ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Paper ID #40824

A Practical RF Engineering Curriculum for Engineering Technology Students

Dr. Doug Kim, Farmingdale State College

Dr. Kim is currently an associate professor in Electrical and Computer Engineering Technology at Farmingdale State College. He worked in RF and wireless industry for more than 15 years before joining academia. Dr. Kim received B.S. in EECS from University of California Berkeley, M.S. in EE from University of Southern California and Ph.D. from Stony Brook University,

A Practical RF Engineering Curriculum for Engineering Technology Students

Abstract

One of the most difficult areas in electrical engineering to teach in classroom settings to engineering technology students is Radio Frequency (RF) engineering. This is mostly due to two aspects of RF engineering. The first is the high levels of theoretical understanding of both physics and mathematics including statistical modeling, which are not regularly taught to engineering technology students. The second potential issue is the lack of essential equipment used in RF engineering that the students can learn with because the equipment used by RF engineers in the field most of the time is too costly to have in the undergraduate teaching labs. For these reasons, many engineering technology students do not have an opportunity to be properly trained on the basic skills required to qualify for RF engineering positions. For these reasons, electrical engineering technology programs must carefully design a curriculum that meets the requirements of the RF industry as starting RF engineers. The curriculum proposed in this paper is devised with three main goals: To provide easy-to-understand lesson contents with a minimum mathematics and physics backgrounds, to provide hands-on exercises with the lab equipment, and to prepare the students with the practical applications of the theory learned. The curriculum is comprised of three courses in sequence, The first course covers fundamental knowledge in RF engineering, which includes topics such as RF power, Passive Components, Transmission Lines, and Antenna. The second course expands upon the first class with more advanced topics on Propagations, Microwave Devices, Amplifiers, and Noise Management. The third course in the sequence is a practical application design course, which can replace the senior project or an internship to apply the learnings to practical uses. The curriculum can be used to award a micro-credential in basic RF engineering to the students that can help showcase their achievement in the area. The paper will describe in detail how each course can be designed and taught including the lab activities in a structured and practical approach.

Introduction

Graduates with industry-ready RF engineering skills are in high demand due to the expanding influence of the RF and Microwave engineering industry [1]. This influence now reaches beyond the military and cellular communications sectors, including connected cars, remote sensing, and RFID. However, implementing an RF engineering curriculum presents many difficulties for engineering technology programs such as limitations on the number of available course credits to use, a higher level of math and physics, and a high cost of equipping the lab. In this paper, a practical approach to RF engineering curriculum is discussed that could lower the entrance barriers to having an RF engineering curriculum.

Curriculum Design - Limitations

In general, curriculums at the undergraduate level in RF engineering are based on an approach that primarily emphasizes theoretical backgrounds first and then the analysis of the applications using them. This approach is used in many different areas of electrical engineering and with success in engineering science programs. However, many of the engineering technology programs would not be able to implement this approach easily due to the limitations on extra course credits available, and the time needed to complete prerequisite courses in math and physics as well as the higher levels of math and physics required compared to engineering science programs. Another obstacle to a practical teaching approach is a lack of properly equipped laboratories because of the prohibitively higher prices of the equipment used in RF engineering compared to other areas in electrical engineering [2].

Curriculum Design – Industry Input

As engineering technology programs put more emphasis on the application aspects of engineering, there needs to be a more practical approach to the curriculum that can help the students acquire practical skills that are being used in the industry. This requires input from the industry members on specific skill sets expected from our graduates and the types of equipment currently being used in the industry. Most engineering programs have an Advisory Board with members from the industry. The board can offer insights on the latest trends and developments in RF engineering. These insights are invaluable to keep the programs up to date so that the graduates have an advantage in the competitive job market. The inputs can also be solicited by sending surveys to RF companies in the area. The survey questions need to be specific and relevant to each company for a better response rate. The following are some of the questions we have used:

- *What are the most desired skill sets for RF amplifiers would you like our graduates to possess as new hires?*
- *Does your RF engineering department prefer to use a PC-based analyzer or a standalone spectrum analyzer?*

The second benefit of seeking input from the companies is the increased level of exposure to the program, which can positively influence their hiring of the graduates from the program. The survey sometimes results in a donation of older equipment that is not being used by the companies.

The most important part of the feedback process is responding to the input. If the curriculum is updated in response to the input, it should be communicated back to the company as well as the students in the program. Overall, the curriculum designed with a practical and industry-oriented approach can enable the instructors and the students to concentrate on the most common tasks in RF engineering.

Curriculum Design – Prerequisites

One of the main reasons why RF engineering is not taught in depth at the undergraduate level, especially in engineering technology programs is that relatively higher levels of mathematics such as vector calculus and random processing to fully understand the theories in RF engineering. An RF engineering program in engineering technology must practically consider prerequisites in mathematics for the students so that any new prerequisites other than the ones already required by the electrical engineering technology program.

It becomes necessary for the instructors to carefully assess each topic covered in the course and implement a teaching strategy that only utilizes the practical level of math and physics. The practicality must come from the understanding of how the topic is being utilized and practiced in the field to avoid any unnecessary complexity. Running a pilot course before the final course implementation can help assess and adjust to the proper level of prerequisites. For example, with two-port S-parameters, it is more important to understand the physical meanings of each of the four parameters rather than taking time to learn how to get those values from an RF circuit. The S-parameters are usually measured using network analyzers rather than analytically solved. It would be more beneficial to explain what S_{21} physically represents, i.e., "Insertion Loss" incurred by the network and the effect it has on the output signal. By approaching the topics in the course conceptually and practically, we can minimize the time and effort needed by the students for the mathematical aspect of the topics while helping them learn industry-ready skill sets. Another example would be "path loss" models, which require a good understanding of statistical analysis. Most signal coverage analysis in wireless networks for complex topologies is usually done by simulation software. It would be highly impractical to teach Rayleigh or Ricean fading models to engineering technology students. Instead, the log-normal distance path loss model with the Gaussian (or Normal) distribution would be a better choice to explain the randomness of received signal strength. The curriculum should be designed without any new perquisites other than the existing prerequisites for the electrical engineering technology programs. Most electrical engineering technology programs require students to take "Calculus with Applications" in math and Electromagnetism in physics, which should suffice as prerequisites for the RF curriculum.

Curriculum Design – Courses

To give the students better accessibility to the RF program, the curriculum must be carefully designed and implemented so that it would not force the students to take extra courses over what is required for graduation. This means that we must utilize as many existing and technical elective courses as possible. Some of the basic concepts used in RF engineering are already parts of the introductory or intermediate courses such as AC circuits and Amplifiers. These courses would not need to change the contents as RF-related concepts such as AC signals, filtering, and frequency responses are already embedded in them. One of two technical electives can be utilized to provide core RF engineering topics such as transmission lines, antennas, oscillators, and filters while the other technical elective course can be adapted to cover more advanced topics such as signal propagation, phase distortion, and advanced wireless networks. To demonstrate the practical knowledge the students learned from the RF curriculum, the program should require a student-driven RF-related project. This senior capstone project does not necessarily have to involve building an RF device. It could be a methodology in measurements or an automated process development. The only requirement is that the project should fully display the knowledge and skills acquired from the curriculum. The project demonstrates the capabilities and readiness of the students to take on real-life RF engineering tasks.

Curriculum Design – Lab Activities

The laboratory activities are centered around three major RF test equipment, Vector Network Analyzer (VNA), Spectrum Analyzer (SA), RF Power Meter. The learning objectives and outcomes should focus on developing competency in using the equipment for various measurements, troubleshooting, and verification. In general, electrical engineering laboratory activities mostly involve the comparison of theoretical analysis to experimental results. In the practical RF curriculum, the comparison should be made more in terms of the specifications of DUT (Device Under Test) and the measurement results. Through these activities, students can learn key specifications for different types of RF devices and the knowledge on what is or is not acceptable for each specification without mathematically calculate and expect certain values. The causes for deviation from the expected results should be found not only by considering theoretical error tolerance but also by measuring the effects of all potential variables involved in the experiment methodically. The thorough lab activities help students develop a good level of Root Cause Analysis (RCA) capabilities. To gain practical knowledge through the lab activities, it is essential that the curriculum integrates the inputs provided by the industry into the lab experiments. When a graduate from the program is hired, they will be very familiar with the many engineering tasks performed daily.

Curriculum Design – Micro-Credentials

According to the State University of New York (SUNY), a micro-credential is a valid learning experience with learning outcomes, assessments, and examples of student work [3]. The program with a micro-credential will not only attract a higher level of interest from the students but also reward the students in the form of a competitive edge in the job market for completing the curriculum. For SUNY, the micro-credential is recorded in the student's transcript. The micro-credential can also be an attractive outcome for potential part-time students when the RF curriculum is a track in a professional development program for even wider participation in the RF curriculum.

Curriculum Implementation Plan – EET Department at SUNY Farmingdale State College

1. Course Map

The course map in Figure 1 illustrates the planned sequence of courses in the RF engineering curriculum at Farmingdale State College (FSC). All courses in the course map are existing courses. The current degree program offered in Electrical Engineering Technology (EET) allows only two technical electives without room for any new course. EET 450 and 452 are two-semester senior capstone courses required for all students in our degree program.

The three main courses in the curriculum are EET 414, EET 450, and EET 452. Three lower-division courses, EET 113, EET 224, and EET 225 lay the groundwork for the seamless transition from circuits and devices by familiarizing the students with the concepts used in the frequency domain such as complex impedances, bandwidth, signal filtering, and so on.

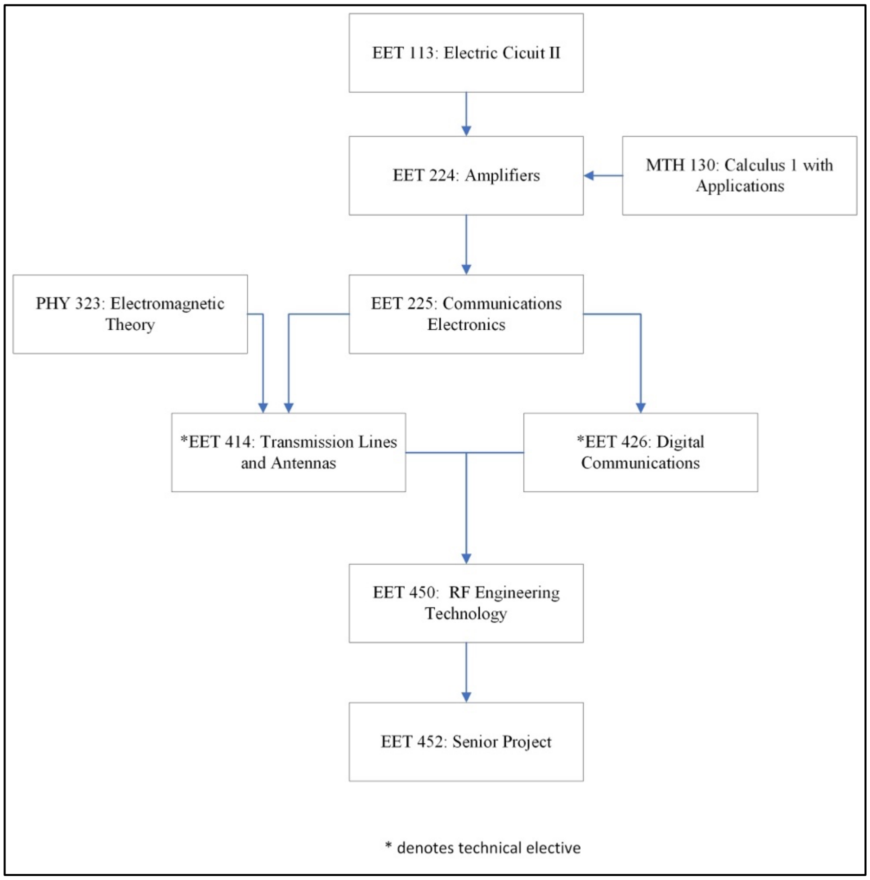

Figure 1: FSC Course Map for RF Engineering

2. Lab Equipment

A dedicated RF engineering lab with eight lab stations is equipped with the following for each station:

- Vector Network Analyzer: Rhode & Schwarz ZNL 6 with calibration kit, C-Band
- Phase Stable Cables – Rhode and Schwartz
- Spectrum Analyzer: Rhode & Schwarz ZN-Z135, C-Band
- RF Signal Generator: Rhode and Schwarz SMB100B C-Band
- RF Power Meter with Power Head: Boonton PMX40
- Noise Source: Noisecomm NC346
- Microscope: Olympus SZ6145TR
- Oscilloscope, Multimeter, DC Power Supply

3. Core Lab Experiments

The following are the required experiments for the curriculum. Other experiments will be added per each instructor.

- ESD Awareness and Training
- Calibration of the Vector Network Analyzer

- Wilkinson Power Divider Measurement with VNA
- Measurements: Isolation, directivity, s-parameters for 3-dB Coupler
- Filter Measurement: VSWR, Insertion Loss, Insertion Phase, Passbands, Rejection bands for Low-band and microwave band
- Oscillator Measurement with Spectrum Analyzer: Frequency, Amplitude, Harmonics, Noise
- Mixer Measurement: Conversion, RF/IF/LO
- Signal Chain Measurement

Figure 2: FSC RF/Microwave Lab

4. RF Engineering Project

The capstone project from the RF curriculum is an independent project that the students can work on as a group. Each group consists of a maximum of 3 students. They are required to employ project management with specific roles and responsibilities of each member, project scheduling with milestones, and weekly project progress reports. The project is determined by the students in consultation with a faculty advisor. The completed project will be presented at the end of the semester to the entire EET department.

As an example, a project was completed by a group of 3 students in the pilot program. The project was to empirically determine the path loss exponent inside a building on campus and to predict coverage probabilities in similar buildings using a transmitter in the ISM band. The group collected data at every 1 meter along the hallways and estimated the path loss exponent using MMSE estimation. The project used a very practical way of learning indoor propagation parameters. The students took into consideration noise and interference from the Wi-Fi routers in the building. They also investigated inter-floor path loss under many different circumstances.

The capstone project is the highlight of the RF engineering curriculum as students put together all the knowledge acquired from the courses into practical applications.

Conclusion

This paper introduces a practical approach to an RF engineering curriculum from different aspects. Yet, there remain many hurdles to overcome to set up an effective RF engineering curriculum. RF Engineering curriculum requires a constant cycle of feedback and adjustment to be successful. The current curriculum that produces industry-ready graduates now may not be effective or practical any more in a few years. We will continuously assess our curriculum and make necessary adjustments as we strive for student success.

References

[1] Barb Jorgensen, "Why Demand for RF Engineers Outstrips Supply" *ESPNews*, June 29, 2023. https://epsnews.com/2023/06/29/why-demand-for-rf-engineers-outstrips-supply/ (accessed September 16, 2023).

[2] Jack Browne "Why Such High Costs for Test Equipment" *Microwaves&RF*, April 22, 2015. https://www.mwrf.com/technologies/test-measurement/analyzers/article/21846228/microwaves-rf-why-such-high-costs-for-test-equipment (accessed September 16, 2023).

[3] The State University of New York "Our Story: Building SUNY's Microcredential Program and Initial Lessons Learned" *The State University of New York*. https://www.suny.edu/microcredentials/program-development/ (accessed September 16, 2023).