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Microwave Measurements and Techniques Laboratory in a Undergraduate Radar Systems Course

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Abstract

This paper outlines the development of microwave measurement and techniques laboratory experiments for instruction of undergraduate avionics (aviation electronics) students. The experiments are applications of the theory provided to students in a separate and independent lecture course. The senior level lecture course provides the students with the fundamentals of electromagnetic principles and of radar systems in a senior level course on radar systems. It is taught as part of a four year aviation electronics degree program at Parks College of Engineering and Aviation, Saint Louis University.

I Introduction

Recent technological advances in the applications of microwave frequencies have mandated the need for their understanding by engineering technology as well as engineering science graduates. Studies of microwave frequency measurement techniques are usually attained in upper division courses, mainly in preparation for graduate programs geared towards research in this field. Few schools provide an opportunity for undergraduates to learn to use techniques in the installation and maintenance of such systems at frequencies above 1 GHz. At Parks College of Engineering and Aviation, a lecture course and accompanying laboratory are designed to give avionics students an introduction to Radar systems in which microwave measurements and techniques are a major portion of the exercise.

This lecture/laboratory combination provides our students with the opportunity to demonstrate the basic theory of transmission, reflection and attenuation measurements of microwave signals at frequencies up to 12GHz. This is explored in a variety of laboratory experiments designed to give an understanding of microwave signal measurement, characteristics of microwave devices and transmission media, and an evaluation of their application in various situations. Of special interest to the avionics student are the applications in aviation related settings.

The laboratory experiments are arranged to coincide with the lectures in the course. The intent is to familiarize the student with the use of microwave test and measurement instrumentation, and the techniques and associated parameters. The student learns to verify the theory learned in the co-requisite lecture and gain hands-on experience. The laboratory helps in understanding the physical processes through controlled demonstrations. The student is expected to apply the knowledge gained from the lecture course to analyze and evaluate the system studied, and to verify the measurements obtained in the laboratory. The student learns how to interpret the readings obtained using specialized microwave frequency measuring instruments. Subject areas discussed in the laboratory include coupling, directivity, insertion loss, reflection coefficient, VSWR measurements, and basic radar signal generation and transmission. The Smith Chart is introduced and used as a measurement tool. A weather radar test set deployed in the laboratory is used to measure and test the capability of the weather radar. A sample experiment related to the microwave measurements portion of the course work is included in the attached appendix.

II Student Background-Course Pre-requisites and Co-requisites

The prerequisites to the microwave measurements and techniques laboratory are the typical electrical/electronics engineering technology laboratory courses. This includes electrical circuits analysis, electronics, and electronic communication laboratory. These prerequisites are spread over the first three years of the program. In addition, the student is expected to have completed a four semester differential calculus courses work, two semesters of physics, and one semester of non-organic chemistry lecture/laboratory work. Students are also to have completed a course on signals and system analysis.

The co-requisite radar systems lecture course begins with the introduction of the fundamental principles of microwave signal generation, transmission, reflection, attenuation and reception. The course outlines the basic principles of microwave signal usage in ranging and detection. The lecture provides some background in electromagnetic (EM) theory with emphasis on the wave equation solutions as related to transmission lines and waveguides. Transmission line terminology, theory of DC pulses and bounce diagram are explained and demonstrated. Impedance and associated parameters measurement along a doubly terminated transmission line are discussed. Impedance matching techniques and the use of the Smith Chart as a impedance measuring tool are also introduced. An introduction to EM wave propagation theory is given in order to quantify the wave equation and provide solutions to be used in laboratory measurements.

The lecture is divided into three main components. The first component represents an introduction to microwave frequency transmission and reception. The second concerns the specialized case of radar and its applications, and the third provides further discussion of topics in radar systems. In some instances, the advanced topics are pursued by students in completion of a design core-requirement in the degree program. Table 1 illustrates the content of each of the three topics presented in the lecture course.

Table 1. A listing of Radar System's course content.

Part One Transmission line theory	Transmission line theory The Smith chart Impedance matching Voltage standing wave ratio Reflection coefficient Load determination from VSWR and null location of Waveguides S-parameters
Part Two Basic Radar Systems	Basic radar system Radar range equation Radar system analysis Radar cross section Antenna gain Probability of detection and false alarm rate Noise Related topics
Part Three Advanced Topics	Environmental effects Transmitters, Receivers and technology Waveform encoding and decoding Doppler radar Continuous Wave radar Monopulse and Conical scan techniques Countermeasures

III Laboratory Experiments

The experiments for this laboratory employ specialized equipment located in the department's Radar Laboratory. Equipment in a typical microwave laboratory are expensive and extremely fragile. Our laboratory is no exception. The specialized equipment available in this lab include a spectrum analyzer, a network analyzers, S-parameter test units, sweep frequency generators, single and double stub tuners, attenuators, frequency meters, waveguides and other necessary equipment. In addition, a phased-array weather radar and a radar test set are deployed for experimentation of the applications of microwave devices. Other devices used in testing include: coaxial cable of known length, loads of known impedances to measure for VSWR, reflection and transmission coefficients, and sources of microwave signals. Some experiments have a simulation component using PSPICE[16] as the simulation software tool. Other computer simulation tools have been recently purchased and are being evaluated for this and other laboratory usage. An example of PSPICE simulation is given in Appendix B.

Most of the experiments are performed in groups of two students per station. Some experiments are performed by larger groups mainly due to the lack of availability of an adequate number of stations and equipment to complete these experiments. In these cases, the workload is divided among the students and the results are shared. Each student is expected to keep a laboratory notebook to keep track of the methodology and measurements. The notebook is then used in writing a report on the tasks performed.

The laboratory experiments provided to the student touch on many of the topics introduced earlier. Instructors are always in search of new ideas and techniques to introduce into this laboratory. A current list of laboratory experiments that are used are given in Table 2. The list is divided into two main parts, the transmission line measurement part and the radar systems part.

Table 2. List of laboratory experiments used in microwave measurements

Part I Transmission line theory	Frequency and wavelength measurements Transmission line characteristics Simulation of transmission lines Reflectometer techniques Transmission line analysis with a nonlinear load Detector characteristics vs. power level Transmission line matching-single stub tuning VSWR measurement and load characterization
Part II Basic Radar Systems	KWX-56 radar performance evaluation Band-limited Gaussian noise analysis Antenna characterization Radar cross section FM chirp pulse compression

Each of the experiments is provided to the student prior to the experiment's date. The student is expected to perform initial calculations necessary to proceed in the laboratory. The student is also expected to keep a complete record of an experiment in an organized and comprehensible manner. As previously mentioned, a laboratory notebook is required of every student. The notebook should be neat, written concisely with care and in good English. The notebook is expected to contain a record of essential features describing each of the experiments performed. Essential features required by the instructor include: Experiment title, Author, Date, Objective, Apparatus, Block diagrams, Equipment list, Conditions, Experimental procedure, Data with comments and preliminary plots/graphs, Sample calculations, Results and observations, Discussion, Conclusions, and Recommendations. Each student is required to prepare formal reports of the experiments. A report on an experiment is based upon the records in the notebook, and is due to the instructor for grading a few weeks after it is performed.

In some cases, it was necessary for the instructor to assist the students in performing the task at hand. The experiments were designed to be complete; however, the length of time it takes to complete each of the experiments varied. In some instances, time proved to be inadequate. In those cases, the experiments were divided into two or more laboratory sessions.

IV Discussion

The lecture and laboratory are offered to seniors in a B.S. degree program. Students are expected to have completed math courses, including differential equations, and electronics communication theory and applications. Basic EM[10,12,15] theory is made part of this course in order to bridge the gap necessary to a full understanding of EM wave propagation, an essential part of microwave signals and devices. In addition, avionics students are not required to enroll in a probability and statistics[11] course, a requirement for the understanding of ranging and detection experiments. This is a challenge given the time and context constraints. In these cases adjustments are necessary to overcome the shortfall in the background of the students in meeting the objective. The challenge of lack of adequate prerequisites is met by providing extra reading materials covering those topics, and by dedicating a few lectures to discuss those materials following the just-in-time approach, which proved to be effective.

Although there is a plethora of textbooks[1-8,18] on radar systems and microwave[9,13,14] measurement and techniques, most are dedicated to the specialist or the advanced graduate student. The undergraduate's lack of adequate prerequisites inhibits the grasp of the materials from such textbooks. A textbook, *Radar Principles, Technology and Applications*[5], is currently recommended as the text for the lecture, and as one of the references for the laboratory, is supplemented by class handouts. Students are frequently instructed to avoid parts of the chapter containing mathematical complexity.

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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. Geophysics candidate at Saint Louis University. He was the Coordinator of the Avionics programs for twelve years, and is currently an Assistant Professor Avionics in the Department of Aerospace Technology. His research interests are in flight cockpit simulation.

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Dr. Habib Rahman received his Ph.D. degree from Syracuse University, New York, in 1984 in electrical engineering Prior to joining Saint Louis University in 1984 where he is currently Professor of Electrical Engineering, he taught electrical engineering at Bangladesh University of Engineering & Technology (BUET) for three years, and at Sulaimania University, Iraq, for one academic year. His research interests have been in the general areas electromagnetic fields, radar, and engineering education.

Appendix A

An experiment on Reflectometer Techniques
Part I

Introduction

Reflectometer techniques involve the use of methods to measure the reflection and transmission characteristics of networks. Three typical reflectometer measurements are to be use in this experiment. The directional coupler is considered as the basic tool utilized in reflectometer experiments. The directional coupler used will be considered to have high directivity to ensure good isolation between the incident and reflected waveforms applied in each of the experiments.

First, consider the swept reflectometer technique to measure the characteristics of a network over a range of frequencies. Second, consider a vector voltmeter to measure directly the amplitude and phase characteristics of networks. Third, use a network analyzer to measure reflection and transmission characteristics of a network. All three setups utilize the use of a directional coupler as given below and are applied to the same device under test. A comparison of the three methods should yield an acceptable degree of agreement in the measurement of the characteristics of the devices under test. These characteristics include attenuation, transmission, and reflection coefficients of the given loads or networks.

This experiment is in three parts. Part I will cover the swept frequency technique, Part II will cover the vector voltmeter method, and Part III will use the network analyzer to complete the task.

List of equipment used in the Experiment

Sweep generator
Oscilloscope
Attenuator
Device/network under test (DUT)
Short circuit
Directional coupler
Detector diode
Vector voltmeter
Network Analyzer
Power source
Printer/plotter

The swept frequency technique

The swept frequency reflectometer technique is used in this experiment to display the characteristics of a low pass filter, a microstrip line, a 50 ohm load, a 100 Ohm load and an unknown load over a range of frequencies. The characteristics to be measured are the transmission, reflection and attenuation coefficients of these devices.

A typical swept frequency technique utilizes the experiment setups given in Figure 1 and Figure 2. Figure 1 provides a tool to measure the reflection coefficient and Figure 2 measures for the transmission coefficient of the device under test.

To measure reflection coefficient characteristics perform the following two steps:

Calibration procedure:

1. Connect the setup of Figure 1.
2. Start with maximum attenuation level on the variable attenuator and a short on the output of the directional coupler, i.e. in place of the DUT.
3. Set the scope to DC.
4. Select the start and stop frequencies of the sweep generator at convenient positions. Turn the knob to CW position.
5. Adjust the RF level until the ALC loop is locked.
6. Adjust the variable attenuator to a convenient level to allow for adequate range on the scope/recorder for measurement.
7. Set the start and end horizontal limits on the scope/recorder using the sweep generator's manual mode and tracing back and forth the frequency range to be displayed.
8. Repeat step 7 for the vertical limits representing the recorded RF amplitudes.
9. Use various values of attenuation to mark a set of calibration lines for the amplitude of the reflection coefficient plotted on the recorder.
10. Reset the VSWR meter and the attenuator to initial settings.
11. Remove the short.

Now, the test setup is calibrated to be used in measuring the characteristics of the devices under test.

Measurement and calculations

1. Place the device to be tested at the output of the directional coupler, i.e. the DUT position.
2. The oscilloscope should show a swept frequency display of the amplitude of the reflection coefficient of the load as a function of frequency.
3. Record the result of 2.
4. Determine the VSWR for the loads from the calibration curves.
5. Repeat the above for all the loads provided by the instructor.

Make a file of your results from this part of the experiment. You will need to make comparisons of these results with the results obtained from Part II and Part III.

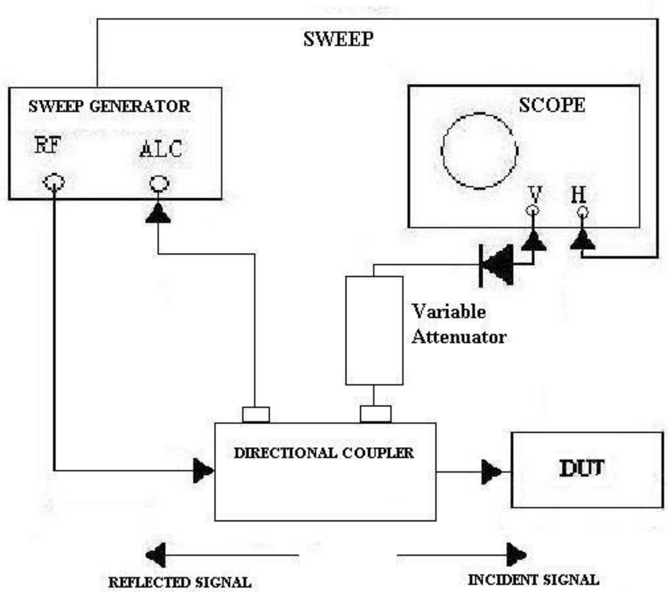

Figure 1. Typical swept frequency reflectometer setup for reflection coefficient measurement

Appendix B

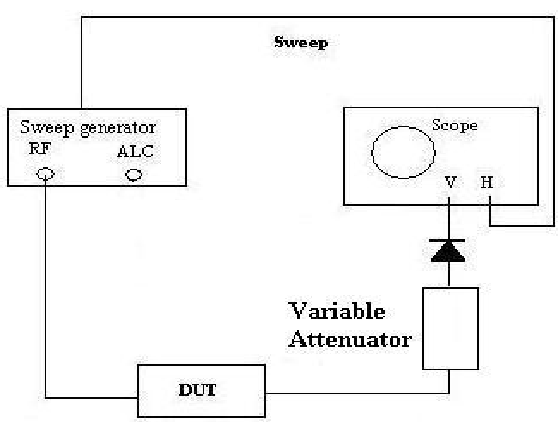

Figure 2. Typical swept frequency refloctometer setup for transmission coefficient measurement.

TRANSMISSION LINE CHARACTERISTICS
PSPICE Simulation
Part B

The purpose of this experiment is to verify your knowledge of transmission line theory and reinforce your laboratory experience with the results produced by a typical analysis using PSpice. In this experiment you will observe the interaction of voltage pulses on a 100 meter, 50 ohm transmission line with varied load resistance.

References

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Microwave Theory and Applications, by Adam;
Transmission Lines, Waveguides and Smith Charts, by Liboff and Dalman.
Spice: a Guide to Circuits Simulation & Analysis Using Pspice by Tuinenga.

Instructions

1. Using Pspice, analyze a coaxial transmission line having a characteristics impedance of 50 Ohms and 100 meters length. (Note: this is the same circuit used in Part A)
2. Create a circuit file which analyzes the circuit out to 5 time delays and plot load and source voltages using the Probe utility. That is, print-out values of load and source also.
3. Use the "TD" option in the "T" device (for transmission line) which corresponds to the time delay of the 100 meter length of Z_o = 50 Ohms.

Analysis

1. Analyze the waveforms mathematically using techniques presented in lectures and previous labs. From the data gathered for each load, determine whether the experimental data and simulation data matches what you would expect from theory. You must show all calculations and explain thoroughly.
2. Compare your results with those of the previous lab 1A and determine the causes of any errors.
3. How does the actual signal generator deviate from the ideal generator in this lab?