Electrical Engineering Quals Questions

2005

John Cioffi

Quals Solution

a). $E_n = g_n \cdot (2^{b_n} - 1)$

b). $b_n = \log_2\left(\frac{E_n}{g_n} + 1\right)$

c). $\max \sum_{n=1}^{N} \log_2(E_n/g_n + 1)$ $\quad L = \sum_{n=1}^{N} \log_2\left(\frac{E_n}{k_n}+1\right) + \lambda\left(E - \sum_1^N E_n\right)$

st: $\sum_{n=1}^{N} E_n = E$

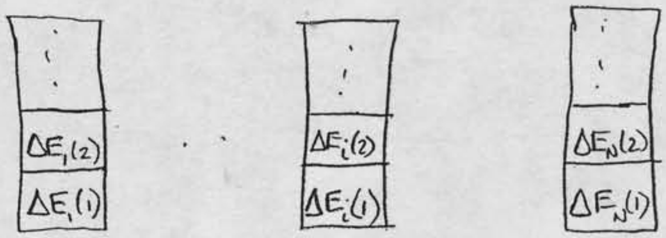
$E_n \geq 0$

i. $\frac{dL}{dE_n} = 0 = \frac{1/g_n}{\frac{1}{g_n} + E_n/g_n} \cdot \frac{1}{\ln 2} + \lambda$ $\quad$ so $\quad \frac{1/\ln 2}{E_n + g_n} = -\lambda$

or

$E_n + g_n = \text{constant} \;\; \forall n$ or $E_n = 0$

d). Set up N tables of incremental energy



Take tasks, one by one, and assign each successively to the robot i for which $\Delta E_i(b_i + 1)$ is smallest.

	task 1	2	3		
e). Robot 1 needs	10	20	40	80	more units
2	50	100	200 ..		

$E = 10 + 20 + 40 + 50 + 80 + 100 + 160 + 200 + 320$ $\quad$ (120, 300, 660, 980 < 1000)

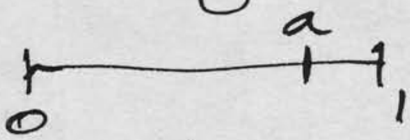
9 tasks

Quals questions
Tom Cover 1/12/05

1)

A hoop is placed (off center) on a ~~frictionless~~ sphere. Is it stable? Why or why not.

2)



A number a in the unit interval is expressed in binary $.x_1 x_2 \cdots$ and base 3, $.y_1 y_2 \cdots$

Thus $a = ._2\, x_1 x_2 \cdots$

$= ._3\, y_1 y_2 \cdots$

Someone throws away the first n "digits" of x and y, leaving

$x_{n+1} x_{n+2} \cdots$,

$y_{n+1}\, y_{n+2} \cdots$ can a be recovered?

Answers

1) The hoop will slide. the center of gravity of the hoop lies on a smaller concentric sphere. The tangent force is readily determined.

2) Yes $\underline{\underline{a}}$ can be recovered. There are 2^n ways to fill in the missing $x_1 x_2 \cdots x_n$, yielding candidates

$$a + \frac{j}{2^n} \pmod 1.$$

There are 3^n ways to fill in the missing $y_1 \cdots y_n$, yielding candidates

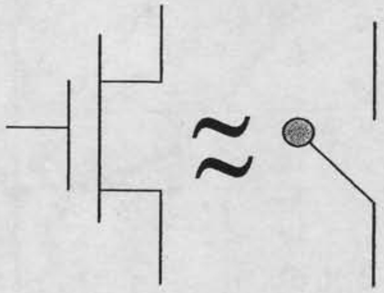
$$a + \frac{k}{3^n} \pmod 1.$$

The difference is $\frac{j}{2^n} - \frac{k}{3^n}$ which $= 0$ only for trivial j, k, yielding a unique solution for a.

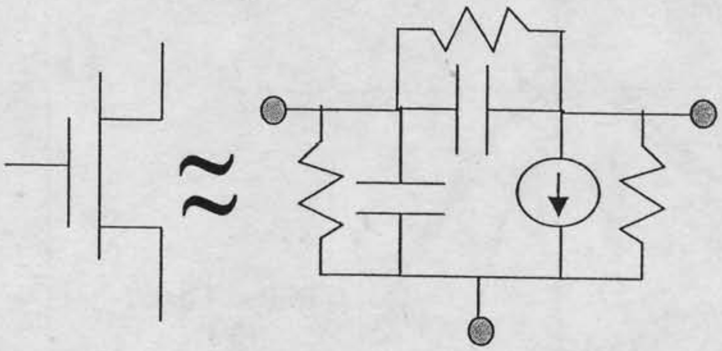
Note that if <u>a</u> is expressed in base 2 and base 4, then <u>a</u> cannot be uniquely recovered from the tails. The bases must be relatively prime.

Robert Dutton

For DIGITAL MOS scaling, what are the TOP (3) ISSUES for ongoing improvement of CIRCUIT PERFORMANCE*.



How do the above digital "care about" issues impact analog MOS circuit performance?*

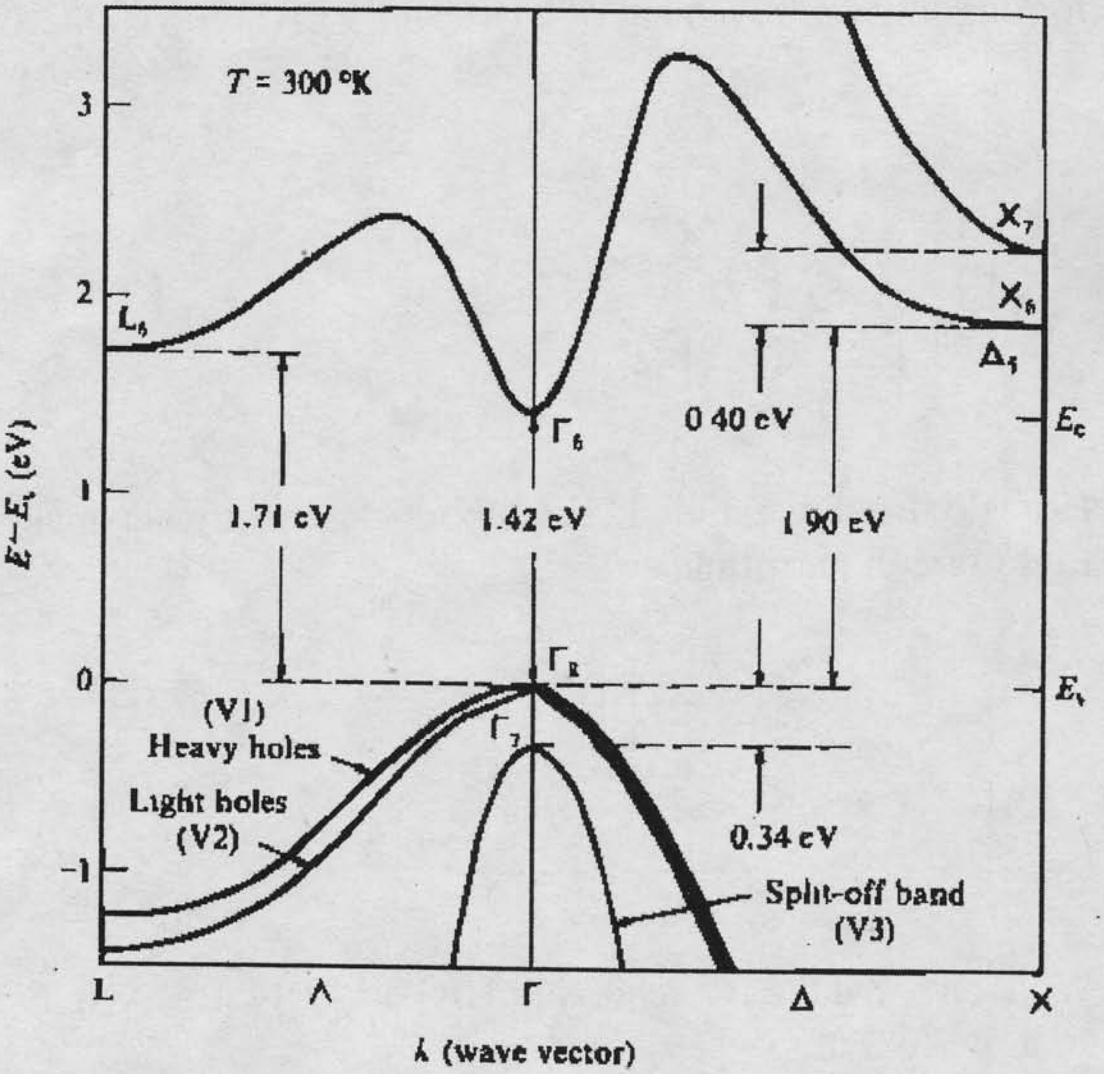


What else matters for achieving HIGH PERFORMANCE analog MOS?*

*Footnote: I do not give out answers to my Quals questions. This is for student benefit in finding good things to THINK ABOUT versus a "study guide". RWD

Shanhui Fan

Here is the band structure for GaAs:



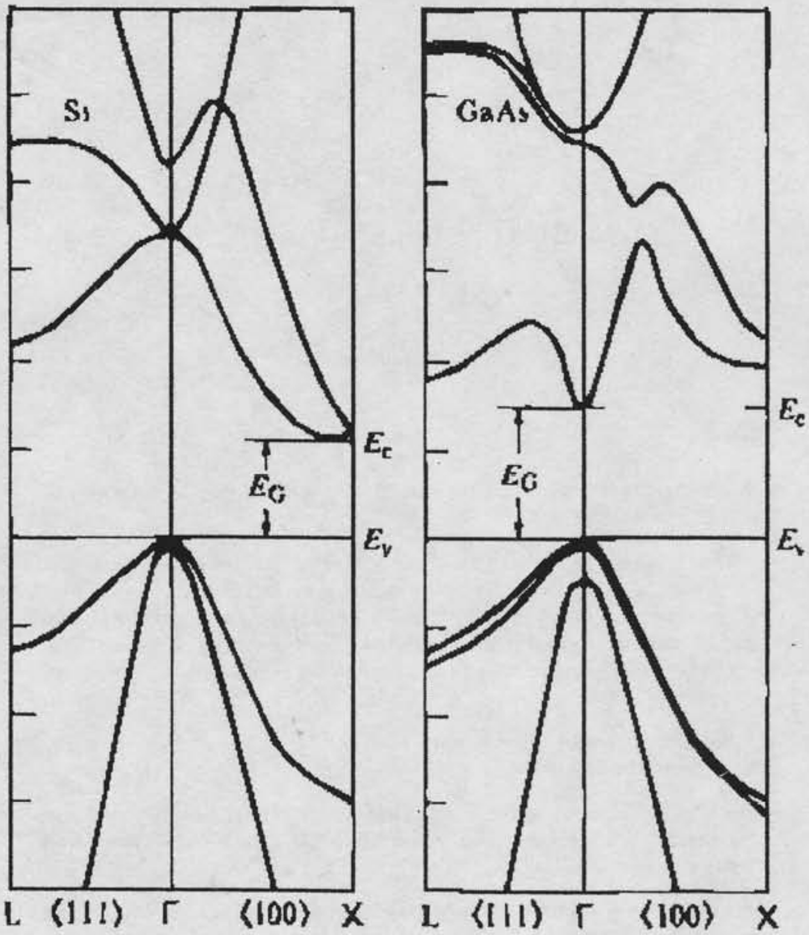
(a) For photons with what energy will GaAs be strongly absorbing?

(b) As can be seen from the band structure, the conduction band has an absolute minimum at Γ, and local minima at L. For these two minima, which one has the larger effective electron mass along the [111] direction?

(c) At room temperature T=300K, suppose the GaAs is n-doped, with a dopant concentration of 10^{18} cm^{-3}, and with a dopant level that is 0.02eV from the band edge, what is the concentration of electrons in the conduction band?

(d) Continuing the question from (c), could you estimate what percentage of the electrons that are in the L-minima? (Note: T=300K represents an energy scale of 0.025eV)

(e) Compare the bandstructures of GaAs with that of the Si, both of which are shown below, what is the most important difference in terms of band structure that prevents Si from being a good light emitting material?



Scoring (a) 1 (b) 2 (c) 2 (d) 4 (e) 1

EE Architecture Quals Winter 2005

Armando Fox

January 2005

Part 1

- What are the 3 types of cache misses? For each type, which type(s) of caches can it occur in (DM, SA, FA)?
- I have a 2-way SA cache with 1K sets, and a 4K-element array aligned in memory so that its first element would map to the first set. (I drew this on the whiteboard to make it easier for the student to visualize.) The size of each array element is exactly the size of a cache line. What's the cache behavior time for a loop that repeatedly reads each array element in sequence?
- What's the behavior if it's 3-way instead of 2-way SA? Is there any way to improve the hit rate?
- Back to the 2-way SA with 1K sets; but now you access every N'th element repeatedly. What value of N achieves best AMAT (other than the trivial value N=array size)?
- A motivation for data caching is to hide memory access latency. If you miss in L1 cache, what options remain to avoid incurring main memory latency, and what hardware challenges arise?

Part 2

- Say you do all the right things, and your L1 cache has a 1-cycle average access time for both reads and writes. Management says: "Oh great, then you can do away with having a register file, and just do memory-to-memory operations all the time." Why might you object to this suggestion?
- OK, I give you a "magical" L1 cache design that overcomes your objections about eliminating the register file. How would eliminating the register file affect the work of programmers, compiler writers, etc?

Part 3

- Management wants to now send your CPU into space, which means you have to protect against rad-induced bitflips. What's the implication of a rad-induced bitflip in the L1 cache or register file? in the ALU during an operation? How could you protect against them?

- Management is dismayed this would be so challenging, so instead they decide they'll sell your CPU to cell-phone makers. So now you have to optimize for low power operation. Considering the CPU as well as the overall system that comprises it, where would you look for power savings and why?

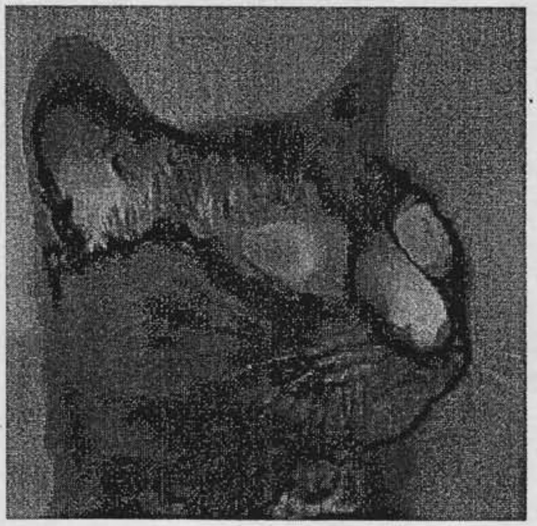
Note: I conducted the exam by allocating roughly equal amounts of time for each part, to avoid overly penalizing students who happen to know one area of architecture/logic design much better than another. Therefore, roughly speaking, all students got a shot at each section, with the strongest students completing the most difficult parts of each section.

Ph.D. Quals Question
January 2005
A.C. Fraser-Smith
Space, Telecommunications and Radioscience Laboratory

BLACKBODY RADIATION

To start, the figure below was shown to the students and attention drawn to its label: "A Cat in Infrared." They were asked, "Do you have any comment about the label on this figure?"

A Cat in Infrared



At this stage, most students began discussing blackbody radiation, which is good, but once again their attention was drawn to the label on the figure and asked if they could comment on it. The expected answer was "Oh, we cannot see infrared. The picture must have been prepared by using some process that converts the infrared radiation emitted by a cat to some visible representation." This usually led to a brief discussion of possible conversion processes and how the cat's ears and eyes in the above figure are hot and its nose cold. The use of night vision 'scopes was sometimes discussed at this stage (good). After this introductory start the students were asked specific questions about blackbody radiation. For example, "why is the term 'blackbody' used?" Importantly, students were expected to know that blackbody radiation depends only on the temperature of the source.

A schematic chip layout was now shown to the students and they were asked how blackbody radiation might be used in an electrical engineering context to diagnose chip problems. Most knew that heating of modern microprocessors is a major problem (good), but once again they were directed to the chip layout. Here they were expected to point out that hot spots (as revealed by blackbody radiation – in this case infrared – measurements) might indicate shorting or some other form of circuit failure, and cold spots and regions might indicate an open circuit preventing current from flowing. This was all hypothetical, but logical. Some students pointed out that chip features are now of nanometer scale, whereas typical infrared wavelengths are of micrometer scale, so the diagnostics technique will lack resolution: another important point.

Finally, students were asked if they have heard about cosmic microwave radiation (CMR), which is understood to have originated shortly after our universe originated according to the "big bang" theory. It was pointed out that the gases doing the radiating would be extremely hot. Next, it was pointed out that the measured spectrum of CMR corresponded to that of a black body at a temperature of around 3 K. How could the "extremely hot" be reconciled with the measured 3 K? Students went off in a number of different directions, but many pointed out that the CMR was being emitted by gases traveling at very high speed away from the earth and that it would be subject to a doppler shift that could go some way to accounting for the low frequency of the 3 K CMR. The key points were to convert from temperature to a frequency point of view and then to realize that the CMR sources were traveling away from the observer and thus the CMR would undergo a doppler shift to lower frequencies.

Hector Garcia-Molina
EE Quals Question 2005

Consider a STACK data structure. Each record on the stack has 3 fields:

* next: pointer to the next record, further down the stack
* prev: pointer to the previous record, up the stack
* val: an integer value

A global variable TOP points to a dummy record which is always at the very top of the stack. An empty stack has the dummy record only, with both pointers null. If there is one element, top.next points to it.

(a) Write (pseudo-code) a procedure POP which returns the top value in the stack, and removes the record for that value.

(b) Write a procedure PUSH that adds a value X at the top of the stack. The procedure creates a new record.

(c) Write a procedure that deletes the last record from the stack (the one furthest away from TOP).

2005 PhD Quals Question
J. S. Harris

1. Draw an energy band diagram for either GaAs or Si and tell me what the drawing represents?
   (a) What is the vertical axis? Total Energy, Potential Energy, Kinetic Energy and can you distinguish between PE and KE?
   (b) If I have a photon with energy E_g incident on the semiconductor, where does this transition occur and what happens?
   (c) If I now have a photon with energy 1.5 or 2 x E_g incident on the semiconductor, where does this transition occur?
   (d) What happens to the excess energy in this process?

2. Draw an energy band diagram for a p/n junction. Is there any relationship between these two energy band diagrams?

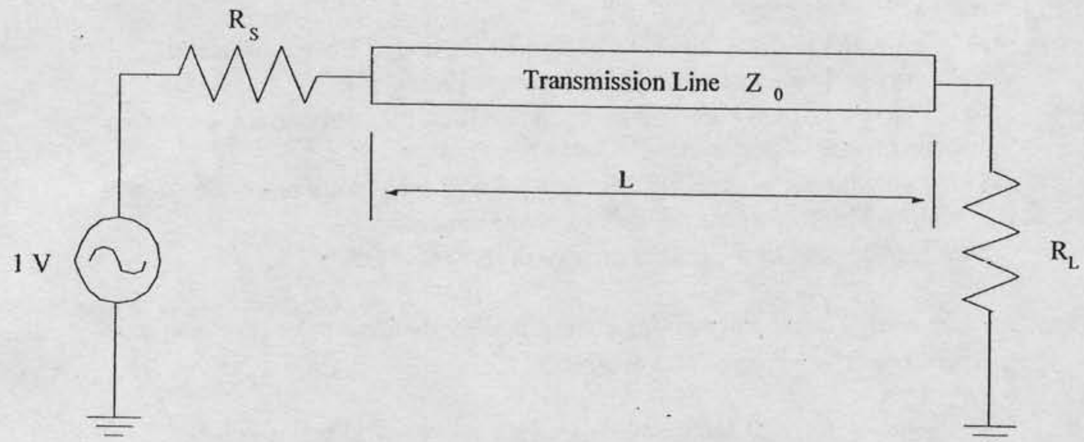
3. If we apply a voltage to such a diode, current will flow. Draw the I-V characteristic we might expect for such a diode.
   (a) We can divide this into 3 regions—describe the character in each of these 3 regions and explain what it's due to.
   (b) If I now decrease the temperature of the diode by 100°C, how will each of these 3 regions change and why?

4. If I were now to replace the n-type side of the diode with a wider bandgap material but with the same doping and electron affinity as the original material,
   (a) What would the energy band diagram look like and why?
   (b) How might this effect the I-V characteristic?
   (c) Are there any devices in which you think such a junction would be advantageous? And if so, how and why?

Butrus Khuri-Yakub

Name: ______________________________

In the figure shown, you are to sketch the power delivered to the load R_L as a function of frequency. For a numerical example, use $R_s = 100\ \Omega$, $Z_0 = 10\ \Omega$, and $R_L = 1\ \Omega$.



G. Kovacs Quals Question 2005

The student is told about self-flashing LED's, which are explained using a block diagram. The LED consists of a standard LED light emitting chip and a CMOS chip that generates a squarewave of current through the LED alternating between zero and twenty milliamps. The student is then asked to think about 100 of the same blinking LEDs wired in parallel, with the total current from all 100 flowing to ground through a 0.1 Ohm resistor. The student is asked to sketch the voltage waveform at the node between the resistor and the negative terminals of the blinking LEDs from time zero to a minute or so.

The student is then shown the actual waveform from the circuit. They are asked to compare to their sketch and explain any differences.

The student is then asked to consider the power spectrum of the signal presented to them over a minute or so. The emphasis is not on minute detail, but understanding how large-scale changes in the waveform over this time would manifest in changes in the power spectrum.

The student is then shown the actual power spectrum and asked to compare their sketch or comments to it and comment.

EE Quals 2005 Name: Christoforos Kozyrakis

Vector architectures use instructions (load/store and arithmetic) that define operations on arrays of numbers (vectors). The following vectorizable loop:

for (i=0; i<64; i++) c[i] = a[i] + b[i];

can be expressed with two vector loads for a and b, an element-wise vector add, and a vector store for c. Each instruction specifies 64-bit independent element operations. A vector processor typically executes multiple of these operations per cycle (e.g. 8 elements adds per cycle for the vector add in our example).

For vector processors to be useful, the loop must be vectorizable. For the following loops:

- Identify if they are vectorizable: yes/no, why, how, under which conditions, or with what hardware or instruction set extensions/requirements…

You can discuss the loops in any order you want. Assume N is large (100s or 1000s).

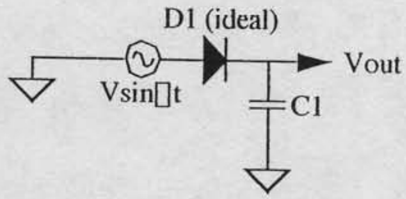
1	for (i=0; i<N; i++)	c[i] = c[i+1] + b[i];
2	for (i=0; i<N; i++)	c[i] = c[i-1] + b[i];
3	for (i=0; i<N; i++)	if (b[i]!=0) c[i] = a[i] / b[i];
4	while (b[i]!=0)	{ c[i] = a[i] / b[i]; i++; }
5	for (i=0; i<N; i++)	t += a[i] * b[i];
6	for (i=0; i<N; i++)	c[i] = a[d[i]] + b[i];
7	for (i=0; i<N; i++)	c[d[i]] = a[i] + b[i];
8	for (i=0; i<N; i++)	c[d[i]] += a[i] + b[i];
9	for (i=0; i<N; i++)	c[2*i] = a[2i+1];

1	for (i=0; i<N; i++) c[i] = c[i+1] + b[i]; Always vectorizable
2	for (i=0; i<N; i++) c[i] = c[i-1] + b[i]; NOT vectorizable (loop-carried dependency distance 1)
3	for (i=0; i<N; i++) if (b[i]!=0) c[i] = a[i] / b[i]; Vectorizable Requires support for conditional vector execution
4	while (b[i]!=0) {c[i] = a[i] / b[i]; i++} Partially vectorizable (vector search for zero, set vl, vector divide) Fully vectorizable with speculative vector support
5	for (i=0; i<N; i++) t += a[i] * b[i]; Partially vectorizable by using tree reduction (vector temporary) Fully vectorizable if reduction permutation supported
6	for (i=0; i<N; i++) c[i] = a[d[i]] + b[i]; Vectorizable Requires support for indexed instructions
7	for (i=0; i<N; i++) c[d[i]] = a[i] + b[i]; Vectorizable if - d[i] elements are disjoint OR - HW executes vector stores in order
8	for (i=0; i<N; i++) c[d[i]] += a[i] + b[i]; Vectorizable ONLY if d[i] elements are disjoint
9	for (i=0; i<N; i++) c[2*i] = a[2i+1]; Vectorizable with strided accesses

Comments:

First consider the following:

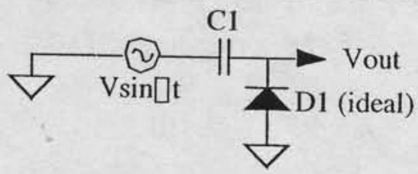
FIGURE 1. Diode-capacitor circuit



What is the steady-state output voltage? ***Ans:* V (The diode charges up to V in the first quarter-cycle. There is nothing to discharge the capacitor, so the output voltage stays at V forever.) This circuit is a filtered halfwave rectifier.**

Now exchange the diode and capacitor positions as follows:

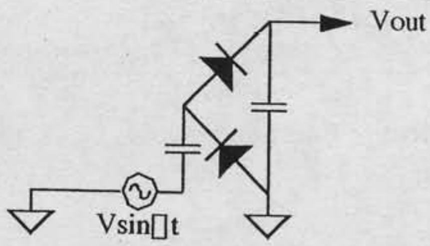
FIGURE 2. Another diode-capacitor circuit



Sketch the output voltage in steady-state: ***Ans:* The same three elements remain in series. The capacitor here charges up to V in the first *negative* quarter-cycle, and stays charged forever. Note that the polarity of the capacitor's voltage is such that it *adds* V to the sinusoidal drive. The output is thus still a sinusoid, just shifted upward by V, swinging between ground and 2V. This circuit is a level shifter (or clamp).**

Next, combine the two circuits in the following fashion:

FIGURE 3. Combined diode-capacitor circuit (all elements remain ideal)



What is the steady-state output voltage? ***Ans:* On each negative-going quarter cycle of the sinewave drive, the input capacitor charges up to V (bottom diode on, top diode off). On each positive-going edge, some stored charge transfers to the output capacitor. Again, with nothing to discharge the output capacitor, this charge pumping continues until the output voltage is 2V (the peak output value of the previous circuit). This circuit is thus a voltage doubler.**

EE Ph.D. Qualifying Exam, January 2005 Question

David Miller

Coupled oscillators

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

Preliminary question (background – not part of assessment)

Consider a mass and two springs, as shown in Fig. 1, where the mass can only move left or right (not up and down), and where there is no friction. Suppose I pull the mass to the left and then let it go. Describe the form of the subsequent motion of the mass.

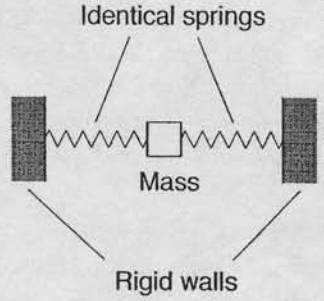


Fig. 1

Questions

Suppose now I have two masses and three springs, as shown in Fig. 2. The masses are equal, and the strengths of the leftmost and rightmost springs are equal. (The middle spring might have a different strength.)

We are interested in specific ways or "modes" in which these masses can oscillate. In each such mode, both masses oscillate at the same frequency, though the frequency may be different for different modes.

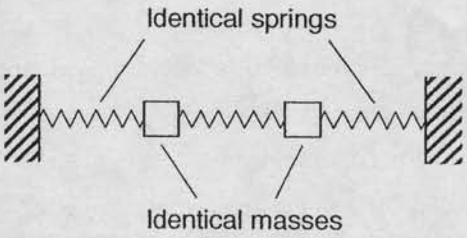


Fig. 2

(i) Qualitatively describe two different such modes of oscillation of these two masses.

(ii) Which mode has higher frequency, and why?

(iii) Qualitatively, what would happen to the frequencies of these modes if I increased the strength of the spring in the middle (i.e., made it more difficult to compress or stretch it)?

(2^{nd} sheet)

Supplementary question 1

Suppose now we had three equal masses, and four springs (which we can consider all to have equal strength). Qualitatively describe three different modes of oscillation of these three springs.

(3^{rd} sheet)

Supplementary question 2

Suppose in the case of the two masses and three springs (which you can assume now all to have the same strength) that I repeated the experiment many times, progressively changing one of the masses from being much lighter than the other mass to being much heavier. Sketch the frequencies of the modes as a function of that mass.

Solution

This question was done orally with the examiner. The student did not have to write down any answers unless that was helpful to them. Most students got most of the question on the first sheet completed reasonably successfully, often with some help from the examiner. All students got to at least the Supplementary Question 1 (the three mass case), getting at least the first two modes. The majority got the third mode with some help from the examiner. Some students got to the second supplementary question. No students finished that (nor would I have expected that they possibly could), but some had some reasonable intuition and success in getting at least some of the behavior. No student who got this far had heard of the "anti-crossing" behavior of coupled linear oscillators.

Of course, all these problems are quite solvable if one writes down the coupled linear differential equations, and solves for the eigenstates or normal modes of the system using standard linear algebra techniques, but I definitely did not want people to attempt that, which would be quite impossible in the time available, and no one did. The qualitative results can all be obtained by reasoning and intuition.

First of all, for the preliminary question, the mass will oscillate for ever in simple harmonic (sinusoidal) motion from side to side.

For the actual questions

(i) The two modes are

> (a) the two masses oscillate together side to side in the same direction with the same amplitude (the distance between them does not change). (We'll call this the "even" mode.)
>
> (b) the two masses oscillate side to side in opposite directions with the same amplitude. (We'll call this the "odd" mode).)

(ii) The "odd" mode has a higher frequency. This is because in the odd mode the center spring is also being compressed and expanded, thereby giving more total force on the masses for a given displacement (and hence larger acceleration for a given displacement, and hence higher frequency)

(iii) The frequency of the even mode is unaffected. The center spring is neither compressed or expanded in this mode. We could leave it out or replace it with a (light) steel rod, and it would make no difference.

The frequency of the odd mode will increase, because there will be more force on the masses for a given displacement.

Supplementary question 1

The first mode is all three masses moving in the same direction (with the same amplitude). (This mode is analogous to the one mode of the single mass in Fig. 1, or to the even mode of the two masses in Fig. 2).

The second mode is for the outer two masses to move in opposite directions (with the same amplitude), and for the center mass to stay stationary. (This mode is analogous to the odd mode of the two masses. In fact, if we added a mass in the middle of the center spring in the two mass case, it would make no difference to that even mode, because this additional mass does not move.)

The third mode (which was the hardest for most people to find) is one in which the two outer masses move in the same direction (with equal amplitude), and the center mass moves in the opposite direction (actually with twice the amplitude, though I did not ask or expect people to get that fact).

Most students got to the third mode simply by looking at all the various directions the masses could oscillate in. A key point is that in a mode (by the definition given in the question) everything that is oscillating is oscillating at the same frequency. Proposed modes in which one mass has only one spring pulling on it, whereas other masses have two springs pulling on them, will not work because the different masses have different restoring forces for a given displacement, and hence would not be oscillating at the same frequency. Others tried to figure out the "vector" for the third mode by formally looking for orthogonality with respect to the first and second modes (the reader can verify that the vectors [1,1,1], [-1,0,1], and [1,-2,1] are all orthogonal), which is a rigorous approach. One other way of deducing the third mode qualitatively is to realize that these problems of masses and springs are discretized versions of standing waves on a string, with this third mode corresponding to the third possible standing wave, though no students looked at the problem this way.

Supplementary question 2

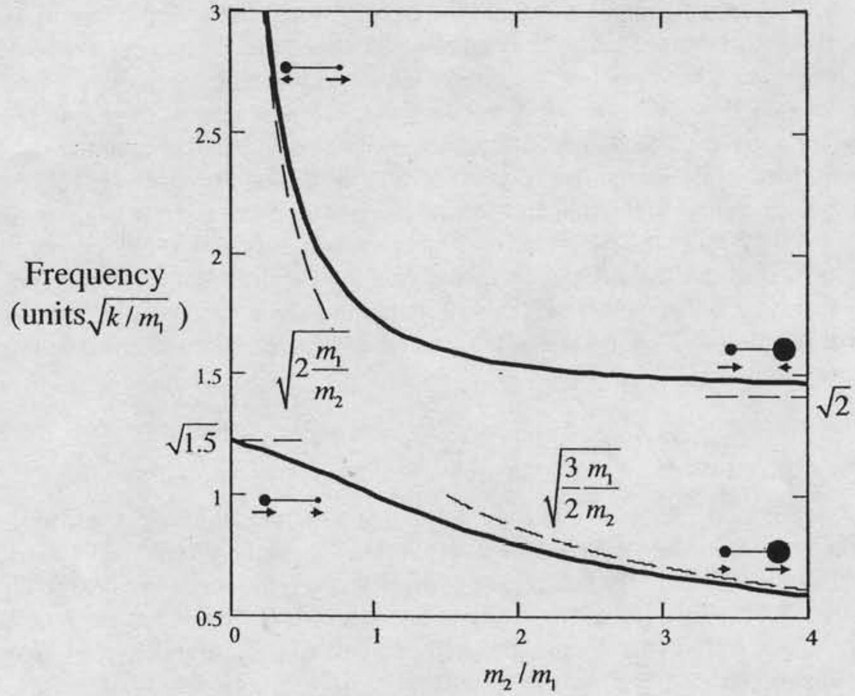
For the sake of definiteness, let us say that the mass that stays constant is the left mass, m_1, and the right mass, m_2, changes from being very light to being very heavy. The key to solving this problem is to look at the limit cases of m_2 being very light or very heavy. The problem is relatively easy to solve qualitatively if one recognizes that, when the masses are very different, we really do not have coupled oscillations any more. In any given mode, we are either dominated by one mass or the other.

In one mode for light m_2, as far as m_1 is concerned, it is almost as if m_2 is not there, and m_1 oscillates with two springs, though the right spring is twice as long, reducing the frequency somewhat (actually, to $\sqrt{3k/2m_1}$). This mode is the "even" one, because the midpoint of the right pair of springs simply moves half as much as the mass m_1.

When m_2 is very light, another mode is that m_1 essentially looks relatively very heavy, so it is almost like a wall, and m_2 simply behaves like one mass with two springs, in which case it oscillates very fast (actually, with frequency $\sqrt{2k/m_2}$). Since we have already found the even mode, this must be the odd mode, with the two masses moving in opposite directions (though the movement of the larger mass (m_1) is relatively quite small).

A similar pair of arguments can be used to deduce similar behavior for the case where m_2 is very heavy, in which case m_1, relatively, becomes the light mass.

The results are plotted in the figure below, together with the limiting curves and asymptotes. One key interesting point of this behavior is what is called "anti-crossing". There are two general kinds of behavior one might guess for these masses, one being a frequency that decreases roughly as $\sqrt{1/m_2}$ as m_2 is made heavier, and the other corresponding to a roughly constant frequency associated with the constant mass, m_2. These two curves would cross round about the point of equal masses if one simply drew them. In fact, the curves bounce off one another, with the upper branch being consistently the "odd" mode, and the lower branch the "even" mode.



For this question, any reasonable qualitative results were sufficient. For the moderate number of people who got to this, some did deduce some of the limiting cases, and a few guessed the overall behavior.

Incidentally, this is quite a common kind of behavior, and it occurs for any case of linearly coupled oscillators. There are many examples in classical and quantum mechanics, and in electrical circuits. One other example is the "wolf note" on the cello. For a specific note on that instrument, there is a coupling between the resonance corresponding to one of the body resonances in the cello, and that corresponding to the standing wave on the cello string. The instrument can refuse to play the desired note (note above that there are some frequencies at which the system cannot oscillate in the figure above), and instead hops annoyingly between two closely spaced frequencies (which are the two different coupled mode frequencies of that coupled oscillator)!

Analytic solution

For completeness, here is the analytic solution to this problem (here for the simple case of equal spring constants), though I did not expect, and certainly did not want, anyone to attempt this (and nobody did!).

Newton's second law for a mass and a spring of spring constant k.

$$F = ma = m\frac{d^2x}{dt^2} = -kx$$

Differential equations for the two masses

Mass 1
$$m_1\frac{d^2x_1}{dt^2} = -kx_1 - kx_1 + kx_2 = -2kx_1 + kx_2$$

Mass 2
$$m_2\frac{d^2x_2}{dt^2} = -kx_2 - kx_2 + kx_1 = -2kx_2 + kx_1$$

We propose oscillating solutions at angular frequency ω. Then

$$-\omega^2 m_1 x_1 = -2kx_1 + kx_2$$
$$-\omega^2 m_2 x_2 = -2kx_2 + kx_1$$

i.e.,
$$\begin{bmatrix} -\omega^2 m_1 + 2k & -k \\ -k & -\omega^2 m_2 + 2k \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = 0$$

Using the usual determinantal equation for eigensolutions

$$\left(-\omega^2 m_1 + 2k\right)\left(-\omega^2 m_2 + 2k\right) - k^2 = 0$$

So

$$\omega^2 = \frac{k\left(m_1 + m_2\right)}{m_1 m_2}\left[1 \pm \sqrt{1 - \frac{3m_1 m_2}{\left(m_1 + m_2\right)^2}}\right]$$

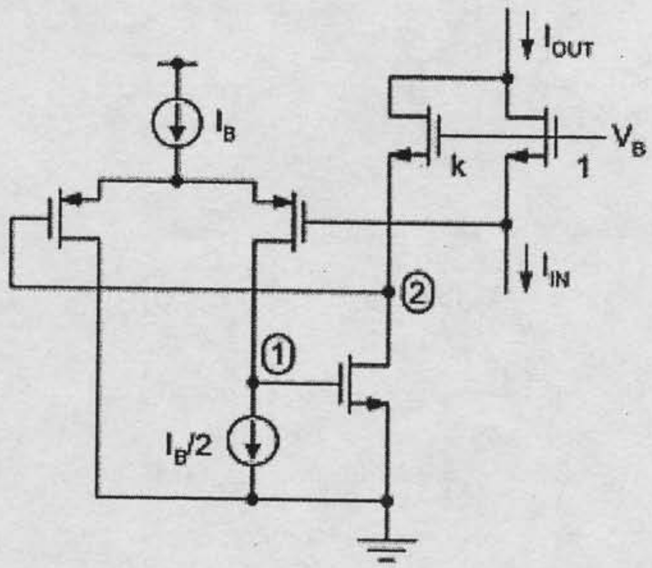
Extreme cases

$m_2 \to 0$:
$$\omega^2 \simeq \frac{2k}{m_2} \quad or \quad \frac{3}{2}\frac{k}{m_1}$$

$m_2 \to \infty$:
$$\omega^2 \simeq \frac{2k}{m_1} \quad or \quad \frac{3}{2}\frac{k}{m_2}$$

$m_1 = m_2 = m$:
$$\omega^2 = \frac{3k}{m} \quad or \quad \frac{k}{m}$$

Name:	Quals 2005, Murmann



a) What is the intended function of the above circuit?
b) Draw a Bode plot for the loop gain in this circuit.
c) Estimate the phase margin of the loop. For simplicity, assume that all device transconductances are equal and that nodes 1 and 2 have the same amount of parasitic capacitance.

quals2005.pdf

To:
From: Diane Shankle <shankle@ee.stanford.edu>
Subject: Fwd: Re: Last Chance to Submit Your Quals Question 2005
Cc:
Bcc:
Attachments:

2004-2005 Quals question
John Pauly

1) Assume you have a bandlimited signal sampled at the Nyquist rate.
How would you resample the signal at a delay tau, where the delay tau is less than the sampling period T.

2) How would you implement this as an FIR filter? Sketch what the filter looks like.

3) Assume that the signal is now sampled at twice the Nyquist rate.
How does that effect your answer for (2). What does the FIR filter look like now?

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. 165
Stanford,CA 94305-9505
http://www-ee.stanford.edu

Date: Sat, 15 Jan 2005 16:29:19 -0800
From: Fabian Pease <pease@cis.stanford.edu>
X-Accept-Language: en-us, en
To: Diane Shankle <shankle@ee.Stanford.EDU>
Subject: Re: Quals Questions 2005

Pease's question(s):

1. Define 1 volt
2. How do you measure voltage (several ways are possible)?
3. Have you ever heard of a Kelvin Generator? (no one had)
4. Here is one. When the water flows a voltage is generated. How does it work?
5. Try using this multimeter to measure the voltage (get a transient indication of voltage, then nothing). Why doesn't the meter work?
6. Devise a voltmeter with infinite (>1e14 ohms) resistance.

Kunle Olukotun

Perfect Branch Prediction vs. Perfect Data Cache

Warm up question

The genie of computer architecture has give you one wish. You can have a processor with perfect branch prediction or a perfect cache. Which do you choose and why?

Perfect Branch Prediction vs. Perfect Data Cache

Assumptions

- Single issue out-of-order processor, unlimited window size
- 10 cycle branch delay
- Single cycle access, nonblocking cache, 1 word block size
- Memory accesses have 10% miss rate
- 100 cycle main memory access
- No structural hazards

```
for (i=0; i < 100,000; i++)
      Y(i) = (X(i) == 0.0) ? X(i) : Y(i-1);

      addiu  $s3, $s0, #400000      ; initialize $s3
loop: lw     $f2, 0 ($s0)           ; load X(i)
      c.eq.s $f0, $f2               ; X(i) == 0.0
      bfpf   yi-1                   ; 50% mispredict
      j      yi                     ;
yi-1: lw     $f2, -4($s1)           ; Y(i-1)
yi:   sw     $f2, 0($s1)            ; store Y(i)
      addiu  $s0, $s0, #4           ; increment X index
      addiu  $s1, $s1, #4           ; increment Y index
      slt    $s2, $s0, $s3          ; test if done
      bnez   $s2, loop              ; 0% mispredict
```

Which performs better perfect branch prediction or perfect cache?

Perfect Branch Prediction vs. Perfect Data Cache

Assumptions

- Single issue out-of-order processor, unlimited window size
- 10 cycle branch delay
- Single cycle access, nonblocking cache, 1 word block size
- Memory accesses have 10% miss rate
- 100 cycle main memory access
- No structural hazards

```
for (p=head; p!=NIL;)
    if (p->value == 0)
        p = p->link1;
    else
        p = p->link2;
```

```
        J       test
loop:   lw      $s0, 0($s1)
        bnez    $s0, link2        ; 50% misprediction
        lw      $s1, 4($s1)
        J       test
link2:  lw      $s1, 8($s1)
test:   bnez    $s1, loop         ; 0% misprediction
```

Assume 100,000 iterations

Which performs better perfect branch prediction or perfect cache?

EE Qualifying Exam
January 2005

Find the Fourier transform of $f(t) = |t|$.

Subject: quals question
Date: Fri, 14 Jan 2005 11:55:46 -0800
Thread-Topic: quals question
Thread-Index: AcT6cZpfOREHVfCwSXGpazl/1zFGRg==
From: "Pianetta, Piero" <pianetta@slac.stanford.edu>
To: "Diane Shankle" <shankle@ee.Stanford.EDU>
X-OriginalArrivalTime: 14 Jan 2005 19:55:46.0717 (UTC)
FILETIME=[09E174D0:01C4FA73]

Diane,

Here is my quals question.

Piero

Consider a simplified model of an atom with a positive core and with the outer or valence electrons modeled as a spherical shell of charge. Also, consider one of the core electrons with a binding energy of Eb. If I were to remove charge from the outer valence shell, for example, by oxidation of the atom, how does the binding energy of the core electron change? (A drawing illustrating the situation would also be.)

Answer: the binding energy becomes larger.

Ways of arriving at the answer (both look at the problem from an electrostatics point of view):
1) consider the definition of binding energy which is the work required to bring the core electron from its bound state to infinity. The oxidized atom sees a greater net positive charge so the amount of work done would be higher for the oxidized case.
2) calculate the potential and the associated potential energy inside the spherical shell on a test charge. This is a smaller number for the oxidized sample. When that is added to the negative potential due to the positive core, it shows that the oxidized sample has an overall energy that is more negative, or that the binding energy is again higher for the oxidized case.

Peter Peumans

NAME:

The best answers are short and to the point. Answer the second question (next page) if you have time left.

Pn junction diode

(a) Draw the band diagram of a pn-junction in equilibrium, reverse and forward bias. Indicate the (quasi)Fermi levels.
(b) Based on this diagram, can you write down an expression for the current density flowing through this device as a function of the applied voltage?
(c) What happens to the current density when you illuminate the structure with light that is absorbed by the semiconductor?
(d) How would you calculate the efficiency of conversion from light to electricity? How large do you think this number can be (~1%, ~10% or ~100%)?

If you have time left: MOSFETs

A company called *Shakey Semiconductor Devices* sold you a bunch of n-channel MOSFETs for use in your new product. Unfortunately, you discover that the MOSFETs' drive current is slowly decreasing. In addition, you find that this degradation is less severe in your low-cost application that does <u>not</u> have a fan to cool the MOSFET.

(a) What could be causing the degradation?
(b) How would you verify this?
(c) Do you know how to fix this problem?

Mendel Rosenblum 2005 EE qualifying exam questions:

1) Pipelining
    a) Explain how pipelining allow a CPU to execute faster?
    b) What happens when an instruction executing in a pipeline has an error (e.g. Illegal instruction, Page Fault)?
    c) What can be done to speedup exception processing?
    d) What changes would be needed to a pipeline to support very low overhead exceptions?

2) Translation lookaside buffer (TLB)
    a) What does a TLB do?
    b) Is the TLB typically visible to the software?
    c) How would you design a TLB so that it was invisible to the software including the operating system?

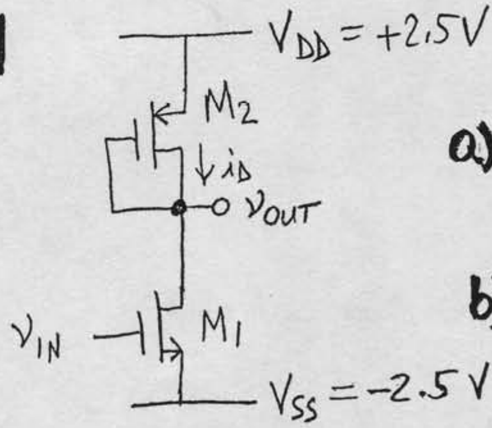
Saraswat

1. The laptop I recently purchased runs very hot. Why does the temperature of a laptop increase?
2. How is power converted to heat?
3. Where is power dissipated in a chip which has various components like transistors, capacitors, interconnects, etc?
4. Where is power dissipated in a transistor, by which mechanism and in which operation?
5. How would you optimize the dynamic and static power dissipation in a CMOS inverter keeping same performance (delay).

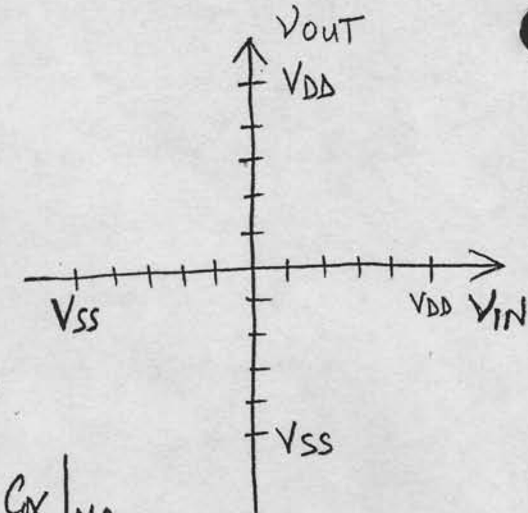
2005 EE QUALS QUESTION

SHENOY

Q1



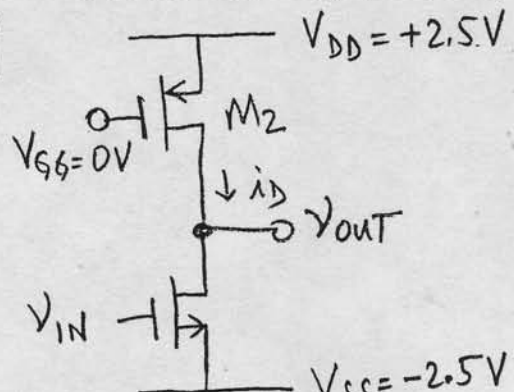
a) SKETCH LARGE-SIGNAL TRANSFER CURVE. →



b) WHAT IS MAX. VALUE OF v_{OUT}?

$V_{T_1} = |V_{T_2}| = 0.5\,V$; $\frac{W}{L}\mu C_{ox}\Big|_{M_1} = \frac{W}{L}\mu C_{ox}\Big|_{M2}$

Q2



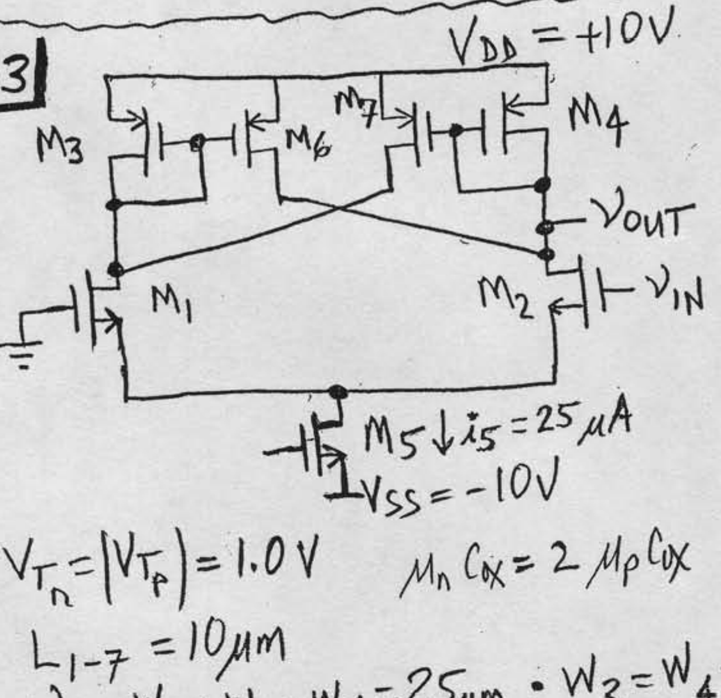
a) SKETCH LARGE-SIGNAL TRANSFER CURVE (ON PLOT ABOVE).

b) WHAT IS MAX. VALUE OF v_{OUT}?

c) IS GAIN LARGER/SMALLER THAN IN Q1?

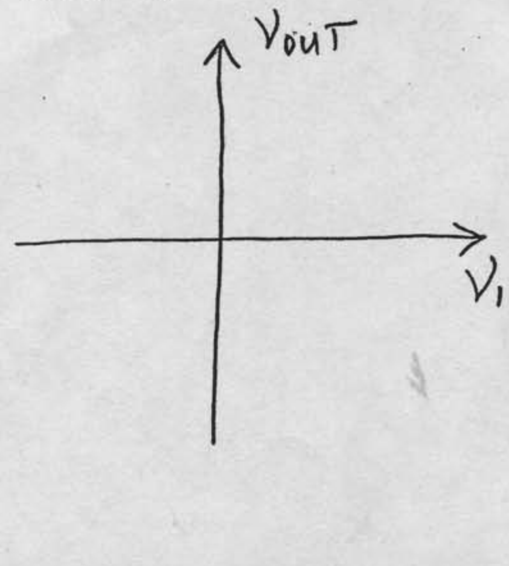
$V_{T_1} = |V_{T_2}| = 0.5\,V$; $\frac{W}{L}\mu C_{ox}\Big|_{M_1} = \frac{W}{L}\mu C_{ox}\Big|_{M_2}$

Q3



a) SKETCH LARGE-SIGNAL TRANSFER CURVE (BELOW).

b) WHAT COULD YOU USE SUCH A CIRCUIT FOR?



$V_{T_n} = |V_{T_p}| = 1.0\,V$ $\quad \mu_n C_{ox} = 2\,\mu_p C_{ox}$

$L_{1-7} = 10\,\mu m$

$W_1 = W_2 = W_6 = W_7 = 25\,\mu m$; $W_3 = W_4 = 10\,\mu m$

Benjamin Van Roy

Quals Question 2005

Here's my question:

Are Fourier transforms important and why?

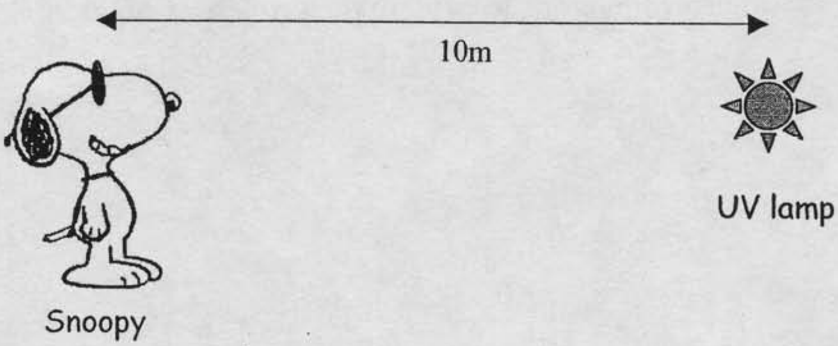
Why do people use transfer functions to explain the properties of certain systems?

Cheers,

Ben

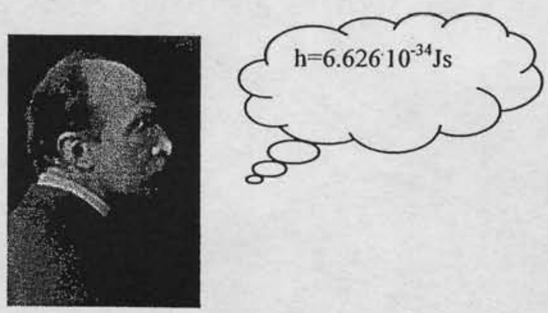
---

1. A 10 mW mercury-based lamp emits ultraviolet (UV) radiation at the wavelength of 250nm. Assume that the lamp radiates uniformly in all directions. Give order-of-magnitude answers to the following questions.
   (a) At what rate are the photons emitted from the lamp?
   (b) At what distance from the lamp will the average flux of photons be 1000 photons/($cm^2 \cdot s$)?
   (c) How many UV photons would get into Snoopy's eyes every second if he's standing at 10m from this lamp and looking directly into it?



(© United Feature Syndicate, Inc.)

2. Devise an experimental setup that can be used to measure the value of the Planck's constant $h=6.626 \cdot 10^{-34}$Js. Discuss all the equipment that one would need for such an experiment. (The setup should be as simple and cheap as possible.)



Max Planck

Tsachy Weissman

Quals Question

1. What is a Gaussian random variable ?

2. What is a Gaussian random vector ?

3. If X and Y are each Gaussian, is (X, Y) a Gaussian random vector ?

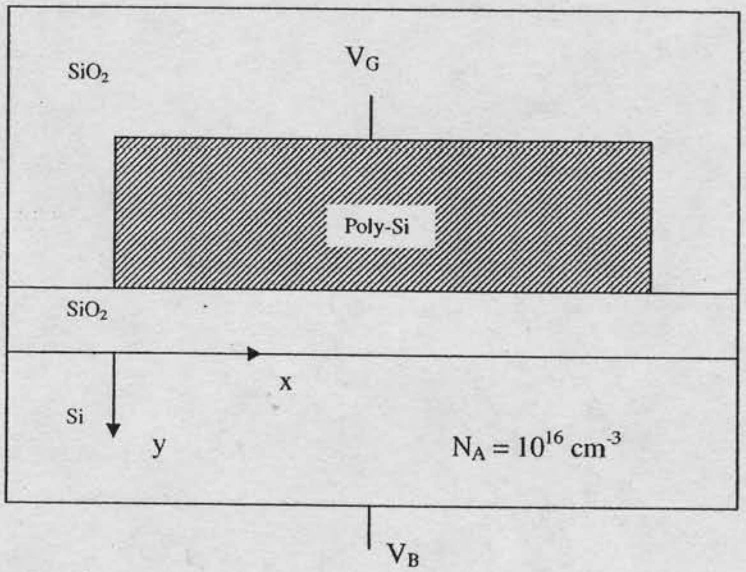
4. If (X, Y) and (Y, Z) are both Gaussian random vectors, is (X, Y, Z) a Gaussian random vector ?

5. If (X, Y), (Y, Z) and (Z, X) are all Gaussian random vectors, is (X, Y, Z) a Gaussian random vector ?

2005 Qual Exam Questions

Prof. H.-S. Philip Wong

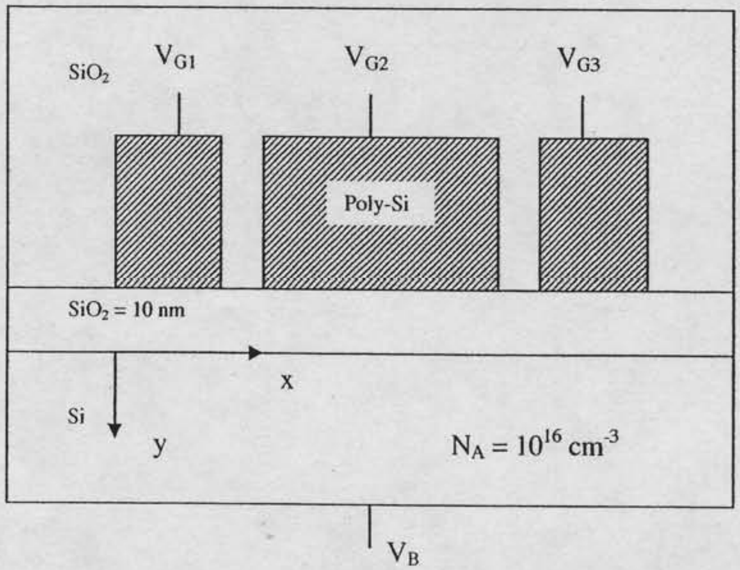
1. Draw the band diagram along the y-direction of the following device in thermal equilibrium:



$V_B = 0V$, $V_G = 2V$. $SiO_2 = 10$ nm.

Show the Fermi level.

2. Draw the band diagram along the x-direction of the following device in thermal equilibrium:



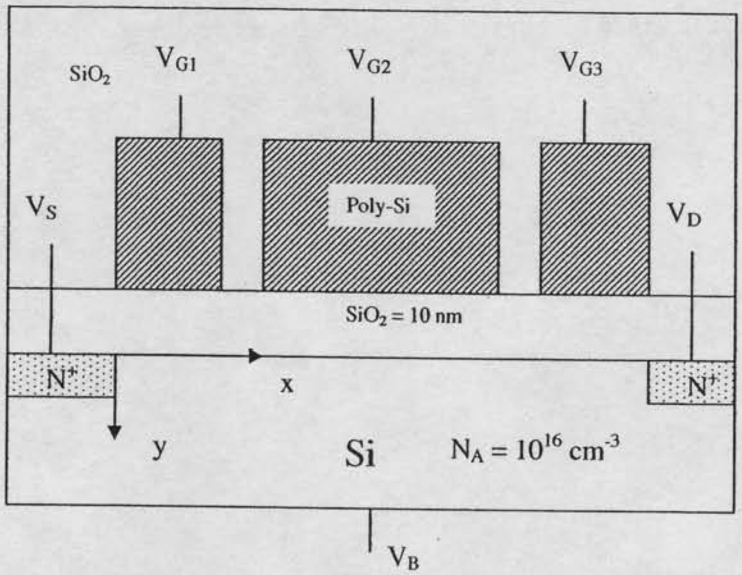
Case A: $V_B = 0V$, $V_{G1} = 2V$, $V_{G2} = 2V$, $V_{G3} = 2V$.

Case B: $V_B = 0V$, $V_{G1} = 1.5V$, $V_{G2} = 2V$, $V_{G3} = 1.5V$.

Case C: $V_B = 0V$, $V_{G1} = 2V$, $V_{G2} = 1.5V$, $V_{G3} = 2V$.

3. If you want to reduce the potential bump in between the electrodes, how would you change the device structure and/or device design?

4. Now, we add two heavily doped regions on both sides of the electrodes.



Assume the gates are very long (e.g. 5 um).

Case A:
$V_B = 0V$, $V_{G1} = 2V$, $V_{G3} = 2V$, $V_S = 0V$, $V_D=2V$. Sketch the I_D vs V_{G2} behavior of this device. Also sketch the I_D vs V_{G2} behavior of this device for $V_D=50$ mV.

$V_B = 0V$, $V_{G1} = 2V$, $V_{G3} = 2V$, $V_S = 0V$. Sketch the I_D vs V_D behavior of this device for various V_{G2}.

Case B: $V_B = 0V$, $V_{G1} = 0.2V$, $V_{G3} = 0.2V$, $V_S = 0V$, $V_D=2V$. Sketch the I_D vs V_{G2} behavior of this device.

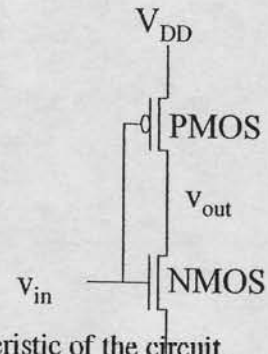
$V_B = 0V$, $V_{G1} = 0.2V$, $V_{G3} = 0.2V$, $V_S = 0V$. Sketch the I_D vs V_D behavior of this device for various V_{G2}.

Explain the physical origin of various current-voltage characteristics you sketched.

5. Continuing on the previous questions, if the gate lengths of the gates are shortened by a factor of 2, sketch the I_D vs V_G and I_D vs V_D characteristics again.

Explain the physical origin of various current-voltage characteristics you sketched.

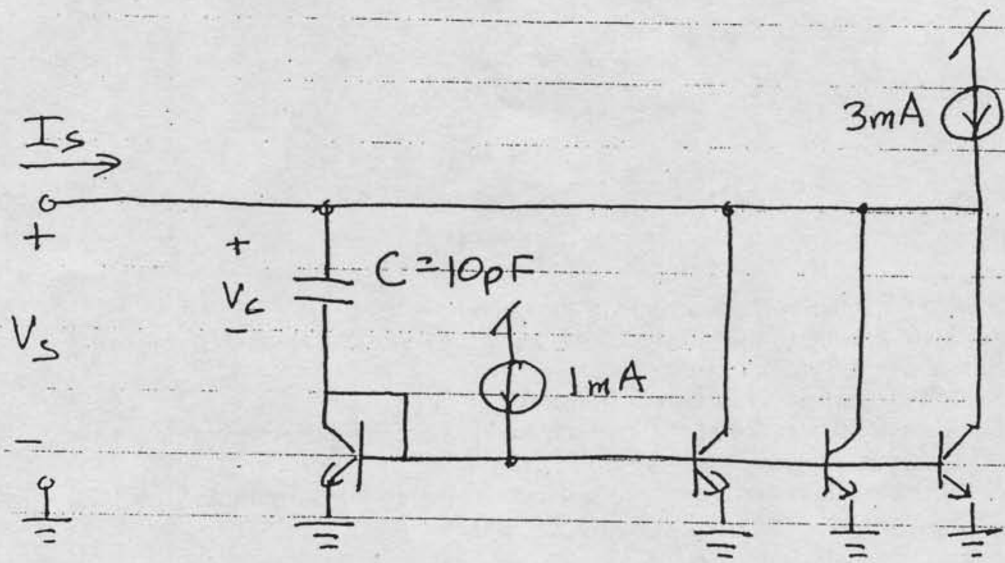
2005 Qualifying Examination
Simon Wong



1. Sketch the transfer characteristic of the circuit.
2. At the mid-point of the transfer characteristic, express the slope in terms of transistors' parameters.
3. Sketch the gain as a function of frequency.
4. Build an oscillator. You are allowed to add passive components, but no active components.
5. What parameters determine the oscillation frequency and amplitude ?

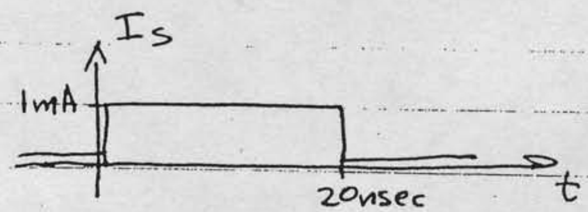
Bruce Wooley

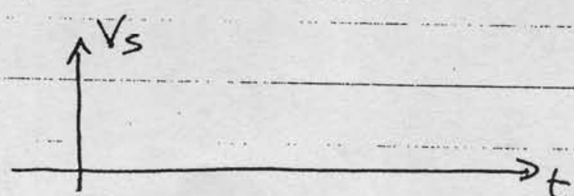
EE Quals '04-'05



Identical BJT's with large β_o & r_o

$V_c(0) = 0$





1. Plot $V_s(t)$ for $t > 0$

2. what is the small-signal input impedance?

Qualifying Exam Questions

January 10 – 15, 2005

Yoshi Yamamoto

Explain thermal noise, quantum noise and 1/f noise. You can choose any one of the following systems and describe the physical origins of those fluctuations.

(1) Simple macroscopic conductor
(2) Mesoscopic conductor
(3) pn junction
(4) Tunnel junction
(5) Laser/maser
(6) Parametric oscillator
(7) Mechanical oscillator