Military Communications Graduate Education Curriculum

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Abstract -- The dawning of the information age with its diversity of communications and computer systems poses a formidable challenge to the graduate student of "communications engineering". To keep pace with this expanding field graduate communications engineering students at the Air Force Institute of Technology (AFIT) advance through an integrated curriculum that weaves a web of connections between traditional analog/digital communication theory, discrete signal processing, communications/computer networks, spread spectrum techniques, and coherent applications sequences of courses in military communications, radar, stealth, and antenna engineering. The approach is to teach broad system level concepts and analyses first followed by in depth treatments of the pertinent subtopics. This ensures that the engineer always has the "forest" in mind while he or she tackles the "trees". Furthermore, the applications courses "close the loop" by reemphasizing system level concepts and exploiting the deep analytic tools developed earlier. The program culminates in a thesis that addresses an immediate aerospace communication problem. In addition to a detailed description of the AFIT communication engineering program, this paper explores the potential academic alternatives that merging technologies and techniques demand.

I. INTRODUCTION

The School of Engineering at the Air Force Institute of Technology (AFIT) grants degrees at both the Masters and PhD level in numerous engineering and science disciplines. The diverse student population comes from the military services, numerous US government agencies, foreign countries, and the civilian population at large. AFIT's graduate programs are rigorous and demanding[2] yet are dedicated to being student centered and responsive to the students' prospective employers' needs without compromising educational excellence.[3] This paper focuses on the communication engineering curriculum and how it serves students, employers, and the overall US aerospace research effort. We show what drives and shapes the curriculum and how the curriculum

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[1] **The authors are members of the graduate school faculty in the Electrical and Computer Engineering Department of the Air Force Institute of Technology, Wright-Patterson Air Force Base, Dayton, Ohio.**

[2] **All Masters degrees require at least 12 quarter hours of successful thesis work.**

[3] **For example, the computer and electrical engineering department has always received the longest ABET accreditation term possible.**

is devised to create a comprehensive and coherent treatment of this diverse and often multidisciplinary field. - Finally we explore some ways to meet the educational challenge presented by the rapid convergence of many previously distinct technologies and sciences into the field of communications. In particular, we postulate a separate multidisciplinary communication engineering degree. Although this paper uses the communications engineering curriculum as an example, the ideas are universal and directly applicable to almost any area of engineering.

II. CURRICULA INFLUENCES

Four factors are particularly important influences on AFIT's curricula: 1) academic standards and accreditation, 2) employers of our graduates, 3) advances in science and technology, and 4) an aggressive commitment to a student centered education. We will briefly discuss these in order.

We are one of the few schools in the country accredited at the graduate level. Most schools are accredited at the undergraduate level and are not scrutinized as closely at the graduate level. For example our electrical engineering program is accredited at the graduate level by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (EAC/ABET). In addition to ABET requirements, the US Air Force imposes extremely high standards and expectations on our programs. Thus most of our masters degree programs are approximately 72 quarter hours long of which 12 hours are devoted solely to thesis research. This gives our students much more breadth and depth than is normally expected for a masters degree. This will become apparent in section III where we discuss curriculum details.

The instructional system development (ISD) model shown in figure 1 is the basis for ensuring our curricula is responsive to the needs of the Air Force and other employers of our graduates. (See references [1], [2], [3] for more details.) Formal and informal procedures are in place to ensure our curricula is continually updated to reflect changing requirements. The implementation details are beyond the scope of this paper, but we feel the model itself is instructive and somewhat unique to graduate education. How a particular school would implement the model depends on the culture and personalities associated with the school.

Advances in science and technology are also implicit in the model because the employers' requirements are somewhat determined by these factors. Also the heavy emphasis on research in the curricula and the fact that most of the employers are prominent aerospace research organizations ensures that our instruction keeps pace with scientific and technological advances. Again the ISD model provides the management foundation to ensure our educational is current.

Finally, we are extremely committed to optimizing the students' learning experience. We describe our approach as being "student centered". Our commitment to this starts by ensuring every new assistant professor attends a formal school on education theories and methods. In practice, classes are kept small (15 students is the maximum allowed), all classes are taught by professors, and students provide continual feedback on courses, curricula, and professors. Students even anonymously assign letter grades to the professor's performance at the end of every course. A student's future employment as well as student preferences are

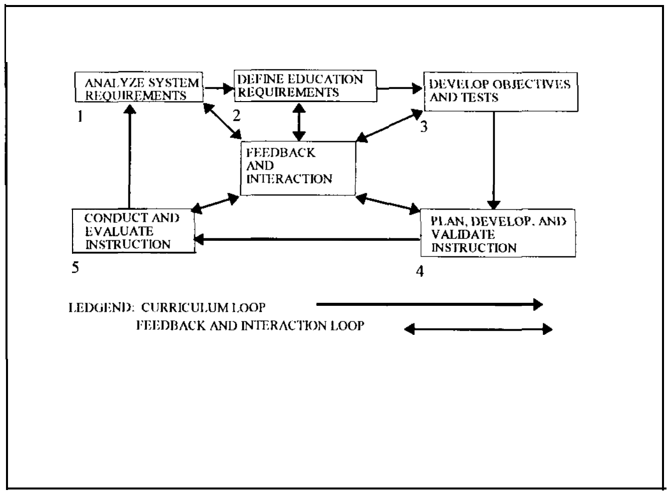

Figure 1 Instructional System Development Model

factors in designing individual student programs and matching research efforts to the most appropriate student. Student feedback is also solicited a year after graduation.

These factors are all manifest in the military communication curriculum discussed in the next section. The result is a program in communications engineering that leads to an ABET accredited MSEE degree, provides the educational background required by employers, is technically current, and according to student feedback provides an exceptional learning experience.

III. COMMUNICATION CURRICULUM

All students must study two approved sequences of courses. We offer approximately twenty-five standard sequences that range from general sequences such as the Signal Processing Sequence and the Control Theory Sequence to specialized sequences such as the Optical Signal Processing Sequence and the Robotic Systems Sequence [4], [5]. Some are hybrids such as the Radar, Stealth, Antenna, and Microwave Engineering Sequence. In addition, specialized sequences can be created from existing courses to meet a specific student's needs. This requirement to study two full sequences provides breadth, depth, and flexibility. It also comfortably accommodates multidisciplinary study requirements because some sequences cross departmental lines and students are allowed to take sequences from different departments as well. In this section we describe how one designs a sequence from the bottom up and then we provide the details of our military communications sequence.

Most of AFIT's research in the communications engineering area is sponsored by aerospace organizations. Many of these organizations also employ our graduates after graduation. The curriculum is designed to culminate in a thesis or dissertation that in the ideal case provides a nice transition into post graduation employment. The organization of the courses is designed from the bottom up. That is, we designed the curriculum using the ISD model to determine the topics that need to be included and to determine the order. Thus one considers prerequisite and corequisite topics rather than classes in this initial phase of the design. Once all of the series and parallel connections between topics are laid out, one simply carves out sections of this topical map to form courses as illustrated in figure 2. This is in contrast to traditional top down methods of designing classes and then trying to see how they fit together to make a curriculum. Due to the influences discussed in section II, the topical map will change from time to time and hence the course organization will also change. This effort is rewarded with a coherent integrated curriculum instead of a number of disjoint courses somewhat arbitrarily strung together.

The underlying philosophy used in designing the topical map is to teach broad system level concepts and analyses first followed by in depth treatments of the pertinent subtopics. This ensures that the engineer always has the “forest” in mind while he or she tackles the “trees”. Furthermore, the applications “close the loop” by reemphasizing system level concepts and exploiting the deep analytic tools developed earlier. Since the program culminates in a thesis that addresses an immediate aerospace communication problem, research goals are a major consideration in the topical design. This ensures students will be adequately prepared to make a significant research contribution (see figure 3). Since there is a wide variety of research areas in communication engineering, the topical map must have sufficient flexibility (paths) to accommodate various interests.

Specifically, the communications curriculum is designed to provide a comprehensive background in modern communication and signal processing theory while allowing the student to pursue in depth one or more specialty areas. It treats the theory and techniques used in processing analog and digital communication signals and in analyzing or designing a complete communication system. Because of recent technology trends, the emphasis throughout is on the transmission and analysis of information in digital form. Advanced applications include satellite communication, spread-spectrum techniques, optical information processing, modern electronic navigation systems, speech processing, image transmission techniques, and network optimization. Advances in device and computer technology, information transmission, electronic navigation, radar and remote sensing systems, and information warfare are integrated into the curriculum.

Prerequisite courses include “Probability Theory for Communications and Control” and “Linear Systems and Fourier Transforms.” Core courses are “Analog Communication Theory,” “Random Signal and System Analysis,” and “Digital Communications.” Highly recommended application sequences of study are “Military Communications Systems,” “Radar, Stealth, Antenna, and Microwave Engineering,” “Computer Communication Networks,” “Optical Information Processing,” “Pattern Recognition, Signal Processing,” “VLSI/VHSIC Systems,” “Electromagnetic,” and “Electronic Combat.”

As an example, in addition to the prerequisite and core courses listed above, the Military Communications Systems Sequence requires “Communications Networks and Digital Communications II” and any two of the following: “Radar Systems Analysis,” “Discrete Time Signal Processing,” “Spread Spectrum Communications and Applications, Optical Communication Systems, Electronic Combat,” or “Advanced Topics in Communications.” Suggested electives include “Human Factors Engineering,” “Introduction To

. Statistical Pattern Recognition,” “Signal Detection and Estimation,” “Advanced Radar Systems Analysis,” “Statistical Optics,” “Multidimensional Signal Processing,“ “Multirate and Wavelet Signal Processing,” and “Spectral Estimation” and “Adaptive Filtering.”

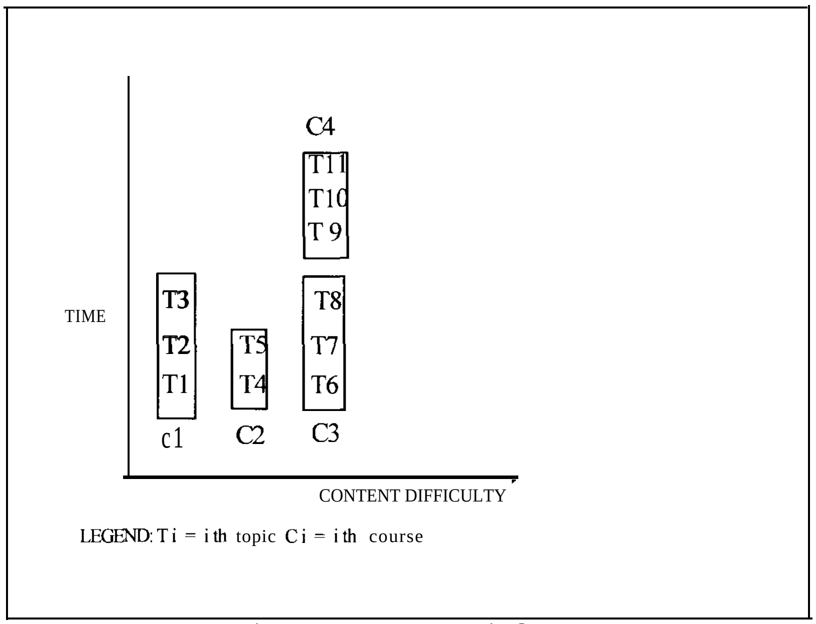

Figure 2 Sequence Topical Map

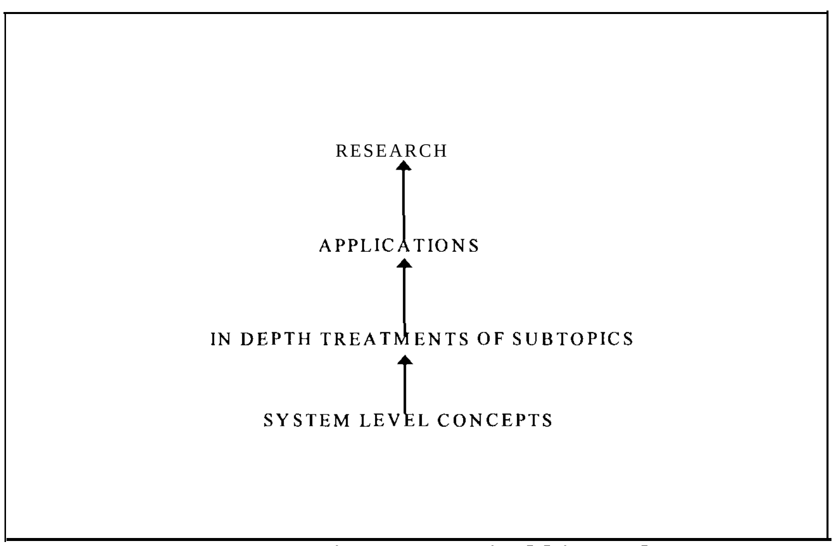

Figure 3 Topical hierarchy

As another example, the “Computer Communication Networks Sequence” requires “Communications Networks,” “Queuing in Computer Systems,” and any two of the following: “Data Security, Communications for Space Operations,” “Digital Communications II,” “Spread Spectrum Communications and Applications,“ “Optical Communication Systems,” “Advanced Topics in Computer Networks,” or “Advanced Topics in Communications.”

The variety and flexibility apparent in these two sequences exists in all of our sequences. In the appendix, we have included some of the topical details for three courses to illustrate how depth is also built into the sequences. The overall program has been exceptionally well received by both students and employers [6], [7], [8].

IV. A COMMUNICATIONS ENGINEERING DEGREE

Looking ahead to the multidisciplinary face of future communication engineering, it is clear that technologies and techniques in various areas and disciplines are emerging and merging. AFIT's two sequence structure lends itself to a multidisciplinary curriculum both within a single department and across departments. An intradepartmental communication example might be a study of the “Military Communication Systems Sequence” and the “Optical Information Processing Sequence.” An interdepartmental communication example might be a study of the “Military Communication Systems Sequence” and an “Ionospheric Physics Sequence.” In fact communication engineers today come in so many different “colors and flavors” that often the only unifying theme is that they are all working on this thing we call communications.

So why not have an advanced degree in Communications Engineering rather that the even less descriptive degree in Electrical Engineering. The shear breadth of the field justifies an independent degree. This is directly analogous to and intimately tied to the trend towards separate computer engineering degrees. One is further faced with the question of how to distinguish between computer engineering and communication engineering. The fields are inextricably linked.

In the end, it comes down to the student’s choice and how the student wants to market him or her self. Communication engineering is almost by definition multidisciplinary. A degree in communication engineering simply indicates a connection to the general area of communication but no doubt would include course selections from a variety of computer and electrical engineering courses. At least with a Communications Engineering degree, the engineer has an identity that others can relate to. Then maybe neighbors and relatives will stop asking communication engineers (currently called electrical engineers) to help them fix the wiring in their house (unless, of course, the “wire” is a fiber optic cable).

V. CONCLUSIONS

By using the Instructional System Development (ISD) model, AFIT is able to keep its curricula accredited, responsive to the students future employers, adaptive to advancing science and technology, and student centered. The two sequence structure and the research emphasis is readily adapted to multidisciplinary studies. In particular, the dawning of the information age with its diversity of communications and computer systems poses a formidable challenge to the graduate student of "communications engineering". To keep pace with this expanding field, graduate communications engineering students at the Air Force Institute of Technology (AFIT) advance through an integrated curriculum that weaves a web of connections between traditional analog/digital communication theory, discrete signal processing, communications/computer networks, spread spectrum techniques, and coherent applications sequences of courses in military communications, radar, stealth, and antenna engineering. The field of communications engineering has grown so complex and diverse that it justifies a distinguishable degree -- a Masters Degree in Communication Engineering.

APPENDIX

EENG 669-- Digital Communications I

Prerequisites: EENG 530, Analog Communication Theory and STAT 586, Probability Theory for Communication and Control

Catalog Listing: The objective of this course is to present the significant considerations necessary for the design and analysis of digital communication systems. The course develops a mathematical representation of baseband digital signals including signal space concepts. Signal detection in the presence of noise and matched filters are described. The use of source coding for efficient descriptions of information sources is motivated. Channel coding concepts are developed and shown to improve communication system performance. Block and convolutional codes are described and their performances analyzed.

Course Outline:
Signals and Spectra
Digital Communication Signal Processing
Classification of Signals
Random Signals
Autocorrelation and Spectral Density
Signal Transmission through Linear Systems
Bandwidth of Digital Data
Formatting and Baseband Transmission
Baseband Systems
Messages, Characters, and Systems
Formatting Analog Information
Sources of Corruption
Pulse Coded Modulation
Quantization (uniform/nonuniform)
Baseband Transmission
Detection of Binary Signals in AWGN
Multilevel Baseband Transmission
Intersymbol Interference
Signal Space Concepts

Link Budget Analysis Techniques
Source Coding
Information Sources and Introduction to Information Theory
Amplitude Quantizing
Differential Pulse Code Modulation
Synthesis/Analysis Coding
Channel Coding: Part I
Waveform Coding
Types of Error Control
Structured Sequences
Linear Block Codes
Cyclic Codes
Channel Coding: Part II
Convolutional Encoding
Properties of Convolutional Codes
Interleaving and Concatenated Codes
Viterbi Decoding

EENG 670-- Digital Communications II

Prerequisites: EENG 665, Random Signal and System Analysis, and EENG 669, Digital Communications I

Catalog Listing: The objective of this course is to present the significant considerations necessary for the design and analysis of bandpass digital communication systems, including spread spectrum systems. This course examines coherent and noncoherent detection of digital bandpass signals in Gaussian noise and the corresponding error performance for binary and M-ary signaling. Modulation and coding trade-offs are presented. Methods of synchronization at the carrier, symbol, and frame rates are examined. Multiplexing and multiple access networking techniques are also explored, and a brief introduction to spread spectrum systems is provided.

Course Outline:
Bandpass Modulation
Signal Space Concepts
Phase Shift Keying
Frequency Shift Keying
Performance in Gaussian Noise
Modulation and Coding Tradeoffs
Comparison of Digital Communication Modulation Methods
Error Probability Plane
Bandwidth Efficiency Plane
Bandwidth Limited vs Power Limited Systems
Bandwidth Efficient Modulation Techniques
Trellis Coded Modulation

Synchronization
Phase Locked Loops
Carrier Synchronization
Symbol Synchronization
Frame Synchronization
Network Synchronization
Multiplexing and Multiple Access Methods
Overview of Multiple Access Methods
Access Algorithms
Multiple Access Techniques Employed in INTELSAT
Multiple Access Methods for Local Area Networks
Spread Spectrum Communications
Brief Introduction and Motivation

EENG 673-- Spread Spectrum Communications

Prerequisites: EENG 670, Digital Communications II

Catalog Listing: This course examines the design and analysis of spread spectrum communications systems. The various forms of spread spectrum modulation, such as direct sequence, frequency hopping, time hopping, and hybrid forms, are discussed. Coding techniques for ranging and multiple access are also developed. Methods of code acquisition and tracking are briefly explored. A major portion of the course is dedicated to applications of spread spectrum techniques, such as antijam and low-probability-of-intercept communications, code division multiple access and digital cellular communications, and Global Positioning System.

Course Outline:
Introduction to Spread Spectrum
Direct Sequence Spread Spectrum
Frequency Hopping Spread Spectrum
Coherent vs Noncoherent
Spread Spectrum Code Sequences
Polynomial Representations of Code Sequences
Maximal Length Codes
Generation of M-L Codes
Gold Codes and Nonlinear Codes
Synchronization
Code Tracking Techniques
Code Acquisition
Performance in Jamming Environments
Jamming Strategies
Performance Analysis in Presence of Jamming
Worst Case Jamming Conditions
Performance Analysis with Forward Error Correction Coding

Low Probability of Intercept Communications
Energy Detection
Feature Detection
LPI Quality Factors
Waveform Design for LPI Purposes
CDMA and Digital Cellular Systems
Overview of Cellular Systems
Digital Cellular Standards (IS-95, GSM, etc.)
Personal Communications Service
Other Applications
Ultrawideband Radar and Pulse Compression
Global Positioning System

REFERENCES

[1] *Air Force Manual 50-62, Handbook for Air Force Instructors,* Department of the Air Force, 1984.

[2] *Air Force Manual 50-2, Instructional System Development,* Department of the Air Force, 1979.

[3] *Air Force Pamphlet 50-58, Handbook for Designers of Instructional Systems,* Department of the Air Force, 1978.

[4] *Graduate Study in Electrical Engineering Handbook,* Air Force Institute of Technology, 1995.

[5] *Graduate Study in Computer and Engineering and Computer Systems Handbook,* Air Force Institute of Technology, 1995.

[6] Student course critiques.

[7] Student instructor critiques.

[8] Student end of program critiques.