DEPARTMENT OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE

ELECTRICAL ENGINEERING PROGRAM: GUIDELINES FOR THE QUALIFYING ORAL EXAMINATION

NOVEMBER 1999

INTRODUCTION

In order to enter the Ph.D. program in the electrical engineering program, an important examination the students must undergo is the qualifying oral exam. Essentially all Ph.D. programs use some sort of qualifying exam as a filter before students are allowed to join the program. Different programs have different kinds of "quals" — some involving just written exams, some just oral exams and some using a combination of oral and written exams. There are merits and drawbacks of each approach. At present in our electrical engineering program we use only an *oral exam* to evaluate the students.

The use of only an oral exam is by no means a perfect approach, but it may be justified on the following basis:

- The students have already been examined in many written exams during the period of their required course work. Only students with a high GPA are allowed to take the quals and therefore another written exam may not be necessary.

- The oral exam allows the examiners to delve into aspects of problems in a far greater scope than is possible in any cut and dry written question.

- The oral exam allows the student and examiners to have an exchange of ideas. This could benefit students who may not be able to answer a question initially, but through probing may be able to convey some measure of their understanding.

• Oral discussion and communication of technical ideas is a critical part of modern research. The oral exam therefore provides the student and the examiners a forum for evaluating this important skill.

WHAT IS BEING TESTED?

The oral exam is designed to test whether or not a student is fit for a career in research. This places an important responsibility on the examination committee whose members take their task very seriously. It may appear that the allocated exam time is insufficient for making a decision on a student's research ability. One also hears stories on how a famous scientist flunked out of high school or could not figure out what his change was after buying a ticket. However, given the present maturity of electrical engineering as a scientific field, it is possible to use the oral exam as a good filter (along with the directed study report and GPA). Most fields of electrical engineering are at a stage where it is almost impossible to carry out research if certain basic concepts and their inter-relationship is not understood. The ability to think logically and clearly is obviously of great importance, as opposed to simply collecting a data base of information. Also the ability to use the scientific process to build complex systems or explain complex phenomena using simpler concepts is critical in today's research. The examination committee strives to see if the student does indeed have these qualities.

The questions the committee members ask serve to clarify the following:

• **A basic understanding of the field**: These questions, which are based mostly on 400 level courses, allow the committee to check if you have a certain minimum level of understanding of your field. One may ask the question, "Why is this check necessary when I have already taken all the required courses?" The answer is twofold: i) Many students prepare for final exams and after finishing the exams retain very little of the courses' content. Also, the oral questions allow the examiner to probe further into the basic concepts than what is possible in a written exam. ii) In a particular course, the exams only pertain to the material covered in that course. One rarely gets questions linking a concept, say in an EM course and a solid state course. The oral questions allow such a link to be checked.

- **Questions that determine how well a student can explain issues that may not have been explicitly covered in courses**: These questions are very important in the exam and allow the committee to judge if the student can move beyond what has been learned in class. This is, after all, what research is all about.

- **Questions dealing with specialized knowledge or directed study** : These questions will probe a deeper level of the student's knowledge. They may involve concepts learned in 500 or 600 level courses the student has taken in the major area, or may relate to the directed study work.

PREPARING FOR THE ORAL EXAM: SOME NON-TECHNICAL ASPECTS

While the faculty feel that the oral exam is the best way to evaluate the student (along with GPA and directed research) there are many students who feel threatened by an oral exam. For whatever reason, some students feel that they get nervous in an oral exam or are unable to *think on their feet*. The examination committee will try its best to put the student at ease during the exam. *It is absolutely not the intention of the committee to see how a student performs under pressure*. However, the student should prepare himself/herself for the oral exam.

Here are a few suggestions on how to prepare for the non-technical aspects of the exam:

• The exam can be quite draining even if you are able to answer all of the questions. You may want to bring some water or juice. Not only will this satisfy your thirst, you can use a water break to calm yourself or get a moment to reflect upon an answer.

• If you are not used to talking to a group of people (most students are not) you should practice answering questions from a group of your friends. Even a little practice will be helpful.

• Remember that you can't answer a question unless you understand what is being asked. It is certainly not impolite to ask the examiner to repeat a question or to explain it in more detail.

• If for whatever reason you feel "pressured" by an examiner politely explain your discomfort. None of the examiners will try to make you uncomfortable on purpose. However, different people have different ways of wording and asking questions.

• If you have difficulty expressing yourself in English, practice as much as possible before hand.

• The qual exam is a serious endeavor for both you and your examiners. Please don't take the exam casually because some of your friends have said, "Don't worry, its a piece of cake!"

PREPARING FOR THE ORAL EXAM: TECHNICAL ASPECTS

Here are some guidelines for preparing for the qualification exam.

- *Take the exam seriously*

A surprising number of students don't spend adequate time preparing for the exam. Often students are busy working on demanding research projects. Some may feel pressure to make rapid progress in an assigned research area. However, remember that until you've passed the quals, you are not a Ph.D. student. The preparation for quals should be given adequate time. You may want to discuss with your directed study advisor how you should prioritize your time. Preparing for the quals also gives you a last chance to review all the courses and their inter-relationship before getting lost in a highly specialized research area.

- *Recall the basic equations*

The oral exam is not a test of your memory skills. However, if you've forgotten basic equations like Poisson equation or Newton's equation or the wave equation for light, you will have a hard time during the exam! You must be able to recall basic equations in your major and minor areas simply because you've used them so much during your courses. It is important to develop an intuitive feel for the inter-dependence of parameters in the equations so that even if you make a slip you can catch it right away.

Usually the examiners tend to be quite negatively influenced by poor performance on the basics. Also, though knowledge of fundamental equations/algorithms is expected, detailed algebraic or numerical manipulation is seldom asked for. What is usually looked for is a good understanding of the meaning, range of application and limitations of equations.

Most oral questions in the exam will start off from the basic material and gradually get more and more complex.

- *Directed Study*

Questions in the directed study area may be asked by the examiners. You should try not to give the impression that you simply carried out your advisor's instructions. Present yourself as someone who understands the *whys* as well as *hows* of issues involved in your project.

- *Nature of questions*

As you prepare for the quals, you may want to keep in mind that in an oral exam you will not be asked just one question on a topic but a series of questions probing various aspects of a problem. In this sense the oral questions are different from a written question. The examiners will probe you at various levels until they feel satisfied.

In the following pages you will find a wide range of questions. These questions are included so that you can check how your preparation is going. Of course, the actual questions in the exam may be quite different. Also some of the questions included here are *open ended* in the sense that there may be no clear answers to the question. Such questions are sometimes quite useful to test a person's understanding of the depth of a problem. The questions are categorized in different topics (much like your major and minor). However, some questions could cross boundaries. For example, a question listed in electromagnetics could be asked of a student with optics as a major.

DEALING WITH THE OUTCOME OF THE EXAM

The outcome of the Ph.D. qualification exam depends upon your performance in the oral exam, your GPA and your evaluation in the directed study. The oral exam is quite important and carries a higher weight than the other two factors. About a week to ten days after the quals there is a meeting of relevant faculty where each student's results are evaluated and debated. At the end of this meeting the results will be announced.

- *You have passed*

You are now ready to start research as a Ph.D student. Most likely you will continue research under the advisor who guided you for your directed research. In some rare cases the directed study advisor may not be available to guide you. In this case you must find a new advisor. Once you start your research, your next check point is the candidacy.

- *You have not passed*

Usually you can avail of two chances to pass the exam. It is possible that in spite of your preparation you may not be able to pass the exam. In such a case you will have to leave the EE program (with a master's degree). While this is obviously not something you plan for, it is very important to understand that *this does not mean that you cannot have a great career as an electrical engineer.* Many successful engineers in industry have a masters degree and not a Ph.D. A negative outcome may allow you to go into industry and work on problems of relevance to todays technology. You still have the option to go into research either at a later time after spending time in industry or at another school.

CIRCUITS AND MICROSYSTEMS

The examiners may bring a pre-drawn circuit and ask you to analyze various aspects of it. The best way to prepare is to re-familiarize yourself to all the basic circuits you have covered in your 300 and 400 level courses. For digital circuits examine their operation during various stages of switching. Similarly for analog circuits examine the amplification or oscillation behavior. Here are a few questions that may help you prepare. Also examine the questions in the SOLID STATE and VLSI sections.

Note that some of the more circuit oriented questions can be asked from students majoring in the VLSI area.

- Discuss the switching from the ON to OFF and OFF to ON states of i) a $p-n$ diode; ii) a BJT.

- The edges of a cube consist of equal resistors R joined at the corners. If a battery is attached to the opposite corners of a cube face, what is the effective resistance presented by the resistors?

- Discuss the switching of an NMOS inverter with a resistive load. How will you determine the noise margin of the device?

- Discuss the use of enhancement and depletion mode NMOS transistors as load elements. Which type of device has better performance (and why?) as a load element in circuit design?

- Are there any design advantages of having both depletion and enhancement mode devices on the same chip? Give a couple of examples.

- Discuss the possible reasons why a Si microprocessor does not operate reliably above $\sim$200 C.

- Discuss the operation of Schottky clamped TTL. How is the speed of the logic gates improved?

- Discuss the operation of a CMOS NOR gate with two inputs. Discuss the requirements on the gate length to gate width ratios for the devices involved.

- What do you understand by fan out of a driver gate? Use the example of a bipolar inverter and discuss the importance of gain infan out.

- What is Early effect in bipolar devices? How does this effect influence circuit design?

- Compare (using a simple example) the pros and cons of Schottky-clamped TTL circuits, TTL circuits and ECL circuits.

- Draw an example of MOS based ROM cell arrays with: i) NOR and ii) NAND based memory.

- Draw and analyze (any) circuit for a: i) low pass and ii) high pass network. How do the elements of your network control the frequency response.

- Discuss how a diode can be used to demodulate an AM signal.

ELECTROMAGNETICS

Many questions in the electromagnetics section may be quite similar to those in the optics section. You may want to browse through those questions as well.

General

- Describe the approaches you would use to measure the wavelength of a coherent electromagnetic source if the wavelength is in the range: i) 1–10 $\AA$; ii) 2000–10000 $\AA$; iii) 1–10 m.

- Why is the sky blue?

- Estimate the time it takes for a charge disturbance to decay in a copper wire. The resistivity of copper is $1.7 \times 10^{-6}\ \Omega cm$.

- When an em radiation impinges on an amplifier the effect can be repres ented by a sinusoidal E-field ignoring the H-field. Why is this possible?

- Consider two rectangular iron bars which are identical. One of them is magnetized while the other one is not. How can you tell which one is magnetized without any external magnetic field or apparatus?

- Discuss how a microwave oven cooks food. Why can't we place certain kinds of cook ware in the oven?

- A charged particle going in a circular orbit radiates energy. However, an electron in an atom going around the nucleus does not radiate. How do you resolve this apparent contradiction?

- An em beam with intensity I_o impinges along the $+z$-axis on a perfect mirror in the $x-y$ plane. the mirror is moving in the $+z$- direction with a velocity v_o. What is the intensity of the reflected beam?

- How would you measure the wavelength of coherent radio waves?

- Discuss how you would measure a magnetic field with value close to :

i) earth's field;

ii) 1 T

iii) 10 T

• Discuss the physics of the shielding process. Why can one use a mesh for shielding and have shielding almost as good as offered by a solid sheet?

• Why does lightning often strike on the same spot in a storm?

• Calculate the force between the plates of a capacitor.

• An amplifier is able to detect a signal of 10^{-9} W/cm^2. What is the E-field associated with this signal?

• There is a vertical electric field of 100 V/cm as we move away from the earth. Thus there is a 200 V across the height of a typical person. Why don't we get a shock from this field?

• The earth is negatively charged and there is a potential difference of $\sim$ 400000 V between the top of the atmosphere and the earth. This causes a current of 1800 A to flow into the earth. Why does this current not discharge earth's charge?

• What do you understand by *gauge invariance* in em theory?

Propagation of waves in plasma

• Discuss the need for high frequency waves for satellite communication.

• A typical free electron density in the ionosphere is 5×10^6 cm^{-3}. Estimate the plasma frequency of the carriers. What is the effective dielectric constant for em waves?

• Derive the maximum usable frequency for em waves sent from the earth towards the sky.

• Describe how an earth-bound radar system is able to look beyond the visible horizon. What kind of em waves would you use to see beyond the horizon.

• A X-ray with wavelength λ impinges on a metal plate with N free electrons per unit volume. Estimate the critical angle for total reflection.

Guided Waves and Transmission of Waves

• Show that it is possible for em waves to propagate in a hollow metal pipe of rectangular cross-section. Show that there is a cutoff frequency below which there is no propagation.

• Discuss the importance of load matching in sending signals from an antenna to a receiver.

• You are to design transmission systems to transfer AC power across two points. What is the simplest (most cost effective) system you would use for the following frequencies:

i) signals at $\sim$ 50 Hz?

ii) telephone signals?

iii) cable TV signals at $\sim$ 5 GHz?

• Compare a coaxial cable and a waveguide in terms of their ability to transmit high power-high frequency ($\sim GHz$) signals.

• Discuss the operating principles of a *unidirectional* coupler for a waveguide. This coupler should be able to detect the direction of flow of power inside the guide.

• Derive the propagation speed of electronic signals on a VLSI chip.

Radiation Sources

• Discuss the radiation emitted from a dipole.

• How would you combine a series of dipole radiators to produce highly directional radiation.

• A spherically symmetric charge distribution of finite extent pulsates with a frequency ω. How would you detect the pulsations?

• calculate the em energy radiated by a rotating flywheel whose rim has a uniform charge distribution.

Radar and Antennas

- Describe how the SAR works. What is the advantage of an airborne radar over a ground based one?

- Why are the antennas of most cars vertical?

- Discuss the physical basis for the expression for the radar cross section of a target.

- Discuss why the use of high frequency electronics has allowed the TV antennas to shrink in size.

- How does an aircraft with radar use the Doppler effect to calculate its velocity?

- You are to design an earth-based antenna for a space project to observe stars. Discuss the considerations involved in the design. Examine considerations such as size of the antenna, size of the stars to be observed, detection frequency, etc.

- Discuss the principles of operation of a phased array radar. Discuss its pros and cons with respect to ordinary radars.

OPTICS

• What is the difference between light coming from a laser and from a light bulb?

• Describe what you mean by polarization of light. What does one mean by linearly and circularly polarized light?

• How can you use a few glass plates to create linearly polarized light from an unpolarized light source?

• Discuss the conditions under which you would use wave optics and not ray optics.

• Why does the reflectivity of a periodic structure have strong dependence on the wavelength of the incoming light?

• Discuss why and how certain crystals can be used to make polarizers.

• Discuss the principle of operation of a half plate.

• Light of wavelength λ impinges vertically on a horizontal plane film of thickness d (adjustable) and index n_1 placed on a semi-infinite substrate of index n_2. How would you choose d to design an anti-reflecting coating?

• You make a pinhole camera in which the distance from the pinhole to the film is 15 cm. You want to take the image of the moon in the visible ($\lambda \sim 5000 \AA$) spectrum. What should the diameter of the hole be for the sharpest image?

• You are to design a transmission grating on a 5 cm wide region to resolve the sodium doublet D at 5890 $\AA$ and 5896 $\AA$ in first order. What is the minimum number of lines you need?

• In a liquid crystal display and electric field can alter the optic axis of the crystal through rotation of molecules. Discuss how this property can be used for displays where a back light (unpolarized) illuminates a liquid crystal cell.

• Using a simple ray optics description discuss why in a rectangular waveguide only certain modes can propagate.

• Discuss why in a crystal one has ordinary and extra-ordinary indices n_o and n_e respectively. Using a graphical approach describe how light polarized along different axes propagates in a crystal.

• Discuss the relationship between the absorption coefficient of light in a medium and the conductivity of the material.

• In optical communication systems why is the preferred wavelength of transmission 1.55 μm or 1.33 μm? Compare the pros and cons of the two wavelengths.

• Why is CAEN able to use a $0.98\mu m$ transmission system in its fiber system but for long haul communications one needs a $1.55\mu m$ system?

• Describe how a prism coupler works.

• You have laser system that produces 100 fs pulses. You are interested in compressing these pulses. How would you go about designing a system to do so?

• What do you understand by dispersion shifted fibers? How do they function?

• What does one mean by the chirp of a pulse? How can the chirp produced in a laser pulse be exploited for pulse compression?

• An ultrafast laser system produces optical pulses of 15 fs width at $\sim 0.98\mu m$. Estimate the spectral width of the pulse.

• The dispersion in a particular material is given by

$$n(\omega) = n_o - \frac{\Gamma(\omega - \omega_o)}{\Gamma^2 - (\omega - \omega_o)^2}$$

Calculate the group velocity and group velocity dispersion in the material.

• Discuss how the f-stop in a camera influences the depth of view of a photograph.

• Discus how an optical wave of wavelength λ confined in the transverse direction by an aperture of radius r spreads in the far field.

- Describe the electro-optic effect. How is it used in designing directional couplers?

- How would you design a tunable filter using a periodic structure made from an electro-optic material?

- What is the difference between guided and radiation modes in a waveguide? Using a simple ray optics approach discuss the conditions for cutoff for a slab waveguide with a core of index n_1 and thickness h and cladding of index n_2.

- Derive an expression for the numerical aperture of a multi mode fiber.

- What is the maximum radius of an optical fiber with numerical aperture NA if it is to serve as a single mode fiber?

- How can a tunable Bragg reflector be used to tune the frequency of a laser?

- How can you use a non-linear material to detect infrared radiation (you don't have a detector that can detect long wavelengths but you can detect short wavelengths)?

- A laser pulse of power 10^{12} W is generated by an ultrafast laser. Calculate the electric field associated with the pulse which is centered at 1.0 μm and has a beam diameter of 10^{-4} cm^2.

- In an experiment light from a ruby laser ($\lambda = 6943$ $\AA$) is focussed on a quartz crystal. Some of the out coming light is found to have a wavelength of 3471.5 $\AA$. Explain what is happening.

- Discuss the issues involved in phase matching and coherence length in second harmonic generation. Estimate the maximum useful thickness of a non-linear material for $\lambda = 1.0$ μm and $n(2\omega) - n(\omega) \sim 10^{-2}$.

- Discuss the principles of phase conjugation. How can phase conjugation be used to send an image through a multi mode fiber?

- Describe how phase conjugation is achieved in four-wave mixing.

- Why does a film of oil on water display a rainbow of colors?
- Describe how sunglasses with polarizers cut down on the glare from a water surface.
- What kind of image do you expect to see from a laptop display screen if you are wearing polarized glasses?
- Describe how you would go about designing a telescope.
- Describe how you would design a microscope. Why is an objective and an eyepiece used in a microscope instead of a single lens?
- Describe the operation of a Fresnel lens.
- Describe the basis of holography.
- What is a Fabry Perot interferometer? How would you calculate the finesse of a Fabry Perot cavity?
- How would you find the refractive index of a fluid using an interferometer?

SOLID STATE

Many of the questions listed below could be asked from students in optics or VLSI or electromagnetics.

Materials Related

• Al and Si crystals both have approximately 2×10^{22} cm^{-3} electrons. Explain why Al is a metal and Si is a semiconductor.

• Explain why the control of impurities in the fabrication of semiconductor devices is extremely critical, but in the fabrication/synthesis of metals or insulators it is not.

• If you were to accidentally drop a GaAs wafer it shatters along certain planes. Why does this happen? What the planes along which the crystal shatters?

• Explain why without doping, semiconductor technology is useless.

• Discuss the fundamental limits to the high temperature operation of an electronic device such as a memory device.

• Discuss the possible reasons why a Si microprocessor does not operate reliably above ∼200 C.

• Discuss why by using higher doping chips can be used upto higher temperatures.

• *Estimate* the upper temperature upto which a Si based and a C (diamond) based microprocessor could operate.

• What is an ohmic contact and why is it difficult to make an ohmic contact to a large gap semiconductor?

• In a semiconductor device, it is possible to have more than 6 orders of difference in the conductivities of an ON and OFF state. Why can't we build such devices from metals?

• You are given a Si crystal. describe how you would find the crystal quality of the sample and find out its planes.

- How can you find out the free carrier density in a Si sample?

- A DRAM fab line wants to increase the memory density of its product. Discuss the limits placed by modern oxide fabrication technology.

- Estimate the resistivity of undoped Si at 300 K and compare it to a sample with 10^{18} cm^3 free carriers.

- Discuss Grove's law for oxide thickness. Why is the oxide thickness not proportional to the oxidation time?

- Discuss how dopant diffusion through a mask opening influences the minimum distance at which devices can be placed on a layout.

Junctions

• Explain the structure and band profile of a Schottky junction. Why is it that in *real* Schottky junctions the barrier height is almost independent of the metal?

• How would you convert a Schottky junction into an ohmic contact?

• Consider a $p - n$ junction. Explain the various current components under equilibrium.

• Discuss why the reverse current density in a Schottky junction is much larger than in a $p - n$ diode made from the same semiconductor.

• Why is the Fermi level pinned at the surface of most semiconductors?

• Why is there such a large difference between the mobility of electrons in bulk Si and in a n-MOS?

• Why is the Schottky barrier technology more difficult to stabilize than the $p - n$ junction technology?

• Discuss the band profile of a modulation doped heterostructure.

• In the fabrication of Si/SiO_2 interface technology what are the important issues that determine technology performance?

• Discuss the band profile of a heterostructure $p - n$ junction. The n and p sides have different gaps.

Diodes

• Discuss why the reverse bias current of diodes does not change much with bias upto the breakdown point.

• Discuss the causes of breakdown in a $p - n$ diode.

• How can you use a $p - n$ diode as a varactor (device with a variable capacitance).

• Why is the $p - n$ diode time slower in the forward bias mode than in the reverse bias? How can you speed up the forward bias response of a $p-n$ diode?

• Compare the current flow in a $p-n$ diode and a Schottky diode. Based on this discuss why a Schottky diode has a faster response than a $p-n$ diode.

• *In a narrow gap material it is possible to make a good p-n diode but not a good Schottky diode.* Discuss this statement.

• Discuss the benefits and problems associated with a *narrow* $p-n$ diode.

• Discuss how you would determine the built-in voltage and p-doping in a n^+p diode.

• Discuss how a Schottky barrier diode is exploited in high speed bipolar logic.

• Even though most logic functions can be obtained by diode based logic, we use transistor based logic instead. Why is this?

Transistors

• Discuss how important high gain is in transistors used for various com ponents in a microprocessor.

• Discuss the current paths in a $n-p-n$ bipolar transistor biased in the forward active mode. Discuss why doping the emitter, base and collector all at 10^{17} cm^{-3} is not a good design.

• Estimate the base transit time for minority charge in a BJT.

• Discuss why the output conductance of a BJT is not zero. Why is this a problem in circuit design?

• Discuss the switching of a BJT from the ON to OFF state and back. Discuss the minority charge in the base at various points during the switching.

• Discuss the various considerations in the design of a Si BJT.

• Discuss the benefits of a HBT over a BJT.

• How would you alter the dimensions of a transistor if the gate length were to shrink from 1.0 μm to 0.1 μm?

- A high speed Si based BJT must have a thin emitter (why?). Discuss the problems associated with too thin an emitter. How does poly Si technology help in this problem?
- The MOSFET has only been made in Si technology. Speculate why.
- Draw the band profiles of a n-MOS under depletion, accumulation and inversion. Why does the depletion width in the semiconductor remain unchanged with gate bias once inversion starts?
- Discuss the $C - V$ characteristics of an n-MOS. From the $C - V$ measurements how would you calculate the gate bias at which inversion starts? Discuss what happens to the $C - V$ measurements under low and high frequency measurements.
- Why is it important in the MOSFET technology to have a stable threshold voltage? Discuss the physical problems that can lead to threshold variations.
- Discuss how the CMOS technology provides a low power switching solution.
- Discuss how latch up occurs in CMOS technology. How would you design a process to avoid latch up?
- Discuss the advantages and challenges of the SOI technology.
- Discuss the pros and cons of the MESFET and JFET technology.
- Discuss the importance of the ohmic and Schottky metal technologies in a MESFET performance.
- Discuss the f_{max} and f_T of transistors. Why are the two different?
- Outline the benefits of a MODFET over a MESFET.
- Discuss why it is difficult to control the output conductance of a short channel FET.
- Discuss the parameters controlling the transconductance of a FET. How would you design a technology with high g_m?

Semiconductor Optoelectronics

- Discuss why direct gap materials have excellent light emission and absorption properties, but indirect gap materials do not.
- How does introduction of impurities in indirect gap materials improve radiative processes?
- Discuss the physical processes involved in the non-radiative Shockley, Hall and Reed recombination and in Auger processes.
- Discuss why in a homo junction LED the n and p doping is asymmetric.
- Discuss the differences in the fabrication of a laser diode and a LED.
- In optical communication systems why is a LED adequate for LANs but not for long haul systems where laser diodes are needed?
- Estimate the spectral width of emission from a 1.0 μm LED at 300 K.
- Compare the light-current plots for a LED and a laser diode. Discuss the differences.
- Discuss the failure mechanisms for a laser diode and a LED.
- Design an experiment to find the quantum efficiency of a laser diode.
- The threshold current and carrier density of a 1.0 μm laser is 1.0 mA and 10^{18} cm^{-3} respectively. Estimate the power in the lasing mode if the laser is pumped at 10 mA. Assume single mode operation.
- Discuss the intrinsic time response of a laser and a LED.
- Discuss why it is possible to use Si photodetectors for GaAs based sources in communication systems.
- Discuss the photo current of a $p-i-n$ photodetector. Discuss the prompt and slow photo current.
- Discuss the pros and cons of an APD. Why is it difficult to use APDs in undersea communication systems?

- Why is it possible to get gain in a $n^+ - i - n^+$ detector but not in a $p - i - n$ detector? Discuss the pros and cons of the two detectors.
- Why is an APD more noisy than a $p - i - n$ detector?
- Discuss the factors determining the detectivity of a detector.
- Why is it difficult to make high quality far infrared detectors?
- Discuss the advantages and disadvantages of Schottky barrier based detectors.

VLSI CIRCUITS

In the VLSI area, students can have a solid state or computer science background. These students will naturally have some differences in their course work and as a result the questions they will be asked may differ. Thus it is not expected that all students would be able to answer all of these questions.

Students should examine some of the more circuit related questions presented under the *CIRCUITS AND MICROSYSTEMS* heading in this write-up as well as MOSFET device and processing questions under the *SOLID STATE* heading.

- Discuss how the defect density on a wafer affects the die size that can be used in chip fabrication.

- A silicon processing plant is known to produce a fatal defect density of $2\ cm^{-2}$. What is the yield if the die size is $2\ cm^2$? How can redundancy in design improve the yield?

- What do you understand by *self aligned technology*? Describe how it is implemented in a MOSFET process and a bipolar process.

- Estimate the maximum current density flowing in the metal interconnects in modern VLSI chips.

- "The inability of high T_c super conductors to withstand current densities $> 10^4\ A/cm^2$ have made it difficult to implement them as interconnects in VLSI chips". Discuss this statement.

- What is electro migration and how does it influence circuit layout and design?

- What are typical transmission velocities for pulses in interconnects in VLSI chips?

- Estimate the charge stored on a cell of a 1 M DRAM. How many electrons does a state 1 correspond to?

- Discuss the performance improvement that would occur in a microprocessor if Si transistors switching at 0.1 ns were to be replaced by GaAs transistors switching at 20 ps.

- Why do device speeds improve with greater switching power? How does this impact VLSI design? What are typical allowable power dissipation (in Watts/area) for modern VLSI chips?

- Explain the basis of I.C. design rules. Given a CMOS process, how would you go about determining a set of design rules?

- What is body effect and why does it have important effects on digital (and analog) IC design?

- Define and discuss the major types of field-programmable gate arrays (FPGAs) in terms of their programming methods.

- Distinguish static and dynamic RAMs. What are their respective roles in a typical computer system?

- Where in a microprocessor would you use a PLA? What are the pros and cons?

- Consider a system which consists of a number of chips. Rent's law gives the relation between the number of external connections in a chip and the number of logic gates. The relation is (P is the number of connections and N is the number of gates)

$$P = BN^s$$

with $B \sim 1.2$ and $s = 2/3$. Discuss the basis of this law. Does a microprocessor obey this law?

- Compare and contrast ripple-carry and carry-lookahead addition. What are their layout implications?

- Discuss design using flip-flops vs. latches in terms of timing requirements and resulting advantages and disadvantages.

• Describe some different approaches to building fixed point adders.

•. What are important issues in the design of logic for floating point operations?

• Discuss dynamic vs. static logic and give examples.

• Explain the operation of fully-associative, direct mapped, and set-associative caches. Explain what the following types of misses are: conflict, capacity, and compulsory.

• Discuss write and replacement strategies for caches, in particular, what do the terms write-through, copy-back and non-allocate mean?

• Explain the principles, pros and cons of pipelining microprocessors.

a. Derive an expression for the speedup of an n-stage pipeline.

b. What are precise interrupts?

c. What is a restartable process?

• Discuss virtual memory implementation.

a. What problems do virtual memory create for caches?

b. Give some solutions.

c. What is PC relative addressing? Why is it useful?

d. What is a zero address machine, one address, two address, etc?

e. What are disk blocks used for?

f. How is the data on disks usually organized?

• Compare the design approach of the *RISC* and *CISC* architectures. Give an example of some instructions that are different in the two approaches.

• Explain the benefits of microcode, hardwired logic, or PLA for a microprocessor control unit.

• Describe the switching noise problem for I/O, and give several solutions.

- What is meant by load-store architecture (as used in the RISC context) and what are its implications on performance?
- Identify some typical exceptions encountered in instruction processing. Discuss a general way to handle them.
- Describe an application of a LIFO stack in instruction processing. How would you implement a large stack (a) in hardware and (b) in software?
- What is microprogramming? Suggest why recent technological developments have greatly reduced its role in computer design.
- What are the distinguishing features of a superscalar microprocessor? What are their design implications?
- Discuss the D-Algorithm and PODEM logic testing methods.
- Explain the stuck-at fault model. How many possible stuck-at fault does a circuit with one line have?
- What is bridging faulti (BF)? How many BFs does a 1-line circuit have?
- What are redundant faults and what effect does their presence have on the testability of a circuit?
- What is the goal of timing verification?
- Compare and contrast two or three approaches that can be used to verify the functionality of a digital system.
- Describe and explain any routing algorithm you are familiar with.
- Explain the advantages/disadvantages of compiled-code versus driven logic gate simulation.
- What is a binary decision diagram?
- What is a retiming transformation?
- Explain the difference between Boolean and algebraic division in logic synthesis.

- Briefly describe force-directed scheduling in high-level synthesis.
- Outline the main steps of the left-edge channel routing algorithm.
- Give a brief pseudo-code description for an algorithm that levelizes and topologically sorts a directed acyclic graph (DAG). What is the complexity of your algorithm?