INNOVATIVE COMMUNICATIONS EXPERIMENTS USING AN INTEGRATED DESIGN LABORATORY

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Abstract

In traditional undergraduate teaching laboratory environments, many communication topics are difficult to convey because of their complexity in implementation. This paper describes laboratory experiments that explore challenging communication topics using the University of Wyoming's new integrated design undergraduate teaching laboratory. Each lab station comprises a PC using LabVIEW and GPIB to control oscilloscopes, arbitrary waveform generators, power supplies and a data acquisition card. In this environment, the approach is for the students to use a combination of hardware and software to generate and manipulate real-world communication signals. Topics such as AM modulation and demodulation including SSB and digital communication systems can easily be covered under the realistic time constraints of a two-hour laboratory. Furthermore, these benefits are achieved without requiring students to assemble overly complicated circuits or conduct pure simulations. Advantages of this approach to communications experiments are discussed in comparison to more traditional approaches such as simulation, breadboarding, or modular communication systems.

Introduction

The University of Wyoming offers a required three-hour introductory communication theory course at the junior level. The course includes three lectures per week and a two-hour lab session that meets every other week. One vexing problem with introductory communications labs has been to provide meaningful hands-on laboratory experiences that supplement the lecture material.

In traditional lab environments, analog and digital communication concepts are difficult to demonstrate. Although amplitude and frequency modulation can be studied by requiring students to breadboard their own circuits, many of these circuits are beyond their electronics background, and ultimately they spend valuable lab time debugging electronics rather than exploring concepts relevant to the lectures. More complicated topics such as digital line codes and digital carrier systems can only be considered using simulation environments such as Electronic Workbench or MATLAB/Simulink, but such software experiments are much less effective compared to hands-on laboratory experiences. Books such as those by Proakis et al[1], use MATLAB/Simulink to reinforce students theoretical understanding of communications. Another approach is to use commercial, modular systems, which have some distinct advantages over breadboarding in being able to examine more complex communication topics and in being able to deliver a hands-on laboratory experience. However, modular systems are usually very expensive and are not systems that students will typically see in industry. One example is the TIMS system from Emona Technologies[2], which provides an excellent set of modules for studying communication systems. Unfortunately, these systems are expensive and only support communication courses. In contrast, the system described here uses conventional test and measurement equipment and can support a variety of electronic engineering courses.

This paper describes laboratory experiments that explore complex communication topics while retaining a hands-on learning environment. These laboratory experiments are performed in our new integrated design laboratory[3,4], which utilizes equipment

common in industry. Using LabVIEW in conjunction with data acquisition cards and interconnected instruments, communications concepts are presented using real-world signals that students can investigate and manipulate. Furthermore, these benefits are achieved without requiring students to assemble overly complicated circuits or conduct pure simulations. In this environment, a balance can be reached between what is provided for the students and what the students need to design and implement to reinforce a particular concept. The lab exercises cover the following topics: Fourier analysis, amplitude modulation, frequency modulation, sampling theory[5], digital line codes, and digital communication over a simple channel.

Laboratory

The lab exercises described in this paper are all conducted in a lab classroom with six identical lab benches, such as the one shown in Figure 1. Each lab bench consists of an Agilent digital oscilloscope with FFT capability, an Agilent arbitrary waveform generator, a power supply, a digital multi-meter, and a Windows PC equipped with a data-acquisition card. All of these devices are linked together through the IEEE-488 GPIB interface bus. This bus allows the computer to control and share information with the instruments and for the instruments to communicate with one another.
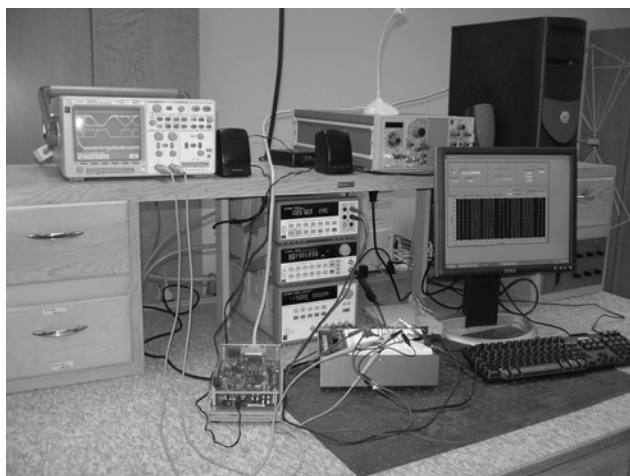

Figure 1 - Typical Lab Bench.[2]

The Windows PC at each lab bench not only interfaces with the instruments, but also with a National Instruments data acquisition (DAQ) system. The DAQ card has up to a 1.00 MSample/second output sampling rate and 1.25 MSample/second input sampling rate. With 2 analog output channels and 16 analog input channels, these DAQ cards can create and examine real-world analog communications signals. The DAQ is controlled via LabVIEW to generate and obtain physical signals in the lab environment. These signals can be processed in a variety of methods inside LabVIEW to provide meaningful results or explore different aspects of a given topic. This analysis can include changing the output waveform or analyzing the spectrum of a signal, both of which are done in real-time.

Experiments

The integrated design laboratory is used extensively for a 3-credit hour communication theory course. Through six laboratory exercises, the course explores various introductory aspects of analog and digital communications. The individual labs are listed in Table 1, along with a brief description of the topics covered in each lab. For this paper, three labs are described in detail: Amplitude Modulation, Line Codes, and Communication System. These three labs demonstrate the flexibility of the integrated design laboratory and illustrate how it allows previously difficult topics to be presented with ease in a theory oriented course. Previous labs covering these topics involved complicated circuits that required students to spend more time debugging their circuit than actually learning the topic at hand.

Experiment - Amplitude Modulation (DSB-AM and SSB-AM)

This exercise focuses on amplitude modulation (AM) and introduces topics such as modulating different signals, modulating using different carrier waves, single side-band

Table 1 - Communication Theory Lab Exercises.

| Lab Title	Topics
Equipment and Time/Frequency Analysis	Equipment introduction, Fourier theory review
Amplitude Modulation	Amplitude Modulation characteristics, signal parameters, and modulation & demodulation
Frequency Modulation	Frequency Modulation characteristics, signal parameters, instantaneous frequency, and simple demodulation
Sampling Theory[5]	Sampling theory, analog-to-digital conversions, quantization noise, and digital instrumentation limitations
Line Codes	Basic binary line codes, line code characteristics, and pulse shaping
Eye Diagrams and Communication System	Line code eye diagrams, channel effects, equalizers, and signal decoding
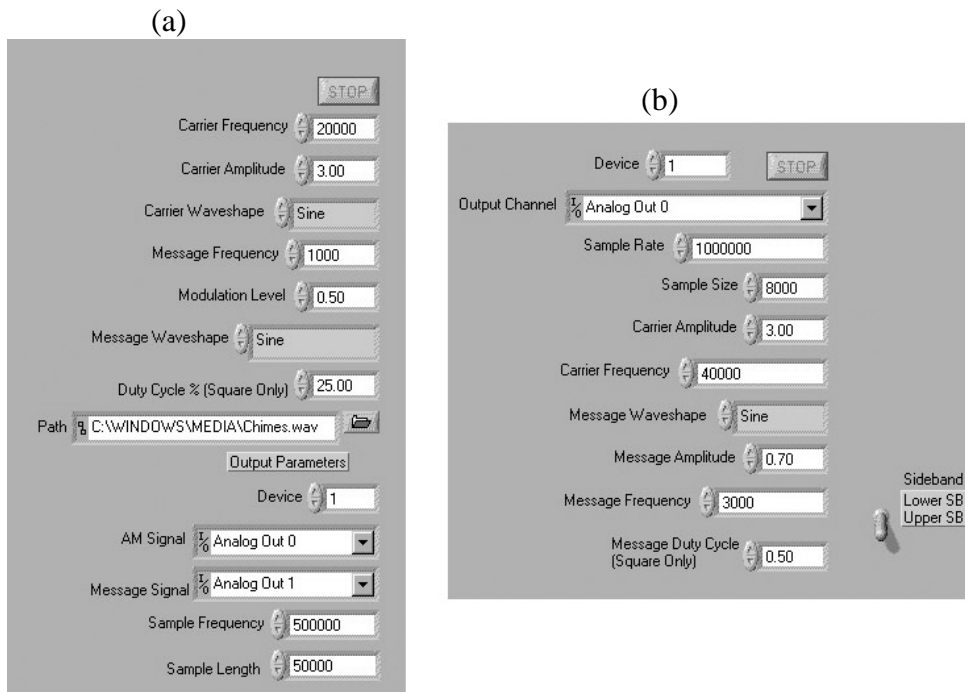
Figure 2 – (a) DSB-AM and (b) SSB+C LabVIEW interface GUIs.[4]

AM (SSB-AM), and demodulating an AM signal. The lab begins with an investigation of a simple pure tone message AM signal. The signal is created within a provided LabVIEW module. The LabVIEW interface is shown in Figure 2a. The oscilloscope provides time domain and frequency domain displays of the signal. The students analyze the effects of real-time adjustments of various AM wave properties in LabVIEW such as the carrier wave shape, carrier frequency, message wave shape, message frequency, and modulation depth. The students also determine the modulation depth of the real signal and how it compares to the ideal value requested from LabVIEW. This provides not only verification of their results, but also to forces the students to think about just how the Fast Fourier Transform (FFT) is scaling the frequency display on the oscilloscope.

The students also investigate demodulation of AM signals. The students construct a simple envelope detector using a diode, resistor, and capacitor. The students also study a software envelope detector that takes a more "idealized"

approach to AM envelope detection. The absolute value of the AM signal is passed through a digital low pass filter to keep only the relevant, lower frequency terms. The students design the filter using basic Fourier knowledge. The simplest solution is an averaging filter of about 25 terms. The filter is implemented via a MATLAB script window inside LabVIEW. This allows the students, who may have a limited background in digital filters, to implement the filter using a familiar interface. This keeps the learning curve to a minimum and helps keep the lab tractable.

Once the two envelope detectors are in place, the students generate both a sinusoidal message and triangle wave message AM signal and observe the demodulated output from both the hardware and software envelope detectors on the oscilloscope. The students again adjust different AM parameters, such as modulation depth and message and carrier frequencies, and observe the effects on the envelope detectors. The students evaluate the performance of the envelope detectors and provide the advantages and disadvantages of both when demodulating simple signals. The main disadvantage of the hardware demodulator is the ripple and roll-off effect introduced by the resistor-capacitor combination, as Figure 3 shows. The software detector's biggest disadvantage is the component overhead it requires; the hardware demodulator is constructed of very simple, cheap components while the software demodulator would require items such as a digital signal processor and analog-to-digital converter.

The students next use LabVIEW to investigate a single side-band with carrier (SSB+C) signal. This example uses the Hilbert Transform to suppress either the upper or lower side band of a double side band AM signal, which requires half the bandwidth of a normal AM signal. A provided LabVIEW module, shown in Figure 2b, performs all of the Hilbert Transforms and signal manipulation to ensure all phases are aligned and the SSB+C signal is generated properly. Traditionally, implementing SSB+C
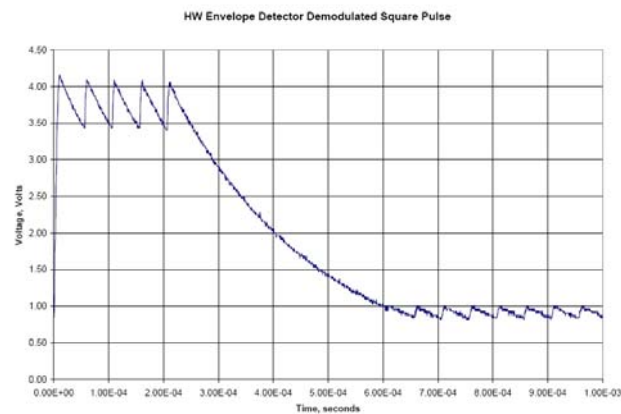

Figure 3 - Hardware demodulated square wave.[4]

directly in hardware requires too much time debugging circuits and leaves very little time for the students to investigate the phenomenon in any depth.

To demonstrate the downside to SSB+C AM, students pass the generated signal through the simple hardware envelope detector created earlier. Observing the results and consulting their text book, they realize that successful demodulation of SSB+C signal requires much more transmission power.

Experiment - Line Codes

Later in the semester, the students investigate how data bits are encoded into analog waveforms using different line codes. On-off, polar, bipolar, and Manchester (split-phase) line codes are studied with normal rectangular pulses and a bandwidth efficient raised-cosine pulse. Through the observations of these different line codes, the students observe and evaluate the different parameters of the line codes such as transparency, bandwidth requirements, and channel-coupling requirements.

As with the AM lab exercise, LabVIEW is used to generate the line codes. However, LabVIEW also provides a simple spectrum analyzer to view the line code spectrum, as Figure 4 shows. LabVIEW and the DAQ card provide a greater flexibility in generating the
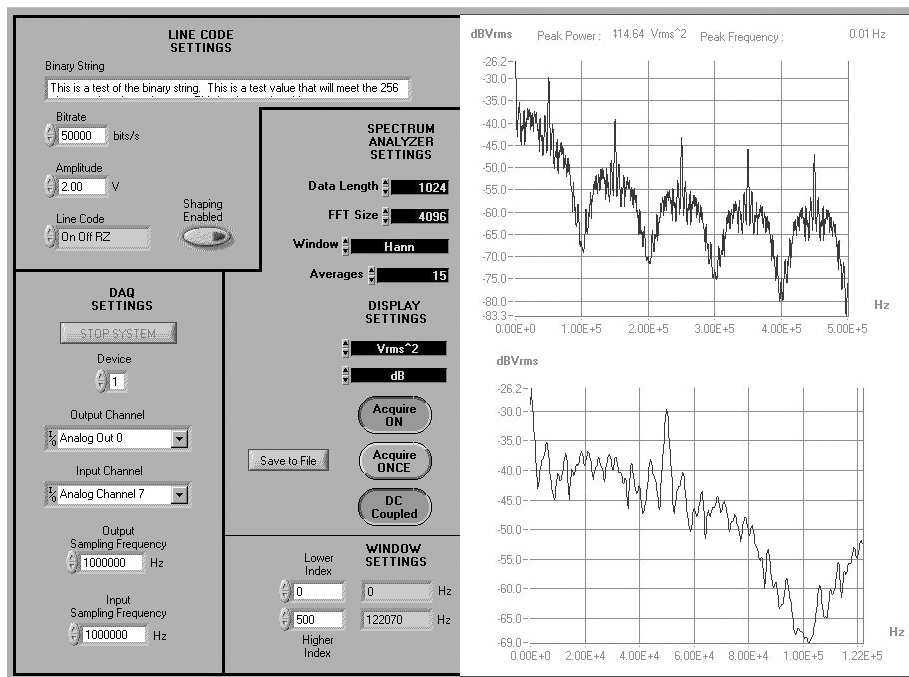
Figure 4 - LabVIEW line code generator and spectrum analyzer GUI showing results for on-off line code.[4]

line codes than a traditional arbitrary waveform generator. The arbitrary waveform generators typically have memory limitations that prevent long, pseudo-random data streams from being observed. LabVIEW is able to generate arbitrarily-long sequences of bits to provide a realistic data stream.

The LabVIEW module encodes a 256-character long repeated ASCII sequence into the desired line codes. This provides a long-cycle pseudo-random waveform at the DAQ output. The oscilloscope's FFT capabilities provide no averaging, so the displayed spectrum is not very representative of the line code spectrum. On the other hand, the simple LabVIEW spectrum analyzer does averaging using a Welch periodogram method and provides a much better spectral representation, which more closely resembles the ideal results presented in the text book.

The students begin by observing the line codes on both the oscilloscope and LabVIEW spectrum analyzer. Initially, the line codes are implemented using rectangular pulse shapes. The students capture 6 bits of each line code,

including full and half pulse width line codes of on-off, polar, and bipolar line codes. The students label the bit representations on these diagrams as part of the post-lab write up. Using the LabVIEW spectrum analyzer results, the students comment on the bandwidth of each of these cases as well. It is quickly demonstrated that the rectangular pulses are not bandwidth efficient and are not very suitable for transmitting digital data across a limited bandwidth channel. The students next observe the effects of changing the line code pulse shape from rectangular to a smoother, raised-cosine shaped pulse. In particular, they observe the resulting significant reduction in bandwidth produced by raised-cosine pulses.

The final portion of the lab investigates the transparency of each line code. Transparency describes the ability to distinguish individual bits in the waveform, especially if a long sequence of all 1's or all 0's is transmitted. This is simulated using a sequence of four random characters followed by 252 all-zero characters. The students focus on the long sequence of zeros and if they can still distinguish each individual bit, the line code has transparency to

long sequences of binary zeros. For example, if a polar line code is used in an AC-coupled channel, the 0's quickly decay to zero volts and become indistinguishable from 1's.

Experiment – Basic Digital Communications System

The last lab for the semester long Communication Theory course investigates a basic communication system that includes several of the course's concepts such as noise, channel effects, equalization, and matched filters. Figure 5 represents an overall block diagram of the basic communications system. The bolded blocks include parameters that the students manipulate such as the equalizer coefficients, the noise level of the system, and the phase alignment of the clock signal. The other blocks are provided to the students.

The LabVIEW module shown in Figure 6 is used to decode the digital waveform and control the function generator source. The function generator is loaded with four different test waveforms to pass through the communications system. For this lab, it is more convenient to generate the line code data using the arbitrary waveform generator rather than LabVIEW. This keeps the block diagram modular to help the students understand the system and facilitate analysis.

In lecture and homework exercises, the students learn how to design a simple equalizer. As a prelab exercise, they are given sample input and output signals for the implemented channel and are asked to design the equalizer coefficients. They begin the lab by entering the coefficients and evaluating the system with a noise-free signal. With the oscilloscope, they observe the pre-channel and post-channel waveforms and examine how the "channel" is distorting their transmission. The LabVIEW module shows the decoding process and allows the students to examine the signal at the 5 probe locations shown in Figure 5, and quickly determine whether their equalizer coefficients are operating properly. The noise-free signal

also allows the students to observe how the signal should look at each receiver stage and gives them a basis of comparison for the noisy waveforms.

Finally, signals with additive Gaussian white noise and signal-to-noise ratios of 26.0, 6.02, and -7.8 dB are studied. The students observe the slow degradation of the system and the increase in bit errors. Despite the extremely low signal-to-noise ratio of -7.8 dB, the students notice that the system continues to decode some of the bits properly. Coupling this knowledge with their initial observations of the noise-free waveform, they are required to think of ways to improve the system. The changes are not implemented and thus can be reasonably complicated, but they must meet a set of real world constraints. For example, the students are not allowed to increase the amplitude of the signal or reduce the data rate.

Conclusion

This paper describes an alternative way to implement introductory communication theory labs that avoids the disadvantages of pure simulations, breadboard-based circuits, and commercial lab modules. In this new approach, a set of LabVIEW-based exercises has been developed that interact with computer-controlled industry-standard test and measurement equipment. This environment provides students with vital hands-on experience, and makes it possible to investigate a wide range of communication concepts. In contrast to expensive commercial lab modules, which may not fit tight budget constraints and support only communications courses, the integrated design lab can be used for a variety of electronics courses.

The LabVIEW/integrated design laboratory exercises have been used in two semesters of our EE4440 Communication Theory course, and have fully met our objectives. Student response has been quite positive; computer types like working with the LabVIEW modules and hardware types like the hands-on experience
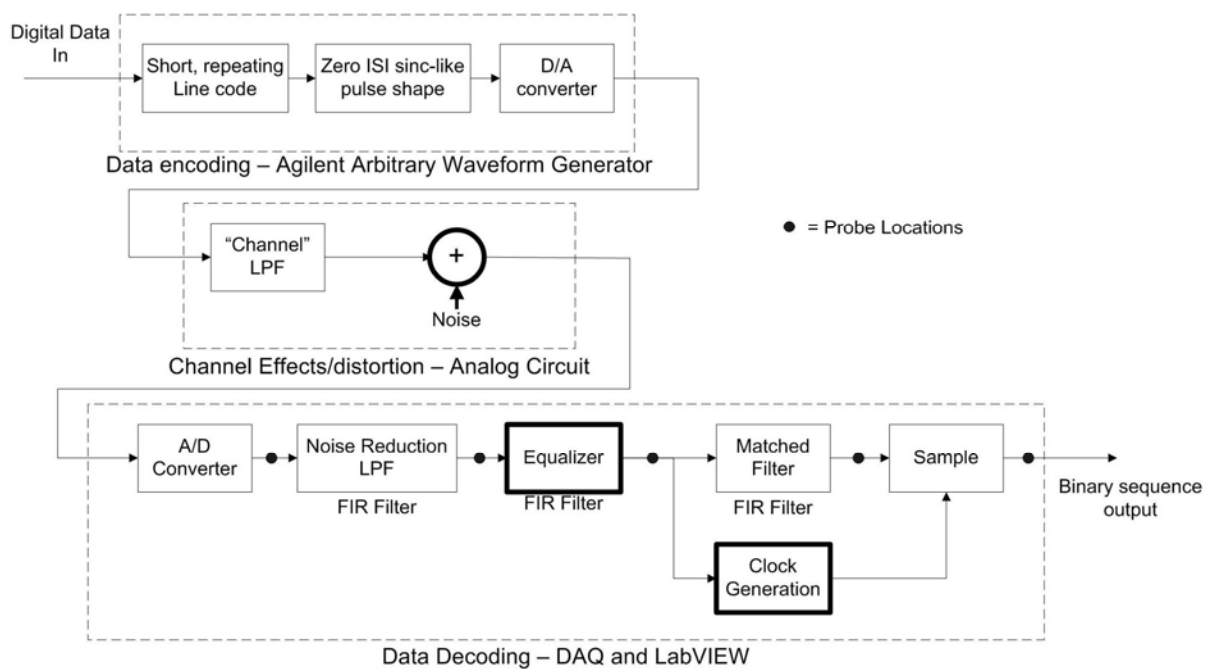
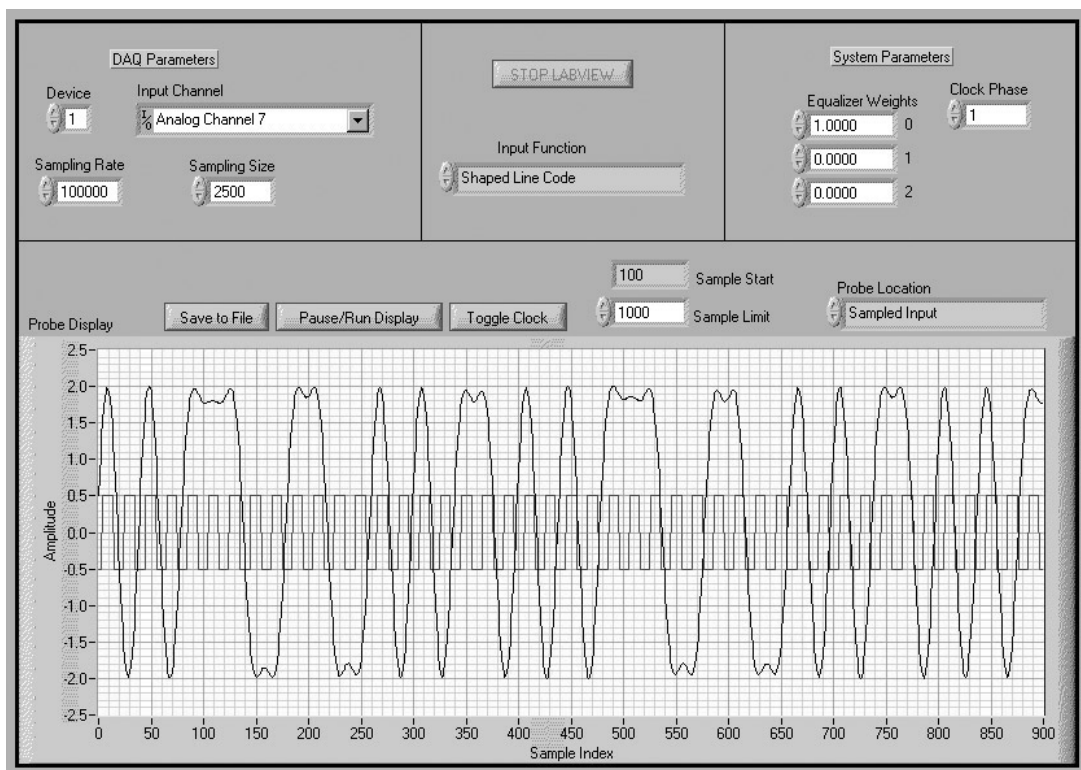Figure 5 - Basic communication system block diagram.[4]

Figure 6 - Basic communication system LabVIEW GUI[4]. The waveforms shown include the recovered timing signal and the sampled input signal.

with oscilloscopes and signal generators. Students especially like using the integrated computer to capture voltage measurements, signal traces, and other data – tasks that must be done manually in other labs. In conclusion, we note that additional lab exercises are easily developed. For example, we are developing a LabVIEW-based vector signal analyzer for use in lab exercises. Typically, these devices are too expensive for most departments to put on undergraduate workbenches.

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