AC 2007-2549: RF AND MICROWAVE ENGINEERING ELECTIVE COURSE WITH A CO-REQUISITE IN THE ELECTROMAGNETICS COURSE

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RF and Microwave Engineering Elective Course with a Co-Requisite in the Electromagnetics Course

Abstract

The requirement of a completed engineering electromagnetics course in order to register for an undergraduate RF and microwave engineering course has been eliminated for the last two years in our Electrical Engineering Program at the University of _____________. Instead, the requirement to register for the RF and microwave engineering elective has been change to concurrent registration in engineering electromagnetics.

The completion of an electromagnetics course is, at first glance, seemingly desirable for students wishing to study RF and microwave engineering. However, it has become evident that when students are concurrently registered in both courses, there is a bridging of concepts between the two courses. Fundamental concepts are emphasized in the electromagnetics course. In the RF and microwave engineering, emphasis has been placed on design using the concepts introduced in the electromagnetics course. Extensive use of electronic design tools and laboratory experiences in the RF and microwave engineering course creates a synergistic relationship between the two courses and allows solidification of concepts introduced in each course.

Curricular design of both courses as well as assessments of concurrent registration in the courses is presented. Specific laboratory design, fabrication, and measurement experiments conducted in the RF and microwave engineering course that helps emphasize concepts introduced in the engineering electromagnetics course are outlined.

Introduction

Radio frequency (RF) and microwave engineering courses are commonly taught as an electrical engineering elective in the senior or graduate years of study.[1] Concepts introduced in RF and microwave courses benefit from a solid understanding of passive and active circuits, and time-varying electromagnetic field theory.[2] With regard to electromagnetic fields, wave propagation concepts are fundamental in many of the RF and microwave engineering applications.

At the University of ________________, the institution's liberal arts tradition places heavy non-engineering graduation course requirements of the program conferring a dual B.S./B.A. with the B.A. degree awarded in recognition of the large number of required liberal arts courses taken by our graduates. These undergraduate graduation requirements demand an efficient application of material in the engineering offerings. Therefore, electrical engineering students are offered one required electromagnetics course. The required electromagnetics course content is focused on time-varying electromagnetic fields. It is assumed that static electromagnetic field theory is adequately covered in a sophomore level physics course.

A laboratory content with a required electromagnetics course in an electrical engineering program has the advantage of allowing students to solidify their understanding of the theoretical and mathematical concepts introduced in the lecture portion of the course. The very nature of electromagnetics theory lends itself to the development and bridging of those concepts with experiential realizations. By including a three-hour weekly laboratory to the course, important theoretical concepts can be applied to engineering implementations using engineering design methodology. The lectures can then be tailored to complement the laboratory exercises that can often include engineering design concepts.

A typical electromagnetics course topical coverage at our institution is:

1. Review: Vectors and Vector Calculus (1 week)
2. Maxwell's Equations (1.5 weeks)
3. Uniform Plane Waves and Propagation (2 weeks)
4. Reflection and Transmission of Waves (1.5 weeks)
5. Transmission Lines and Waveguides (2.5 weeks)
6. Transmission Line Principles in Circuit Design (2 weeks)
7. Antennas and Radiation (2 weeks)

The laboratory content of the electromagnetics course (for Fall 2006) was:

1. Transmission Line Characteristics (1 week)
2. "Microwave Training Kit" Experiments (4 weeks)
3. Introduction to Agilent Advanced Design System (ADS) (2 weeks)
4. Designing matching networks with ADS (2 weeks)
5. Investigating Wave Propagation and Attenuation using ADS (1 week)
6. Antenna Design using MathCad (1 week)
7. Network Analyzer usage/experiments (2 weeks)

The large part of the laboratory exercises consisted of utilizing mathematical modeling and an X-band waveguide training kit to demonstrate basic principles such as standing wave ratio and termination.

The microwave training kit was used to familiarize the students with basic microwave measurements. Students would initially carry out simple software experiments to observe variations of VSWR for different load impedances, reflection coefficients, etc. and Smith Chart graphing. This prepared the students to make microwave measurements using rectangular waveguides. Specific lab activities was a selection from the following experiments from the Microwave Training Kits:

- Measurement of Microwave Power
- Measurement of VSWR
- Measurement of Frequency and Wavelength
- Measurement of Impedance
- Waveguide Attenuators
- Klystron Characteristics

Students became familiar with various microwave components which include:

- Power Supply/Thermistor & amplifier; Thermistor Mount; Solid State Oscillator
- Klystron Tube Mount; Frequency Meter; Slotted Line; Termination
- Waveguide Stands; Shorting Plate; Waveguides and Dimensions
- Variable Flap Attenuator; Tuning Probe; Detector Mount

A vital lesson students learned in Microwave Measurements was unlike many of their other laboratory experiences that used lumped parameters,

RF and Microwave Engineering Course

A senior elective course entitled "RF and Microwave Engineering" has been taught at the University since 2001. At the beginning, this course required electromagnetics course was a prerequisite for enrollment in the RF and microwave engineering course. The rationale for requiring a prerequisite in the electromagnetics course was three fold:

- Students are required to have a firm grasp of transmission line theory
- Familiarity with Smith Chart design and analysis techniques is required
- Familiarity with the network analyzer is desired

The prerequisite was enforced until 2005 when registration in the electromagnetics course[3] and its associated laboratory were designated as co-requisites for the RF and microwave engineering elective course. The change was initiated partly due to the desire to allow students the flexibility to compress their degree curriculum from the University's standard of four and a half year electrical engineering curriculum (with the liberal arts B.A. component) to four years for graduation with the dual degree.

The compression of the curriculum and the designation of the electromagnetics course as a co-requisite for the RF and microwave engineering course offered challenges. However, the result had some unexpected benefits.

The typical topical coverage for the RF and microwave engineering course at are institution is:

1. Components of RF and microwave design (1 session)
2. Behavior of passive components (3 sessions)
3. Scattering parameters and signal flow diagrams (4 sessions)
4. Using Smith Chart for design (4 sessions)
5. Microstripline circuits (4 sessions)
6. Passive networks and RF filters (5 sessions)
7. Active RF components (3 sessions)
8. Matching networks to active components (2 sessions)
9. Transistor amplifiers (4 sessions)
10. Oscillators (4 sessions)
11. RF Design Topics (Mixers, Attenuators, AGC, TBD) (4 sessions)

Associated with the lecture sections is a three hours per week laboratory with topics such as:

1. Introduction to S-Parameter Design (1 week)
2. Measurement of passive components (1 week)
3. Scattering parameter measurements (1 week)
4. Introduction To Ansoft Designer (1 week)
5. Matching Networks with RF Software (1 week)
6. RF and microwave filter design (2 weeks)
7. RF Transistor Amplifier Design (2 weeks)
8. RF Design Topics (Oscillators, Mixers, Attenuators, AGC) (4 weeks)

In most instances, the RF and microwave course used freeware for software tools. Two freeware tools were used extensively in the course. The first is the Berner Smith Chart tool created by Professor Fritz Dellsperger at the Berne University of Applied Sciences (Switzerland). The demonstration version of Berner Smith Chart program is used. This software tool offers a very easy graphical user interface that allows designers to select circuit elements and their values and allow use of stability, gain, VSWR and noise figure circles as well as map constant Q contours. A truly added bonus of this free demonstration software package is the ability to import device S-parameters to the designs. The S-parameters are imported at .s2p extension files identical to that found in the Agilent ADS software package.

The second free demonstration software package used is the Ansoft Designer SV (SV for Student Version). Ansoft Designer provides a highly integrated schematic and design front-end for RF applications.

Both software tools are used in conjunction with Matlab to facilitate design of RF and microwave circuits.

Synergy Between Courses

Until about week three or four, the two courses, eletromagnetics and RF and microwave engineering, are fairly independent of each other. During the first weeks of the semester, the electromagnetics course covers vectors and vector calculus, Maxwell's equations, and uniform plane waves and propagation. The RF and microwave engineering course covers RF and microwave lumped components scattering parameters and begins touching on Smith Charts.

It is at the beginning of the introduction to Smith Charts that appears to exploit the advantages of concurrent registration in the two courses. Basic theoretical foundations used in transmission line theory are presented in the RF and microwave course. Although transmission line theory is not covered in as great a detail as in the electromagnetics class, sufficient mathematical and theoretical background is presented so that scattering parameters can be discussed in a meaningful manner.

With discussion of the basic concepts and mathematical relationships for reflection and transmission, an introduction to Smith Charts and its use can be presented. It is at this point that the synergy between the two classes appears to form.

In particular, the classical Smith Chart problems involving stub tuners is expanded upon in the RF and microwave lecture session nearly simultaneously with the electromagnetics course. The exception is that in the RF course, microstriplines are used in the impedance matching designs on standard FR4 printed circuit board material. A standard 63 mil thick 1 ounce copper single-sided board is used with 1/8" wide copper tape (which is close enough to 50 Ω for student laboratory experiences) is used to fabricate the matching circuits as shown in Figure 1.

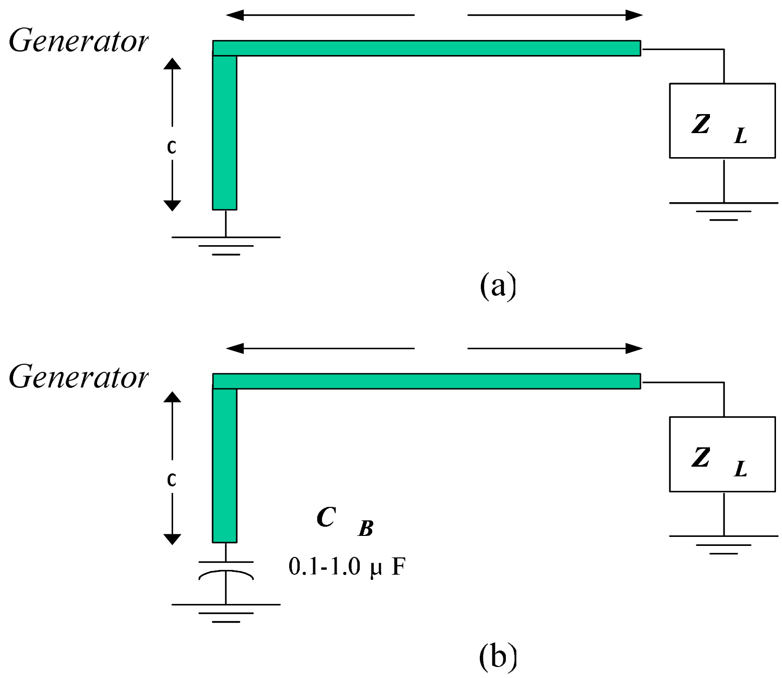

Figure 1. (a) DC Shorted Stub. (b) AC Shorted Stub with C_B .

The two simple configurations shown in Figure 1 can be used to illustrate situations where DC or AC coupling between the generator and load is desired. This is one of the important details that is offered in the RF course but not in the electromagnetics course.

Quarterwave transformers can also be designed using the Smith Chart. The circuit can then be developed again using 63 mil thick FR4 circuit boards as shown in Figure 2. As in the stub tuner design, a carefully chosen resistive load can be used so that standard copper tape sizes can be used to match the generator to the load. In this experiment, Z_o is 50 Ω and the load is a 95.3 Ω resistor. The quarterwave transformer section thus has an impedance of approximately 69 Ω. A standard 1/16" copper tape has an impedance of a little more that 68 Ω can be used in the quarterwave section connecting the 50 Ω generator to the load.

Through the continual reinforcement in the RF course of the basic principles learned in the electromagnetics course, meaningful experiences of the fundamentals of electromagnetics are achieved.

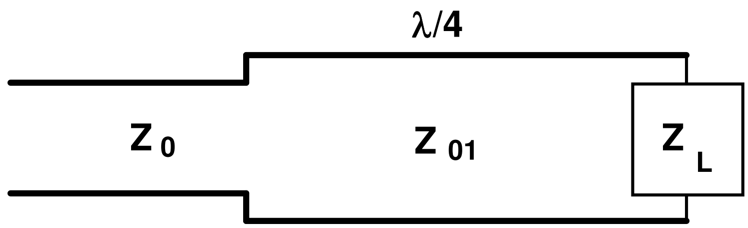

Figure 2. Quarterwave Transformer

Assessment and Conclusions

To assess the effectiveness of the synergy of the electromagnetics and RF courses, teacher evaluations for the RF course was studied. The RF course effectiveness was rated an average of 4.5 out of 5.0 (5.0 being excellent) over the course of three offerings of the class from 2004 – 2006. Of particular interest was the question, "Relevance and usefulness of the course was:" which rated 4.8 out of 5.0 on the average over the three semesters. This is an indication that there was adequate instruction in electromagnetics to allow understanding of RF and microwave engineering.

This assessment is compared to the pre-2004 RF course where the electromagnetics course was designated a prerequisite. In those three class offerings (2001-2003), the RF course effectiveness was rated an average of 4.7 out of 5.0 (5.0 being excellent) with the relevance question being rated 4.9 out of 5.0.

In 2006, students were asked to comment specifically about the effectiveness of allowing simultaneous enrollment in electromagnetics and RF courses. 90 % of the students found that concurrent enrollment in the two courses helped their understanding or electromagnetics theory. 10 % of the students thought that had they have already completed the electromagetics course, some of the more complex RF and microwave engineering concepts would have been easier to understand.

The assessment indicates successful implementation of an RF and microwave engineering course that has an electromagnetics course co-requisite. While it is desirable for students to have completed the electromagnetics course prior to registration in the RF course, it appears that there is synergy between the two courses when taken by students concurrently.

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