

A New Introductory Laboratory Course for Electrical and Computer Engineering

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Abstract

A new Electrical and Computer Engineering (ECE) curriculum was recently adapted at North Carolina State University, ECE Department. In this curriculum, students choose their specialization areas starting from the second semester of the junior year. The system is carefully designed to ensure that students acquire both breadth and depth in their studies. The flagship of this curriculum is a new laboratory course, which the students take during the first semester after the first year common to all engineering students. The objectives of the new laboratory are: i) To introduce different ECE specialization areas to encourage students to start thinking about which specialization areas appeal more to them ii) To motivate the students through practical, hands-on experiments connected to real-life applications iii) To teach fundamental concepts and basic laboratory skills. In this laboratory, students learn to use standard ECE laboratory equipment including power supply, multimeter, function generator, and oscilloscope and spectrum analyzer. The laboratory relies on dedicated hardware in the form experiment boxes specifically designed for the laboratory. The dedicated hardware allows the students to perform experiments on advanced yet practical and exciting applications. To accompany the laboratory a textbook was written by representatives of different specialization areas in our department. In this paper, we present an overview of the course contents and the hardware developed for the laboratory.

Introduction

During the last three decades, the scope of electrical and computer engineering (ECE) has widened dramatically largely due to advances in digital technology and computers. The ECE educators responded to this continuous expansion by modifying their core courses and introducing new electives. In recent years however, it became clear that it would no longer be possible to maintain a modern ECE curriculum by adding a course or two when the need arrived. The changes prompted the ECE departments to consider innovative ideas in curricula design. The new curricula often included introductory courses, which were fundamentally different than traditional first courses on electric circuits. The new courses focused on ‘what’ to teach instead of ‘how’ to teach. In the following paragraphs, we provide examples from these new courses with brief descriptions of their objectives and contents.

A sophomore level course was developed in the Electrical and Computer Engineering Department of the Rice University¹. Guided by the breadth-first principle, the new introductory course was designed to provide information on virtually all topics that the students would learn throughout their undergraduate education. The course was also intended to help the students understand what to expect from future advanced courses and eliminate the surprise factor. The course was designed as a two-semester sequence and included diverse concepts such as signals in time and frequency domains, modulation, A/D conversion, semiconductor devices and computer networking, which are definitely not included in traditional introductory circuits courses. The course was also supported by a hands-on laboratory, which emphasized tools such as the spectrum analyzer and distortion analyzer.

Another similar course is a freshmen level course developed at Carnegie Mellon University². The fundamental concept behind this course is to develop an intellectually stimulating laboratory course that can be taught during the first year by carefully selecting a set of topics that do not require any more than standard high school algebra and physics. This course too covered a broad range of ECE topics while providing fundamentals concepts such as Kirchoff’s laws and superposition.

A third is a laboratory course developed at Penn State University³, which used components of a compact disc player to unify and motivate lecture topics and modular lab assignments throughout the semester. Similar to the examples given above, the course included non-linear circuit elements as well as higher level concepts such as amplification of signals and D/A conversion.

Other examples of similar courses include those developed at University of Illinois⁴ and Santa Clara University⁵. The common thread between these new courses is a distinct departure from an introductory course on electric circuits limited to analysis of RLC circuits. Instead, the new courses span a wide range of topics with emphasis on experiments that connect the fundamental concepts to real life applications.

In this paper, we present a similar course developed at North Carolina State University for Electrical and Computer Engineering sophomores. The course shares the fundamental philosophy

of the courses described above. Application oriented experiments are used to introduce fundamental concepts while providing the students an overview of Electrical and Computer Engineering.

Objectives and the Structure of the New Course

A new Electrical and Computer Engineering curriculum was recently developed at North Carolina State University. In this curriculum, the students matriculate into the ECE department as sophomores after successfully completing the requirements of a first year common to all engineering students. The students continue taking core courses until the second semester of their junior year, when they begin choosing their electives from different specialization areas.

The first step in the new curriculum is a new core course entitled ‘Introduction to Electrical and Computer Engineering Laboratory’ created by a team of eight faculty members from the ECE Department at North Carolina State University. The course was offered for the first time in fall 2000. Since then, we have been regularly teaching the course every semester including summer.

The objectives of the course are:

1. To provide an overview of ECE specialization areas to help students find topics that excite them and choose their specialization areas accordingly.
2. To motivate the students through innovative experiments connected to real-life applications.
3. To introduce fundamental concepts through hands-on experiments in a state-of-the-art hardware laboratory.
4. To provide fundamental skills for using standard measurement tools.

Throughout the course, the students are exposed to concepts such as analysis of signals in time and frequency domain, amplification of signals, modulation for RF transmission and reception, sampling and reconstruction, semiconductor devices, IC fabrication and logic gates, which are not included in traditional introductory level courses on “electric circuits”.

In the laboratory, each lab station is equipped with a multimeter, a power supply, a function generator an oscilloscope and a desktop personal computer. The oscilloscope has the Fast Fourier Transform (FFT) capability, which allows the students to display their signals in both time and frequency domains. The desktop computer serves a variety of functions, which include a) accessing the online course material such as recorded sounds of different musical instruments, b) generating high fidelity music signals using the internal CD player b) storing the oscilloscope displays to image files and c) creating the first drafts of the lab reports.

Experiments rely on dedicated hardware designed and manufactured at North Carolina State University which allows the students to approach applications at a systems level. The hardware is designed to minimize experimental errors providing the students more time to focus on the

concepts instead of broken or missing wires on their breadboards.

The course consists of two seventy five minute lectures and a three hour laboratory every week. The hardware laboratory features eleven work stations. Each laboratory session can accommodate a maximum of twenty two students in groups of two. The lectures are given by the professors and the laboratory sessions are taught by graduate students.

A new textbook was created realizing that it would be very difficult to adopt an existing text for the course. The chapters were written by faculty members representing different specialization areas. Chapters include step-by-step instructions to run the experiments. The first five chapters provide the foundation for future chapters. The remaining chapters introduce different specialization areas including electronic circuits, radio frequency communication, digital signal processing, solid-state electronics, digital circuits and computer networking.

Laboratory Experiments and Dedicated Hardware

The laboratory consists of ten experiments utilizing the dedicated hardware and two experiments based on computer simulations. A brief description of each chapter and its experiment is provided in the following paragraphs.

Resistive Circuits

In this section, the students are introduced to DC voltage sources, linear and non-linear resistive elements, Ohm's law, Kirchoff's voltage and current laws. Students learn about the properties of linear and non-linear circuit elements including resistors, photocells, diodes and light emitting diodes.

In the laboratory, a practical circuit featuring a photocell and a light emitting diode (LED) is used to demonstrate Kirchoff's voltage and current laws. The circuit, shown in Figure 1 functions similar to a night-light, which turns on the LED when the ambient light is not sufficient.

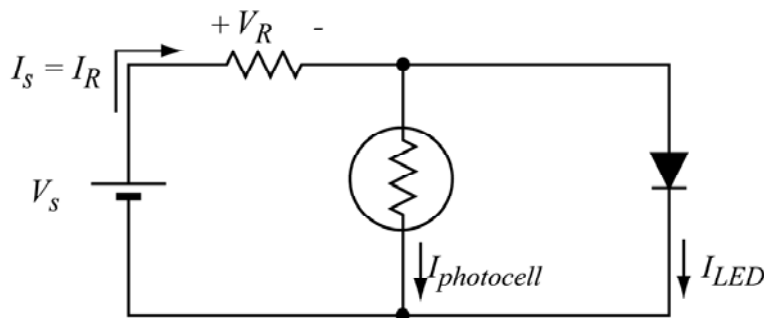


Figure 1 Night-Light circuit used in the first experiment. When the ambient light is low, the photocell resistance increases and its current decreases. This results in a larger current flow through the LED, which turns it on.

The experiment box used in this first experiment is shown in Figure 2. The box consists of banana jacks designed to create simple circuits with a few series and parallel branches. Individual components are mounted on small printed circuit boards with banana plugs as shown in Figure 3 for easy circuit assembly. Breadboards are intentionally avoided to simplify circuit construction and minimize errors during a three-hour laboratory period. In this experiment, students learn how to use the multimeter to measure voltage, current and resistance.

Periodic Signals in Time Domain

In this section, students learn about the properties of sinusoidal and other periodic signals. Fundamental concepts such as frequency, period, phase, duty cycle and DC value are introduced. The circuit laws learned in the previous experiment are applied to circuits with AC voltage sources.

In the laboratory, students learn to use the oscilloscope. A half wave rectifier is used to demonstrate rectification and its effect on the DC value of a periodic signal. Experiment box shown in Figure 2 is used with different circuit elements to construct the half-wave rectifier. Students understand that this is the first step of AC-to-DC conversion in power supplies. In the second part of the experiment, more complex signals are observed on the oscilloscope including voice signals from a microphone and music from the CD player of their desktop computer.

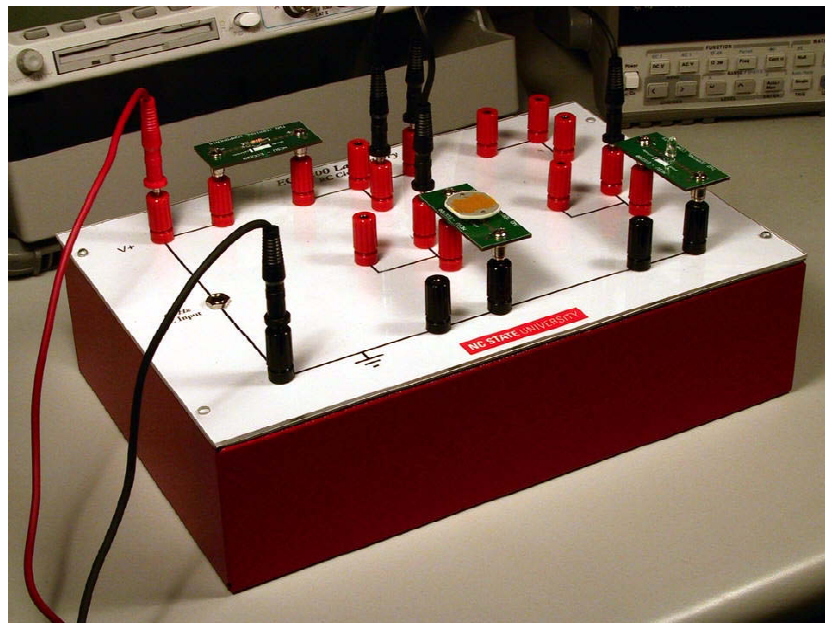


Figure 2 Experiment box used for the first four experiments. Two-terminal circuit elements are mounted on PC boards with banana connectors. Simple circuits with two loops can be easily assembled using the banana jacks on the front panel.

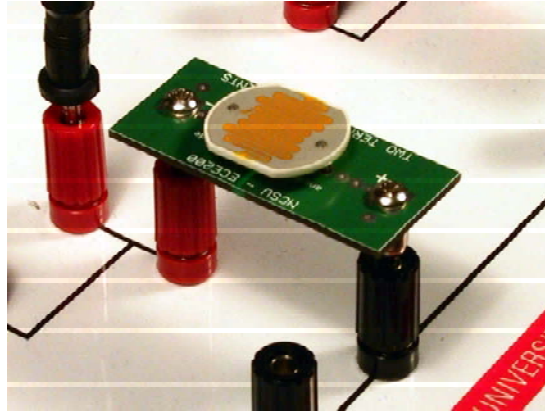


Figure 3 Two terminal elements are mounted on individual PC boards with banana plugs. Shown in the figure is a photocell used in the first experiment.

Capacitors and RC Circuits

In this section, the capacitor is introduced as a new passive circuit element. Circuit laws are used to understand capacitor charging and discharging in simple RC circuits. Examples of simple circuits with resistors, capacitors and diodes are given.

In the laboratory, students experiment with an analog timer and learn about capacitor charging and RC time constant. The circuit diagram of the timer is shown in Figure 4. When the switch short-circuiting the capacitor is opened, the capacitor starts charging through the resistor. The LED lights up when the capacitor voltage reaches the LED turn-on voltage. Students perform the experiment with different capacitors. In the second part of the experiment, a capacitor is added to the half-wave rectifier circuit of the previous experiment and its effect on the DC (average) value of the output voltage is measured.

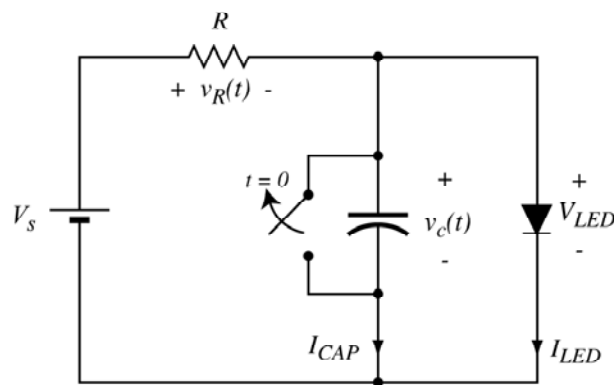


Figure 4 Timer circuit used to demonstrate capacitor charging and RC time constant. LED lights up when the capacitor voltage reached the LED turn-on voltage.

Electric Power

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In this section, students are introduced to concepts such as real power, apparent power and power factor. The phase concept introduced in previous experiments is revisited.

In the laboratory, a dedicated experiment box with a commercial dimmer is used to control the power consumed by an electric lamp. The hardware is shown in Figure 5. The load current is measured by a Hall Effect probe, which clamps onto an insulated wire. Students observe load voltage and current signals, find the instantaneous power by multiplying the two signals and then find the real power by finding the average value of this signal. For safety, the oscilloscope probes are plugged into the standard AC outlets on the experiment board. The probes also feature a 100:1 voltage division. In this experiment, students learn new oscilloscope features such as signal multiplication. In the second part of the experiment, the experiment is repeated with an electric fan equipped with an AC motor. The difference is the phase angle between voltage and current signals due to the inductive nature of the motor.

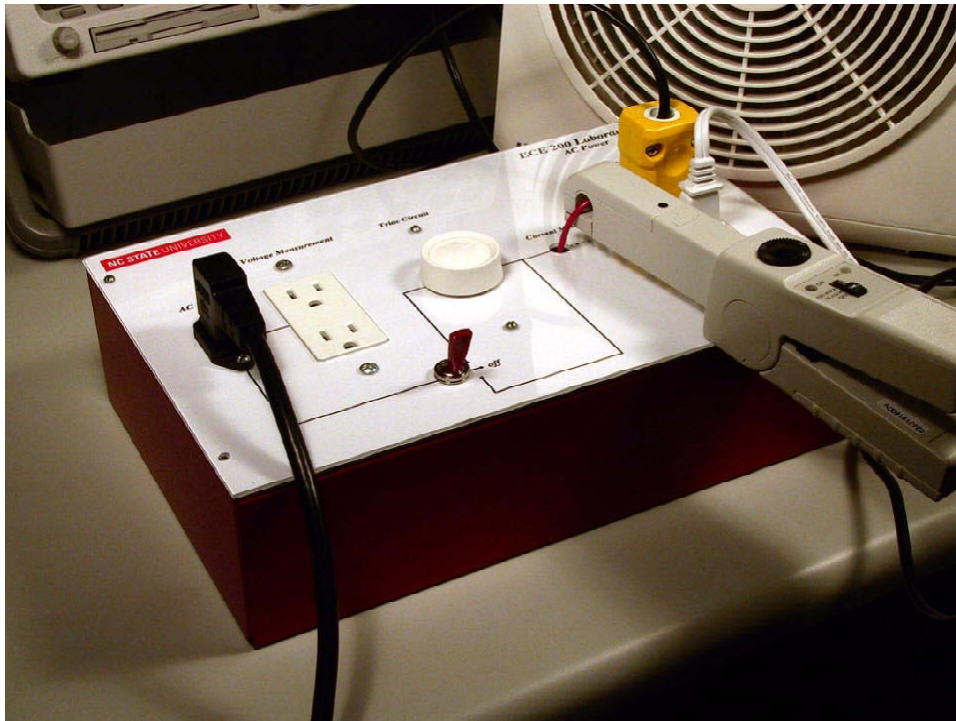


Figure 5 In Experiment 4, a commercial dimmer is used to adjust the speed of an AC motor. The motor voltage and current signals are observed on an oscilloscope. The motor current is measured by a Hall Effect probe as shown in the figure.

Periodic Signals in Frequency Domain

In this section, periodic signals are analyzed in frequency domain. Phase and magnitude spectra of different periodic signals are demonstrated with examples. Fourier series representation of periodic signals is introduced at an elementary level with examples that demonstrate how a series of sinusoids can make up a complex periodic signal.

In the laboratory, students learn to use the function generator and Fast Fourier Transform (FFT) capability of their oscilloscopes, which provides the capability to display periodic signals in time and frequency domains simultaneously. Electrical signals from a microphone, recordings of different musical instruments and a CD player are studied. The students are encouraged to bring their own musical instruments to analyze their sound output in frequency domain.

Signal Amplification

In this section, students are exposed to new concepts such as “two-port circuits”, “transfer characteristic” and “signal amplification”. Students learn how to determine the output signal of an amplifier given the input signal and its transfer characteristic. The Metal Oxide Silicon Field Effect Transistor is introduced at an elementary level. The transfer characteristic of a common-source amplifier is introduced emphasizing the non-linearity of the transfer characteristic and its impact on the output signal. In the laboratory, students experiment with a 3-stage amplifier. The dedicated experiment box for this experiment is shown in Figure 6, which can be used to create a three-stage amplifier consisting of two common-source amplifier stages and a unity gain power amplifier stage. Individual amplifier stages are built on printed circuit boards, which can be inserted in the card edge connectors on the experiment box. In the laboratory, students are exposed to the concepts of voltage gain, clipping, harmonic distortion and frequency response. The experiment reinforces the advantages of analyzing signals in frequency domain.

Radio Fundamentals

In this section, the fundamentals of radio frequency signal transmission and reception are introduced. Amplitude Modulation is used as a simple example to illustrate the concept of signal modulation. Students learn the components of a simple radio receiver including the antenna, the resonance circuit and the demodulator.

In the laboratory, students use the modulation feature of their function generators to create short-range transmitters. Students broadcast music from their CD players. The signals are received by a commercial radio as well as simple radio constructed on a dedicated experiment board shown in Figure 7. The printed circuit boards shown on the board are the demodulator and the audio amplifier. The demodulator circuit features an LC resonant circuit, RF amplifier and a diode envelope detector. The experiment begins by winding the inductor for the radio. The concept of “envelope detection” is explained relying on students’ prior knowledge on half-wave rectification.



Figure 6 The experiment box used for Experiment 6 is a three-stage microphone amplifier consisting of two common-source MOSFET amplifier stages and a unity gain power amplifier stage. Students can easily monitor the signals at different stages of the amplifier using the connectors on the front panel of the experiment box.

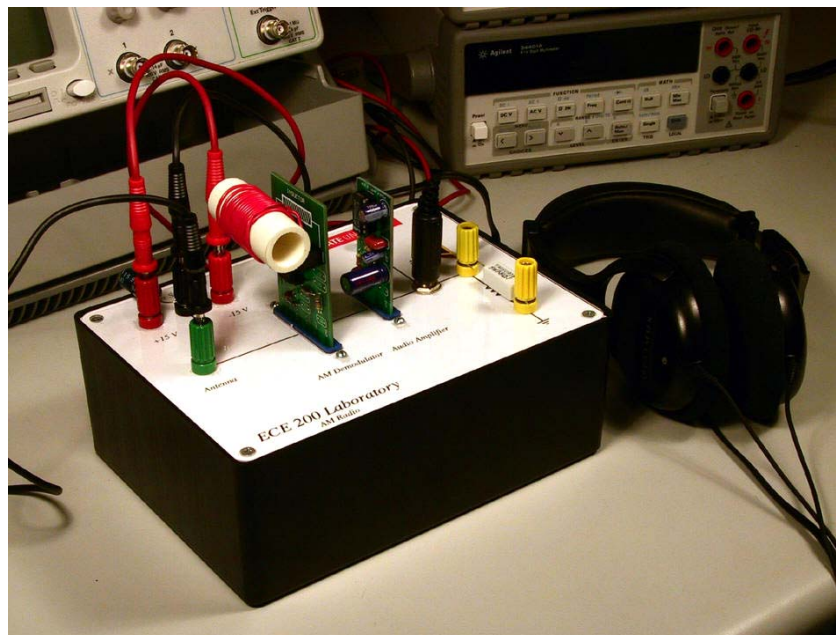


Figure 7 In the experiment for Radio Fundamentals students use a transmitter and a receiver. Shown above is the AM radio consisting of a simple envelope detector (crystal radio) for demodulation followed by a Sampling and Reconstruction

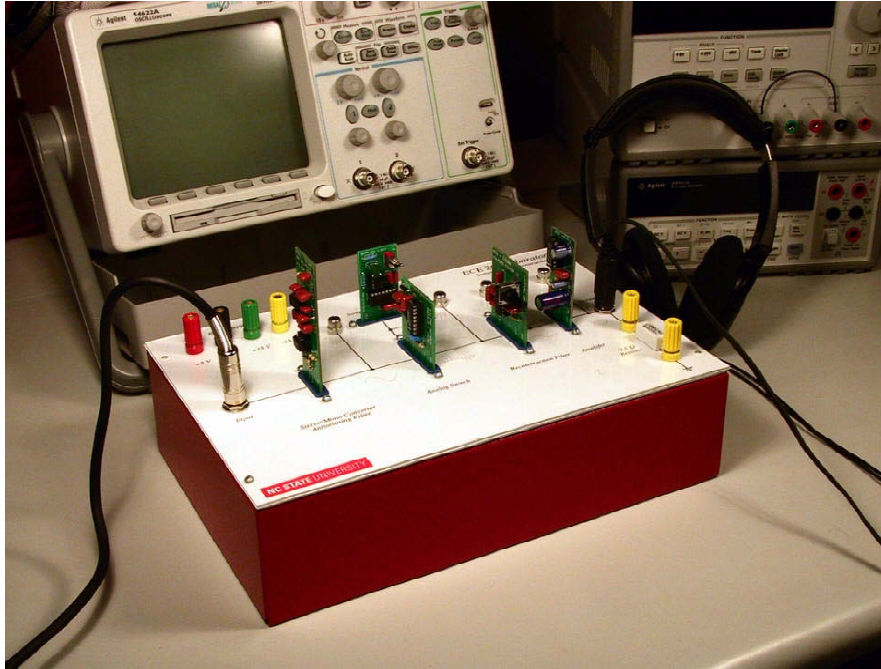


Figure 8 Experiment box designed for digital signal processing combines all essential functions for sampling and reconstruction on a single front panel. Students can easily monitor signals at different nodes using the connectors on the front panel.

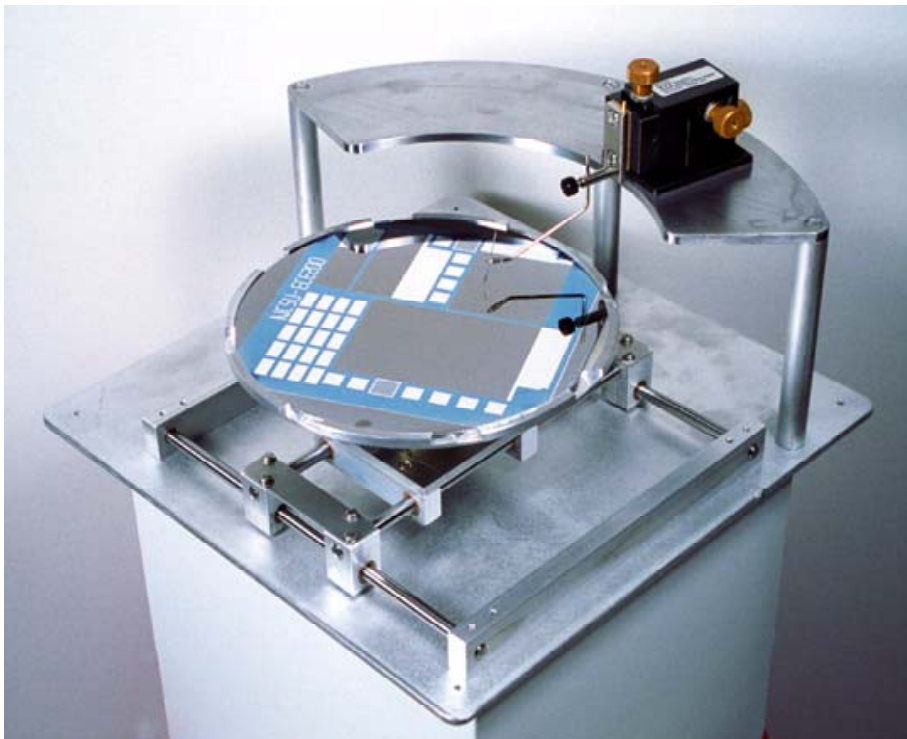


Figure 9 Semiconductor probe station used shared by two students to probe ECE200 wafers containing diodes and solar cells.

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Sampling and Reconstruction

This section begins with an overview of digital signal processing with examples from practical applications. This is followed by the concept of ‘sampling of analog signals’ as the first step of the analog-to-digital conversion. Sampling is introduced at an elemental level sufficient to explain the location of different peaks in the sampled signal spectra. In the laboratory, students use the dedicated experiment box shown in Figure 8. The essential blocks of the sampling-reconstruction process are constructed on individual printed circuit boards. The system consists of an antialiasing filter with a fixed bandwidth, a sampling clock which provides two sampling frequencies selectable by a toggle switch, an analog switch and a low-pass reconstruction filter with a continuously variable cut-off frequency.

In the laboratory, the students can observe the sampling and reconstruction processes in both time and frequency domains using signals from the function generator. In the second part of the section, music signals are used to demonstrate the impact of sampling rate and the filter cut-off frequency on the quality of the sound output.

Solid State Electronics

This section provides an overview of semiconductors and introduction to devices and fabrication. Topics include electrons and holes, current conduction, semiconductor doping, pn-junctions and solar cells.

In the laboratory, students probe 6” Si wafers containing PN junction diodes and solar cells fabricated at the NC State University microelectronics facility. Figure 9 shows the probe station and the silicon wafer used in the experiment. The probe station was also designed and manufactured at NC State University. Large metal pads used on the wafer eliminates the need for an expensive microscope.

Digital Logic Gates

In this section, an introduction to digital logic gates and logic truth tables is given with simple logic circuits consisting of AND, NAND, OR, NOR and NOT gates. Relying on the background knowledge on transistors and semiconductors from previous sections, students learn how to construct logic gates from individual transistors.

In the laboratory, students use the dedicated box shown in Figure 10, which allows construction of the basic gates using individual transistors mounted on small PC boards with banana connectors shown in Figure 11. The experiment box provides switches and light emitting diodes to manually create truth tables. The box also allows application of a square wave from the function generator. The students use this feature to test the ultimate speed of their logic gates, which they can relate to their everyday terminology used to describe the speed of personal computers.

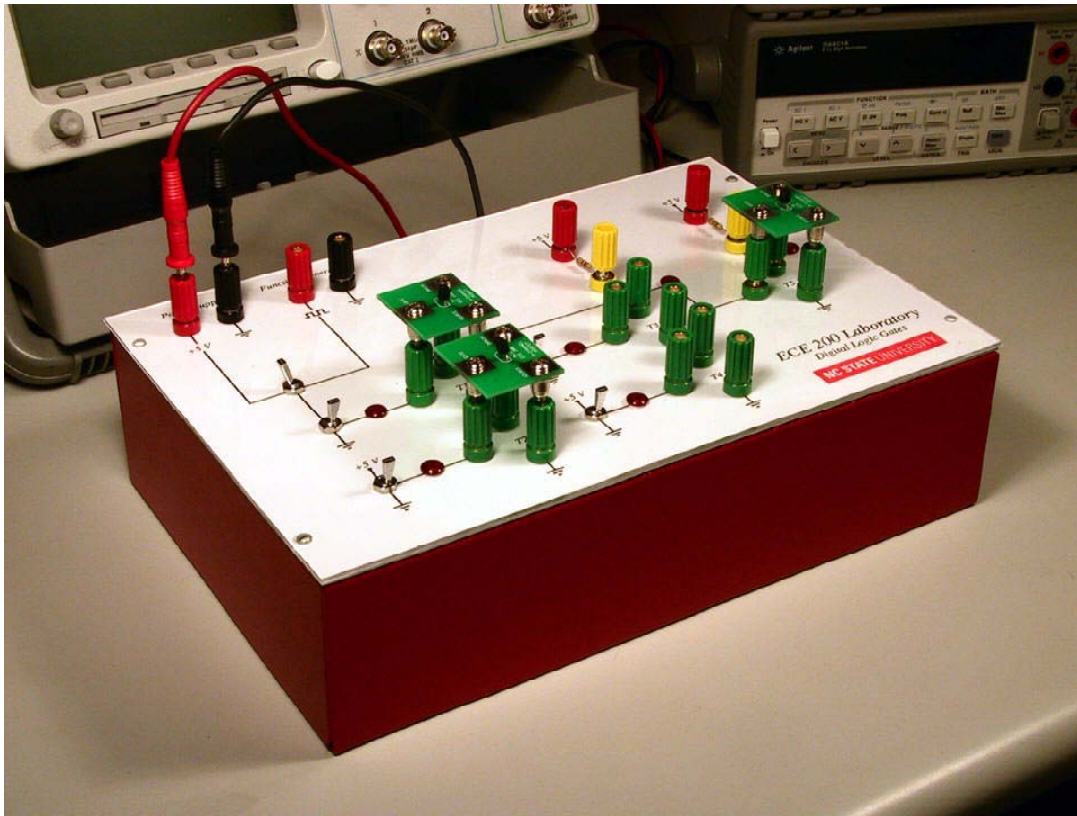


Figure 10 The experiment box for digital logic gates makes use of MOSFETs mounted on PC boards with banana connectors. Using the transistors, simple logic gates including AND, NAND, OR, NOR can be easily assembled.

Cache Memories

This section reviews computer engineering in general. Cache memory operation is introduced as practical yet simple example of computer engineering. In the laboratory, students use a simulation package for cache memory operation. The simulation is written as a JAVA applet, which can be accessed with a browser.

Computer Networking

This section provides an overview of computer networking defining key concepts at an elementary level. In the laboratory, students measure networking delays occurring between their workstations and other computers on the World Wide Web.

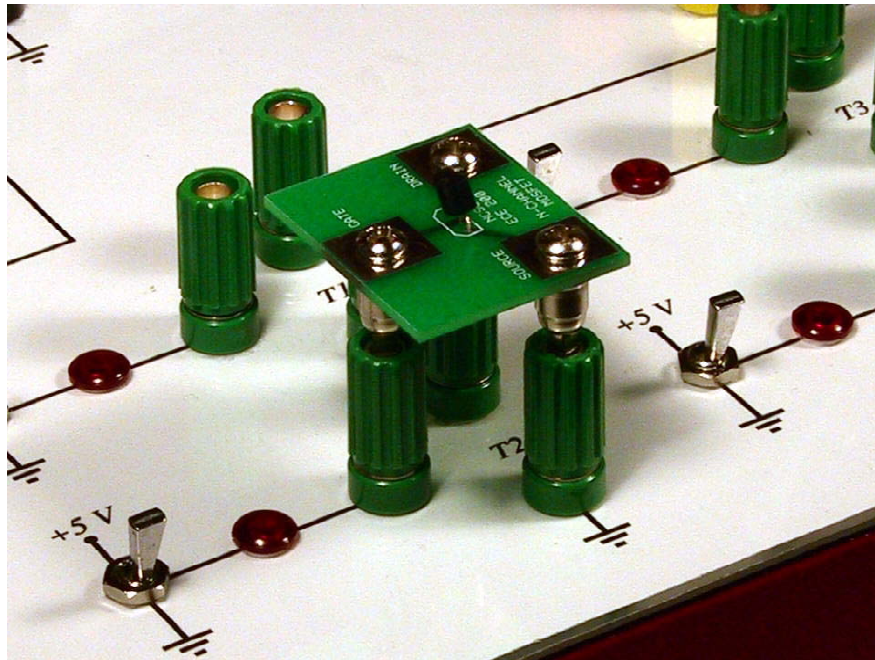


Figure 11 Each transistor is mounted on a small PC board with three banana connectors. Also shown in the figure is the input switch used to select 0 or 5 V. Between the switch and the transistor is an LED used as state indicator.

Virtual Laboratory

JAVA applets have recently provided a very effective means to simulate the laboratory environment on personal computers. The advantage of this approach is clearly the ability to run the programs on any personal computer with a web browser such as Netscape™ or Internet Explorer™. Several successful examples of these educational efforts in electrical and computer engineering can be found on the World Wide Web.

While the existing course material has been designed for a hardware laboratory, we believe that a virtual laboratory environment will significantly enhance the effectiveness of the course for the following reasons:

1. It will bring the laboratory environment to homework problems allowing creation of exciting homework assignments.
2. It will allow students to experiment with alternative circuits after completing the experiment in the hardware laboratory.
3. It will allow electrical and computer engineering departments who are unable to afford the hardware to adopt the course via online experiments.
4. It will provide other institutions to evaluate the textbook and the experiments before

they commit themselves to acquiring the hardware.

We are currently in the process of writing Java applets to create a ‘virtual laboratory’ .

Dissemination of the Course Materials

The laboratory course presented in this paper is currently sponsored by National Science Foundation (NSF). One of the goals of this program is to make the course materials available to other educational institutions in the country. We are working on two parallel paths to achieve this goal. The first path involves construction of a web site, which will provide detailed instructions to create the hardware. The alternative route we are working on involves an outside company to make the hardware available for purchase to institutions that do not want to manufacture their own hardware.

Acknowledgements

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