

PRELAB 1

PHYSICAL & VIRTUAL INSTRUMENTS FOR ELECTRONICS

The Future Begins Tomorrow!

Motto of YoyoDyne Engineering in the movie Buckaroo Banzai

OBJECTIVES (Why am I doing this prelab?)

- Review of basic instruments (physical and virtual).
 - Review of electronic components.
 - Introduction to the design process.
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THE BASICS OF ELECTRONIC INSTRUMENTS

The whole purpose of this prelab is to prepare you for going into the lab and using various electronic instruments. There are two types of instruments that you should be familiar with: physical instruments and *virtual* instruments

Physical instruments are the type you can pick up (admittedly, you need help lifting the big ones!). You are probably familiar with several physical instruments such as multimeters, battery testers, etc.

Virtual instruments are those that are mainly (or entirely) software and are used with computers. The main virtual instrument that we will use in this course is a variation of the program “SPICE” which allows circuit designs to be simulated on a computer. This means that you can design and “prototype” an electronic circuit entirely in software. You don’t even need a soldering iron!

INTRODUCTION TO *PHYSICAL* INSTRUMENTS

Please refer to the lecture materials regarding the instruments to be used in the laboratory.

The Hewlett-Packard Model 34401A Digital Multimeter

This is an auto-ranging digital meter capable of measuring several basic electrical

parameters (hence the names “multimeter,” “digital multimeter,” or “DMM”, “digital voltmeter,” or “DVM”.... we'll refer to it as a DVM from here on). The basic principle of early meters was to magnetically deflect a mechanical needle in proportion to an electrical current. The electrical parameter to be measured was obtained by noting the position of the needle against a numerical scale behind it. By converting the desired electrical parameter into a current to deflect the needle, voltage, resistance, and of course, current could be measured. While so-called *analog* meters still turn up occasionally, *digital* meters have largely taken their place. Here, the electrical parameter being measured is digitized and displayed as numbers (no squinting at a needle required). Some newer digital multimeters even include a “simulated needle” to provide a graphical display of varying levels of voltage, for example.



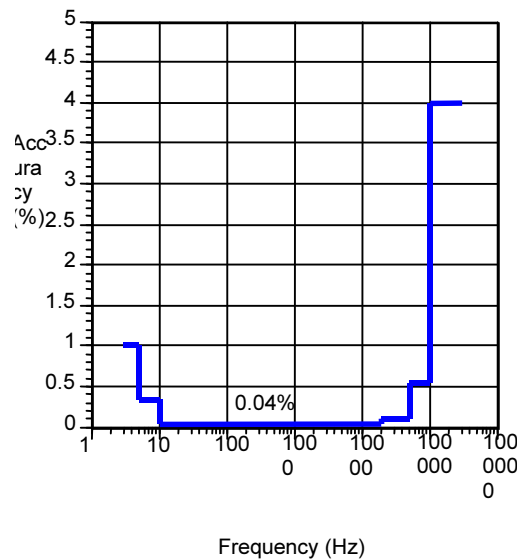
Briefly consider the measurement capabilities (“specs”) of the Hewlett-Packard 34401A. In the "old days" (a few years ago), we really worried about the basic accuracy of DVM's, since they typically only had a few digits (e.g., 3 1/2, where the "1/2" digit can read 1 or 0). Typical accuracies were 0.1%. Now, DVM's like the 34401A have many digits (6 1/2 in this case) and basic accuracies on the order of 0.002% or better for all functions! What input range you set the DVM to used to be a big issue, but now they are "intelligent" (microprocessor controlled) and automatically select the best range to give you the most accuracy.

The HP 34401A can measure AC (RMS) or DC current and voltage, resistance, as can virtually any DVM. It can also measure frequency, test diodes and provides a "continuity" function that beeps when there is a good connection (or unwanted short-circuit) between the two input leads. Six and 1/2 digits of display are more than adequate for nearly any application in EE122 (and elsewhere, for that matter), so we won't spend much time on accuracy here (if you want to, refer to the manual in the lab).

DC or AC voltages can be measured up to 1000 V with a maximum resolution (on the 100 mV full-scale range) of 100 nV!!! Resistances can be measured up to 100 M Ω , with a maximum resolution of 100 $\mu\Omega$ (on the 100 Ω full-scale range). DC or AC current can be measured up to 3A (**a fuse will blow above that, so be careful!**) with a maximum resolution of 10 nA (!) (on the 10 mA full-scale range).

AC voltages are read as true RMS (root mean square). The RMS function is frequency-

dependent (an actual analog computational circuit is used). A plot of the accuracy (using specs from the manual) shows that you really have to be careful for low or high frequencies.



PRACTICAL POINT: An important concept for any instrument is the input impedance. This specification is an indication of how much of a load the instrument places on the circuit you are measuring. For the HP 34401A, the input impedance is $1\text{ M}\Omega$ ($10\text{ M}\Omega$ for DC measurements) in parallel with less than 100 pF of “shunt capacitance” between the leads.

IF YOU ARE NOT USING AUTORANGING, ALWAYS USE THE DIGITAL VOLTMETER (DVM) SETTING THAT YIELDS THE LARGEST NUMBER OF SIGNIFICANT FIGURES. Otherwise, you are getting much less information than it can deliver. (Also remember to take off your shades when using oscilloscopes...)

The HP Model 33120A 15 MHz Function Generator

The 33120A is the main function generator you will use. It can synthesize all of the basic waveforms (square, sine, triangle, ramp, etc., as well as noise and programmable “arbitrary” waveforms). It can also synthesize AM and FM waveforms with somewhat limited parameters. It is menu-driven and quite intuitive. During the lab, you are encouraged to study its user’s manual.



The HP Model 8904A Multifunction Synthesizer

The 8904A is a four-channel signal generator, and likely only to serve as a backup instrument to the 33120A. Each channel can be set independently to a chosen frequency, phase, amplitude and waveform. These channels can then be fed simultaneously to the same output, the resulting voltage being the *sum* of the voltage in each channel. Alternately, the output of one channel can be *multiplied* by that of another, thus providing amplitude modulation (AM). Frequency modulation (FM) can also be achieved using this unit. Such a synthesizer is an important tool for generating test signals to use as inputs to circuits (or to demonstrate test instruments!).

An interesting feature of this unit is the multiple outputs that can be summed. This allows you to prove to yourself some of the concepts about Fourier series that you have probably been dying to test... As you may recall, the Fourier series for a signal tells you what combination of amplitudes and frequencies of sine and cosine waves to sum together to make the original signal.



Overview of Spectrum Analyzers

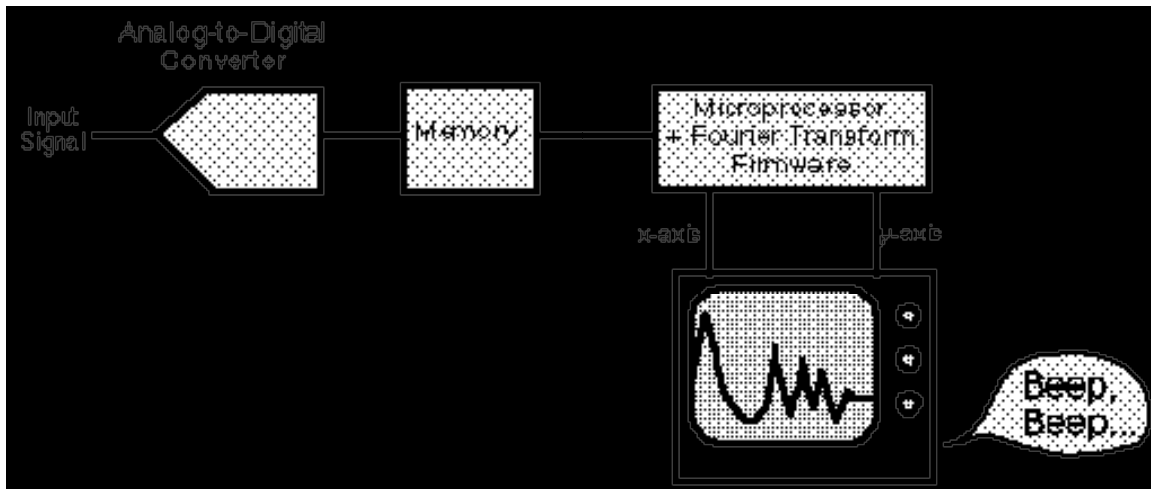
The Spectrum Analyzer is the frequency domain counterpart of an oscilloscope in the time domain. In other words, it can give you a plot of amplitude vs. frequency as opposed to amplitude vs. time. In practice, you look at the amount of energy present at each frequency plotted as the y-axis against the frequency (the x-axis).

Spectrum analyzers are extremely useful instruments, providing nearly instant information about the frequency content of signals. They can also be used to assess such things as the frequency responses of filters, distortion in amplifiers, and noise levels in signals.

There are two types of spectrum analyzers: analog and digital. In EE122, you will probably only deal with the digital type, but the analog ones are important enough that they need to be considered.

Digital Spectrum Analyzers

Digital spectrum analyzers first digitize (record a continuous analog function as rounded numbers with n bits of precision using an analog-to-digital converter) and discretize (sample at a high frequency) the input waveform so that it is simply numbers. Then they take a discrete Fourier transform (DFT) of the data to compute the frequency components. This type of spectrum analyzer can provide phase information but needs to have a fast enough digitizer to handle the frequency range of interest.



Hewlett-Packard Model 3561A Dynamic Signal Analyzer

This instrument obtains frequency domain information from time-domain input signals by digitizing them and digitally computing the desired results using the “Fast Fourier Transform,” which is a computationally efficient version of the DFT.

Think (if you can) about some situations in which you would want to use each type of instrument. If you don't do this, its o.k., because we'll force you to try them all out anyway when you do the lab!



NOTE that you can always capture a signal using the digitizing oscilloscope (see below) and compute the Fourier spectrum of the data using your computer (e.g., with the FFT or DFT in Matlab). Depending on the resolution, this method could be either more or less accurate than using the 3561A. Of course, it's not real-time...

Hewlett-Packard INFINIUM Digitizing Oscilloscope

This instrument is a digitizing oscilloscope or digital storage oscilloscope (“DSO”). The DSO is a versatile instrument that operates by digitizing the input signals with an analog-to-digital converter, storing the corresponding numerical values, and then displaying them on a display. This allows a waveform (even from a “one-shot” event) to be stored indefinitely as numbers. The resulting display can be modified (zoomed in on, scaled, etc.) and printed. Also, since the information is already stored as numbers, measurements on the waveform are easy and accurate, and most can be displayed in “real-time” on the device (frequency, peak-to-peak voltage, amplitude, etc...). This makes many measurements (such as those done for EE122 labs!) much easier.



Please refer to the User's Manual for detailed instructions (which are pretty simple). Also, please be careful to observe that you can save acquired waveforms to disk and then import them into a computer for further analysis or incorporation into write-ups.

INTRODUCTION TO SPICE: A *VIRTUAL* INSTRUMENT

Spice (and several variations that are now available) is a circuit simulation tool that can be run on many types of computers, from mainframes to personal computers. This prelab provides an overview of Spice. Additional information will be available as separate handouts and by referring to the various books and manuals for Spice in the lab room, or on the web. Be sure to read the manuals that apply to the version of Spice you are using!

In EE122, we currently use PSPICE¹. Your TA's will be telling you how to download and use it. You can find detailed information at:

<http://www.orcadpcb.com/pspice/default.asp?bc=F>

¹ Another free version of Spice, LTSpice (from Linear Technology), can be downloaded for free at <http://www.linear.com/software/>. This package includes a schematic editor, a circuit simulator and a waveform viewer.

PRELAB 1 EXERCISES

Work With Your Team

EXERCISE 1:

Consider the situation illustrated in Figure 1 below. What is the actual voltage at the outputs of the simple circuit at the left? What is the voltage measured at the meter when connected to the circuit on the left (note the old-fashioned analog meter is the symbol still used for most schematics!)?

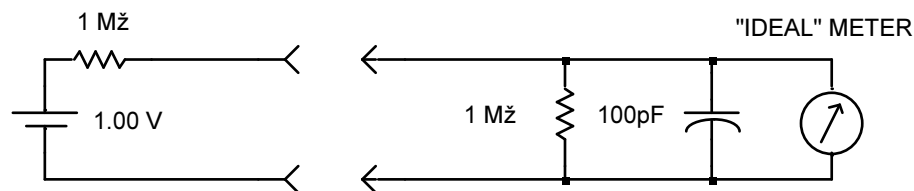


Figure 1: Equivalent circuit of HP 34401 measuring an external test circuit.

Now describe what you would measure if the battery on the left was replaced with a 1V RMS AC voltage source at 10 Hz. How about 10 KHz? Do you see why it is as important as considering what you are measuring to consider what *you are measuring it with?*

EXERCISE 2:

Consider a circuit consisting of a signal generator (AC voltage source), V_s , having a source resistance, R_s , connected to a load (R in parallel with C). The load voltage is V_L .

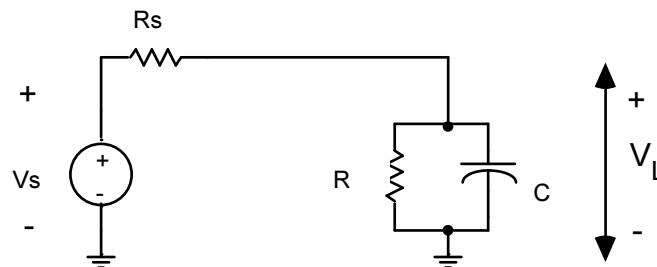


Figure 2: Simple, one-pole low-pass filter.

Derive an expression for the transfer function, $T(f) = V_L / V_s$, as a function of frequency.

Derive a formula for the (upper) cut-off frequency, f_u (the frequency at which the output signal is at 1/2 power or 3 dB down). Note that 3 dB down corresponds to an amplitude of 0.707 (one over the square root of two) times the starting amplitude (at DC). This

makes sense because the power in a signal into a given resistance goes as the square of the voltage ($P = V^2/R$). One-half the power means the voltage would have to be the square root of 1/2, or 0.707...

Above f_U , what is the roll-off rate of the amplitude versus frequency (dB/decade)? Hint: your equation should show that the output voltage is 20 dB lower per decade of increase in frequency - in other words, the signal should be 10X smaller if the frequency is raised 10X.

If the load consisted of **two** identical parallel RC circuits, what would the roll-off rate be? (i.e., put a second parallel RC stage in parallel with the parallel RC shown in Figure 2, and recalculate the transfer function)

As your transfer function should show, this circuit is a low-pass filter. As the frequency increases, the output voltage, v_L decreases because the capacitor tends to act more like a short circuit to ground.

Design a simple RC low-pass filter (as shown above) that has an upper cut-off frequency of 3 kHz (top of the voice band), assuming that $R_s = 1 \text{ k}\Omega$. Use standard components (see table on the course webpage).

Use the expression you derived above to select the components. Make a SPICE model and verify that your design is correct (generate frequency and phase response plots).

HINTS

1. A hint to find the cutoff frequency - get the transfer function in the following form $H(j\omega) = 1/(1+j\omega/\omega_c)$. As you can see, when $\omega = \omega_c$, $|H(j\omega_c)| = .707$.
2. To find the roll-off rate, use the rules of logarithms and simplifying approximations of $1+j\omega/\omega_c$ at the various values of ω .
3. To demonstrate that the roll-off is 20dB/dec, evaluate what the expression would be if $\omega = 10\omega_c$ was inserted. Also, note that you can make certain approximations when ω becomes very large.

LAB 1

HANDS-ON LEARNING WITH ELECTRONIC TEST INSTRUMENTS

We're having fun now, aren't we?

Prof. Bernard Widrow

Note: Please remember to bring a lab notebook and a floppy disk. There are no “right” or “wrong” answers here. The idea is to learn and explore as a team. Record your observations in your lab books and then (more neatly) in your write-up, which is due at the beginning of the next lab. That said, please be sure to check with your TA to see what format, and what level of detail/rigor s/he expects.

1) Familiarize yourself with the basic operation of all of the instruments on your bench. Please refer to the user's manuals (particularly for the digital oscilloscope) to get a sense for the instruments' features.

Do not worry about all of the details, as you will learn these as you go.

2) Use the digital multimeter to measure the resistance of various objects (some resistors, your fingertips, some wire). Note the values of the resistors as they are marked, and the values you measure. Note the resistance of your fingertips and how you made the measurements (e.g., two leads on one finger, one lead in each hand, etc.). Yes, these instructions are intentionally vague. Play around. Have fun.

3) Connect the 33120A function generator to the input of the digitizing oscilloscope (Infinium). Note that the voltage that you set the function generator to assumes that you have connected a $50\ \Omega$ load (i.e., a $50\ \Omega$ resistor to ground). If you do not do this (e.g., use the scope probe, which is high impedance) the output voltage will be larger (theoretically double what you set it to if it is into a very high impedance). Why is this? What happens when you change the input impedance of the Infinium between $1\ \text{M}\Omega$ and $50\ \Omega$?

Set the generator to produce a 1 V (peak-to-peak) sinewave at 10 kHz. Set up the oscilloscope so that you have a steady display of a few cycles on the screen (you may have to adjust the triggering). Measure the amplitude.

Capture the waveform to disk and import it into your computer to include in your Lab 1 report. Import it into an Excel spreadsheet (or spreadsheet program of your choice) and

plot its square (i.e., compute the square of each point's value and plot the squares versus time).

Set the generator to produce a squarewave at the same amplitude and frequency. Zoom in (show just a microsecond or so) to the time around the rising edge. Capture the waveform to disk. Do the same for the falling edge (remember to set the triggering for the falling edge!). Capture the waveform to disk.

4) Connect one of the small electromagnets to the oscilloscope's input. Hold it up to various things (operating power supply, oscilloscope, AC line cords, etc.). Look at the signal you pick up and comment on what you see. If you can, try using the dynamic signal analyzer to look at the frequency components of the signal (do not worry about capturing the waveform, but comment - e.g., is there a lot of 60 Hz line pickup?).