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

Marion O. Hagler
Department of Electrical and Computer Engineering
Mississippi State, MS 39762 USA
hagler@ece.msstate.edu
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

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

- $R = 4700\Omega$, $C = 0.1\mu F$, $RC = 0.47$ msec
Non-inverting op amp configuration

- Op amp GBW $\approx 1$ MHz
Non-inverting op amp configuration

- **Analysis:**
  - **Gain without feedback:**
    \[ A = A_{LF} \frac{1}{1 + j \frac{f}{f_{BW}}} \]
  - **With feedback:**
    \[ G = G_{LF} \frac{1}{1 + j \frac{f}{A_{LF} G_{LF} f_{BW}}} \]
  - **In both cases:**
    \[ GBW = A_{LF} f_{BW} \]
    - Feedback conserves GBW
Non-inverting op amp configuration

- Response when $G = 96$

<table>
<thead>
<tr>
<th>Measured input:</th>
<th>Measured output:</th>
<th>Simulation:</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Oscilloscope" /></td>
<td><img src="image2.png" alt="Oscilloscope" /></td>
<td><img src="image3.png" alt="Simulation" /></td>
</tr>
</tbody>
</table>
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:**
  
  \[
  G = \text{measured (analytical)}
  \]
  
  \[
  \begin{align*}
  G &= 112 \ (102) & G &= 399 \ (353) & G &= 563 \ (551) \\
  \text{BW} &= 7 \text{ kHz} & \text{BW} &= 2.2 \text{ kHz} & \text{BW} &= 1.6 \text{ kHz} \\
  \text{GBW} &= 786\text{kHz} & \text{GBW} &= 877 \text{kHz} & \text{GBW} &= 901 \text{kHz}
  \end{align*}
  \]
Wien bridge op amp oscillator:

$f = 1592 \text{ Hz}$

- $R = 1000\Omega$, $C = 0.1\mu\text{F}$, $f = 1592 \text{ Hz}$
Wienbridge op amp oscillator: $f = 1592$ Hz

$G = 1.025$  $G = 1.030$

Waveform:

Spectrum:
Wienbridge op amp oscillator:
\[ f = 1592 \text{ Hz} \]

\[ G = 1.025 \]

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

- \( R = 10,000\,\Omega \), \( C = 10\,\text{nF} \)
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:

![Graph showing power dissipated vs. load resistance]
R-2R digital-to-analog converter

\[ R = 5000\Omega \]
BJT RS latch

- $R = 10k\Omega$
### Approximate parts list

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

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