EE122A – Instruments, Simulation, and the Design Process

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The Design Process

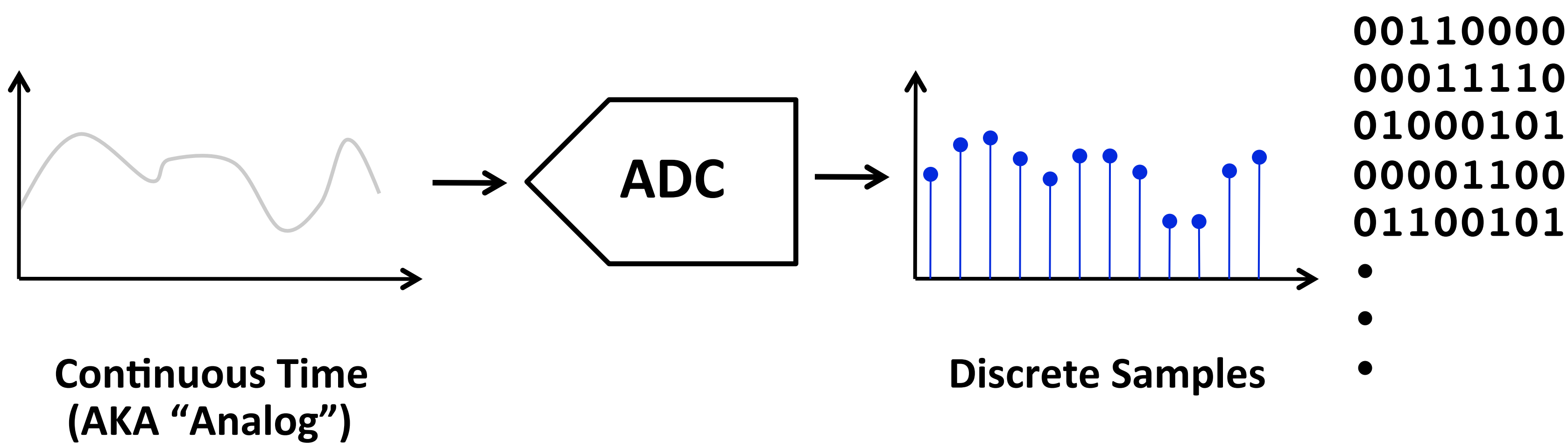
- **Definition of function - what you want.**
- **Block diagram - translate into circuit functions.**
- **First Design Review.**
- **Circuit design - the details of how functions are accomplished.**
  - **Component selection**
  - **Schematic**
  - **Simulation**
  - **Prototyping of critical sections**
- **Second Design Review.**
- **Fabrication and Testing.**

Analog Versus Digital…

- Analog, or "continuous time" signals are the actual physical signals (voltages, currents, etc.) that exist in nature.
- These signals are theoretically "pure" and can be amplified and "zoomed in on" until the limits of noise in the system are reached – analog signals are "floating point" representations of reality.
- Digital signals are integer approximations of actual analog signals. By definition, they are "lower fidelity."
- If the resolution is so high that the smallest representable signal is less than the inherent noise, it really does not matter if you go analog or digital.
- Computation can be done in either domain or both.

Analog to Digital Conversion

- Today, digital processing of signals is ubiquitous. Biomedical instrumentation is no exception.
- EE122A/B will rely on data acquisition (digitization) and digital processing for some labs and projects.
- A short introduction is given here.

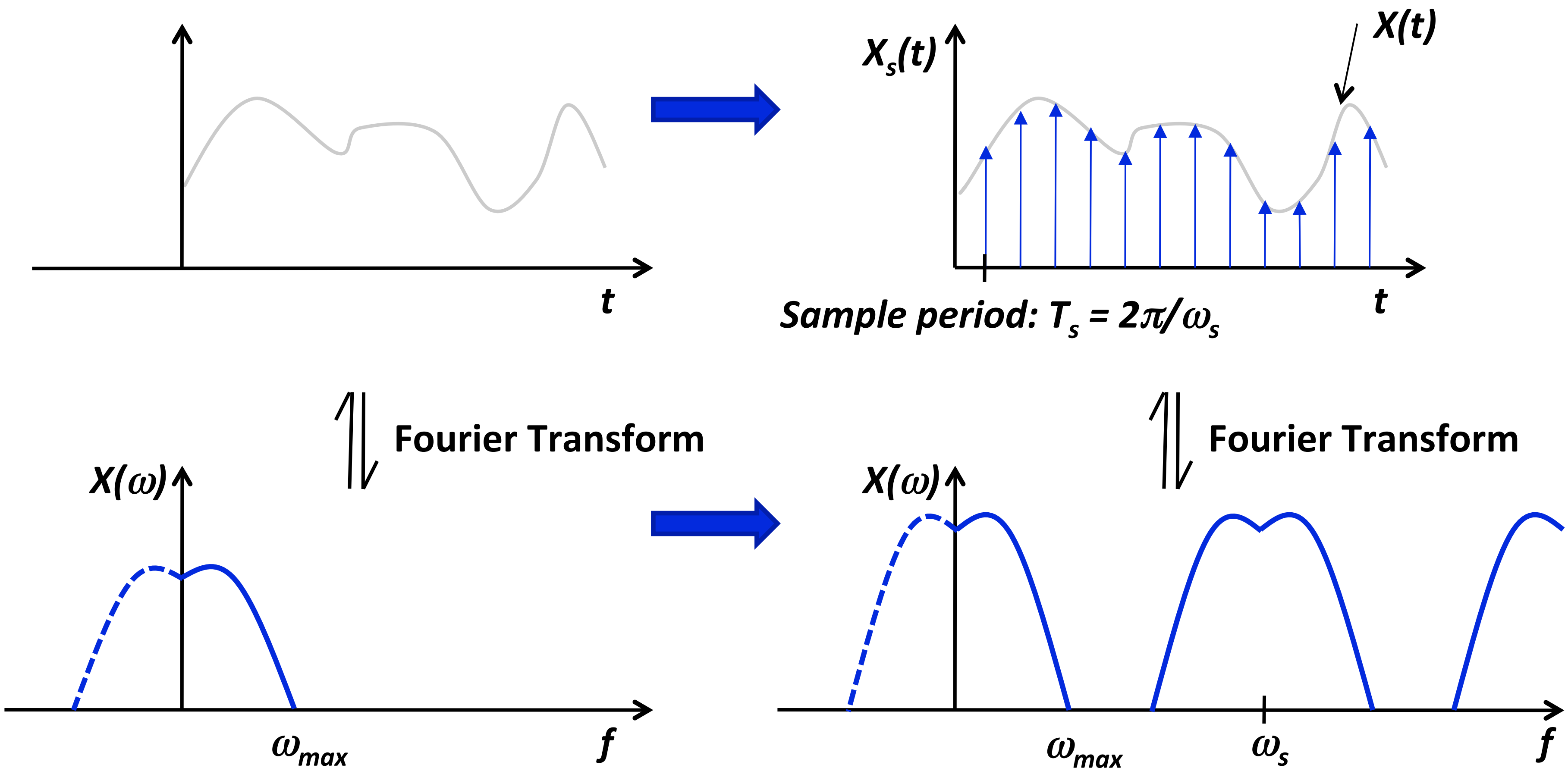


Graphics: Laurent Giovangrandi

Digitization – Time/Frequency

$$x_s(t) = x(t)\sum_{k=-\infty}^{+\infty}\delta(t - kT_s)$$

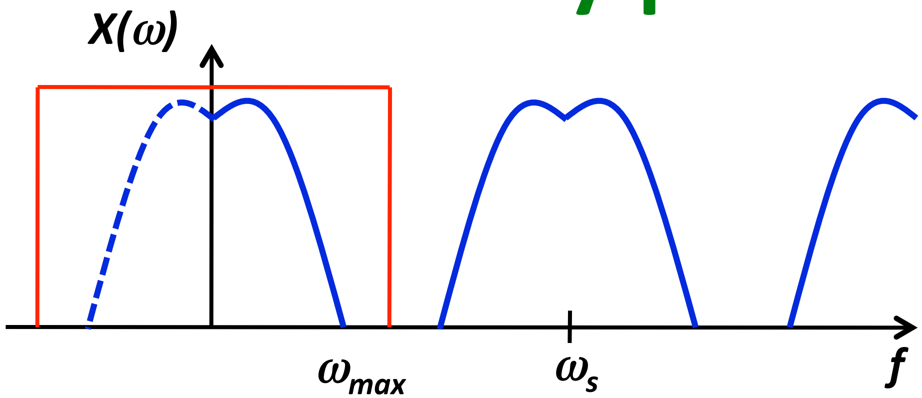
Sampling in time domain results in periodic spectra.



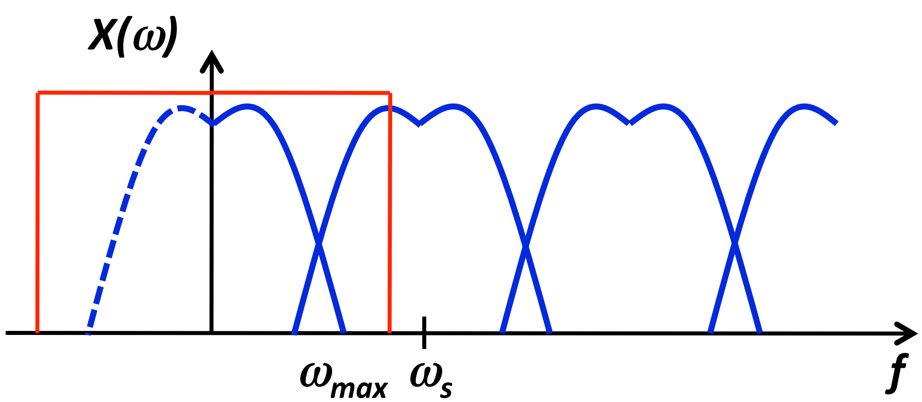
Multiplication in time domain is convolution in frequency domain.

  Graphics: Laurent Giovangrandi

Nyquist Sampling



If $\omega_s \geq 2\omega_{max}$ (Nyquist frequency), the signal can be reconstructed accurately.



Reconstruction filter (low-pass filter)

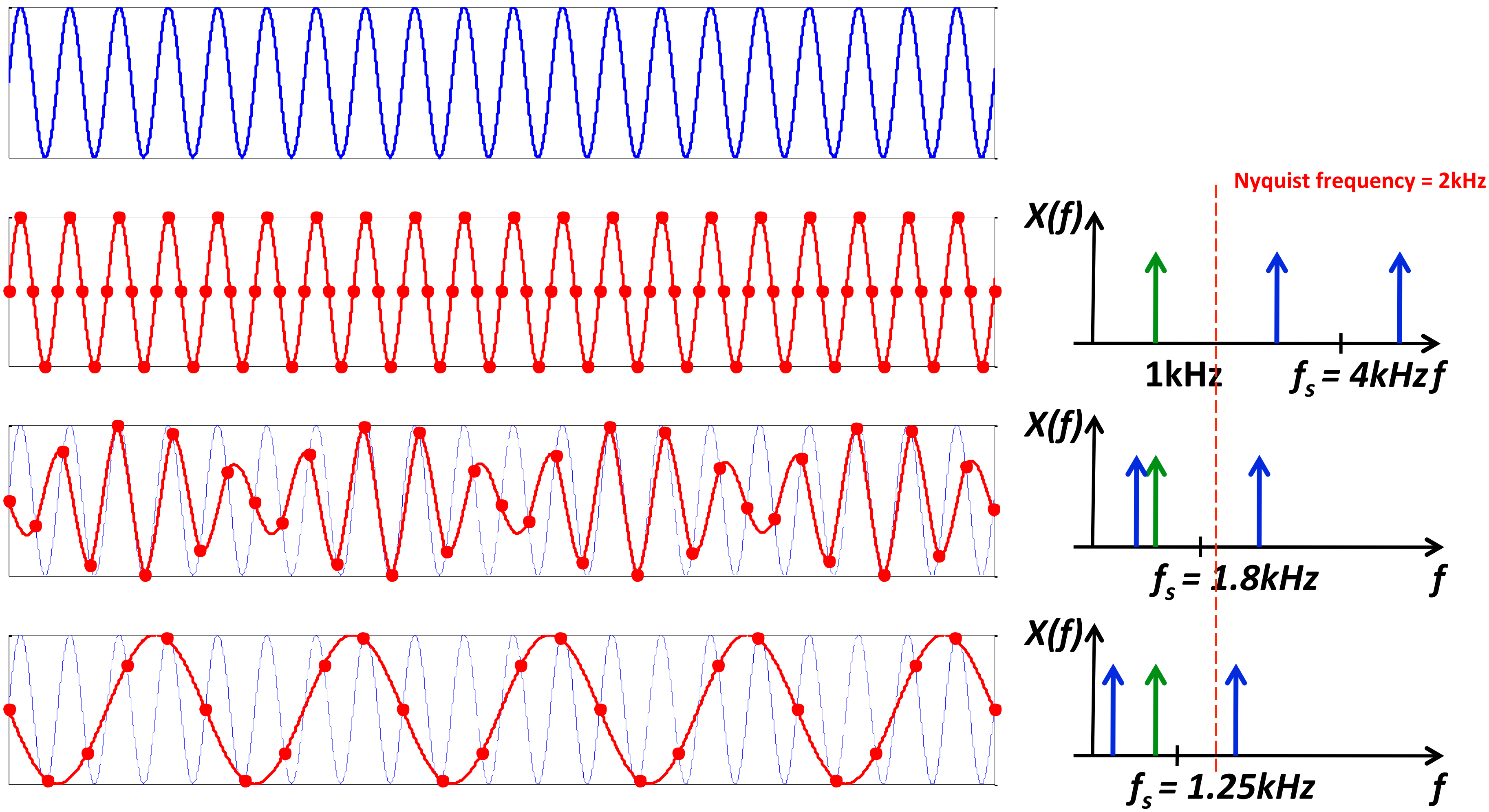
If $\omega_s < 2\omega_{max}$, the signal is irreversibly corrupted.

This is called *aliasing* because a high frequency signal can look like a lower frequency.

Graphics: Laurent Giovangrandi

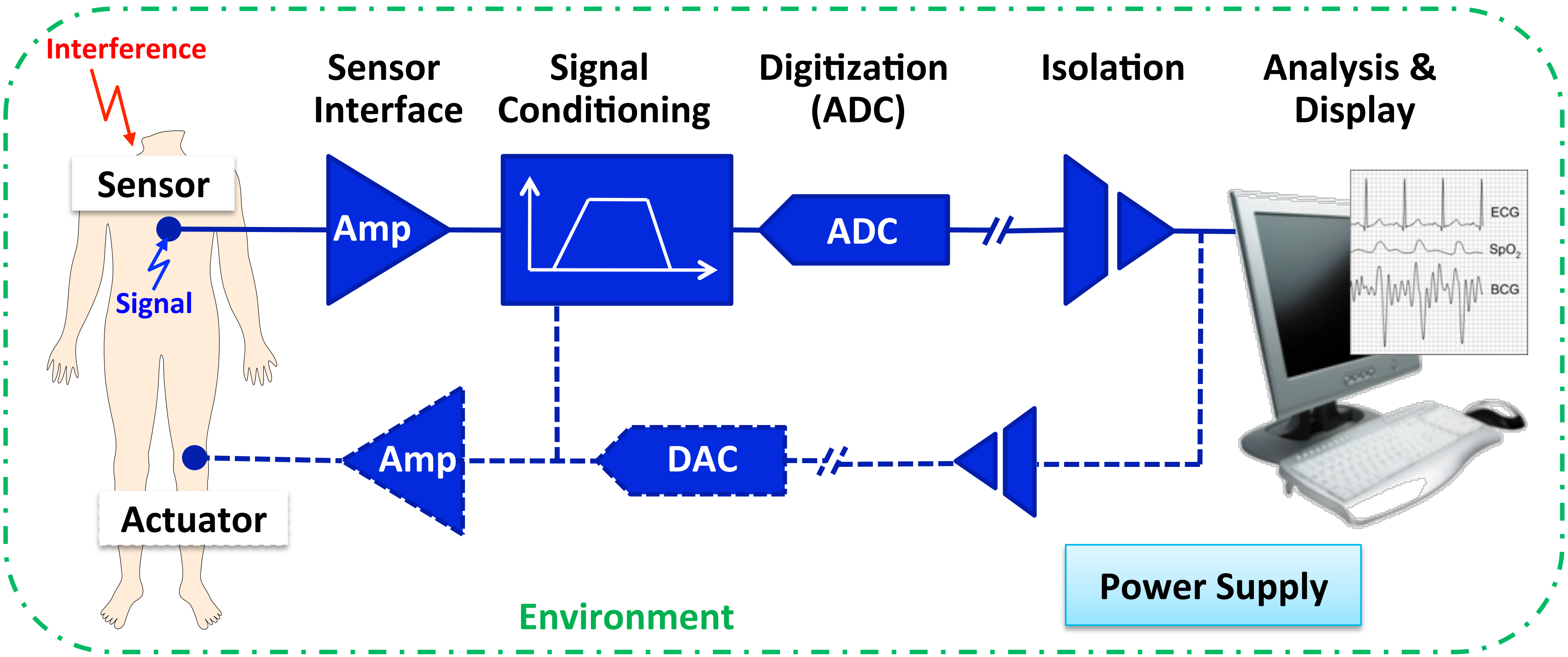
Aliasing - Demonstration

A 1kHz sine wave (Nyquist frequency = 2 kHz) sampled at 4 kHz, 1.8 kHz, and 1.25 kHz



Graphics: Laurent Giovangrandi

Example System: Biomedical Instrument



Sensor: electrodes, pressure sensor,…

Sensor interface: pre-amplifier, bias circuit, etc.

Signal conditioning: filter, amplifier, etc.

Digitization: analog-digital converter (ADC)

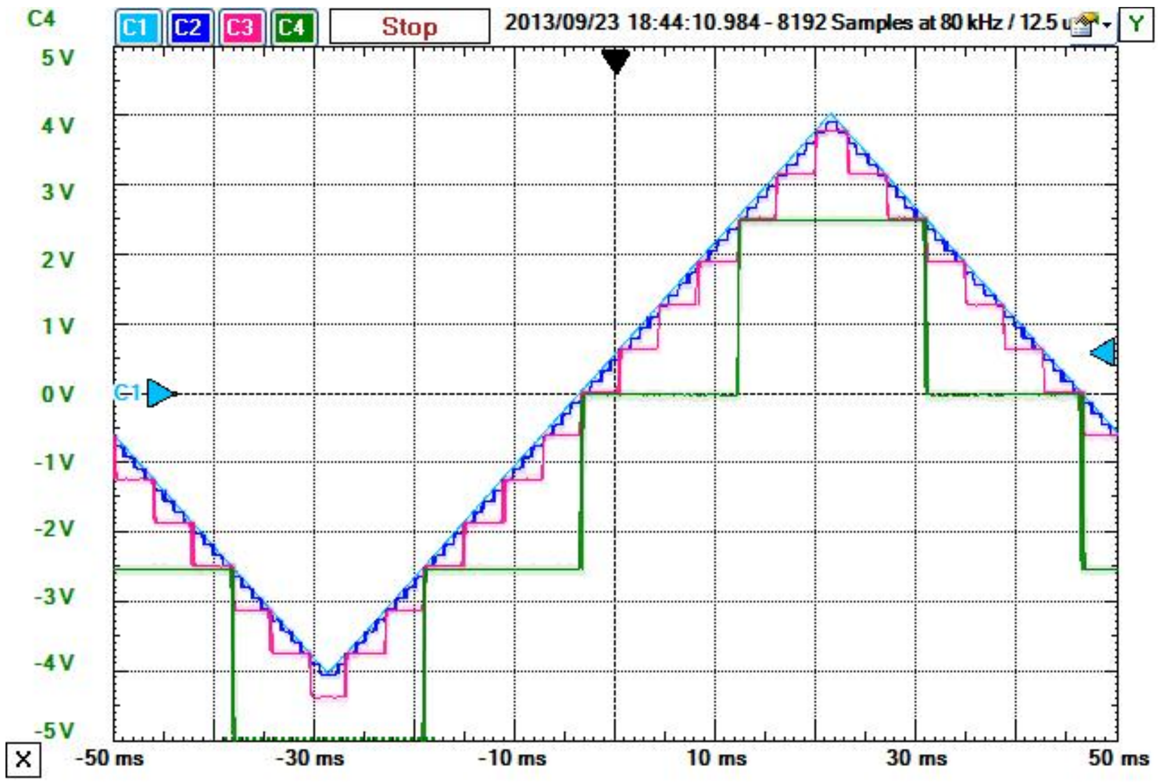
Isolation: optocoupler, inductive, et al.

Analysis: data processing (off- or on-line)

ADC Characteristics

- There are many types (Integrating, SAR, Flash, Sigma-Delta,…)
- Resolution (e.g., 16-bit = 2^{16} = 65536 levels)
  - 16-bit resolution may not give 16 bits of accuracy!
  - ENOB (equivalent number of bits) is the important specification – the effective resolution you actually get.
- Dynamic range (e.g., ±5V)
  - Along with resolution, this defines voltage resolution.
- Linearity (e.g., 0.01%)
- Sampling rate (e.g., 2000 samples/second)
  - Along with resolution, set requirements on anti-aliasing filter for a given accuracy.
- Sequential vs. Simultaneous (multichannel)
  - Settling time consideration (multiplexed ADC)
  - Crosstalk

Resolution Example



- Here we see 16-bit input (C1), with superimposed 6-, 4- and 2-bit quantization. This is from Lab 1.

The Mixed Signal Continuum

- So, there is a continuum between analog (infinitely fine resolution against noise provide by nature) and digital (quantized information, represented by ones and zeroes – finite resolution but easy computation).
- How accurate the digital representation of a real world signal (analog) is depends upon the number of bits we are willing to use. **It's roughly 6 dB of dynamic range per bit.**
- Continuum? Yes. It depends on the number of digital bits representing the information – the resolution or information entropy. Infinite bits = analog. Few bits = crap.
- Mixed signal represents the concept that we can move between both extremes intelligently and build systems that harness the best aspects of both.

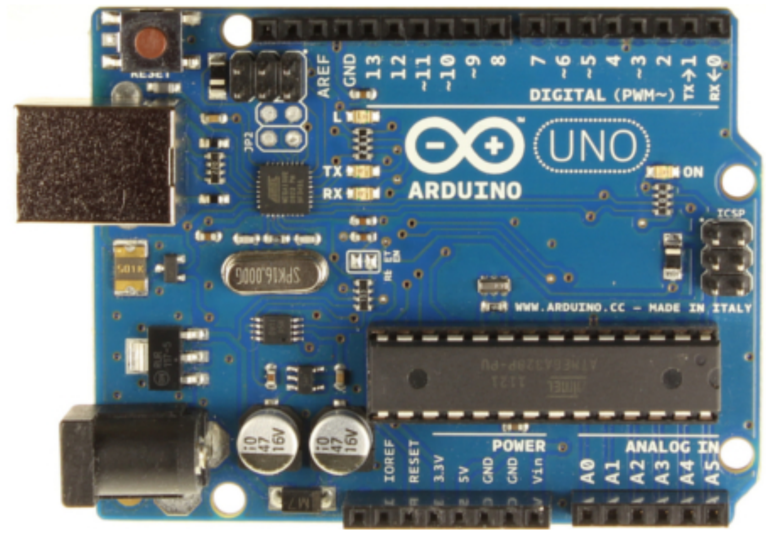
DSP

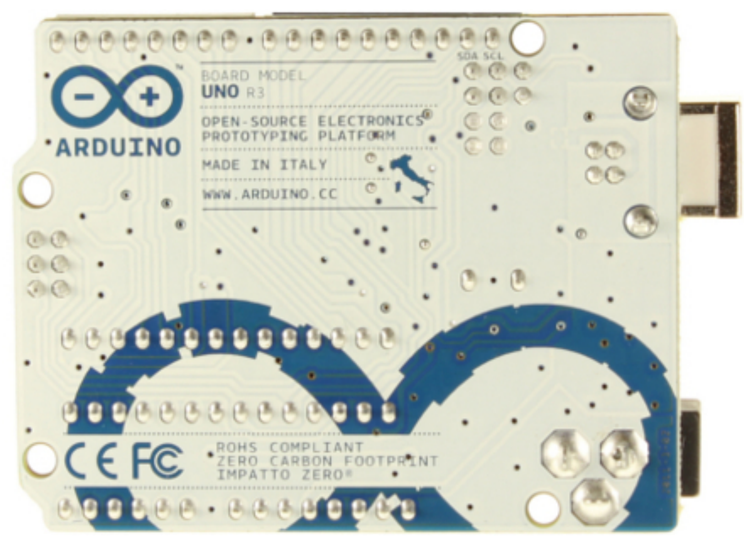
- Digital signal processing (DSP) is the use of digital techniques (adds, multiplies, XOR's, etc) to modify or analyze signals that start and/or finish as analog quantities such as sounds.
- Where we draw the line between analog and digital circuitry is not obvious, and is determined by factors such as power, cost, programmability, etc.
- In EE122A, we will explore the trade-space and consider the pros and cons of each option.
- The truth is that the designer (you) gets to decide.
- Our goal is to illuminate the choices.

Break for Discussion

Arduino!

- The Arduino is a globally successful microcontroller family that allows anyone with a basic intellectual skill set to write simple programs that interact with the world (blink LED's, make video, make sounds, etc.).
- Arduino includes a 10-bit ADC (1024 possible levels between 0 and 5V).
- Everything is open source, meaning we share it and build on each others' work. It's awesome!
- The basic Arduino is cheap ($30).
- The programming environment is approachable, cross-platform (Windows, Mac, Linux) and free.

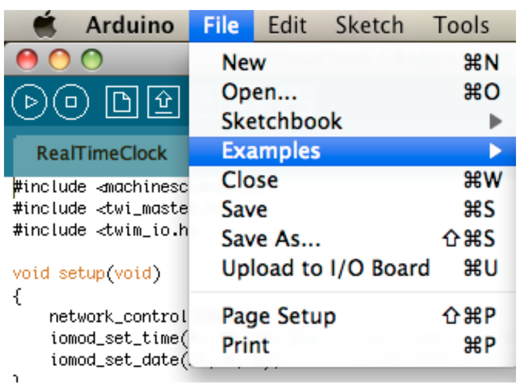


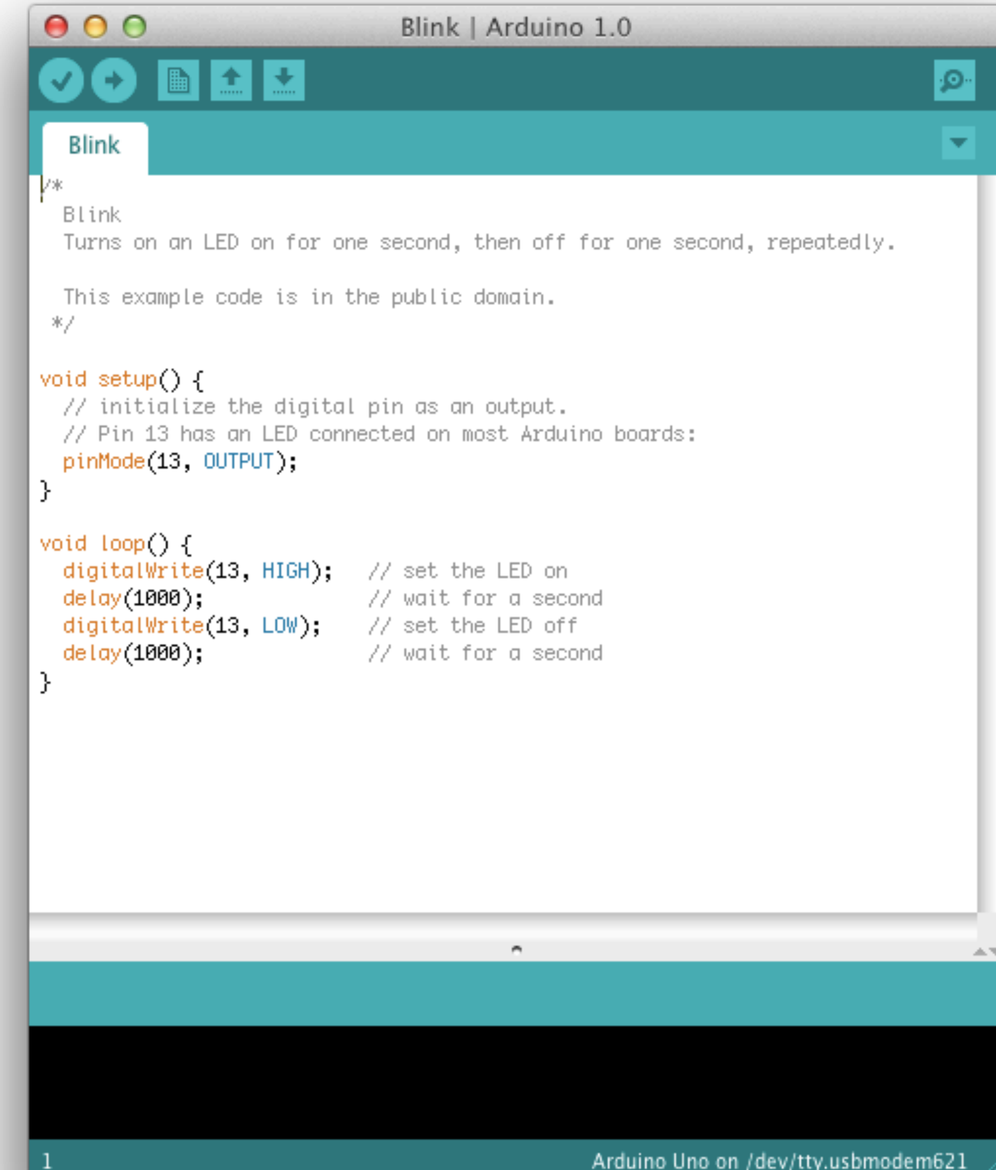


http://www.arduino.cc

Arduino Programming Environment

- Simple structure…
- Code has setup and loop sections, loop gets done forever.
- Download programming environment, set it up, plug Arduino into USB, go!
- Look at the examples included under File, Examples.





Quick Arduino Demo

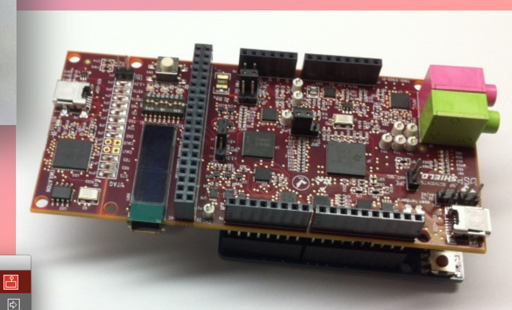
Stanford/Texas Instruments Shields

- **Co-developed by Stanford and Texas Instruments (TI).**
- **Stanford lead = Bill Esposito (your TA).**
- **Analog Shield allows Arduino to access and produce precision analog signals.**
- **DSP shield allows for full digital signal processing power to be added.**

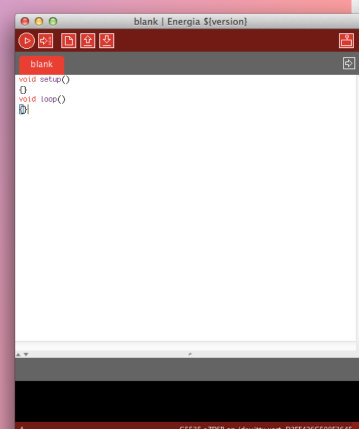
Addressing the Online Learning Gap

Development of novel, Arduino-based hardware and software solutions to provide tools for remote hands-on learning of analog & digital electronics, and signal processing concepts.

Analog shield for the Arduino platform – includes ADC, DAC, power supplies



DSP shield – C5000-based DSP shield for the Arduino platform, with audio ADC/DAC



Arduino-style programming interface for the DSP shield. The goal is to make signal processing concepts as accessible as embedded systems are today.

In collaboration with Texas Instruments

Test Equipment

Your Eyes and Ears In EE122A/B.

2020 note – the specific instruments shown here are now obsolete, but on the other hand, these are the types easily available on the used market for home labs, so no updates to cover 10X more expensive newer ones for now. The internet is at your disposal.

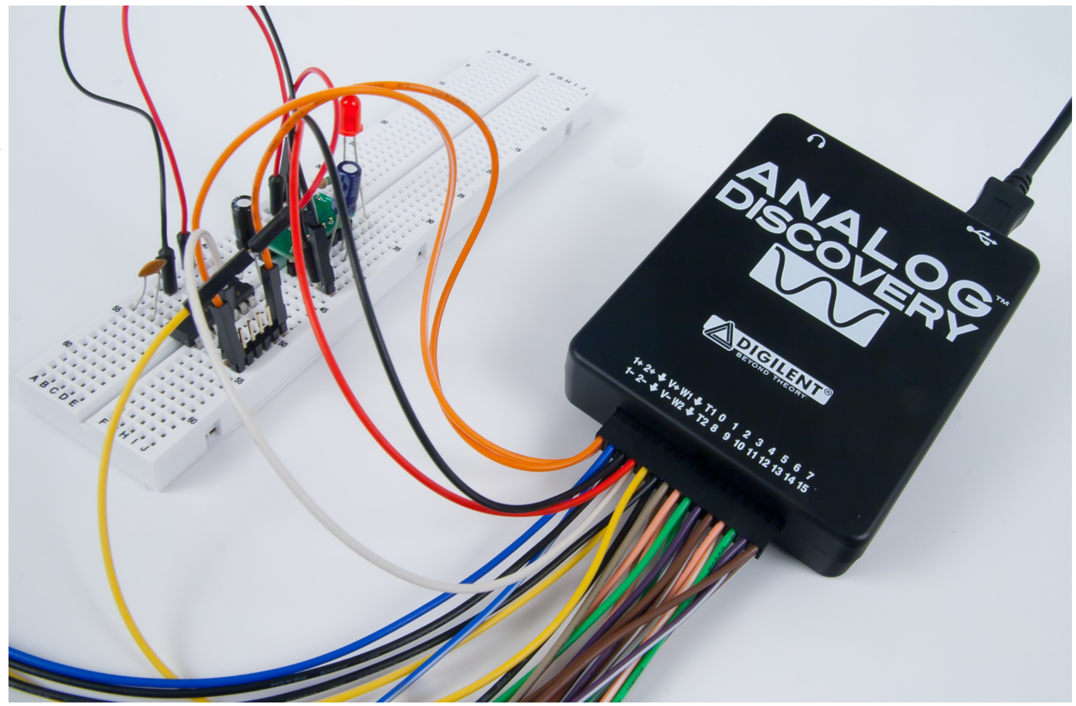
Basic Equipment

- Multimeter.
- Power supply (battery, bench unit, etc.).
- Signal generator.
- Oscilloscope (bench, USB, etc.).
- Soldering iron.
- Miscellaneous hand tools.
- Microcontroller (for controlling circuits).
- DSP (hardware or software).
- Computer
  - Simulation software
  - Spreadsheet
  - Word processor
  - Web browser (for data sheets)
- Reference books (yes, we still use books).

And of course…

Digilent Analog Discovery™ System

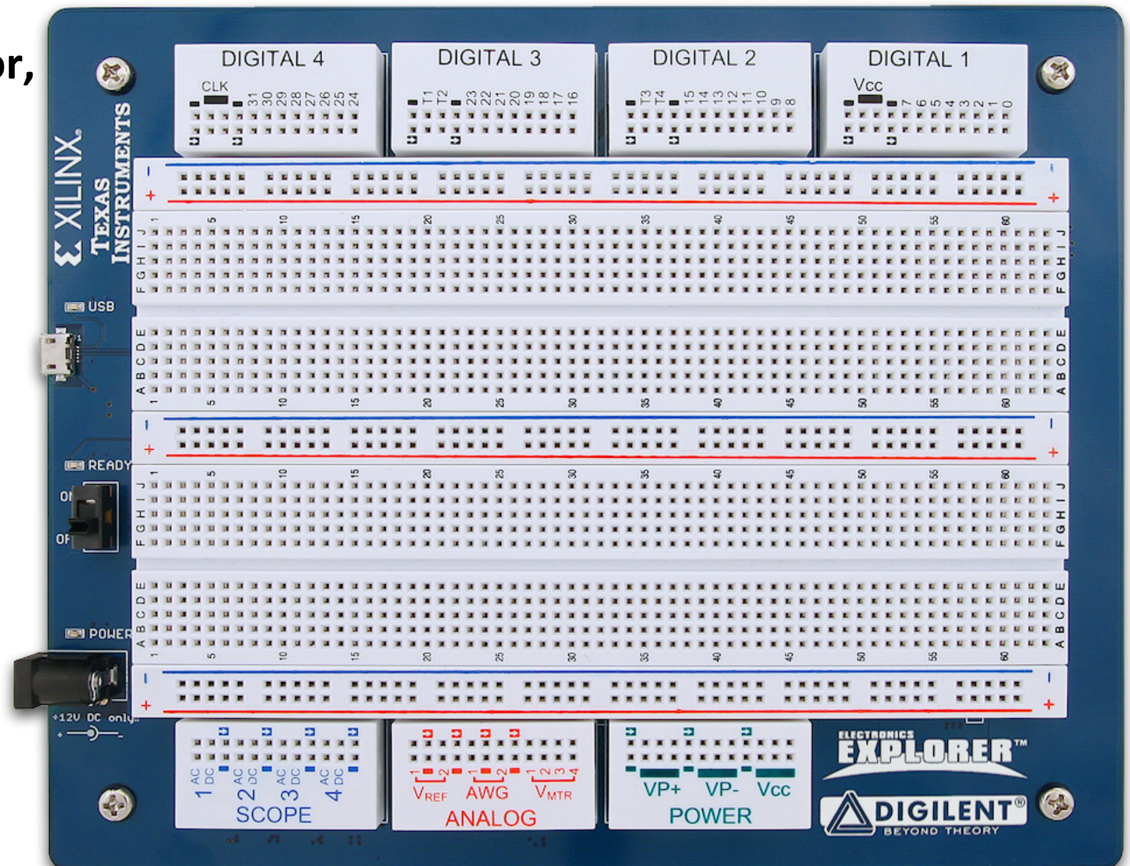
- Two-channel oscilloscope (100 MHz, 14 bit, *differential* channels).
- Two-channel waveform generator
- 16-channel logic analyzer
- 16-channel digital pattern generator
- ±5 VDC supplies (50 mA each)
- Spectrum analyzer
- Network analyzer
- Voltmeter
- Digital I/O
- Supported by Matlab
- Discount for students



http://www.digilentinc.com/Products/Detail.cfm?NavPath=2,1040,1043&Prod=ANALOG-DISCOVERY

Digilent Electronics Explorer™ System

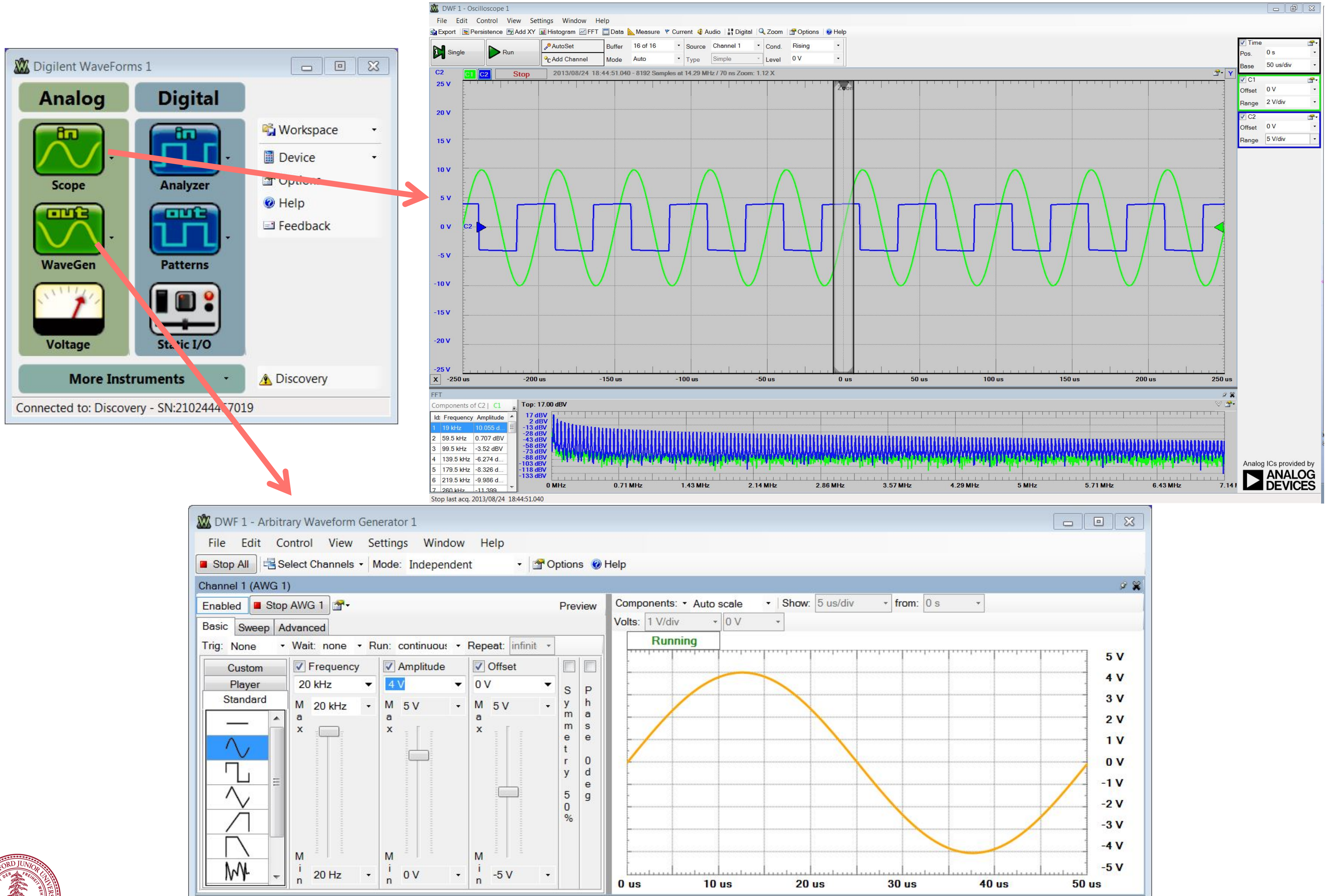
- Four-channel oscilloscope (40MHz, 10 bit).
- Two-channel waveform generator, up to 4 MHz.
- 32-channel logic analyzer
- 32-channel digital pattern generator
- ±9 VDC programmable power supplies, up to 1.5A
- Spectrum analyzer
- Network analyzer
- Four voltmeters
- Digital I/O
- Prototyping area
- Supported by Matlab



Windows only... ☹

http://www.digilentinc.com/Products/Detail.cfm?NavPath=2,842,883&Prod=EEBOARD

WaveForms™ Tools



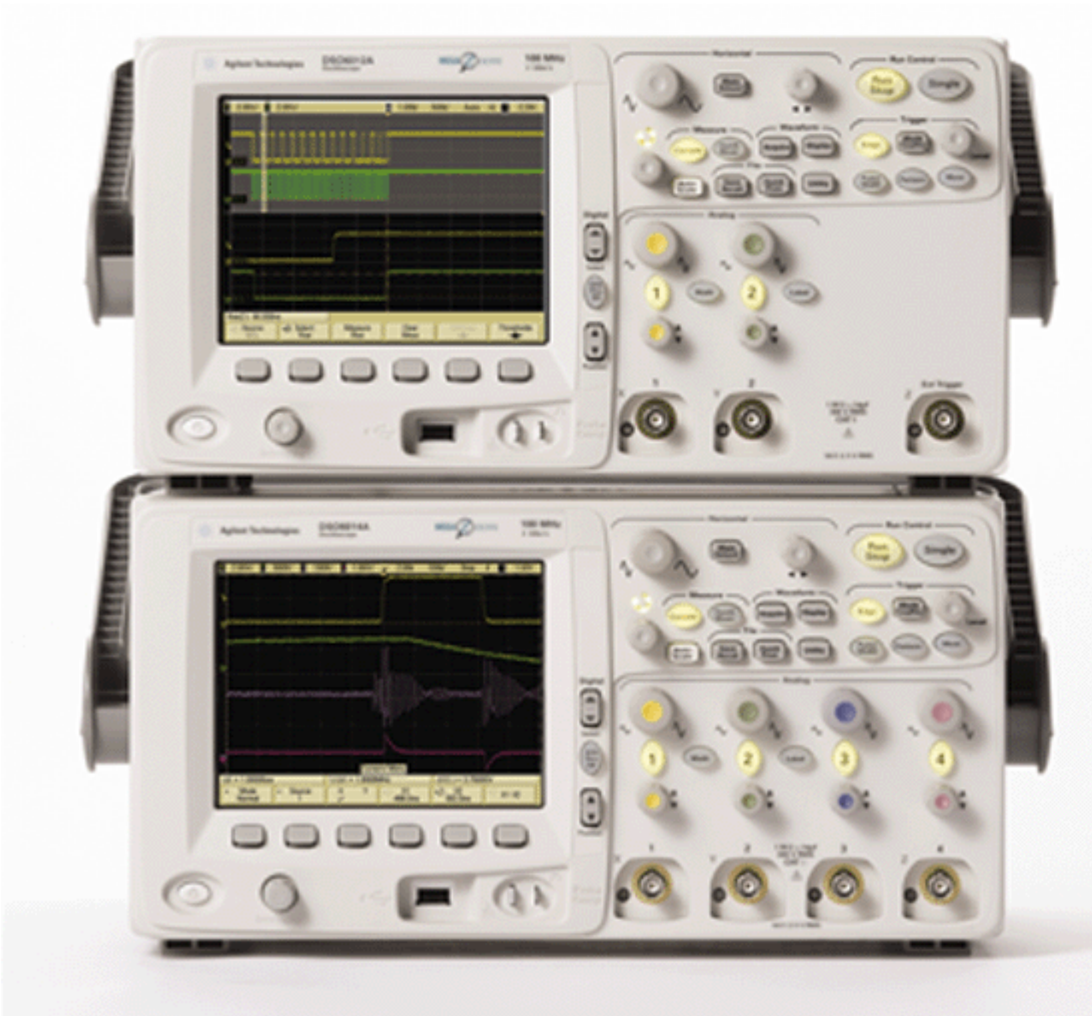
Agilent 34401A Digital Multimeter

Agilent E3648A Power Supply

- **Two separate outputs.**
- **Range 1: 0 to 8 V, 5A max**
- **Range 2: 0 to 20 V, 2.5A max**

Agilent 33250A
80 MHz Function Generator

Agilent DSO6054A Oscilloscope



www.agilent.com

- 4 channels
- 500 MHz / 4 GS/s
- 8 Mpts deep memory
- XVGA display
- LAN and USB I/O

USB memory stick strongly recommended for data transfer.

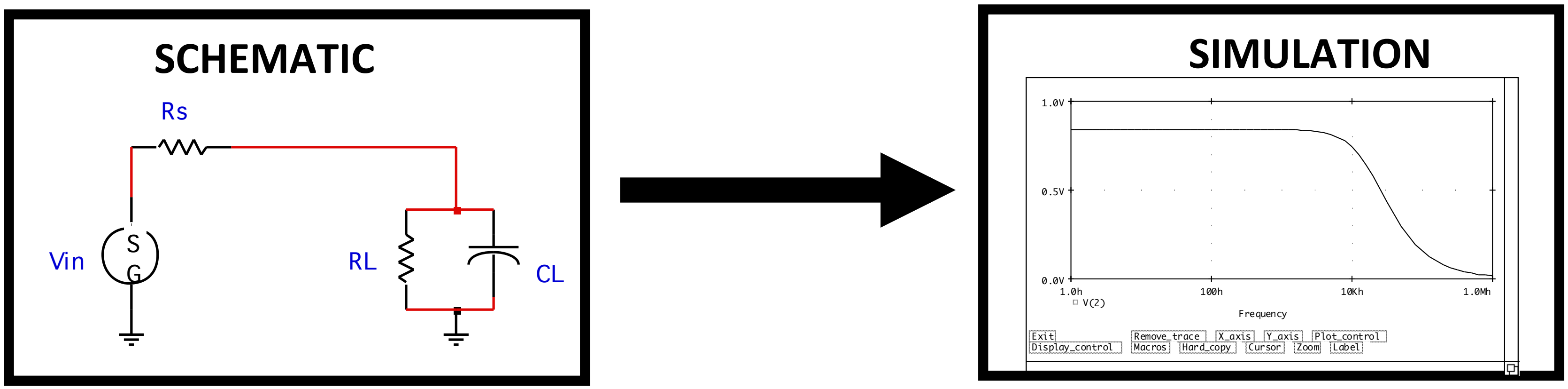
Don’t Forget Manuals

- **Tons and tons of vital information about instruments is in the operation manuals.**
- **Manuals for most instruments used in EE122A/B are kept in the lab.**
- **Please refer to them (although few do ☺).**
- **Many can be downloaded, and for newer instruments it is assumed that you will do this if needed.**

Circuit Simulation
and
Printed-Circuit Layout Software

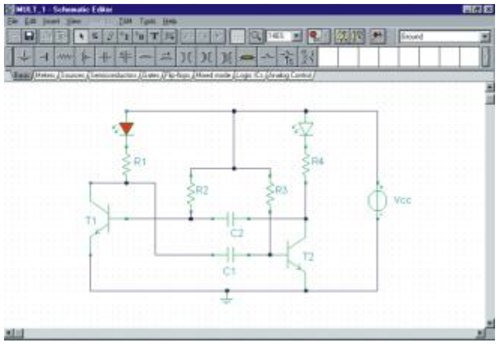
Mantra: "If it takes longer to simulate than to build a circuit, build it!"

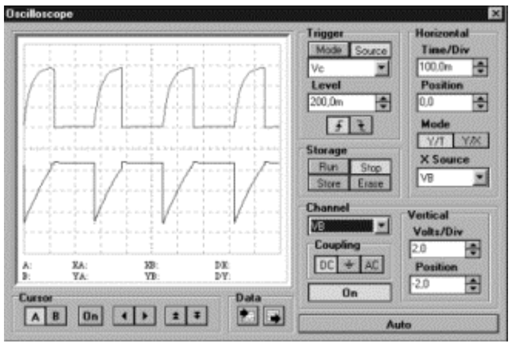
CIRCUIT SIMULATION

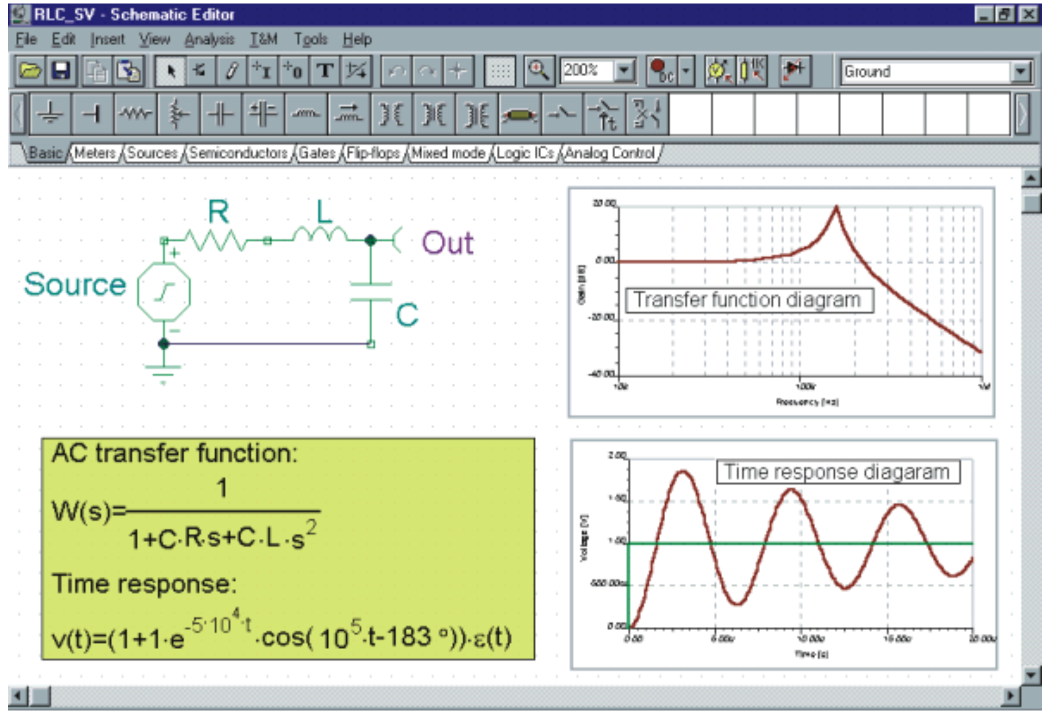


- Very powerful way to simulate circuits without having to physically build them.
- With care, simulations can be very accurate.
- Kovacs' Rule of Thumb: **"If it takes longer to simulate than build the circuit, build it!!!"**
- Not all simulation tools are intuitive nor have a fast learning curve. Also, they often give you BS results unless you make funky assumptions or tweak them to work. Think. Think. Think.

TINA Design Suite (Example)

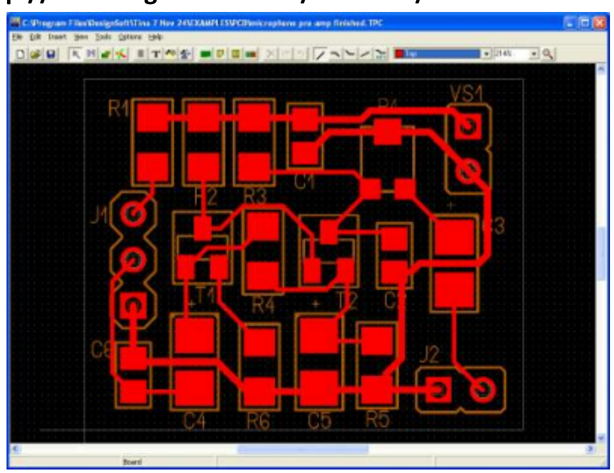


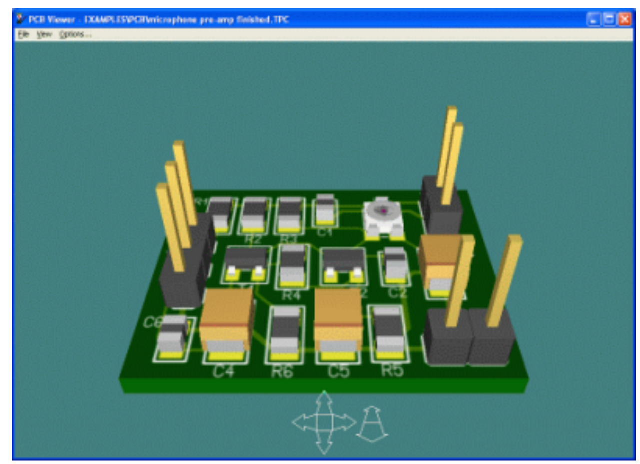




http://www.digilentinc.com/Products/Detail.cfm?NavPath=2,842,1070&Prod=DESIGNSOFT-TINA

Schematic capture, simulation, printed circuit board layout…





What You Will Do In Lab 1

- Learn how to use the Digilent Electronics Explorer™ USB-connected analog/digital I/O system and its associated software.
- Begin to explore the basic traditional instruments (oscilloscope, multimeter, power supply, etc.).
- Familiarize yourself with how to hook up simple circuits using the prototyping tools provided.
- Revisit Fourier (harmonic series) and look at a basic (RC) filter, measuring its transfer function (compare to Bode).
- Use the Arduino and Analog Shield to explore digitization and sample rate effects when taking signals from analog to digital.

What You Will Do In Tutorial 1

- **Learn the basics of the Arduino programming environment (after installing on your laptop).**
- **Understand the Arduino hardware (and its limitations).**
- **Learn the basics of Arduino programming, including:**
  - Loops
  - Timing control
  - Digital I/O
  - Analog I/O (including how to use pulse-width modulation or PWM)
- **Understand what the Analog Shield can do and how to use it.**

Design Note: Hacking Toys...

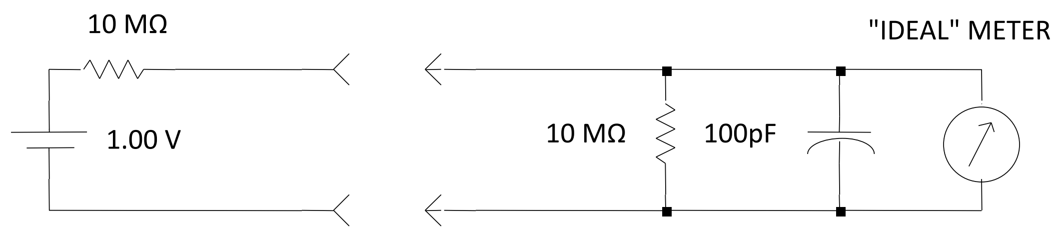
- **Toys are an excellent, low-cost source of components for projects.**
- **Many are built to produce sounds - they can be wired into your designs.**
- **Others contain interesting motors and other actuators.**
- **Last year's toys are often very inexpensive and a great source of inspiration.**

Reference Materials

- This section contains slides describing the operation of many of the basic bench instruments present in the EE122A/B lab.
- It is meant as a resource. Please review these charts.

Practical Aspects of Digital Meters

1) They affect the circuit you are measuring!



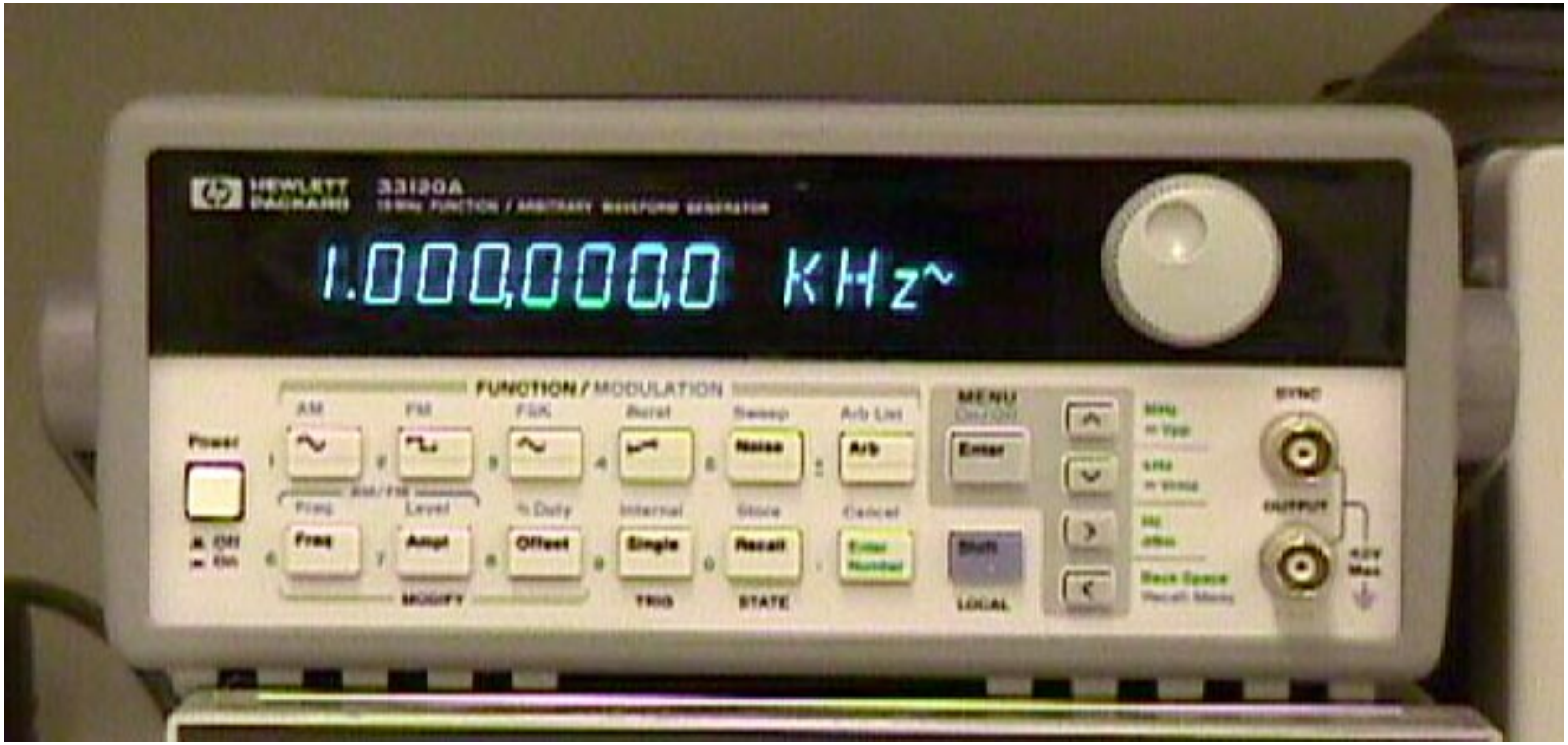
Scale Selected	DVM Display
200V	00.1 V
20V	0.11 V
2V	0.106 V
200 mV	106.4 mV

2) They must be properly operated to give the most accurate readings! Luckily, most modern DMM's are Autoranging.

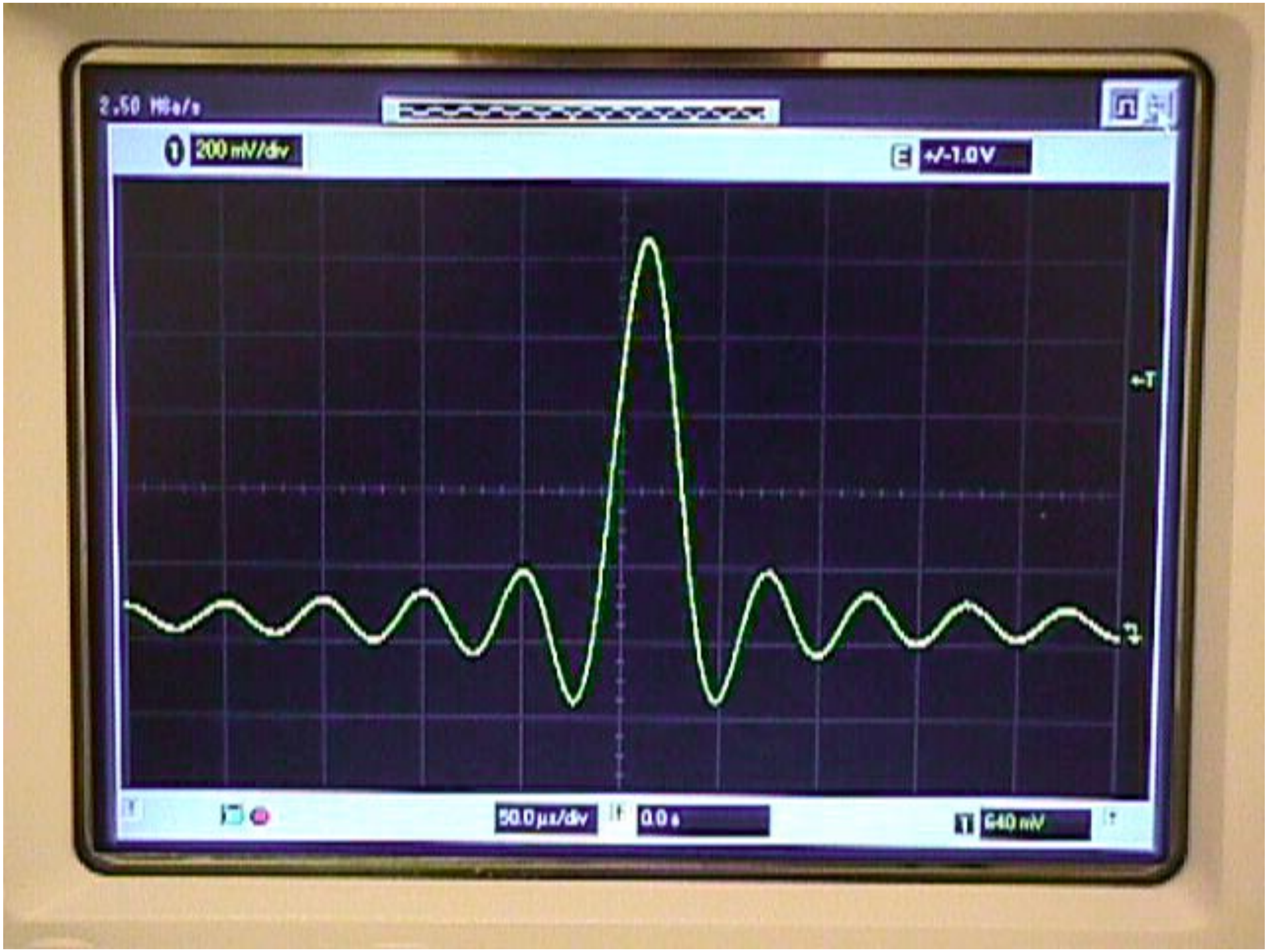
Power Supplies

- **HP6253A Dual 0 - 20V, 0 - 3A**
- **HP6236B Triple 0 - 6V, 0 - 2.5A, 0 +/- 20V, 0 - 0.5 A**
- **Current limit settings can be confusing at first.**

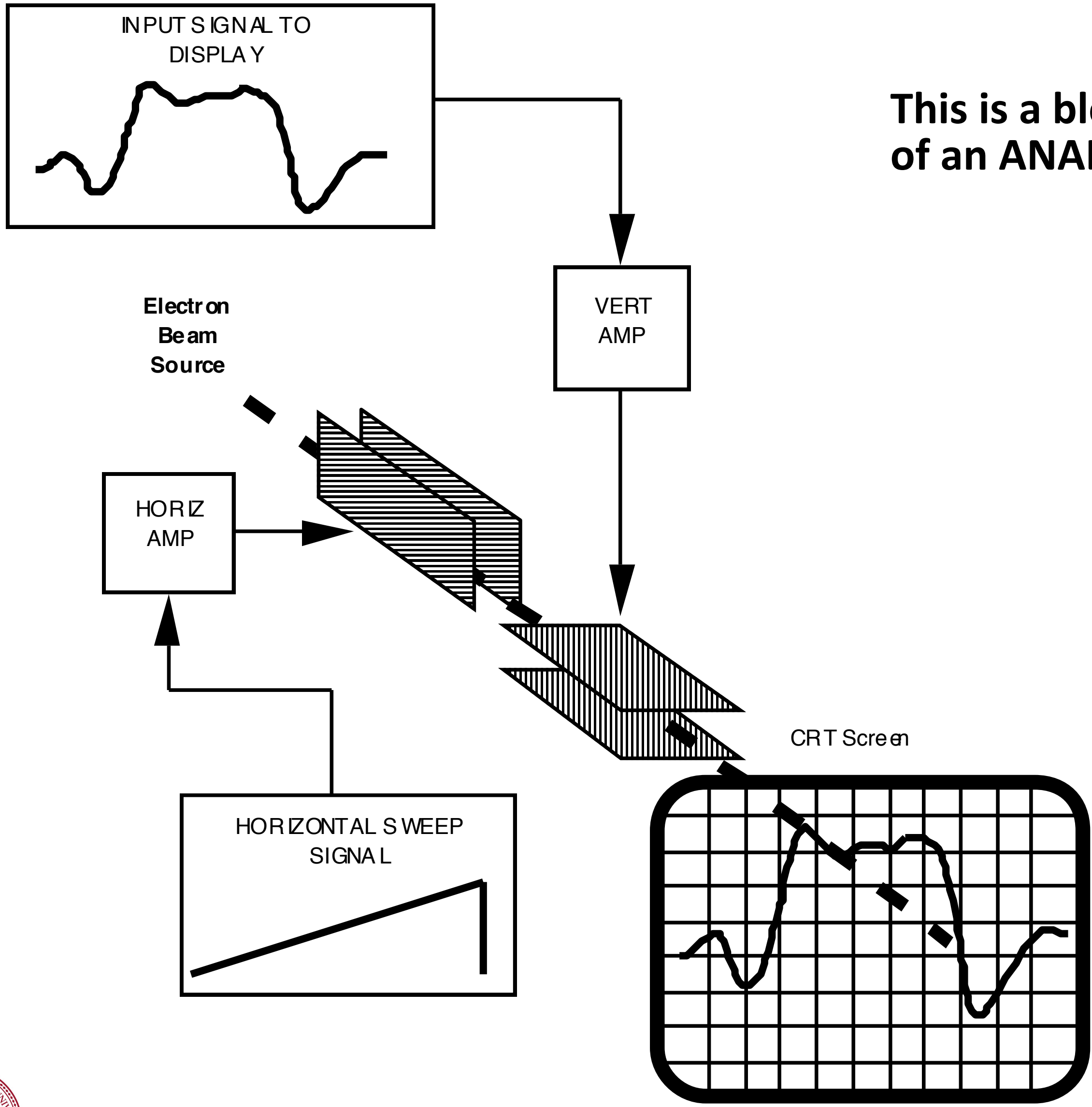
HP33120A 15 MHz Function Generator



HP33120A 15 MHz Function Generator

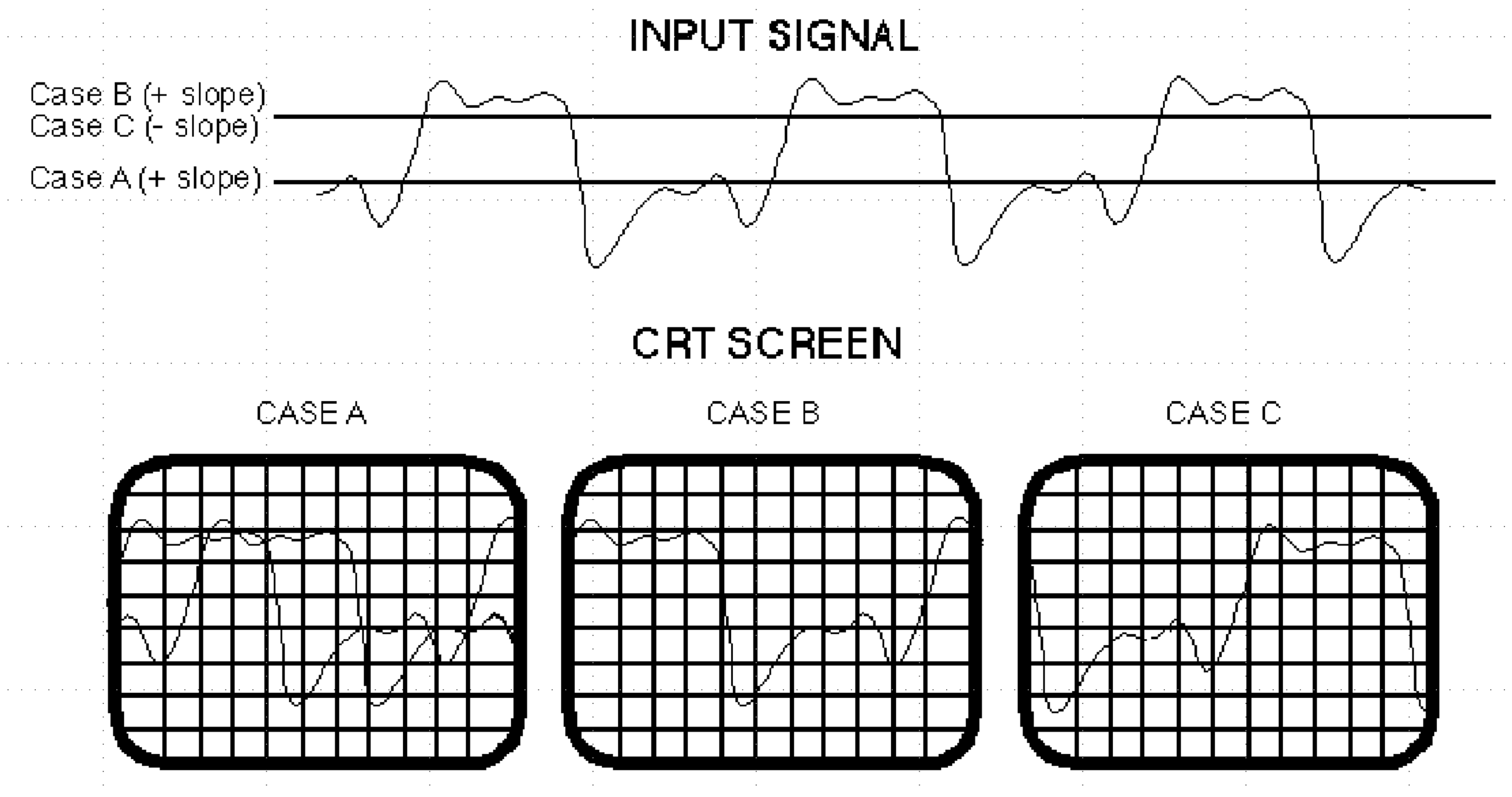


Oscilloscope Basics



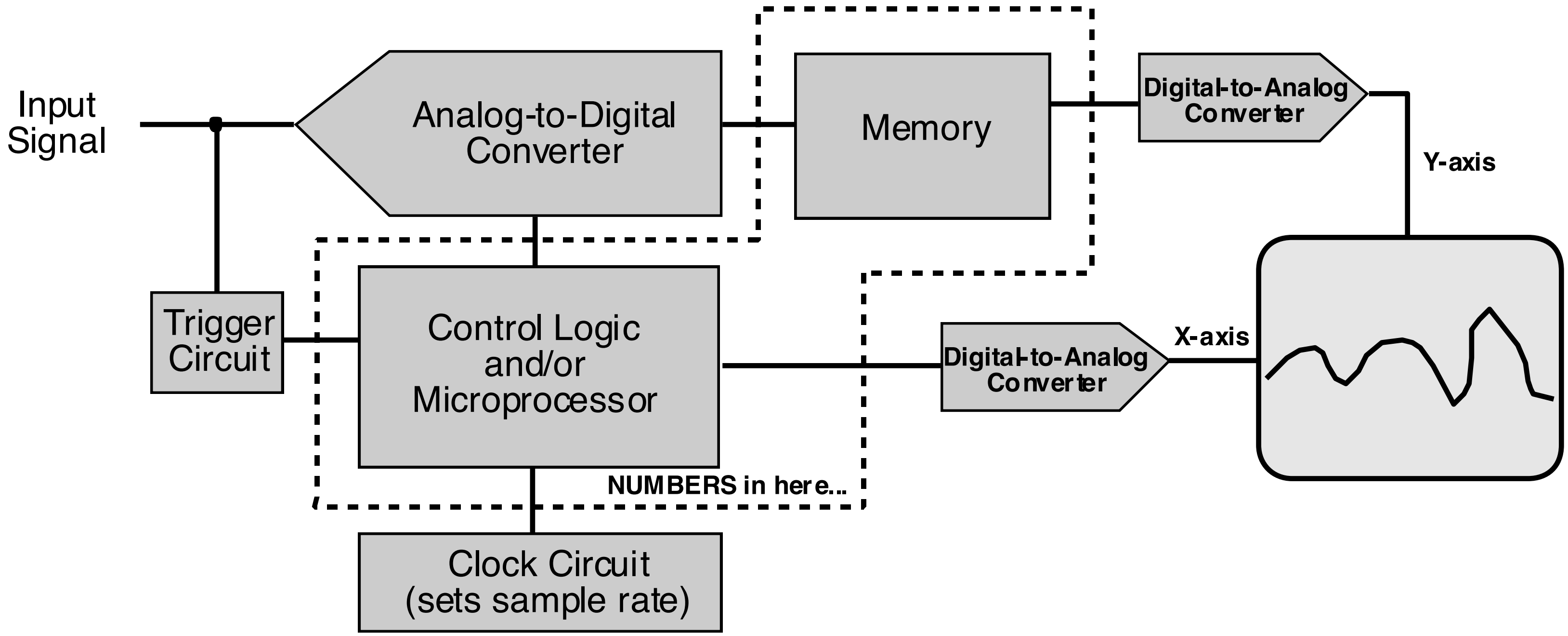
This is a block diagram of an ANALOG oscilloscope...

Triggering an Oscilloscope



HP1704A Analog Oscilloscope (100 MHz)

Digital Oscilloscopes



Voltages are first digitized and then displayed (or printed!) ...

These are not true "real-time" oscilloscopes.

Analysis can be done on the numbers!

One-shot events can be stored for later examination...

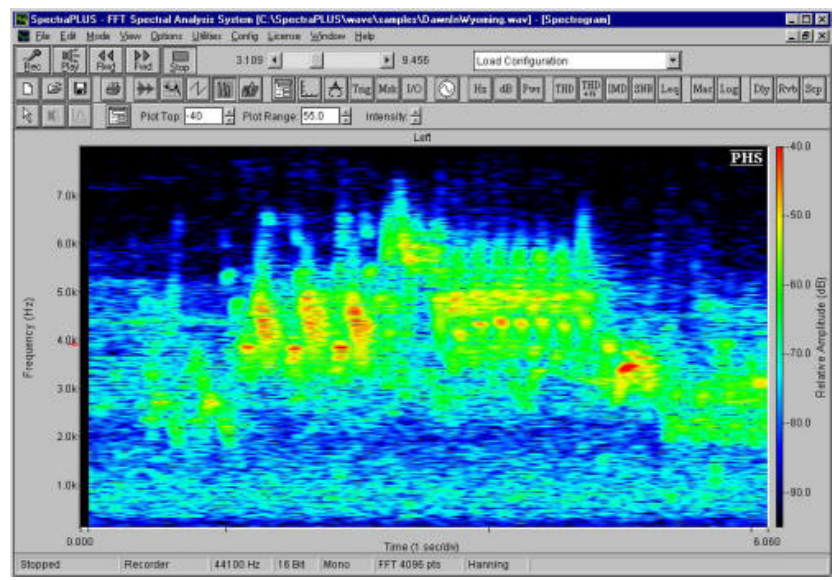
VERY slow "sweep" (actually "sample") rates can be used for slow stuff.

HP3561A Dynamic Signal Analyzer (100 kHz)

Audio Analyzer Software

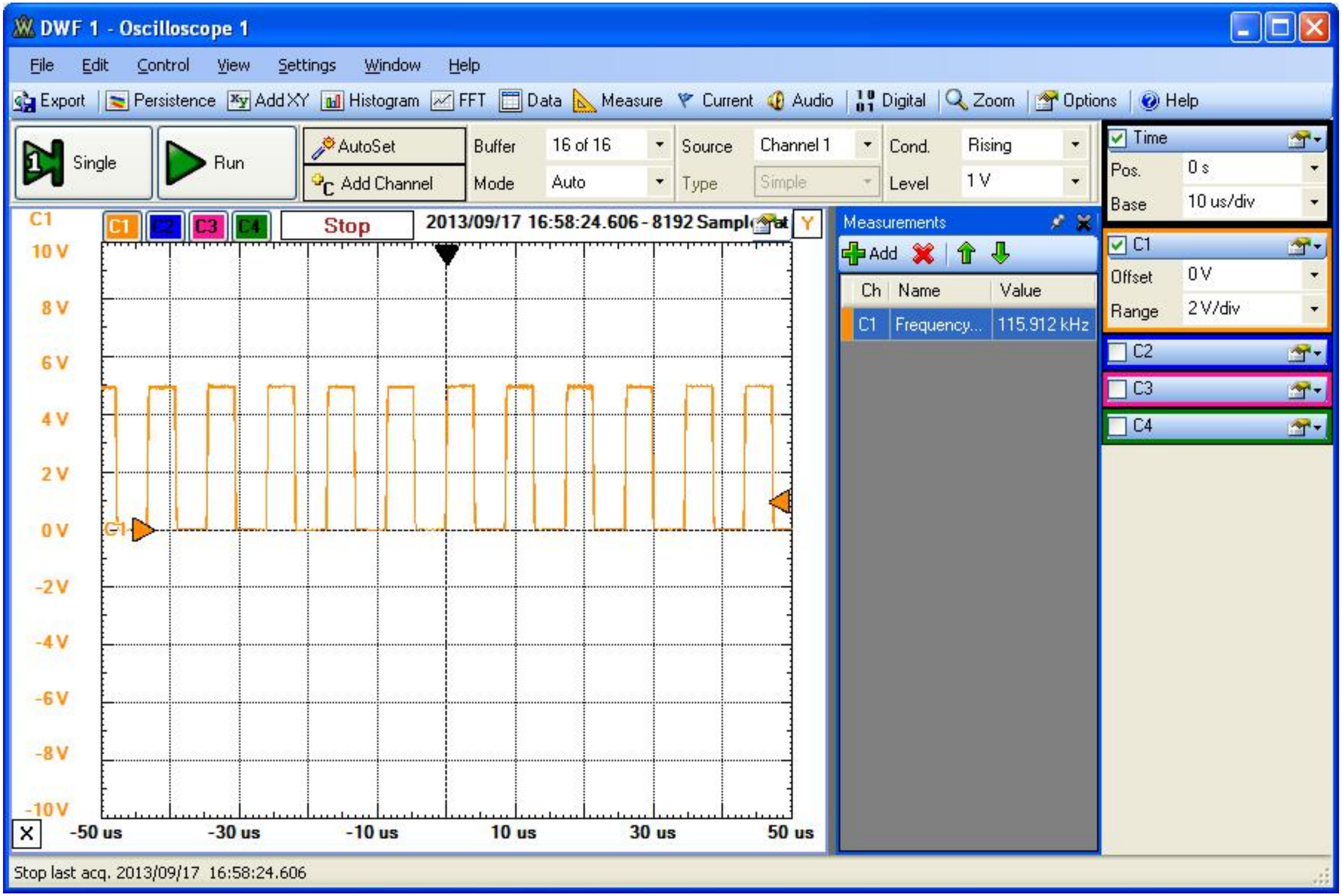
http://www.spectraplus.com

- **Audio analysis using analog I/O on laptop of desktop computer.**
- **Amazing, but expensive.**
- **Demo version (30 days) worth a look.**



"FastBlink"


Lab1_Fast_Blink | Arduino 1.5.2
Lab1_Fast_Blink
/*
Blink
Turns on an LED on for one second, then off for one second, repeatedly.
This example code is in the public domain.
*/
// Pin 13 has an LED connected on most Arduino boards.
// give it a name:
int led = 13;
// the setup routine runs once when you press reset:
void setup() {
// initialize the digital pin as an output.
pinMode(led, OUTPUT);
}
// the loop routine runs over and over again forever:
void loop() {
digitalWrite(led, HIGH); // turn the LED on (HIGH is the voltage level)
// delay(1000); // wait for a second
digitalWrite(led, LOW); // turn the LED off by making the voltage LOW
// delay(1000); // wait for a second
}
Done uploading.
Binary sketch size: 882 bytes (of a 32,256 byte maximum) - 2% used
9
Arduino Uno on /dev/tty.usbmodemfd1411


DWF 1 - Oscilloscope 1
File Edit Control View Settings Window Help
Export Persistence Add XY Histogram FFT Data Measure Current Audio Digital Zoom Options Help
Single
Run
AutoSet
Add Channel
Buffer 16 of 16
Mode Auto
Source Channel 1
Type Simple
Cond. Rising
Level 1 V
Stop
2013/09/17 16:58:24.606 - 8192 Sampl
Measurements
Add
Ch Name Value
C1 Frequency... 115.912 kHz
Time
Pos. 0 s
Base 10 us/div
C1
Offset 0 V
Range 2 V/div
C2
C3
C4
10 V
8 V
6 V
4 V
2 V
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-4 V
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