122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #11563

A NEW INTERACTIVE COURSE IN COMMUNICATION ELECTRONICS

Dr. Jay R Porter P.E., Texas A&M University

Jay R. Porter joined the Department of Engineering Technology and Industrial Distribution at Texas A&M University in 1998 and is currently the Program Coordinator for the Electronics Systems Engineering Technology Program. He received the BS degree in electrical engineering (1987), the MS degree in physics (1989), and the Ph.D. in electrical engineering (1993) from Texas A&M University. His areas of interest in research and education include product development, analog/RF electronics, instrumentation, and entrepreneurship.

A New Interactive Course In Communication Electronics

Abstract

In 2012, the Electronics Systems Engineering Technology program at Texas A&M University went through a major curriculum revision. This revision was primarily to create a strong emphasis in intelligent product and system development that spanned many industry sectors including automotive, healthcare, oil and gas, communications, and quality of life. During the revision process, the faculty surveyed industry and, based on need, added both required and technical elective courses to the curriculum. One of these courses was a technical elective in the area of communication electronics. This course was recommended because many students are hired by companies that manage their own communications infrastructure, that consult and maintain communication systems for customers, and that manufacture and provide communication equipment. The course was developed in the Summer of 2013 and has been delivered twice, once in Fall 2013 and again in Spring 2014.

The communication electronics course is offered as an elective and covers both basic communication concepts as well the implementation of these concepts in hardware and software. One of the unique aspects of the course is the teaching format. In 2013, the College began an initiative to double its enrollment over a period of about ten years. As part of this initiative, departments have been asked to find novel teaching approaches that allow for increased capacity without sacrificing quality of instruction. From this standpoint, a hands-on laboratory is one of the primary distinguishing components of engineering technology education and is also one of the major limiting factors to throughput. This course was the perfect opportunity to investigate methods for offering a laboratory component without the requirement for a multiple, two to three hour, facility intensive laboratory sections. To this end, the course was designed to have two traditional lectures each week as well as one interactive lecture where students investigated concepts using simulation and instructor-led demonstrations. In addition, the students were also required to perform hands-on homework assignments that included filter design, communication circuit analysis, and the implementation of a simple communications receiver.

This paper will present an outline of the course including a discussion of topics and hands-on experiences. The interactive portion of the course will be specifically discussed and details will be given about the format and resources needed. Finally, results will be discussed including instructor comments and impressions from the students on the effectiveness of the new course format.

Introduction

Looking at how electronics technology has changed over the past four decades, on can identify several threads in how devices and systems have evolved. For example, most electronic products have continued to shrink in size, primarily due to the advent and growth of the integrated circuit. Another change is in speed. As microcontrollers, microprocessors, and signal processors have continued to grow in capability, the frequencies involved in the design of electronic circuit design have increased by orders of magnitude. A third change is in the ability to communicate. Most modern products and systems now communicate both internally and with external entities through multiple wired and wireless protocols including USB, 802.3, Bluetooth, Zigbee, NFC, etc. In fact, if one considers the trends in IoT (Internet of Things) then it is easy to visualize that one day soon most devices used in people's everyday lives will communicate electronically in some fashion. Thus, it is important that the electronics engineering technology major have a strong background in high frequency design and in communications. In fact, this trend has been recognized for a long time[1] and continues to grow today[2]. To this end, the Electronic Systems Engineering Technology program at Texas A&M University has been working to enhance these aspects in their curriculum for many years.

In 2012, the Electronics Engineering Technology program went through a change in focus, a major curriculum revision, and a name change. The Electronic Systems Engineering Technology (ESET) program, as it is now named, has a strong focus on embedded system-based product and system development[3] and prepares students for long-term careers that cut across many industry sectors including automotive, energy, oil/gas, communications, medical technology, semiconductor and quality-of-life. In fact, the value proposition of offering an experiential learning-based degree that prepares students for careers in electronics-based product development has proven to resonate well with both transfer and freshman students and has had a significant impact on recruiting and outreach. In addition, the new emphasis meshes well with the faculty's interest in introducing students to entrepreneurship. Currently, products being developed by student teams are occasionally acquired by industry for commercialization and have even resulted in graduate-led startup companies.

The new ESET curriculum has four focus areas. These include analog/digital electronics, communications, embedded systems, and a product development emphasis that covers subjects such as test, engineering statistics, quality, and product development. In addition, the curriculum has several system-level courses including instrumentation, controls, as well as two technical electives where the students have the opportunity to integrate their technical knowledge through project-based learning. The focus on communications is particularly important and has resulted for two primary reasons:

- Traditionally, the ESET program has produced many students who go on to have careers in the telecommunications and computer networking industries. Consulting companies, communications companies and communication equipment manufacturers hire these students because of the background in communication systems design, implementation, test and troubleshooting.
- Modern embedded system-based products typically have to communicate either internally or with external entities through wired and wireless communication protocols. For example, most embedded products and systems communicate through subsystems using various interfaces including UART, USB and even 802.3. In addition, it is getting harder to find electronic products that don't communicate in some way with many other devices.

For these reasons, ESET students take multiple courses in communications. These include a basic electromagnetics course, a computer networking course, and a wireless communications course. In addition, data communication topics are inserted in the three embedded systems courses as well. In fact, this strong focus on communications often distinguishes ESET graduates and is a strong contributor to ESET graduate placement. One area that has been recently identified as missing is communication system design. Looking at the communications track, one can note that most of the courses are taught from at the systems level. In fact, many other engineering technology programs also approach communications from a system perspective.[4] In a recent review of the curriculum, industry noted that ESET students would benefit from having a deep understanding of communications systems "in the box."

In 2013, it was decided that a course in communication electronics would be an appropriate addition to the curriculum. Originally, this course was intended to be a required course. However, due to state mandates to reduce the number of hours in college-level programs, it was decided the course would be an upper-level (second semester, junior) technical elective. In the end, this seems appropriate since the majority of upper-level students have a better understanding of their interests and can decide whether this course fits their career goals. This paper will discuss the course curriculum and laboratory in detail. Lessons learned will also be presented.

Course Curriculum

The new course is taught as a technical elective that is designed for students looking at careers in the communications, information technology and telecommunication industries. However, it is also hard to envision very many electronic intelligence-based products and systems that do not communicate in some way. With that in mind, students with a working knowledge of fundamental components and architectures of wired and wireless communication systems are well suited for careers involved in the design, implementation, maintenance and even sales of these devices and systems. Thus, this course is also useful for careers in many other industries such as automotive, medical technology, oil/gas, building automation and quality of life product development companies. It has as a prerequisite an applied electromagnetics and high frequency systems course. The prerequisite prepares the students by introducing topics such as logarithmic units, parasitic components, transmission lines (in particular, micro-strip), antennas, and wave propagation.[5] Thus, the students are well prepared to understand the issues associated with high frequency system design. In addition, students are also required to take a course in wireless communications. Because the wireless course is taught from a "black-box" perspective, this elective helps the interested student delve into "what is inside the box."

Course Format

As part of the College of Engineering's new growth initiative, the faculty are being encouraged to look at novel teaching methodologies where larger numbers of students can be taught effectively without sacrificing learning and engagement. In engineering technology programs, large classes are of particular concern due to the laboratory-oriented nature of the courses. Specifically, most laboratories require small sections due to facility and equipment availability, space required to perform laboratories, and level of interactivity required between students and instructor. As the enrollment increases in the ESET program, lab resources are becoming a commodity. This new course presented an excellent opportunity to design a course from the ground up experimenting with alternative teaching methodologies.

For this reason, the Communications Electronics course is designed as a three hour course with no formal laboratory. The course is taught using three fifty minute sessions per week. The first two sessions each week are traditional lecture style classes where new material is presented. The third session, in lieu of a formal laboratory, is taught as an interactive demonstration/experimentation session. Simulation and experimentation is used to demonstrate the new concepts from each week. In addition, students are grouped into teams (the size of the teams can vary from two to six and depends on the topic and the equipment available) and are given an opportunity to perform their own experimentation as well. Some of this work is done in class while some is given to the students as hands-on work to be done outside of class. Finally, the course has a final project (design of a simple direct-conversion receiver) that the students perform in teams of six outside of the normal class time. The lectures, interactive exercises, and the project are discussed in more detail below.

Lectures

Currently, the course is based on the textbook Electronic Communications: A Systems Approach by Beasley, Hymer, and Miller and published through Prentice Hall.[6] The course essentially covers the first eight chapters of the text. Because the book is written at a fairly high level, the course is augmented by more in-depth material on actual communication electronics design. Table 1 outlines the weekly topics that are introduced in the two weekly lecture sessions.

Table 1. Weekly Lecture Topics

Week	**Topic**
1	Signals in the Time Domain, Log Units, Noise
2	Information, Mixing
3	Modulation, Analog
4	Modulation, Digital
5	Basic Communication System Architectures
6	Communications Hardware - Mixers
7	Communications Hardware - Filters
8	Communications Hardware – Oscillators, PLLs
9	Communications Hardware – Amplifiers
10	Transmitter Design
11	Transmitter Design
12	Receiver Design
13	Receiver Design
14	Software Defined Radio
15	Communication System Considerations

The first two weeks of the course start with refresher and introductory material. While the students have discussed the frequency domain in previous courses including circuits (Fourier series, filters), electronics (filters), instrumentation (aliasing and noise), and applied electromagnetics, they have not had a rigorous treatment of bandlimited signals in the frequency domain. Thus, the concepts of the frequency domain, the use of logarithm units, noise, and visualizing band-limited signals in the spectral domain are reintroduced. The concepts are reinforced through experimentation in the interactive session as well. Finally, the students are given a good understanding of the concept of mixing and how it occurs since it is a primary concept in communication systems. While mixing is introduced in earlier courses, it is explored in more detail including a mathematical treatment of how signals can be shifted in the frequency domain using non-linear devices.

Next, amplitude, frequency, and phase modulation is explored over the next two weeks. Students look at modulation from both a time and frequency domain perspective. The different modulations are studied from the perspective of modulation index, efficiency, noise immunity, and bandwidth. The students are also introduced to how the different modulations are used both with analog and digital data. At this point in the course, modulation is discussed from primarily a "black box" perspective but this is expanded on later in the course. In addition, a week is spent introducing communication system architectures from a high-level system perspective. The building blocks used in most communication systems are introduced including amplifiers, filters, mixers, oscillators, and attenuators. More specifically, the specifications unique to these building blocks when used for communications are introduced including topics such as input/output impedance, gain, loss, conversion loss, noise figure, etc. The students then look at block diagrams for typical transmitters and receivers.

In weeks six through nine, the course explores these building blocks in more depth, looking at circuit-level implementation of mixers, filters, amplifiers, and oscillators. Also, an important part of the course is introducing industry terminology and specifications. Students have the opportunity to compare circuits studied in class to actual commercial mixers. To this end, substantial amounts of time are spent looking at datasheets for real devices. The company, Mini-Circuits[7], provides detailed data and specifics on their devices and makes an excellent reference for this activity. In the case of mixers, single and double balanced passive filters are studied. From the perspective of filters, the students learn about different implementation technologies (passive, active, crystal, SAW,etc) and also have a more formal introduction into filter design. An area which is new to all students is the study of oscillator design. Thus, this course introduces the conditions for oscillation and looks at several transistor and operational amplifier oscillator designs. The students also learn about phase-locked loops and the different implementations, both analog and digital. Finally, different types of communication system amplifiers are studied including pre-amplifiers, small signal amplifiers and power amplifiers. The lecture also introduces different classes of amplifiers and distinguishes between traditional, linear, analog designs versus today's "digital" amplifiers.

With the necessary building blocks covered, actual transmitter and receiver architectures are reviewed next. Currently, the course focuses on analog applications including AM, FM, and ham radio. However, as the course evolves, this will be changed to include modern applications such as digital radio, digital television, WIFI, and/or Bluetooth. The current problem is that most of these technologies require a discussion of additional topics including multiplexing, channel coding, and use of symbols. While many of these topics are introduced in the wireless communications class, this is a senior level course and thus difficult to enforce as a prerequisite.

The final two weeks of the course are used to introduce the concept of software-defined radios (SDR) and general considerations when designing communication systems. Interestingly, many students have realized by this time that most of the operations being studied in hardware could have been implemented through math. Thus, the evolution of SDR is discussed and why a true SDR is limited by the state of current technology including the speed of current data converters and the processing power of current microprocessors, FPGAs, and digital signal processors.

Interactive Exercises

The third weekly session of the communication electronics course is devoted to interactive exercises, demonstrating lecture concepts and giving the students hands-on experience with communication components, systems and test equipment. To this end, the third session meets in a laboratory (Figure 1) designed specifically to accommodate larger numbers (up to thirty) of students for interactive activities. Equipment available in the lab includes four spectrum analyzers, a network analyzer, a software defined radio demonstration setup, as well as twelve computer stations running LabVIEW and Multisim. Examples of the equipment can be seen in Figure 2. Because of the limited availability of equipment, the number of students who work together in teams varies from week to week. For interactive sessions that only involve simulation, teams can be as small as two students. In contrast, during weeks where students are using spectrum and/or network analyzers, the team sizes are much larger. Table 2 shows the weekly exercises and outlines the size of the team and the equipment needed for a given exercise.

Figure 1. Communications Laboratory

Figure 2. Lab equipment (Top left, clockwise): HP 8712 Network Analyzer, HP 8592L Spectrum Analyzer, Tektronix MDO3022 Spectrum Analyzer, NI USRP Radio, Agilent N9310A RF Generator

One of the first interactive exercises is to help the students develop an appreciation for the frequency domain as they use LabVIEW to develop a simple program, or 'virtual instrument (VI)' where they could input different waveforms (sinewave, square wave, multitones, etc) and then visualize the signals in the frequency domain. This is a simple process in LabVIEW due to the numerous fast Fourier transforms and spectral conversion routines that exist. Once the student teams developed their VIs, they were asked to explore the frequency content of different waveforms. They then used the sound card input to digitize their voice and look at its spectral content. By making different sounds such as whistles and regular speech, they developed a better appreciation what the frequency domain actually represents.

Another set of interactive exercises were designed to introduce students to the use of spectrum analyzers, RF generators, and the network analyzer. It should be noted that all students had seen this equipment in the course on applied electromagnetics, but a review was necessary. This course also required the students to be able to operate the equipment independently without step-by-step instructions. Thus, they learned to create modulations using RF generators, to calibrate and setup the network analyzer and to use the more advanced features on the spectrum analyzer to capture peak signals, to average, and to reduce the noise floor.

Next, they explored different modulations by simulating them in LabVIEW, then by capturing modulated signals they created using the RF generators and the spectrum analyzers, and finally capturing real modulated signals from broadcast stations. From the lectures, they had learned the concepts of modulation index, bandwidth, and the frequency domain characteristic of particular modulations. During the interactive exercises, the instructor demonstrated these concepts and the students worked in teams to explore and analyze real modulated signals using appropriate test equipment.

From the perspective of component design, the students had the opportunity to see demonstrations and have hands-on experience exploring mixers and amplifiers as well as designing and testing simple RF low-pass, high-pass, and band-pass filters. For example, in the case of filters, the class worked together to design a simple band-pass filter using techniques learned in the lecture. Teams then simulated their design using Multisim. Finally, teams had a week to implement their design and then test it during class using a network analyzer. While the frequency regime they were working in was rather low (MHz), they were able to see the effects of parasitics on their designs demonstrating a concept they had learned in previous courses. Finally, the students had an opportunity to design simple AM and FM receivers using the USRP systems from National Instruments. Using LabVIEW, they created software demodulators and received simple broadcast signals.

Table 2. Laboratory Assignments

Lab	Description	Team Size	Software and Hardware Tools Used
1	Frequency Domain	2	LabVIEW Computer Workstation
2	AM Modulation I	2	LabVIEW Computer Workstation
3	Introduction to Spectrum Analyzers	4	Spectrum Analyzer (3 GHz) Antenna RF Generator
4	AM Modulation II	6	Spectrum Analyzer RF Generator w/ Modulation Antennas
5	FM and Phase Modulation I	2	LabVIEW and Computer Workstation
6	FM and Phase Modulation II	6	Spectrum Analyzer RF Generator w/ Modulation Antennas
7	Mixing	6	Discrete Mixers RF Generators (2)
8	Filter Design I	2	Multisim and Computer Workstation
9	Introduction to Network Analyzers	6	Network Analyzer (1GHz) Calibration Set Attenuators Mixers
10	Filter Design II	2	Multisim and Computer Workstation
11	Filter Testing	6	Network Analyzer Student Filter Circuits
12	Amplifier Testing	6	Network Analyzer Discrete RF Amplifiers
13	AM Radio Demos	6	--
14	Software Defined Radio	6	NI Software Defined Radio Kits

Course Project

The course project seeks to integrate concepts from the course into an experiential learning problem, giving the six-person student teams the opportunity to design a simple receiver. The project required the students to create a simple commercial AM receiver with a front-end filtering and amplification stage, a single mixing stage with programmable oscillator, and a base-band stage with appropriate filtering, intermediate amplification, and power amplification (for driving a speaker). To this end, the students were to specify all components as a class, develop a printed circuit board, and then, as teams, implement their receiver. The deliverables for the project included a final demonstration of their unit and presentation that covered the following topics:

- A discussion of receiver operation explaining type of demodulation, operation of RF amplifier, mixer, VCO, and base-band audio circuit
- An overall system functional block diagram
- An overall schematic
- A board layout using Ultiboard with discussion of the component choices, layout position, etc
- A complete bill of materials including all parts with part type, part number, values, reference designators, sources, footprints
- Testing results using an AM modulated input signal from a table-top generator (1MHZ carrier with 500 Hz sidebands) with captures of signal at the output of each stage
- Discussion of problems encountered with solutions

Overall, the project was successful both semesters the course was offered with all student teams successfully designing a receiver and demonstrating its function. However, modifications did have to be made to the scope. These will be discussed in the section on lessons learned. It was clear from student implementations that they were able to employ the knowledge learned in the course in order to design a simple receiver. Elements of the project that demonstrated this were the ability of teams to design an RF filter to select the AM radio band, the ability to choose correct local oscillator frequencies and output powers to down-convert local AM radio stations, the ability to measure input signal level and correctly choose stage gains, and the recognition of a need for a base-band low pass filter to remove unwanted mixing products. A point that should be made was the level of excitement and the satisfaction that the teams demonstrated when they were first able to receive an AM signal.

Lessons Learned

The communication electronics elective course has been offered now for two semesters. Student feedback from the course has been very positive as assessed through strong enrollment, student evaluations, and anecdotal information. In addition, the creation of this course has increased student interest in communications systems and RF electronics and electromagnetics and an increase in capstone projects involving these principles. As part of the course evaluation, students are asked if class activities are well prepared. Out of a total of five points, the average response was 4.23 in Fall 2013 and 4.78 in Spring 2014. The students are also asked if the assignments and projects aided in achieving course objectives. The average response was 4.31 in Fall 2013 and 4.72 in Spring 2014. One can see that the responses were good and also increased for the second offering of the course. This can be attributed to "fine tuning" that was done to the interactive exercises and the course project between semesters. As part of the evaluation, student comments were also solicited on what they liked about the course. These were also good with comments such as "get to understand how radio communication works and how simple it is to build one for our own" and "It was fun learning about communications systems. It was an interesting class!" The course has also been discussed with industry members and feedback about the new curriculum has been positive. Those industry members involved in data networking, telecommunications, and communication equipment design/manufacturing have been particularly supportive of this new course.

While only having a fifty minute interactive experience as part of the course is not a direct substitute for a weekly lab period simply due to the shorter amount of time spent, it is clear that it has a strong impact on learning. The initial exercise where the students explore signals in the frequency domain was added in the second offering of the course. This was because during the first offering it was clear that simply discussing the frequency domain in the lecture did not adequately prepare students for concepts later in the course. For example, they had trouble visualizing the concept of mixing and, in particular, the idea of imaging in the mixing process. Adding that particular interactive exercise allowed students in the second course offering to practice visualizing signals in the frequency domain and they had less trouble using these concepts later in the course.

In the first semester offering, the course project turned out to be somewhat overwhelming for the student teams. In particular, the requirement to layout and commit their designs to printed circuit boards turned out to be challenging for the time allocated to the project. This was remedied towards the end of the semester but allowing teams to build their designs using packaged amplifiers, mixers and oscillators and to implement their base-band stages on breadboards. A solution to this issue is currently being studied. This is discussed in more detail in the section on future work.

Finally, it should be noted that LabVIEW made an excellent environment for simulating and visualizing many of the concepts in the course. In particular, it was efficient and simple for the students to create LabVIEW routines to explore different modulations both in the time and frequency domain. These exercises prepared the students well for using actual RF test equipment and working with real-world signals, components, and systems.

Summary and Future Work

To augment the ESET program curriculum, a new course on communication electronics has been created. The course has between delivered twice and in lieu of a typical lecture/laboratory class format, uses alternative delivery methodologies. The course is taught as a lecture-only course with one session per week devoted to interactive demonstrations and hands-on experiences. The course has been well received by the students and, based on the success in the course project and the increased number of capstone projects that leverage communication electronics, is adding value to the capability of ESET graduates. It is anticipated that the course will be taught during the next academic year, potentially during Summer 2015.

In terms of next steps, several actions are being considered for future offerings. First, in order to ensure that the course project can be completed in a timely fashion, the base-band portion of the project, including low-pass filters, low-frequency amplification and power amplification, may be moved to the electronics course where it can be treated as the course project. If students can come into the communication electronics course with this portion of the project completed and already laid out as a printed circuit board, they will have more time to complete the RF, oscillator, and mixer portions of the project.

Another improvement that is being considered is moving the course project from the AM radio band to a higher frequency, such as commercial FM. While using AM makes circuit implementation simple and allows for direct-conversion, there is potentially more practical learning if the student teams have to produce higher frequency designs.

Next, while the interactive exercises that introduce the frequency domain are important and necessary, they could be moved back earlier in the curriculum. For example, if students had already studied basic signal analysis in the frequency domain in the previous course on applied electromagnetics, then they could bring that knowledge (and their LabVIEW VIs for visualizing frequency domain signals) with them to the communication electronics course. This would accelerate the interactive portion of the course and allow for more time to be spent on more advanced concepts.

Finally, while ambitious, ideally students will eventually design their communication links (transmitter and receiver) using software defined radio techniques. Because of their background in embedded hardware and software, it is possible for the project to include the use of a microcontroller and high-speed converters (both A2D and D2A) to create a simple SDR-based communication link. To look at this possibility, an undergraduate capstone project will be commissioned starting Fall 2015.

REFERENCES

[1] Hofinger, R.J., “Foreseeing Electrical Engineering Technology - Expectations in the 21st Century,” 2001 American Society of Engineering Education Annual Conference, Seattle, WA, June 28 - July 1, 2001.

[2] G.J. Mullet, “The Internet of Things (IoT) will create the need for the Cyber-Physical System Technician,” 2014 American Society for Engineering Education Annual Conference, Indianapolis, IN, 2014.

[3] Porter, J.R., Zoghi, B., Morgan, J., Zhan, W., " Product and System Development: Creating a New Focus for an Electronics Engineering Technology Program,” 2012 American Society for Engineering Education Annual Conference, San Antonio, TX, 2012.

[4] Zhang, J.A., Burbank, K., Adams, R., “A Systems Approach to Teaching “Introduction to Electronic Communications” for ECET Students,” 2004 American Society for Engineering Education Annual Conference, Salt Lake City, UT, 2004.

[5] Porter, J.R., “Teaching Applied Electromagnetics to Engineering Technology Students,” *2004 American Society of Engineering Education Annual Conference*, Salt Lake City, UT, June 20-23, 2004

[6] Beasley, J.S., Hymer, J.D., Miller, G.M., “Electronic Communications: A System Approach”, Prentice Hall, 2014.

[7] Mini-Circuits, Brooklyn, NY, http://www.minicircuits.com/