Jim Siegrist
Phone: 486-4397
Email: JLSiegrist@lbl.gov
Room (at LBL): 50-4055
Room (Campus): 309 Old Leconte

Administrative Issues

Lectures

Reserve T & Th 5-6 PM (location)
Only about 12 lectures for the semester, mostly they will be on Thursdays.

--- Must watch for lecture dates. ---

Current Plan, next 3 lectures:

Today	lec 1	Thur	Jan 18
	lec 2	Tues	Jan 23
	lec 3	Thurs	Jan 25
	lec 4	Tues	Jan 30

Course Grades

1. Must hand in all labs to pass, including P/F labs.
2. See yellow sheet for grade breakdown.

Grading:

Full Write-Ups:
- Introduction 10 points
- Conclusion 10 points + 3 or 4 random questions x 15 points
- Prelab Questions 20 points = 100 points

- Will not grade all the problems all the time (up to TAs)
- Supplemental Problems +2 points each
- -2 points per question with no answer
- –3 points per day late
- Work will not be accepted after the solutions have been posted.

P/F Labs:
- +50 points if you attempt all the questions
- –2 points per question with no answer
- –3 points per day late

Final Projects MUST be in on time.
Send me an email if you don’t want your paper posted.

Course Content

- Goal of this course is to teach the basics of modern electronics. You’ll need this for the next semester of Advanced Lab. We assume you know electricity and magnetism at the level of

Physics 7 and take you to the point that you can design your own circuits by the end of the semester.

- Main elements that we'll learn about in lecture:
  - Concepts
  - Instruments & Devices
  - Measuring Techniques
  - Circuit Analysis Techniques
  - Tools
- Topics in lectures tend to jump around among these – I'll try to note which area I am talking about as I change topics.
- I'll also give advice and information at the start of each lecture – the most important stuff will be in the front of the notes, so I hope you don't miss it. Notes will be posted to the web after lecture.

<u>Advice</u> for the course:

* Reading material for each lab at front of each handout.
* Labs are quite long, so come in early.
* This course is harder than you think – give it plenty of time.
* Find a partner, sign up for 2 afternoons/week (yellow form)
* Course grade strongly correlated with lecture attendance; will work some problems in lecture
* Some labs P/F – see handout. No introduction or conclusion write-up needed for P/F labs.
* Office Hours: by appointment
* Schedule of write-up due dates in handout.
* All write-ups must be NEAT.
* Example write-up in handout is minimum acceptance for P/F labs – really need diagrams and descriptions.
* Label axes on plots.
* Indicate units.
*** Note hand symbol for TA signoff – get before proceeding.

<u>Advice</u> this week:
Scope manuals in lab if needed – triggering, x-y mode
DMM description in notes – read it!
Read this & next week's lab – I'll talk about next week on Thursday.

Motivation – Why is the course goal important?

Physics is <u>Experimental Science</u> ⇒
What we know about nature determined by what we can <u>measure</u>.
Experiment crucial to guide theoretical development – witness development of
    <u>Quantum Mechanics</u> in 20's
    <u>Standard Model</u> in 70's

<u>What limits experiment?</u> – Instrumentation! (brains)
Why is electronics important in this?

1. Huge technology base (industry) around electronics ⇒ opportunity to exploit for new science.
2. ~ All modern instruments depend crucially on electronics for read out (and data handling!).
3. Many electronic devices operate at or near the theoretical limit allowed by quantum mechanics or thermodynamics. [e.g. position & momentum, noise in amplifiers]
4. Beating limits of measurement therefore is a major industry for physical science – other limits cost, size, sensitivity, etc. exist and also have to be beat.
5. Therefore you need to know this to be a physicist (theory or experimental)

Concepts

I. Circuits

Definitions – Units

Charge electron charge is -1.6×10^{-19} Coulombs

Current I_1 → flows in arbitrary reference direction

I_1 is positive if positive charges move in the reference direction, else negative

Charge dQ moves past a point in time dt ⇒

current dQ/dt in $Ampere \equiv \frac{Coulombs}{\text{sec}onds}$

Voltage $V(x) = \frac{Electrical\ Potential\ Energy(x)}{Q}$ – Unit = Volts

Zero is arbitrary!

Zero = reference point ⇒ common

Only Differences Matter

Power Charge +Q moves from V_1 to V_2 ⇒ a charge in energy of $Q(V_2 - V_1)$ Joules

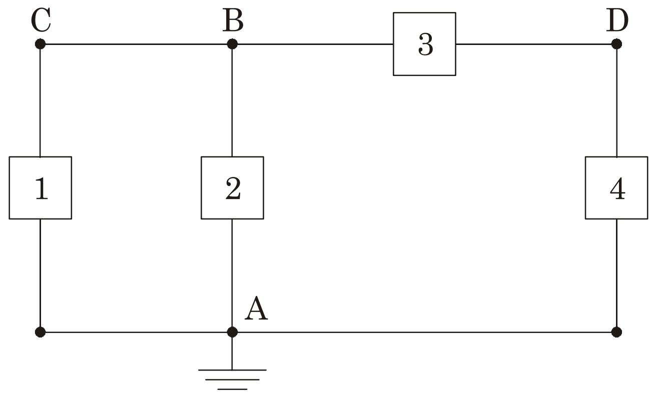
For a steady state current I,

$P = I(V_1 - V_2) \equiv IV$ = Joules/sec ≡ Watt ≡ Amp • Volt

Circuits imply a closed loop.

In the lab, be sure you have made complete circuits.

Equivalent Circuits, Kirchoff's Laws



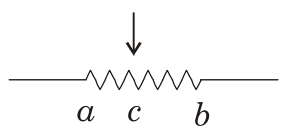
Definitions: Wire from C – B has no resistance (ideal wire) ⇒ $V_C = V_B$

Node: point at which 2 or more circuit elements are connected
Branch: two-terminal circuit element connected between nodes
(ABOVE: 3 nodes, 4 branches)
Nodes are NOT separated by wires.

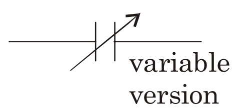
Kirchoff's Current Law: no charge accumulates on a wire ⇒
[sum of all currents entering a node is zero] (charge conservation)

Kirchoff's Voltage Law: sum of all voltage drops around a complete loop is zero
(potential at any instant is well defined)
(⇒ physical size of circuit is much less than λ at frequency in question)

Circuit Elements & Symbols

R  or 

$0 \le R_{ac} \le R_{ab}$; Ohms, V = IR

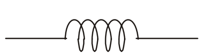
C  

$$V = Q/C = \frac{\int I\,dt}{C} \;\; Farads$$

$$\Rightarrow I = C\frac{dV}{dt}$$

$$Q = CV$$

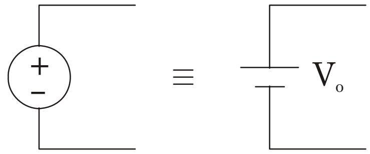
NOTE: Stored energy $U = \frac{1}{2}CV^2$ so be careful – big capacitor can give you a nasty shock.

L  $V = L\frac{dI}{dt}$ *Henries*

- Real signals come from transducers, e.g. phototube, photodiode, radiation detector, etc.
- Learn more about these mostly next semester

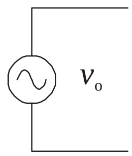
- Here, consider 'ideal' sources

DC Voltage Source



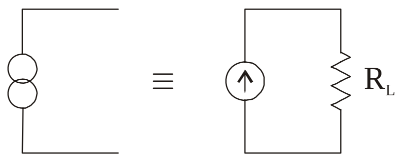
'ideal' ⇒ V independent of I

AC Voltage Source



v_o = V_o sin ωt or V_o cos ωt
— lowercase, usually

Current Source



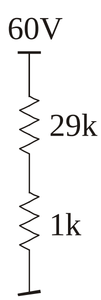
'ideal' ⇒ I independent of load resistor R_L
'compliance' – limit source can provide

* Useful to review <u>microscopic</u> definition of resistance –
Berkeley Series, Vol. II, Sec. 4.3 – 4.7

<u>Component Specs</u>

- <u>Resistors</u> – $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$ Watt – carbon composition in lab
  Color Code
  Tolerances
  Resistance varies with T, V, time, humidity, etc.
  Power = IV = I^2R

<u>Example</u>



What's the power dissipated in the 1k?

$I = V/R = \frac{60V}{(29k + 1k)} = 2mA$ & I is the same for both resistors since they are in series

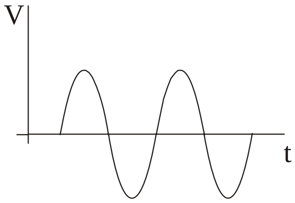
$P = I^2R = (2mA)^2(1k\Omega) = 4mW$ ($\underline{not}$ MW) *be* $\underline{NEAT}$

- <u>Capacitors</u> Electrolytic
  Ceramic
  Mica
  Tantalum

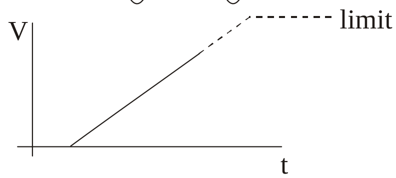
  NOTE: Some capacitors have <u>polarity</u> & must be connected in the 'right' direction
- List of other components & symbols in the lab book.
- See section in Hayes & Horowitz on capacitor values; pp. 51 – 53.

<u>Signals & Waveforms</u> (as seen on scope)

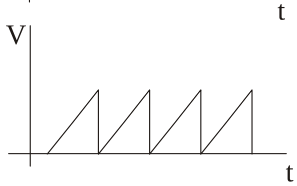
Sine Wave
(already
discussed)



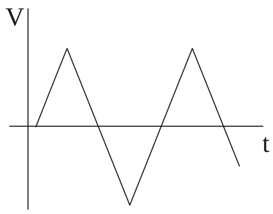
Voltage Ramp



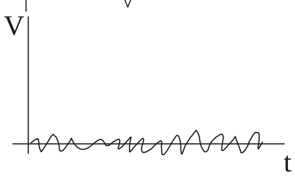
Saw Tooth
(repeating ramp)



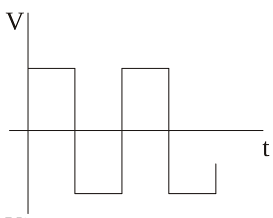
Triangle
(linear sine)



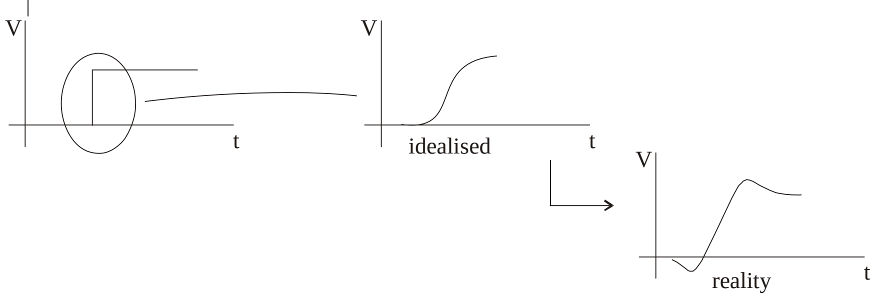
Noise



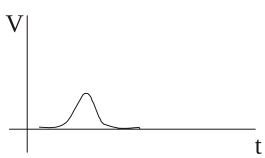
Square Wave



Step



Pulse



Logic levels – 0 or 1 for digital circuits – we'll discuss later

AC Circuits – Amplitude & Phase

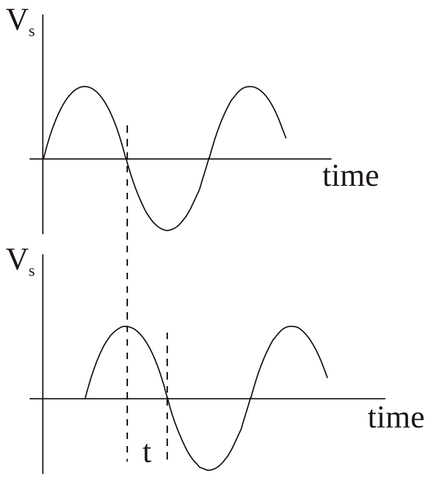
$$V_s = V_o \sin(\omega t + \phi) = V_o \sin(2\pi f t + \phi) = V_o \sin\left(\frac{2\pi t}{T_o} + \phi\right)$$

$$\omega = 2\pi f \quad rad/\sec$$

$$f = \frac{1}{T_o} \ Hz \quad \Rightarrow \quad T_o = \frac{2\pi}{\omega}$$

$$\phi = phase \ \ angle \ \ (rad)$$

$$V_o = amplitude$$



$$phase \ difference \ \ \phi = \frac{t}{T_o} 2\pi$$

$$amplitude = V_o$$

$$peak \ voltage = V_o$$

$$V_{p-p} = 2V_o$$

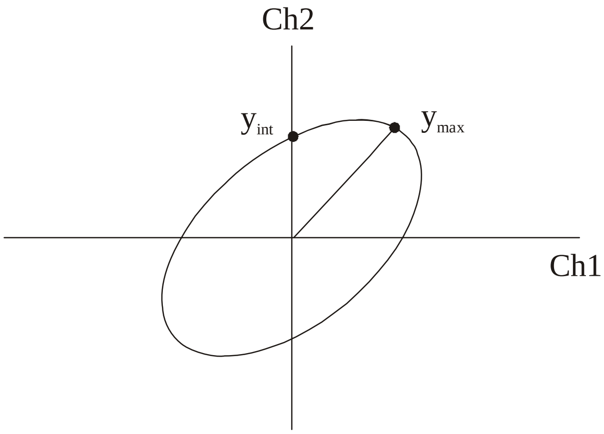
$$V_{rms} = root \ mean \ square \ V_s = \sqrt{\frac{1}{T_o}\int_0^{T_o} v_s^2(t)\,dt} \quad (over \ 1 \ period)$$

$$= \frac{V_o}{\sqrt{2}} \qquad (do \ integral) - over$$

Using x-y mode of the scope, you can find the phase Δ between 2 signals:

Ch1 A sin ωt

Ch2 B sin (ωt + ϕ)



$$At\ \omega t = 0, \quad A \sin \omega t = 0 \Rightarrow y_{int} = B \sin \phi$$
$$At\ y_{max}, \quad \sin(\omega t + \phi) = 1\ \ so\ \ y_{mzx} = B$$
$$\& \ \ {y_{int}}/{y_{max}} = \sin \phi$$
$$or\ \ \phi = \arcsin\left({y_{int}}/{y_{max}} \right) - \ use\ in\ lab\ II$$

Also, look at these signals in the frequency domain – e.g. look at response of linear circuits to pure sine waves.

* Linear ⇒ output, driven by sum of 2 signals, equals output sum if driven by each signal independently, e.g. O(A+B) = O(A) + O(B)
* Linear circuit driven by sin results in a sin, but phase & amplitude of the output changes ⇒ frequency response is a very useful concept –
  how do amplitude & phase change with ω?
* A useful hint to compare amplitudes of 2 signals; or of 1 signal relative to a 'standard' reference – decibel dB defined by $dB = 20 \log_{10} \left({V_2}/{V_1} \right)$

Measuring Techniques

- In working through labs this semester, think carefully about errors on your measurements:
  What limits the accuracy of the measurements you make?
  Are component values & their variation important?
  Can such errors be reduced?
  {many circuits are designed to avoid such problems – feedback}
  Precision vs. Accuracy – You can make a very precise, inaccurate measurement – systematic errors can mess you up. (time variation, thermal variation, etc.)
- e.g. Voltage across a resistor – (Horowitz & Hill pg. 430)
  All resistors have a 'noise' voltage (Johnson noise) across their terminals
  frequency spectrum is flat, (same noise power in each Hz of frequency, up to some limit)

⇒ call 'white noise'

$V_{noise}(rms) = (4kTRB)^{1/2}$

k is Boltzmann constant

T is temperature

R is resistance

B is frequency bandwidth to which you are sensitive

At room T, $4kT = 1.6\times10^{-20}\, V^2/Hz\cdot\Omega$

& $(4kTR)^{1/2} = 1.3\times10^{-4} R^{1/2}\, \mu V/Hz^{1/2}$

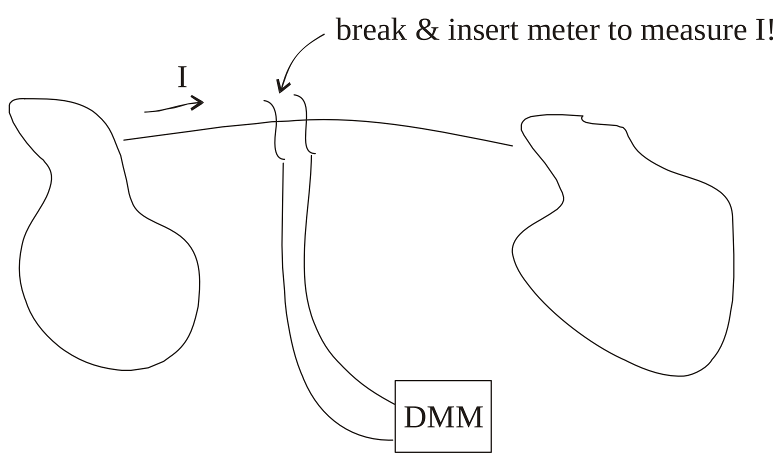
So 10k R at room temperature looked at by 10kHz band-pass oscilloscope has $V_{rms} = 1.3\,\mu V$ (pretty small!)

Many other kinds of noise, thermal noise discussed here related to fundamental constants; others are not fundamental. ('noise' in circuits usually not at thermal limit!) Many folks don't even know such limits exist! (sec. 7.11, H&H)

Instruments & Tools

ONE NOTE:

On ammeter, must connect to circuit in series to measure I!



Real Life:

Use a shunt. Low-resistance element permanently in circuit, measure ΔV to get I

⇒ $I = \Delta V/R$