Communications Laboratory with Commercial Test and Training Instrument

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Abstract

A communications laboratory course has been designed around the Telecommunications Instructional Modeling System (TIMS) of Emona Instruments. This instrument includes a sampling oscilloscope and spectrum analyzer, the PicoScope of Pico Technology.

There are three main learning objectives for this laboratory course. First, students use fundamental concepts of signals and systems in different situations, gaining more fluency with these concepts. Second, students rehearse the important techniques of communications, including modulation, demodulation, synchronization, and sampling. Third, students get more practice and acquire more confidence in experimental methods.

Introduction

A laboratory course was developed to complement a lecture course ("Communication Engineering") that covers Fourier series and transforms, filtering, analog modulation and demodulation, synchronization, sampling, and receiver architectures. The laboratory course uses the Telecommunications Instructional Modeling System (TIMS) of Emona Instruments [1], see Figure 1. This instrument incorporates a sampling oscilloscope and spectrum analyzer called the PicoScope [2]. The PicoScope is connected (by means of a USB) to a desktop computer, whose monitor and mouse provide the display and control. This paper summarizes the learning objectives of this laboratory course and then discusses some typical experiments.

The TIMS instrument comes with a set of removable modules that permit a wide variety of communication circuits to be built and tested. There are signal generators of different type, including oscillators, pulse train generators, and pseudorandom noise (PN) code generators. A selection of filters is offered. There are narrowband phase shifters and quadrature phase splitters. Some modules enable arithmetic operations, such as multiplication and weighted summation. There are a number of modules that support frequency control, such as a voltage-controlled oscillator (VCO), frequency multipliers, and frequency dividers. A great selection of advanced modules are available for the TIMS instrument, but even with just the basic set of modules, it is possible to demonstrate the most important ideas covered in an introductory course in communication systems.

The advantage of a modular communication test and training instrument like TIMS is that it permits rapid exploration of design concepts using physical circuits. In one laboratory session, students can implement a transmitter and receiver, make measurements, and experiment with the optimization of system parameters. An instrument with similar functionality, the Berkeley Communication Laboratory, was used at the University of California Berkeley in the 1970s [3].

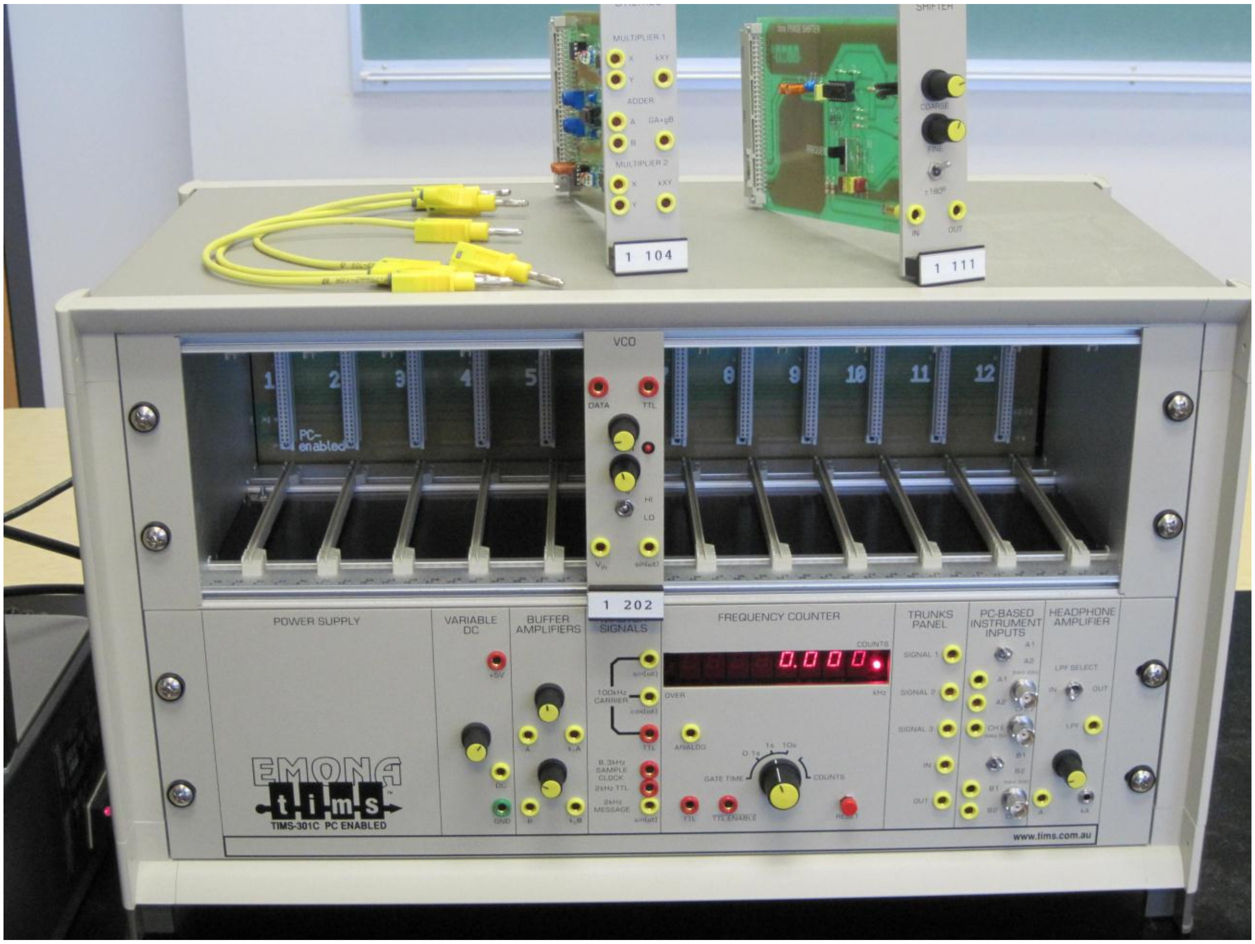

Figure 1: Telecommunications Instructional Modeling System (TIMS), Emona Instruments

Learning Objectives

There are three main learning objectives for this laboratory course. First, students use fundamental concepts of signals and systems in different situations, gaining more fluency with these concepts. Second, students rehearse the important techniques of communications, including modulation, demodulation, synchronization, and sampling. Third, students get more practice and acquire more confidence in experimental methods.

Throughout the series of laboratory exercises, students see the principles of signals and systems in action. They see how the time domain, as viewed on an oscilloscope, and the frequency domain, as viewed on a spectrum analyzer, permit complementary descriptions of a signal. Students exercise what they've learned about aliasing when they use the sampling spectrum analyzer. They see how different classes of systems react to sinusoids and weighted sums of sinusoids. For example, the following properties of systems are observed. A linear, time-invariant system produces no new frequencies at its output that are not present on the input. A nonlinear system produces harmonics. A time-varying system produces, in general, frequencies that are not present on the input and are not harmonics.

Students rehearse what they learn in a communication systems lecture course. In the communications laboratory they implement and test several modulation schemes and demodulation methods. These include: double-sideband and single-sideband modulation with synchronous demodulation, amplitude modulation with envelope detection, frequency modulation with both zero-crossing and phase-lock demodulation. Students build and test closed-loop synchronization circuits: a simple phase-locked loop and a Costas loop. Students experiment with receiver architectures: superheterodyne and Weaver.

Students learn about good experimental technique. They learn that a periodic signal can be used to achieve a stable oscilloscope display while affording continuous capture of that signal. They learn the importance of gain in a succession of stages and about the need to prevent overload. They get accustomed to thinking in terms of decibels. They experiment with different phase relationships among sinusoids and how these relationships can be exploited in certain receiver architectures.

The students were queried about the perceived value of this course to their careers. The results of that survey are shown in Table 1. Since this course is new and not a modification of an existing course, there are no previous results with which to compare the data of Table 1.

Table 1: Survey of Students

"This course enhanced my …"	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
"… skills to formulate and solve problems."	73%	27%	0%	0%	0%
"… ability to do engineering."	73%	27%	0%	0%	0%

Experiments

The complete list of experiments for this laboratory course is given in Table 2.

Experiment 1. Students become acquainted with TIMS and with the use of the oscilloscope and spectrum modes of the PicoScope. They see the response of different classes of systems to a sinusoid. An amplifier (with small-signal input) serves as an example of a linear, time-invariant system. A clipper exemplifies nonlinear systems, producing harmonics. A multiplier together with local oscillator (that is, a frequency converter) is representative of linear but time-varying systems.

Experiment 2. With TIMS the carrier is 100 kHz. The message signal can be a sinusoid or recorded audio. In this experiment double-sideband modulation is used with synchronous demodulation. A carrier "stolen" from the transmit side is used in the synchronous demodulator. (This is corrected in a later experiment, after phase-locked loops have been introduced.)

Experiment 3. Amplitude modulation is employed with envelope detection. The message is first a sinusoid and later recorded audio. In the latter case, the X-Y mode of the oscilloscope is found to be useful for adjusting the modulation index.

Table 2: Experiments

1	Linear time-invariant systems, nonlinear systems, time-varying systems
2	Double-sideband modulation, synchronous demodulation
3	Amplitude modulation, envelope detection
4	Single-sideband modulation
5	Single-sideband demodulation
6	Frequency modulation, zero-crossing detection
7	Armstrong (narrowband) phase modulator, frequency multiplication, FM spectrum
8	Superheterodyne receiver, Weaver architecture
9	Phase-locked loop, Costas loop
10	Phase-locked loop demodulation of FM
11	Pulse width modulation
12	Ideal sampling, sample-and-hold
13	Binary phase-shift keying, Costas loop demodulation

Experiment 4. A single-sideband modulated carrier is produced. In the first instance, a sinusoidal message is employed and the necessary 90° phase shift of that message is accomplished with a narrowband phase shifter. In the second instance, a quadrature phase splitter provides a wideband 90° phase shift.

Experiment 5. A single-sideband carrier with an audio message is recovered with a synchronous demodulator, and this is found to work well as long as the (receive-side) local oscillator has a frequency within a few hertz of the carrier. Then a true signal-sideband demodulator is built using a phasing technique; this demodulator is found to be sensitive only to sidebands on one side of the carrier.

Experiment 6. Frequency modulation is implemented with a voltage-controlled oscillator (VCO), and demodulation is done with a zero-crossing detector. The frequency deviation is set using the method of Bessel nulls when the message is sinusoidal.

Experiment 7. A narrowband phase (Armstrong) modulator is implemented, and the frequency deviation is increased by frequency multiplication. The spectrum of an angle-modulated carrier with a sinusoidal message is studied.

Experiment 8. Two different receiver front-ends are implemented and studied. The first is the classic superheterodyne receiver, for which the problem of the image frequency is solved with a bandpass filter in front. The second receiver architecture is that due to Weaver, for which the image frequency is canceled through careful phasing.

Experiment 9. A phase-locked loop is built. Phase-lock to a 100-kHz unmodulated carrier is achieved. A Costas loop is built, and it is used for carrier synchronization on a double-sideband modulated carrier, obviating the need for a "stolen" carrier. Demodulation is achieved in the same circuit.

Experiment 10. A frequency modulator is implemented as an integrator, followed by an Armstrong (narrowband) phase modulator, followed by frequency deviation multiplication. Demodulation is accomplished with a phase-locked loop.

Experiment 11. A pulse-width modulator is calibrated. Using a sinusoidal message, a PWM signal is double-sideband modulated onto a 100-kHz carrier. Envelope detection and filtering is used to recover the original message.

Experiment 12. Multiplication of a low-pass message signal by a pulse train is used to approximate ideal sampling. The relationship between message bandwidth and sampling frequency is investigated. Recovery of the original message is accomplished through filtering. The more practical sample-and-hold circuit is then demonstrated.

Experiment 13. Binary phase-shift keying (BPSK) is implemented as an example of digital communications. A Costas loop receiver is used for carrier synchronization and demodulation.

Example: BPSK with Costas Loop Demodulation

This section illustrates the capability of TIMS by offering more detail on Experiment 12.

As usual for TIMS, the carrier frequency is 100 kHz. The data come from a PN code generator. BPSK is accomplished with a multiplier. The receive side consists of a Costas loop, which provides carrier synchronization and demodulation. A block diagram of a Costas loop appears in Figure 2.

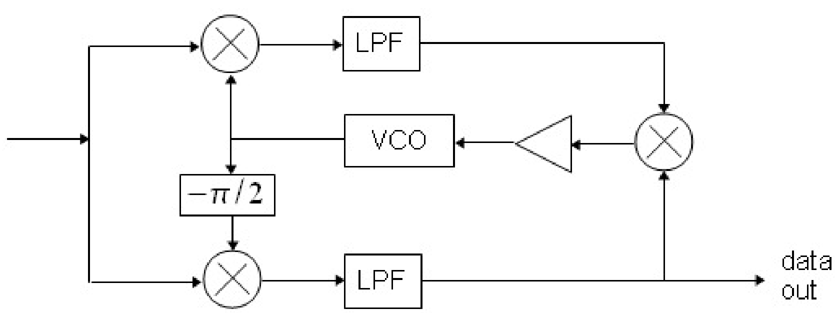

Figure 2: Costas Loop

The Costas loop is an interesting example of feedback control. As implemented here, this is a first-order loop, and its tracking properties are therefore poor. This means that getting the loop to lock requires that the best-lock frequency of the VCO must be close to the carrier frequency. Moreover, the total loop gain must lie within a fairly narrow range. Figure 3 shows the experimental arrangement.

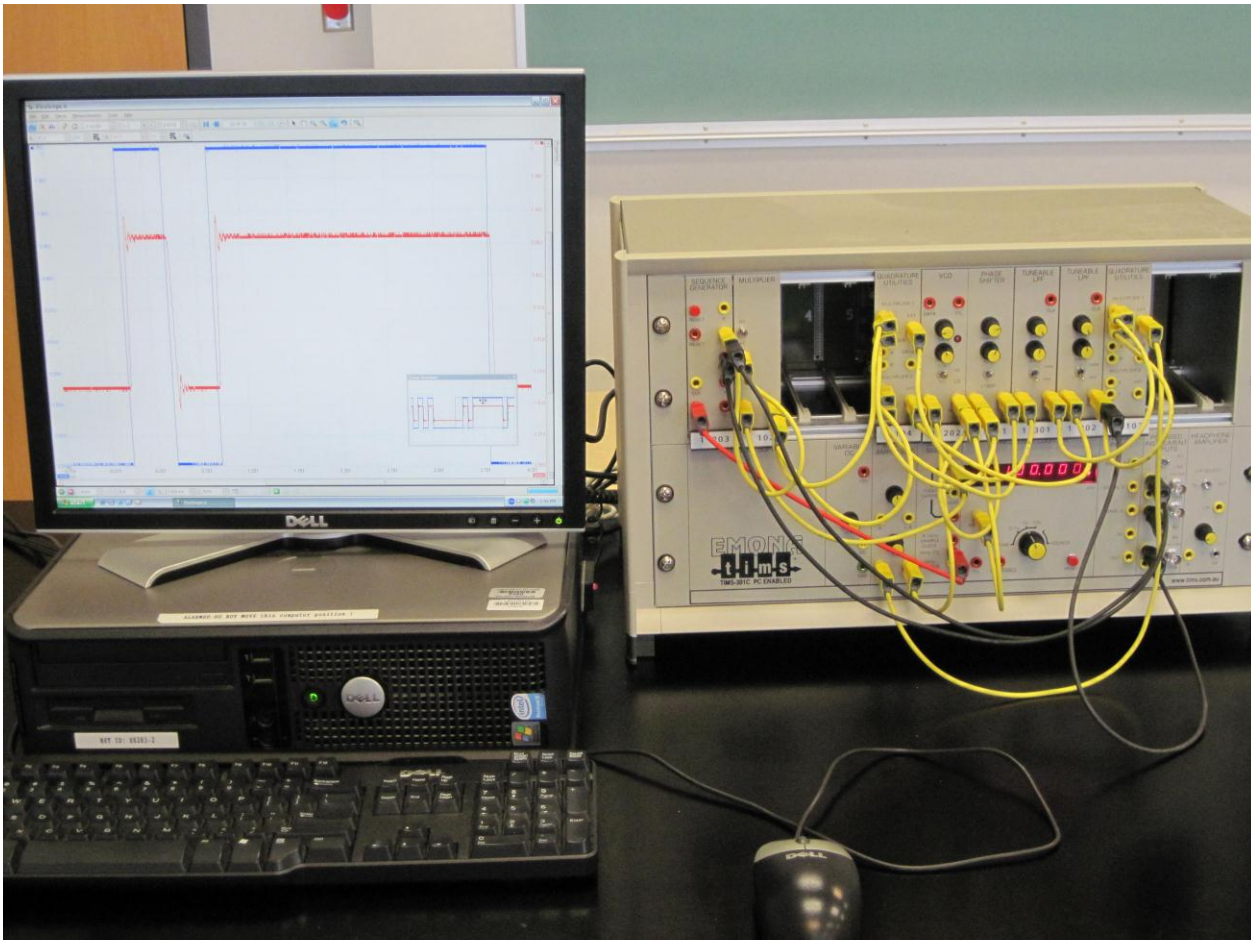

Figure 3: BPSK Modulator and Costas Loop Demodulator as Implemented on TIMS

The total loop gain is positive in this arrangement, and as a result the recovered data appear at the output of the low-pass filter (LPF) on the bottom branch of the loop that is illustrated in Figure 2. Because of the two-fold phase ambiguity inherent in a Costas loop, the data may have either correct or opposite polarity. Students experiment with taking the loop in and out of lock, in order to see that the data sometimes appear "right-side up" and sometimes "upside down", depending on which of two stable lock points is realized.

Students also change the algebraic sign of the total loop gain, making it negative; and this causes the data to appear (either of correct or opposite polarity) on the top branch of the loop that is illustrated in Figure 2. Students gain a good intuitive understanding of the phase relationships in the Costas loop by experimenting with the two-fold phase ambiguity and with the algebraic sign of the total loop gain.

Figure 4 shows the PicoScope display for the original (transmit-side) data (in blue) and the recovered data (in red) appearing on the bottom branch of the Costas loop (with positive total loop gain).

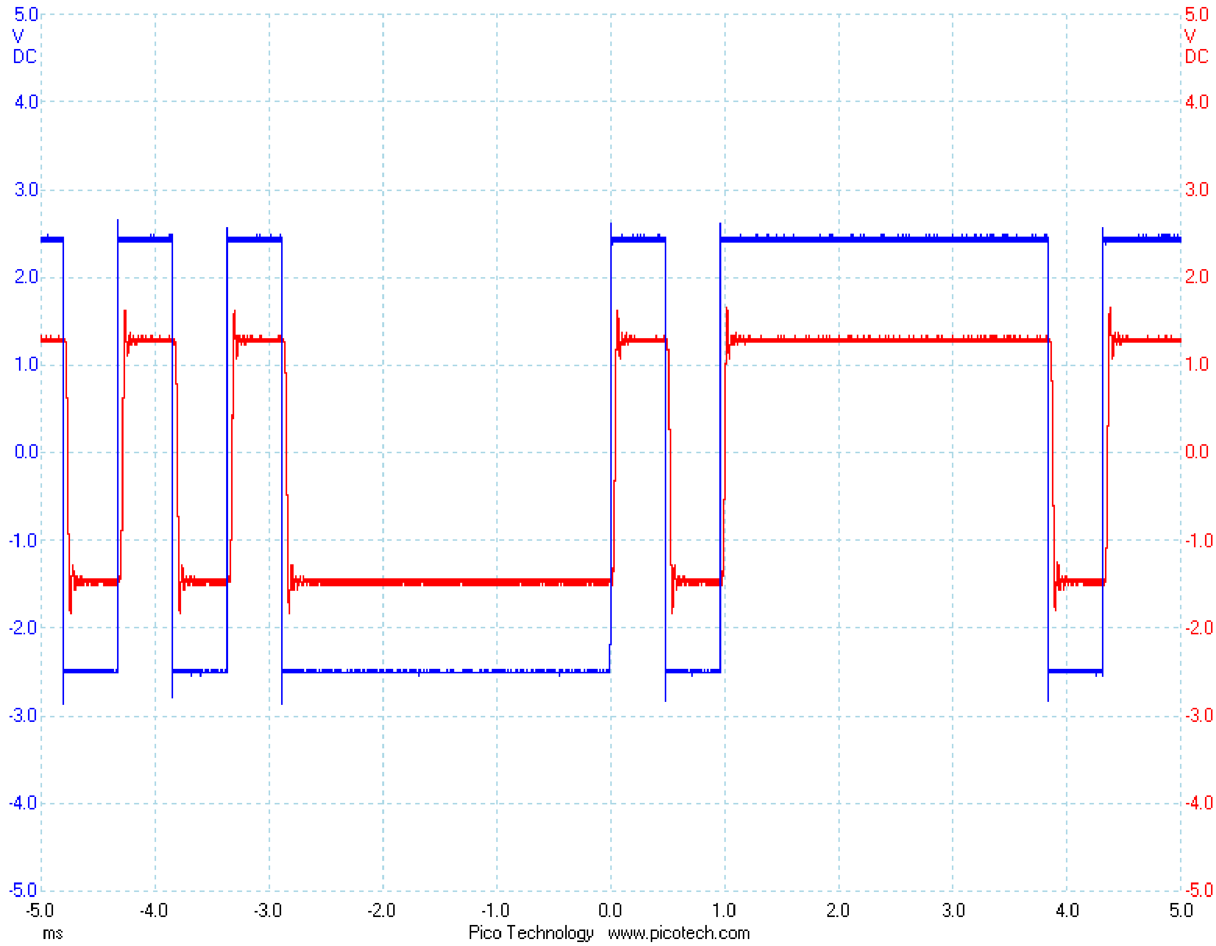

Figure 4: Data at Transmitter (Blue) and Recovered Data in Costas Loop Receiver (Red)

Conclusions

A communications laboratory course was developed around the TIMS instrument. Modular in design, this instrument permits rapid exploration of design concepts. The course has three main learning objectives. First, students gain more fluency with fundamental concepts of signals and systems. Second, students rehearse the important techniques of communications. Third, students acquire more skill and confidence in experimental methods.

References

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3. G. L. Turin, “The Berkeley Communication Laboratory,” *Communications Society: A Digest of News and Events of Interest to Communications,* Vol. 14, Issue 2, pp. 12-21, March 1976.