Development of an Undergraduate Course in Radar Systems

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Abstract

This paper outlines and presents the results of the development and teaching of a unique course in radar systems to undergraduate students in electrical engineering and avionics majors at Saint Louis University. It also discusses the challenge of offering such a course, and proposes a course curriculum that is specifically tailored for undergraduate students.

The important and fascinating topics of radar enjoy an extensive audience in industry and government, but deserve more attention in undergraduate education to better prepare graduating engineers to meet the demands of modern mankind. Radar is not only one of the major applications of electronics and electromagnetic communications; but also a mature scientific discipline with significant theoretical foundations that may warrant an intellectual and educational challenge specifically to undergraduate students. The course is developed in an attempt to provide a broad concept underlying the basic principle of operations of most radar systems. It is tailored to maintain a good balance of mathematical rigor suitable enough to convince students without causing them to lose interest. Topics are presented not as abstruse and esoteric to the point of incomprehensibility. It is an attempt to distill the very complex and rich technology of radar into its fundamentals. Examples and exercises are chosen to reinforce the concepts presented, and to illustrate the radar applications. The course also includes some laboratory components to emphasize the principles and concepts of some radar systems. The challenge encountered in offering this course is a good text. Although there is a plethora of books on radar systems, all of them are written for the specialist or the advanced graduate students. Hand-outs are widely used to meet the course requirements.

I Introduction

Saint Louis University, a private university under Catholic and Jesuit auspices, traces its history to the foundation Saint Louis Academy in 1818, and was renamed Saint Louis University in 1832, becoming the first university established west of the Mississippi River. The University settled at its present site on Grand Boulevard in 1888. Saint Louis University is classified as Research Level II institution by the Carnegie Foundation. The University enrolls more than 11,000 students. Parks College of Engineering and Aviation, one of the twelve colleges or schools of Saint Louis University, prepares students for careers in engineering, aviation, computer science and related fields. The Department of Electrical Engineering was established in

1987, and is committed to excellence in undergraduate teaching and research. The Electrical Engineering Program, which offers B.S. in electrical engineering, is accredited by the Accreditation Board for Engineering and Technology (ABET). Currently, the curriculum includes three elective courses, three-credit hours each, at the senior level. The Radar Systems course, EE-P409, is a logical choice for inclusion in the list of EE Electives due to popular demands of local aerospace industries.

Radar is an emerging technology, and its applications have increased to the point where it affects virtually every facet of our modern lives. The world wide air traffic control system is fully based on radar principles. Defense systems rely heavily on radar to locate friendly, hostile and unknown aircrafts, ships, and other vehicles. Radar is widely used by ships and pleasure vessels for avoiding collision at sea, for detecting navigation markers in poor weather, and for mapping nearby coastlines. Tracking radar may be used to track a moving target to predict its future position. Large ground-based radars are used for satellite tracking. Space vehicles may incorporate radar for rendezvous and docking. Radar can provide much information about physical environment such as rainfall, precipitation, crop growth, insect swarms, and environmental pollution. Further applications include speedometers, speed traps, proximity detectors, and devices for collision avoidance and intruder alarms. Thus radar systems find extensive and fascinating applications in industry and government, but deserve more attention in undergraduate education to better prepare graduating engineers to meet the demands of modern mankind. Radar is a mature scientific discipline with significant theoretical foundation that may warrant an intellectual and educational challenge specifically to undergraduate students with insufficient background knowledge. The course is developed in an attempt to provide a broad concept underlying the basic principles of operations of the most commonly used radar systems. It is tailored to maintain a good balance of mathematical rigor suitable enough to convince students without causing them to loose interest. It is an attempt to distill the very complex and rich technology of radar into its fundamentals. The course also includes some laboratory components, in the form of laboratory demonstrations, to emphasize the principles and concepts of some radar types. There are only a few universities in the nation that offer a radar course to undergraduate students. There are several reasons to explain why most of the undergraduate programs avoided attempting to offer a radar course. These are explained in sections III—V.

II Course Outline

The objectives of the Radar Systems course are to introduce the general principles and fundamentals of radar systems, and to introduce specific radar topics and radar types. Topics covered in this course include:

1. Radar Fundamentals
   - Introduction
   - Radar classification
   - Doppler frequency
   - Radar frequency

2. Radar Equations, Radar Cross-section and Receiver Noise
   - Low PRF radar equations

- High PRF radar equations
- Bi-static Radar equations
- Radar Cross-section
- Noise figure

3. Radar Wave Propagation
   - The propagation process
   - Multi-path phenomena and effects

4. Basic Elements of Radar Systems
   - Radar transmitters
   - Radar receivers
   - Radar antennas
   - Radar indicators and displays

5. Continuous-Wave and Pulsed Radars
   - Frequency modulated CW radar
   - Linear frequency modulated CW radar
   - Multiple-frequency CW radar
   - Pulsed radar

6. Radar Waveforms and Radar applications
   - Moving target indicators (MTI)
   - Pulse-compression techniques in radar systems
   - Synthetic aperture radar (SAR)

7. Target Tracking radar systems
   - Angle tracking: sequential lobing, conical scanning, monopulse radar
   - Range tracking
   - Track-while scan

8. Radar Projects
   - Projects are assigned dealing with practical aspects of radar types. A written report is required with classroom presentation of the completed project.

III Proper Prerequisites

The Radar Systems course is offered at the senior standing, and, therefore, the students are expected to have completed math courses including differential equations and the elementary theory of probability, and the electromagnetic fields course. However, in order to fully comprehend the concepts of radar principles, some knowledge of communications theory is required. But the required course of communication systems is also offered at the senior level due to some constraints of prerequisites. In addition, some students from avionics program, who do not have background of probability theory and electromagnetic fields, are also allowed to take this course. Therefore, students taking the radar course may or may not have completed the prerequisite courses posing a challenge of offering this course to the undergraduate students.

This challenge of lack of adequate prerequisites is met by providing extra reading materials covering those topics usually not expected of some students, and by dedicating a few lectures to briefly discuss those materials following the just-in-time approach which proved to be very fruitful. A few examples are in order:

(a) The radar detection process is statistical in nature. The radar engineer must use statistical techniques to assess detection performance. The concept of continuous probability density function is developed through discrete probability histogram[1], and is used to explain the probability of detection without overwhelming students with the complexities of probability theory.
(b) Antenna is one of the integral components of a radar system. The concept of antenna theory is quite complex, so only pertinent features of antenna are covered with minimum amount of mathematical rigor. Only the antenna types commonly used in radar systems are discussed, specifically the dish antenna and the phased-array antenna.
(c) In discussing the transmitter and receiver in radar systems, knowledge of microwave theory and techniques is required. However, the topics dealing with microwave magnetron, klystron, traveling-wave tube, crystal detector are included in the course contents, and discussed avoiding mathematical complexity.
(d) The concept of modulation theory is provided while discussing some types of radar systems without burdening any extra efforts.

In fact, the course presents information in logical chunks which are meant to be self-contained. Most topics stand alone, and are scaled to their information content. There are two levels of comprehension provided: students may simply memorize key relationships or may master principle and its derivations. Exercises at the end of each topic are provided not to stump the students, but to reinforce the concept presented and illustrate their applications. Exercises are chosen such that students can handle without deeper understanding of prerequisite materials.

IV Required Textbooks

The approach required for an undergraduate level text in radar systems is to provide a broad concept underlying the basic principles of most radar types by maintaining a good balance of mathematical rigor and avoiding the point of incomprehensibility suitable enough to convince students without causing them to lose interest, illustrate some radar applications, and finally present some worked-out examples as well as end-of-chapter problems to reinforce the concepts. Although there is a plethora of textbooks[2-8] on radar systems, all of them are dedicated for the specialist or the advanced graduate students. The problem facing the undergraduate students is lack of adequate prerequisites that inhibit the grasp of the materials. A textbook, *Introduction to Radar Analysis*[2], is currently recommended as a text supplemented heavily by handouts. Students are frequently instructed to avoid parts of the chapter containing mathematical complexity.

V Usefulness of Laboratory

Hands-on laboratory experience is another challenge in offering this course to undergraduate students. Elective courses in electrical engineering curriculum are usually three-credit hours resulting in a radar course without a formal laboratory. However, the avionics program at Saint

Louis University has an Avionics Radar Lab, which is used for lab demonstrations to provide some lab experience. Lab demonstrations include basic and important experiments illustrating the principles of radar systems, and thus provide an insight to microwave signal measurements, transmission line characteristics and matching, klystron, color-weather radar and FM chirp radar. Students are encouraged to visit the lab during the semester to get familiarized with some radar equipment. This approach has certainly an inherent weakness, since students do not spend enough time to acquire deeper understanding of practical aspects of the material. Curious students are encouraged to engage in projects dealing with some practical radar systems.

VI Conclusion

The Radar Systems course has been very successful. It is well received by students in terms of its contents and comprehensibility of materials. The lack of adequate prerequisites does not pose a serious problem. Most of the prerequisites that are lacking are discussed following the just-in-time approach. The lack of suitable textbook is still a major problem, which is compensated by generous handouts. The course presents information in logical chunks, which are meant to be self-contained. Most topics stand alone, and are scaled to their information contents. Homework assignments are carefully chosen such that the students can handle without any hidden prerequisites. The lab demonstrations and radar projects reinforce the principles and techniques learned building confidence in students. However, it is desirable to integrate the formal lab into the course, which would require major overhauling of the course contents.

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Beshara Sholy received the B.S. and M.S. degrees from the University of Mississippi in 1983 and 1986 respectively, all in electrical engineering. Currently, he is a Ph.D. candidate at Saint Louis University. He was the Coordinator of avionics programs for twelve years, and is currently an Assistant Professor of Avionics in the Department of Aerospace Technology. His research interest has been in flight cockpit simulation.