Reengineering Electrical Engineering Undergraduate Laboratories at Escola Politécnica, University of São Paulo

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Abstract *- Brazilian Engineering Schools are under a strong program to re-engineer their courses with the financial support of Federal Agencies. At our Department, this process started by modifying the Basic Electricity and Electronic Laboratories. In this work, we describe the new structure of these labs and the approaches taken in order to improve our experimental engineering courses. After one year, various benefits resulting from these actions could already be observed: higher level reports, higher marks, less failures, and above all, a great enthusiasm and interest that the new equipments and methodologies have risen in our students.*

I. Introduction

Brazilian Engineering Schools are under a strong program, named REENGE [1], to re-engineer their courses and curricula with the financial support of Federal Agencies (FINEP, CAPES, CNPq and MEC/SESU). The REENGE started at the end of 1995, involving 24 Institutions all over the country. The main goal during the first step of the program (1996-1997) was to adapt the basic engineering courses to the new available technologies, in order to increase motivation among the students and meet the requirements for modern engineering education.

At the Dept. of Electronic Engineering, Escola Politécnica, University of São Paulo (EPUSP), this process started by modifying the Basic Electricity and Electronic Laboratories.

The four disciplines associated with these laboratories are offered to all 180 third-year Electrical Engineering students, during two semesters. They are composed of 40 experiments and count for 240 credit hours of our five-year curriculum.

These two laboratories are the first engineering practical disciplines our students are faced with. Therefore they must be appealing, yet giving a solid understanding of basic electrical principles and the real taste for hands-on practice.

Before the REENGE program, the procedure involving each experiment was divided into three steps: - *the pre-Lab activities* consisted on a review of theoretical concepts and the design of the experiment (based on given instructions), including calculations and simulations; -*the Laboratory session*, where the students assembled components and equipments, made the measurements (usually very time-consuming), and quickly checked the results; - and *the post-Lab activities* which meant heavy work on analyzing data and preparing reports with graphs, tables, comparisons between expected and measured results and conclusions.

Our modernization project has been motivated by observing several problems we had in the past with such structure, including a low impact on students' interest, the poor interrelation between theoretical and experimental disciplines, the excessive time to conduct the experiments and to elaborate the reports.

The most serious problem was that the experiments could not be carried out with immediate careful correlation and analysis of results. For this reason, the students frequently would come to the conclusion (after the laboratory session) that their setup was defective and that their results were not as expected. This led many of the students to the impression that practical experiments (or real-world engineering) were well beyond their capacity of understanding. Also, although experiments were conducted by teams of three students, the processing and analysis of results, being a post-class activity, was usually limited to individuals and lost all the benefits of cooperation and team work.

Other deficiencies of these laboratories and related courses were also brought up: a proper environment for practicing electronics was missed by the students who came to engineering expecting a more experimental course; no resources were available that could extend the learning process to the students' home, increasing their interest and motivation; the experiments were excessively guided, giving no chances (or time) for free investigations and development of creativeness; assessment was considered inadequate, as reports could be faked, and written examinations were applied, not really measuring students' abilities at the Laboratory benches.

II. The Modernization of the Basic Electricity and Electronic Laboratories at EPUSP

1. The new structure

In order to change the situation and try to solve the problems we have identified, our re-engineering

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project established some new approaches and methodologies. Each experiment is now divided into two phases (figure 1):

a) Before laboratory session, the students are assigned with some tasks, such as the re-enforcement of basic concepts, or the design of a given circuit and its simulation. Therefore, they have previous knowledge on what to expect during the practical experiment.

b) In the laboratory, the students must assemble the circuits, connect the equipments, make the measurements, compare the data to the expected behavior (and correct deviations) and deliver a report to the professor. They have approximately 4 hours to conduct each laboratory session (they are throughout assisted by a professor during the practical session). This integrated sequence heavily stimulates interaction among students and between students and professor.

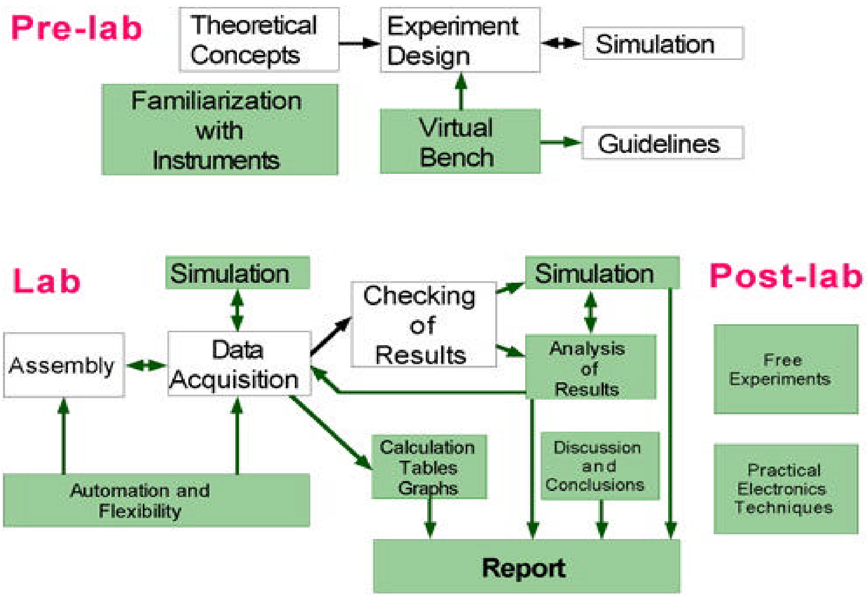

Figure 1. Laboratory activities: the shaded boxes denote items included in the new approach.

In addition to this, an open laboratory environment has been conceived, where students can explore other experiments, born from their own creativeness; they can repeat any procedures that have not been clearly understood during the laboratory session, or get better acquainted with measuring equipments and instrumentation practices. In this laboratory, the students are self-guided and no credit hours are counted or demanded for their activities.

2. The new resources

As the laboratory session is highly demanding in terms of efficiency and reliability, it required new instruments and general hardware and software [2]. A diagram of the laboratory arrangement is shown in figure 2.

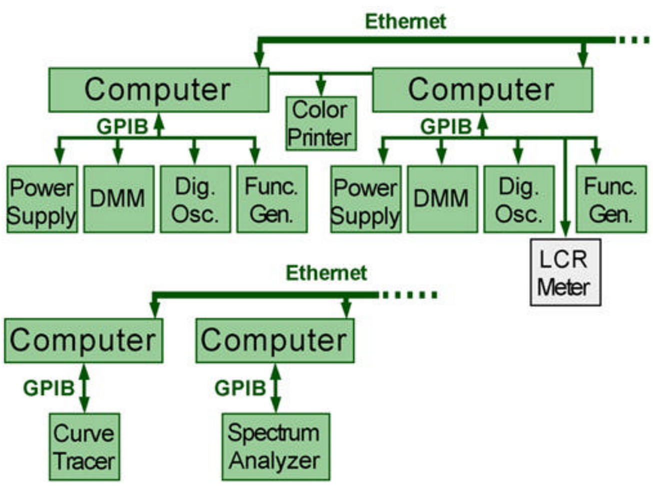

Figure 2. Laboratory setup. Each two benches share a color printer.

Each of the 20 benches is equipped with a 100MHz dual channel digital oscilloscope, a 15MHz arbitrary waveform generator, a digital multimeter and an adjustable power supply. Besides, some extra equipments are also available: 10 benches have variable frequency RLC meters, one bench has a Semiconductor DC Characterization Curve Tracer and one bench has a 9kHz-1.8GHz spectrum analyzer.

A key point of innovation is that all equipments have GPIB ports, so that the students can make measurements through a computer link (some of the equipments can be shared by all benches). The benches have a computer connected to the instruments via a GPIB board. A 12 bit DAQ board is also installed within each computer. The communication between computer and instruments is handled by the software LabVIEW Full Development System for Windows 95, by National Instruments [3]. A color inkjet printer is shared by every two benches.

Experience has shown that this arrangement has enough flexibility to easily accommodate new experiments and to allow further investigation by the students. At the same time it has the necessary robustness to survive 24 hours per week of intensive use.

3. Designing the experiments in the new approach

The list of current experiments is shown in table 1. Basically, these experiments tackle the same topics as before the modernization. However, all experiments have been redesigned using the new resources and approach.

Table 1. Current list of experiments

	Electricity Sessions	Electronic Sessions
1st semester	1- Analog Oscilloscope 2- Analog Multimeter 3- Digital Multimeter 4- Digital Signal Acquisition 5- Wheatstone Bridge 6- Inductors and Inductance 7- LC Parameter Measurements 8- Digital Oscilloscope 9- Grounding Resistance Measurements 10- Fourier Analysis of Periodical Signals 11- Natural Complex Frequency Measurements 12- Passive Filter Design	1- Rectifiers 2- Voltage and Current Linear Power Supplies 3- Transistor Bias 4- Junction FETs 5- Transistors as Switches (Bipolar and PowerFET) 6- Power Devices 7- Differential Amplifiers 8- Small Signal Amplifiers
2nd semester	1- Industrial Anmeters and Voltmeters 2- Power and Power Factor Measurements 3- Resonant Circuits 4- Modeling of Fluorescent Lamps 5- LabVIEW Tutorial 6- Frequency Response of Electronic Amplifier 7- Three-Phase Circuits 8- Losses in Magnetic Materials 9- Impedance Bridges 10- Characterization of Magnetic Materials 11- Transients in Transmission Lines 12- Signal Spectral Analysis	1- Operational Amplifiers 2- CMOS Integrated Circuits 3- Multistage Amplifiers 4- RC Oscillators 5- Schmitt Trigger Circuits 6- Sweeping Generators 7- Switched-Mode Power Supplies 8- Multivibrators

During the first experiments, the laboratory environment [4] is carefully prepared so that the students can become familiar with instrumentation, its operation and procedures for assembling and testing electronic circuits. Furthermore, they are able to confront expected figures with real circuit data during the lab session from the beginning of the course. A useful tool in this process is the use of data grabbers, which are only possible in this automated environment: the students implement the circuit under analysis, adjust the instruments as required, and run a software routine to grab all important data such as instrument settings, waveforms, and voltage/time magnitudes, as illustrated in figure 3 for the oscilloscope data grabber. These data are automatically printed and appear on the report. During the assessment, special attention is placed on the students' ability to set the instruments and to make the circuit operate properly. A mistake is easily identified by the professor as all settings are available, without subjective interpretation.

As the students become proficient with the instruments, the experiments become more complex, involving large amounts of data extraction and analysis. This typically includes the concept of setting parameters, reading variables, analyzing and presenting data in a step-by-step procedure, which could be boring, time consuming and prone to error. In these cases, automation of the measurement procedures was introduced to allow time for careful analysis of results during data extraction. An example of this approach is shown in figure 4 for the analysis and characterization of a resonant circuit. Two factors are evaluated before automating a procedure: a) the students must have done that procedure manually at least once before; b) the automation should run smoothly only if students set the instruments correctly at the first step of the process and make an educated guess of what the expected values are.

Active learning and group discussions on complex concepts are also stimulated by routines which allow interactive analysis, using various different values of parameters, such as illustrated in figure 5.

Another situation arises when the quantities to be analyzed are not measured directly, involving complex calculations that by themselves are part of the experiment interpretation. In this case, an interactive tool is used for the students and for the professor. The students acquire the data that are transferred to tables in a software program. In this program, side by side with the table, there is a blank panel which mimics a chalkboard where the students write literal expressions with the purpose of determining the quantities that cannot be measured directly but are related to the measured parameters. By running the program, the expressions are evaluated considering the actual parameters of the experiment, and the results are automatically placed on a table of results. In this case, data analysis is more complex: the students have a feeling about the order of magnitude, but they cannot straightforwardly verify if their analysis is correct. This task is time consuming even to the professor, since the calculation is made with real data. To solve this problem, a third table can be password activated by the professor giving the correct results. From this point on, if necessary, the students analyze their calculation procedures based on true expected calculations. An example is illustrated in figure 6, where the rise and fall times of voltage and current waveforms are used to estimate basic switching parameters of a transistor.

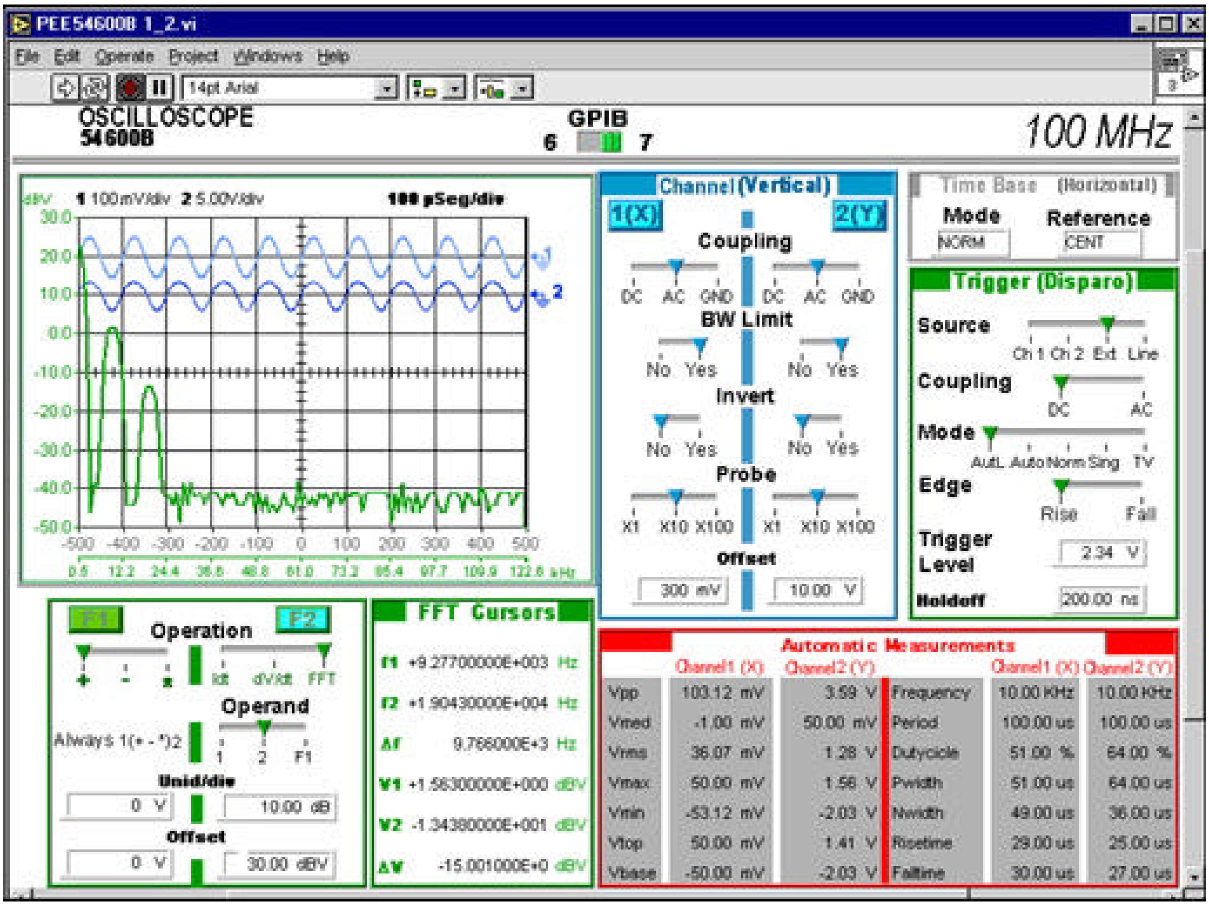

Figure 3. Oscilloscope Data Grabber showing an input sine wave on channel 1 (top), the output sine wave on channel 2 (middle) and its FFT (bottom). The professor can immediately visualize all settings of the oscilloscope.

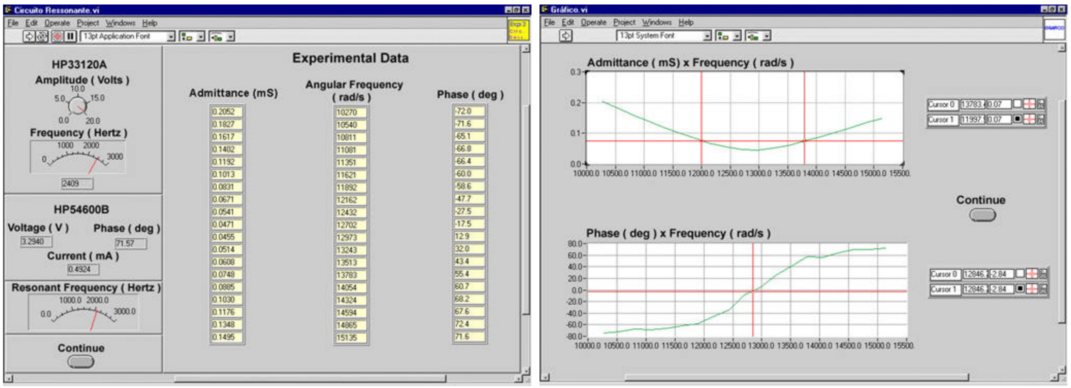

Figure 4. Resonant circuit analysis: Table showing collected admittance data and graphs for identifying resonance.

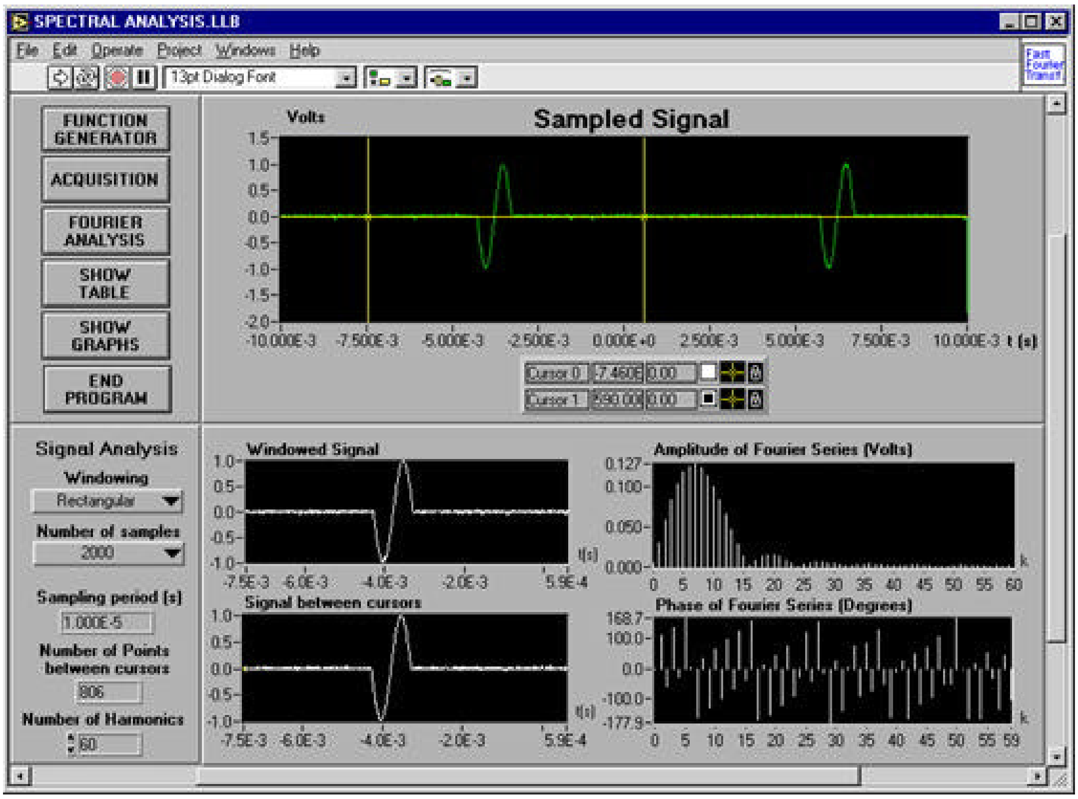

Figure 5. Routine for Fourier analysis of signals: spectra of various signals, calculated through DFT are presented; effect of windowing and sample rate can be easily analyzed.

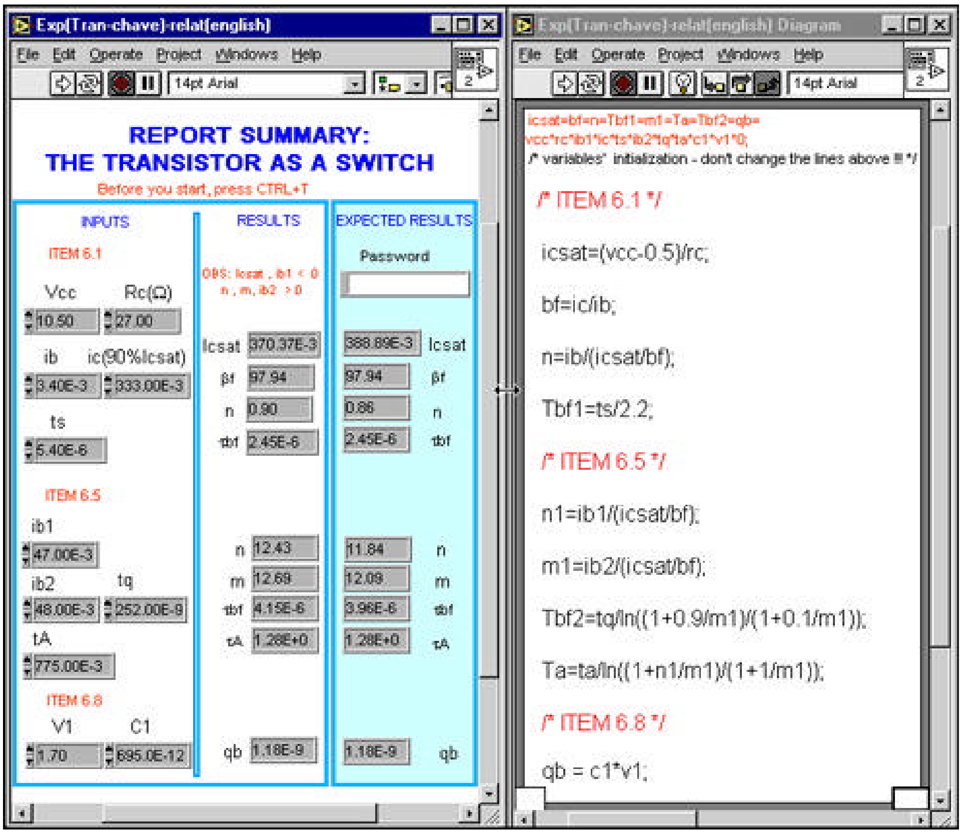

Figure 6. Electronic chalkboard with tables on the left and the board on the right.

With the new approach, it is also possible to explore experiments within a higher level of abstraction: the students are challenged to design an experiment on Fourier synthesis, by means of a routine that instructs an arbitrary waveform generator to produce a signal in the time domain, which contains the requested frequency components, as shown in figure 7. To check their implementation, the students measure the synthesized signal with an oscilloscope equipped with an FFT module. In this case, nothing runs without the commitment of the students. This experiment was idealized by some of our own undergraduate students, who are closely involved with the laboratory project.

These examples clearly show that the new approach keeps the basic concepts of the disciplines, while enhancing their interactivity.

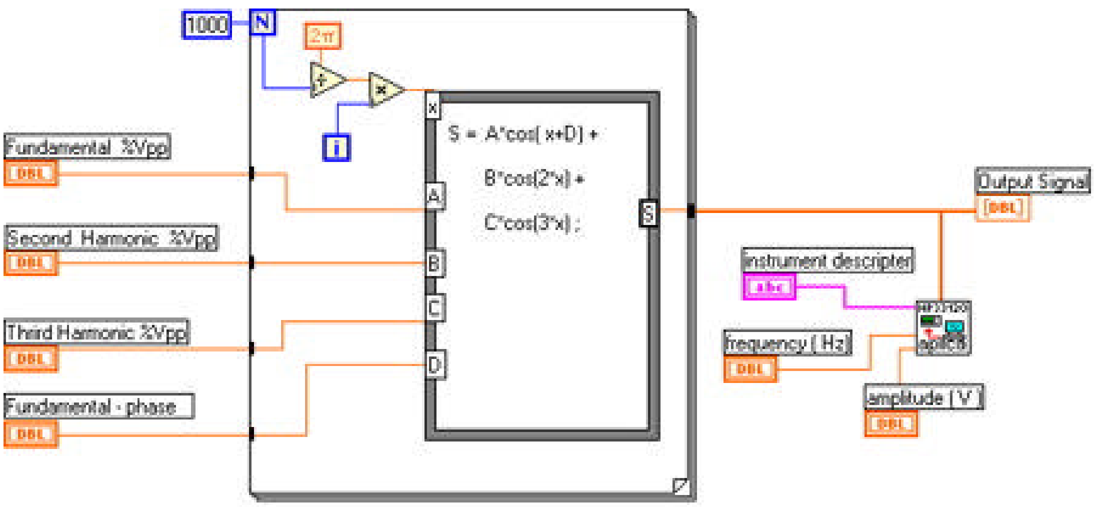

Figure 7. Graphical language program of the Fourier synthesis. The smalll squared box on the right of the instrument descripter label is a subroutine to communicate with the arbitrary function generator.

III. The Open Laboratory

The Open Laboratory, currently under construction, occupies an area of 50 m^2 as shown in figure 8. It is being implemented with four inner rooms equipped with the same kind of instruments as the Basic Electricity and Electronic Laboratories, but without GPIB connections. These equipments are in fact the ones previously used in the Laboratories.

Additionally, in the Open Laboratory there is a Design Center where students can simulate electronic circuits and design double-face PCBs directly from the schematic circuit using the PSpice & PCboards Professional Software Package from MicroSim Corporation [5], as well as generate output to manufacture the boards. Finally there is a simple bench where they can manufacture and assemble the boards. This way, the Open Laboratory gives opportunity to the students of going from design to production in a single environment.

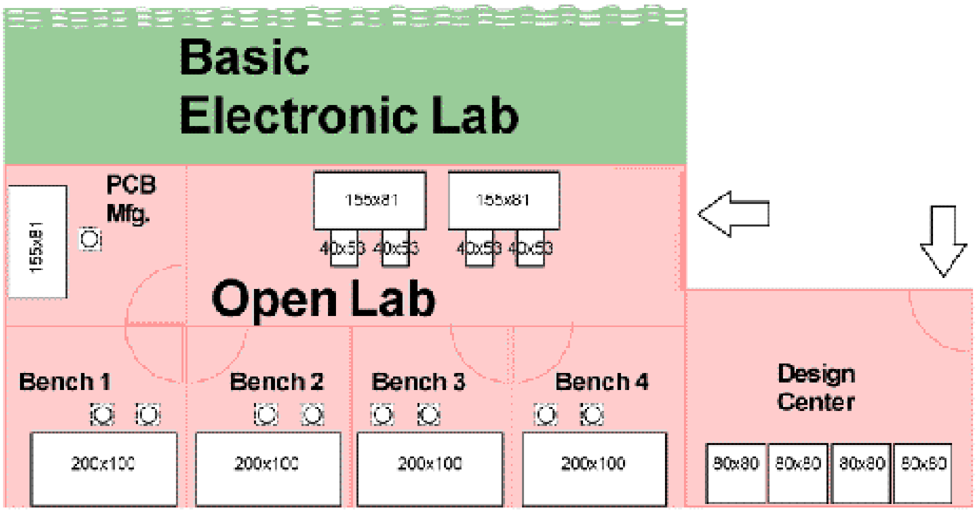

Figure 8. The Open Laboratory (dimensions in cm). A typical product cycle goes from the Design Center to the PCB Manufacturing Room and then to one of the four measurement benches.

In order to have access to one of the rooms, the student must make a reservation at the entrance desk in advance. The student receives an electronic access card which allows the use of that room for a pre-defined 2-hour period. The Open Laboratory will be open from 8:00am to 6:00pm during working days and depending on demand, this time-table can be expanded.

The students must be enrolled in one of the laboratory courses to use the Open Laboratory. They can complement their laboratory skills in several ways: making course related projects, acquiring as much hands-on experience as they feel necessary, developing their own designs, etc.

IV. Conclusions

Innovative resources and teaching techniques have been implanted at the Basic Electricity and Electronic Laboratories, Dept. of Electronic Engineering, Escola Politécnica, University of São Paulo (EPUSP). Under this re-engineering program, the Laboratories have been fully re-equipped with basic modern instruments, all containing GPIB interfaces for providing automated computer-controlled measurements. A graphical programming language for building instrumentation systems has been installed for control and data processing, and it has been applied in many procedures for enriching the original experiments. With these new resources, the students can promptly compare experimental and theoretical data; develop their ability in designing, assembling and characterizing engineering sub-systems; make use of interactive tools for understanding complex concepts; and produce their reports in real-time. As part of the same program, an Open Laboratory is being mounted with facilities (computers, software, instruments and printed circuit manufacturing benches) to allow the students to complement their laboratory skills, for example, developing their own designs, and acquiring as much hands-on experience as they feel necessary.

We are finishing our second semester after implementing the changes in our Laboratories. Various benefits could already be observed: higher level reports, higher marks, less failures, and above all, a great motivation and interest that the new equipments and methodologies have risen in our students.

An initial assessment of the program has been applied at the end of 1997: the third year students, who have experienced the first two disciplines under the old structure (1st semester 1997), and the two last, already affected by the new model (2nd semester 1997), were asked to fill a questionnaire, comparing both schemes. All the replies were very favorable to the modifications. Some suggestions regarding the experiments instructions are being implemented, together with many other improvements to the experiments.

Response from professors has also been positive. Extra efforts have been demanded from them in terms of learning how to operate the new equipments, using the new software, and applying techniques to stimulate students to get the reports finished at the end of the laboratory session. However they have been motivated by the potential offered by the new resources, and some are planning to use the laboratories and to apply the new techniques in their research projects and with their graduate students.

V. Acknowledgments

The REENGE program has been supported by MEC/SESU, FINEP, CAPES and CNPq, Brazilian Federal Agencies. We are grateful to many professors at our Department who are greatly contributing to the success of this project. In special, we thank our talented students, who intensively participated as trainees in the project, and dedicated their time and enthusiasm in making our dreams come true: Alexandre Tau Lema, Edison Pereira de Almeida, Eduardo Prevedello Bento, Emerson Hideki Deguchi, Filipe Medeiros Braga, Harm Daenekas Petrola Jorge, Jan Leduc de Lara, Kleber Wellington Tolezani, Luciano Otávio Gomes Fonseca, Luís Augusto Derani, Luiz Henrique Soares Rosa, Marcos Eiji Otsuki, Mílton S. Morais Jr., Paulo Roberto da Silva Sobrinho, and Rogério Takashi Fujimoto.

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[2] http://www.lsi.usp.br/poli/graduacao/projgrad.html

[3] LabVIEW is a registered trademark of National Instruments, 6504 Bridge Point Parkway, Austin, Texas, U.S.A. (http://digital.natinst.com/brazil.nsf)

[4] Seabra, A. C. e Consonni, D. "Re-engineering Undergraduate Laboratories with LabVIEW", Instrumentation Newsletter, National Instruments, vol. 10(2), Summer 1998, pp. A-3.

[5] PSpice is a registered trademark of MicroSim Corporation, 20 Fairbanks, Irvine, CA, USA. (http://www.microsim.com)