Quals Questions

2006

Electrical Engineering

Stephen Boyd

Ask me about anything that isn't clear.

Linear dynamical system $\dot{x} = Ax$, with $x(t) \in \mathbf{R}^n$

System is called **constant norm** if for every trajectory x, $\|x(t)\|$ is constant, *i.e.*, doesn't depend on t

System is called **constant speed** if for every trajectory x, $\|\dot{x}(t)\|$ is constant, *i.e.*, doesn't depend on t

Give an example of a constant norm system.

Give an example of a constant speed system.

Find the conditions on A under which the system is constant norm.

Find the conditions on A under which the system is constant speed.

Is every constant norm system a constant speed system?

Is every constant speed system a constant norm system?

Discussion/solution.

The system is constant norm if and only if

$$\begin{aligned} 0 &= \frac{d}{dt}\|x(t)\|^2 \\ &= 2x(t)^T\dot{x}(t) \\ &= 2x(t)^T Ax(t) \\ &= x(t)^T(A+A^T)x(t) \end{aligned}$$

for all $x(t)$, which occurs if and only $A+A^T=0$, which is the same as $A^T=-A$, *i.e.*, A is skew-symmetric. There are many other ways to see this. For example, the norm of the state will be constant provided the velocity vector is always orthogonal to the position vector, *i.e.*, $\dot{x}(t)^T x(t) = 0$. This also leads us to $A+A^T=0$.

Another approach uses the state transition matrix e^{tA}. The system is constant norm provided e^{tA} is orthogonal for all $t \geq 0$. From here, you'd have to argue that A must be skew-symmetric.

The system is constant speed if and only if

$$\begin{aligned} 0 &= \frac{d}{dt}\|\dot{x}(t)\|^2 \\ &= \frac{d}{dt}\|Ax(t)\|^2 \\ &= 2(Ax(t))^T A\dot{x}(t) \\ &= 2x(t)^T A^T A^2 x(t) \\ &= x(t)^T A^T(A+A^T)Ax(t) \end{aligned}$$

for all $x(t)$, which occurs if and only $A^T(A+A^T)A=0$. In other words, the matrix A^TA^2 is skew-symmetric.

We see that if a system is constant norm, then it must be constant speed, since $A+A^T=0$ implies that $A^T(A+A^T)A=0$.

But the converse is false, as the simple system

$$\dot{x} = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} x,$$

which is a double integrator, shows. This system has trajectories of the form

$$x(t) = \begin{bmatrix} x_1(0) + tx_2(0) \\ x_2(0) \end{bmatrix}.$$

It doesn't have constant norm, but it does have constant speed, since $\dot{x} = (x_2(0), 0)$.

2006 Quals — J. Cioffi

TOTAL - 10 pts

Noise- 10 pts

A continuous uniform random variable is used to model the quantization error (or noise) of a digital-to-analog converter (DAC). This error is between $-\frac{\Delta}{2}$ and $+\frac{\Delta}{2}$.

a). What is the mean of this error. (0.5 pt)

b). What is the variance of this error (or energy of the noise)? (1 pt)

c). Two independent signals both occupy the same electrical medium and both were generated by identical DACs of the form in this exam. Provide the distribution, mean, and variance of the sum of the errors (or new noise). (2 pts)

d). Extend part c to 20 signals (say an unlicensed wireless band) to determine the distribution, mean, and variance. (3 pts)

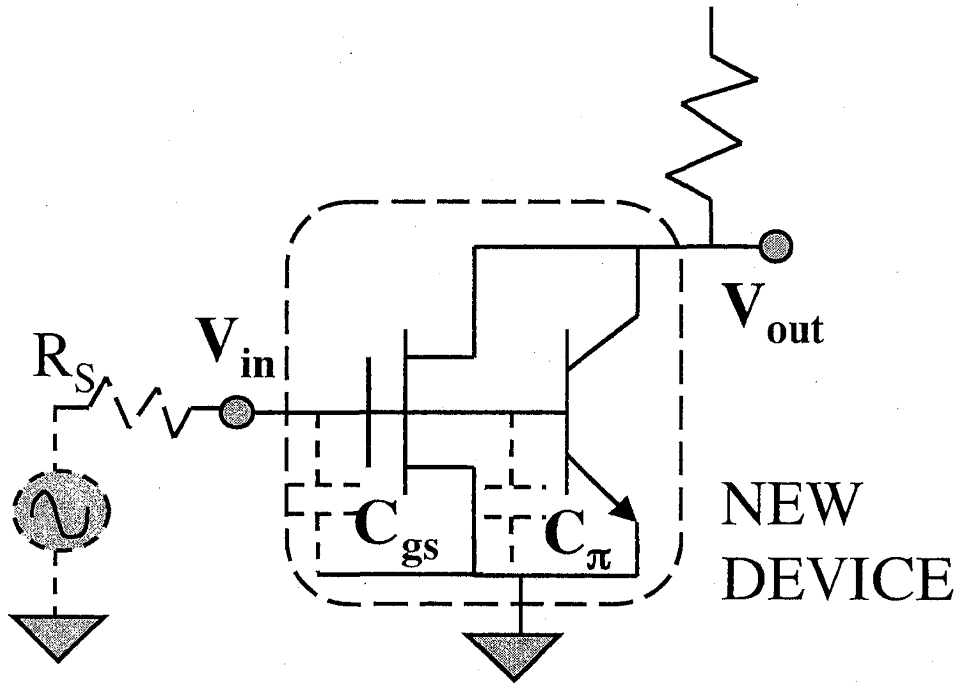
e). Suppose all the DACs have $\Delta = .001$ and the signals themselves have unit energy. What is the signal to noise ratio for a single signal with no others occupying the medium. (1 pt)

f). Now suppose that all signals but one have very small transmit energy but their DACs continue to have the same noise even when zero signal is transmitted (the designer saved some money and did not care about quantization noise if not transmitting). What is the new SNR for that one signal? (1 pt)

g). Qualitatively describe what you expect would happen to the distribution of the noise if the situation in part f applied, but each of the DACs had a different Δ. (1.5 pts).

Robert Dutton

A device technologist has created a NEW DEVICE-- part MOS, part BJT--with "drive current" given by: $I_{Drive}=I_D(MOS)+I_C(BJT)$. The schematic is as follows.

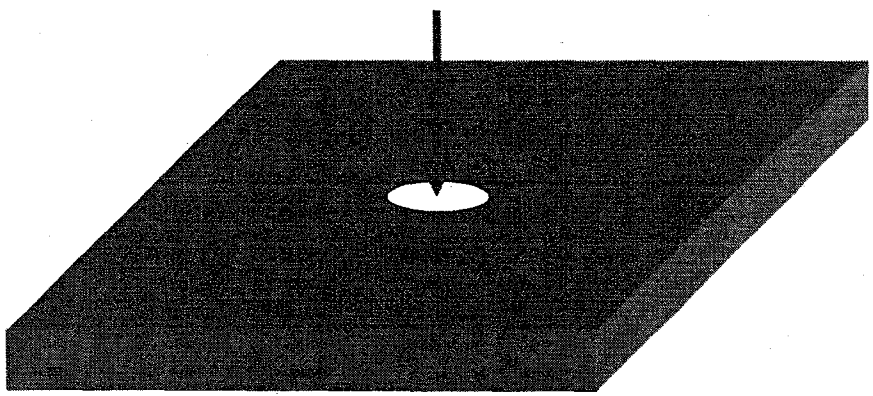


To achieve maximum small-signal (ac)voltage gain, at what operating point should we bias the NEW DEVICE? What is the ac gain and bandwidth?

Shanhui Fan

In this exam, the metal is all assumed to be perfect metal. (i.e. perfect electrical conductor).

(a) What are the boundary conditions for the electric fields at the metal-air interfaces?
(b) What are the boundary conditions for the magnetic fields at the metal-air interfaces? Why?
(c) Consider an infinitely long cylindrical air hole inside a metal, sketch qualitatively the $\omega \sim \beta$ diagram for the lowest order propagating modes inside the hole, where ω is the angular frequency for the waves and β is the propagation constant. (i.e. the field varies along the z-direction, defined as the axis of the cylinder, as $e^{-i\beta z}$.)
(d) Sketch the electric field vector distribution of the lowest order propagating inside the hole.
(e) Consider the following experiment, where a plane wave is incident upon a metal film with a hole introduced in it. Could you sketch the amount of transmitted power as the wavelength is varied from $\lambda >> a$ to $\lambda \sim a$, where a is the radius of the hole?

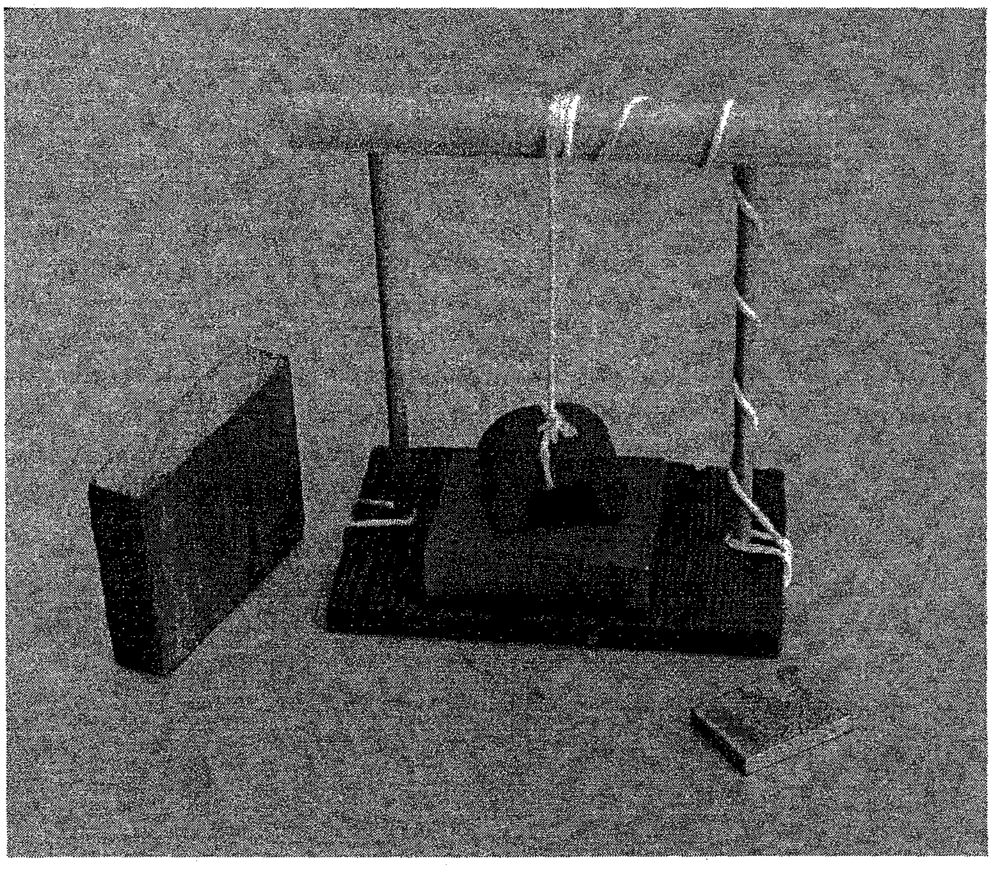


Scoring: (a) 1; (b) 2; (c) 2; (d) 2; (e) 2; (f) 3.
In (c), a rough estimate of the cut-off 1 point
In (f), plot of the cut off 2 point, Fabry Perot oscillation 1 point.

Ph.D. Quals Question
January 2006
A.C. Fraser-Smith
Space, Telecommunications and Radioscience Laboratory

Faraday's Law

The figure below shows the experimental arrangement that was shown to each student. The key item is a powerful horseshoe magnet (red) that is hanging by a piece of string from a wooden suspension. When the students first see it, it has a steel "keeper" across its two ends. This is the silvery colored piece of metal sitting off to the right in the figure; the instructor or student has to really wrestle with that piece of metal to disconnect it from the magnet – thus emphasizing the strength of the magnet. The student is next asked to identify the object to the left in the figure. Many say "wood," whereupon the instructor reminds them that they are electrical engineering students and in most cases they amend their description to "insulator" or better, "poor conductor." Next, they are presented with the heavy, reddish object shown here under the magnet. Better prepared. most students will say "it is copper, a good conductor." The instructor next pokes the magnet to set it in oscillation, without either the wood or copper block beneath it, and asks the student to watch its motion, which can go on, seemingly unimpeded, for a long time. Next he places the "poor conductor" under it, without any noticeable change in the magnet's oscillations. He then asks the student to put the copper under it, whereupon it stops. The student is asked to get it oscillating again, but without much success. Quite noticeably, its motion is heavily damped. Now begins the academic part: the instructor asks the student to explain what is going on from an electrical engineering point of view, with emphasis on the basic laws involved.



Points were awarded for (1) simply working out what was going on from an EE point of view, i.e., the moving magnet was creating a time-varying magnetic field in the conductor – as well as in the insulator (wood) – which produced eddy currents whose magnetic fields opposed the motion creating them. Then (2) the wood produced a negligible effect because the eddy currents were inhibited by the lack of conductivity and were small/negligible, while the eddy currents could flow relatively freely in the copper.

Further points were awarded for (3) identification of Faraday's Law as the physical basis for the hypothesized link between time-varying magnetic field in the conductor and the induced eddy currents. This identification most succinctly made use of Faraday's law in the form:

$$EMF = -\, \partial N / \partial t$$

where *EMF* indicates the induced emf, N is the magnetic flux threading the circuit, and t is the time. In addition, since the pendulum motion of the magnet was most clearly opposed by the currents in the conducting material, it was expected that the student would mention (4) Lenz's Law (essentially the minus sign in the above equation). Finally, (5) in response to a query from the instructor about why the motion of the magnet was opposed and not assisted by the eddy currents, some mention of conservation of energy led to the final assignment of points for this part.

To end this brief exam, the instructor held the wooden stand down firmly on the table and asked the student to remove the copper block without touching or otherwise disturbing the magnet. To cut a long story short, this can only be done by slipping the copper block out from under the magnet at an extremely slow rate, i.e., so that the rate of change of magnetic field in the block is so slow that the induced currents are negligible. Slipping the block out quickly leads to a substantial disturbance of the magnet. At this stage the final points were awarded based on the student's recognition that the disturbance of the magnet was simply another aspect of the original problem. A student who laughed and said "you are having me on – there is no way I can avoid disturbing the magnet except by taking the copper away very slowly" got full marks for this part.

Date: Fri, 27 Jan 2006 21:43:25 -0800
To: Diane Shankle <shankle@ee.Stanford.EDU>
From: Mark Horowitz <horowitz@stanford.edu>
Subject: Re: Quals Meeting Time Change Please see below!

Quals questions:

Basic setup: We have a new type of transistor called QMOS, which has no leakage current when it is off, and roughly the same one resistance as a normal MOS device when turned on. The big advantage of QMOS is that it operates at 100mV, and nicely turns on when Vg is about 30mV. The downside is that to conduct current a nano-structure must move a nano distance and that takes 1-2ns. So the current is delayed by this amount of time. The input cap is 2fF/u, and assume the output resistance is 10K/sq.

Is this technology interesting? Why?

How should you think about logic design if this is your implementation technology. What are the rules of thumb you should use? What kinds of logic gates should you build?

Mark

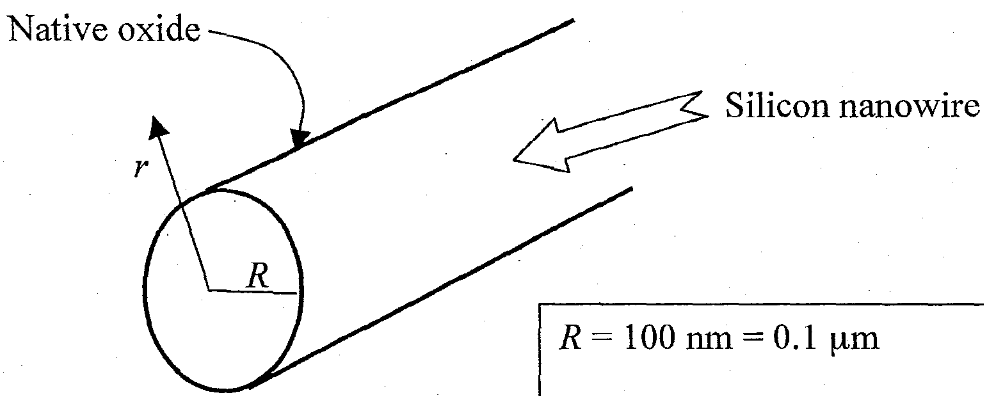
At 04:23 PM 1/27/2006, you wrote:

> Quals Meeting
> Tuesday, January 31st.
> 4:30 P.M.
> CIX-X AUD
>
> Coffee,Tea and Cookies will be served before the meeting.
>
> Please send me a copy of your Quals Question either by email or a
> hard copy to the address listed below!
>
> Happy Friday,
> Diane
>
> --
>
> Any other questions feel free to call me!
>
> Diane Joan Shankle
> Tel: (650) 723-3194
> FAX: (650) 723-1882
> shankle@ee.stanford.edu
> Stanford University
> Electrical Engineering
> Student Services
> Packard Building Rm. 177
> Stanford,CA 94305-9505
> http://www-ee.stanford.edu

Stanford University
Dept. of Electrical Engineering

Device Physics Qualifying Exam

R. T. Howe — Winter 2006



$R = 100$ nm $= 0.1$ μm

Acceptor concentration $= N_a = 10^{17}$ cm^{-3}

Native oxide thicknesss $= t_{ox} = 5$ nm

Density per unit area of positive charges in the native oxide $= 10^{11}$ cm^{-2}

Oxide charge is *fixed and uniformly distributed* through the thickness

a) Sketch (on the white board) the band diagram in thermal equilibrium from $r = 0$ to $r = R + t_{ox}$. Make reasonable assumptions and then verify them.

b) If the doping is reduced to $N_a = 10^{16}$ cm^{-3}, how does the band diagram change?

From: "Ramesh Johari" <rjohari@stanford.edu>
To: "'Diane Shankle'" <shankle@ee.Stanford.EDU>
Subject: RE: Quals Meeting Time Change Please see below!
Date: Fri, 27 Jan 2006 16:31:55 -0800
Thread-Index: AcYjoSTBdzWaCh9JQ+GZBZdis/ufxwAALfYQ

Hi Diane,

My quals question is below. Am I required to attend the quals meeting?

Ramesh

There are two questions, you may do them in any order.

Q1. You are given three random variables, X_1, X_2, X_3.

X_1 is independent of X_2.
X_2 is independent of X_3.
X_3 is independent of X_1.

Is it true that (X_1, X_2, X_3) are jointly independent? Either prove or provide a counterexample.

Q2. Can you find three random variables X_1, X_2, X_3 such that:

$P(X_1 > X_2) > 1/2$
$P(X_2 > X_3) > 1/2$
$P(X_3 > X_1 > 1/2$?

If so, provide them.
If not, prove you cannot.

Does your answer to the question depend on whether or not (X_1, X_2, X_3) are assumed to be jointly independent?

\> -----Original Message-----
\> From: Diane Shankle [mailto:shankle@ee.Stanford.EDU]
\> Sent: Friday, January 27, 2006 4:23 PM
\> To: quals-examiners@ee.Stanford.EDU; EE-adminlist@ee.Stanford.EDU
\> Subject: Quals Meeting Time Change Please see below!
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\>
\> Quals Meeting
\> Tuesday, January 31st.
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\> CIX-X AUD
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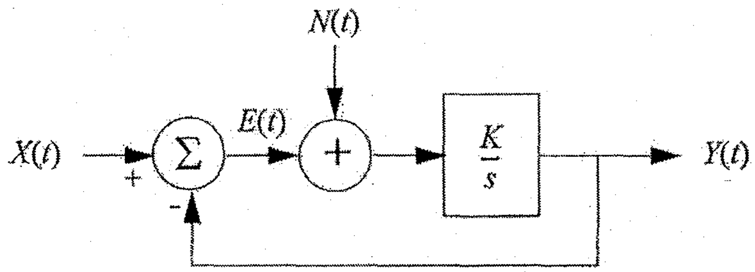
\> Coffee,Tea and Cookies will be served before the meeting.
\>
\> Please send me a copy of your Quals Question either by email
\> or a hard copy to the address listed below!
\>
\> Happy Friday,
\> Diane
\>
\>
\>
\>
\> --

Stanford University
Department of Electrical Engineering
Qualifying Examination Winter 2005-06
Professor Joseph M. Kahn



This system attempts to make the output $Y(t)$ follow the input $X(t)$. The input is a Wiener process with power spectral density:

$$S_X(\omega) = \frac{X_0}{\omega^2}.$$

The signal $E(t)$ represents the tracking error. The error signal is corrupted by addition of the noise $N(t)$, which is statistically independent of $X(t)$. $N(t)$ is a zero-mean Gaussian random process with power spectral density:

$$S_N(\omega) = N_0.$$

You are free to choose the parameter K.

Question: what value of K minimizes σ_E^2, the variance of the tracking error?

Hint: you may need to use the integral:

$$\int_{-\infty}^{\infty} \frac{d\omega}{\omega^2 + K^2} = \frac{\pi}{K}.$$

Answer:

By linearity of system,

$$E(t) = E_1(t) + E_2(t)$$

where $X(t) \rightarrow E_1(t)$ and $N(t) \rightarrow E_2(t)$

By independence of $X(t)$ and $N(t)$, $E_1(t)$ and $E_2(t)$ are independent, and:

$$\sigma_E^2 = \sigma_{E_1}^2 + \sigma_{E_2}^2$$

Find $\sigma_{\epsilon_1}^2$:

If $X(t)$ and $E_1(t)$ were deterministic, we would have:

$$\frac{E_1(s)}{X(s)} = \frac{X(s)-Y(s)}{X(s)} = 1 - \frac{Y(s)}{X(s)} = 1 - \frac{K/s}{1+K/s} = \frac{s}{s+K}$$

Now consider stochastic $X(t)$:

$$\sigma_{E_1}^2 = \frac{1}{2\pi}\int_{-\infty}^{\infty} S_X(\omega)\left|\frac{s}{s+K}\Big|_{s=j\omega}\right|^2 d\omega$$

$$= \frac{1}{2\pi}\int_{-\infty}^{\infty} \frac{X_0}{\omega^2}\,\frac{\omega^2}{\omega^2+K^2}\, d\omega$$

$$= \frac{X_0}{2\pi}\int_{-\infty}^{\infty} \frac{d\omega}{\omega^2+K^2} = \frac{X_0}{2K}$$

Find $\sigma_{E_2}^2$:

If $N(t)$ and $E_2(t)$ were deterministic, we would have:

$$\frac{E_2(s)}{N(s)} = \frac{-K/s}{1+K/s} = \frac{-K}{s+K}$$

Now consider stochastic $N(t)$:

$$\sigma_{E_2}^2 = \frac{1}{2\pi}\int_{-\infty}^{\infty} S_N(\omega)\left|\frac{-K}{s+K}\Big|_{s=j\omega}\right|^2 d\omega$$

$$= \frac{1}{2\pi}\int_{-\infty}^{\infty} N_0\,\frac{K^2}{\omega^2+K^2}\, d\omega$$

$$= \frac{N_0K^2}{2\pi}\int_{-\infty}^{\infty} \frac{d\omega}{\omega^2+K^2} = \frac{N_0K}{2}$$

Total:

$$\sigma^2 = \sigma_{E_1}^2 + \sigma_{E_2}^2 = \frac{X_0}{2K} + \frac{N_0K}{2}$$

$$\frac{d\sigma^2}{dK} = -\frac{X_0}{2K^2} + \frac{N_0}{2} = 0$$

$$K = \sqrt{\frac{X_0}{N_0}}$$

Date: Sun, 05 Mar 2006 20:43:16 -0800
Subject: Re: Reminder Quals Question 2006
From: Gregory Kovacs <kovacs@cis.stanford.edu>
To: Diane Shankle <shankle@ee.Stanford.EDU>

Diane,
Here you go.

Best,
Greg

G. Kovacs Quals Question 2006

Area: Circuits

The student was shown a schematic depicting two components, an N-channel power MOSFET and an inductor, in series, with the inductor tied between a positive supply voltage and the drain of the MOSFET. The student was offered the MOSFET datasheet. The source of the MOSFET was grounded. The gate was driven by a squarewave of sufficient amplitude to fully turn the MOSFET "on" and "off." He or she was asked to describe the operation of the circuit and predict the output voltage waveform. The student was then shown actual oscilloscope photographs of the circuit in operation and asked to compare his/her predictions to what was actually observed.

On 3/1/06 8:58 AM, "Diane Shankle" <shankle@ee.Stanford.EDU> wrote:

> Hi,
>
> Reminder!
>
> Please send me your Quals question.
>
> Thanks and Enjoy Your Day,
> Diane

Ivan Linscott

EE Quals

January 2006

The four laws that form the cornerstones of electricity and magnetism are:

a. Gauss's Law for electricity.
b. Gauss's Law for magnetism.
c. Ampere's Law for magnetism.
d. Faraday's Law for magnetic induction.

These four laws can be represented in both a global, i.e. integral, form or a local, i.e. differential form.

1. Express in either form these four laws in terms of the electric and magnetic fields and the charges and currents with it in mind that we will be looking toward Maxwell's Equations..

2. Are these Maxwell's equations? Or how are they modified to obtain Maxwell's Equations?

3. From Maxwell's equations in vacuum, derive the wave equation.

4. What is the velocity of the waves? What are the values of mu_zero, and epsilon_zero?

5.. How would the derivation of the wave equation change for waves in say a person such as yourself? Consider, for example, the principal material that your composed of.

6. What would be the speed of the waves then in you?

7. If magnetic charge existed, how would that change the laws and Maxwell's equations?

8. Derive the wave equation in the presence of magnetic charge.

EE Ph.D. Qualifying Exam, January 2006 Question

David Miller

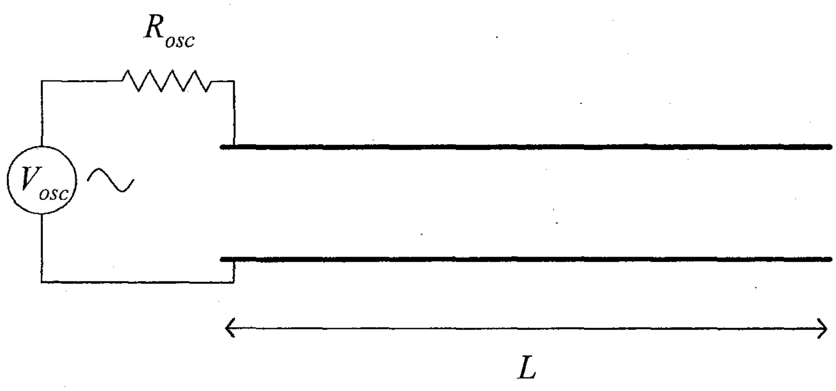
Transmission Line Resonances

Note: if you finish the questions on this sheet, subsequent questions will be asked.

Consider a uniform electrical transmission line of length L. An electrical oscillator produces a sinusoidally oscillating voltage of some fixed amplitude V_{osc} at a frequency f that can be varied. The oscillator is connected through a resistor to the transmission line at a point just inside one end of the transmission line as shown in the figures. The value of this resistor, R_{osc}, is very much greater than the characteristic impedance of the transmission line, Z. We will consider resonant frequencies in this line, i.e., frequencies at which the amplitude of the oscillating voltage on the line can build up to very large values at points or regions on the line.

For this problem, the line can be assumed to have very low loss, and to have a wave propagation velocity of c, the velocity of light in free space.

(a) For the case where the line has an open circuit at both ends,



(i) what is the lowest frequency at which there is a resonance?

(ii) what is the next frequency at which there is a resonance?

(iii) in general, at what frequencies are there resonances?

(b) For the case where the line is short-circuited at one end,

(i) what is the lowest frequency at which there is a resonance?

(ii) what is the next frequency at which there is a resonance?

(iii) in general, at what frequencies are there resonances?

(c) Returning again to case (a) (open circuit at both ends), what is the effect on the resonances of adding a resistor with value $R_{shunt} << Z$ across the line at the middle?

[Part (d) was on a separate sheet.]

(d) For the case (b) above of the line short circuited at one end,

(i) where would you place a resistor so as to suppress the lowest frequency resonance of the line, but leave the next higher frequency resonance approximately unchanged?

(ii) what fraction of all resonances would this resistor then suppress?

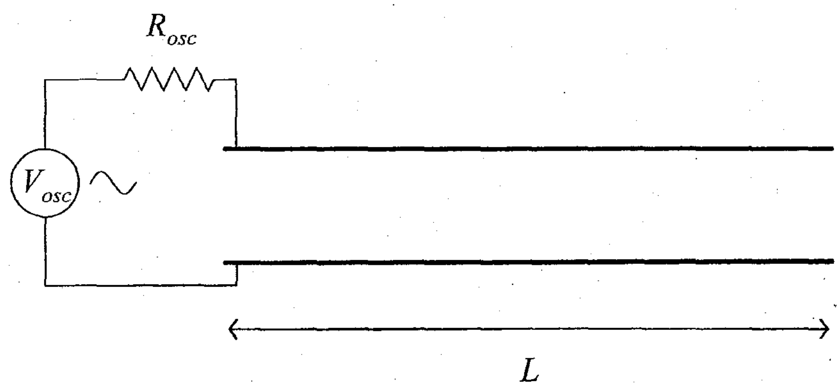
[Part (e) was on another separate sheet.]

(e) What would happen to the resonances on the line in case (a) above (both ends open circuit) if I cut a very small gap in the electrical conductors in the middle of the line? What would happen as I made the gap larger?

[Note: Most students got through parts (a) through (c) with some help. The more successful students got through most of part (d). Only a very few students got to start thinking about part (e).]

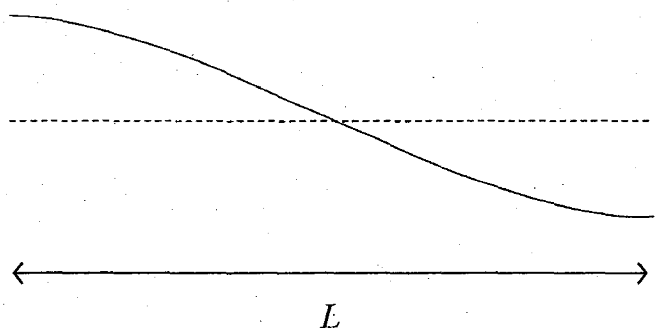
EE Ph.D. Qualifying Exam, January 2006 Solution

(a) For the case where the line has an open circuit at both ends,



(i) what is the lowest frequency at which there is a resonance?

The line will have a standing wave resonance on it with voltage maxima at the ends. The voltage is a maximum at either end because the voltage wave reflects constructively on itself there. The voltage wave looks like



Equivalently, one can say there are zeros in the current at both ends. The lowest frequency for which this can happen is the one for which one half wavelength fits in between one end and the other, i.e.,

$$\frac{\lambda}{2} = L$$

The wavelength is given by

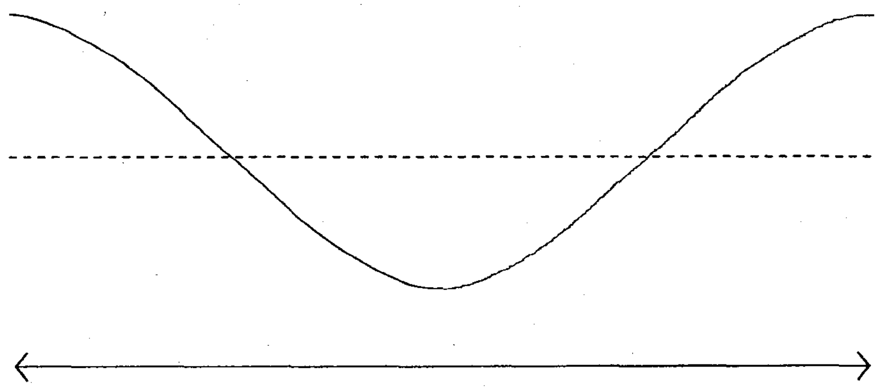
$$\lambda = c / f$$

So the frequency of this first mode is

$$f_1 = c / 2L$$

(ii) what is the next frequency at which there is a resonance?

The next possible resonance is when two half waves fit within the line, i.e., $L = \lambda$ and so the frequency is $2f_1$



L

Note this wave has a maximum in the middle.

(iii) in general, at what frequencies are there resonances?

The resonances are at frequencies mf_1, where m is a positive integer (starting at 1)

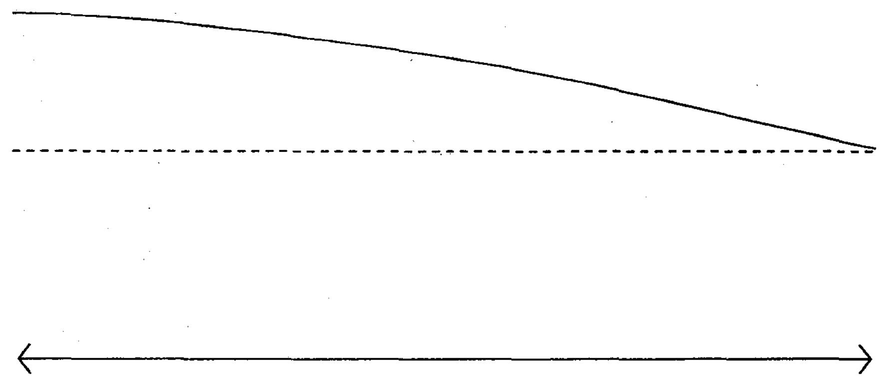
(b) For the case where the line is short-circuited at one end,

(i) what is the lowest frequency at which there is a resonance?

In this case, the voltage is zero at the short-circuited end, while still being maximum at the open end, so the standing wave for the lowest frequency is a quarter wave, and so the frequency of this lowest resonance is

$$f_{1short} = c/4L$$

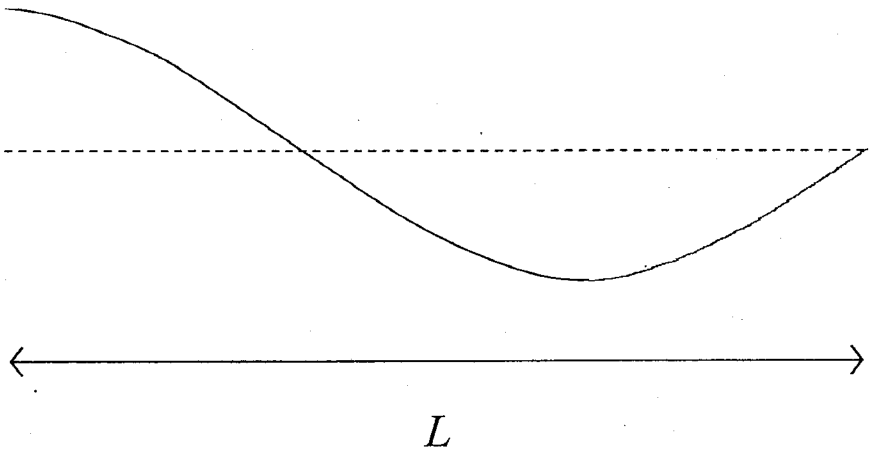
i.e., for the case where the short circuit is on the right end of the line



L

(ii) what is the next frequency at which there is a resonance?

The next possibility is for three quarter waves to fit on the line, so the corresponding frequency is $3f_{1short}$.



(iii) in general, at what frequencies are there resonances?

We have to fit an odd number of quarter waves in the length of the line in general, so the frequencies are $(2m-1)f_{1short}$ where m is a positive integer (starting at 1)

(c) Returning again to case (a) (open circuit at both ends), what is the effect on the resonances of adding a resistor with value $R_{shunt} << Z$ across the line at the middle?

It will have no effect on all of the resonances with m odd, because they all have a zero in the voltage at the middle, so there will be no current across the resistor in those cases, and the resistor does nothing. For all of the resonances with m even, there is a maximum in the voltage there (without the resistor). Adding the resistor in the middle therefore suppresses those resonances because they would now become very lossy.

(d) For the case (b) above of the line short circuited at one end,

(i) where would you place a resistor so as to suppress the lowest frequency resonance of the line, but leave the next higher frequency resonance approximately unchanged?

The resistor should be placed one third of the wave along the line from the open end, so as to coincide with the zero in the second resonance (hence not affecting it). Though not at a maximum of the first resonance, the amplitude of the first resonance is substantial, and so it would experience significant loss from this resistor, and is therefore suppressed.

[Note for interest: This is the reason why the register key in a clarinet is placed 1/3 of the way along the pipe from the mouthpiece end of the instrument. The mouthpiece behaves as a stopped end on the pipe; the other end of the pipe is open. In this acoustic case, though, one should consider the pressure, in which case the mouthpiece end is a pressure maximum, so that stopped end is analogous to the open end of this transmission line if we are drawing an analogy between pressure and voltage, and the open end of the pipe is a pressure minimum, analogous to the closed end of the transmission line. The register key hole is therefore placed at a pressure node for the next resonance of the entire pipe. Opening this hole makes the clarinet play in its second, "clarion" register, a frequency three times higher than that of the lower, "chalumeau" register.]

(ii) what fraction of all resonances would this resistor then suppress?

It will suppress 2/3 of all of the resonances of the initial line. Since we must now have a zero at $L/3$ from the open end of the line, it is as if the line is only one third as long, so the (low-loss) resonances are three times as far apart as those on the original line. All the other resonances of the original line are suppressed.

(e) What would happen to the resonances on the line in case (a) above (both ends open circuit) if I cut a very small gap in the electrical conductors in the middle of the line?

For a very small gap, it is as if we put large capacitors connecting two pieces of transmission line, and such capacitors behave as short-circuits for oscillating voltages, so there is no effect on the resonaces of the line for a very small gap. It is also true that there will simply be wave coupling between the different parts of the line (which is not really a separate statement from the capacitive coupling).

As the gap size is increased, the break does become a significant, and in the limit of a large gap, the two parts of the line will behave as if they are separate lines of half the length.

Date: Wed, 1 Mar 2006 17:22:45 -0800
From: "Subhasish Mitra" <subh.mitra@gmail.com>
To: "Diane Shankle" <shankle@ee.Stanford.EDU>
Subject: Re: Reminder Quals Question 2006

Hi Diane,

Here are the questions.
-Subhasish

Suppose you have a system where bits are coming in serially, 1 bit at each clock cycle. With each bit coming in, you create a binary number where the last received bit is treated as the Least Significant Bit (LSB) and so on. For example, suppose that everything is initialized to 0. The first bit that comes in is 1 – the number is 1; the second bit received is 0, so the number is now "10" = 2; the third bit received is 1, so the new number in the third cycle is "101" = 5, and so on. At each clock cycle the system output is 1 if and only if the number at that clock cycle is divisible by 7.

Create a state diagram for the corresponding sequential circuit.

What is the minimum number of states you can have?

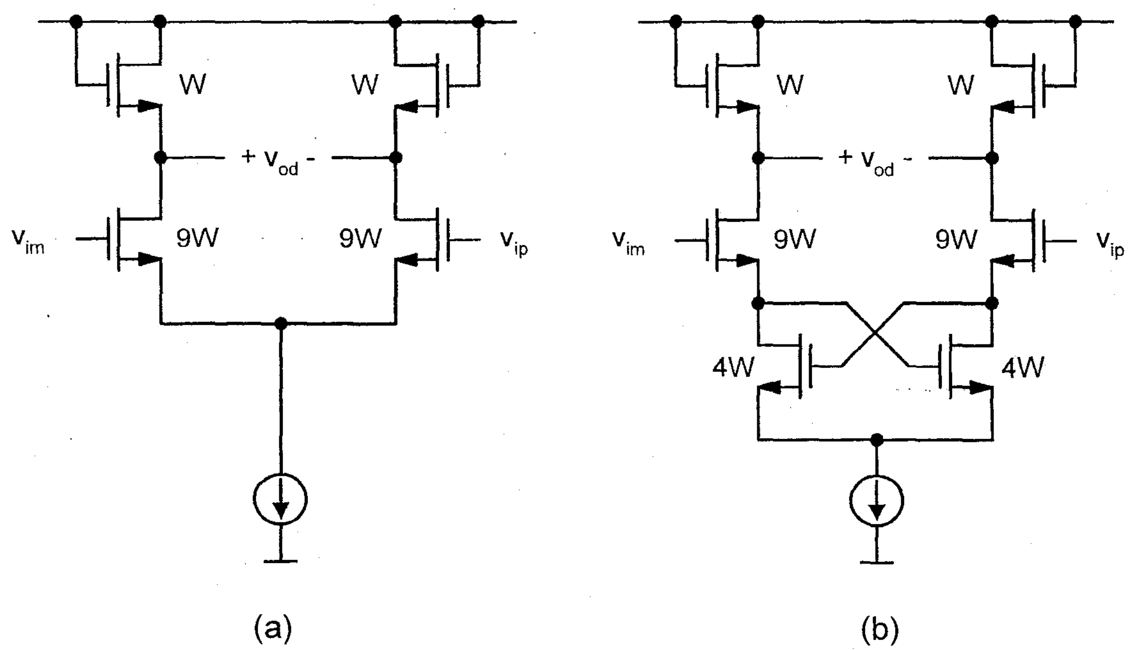
How will you implement a similar circuit for which we want to find out if the number at each clock cycle is divisible by 28?

What happens if we want to find out if the number at each clock cycle is prime?

On 3/1/06, Diane Shankle <shankle@ee.stanford.edu> wrote:
> Hi,
>
> Reminder!
>
> Please send me your Quals question.
>
> Thanks and Enjoy Your Day,
> Diane
>

Name:	Quals 2006, Murmann

In the circuits below, neglect second order effects such as finite output resistance and body effect and assume ideal square law behavior. All devices have the same channel length and operate in the forward active region.



a) What is the low frequency differential voltage gain in the above circuits?
b) Discuss potential issues, subtleties and disadvantages of circuit (b).

2006 PhD Qualifying Examination Prof. Yoshio Nishi

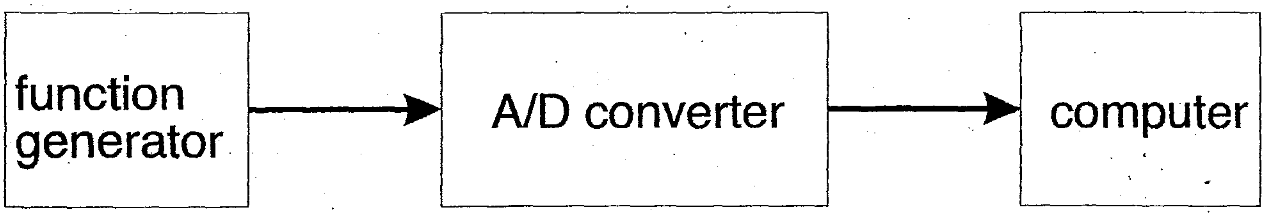
1. Please explain MOSFET operation at low Vg and Vd.

2. What are the factors which influence the subthreshold characteristics, i.e. s-factor, for long channel MOSFET, and for very short channel MOSFET?

3. When you see a steeper experimental subthreshold slope than theory tells, what would you question about that?

Class Demo Set-up

NISHIMURA 2006



knob set for sinusoidal output

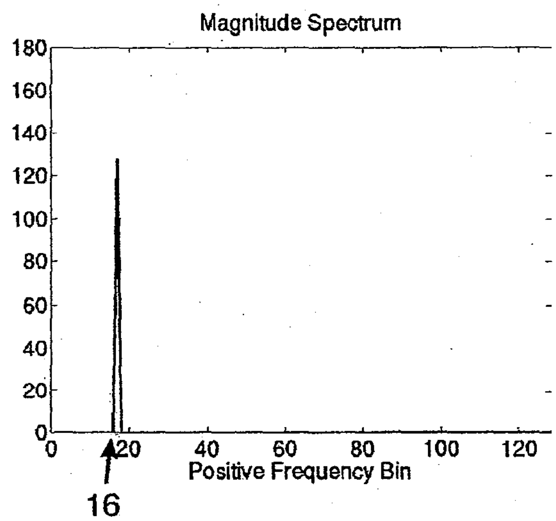
adjustable knob changes frequency.

adjustable knob changes sampling rate.

creates file of 256 data pts

A program was written to read in file and take 256-pt FFT of data.

We hope to show the following magnitude spectrum of the collected data.



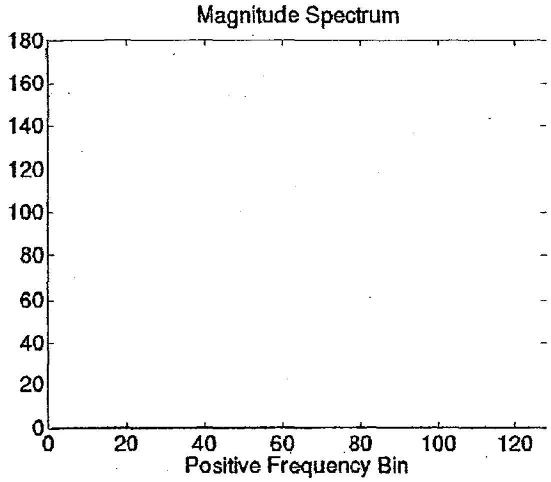
What sinusoidal frequency and A/D sampling rate could you use?

Debug the Situation

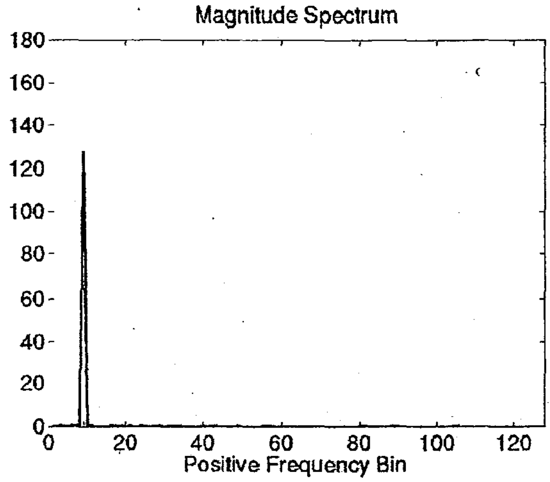
It works perfectly in the office a week before class. On class day however, the set-up creates a new data file during lecture that results in a different magnitude spectrum. Something has unexpectedly changed!

For each case below, assess the nature and possible cause(s) of the problem.

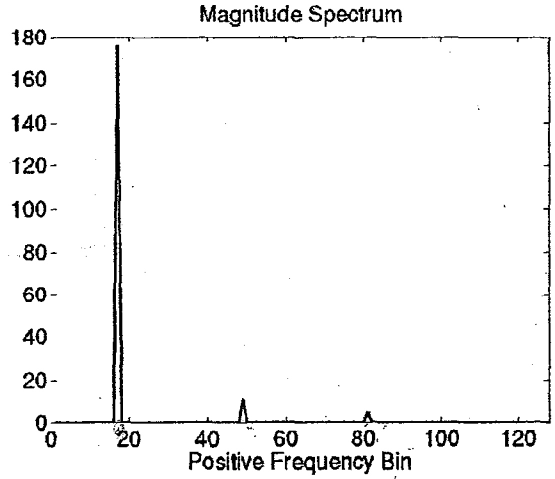
(1)



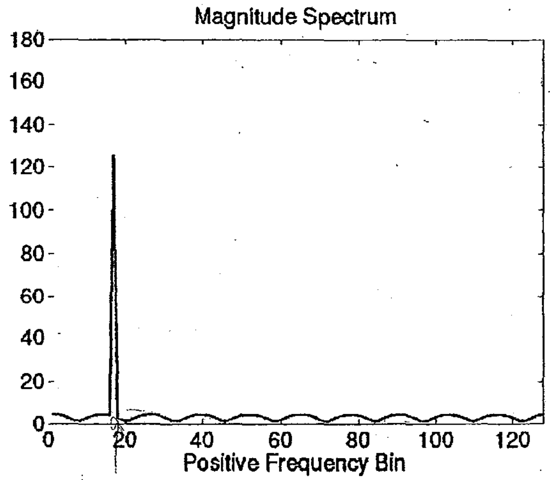
(2)



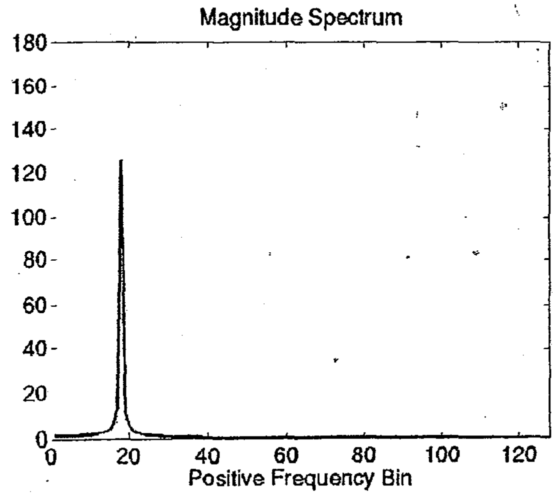
(3)



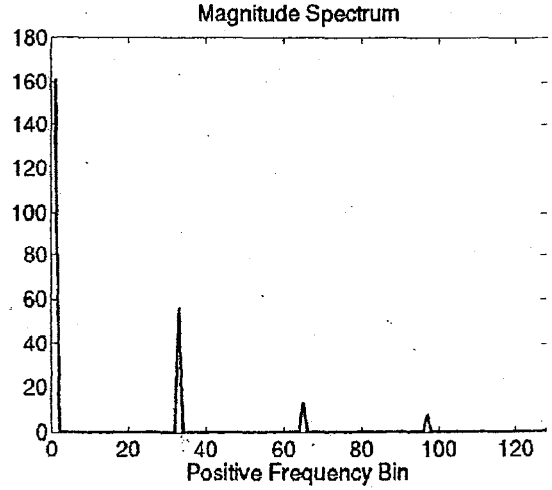
(4)



(5)



(6)



ANSWERS

Page 1

$$f_{in} = \frac{16}{256} f_{samp}$$

Page 2

1) check power, connections
2) f_{IN} was reduced and/or f_{samp} was increased
3) signal being clipped
4) spike noise in time signal
5) leakage
6) time signal rectified

> General debugging approach was judged.

Kunle Olukotun

Hiding Memory Latency

<u>Assumptions</u>

- 32 KB cache
- 1 GB data structure

```
for (i = 10,000; i > 0, i--)
    for (p=head; p!=NIL;)
        if (p->value < i)
                p = p->left;
        else
                p = p->right;


        addiu    $s2, $s0, #10000          ; initialize $s2
iloop: J         test
jloop:  lw       $s0, 0($s1)
        slt      $s0, $s0, $s2             ; p->value < i
        bnez     $s0, right
        lw       $s1, 4($s1)               ; p = p->left
        J        test
right:  lw       $s1, 8($s1)               ; p = p->right
test:   bnez     $s1, jloop
        addiu    $s2, $s2, -1              ; subtract 1
        bgtz     $s2, iloop
```

How well will your techniques work on this loop?

Hiding Memory Latency

- Name some techniques for hiding/tolerating memory latency?

- What characteristics of applications and architecture are required to make these techniques work?

Date: Wed, 01 Mar 2006 16:09:02 -0800
From: Fabian Pease <pease@cis.stanford.edu>
X-Accept-Language: en-us, en
To: Diane Shankle <shankle@ee.Stanford.EDU>
Subject: Re: Reminder Quals Question 2006

Diane Shankle wrote:

> Hi,
>
> Reminder!
>
> Please send me your Quals question.
>
> Thanks and Enjoy Your Day,
> Diane

Peases's Question:
Here is a pair of Bose sound-cancelling headphones. Try them on.
How would you design a sound-cancelling headphone?
fp

Peumans, Peter

Qualifier Exam Questions – Week of 01/23/2006

NAME:

1. (5min) Sketch the band diagram of an npn bipolar transistor in the linear regime. Draw the quasi Fermi levels. Define current gain and explain what limits it. What are some of the tricks I can use to improve the current gain of this device?

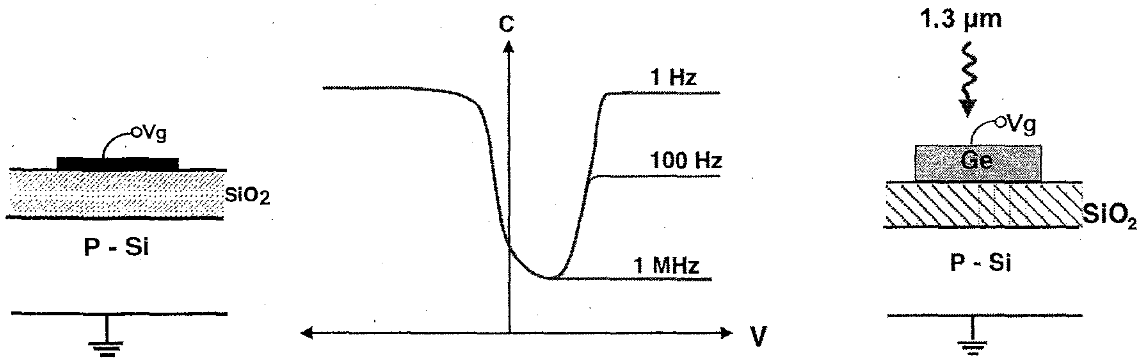
2. (3min) I have an LED in a dark room. I bias the LED at a voltage just below the bandgap E_G (in eV) and see efficient light emission with wavelength λ=1240/E_G (in nm) (photon energy = E_G).

Why do I find this strange? What is happening?

3. (3min) Suppose I have two parallel plates. One is heated to a high temperature, say 1800K. The other plate is at room temperature: 300K. Between the plates there is a vacuum.

Can you sketch the current-voltage characteristics of this two-terminal device?

Krishna Saraswat - PhD Quals 2006 Question



The CV characteristics of Al/ SiO_2/Si MOS capacitor are shown. If the gate electrode is changed to Ge with doping identical to the Si substrate and you illuminate this device with 1.3 μm light what will be the CV characteristics with and without the light?

Problem 1

Consider an n-channel MOSFET with: μ_n, C_{ox}, W, L, V_t, V_{GS} and V_{DS}.

(a) What is this transistor's transconductance if operating in triode (linear) mode?

(b) If this transistor is operating in saturation mode rather than in triode (linear) mode, is the |gain| of an amplifier larger or smaller? Please show why.

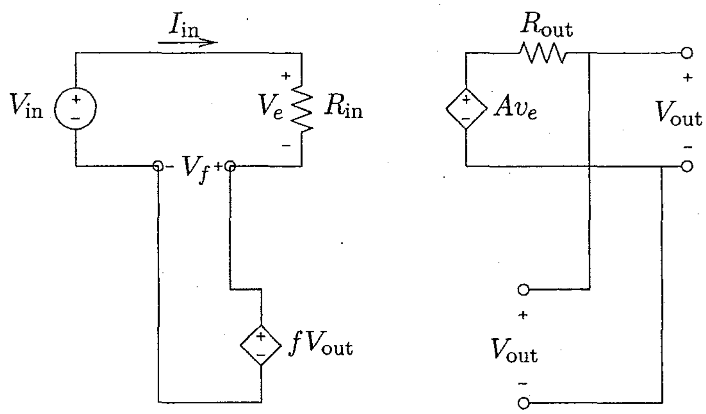
Problem 2

Consider an amplifier with three capacitors C_1, C_2 & C_3. Each capacitor "sees" a resistance, found with the other capacitors removed. These resistances are R_1, R_2 & R_3.

(a) You need to increase the high frequency cutoff of the amplifier and can adjust only one capacitor. Which capacitor should you adjust? Why, and how?

(b) Is this amplifier's dominant pole given by 1/(RC), where R is R_1, R_2 or R_3 and C is C_1, C_2 or C_3?

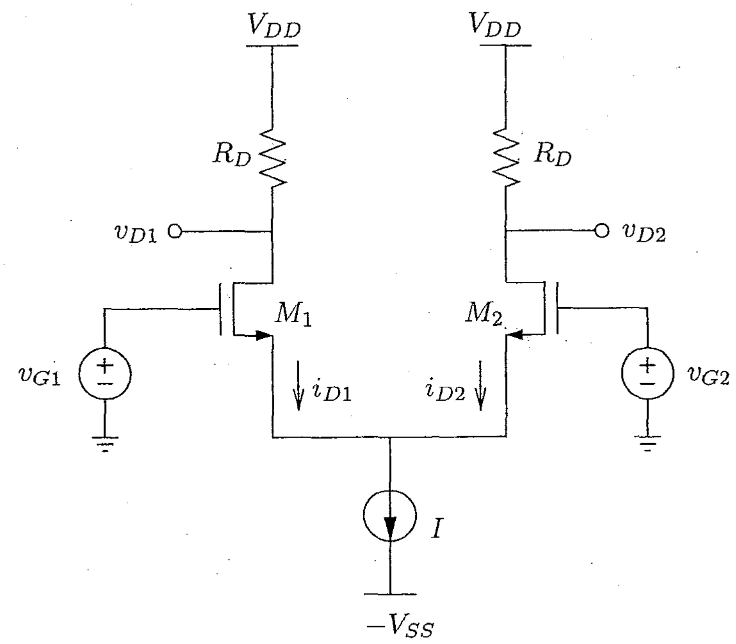
Problem 3



(a) What is the gain ($G = \frac{V_{out}}{V_{in}}$) of this circuit?

(b) The input resistance of this circuit is $R_{in,f\neq 0}$. If f is reduced to zero ($f = 0$), the input resistance is $R_{in,f=0}$. How is $R_{in,f\neq 0}$ related to $R_{in,f=0}$?

Problem 4



- This is a symmetrical differential amplifier, with M_1 and M_2 operating in saturation mode.
- When there is no differential input voltage ($v_{ID} = v_{GS1} - v_{GS2} = 0$) the tail current divides evenly between the two arms ($i_{D1} = i_{D2} = I/2$).
- The gate to source voltages must then also be equal: $V_{GS0} = v_{GS1} = v_{GS2}$.
- And $\frac{I}{2} = K_N(V_{GS0} - V_t)^2$ where $K_N = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}$.

(a) What is the minimum differential input voltage (v_{ID}) that can be applied to cause all current to flow through M_1? Please write expression in terms of $V_{GSO} - V_t$.

(b) What is the common mode rejection ratio? What is it for this circuit (assume differential input and differential output)?

Problem 5

Please describe the major sub-circuits of an op-amp, and the critical design considerations of each.

Date: Fri, 27 Jan 2006 16:33:42 -0800
To: Diane Shankle <shankle@ee.Stanford.EDU>
From: Olav Solgaard <solgaard@stanford.edu>
Subject: Re: Quals Meeting Time Change Please see below!

Diane:

My questions are appended.

Olav

Qualifying Exam for the Electrical Engineering PhD program, Stanford University, January 2006
Olav Solgaard
Questions:

1) What is this? (Showing a post card with two pictures that appear alternately as the card is viewed from different directions)
2) How does it work?
3) How is the information of the two pictures structured?
4) What type of lens is used? How far away from the lens are the images placed?
5) Why do you see several transitions as you vary the viewing angle?
6) Do the two pictures create the illusion of depth beyond that of a normal picture?
7) How can you create the illusion of depth in pictures that are multiplexed in this way?
8) How would you use this picture-multiplexing effect to create a better computer screen?

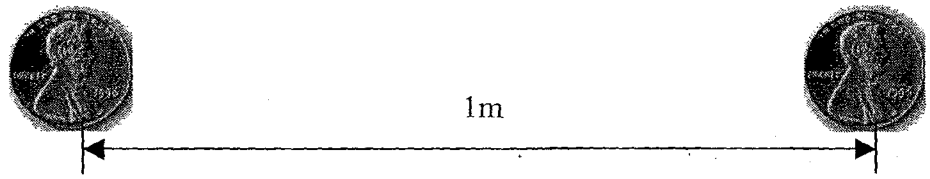
At 04:23 PM 1/27/2006, you wrote:

> Quals Meeting
> Tuesday, January 31st.
> 4:30 P.M.
> CIX-X AUD
>
> Coffee,Tea and Cookies will be served before the meeting.
>
> Please send me a copy of your Quals Question either by email or a
> hard copy to the address listed below!
>
> Happy Friday,
> Diane
>
> --
>
> Any other questions feel free to call me!
>
> Diane Joan Shankle
> Tel: (650) 723-3194
> FAX: (650) 723-1882
> shankle@ee.stanford.edu
> Stanford University
> Electrical Engineering
> Student Services
> Packard Building Rm. 177
> Stanford,CA 94305-9505
> http://www-ee.stanford.edu

2005-2006 EE Ph.D. Qualifying Exam
Question area: *Engineering Physics*
Examiner: *Jelena Vuckovic*

---

1. We know that the magnitudes of the negative charge of an electron and the positive charge of a proton are equal. Suppose, however, that these magnitudes differ from each other by 0.0001%. With what force would two copper cents placed 1m apart then act on each other? Is this force larger or smaller than the force of gravity acting on a cent at the surface of the Earth?

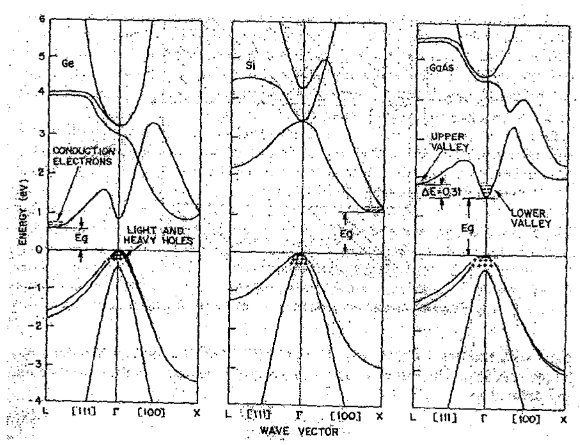


Hints:

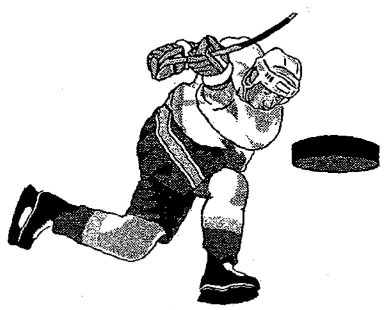
- Give order of magnitude answers.
- You may assume that a cent is made of copper only, and has the mass of 2.5g.
- You can use the attached periodic table of elements.
- Some useful constants: the dielectric constant of vacuum is $\varepsilon_0=8.85 \cdot 10^{-12}$F/m, the charge of an electron is $e=-1.6 \cdot 10^{-19}$C, and the mass of a proton is $m_p=1.67 \cdot 10^{-27}$kg.

2. When studying semiconductors, we plot their energy band diagrams, as shown in the figure on the right for Ge, Si and GaAs.

   Explain what these diagrams mean and how they are calculated. How would the states (wavefunctions) of electrons differ at various points of these band diagrams? What about the probability distributions of electrons throughout such materials?



3. Why is ice slippery?



Isachy Weissman

Quals Question

Suppose I give you a random variable $U \sim \text{Unif}[0, 1]$.

Can you use it (and only it) to generate

1. An unbiased bit $B \sim \text{Bernoulli}(1/2)$?

2. Two independent unbiased bits B_1, B_2 ?

3. An infinite stream of independent unbiased bits $B_1, B_2, B_3, \ldots$?

4. Two independent Unif[0, 1] random variables U_1, U_2 ?

5. An infinite sequence of i.i.d.$\sim$ Unif[0, 1] random variables $U_1, U_2, U_3, \ldots$?

Date: Wed, 01 Mar 2006 09:34:51 -0800
From: Jennifer Widom <widom@cs.stanford.edu>
X-Accept-Language: en-us, en
To: Diane Shankle <shankle@ee.Stanford.EDU>
Subject: Re: Reminder Quals Question 2006

Jennifer Widom EE Quals 2006

QUESTION
========
Consider a hierarchical sensor data processing setup with:

(1) A high-end processor H at the root.

(2) A set of k low-end processors L_1, L_2, ..., L_k that can send values to H.

(3) For each processor L_i, a set of n_i sensors that can send values to L_i.

Each sensor reads one value and sends it to its parent L_i. At the root H, we want to know the average of all the sensor values.

Let a_L denote the cost of performing a binary arithmetic operation (e.g., addition, division) at an L_i processor, and let a_H denote the same for processor H. We expect a_H to be lower than a_L.

Let m_i denote the cost of sending a message with a single numeric value (and a few status bits if needed) from L_i to H. Assume this cost metric is compatible with the one used for a_L and a_H.

** Describe alternative algorithms for performing the average
** computation, and explain how to decide which of your algorithms is
** cheapest.

EXTRA 1: Modify your answer for the case where we want to compute the minimum instead of the average. Assume comparison costs are the same as arithmetic costs: a_L and a_H for a binary compare.

EXTRA 2: Modify your original answer for the case where we want to compute the median instead of the average.

ANSWER
======
Each L_i has to decide whether to:

(a) Simply pass its sensor values on to H, or
(b) Compute a sum and count of its sensor values and pass those to H.

In either case, H must compute the sum of all the values it receives and divide it by the total counts.

Cost of option (a):

    Arithmetic at L_i: 0
    Messaging: n_i * m_i
    Arithmetic at H due to L_i: a_H * n_i

Cost of option (b):

    Arithmetic at L_i: a_L * (n_i - 1)

```
   Messaging: 2 * m_i
   Arithmetic at H due to L_i: 2 * a_H

Prefer option (a) when (n_i * m_i) + (a_H * n_i) <
                       (2   * m_i) + (a_L * (n_i - 1)) + (2 * a_H)

EXTRA 1: Very similar to original except replace:
  (a_H * n_i) with (a_H * (n_i - 1))
  (2 * m_i) with m_i
  (2 * a_H) with a_H

EXTRA 2: Except for certain extreme cases, all values must be
transmitted to a single site in order to compute a median, so only
option (a) is feasible.
```

2006 Qual Exam Questions

Prof. H.-S. Philip Wong

1. Consider a semiconductor with a bandgap of 0.5 eV. Draw the energy band diagram of the semiconductor if it is intrinsically doped. Indicate the workfunction of the semiconductor in the band diagram.

2. If a metal with a workfunction that is the same as the semiconductor is brought in contact with the semiconductor, draw the energy band diagram again.

3. If the workfunction of the metal is smaller, draw the band diagram.

4. If the workfunction of the metal is larger, draw the band diagram.

5. Now, focus on the case in which the workfunction of the metal is larger. Assume we make a MOSFET with the source and drain with the metal directly in contact with the semiconductor. Draw the Id vs Vds curve (with different Vgs) for this transistor. Explain the features of the IV curve and contrast this with a conventional MOSFET.

6. How can you improve the IV characteristics of this transistor? What is the physics behind your solution?

7. Now, draw the Id vs Vgs curve (at high Vds) of the unmodified transistor. Explain the features of the IV curve and contrast this with a conventional MOSFET.

8. Can we use this ambipolar transistor in conventional CMOS circuit families? Which circuit types will not work with the ambipolar transistors?

9. Draw the circuit diagram of a 2–input CMOS NAND gate. Will this circuit work if the transistor is made of the ambipolar transistor above?

USgood

EE Qualifying Exam
January 2006

Let $\underline{f}$ and $\underline{g}$ be discrete, real signals, each periodic of period N. Define their correlation by the formula

$$(\underline{f} \star \underline{g})[m] = \sum_{n=-\frac{N}{2}+1}^{\frac{N}{2}} \underline{f}[n]\underline{g}[n+m]$$

(a) Show that

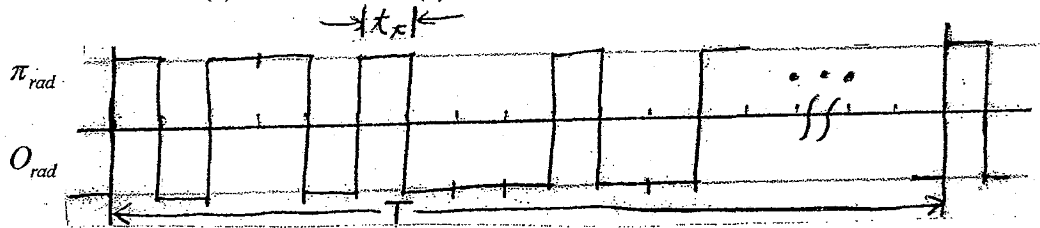
$$\underline{\mathcal{F}}\,(\underline{f} \star \underline{g}) = \overline{\underline{\mathcal{F}}\,\underline{f}}\,\underline{\mathcal{F}}\,\underline{g}\,,$$

where $\underline{\mathcal{F}}$ is the discrete Fourier transform.

(b) Give an upper bound for $(\underline{f} \star \underline{g})[0]$.

I will describe waveform $\phi(t)$ and signal $s(t)$ then I will ask a few questions.

Given $\phi(t)$



A. Periodic signal $\phi(t)$ with minimum change period t_t and period T

a, b, k are integers

a = number of t_t intervals that are $+\pi$

b = number of t_t intervals that are O

k = a + b and $kt_t = T$

Prof. Donald Cox
Quals Question
Jan. 2006

B. Sinusoidal signal s(t) with frequency f_c

$f_c \gg 1/t_t$ and $\phi(t)$ represents phase of s(t)

1. Write a mathematical representation of s(t) either complex exponential or trigonometric representation.

2. Rough sketch s(t) showing important features

3. Is it possible to choose a and b such that there is no spectral component of s(t) at f_c in the frequency domain?

4. What is relationship between a and b for no spectral component of s(t) at f_c?

5. If $a \neq b$, what is the minimum possible spacing between spectral components of s(t)?

6. For $a \neq b$ in terms of a and b, what is the power of the spectral component at f_c compared to the total power in s(t)?

7. With a = b, i.e., no spectral component at f_c, how could you recover (estimate) f_c from s(t)?

Date: Wed, 01 Mar 2006 22:45:39 -0800
To: Diane Shankle <shankle@ee.Stanford.EDU>
From: Simon Wong <wong@ee.Stanford.EDU>
Subject: Re: Reminder Quals Question 2006

Simon Wong,

Given the layout of a circuit, identify each layer, the transistor, connection and determine the circuit.
Answer : first circuit is a CMOS inverter, 2nd circuit is a CMOS cascode amplifier

At 08:58 AM 3/1/2006, you wrote:

> Hi,
>
> Reminder!
>
> Please send me your Quals question.
>
> Thanks and Enjoy Your Day,
> Diane

EE Qualifying Examination

January 2006

Yoshihisa Yamamoto

1. **A linear amplifier enhances the signal and noise powers by the same gain factor. In addition, amplifier internal noise is added to the output signal and so the signal-to-noise ratio is always degraded by linear amplification. Why is a linear amplifier used in optical communication systems?**

2. **A nonlinear regenerator reproduces a clean signal pulse from a distorted signal pulse. The signal-to-noise ratio of the output pulse is larger than that of the input pulse. However, there is a price we have to pay. What is the cost we have to pay for improving the signal-to-noise ratio in a nonlinear regenerator?**