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The Use of Digital Instrumentation and the IEEE-488 Interface in the Electric Circuits Laboratory

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The electrical circuits laboratory at Christian Brothers University is a key element in the electrical engineering department plan for increased use of digital instrumentation, computer controlled experiments and digital data acquisition. This laboratory is the second electrical engineering laboratory following the introductory interdisciplinary instrumentation course set up under the National Science Foundation Grant. The objectives of the electric circuits laboratory are: (i) to introduce electric laboratory safety; (ii) to make the theory clear and tangible to the student; and (iii) to introduce the personal computer as a testing, analysis, simulation and reporting tool. The PC workstations utilize IEEE-488/GPIB for computer–instrument interaction. Software packages include MathCAD, MICROCAP, PSPICE, QUATTRO, WordPerfect and a Quick-Basic compiler . This paper presents an overview of the hardware and software utilized in the laboratory, the set of six experiments designed for this electrical engineering laboratory course, as well as examples of student work to demonstrate results. This paper also shows the effectiveness of digital instrumentation and the capability of GPIB for controlling instruments and acquiring digital data.

EDUCATIONAL SUMMARY

1. The paper describes instrumentation used by students from diffeent engineering disciplines that enables them to acquire data from multiple test points and instruments for analysis on a PC. Experiments that use this setup are included.
2. The paper describes new equipment useful mainly in courses for the circuit analysis laboratory, but instrumentation and controls are included in the references.
3. Sophomore, juniors and seniors of different disciplines use this equipment in a variety of courses.
4. The new apsects of this contributin is the use of computer-controlled equipment in electric circuits to increase the learning capability of the student within the time allotted. This thoroughly tests difficult concepts and theory discussed in class.
5. The curriculum was restructured to accommodate such a laboratory course since automation made the learning process more accelerated.
6. A laboratory notebook was developed and written by the authors of this paper.
7. All concepts presented have been tested in the classroom and sample student results are included. Conclusions for each experiment are tabulated.
8. Digital instrumentation, computer-controlled experiments and digital acquisition are a plus in speeding up the learning process of a student. This approach provides visual and graphical aids and makes the abstract concepts more clear and tangible to the engineering student. If such a lab is economically viable to an institution, we recommend the capable programs to move in that direction.

INTRODUCTION

THIS PAPER describes the initiation of GPIB/IEEE-488 computer-controlled experimentation and digital instrumentation in the sophomore electric circuits laboratory at Christian Brothers University from the spring of 1991 [1–3] until present.

This adjustment and upgrade was necessitated by the creation of an introductory instrumentation laboratory in 1990 under a National Science Foundation ILI grant. In that laboratory, electrical engineering students become well-acquainted with digital instrumentation and digital data acquisition prior to the electric circuits laboratory. In the electric circuit analysis course, students study topics on complex frequencies, their applications, transformers, two-port networks, and finally the Fourier and Laplace transforms and their transient and steady-state interpretations in time. The process of measuring and testing circuits which render such responses tend to be very tedious and time consuming. In addition, most of the time, the data taken to plot these responses has a low resolution and is vulnerable to human errors.

The use of the GPIB-ready instruments in the laboratory education environment made the laboratory experience diverse and the use of laboratory time more efficient. Conventionally, the average student has time to perform one circuit-testing procedure involving the reading and documentation of a frequency response sweep of the input and output of a reactive circuit during a laboratory period. However, with the GBIP/IEEE-488 control a student is able to perform multiple runs on a multitude of circuitry or a more complex single circuit in the same amount of time. This paper will demonstrate and discuss results of such procedures using the hardware capabilities of the GPIB.

BACKGROUND ON IEEE-488 INTERFACE

The IEEE 488 bus was developed in 1975, as a standard that will allow instruments to interface to a computer using general-purpose rules [4]. This standard was revised in 1978 and was called the GPIB (General-Purpose Interface Bus). Before this breakthrough each programmable instrument had to have its own dedicated interface card. The computer, or controller, used in a given test or experiment had to have enough expansion slots or communication ports to accommodate the instrumentation necessary to collect the valuable data. Thus, making the number of instruments limited and the complexity of the experiment minimal.

With the birth of GPIB a solution to such a scenario was conceived, hence creating a new generation of GPIB-compatible instruments which can be interfaced with ease. More than 15 devices can be connected to a system with the help of GPIB [5].

HARDWARE AND SOFTWARE

Each of the eight stations uses a 386 computer as a controlling unit. The GPIB-compatible instruments used are made by Tektronics and are connected in a linear or bus configuration. The following is the list of the additional Tektronix equipment:

- 2424L 60 MHz digital oscilloscope
- DM5520 digital multimeter
- AFG5101 arbitrary function generator
- PS503 DC power supply
- SI5010 multiplexer/scanner

Figure 1 shows a block diagram of the hardware interconnection per station. Each station is equipped with two types of software packages: the control and testing software, and the data presentation software. The control software consist of three packages. QuickBasic, which is a highly structured language, is an essential programming tool for advanced testing procedures. EZGEN, a software developed by Tektronix, is a menu-driven procedure-generating package which has the capability of translating testing or measurement procedures into QuickBasic code. The last control software is SPDmenu (Signal Processing and Display software), which uses the GPIB to grab any waveform off the oscilloscope's screen.

Each PC workstation is equipped with two data presentation programs: QUATTRO, and MathCAD. In addition, each workstation is equipped with PSPICE and MicroCAP programs for the purpose of circuit simulation. These software packages are utilized in this laboratory for analysis, presentation and evaluation of real-time experimental results.

POSITION IN THE CURRICULUM

For electrical engineering students, the electric circuits laboratory course follows both the Circuits I lecture course and the interdisciplinary engineering instrumentation laboratory course and is concurrent with the Circuits II course.

In this position, the course builds upon the students' elementary knowledge of computer-controlled experimentation using the IEEE-488 interface for digital data acquisition, thus preparing them for the junior year laboratories in control, and the electronics laboratory sequence.

COURSE OBJECTIVES

Traditionally the electric circuits laboratory has been made up of 10 one-week experiments paralleling topics covered in two semester lecture courses in linear electric circuit analysis at the level of standard texts [6–8].

Although revision of the experiments and updates of the circuits laboratory manual have occurred at regular intervals, the objectives for this laboratory have remained the same over the years. These objectives include:

1. Introduction to the basic instrumentation available in electrical engineering.
2. Reinforcement and validation of the principles studied in linear circuit analysis courses.
3. Experience with a variety of circuit components, power sources, and methods of interconnection found in various areas of electrical engineering.
4. Development of good laboratory techniques in building networks and designing test strategies to obtain desired results.
5. Practice in the process of report writing, analysis, critical thinking, discussion and presentation of results.

The computer software introduced in 1989 [3] and the hardware introduced in 1991 [2] are enhancements consistent with the objectives of the course. They reinforce student learning and

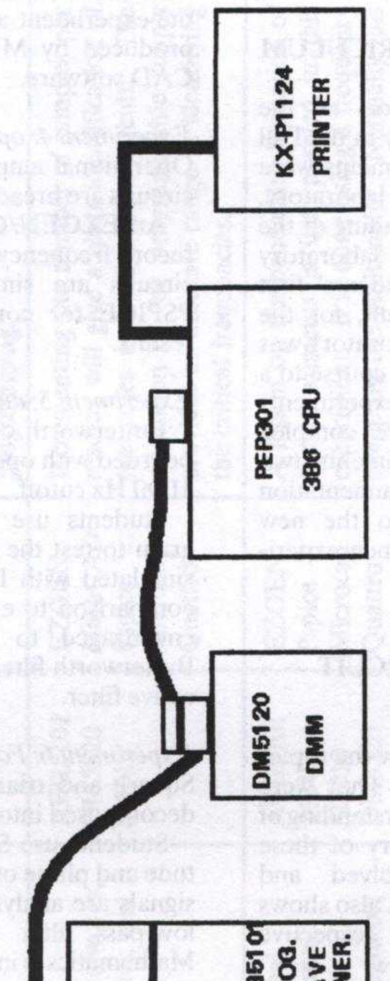

Fig. 1. Block diagram of hardware/station

provide more powerful tools for experimentation, analysis, simulation and presentation.

REVISION AND IMPACT ON CURRICULUM

During the design and installation of the engineering instrumentation laboratory in the Fall of 1990 several basic electrical experiments were assimilated from the electric circuits laboratory. This demanded a rethinking and upgrading of the experiments for the electric circuits laboratory since it was no longer to be the students' first engineering laboratory [3]. As a result, for the Spring of 1991, the electric circuits laboratory was reduced from a two-credit sophomore course to a one-credit course. The 10 one-week experiments were revised to six two-week, more complex experiments. Of the original 10 experiments, two had been absorbed into the instrumentation laboratory, four were upgraded into the new laboratory, four were dropped and two new experiments were devised.

THE REVISED ELECTRIC CIRCUIT EXPERIMENTS

The six two-week experiments follow the topics discussed in circuits analysis courses. They were designed to enhance the students' understanding of the material. Table 1 gives a summary of these experiments, the instruments involved and software needed to run each of them. It also shows the pros and cons of using the respective approaches.

Experiment 1: the study of series-parallel circuits with complex algebra

A passive series-parallel circuit driven by a 2000 Hz, 10 V source is tested to verify the circuit impedance values using complex algebra and phasor diagrams.

Students review the use of the digital oscilloscope, the arbitrary function generator, passive circuit components, as well as PSPICE and MICROCAP software.

Experiment 2: MathCAD in the analysis of experimental data

The MathCAD software is introduced and students practice plotting experimental data, determining the least-squares fit for semi-log curves, and displaying frequency responses for network functions.

This is primarily an exercise in the use of MathCAD to enable students to become acquainted with data display and frequency responses.

Experiment 3: pole-zero characteristics of L–C networks

The pole-zero characteristics of four different L–C circuit combinations are tested experimentally and compared to the mathematically predicted results and those of software simulations.

Students write an EZGEN program to perform the experiment and compare results to responses produced by MICROCAP, PSPICE and MathCAD software.

Experiment 4: operational amplifier circuits

Operational amplifier adder, integrator and filter circuits are breadboarded and tested.

An EZGEN/QuickBASIC program is used to record frequency responses. Operational amplifier circuits are simulated with MICROCAP and PSPICE for comparison with the experimental results.

Experiment 5: analysis and scaling of filters

Butterworth and Chebychev filters are breadboarded with operational amplifiers and scaled for 1000 Hz cutoff.

Students use an EZGEN/QuickBASIC program to test the circuits. The original circuits are simulated with PSPICE and MICROCAP-II for comparison to experimental results. Students are encouraged to design a passive fourth-order Butterworth filter and compare its response to the active filter.

Experiment 6: Fourier analysis of signals

Square and triangular waves are generated and decomposed into their respective spectra.

Students use SPDmenu to measure the magnitude and phase of every significant harmonic. Both signals are analyzed after being passed through a low-pass filter at variable cutoff frequencies. Mathematics is involved to compute the magnitude and phase spectra. Emphasis is placed on the notion of bandwidth and transmission delay.

EXAMPLES OF STUDENT WORK

The results of three experiments are discussed in this section to show the versatility and ease of programming and control of the GPIB-ready facility.

In the first experiment, the analysis of the phase delay between input and output and the phasor diagram of currents and voltages of an R–L–C circuit are examined. SPDmenu is used to download waveforms from the oscilloscope's screen. The data is acquired and imported into a non-Windows version of QuattroPro 4.0. This is a process that would introduce a lot of 'human error' into measurement if the programmable digital oscilloscope were not used. Figures 2 and 3 show the R–L–C circuit used in this experiment, and the phasor diagram drawn using the data placed in the spreadsheet, respectively.

The third experiment studies the poles and zeros of three different L–C circuits. The testing data of one of these circuit is shown in Fig. 4. The values for the critical frequencies are derived mathematic-

Table 1

Experiment	Objective	Hardware	Software	Comparison with conventional instruments
The Study of Series-Parallel Circuits with Complex Algebra	To introduce the student to phasor analysis and calculations.	AFG5101 2424L PEP-301	SPDmenu MicroCap Pspice	SPDmenu allows to grab an accurate waveforms from the oscilloscope's screen. Minimizes "human error" when measuring phase delays.
MathCAD in the Analysis of Experimental Data	To practice plotting linear and logarithmic experimental data using least-square fit.	PEP-301	MathCAD	The use of a mathematical formula and graphic editor to replace conventional programming.
Pole-Zero Characteristics of L-C Networks	To determine the pole-zero characteristics of four L-C networks, using acquisition, mathematics, and simulation.	AFG5101 DM5520 SI5010	EZGEN MathCAD Pspice Microcap Quattro	Incrementing the number of samples per reading will give a clear identification of the poles and zeros of a circuit. The resolution of the programmable supply provides an accurate range in identifying the critical frequencies.
Operational Amplifier Circuits	To understand the operational amplifier as a versatile electronic device, and study some its applications. Amplifier, integrator, filter.	AFG5101 2424L SI5010 DM5520 PS503	EZGEN Pspice Microcap Quattro QBasic	A lesson on the bandwidth limitation of the instruments is incorporated in this experiment. It is done using a frequency sweep on the multimeter. Normally this can be determined by reading manufacturer's specifications.
Analysis and Scaling of Filters	To explore highpass butterworth and chebychev filters and compare their frequency responses.	AFG5101 SI5010 DM5520 PS503	EZGEN Pspice Microcap Quattro	The student learn the limitation of the op-amp for high frequency operations and advanced filtering, with conventional measuring methods noise found in high pass filters make the data very difficult to analyze.
Fourier analysis of periodic waveforms	To study the fourier series of periodic functions.	AFG5101 DM5520 2424L	SPDmenu Quattro Pspice	Spectrum analyses is done without the use of a spectrum analyzer. A commodity on the sophomore level in most curriculums.

ally in the students reports to justify the experimental values. Figure 5 shows the frequency response of the impedance of the circuit shown in Fig. 4. A sample EZGEN procedure that would generate such a frequency sweep is given in the Appendix. The program is menu driven, and prompts the user for all of the values needed to generate the procedure. In this case, the EZGEN program reads 175 multiplexed points between input and output, and plots each separately. Meanwhile, it generates a data file that can be imported into Quattro for presentation of the input/output ratio on a semilog scale. Due to the ease of programming and time allotted for the laboratory meeting, three different circuits are tested and discussed within a 3 hr period.

In the sixth experiment, the harmonic waveforms of a square wave are generated (see Fig. 6). Figure 7 shows the signals passed through a low-pass filter that attenuates the magnitude of the frequencies higher than the 10th harmonic. Using the fast Fourier transform option found in the SPDmenu program, one can look at the magnitude and phase spectra (see Fig. 8) of the periodic signal and discuss the notion of bandwidth.

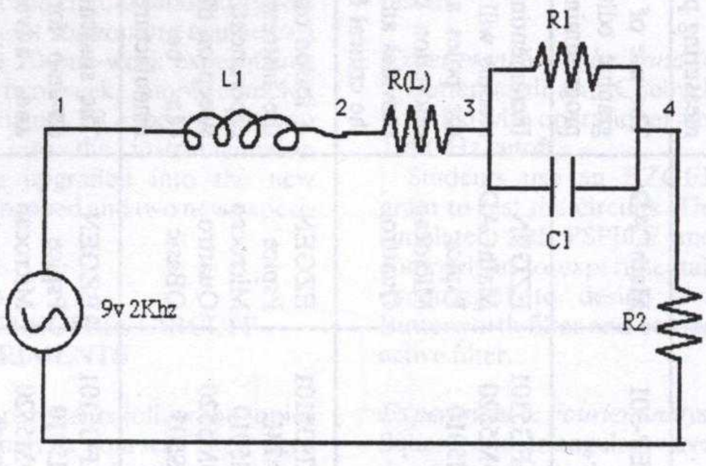

Fig. 2. Circuit used to study phasors

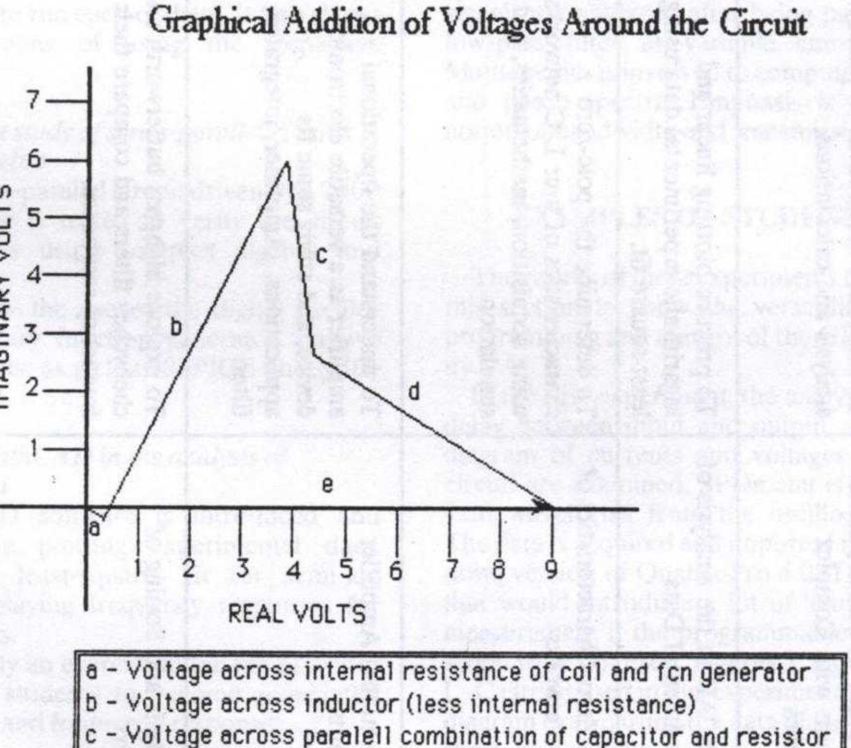

Fig. 3. Phasor diagram of circuit in Fig. 2

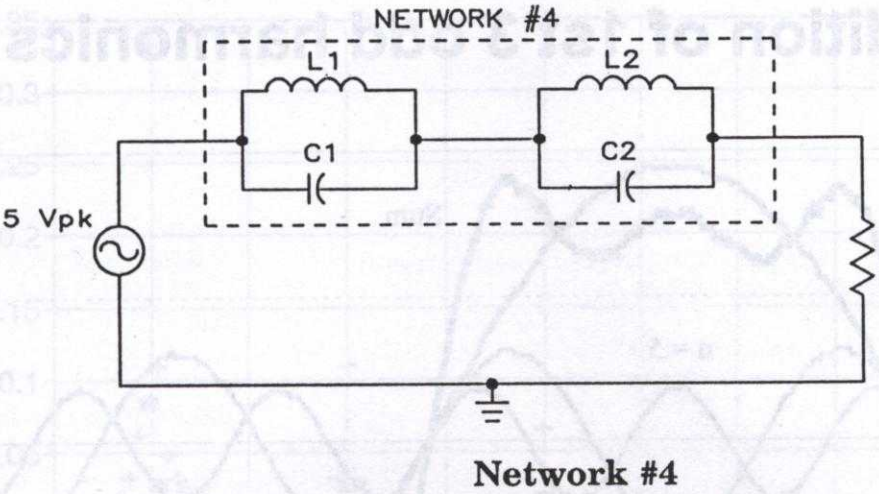

Fig. 4. Circuit used to generate poles and zeros

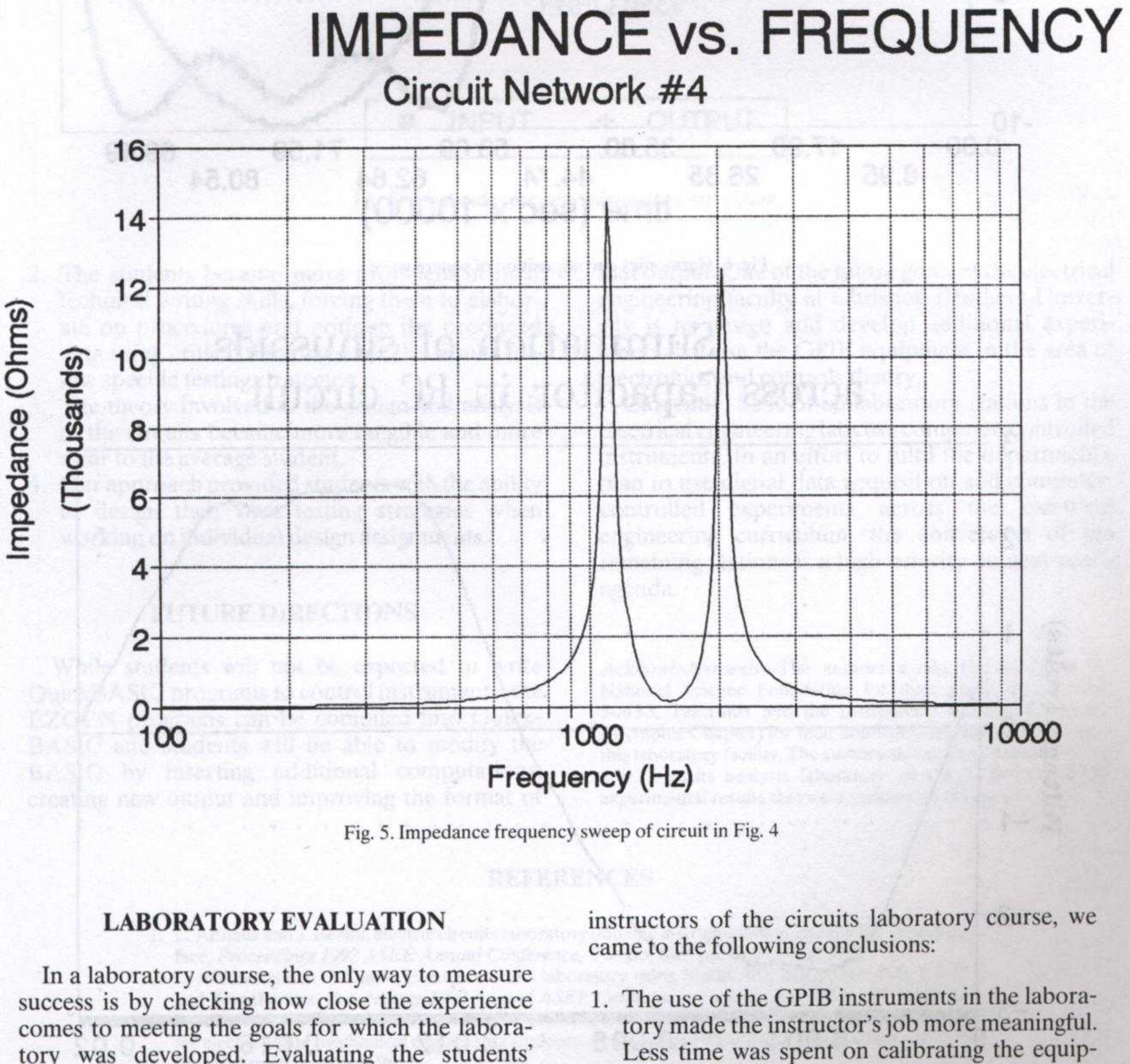

Fig. 5. Impedance frequency sweep of circuit in Fig. 4

LABORATORY EVALUATION

In a laboratory course, the only way to measure success is by checking how close the experience comes to meeting the goals for which the laboratory was developed. Evaluating the students' experience is not appropriate in this case because they did not have the chance to work with equipment of lesser caliber. However, as observers and instructors of the circuits laboratory course, we came to the following conclusions:

1. The use of the GPIB instruments in the laboratory made the instructor's job more meaningful. Less time was spent on calibrating the equipment and more time was spent in the labs studying the electrical concepts discussed in the classroom.

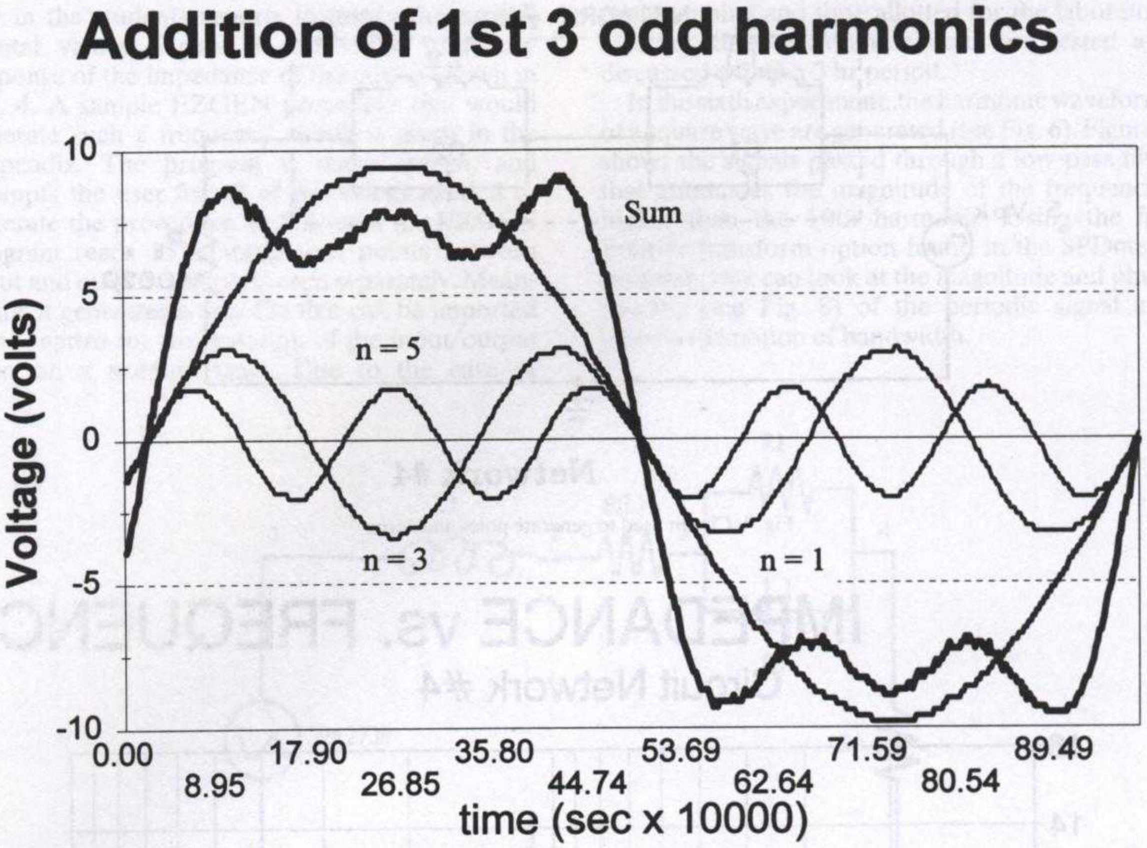

Fig. 6. Harmonics decomposition of square wave

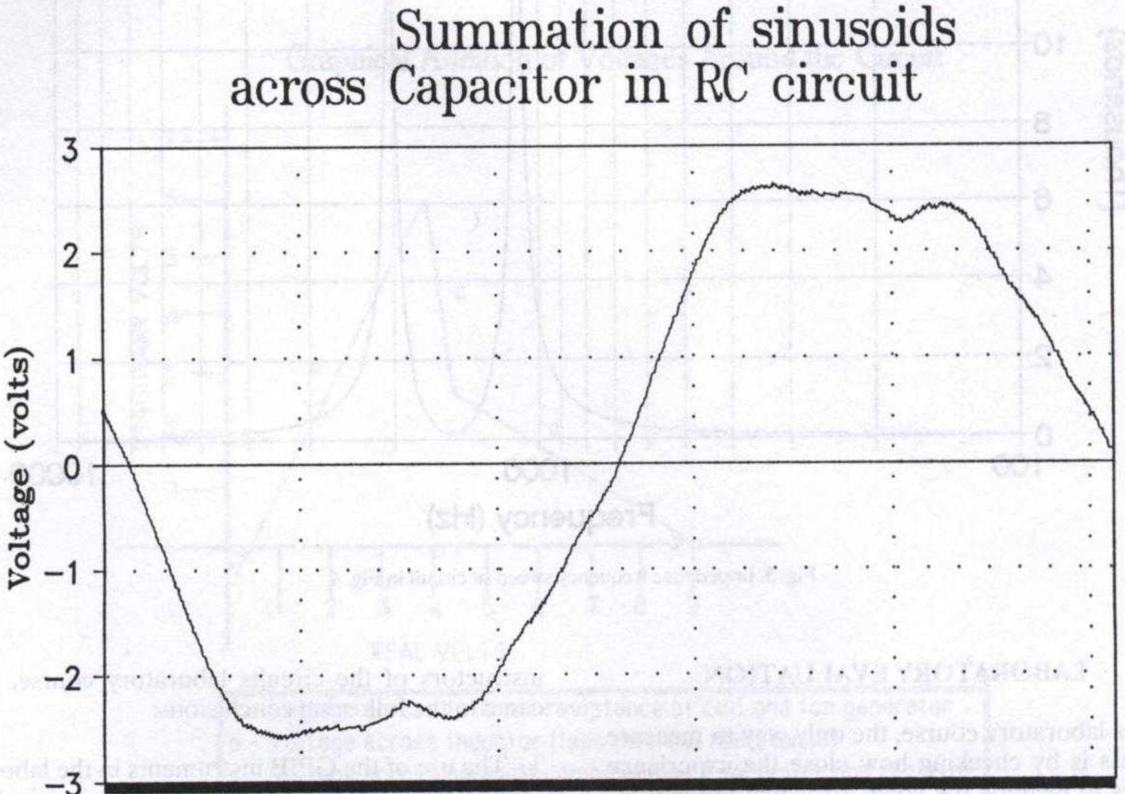

Fig. 7. Square wave with *n* 10 filtered

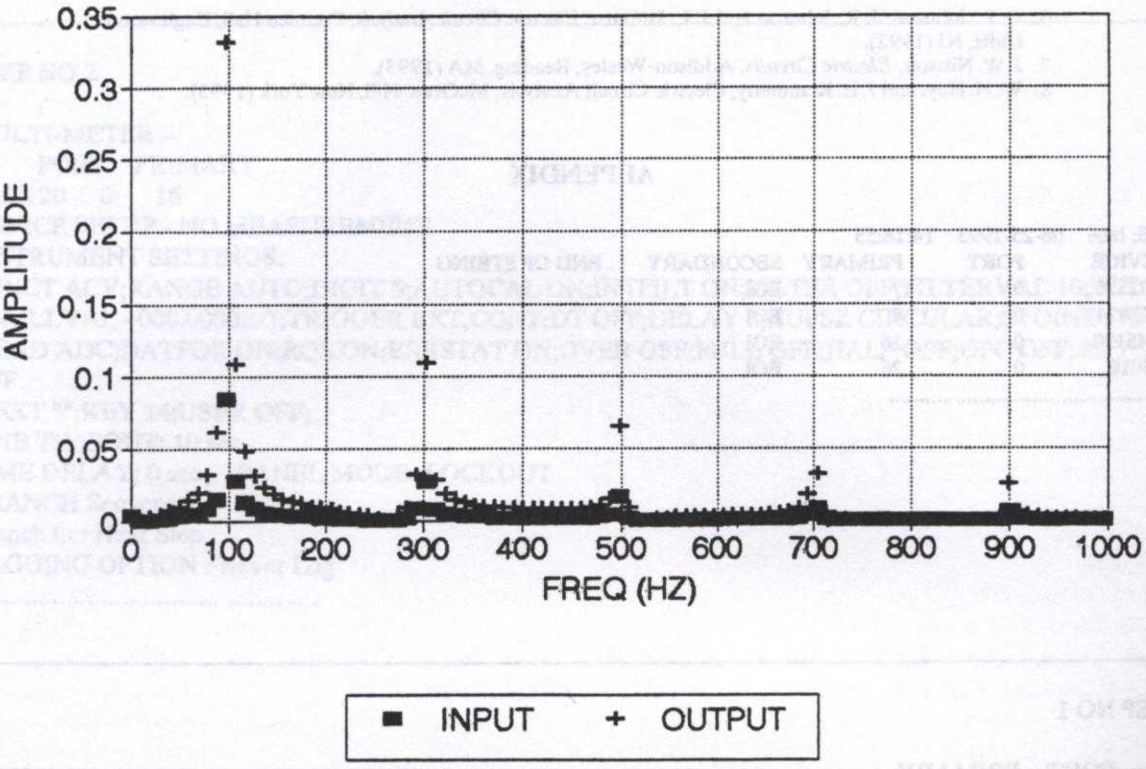

Fig. 8. Amplitude spectrum using square wave input.

2. The students became more proficient in their technical writing skills, forcing them to elaborate on procedures and critique the produced data using critical thinking since the results follow specific testing strategies.
3. The theory involved in the design and analysis of the circuits became more tangible and more clear to the average student.
4. Our approach provided students with the ability to design their own testing strategies when working on individual design assignments.

FUTURE DIRECTIONS

While students will not be expected to write QuickBASIC programs to control instruments, the EZGEN programs can be compiled into QuickBASIC and students will be able to modify the BASIC by inserting additional computations, creating new output and improving the format of that output. One of the future goals of the electrical engineering faculty at Christian Brothers University is to design and develop additional experiments that use the GPIB equipment in the area of electronics and controls theory.

Currently, 85% of all laboratory stations in the electrical engineering labs use computer-controlled instruments. In an effort to fulfil the department's plan to use digital data acquisition and computer-controlled experiments across the electrical engineering curriculum, the conversion of the remaining stations is a high priority on next year's agenda.

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APPENDIX

FILE: lab4 08-25-1993 14:18:55

DEVICE	PORT	PRIMARY	SECONDARY	END OF STRING
AFG510	0	7	EOI	
XX2424	0	8	EOI	
DM5120	0	16	EOI	
SI5010	0	26	EOI	

..

STEP NO 1

'

ID	PORT	PRIMARY
AFG510	0	7

DEVICE SETUP - NO MEASUREMENT
INSTRUMENT SETTINGS:
FREQ 100.0;AMPL 0.01;OFFS 0;DC 0;RATE 10.0E-6:S;NBUR 2;FRQSTART 1.0;FRQSTOP 1.2E +3;FRQMARK 0;SWEEP OFF;ARBSEL 1;ARBADRS 0;ARBSTART 0;ARBSTOP 8191;FILTER OFF;FUN C SINE;MODE CONT;TRIG INT;AM OFF;FM OFF;OUT ON;FRQL ON;RNGLCK OFF;ARBHOLD OFF;AR
BPROG OFF;DT OFF;RQS ON;USER OFF;OPC OFF;DISP FREQUENCY;
GPIB TIMEOUT: 10 sec.
TIME DELAY: 0 sec. PANEL MODE: LOCKOUT
BRANCH Sequences
Branch to : Next Step
LOGGING OPTION : Never Log
..

STEP NO 2
'
MULTI-METER --
ID PORT PRIMARY
DM5120 0 16
DEVICE SETUP - NO MEASUREMENT
INSTRUMENT SETTINGS:
FUNCT ACV;RANGE AUTO;DIGIT 5;AUTOCAL ON;INTFILT ON;FILTER OFF;FILTERVAL 10;NULL 0;NULLVAL +000.0000E-3;TRIGGER EXT,CONT;DT OFF;DELAY 0;BUFSZ CIRCULAR;STOINT 175 ;READ ADC;DATFOR ON;RQS ON;ERRSTAT ON;OVER OFF;FULL OFF;HALF OFF;OPC OFF;RDY OFF
;TEXT "";KEY 14;USER OFF;
GPIB TIMEOUT: 10 sec.
TIME DELAY: 0 sec. PANEL MODE: LOCKOUT
BRANCH Sequences
Branch to : Next Step
LOGGING OPTION : Never Log
....

STEP NO 3
'
SIGNAL SCANNER --
ID PORT PRIMARY
SI5010 0 26
DEVICE SETUP - NO MEASUREMENT
INSTRUMENT SETTINGS:
OPEN ALL;CLOSE 13;
GPIB TIMEOUT: 10 sec.
TIME DELAY: 0 sec. PANEL MODE: LOCKOUT
BRANCH Sequences
Branch to : Next Step
LOGGING OPTION : Never Log
....

STEP NO 4

' DM meas
' - - LOOP STIMULUS - -
ID PORT PRIMARY
AFG510 0 7
DEVICE SETUP - NO MEASUREMENT
GPIB TIMEOUT: 10 sec.
TIME DELAY: 0 sec. PANEL MODE: LOCKOUT
PARAMETER: FREQ
LOGARITHMIC STIMULUS INCREMENTS
INCREMENT: 10 to 100000 for 121 iterations
' - - LOOP ACQUISITION - -
MULTI-METER --
ID PORT PRIMARY
DM5120 0 16
MEASUREMENT
GPIB TIMEOUT: 10 sec.
TIME DELAY: 0 sec. PANEL MODE: LOCKOUT
MEASUREMENT UNITS: VOLTS
BRANCH Sequences
Branch to : Next Step
LOGGING OPTION : Always Log
LOOP PLOTTING: ON
....

STEP NO 5
'
SIGNAL SCANNER --
ID PORT PRIMARY
SI5010 0 26
DEVICE SETUP - NO MEASUREMENT
INSTRUMENT SETTINGS:
OPEN ALL;CLOSE 14;
GPIB TIMEOUT: 10 sec.
TIME DELAY: 0 sec. PANEL MODE: LOCKOUT
BRANCH Sequences
Branch to : Next Step
LOGGING OPTION : Never Log
....

```
STEP NO 6
' DM meas
' - - LOOP STIMULUS  - -
ID      PORT   PRIMARY
AFG510    0      7
DEVICE SETUP - NO MEASUREMENT
GPIB TIMEOUT: 10 sec.
TIME DELAY: 0 sec.   PANEL MODE: LOCKOUT
PARAMETER: FREQ
LOGARITHMIC STIMULUS INCREMENTS
INCREMENT: 10 to 100000 for 121 iterations
' - - LOOP ACQUISITION  - -
MULTI-METER --
ID      PORT   PRIMARY
DM5120    0     16
MEASUREMENT
GPIB TIMEOUT: 10 sec.
TIME DELAY: 0 sec.   PANEL MODE: LOCKOUT
MEASUREMENT UNITS: VOLTS
BRANCH Sequences
Branch to : Next Step
LOGGING OPTION : Always Log
LOOP PLOTTING: ON
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