Abstract

It is well known that students of electrical engineering tend to avoid technical electives involving electromagnetics, due to the inherent analytical content of these courses. In an effort to combine theory and numerical modeling involving analysis and design, an Instructional Enhancement Grant was obtained from the University of Nevada, Reno. The objective of this grant was to develop a series of computational exercises in antenna analysis and design which could be used in conjunction with the senior level electromagnetics technical elective as well as with a graduate level course in Antenna Theory and Design. These exercises have been successfully developed and are being used with both these courses. They are assigned to the students at appropriate times during the semester when the theory underlying the topic of a particular computational exercise is being discussed in class. This gives the student an immediate opportunity to compare theory with the results of numerical modeling. The exercises utilize existing antenna analysis and design software for personal computers to which students have easy access either at home or at the university. They are asked to write a written report on each exercise. Student evaluations from these courses indicate that these computational exercises give them a better perspective on an otherwise abstract subject. This paper discusses the exercises and how they are implemented in the two classes.

Introduction

Traditional courses in electromagnetics generally introduce the students to Maxwell's equations and their application to simple antennas and transmission line systems. Many of these simple problems lend themselves to closed-form analytical solutions. In the real world however, an engineer has to deal with problems like the coupling between an antenna and its mounting structure, presence of ground planes (perfect and imperfect), structures in the vicinity of the antenna, mutual coupling between various elements in an antenna array, etc. The majority of these problems do not lend themselves easily to analytical solutions and hence an engineer has to gain familiarity with numerical techniques.

The objective of developing a series of computational exercises in antenna analysis and design was not only to introduce the students to the use of numerical methods, but also to familiarize them with the importance of accuracy in numerical modeling. In several of the exercises, they are asked to implement antenna models with different numbers of wire segments and study the effect of varying this parameter. They are also asked to compare results of numerical modeling with formula's derived in the textbook. In summary, the exercises have been designed so that the students are introduced to the solution of real-world problems dealing with antenna design and analysis. The following section briefly describes the eight exercises and how they are implemented.

The computational exercises have been designed for use in two electrical engineering classes. The first is EE451/651, which is a senior undergraduate/graduate level class entitled "Distributed Systems and Antenna Design". The second is EE751, which is a graduate level class entitled "Antenna Theory and Design". EE451/651 usually has between 20 - 25 students, mainly undergraduates, who have already taken the basic junior level electromagnetics course and EE751 has between 6 - 10 graduate students. These courses are a semester long and typically taught once a year.

The main software package used in the computational exercises is MININEC [1,2], although three others, DIPOLE [3], YAGIMAX [4] and ARRAY [5] are also used to a limited extent. To date, one of the widely used numerical methods for frequency domain antenna design and analysis is the Method of Moments. Other methods like the Finite-Domain Time-Difference technique are also gaining popularity, especially for time-domain calculations. The Method of Moments allows the user to decompose a complex structure into several short wire segments and to solve an electric field
integral equation by reducing it to a set of matrix equations. MININEC is a Method of Moments software package which runs on a PC. DIPOLE; ARRAY and YAGIMAX are simple-to-use programs which handle analysis of dipole antennas, arrays and Yagi-Uda antennas, which take as inputs various design parameters like antenna dimensions, frequency, etc.

The following section will describe the eight exercises and their implementation.

**Description of the Exercises**

The exercises start with the design and analysis of the simplest type of antenna - the elementary half-wave dipole, which is usually regarded as the standard reference antenna with regard to which the gain of most commercially available antennas is referenced. This antenna is also widely used in applications like large high-power FM and television transmitting antennas on the one extreme, to printed circuit board antennas at microwave frequencies on the other end. This is also an antenna whose performance is well known and has analytical, empirical and numerical solutions with which the students can compare the results of their modeling efforts. The students are asked to design the antenna viz. to determine the antenna dimensions for a certain operating frequency assigned by the instructor. They then model the designed dipole antenna using MININEC and calculate parameters like input impedance as a function of number of segments. They also plot radiation patterns. All MININEC results are compared to analytical results that the students have encountered in class.

The dipole exercise then leads to the modeling of a monopole antenna above a perfectly conducting ground plane. This is an important antenna at AM broadcast frequencies where the center-fed geometry of the dipole is impractical. The students have also learned that in order to approach a perfectly conducting ground plane, a copper ground screen is usually installed. In this exercise, the students are assigned a monopole length and asked to compute the frequency at which this antenna is resonant. They then model this antenna with a conducting ground plane using MININEC, but this time they vary the height of the antenna tower to achieve maximum gain in the horizontal plane. The MININEC result for this height is then compared to that calculated at the resonant frequency.

Modeling of the dipole and monopole above ground antennas naturally leads to design and analysis of antenna arrays. The objective of this exercise is to convey the importance of the proximity of other antennas and structures and in particular the effect of parasitic elements. In this exercise, the students first design a Yagi-Uda antenna based on principles they have learned in class, for a specified VHF television channel. Each student is assigned a different television channel. At this point, they use a program called YAGIMAX to compare various parameters like gain, input impedance, etc. for the antenna they have designed with values available in their book. They are then asked to "tweak" their design if their results differ by more than 10% from those in the book and also to explain any adjustments made. They are also asked if a certain commercially available cable would be compatible with the input impedance of their antenna and if not, to suggest another suitable cable. They then proceed to model their antenna using MININEC and plot the radiation patterns, comparing these to the patterns obtained previously using YAGIMAX. They also experiment with segmentation if necessary. Then in order to see what effect the parasitic elements have, they remove one of the directors and recalculate the patterns and explain any differences.

The fourth exercise involves analysis and design of loop antennas. The students model loop antennas of various shapes - square and polygon approximations to a circular loop, maintaining the same perimeter in all cases. MININEC is used to calculate radiation patterns and input impedance in all cases and the results compared to those in the textbook.

Exercise five deals with three-dimensional modeling of a helical antenna. All published equations for this antenna are based on experimental measurements and empirical equations. The objective of this exercise is not only to give the students some experience in three dimensional modeling, but also to show them that with careful modeling one can obtain accurate results for complex antennas. They are assigned all the dimensions of the helix and its ground plane and a frequency. MININEC results for radiation patterns and input impedance are compared with those calculated using the textbook equations. If the results are not satisfactory they are asked to devise a new segmentation scheme and repeat the calculations. The students then are taken to the state-of-the-art anechoic chamber and shown how to make antenna pattern measurements using the helix as the transmitting antenna. The students in the graduate class EE751 actually make the measurements themselves in groups of two. The set-up is completely automated with a computer-controlled turntable and data acquisition system, including a spectrum analyzer and personal computer. Since the number of students in EE451/651 usually exceeds 20-25, it is not practical to have them
each make the measurements. They are divided into groups of 5-6 and shown how to make the measurements. They then compare the patterns measured with those generated by modeling and try to explain any discrepancies between measured and numerical or theoretical values.

Exercises 6, 7 and 8 deal with phased array antenna design and the analysis and design of a feeder system. From exercise 3 the students have learnt that the use of parasitic elements results in the directionality of the Yagi-Uda antenna. However, it is not possible using this type of antenna to achieve precise pattern control, since it is not possible to easily vary the geometry of this antenna once it is built. Hence the necessity to design phased array antennas, where in addition to the physical dimensions of the antenna, orientation and interelement spacing, one can also vary the amplitude and phase of the excitation signal applied to each element of the array. Exercise 6 involves calculating the electrical parameters necessary to obtain a given radiation pattern for a Reno AM radio station (KQLO) two element phased array antenna. The students then give the calculated parameters as input to the program ARRAY and obtain the horizontal plane radiation pattern and compare it with the given pattern. They are asked to comment on any differences.

In exercise 7 they use MININEC to model the 2 element phased array and obtain the driving point impedance, excitation current and radiation power of each element. The radiation pattern is also computed and compared to the given pattern as well as to that obtained from ARRAY.

The last part of the array exercise (#8) involves the design of the circuit for the feeder system of the array. The students design a suitable LC network system to divide the power from a single transmitter between the two elements. They are given the lengths of the coaxial lines feeding each tower, and also the velocity of waves on these lines.

A detailed written report is submitted by each student for every exercise. These reports are graded based on presentation style and completeness of calculations, analysis, design and explanations.

Summary

The above described exercises have been compiled into a manual and have been utilized in both the courses for two consecutive years. The first year the students were assigned all the exercises during the last few weeks of the semester and the second year they were assigned throughout the semester (in EE751) as the various topics were covered in class. This latter approach obviously worked better. In EE451/651, it is up to the instructor to either assign all the exercises if time permits or to choose a selected few. Student feedback to these modeling exercises has been in general very positive. The authors hope to soon acquire the windows version of MININEC (MININEC Professional) and update the eight exercises and add a few more to the manual.

References