Session 2532

A Discovery Based Systems Laboratory using LabVIEW and MATLAB

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Abstract

The development of a discovery based learning laboratory for Systems is described. Sophomore Electrical Engineering and Computer Engineering students are introduced to concepts such as linearity, time invariance, frequency response, transient response, delay, and filtering by analyzing "black boxes" containing unknown electrical systems. LabVIEW is used to control programmable function generators which provide inputs to the systems and to gather output data from oscilloscopes. This testing environment can be automated to allow students to perform a wider range of tests than would be possible with manually controlled equipment. MATLAB is used to analyze the data and perform some simple system identification. Example systems given to students as "black boxes" range from simple filters to unusual non-linear and time-variant systems. A goal of this laboratory is to develop in students an intuitive and analytical understanding of the role that system properties play in design and characterization.

1. Introduction

In a typical linear systems course, students are expected to appreciate system properties such as linearity and time-invariance primarily by applying mathematical definitions to circuit or system models. In the laboratory, they typically have a limited appreciation of the importance of such properties. Much of their time is spent building and debugging simple circuits, and limited time remains for a detailed exploration of the behavior of the systems that they build. In early laboratories, we believe that learning can be increased by providing students with the equipment and resources to conduct their own investigation of the behavior of several "black box" unknown systems provided by the instructor. Concepts such as linearity can then be approached from a guided discovery standpoint. As their understanding of linear systems increases, this activity can progress to more formal and sophisticated modeling or system identification. Finally, when major concepts such as frequency response have been mastered the black boxes can be used to motivate the student design of equalizers or approximate inverse systems.

In a chemistry laboratory, students are frequently presented with an "unknown" sample which needs to be identified by testing for the presence of various substances. In a systems lab, a similar educational experience can be gained by giving students an unknown system and asking them to describe its behavior and properties qualitatively and quantitatively. With appropriate equipment at their disposal, they can ask questions like "What would happen if I applied a particular input?" "How does the output change when I modify the input in a particular way?" System properties like time-invariance and linearity become naturally important since they affect the ability to easily predict the output to new inputs. Having students discover for themselves some of the difficulties associated with nonlinear systems gives them greater understanding than merely memorizing definitions.

A laboratory to support discovery-style experiments must allow students to easily create any desired input and to measure and compare various outputs. Computer controlled programmable instruments combined with appropriate software packages are thus essential to such a lab. An arbitrary function generator (Hewlett Packard 33120A) and a storage oscilloscope (Hewlett Packard 54603B) controlled with LabVIEW allow for flexible input/output comparisons, and MATLAB is used for signal analysis.

1.1 Design Process

The systems laboratory is a part of a sequence of courses and laboratories intended to give students experience and understanding of an entire design process for electrical systems. In part, this is to prepare them for the larger and more open-ended design projects that they will face in their senior year. One model for such a design process is shown in Figure 1. For simplicity, the needed iterations and feedback paths are not shown. Students specify performance criteria by answering questions like: What is this system supposed to accomplish? How will I know if it works? They then design a circuit to meet the specification. They simulate the circuit and if it performs as expected, they construct it on a protoboard. Testing and measurement gather data that can be analyzed to see if the systems meets its performance criteria. For simplicity, the needed iterations and feedback paths are not shown.

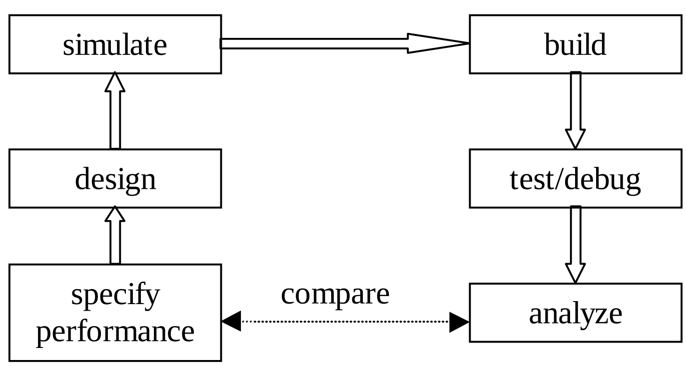

Figure 1: The Design Process

While the above mode is an eventual goal, students entering the systems laboratory are not yet prepared for it. Instead, we begin by using the simplified structure shown in Figure 2.

Students test a black box, analyze its behavior, and then try to construct a model that would exhibit similar behavior. Experience with this process prepares them for the complete design process.

Figure 2: Black Box Process

2. Course Background

The systems laboratory is part of the second course in circuits and systems taken typically in the middle of the sophomore year. The course covers models for signals and systems, transient analysis of simple RC and RL circuits, modeling using differential equations, convolution, the Laplace Transform, Frequency Response, Bode plots and Filter design. The ten weekly three hour laboratories are designed to closely follow the classroom portion of the course.

Upon entering, students have taken one course in steady state AC and DC circuits. They have considerable experience with MATLAB, but have not used LabVIEW, or computer controlled instruments. In order to avoid overloading students with new hardware and software systems, only a small subset of the capabilities of each system is used.

2.1 Goals of the Laboratory

Our experience in teaching previous versions of this course is that students fail to relate the abstract definitions of systems properties such as linearity to the behavior of a real system in the laboratory. They also confuse a model of a system with the system itself. Early laboratories are designed to take them through the process of gathering data from a physical system and contrasting it with the behavior of a model. They also analyze the data to determine if properties such as linearity are satisfied.

At the start of the course, students have limited experience with electronic circuit construction and debugging. One goal of the course is to prepare them for subsequent larger designs by developing good construction and testing skills. One way to insure this is that before building a circuit, students have analyzed a model so that they know approximately what to expect from the physical circuit. Minor discrepancies lead to an appreciation of the limitations and capabilities of physical components and commercial software packages.

2.2 Test Equipment

Student exposure to test equipment is kept as simple as possible, especially in the early laboratories. In the first experiment, students are shown how to use HPs Excel plug-in to copy waveform data and oscilloscope images into a spread sheet and from there into MATLAB. This allows them to perform basic analysis on laboratory data using very simple commands. By defining a theoretical waveform in Excel or MATLAB, they can easily compare it to their laboratory data and perform an error analysis. This type of comparison between theoretical prediction and experimental results becomes part of nearly every subsequent laboratory.

More sophisticated testing using LabVIEW virtual instruments is done primarily to simulate testing devices, such as spectrum analyzers, that are not present in the lab. Simple magnitude frequency response plots are obtained by having a LabVIEW virtual instrument (VI) program the function generator to output a sequence of frequencies while the oscilloscope measures the response. Students enter the start and stop frequencies and the step size, but do not need to be familiar with LabVIEW programming to use the VI. Future work will involve designing VIs to specifically test for system properties such as linearity and time invariance.

3. Black Box Example Systems

The "black box" example systems used in the labs have been designed to be as easy to use as possible. Figure 3 shows a diagram of one system. The input and output connections use BNC connectors and coaxial leads for noise suppression, while the power connections are through standard banana plugs. Voltage follower op-amp stages are used at the input and output to provide input and output impedances that are independent of the system being implemented. Voltage regulators are used to provide protection against errors in providing power, and the physical structure is designed to withstand dropping from a standard lab bench. The system being implemented is contained on a separate plug-in daughter board to allow easy replacement, and there are no external indications to the student of the type of system implemented inside. A serial number allows the instructor to identify the specific system. A schematic diagram of the motherboard is shown in Figure 4. The experiments summarized below involve teams of 2 students provided with one or more of the “black boxes” described above.

3.1 Illustrating System Properties

Linearity is illustrated in the first lab by providing each team with two systems, one of which is non-linear. Each team has systems that slightly different (in terms of gain or frequency response) from every other team. The linear system implements a simple one pole low pass or high pass filter with a cutoff frequency in the range from 1,000 Hz to 10,000 Hz, and the non-linear system is a square law device implemented using a balanced mixer. Students are asked to test each system and see if it obeys superposition. Input and output waveforms are analyzed in MATLAB to determine if the system is additive and homogeneous. They are also asked to qualitatively describe the effect that each system has on a variety of inputs (various frequencies, polarities and shapes) and to speculate about what the system is doing.

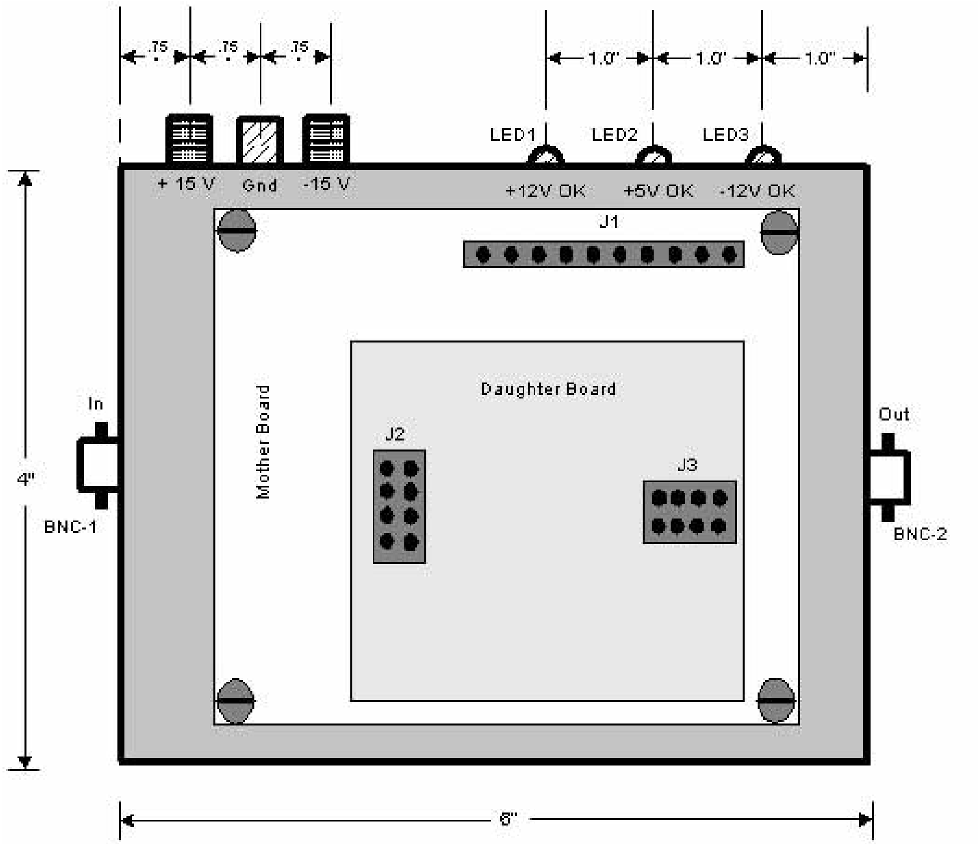

Figure 3: "Black Box Layout

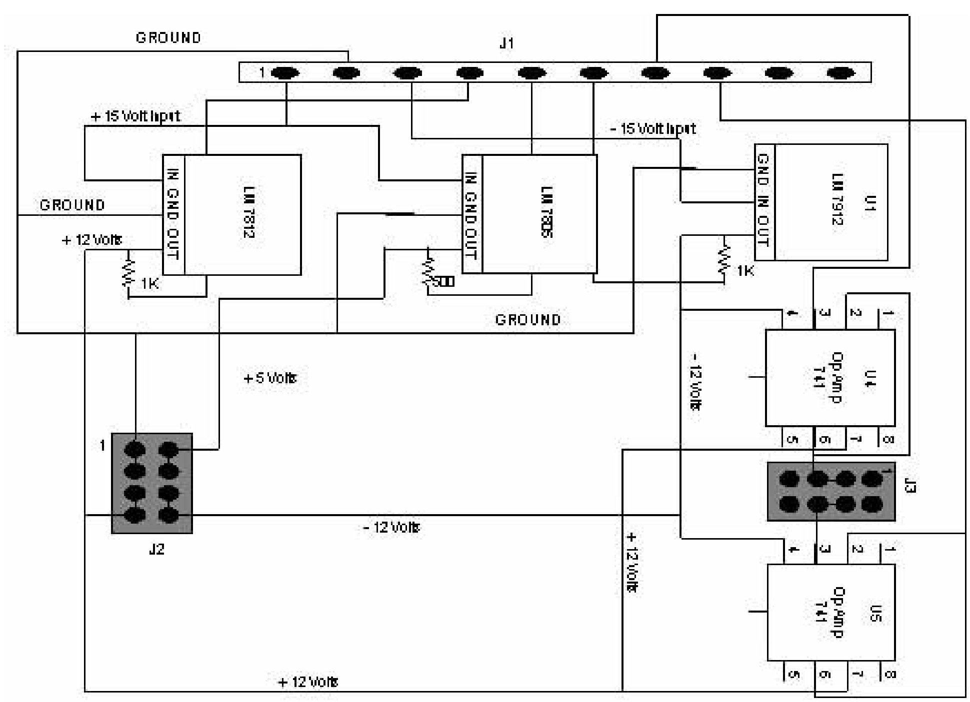

Figure 4: Motherboard Schematic

3.2 System Identification

After students have an understanding of the frequency domain model of systems, they are given a system that, unknown to them, implements an eight pole Butterworth low pass, or band pass filter. The daughter board schematic for this system is shown in Figure 5. Students are asked to produce a magnitude frequency response of the system (using the LabVIEW VI described in section 2.2) and to determine approximately the location of any poles and zeroes. They then use the frequency domain model to compute the output to various inputs, and compare the predictions with their laboratory observations. This experiment occurs in the course prior to a formal discussion of filtering and filter types, and serves to motivate subsequent classroom study. Formal system identification methods are not used.

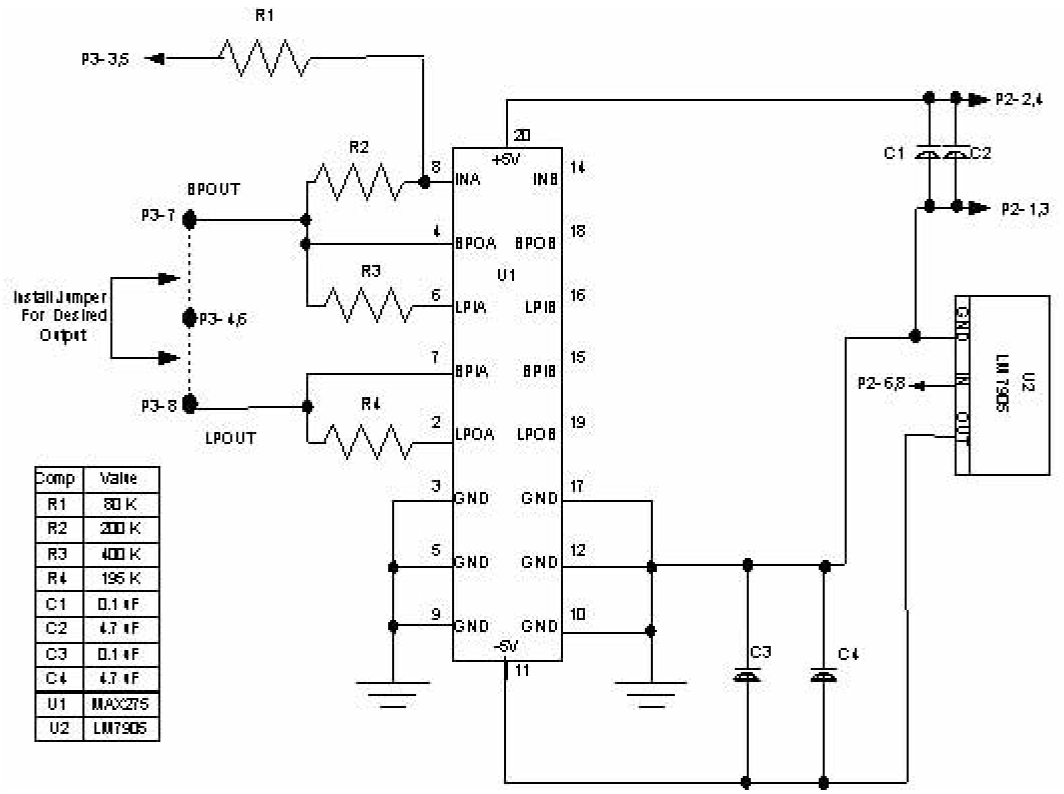

Figure 5: A Daughter Board Schematic

3.3 Motivating Design

The final experiment in the course again provides students with a filter. Now they are to consider this filter to provide unwanted coloration of the audio spectrum. They are asked to design an equalizer to place in series with the filter to achieve as flat a magnitude response as possible in the range from 20 Hz to 20,000 Hz. Salen-Key circuits constructed in previous labs are available for their use. They need to use their system identification skills developed earlier to model the given filter, and then try to design an equalizer that comes as close to an inverse system as possible. This type of constrained design project helps to prepare students for the more open-ended projects that appear later in their curriculum.

4. Conclusions

Experience with unknown systems forces students to consider the meaning and implications of topics such as linearity and frequency response that are learned in a typical systems course. The need to identify, characterize, and finally compensate for such an unknown system helps students to appreciate the importance of linear system design and analysis. When properties, such as filtering, are "discovered" in the laboratory before they are discussed in the classroom it can lead to a greater appreciation of the material.

Bibliography

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