AC 2011-2463: USE OF COMPUTERS IN THE INSTRUCTION OF EM PROPAGATION IN THE CLASSROOM

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Abstract

Transmission of information is the basis for all societal activities and is the basis of communication all over the world and through space. Its importance in day to day activities cannot be overstated. Progress in human activities has been possible largely because of progress in the transmission of information. The explosion of information transmission in the information age has necessitated the use of wider bandwidths for different applications and this is conveniently accommodated in the radio frequency range.

Information transmission systems can be broadly categorized into two groups, wired and wireless. Even though wired transmission form a part of all communications equipment, wireless applications support a wide variety of communications systems both on land, across the oceans and through space. Antennas form a necessary component for wireless systems for both transmission and reception of information and therefore students need to have a good practical understanding of antennas just as they learn the theory, and they need to appreciate how practical results conform to theory. The computer can be used to facilitate this process in the learning environment by providing the students with realizable concept of electromagnetic radiations. The versatility of the computer enables different types of antenna measurements to be made, and various parameters to be determined. This paper discusses the usefulness of computers in antennas laboratory exercises in a Telecommunications course. It also discusses student design experiments, and experiments planned for the next step of the learning experience.

Introduction

Explosion of information transmission in the information age is evidenced by the dependence on information in all spheres of life. In its electrical form, information may be in the form of voice, video, or data and transmissions of these require different ranges in the frequency spectrum. As a result of the large quantities of information that have to be transmitted at any given moment, large bandwidths are needed. The need for more bandwidth to accommodate different applications has resulted in extensive use of the radio frequency (RF) range of the frequency spectrum. In some cases, applications such as voice that occur at low frequencies are translated to higher frequencies for transmission at the transmitting end, and at the receiving end are stepped down in frequency to the low frequencies needed for reception.

Increase in frequency is associated with decrease in wavelength of the generated electromagnetic waves which become comparable to the dimensions of discrete circuit components. Higher frequencies lead to smaller dimensions and this has facilitated miniaturization which in turn has fed into the explosion of information use by making it easier to transport the equipment needed for transmitting the information. In the case of applications that should occur at low frequencies but have been translated to higher frequencies, component behavior no longer shows electrical responses that conform to the ideal low frequency behavior. In such situations, conventional Kirchhoff-based voltage and current law analyses have to be replaced with those that apply to electromagnetic wave propagation [1]. For this, transmission lines, for example are formed by traces of conducting material on substrates (microstrips) instead of the traditional use of the twin copper wires.

For the engineering or the technology student who intends to go into a communications related field after graduation, introduction to RF applications is useful. This paper describes the design of an RF course for technology students.

Design of RF Course for Technology Students

Prior to starting a course in High Frequency Circuit Design at Penn State Wilkes-Barre campus, the students would have taken courses in Electronic Circuit Design. Considering the current direction of applications in the telecommunications industry, a decision was made by the Electrical Engineering Technology (EET) Department to start a course in RF applications. The High Frequency Circuit Design course is a 400 level course.

The course is started with discussion on how the basic components of resistance, R, inductance, L, and capacitance, C appear to an electromagnetic (EM) wave as it propagates through these components. At high frequencies, both the resistor and capacitor exhibit inductance just as the inductor does [1]. This suggests how the EM interacts with each of the components. Along the same lines, it can be discussed that surface waves [2] exist that can couple components even when that is not desired.

The statement above point to wave propagation on transmission lines [3]. This demonstrates the effectiveness in the use of microstrip lines which are strips of conducting material on a substrate. The close proximity between these lines contributes to the coupling effect between them. It also points to the fact that it is appropriate to present microstrips in lumped component form, just as twin wire and coaxial cable and that there is no loss of content. The Smith's Chart is presented as a graphical approach to solving problems relating to transmission lines.

The comments above become informative when discussing microstrip patch antennas. In the case of circuitry, a high density of component layout can be achieved if a substrate that has a high dielectric constant (for example ε_r = 10.0) is used as this minimizes field leakage and cross coupling. The converse is therefore the desired product in using a substrate that has low dielectric constant (for example ε_r = 2.55) if the intention is to achieve radiation as in the case of antennas.

To complete the course, there are topics such as single- and double-stub matching, single- and multi-port networks, Z, Y, H, and ABCD parameters.

Students who take this course have already taken courses in electronic circuit design as stated above. They posses a knowledge base built on calculations performed with parameters that are familiar to them. Their knowledge is founded on working with components that they can "see and measure", and calculations assure them of what the expected outcome in the laboratory should be. In dealing with EM wave which is a coupled electric field (*E-field*) and magnetic field (*H-field*) that are orthogonal in free space, they encounter a situation in which invisible waves interact with visible components to provide resultant, measureable, effects.

Most of the students prefer the hands-on approach to learning and this is the case in the electronic laboratory. Even though there is a mathematical component to the program and the students are usually performing calculations, they are generally working with components they can pick off the shelf, and applying these at audio frequencies. A point must be made too that they are familiar with applications such as radio, TV, and cell phones. However to understand RF technology as is required of an engineer or a technician raises some issues. A common question many students ask is

"You cannot see the waves even though you know they are working for instance as in cell phones, but how do you know exactly what they are doing?"

To get the students to appreciate the course, it becomes necessary to approach it from this point of view, that is present it such that they have something to relate to. It is for this reason that the Lab Volt Antenna Training and Measurement System 8092 become very useful. It provides a hands-on experience to the user in working with antennas at 1 GHz and 10 GHz. The system comprises a Data Acquisition Interface/Power Supply that is patched into a computer using a parallel port cable, an RF Generator and an Antenna Positioner. SMA cables and antenna masts with clips are supplied for mounting the antennas. Also included are a variety of antennas as well as various microstrip patch antennas for different experiments. Documentation includes the Data Acquisition and Management Software User manual, Data Acquisition/Power Supply manual and an Antenna Fundamentals laboratory exercises manual and an Instructors' Guide [4]. A computer is used to manage the operations of the system.

A major advantage in using a training system such as this is the cost. Currently the cost for the whole set is about $ 19,000. To replace this with individual pieces of desk top equipment will be prohibitive cost wise. The cost of an RF Signal Generator alone ranges from $ 21,000 to $ 90,000 for the range of frequencies used in the Lab Volt system. On top of that will be the cost of a Spectrum Analyzer which will be about $ 4,000 for a desk top. In addition to these will be the cost of a variety of antennas, antenna masts, and cables to complete the set up.

As stated above the operation of the system is based on a computer. Use of computers as tools in the educational environment is not new. Among the various uses include extensive laboratory simulation of real life applications. This helps the student to have a better understanding of the expectations of the technology [5, 6]. Computers as aids in the class room have enhanced teaching effectiveness and student learning [5].

Student Exercise

One of the student exercises was to measure and record the levels of the *E*- and *H-fields* of a half-wavelength ($\lambda/2$) dipole. Step-by-step detailed instruction on setting up experiments is provided in the laboratory manual [4] and the amount of connections to be made is minimal. Once it's powered up, the computer takes over and run the whole procedure. The data is compiled in 2D, and by just clicking on the EH, 3D or Cartesian icons, the other plots can be produced. To get the plots into view, an Attenuation factor may be needed. For the dipole this was 15 dB. Each time the experiment is run it is necessary to reset the display to 0^o for the next run. Maximum Signal Level (MSL), Maximum Signal Position (MSP), and Half Power Beam Width (HPBM) are displayed in the data block. Two cursors (not shown) can be activated under the View menu to manually determine the half power points; 3 dB lower on either side of the MSL.

Data can be collected for multiple antennas for comparison; this is one of the advantages of the use of computers in this exercise. Analysis of antennas is performed using Maxwell's equations and is rather rigorous and may be beyond many EET students' abilities. For this reason, using a computer package that performs the analysis and provides the solution of a radiation pattern for instance, is very helpful and students as well as practitioners in industry can find this useful. This is a major advantage to the EET student. As stated above parameters such as MSL, MSP, and HPBM are provided as part of the results by the code based on the radiation patter.

Figure 1 shows *E*- and *H-field* patterns present in the electromagnetic radiation, and demonstrate some irregularities in the patterns, and helps the students to relate theory to the experimental results observed. Had this experiment been performed in an anechoic chamber where reflections are eliminated no irregularities will be present. This demonstrates to the students the effect of reflections from objects that are present in the laboratory setting.

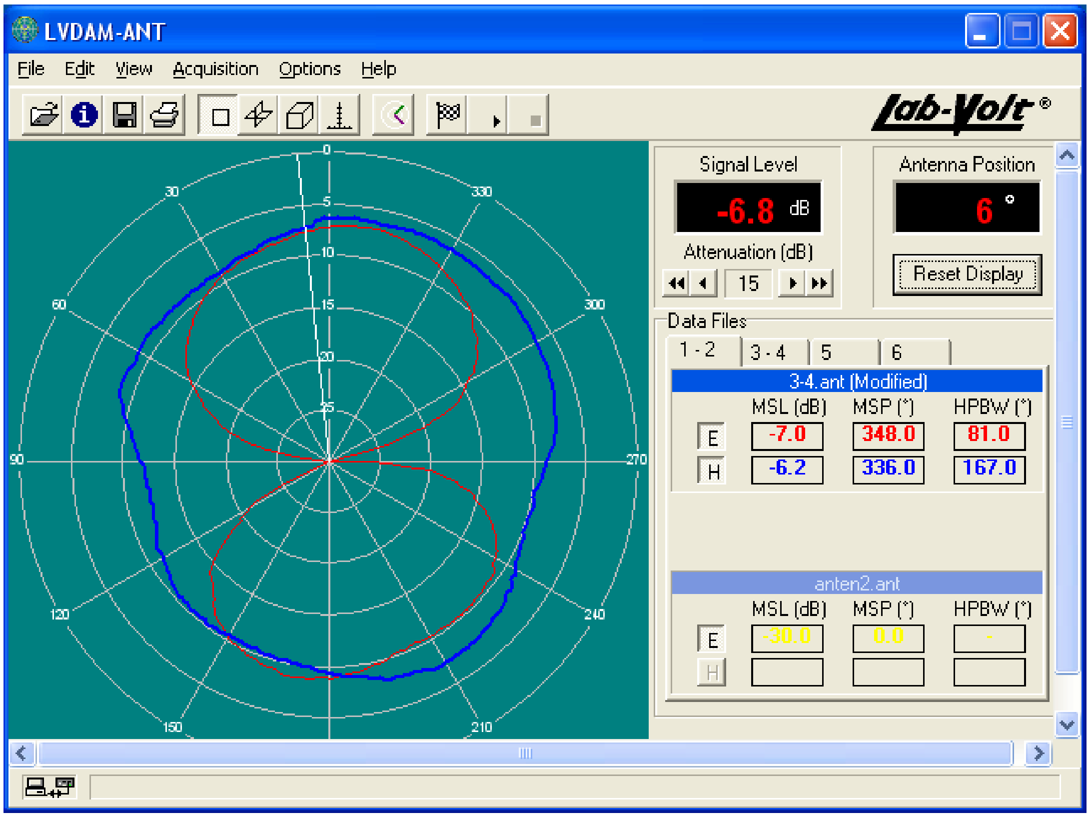

Figure 1. E- and H-fields of a Half-wave (λ/2) Dipole

From this, the students get to appreciate reflections from objects such as buildings in a real life application of radio transmission. For this example, students can place objects at different locations in the laboratory in close proximity to the set-up and observe the effects of their reflections at the receiver. Another extension students have found interesting is passing objects that are opaque to radio waves between the transmitter and receiver while data acquisition is in progress, and in this case observing the break in acquisition. Once the concepts are understood, students are able to design their own antennas, starting with a dipole, folded dipole, and different antenna configurations. The design experiments are selected for cases where the necessary materials such as metal wires can be easily found. Exercises such as designing microstrip antennas [7] are planned as the next stage of the learning experience. The laboratory currently does not have the facility to do etching. An example such as this will demonstrate the effect of masking which will lead to discussions on how masking is done in the fabrication of electronic components, and the use of different substrates with different permittivity values. The laboratory exercises help students to have deeper understanding of the concepts leading to retention of the lessons.

Students' Experiences

The number of students in the class discussed in this paper was 16. During the course of their study, they have had opportunities to work with computer packages such as PSpice and Multisim, hence they are familiar with the computing environment. The students started with a set of laboratory exercises that gave them a clear indication of how the reception of the EM radiation manifested. They became aware of how the radiated energy could be reflected off objects and the resultant effect of the addition of the direct line-of-sight and reflected waves. Going through the laboratory exercises demonstrated to them the presence of the *E-field* and the *H-field* in the radiated wave. While there were no negative comments, some comments were similar to others presented below. The following comments generally describe the students' reactions.

Student 1: In previous years the lab component greatly impacted my learning ability, in that I was more aware of what the components were doing and was actually able to see the results of using the equations that were used in the lecture portion of the classes. The lab itself makes all the more difference. Without it, I feel that the knowledge taught to us would be somewhat lost on me. I feel the lab portion of the class add a more real life experience to the whole subject.

Student 2: The labs are a crucial part in understanding the information we are covering in class. It gives us a way to sort of visualize in our heads what is going on. Learning a topic and then using it in a real-world application is one of the easiest ways to thoroughly understand a topic. We will be able to see the way we can figure out certain aspects of our waveforms by using mathematical equations.

Student 3: If we were just given the equations we would have a hard time visualizing the interactions between the waves. Even though we cannot see the electromagnetic waves we are working with, we can measure them experimentally. We can then take those measurements and compare them to our theoretical results. The experiments answer questions like, what *can* I use this for, and what can I expect to find out there.

Student 4: The results obtained in the lab are often slightly different from the theory. This happens mostly because equations represent how circuits or equipment will perform under perfect, ideal conditions, without influence from any other outside stimulus in close proximity.

Student 5: Experimentation presentations give some sort of tangibility to that which cannot be seen, electromagnetic waves. Only by experimenting with this can it be "seen".

Student 6: Electromagnetic waves cannot be seen, but experimenting with them demonstrates that while one cannot physically see the waves, they are still there and the energy in those waves is real. Being able to see something work in person is worth much more than just reading about it for those of us who learn by seeing and doing.

Student 7: Electromagnetic theory can be difficult to grasp due to the students' inability to actually see the waves. The use of physical experiments can provide checks and balances to lengthy calculations performed.

Student 8: EM waves cannot be seen so if a professor talks of them in a lecture it does not show what the waves can do. If equipment in the lab puts out the waves, the waves can be measured and viewed. In this sense the student can see what the professor was talking about in the lecture. As a student, I learn more on hands-on basis than I do in a lecture so I prefer labs more.

Conclusion

Electromagnetic waves propagate in the form of energy in the radio space and the shape it assumes depend on the element that converts the signal to the energy. Antennas are used to perform this function and the different designs of antennas ensure that any specified coverage area is effectively served. The result obtained helped to demonstrate the presence of *E*- and *H-fields* in the radiated wave to the students. It also helped to show the effect of reflections which will be present in real life applications. For the student, this may present some problems because the waves are not visible to the human eye. The LVDAM Antenna software therefore is an effective tool in providing a visualization that the student can relate to. Achieving this with the computer provides a means by which other parameters such as gain of the antenna can be readily determined. This helps the students to effectively conceptualize electromagnetic radiations and be able to relate theory to practice. Students' experiences are also presented to demonstrate what they learned.

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