Textbook Principles to Communications Hardware: Making It Work*

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Abstract

Undergraduate courses in communications traditionally focus on classical communications theory with little attention given to the actual implementation aspects of analog or digital systems. For the most part, the hardware implementation is predisposed to the electronics curriculum. This paper details a unique new effort in the Department of Electrical Engineering and Computer Science at the United States Military Academy to combine the theoretical aspects of communications systems design with integrated circuit implementation. Through a new project design approach, cadets make the theory of communications systems come to real life using a design, build, test process. It is shown that this is a very effective method to overcome the obstacles in making the transition from theory to practice.

Introduction

The presentation of classical communications theory courses has traditionally been accomplished by purely textual based methods. Numerous textbooks are available that present the subject matter in varying and in most cases outstanding fashions. The dilemma for the student is making the transition from textbook learning to practical application. The presentation of theory through the use of text books rarely considers actual hardware implementation. In some cases, laboratory courses are provided either concurrently or separately and provide an experiment- and test instrument-based introduction to communications principles and phenomenon. Unfortunately, few students have the opportunity to actually build a communication system or even a modulator or demodulator. Additionally, students traditionally have little opportunity to gain an appreciation for the subtleties of communication system or component implementation.

An associated problem in undergraduate electrical engineering programs that is rarely addressed is the requirement for the student to move from the theory of circuits and systems to the actual implementation on printed circuit board or integrated circuit fabrication.

This paper presents a unique approach taken at the United States Military Academy to overcome the shortfall in making the transition from purely communications theory to actual hardware implementation. Consistent with the ABET[1] driven design thread requirements of an electrical engineering program, the Department of Electrical Engineering and Computer Science instituted a new hardware implementation design project in the communications systems course. The following paragraphs detail in overview form the outline of the classroom presentation of the communications theory. Subsequently, a description is given of a unique design project approach that allows cadets to not only accomplish some independent parametric design of modulators and demodulators, but also helps them to make the transition to actual hardware via integrated circuit implementation on printed circuit boards.

The Communications Course

The communications systems course, EE 477, Communication Systems, is a senior level course that provides a breadth option in the electrical engineering program. The goals of the course are to have each cadet have a thorough understanding of the principles of analog and digital communications systems and be able to apply these principles to analyze and design analog and digital communication systems. It is a required course that has a traditional linear time-invariant signals and systems course as its prerequisite and is the precursor for a follow-on course in telecommunications systems. The course is a standard three credit hour course with no concurrent laboratory requirement. It is

* The views expressed in this paper in no way express the official position of the United States Military Academy, the US Army, or the Department of Defense. All insights are the author's own.

taught over 40 one-hour lessons during the seventh semester of a typical cadet program. As a three credit hour course, it is expected that cadets spend two hours in preparation (study, homework, projects) outside of class for each hour of in class time.

The course syllabus reads as most traditional communications theory courses. The course analyses modern analog and digital communications systems. Amplitude, frequency, and phase modulation are considered for both analog and digital schemes. Time and frequency domain analysis are the basis for study of bandwidth considerations, filtering, and channel and communication systems modeling. Fundamental information theory concepts are used to characterize input data content and Fourier analysis is used to characterize the input and modulated signals in the frequency domain. Analog communications systems study includes frequency multiplexing and transmission and reception concepts. Digital communications systems study also includes waveform sampling, time multiplexing, digital modulation and detection techniques. The course includes an analysis of system performance limitations due to noise. This analysis addresses the statistical properties of noise in linear systems, signal-to-noise ratios, and probability of error.

The normal course work is presented from a textual perspective based on the text by John G. Proakis and Hasoud Salehi, *Communications Systems* [2], which is an excellent 'theoretical' presentation of communications systems design and analysis. The text by Wayne Tomasi, *Electronic Communications Systems, Fundamentals Through Advanced*[3], is used as a supplementary text since numerous hardware examples are given. Additionally since the cadets previously were introduced to MathCAD®[4] as a mathematical scratchpad, it is used extensively in the solution of homework exercises. In addition to a term end examination and two midcourse examinations, the cadets are evaluated by weekly homework problems done outside of class.

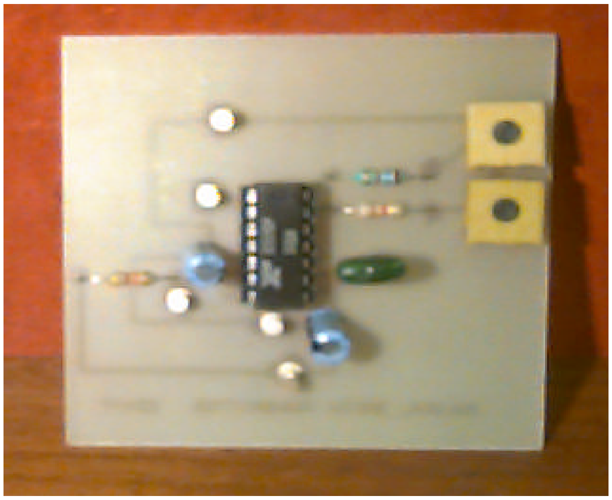
The Design Project

The uniqueness of this course presentation and its learning objectives is the cadet design project. As part of the course, cadets are required to complete a design project that requires them to design a modulator/demodulator pair. Cadets are assigned in teams of two to accomplish the design. Using integrated circuits and circuit configurations that accompany the integrated circuit data sheet from the manufacturer, the design team must formulate the specifications of the modulation/demodulation combination including the parametric design of the system (e.g., carrier frequency, frequency deviation, etc.), and the parametric design of the component values to meet the system design specifications. Then the team must implement the configuration using the integrated circuits on printed circuit boards. Separate modulator and demodulator boards must be built.

There are numerous multifunction integrated circuits available to perform either digital or analog operations. The XR2206 from Exar Integrated Systems Inc. as well as the MC1496 and MC3417L from Motorola Semiconductors Inc. are examples of the integrated circuits that may be used. While information on these particular chips was provided to the cadets, they had the option to review the literature and use any other integrated circuit at the discretion of the instructor. Several different modulation schemes were done including conventional amplitude modulation (AM), conventional frequency modulation (FM), and continuously variable slope delta modulation (CVSD).

Once the cadet team completed its parametric design, a prototype of the implementation was constructed to insure proper functionality. Time and frequency domain analysis were performed to insure proper operation of the circuits. Once this functional test of the prototype was accomplished, the cadets used a software design tool to design their printed circuit board layout. In very short order and with minimal outside of the classroom instruction, the cadets were able to learn and use *EEDesigner III (Version 1.6/2.4)* to create a .gbr file that was then used to create the artwork for their printed circuit board. Once completed, the artwork was submitted to a department technician who actually fabricated the circuit boards for the cadets. Turn around time on the board production was typically only a few days. The cadets then completed construction with the assembly of the circuit components onto their circuit boards.

The *design, build, test,* methodology was completed with laboratory testing of the completed circuit boards to insure that the system specifications were met. Once again, time and frequency domain analysis and test were accomplished to insure that the specifications for the modulator/demodulator were met. Finally, a technical report was written and submitted documenting their project. In addition, each pair of cadets was required to demonstrate to the instructor the proper operation of their modulator/demodulator configuration.



Results

All of the cadets were able to accomplish functional designs and implementations. Naturally, some performed better than others. An example of a cadet project is shown in the accompanying photographs. This particular case illustrates an FM modulator using the XR2207CP in the first figure and the demodulator implementation using the XR2211CP chip in the second.

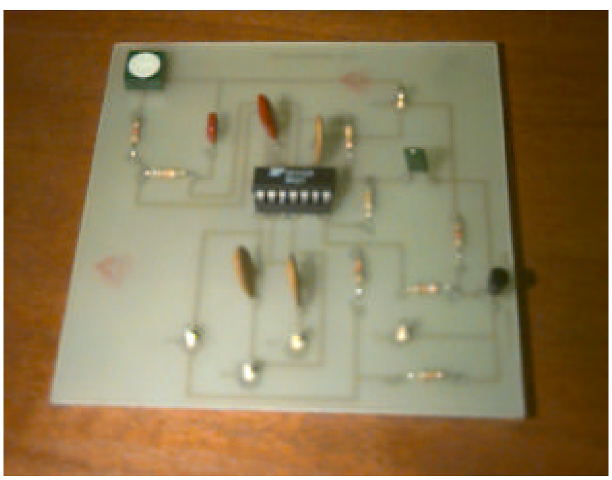


Figure 2 FM Demodulator

The integration of these design projects into the communications course was an unqualified success from many perspectives. First and foremost, the cadets learned how to go from a purely theoretical, block diagram, and mathematical description of a communications system to a real solid piece of hardware that worked! The transition from theory to practical application became much more than purely intuitive; it became reality for the student.

Secondly, for the first time students were placed in an environment where they were required to actually build an electrical device to perform a specified function. While it was somewhat superficial in the sense that some of the integrated circuit data sheets were provided for them, nevertheless, students were required to find a way to perform an electrical engineering task with little prior direction. Along the way, the cadets encountered many of the real life subtleties of hardware design that they had yet to experience. Some of the issues that the cadets learned to face in the transition to practical applications were such things as component data sheets and specifications, power supply requirements, interface requirements, level requirements, and component availability and variability. All of these were extremely valuable experiences preparing them for their capstone design projects.

The third result was a new experience in the use of laboratory equipment in a testing mode rather than an ‘experimental’ mode. The students had to learn to use the test equipment for its intended purpose and use it without preordained procedures and parameters. In testing their hardware, they came to grips with the real life issues of spectrum, noise, and actual circuit performance in terms of such things as harmonic distortion, signal-to-noise ratio, and error rate. In addition, they were forced to apply trouble shooting techniques that they had not previously had the opportunity to learn. Once, again, these factors were very important leading into their capstone experience.

Conclusions

The use of design projects that require students to design, build, and test actual communication subsystems components was extremely valuable in bringing to life the issues involved in communication systems design. It significantly enhanced the presentation of an undergraduate communication systems course.

Future Work

The success of this project approach can be enhanced in a number of ways. First, consideration should be given to expanding the design requirements of the project. Little or no effort was invested in any circuit simulation prior to implementation. While these projects are part of a communications theory course, the current conduct of the projects did not provide for any design simulation work prior to actual hardware implementation. There are many opportunities to expand this project so that simulation may be included. It should be emphasized at this point though that a substantial commitment to learning a software design tool for communications system simulation is required. There are several very good packages available, but most require a commitment to learn them that may be beyond the scope of most undergraduate communications courses.

Another opportunity that should be considered is the expanded use of systems level design and testing. The effort reported in this paper is a very low level subsystem design and implementation. With some thought, more sophisticated communications systems could be built in a project mode by having various teams design and build different components and then integrate the various parts into one system. Such simple circuitry as coders, multiplexers, IF modulators, or filters could be used and then integrated to form a larger functional system.

References and Endnotes

1. Accreditation Board for Engineering and Technology of the Engineering Accreditation Commission.
2. Proakis, John G. and Salehi, Masoud. *Communication Systems Engineering.* Prentice-Hall, 1994.
3. Tomasi, Wayne. *Electronic Communications Systems Fundamentals Through Advanced, 2ed.* Prentice-Hall, 1994.
4. MathCAD is a registered trademark of MathSoft Inc.
5. *EEDesigner III* is a copyrighted software package from TEAm Visionics Corp., 1991.

About the Author

Colonel William D. Lane is an Associate Professor and the Acting Deputy Head of the Department of Electrical Engineering and Computer Science at the United States Military Academy at West Point. He is an active duty Army officer with over twenty-six years of service. He received a Bachelor of Science degree from the United States Military Academy in 1970 and the MSEE and Ph.D. degrees from the Georgia Institute of Technology in 1978 and 1988 respectively. He also received an MBA degree from Long Island University in 1981 and is a graduate of the US Army War College. He is a member of Phi Kappa Phi, Eta Kappa Nu, and Upsilon Pi Epsilon. His research interests include spread spectrum communications, low probability of intercept, and multimedia education.