2006-2473: A NEW INTRODUCTORY COURSE ON SIGNALS, CIRCUITS AND SYSTEMS

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A NEW INTRODUCTORY COURSE ON SIGNALS, CIRCUITS AND SYSTEMS

INTRODUCTION

In this paper, we present a new sophomore level Electrical and Computer Engineering (ECE) course on introductory concepts in signals, circuits and systems. This is the first required ECE course that ECE majors take after they complete the required courses common to all engineering students during their first year in the college. This course is a prerequisite for two other required core courses offered during the second semester of the second year: a course on electric circuits and another course on mathematical foundations of electrical and computer engineering. The new course was first offered in Fall 2000 semester. Since then, the course contents were periodically reviewed and revised based on the results of the course instructors' assessment studies on student learning, discussions with the instructors of the follow-up courses and student feedback surveys.

BRIEF HISTORY OF THE COURSE

The new course is the result of an evolutionary process, which started as a one-semester course to introduce different specialization areas in electrical and computer engineering. The need for such a course came about as a result of a new ECE curriculum, which emphasized junior and senior level elective courses to achieve depth in at least one of the ECE specialization areas. The new course was intended as a catalyst encouraging the students to consider their interests in different ECE specializations as early as possible to help them in choosing their elective courses.

At the time, the ECE faculty participating in the development effort for this course was strongly against creating just a survey course, which would most likely lack the rigor of a typical introductory course. A consensus was reached to create a course with a strong hardware laboratory component reviewing different ECE specializations while providing key fundamental concepts. It was decided to devote approximately one third of the course to introductory material followed by eight weeks on different specialization areas. According to the initial plan, two 75 minute lectures per week would be used to cover the theoretical material necessary to perform the experiments in laboratory, which would meet almost every week for three hours. The specializations to be included in the course were decided on based on the strengths of our department. The list included circuits, electric power, communication, digital signal processing, solid state electronics, logic design, computer architecture and computer networking.
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One of the great challenges of this plan was to create the hardware laboratory: the experiments had to be representative of the respective specialization areas and they had to be chosen from exciting real-life applications. This approach required dedicated laboratory hardware to be designed and constructed in order to be able to demonstrate complex applications at a level that would be accessible to beginning students. In addition, a new textbook had to be written since none of the existing textbooks would fit the course contents. This job was assumed by several faculty members representing different specializations.

Soon after we began offering the course, we began to realize that the initial plan was too ambitious for a one-semester course. According to the results of the student surveys, the students enjoyed learning about different specializations, which gave them a better understanding of their chosen professions, however, they felt rushed throughout the semester and they were not able to retain the material, which affected their morale and level of confidence. In the laboratory, we have found that a few introductory experiments were not sufficient to cover the basics. Furthermore, learning to operate the standard bench-top equipment, which included a multimeter, an oscilloscope, a function generator and a power supply took much more time than we originally anticipated. It was clear that the students needed extra time and support in the beginning of the semester. Even though the students were able to follow the step-by-step instructions to run the specialization experiments they were unable to enjoy and benefit from them because they were still busy catching up with the basics.

After the first two years, it was clear that we had to make some changes. It was impossible to turn the course into a two-semester sequence because we did not have any room in the curriculum. Thus, the only option we had was to reduce the course material, which was not an easy task. After all, the changes required eliminating some of the specializations thus postponing students' first exposure to this material. Fortunately, because concepts related to logic design and computer architecture were already introduced in two other ECE courses, we were able to remove two chapters from the book and two experiments from the lab without experiencing a significant loss. Without the introductory material on digital signals, it was no longer possible to effectively discuss examples on computer networking; hence, it too had to be dropped. Also, we had always found it difficult to connect the material on networking to the introductory material covered during the first part of the course. Finally, the material on solid state electronics was also removed due to the lack of an organic link with the rest of the material.

We have found by removing approximately one fourth of the course material it was possible to teach the rest effectively. Some of the older material was also replaced with new material to improve the continuity within the course and continuity with the future ECE core courses. These changes required major changes in the textbook in the form of either writing new chapters or major revisions. One of the most successful additions was a chapter on operational amplifiers, which came with an accompanying experiment.

During this time, the lab manual and the experiments were continually revised based on the results of the student feedback surveys conducted after each experiment. The experiments, which were found too difficult were replaced with simpler experiments to help the students understand the concepts better. In the mean time, a virtual laboratory was created to allow the students experiment with virtual test instruments, which looked much like the equipment they used in the hardware laboratory. A semester-long mandatory hardware project was added to the laboratory, which also turned out to be a great success. Finally, an optional golden solder project was created for students interested in applying their new knowledge to a simple design project.

When the dust settled after these changes, we were left with a new introductory course on signals, circuits and systems, which is the subject of this paper. The first part of the course covers fundamental concepts such as Kirchoff's laws, Ohm's law, AC and DC voltage sources, linear and non-linear resistive elements, capacitors, and representation of periodic signals in both time and frequency domains. As such, aside from the coverage on frequency domain, the first part closely resembles a traditional course on circuits. This however is not entirely true because the inclusion of frequency domain at this level represents a major deviation from the traditional approach, which truly affects the nature of the course contents. In every experiment, the response of a system (e.g. amplifier, filter etc.) is analyzed in both time and frequency domains. Consequently, the students completing the course attain an excellent understanding of how the two domains relate to each other before they begin to learn mathematical foundations of signals and systems in future core courses.

Instructional objectives for the first part of the course are:

1. Explain the concepts of electric charge, current, voltage, resistance, and capacitance.
2. Identify resistors, diodes and capacitors in circuit diagrams.
3. Interpret the basic current-voltage (I-V) characteristics of key circuit elements, including resistors, photocells, diodes, and capacitors.
4. Calculate the equivalent resistance of resistor circuits (i.e. series and parallel), and the equivalent capacitance of capacitive circuits (i.e. series and parallel).
5. Apply Ohm's Law and Kirchoff's Laws to simple circuits consisting of DC voltage sources, linear and non-linear resistive elements and capacitors.
6. Given a first order RC Circuit, calculate the time constant and the time required to charge/discharge the capacitor to a certain voltage level.
7. Given a first order RC Circuit, calculate the current flowing in the circuit at a given instant of time during charging or discharging.
8. Identify/Measure/Calculate time-varying waveform parameters including amplitude, peak-to-peak value, frequency, period, duty cycle, average (DC) value, root-mean-square, phase angle and time delay, from graphs, oscilloscope screenshots, and equations.
9. Apply Ohm's Law and Kirchoff's Laws to simple circuits consisting of AC & DC voltage sources, linear and non-linear resistive elements.
10. Apply Ohm's Law and Kirchoff's Laws to fully analize half and full-wave rectifier circuits consisting of resistors and diodes to find the key voltage and current waveforms in the circuit given an arbitrary periodic input signal
11. Determine and plot the instantaneous power dissipated on a resistive load given an arbitrary voltage waveform applied to the load in graphical or equation form, and use the instantaneous power to determine the real power.
12. Determine and plot the instantaneous power dissipated on a non-resistive load given the sinusoidal voltage waveform and the resulting sinusoidal current including the phase angle between the two waveforms, use the voltage and current waveforms to determine the real and apparent power and power factor.
13. Generate and analyze amplitude, phase and power spectra of periodic signals.
14. Given amplitude or power spectrum of a periodic signal identify the waveform parameters including frequencies of the harmonics, average (DC) value, signal amplitude and power of each harmonic and total signal power.

During the second half of the course, the fundamental concepts are applied to different examples of analog signal processing, which serve as exciting, real-life demonstrations of the material covered in the course. Applications include filtering, amplification, RF modulation/demodulation, sampling and reconstruction, which provide the natural platform to talk about different specialization areas. Fundamental concepts used under each application are shown in Figure 1 with links to other applications.

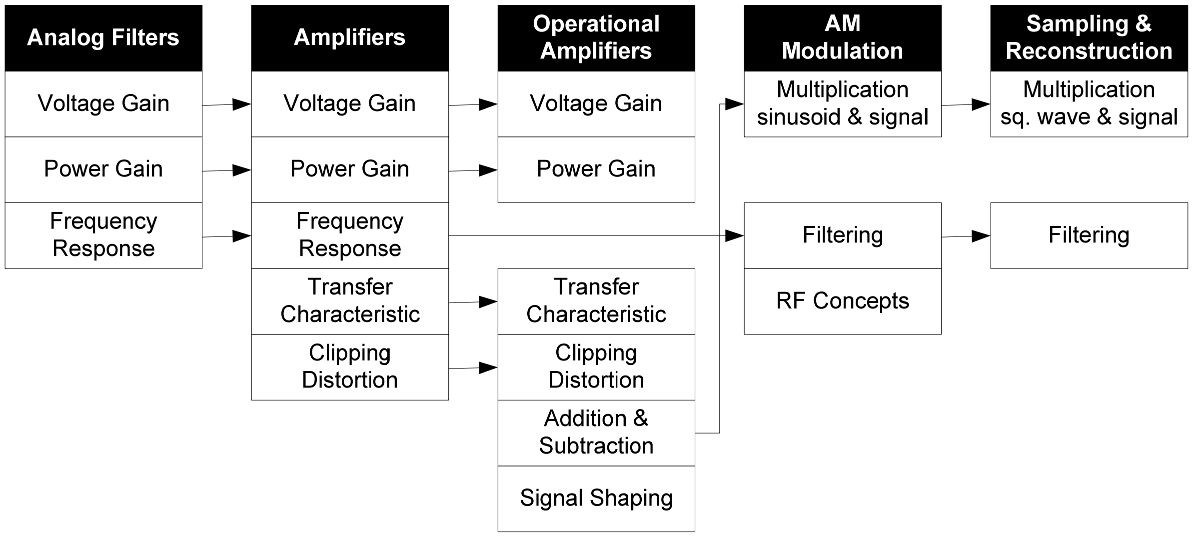

Figure 1: Analog signal processing applications covered in the second half of the course and the fundamental concepts covered under each application.

TEXTBOOK AND LABORATORY EXPERIMENTS

In this section, we provide brief descriptions of the material covered in different chapters and provide examples from experiments included in the the hardware laboratory.

Part I: Introduction to Signals and Circuits

Chapter 1: Resistive Circuits:

In this chapter, the students are introduced to Ohm's law and Kirchoff's laws. These laws are applied to analysis of simple circuits, which include DC voltage sources and resistive elements. Lectures emphasize the physical principles instead of techniques used to apply complex circuits. Concepts such as mesh and nodal analysis are left out to be covered in a follow-up course, which provides a more rigorous approach to circuit analysis. The guiding principle is to exclude abstract concepts, which can not be readily demonstrated to beginning students in the hardware laboratory. For instance, current sources are not mentioned because it is easy to talk about voltage sources by referring to batteries the students are already familiar with.

The chapter includes both linear and non-linear resistive elements. Specifically, rectifying diodes and light emitting diodes are discussed and used in circuits with DC voltage sources. Inclusion of these non-linear elements provides opportunities for exciting experiments in the laboratory.

The experiment for this chapter relies on the dedicated hardware box shown in Figure 2. The box allows construction of simple circuits with two independent loops sufficient to demonstrate basic concepts. The components are installed on small printed circuit boards with banana connectors. Switches on the board allow easy shunting of the circuit elements. This approach is preferred as opposed to using breadboards in order to allow the students to concentrate on their circuits instead of troubleshooting their connections on the breadboard. We have found this approach to be extremely helpful for beginning students who have no experience in using the breadboards.

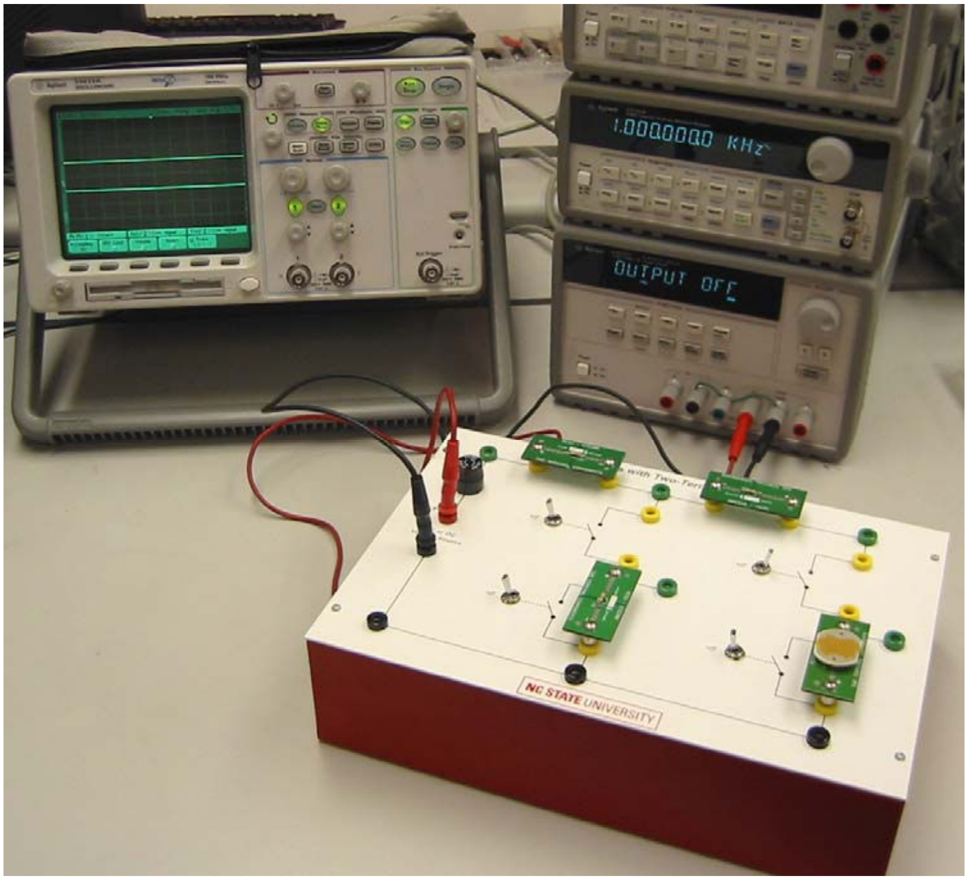

Figure 2: Experiment box used to construct and test circuits with two-terminal elements.

The first half of the experiment for this chapter demonstrates the following concepts, which are standard in all introductory experiments on circuits.

- How to use the multimeter to measure DC voltages and currents.
- Resistor color coding
- Resistors in series and parallel
- Ohm's law and Kirchoff's laws
- Voltage and current division

In the second half of the experiment, the students combine the above concepts with their knowledge of rectifying diodes to construct and test a night-light circuit, which turns on an LED when the ambient light is not sufficient. The circuit diagram is shown in Figure 3. The circuit works on the principle that when the ambient light is not sufficient, the photocell has a large resistance, hence, sufficient current can flow through the LED to turn it on. This is a practical circuit, which performs a familiar function, which the students are already familiar with.

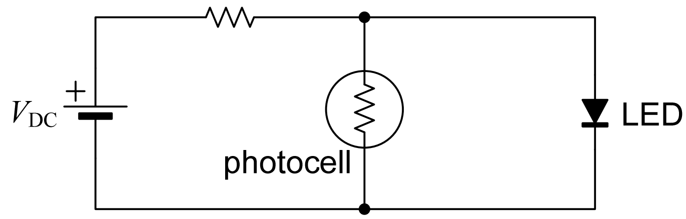

Figure 3: Night light circuit demonstrating Kirchoff's voltage and current laws.

Chapter 2: Capacitors and RC Circuits:
In this chapter, physical principles of charge storage in a capacitor are explained. This knowledge is then applied to analysis of first order RC circuits. Equations for capacitor charging and discharging are derived using the circuit laws introduced in the previous chapter. The solution to the differential equation is given and verified without teaching the techniques used to solve differential equations. Similar to the first chapter, the primary objective of this chapter is to emphasize the fundamental concepts such as understanding of the RC time constant as opposed to analysis of complex RC circuits, which are covered in the next course on circuits.

In the laboratory, the students use the same experiment box used in the previous experiment. The experiment begins with measurements performed on a simple, first order RC circuit. Charge sharing in series and parallel capacitor connections is demonstrated. The final experiment for this chapter combines the new information on capacitors with their prior knowledge on LEDs in the timer circuit shown in Figure 4. In this circuit, LED remains off until the capacitor reaches the turn-on voltage of the LED. By using large electrolytic capacitors, the capacitor charging time can be increased to tens of seconds. Students use different capacitors and measure the time needed to turn on the LED. From these measurements and using the capacitor charging equation the students calculate the RC time constant of the circuit for different capacitors. Similar to the first experiment, this circuit applies the new knowledge to an exciting practical circuit, which the students can easily relate to.

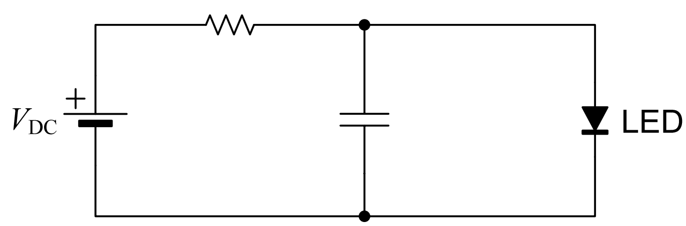

Figure 4: Analog timer circuit used to demonstrate capacitor charging and Kirchoff's laws.

Chapter 3: Periodic Signals in Time Domain
The objective of this chapter is to introduce basic properties of common AC signals including the square and sinusoidal waveforms. Concepts of period, frequency, duty-cycle, phase, amplitude, peak-to-peak value and DC value are introduced with examples from standard test signals as well as signals generated by musical instruments.

In the laboratory, the students are introduced to the function generator and the oscilloscope. The oscilloscope is networked, which allows the students to save their oscilloscope screenshots on their computers. The experiment begins with basic measurements on signals from the function generator. The laboratory hardware also includes a microphone allowing the students to observe different sound signals such as speech and sounds from different musical instruments on the oscilloscope. The students are encouraged to bring their own musical instruments to the lab for measurements. In addition, the course web-site provides recorded sounds of different instruments including classical guitar, flute and drum.

The experiment box used for the two first experiments is again used to construct a half-wave rectifier circuit, which applies their prior knowledge on diodes to a simple circuit including a sinusoidal voltage source. This is a key experiment, which provides an introduction to the mandatory semester long hardware project, which involves construction of a power supply. This project will be described later in this paper.

Chapter 4: Electric Power

In this chapter, students are introduced to the concept of electric power for both AC and DC signals. In addition to introducing electric power as a specialization area, this chapter provides fundamentals that will be used in analysis of periodic signals in frequency domain. The origin of the root-mean-square voltage of a periodic waveform is introduced as the DC equivalent voltage, which results in the same power consumption. The chapter begins with multiplication of voltage and current waveforms in time domain to find the instantaneous power dissipated on resistive elements. The students' prior knowledge on average (DC) value of periodic signals is applied to finding the average value of instantaneous power defined as real power. The coverage on non-resistive loads is limited to sinusoidal waveforms with a phase angle between voltage and current waveforms. The chapter provides a brief introduction to concepts of power factor and apparent power. The derivations are made entirely based on students' prior knowledge of trigonometric identities.

In the laboratory, experiments are carried out using a dedicated experiment box shown in Figure 5, which houses a commercial light dimmer. A switch allows the user to bypass the dimmer if desired. A few inches of the wire carrying the load current is left outside the box, which allows the user to clamp a current probe over the wire. This way, the load voltage and current waveforms can both be displayed on the oscilloscope screen and then graphically multiplied to display the instantaneous power, using a standard feature on all modern oscilloscopes. Digital oscilloscopes can also compute the average value of the displayed signal, which in this case is the real power. The input voltage to the box is 120 V/ 60 Hz supply voltage. Standard electric outlets are used to measure the input and output voltage waveforms. A specially made, 100:1 oscilloscope probe featuring a heavy-duty standard electrical plug is used to ensure safety during measurements. The experiment makes use of a desk lamp and an electric fan as examples of resistive and non-resistive loads. In the second part of the experiment, the light dimmer is used with the desk lamp. The students display the instantaneous power, evaluate the real power and correlate these numbers to the observed light intensity.

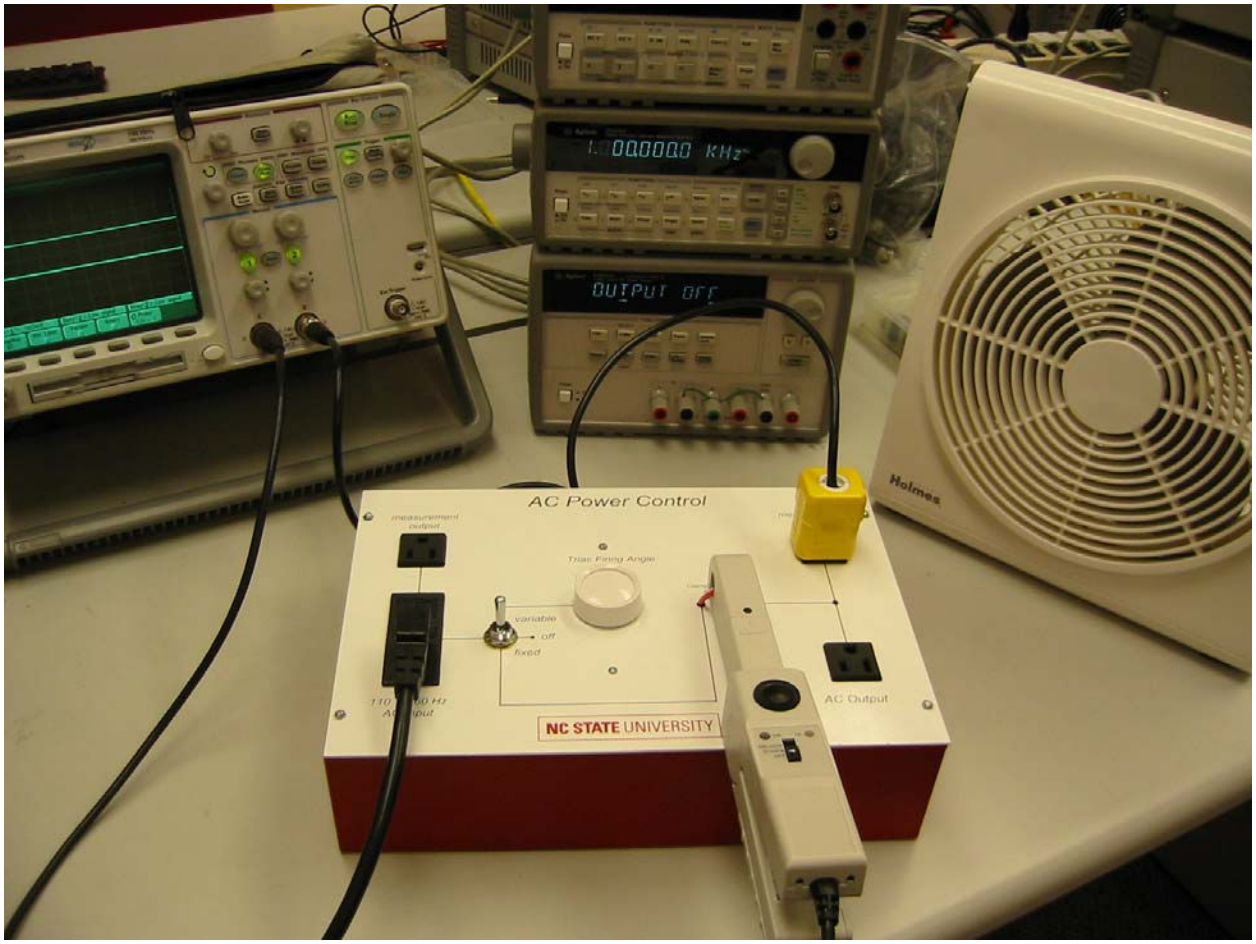

Figure 5 – Experiment box used in Electric Power experiments.

Chapter 5: Periodic Signals in Frequency Domain

In this chapter, we introduce fundamental concepts used to analyze signals in frequency domain. Signal power at a given frequency is defined as the real power dissipated on a load resistance of 1 ohm building on the information provided to the students in the previous chapter. Students learn how to plot the amplitude, power and phase spectra of periodic signals. The decibel concept is introduced along with dBW as a unit of power. In this chapter, one of the key concepts is that every periodic signal can be represented as an infinite sum of sinusoids. We refer to Fourier series as the mathematical representation of a periodic signal but leave the derivation to future courses. During the lecture, students are shown how a square wave can be created by adding sinusoidal waveforms. Examples are given from nearly periodic signals generated by different musical instruments. The concept of noise is introduced along with definition of signal to noise ratio of a system.

Representation of periodic signals in frequency domain is supported by actual measurements in the laboratory where students display the power spectra of various signals from the function generator, microphone or recorded music. Instead of dedicated spectrum analyzers, oscilloscopes with Fast-Fourier-Transform (FFT) capability are used to display the power spectra.

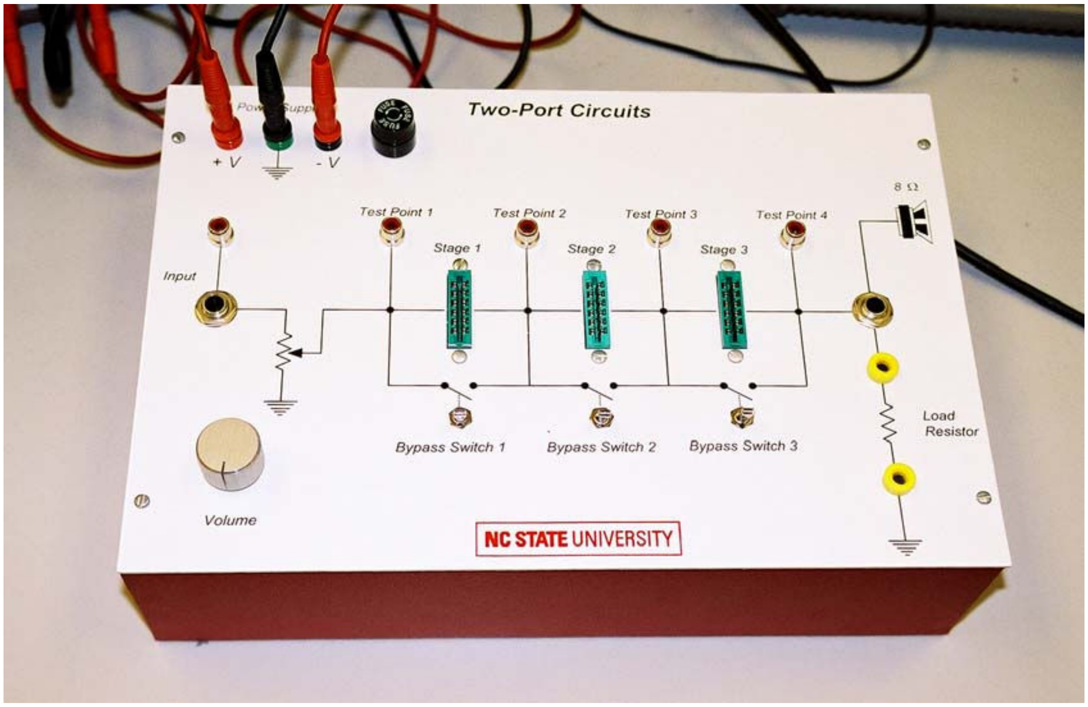

Figure 6: Experiment box used for experiments on two-port circuits.

Part II: Introduction to Analog Signal Processing and Systems

Chapter 6: Filters

This chapter covers basics of analog filtering. The frequency response of a two-port circuit is discussed along with discussion on the voltage and power gain of a filter. Ideal low-pass, band-pass and high-pass filter are introduced. Examples of non-ideal filters are provided and the concept of 3-dB cut-off frequency is introduced. Students learn how to find the output power spectrum given the power spectrum of the input signal and the arbitrary frequency response of the filter using the the fundamental knowledge provided in the previous chapter.

In the laboratory, the experiment box shown in Figure 5 is used. This box provides card edge connectors for two-port circuits on PC boards to create a multi-stage system. The input signal to the box can be supplied from a function generator or an audio source. The output can be connected to headphones or to an audio speaker. The user can display the signal at various points on the circuit via BNC connectors provided.

In this experiment, an 8^{th} order low-pass filter with a variable cut-off frequency is used to demonstrate the filtering action. An amplifier is used as a second stage allowing the output signal to be applied to an audio speaker. First, filtering of a square wave is demonstrated. By observing the output signal in both time and frequency domains the students can see how the output signal transforms from a square wave with sharp corners to a pure sinusoid as the harmonics are eliminated one by one. The 8^{th} order filter is sharp enough to create a beautiful demonstration of this phenomenon. The filter is then tested with audio signals again observing the signals in both domains. Audio files available on the course web site are used as examples of signals generated by different musical instruments. Students as usual are encouraged to bring their own musical instruments.

Chapter 7: Amplification

This chapter builds on the concepts introduced for filters in the previous chapter. The fact that an amplifier needs an external voltage source to operate is emphasized as a property of real electronic systems. Students learn how to sketch the transfer characteristic of an amplifier given its voltage gain and the power supply voltage. Output clipping is discussed as a form of harmonic distortion. Students use the transfer characteristic of an amplifier to determine the largest input signal that can be amplified without clipping.

In the laboratory, the *two-port circuits* box shown in Figure 6 is used with different amplifier circuits (Figure 7) inserted in the card edge connectors. The experiment includes measurements of the voltage gain, clipping and observing the clipping distortion in both time and frequency domains. The students learn how to compute the total harmonic distortion of an amplifier given the power spectrum resulting from a clipped sinusoidal test waveform. During the experiment, the students observe the waveforms in both time and frequency domains while they listen to the changes in the sound output.

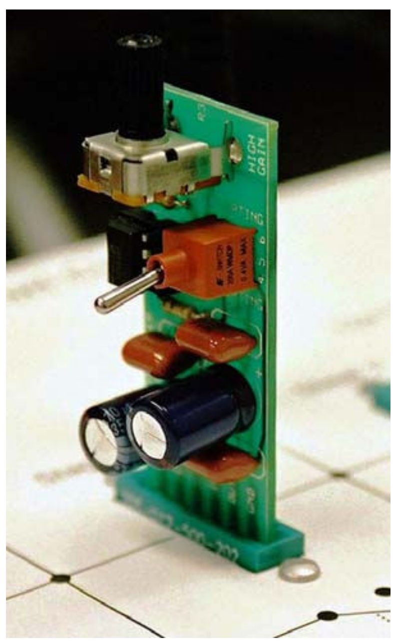

Figure 7: An amplifier with a variable voltage gain.

These experiments are designed to reinforce the power spectrum and Fourier series concepts. For instance, it is emphasized that a clipped sinusoid is a periodic signal, hence, it should have harmonics appearing at multiples of the fundamental frequency.

Chapter 8: Operational Amplifiers

This chapter introduces the students to versatile operational amplifiers, which can be used to realize the filters and amplifiers discussed in the previous two chapters. Students learn how to analyze operational amplifier circuits following standard procedures including the virtual short concept. Examples mostly cover circuits with resistive elements. A few examples of circuits involving capacitors and non-resistive elements (e.g. integrators and differentiators) are also given as examples of signal shaping circuits.

In the laboratory, operational amplifiers are used to amplify signals in two practical applications. In the first experiment, students amplify the signals from an ultrasonic emitter/receive pair. The objective of the experiment is to measure the speed of sound by measuring the time delay between the original and reflected signals. In the second experiment, an operational amplifier is used to amplify the signal from an infrared emitter/detector pair used to measure the speed of a variable speed DC motor. Both the motor and the emitter/detector pair are mounted on a PC board, which can be readily inserted into a card edge connector.

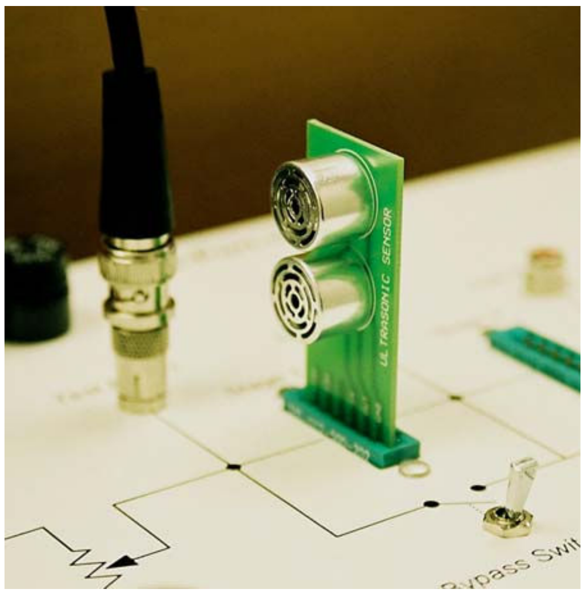

Figure 8: Ultrasound emitter/detector pair.

The applications mentioned above were both taken from a senior level robotics class. We believe that they lead to exciting experiments while demonstrating the versatility of operational amplifiers.

Chapter 9: AM Modulation

In this chapter, signal multiplication is introduced as a new signal processing technique and AM Modulation is discussed as an application of signal multiplication. Again, the AM signals are analyzed in both time and frequency domains. This opportunity is used to introduce a variety of general concepts on transmission and reception of radio frequency signals and talk about communication as a specialization area.

In the laboratory, students create their own radio stations using the AM feature of their function generators. The Agilent™ function generators used in our laboratory can generate a carrier sinusoid, while accepting the modulating signal from an outside voltage source (e.g. an audio source) providing a simple method to construct a transmitter. A loose banana cable is used as the antenna for the transmitters. The range of these transmitters is no more than a few feet allowing many radio stations to function in the same laboratory simultaneously. The transmitted signals are first received by commercial radio receivers and then by students' very own crystal radios. The students' prior knowledge of the half-wave rectifier is used to explain how the envelope detectors (crystal radio) demodulate the AM signals. Shown in Figure 9 is the experiment box used featuring the crystal radio and an amplifier allowing the output signal to be applied to an audio speaker.

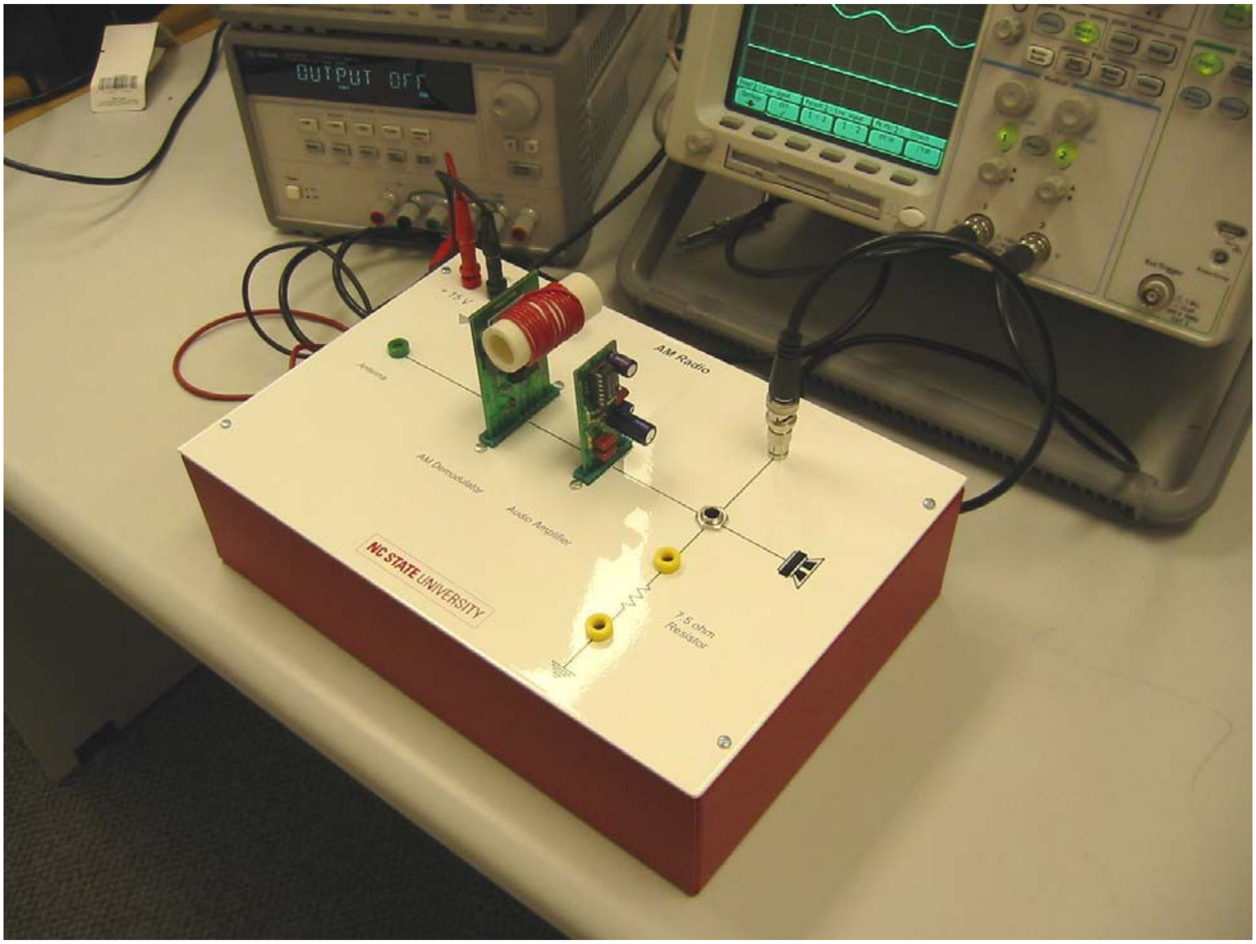

Figure 9: AM Radio box.

Chapter 10: Sampling and Reconstruction

This chapter builds on the concepts introduced in the previous chapter. We use a simple method to teach sampling based on signal multiplication and trigonometry. In the lectures, it is stated that the sampling is equivalent to multiplying an arbitrary signal with a square pulse train with narrow pulse widths. Since the sampling signal can be represented as an infinite sum of sinusoids at multiples of the sampling frequency, we can view the sampling process as multiplying the original signal with each harmonic of the square wave one by one. Since each multiplication results in sum and difference frequencies, the original spectrum and its mirror image is repeated at multiples of the sampling frequency. Since the original square wave also has a non-zero average value, it produces a smaller replica of the original spectrum without changing the frequencies of the original harmonics. Reconstruction is achieved by low-pass filtering to eliminate all the higher frequency doubles except the replica of the original spectrum.

This chapter provides ample opportunity to discuss various specialization areas including digital communications, digital signal processing and electronic circuits. The chapter also provides an exciting medium for applying a large variety of concepts introduced in the course to practical systems such as CD players.

In the laboratory, a dedicated experiment box is used, which accepts different components of the sampling and reconstruction system on PC boards. These include two low-pass filters with variable cut-off frequencies, analog switch for sampling, a 555 timer circuit generating the clock signal to derive the analog switch and an amplifier. The students can change the sampling rate as well as the cut-off frequency of the low-pass reconstruction filter and listen to the effects of these changes on the produced sound.

VIRTUAL LABORATORY

The virtual laboratory was created to support the experience gained in the hardware laboratory. Our assessment studies revealed that it took several weeks before the students could feel themselves comfortable with many features of their oscilloscopes. Clearly, we needed more than a 3-hour laboratory period during the early stages, which was impossible to fit into students' schedules. Our solution to this challenge was to create the virtual laboratory consisting of a series of Java applets simulating the test instruments connected to different systems. Figure 10 shows the home page of the virtual lab, which is open to all users around the world. By clicking on the buttons provided on this page, the user can start different applets, which make use of the same software engines for the test instruments.

An example is given in Figure 11, which provides the user a Butterworth low-pass filter. The filtered signal is displayed by the oscilloscope in time domain and by the spectrum analyzer in the frequency domain. The virtual instruments provide the same fundamental controls found on all test standard test equipment. The user can change the cut-off frequency of the filter and change the filter order.

In this course, the virtual laboratory is primarily used in homework assignments. Using this approach, creative homework questions can be generated, which resemble the same steps followed in the hardware laboratory. This not only increases the students' exposure to the test equipment but provides the students an excellent opportunity to create their own experiments in their own time, which ultimately helps them understand the fundamental concepts better.

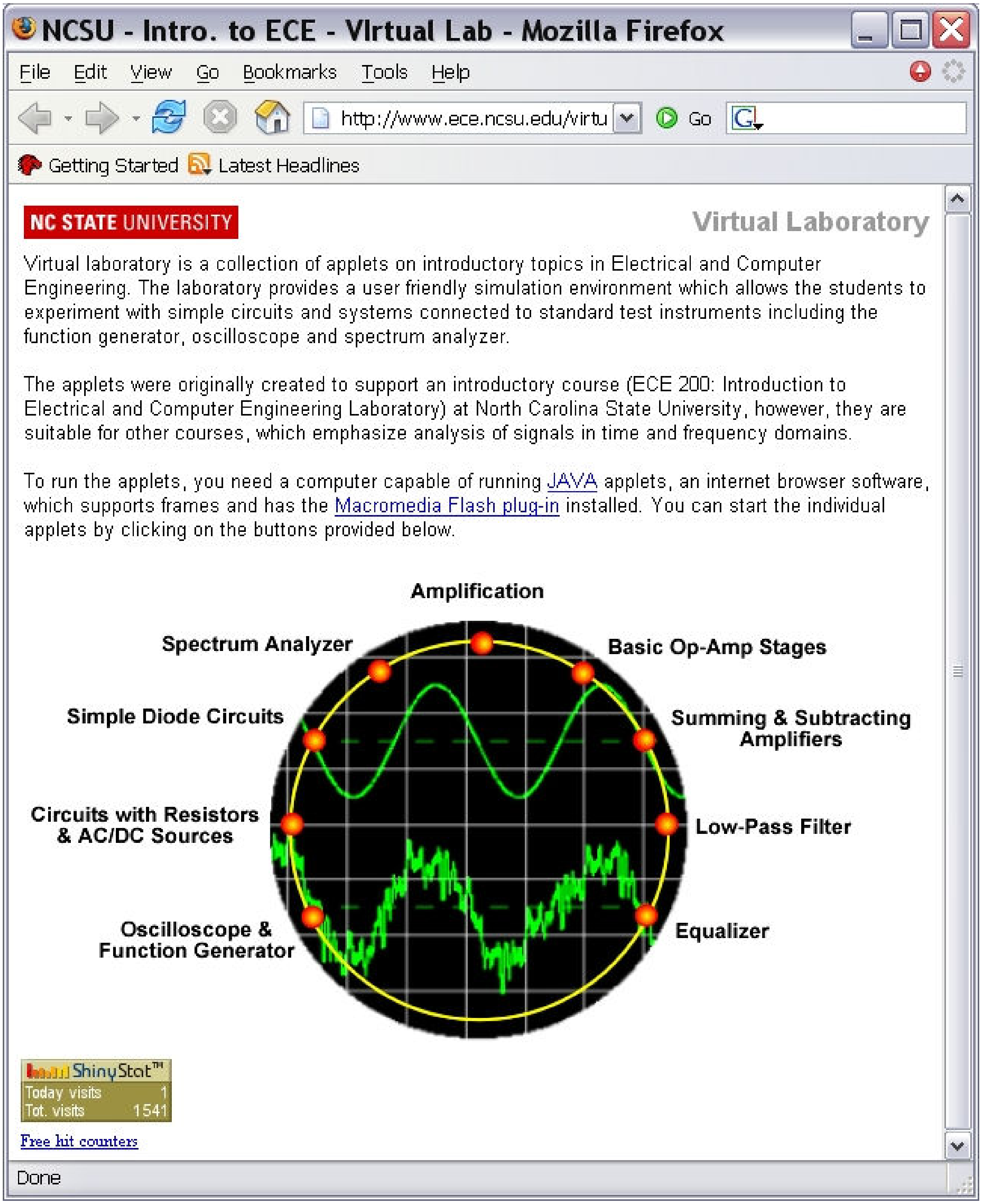

Figure 10: Front page of the virtual lab. URL: http://www.ece.ncsu.edu/virtuallab/virtuallab.htm

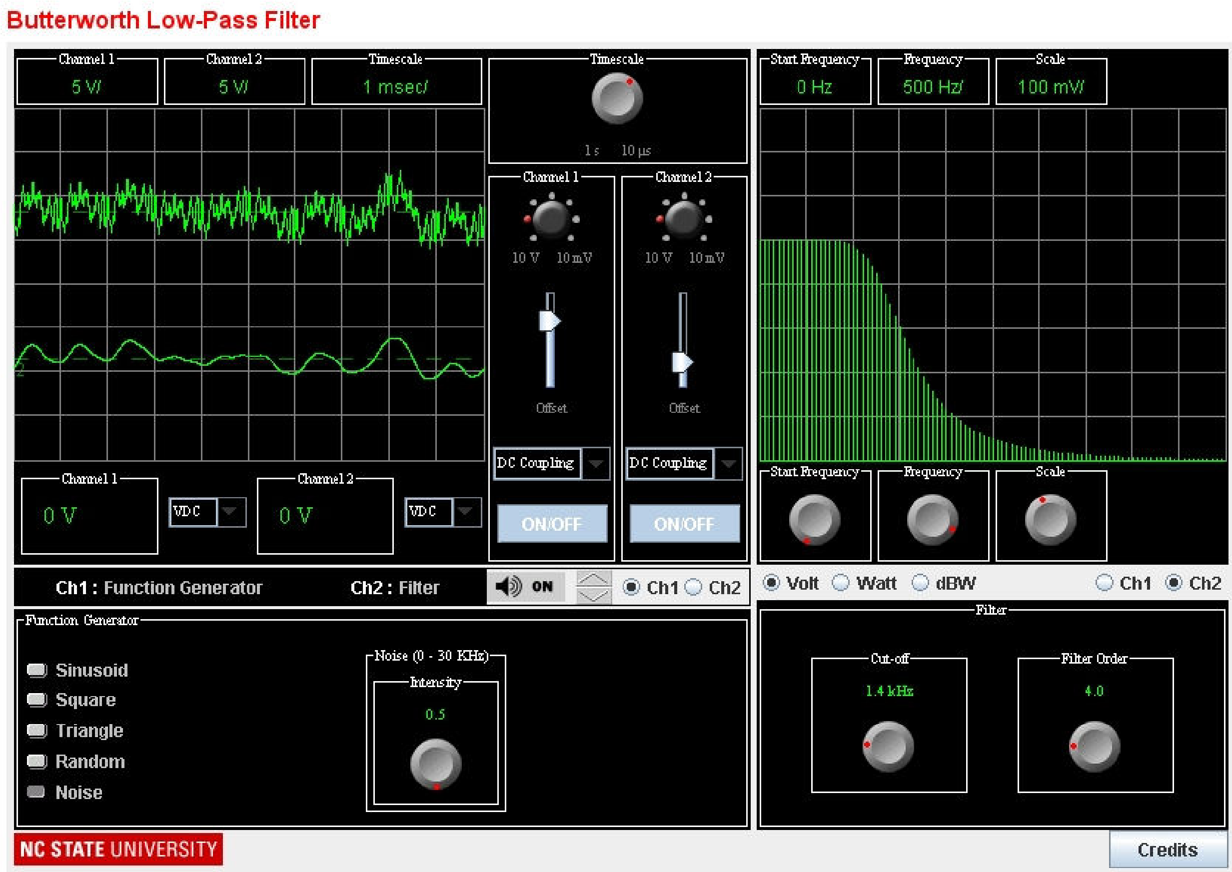

Figure 11: Butterworth Filter simulation from the virtual laboratory.

HARDWARE PROJECT

In addition to the regular weekly experiments, the students work on a mandatory hardware project, which involves construction of the power supply shown in Figure 12. This project was initiated as a result of the input from senior exit surveys, which indicated that we had a gap in our curriculum. Basically, the survey results showed our students wished they had the opportunity to work on a hardware project long before they began to work on their senior design projects. The hardware project was first tried as an optional project in Spring 2004. Based on the strong positive feedback from the students, it became a mandatory project during the following semester.

The objectives of the project are:

1) To teach how-to use breadboards for testing electronic circuits.
2) To teach soldering and principles of constructing circuits on printed circuit boards.
3) To provide the experience of working on a hardware project.

During the semester, the project follows a detailed weekly plan. The students are given the list of components and asked to acquire them from local or online distributors. In the laboratory, the power supply circuit is constructed and tested in several stages. The project begins with testing of the first stage, i.e., the full-wave rectifier circuit. This is followed by characterization of the circuit with the filter capacitor during the following week. Finally, the electronic regulator is added and the complete circuit is fully tested on breadboards. Then, the circuit is transferred to a pre-drilled printed circuit board. During this step, majority of the students learn how to do soldering for the first time. Finally, the PC board is installed in a project enclosure complete with components on the front panel. The laboratory provides a drill press for drilling holes on the project box.

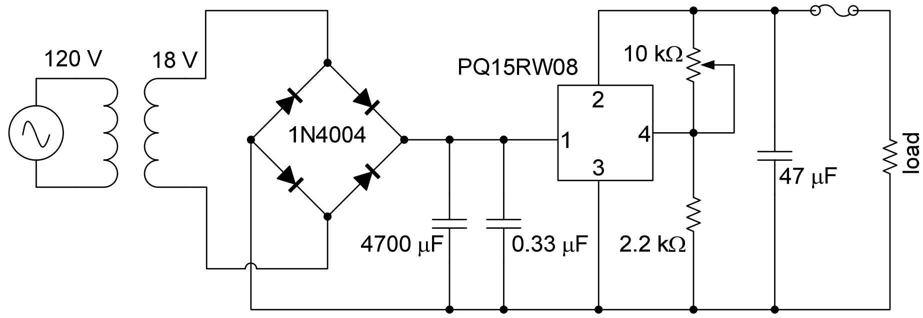

Figure 12: Circuit diagram for the mandatory hardware project.

The feedback from the students is extremely positive. We have found that the students think that the hardware project is just as important as the regular experiments performed during the semester. Majority of the students take pride in their creations greatly influencing their participation in the project.

GOLDEN SOLDER PROJECT

Golden solder project was created to provide an opportunity for our students to be creative and apply their knowledge to produce the hardware of their choice. The participating students are expected to either design their own circuit or find them from the literature. Complex projects, which can not be understood based on the knowledge provided in the course are not allowed. At the end of the semester, students demonstrate their projects in front of the class after which the entire class votes to choose the winner, who is given a golden soldering iron. The pictures from the competition are displayed on the departmental web site as a source of motivation for other students. In our experience, a variety of circuits employing operational amplifiers were most frequently used for applications such as guitar distortion pedal and karaoke machine. An exciting project from the past semester is given below as a good example of these projects.

In the Fall 2005 semester, our Golden Solder Competition winner designed and built a "Magnetic Coil Projectile Launcher". This impressive project clearly applied the basic circuit principles that we covered in the laboratory experiments and lectures, and even involved some self-study. As you can see in the Figure 13, the launcher operated by storing a large amount of charge in a large bank of capacitors that is subsequently discharged into large inductor. The large stored electrical energy then becomes a strong magnetic field in the center of the coil, which is capable of forcefully launching a projectile (e.g. iron rod) situated inside. In his class demonstration, he "shot" a nail easily through a soda can without even bending it. The student built his own AC/DC charging circuit based on a full- wave rectifier (similar to our hardware project), designed his own fail-safe and activation circuits, and constructed the rigid frame. He based his design on physics demonstration resources he was aware of, and he acquired most of his components (especially the large capacitance, high voltage capacitors) from surplus. Throughout the project, he was naturally concerned with safety, and consulted both the class instructor and other support staff.

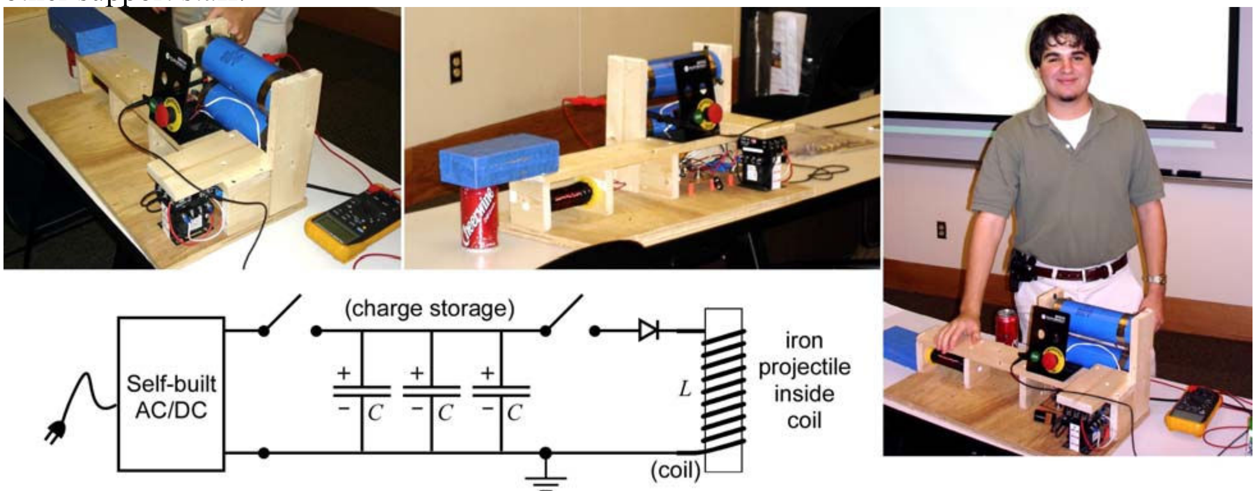

Figure 13. Winner of the Fall 2005 golden solder competition

CONCLUSIONS

After a long journey, we feel that the course has finally reached a maturity level to offer an exciting alternative to traditional introductory courses on electrical and computer engineering. As a result of the changes described in this paper, the student evaluations for the course and the instructors have greatly improved surpassing the departmental averages, which is unusual for an introductory course, at least in our department.

We believe that the students completing this course gain valuable knowledge on a host of fundamental concepts and apply them to exciting real-life applications in a novel hardware laboratory. Even though the course no longer provides a comprehensive coverage of all specialization areas, it provides a good general feeling about the profession.

The lectures and experiments are supported by a virtual laboratory consisting of Java applets, which the students can use in their own time. The applets are used in homework assignments to reinforce the concepts introduced in the laboratory. A mandatory hardware project and an optional golden project provide the first experiences on working on a hardware project. We believe that this is a very important aspect of the course because unlike their professors, very few of our students enter the ECE profession as hobbyists, which we believe is unfortunate.

The instructors are currently working on publishing the textbook. Institutions interested in using the laboratory hardware can already purchase the experiment boxes at a moderate cost from a non-profit organization employing disabled people. Interested institutions should contact the principal author of this paper for the necessary contact information. The virtual laboratory is available online for general use without any restrictions for outside users.

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