Laboratory Enhancement of Digital and Wireless Communications Courses

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Introduction

Over the past decade, the field of wireless communications has come into its own and is posed to become a ubiquitous technology with the recent arrival of 3G cellular, wireless local area networks and wireless sensor networks. As such, today's graduating electrical engineers need marketable skills which are typically not developed in undergraduate curricula. This paper describes an ongoing program at the University of Vermont (UVM) which addresses this need through the integration of both wireless communication system test methods and device characterization techniques into its curriculum. In its first year, this program, enabled by a NSF CCLI A&I award, developed infrastructure and adapted experiments from the University of South Florida into a senior-level laboratory course[1]. Now in its second year, new experiments have been developed and have been integrated into a junior-level introductory communication systems course and two senior/graduate-level courses in digital and wireless communication systems. Herein, we discuss the new experiments, enabling infrastructure, and longitudinal assessment data.

Laboratory Enhancements

Our motivation for integrating laboratory exercises into existing courses was threefold. First and most importantly, we wanted to utilize hands-on activities to improve an individual student's understanding of telecommunication concepts. Second, we wanted to give the students early exposure to relevant test equipment (namely, spectrum analyzers) utilized in the senior-level laboratory course, *Telecommunications Lab*. Finally, we wanted to develop basic measurement skills so that students have the appropriate background to work on team-based investigations in the area of modern communications. The three courses to be discussed are *Intro to Communication Systems*, *Digital Communications* and *Wireless Communication Systems*. Laboratory exercises are summarized herein but the author encourages interested parties to visit the project website for details: www.cem.uvm.edu/~jfrolik/nsf_ccli_03.htm.

Intro to Communication Systems

Among other concepts, this course deals with the theory behind modulation, spectral analysis and the fundamentals of digital communications. These concepts are reinforced using the lab exercises described in Table 1. In addition, these labs give students their first exposure to of the use of RF signal generators and spectrum analyzers. The lab assignments constitute 10% of the student's final grade. Students nominally take the course in the junior year as a follow-on to *Signals and Systems*. The course is a requirement of all ECE majors regardless of concentration of study (General, Computer, Biomedical or Pre-Medical).

Table 1. Labs incorporated into *Intro to Communication Systems*

No.	Subject	Objectives	Equipment
1	*Spectrum Analyzer Basics*	▪ To learn the basic operation of the spectrum analyzer ▪ To verify the harmonic composition of common baseband signals ▪ To illustrate the frequency domain characteristics associated with AM	▪ Spectrum Analyzer ▪ RF Signal Source ▪ Function Generator ▪ Oscilloscope
2	*Frequency Modulation*	▪ To illustrate the frequency domain characteristics associated with FM	▪ RF Signal Source ▪ Oscilloscope ▪ Spectrum Analyzer
3	*Antennas*	▪ To illustrate the relationship between antenna size, gain and beamwidth ▪ To illustrate the effectiveness of polarization isolation	▪ RF Signal Source ▪ Spectrum Analyzer ▪ Omnidirectional and Yagi antennas
4	*Digital Communication Basics*	▪ To become familiar with the waveform generation package WinIQSIM ▪ To simulate common digital communication techniques operating in corrupting environments	▪ Digital Signal Generator ▪ Oscilloscope ▪ WinIQSIM

The first two experiments have been found to not only reinforce the modulation theory developed in this course, but also to clarify the time/frequency duality of signals presented in the prerequisite *Signals* course. Utilizing the spectrum analyzer, the harmonic composition of common waveforms (sine, square and triangle) can be visualized and measured to show agreement with Fourier series coefficients. Clearly this validation can be done in simulation, but the advantage of utilizing lab equipment is connecting a student's familiarity with lab equipment (i.e., waveform generators) to what is often an initially abstract concept. Likewise, the FM lab not only demonstrates the nonlinear aspect of exponential modulation but also that the relative magnitudes of the carrier and sideband components for tone modulation are indeed determined by Bessel functions.

A key instructional enabler for this program is the Rhode & Schwarz simulation software, WinIQSIM. While there are many powerful packages for communication system simulation and analysis (e.g., MATLAB's Simulink or Elanix's SystemView), the advantage of WinIQSIM is both its ease of use and its ability to load arbitrary waveforms into the Rohde & Schwarz digital RF signal generator (SMIQ). As shown in Figure 1, WinIQSIM provides a user with a block diagram of digital communication system along with the means to modify various parameters. WinIQSIM does not provide flexibility to add additional modules to the block diagram (as does Simulink and SystemView); but the real advantage to instruction is that concepts can be readily demonstrated *without* students having to perform any programming. As such, the author views this package as extremely powerful for undergraduate instruction. WinIQSIM is available as a free download through the Rohde & Schwarz website[2].

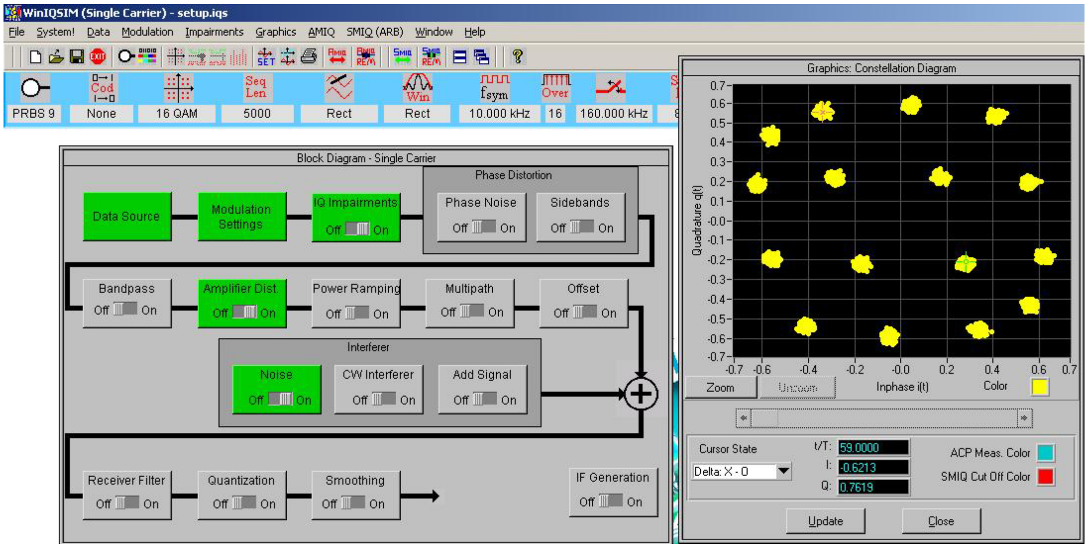

Figure 1. WinIQSIM User Interface

Digital Communications

This course analyzes the theoretical performance of various digital techniques in the presence of noise. This theoretical material builds upon that presented in the prerequisite course, *Intro to Communication Systems*. As such, the integrated labs (Table 2) also build upon a student's experience. For example, students will already be familiar with most the equipment but will in addition gain expertise with the use of the vector signal analyzer (VSA). In addition, students develop, conduct and present a team-based lab project of their own design. The three lab assignments constitute 10% of the student's final grade and the projects constitute another 10%. The course is a senior-level technical elective, offered in alternating years, that can also being taken by graduate students.

Table 2. Labs incorporated into *Digital Communications*

No.	Subject	Objectives	Equipment
1	*Binary Communications in Noisy Channels*	▪ To use MATLAB to illustrate the Central Limit Theorem ▪ To become familiar with the digital communications waveform generation package, WinIQSIM ▪ To use WinIQSIM to illustrate the noise effects on binary communication systems	▪ MATLAB ▪ WinIQSIM
2	*Amplitude and Frequency Modulation*	▪ To gain a better appreciation of the spectral components of some common signals. ▪ To utilize the spectrum analyzer for investigating amplitude and frequency modulated signals.	▪ Spectrum Analyzer ▪ RF Signal Generator ▪ Function Generator ▪ Oscilloscope

3	*Digital Communication Techniques*	▪ To investigate common digital communication techniques in the time and frequency domains ▪ To characterize digital communication performance by performing eye pattern and constellation measurements ▪ To gain experience using a Vector Signal Analyzer ▪ To demonstrate the use of pulse shaping	▪ WinIQSim ▪ Digital Signal Generator ▪ Vector Signal Analyzer ▪ Oscilloscope
Project	*Student Selected*	▪ Students introduce various sources of distortion and determine the resiliency of modulation techniques to them.	▪ Various from above

One will note that Lab 2 above is effectively the combination of Labs 1 and 2 from *Intro to Communication Systems*. Implementation of the lab enhancements is being performed in parallel and thus currently the course lab assignments have some overlap. As a result, some students are seeing these similar (but not identical) exercises twice (or three times if they also take the dedicated lab course: *Telecommunications Lab*). However, since these courses are also taken by graduate students who completed their undergraduate studies elsewhere, it is unclear whether this overlap can be completely eliminated. The plus side is that students seeing these exercises for the second time (1) help teach those without this experience and (2) have commented that they get more out of the experience the second time.

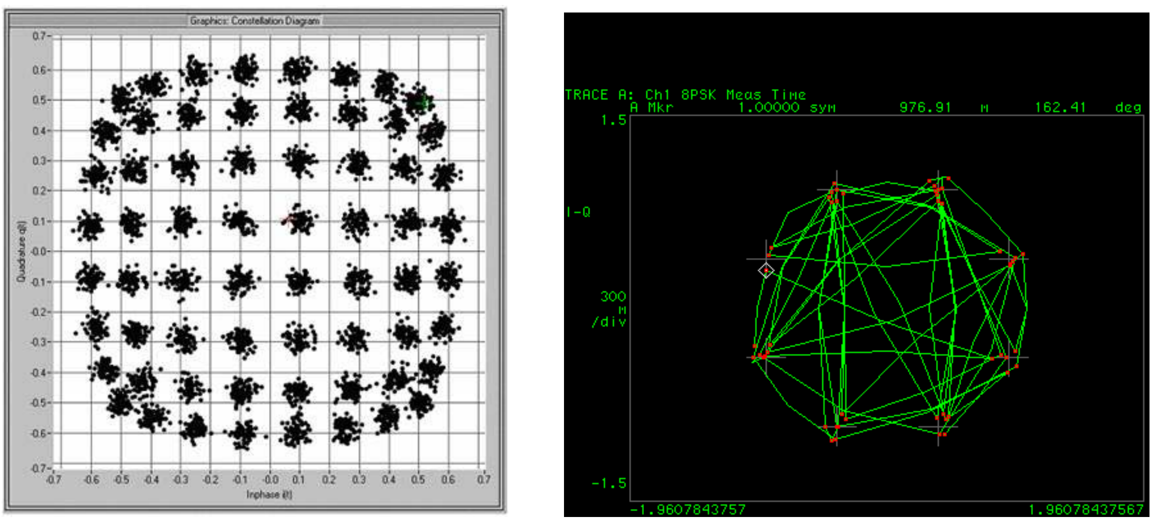

Figure 2. Student Digital Communication projects: Amplifier distortion and noise for 64-QAM (left) and Demodulated 8-PSK signal showing effects of minor multipath (right)

Example student projects have included investigating EDGE modulation, and the effects of amplifier distortion (Fig. 2-left), quadrature error, multipath (Fig. 2-right) and bandlimiting effects on digital communication systems. Students present their projects to the class at the semester's end and are peer graded (both by team members and the class as a whole).

Wireless Communication Systems

The final course in the sequence addresses wireless communications from a systems perspective down to subsystem performance requirements. This course is also a senior-level EE engineering science elective offered in alternating years and open to graduate students. The first half of the course deals with propagation issues that differentiate wireless communication systems from those that are "wired." While students have an intuitive basic understanding of path loss effects, this course provides a theoretical background for these effects. Labs (Table 3) are incorporated where student teams measure both large-scale and small-scale fading effects in the field (Fig. 3). A third lab is provided to introduce/review digital communication methods to students prior to discussing specific mobile communications methods.

Table 3. Labs incorporated into *Wireless Communication Systems*

No.	Subject	Objectives	Equipment
1	*Large Scale Fading Effects*	▪ To implement the methodology used to characterize large scale propagation loss in wireless systems. ▪ To characterize a wireless environment at 915 MHz or 2.4 GHz using measured data and the log-normal shadowing model.	▪ Portable Signal Generator ▪ Portable Spectrum Analyzer
2	*Small Scale Fading Effects*	▪ To characterize the small-scale fading effects of a wireless environment at 2.4 GHz using measured data.	▪ See above
3	*Digital Communication Techniques*	▪ To simulate common digital communication techniques operating in corrupting environments. ▪ To illustrate the effectiveness and implications of pulse shaping.	▪ WinIQSIM

Figure 3. Student field investigation of large scale and small scale fading effects.

For the propagation labs, teams use their field data (e.g., Fig. 4) to develop models (e.g., log shadow models for large scale effects) and present their results to the class. Since each team selects uniquely different environments results vary greatly and as such these presentations have led to good peer discussions and are thus greatly preferred (by students and the author) to written reports.

The large scale measurements are performed at a single frequency and the small scale effects are measured as a function of time, space and frequency. Our labs have concentrated on the 915 MHz and 2.4 GHz ISM (Industrial, Medical and Scientific) bands. As such, these labs require both a spectrum analyzer and a sweeping RF signal generator that are portable and rugged enough for field use. Both Anritsu and Rohde & Schwarz (R&S) offer suitable spectrum analyzers units for such investigations. At UVM we have utilized the R&S FSH-3 (Fig. 5-left) in the field, classroom and outreach demonstrations and in the teaching lab itself. As a signal source, we have utilized both the PSG-10 (915 MHz band) and PSG-27 (2.4 GHz band) portable signal generators by A-Systems (Fig. 5-right). In comparison to typical RF equipment, both the generator and analyzer are reasonably priced and obviously enable field exercises due to their portability.

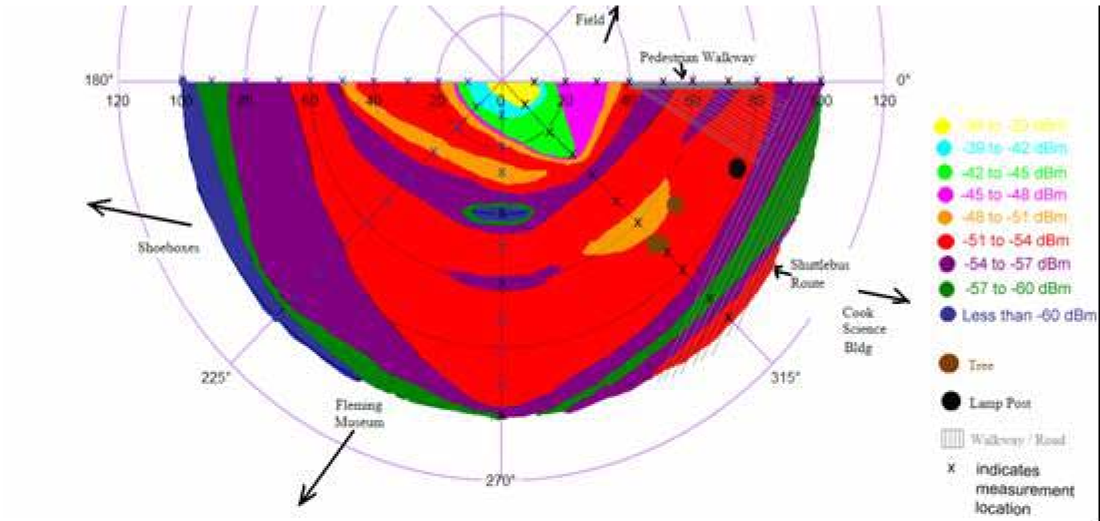

Figure 4. Example result of fading investigation

Figure 5. Rohde & Schwarz FSH-3 (left) and A-Systems, Inc. PSG-10 (right)

Results to Date, Lessons Learned and Remaining Work

To date, each enhanced courses has been offered once. Response from the students has been generally positive. Shortcomings of the implementation noted have been poor timing with the presented material (labs distributed too early in *Intro to Communication Systems*) and additional work load without additional credit. To their benefit, the labs have been overwhelming viewed as “useful” (Table 4).

Table 4. Survey response for *Wireless Communication Systems*

Please rate the usefulness of the labs in reinforcing the course material	**Response**
Very useful and worth the time	50.0 %
Somewhat useful for the time expended	16.7 %
Useful but too time consuming	33.3 %
A waste of time	0 %

Clearly, student perception/satisfaction is important, but does not objectively quantify student learning. Given that UVM is a small institution, there is no opportunity for a true controlled investigation as to the effectiveness of incorporating the discussed lab experiences. As such, we present our limited longitudinal results to date in terms of overall course performance and performance on a comprehensive final (Tables 5 and 6, respectively). Prior to the start of the project, the author had instructed each course at least twice. Using these most recent offerings as a baseline, we find below, that the greatest improvement is seen in the introductory course.

Table 5. Final Course Grades

Course	**w/o enhancements**		**w/enhancements**
Intro to Comm Systems	FA 2001 (TTU) [31] $\bar{x}$ = 80.9 σ = 8.7	SP 2003 (UVM) [16] $\bar{x}$ = 81.8 σ = 9.0	SP 2004 (UVM) [10] $\bar{x}$ = 87.4 σ = 6.0
Digital Comm Systems	FA 2000 (TTU) [17] $\bar{x}$ = 80.8 σ = 12.5	FA 2001 (TTU) [22] $\bar{x}$ = 80.1 σ = 15.7	FA 2003 (UVM) [16†] $\bar{x}$ = 83.4 σ = 8.5
Wireless Comm Systems	SP 2001 (TTU) [6*] $\bar{x}$ = 89.8 σ = 6.5	SP 2003 (UVM) [10†] $\bar{x}$ = 89.4 σ = 8.4	FA 2004 (UVM) [18†] $\bar{x}$ = 87.7 σ = 4.4

Table 6. Final Exam Grades

Course	**w/o enhancements**		**w/enhancements**
Intro to Comm Systems	FA 2001 (TTU) $\bar{x}$ = 82.1 σ = 9.5	SP 2003 (UVM) [16] $\bar{x}$ = 86.6 σ = 7.9	SP 2004 (UVM) [10] $\bar{x}$ = 89.1 σ = 8.4
Digital Comm Systems	FA 2000 (TTU) [17] $\bar{x}$ = 86.0 σ = 14.6	FA 2001 (TTU) [22] $\bar{x}$ = 84.1 σ = 9.6	FA 2003 (UVM) [16†] $\bar{x}$ = 82.8 σ = 6.1
Wireless Comm Systems	SP 2001 (TTU) [6*] $\bar{x}$ = 87.4 σ = 7.2	SP 2003 (UVM) [10†] $\bar{x}$ = 92.5 σ = 5.4	FA 2004 (UVM) [18†] $\bar{x}$ = 88.14 σ = 6.0

[31] Number of student (undergraduate unless otherwise noted)
* Graduate students only
† Undergraduate and graduate students
Courses offered at Tennessee Technological University (TTU) and UVM

The finals for these courses are a comprehensive, take home exam for which students typically have a week to complete. The exams consist of at least 20 questions requiring multi-step solutions and discussions. Again, we see good improvement in the introductory course but contrary results for the follow-on courses. It is worth noting that the follow-courses are typically more advanced than what will be found in an undergraduate curriculum and at UVM are also offered to graduate students. As such, there is less consistency in content in these courses in comparison to the introductory course; especially since these upper level courses are only offered every other year. In short, our project results for these three courses are currently inconclusive and only after additional course offerings may the true benefits be known.

However, we view this project to have had broader beneficial impacts. As was noted, these three courses are complemented with a dedicated *Telecommunications Lab* course. Since students in the introductory course now have basic exposure to spectrum analysis, this lab course's material has been advanced to build upon this base. In addition, students have been able to parlay this experience in terms of new summer internships in the wireless communications field.

A challenge for the project continues to be accounting for the variable student experience in the upper level courses. As such, the author will be developing tutorials to introduce unfamiliar students to basics of RF test equipment use. Clearly, additional offerings of the courses are needed to ascertain the overall effectiveness of this project. Again, all content developed as a result of this project is currently available online and any related questions can be directed to the author (jfrolik@uvm.edu).

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BIOGRAPHY

JEFF FROLIK received the B.S.E.E. degree from the University of South Alabama, Mobile in 1986, the M.S.E.E. degree from the University of Southern California, Los Angeles in 1988 and the Ph.D. degree in Electrical Engineering Systems from The University of Michigan, Ann Arbor in 1995. He is an Assistant Professor in the Electrical and Computer Engineering Department at the University of Vermont. He is the recipient of the ASEE Southeastern Section New Teacher Award in 2002 (while at Tennessee Technological University).