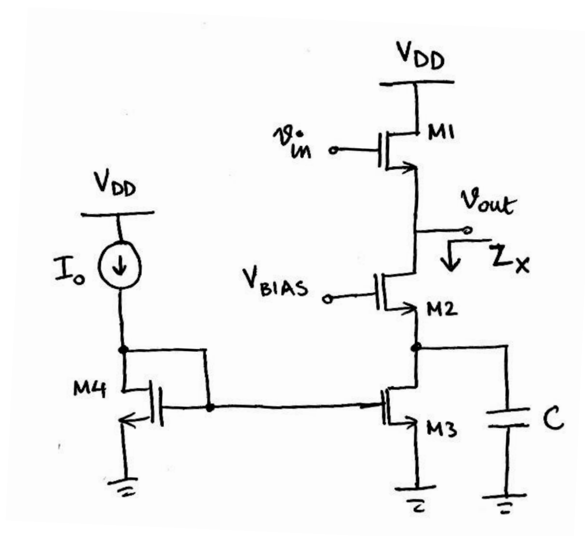
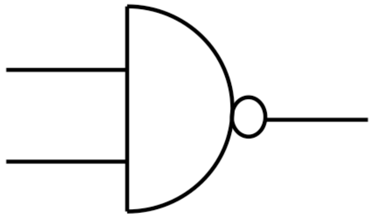
EE Qualifying Examination – Winter, 2017
Professor Amin Arbabian

1. **Describe the operation of the circuit below.**
(Note: complete biasing is not shown, assume gm = 1 mS for all transistors, gm×ro = 3 for M2 and M3, ignore ro for M1, C = 1 pF, ignore all other capacitances, ignore body effect).



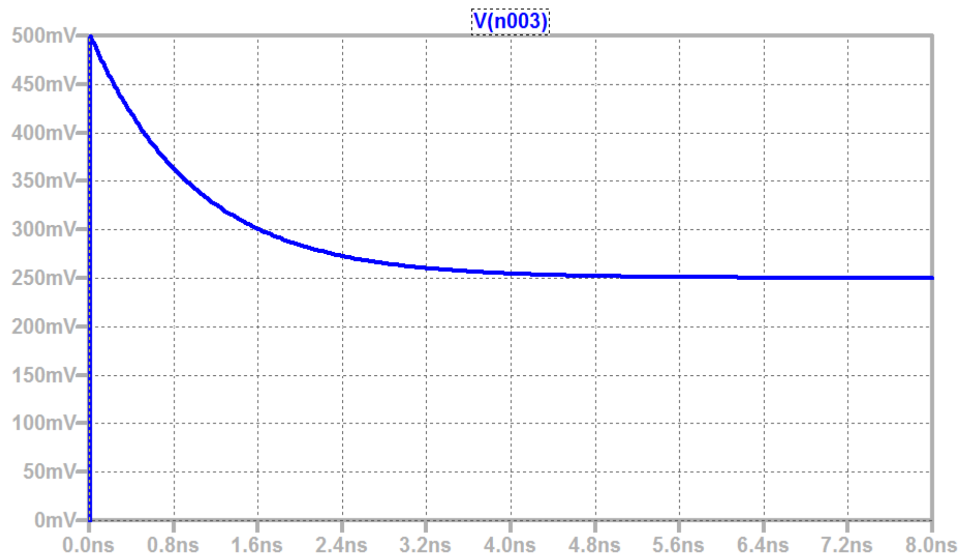
2. **Find the transfer function for the gain from vin to vout.**
(Hint: start by calculating the impedance Z_X).



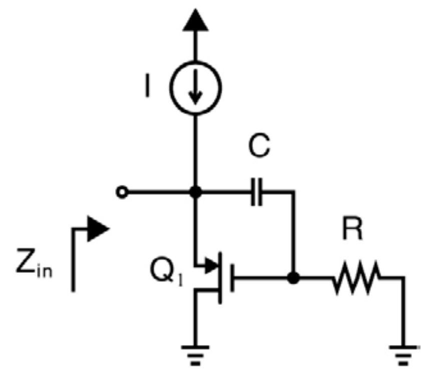
- Consider this NAND Gate. I'd like for you to show how to make it function as a linear amplifier: $V_O=A_V V_I$ How will it be biased
- Can you show me what's inside the gate and how your scheme works (i.e. how does it really bias up in the linear region)
- What if I postulated the gate, internally to look as follows (2 MOS + Resistor). Now what would you do. Is that the only way
- Finally, let's assume we want to use NAND gates to make an Oscillator. How would you do that

Name:	Stanford EE Quals 2017 Murmann

Draw a passive circuit that produces the output response below when a perfect 1-V step is applied at its input. Determine approximate component sizes for your circuit.



For the circuit below, sketch the magnitude of Z_{in} versus frequency. Neglect all capacitances, except the explicitly shown C.



EE Qualifying Exam
January 2017

The following questions are on sampling and filtering audio signals and images.

Audio You are listening to the musical note A at 440 Hz, modeled by a sine function.

1. Sketch the spectrum of the signal.
2. If the signal is sampled at a rate 440 Hz and played back, what do you expect to hear? Why? Sketch the spectrum of the signal you expect to hear.
3. I'll suggest several reconstructed signals at different sampling rates. In each case tell me what you expect to hear and why.

Images Consider the following image.

1. The image is subjected to several low pass and high pass filters, which I will show you. Describe the process, what you would expect to see, and why.

2017 EE Qualifying Exam Question – David Miller

Coupled waveguides

Note: The goal of this set of questions is to see how you think about solving them, and that will be more important than whether the answers are "right" or "wrong". The answers are mostly qualitative, and little or no algebra should be required for them. We will proceed mostly by discussing and sketching the answers rather than by extensive writing or algebra. If you finish the questions on this sheet, subsequent questions will be asked.

Introduction

This question will be based on simple waveguides, which here we could imagine consist of some very thin glass fiber that locally is just a uniform cylinder of solid glass, surrounded by air or vacuum. For simplicity here, we presume the fiber is very thin, with a diameter somewhat smaller than the wavelength of light of interest to us, as sketched in Fig. 1. The fiber is so thin that it is what is called "single-mode", which means there is only one specific shape of beam that can propagate along it.

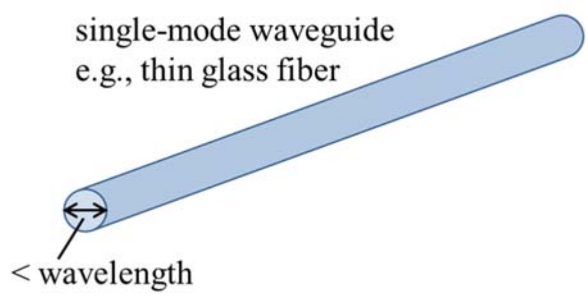


Fig. 1

Before starting the question itself, can you sketch or describe what you think the profile is of the amplitude of the electric field of the propagating mode? (If not, we can discuss this to clarify this point.)

Question

Suppose we have two such waveguides of length L, as in Fig. 2 in a "top" view, separated by some distance s that is small enough that fields in the two waveguides will start to interact. Suppose now we launch some light into the left end of only the upper waveguide.

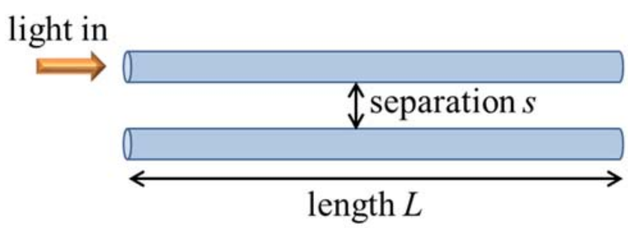


Fig. 2

(i) What will happen to the light as we move from the left in Fig. 2 towards the right? (You can reason about this any way you like, such as by analogies to other coupled systems.)

(ii) How would this change if we increased the length L

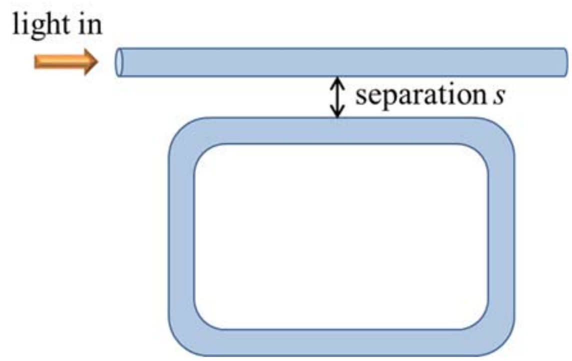
(iii) How would this change if we reduced the separation s?

Supplementary question (on a separate page)

Are there any ways of launching light into the waveguides in which the pattern of light in the guides does not change as we move from left to right?

Supplementary question 2 (on a separate page)

Consider the situation as in the figure, where one of the waveguides is formed into a loop. Describe what you think will happen now. For example, what if anything would happen to the light leaving the guide on the right as we vary *s*?



Solution

Introduction

In the introduction here, which was not graded, the key point is that the light is bright in the middle of the fiber, falling off towards the sides, but not hitting zero at the walls of the guide. (It would do that in a hollow metal guide, but not in a dielectric guide.) Beyond the walls of the guide there is an "evanescent" tail, that is some quasi-exponential function, falling off with distance. Though there are such evanescent tails outside the guide, the light is still "bound" to the guide, and in an otherwise loss-less guide, it propagates without change or loss of power as it goes down the guide.

Question solution

Most students realized that there must be some light that transfers from the top guide to the bottom guide. There are several ways of approaching what might happen. One guess taken by many students as a starting point was that the light would end up being equally divided between the two guides. That is a reasonable hypothesis, but it has a problem: if we launched the light into the bottom guide, we could come to the conclusion that we get the same result, with light also equally divided between top and bottom; that leads to us having the same output for two different inputs, and if we time-reverse the problem, shining such an output back in on the right, we don't know which one we would get at the left – would all the light be in the top guide or in the bottom guide? We violate some kind of uniqueness theorem. (It is important in this counter argument here that the system is loss-less; lossy systems do not have to be reversible, and students were told if this came up that the system was lossless.)

Perhaps the best way to reason about what happens is to reason from some understanding of coupled systems and how they behave. There are many coupled systems one could use for analogies. The simplest is possibly coupled pendula (two equal masses hanging on two equal length strings, with the masses coupled together by some weak spring). In such a system, if we start one mass oscillating (i.e., swinging), it will gradually transfer all of its oscillation to the other mass, which will then transfer it back, and so on. In the waveguide problem here, the analogy is that the light progressively transfers (totally) from the top guide to the bottom guide and back again as we move along the guide (or increase L).

Students who did not know or think of coupled systems such as coupled pendula, coupled wells, or masses on springs instead had to reason creatively to propose that this kind of behavior, of oscillation back and forth, would happen. They could do this by a process of elimination of other hypotheses.

If we reduce s, we increase the strength of the coupling, which leads to the transfer of light back and forward between the two guides occurring over a shorter total distance.

Supplementary question

There are two ways we can launch light into both guides that will lead to a pattern in the guides that does not change as we move down the guides. These correspond to the eigenmodes of the coupled system. Like other equal, coupled systems, there is a symmetric mode, in which we launch equal power into both guides with the same phase, and an antisymmetric mode, in which we launch equal power into both guides with the opposite phase. Students who got to this point could usually come up with one of these if not both.

Supplementary question 2

In this question, since there is nowhere else for the light to go in the steady state (there is essentially nothing to back-reflect the light in the problem), all the light that goes into the guide on left comes out on the right. However, as we change the separation s, the phase of the light coming out will in general change.

The actual behavior of this system is quite subtle, and the details were not important for the exam. For interest, the behavior of systems like this is discussed and reviewed in, for example, W. Bogaerts, P. De Heyn, T. Van Vaerenbergh, K. De Vos, S. K. Selvaraja, T. Claes, P. Dumon, P. Bienstman, D. Van Thourhout, and R. Baets, "Silicon microring resonators," Laser Photonics Rev. 6, No. 1, 47–73 (2012) DOI 10.1002/lpor.201100017

Quals Questions 2017

David Tse

Question:
n persons belong to two groups. A priori we do not know which individual belongs to which group. We are given pairwise measurements whether two individuals are in the same group or different groups. For each pair of nodes, there is a measurement with probability p and no measurement with probability 1-p, independently across different pairs.

a) Suppose $p = 1$. Find an algorithm to separate out the two groups from the measurements.

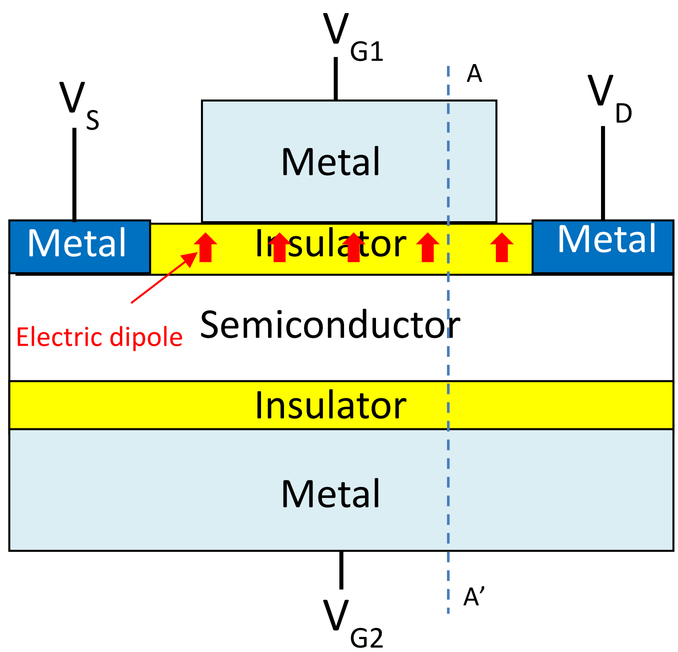
b) Suppose $p < 1$. What is the expected number of measurements? Find a simple algorithm to separate out the two groups, and justify that your algorithm succeeds with high probability in the regime that p is fixed and n is large.

2017 Qualifying Exam Questions

Prof. H.-S. Philip Wong

Consider the device below (first without the dipoles):

1. Draw the band diagram across the metal/insulator/semiconductor/insulator/metal stack (section A-A')
2. Sketch the I_{G1} vs V_{G1} curve as V_{G1} ramps from negative to positive linearly slowly (e.g. 10 mV/s) and then from positive back to negative linearly slowly (i.e. you apply a triangular voltage ramp).
3. Now, add the dipoles in the picture. The dipoles initially have positive charges near the metal electrode and negative charges near the semiconductor.
4. The dipoles will change direction if the electric field exceeds a certain value.
5. With the dipoles now in place, sketch the I_{G1}-V_{G1} curve of the device, for V_{G1} range from negative to positive, for $V_D = V_S = 0$ V
6. Consider putting a capacitance measurement unit on the device with $V_{G2} = 0$ V and V_{G1} range from negative to positive. What does the C-V curve look like?



2016-2017 EE Ph.D. Qualifying Exam
Question area: *Modern and Quantum Physics*
Examiner: *Jelena Vuckovic*

Clearly state any assumptions you make while solving the problems. Good luck!

1. A laser beam with a free space wavelength λ and electric field amplitude E_i is incident from free space (in the x direction) onto a barrier with dielectric constant ε and thickness d, as shown in Figure 1. Explain what can happen in each of the three regions shown in in the figure.

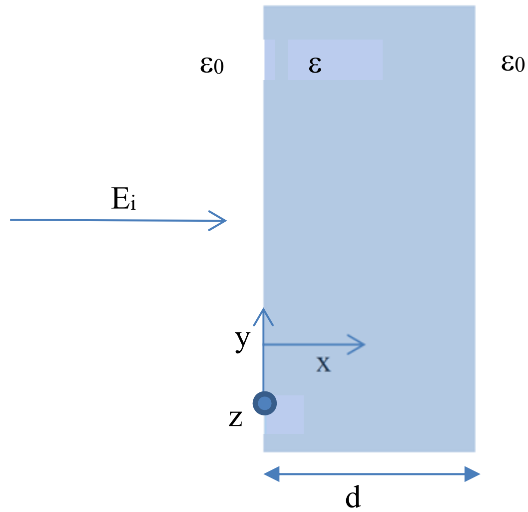


Figure 1.

2. Now assume that the same barrier is periodically repeated N times, as shown in Figure 2. Explain what happens with the same laser beam in this case.

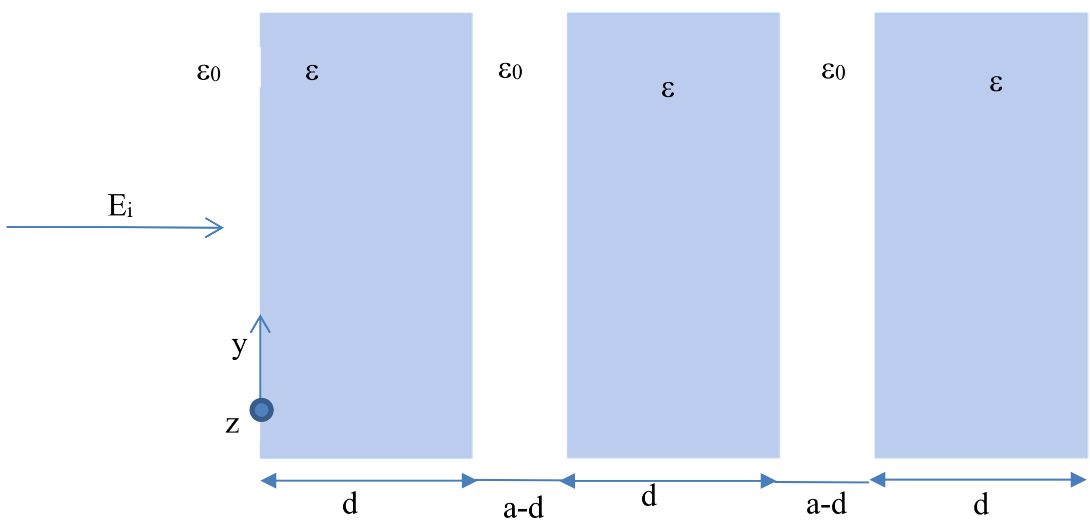
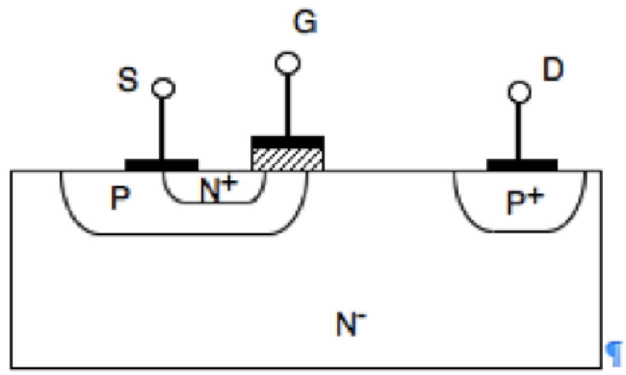


Figure 2.

3. Assume now that instead of a laser beam, a single photon is incident onto the barrier in Fig. 1 and on periodic barriers in Fig. 2. Would your answers to the questions above be the same or different?

2017 Quals
J. Plummer



I asked a series of questions about the semiconductor device structure shown above. These questions focused first on the expected I-V characteristics of the device, developing an equivalent circuit for the device and explaining why it would behave the way the student thought it would.

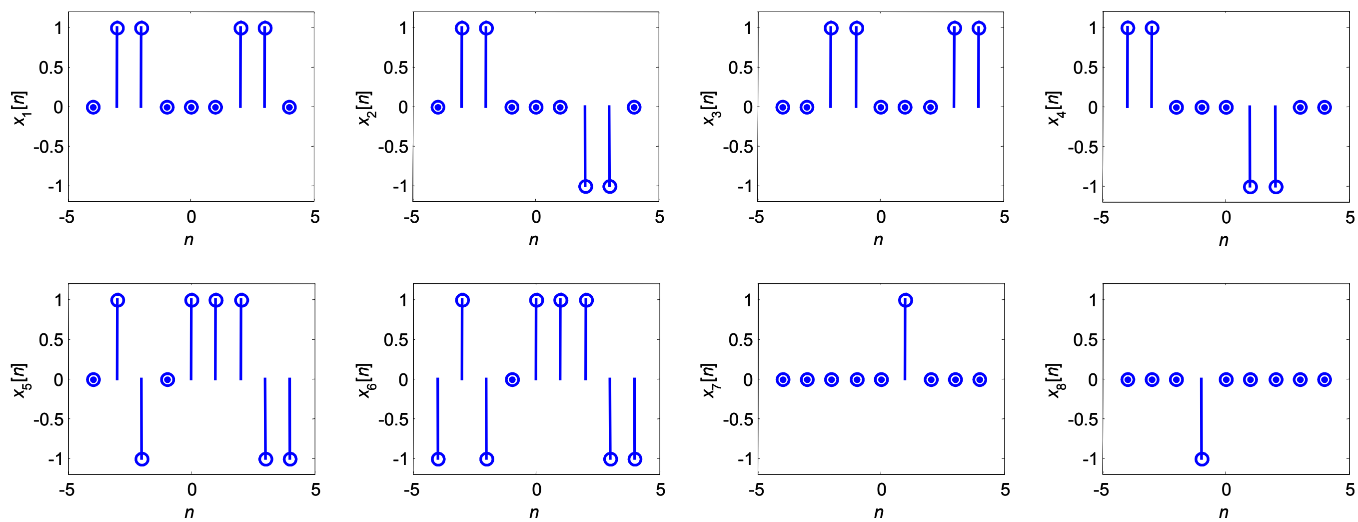
While this looks initially like a simple structure, its behavior is actually quite complicated. Most students started by noting that it looks like an MOS transistor in series with a PN diode and therefore thought about MOS like I-V characteristics, offset from the origin by about 0.7 volts. This usually led to the observation (sometimes with some help), that actually there is a lateral PNP transistor which provides a parallel current path. So a better equivalent circuit is an MOS device driving a bipolar PNP. This gives MOS like I-V characteristics but with higher gain. Finally, some students noticed that the PNP collector current actually flows through the P region resistance on the left, generating an IR drop. This can result in latchup in the device because there is also a parasitic NPN bipolar transistor. Most students who got this far needed help to see this last possibility.

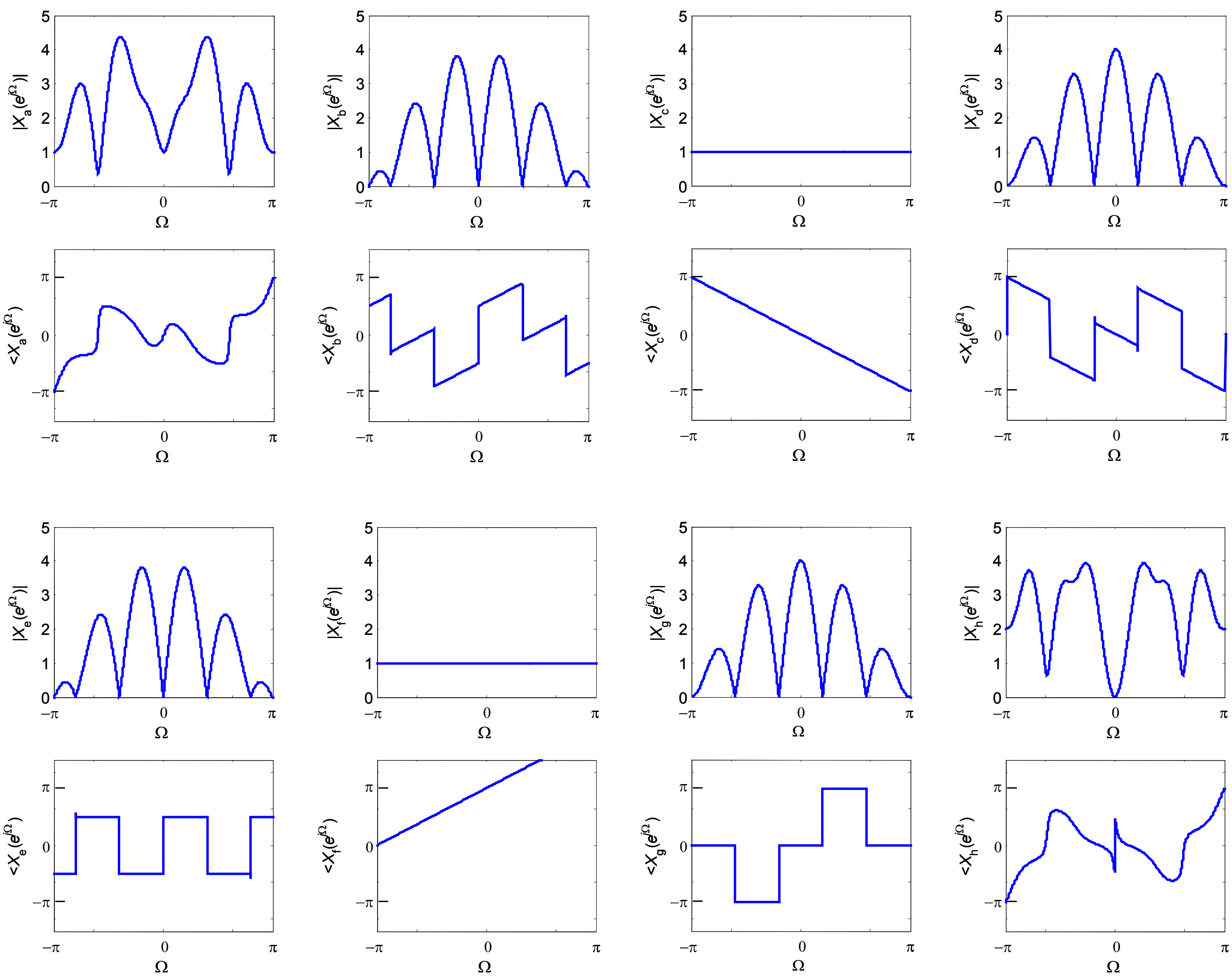
I also asked about the role that holes and electrons play in the current flow in the device. The scores I gave depended on the student's ability to reason through the operation of the device, and on how much help I needed to give during the exam.

Stanford University, Department of Electrical Engineering
Ph.D. Qualifying Examination, Linear Systems, Winter 2016-17
Professor Joseph M. Kahn

Eight real signals $x_1[n],\ldots,x_8[n]$ are shown. Their discrete time Fourier transforms $X_a\left(e^{j\Omega}\right),\ldots,X_h\left(e^{j\Omega}\right)$ are shown (in magnitude and phase form). Match each signal to its DTFT, entering the appropriate letter in the second column. Provide a brief justification based on symmetry, slope of the phase $\angle X\left(e^{j\Omega}\right)$, d.c. value $X\left(e^{j0}\right)$, etc.

Signal	DTFT	Explanation
1		
2		
3		
4		
5		
6		
7		
8		


x1[n]
x2[n]
x3[n]
x4[n]
x5[n]
x6[n]
x7[n]
x8[n]
n


|Xa(e^jΩ)|
|Xb(e^jΩ)|
|Xc(e^jΩ)|
|Xd(e^jΩ)|
<Xa(e^jΩ)
<Xb(e^jΩ)
<Xc(e^jΩ)
<Xd(e^jΩ)
|Xe(e^jΩ)|
|Xf(e^jΩ)|
|Xg(e^jΩ)|
|Xh(e^jΩ)|
<Xe(e^jΩ)
<Xf(e^jΩ)
<Xg(e^jΩ)
<Xh(e^jΩ)
Ω

Answer

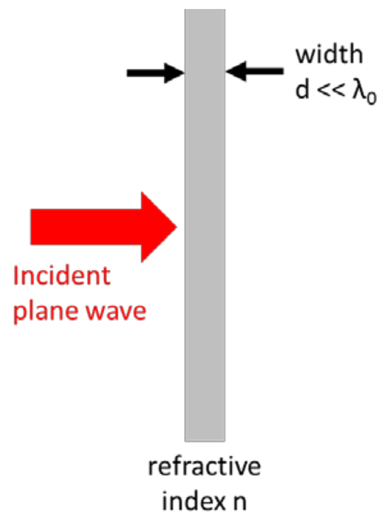
Signal	DTFT	Explanation
1	g	$x[n]$ real, even $\leftrightarrow$ $X(e^{j\Omega})$ real, even, $\angle X(e^{j\Omega}) \in \{0, \pi\}$
2	e	$x[n]$ real, odd $\leftrightarrow$ $X(e^{j\Omega})$ imaginary, odd, $\angle X(e^{j\Omega}) \in \{-\pi/2, \pi/2\}$
3	d	$x[n]$ delayed real, even signal $\leftrightarrow$ $X(e^{j\Omega})$ real, even, but with added negative phase slope
4	b	$x[n]$ advanced real, odd signal $\leftrightarrow$ $X(e^{j\Omega})$ imaginary, odd, but with added positive phase slope
5	a	$x[n]$ has unit d.c. value $\leftrightarrow$ $X(e^{j0}) = 1$
6	h	$x[n]$ has zero d.c. value $\leftrightarrow$ $X(e^{j0}) = 0$
7	c	$x[n]$ delayed impulse $\leftrightarrow$ $\lvert X(e^{j\Omega})\rvert = 1$, negative phase slope
8	f	$x[n]$ advanced impulse $\leftrightarrow$ $\lvert X(e^{j\Omega})\rvert = 1$, positive phase slope

Electrical Engineering Qualification Exam

Winter 2017

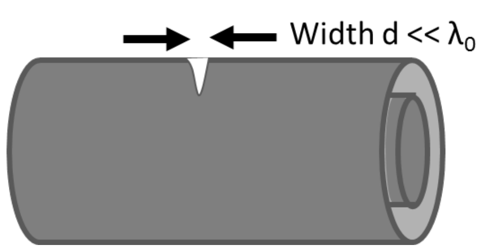
Jonathan Fan

Question 1: A plane wave is normally incident onto a isotropic dielectric film with a refractive index *n*. The width *d* of the film is highly subwavelength, i.e. $d << \lambda_0$ where λ_0 is the free space wavelength of the incident wave:



What is the intensity of the transmitted wave?

Question 2: A coax cable has a small dent with length scale *d* that is highly subwavelength, i.e. $d << \lambda_0$. Do you expect the transmission in this case to be similar to that of the thin film system in question 1? Why or why not?



Name:

Consider the schematic of the Tesla coil shown in Fig. 1. Figure 2 shows pictures of some Tesla coils.

The 10:1 input transformer is a tightly coupled transformer wound on a high permeability iron core (e.g., neon sign transformer). In this transformer the coupling coefficient $k \approx 1$.

The Tesla coil proper is a loosely coupled set of "air-core" coils with the N_p turns primary coil having a diameter d_p. The secondary coil has N_s turns and has a diameter d_s. The coupling coefficient for the coil is $k \approx 0.1$.

The inductance of an air-core solenoid is: $L_c = \frac{\mu_0 N_c^2 A_c}{h_c}$, where N_c is the number of turns, A_c the area of the coil, h_c the height of the coil.

- Explain how the Tesla coil operates, and how you would design/tune one.
- What is the voltage the "spark-gap" should trigger to maximize output voltage.
- Why does a Tesla Coil use loosely coupled coils?
- What's the role played by the toroid at the top of the secondary coil?
- What are the conditions for the Tesla Coil to operate?
- How would you select values for C_p given N_p, N_s, k and the other physical dimensions of the coils and top torus?
- Where the voltage gain come from?
- What is the frequency of the output?
- How can you estimate the amplitude of the output voltage?

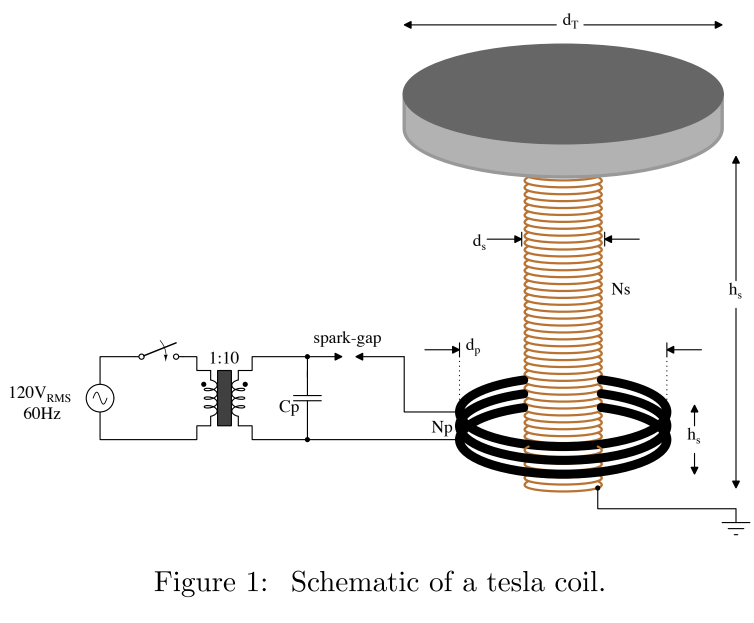
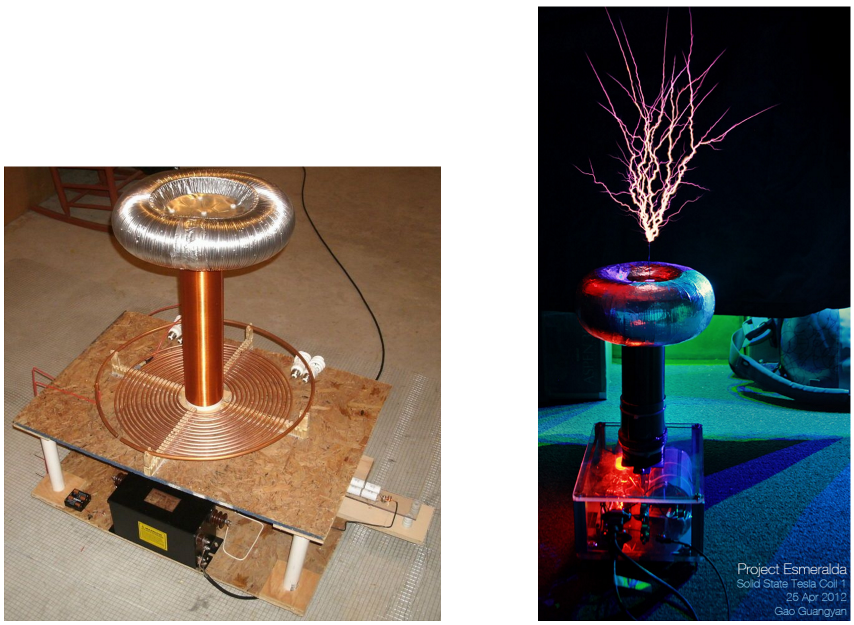


Figure 1: Schematic of a tesla coil.



(a) Tesla Coil (b) Tesla coil

Figure 2: Photographs of Tesla Coils.

Quals Questions 2017

Krishna Saraswat

1.Why does the temperature of a laptop increase? What do you understand by power dissipation?

2.Where is power dissipated in a chip, transistor vs. interconnect?

3.Where is heat dissipated in a transistor and interconnect and by which mechanism?

EE Quals Question, Linear Systems

Mary Wootters

2017

Consider the $n \times n$ matrix

$$M = \frac{1}{2}\begin{pmatrix} 0 & 1 & 0 & 0 & \cdots & 0 & 1 \\ 1 & 0 & 1 & 0 & \cdots & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & \cdots & 0 \\ 0 & 0 & 1 & 0 & 1 & \cdots & 0 \\ \vdots & & & & & & \\ 0 & 0 & \cdots & 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & \cdots & 0 & 1 & 0 \end{pmatrix}$$

(a) Given $x \in \mathbb{C}^n$, describe the product Mx; what operation does "left-multiplication-by-M" correspond to?

(b) Give a diagonalization of M.

(c) What are the eigenvalues of M?

— I didn't expect too many people to make it past this point; a few got to part (d), though no one got to part (e) —

(d) Suppose that n is odd, and consider M^k for really large k. What does M^k approach as $k \to \infty$ (where n is fixed)?

(e) Notice that M is the transition matrix for a random walk on a graph that is a cycle. In this light, what does part (d) mean?

(f) In terms of n, about how big does k have to be before your conclusion in (e) is qualitatively true? (I'm only interested in the rate of growth of k as a fuction of n, eg, "k needs to grow exponentially quickly in n" or "n doesn't matter for this value of k", not an exact formula).

Solutions:

(a) Multiplication by M is circular convolution with the vector $v = (0, 1/2, 0, \ldots, 0, 1/2)$. (Though it was okay just to describe what this operation is, without coming up with the phrase "convolution").

(b) A diagonalization of M is given by the rows of the discrete Fourier transform. To see this, we can use the fact that pointwise multiplication in the Fourier domain is the same as convolution in the time domain. More precisely, let F be the $n \times n$ DFT. By part (a), $Mx = v * x$, and so $\widehat{Mx} = \hat{v} \circ \hat{x}$. In matrix notation,

$$FMx = DFx,$$

where D is a diagonal matrix with $\hat{v}$ on the diagonal. Since this is true for all x, we have

$$FM = DF,$$

aka

$$M = F^{-1}DF.$$

This gives a diagonalization of M (after normalizing the rows of F).

(c) Following part (b), the eigenvalues of M are the diagonal entries of D, which are the entries of $\hat{v}$. These are

$$\hat{v}[\ell] = \frac{1}{2}\left(e^{-2\pi i\ell/n} + e^{-2\pi i\ell(n-1)/n}\right) = \frac{1}{2}\left(e^{-2\pi i\ell/n} + e^{2\pi i\ell/n}\right) = \cos(2\pi\ell/n).$$

(d) Using the decomposition we found in parts (b)-(c), we see

$$M^k = (F^{-1}DF)^k = F^{-1}D^kF$$

Since n is odd, the only ℓ so that $|\cos(2\pi\ell/n)| = 1$ is $\ell = 0$; all the rest have $|\cos(2\pi\ell/n)| < 1$. Thus, for really big k, D^k approaches the matrix

$$D' := \begin{pmatrix} 1 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & \cdots & 0 \\ \vdots & & & & \\ 0 & 0 & 0 & \cdots & 0 \end{pmatrix}.$$

The whole thing thus tends to $F^{-1} \cdot D' \cdot F$, which is the matrix where every entry is $1/n$.

(e) Eventually, a random walk on an n-vertex cycle converges to the uniform distribution.

(f) Part (e) assumed that the second eigenvalue λ_2^k was really small. This second eigenvalue is equal to

$$\lambda_2 = \cos(2\pi/n) = 1 - \frac{(2\pi/n)^2}{2!} + \frac{(2\pi/n)^4}{4!} - \cdots = 1 - O(n^{-2}).$$

Thus,

$$\lambda_2^k = \left(1 - O(n^{-2})\right)^k = O(\exp(-k/n^2)).$$

So when k gets to be larger than n^2 or so, this starts getting small; thus we expect that $O(n^2)$ steps are enough for this random walk to mix.

EE Quals 2017

Systems and Software

Nick McKeown

Question 1

My home router can send data to Comcast at 100Mb/s. Inside, it has a single FIFO packet buffer that can hold up to 125,000 bytes of data. If the buffer is currently full, how long will it take to empty (assuming no more packets arrive)?

Question 2

My laptop starts sending 200,000 packets per second to my router, each one 125bytes long. How long before the router buffer overflows, if the buffer was initially empty?

Question 3

Sketch the cumulative arrival and departure process as a function of time. Indicate the queue occupancy, the delay of bits up to the first overflow. What happens after the overflow?

How are your answers different if the queue is LIFO (bit by bit) instead of FIFO?

Qualifying Exam for the Electrical Engineering PhD program, Stanford University, January 2017

Olav Solgaard

1) What is this? (Showing the student a Barlow wheel.)

2) How does it work?

3) In earlier implementations, Hg was typically used. How and why?

4) Comment on the efficiency of the motor? Start by defining efficiency.

5) If efficiency is OK, what makes this motor impractical?

6) How does this motor work? (Showing the student a toy electric motor.) And why is it more practical? In general, how do you make the motor more practical, i.e. able to accept more electrical input power and convert it to mechanical rotation power?

7) How can you change the motor to run on AC voltage?

Quals Questions 2017 – Piero Pianetta

Question:

What do you know about the photoelectric effect? This is to make sure everyone starts at the same level of knowledge.

Now consider a metal with a valence band width of 10 eV, a work function of 5 eV and an atomic core level at 50 eV below the Fermi level. Assume that a constant flux of photons of energy E is incident on the surface of the metal. Plot the number of electrons (or current) emitted from the surface as a function of photon energy.

Quals 2017
Sachin Katti

1) Explain whether the following are causal, linear or time-invariant:
   a. $y[n] = \sum_{k=-\infty}^{k=n} x[k]$

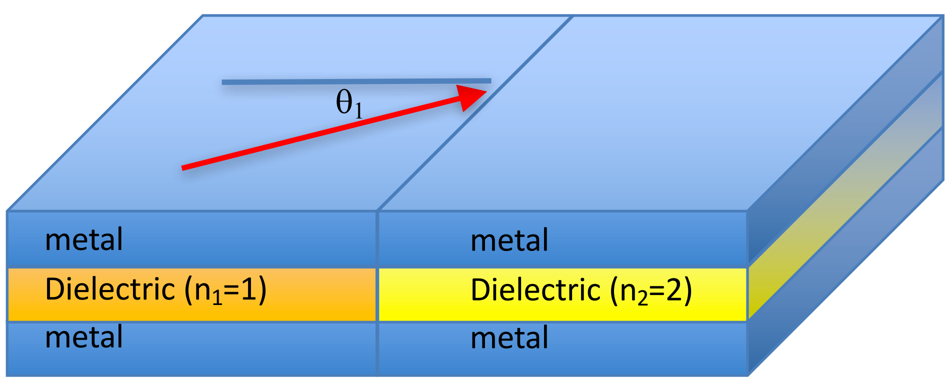
   b. $y[n] = \sum_{k=-\infty}^{k=\infty} x[k]x[k+n]$

   c. $y[n] = \begin{matrix} x[n] \ \ if \ \ x[n] \geq 0 \\ -x[n] \ if \ \ x[n] < 0 \end{matrix}$

2) Can you design an LTI system that can take in a song as input and output the same song one octave higher?

(a) Consider a parallel plate waveguide where a dielectric plate with a refractive index n is sandwiched between two perfectly conducting metallic plates. The thickness of the dielectric plate is *a.* Provide the ω–k relation for the first two TE modes. (TE modes have their electric field parallel to the plate), for both cases of n = 1 and n = 2.

(b) Consider the following scenario where an interface is formed between two parallel plate waveguides. A fundamental TE mode with a frequency $\omega = \sqrt{2}\pi c/a$ is incident from one of the parallel plate waveguide to the interface at an angle θ_1. Determine the direction of the transmitted wave in the other parallel plate waveguide.



Name

Start time

I am assuming students do NOT know error-correcting codes. I am looking for how they think about solving these problems.

Suppose that you have n bits of data, and one of the bits (or none) can be erroneous. You don't know which one.

1. What is the minimum number of additional bits you will need to figure out if there is any erroneous bit?

2. What is the minimum number of bits you will need to find out which bit is erroneous and fix it?

3. Suppose that the data bits are: d0, d1, d2, d3, …, d7, and suppose that I am using only XOR gates to create check bits. How will you go about implementing 2?

Hint: Suppose c0 = d0 XOR …; c1 = d0 XOR …; c2 = d0 XOR …; c3 = d0 XOR ….

3. The bits are organized in a memory array, and suppose that one of the address bits inside the array turn out to be erroneous. How can you detect that?

4. Suppose that somehow I know which bit "can be" erroneous. How many check bits do I need now for correcting the error, and what is the implementation?

Quals Questions 2017 – Tom Soh

Question 1

A) Please sketch a dipole and draw electric fields that result from it

B) Draw equipotential lines

C) How does the electric field drop-off as a function of distance?

Question 2

Imagine an infinite two-dimensional plane of charge with an areal charge density of (ρ_s) in free space.

A) What is a the electric field at point P which is 3 meters away from its surface?

B) What is the potential at point P?

Question 3

Now, imagine that you immerse the infinite plane of charge into a solution that has a high density of free ions.

A) What do you think will happen? Please sketch it

B) What will be electric potential at point P, which is 3 meters from the surface?

C) What is the potential at point P?

Quals Question - 2017

(a) How many leading 0s in 100!?

(b) Let X be uniformly distributed over $\{1, 2, \ldots, 30\}$. What is the expected number of leading 0s in X!?

(c) Consider a party of 6 people. During the party, anyone may or may not choose to shake hands with any one of the others. Show that at the end of the party there will be a subset of 3 people in which either everyone shook the other two's hands or everyone shook none of the other two's hands.

2016-17

PhD Qualifying Examination

Prof. Yoshio Nishi

1. Draw a cross section of nMOSFET from source to drain, and describe potential and electric field distributions in the channel direction (1) low drain voltage condition and (2) high drain voltage condition. Applied gate voltage is higher than the threshold voltage.

2. Discuss behavior of electrons in
   (a) Within the source electrode
   (b) At the moment when injected into conductive channel
   (c) Within the conductive channel
   (d) Arriving at the drain electrode