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An Open-ended Laboratory System with Computer-aided Simulation for Undergraduate Electronic Engineering*

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An open-ended laboratory experiment program with computer-aided simulation has been successfully operated for undergraduate electronic engineering course over ten years. Such an innovative exercise gives students the feeling of a design environment for the real industry outside the academic world. It also encourages students using their individual creativity to learn about a particular electronic component or system in great detail.

INTRODUCTION

FOLLOWING the emergence of information technology and demands from industry, new initiatives on engineering education are progressively introduced into universities around the world, such as quality assurance management, creativity, communication processes, and project management [1–6].

We have introduced an open-ended laboratory system with computer-aided simulation for our undergraduate electronic engineering course. The new initiative has addressed all the criteria for our curricula implementation over a ten-year period. It had been proved to be very successful from the performance and feedback of students both during their course of studies and after graduation.

The new system is an open-ended experiment together with computer-aided simulation. Students can use their own initiative to decide which path to follow and how to do it properly and successfully, so that they really understand what is done in the experiments.

Feedback from graduates working in industry emphasizes that such systems improve learning ability and helps in employment opportunities.

CONVENTIONAL LABORATORY SYSTEM

Conventional undergraduate electronic engineering laboratory exercises use a step-by-step and carefully guided system for students to construct the circuit and measure a particular set of parameters. Generally, the preset exercises were produced many years ago by some academia, and are carried on for many years. Students generally do not understand the reason for doing the exercise but nevertheless will just do as asked. Sometimes, due to changing the lecturing order of the topic, students do not even know the basic principle of the components used in the experiment.

In this manner, they will spend many hours in library to collect information and produce many pages of theory for report writing. Some students may fabricate false results to fit the theory, and some may copy results from students of previous years or from other groups of classmates. The effectiveness of the program is thus seriously compromised in that students will learn very little from the exercise [7].

In the point of evaluation and assessment, traditional laboratory exercises have also proved to be ineffective and inefficient. Since the experiments were preset and pre-determined by the original compilers of the exercises, it is hard to determine what is good and what is bad in reports written by students. From their reports, it is difficult to assess the ability of an individual student in conducting the experiment. The so-called 'sign-on-spot' technique had been used previously and had overcome partial obstacles, in that a logbook of measurement must be kept by all students and is signed by the supervisor at the end of the session. The logbook is submitted to the supervisor with the full report [8]. However, it can prevent students using false results but still cannot answer the question of whether students fully understand the experiment that he or she had performed.

Due to financial constraints [9], students work in groups to perform an experiment. How to assess

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and determine the ability and capability of individual students becomes a problem. It is unfair to grade the group of students with equal marks. This is because the measurements and data collection may be performed only by one of the group, the analysis of the data may be done by another one, and the report may be written by yet another student (if there are more than two students in a group). It is also difficult to assess the creativity, mobility, and self-discipline of individual students, let alone the depth of his/her knowledge about the circuit, the system, and the function of the components that the students gained from the exercise [10].

OPEN-ENDED LABORATORY SYSTEM

Therefore, the present authors developed a system for undergraduate electronic engineering laboratory experiments. In the system, open-ended experiments together with computer-aided simulation is employed. This will not only lighten the budget for the department but also make students learn in greater detail during laboratory. Every one of the students can use his or her own initiative to decide which path to follow and how to do it properly, so that greater understanding is achieved later.

Feedback from former graduates in the last ten years or so indicates that all of them really enjoy such laboratory exercises. Furthermore, the graduates emphasize that such systems improve their learning ability and help them in their employment. Their supervisor or manager in industry often comments on the new graduates' initiatives and creativity in tackling problems; that is probably partly due to the influence by such a laboratory system.

The authors keep a copy of all the students' laboratory reports for the previous years to check out whether any copying of old reports has occurred.

Self-motivated technique

A self-motivated experiment is one that is open-ended in that no set pattern of experiment is pre-determined. Students use their own initiative and creativity to investigate a particular electronic component or system. The components can include various types of semiconductor diodes, bipolar junction transistors (BJTs, both NPN and PNP types), MOSFETs (both n-channel and p-channel), operational amplifiers (consists of either BJTs or MOSFETs, or both), combinational logic gates (different technologies), sequential logic gates, etc.

At the beginning of the semester in laboratory exercises, students will start with a common, simple circuit to introduce them into the experiment and concept of the particular component in circuit. For instance, we can investigate and plot the transfer and output characteristics of a NPN or PNP BJT. After the experiment, students will have the feeling of the physical property of a BJT. Following this, the future experiment(s) to be performed will depend entirely upon individual student. They will use their own creativity, ability and willingness to determine and design further and future experiments using the same component or integrated circuit as its core system component. Since students are expected to have reasonable knowledge of application principle of such component, the present experimental technique does not suit the first-year course and is only offered for second- and third-year undergraduate courses in countries such as the UK and Malaysia. For a four-year course such as those operated in Australia, New Zealand, Singapore, China, and the USA, the technique can be extended to the final year as an optional or elective subject.

After the first pre-set experiment, the supervisor must explain carefully in detail to the students about the method of the experiment so that they will know in advance what is expected of them. In this way, an opportunity is provided for the students to learn the proper use of library, methods of searching and selecting materials from a vast amount of information available, familiarity with the library system (both inside and outside the university), and the access of Internet information.

After all the information collection and selection, individual students will decide and design their own future experiment(s) for the whole year. At this stage, they should make very sure that they understand all the experiments in details. Any doubt of any part in any experiment must be cleared up either by researching or consulting with classmates and supervisor before actually engaging on the real experiment(s). Of course, small and unforeseen problems may come up during the time of experiment, and consultation with the supervisor or laboratory tutor is necessary. Since the experimental exercises are open-ended, there will be no problem about completion on time.

Let us consider a simple example of an operational amplifier experiment so that the concept of the present system and method of exercises can be made crystal clear.

A simple operational amplifier (e.g. op-amp 741-type with power supply of 15 V) for linear inverting, non-inverting, and voltage follower functions is to be investigated with input from DC up to 1 MHz, and from a signal level of 0.1 V to 10 V. This simple circuit operation will demonstrate very clearly the function, capability, and limitation of the op-amp.

For the inverting and non-inverting amplifier configuration, only a pair of resistors is required as the passive component. By varying the resistance ratio of the circuit, different gain (output/input voltage level) of the stage can be obtained. The capacity of the op-amp is clearly shown in this example since the gain of the stage is completely independent of parameters of the op-amp. (Very detailed mathematical calculations on tolerances of the op-amp is not required for undergraduates). It is noted that for very large input signal such as 10 V, a large resistance ratio (e.g. 10:1) will produce a distorted output because it is larger than the supply rail (15 V). In other words, expected output of $10 \times 10 = 100$ V had been clamped down to about 15 V, which is obviously not the correct answer. Again, if input signal is of a very high frequency nature such as 1 MHz, the output will drop down to near zero because the maximum op-amp frequency of a 741-type is in the range of a few kilohertz. Limitations and abilities of the op-amp are clearly indicated in such an experiment.

The computer simulation of the circuit is simple. Generally, the simulated results are very close to the physically measured values. However, due to the tolerances of the two resistors, 100% matching of data from measured and simulated results is impossible. Such simple circuits thus provides fundamental information about the components for students in carrying out their future experiments and computer simulation.

After the initial experiment together with some theoretical background knowledge of electronic application, students will understand the basic principles of op-amps. Individual students will decide the next few experiments that are using op-amp(s) as the core component. Many different paths can be followed depending solely upon the students' creativity, willingness, and capability. In general, no one will do the same experiment as others do. For instance:

- one student may perform addition, subtraction and scaling, differentiation and integration, analog computation;
- the second student may perform logarithmic and antilogarithmic amplification, voltage comparison, Schmitt triggering;
- the third student may perform instrumentation amplification, waveform generation using various techniques;
- the fourth student may perform clipping, clamping, rectification, active filtering;
- the fifth student may perform feedback-regulated power supplies, 4-quadrant multiplication, automatic gain controlling (AGC);
- the sixth student may perform active filtering using different configurations and different degrees of orders.

No student need follow a set pattern to perform and engage the experiments. Since it is open-ended, the extensiveness and details of the experiment are unlimited.

This method provides opportunity for students to learn to use library, method of searching for required material information, familiarize with the library system, and the ability in using the Internet to collect information. It also trains them to be able to assimilate and select the useful and appropriate materials from a vast amount of information available.

Assessment of the experiment will be based on certain factors such as creativity, depth of the experiment, report writing, result discussion and analysis, originality of the experiment including techniques and analysis, etc. The number of experiments that a student has completed is unimportant in this case because rushing to complete as much experiments as possible does not make them understand and comprehend the experiment.

Computer-aided simulation application

Present-day industry requires and demands engineers to possess the skill and ability to use computer-aided simulation techniques and construct hardware systems to physically measure the data. Therefore, in the present open-ended, self-determined laboratory experiment, students must perform a computer-aided simulation for every experiment before carrying out the physical construction and measurement of the system.

Computer-aided technique uses a simulator to implement test instrumentation in software form. The design is analyzed and verified by displaying waveforms and timing information without building the real hardware [11].

Systems designed by computer simulation procedures are typically of higher quality. In other words, simulation makes it much easier to optimize a design. When the design is optimized, transition from design stage to manufacturing stage is much smoother. Computer circuit design goes through many technical procedures that are otherwise impossible in physical assessment, such as:

- probe nodes which may not be accessible in an actual circuit or system;
- observe waveforms and frequency response without loading the circuit or system;
- avoid parasites introduced by the breadboard but which will not be present when the actual circuit is fabricated;
- use device models which represent the integrated circuit devices as opposed to their discrete approximations;
- do sensitivity, worst case, and statistical analysis;
- do circuit optimization routines;
- gain better understanding of the circuit or system behavior by using ideal devices selectively to isolate the effects of various device parameters;
- feeding ideal waveforms, such as extremely fast pulses, into the circuit;
- separating DC, AC, and transient behavior;
- opening feedback loops without disturbing the circuit or system behavior.

The simulation exercise is usually done outside normal laboratory time, either using laboratory computers or using PC at home. Such simulation software packages as PSPICE, Micro-CAD, and Electronic Workbench are to be made available for students to use at home computers.

Table 1.

Conventional laboratory	Open-ended laboratory
pre-set parameter measurement	individual initiative
experiment set by former academia	decided by individual student
with little or no knowledge of the experiment	completely understand the theory and procedure of the exercise
report writing contains large portion of theory that the student may not understand	student knows anything that he/she writes
students tend to fabricate data that do not agree with the theory	any out-of-ordinary text points can be checked and corrected immediately
group of students doing the same experiment	single student doing individual experiment
evaluation and grading of reports is difficult to be unbiased due to group exercise	individual performance gives unbiased assessment
if theory is not covered in lecture, mistakes of measured results cannot be corrected	computer-aided simulation before physical measurement will reveal any mistakes during the measurement period
only physical measurement is performed	both physical measurement and computer-aided simulation are performed

Students can optimize the circuit or system from simulation, and record the required result (behavior). Physical measurement is performed during normal laboratory time with supervision of instructors and tutors with the help of technical staff members [12]. When it is necessary, students are allowed to come back at evening to do further measurement work without the guidance of staffs but with the approval of the supervisor.

Results obtained from measurement in the laboratory are used to compare with those obtained by simulation. Any discrepancy can be rectified and corrected immediately during the laboratory classes. In the report writing stage, discussion and comparison of results on both parts are required.

Assessment and evaluation of students' performance is an enormous task for the supervisor because every student will submit a different report with each experiment. In this case, the task in most cases cannot be assigned to postgraduates unless they have a lot of instruction and/or industrial experience. However, since the supervisor does understand individual students' laboratory exercises and has personally involved with the physical measurement process, he/she will be able to assess every student's performance, effort, ability and capability much fairer. No result or data copy from each other or from students of previous years will be possible.

COMPARISON OF CONVENTIONAL AND OPEN-ENDED LABORATORY SYSTEMS

Conventional undergraduate electronic engineering laboratory exercises lack consistency and the capability to fully utilize the students' creativity and willingness in reading and learning. The step-by-step guided manner for students to construct the circuit and measure a particular set of parameters completely ignores the students' ability and knowledge of the topic they are engaged upon. The present open-ended system with computer-aided simulation overcomes such problem as indicated above. It also improves the students' ability in using computer as simulation tools since it is required by industry for all the engineers.

Table 1 compares the two systems of laboratory experiment.

CONCLUSION

A new approach to electronic laboratory experiment for undergraduate course has been implemented with success. The new technique uses an open-ended approach with the aid of computer simulation to complete the task.

After completing the exercise, all students will learn in great details of the principle, function, capability, range of application, and the limitation of a particular electronic component or system. The students do not follow a preset pattern to perform an experiment. Instead, all of them use their individual talent, ability, electronic knowledge, and effort to select appropriate experimental exercises to perform. By the combination of physical measurement and computer simulation, they also learn to use and appreciate the available software in the market. After going through such exercises, the students had equipped themselves fully to face the real industrial world.

The present technique does have some drawbacks, mainly:

- it can not be used for first-year undergraduate laboratory because the students have too little knowledge of electronics;
- it puts heavy loading on the supervisors in report assessment and evaluation because all students perform different experiments and write different reports;
- laboratory supervision is difficult because every student works on different experiments at the same time;
- supervisor and laboratory staff require more time to prepare and assemble the required instruments for the laboratory experiments;
- normal laboratory period is not sufficient, and

evening classes for the experiment is generally necessary;

- due to constraints of time, less than normal (conventional) exercises will be able to be carried out over the whole year (that is in quantity and not in quality).

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