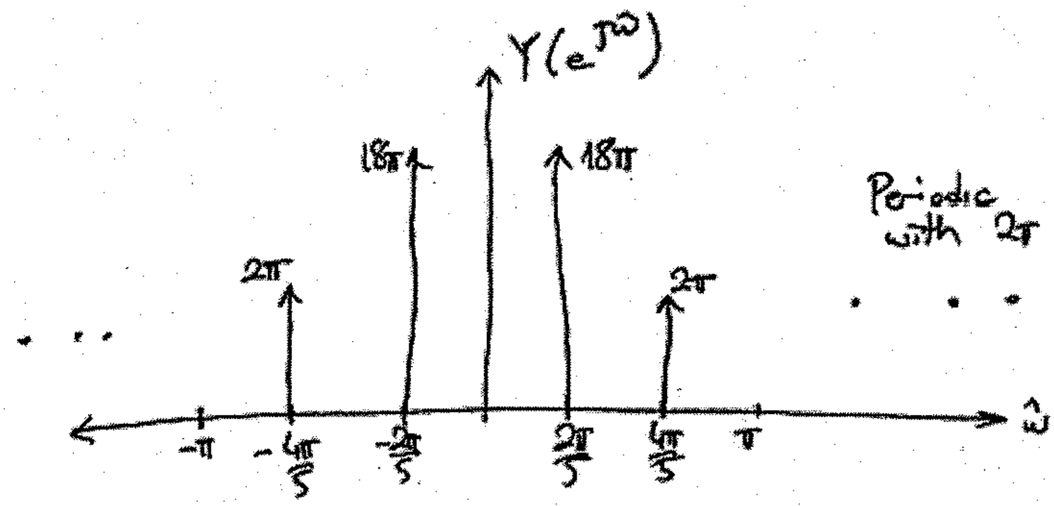
Problem 13 (Core: DSP-ECE2025) **Code Number:**__________

page #2



c) Gain at $\frac{2\pi}{5} = 1 - \frac{1}{\pi} \cdot \frac{2\pi}{5} = 0.6$

Gain at $\frac{4\pi}{5} = 1 - \frac{1}{\pi} \cdot \frac{4\pi}{5} = 0.2$



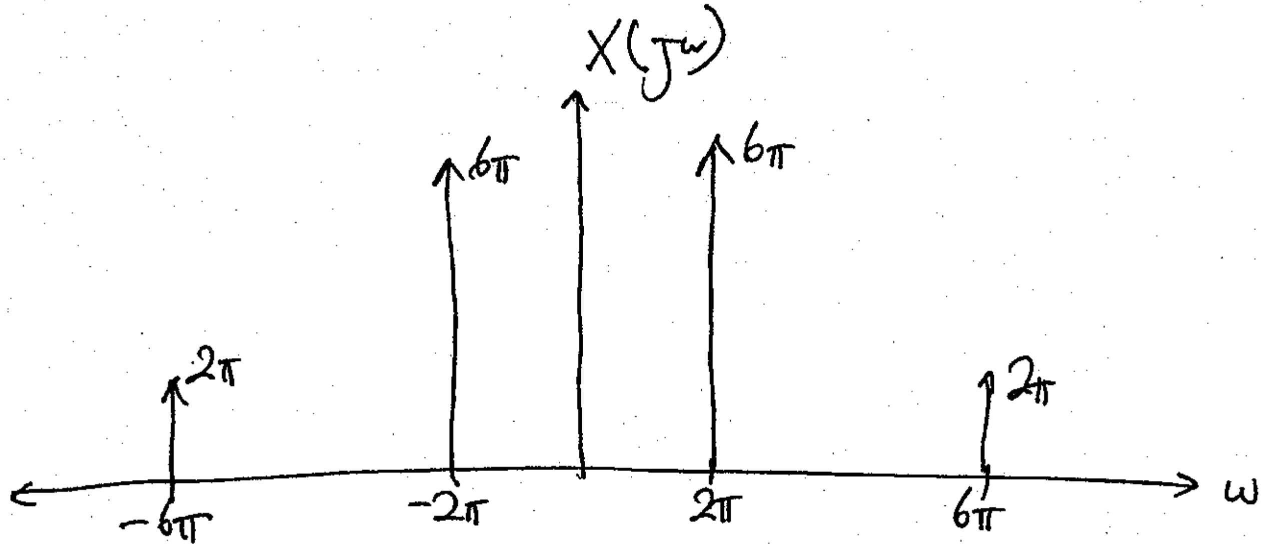
Fall 2008 Prelim Exam
Problem 13 Solution

Solution:

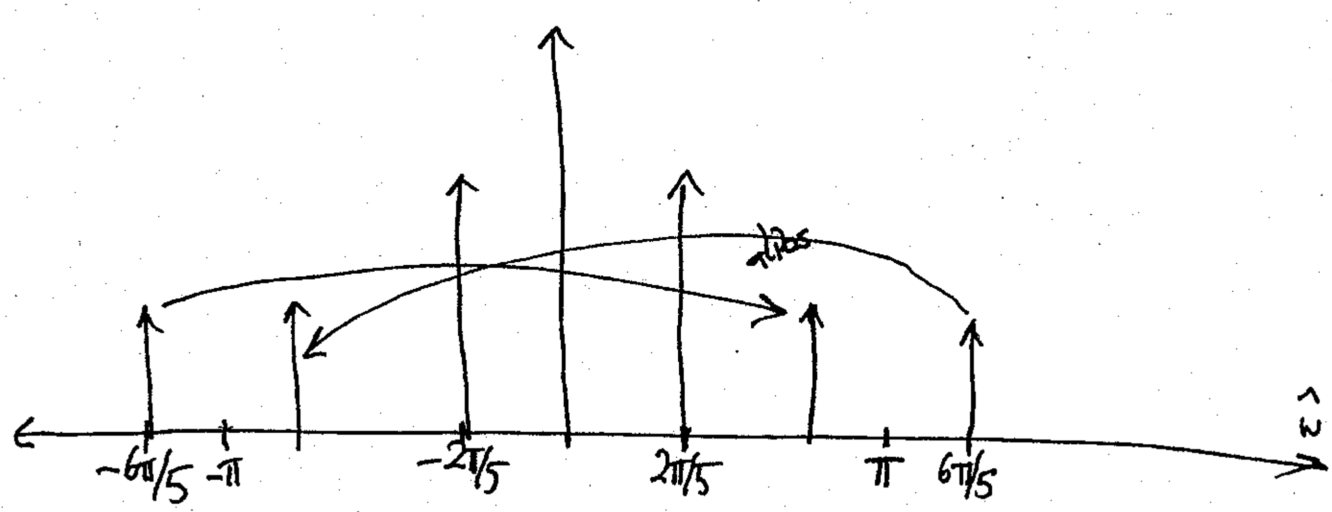
$$8\cos^3(2\pi t) = 8\left(\frac{e^{j2\pi t}+e^{-j2\pi t}}{2}\right)^3$$

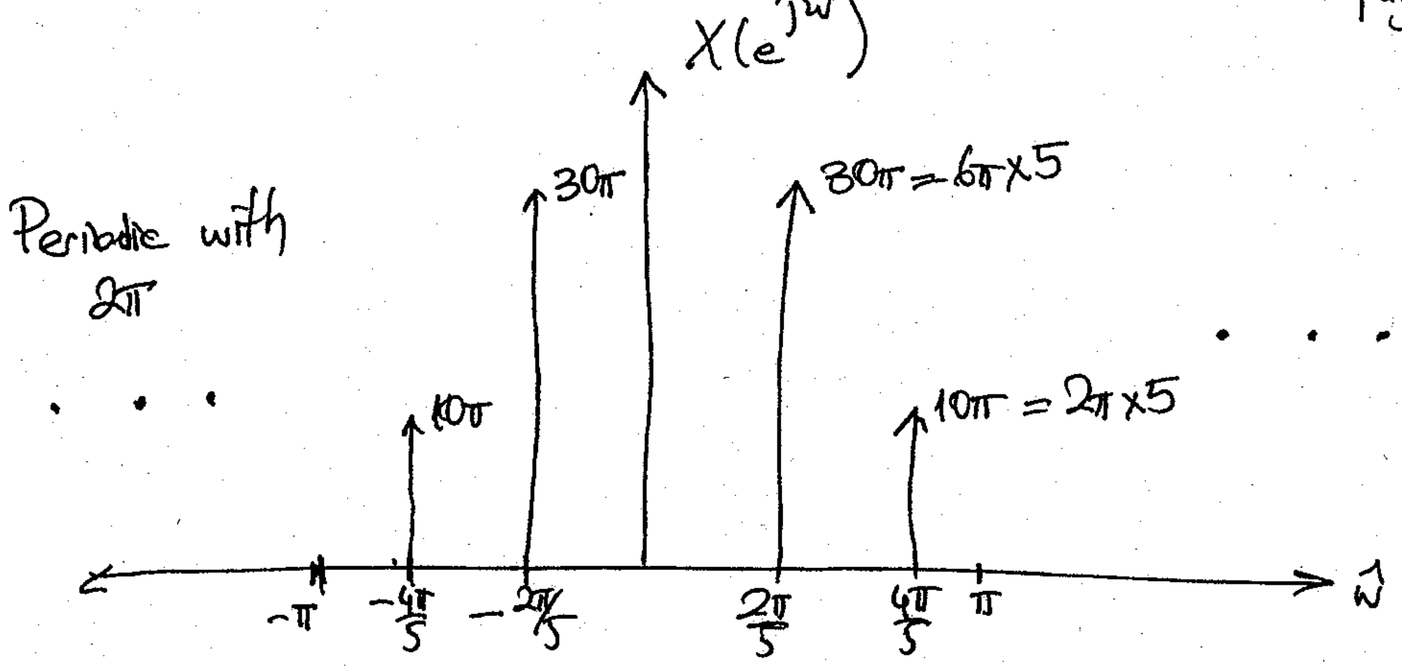
$$= e^{j6\pi t} + 3e^{j2\pi t} + 3e^{-j2\pi t} + e^{-j6\pi t}$$

a)



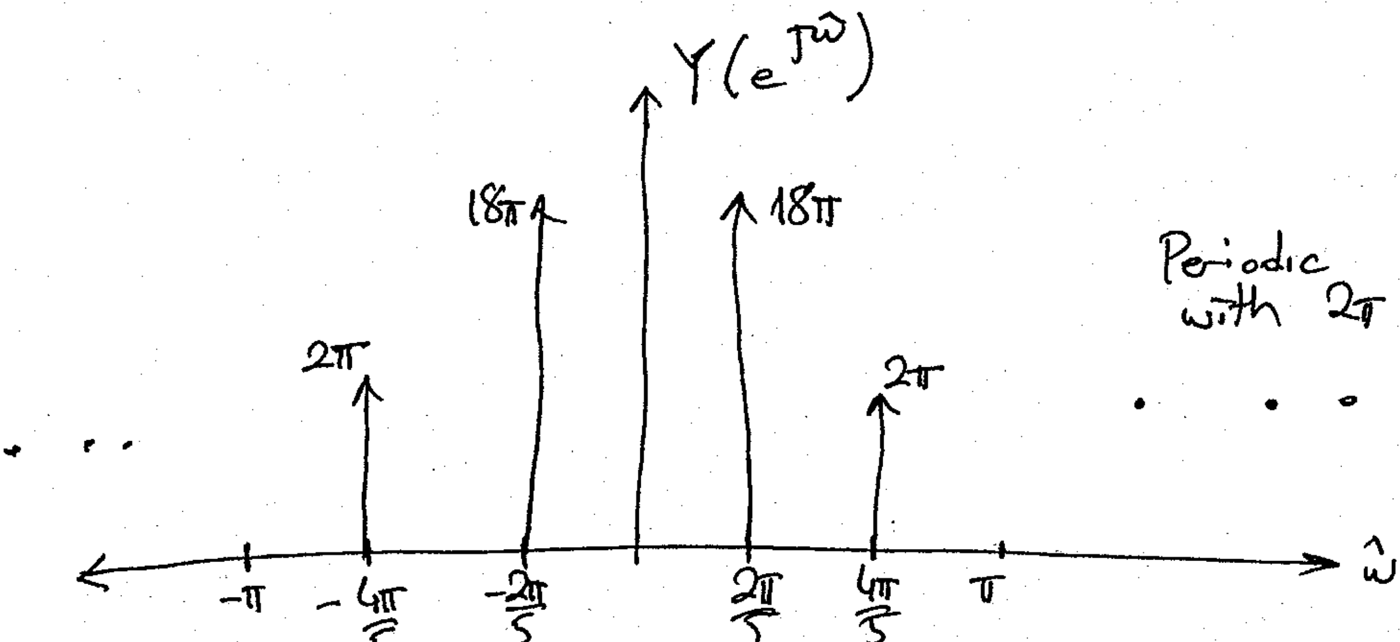
b).



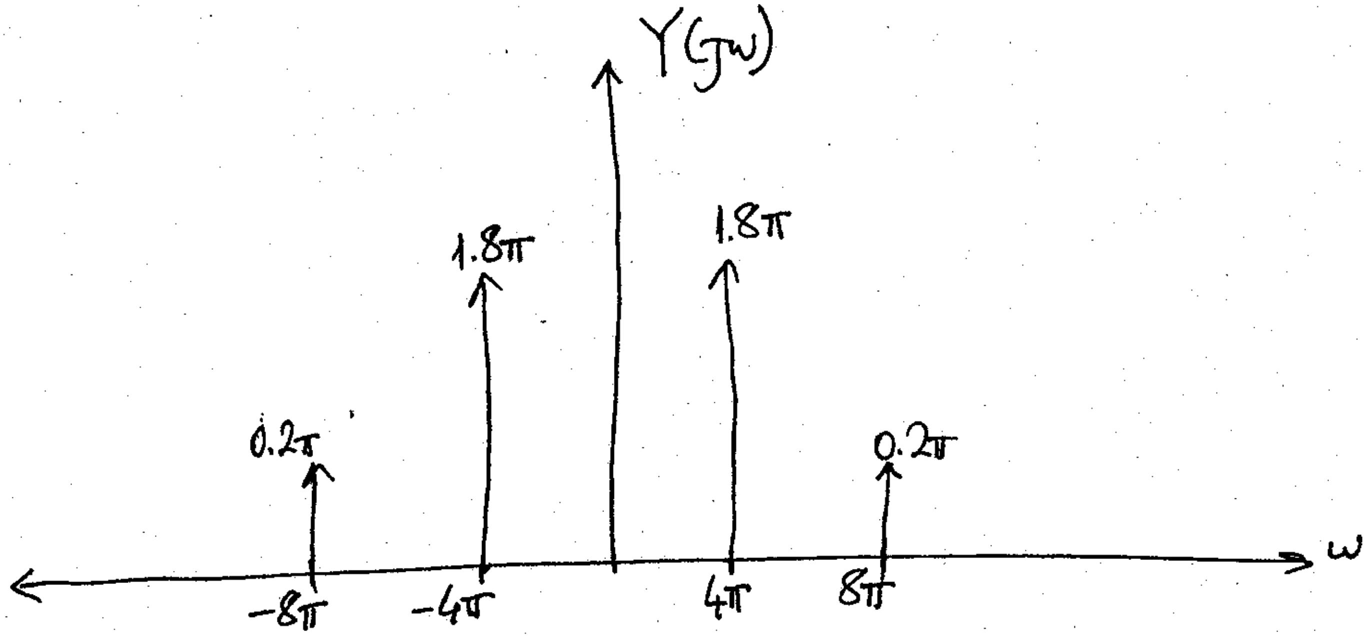


c) Gain at $\frac{2\pi}{5} = 1 - \frac{1}{\pi}\cdot\frac{2\pi}{5} = 0.6$

Gain at $\frac{4\pi}{5} = 1 - \frac{1}{\pi}\cdot\frac{4\pi}{5} = 0.2$



d)



e) $y(t) = 1.8\cos(4\pi t) + 0.2\cos(8\pi t)$

Problem 14 (Core: DSP-ECE3075) Code Number:__________

Suppose $X(t)$ is a continuous-time, zero mean, wide-sense stationary random process with autocorrelation function

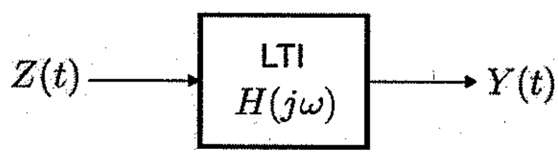
$$R_{XX}(\tau) = \delta(\tau).$$

Set

$$Z(t) = X(t) - X(t-4).$$

(a) Find the autocorrelation function $R_{ZZ}(\tau)$ for $Z(t)$.

(b) Now suppose we pass $Z(t)$ through an LTI system:



with frequency response

$$H(j\omega) = \begin{cases} 2 & 0 \leq |\omega| \leq \pi/8 \\ 0 & \text{otherwise} \end{cases}.$$

What is the power spectral density $\hat{P}_Y(\omega)$ of the output?

(c) What is the power $\mathrm{E}[|Y(t)|^2]$ of the output?

Problem 14 (Core: DSP-ECE3075) Code Number:__________

SOLUTION

(Core-DSP: 3075)
Suppose $X(t)$ is a continuous-time, zero mean, wide-sense stationary random process with autocorrelation function

$$R_{XX}(\tau) = \delta(\tau).$$

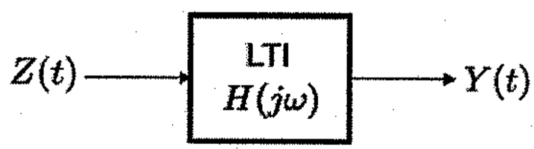
Set

$$Z(t) = X(t) - X(t-4).$$

(a) Find the autocorrelation function $R_{ZZ}(\tau)$ for $Z(t)$.

$$\begin{aligned} R_{ZZ}(\tau) &= \mathrm{E}[Z(t)Z(t+\tau)] \\ &= \mathrm{E}[(X(t) - X(t-4))(X(t+\tau) - X(t-4+\tau) \\ &= R_{XX}(\tau) - R_{XX}(\tau) - R_{XX}(\tau+4) + R_{XX}(\tau) \\ &= -\delta(\tau+4) + 2\delta(\tau) - \delta(\tau-4) \end{aligned}$$

(b) Now suppose we pass $Z(t)$ through an LTI system:



with frequency response

$$H(j\omega) = \begin{cases} 2 & 0 \le |\omega| \le \pi/8 \\ 0 & \text{otherwise} \end{cases}.$$

What is the power spectral density $\hat{P}_Y(\omega)$ of the output? First, the PSD of the input $Z(t)$ is

$$\begin{aligned} \hat{P}_Z(\omega) &= \int_{-\infty}^{\infty} R_{XX}(\tau) e^{-j\tau\omega} \\ &= -e^{-j4\omega} + 2 - e^{j4\omega} \\ &= 2 - 2\cos(4\omega). \end{aligned}$$

The PSD of the output is then

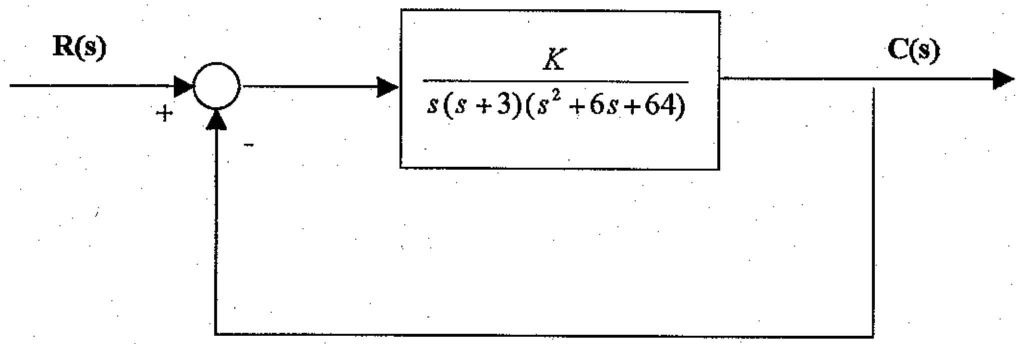
$$\hat{P}_Y(\omega) = |H(j\omega)|^2 \cdot \hat{P}_X(\omega) = \begin{cases} 8(1-\cos(4\omega)) & |\omega| \le \pi/8 \\ 0 & \text{otherwise} \end{cases}$$

(c) What is the power $\mathrm{E}[|Y(t)|^2]$ of the output?

$$\mathrm{E}[|Y(t)|^2] = \frac{1}{2\pi} \int_{-\infty}^{\infty} \hat{P}_Y(\omega) = \frac{1}{2\pi} \int_{-\pi/8}^{\pi/8} 8(1-\cos(4\omega))\, d\omega = 1 - 2/\pi \approx 0.3634$$

Problem 15 (Core: S&C-ECE3085) **Code Number:__________**

Given the system pictured below: (a) Sketch the root locus plot of the system including any relevant information pertaining to the plot (i.e., asymptotes, asymptote angles, and break-away/break-in points), (b) If there is a complex pole in the upper half of the S-plane, determine the departure angle of that pole, and (c) find the value of the gain K for which the system is stable.



Problem 15 (Core: S&C-ECE3085) **Code Number:__________**

Solution:

Step 1:
Open loop Transfer Function:

$$KGH = \frac{K}{s(s+3)(s^2+6s+64)} = \frac{K}{s(s+3)(s+3-j7.4)(s+3+j7.4)}$$

zeros: none
poles: $s = 0, -3, -3+j7.4, -3-j7.4$

Step 2:
Asymptote Intersection Point:

$$\sigma_a = \frac{\sum poles - \sum zeros}{n-m} = \frac{(0-3-3+j7.4-3-j7.4)-(0)}{4} = \frac{-9}{4} = -2.25$$

⇨ asymptotes intersect at =2.25

Step 3:
Asymptote Angles

$$\sigma_a = \frac{(2q+1)180^\circ}{n-m}$$

$$a_0 = \frac{180}{2} = 45^\circ$$

$$a_1 = \frac{3}{4}(180) = 135^\circ$$

$$a_1 = \frac{5}{4}(180) = 225^\circ$$

$$a_1 = \frac{7}{4}(180) = 315^\circ$$

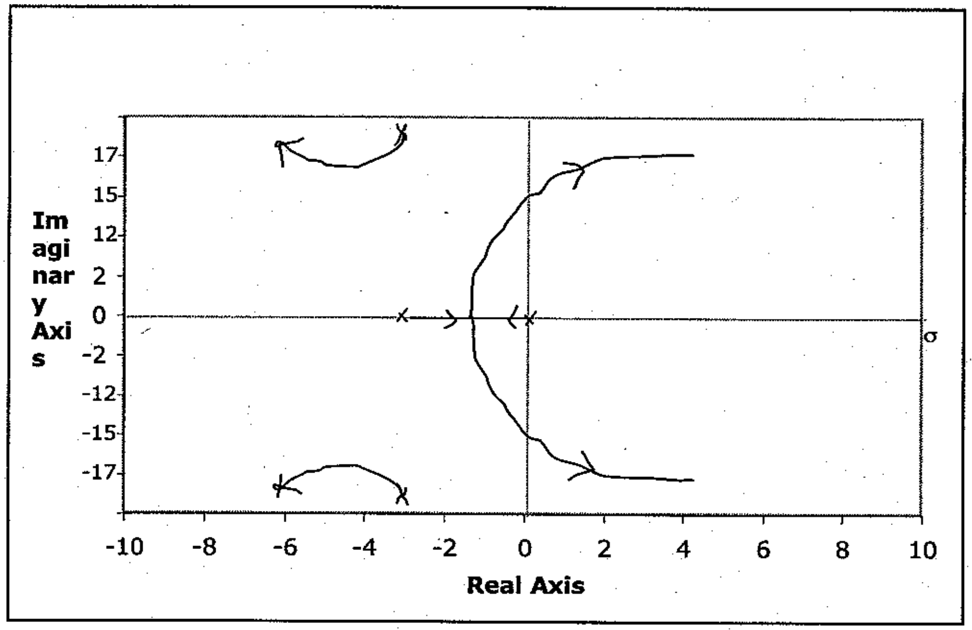
Step 4:
Breakaway Point

$$0 = \frac{1}{s} + \frac{1}{s+3} + \frac{1}{s+3-j7.4} + \frac{1}{s+3+j7.4} \Rightarrow \frac{1}{s} + \frac{1}{s+3} = -\left[\frac{1}{s+3-j7.4} + \frac{1}{s+3+j7.4}\right]$$

$$\frac{2s+3}{s^2+3s} = \frac{2s+6}{s^2+6s+64} \Rightarrow 3s^2+128s+192 = 0$$

$$s = \frac{-128 \pm \sqrt{16384-4(3)(192)}}{2(3)} = \frac{-128 \pm 119}{6} \Rightarrow s = -1.5$$

⇨ Root locus has breakout pt at s=-1.5, Departure angle at $s_1 = -3+j7.4$



(b) Departure angle at $s_1 = -3 + j7.4$

Using Angle Criterion: $\angle KGH = [\angle zerosKGH - \angle polesKGH]|_{s_1=-3+j7.4}$

$\theta_D = \sum$zero angles of KGH - $\sum$other pole angles of KGH + 180

$\theta_D = \phi = [\angle(-3+j7.4) + \angle(-3+j7.4+3) + \angle(-3+j7.4+3+j7.4)] + 180 = -[112+90+90]+180$

$\Rightarrow \theta_D = 112^\circ$ or $\theta_D = 248^\circ$

(c)

$$T(s) = \frac{C(s)}{R(s)} = \frac{K}{s^4 + 9s^3 + 82s^2 + 192s + K}$$

Routh Array is:

s^4:	1	82	K
s^3:	9	192	0
s^2:	b_1	$b2$	0
s^1:	c_1	0	0
s^0:	d_1	0	0

$$b_1 = -\frac{(1)(192) - (82)(8)}{9} = -\frac{192 - 738}{9} = 60.67$$

$$b_2 = -\frac{(1)(0)-(K)(9)}{9} = -\frac{0-9K}{9} = K$$

$$c_1 = -\frac{(9)(K)-(192)(60.67)}{60.67} = -0.148K + 192$$

$$d_1 = -\frac{b_1(0)-c_1(K)}{c_1} = K$$

For stability:

$$K > 0 \quad (1)$$

$$-0.148K + 192 > 0 \quad (2)$$

$$K > 0 \quad (3)$$

Therefore, limits on K for stability is: $0 < K < 1297$

Problem 16 (Core: S&C-ECE3085) Code Number:__________

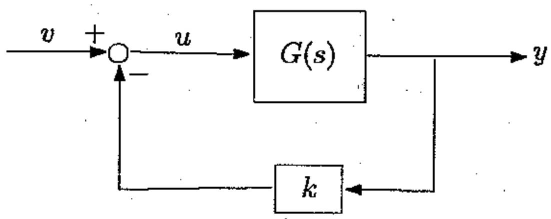
Consider the closed-loop system below, where the transfer function is either

$$G_1(s) = \frac{1}{s^2 + 2s + 5}$$

or

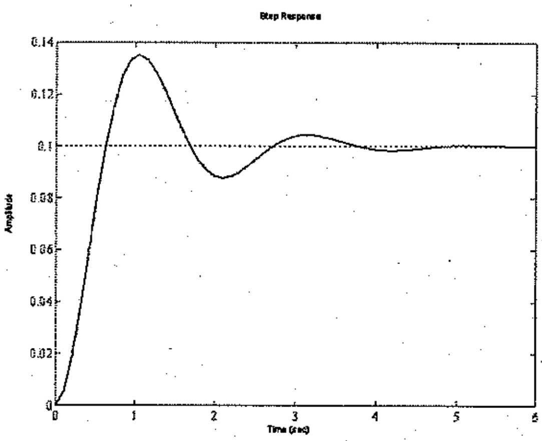
$$G_2(s) = \frac{1}{s^2 + 4s + 5},$$

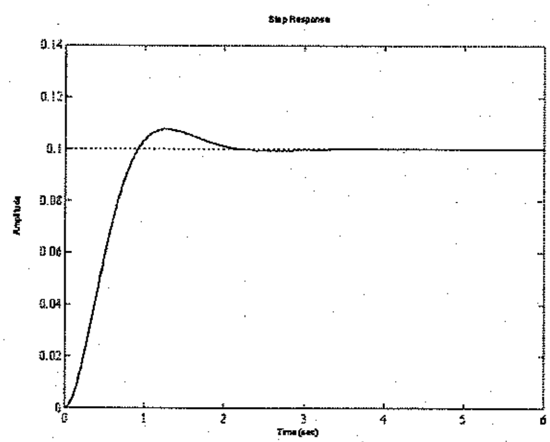
and where $u = -ky + v$ for some constant k.



Now, consider the two step responses below that were produced with a particular choice of k. **Find this k and determine which step response belongs to which closed-loop system** (as defined by G_1 or G_2).

Note, you must motivate your answer carefully - just giving an answer without justification will give no points, even if the answer happens to be correct.





Problem 16 (Core: S&C-ECE3085)   Code Number:__________

SOLUTION

We note that

$$\ddot{y} + \alpha\dot{y} + 5y = -ky + v,$$

i.e.

$$Y(s) = \frac{1}{s^2 + \alpha s + (5+k)} V(s),$$

where α is either 2 or 4.

From the step responses, we see that the limit is well-defined and, as such, we can apply the final value theorem:

$$\lim_{t\to\infty} y(t) = \lim_{s\to 0} s \frac{1}{s^2 + \alpha s + (5+k)} \frac{1}{s} = \frac{1}{5+k}.$$

But, from the plots we see that this limit is in fact equal to 0.1 ($= 1/10$) and hence

$$k = 5.$$

Now, the poles and modes associated with the two systems are:

System 1:

Poles: $s^2 + 2s + 10 = 0 \Rightarrow s = -1 \pm \sqrt{1-10} = -1 \pm 3j$
Mode: $e^{-t}\sin(3t)$

System 2:

Poles: $s^2 + 4s + 10 = 0 \Rightarrow s = -2 \pm \sqrt{4-10} = -2 \pm \sqrt{6}j$
Mode: $e^{-2t}\sin(\sqrt{6}t)$

As a consequence, the oscillations in system 1 decay slower than those in system 2 (e^{-t} vs. e^{-2t}), while the oscillations in system 1 have a higher frequency than those in system 2 (3 vs. $\sqrt{6}$). Based on this, combined with a careful inspection of the two step responses, we see that step response 1 belongs to system 1, and step response 2 belongs to system 2.

Problem 17 (Specialized: Comp Science-CS3210) Code Number:______

Synchronization is an important functionality provided by an operating system to support concurrent operations on shared data structures.

(a) (2) What is a **spin-lock** and how does it differ from a blocking lock, such as a **semaphore**. Under what circumstances might one choose one over the other?

a spin lock busy waits to acquire a lock, as opposed to blocking. If we expect the wait to be relatively short, spin waiting may be preferable to the high overhead to have the OS put the process in a wait queue, even though it burns processor cycles doing absolutely nothing.

(b) (2) What is a **read-write spin-lock**, and when might its use be desirable?

A read-write spin lock allow multiple readers to acquire a lock (i.e enter a critical section to read shared data), but only allows one writer to acquire the lock. It is used when many threads or processes need to access the shared data concurrently.

(c) (6) Using the hardware primitive **result = test-and-set(location)** (which atomically returns the value stored at Memory[location], and then sets Memory[location]=1), provide a pseudo-code or C implementation of a read-write spin-lock. Specifically, provide code for the functions **RW_spin_acquire(lock,mode) and RW_spin_release(lock)**, where mode is either read (R) or write (W), as well as the declaration for the lock data structure. You do not need to ensure fairness, or acquisition priority in your implementation.

```
struct lock {
    int flag =0;        /*spin on this */
    int value=1;        /* 2 is write, 1 is free, if value < 1, |value|+1 */
```

```
                        /* is number of readers */
}
```

Problem 17 (Specialized: Comp Science-CS3210) Code Number:______

```
RW_spin_acquire(lock,mode){
int acquired = 0;
while (!acquired)  {
    while (test-and-set(lock.flag))  {}     /* here is where we spin */
    if (mode == W && lock.value = 1)  {         /* get the lock in write mode */
            lock.value = 2;          /* only one writer */
            acquired = 1;
    }
    else
    if  (mode == R && lock.value <= 1) {
            lock.value -= 1                 /* decrement for each reader */
            acquired = 1;
    }
  lock.flag = 0;
 }

RW_spin_release(lock) {
while (test-and-set(lock.flag))  {}         /* here is where we spin  again*/
if  (lock.value == 2) lock.value = 1 else lock.value += 1;
lock.flag = 0;
}
```

Problem 18 (Specialized: Software Sys- ECE3035) Code Number: _____

Part A: Perform the following standard compiler optimizations on the body of the C subroutine below by writing the optimized version (in C) to the right: strength reduction, loop invariant removal, common subexpression elimination. You may add additional local variables if needed.

```
int foo(int x, int y) {

  int i, d, z = 0;

  for (i=0; i < 5000; i++) {

    z = z + x * i;

    d = x/y + (z+y)*(z+y);

    }

  return z+d;}
```

⇨

```
int foo(int x, int y) {
```

Part B: Consider the following C fragment. Assume a 32-bit integer datapath with a 32-bit memory address space. Assume *int* datatypes are 1 word long and *double* datatypes are 2 words long. In C syntax, "&" is the address operator and "*" is the dereference or indirection operator.

```
int F (int A) {
   int    x = 5;
   double y = 20.0;
   int    *p = &x
   int    Vector[3] = {4, 9, 16};
   double G(int, *double, int V[]);
   y = G(*p, &y, Vector);
   return x+A;}
```

What is the total number of words of storage allocated in F's activation frame for F's input and output parameters and local variables?

____**words for F's I/O and local variables.**

What is the total number of words of storage allocated in G's activation frame for G's input and output parameters?

____**words for G's I/O and local variables.**

Part A: Perform the following standard compiler optimizations on the body of the C subroutine below by writing the optimized version (in C) to the right: strength reduction, loop invariant removal, common subexpression elimination. You may add additional local variables if needed.

```
int foo(int x, int y) {
  int i, d, z = 0;
  for (i=0; i < 5000; i++) {
    z = z + x * i;
    d = x/y + (z+y)*(z+y);
    }
  return z+d;}
```

⇨

```
int foo(int x, int y) {
  int a, b=0, i, d, z = 0;
  int r = x/y;
  for (i=0; i < 5000; i++) {
    z = z + b;
    b = b + x;
    a = z+y;
    d = r + a*a;
    }
  return z+d;}
```

Part B: Consider the following C fragment. Assume a 32-bit integer datapath with a 32-bit memory address space. Assume *int* datatypes are 1 word long and *double* datatypes are 2 words long. In C syntax, "&" is the address operator and "*" is the dereference or indirection operator.

```
int F (int A) {
   int    x = 5;
   double y = 20.0;
   int    *p = &x
   int    Vector[3] = {4, 9, 16};
   double G(int, *double, int V[]);
   y = G(*p, &y, Vector);
   return x+A;}
```

What is the total number of words of storage allocated in F's activation frame for F's input and output parameters and local variables?

__________9__________ **words for F's I/O and local variables.**

What is the total number of words of storage allocated in G's activation frame for G's input and output parameters?

__________5__________ **words for G's I/O parameters.**

Problem 19 (Specialized: Telecom-ECE3076) Code Number:__________

What is the primary advantage of a packet store-and-forward network?

What is the primary advantage of a circuit-switched network?

Which type of network (packet or circuit-switched) is the Internet?

How do Internet routers build a Forwarding Table that is used 10 decide what outbound network link is best for forwarding a particular IP datagram?

How do Ethernet switches build a Forwarding Table that is used to decide what outbound network link is best for forwarding a particular Ethernet frame?

How does your PC determine the 32-bit IP address for "www.nationalcarbuy.com"?

Once the IP address is known, how does your PC (on an Ethernet LAN) determine what destination Ethernet address to use?

What does Flow Control do?

How does TCP implement Flow Control?

How does TCP implement Congestion Control?

Problem 19 (Specialized: Telecom-ECE3076) Code Number:__________

ECE3076 Fall 2008 Prelim Question Answers

What is the primary advantage of a packet store-and-forward network?

Statistical multiplexing allows many users to share the available bandwidth.

What is the primary advantage of a circuit-switched network?

Users can be guaranteed resources (minimum bandwidth, maximum delay, ...)

Which type of network (packet or circuit-switched) is the Internet?

Packet store and forward.

How do Internet routers build a Forwarding Table that is used to decide what outbound network link is best for forwarding a particular IP datagram?

They communicate with each other, using a routing protocol, so that they find out the minimum cost routes to other areas of the Internet (address space).

How do Ethernet switches build a Forwarding Table that is used to decide what outbound network link is best for forwarding a particular Ethernet frame?

When Ethernet frames are received, the switch remembers the source address and which link the frame came from. Frames to that address are then sent out over that link.

How does your PC determine the 32-bit IP address for "www.nationalcarbuy.com"?

It sends a UDP request to the local DNS server for a recursion-requested lookup.

Once the IP address is known, how does your PC (on an Ethernet LAN) determine what destination Ethernet address to use?

It sends an Ethernet ARP broadcast frame asking "Who has IP address ...". The local router will answer if the IP address is not on the local network.

What does Flow Control do?

It stops the sender from sending too much data and causing the receiver's buffer to overflow.

How does TCP implement Flow Control?

Each byte in the stream has a sequence number. Each received TCP header has an ACK number (sequence number) and Window size. Bytes with sequence numbers greater than or equal ACK + Window can not be sent.

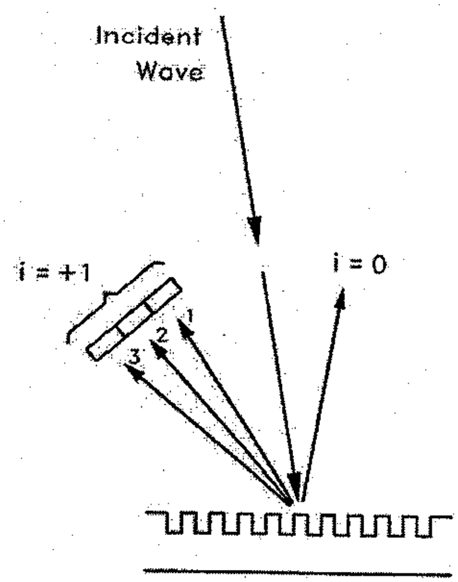
How does TCP implement Congestion Control?

The sender has a Congestion Window (CongWin) that becomes smaller whenever a packet has to be retransmitted, then grows slowly afterward. Only CongWin bytes can be sent without acknowledgement, so the sending rate decreases when CongWin decreases.

Problem 20 (Specialized: Optics-ECE4500) Code Number:__________

Waveguide Grating Spectrometer - Wavelength Division Demultiplexing

A waveguide reflection grating spectrometer is used for wavelength division demultiplexing. Three telecommunication signal waves from the waveguide are incident in air upon the metallic grating at an angle of 15° counter-clockwise from the normal as shown in figure. The three waves have frequencies of 195.5 $TeraHz$, 196.0 $TeraHz$, and 196.5 $TeraHz$ which are frequencies on the ITU standard grid. The three wavelengths are dispersed by the grating into +1-order backward-diffracted waves as shown in the figure. The grating is designated as having 800 *lines per mm*. An array of photodetectors is oriented normal to the 196.0 $TeraHz$ (no. 2) beam as shown.



1) Calculate, showing all work, the wavelengths in nanometers of the waves numbered 1, 2, and 3 in the figure.

2) Calculate, showing all work, the backward-diffracted wave angles (measured counter-clockwise from the normal) in degrees for these waves.

3) The photodetector for the no. 2 beam is placed 10.0 mm away from the point of incidence upon grating. Calculate, showing all work, the ideal center-to-center distance that is needed between the photodetectors so that each beam is incident exactly at the center of its corresponding photodetector.

Problem 20 (Specialized: Optics-ECE4500) Code Number:__________

Express wavelengths accurately to six significant figures. Express the angles in degrees accurately to within $\pm 0.001°$. Express photodetector the center-to-center distances in microns accurately to five significant figures. Put your answers in the spaces provided.

Wave No.	Wavelength (nm)	Angle of Diffraction (°) (CCW from normal)
1	________	________
2	________	________
3	________	________

Center-to-center distance between photodetectors for beams 1 and 2

= ______________ μm

Center-to-center distance between photodetectors for beams 2 and 3

= ______________ μm

Problem 20 (Specialized: Optics-ECE4500) Code Number:__________

Waveguide Grating Spectrometer - Wavelength Division Demultiplexing

$\theta' = +15°$

$n_1 = 1.000$

$\Lambda = 1/800\, lines/mm = 0.00125\, mm = 1.25\, \mu m$

$D = 10.0\, mm$

$f_3 = 195.5 \times 10^{12}\, Hz \qquad \lambda_3 = c/f_3 = 1533.465253\, nm$

$f_2 = 196.0 \times 10^{12}\, Hz \qquad \lambda_2 = c/f_2 = 1529.553357\, nm$

$f_1 = 196.5 \times 10^{12}\, Hz \qquad \lambda_1 = c/f_1 = 1525.661364\, nm$

Grating equation for backward-diffracted orders

$$sin\,\theta' + sin\,\theta'_i = \frac{i\lambda}{n_1\Lambda}$$

For $i = 1$ and $n_1 = 1$

$$\theta'_1 = sin^{-1}\left[\frac{\lambda}{\Lambda} - sin\,\theta'\right]$$

$(\theta'_1)_3 = 75.45556295°$

$(\theta'_1)_2 = 74.75791282°$

$(\theta'_1)_1 = 74.09346288°$

Distance between photodetectors nos. 3 and 2

$$= D \cdot tan\{\Delta\,[(\theta'_1)_3 - (\theta'_1)_2]\} = 121.76893592\, \mu m$$

Distance between photodetectors nos. 2 and 1

$$= D \cdot tan\{\Delta\,[(\theta'_1)_2 - (\theta'_1)_1]\} = 115.97359139\, \mu m$$

Problem 21 (Specialized: Optics-ECE4501) Code Number:__________

Prelim Problem – ECE4501

A point-to-point fiber communication link employs a laser transmitter having an average emitted power, $P_t = 10$ mW, a PIN-based receiver having sensitivity $P_{rec} = -30$ dBm at the required BER. The single-mode fiber link will consist of two end-to-end joined fiber segments. The first fiber has loss coefficient, $\alpha_1 = 0.25$ dB/km, length L_1 (to be found), and dispersion $D = 5$ ps/nm-km. The second fiber has loss coefficient, $\alpha_2 = 0.40$ dB/km, length L_2 (to be found), and dispersion $D = -10$ ps/nm-km. The total length between source and receiver is $L = 150$ km. No other loss sources are present.

a. Write down the power budget equation that includes the transmitter power and receiver sensitivity (both in dBm), the fiber losses (including the unknown lengths, L_1 and L_2), and an assumed maximum dispersion penalty of 1 dB.

10mW ⟶ 10dBm

have $10\text{dBm} = -30\text{dBm} + 0.25L_1\text{dB} + 0.40L_2\text{dB} + 1\text{dB}$

If the link were to be constructed using Fiber 1 alone, the dispersion-limited transmission distance would be $L_{max,D1} = 140.0$ km. If the link were to be constructed using Fiber 2 alone, the dispersion-limited transmission distance would be $L_{max,D2} = 70.0$ km. For this link, the dispersion-limited distance corresponds to an effective loss penalty of 1 dB, which is the maximum allowable.

b. Using the loss budget equation and assuming a 1 dB disperson penalty, evaluate L_1 and L_2.

$0.25L_1 + 0.40(L - L_1) + 1 = 40$ where $L = 150$km

$\Rightarrow L_1 = 140$ km

$L_2 = 10$km

c. With the lengths as found in part b, find the dispersion-limited transmission distance for the total link. With this result, is the link viable? Explain.

Path-average dispersion $= D_{avg} = \dfrac{D_1L_1 + D_2L_2}{L_1+L_2} = \dfrac{140(5) - 10(-10)}{150}$

$= 4$ ps/nm-km

$L_{max,D} = 140\text{km} \times \frac{5}{4} = \underline{175\text{km}}$

Link is viable as $L < 175$km, and so the dispersion penalty is less than 1dB

Problem 22 (Specialized: Microsystems-ECE4752) Code Number:_____

A boron diffusion into a 1 ohm-cm n-type wafer results in a Gaussian profile. The diffusion process was 20 minutes at 1000 C in a nitrogen environment.

(A) What is the background doping concentration in the wafer?

(B) What is the diffusion coefficient for boron at 1000 C?

(C) What is the junction depth?

Constants: q=1.6E-19 Coulombs, D_o=0.76 cm^2/sec, E_a=3.46 eV, k=8.61E-5 eV/K, μ_n=1350 cm^2/V-sec, μ_p=480 cm^2/V-sec, C_s=1E18 cm^{-2}, g=9.8 m/sec^2

ECE4752 Preliminary Examination Problem

A boron diffusion into a 1 ohm-cm n-type wafer results in a Gaussian profile. The diffusion process was 20 minutes at 1000 C in a nitrogen environment.

(A) What is the background concentration in the wafer?

(B) What is the diffusion coefficient for boron at 1000 C?

(C) What is the junction depth?

A) $$\rho = \frac{1}{\sigma} = \frac{1}{q(\mu_n n + \mu_p p)} \Rightarrow n = \frac{1}{q\mu_n \rho}$$

$$n = \frac{1}{(1.6\times10^{-19}c)(1350\ cm^2/V\text{-}s)(1\ \Omega\text{-}cm)} = 4.63\times10^{15}\ cm^{-3}$$

B) $$D = D_o e^{-E_a/kT} = (0.76\ cm^2/sec)\, e^{-3.46/(8.61\times10^{-5})(1273)}$$

$$D = 1.484\times10^{-14}\ cm^2/sec$$

C) $$x_j^2 = -4Dt \ln\left(\frac{C_B}{C_s}\sqrt{\pi D t}\right)$$

$$= -4(1.484\times10^{-14})(1200\ sec)\ln\left(\frac{4.63\times10^{15}}{1\times10^{18}}\sqrt{\pi(1.484\times10^{-14})(1200)}\right)$$

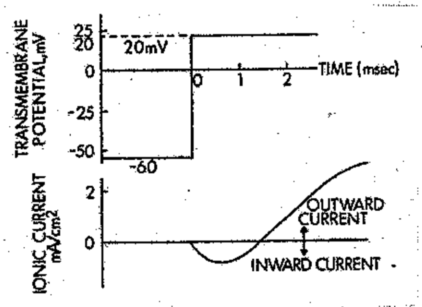
$$x_j = 0.35\ \mu m$$

Problem 23 (Specialized: Bio Eng-ECE4784) Code Number:__________

a) First sketch the full circuit model for the plasma membrane of an axon. Explain the physiological origin of each of the components.

b) Write the differential equation for the total membrane current associated with the model.

c) Based on this model and looking at the curves from a voltage clamp experiment presented below, what is not right about the curve for the ionic current.



Problem 24 (Specialized: Bio Eng-ECE4781) Code Number:__________

Describe three different electrode problems that can occur when measuring the human EEG and ways to prevent each problem from producing an artifact.

Acceptable Answers:

1. The patient is usually not grounded, so EM noise is a huge problem. Twist the electrode wires and move the first stage amplifier as close as possible to the patient. High and low frequency noise can be band-pass filtered, but 60hz noise is close to the frequencies of interest. A 60hz notch filter can produce significant phase shifts at lower frequencies. It is better to use digital filtering as much as possible.

2. It is very common for the EEG paste to begin drying during prolonged EEG measurements, e.g. during surgery. If this happens, the EEG amplitudes will decrease. It is important to periodically check each electrode impedance during prolonged measurements.

3. It is also very common for EEG electrodes to pull away from the scalp, which reduces the area of contact. Again, the EEG signal will appear to decay. Pushing on each electrode at periodic intervals will help prevent this problem. Also, the electrode wires can be clipped to the patient's garment.

Other answers will be acceptable, e.g. electrode polarization can be reduced by using a high input impedance amplifier that reduces the current passing through the electrode, and common mode noise can be reduced by using a Differential Amplifier with high Common Mode Rejection.

Problem 25 (Specialized: Bio Eng-ECE4782) Code Number:__________

Describe the pros and cons of using multiple pulse stimuli as advocated by Volterra to reveal time-dependant nonlinearities of a biological system.

Answer:
The Volterra method for analyzing a time-invariant nonlinear system uses Volterra kernels to quantify how one pulse response can change the responses to other future pulses. For example, during the absolute refractory period of a neuron, the neuron cannot respond to a second pulse stimulus. The main problem with the Volterra method is that it takes too long to test a biological system with all of the possible spacings between two pulses. Testing the system with three or more pulses is even worse. On the other hand, the Volterra kernels are easy to interpret, e.g. the third-order kernel quantifies the system nonlinearities associated with three pulses. Students will receive extra points for remembering and writing the first few terms of the Volterra expansion.