AC 2012-3065: A HANDS-ON COURSE IN DATA COMMUNICATIONS FOR TECHNOLOGISTS

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A HANDS-ON COURSE IN DATA COMMUNICATIONS FOR TECNOLOGISTS

Abstract
Traditional undergraduate communication courses have focused on analog transmission systems, which can be coupled with a fairly simple laboratory component. The emergency of modern technologies has changed the focus from analog to digital systems, making data communications an essential area of study for students of several technology majors. However, due to the complexity and cost of equipment that can emulate digital concepts, offering an undergraduate course in data communication with a supplemental hardware laboratory is not as straightforward as in the analog case. Simulation only based laboratory is an alternative solution but are not a substitute for hands-on experiments with circuit hardware and real signals. A reasonable solution for this dilemma is to offer a data communication laboratory component with a mixed of computer-aided techniques, traditional communication circuitry and basic instruments, Emona Telecoms-Trainer ETT 101 communications modules, and an end of semester practical application project. This hybrid solution allows for a relatively low-cost and flexible data communications laboratory experience. This paper presents an overview of the experiments that have been developed for a data communication course, and discusses the main challenges and teaching methods that the author has used to encourage student's active learning and engagement. Assessment data indicates that there was improvement in achieving the student learning outcomes for the course as a result of the introduction of the new hybrid laboratory experiments and the teaching methods used.

1. Introduction
Nowadays, modern technologies are interdisciplinary and often require knowledge of several fields. For instance, students graduating from technology majors such as computer network and system administration, electrical engineering technology (EET), computer engineering technology, and audio production must have at least a basic understanding of modern communications principles, since they will be working with electronic/computer systems and devices in their careers. Traditional undergraduate communication courses have focused on analog transmission systems, which can be coupled with a fairly simple laboratory component. The emergency of modern technologies to support new services in cellular telephony, Internet, and data networks in general, has changed the focus from analog to digital systems, making data communications an essential area of study to any of the previously mentioned majors. However, courses in digital or data communications systems are traditionally taught by examining the performance of these systems as a set of analytical equations, which seems to provide little insight or motivation for the undergraduate students [1]. Moreover, the focus of technology degrees is on hands-on oriented learning, with little emphasis in math analysis.

It is a common understanding that the laboratory must serve as a learning resource center in which the students not only perform formal lab assignments, but also have the opportunity to use the equipment and computers to strengthen their understanding of the concepts presented in the lecture section. In Fall 2009, the electrical engineering technology program at Michigan Technological University revised the course in data communications, previously offered as a lecture-only course, to include a weekly two-hour laboratory. The inclusion of the laboratory component was a natural extension for the course since the EET program focus is on hands-on. However, due to the complexity and cost of equipment that can emulate digital concepts, offering an undergraduate course in data communication with a supplemental hardware laboratory is not as straightforward as in the analog case. Simulation only based laboratory is an alternative solution but are not a substitute for hands-on experiments with circuit hardware and real signals. In a traditional undergraduate digital communication laboratory, students are exposed to communication circuit hardware and systems by performing measurements using relatively complex instruments and techniques [2]. The operation of these instruments can be intimidating, especially for non-majors (non EET majors) required to take a data communication class. Rather than adopt only a simulation or a complex hardware approach, a reasonable solution is to offer a data communication laboratory component with a mix of computer-aided techniques, traditional communication circuitry and basic instruments, Emona Telecoms-Trainer ETT 101 communications platform, and an end of semester practical application project. This hybrid solution allows for a relatively low-cost and flexible data communications laboratory experience.

This paper presents an overview of the experiments that have been developed for this course mainly for Fall 2009 – 2011, and discusses the main challenges and teaching methods that the author has used to encourage active learning and engagement among the students, especially non-EET major students. Assessment data indicates that there was improvement in achieving the student learning outcomes for the course as a result of the introduction of the new hybrid laboratory experiments and the teaching methods used.

2. Challenges

In addition to the complexity and cost of equipment that can emulate digital concepts, the data communication class that we describe in this paper is offered as a core-course for EET majors and a service course for other majors (non-EET). Historically, introductory courses in electrical engineering and electrical engineering technology not always have been adequate to satisfy the goals of providing a foundation for EET majors, while providing some EET knowledge and tools needed for other majors to support their field of study[3]. We continue to struggle with the task of imparting knowledge to students who often have little interest in the material, and who are very impatient. We also are often faced with the decision of covering only the most basic information on most topics in the syllabus or focusing on communicating a comprehensive understanding of a subset of topics. Some students hate electronics related classes. They believe that the instructor is the reason why they don't understand the material, forgetting how little time they spend to work on extra class assignments and studying. They question why they are forced to take the course; most importantly what is the use of the course content in their major. Many have little idea of why or how an EET course may be relevant to their future careers. However, to better serve the academic community the key is not to see these challenges as inhibitors but identify ways to overcome them and turn them to advantage. For instance, one can use skill-building exercise to impart substantive knowledge; one can teach a breadth of subjects while allowing students to pursue out-of-class activities that allow a depth of knowledge on particular topics; one can create a small class atmosphere in a large class setting. This point of view is shared by others disciplines[4, 5] and can be fairly easily applied to electrical engineering technology. Although, the author recognizes that without any doubt applying these ideas places more demands on the instructor, who also is pressured to develop research and other scholarly activities.

In order to tailor teaching methods to better serve non-majors, one needs to address questions such as: – What pedagogical assumptions shape introductory courses and lab experiences? – What does research tell us about course-taking patterns after the introductory course for non-EET majors? – How are student learning outcomes for introductory courses determined? – What is the student background on the pre-requisites needed for the course? Based on these questions and on the author's experience, a set of recommendations was put together by the author, who has been following them and obtaining good feedback from the students.

3. Teaching methods for effectively teaching majors and non-majors

In this section the author summarize the teaching methods she used for effective teaching EET major and non-EET major in the same class. These guiding principles are based on the author's teaching experiences at two different Midwest institutions. Teaching philosophy for grading, homework assignments, and exams, are not discussed in detail since the author believes that these topics should be tailored in a case by case basis. More detail on these teaching methods can be found in [6].

3.1. Appropriate pedagogy

Instruction should follow an order that starts with the broad uses and system components and only then delves further down into details. This methodology is known as "outside-in" or "top-down" approach and is widely applicable and is practiced in many fields, especially by engineers [7]. The advantages of the outside-in approach, includes the motivation to students. Students, especially non-majors, want to appreciate why they are putting effort into learning a specific material that at first doesn't appear related to their majors. They need a better answer than, "Because you will need it later." The author has follow an approach consistent to the top-down approach, where the application is briefly discussed first and the teaching of the basic principles follows. For instance, to tailor a given topic to Computer Network & System Administration students, the author talks about the need for different cables to carry out binary data at different data rates before talking about specific characteristics of transmission media.

3.2. Encourage discussions

The author also actively pursues the engagement of the students in the classroom by frequently asking them questions and stimulating them to ask questions to the instructor. In addition to email list, and Blackboard resources for discussions.

3.3. Use of technology

The author makes extensive use of technology such as PowerPoint presentations, i-Clickers, class email list, class website, and educational software such as Blackboard®, Canvas®, and others, which are provided by most universities in the U.S. In addition, the author gives preference to adopt text books with companion websites. The author has noticed that both majors and non-majors take advantage of these resources; however, they are particularly more relevant for non-majors, as they have the tendency to use these resources more often than EET majors. Blackboard® is an extremely helpful teaching tool that can be used to complement classroom instruction in a variety of ways, such as:

- To develop and apply online exams and quizzes;
- To post lecture PowerPoint presentations;
- To post homework assignments;
- To post solutions of homework, exam, and quizzes;
- To obtain statistics of online taken exams and quizzes, such as statistics of each problem, class average, and class standard deviation;
- To provide any class related document;
- To post grades online. Blackboard is an excellent tool to post grades as the university are making more strict the students privacy policies, in which the grades can only been seen by each individual students;
- Email a specific student or a group of students, since Blackboard contains the email address of all the students registered for the class.

3.4. Frequent feedback

While it is important for any class, frequent feedback is particularly important for non-majors. Timely and adequate feedback is important is various forms, such as in class discussions, written comments, graded homework, quizzes, and exams. The author also applies Blackboard® based mid-term instruction evaluation as a way to collect feedback from students while there are still several weeks before the end of the semester to make appropriate and timely changes. In addition, the author has been using i-Clickers® as a way to give short quizzes in the beginning of each lecture covering the material of the previous class. The questions are multiple-choice type, covering basic concepts that students should know with a closed-book, closed-notes. Each question takes only about 60 seconds to be presented and answered by the students. The i-Clicker software collects the answers, which are displayed in a graph for the whole class. The graph with student answer doesn't identify the students and serve for the instructor to access the knowledge about specific topics previously covered in class. If a given question is not answered correctly by at least 70% of the class, the instructor discuss about the topic again before moving on to another topic.

4. Data Communication Course description

The data communication course is an introductory course to the fundamentals of digital communication methods. Topics include data transmission, signal encoding techniques, digital data communication techniques, transmission media, and introduction to optical fiber communications.

4.1. Student Learning Outcomes (SLO)

Upon successful completion of this course students should be able to understand:

a. The characteristics of signals propagated through different transmission media, including concepts of attenuation, delay distortion, and noise (SNR, BER, noise figure);
b. How bandwidth affects the operation of communication systems, including frequency domain analysis and application of fast Fourier transforms (FFT) ;
c. The concept of channel capacity: ideal and noise channels;
d. The use and application of different transmission media;
e. The basic principles of signal encoding techniques for analog and digital data;
f. The basic principle of Transmission Lines, importance of matching impedance, and time-domain reflectometry (TDR);

g. The difference between asynchronous and synchronous transmission, and specifications for RS-232 standard;
h. The basic principles of optical fiber communications.

5. Lab Experiments and simple simulations

It is a common understanding that the laboratory must serve as a learning resource center in which the students not only perform formal lab assignments, but also have the opportunity to use the equipment and computers to strengthen their understanding of the concepts presented in the lecture section[8]. We can't stress enough the value of hands-on learning. The laboratory adds realism and solidity to the topics covered course. Students usually enjoy laboratory work, especially as it can be related to some of their own major interests. Therefore, it is imperative to choose experiments that provide students with real life applications that are challenging but achievable, and most importantly that the lab experiments are tightly couple with lecture. We also receive input from our Industrial Advisory Board for experiments that would be beneficial for our students in their professional careers. Therefore, undergraduate laboratories require constant updating and development of new and innovative experiments each semester, which requires a fairly large amount of time on the instructors' side. The majority of books in data communication don't offer a companion lab manual suitable for a technology course in data communication, rather the majority of the experiments are focused on networking. A very recent published book [9], however, includes a set of experiments that can easily be tailored to this class. In addition to well chosen experiments, students' data should be checked before they leave the lab to make sure that the data is at least acceptable to complete the lab assignment, this policy is particularly important for non-major students taking possibly their only EET laboratory session.

It is also of great use to have a computer on each bench that can be used for instrument control and data acquisition, data processing and plotting, and circuit simulation. The author encourages students to simulate circuits and system setup using software such as Electronic Workbench Multisim® by assigning them simulated lab homework prior to the hand-on lab experiment. The simulations provide a link between the theory learned in class and the actual lab experiment. Computer-based lab experiments speed up student progress in hands-on experiments and make the learning experience in the lab more efficient. However, careful attention should be paid to avoid the use of simulation as a substitute for thinking, as can be the case for some students. Students have reported in their end of course surveys that the laboratory experiments were valuable elements of their learning process, through meaningful hands-on experience gained in the laboratory. *We include below a list of hybrid lab experiments based on simulations, traditional circuitry and basic instruments, and Emona ETT 101 modules, which allows for a relatively low-cost and flexible data communications laboratory experience. Most of the lab experiments presented below was developed by the author.*

List of lab experiments includes:

Experiment 1: AC signals generation and measurements

Concepts: Time-varying signals, amplitude, period, frequency, peak-to-peak, peak, and RMS measurements.

Objectives: Students learn (or review) the main characteristics of time-varying signals. They are introduced to the tools used to generate and measure signals that vary with time, such as:

function generator and oscilloscope. They also perform digital multimeter (DMM) measurements.

Experiment 2: Introduction to Virtual Multisim® Lab
Concepts: Time-varying signals, amplitude, period, frequency, peak-to-peak, peak and RMS measurements.
Objectives: Students become familiar with the use of Electronics Workbench Multisim (EWB) in analyzing AC waveforms in time domain, and the operation of virtual EWB oscilloscope (XSC), Function Generator (XFG), and virtual components.

Experiment 3: Frequency-domain analysis using Virtual Multisim® Lab
Concepts: Spectral content of popular waveforms such as: sinusoid, triangle wave, and square wave, in addition to harmonics energy, frequency span, and amplitude range in dB.
Objectives: Students become familiar with the use of Electronics Workbench Multisim (EWB) in analyzing complex waveforms in frequency domain, and the operation of virtual EWB oscilloscope (XSC), Spectrum Analyzer (XSA), Function Generator (XFG), and virtual components.

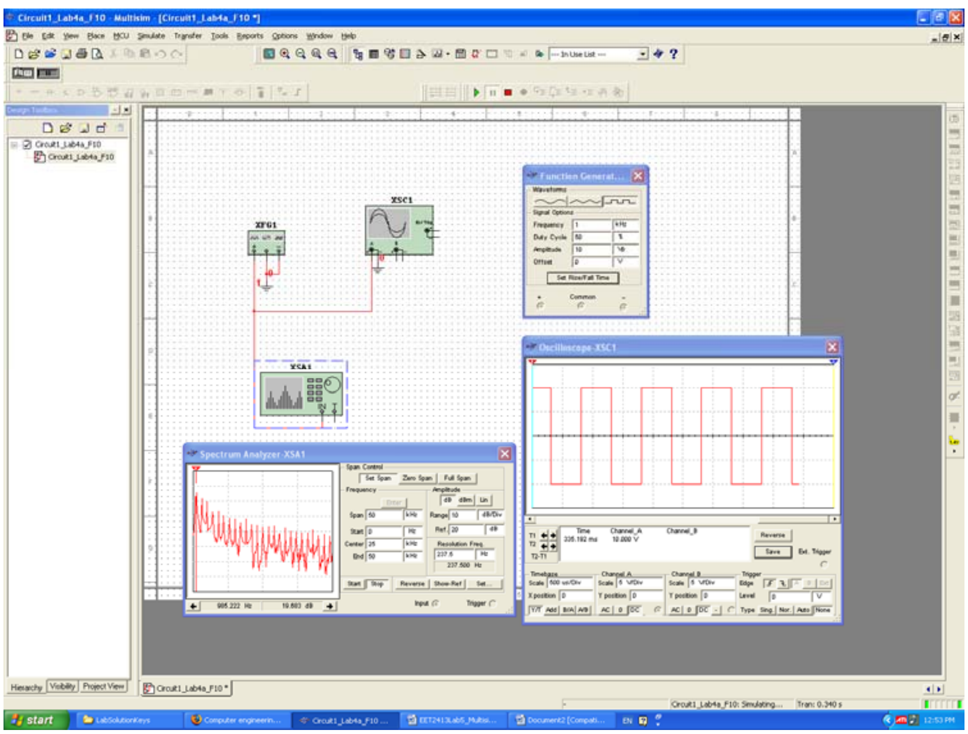


Fig. 1 – Experiment 3 equipment setup using Virtual Multisim Lab.

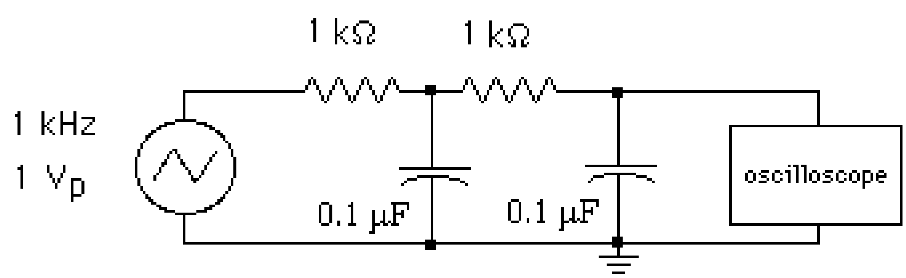
Experiment 4: Frequency Domain analysis using Fast Fourier Transform (FFT) function of Agilent 54621A oscilloscopes
Concepts: Spectral content of popular waveforms such as: sinusoid, triangle wave, and square wave. Harmonics, frequency aliasing, sample rate, frequency span and oscilloscope vertical bandwidth, duty cycle.
Objectives: Students become familiar with main setup of the oscilloscope to analyze signals in frequency domain, and to setup the appropriate sample rate to avoid frequency aliasing.

Experiment 4 Procedure (summary):

1. Connect the oscilloscope to the signal generator and adjust the generator to produce a 1kHz square waveform with amplitude of 1 V_p.
2. Press the "math" key to enable the FFT display.
3. Set the FFT options (sample rate, span, center, scale, offset, and window) accordingly to your signal.
4. Print the waveforms both in time and frequency domain in the same screen shot. Comment on the main characteristics of the signal in time and in frequency domain. What do you conclude as far as the harmonics of the signal are concerned?
5. What happen when you increase or decrease the sample rate?
6. Change the duty cycle to 20%, 50%, and 70%. Print the screen shot for each case both in time and frequency domain. Compare the results for the 3 different duty cycles. What do you conclude as far as the harmonics of the signal are concerned?
7. Repeat the steps 1-5 for a triangular, and for a sine wave. What do you notice?

Experiment 5: Analysis of popular waveforms under a bandwidth limited signal
Concepts: Spectral content of popular, harmonics, emulating effect of bandwidth limited signal with filters.
Objectives: Students become familiar with main setup of the oscilloscope to analyze signals in frequency domain, setup the appropriate sample rate to avoid frequency aliasing, filters, signal distortion due to bandwidth limited signal, measurements of harmonics intensity.
Experiment 5 procedure (summary):

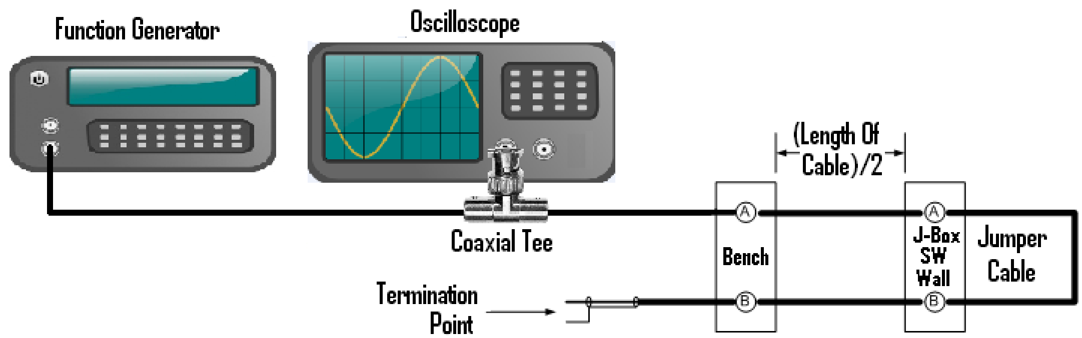
1. Setup the low pass filter of the circuit below (Fig.2). Setup the function generator to a triangular waveform with amplitude 1Vp and 1kHz.



(Fig. 2)

2. Calculate the cutoff frequency of the low pass filter from $f_c = 0.059562/(RC)$.
3. How much does the low pass filter attenuate (in dB) the first, third, and fifth harmonics of the input waveform? Is the output waveform a triangular wave? Support your answer with measured/printed data.
4. How does your answer of item 3 relate to the cutoff frequency of the low pass filter?

Experiment 6: Basic Time Domain Reflectometry (TDR)
Concepts: Impedance matching and mismatching, line loss, reflected wave, cable's propagation velocity, matching load, line discontinuities, transmission line characteristic impedance, load impedance, reflection coefficient.
Objectives: Students become familiar with the use of TDR as a standard procedure in detecting faults in transmission lines. This technique is especially useful in cases where it is difficult to inspect the transmission line visually such as buried cables. One was the goals of this experiment was to observe wave reflection for different loads. Students also learn to determine the approximate location of the fault.
Experiment 6 setup



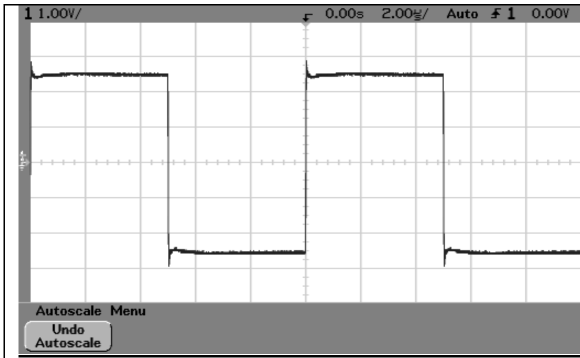
(Fig. 3)
Experiment 6 procedure (summary):
1. Measure the characteristic impedance and the velocity of propagation for the sample of RG-58 cable, based on measured cable capacitance and impedance using the relation $v_p = 1/(LC)^{1/2}$.
2. Set up the transmission line circuit in Fig.3 with the signal generator set up to output a 5 V_{p-p} square wave with a frequency of about 100 kHz (not critical). Trigger the scope on the leading edge of the signal to observe the reflection. Jack A at your bench is the input end of your line, jack B is the end of the line (the cable installed between your bench and the jack panel is RG-58/U). Perform the following steps:

i. Measure T (time of incidence plus reflection) for different loads. Connect different loads (different values resistors, capacitors, and inductors) to the termination point indicated in Fig.3.
ii. Estimate how long is the transmission line in each case of part 3, by using the relation

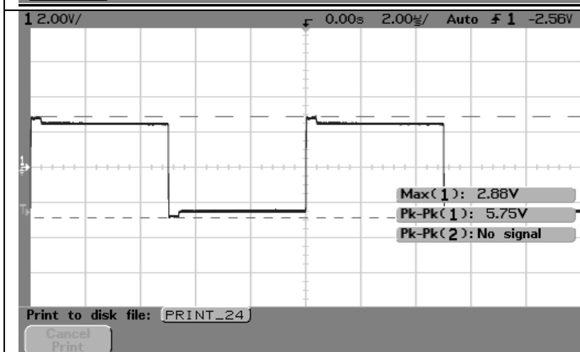
$$\text{Length of cable} = v_p \times \frac{T}{2}$$

iii. Is your line lossless, or do you see any evidence of losses? Compare the input and output signal waveforms observed in the oscilloscope.

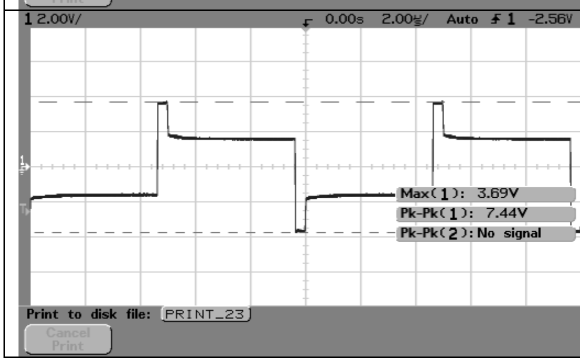
Some of the results of the experiment are shown in the waveforms of Figs. 4-6.



(Fig. 4) Input signal with amplitude of approximately 6 Vpp.



(Fig. 5) Output signal with a resistive load with value close to 50 Ω. There is no reflection in the line, implying matching impedance between the line (50 Ω is also the characteristic impedance for the RG-58/U cable) and the load.



(Fig. 6) Output signal with load other than 50 Ω (pure resistive). There is reflection in the line. The wave shown in the scope is a composition of the input signal (E_i) and the reflected signal (E_r).

Experiment 7: Digital Modulation/demodulation ASK using EMONA® ETT-101
Concepts: Amplitude Shift Keying (ASK) modulation and demodulation, digital signal modeling, ASK generation (using switching mode), sequence generation, envelope detection, noise effects, bit error rate (BER), and carrier frequency.
Objectives: Students become familiar with modulation and demodulation of digital signals onto a radio frequency (RF) carrier, and importance of appropriately choosing carrier frequency. In addition, students add noise to the system, which introduces bit errors in the data transmission, and then perform simple BER analysis in the demodulated/detected signal. The use of traditional measurement equipment such as the scope in combination with the Emona ETT-101 substantiates to the student that the platform is functioning.

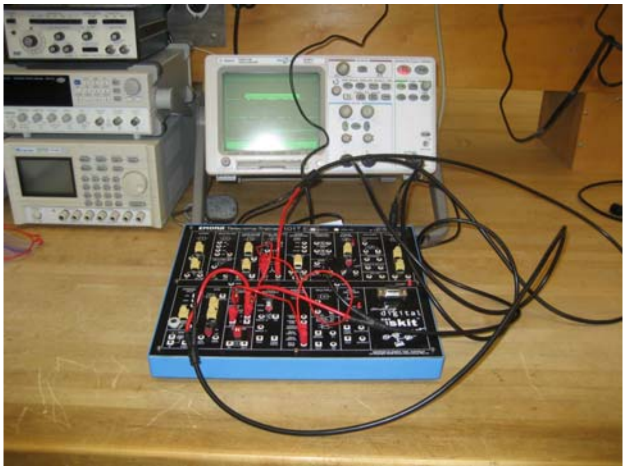


Fig. 7: Emona® Telecoms-Trainer ETT-101 experimental platform connected to an oscilloscope.

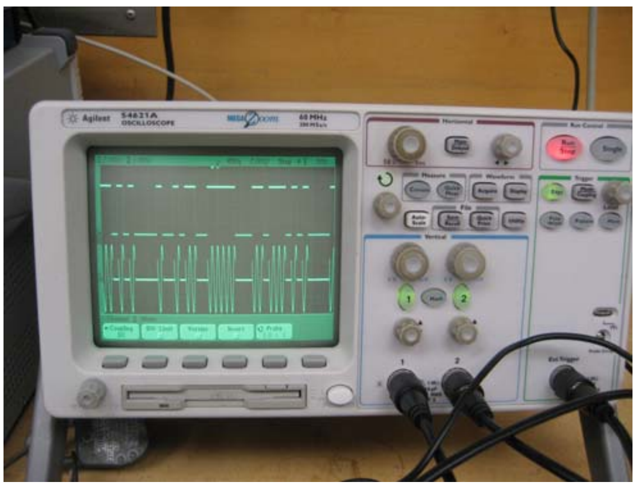


Fig. 8: Input and output of ASK modulator using EMONA platform [10].

Experiment 8: Digital Modulation/demodulation BFSK using EMONA® ETT-101
Concepts: Binary Frequency Shift Keying (BFSK) modulation and demodulation, digital signal modeling, sequence generator, filtering/envelope detector, and carrier frequencies.
Objectives: Students become familiar with another form of modulation of digital signals onto an RF carrier. Students also learn that the general principles of FSK are used in more advanced data encoding techniques.

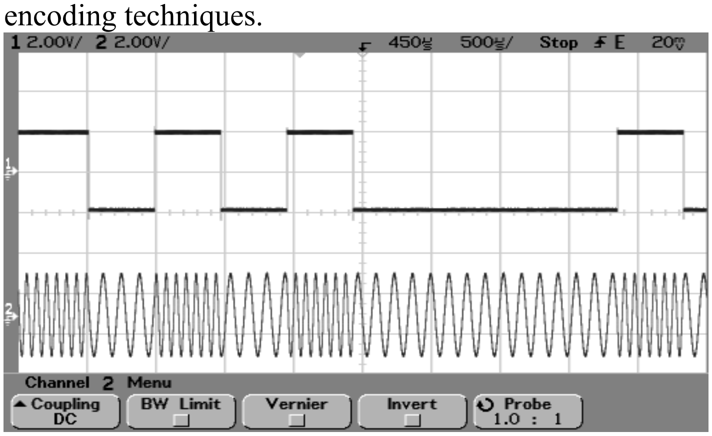


Fig. 9: Input and output of FSK modulator using EMONA platform [10].

Experiment 9: RS-232 standard and LabView® simulations
Concepts: The difference between asynchronous and synchronous transmission, specifications for RS-232 standard, RS-232 control signals and handshaking, LabView® serial communication simulations, DB-9 and DB-25 connectors. This experiment was added based on input from our Industrial Advisory Board.
Objectives: Students become familiar with RS232 communication standard and its limitations, use of computer serial ports, use of RS-232 testing devices, measure RS-232 control signals in different serial communication configurations, such as loopback connection, transmitter to receiver connection, and oscilloscope to computer connection.
Experiment 9 procedure (summary): For this experiment we use a RS-232 break-out-box and LabView® simulations Basic Serial Write and Read.vi, and Basic 2 Port Serial Write and Read.vi. In the loopback connection the students are able to observe the control signals of the RS-232 in a basic configuration. In the transmitter to receiver configuration both ports of the RS-232 breakout box are connected to the two computer ports. The students observe the handshake operation for RS-232 and the voltage levels of the control signal in the connector pins. In the third configuration, the students connect the break-out-box between the scope and the computer and run the Agilent® data acquisition software to capture scope waveform prints outs in the computer. Students once again observe the handshake operation for RS-232 and the voltage levels of the control signal in the connector pins.

Final Lab Project: Serial Communication Project
Concepts: The difference between asynchronous and synchronous transmission, and specifications for RS-232 standard.
Objectives: Students become familiar with RS232 communication standard and its limitations, use of computer serial ports, practical wireless and wired solutions.
Project description summary: An industrial equipment only communicates via RS232 port with a PC, however, the PC is hundreds of feet away from the equipment. What are the ways that you can make the equipment communicate with the PC? Give a wireless and a wired solution with pros and cons.
Note: Each semester a different final lab project may be selected. There are several topics that can be chosen for the final lab project. Factors such as budget, number of students, time, topics covered in class, and students feedback are used to define the selection of final project topic and deliverables.

6. Assessment

Assessment data indicates that there was improvement in achieving the students learning outcomes (SLO) for the course as a result of the introduction of the new laboratory experiments and the teaching methods used. The success indicators were based in direct and indirect quantitative measures such as exams, written lab reports, student surveys, and instructor/students meetings.

To measure the adequacy of the teaching methods, students are given a midterm survey in the beginning of the second half of the semester. This survey is independent of the traditional course evaluations, and is used to solicit students' response to overall course performance and any recommendation that they may have. Informal meetings between the students and the instructor are also conducted. At the end of the semester, the university instruction evaluation surveys are also used as a tool for assessment.

Question	**Rating - Fall 2011** (33 students)	**Rating- Fall 2010** (49 students)	**Rating-Fall 2009** (42 students)
1) The pace of this course is consistent with my ability to learn the material.	3.78 (95%)	3.91 (98%)	3.24 (81%)
2) The instructor is well prepared, and is able to communicate the course material clearly.	3.60 (90%)	3.40 (85%)	3.21 (80%)
3) The instructor's grading policies are fair.	3.74 (94%)	3.67 (92%)	3.24 (81%)
4) Have the labs be useful in helping you understanding the material better	3.57 (89%)	3.35 (84%)	2.83 (71%)
5) Would you take another course with this instructor	3.58 (90%)	3.24 (81%)	2.86 (72%)

Table 1: Midterm instruction and learning evaluation.

In Table 1, the author shows the survey questions and students' responses for the student rating of instruction and learning for the midterm class evaluation. The rating used for the questions in table 1 was: (4) strong agree, (3) agree, (2) disagree, (1) strong disagree. In addition to the questions/ratings listed in Table 1, we also asked the students "What grade do you think you deserve in the course so far. This should be based on what you think you have learned, not the actual grade you have received." This additional question was not included in the evaluation for Fall 2009 that is why it is not shown in Table 2.

Letter Grade (%)	Fall 2011	Fall 2010
A (90-100)	30.4%	17.6%
AB (85-89)	47.8%	47.1%
B (80-84)	17.4%	20.6%
BC (75-79)	0.0%	11.8%
C (70-74)	0.0%	2.9%

Table 2: Student answers to grade based on learning. Note: In Fall 2011, one student (4.3%) answered "CD (60-64)".

Positive comments of students for the class include, "*the laboratory experiments were exciting and a valuable element of their learning process, through meaningful hands-on experience gained in the laboratory*". "*The use of Blackboard and i-clicker review quizzes, and classroom examples were helpful to understand the material*." In the negative side, the students found the textbook difficult to follow. The textbook adopted for the class was "Data and computer communications," by Stallings, Prentice Hall, 2007. The author considers the book by Stallings a well written and structured textbook, however technology students' feedback revels that they have difficulties to follow the book; some consider the book dense, and difficult to solve some of the homework problems. In order to address this issue, the instructor has assign weekly reading assignments of key sections of the chapters covered from the book. The reading assignments require students to write at least two questions for the instructor to answer in one class period dedicated only to answer questions from students' reading assignments. The instruction is also considering another book to be used as textbook in Fall 2012, possibly the book by Moussavi [9].

Some of the students' answers to an additional question in the survey:

What about this class is helping you to learn?

"Instructor working in class problems on the board"

"The iclicker questions to review material that we covered in previous lectures"

"PowerPoint slides of notes posted on Blackboard"

"The material in class is similar to what we practice in the lab"

In Fall 2009 was the first semester that the data communications course was offered with a weekly two-hour laboratory. Due to several factors, the feedback from the students on their lab experience was very negative, as indicated in Table 1. Some of these factors include: the instructor had a very limited amount of time to develop the experiments; the equipment in the lab also presented a challenge, as previously discussed in Section 2 of this paper. In the past two years, however, the instructor has strived to improve the overall class experience for the students. Comparing Tables 1 and 2, there is a clear indication that the overall structure of the course in Fall 2011 have helped to improve the rate of instruction. Although, the results reflect a fairly small sample of students, the author believes that by continuing working and improving the lab experience and teaching methods, more benefits for students and instructors will occur on a continuous basis.

In Table 3, the author shows the summary of student achievement of the student learning outcomes (SLO) for this class and quality of instruction as required by ABET for the class of Fall 2011. Out of 33 initially registered students for Fall 2011, 31 students took the Final Exam. The mean value for the Final Exam was 80.6% with standard deviation of 12.4%. The problems with highest rate of correct answer achieved 100% (Fourier analysis, channel capacity definition, transmission impairment, digital modulation, BER, bandwidth, matching impedance), and the problem with lowest rate of correct answer achieve 29% (channel capacity calculation problem). The results show the correlations between the SLOs listed in the syllabus and the final exam. Overall, the student performed well considering a comprehensive closed-book final exam with 40 problems. In Table 4, the author compares the students' performance on the same SLOs for two semesters. The results in Table 4 indicate a significant performance improvement in all the learning outcomes with exception of one. The student learning outcome with poorer performance in Fall 2011 semester was related to "channel capacity" calculations. The author attributes that to students having issues with calculating logarithmic functions base 2, and intend to provide more assignments on this topic in future semesters. In addition, channel capacity was one of the topics without a lab experiment. This is an indicator that the lab experiments are helping students to retain the material covered in the lectures. Extra time is necessary to cover these topics and solving more practical problems, and one way of doing that is by providing extra tutoring sections. There is still room for improvements, and the author is working on ways to tailor the course to better attend the audience and to provide the material that must be covered for the class. The quantitative direct and indirect measures, however, indicate that the developed new labs and the teaching methods that the author is using have helped to improve the overall class performance.

The results shown in Table 5 clearly indicate significant improvement in the students' grades with an increase in the class average and a reduction in the standard deviation. The author attributes the grade improvement as the result of several factors:

- The instructor has also continuously updated the lab descriptions and developed new lab experiments;
- In addition, instructor has changed the sequence that part of the material is covered in the lectures in order to tightly couple weekly lab activities with lectures;
- Instructor has given more assignments, frequent review quizzes using I-Clickers, has given more problems solving sections, provided solutions to all assignments in a timely fashion, and provided faster feedback for students. Instructor has also correlated more the material covered in the class with practical application examples.

Student Learning Outcome (SLO)	*Assessment Instrument for this SLO*	*Standard*	*Results- Fall 2011 (Based on Final Exam and Labs)*	*Acceptable? Y/N*	*Continuous Improvement Actions Planned*
1.Become familiar with the basic elements and terminologies used in data communications, such as source, transmitter, transmission medium, receiver destination, data, signal.	Labs 1-11 Exam 1, Exam 2, HW 1– 6, Reading assig, Iclicker quiz, Final Exam – Qs:1-40	70% of students will score 70% or better on this question block.	81.7% of students scored 70% or better on this question block	Y	None planned at this time.
2. Understand the importance of frequency domain analysis in determining bandwidth for communication systems.	Labs 4, 5, 6, 7 Exam1- Qs: 1, 2, 6, 7,8,11,12 HW2, 3, 5, Reading assig.Iclicker quiz, Final Exam – Qs: 1, 2, 5, 8, 9, 11,12,16, 22, 24, 25,	70% of students will score 70% or better on this question block.	87.8% of students scored 70% or better on this question block	Y	None planned at this time.
3.Understand the effect transmission Impairments, such as Attenuation, delay distortion, and noise.	Labs 8, 9 Exam 1- Qs: 3,4,5,9,10 Exam 2 – Qs: 2, 3 Reading assig, Iclicker quizzes Final Exam – Qs:6, 13, 17, 33, 37	70% of students will score 70% or better on this question block.	90.4% of students scored 70% or better on this question block	Y	None planned at this time.
4.Become familiar with noise designation such a signal-to-noise ratio (SNR) and bit-error-rate (BER).	Exam 1 – Q:6 Exam 2 – Q:2,3 HW 3, HW5 Iclicker quizzes Final Exam – Qs: 4, 18, 26, 30	70% of students will score 70% or better	76.6% of students scored 70% or better	Y	None planned at this time.
5. Become familiar with channel capacity calculations.	Exam 2 – Qs: 1, 2,3,9,10 HW 3, HW5 Iclicker quizzes; Final Exam – Qs: 10, 11, 18, 29	70% of students will score 70% or better	61.3% of students scored 70% or better	N	Exam 2 about channel capacity has average of 85.1%. However, instructor will give a review assignment on channel capacity before the final exam next time.
6.Understand the importance of impedance matching for transmission lines.	Labs 8, 9 Exam 2 – Q: 5, 6, 7, 8, HW 4 Iclicker quiz; Final Exam – Qs:27, 32, 36	70% of students will score 70% or better	95.7% of students scored 70% or better	Y	None planned at this time.
7.Become familiar with basic testing techniques, such as: Time Domain Reflectometry (TDR).	Labs 8, 9 Exam 2 – Qs: 8, HW4, Iclicker problems;	70% of students will score 70% or better	84.3% of students scored 70% or better	Y	Even though this is an acceptable score. I plan on add an OTDR experiment if equipment become available.
8. Understand the techniques for transforming digital data into analog signals, such as ASK, FSK, PSK.	Lab10, HW6 Iclicker Final Exam – Qs:19, 28, 31, 34, 35	70% of students will score 70% or better	80% of students scored 70% or better	Y	Even though this is an acceptable score. Instructor plan on adding additional lab experiment on this topic.
9. Understand basic difference between asynchronous and synchronous transmissions.	Lab 11 Final Exam – Qs:20, 21, 23	70% of students will score 70% or better	78.2% of students scored 70% or better	Y	None planned at this time.
10. Become familiar with specifications for RS232 data communication standard.	Lab 11 Final Exam – Qs: 20, 21, 40	70% of students will score 70% or better	84.7% of students scored 70% or better	Y	Even though this is an acceptable score. This topic was added based on feedback from students and Industrial Advisor Board members. A new lab was created. Instructor plans to improve the current lab experiment.

Table 3: Summary of Student Achievement of Course Objectives and Quality of Instruction – Fall 2011.

Student Learning Outcome	*Results - Fall 2009 (Based on Final Exam and Labs)*	*Results - Fall 2011 (Based on Final Exam and Labs)*
1. Become familiar with the basic elements and terminologies used in data communications, such as source, transmitter, transmission medium, receiver, destination, data, signal.	81.7% of students scored 70% or better on this question block	84.6% of students scored 70% or better on this question block. (This results were based on class overall average)
2. Understand the importance of frequency domain analysis in determining bandwidth for communication systems.	84.6% of students scored 70% or better	87.8% of students scored 70% or better on this question block
3. Understand the effect Transmission impairments, such as Attenuation, delay distortion, and noise.	79% of students scored 70% or better on this question block	90.4% of students scored 70% or better on this question block
4. Become familiar with noise designation such a signal-to-noise ratio (SNR) and bit-error-rate (BER).	68.2% of students scored 70% or better on this question block	76.6% of students scored 70% or better
5. Become familiar with channel capacity calculations.	72.3% of students scored 70% or better	61.3% of students scored 70% or better
6. Understand the importance of impedance matching for transmission lines.	78.2% of students scored 70% or better	95.7% of students scored 70% or better
7. Become familiar with basic cabling testing techniques, such as: Time Domain Reflectometry (TDR).	68% of students scored 70% or better	84.3% of students scored 70% or better
8. Understand the techniques for transforming digital data into analog signals, such as ASK, FSK, PSK.	76.9% of students scored 70% or better	80% of students scored 70% or better
9. Understand basic differences be between asynchronous and synchronous transmissions.	Reports not assessed this semester.	78.2% of students scored 70% or better
10. Become familiar with specifications for RS232 data communication standard.	Reports not assessed this semester.	84.7 % of students scored 70% or better

Table 4: Comparing results of course objectives.

	Fall 2009 (42 Students)	Fall 2010 (49 Students)	Fall 2011(33 Students)
Exam 1	Av. = 77.2, Sd=16.55	Av. = 83.7, Sd=13.24	Av. = 85.8, Sd= 18.12
Exam 2	Av. = 78.1, Sd=12.63	Av. = 65.3, Sd=21.20	Av. = 85.1, Sd= 11.63
Final Exam/project	Av. = 74.5, Sd=15.66	Av. = 79.8, Sd=18.94	Av. = 80.6, Sd=12.38
Final Grade	Av. = 77.9, Sd=13.95	Av. = 78.4, Sd=12.56	Av. = 81.7, Sd=9.09

Table 5: Comparing grades for Fall 2009, Fall 2010, and Fall 2011.

7. Conclusions

Offering an undergraduate course in data communication with a supplemental hardware laboratory for technology students is not as straightforward due to the complexity and cost of equipment that can emulate digital concepts. In this paper we presented a series of experiments for a hybrid solution based on computer-aided techniques, traditional communication circuitry and basic instruments, Emona ETT 101 plataform, and an end of semester practical application project, which allows for a relatively low-cost and flexible data communications laboratory experience. The assessment methods used to evaluate the overall students' experience indicate that the hybrid laboratory solution have helped students to better understand the data communications concepts covered in the course. The teaching methods used have proved to be efficient tools in responding successfully to the challenge of teaching a data communication class to major and non-major technology students. Additional enhancements and improvements are planned for the laboratory experiments.

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