An Upper-Division Virtual Laboratory in Linear Electronics

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Abstract

The development and implementation of an upper-division (junior-level) virtual linear electronics laboratory utilizing computer software simulation is described. The laboratory course was developed to accommodate distance-learning students who have limited or no access to campus facilities. All students enrolled in the course have completed an associate degree in electronics or electrical engineering technology and, therefore, have completed traditional basic electronic courses taught in a traditional laboratory environment. Moreover, most of the students are working in industry as engineering technicians and have sufficient maturity to understand some of the practical limitations of this approach.

The software utilized is Multisim (Electronics Workbench), which has proven to be very user-friendly and easily learned by students working on their own. Email, a toll-free telephone number, and the transfer of circuit schematics and performance curves over the internet enhance the faculty-student interaction. All of the experiments and projects parallel those offered in the more traditional course on the campus and include numerous linear and non-linear operational amplifier circuits, timers and oscillators, and data conversion circuits. The emphasis throughout the course is on circuit design followed by validation of design specifications by computer simulation of the circuits.

A comprehensive final examination testing the expected outcomes of the course has been developed and implemented. Performance studies thus far indicate that the effectiveness of the virtual laboratory is comparable to that of the traditional laboratory. Students also indicate that they work harder and require more time than with traditional laboratories, but their overall evaluation is very positive.

I. Introduction

Old Dominion University in Norfolk, Virginia, offers TAC of ABET accredited baccalaureate programs in Civil Engineering Technology, Electrical Engineering Technology, and Mechanical Engineering Technology. Although the entire four-year programs are offered on campus, from the very beginning in the early 70s, transfer students entering at the junior level have constituted a major portion of the student body. Students entering at the junior level are required to have an associate degree or its equivalent in the pertinent field of study. This group has always performed at a level comparable to our "natives", and many of our most outstanding graduates have entered the programs in this manner.

Around 1992, the University created the distance learning program called TELETECHNET, in which junior and senior level instruction has been provided by one-way video and two-way audio to numerous sites in the Commonwealth of Virginia and elsewhere. Due to a very high demand on the part of industry, the engineering technology programs were among the first to be offered in this manner, and the televised programs have become an integral part of the department's mission. The overall TELETECHNET initiative has grown to the point where Old Dominion University now has the largest undergraduate distance learning program in the country, and the institution has been cited by Forbes Magazine as one of the "top 20 cyber-universities" in the country.[1]

Lecture courses have presented no special problems other than orienting faculty toward the special preparation required for televised lectures. During the semester when a course is televised, it is normally the only section available, so full-time campus students take the course in the studio at the same time that it is being broadcast. Consistently, off-campus students perform at a level equal to or greater than that of the on-campus students. This is probably due to the higher maturity level of the off-campus students who are typically working full-time as technicians and are more serious about their education than the typical "youngsters" on campus. Communication between students and faculty include email and a toll-free number. While the students are physically "invisible" to the faculty, many faculty feel that they have more day-to-day interaction with these off-campus students than with on-campus students due to the resources available.

II. Laboratory Challenges

The greatest challenge thus far has been the development and implementation of appropriate laboratory experiences for off-campus students. During the early phases when most students were within the immediate geographic region, weekend laboratory packages were developed and they are still being used to a great extent. However, as sites at greater distances became more prevalent, the need for new approaches became evident.

Around 1996, the concept of "virtually-enhanced laboratories" (VEL) became a point of serious discussion. For the purpose of this paper, a VEL will be defined as an educational endeavor in which a portion or all of a traditional laboratory course is replaced by a substitute process that can be achieved by a student at a distance. This includes computer simulation, video-taped (or CD-ROM) experiences, and the remote control of an on-campus device from an off-campus location. Many different approaches have been investigated over the past few years and some are still under development at this time. Several papers have been accepted for presentation at this conference dealing with various approaches in each of the engineering technology disciplines.

It should be emphasized at the outset that none of the faculty believes that VEL's could ever serve as a complete replacement for traditional laboratory instruction. At the freshmen and sophomore levels and in the associate degree programs feeding Old Dominion University, traditional laboratory courses still prevail. However, by the time a student reaches the junior level, he or she should be familiar with the basic laboratory skills in the discipline. At that point, we feel that appropriate experiences can be achieved without necessarily having the student actually "touch real equipment".

Not all faculty were initially warm to the idea of VEL's. As the process has evolved, however, most of these faculty have become more convinced that well designed experiences can be as effective as, and in some cases even more effective than, traditional laboratories. In fact, anyone teaching traditional laboratories is well aware that some students can get through the labs by leaning on a partner without ever experiencing the full value of the work.

III. The EET 335 Model

This particular paper deals with a junior laboratory course, EET 335, *Linear Electronics Laboratory*. This course requires as a corequisite or prerequisite the lecture course EET 330, *Linear Electronics.* The text for the course is *Operational Amplifiers with Linear Integrated Circuits, 3rd Edition,* by William D. Stanley[2].

The original course objectives for the on-campus class are:

(1) Develop proficiency in the design and implementation of circuits containing linear and related non-linear components and modules.

(2) Develop the capability to successfully plan and implement independent laboratory investigations or design assignments with minimum supervision.

(3) Verify some of the representative theoretical properties of linear active devices and circuits.

(4) Improve the capability to prepare written documentation of laboratory assignments using the characteristics of good technical communications.

The VEL version of the course utilizes computer simulation of all the circuits designed and analyzed. When the VEL version was first being developed around 1996, PSPICE was used as the simulation program due to its widespread usage and the fact that a free evaluation version was readily available. Over a period of time, however, the evolution of Electronics Workbench (now called Multisim) and its user-friendly nature has resulted in a change to that software. This software is being used in several courses and off-campus students purchase an educational version at a special price provided by the company.

With the advent of the VEL version of the course, one additional objective was added to the course:

(5) Develop computer models of electronic circuits using Electronics Workbench.

IV. Course Details

The on-campus version of the course requires one three-hour formal meeting per week for about 14 weeks along with open lab hours for students requiring more time. The on-campus structure involves about 12 separate experiments, in which several require more than one week.

The experiments for the VEL version cover the same work, but we have found it better to reorganize the experiments into shorter versions. The result is 26 separate assignments delineated as follows:

Introductory Assignment: Laboratory Instrumentation
1. Inverting Amplifier
2. Non-Inverting Amplifier
3. Voltage-Controlled Current Source
4. Current-Controlled Voltage Source
5. Current-Controlled Current Source
6. DC Offset Effects
7. Operational Amplifier Closed-Loop Bandwidth
8. Operational Amplifier Slew Rate
9. Adding Circuit
10. Closed-Loop Differential Amplifier
11. Instrumentation Amplifier
12. Operational Amplifier Integrator Circuit
13. Operational Amplifier Differentiator Circuit
14. All-Pass Phase Lag Circuit
15. All-Pass Phase Lead Circuit
16. Single Power Supply Operation of an Operational Amplifier
17. Astable Op-Amp Multivibrator
18. Square/Triangle Wave Function Generator
19. 555 Timer (Astable Mode)
20. 555 Timer (Monostable Mode)
21. Low-Pass Active Filter
22. Band-Pass Active Filter
23. State Variable Low-Pass and High-Pass Filters
24. State Variable Band-Pass and Band-Rejection Filters
25. Analog-to-Digital and Digital-to-Analog Converters

Most of the preceding assignments require that the student actually design the circuits and implement them using standard 5% tolerance components. The Multisim library includes all of the required components, and most of the op-amp circuits utilize the 741 realistic model.

All assignments require the submission of an abbreviated report form, and several require a formal report. In addition, a final examination is required.

V. Results Observed

The VEL version of the course has now been offered about four times with two different instructors involved at different times. The qualitative impression is that the approach works quite well for most students. Most of the problems encountered thus far have been more related to the computer configurations of individual students and the "learning curve" associated with computer-aided software. As computer configurations have progressed and student computer proficiency has increased, the difficulties seem to be diminishing.

Some students have shown overwhelming enthusiasm for the approach. One student wrote on a course evaluation that the VEL Linear Lab and the VEL Power and Machinery Lab presented at this conference by Hackworth[3] were the two most effective laboratory courses that he had ever taken.

Two points are very clear from the results obtained thus far: (1) More responsibility in the learning process is shifted to the student; i. e., each person must perform the work without the help of a partner to carry out the assignment. (2) Students indicate that the amount of time required is much greater than in a conventional laboratory. If the amount of learning is a direct function of the time involved, this would certainly suggest that the learning process can be substantial.

During the Spring of 2001, a detailed comparison will be made of the performance of an on-campus control group and a group taking the course in a virtual mode. By the time of the ASEE presentation in June, some quantitative comparison results should be available.

VI. Future Plans

Two different approaches for the future are being considered: (1) Convert all sections of the course (on and off-campus) to the VEL format. (2) Add one or more hardware projects to the course that would require submissions on the part of the students.

The first possibility is based on the fact that industry is increasingly utilizing computer simulation as a basis for initial design, and if all students take the course in this manner, they will develop greater capability in the use of computer simulation software. The second possibility would require the student to submit a hardware design to the instructor with the goal of meeting certain design requirements. This approach is being used in the junior-level digital design laboratory.

VII. Representative Experiment

An example of a portion of one of the shorter assignments and some typical results follow. This experiment utilizes the Multisim 555 timer module in the astable mode. The student is given the following assignment:

(1) Design a 555 astable circuit to operate at 1 kHz with duty cycle not to exceed 52% and a 5-V power supply.

(2) Use Multisim to simulate the circuit in a transient mode. Obtain plots of the waveforms at pins 2/6 and pin 3 over at least two cycles after the waveforms settle. Using the cursor, carefully measure the period and calculate the frequency.

A typical circuit design using standard 5% tolerance components is shown in Figure 1, and the waveforms are shown in Figures 2 and 3. The measured value of the frequency differs from the design frequency by less than 1.5%. Adjustment of either of the resistance values could bring the frequency even closer to the design goal if necessary.

VIII. Summary and Conclusions

A junior-level linear electronics laboratory course utilizing circuit analysis simulation software has been developed at Old Dominion University for the purpose of providing instruction to distance learning students. All students enrolled in the course have completed traditional laboratory courses and most are employed as engineering technicians in industry. The course currently utilizes Multisim (Electronics Workbench), which has proven to be very effective in simulating the circuits involved. The use of internet resources has provided a strong supplement to enhance the communication between instructor and student.

Initial conclusions are that the effectiveness of this approach is comparable to that of a conventional laboratory environment. A by-product is that students also acquire proficiency in the simulation of linear circuits and in the evaluation of the results.

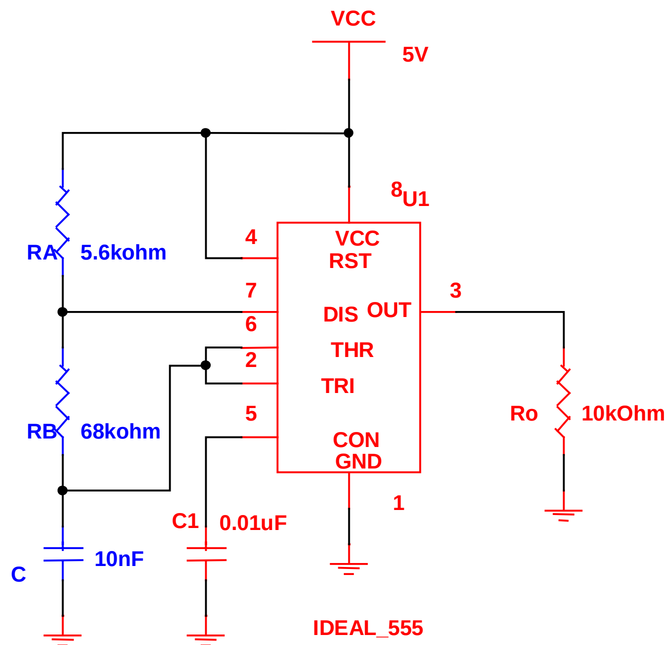

Figure 1. Typical 555 astable multivibrator design with Multisim.

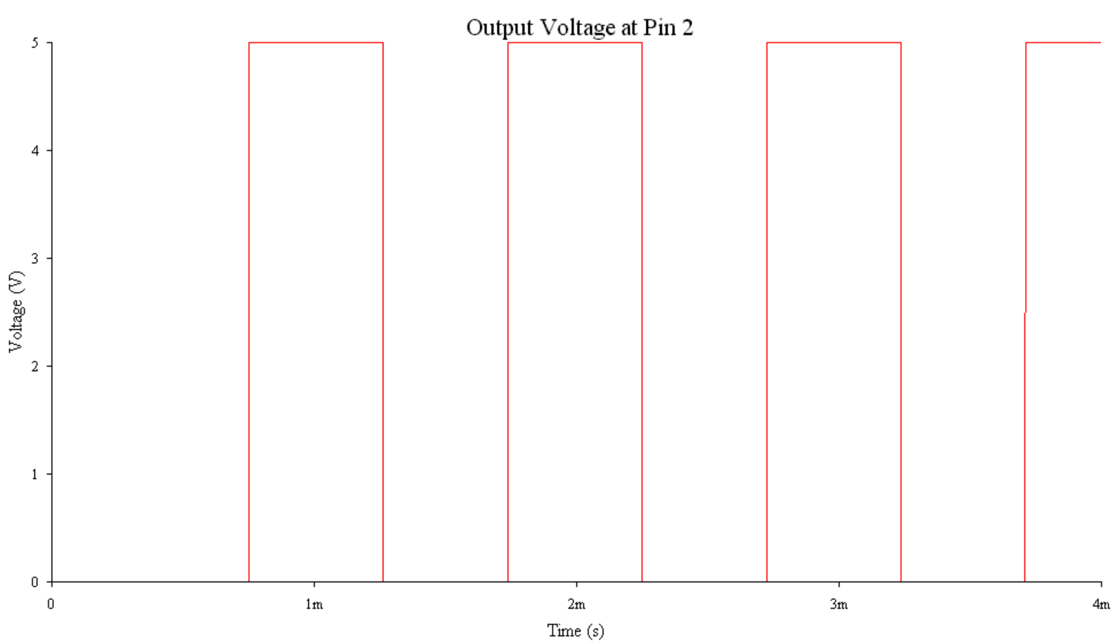

Figure 2. Output voltage of the 555 astable circuit as generated by Multisim.

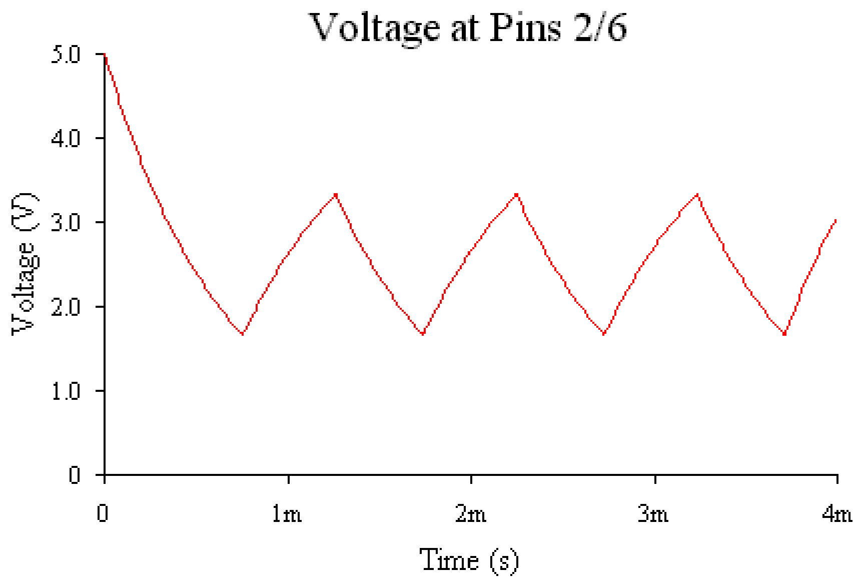

Figure 3. Timing voltage of 555 astable circuit as generated by Multisim.

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