Laboratory Exercises for Analog Circuits and Electronics as Hardware Homework with Student Laptop Computer Instrumentation

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Introduction

- Since 1999, all ECE undergraduate students at MSU have laptop computers
- In spring 2005, first course in electronic circuits will require hardware homework
  - Students construct circuits at home
  - Measure circuit performance with audio capability of laptops as oscilloscope, spectral analyzer, and signal generator

Basic Approach

By pair wise comparison of

- Analysis
- Measurement
- Simulation

students

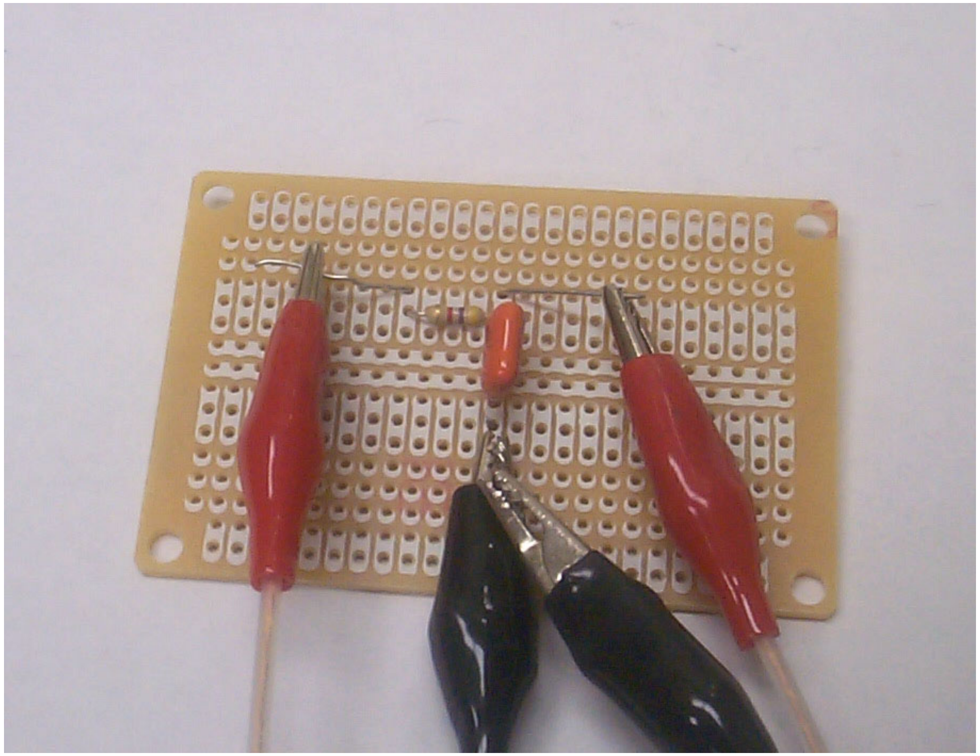
- Deploy complex, intensely interactive, learning environments
- Learn to self-assess their work

Circuits with inductors and capacitors

- Student laptop functions as:
  - Signal generator
  - Oscilloscope
  - Spectrum analyzer
- Software (~US$90):
  - Realtime Analyzer (DSSF3 Light version)
  - http://www.ymec.com/products/dssf3e/

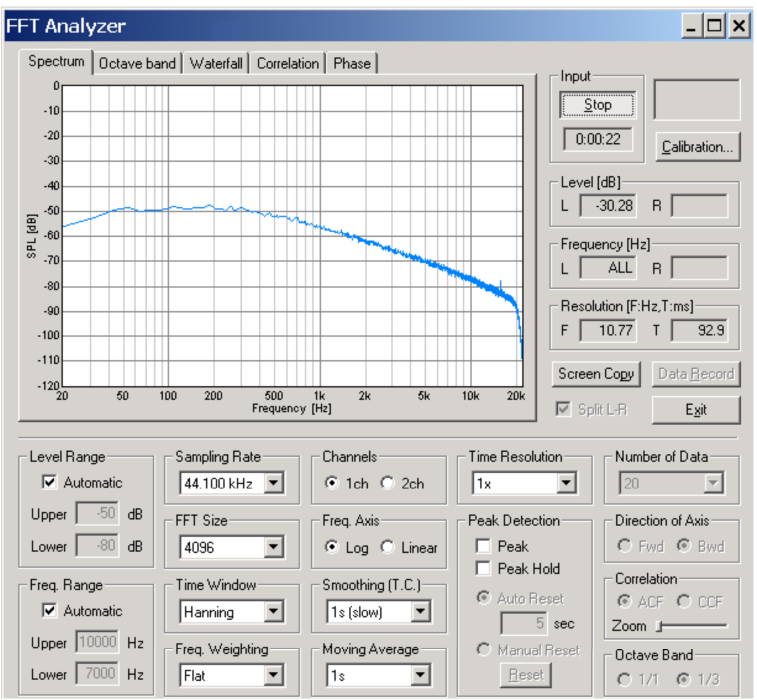
Circuits with inductors and capacitors

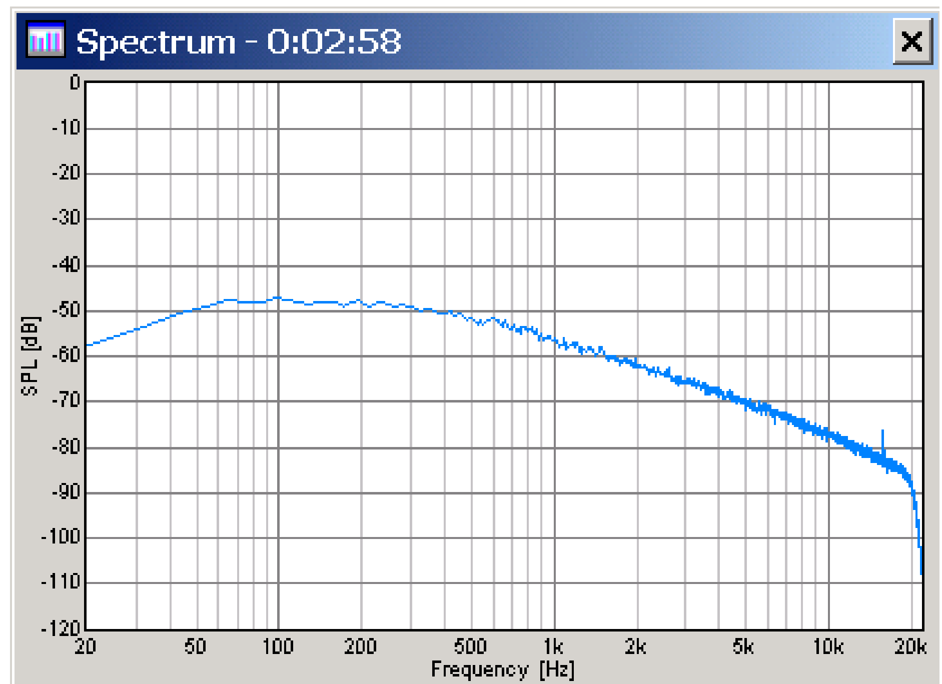
- Simple example: RC low pass filter



RC low pass filter: white noise spectral response

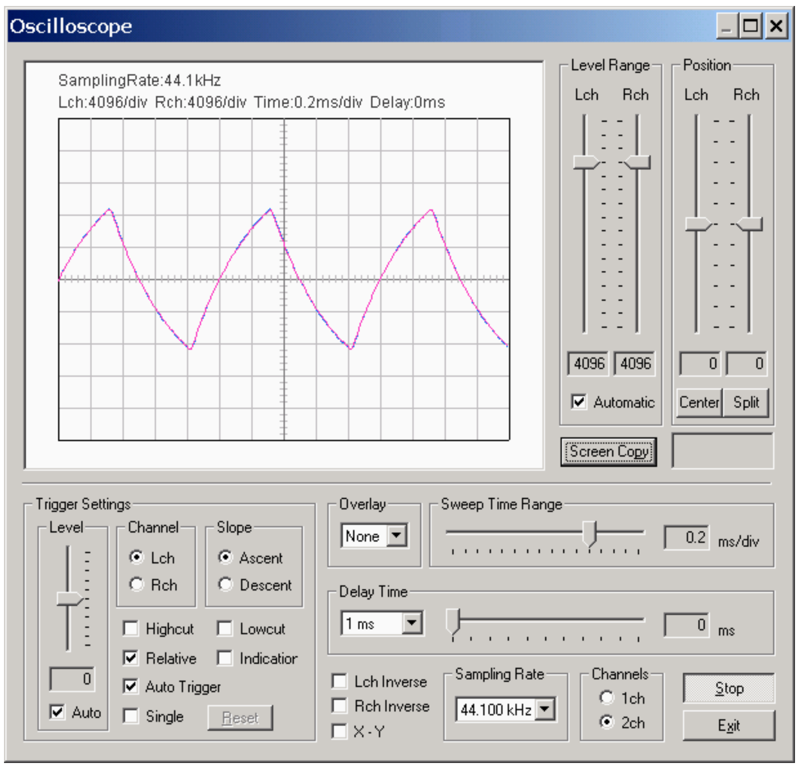
- R = 4700Ω, C = 0.1μF, $f_c \approx$ 340 Hz

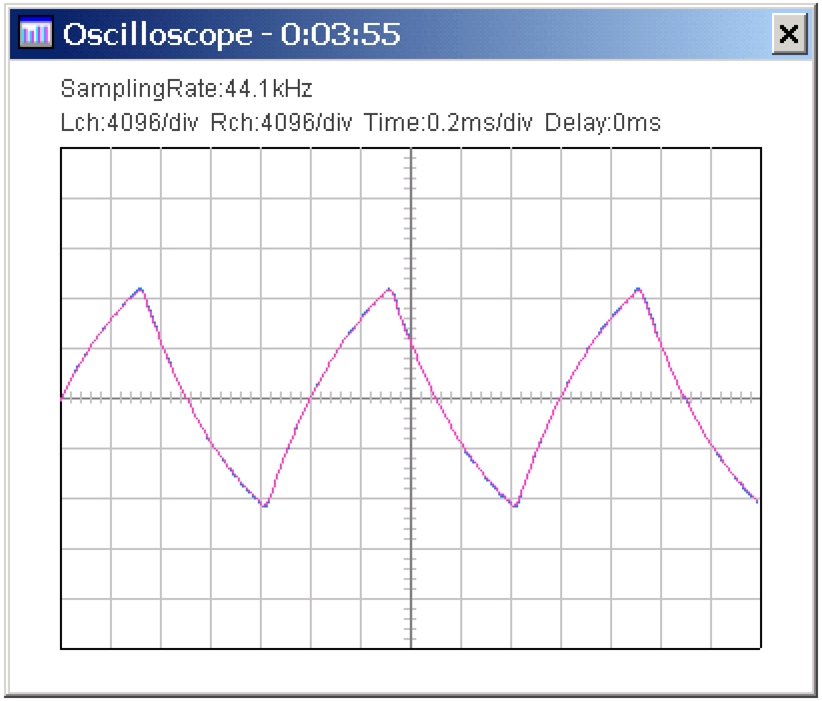




RC low pass filter: 500 Hz square wave response

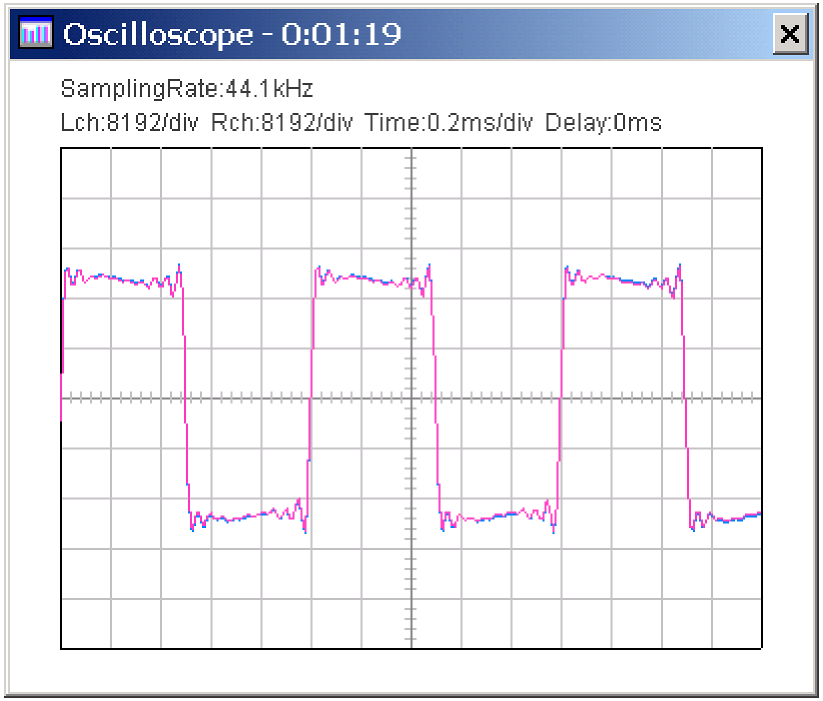
- $R = 4700\Omega$, $C = 0.1\mu F$, $f_c \approx 340$ Hz



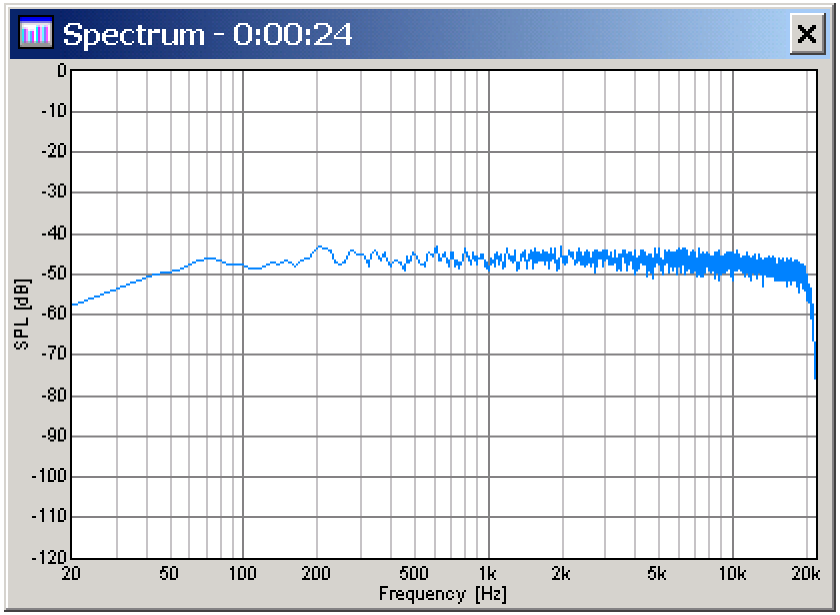


RC low pass filter: square wave and white noise inputs

1000 Hz square wave

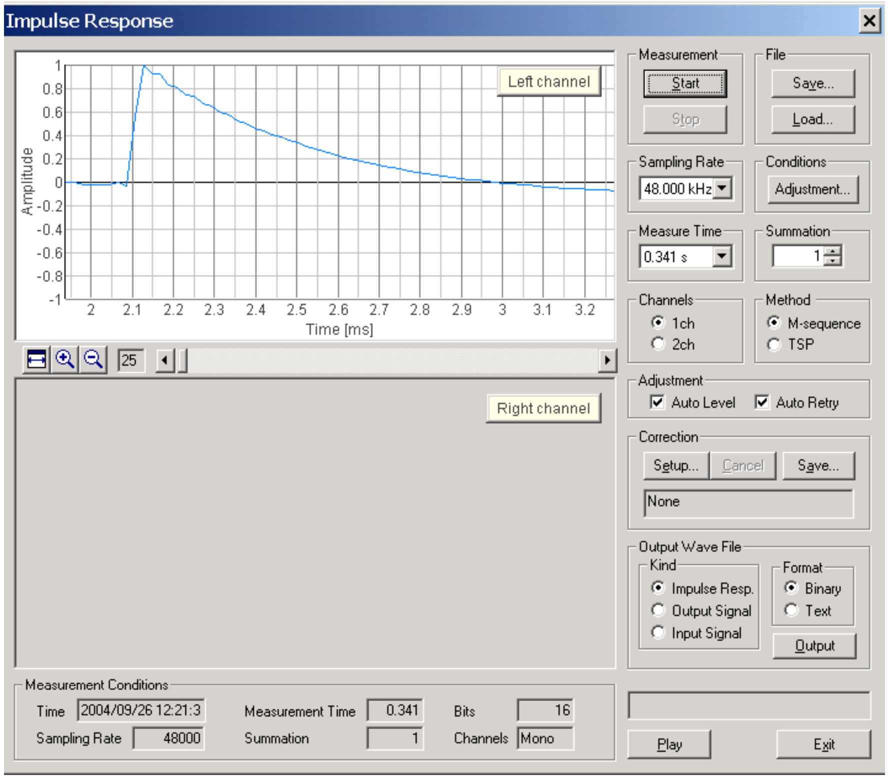


white noise



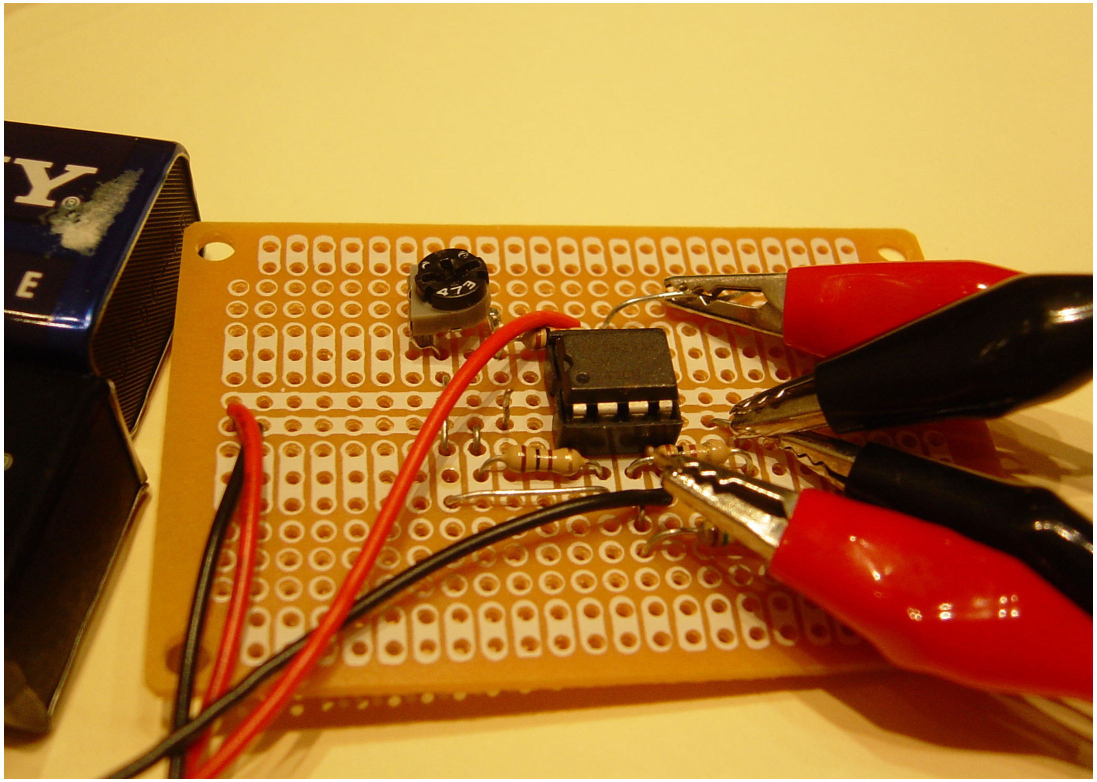
RC low pass filter: impulse response

- R = 4700Ω, C = 0.1μF, RC = 0.47 msec



Non-inverting op amp configuration

- Op amp GBW ≈ 1 MHz



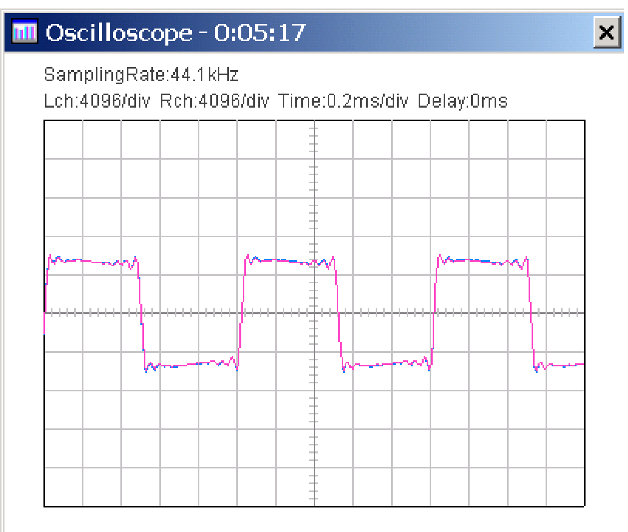
Non-inverting op amp configuration

- Analysis:
  - Gain without feedback: $$A = A_{LF} \frac{1}{1 + j\dfrac{f}{f_{BW}}}$$
  - With feedback: $$G = G_{LF} \frac{1}{1 + j\dfrac{f}{\dfrac{A_{LF}}{G_{LF}} f_{BW}}}$$
  - In both cases: $GBW = A_{LF} f_{BW}$
    - Feedback conserves GBW

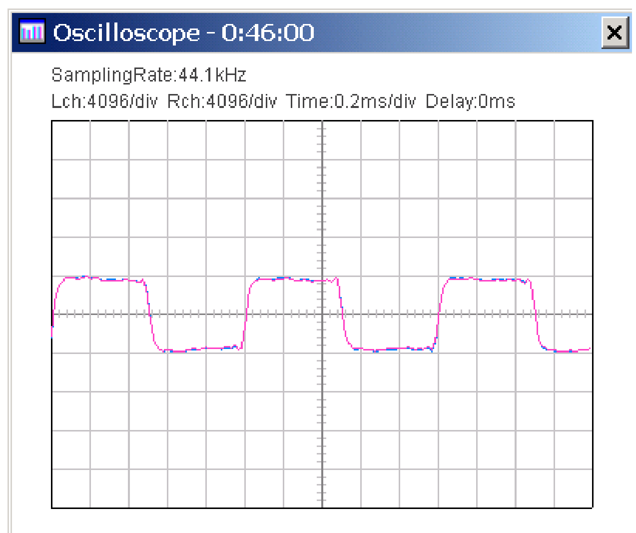
Non-inverting op amp configuration

- Response when G = 96

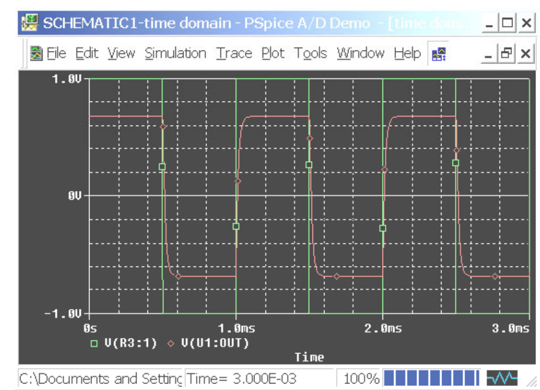
Measured input:



Measured output:



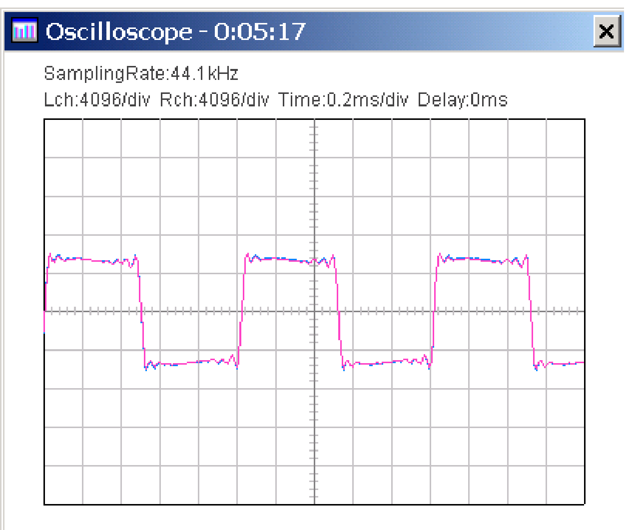
Simulation:



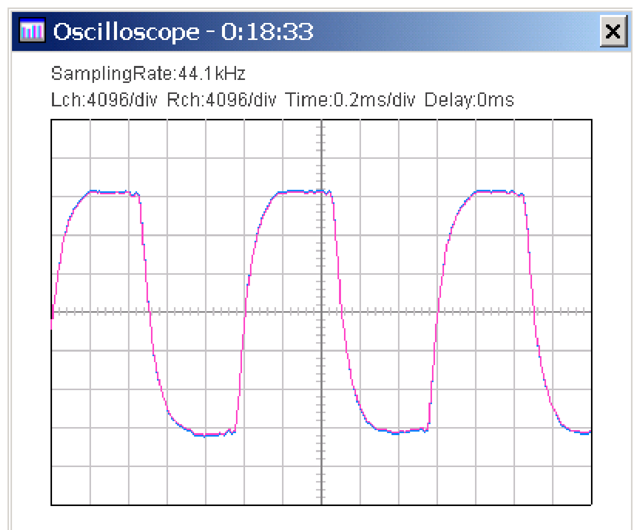
Non-inverting op amp configuration

- Response when G = 342

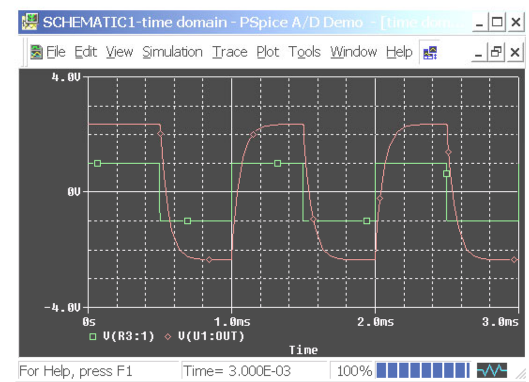
Measured input:



Measured output:



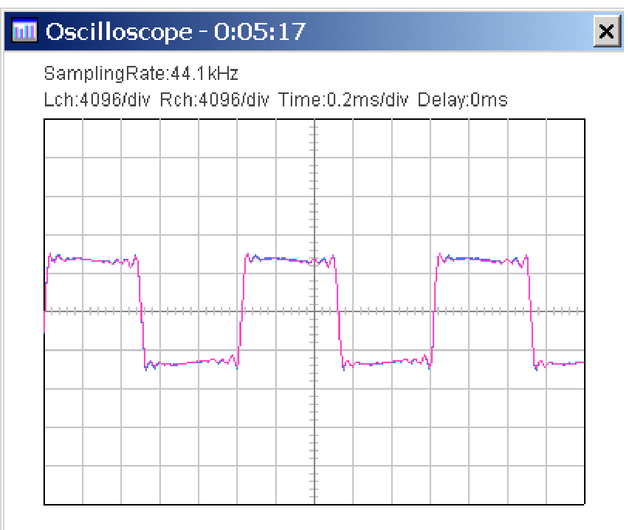
Simulation:



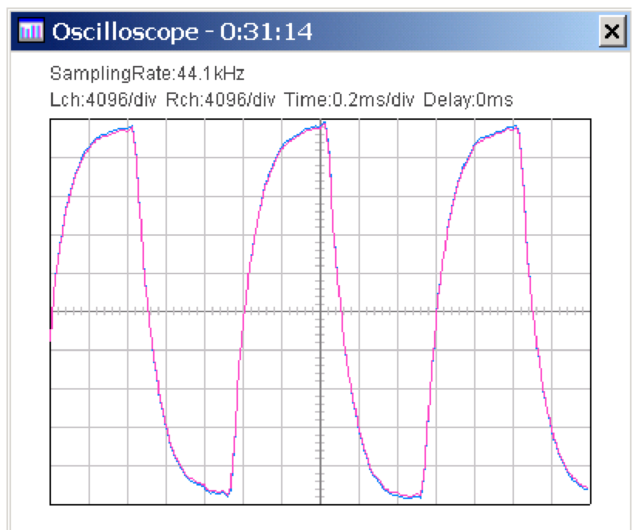
Non-inverting op amp configuration

- Response when G = 535

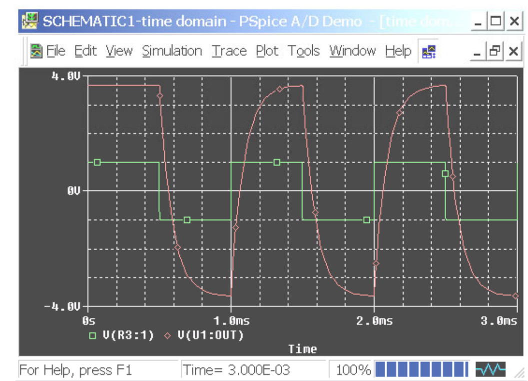
Measured input:



Measured output:



Simulation:

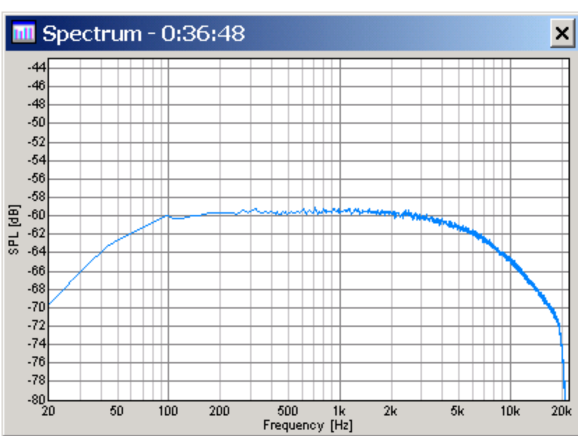


Non-inverting op amp configuration

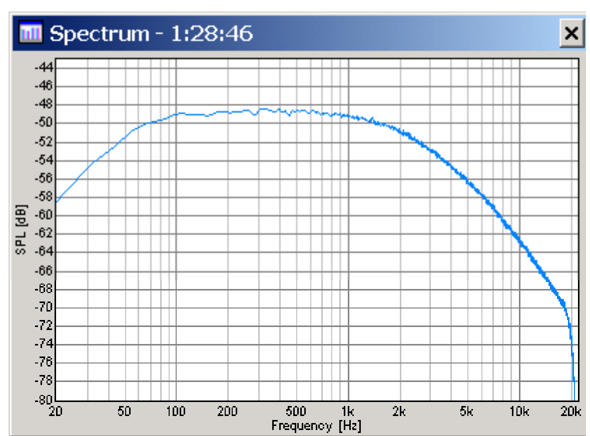
- Spectral response:

G = measured (analytical)

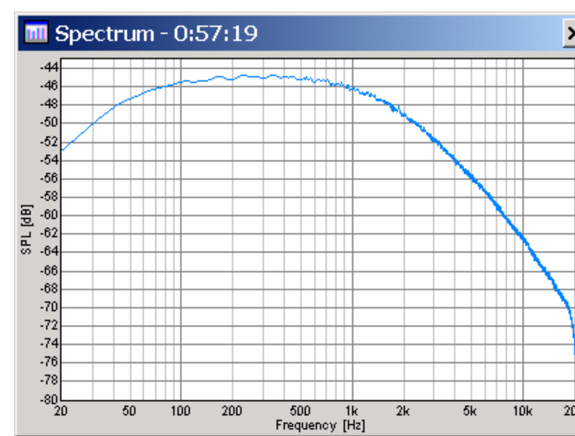
G = 112 (102)
BW = 7 kHz
GBW = 786kHz



G = 399 (353)
BW = 2.2 kHz
GBW = 877 kHz

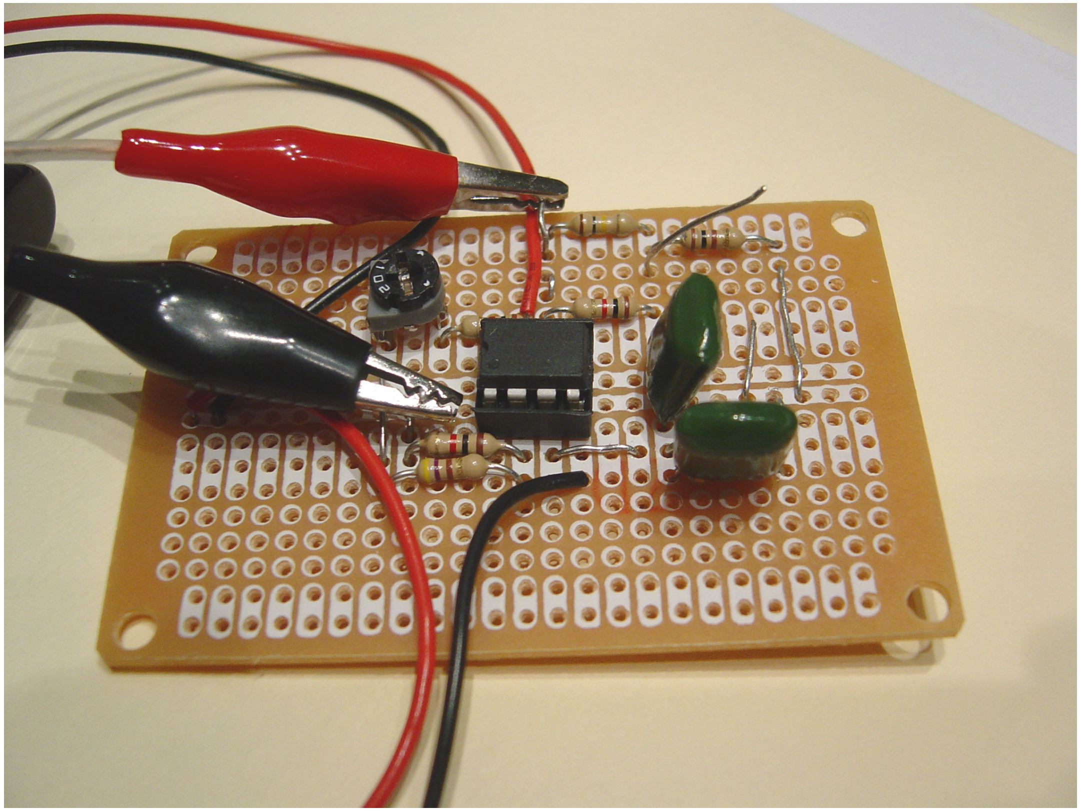


G = 563 (551)
BW = 1.6 kHz
GBW = 901 kHz



Wien bridge op amp oscillator: f = 1592 Hz

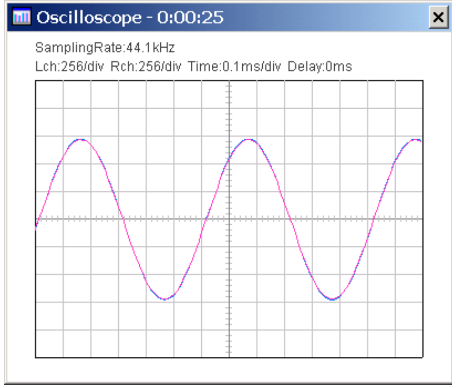
- R = 1000Ω, C = 0.1μF, f = 1592 Hz

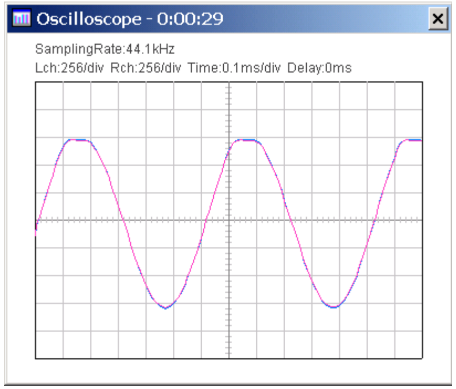


Wienbridge op amp oscillator: f = 1592 Hz

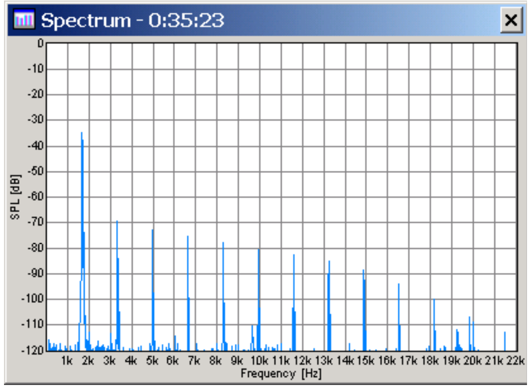
G = 1.025 | G = 1.030

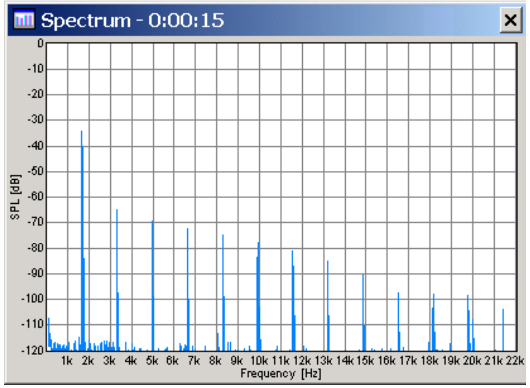
Waveform:





Spectrum:





Wienbridge op amp oscillator: f = 1592 Hz

G = 1.025

Measured spectrum

(unequal battery volts;

even harmonics)

Simulated spectrum

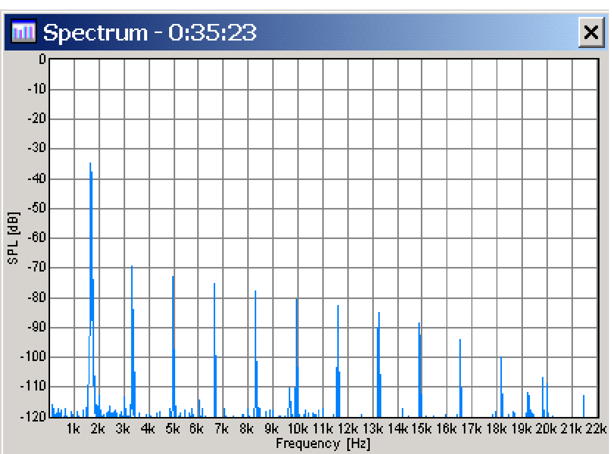
(equal battery volts;

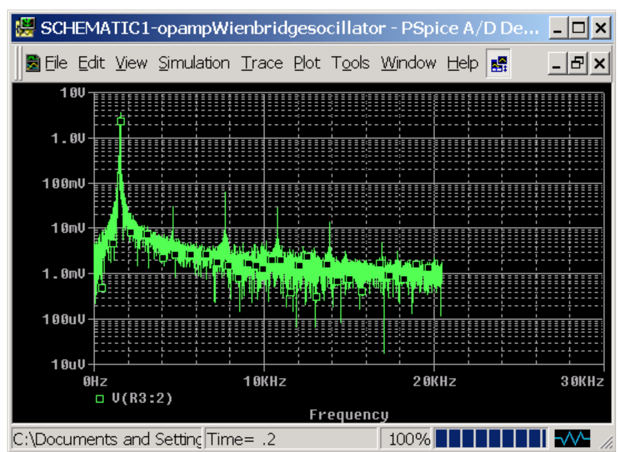
no even harmonics)

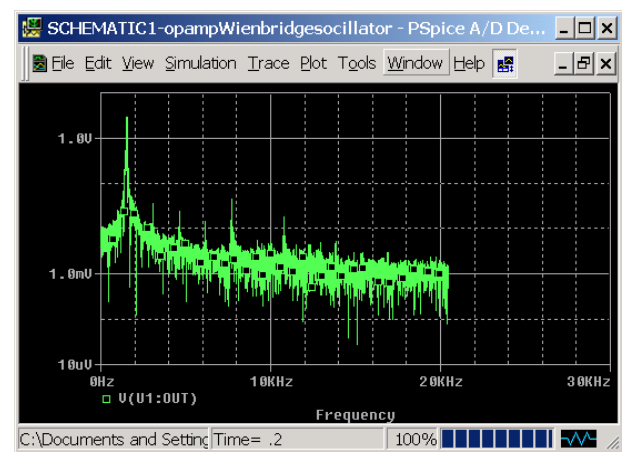
Simulated spectrum

(unequal battery volts;

even harmonics)

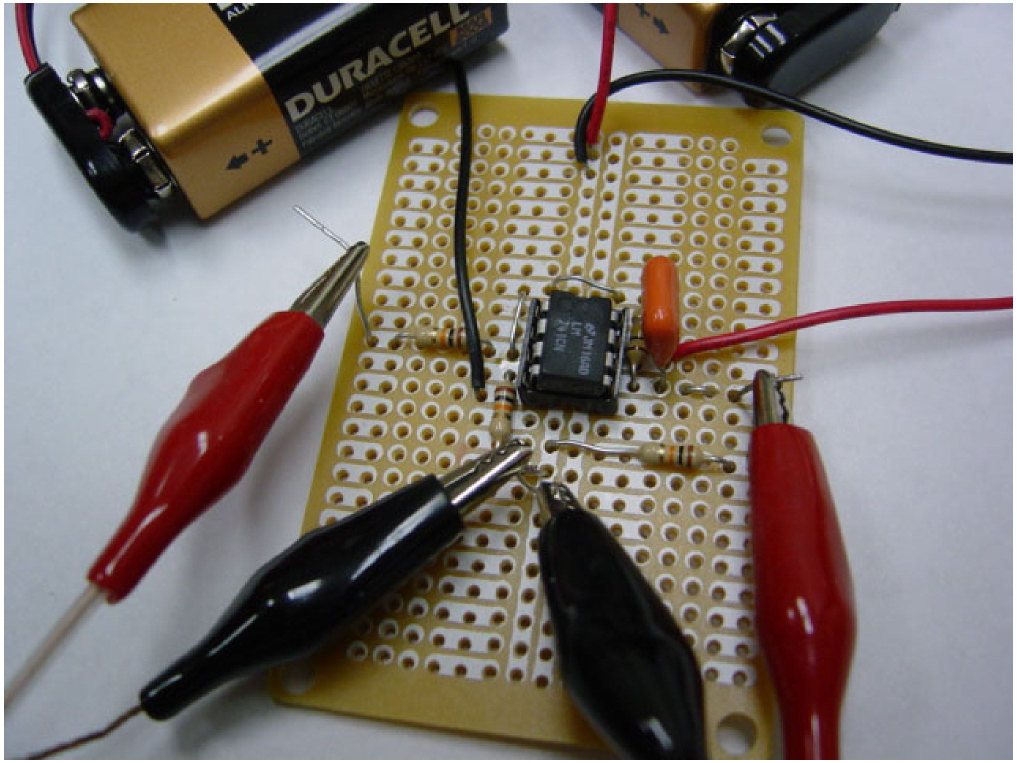






Op amp inverting integrator

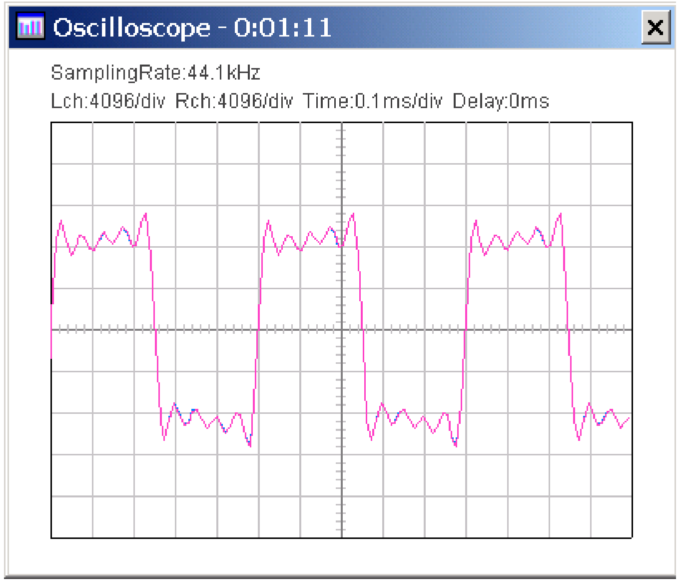
- R = 10,000Ω, C = 10nF



Op amp inverting integrator

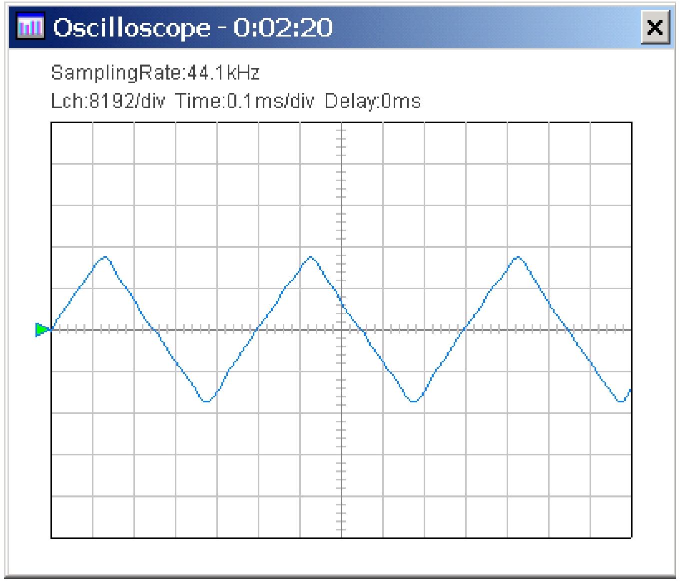
- Input signal

(2000 Hz square wave)



Output signal

(2000 Hz triangular wave)

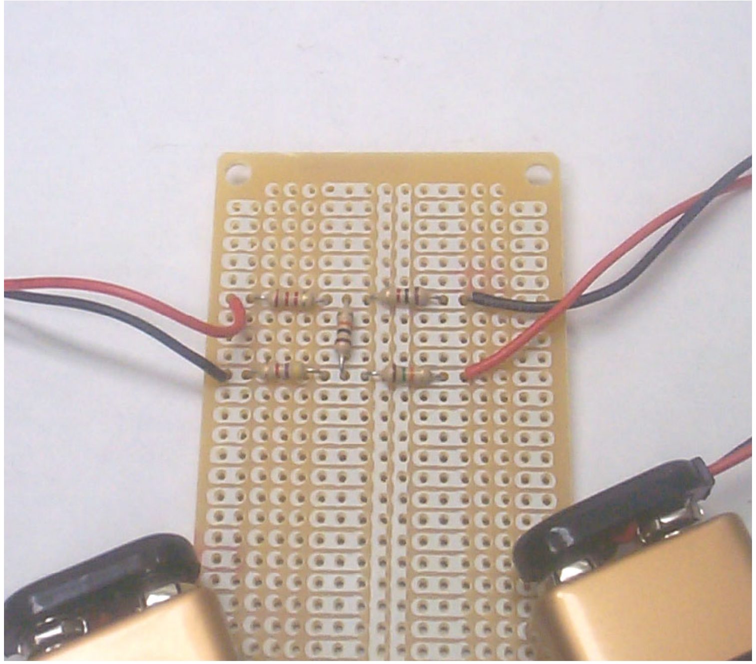


Resistive circuits

- Students purchase and use an inexpensive (<US$25) digital multimeter for measurements

Two loop, 5 resistor circuit

- Resistors: 1k, 2.2k, 4.7k, 10k, 15k
- Batteries: 9V, 9V

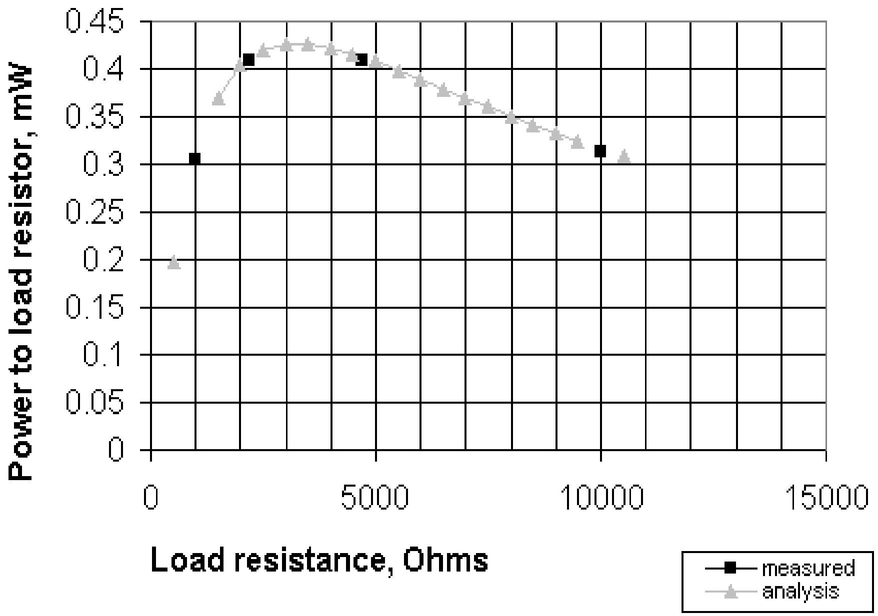


Two loop five resistor circuit

- Write mesh and node equations and solve with MATLAB
- Simulate circuit with OrCAD PSpice
- Measure circuit voltages and currents with digital multimeter
- Interactive learning: comparison of measurements and calculations

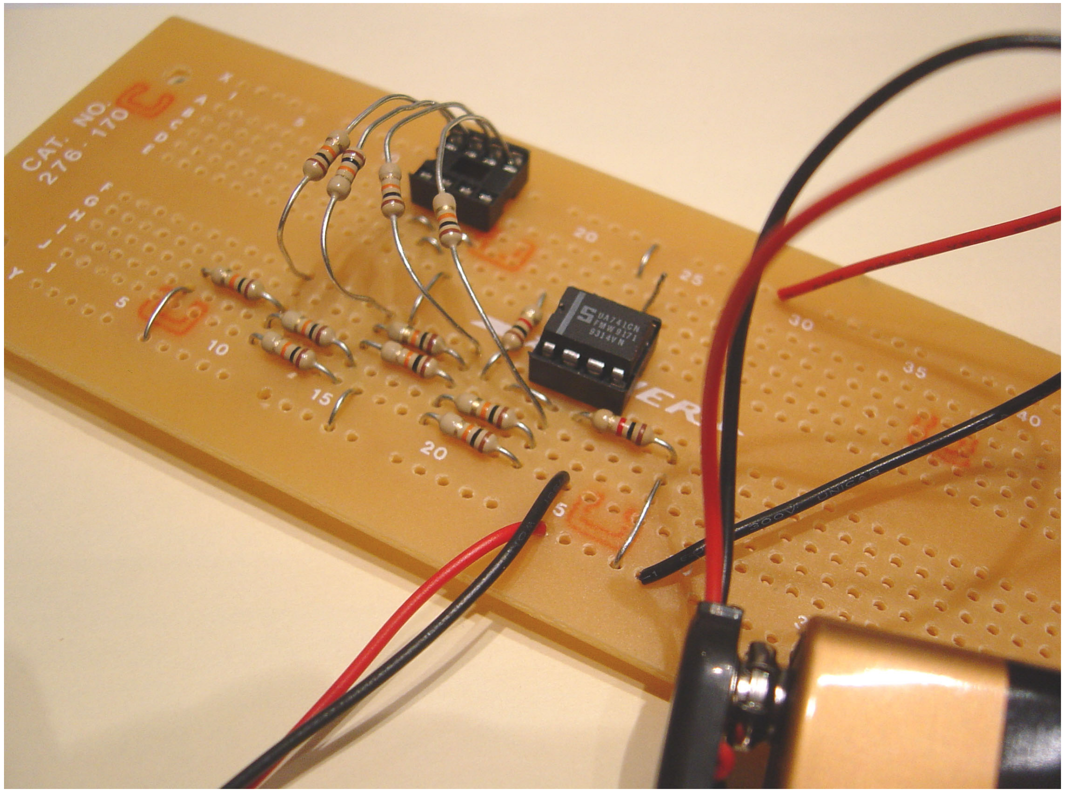
Two loop five resistor circuit

- Plot of the power dissipated in the load resistor vs. its resistance:



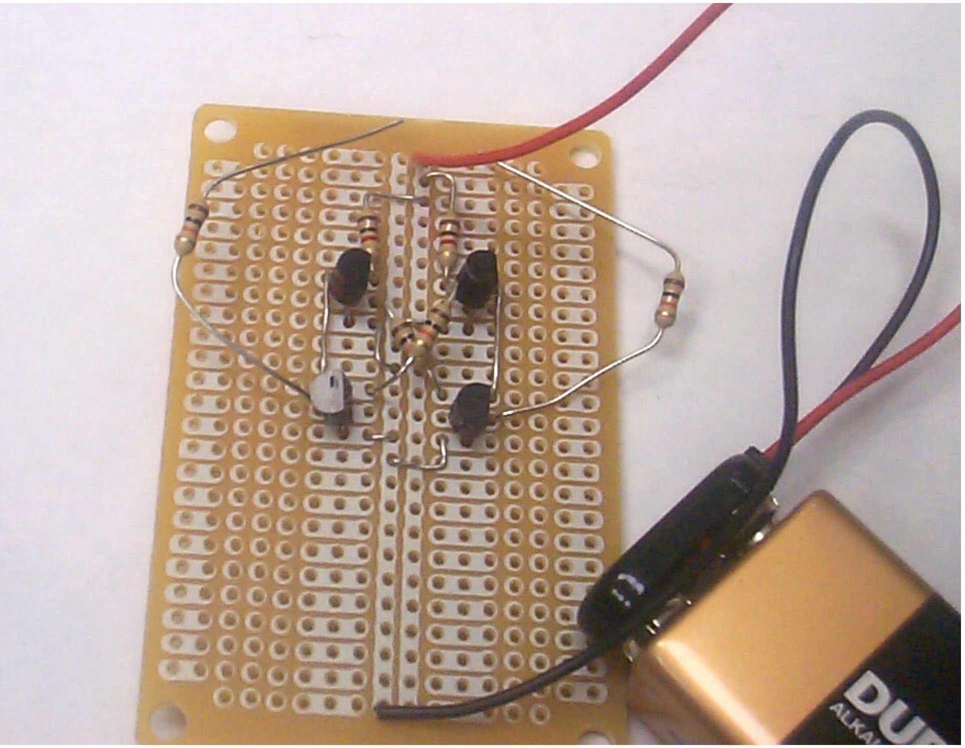
R-2R digital-to-analog converter

R = 5000Ω



BJT RS latch

- R = 10kΩ



Discussion and Conclusion

Approximate parts list

Students already have bought shaded parts and used them for hardware homework in a first year course.

Part description	RadioShack part number	Price $US
15-Range Digital Multimeter, with battery	22-810	23.48
1/4 Watt Resistor Assortment	271-308	6.29
9V Rectangular Battery (2)	23-875	6.58
9V Battery Snap Connectors	270-324	2.59
Adjustable resistor, 10k Ohms	271-282	1.29
0.01µF Capacitor (2)	272-1051	2.38
0.1µF Capacitor (2)	272-1053	2.38
741 Operational Amplifier IC	276-007	0.99
General Purpose IC PC Board (5)	276-150	8.95
8-Pin IC sockets (2 packages)	276-1995	1.38
Shielded Cables, 1/8" phone plug to alligator clips (2)	42-2421	6.58
Long-Nose Mini Pliers	64-2953	4.99
Soldering Pencil, 15-Watt	64-2051	8.39
0.032" Rosin Core Solder	64-017	1.59
Total		77.86

Discussion and Conclusion

- In view of
  - 3 years positive results with hardware homework in a first year course for ECE students,
  - Promise of hardware homework to promote intensely interactive learning environments,
  - Success of prototype projects,
- ECE faculty voted to
  - Deploy hardware homework in first of restructured circuit and electronics courses in spring 2005
  - Strengthen labs in successive courses in view of stronger student lab experience in early courses