Communication Systems/RF Effects & Measurements/ DSP Curricula Development and Integration into New EET Program

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***Abstract* - Radio frequency (RF) communication has emerged as the key technology, after its importance is relegated for years by the fiber optics technology. It established itself as the backbone of the global information technology infrastructure and thereby putting new demands on the RF and wireless industry worldwide for skilled workforce. To meet this requirement there is a need to upgrade the electronic engineering technology (EET) curriculum to provide adequate education and training for graduating engineering technologists. Three fundamental courses are identified as the major requirements the graduating engineering technologist is expected to fulfill and meet the industry requirements. The three courses that are introduced into the newly developed EET program are communication systems, RF effects and measurements, and digital signal processing. This paper describes the initial efforts in developing and integrating these three states of art technology courses into the new EET program, the approach in teaching and the laboratory techniques.**

1. INTRODUCTION

In the past 10-15 years RF communication has emerged as the key technology, after its importance is relegated for years by the fiber optics technology. The RF wireless technology became the backbone of the information technology, which is one of the pillars of the economic and cultural globalization that defines the modern world. To ensure the integrity of the global information technology infrastructure, the RF and wireless systems need to be sustained continuously. These systems are complex and require skilled and qualified engineering technologists to develop, construct and sustain their operations. To meet this workforce demand by the industry, there is a worldwide need to upgrade RF and communication curriculum and provide adequate education and training for the engineering technologist. A number of universities and colleges, in cooperation with the industry, have established a model wireless curriculum modules to cater for this global demand. These modules, Global Wireless Educational Consortium (GWAC) wireless curriculum modules, cover broad spectrum of topics including RF and communication theory [1] [2].

Development of the RF communication curriculum within the new EET program at Bloomsburg University relied on inputs from various sources, the program Industrial advisory board (IAB), the local communication industry, and the experience of other universities and colleges [1] [2] [3]. The general consensus is that the RF communication curriculum must be included in the EET program in such a way to provide the fundamental theoretical background with emphasis on introducing basic concepts rather than diversified knowledge. Consequently, three courses are identified as the fundamental points of knowledge, communication systems, RF effects and measurements and digital signal processing. The EET Industrial Advisory Board (IAB), realizing the lack of skilled engineers in the above mentioned fields, recognized and supported this integration. However, the IAB strongly advised that each course be supplemented by intensive labs to provide hands-on experience and the skills necessary for graduating engineering technologists.

The pedagogical approach is based on providing the conceptual theoretical knowledge for each course, with the laboratory experiments utilized to augment the theory learned in the lectures and provide the required practical knowledge and skills. Project based learning is an important part of each course, "Projects can thus serve as bridges between phenomena in the classroom and real-life experiences." [4]. While the students working on a project as a group, they will be discussing ideas, developing systems, and analyzing data. They will learn how to effectively utilize the tools used during the laboratory periods, such as industrial standard application software and state of the art measurement equipment, to simulate signals and systems, measure and acquire accurate data.

This paper describes the initial efforts in developing and integrating these three states of art technology courses, the approach in teaching each course and the laboratory techniques.

2. CURRICULUM DEVELOPMENT

The application of the emerging RF wireless systems has changed a great deal, requiring diversified knowledge in other closely related fields. The engineering technologist is expected to understand the basics of RF effects at the component and system level. The principles of signal propagation between devices within and between RF receivers and transmitters need to be grasped. This requires an apprehension of the concepts of transmission lines, electromagnetic (EM) wave propagation through free space (or air), and antenna theory. In addition the RF technologist must be skilled with the complex RF equipment and measurements techniques necessary to verify and test the reliable operation of the communication systems.

Understanding the concepts of communication systems is an essential prerequisite. The knowledge of various analog and digital modulation techniques and frequency domain analysis of systems and signals is vital for understanding the operation of RF communication systems, subsystems and components.

In the modern digital communication era, where all signals are digitally processed within the transmitters and receivers, the basic knowledge of digital signal processing (DSP) techniques is essential for design, development and troubleshooting. An RF technologist needs to understand the concepts of DSP, in addition to RF and communication systems concepts, to fully comprehend the function of modern transmitters and receivers. Figure 1 shows a typical RF communication system diagram.

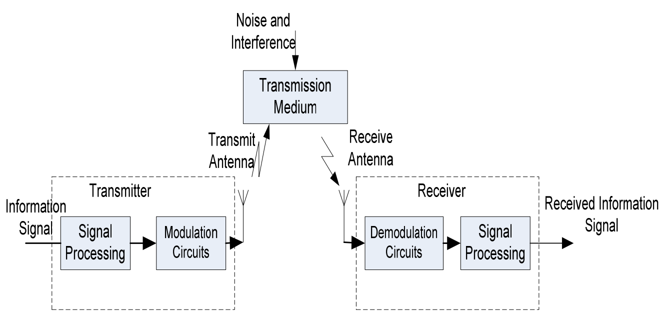

FIGURE 1
BASIC RF COMMUNICATION SYSTEM

The three courses, Communication Systems, RF Effects and Measurements and DSP are all required courses for the EET majors and offered concurrently in the spring semester. In the following subsections, the teaching approach and the laboratory techniques are described. During the semester short student surveys are made for each course, which is an effective feedback loop to identify class problems [5]. These surveys were used to modify the teaching approach and the lectures contents.

a. Communication Systems

The communication systems course is a three hour credit course, two hour lecture and two hour lab and offered in the spring semester of 2005 and 2006. The lectures objectives are to introduce the concept of signal representation and analysis in frequency domain and its relevance to the theory and development of communication systems. Next the basic components and subsystems that are essential to any communication system are explained. Having set the mathematical tools and presented the basic subsystems, the ground is set for introducing the concepts of analog transmitters and receivers and digital communication. Table I shows a summary of communication systems syllabus.

TABLE I
COMMUNICATION SYSTEMS COURSE SYLLABUS OUTLINE

Noise in communication systems
Fourier series and signal and system analysis
Oscillators, mixers, phased locked loop and frequency synthesizers
Principles of AM, FM and PM modulation
Generation, demodulation and detection of AM, FM and PM signals
Information capacity, Bits and Bit rate
ASK, FSK and PSK modulation

The lectures are based on the text book by Tomasi [6], which is adopted for the course, and supplemented with notes from Lathi's book [7]. For a two hour lecture, there was barely sufficient time to cover the introductory topics in digital communication, which include information capacity, bits and bit rate, amplitude shift keying (ASK), frequency shift keying (FSK) and phase shift keying (PSK) concepts.

The communication laboratory aims to augment the theoretical knowledge gained in the lectures and also gives the student hands-on experience in the development and realization of communication subsystems and systems. The lab is based on two sets of experiments and a project. The first set of experiments is developed to introduce Fourier series theory, analysis and its applications. The second set is developed around block diagram representation and modeling of communication systems. Finally the students utilize the knowledge gained to build and test a communication circuit using discrete integrated chip. The lab contents are summarized in table II below.

TABLE II
COMMUNICATION LAB EXPERIMENTS

Set 1-Fourier Series Theory and Analysis
AM and FM waveform Analysis
Set 2- Realization of AM and FM modulation
Realization of DSBSC and SSB modulation
AM and FM demodulation
Phase locked Loop (PLL)
Project-Construction of AM/FM modulator using XR2206 IC Function Generator

The Fourier series theory and analysis experiment is based on Agilent 33120a Function Generator, Tektronix TDS 3000 Scope. The Fourier analysis of various waveforms (pure sinusoidal, square wave and triangular) were performed using the MATH/FFT signal processing capabilities of the scope. This aimed at highlighting two important points. The first is the practical realization and understanding of the frequency spectrum of signals. Second, by introducing the spectral analysis using Fast Fourier Transform (FFT), the student gets his first exposure to an important digital signal processing tool and its application in communication systems. The AM/FM waveform analysis experiment provides an application of Fourier series for the analysis of two fundamental communication signals, the amplitude modulated (AM) and frequency modulated (FM) signals.

The second set of experiments aims at transforming mathematical representation of communication modulation and demodulation techniques into block diagrams. The realizations of these techniques are implemented using Telecommunication Instructional Modules (TIMS) [8]. TIMS modules used as the building blocks of many communication systems block diagrams. These modules are mainly sinusoidal frequency generators, adders, multipliers, VCO, phase shifters.

The feedback from the students, during the spring semester of 2005, indicated great interest in building their own communication circuits using discrete components. In the 2006 spring semester the students are assigned a project to build AM/FM modulators. They were given the data sheet of the XR2206 discrete integrated monolithic function generator and asked to analyze its function, with specific emphasis on the operation of the voltage controlled oscillator (VCO). Then build, implement and test AM and FM modulators around the XR2206. The student response indicated satisfaction with the outcome of their work especially when they utilized the knowledge acquired in the course to design and test a working communication device.

b. RF Effects and Measurements

In RF communication all the information being data, voice, or video are transmitted over carrier frequencies in the range of hundreds of MHz to few GHz. At these frequencies the contemporary circuit analysis ceases to apply. Electrical circuits, devices and the interconnection between them will not obey circuit design rules and electromagnetic theory becomes the tool of analysis. The RF effects and Measurement course has two objectives. The first is to convey the concepts of this complex topic and its practical implications, during a two hour/week lecture, to the engineering technology students with some or no background in EM theory. The second objective is to train the students to be skilled in using the complex RF equipment to carry out accurate reliable measurements, and to safely handle the delicate and expensive RF components and cables.

The lectures introduce the concepts of electromagnetic and RF signal propagation in metallic coaxial cables and in free space, define the parameters of RF signals and systems, and finally the principles of antenna theory. There is no specific text book that sufficiently covers all these topics at an introductory level for engineering technologists. The lecture notes are based on three books [6] [9] [10], which are proven to be viable resources. The course syllabus is outlined in Table III.

Table III
RF EFFECTS AND MEASUREMENT COURSE SYLLABUS

Transmission lines and their characteristics.
Electromagnetic and RF signal propagation through free space.
Propagation coefficient, reflection coefficient, voltage standing wave ratio (VSWR) and their use in analysis of RF systems and devices.
Introduction to Antennas, as the interface device between transmitters, receivers and free space.

The RF course laboratory consists of two parts. The first part runs for the first six weeks of the semester. It aims at providing hands–on experience in using modern RF measurement equipment, performing various RF measurements at system and component level, and handling of specialized RF components. A set of experiments are developed to for this purpose are shown in Table IV.

TABLE IV
RF EXPERIMENTS

Signal analysis using spectrum analyzer
Network analysis using of network analyzers
S parameter characterization of RF networks
Characterization of various RF components, including filters, mixers and couples

The most stimulating is the second part of the lab, where the students are assigned projects developed specifically to apply the knowledge gained during the lectures and the skills gained in the lab. Three projects are assigned to five teams. Two teams working on the construction of AM/FM receiver, two teams working in antenna design, and one team involved in designing university wide wireless internet access network.

TABLE V
RF PROJECTS

Construction and analysis of AM/FM receiver circuit
Antenna design
Wireless Network Design

In the AM/FM receiver project the students construct an elaborate circuit showing, in details, the stages of each receiver. They are asked to perform thorough analysis of the received signal as it passes through each stage. The antenna design teams are asked to design and construct two types of antennas, a helix and a dipole operating at a frequency of 915 MHz then measure their parameters (input impedance, SWR and reflection coefficient) and plot the far field patterns. The measured values are compared to the theoretical calculations, explaining any discrepancies. The wireless team was asked to design a cost effective long distance wireless network covering the university and surroundings. The network is to consist of one high power access point acting as a base station, and multiple Pico cells located at distant locations around the campus. The students are asked to do RF link budget analysis identifying the signal strength at different location and confirming their calculation through RF signal strength measurements.

Projects are proven to be the most interesting part of the course for the students. Even when encountering difficult problems, they are enthusiastically involved in solving them. It is also noticed that encouraging competition between two teams, assigned similar project, stimulates student's learning and encourages critical thinking.

c. Digital Signal Processing

The objective of this course is to introduce the fundamentals of digital signal processing beginning with discrete time signals and systems, followed by digital filter design and its implementation, and ending with spectral analysis of discrete signals and systems. The text book of choice is Signal Processing First [11], and is used as a guideline for lecture preparations and developing the lab experiments. The course content is outlined in Table VI.

TABLE VI
DSP COURSE OUTLINE

Signals and systems and their mathematical representation.
Sinusoidal functions and their parameters, i.e. frequency, period, phase shift and time shift.
Sampling and plotting of sinusoids, and sampling theorem
Complex exponential and their representation of sinusoidal signals.
Spectrum representation of periodic and non-periodic signals.
Fourier series analysis of and its spectrum
Spectrum of discrete signals.
FIR and IIR filters principles and implementation

The initial approach, taking into consideration the background of the students, is to explain the sinusoidal and cosinusoidal signals and the importance of their role in signals and systems theory using fundamental mathematical theories. Then introduce the concept of complex numbers and the complex exponential representation of communication signals.

To clarify the rigorous mathematical analysis required in DSP, the subject matter is continuously supported by MATLAB based application examples. The students are initially introduced to the concepts of computer based discrete sinusoidal signal generations. The sampling theorem, which is one of the most important building blocks of discrete systems theory, is then presented. Next the Fourier series is introduced and the possible representation of any signal by combination of sines and cosines is explained; which leads to the concept of signal analysis in frequency domain.

Having covered the concepts of discrete time signal analysis and their mathematical representation, discrete time systems are introduced starting with the analysis and implementation of Finite Impulse Response (FIR). The ideas gained are then extended to other classes of systems e.g. the Infinite Impulse Response (IIR) filters.

The concept of frequency response is challenging to teach to EET students. With only two hours lectures per week and two hours of lab, there is little time left to thoroughly cover the topic. The frequency response of discrete systems is explained and applied to the design and analysis of FIR and IIR filters. The spectral analysis of discrete time signal using discrete Fourier transform (DFT) and fast Fourier transform (FFT) is briefly introduced.

The teaching approach is continuously revised as the course progresses. The revision is based on the feedback from the students' evaluation on their level of comprehension of the topic. Adjustment to the course content and teaching approach is made accordingly.

The DSP lab experiments are computer based and developed using MATLAB, which is the most widely used industrial tool, to clarify the mathematical concepts learned during the lectures, enhance the students understanding and stimulate their interest in DSP. The developed lab experiment are shown in Table VII

TABLE VII
DSP LAB EXPERIMENTS

Introduction to MATLAB.
Sampling and plotting of signals using MATLAB
Complex exponential representation of signal using MATLB.
Sampling Theory
IIR and FIR filters implementation. And their frequency response
Spectral analysis of discrete signals

The students showed frustration with the topic at the beginning of the semester, which was reflected in the short survey. They were eager to understand the practical importance and realization of DSP, which is not possible till they fully comprehend the theory and the relevant mathematical concepts. At the end of semester the students have a better comprehension of the topic, only then the digital filter design and realization experiment is introduced to illustrate the practical application of DSP.

3. EXPERIENCES GAINED

The paper described the approach in integrating three state of the art courses into the new EET program at Bloomsburg University. The lectures, in all the three courses, aimed at ensuring that the students comprehend the underlying concepts in each topic. The lab periods are utilized to augment the knowledge gained from the lectures and provide the essential practical skills. All the three courses are offered in the spring semester, and experience showed that this not a viable approach. A request was granted to modify the curriculum by offering the communication system in the spring semester, followed by the RF effects and measurement and DSP courses in the following fall.

In the communication course with nine students attending, they showed satisfaction with the way the information is presented and the coordination between the lectures and the labs. But some students weren't happy with using the TIMS modular system, especially when connecting a complex communication system. The lecture hours were insufficient to cover the digital communication concepts. Accordingly a request is granted to change the lecture hours to three hours instead of the two hours /week. Overall student survey in the communication course showed that the labs were very beneficial in augmenting their knowledge gained from the lectures. But one complain was that the labs were going faster than the lectures. This was corrected by coordinating the lecture times and lab times, making sure that the lectures at least introduces the topic before the following lab period.

In the RF effects and measurement course, with 14 students attending, there was some student dissatisfaction with the lack of rigorous mathematical analysis, and that the experiments were too detailed. This indicates an obvious need for modification in the lectures and lab experiments to introduce some mathematical rigor and at the same time break up the experiment handout into brief summarized steps and let the students think their way through. The lab experiments provided hands-on experience in effective use of equipment to analyze RF systems. The projects were an important factor in stimulating students' interest, which is clearly indicated through the student survey. They facilitated critical thinking, and were instrumental to the learning process, where the students effectively applied the lecture knowledge and the skills attained in the experiments.

By far the most challenging was the DSP lab. The experiments were computer based and relied on MATLAB as the basic tool for the analysis of discrete signals and the implementation of DSP systems. The engineering technologist likes to deal with hardware implementation of the system, for a two hour lecture and two hour lab this wasn't possible. But it was continuously emphasized in the class the importance of understanding the principles of DSP and its relevance to the modern communication systems. This was presented through the simulation of wireless link signal nulling experiment, AM/FM signal generation experiment, analysis and synthesis of signals using discrete Fourier series. With the final experiments concentrating on the design and implementation of digital FIR and IIR filters and their spectral representation, the students started to realize the objective of introducing this course into the curriculum. The 14 students' survey had mixed response. As expected, it showed concern about the relevance of the topic to other fields within the electronic engineering technology curriculum as well as to its practical applications. Not many students liked the topic, but some have shown great interest and wanted more practical examples that will give them deeper insight into DSP applications. Accordingly the course is modified to accommodate a project clarifying the application of DSP in digital communication to remedy this concern.

The developments of the three courses are based on input from various industrial and educational resources as well the industrial experience of the faculty. In integrating the three curricula into an engineering technology program it is recommended to set up a coherent lecture/Lab/Project syllabus that will provide the fundamental knowledge, the basic concepts and the strong skills required by the industry.

4. Conclusive Remarks

The three developed courses are distinct, interrelated aimed at providing the required fundamental theoretical points of knowledge. Each supplemented by intensive lab experiments and utilized project based learning approach to represent and apply the knowledge gained. In adopting a similar course sequence in an engineering technology program, in the US or worldwide, careful consideration must be given to the requirements and needs of the local industry. In doing so it is advisable to concentrate on the theoretical concepts and where possible avoid mathematical rigor, provide intensive hands-on experience through labs aimed at training the student to use complex measurement equipment and standard industrial application software. Projects need to be included as an essential part of the curriculum, they facilitate critical thinking and problem solving skills and students feel great sense of satisfaction when redirecting the knowledge gained in the course to design, develop or construct an experimental system and evaluate its performance. It is recommended that a number of short student surveys be performed during each course then used as a feedback in adapting the contents to maximize student learning and comprehension.

The initial efforts in integrating these three courses into the new EET program have developed great interest in the students to pursue the RF communication technologist as a profession, and a number of the first graduating group of students have already accepted positions in the local wireless and satellite communication industry.

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