Write your four digit code here .... ☐ ☐ ☐ ☐

NEW MEXICO STATE UNIVERSITY
THE KLIPSCH SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING
Ph.D. QUALIFYING EXAMINATION

AUGUST 17, 2015
9:00 AM–1:00 PM
CLOSED BOOK (except CRC Standard Mathematical Tables and Formulae)
ONLY APPROVED SCIENTIFIC CALCULATORS ALLOWED
BLANK SCRATCH PAPER ALLOWED

Exam Instructions:

1. **Write the last four digits of your Banner ID number of the top of every page.**
2. **Work six (6) problems from the three (3) areas of specialization selected at the time of registration. Do not work more than two (2) problems in any one area.**
   A. Circuits and Electronics
   B. Communications
   C. Computers
   D. Control Systems
   E. Digital Signal Processing
   F. Electric Energy Systems
   G. Electromagnetics
   H. Photonics
3. **Check the boxes below indicating which six (6) problems you want graded. (You must work two (2) problems each from each of the three (3) areas you specified at the time of registration)**

	1	2	3	4	5	6
A. Circuits and Electronics	☐	☐	☐	■	■	■
B. Communications............	☐	☐	☐	■	■	■
C. Computers.....................	☐	☐	☐	■	■	■
D. Control Systems............	☐	☐	☐	■	■	■
E. Digital Signal Processing	☐	☐	☐	■	■	■
F. Electric Energy Systems	☐	☐	☐	■	■	■
G. Electromagnetics...........	☐	☐	☐	■	■	■
H. Photonics......................	☐	☐	☐	■	■	■

Design a fully differential telescopic operational amplifier for a minimum gain-bandwidth product GB_{min}=50MHz, and minimum slew rate SR_{min}=50V/µs and a load capacitance C_L=20pF. Assume following 0.13µm CMOS technology parameters: kn_n=340µA/V^2, Vth_n=0.40V , kn_p=50µA/V^2, Vth_p=0.40V, λ_n=λ_p=0.25V^{-1}, C_{ox}=10fF/µm^2 C_{gd}=1fF/µm and a capacitive load C_L=10pF (kn=µC_{ox}/2). Determine all transistor sizes *including those in the biasing branch and in the common mode feddback network*. Assume a single supply voltage V_{DD}=1.2V The design requires to determine bias currents, W/L sizes for all transistors. Estimate the dominant and high frequency poles and the open loop DC gain. Calculate the static power dissipation of your design input common mode range and output swing Determine the output impedance and bandwidth of a unity gain buffer (Av=1) and b) a gain ten (Av=10v/v) inverting amplifiers implemented using your op-amp.

A (Problem 2) Circuits and Electronics

Design a Miller (two stage) single-ended operational amplifier for a minimum gain-bandwidth product GB_{min}=100MHz, minimum slew rate SR_{min}=20V/µs and a load capacitance C_L=20pF. Assume following 0.18µm CMOS technology technology parameters: kn_n=170µA/V^2, Vth_n=0.45V, kn_p=25uA/V^2, Vth_p=0.45V, $\lambda_n=\lambda_p$=0.1V^{-1}, C_{ox}=4.2fF/µm^2 (kn=µC_{ox}/2), C_{gd}=1fF/µm. Show the scheme of the circuit. Determine all transistor sizes including those in the biasing branch. Assume a single supply voltage V_{DD}=1.8V. Estimate the open loop DC gain and the high frequency pole. The design requires to determine bias currents, W/L size all transistors, and to determine the value of the compensation capacitance Cc and the compensation resistance Rc.

Design a cascode amplifier with minimum gain bandwidth product GB=100MHz in 0.13μm CMOS technology with kn_n=340μA/V^2, Vth_n=0.40V, kn_p=50μA/V^2, Vth_p=0.40V, $\lambda_n=\lambda_p$=0.25V^{-1}, C_{ox}=10fF/μm^2 , C_{gd}=1fF/μm and a capacitive load C_L=10pF (kn=μC_{ox}/2), ν=0.4$v^{1/2}$. Use an NMOS input transistor. Determine biasing currents, cascode voltages (VCP, VCN) all transistor sizes including those in the biasing branch. Assume a single supply voltage V_{DD}=1.2V, a load capacitance C_L=10pF. Assume the source resistance is 20kΩ. Estimate the open loop DC gain, the bandwidth , the common mode input range, the peak to peak output swing the dominant and the high freqency poles. For your calculations of the high frequency poles take only into account the Cgs parasitic capacitances of the cascode transistors multiplied by a factor 2.

B (Problem 1) Communications

The random variable pair $(X,\ Y)$ has a joint pdf

$$f_{X,Y}(x,y) = \begin{cases} k & 0 < y \leq x < 1 \\ 0 & \text{otherwise} \end{cases}$$

(i) Find the constant k.

(ii) Define a new random variable $Z = 2X + 3$. Find the pdf of the new random variable Z.

(iii) Define a random vector $\mathbf{V} = [X\ \ Y\ \ Z]^T$, where $[\cdot]^T$ denotes transpose. Determine the correlation matrix $E[\mathbf{V}\mathbf{V}^T]$.

B (Problem 2) Communications

(i) A binary transmission channel introduces bit errors so that each bit can be in error with a probability of 0.15. (a) Assume that 5 bits are transmitted. What is the probability that there will be 2 bit errors? (b) Suppose 100 bits are transmitted. Use the central limit theorem to estimate the probability that there will be 20 or fewer errors. The following Q values are provided for your convenience: Q(1.0) = 0.159, Q(1.2) = 0.115, Q(1.4) = 0.0808, Q(1.6) = 0.0548.

(ii) Let U_n be a sequence of iid zero-mean, unit variance Gaussian random variables. Consider a new sequence

$$X_n = \frac{1}{2}(U_n + U_{n-1})$$

Justify if this sequence converges in the mean-square sense.

B (Problem 3) Communications

Let $X(t)$ and $Y(t)$ be independent WSS random processes with zero means and the same autocorrelation function $\exp(-|\tau|)$. Let $Z(t)$ be defined by

$$Z(t) = aX(t) + bY(t)$$

where a and b are constants.

(i) Justify if $Z(t)$ is also WSS.

(ii) If $X(t)$ and $Y(t)$ are jointly Gaussian zero-mean random processes, find the pdf of $Z(t)$.

(iii) Consider the random process $Z(t)$. Suppose the average low pass power below the frequency of 100 Hz is 80 units. Find the value of the constant b if it is given that $a = 1$.

(iv) Discuss if the process $Z(t)$ has a mean-square derivative.

In an election, exit polls show party *A* winning 52% of the vote, and party *B* 48%, with a sample size of 2000. Can one predict party *A* wins the election with 90% confidence level? How about at 97% level? (Hint: winning the election, of course, means getting more than 50% of the vote. $z_{0.9} = 1.282$, $z_{0.97} = 1.881$)

Suppose you are using Monte Carlo simulation to compute π. You can do it by estimating the proportion of random sample points that fall within a circle inscribed in an outer square (the theoretical value of this proportion is π/4). In order to achieve an accuracy of 10^-3 at 90% confidence level, how many sample points do you need to take? (normal quantile $z_{0.95} = 1.645$)

Consider a queueing system that can hold at most 4 customers. The arrival and service times are exponentially distributed. The arrival rate is 1 customer per sec. The serve rate is 5 - n customers per second, where n is the number of customers in the system. Find the average response time and the blocking probability of system.

D (Problem 1) Control Systems

Given the discrete-time system

$$x(t+1) = \begin{bmatrix} \frac{1}{2} & \frac{-5}{2} \\ \frac{1}{2} & \frac{-1}{2} \end{bmatrix} x(t) + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u(t)$$
$$y(t) = \begin{bmatrix} 1 & 0 \end{bmatrix} x(t)$$

Find the state transition matrix, $\Phi(k, \ell)$, for this system.

D (Problem 2) Control Systems

Given the discrete-time system

$$x(t+1) = \begin{bmatrix} -1 & -3 \\ \frac{3}{2} & \frac{7}{2} \end{bmatrix} x\,(t) + \begin{bmatrix} -1 \\ 1 \end{bmatrix} u\,(t)$$
$$y\,(t) = \begin{bmatrix} 1 & 2 \end{bmatrix} x\,(t)$$

Determine if this system is stabilizable and if it is detectable.

D (Problem 3) Control Systems

Given the discrete-time system

$$x(t+1) = \begin{bmatrix} 0 & 0 \\ 1 & -2 \end{bmatrix} x(t) + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u(t)$$
$$y(t) = \begin{bmatrix} 0 & 1 \end{bmatrix} x(t)$$

Find an output-feedback controller such that the closed-loop system tracks a constant input, and all the closed-loop eigenvalues are at the origin.

E (Problem 1) Digital Signal Processing

You wish to analyze a discrete-time signal $x[n]$, $n = 0, \ldots, P$ which has been sampled at sampling rate $\Omega_s = 10,000$ Hz.

(a) What is the minimum length N_{DFT} of the DFT (Discrete Fourier Transform) which will yield a frequency resolution of **at least** 4 Hz?

(b) If you will be using the FFT (Fast Fourier Transform), which gains computational savings for $N_{FFT} = 2^{\nu}$, what is the minimum length FFT which will yield a frequency resolution of **at least** 4 Hz?

(c) For this part, assume that the value of N_{DFT} you found in part (a) is **less** than the length of signal $x[n]$, i.e., $N_{DFT} < P$. Under what conditions would you expect the length-N_{DFT} DFT to be a good representation of the frequency content in signal $x[n]$?

(d) For this part, assume that the value of N_{DFT} you found in part (a) is **less** than the length of signal $x[n]$, i.e., $N_{DFT} < P$. How could you change N_{DFT} to result in a frequency resolution even better than 4 Hz? If this is not possible, so state and justify your answer.

(e) For this part, assume that the value of N_{DFT} you found in part (a) is **greater** than the length of the signal $x[n]$, i.e., $N_{DFT} > P$. How could you change N_{DFT} to result in a frequency resolution even better than 4 Hz? If this is not possible, so state and justify your answer.

(f) You wish to filter signal $x[n]$ through the system characterized by the length Q impulse response $h[n]$. You perform this operation in the time domain using convolution, i.e., $y_1[n] = x[n] * h[n]$. You find this to be computationally intensive and decide to perform the operation in the frequency domain using the DFT, i.e., $y_2[n] = IDFT\{DFT\{x[n]\}DFT\{h[n]\}\}$. You may assume that $P > Q$ and that the DFT and IDFT operations are length P. Will $y_1[n] = y_2[n]$? Clearly justify your answer.

Problem E.2

You have been tasked with replacing an obsolete DSP-based filtering system in your company's widget polishing facility! If you succeed with this one, the company has promised to send you on an all-expense-paid vacation to Cancun for Spring break!!!

What you know about the existing digital filtering system:

- The A/D and D/A are both ideal with ideal antialiasing and reconstruction filters
- Input frequencies in the range from DC to 45 kHz are preserved by the existing system
- Sampling is performed ***exactly*** at the Nyquist rate
- The discrete-time filter in the existing system is a real-valued double-notch filter which eliminates the following two frequency components: $\omega_1 = 0.4\pi$ radians/sample and $\omega_2 = 0.6\pi$ radians/sample.

a) (1/2) Assuming ideal sampling at the Nyquist rate with ideal antialiasing and reconstruction filters in the A/D and D/A, plot the magnitude of the frequency response for the ***effective analog*** filter. The *x*-axis of your plot should be labeled in units of radians/second (i.e.,Ω). Show your work and clearly label the frequencies of all of the transitions points in the filter.

b) (1/8) Off-the-shelf A/Ds and D/As are available with the following sampling rates: 40 kHz, 65 kHz, 80 kHz, 100 kHz, 150 kHz, 200 kHz, 300 kHz, and 500 kHz. Using higher sampling rates will make your system more expensive. Which sampling rate should you choose to make the system as cheap as possible yet still operate just as well as the original system? Justify your answer.

Problem E.2 (Continued)

c) (1/8) Assume now that the sampling rate of 300 kHz is selected. Plot the frequency response of the **digital filter** that will result in the newly redesigned system having exactly the same effect on the analog signal as the original system. The *x*-axis of your plot should be labeled in units of radians/sample (i.e., ω). Show your work and clearly label the frequencies of all of the transitions points in the filter.

d) (1/4) Consider now that in the original system, we only needed to preserve frequencies between 25 kHz and 45 kHz. *What is the lowest sampling rate we could use while still preserving (with no aliasing) the frequency content in this range?* Justify your answer. *Would sampling at this rate require you to redesign the digital filters used in the original system to achieve equivalent frequency elimination?* Explain briefly.

E (Problem 3) Digital Signal Processing

(a) An LTI system has system response

$$H_1(z) = \frac{(z-0.5)(z-a)}{(z-3)(z-b)}$$

If $H_1(z)$ is minimum phase, what do you know about the values of a and b? If you can explicitly specify values, do so. Otherwise, constrain the values (i.e., an inequality). If particular values cannot be constrained, so state and briefly justify your answer.

(b) An LTI system has system response

$$H_2(z) = \frac{(z-0.5)(z-0.4)(z-a)(z-b)(z-c)(z-d)}{(z-3)(z-0.1)}$$

If $H_2(z)$ is linear phase, what do you know about the values of a, b, c, and d? If you can explicitly specify values, do so. Otherwise, constrain the values (i.e., an inequality). If particular values cannot be constrained, so state and briefly justify your answer.

(c) An LTI system has system response

$$H_3(z) = \frac{(z-0.5)(z-0.4)(z-a)}{(z-0.3)(z-0.2)(z-b)}$$

If $H_3(z)$ is linear phase, what do you know about the values of a and b? If you can explicitly specify values, do so. Otherwise, constrain the values (i.e., an inequality). If particular values cannot be constrained, so state and briefly justify your answer.

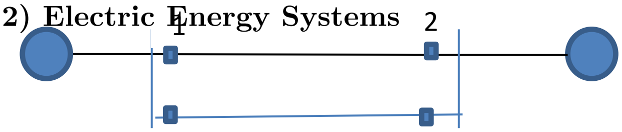
(d) An LTI system has system response

$$H_4(z) = \frac{(z-0.5)(z-0.4)}{(z-3)(z-0.2)}$$

Decompose this system into the cascade of a unity-gain allpass system and a minimum phase system. Explicitly specify which portion of your decomposition is the allpass and which is the minimum phase system.

Ammeters connected to the Wye Grounded (YG) side of a 10 kV (Delta)/1 kV (YG) transformer are showing readings of 1000 A, 1000 A, and 0 A in phases a, b, and c respectively. Find the line currents on the 10 kV side.

F (Problem 2) Electric Energy Systems



Data:

Base Values 10 MVA, 20kV

Generator Bus 1 and Bus 2 Three phase, 4 pole, 60 Hz, 20kV, 10 MVA, Xd=1, Xd’=0.3, Xd’’=0.15, H=6
Generator 1 is wye solidly grounded. Generator 2 is wye ungrounded.

Generator Bus 2 Infinite bus

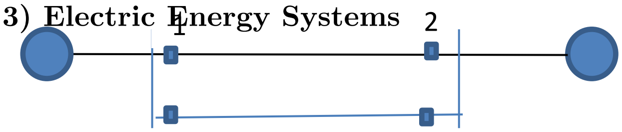
Line Bus 1 to Bus 2 Z= j 0.1 pu, Y = 0 pu

Line Bus 1 to Bus 3 Z= j 0.1 pu, Y = 0 pu

For a bolted single-line-ground fault at bus 1, calculate

1. The phase ‘a’ current in the fault
2. The line-ground voltage for phase ‘a’ at bus 2

F (Problem 3) Electric Energy Systems



Data:

Base Values	10 MVA, 20kV
Generator Bus 1	Three phase, 4 pole, 60 Hz, 20kV, 10 MVA, Xd=1, Xd'=0.3, Xd''=0.15, H=6
Generator Bus 2	Infinite bus
Line Bus 1 to Bus 2	Z= j 0.1 pu, Y = 0 pu
Line Bus 1 to Bus 3	Z= j 0.1 pu, Y = 0 pu

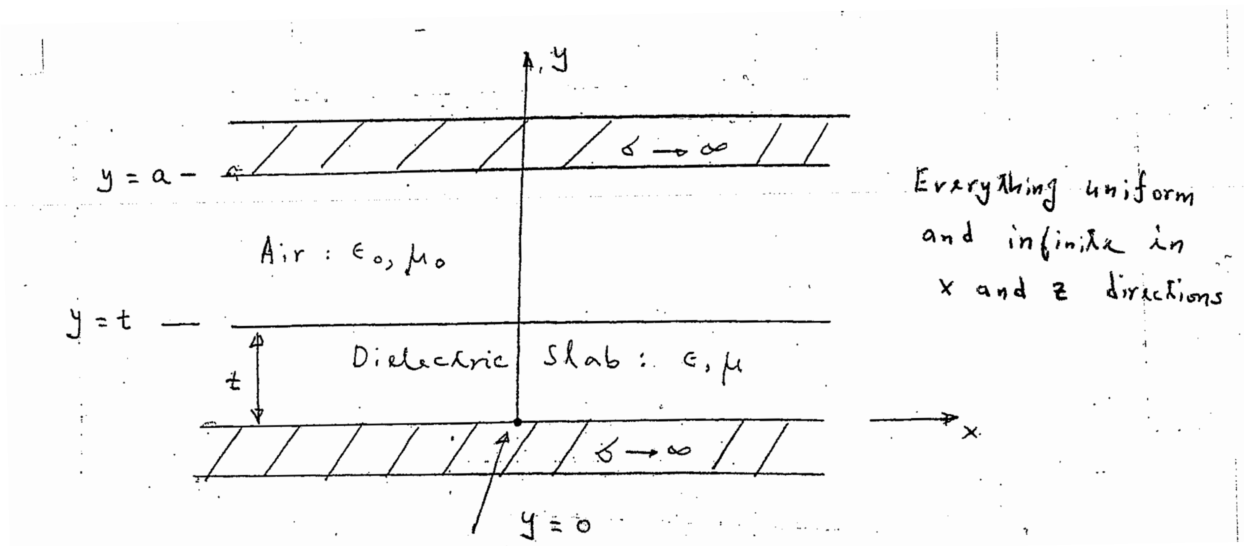
The generator initially supplies rated MVA at 0.8 lagging power factor and 1.02 pu voltage at its terminals. One of the transmission lines trips. Is the system stable? Show all work.

G (Problem 1) Electromagnetics

Shown below is the so-called dielectric-loaded parallel plate waveguide for microwave signal transmission. The structure is uniform in the z direction. It has two infinite and perfectly conducting plates located at $y = 0$ and $y = a$. Between the two conducting plates, we have a lossless dielectric slab with permittivity ε and permeability μ. Above the dielectric slab, we simply have air (ε_o and μ_o). As the structure is uniform in the z direction, the field solutions will not depend on z. Furthermore, we have a source free region. In one solution, the electric field $\overline{E}$ in the air region only has a z component and it is given by

$$E_z = A \sin[\, g\,(a - y)]\; e^{-j\beta x}\;, t \le y \le a, A\text{ - constant},\; g, \beta\text{ - real}$$

Inside the slab, the electric field also only has a z component E_z, and it is found to vary sinusoidally with respect to y.



a) Inside the slab, i.e., $0 \le y \le t$, should E_z be

$B \cos(hy)\, e^{-j\beta x}$ or $B \sin(hy)\, e^{-j\beta x}$

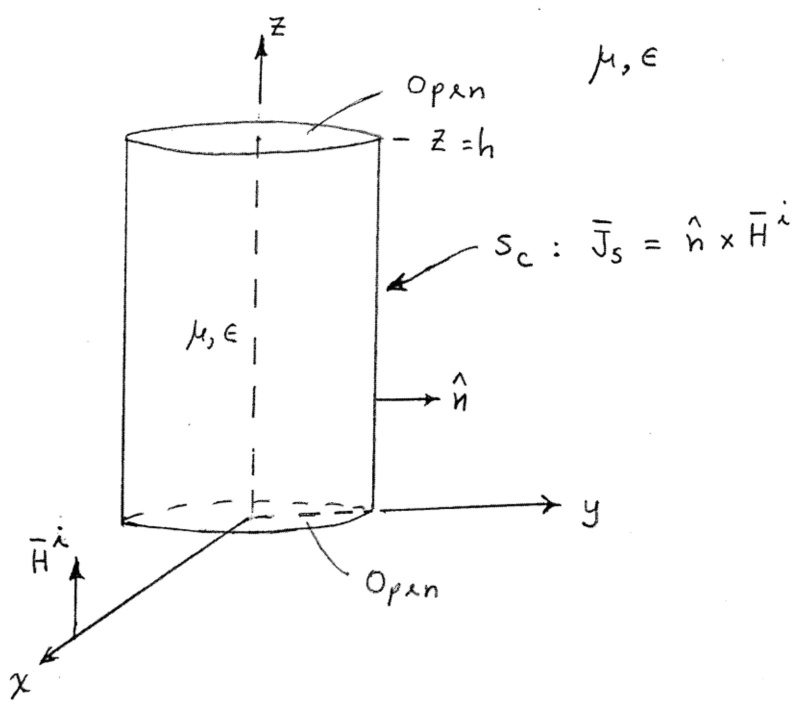
Why ? Explain it in 1-2 sentences. (B — constant, h real, β as given in Equation above)

b) Find an equation relating the constants A and B (the equation can contain A, B, g, h, a and t).

c) Find an equation relating g, β, and k_o, where k_o is the propagation constant for air, i.e., $k_o = \omega\sqrt{\mu_o \varepsilon_o}$.

G (Problem 2) Electromagnetics

You are given a PEC cylindrical surface with radius *a*, height *h* and centered along the *z*-axis, as shown below. The end caps at $z = 0$ and $z = h$ are open, i.e., current only exists on the curved portion S_c of the cylinder. It is illuminated or excited by an incident plane wave propagating in the *x* direction, with the H-field given by $\bar{H}^i = \hat{z}H_o e^{-jkx}$. We will assume that the surface current on the cylinder is given by $\bar{J}_s = \hat{n} \times \bar{H}^i$, where $\hat{n}$ is the outward unit normal vector at the cylindrical surface (pointing away from the region inside). Use far field approximation and find $\bar{H}$ due to the current on the cylindrical surface. You can leave your answer in terms of integrals, but you need to provide me all the details.

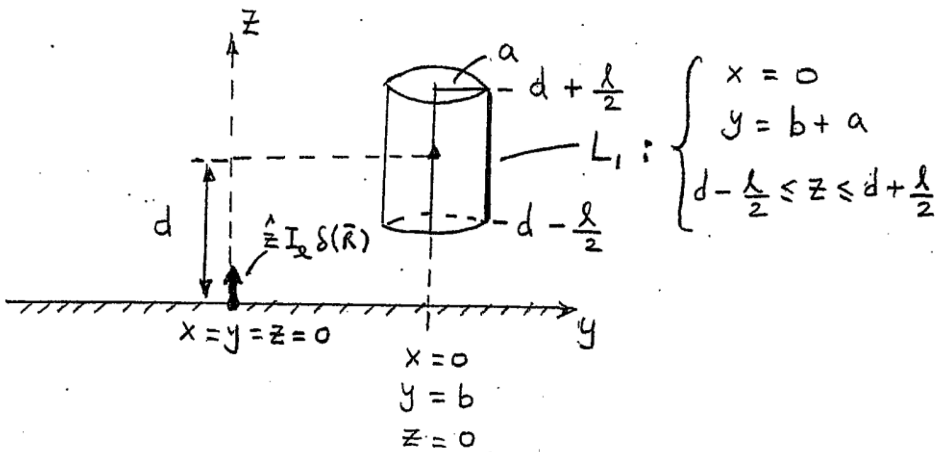


G (Problem 3) Electromagnetics

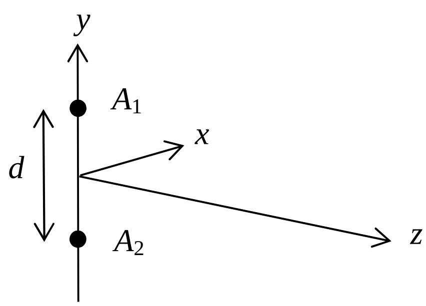
Consider a thin dipole or thin wire directed in the z direction and located at a distance *d* above an infinite PEC ground plane, as shown below. The (fixed) incident field is created by an infinitesimal or Hertzian electric dipole $\bar{I}(z) = \hat{z} I_e \delta(\bar{R})$ located at the origin. As far as calculating the scattered field is concerned, we can consider the thin wire as represented by an unknown line current *I*(*z*) along its axis and the typical thin wire approximation holds. Also, we can assume that the thin wire is in the far-field region of the Hertzian dipole.

a) Find the total E_z at the line segment L_1 as indicated in the figure. The contribution from the thin wire can be represented by some integral(s), but you need to give me all the details about the integral(s).

b) Enforce a boundary condition at line segment L_1 and obtain an integral equation for the unknown current *I*.



Consider the two ideal coherent optical field point sources separated by a distance d where the amplitude of one source is A_1 and the amplitude of the other is A_2 (see diagram). Assume the same wavelength λ for both sources.



(a) Write complex amplitude expressions, U_1 and U_2, for the fields generated by these sources. (Use of the Fresnel approximation for propagation along the z-axis is ok.)

(b) Develop an expression for the intensity created at a plane transverse to the z-axis at a distance z_0 from the source plane. Simplify as much as possible.

H (Problem 2) Photonics

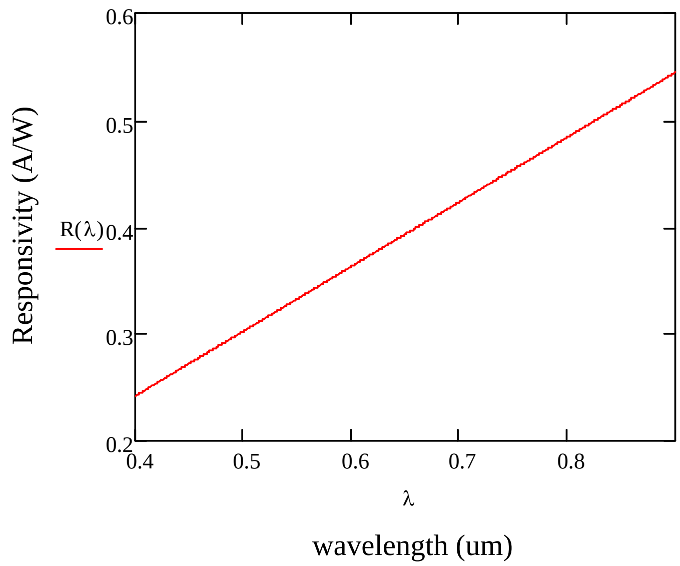
Use 2×2 ray matrices to prove (or derive) the paraxial thin lens imaging equation:

$$\frac{1}{z_1} + \frac{1}{z_2} = \frac{1}{f}$$

where z_1 is the object-lens distance, z_2 is the lens-image distance and f is the lens focal length.

H (Problem 3) Photonics

The responsivity of a photodetector is shown in the following plot:



The detector is connected to an amplifier with a transimpedance gain of 10^5. A laser of wavelength λ = 0.82 μm illuminates the detector and the voltage out of the amplifier is 10V.

(a) What is the current (A) produced by the detector?

(b) What is the laser power (W) received by the detector?

(c) What is the photon flux (photon/sec) received by the detector?

(d) What is the detector quantum efficiency η?

(e) Suppose the bandgap energy of the detector material is 1.11 eV. How does this affect the detector response?