

VI-Based Introductory Electrical Engineering Laboratory Course*

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The introductory electrical engineering laboratory course at the University of Texas has been converted to an approach that relies mainly on virtual instrumentation. Experience with the conversion shows reduced technician demand for the laboratory, increased ease of use for the students, and the capability to add new measurements that were unaffordable with free-standing instruments. The experience also shows how virtual instruments might be adapted to laboratory courses with different emphasis and approach from ours.

INTRODUCTION

THIS PAPER is a progress report on the conversion of the introductory electrical engineering laboratory course at the University of Texas to virtual instrumentation based on National Instruments' Virtual Bench™ and LabVIEW™ software. The new course was taught for the first time during the spring semester of 1997, and there have been continuing updates since. The rationale for the conversion, and the approach to implement it are described below.

RATIONALE

Emerging dominance of daq instrumentation

Industry and research laboratories have felt the pinch of rising costs of laboratory instrumentation along with undergraduate university laboratories. This trend created a strong market for laboratory instruments based on the personal computer. The appropriate software, operating through a plug-in digital acquisition (DAQ) board or card in the computer, can create the virtual instrument equivalent of \$30–80 K worth of conventional electronics laboratory instrumentation with an order-of-magnitude cost reduction. Thus, it is far from surprising that these virtual instruments are rapidly replacing their free-standing counterparts in the industrial facilities that hire many electrical and computer engineering graduates. Since this type of instrumentation will soon be what the typical graduate will encounter on the job, undergraduate laboratory courses need to familiarize students with it.

Age of installed base of instrumentation in undergraduate labs

Whether organized as separate courses or appended to lecture courses, undergraduate

laboratories have typically been poorly equipped, compared to state-of-the-art laboratories inside or outside of academe. This situation has worsened as the pace of improvements in laboratory education has accelerated. The age of the installed base of instrumentation in the typical undergraduate electronics laboratory also imposes additional costs such as a) increased technician demand to keep older equipment operating, and b) the demotivating effect on students having to use such equipment. Some departments have opted to have students do less laboratory work and more simulation of electronic systems on the computer. However, for valid pedagogical reasons, many faculty members are reluctant to abandon real laboratory experiences for the students.

Ease of use as a student motivator

Since virtual instruments reside in the computer, a lot of the drudgery formerly associated with laboratory work and the production of a report on laboratory results can be reduced or eliminated. Both Virtual Bench and LabVIEW provide the capability to produce and print graphical versions of tabulated data, oscilloscope traces, frequency spectra, transistor curve traces, and the like. Furthermore, the look and feel of the instruments in Virtual Bench is so similar to that of free-standing instrumentation that the software becomes a teaching tool for training students to use the available hardware instruments. The principal difference between the two programs is that Virtual Bench provides its VIs to the user as LabVIEW executables, freeing the user from the need to learn any LabVIEW programming before performing measurements.

In summary, the use of *virtual* instruments to measure and test *real* electronic circuits offers these advantages in an undergraduate laboratory course:

1. Savings on both capital and maintenance costs for the laboratories.

* Accepted 9 September 1999.

2. Better student motivation from increased ease of use.
3. Instruction in laboratory techniques using equipment closely resembling what the student will encounter after graduation.

APPROACH AND PHILOSOPHY

Core test and measurement skills

Electronics laboratory courses at universities tend to be organized in one of two ways:

1. *Emphasis on measurement skills.* In these courses, the primary goal is learning to make certain measurements, such as step-function response, impedance or admittance, transfer function vs. frequency, etc. The circuits on which these measurements are performed are often kept very simple; for example, they may consist only of linear, passive components. The simplicity of the circuits may be a demotivating factor for the student, since such circuits often don't perform any 'interesting' function such as amplification, oscillation, etc.
2. *Emphasis on underlying electronics content from associated lecture courses.* These laboratory courses are often associated with certain theory courses in the curriculum. The primary goal is a greater understanding of the behavior of certain circuits; for example, single-stage bipolar junction transistor amplifiers, through observation of the circuit properties in the laboratory. The needed measurement skills are introduced just-in-time to perform a measurement, such as gain and phase shift versus frequency, which confirms the properties predicted by the analysis in the theory course.

The course described here takes the first approach above. To avoid making the example circuits too boring, they are chosen from various operational amplifier applications, since a wide variety of amplifiers, oscillators, filters, impedance converters, etc. can easily be constructed. For courses using the second approach, there is still a core of test/measurement skills that the student must acquire in order to verify the behavior of a circuit. These skills include the following:

1. *Generation of test signals.* Most testing of electrical and electronic circuits entails measuring the response to a test signal applied to an input. This test pattern is generally a combination of DC levels, sine waves, pulse trains, and perhaps white noise.
2. *Measurement of voltage and current waveforms in the time domain.* The oscilloscope is often the first instrument encountered by the student beyond simple voltmeters or ammeters. Issues of triggering, coupling, and limitations of the instrument with respect to sensitivity and speed are common to both virtual and free-standing types of instruments.

3. *Frequency domain measurements.* These tests include measurement of complex transfer function and impedance as functions of frequency as well as spectrum analysis of waveforms. Spectral analyzers, typically well out of the reach of most undergraduate laboratory budgets, are made affordable in Virtual Bench and LabVIEW.
4. *Parametric and small-signal measurements.* These tests include obtaining a family of current vs. voltage with voltage or current at another device terminal as a parameter, such as bipolar or field-effect transistor characteristics. Curve-tracers are typically required to measure the characteristic curves, while signal generators and oscilloscopes are sufficient to provide the parameters of a small-signal model for the device or circuit.

VIRTUAL BENCH, LABVIEW, OR BOTH?

Aside from the question of lab skills versus electronics concept reinforcement discussed above, the organizer of an undergraduate laboratory course built around virtual instrumentation faces yet another decision: whether to rely strictly on applications such as Virtual Bench for all of the virtual instrumentation used in the laboratory, or to let the students build their own VIs using LabVIEW. Neither of these choices is likely to work well in pure form. For an introductory electronics laboratory, Virtual Bench is not complete. For example, Virtual Bench has no curve-tracer for characterizing nonlinear electronic devices. The laboratory can either provide free-standing curve tracers, or a custom LabVIEW application that facilitates curve-tracing with a DAQ board. At the opposite extreme, few laboratory instructors can make time in their syllabi to teach LabVIEW programming from scratch.

Our introductory laboratory course began by using the Virtual Bench instruments for all the tasks they could do, and provided a LabVIEW application for curve-tracing with bipolar junction and field-effect transistors. This approach meshed well with the free-standing function generators, oscilloscopes, and other instruments that were also available at the student laboratory bench. The unique characteristics of computer-based, discrete-time systems, such as the limit on frequency imposed by the sampling theorem, can be easily illustrated if a (typically much faster) free-standing version of the same instrument is available for comparison.

Using Virtual Bench provides a bridge from the free-standing instrument world into the virtual instrumentation world, since its virtual instruments look so much like free-standing ones. However, as most experienced LabVIEW users know, the capability to create customized virtual instrumentation for a particular task changes the way a measurement problem is approached. Since

a virtual instrument is extremely customizable, the need to make it versatile in a general sense is greatly reduced. If the students already knew LabVIEW programming upon entering the laboratory course, or if sufficient time were available to teach it along with the other course content, they could build their own virtual instruments for measurement purposes and learn a great deal about instrumentation and measurement in the process.

A promising compromise, if very little time in the course can be set aside for instruction in LabVIEW programming, is to let the students learn this software the way they learn most other programs they use, such as word processors, spreadsheets, etc. A simple, one-sentence description of the process is this: define some small, but useful task you want to accomplish with the software and work at it until you accomplish it, then branch out into more difficult tasks. If the tasks involve data acquisition and subsequent processing, LabVIEW provides in its examples libraries some generic virtual instruments that the students can readily turn into function generators, oscilloscopes, spectrum analyzers and other virtual instruments useful for electronics measurement and testing with minimal additional modification in LabVIEW. Then, with a little more modification, they can modify these virtual instruments to eliminate some of the drudgery of going from the raw data to the desired measurement result.

As an example of the above argument for introducing custom virtual instrumentation,

consider the measurement of the complex transfer function. An oscilloscope-based solution to this problem consists of:

1. Exciting the input with a sine wave at the desired frequency.
2. Displaying the input and output on the oscilloscope.
3. Comparing amplitudes of the two sine waves and computing the ratio of output amplitude to input amplitude.
4. Measuring the delay between zero-crossings of the two sine waves and calculating the phase shift.

If Fourier transform techniques are used, the magnitude and phase of the transfer function are available directly from the waveforms of the input and output. The excitation need not be sinusoidal. It only needs to have a single dominant frequency. The virtual instrument for this measurement functions as a vector voltmeter at this dominant frequency. It is built by modifying the Acquire N Scans Multistart.vi from the Examples\daq\analogin library in LabVIEW. Figure 1 shows the diagram of this virtual instrument before any modification, as it appears in the LabVIEW library. The specifications for the modified virtual instrument are:

1. Compute the amplitude and phase spectra of the acquired input and output voltage waveforms,

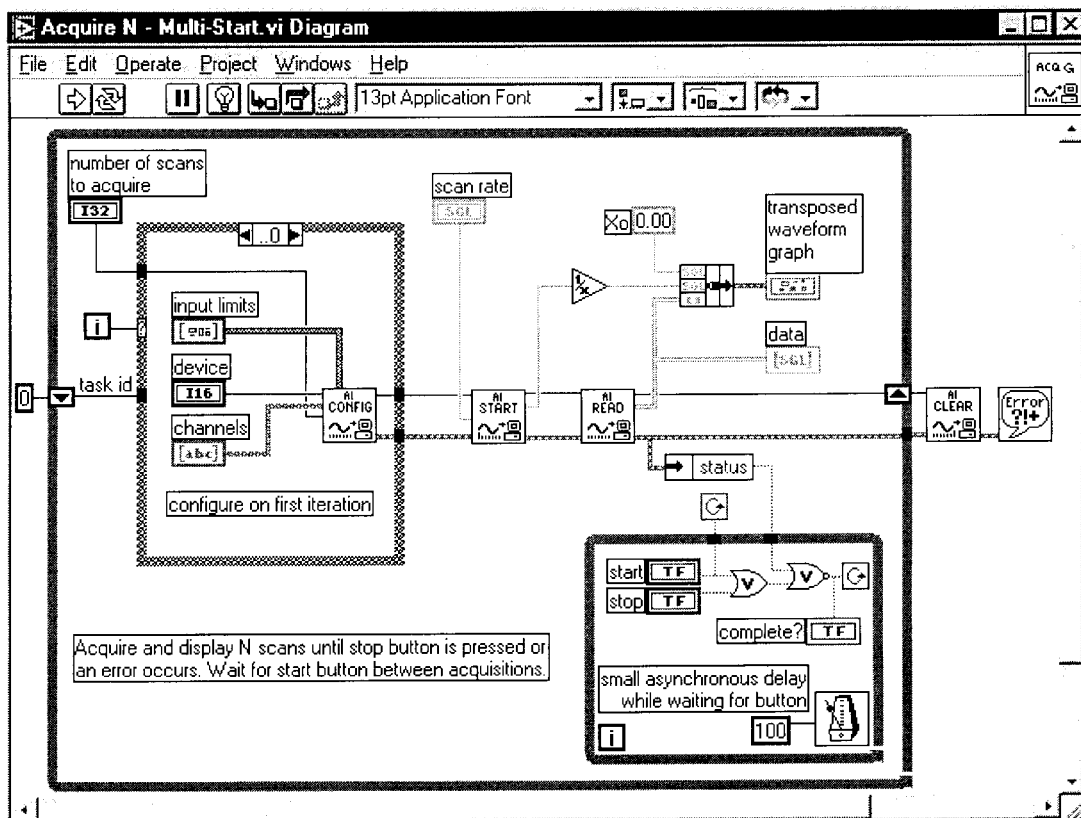


Fig. 1. The Acquire N Scans Multistart.vi as shipped in LabVIEW.

2. Display the amplitude spectra of the two waveforms,
3. Determine and display the peak frequency, f_p , (other than DC) for which the amplitude spectrum of the output voltage is a maximum,
4. Calculate and display the ratio, $|H|$, of the amplitude spectra of output and input at the frequency, f_p , and
5. Calculate and display the phase difference between the output and input components of the phase spectra at the frequency, f_p .

From these specifications, the student can modify the Acquire N Scans Multistart.vi diagram as shown in Fig. 2. The sub-VI, peak vvm, performs all the necessary calculations on the acquired waveforms. Since the student began this task with the Acquire N Scans Multistart.vi, he/she need not deal with any of the issues associated with the intermediate analog input VI's, but can concentrate entirely on building the peak vvm sub-VI, whose diagram is shown in Fig. 3. The data array is transposed, the input and output waveforms separated, and the output frequency with the peak amplitude determined. Last come the amplitude ratio and phase difference calculations at the peak frequency. Figure 4 shows the front panel of the main VI after a measurement.

This custom VI shows the following advantages over determining complex transfer functions using either a free-standing or virtual oscilloscope:

1. The input need not be a sine wave. Square, triangle, sawtooth and badly distorted waveforms work equally well as input.
2. The amplitude ratio and phase difference

calculations are part of the VI and need not be performed separately.

For future sessions of the laboratory course, additional LabVIEW VIs have been prepared which can be built by the student using relatively minor modifications of Examples\daq library VIs to perform the following functions:

- function generator for sine, square, and triangle waveforms;
- triggered waveform acquisition for use as an oscilloscope;
- single-frequency impedance measurement;
- spectrum analysis;
- broad-band transfer function measurement;
- curve-tracing for nonlinear three-terminal devices;
- measurement of exponential time constants.

Choice of example circuits for laboratory work

Every lab instructor has favorite examples for laboratory work. The following criteria were used in selecting circuit examples for our laboratory course:

1. *At least some student familiarity from lecture course content.* Time constraints argue strongly against introducing components which would require much lecture time to explain adequately. Our lab course requires co-registration in the introductory electronics theory course. The students have already taken an electrical circuits course that concentrates on passive, linear circuits.
2. *Many available electronic functions.* A stated

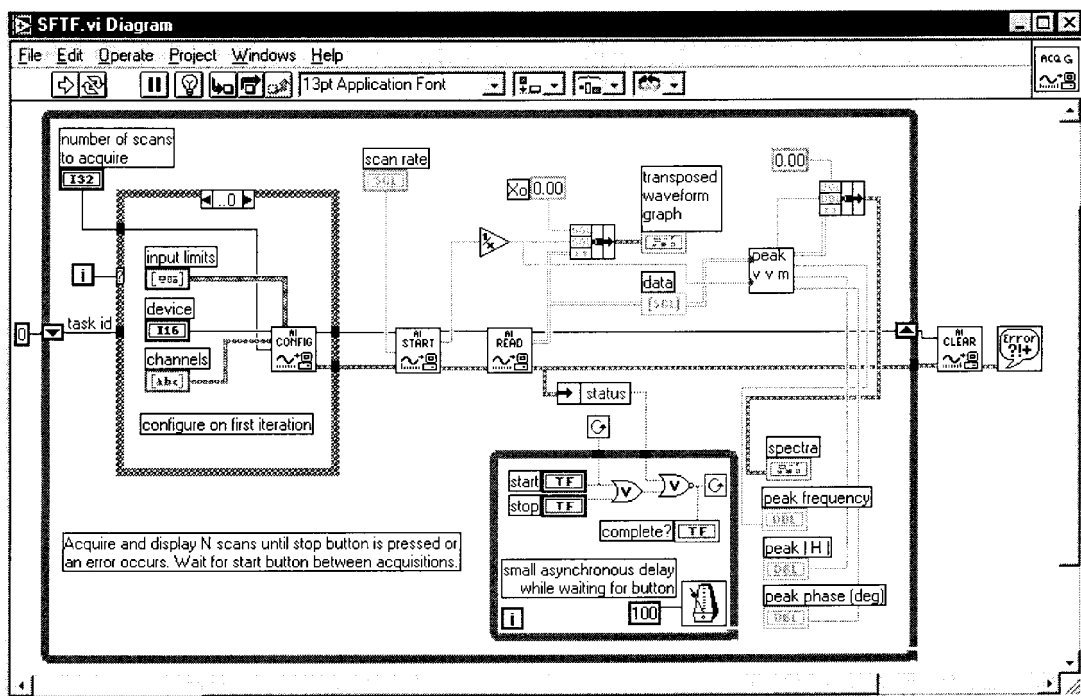


Fig. 2. The Transfer Function.vi diagram as modified from Fig. 1.

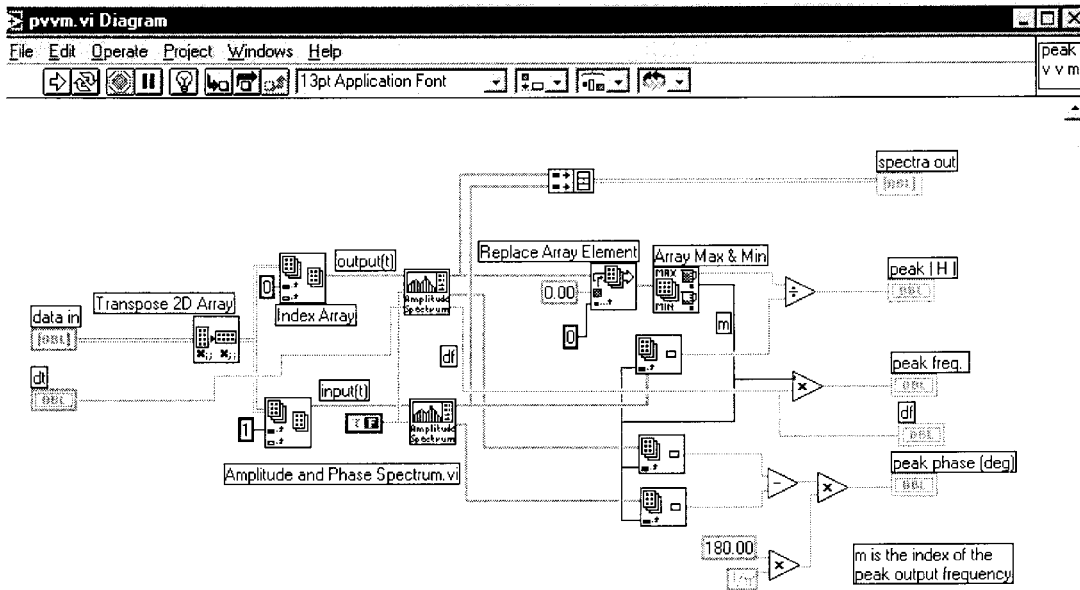


Fig. 3. The peak vvm sub-VI diagram.

goal of our course is to get the students building and testing 'interesting' circuits as quickly as possible. This means the building blocks used for the example circuits should permit realization of functions like amplification, filtering, modulation, and oscillation.

3. *Low cost.* Students typically come to the introductory laboratory course with no experience

building and testing electronic circuits. Inadvertent destruction of some components is inevitable.

4. *PSPICE models available.* PSPICE is the main analysis and simulation tool in the laboratory course. The students typically simulate a circuit before they build and test it. Only devices for which models exist in the freeware version of

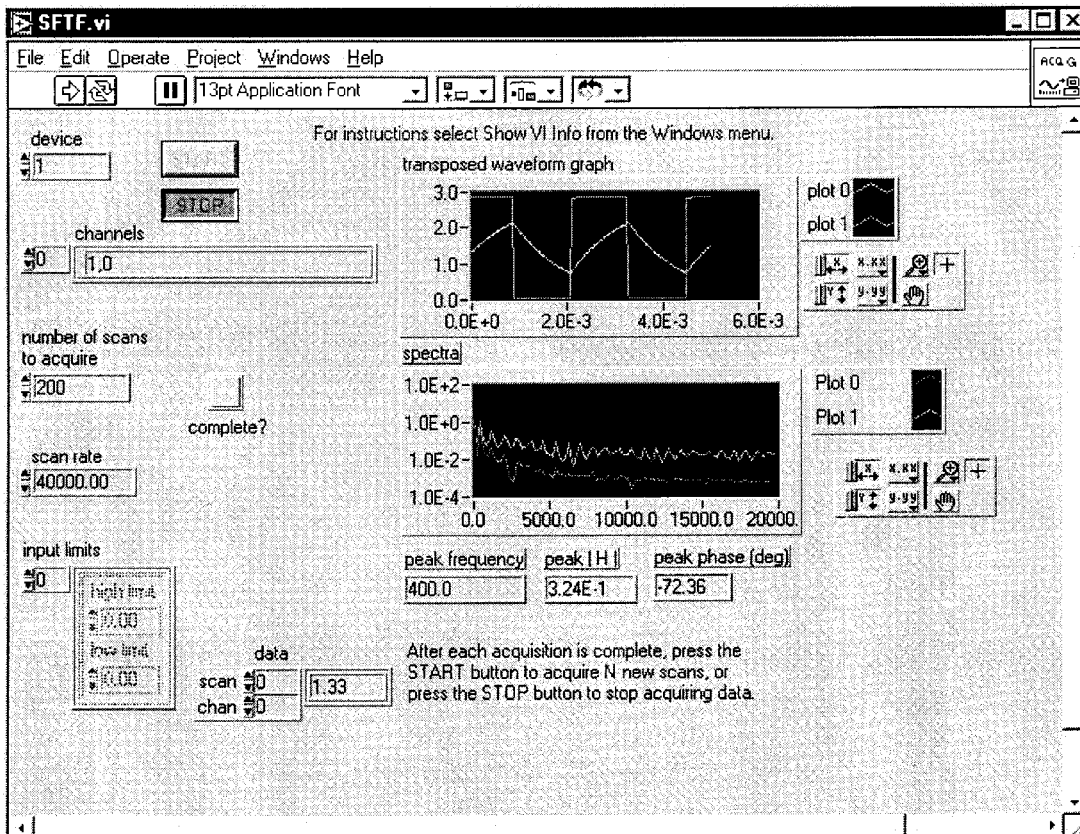


Fig. 4. Transfer Function.vi front panel after a measurement.

PSPICE available to academic institutions were considered for inclusion as circuit examples.

Based on these criteria, amplifiers, oscillators, filters, impedance converters and modulators based on operational amplifiers were chosen as the examples in our course.

SUMMARY AND CONCLUSION

Based on our experience with virtual instrumentation in the introductory electronics laboratory course, it is clear that such a course can be tailored to suit a variety of preferences concerning

content emphasis, amount of LabVIEW programming to be included, and choice of example circuits for laboratory work. If measurement skills are to be emphasized, then they can be studied in sequence and illustrated with chosen circuit examples. For an emphasis on reinforcing theory course content, circuit example selection is paramount and the measurement skills can be introduced only as needed. The amount of LabVIEW programming to be included dictates whether to have the students build their own custom measurement VIs or to rely on Virtual Bench instruments and prepared LabVIEW application programs.

A. Bruce Buckman is Professor of Electrical and Computer Engineering at the University of Texas at Austin, where he has been a faculty member for the past 25 years. His principal research interests are multivariable optical sensors and LabVIEW-based educational tools. His undergraduate and graduate degrees in electrical engineering are from Massachusetts Institute of Technology (1964) and the University of Nebraska (1968) respectively. He began his academic career on the faculty of the University of Nebraska. He is the author of a textbook in guided-wave optics, a text/workbook in computer-based measurements, and over thirty research publications. He serves as a consultant in optical sensors and signal processing for many companies ranging from start-ups to large corporations.