An EET Program's Innovative First-Semester Course in Electricity/Electronics

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Abstract

The EET faculty found in recent years that a large proportion of students entering our four-year baccalaureate programs in electronic, audio and music production technology had little background in technical aspects of electricity and electronics. Without this kind of experience, they appeared to lack the motivation to do well in the fundamentals courses (DC and AC circuit analysis, solid-state devices) which must be taken before students get to the "fun" courses involving amplifiers, oscillators, filters, etc. As a result, excessive time was needed in the fundamentals courses to cover basics, which resulted in some course topics either not being presented or learned adequately to promote success in more advanced courses. This problem was addressed by the creation of a new first-semester course, designed to give students some knowledge, some familiarity with terms and units, and a lot of motivation. An added benefit is that during their first semester students finish the first of four required math classes, so that they have mastered mathematical topics (e.g. simultaneous linear equations, logarithmic and exponential equations) before they are needed in the technical fundamentals courses which begin in the second semester. We also feel that retention will be improved because of both heightened student interest in the major and improved mathematical skills when the technical courses are taken. A description of this new course, including a detailed syllabus and examples of innovative laboratory experiences created for this course, are presented. The experiments are available, in PDF (Adobe Portable Document Format) at http://uhavax.hartford.edu/~banz

I. Introduction

There is a growing awareness by faculty nationwide that students now entering technical disciplines lack the practical experience and technological literacy which students once had[1,2], and our own classroom experiences at Ward College of Technology of the University of Hartford supported this perception. An EET faculty member at Old Dominion University[3] "Strongly believes that students must make the connection between theory and application, and he finds that students understand theory best when it is applied to examples of technology that interest them, such as automobiles, computers, and electronic entertainment equipment." An incoming survey of our first-year students revealed that few had ever soldered, used (or owned) a digital multimeter, or knew what a speaker impedance of 8 Ω meant (or why putting three such speakers in parallel could destroy an amplifier). We decided to address this problem by creating a new lecture/laboratory course to give students a hands-on exposure to and familiarity with electricity and electronics. The goal was to give our new students a practical background in the discipline (the fun and excitement that comes from building and using circuits) by giving them some knowledge, some familiarity with terms and units, and (we hope) a lot of motivation and interest in their field of study.

This new course serves both students majoring in Electronic Engineering Technology (EET), related majors whose students take EET courses (audio engineering technology and music production technology) and any other student at the University. For those in EET, audio and music production, the lecture and laboratory content provide insight into the discipline they are entering; this helps to keep them keep motivated in some of the less than exciting fundamentals courses that follow. Resistors, as devices, are simply not exciting; motors are, LEDs are, speakers (out of an enclosure) are, audio oscillators are, relays are, and solenoids are. Every student gets shocked (by interrupting the current through a relay coil); no calculus is involved here, just the tingling sensation which much later is explained by $\mathbf{v = L\ di/dt}$. Students learn to measure voltage, current, and resistance on the kinds of devices that interest them, not on resistors alone. They test their own hearing (crudely, but effectively) and measure some parameters of an small speaker. On a two-hour tour of the campus electrical system, all students they put their hands on the cooling fins and feel the 60 Hertz hum of a 5,000 kVA 23 kV/4.8 kV step-down transformer which supplies the entire University campus.

II. Course Syllabus for EL 110

Course Lecture Topics: (2 hours per week for 14 weeks)**:**	
Mankind's awareness of electricity/scientific understanding	1.3 hour
Types of electricity - static vs. dynamic, DC vs. AC, terminology & units	1.3 hour
Generation of AC power, distribution	1.3 hour
Electrical safety, hazards	1.3 hour
Basic electrical circuits & devices, schematic diagrams, notation	2 hours
Ohm's law, power law	2.7 hours
Cost of electrical energy, batteries vs. commercial electric utilities	1.3 hour
Block diagram approach to electronics, examples of familiar devices	1.3 hour
Power supplies, diodes as rectifiers	1.3 hour
Amplifiers	1.3 hour
Oscillators	0.7 hour
Other building blocks (mixers, detectors, hardware, connectors, cables)	1.3 hour
Radio systems	1.3 hour
Television systems	1.3 hour
Satellite-based communications	2 hours
Cellular phone technology - present and future	1.3 hour
Global positioning system	1 hour
Computers and their applications	2 hours
Examinations in class	2 hours
	Total lecture contact time = 28 hours

Of necessity, this is a survey course, due both to the wide range of topics covered in the time available and to the preparation of the students (first-semester). Yet, these students have PCs, cell phones, electronic keyboards and sound systems of every description; they have a strong interest in learning about the technology they possess. It is this interest that contributes to the success of the course in meeting its goals.

III. Lecture

The topics listed in the syllabus are presented with lots of numerical examples. Units, and converting between different units for the same parameter are stressed throughout the course. For example, the energy that an alkaline “D” cell can supply is first determined using its voltage and amp-hour rating. Initially, this energy (the product of voltage and ampere-hour rating) is in watt-hours; conversion to watt-sec (Joules), and foot-pounds is then done. When this energy is expressed in the height (in feet) to which a person (160 pounds) could be raised, the answer is very surprising and far in excess of what students (and faculty) estimate.

The topic of parallel resistors is presented after the topic of lawn mowing is explored: Pat can mow a certain lawn in 5 hours, while Fran can mow the same lawn in 4 hours. How long will it take to mow the lawn if both Pat and Fran work together? Students intuitively know that the answer is not 9 hours, and quickly realize the answer must be less than 4 hours. They readily accept that 5 hours/lawn is equivalent to 0.2 lawns/hour, 4 hours/lawn is the same as 0.25 lawns/hour, and working together results in 0.45 lawns/hour being mowed. Once they invert 0.45 lawns/hour to get 2.2 hours/lawn, teaching parallel resistor concepts becomes very easy.

Demonstrations or animated presentations using a PC and video projector are done in most lectures, mindful of the venerable wisdom attributed to Confucius: "Tell me and I will forget, show me and I may remember, involve me and I will understand." The showing happens in lecture, while the involvement occurs in the laboratory, and is carefully synchronized with the lecture topics. Some of the lecture demonstrations, and the principles they reinforce, are highlighted below.

- 12-volt car battery- jumper cables, several high-power loads, lots of sparks (a coarse file works well), lots of heat, absolutely no shock hazard. Reinforces Ohm’s law: 12 V is not enough to push more than a few µA through a person, even though the battery can supply hundreds of amperes (to the right load).

- Tesla coil – electric fields, lighting a fluorescent lamp at a distance. Demonstrates transformers, the reality of invisible electric fields. Students are delighted to learn that its harmonics may well be interfering with the radio communications of campus police who are ticketing cars in the parking lot outside.

- 120-volt primary 60 Hz E-core transformer with changeable secondary windings and loads – 12 V light bulb, magnetic levitation and induction heating of aluminum ring, #18 AWG wire heated to incandescence (similar to a soldering gun).

- 120-volt primary 60 Hz 14 kV secondary oil burner ignition transformer – air turning from an insulator to a conductor, dielectric strength, Jacob’s ladder, electrical safety.

- Charging/discharging of 6 kV, 7.5 µF oil-filled defibrillator capacitor – illustrates stored energy (the analogy to a rubber band is used), safety (the instructor, who keeps one hand in his pocket and uses uninsulated alligator clips, has so far not received a shock). The sound and the light of the discharge are unforgettable.

• Flash module from a $7.00 disposable camera – operates on 1.5 V AA cell, illustrates oscillator (which students can hear), step-up transformer, high-voltage electrolytic capacitor (330 volts), trigger transformer and xenon flash tube. The capacitor is discharged in the normal way, resulting in a very bright flash, and then by a paper clip, which becomes welded to the capacitor leads. Safety is stressed. The "carcass" of a disposable camera may be obtained at no cost from a one-hour photo processor. Figure 1 below shows the flash module mounted on a plastic base.

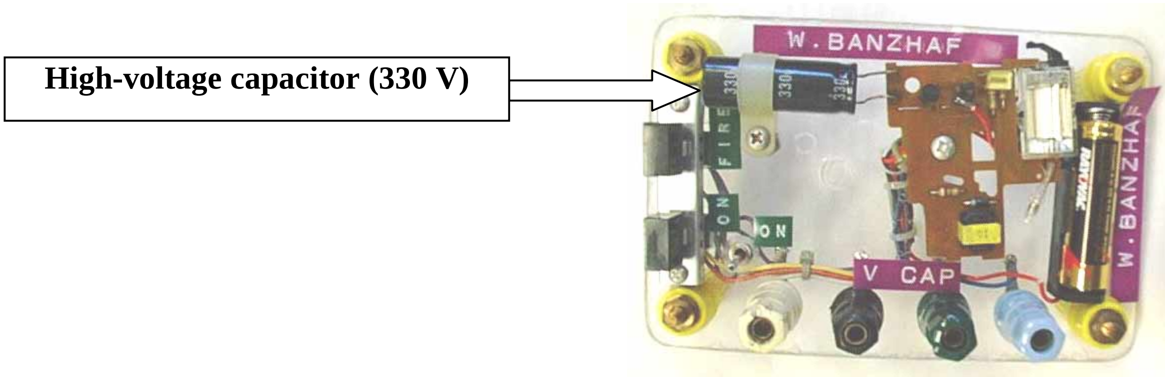

Figure 1 Flash Module From Disposable Camera.

• Ground-Fault Circuit Interrupter (GFCI) – both a GFCI circuit breaker with innards exposed (see Figure 2), and a demonstration board with a GFCI outlet (about $8) are shown to students. The board has a line-to-neutral load of a 100 W bulb, and several line-to-ground load resistors which allows the fault current to be 6 mA, 20 mA and 100 mA. The difference in "trip" times for the different fault currents is very noticeable. Highlighted are electrical safety, toroid transformer core, electronic circuitry and the solenoid which "trips" the circuit breaker.

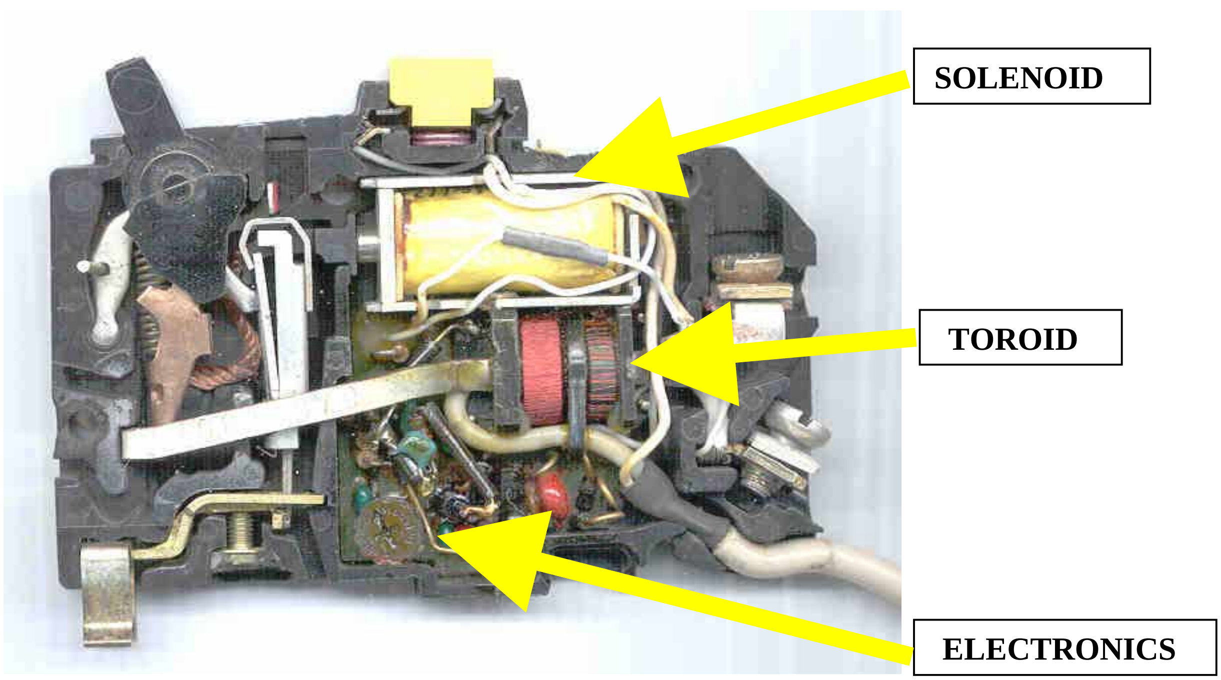

Figure 2 Ground Fault Circuit Interrupter Circuit Breaker.

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IV. Laboratory Experiments - Summary

For each experiment, the title, a brief description of the laboratory equipment and supplies, and the outcomes or principles explored are presented.

Experiment 1 - Familiarization with Lab Equipment, Circuit Construction
Objective: To become familiar with laboratory equipment and construction of circuits from schematic diagrams. Equipment Needed: Small 12 V incandescent lamp, "hobby" motor, Sonalert (tone generator), light-emitting diode (LED), 50 Ω 7-watt resistor, DMM (voltmeter and ammeter). Description: For each device, students apply a voltage (different for each), measure the current, and calculate the power dissipation. The conversion of electrical energy into other forms: light, mechanical, sound, and heat is emphasized. For example, students place 15 V across the 50 Ω resistor, and feel the heating caused by 4.5 W of thermal power. For many students, this is the first time they have used a power supply, voltmeter or ammeter. The instructor is kept quite busy, giving one-on-one assistance and putting out fires (not quite literally).

Experiment 2 - Use of Ohmmeter, Resistor Color Code
Objective: Use of ohmmeter, resistor color code. Equipment Needed: Assorted kΩ resistors, digital multimeter (ohmmeter only). Description: The color code for 5% and 10% 4-band resistors is presented. For each resistor, the nominal coded value and tolerance is determined from the color code. Then, the student calculates the minimum and maximum resistance values for that resistor, and measures the actual resistance.

Experiment 3 – Motors: Measuring Voltage, Current, Power, Efficiency
Objective: To measure voltage and current, and calculate power and efficiency for DC motors. Equipment Needed: Three DC Motors (permanent magnet, low power), analog voltmeter, DC ammeter, 1 cm of sleeving from #18 AWG stranded wire, two 25 cm lengths of #22 AWG solid wire (to attach to motors to wooden stick), one wooden stick (about 1 cm by 1 cm by 7.5 cm, the beam to which motors are attached), one LED. Details of this experiment are given in the next section. The analog voltmeter is needed to see the transient voltage produced when a motor, acting as a generator, is spun by hand.

Experiment 4 - Ohm's Law Verification, Calculating Power
Objective: To verify, by measurement all forms of Ohm's law: $V=IR$, $I=V/R$ and $R = V/I$. Equipment Needed: Assorted kΩ resistors, voltmeter, ammeter, ohmmeter. Description: a current of known value is made to flow through a known resistor, and voltage is both calculated and measured. A known voltage is placed across a resistor, and the current is both calculated and measured. The voltage across and current through a known resistor are used to calculate its resistance. Then, the voltage across a resistor is increased in steps, and the current is measured for each voltage. Graphs of I vs. V and P vs. V are then constructed (by hand!).

Experiment 5 - Electricity on Campus – A Walking Tour of Watt's Up
Objective: To become familiar with electrical distribution systems. Equipment: Feet (1 or 2), eyes, pencil or pen, pad or clipboard to write on, a curious mind. Description: The path taken by electrical energy, from the point where 3-phase power at 23 kV enters the campus, is then stepped down to 4.8

kV by a 5,000 kVA transformer (the size of a faculty office), is fed underground to the campus buildings, and is finally transformed again down to 3-phase 208 V/120 V, through a circuit breaker panel box and finally to an outlet in the laboratory is followed. Along the way, evidence of mishaps is pointed out (e.g. where a dump truck's raised bed created a line-to-line fault on the 23 kV feeder to campus, melting both conductors and causing 8 tires on the truck to explode and burn). Note: due to the New England fall weather, this tour must be completed in early October; pedagogically, it would be better to take it near the end of the course (in December). Details of this experiment are given in the next section.

Experiment 6 - Series Circuits
Objective: To verify voltage, current and resistance relationships in series circuits. Equipment: Assorted kΩ resistors, voltmeter, ammeter, ohmmeter. Description: Series circuit characteristics are explored (including Kirchhoff's voltage law), and the effects on all circuit parameters of decreasing the value of one resistor in a series circuit is explored.

Experiment 7 - Energy, Power, Cost of Electrical Energy
Objective: To learn the cost of running common household electrical loads. Equipment: calculator. Description: This in-lab "experiment" requires calculation of power (in watts), energy used (in joules and kilowatt-hours), and the cost of operating a wide range of devices powered by the local electrical utility. Students are able to get immediate help while doing these computations, either from peers or the instructor.

Experiment 8 - Speakers, Ears, Electro-Acoustic Transducers
Objective: To explore the frequency range of human hearing and the electrical characteristics of permanent magnet speakers. Equipment: Digital multimeter – use it to measure voltage (this time, AC voltage!), current (this time, AC current!), resistance (ohms are always measured with DC, using this instrument), function generator (produces three waveforms: sine, triangle, square), VTVM (vacuum-tube voltmeter, used as a second AC voltmeter) or another digital multimeter, two small permanent magnet speakers. Description: Details of this experiment are given in the next section. (Acknowledgement: Some of the material in this experiment was adapted from an experiment by Professor Richard Kozick, of Bucknell University on the Agilent Educators' Corner[4].)

Experiment 9 - Relays: Electromechanical Tools
Objective: To learn about relays as devices for switching, for isolation of the load circuit from the controlling circuit, and for latching. Equipment: Digital multimeter, DC power supply, relay with 12 VDC coil and 3PDT contacts, Sonalert sound generator, 12 V incandescent lamp, 12 V cooling fan, magnetic reed switch, small permanent magnet. Description: Details of this experiment are given in the next section.

Experiment 10 - Relaxation Oscillator Using 555 Integrated Circuit
Objective: To construct an oscillator circuit on an op-amp designer board, and examine its output using an oscilloscope. Equipment: Digital multimeter – use it to measure voltage, current, resistance, DC power supply, 555 integrated circuit, op-amp protoboard, assorted resistors & capacitors, CdS (cadmium-sulphide) photoresistive cell, speaker, 10 kΩ variable resistor. Description: This is students' first use of the oscilloscope, to measure the period of the waveforms. The photocell and variable resistor allow the frequency to be changed.

V. Highlights of Selected Laboratory Experiments

Experiment # 3 - MOTORS: Measuring Voltage, Current, Power, Efficiency
Students use a DC motor (the four for $1.00 kind, often used in slot cars), and measure its electrical parameters. Then, as shown in Figure 3, they couple a second motor, which acts as a generator, and measure the motor-generator system. Lastly, the generator is used to power other loads (an LED, a third motor). This two-hour lab experiment covers electromagnetism, measuring voltage, current, and power, efficiency, forms of energy, and really captures the students' interest. After performing this experiment, nobody believes that connecting the generator output to the motor input can result in perpetual motion. Students can easily see the permanent magnet, armature coils, commutator and brushes of this open-frame motor.

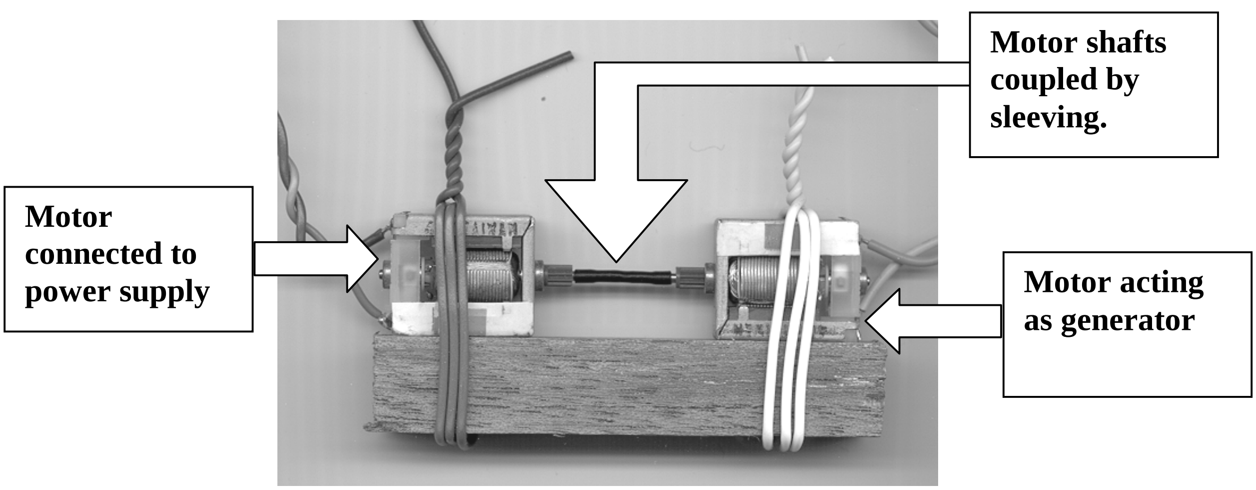

Figure 3 Motor-Generator System For Experiment 3.

Experiment 5 - Electricity on Campus – A Walking Tour of Watt's Up
Many topics that are quite esoteric (e.g. three-phase power, lightning protection, oil-filled transformers, the need for high voltage distribution lines to campus, why 60 Hz is used) are presented and explained in a non-mathematical way, with the assurance that the depth of knowledge will increase as additional courses are taken. Figure 4 shows the three-phase 5,000 kVA 23 kV to 4.8 kV step-down transformer featured on this tour.

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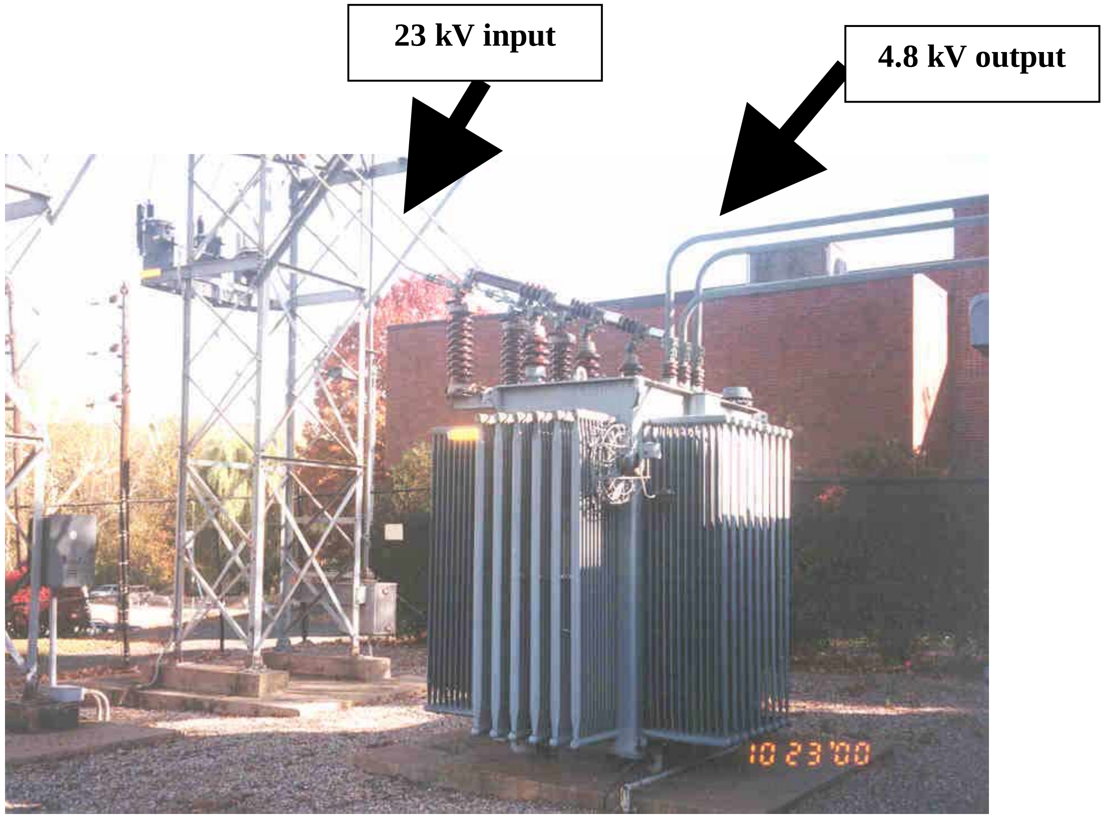

Figure 4 5,000 kVA Transformer Visited During Walking Tour of Campus.

Experiment 8 - Speakers, Ears, Electro-Acoustic Transducers

The first procedure has students view the speaker cone, when driven with a 2 Hz sine, then triangle, and finally square wave; it appears to "breathe", and is inaudible. As the frequency is raised, students are asked to record their perceptions of the sound quality with the three waveforms, and at different frequencies.

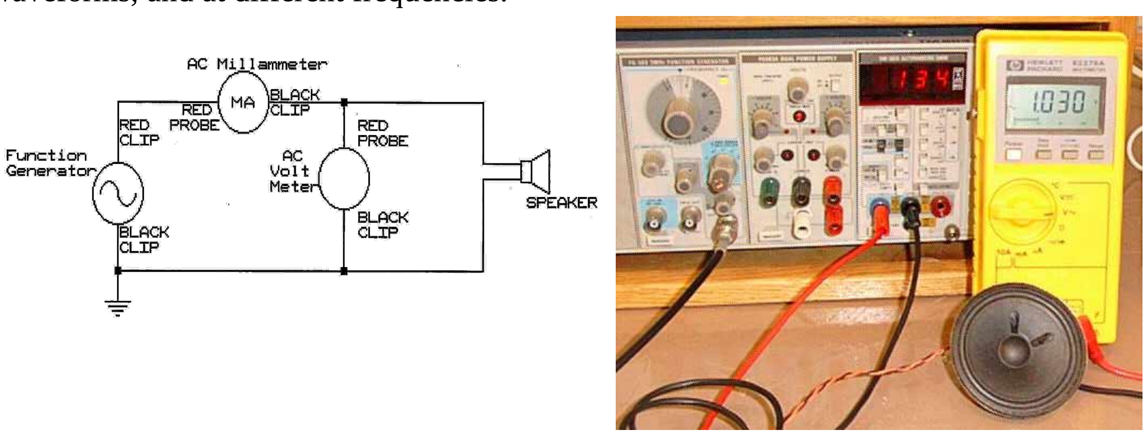

Figure 5 Schematic Diagram and Equipment Used For Experiment 8.

The second part of the experiment involves measuring the speaker voltage and current as frequency is varied over the entire audio range. Figure 5 shows a voltage of 1.03 V, and a current of 134 mA, with a 500 Hz sinusoid source voltage. The calculated impedance is 7.7 Ω, very close to the specified value of 8 Ω. The speakers used have an electromechanical resonance near 210 Hz, which results in very interesting audible results and a marked increase in calculated impedance around the resonant frequency (Z vs. frequency is graphed).

The third procedure is to place a second speaker atop the first, and to record the output voltage from the second speaker (now acting as a microphone) as the frequency of the voltage driving the first speaker is varied. This gives students excellent experience with data collection skills, and again a graph is made (output voltage vs. frequency) with very apparent resonance effects.

Experiment 9 - Relays – Electromechanical Tools

A relay with a 12 VDC coil and triple-pole double-throw (3P2T) contacts is used to turn on a load, to transfer power from one load to another, and to latch in the energized state to simulate an alarm system. Figure 5 shows this latching alarm circuit, triggered by a magnetic reed switch closing, which turns off a green LED and turns on an alarm.

Students can examine the structure of the relay, actuate it by hand, measure the pull-in voltage and current, and the drop-out voltage and current. Each student is asked to put two fingers from one hand across the coil, and to have their lab partner connect the coil to 12 V (by this time, they are aware a human can't feel 12 V). Then, the partner is told to disconnect one wire to the power supply. The mild shock that results is quite perceptible, startling but not painful, unexpected, and provides an excellent opportunity to reinforce the concept that energy is stored in magnetic fields. When these fields collapse an induced voltage is created far in excess of the supply voltage.

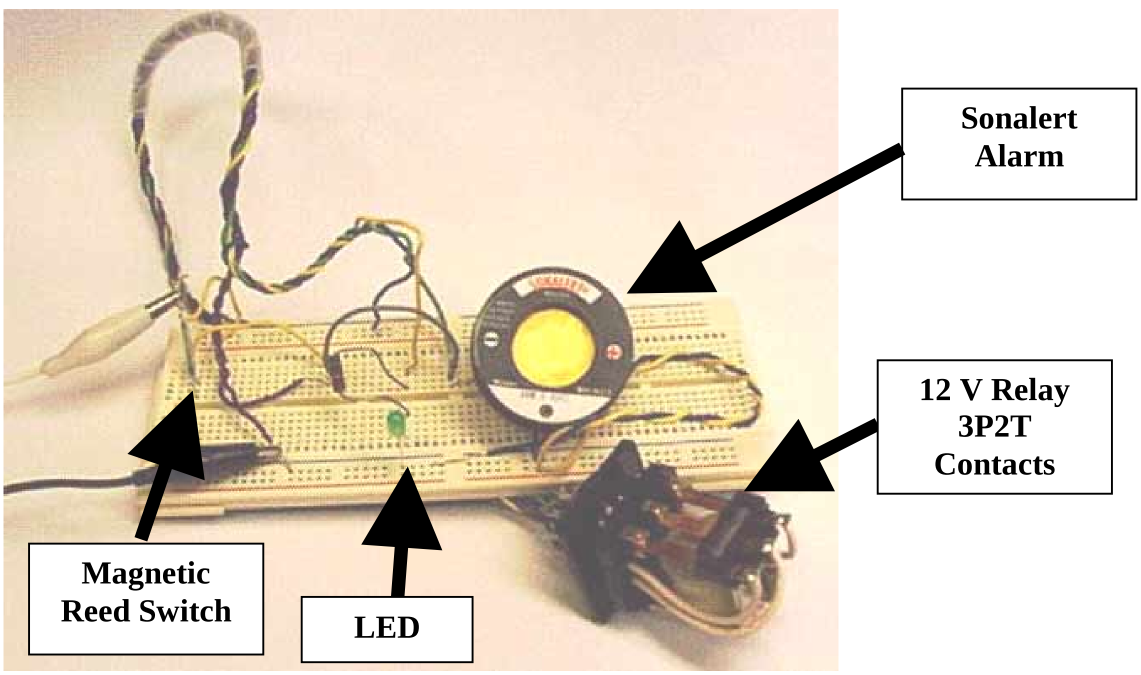

Figure 5 Picture of Components Used in Experiment 8, Relays.

VI. What Did the Students Think of This Course?

20 students (of 26 who finished the course) completed anonymous course/instructor evaluation forms at the end of the fall 2000 semester. Relevant statements, and the responses, follow:

ITEM: For this course ...	Strongly agree	Agree	Disagree	Strongly disagree	Don't know-doesn't apply
1. I had little knowledge of electricity/electronics before this course.	9	5	2	4	0
2. I learned a significant amount in this new course.	9	9	2	0	0
3. The lab experiments illustrated the theory discussed in lecture.	10	10	0	0	0
4. Overall, the labs were a valuable experience and helped me learn.	8	9	2	0	1
5. Overall, the lectures were a valuable experience and helped me learn.	12	7	1	0	0

The data revealed that 6 of 20 students disagreed with statement 1 (i.e. they disagreed that they had only "little knowledge of electricity/electronics before this course"), yet only 2 disagreed with statement 2: "I learned a significant amount in this new course". Apparently, the breadth and depth of material learned satisfied 90% (18 of 20) of the students, even those who said they had significant background in the field. These results are consistent with the evaluations done in the fall, 1999 semester.

VII. Future Directions

In the fall of 2001, for the first time students from outside Ward College of Technology (sophomores majoring in Integrated Information Technology, a new interdisciplinary major) will take this course. As a result, course emphasis will be shifted somewhat, in both lecture and laboratory, away from simply creating a foundation for EET students, and towards achieving a broad technological literacy. The result will be that all students taking this course will be better prepared to live, vote, work and thrive in their digitized, networked, computer-controlled wireless 21st century.

In the spring semester of 2002, I will be on sabbatical leave. One of the goals of the sabbatical is to create a comprehensive laboratory manual for EL 110, with photographs and details (sample lab reports, how to present calculations, graphing techniques, etc.) for students use both at the University and at other institutions. Laboratory experiments and other course materials are available, in PDF (Adobe Portable Document Format) at http://uhavax.hartford.edu/~banz and will be updated on a continuing basis.

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