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

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Abstract—**This paper describes some prototype hardware homework projects that use inexpensive software running on student laptop PCs and an inexpensive digital multimeter. These projects were prepared to assess the feasibility of using hardware homework to provide interactive and experiential laboratory experiences in the first in a sequence of circuit analysis and electronics courses.**

Keywords-laptop PC; oscilloscope; spectrum analyzer; laboratory; LabVIEW.

1. INTRODUCTION

Although laboratory experience has always been an integral part of engineering education, contemporary understanding of how interaction and active experience with learning environments can boost learning underscores the fundamental importance of laboratory experience even more [1]. This paper describes an effort to exploit recent developments in technology to make the laboratory experience early during a sequence of analog circuits and electronics courses more intensively interactive and experiential by extending its availability beyond formal laboratory and classroom settings.

Since 1999, the Bagley College of Engineering at Mississippi State University (MSU) has required each entering undergraduate student to purchase a laptop computer and software that meet certain specifications [2]. As part of a restructuring its sequence of courses in circuit analysis and electronics, the Department of Electrical and Computer Engineering at MSU is now preparing to transfer the laboratory hours that have been associated with the first course in the sequence to a course later in the sequence, where the laboratory projects can be more complex. At the same time, the laboratory experience in the first course will be strengthened by requiring students to construct circuits and make measurements on them with the audio capability built into their laptops and with an inexpensive digital multimeter that they purchase for their own use. Students will accomplish the construction and measurement activities not in a laboratory or in a classroom, but at home. These projects, therefore, are in essence hardware homework.

Hardware homework in the first course in the circuit analysis and electronics course sequence not only will offer more frequent and sophisticated laboratory activities than the present formal laboratory course, it also will employ students' laptops in substantive interactive learning and thereby give students additional tangible return on the financial investment in their laptops. In addition, this approach opens the possibility of offering the first course in the circuit analysis and electronics sequence through distance learning, a possibility that would help break scheduling bottlenecks

that occur when students transfer to Mississippi State from 2-year colleges – a common occurrence – to complete the requirements for degrees in electrical and computer engineering.

In a course for first year undergraduate students in electrical and computer engineering at Mississippi State, hardware homework has been used since 2001 to give a laboratory experience without a formal laboratory [3]. Earlier, hardware homework was used occasionally in an electronics course at Texas Tech University [4]. The recent availability of inexpensive software, such as the DSSF3 Light Realtime Analyzer, that enables the audio capabilities of a PC to function as a relatively sophisticated real time signal generator, oscilloscope, and spectral analyzer extends the range of laboratory exercises beyond those possible with the digital audio editors used before [5]. In contrast to powerful (and expensive) virtual instrument software such as LabVIEW, Realtime Analyzer relies on the sound card built into PCs for data acquisition and thereby permits simple and inexpensive signal acquisition, processing and display in the audio frequency range [6].

This paper describes some prototype hardware homework projects that use an inexpensive digital multimeter and Realtime Analyzer running on each student's laptop PC to assess the feasibility of using hardware homework to provide the laboratory experience in the first in the sequence of circuit analysis and electronics courses at Mississippi State University.

2. RESISTIVE CIRCUITS

Key objectives in the sequence of circuits and electronics courses are for students to learn how to measure the performance of circuits, how to analyze the circuit performance with mathematics and software, and how to compare and combine the results of measurement and analysis to achieve the level of understanding needed for the design of systems that meet performance specifications. Microsoft Office is required on each student laptop so Microsoft Excel is available. The Department of Electrical and Computer Engineering at MSU requires, in addition, each student to purchase and install MATLAB Student Version [7]. Students also are expected to download and install the latest free demonstration version of the OrCAD PSpice circuit simulator [8].

Resistive circuits that consist of voltage sources, operational amplifiers, and resistors offer an environment for integrating software and hardware into an experientially complex interactive learning environment. Consider, for example, a simple two-loop circuit that consists of 5 resistors and two 9V batteries configured with a single battery in each loop. In practice, the value of each resistor is specified, but not their placement in the circuit. Students build the circuit with components and a board that they purchase at a local electronics store or online [9]. An inexpensive (less than US$25) digital multimeter available from the same source permits easy and accurate measurements of voltages and resistances.

Homework based on this circuit consists of multiple parts with completion dates spread over the first several weeks of the first course in the sequence. Of course, these assignments would be complemented by other problem assignments during this time, and not all parts would be assigned during a particular offering of the course. The individual parts range from constructing the circuit and comparing measured, analytically calculated, and simulated values of mesh currents and node

voltages to investigating Thevenin's theorem and the maximum power transfer theorem.

As an illustration of one part related to the maximum power transfer theorem, Fig. 1 shows an Excel plot of power absorbed by a load resistor connected across a pair of terminals in the circuit as a function of the load resistance. The light symbols correspond to theoretical points, while the dark symbols correspond to measured values.
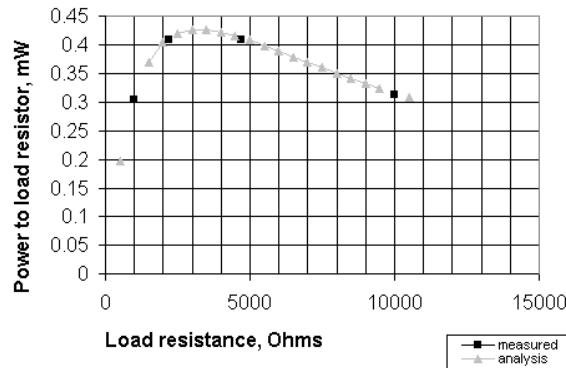

Figure 1.   Screen shot of Excel plot of the power dissipated in the load resistor vs. its resistance.

In a second example, students would consider a 741 op amp IC connected in an inverting amplifier configuration, a practical implementation of a voltage controlled voltage source. Students can plot the output voltage vs. the input voltage and deduce the voltage gain of the amplifier from the slope of the curve. Students can deduce the Thevenin resistance of the amplifier at its output terminals and can observe when the 741 IC begins limiting the output current to prevent damage to the IC. When that happens, students note that the amplifier no longer behaves as a linear circuit, and consequently that the Thevenin equivalent circuit is no longer valid.

3. CIRCUITS WITH CAPACITORS AND INDUCTORS

Teachers can use resistive circuits, an inexpensive digital multimeter, and widely available software to construct surprisingly rich interactive and experiential learning environments. Most practical circuits contain inductors and capacitors, however, and thus require a signal generator, oscilloscope, and spectrum analyzer for implementation of effective learning environments. Although the venerable free demonstration version of Cool Edit 96 enables a PC to act as an excellent audio signal generator and provides oscilloscope and spectrum analyzer functions by recording an audio waveform and then processing it, Cool Edit is no longer available for inexpensive purchase [4]. At a cost of about $90, Realtime Analyzer (DSSF3 Light version) provides more contemporary and sophisticated implementations of a signal generator, oscilloscope, spectrum analyzer and other functions in real time, and hence permits a PC to function much more like more capable instruments that students will use later [5]. Fig. 2 shows a 2000 Hz square wave generated by Realtime Analyzer and displayed with its oscilloscope. Note the capability of the oscilloscope for two-channel display, adjustable triggering, and screen copy, although these features are not used in this particular example figure.
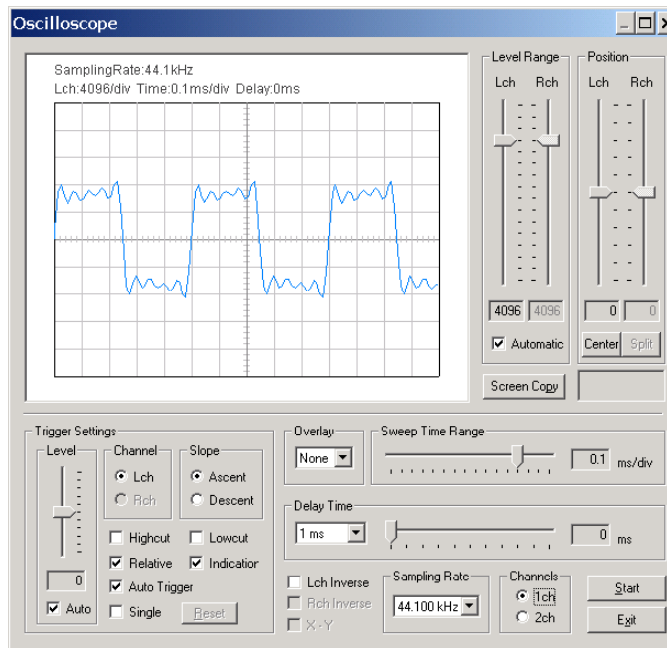
Figure 2.   Realtime Analyzer oscilloscope view of a 2000 Hz square wave from its signal generator.

Fig. 3 shows an inverting integrator circuit built with a 741 IC, a 10 nF capacitor, a 10,000 Ohm resistor, and several ancillary components. Fig. 4 shows the (triangular wave) output of the inverting integrator when the 2000 Hz square wave shown in Fig. 2 is applied to the integrator input. Students can compare the relative magnitudes of the input and output waveforms with analytical calculations and with the results of OrCAD PSpice simulations. If the laptop provides a stereo input, the oscilloscope can display simultaneously the input in one channel and the output in the second channel. In that case, students can compare the relative phases of the input and output waveforms.
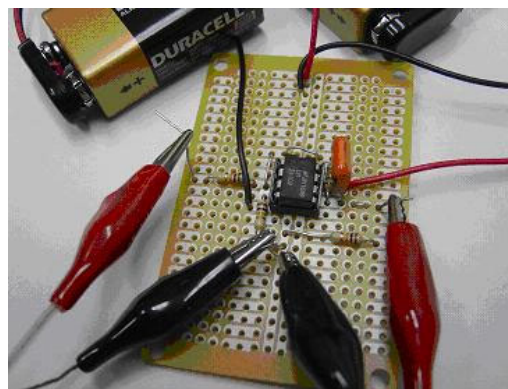

Figure 3.   An inverting integrator circuit built with an 741 op amp IC, a 10 nF capacitor, a 10,000 Ohm resistor, and ancillary components.
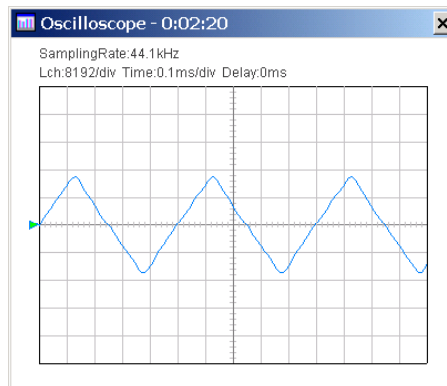
Figure 4.   Triangular wave output of the inverting integrator when the input is the square wave shown in Fig. 2.

To illustrate spectral measurements, consider a simple RC (resistor capacitor) low pass filter circuit with R = 4700 Ohms and C = 10 nF. To measure its spectral response, drive the input to the filter with white noise generated by Realtime Analyzer and the laptop sound circuitry. Measurement shows that the spectrum of the laptop audio output is flat to within a few decibels between 200 and 19,000 Hz. Fig. 5 shows the spectrum of the output from the low pass filter as it is driven by white noise from the headphone output of the laptop. Phasor analysis indicates that the frequency at which the spectrum should fall by 3 decibels from its low frequency value should be about 3400Hz, a value consistent with Fig. 5, which also shows that between 5000Hz and 10000Hz the spectrum drops by about 6 decibels, the value indicated by analysis. Of course, students can compare the measured results with analytical phasor calculations plotted with Excel and with OrCAD PSpice simulations.
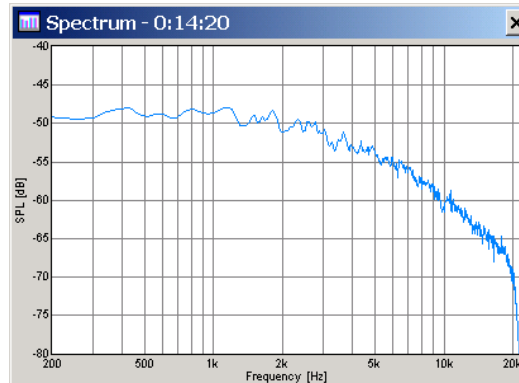

Figure 5.   Spectrum of the output of the RC low pass filter driven by white noise.

Fig. 6 shows illustrates the capability of Realtime Analyzer to measure and display the impulse response of circuits.
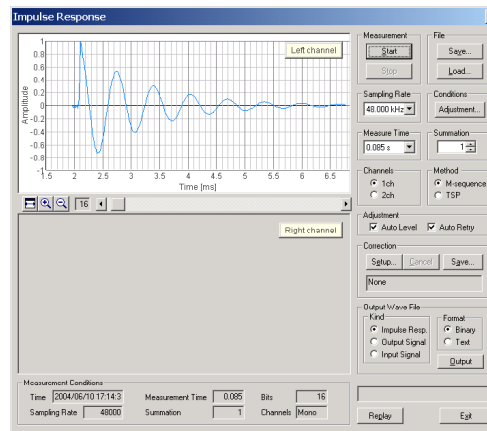
Figure 6.   Impulse response of an RLC band pass filter.

4. DISCUSSION AND CONCLUSIONS

The list of parts and tools needed for construction of the circuits mentioned includes a digital multimeter, 9V batteries, resistors, capacitors, 741 op amp chips, general purpose printed circuit boards, IC sockets, shielded cables with alligator clips, long nosed pliers, solder, and a soldering pencil. The total cost is less than US$80 [9]. Students in the Department of Electrical and Computer Engineering at Mississippi State University have been required to purchase most of these parts and tools during a first year course [3]. The main incremental cost to the students, therefore, would be the cost of the Realtime Analyzer (DSSF3 Light) software, about US$90 and approximately the cost of a typical contemporary engineering textbook.

The promise of the prototype exercises described here to provide intensely interactive and experiential learning environments, in combination with the low incremental costs to the students, has led the faculty of the Department of Electrical and Computer Engineering to approve work aimed at implementing hardware homework in the revised first course in the sequence in circuits and electronics in the Department beginning in the fall semester of 2005.

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