Teaching an Undergraduate Electromagnetics and Antennas Course Using A Hand-Held RF Analyzer - Engaged Learning

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Abstract

This paper describes an experiential learning concept to teach undergraduate electromagnetics and antenna theory using a hand-held RF analyzer and other basic laboratory apparatus. The analyzer contains both an RF source and spectrum analyzer. The RF source serves to enable SWR measurement for stub matching, measuring cable losses, detecting cable faults, cable lengths, and such tasks such as verifying that the half wave dipole has nearly unity SWR at both its fundamental frequency and its odd harmonics. The spectrum analyzer portion of the RF analyzer allows for efficient measurement of radiation patterns for various types of antennas and thus students can design and quickly test several different types of antennas. The increased efficiency enables increased depth and breadth of antenna topics.

Keywords

Antennas, laboratory practice, engaged learning

Introduction

The capabilities of the current generation of modern portable RF analyzers can greatly enhance the laboratory experience for an undergraduate electromagnetics (EM) and antennas course. The increased efficiency brought about by these modern portable analyzers allows for additional experiments that in the past, due to time constraints were not feasible. Particularly noteworthy is the ability for the student to get "quick turnaround" on their design in order to verify that their design has minimal SWR and the desired radiation pattern. This paper builds on previous work described in reference[1-2] that seeks to make conventional EM courses more relevant, engaging and "more fun" to the current generation of electrical engineering students. In this paper, we use the Agilent 9912A RF analyzer, but there are many other excellent portable analyzers available from such companies as Rohde & Schwarz, and LeCroy. This paper seeks the answer to the question often posed by undergraduate electrical engineering students, "Now that we have this wonderful EM theory, what can we do with it?"

We first will present some basic background sources that address current instruction and laboratory practices, and then discuss specific experiments on how a portable RF analyzer can be used to enhance the laboratory experience for an antennas course.

Selvan[2] addresses student centered EM instruction; Mukhopadhyay and Pinder[3] addresses the inherent difficulty of teaching EM, and Crilly[1], Xie, Liang and Wang[4] present laboratory based EM instruction methods. Rao[5], Iskander[6], and Raida[7] address EM instruction using technology; Zhou[8] uses the seminar approach to EM education. With respect to textbooks, Ulaby et al.[9] is a widely used undergraduate EM textbook that includes a good introduction of antenna theory. The classic antennas book by Krauss presents an in depth theory of antennas. Silver[11] covers practical antenna theory and practical projects for the practitioner.

Portable Analyzer to Enhance the Laboratory Experience

In this section we will describe the various experiments that have been done using the portable analyzer.

A. Antenna radiation pattern

As already stated, the portable analyzer has the capacity to both generate and receive an RF signal. Thus we can measure the radiation pattern of the test or prototype antenna. A test setup for measuring the radiation pattern for test antenna is shown in below Figure 1. As Figure 1 illustrates, the test antenna to be characterized is on the spectrum analyzer (SA) side of the instrument and so we are really measuring its received, not radiated pattern. Because of antenna reciprocity, the radiated and received patterns are identical so it doesn't make any difference which side the test antenna resides. However in the interest of minimizing radio frequency interference, we choose the signal source antenna to be the one with minimal effective radiated power (ERP).

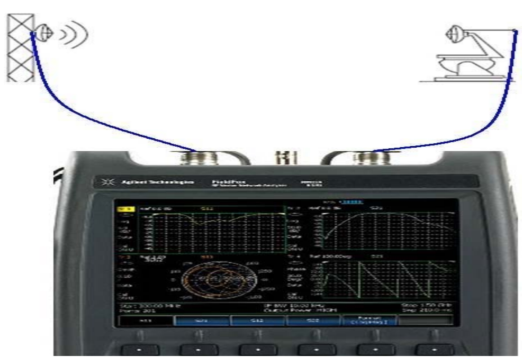

Figure 1. Antenna radiation pattern measurement using the Agilent 9912A.

Test antennas we've characterized include (a) the omni-directional vertical, (b) the Yagi, and (c) phased arrays. Figure 1 implies the two antennas are separated by the length of the two transmission lines, and that the test antenna is mounted on a rotor. Given practical coaxial cable length limitations and near/far field considerations, an alternative is to use two separate analyzers, one as a source, and the other operating in SA mode whose input is the test antenna which is mounted on a pole. The student rotates the test antenna and records signal magnitude versus azimuth angle.

In a similar vein, students can observe the effects of different matching systems and how they affect the radiation pattern. For example, with antenna systems that use the Gamma match and coaxial cable – an inherently unbalanced system often results in an asymmetrical pattern. On the other hand, the T-match, and balun, an inherently balanced system, produces a symmetrical pattern.

To make the lab more interesting and engaging to the students, we also use the SA in combination with their designed directional antenna to locate a hidden RF source. We call this "fox hunting." The "fox" is a small low power intermittent 144 MHz beacon that is hidden somewhere outdoors. The students use their directional antenna with the 9912A to find the hidden transmitter. The fox, SA, Yagi and the hunting team are shown in Figure 2

(a) (b)

Figure 2. Fox hunting team and their apparatus consisting of (a) the fox, and (b) Yagi, portable SA, and hunting team.

B. Direction Finding

Direction finding (DFing) can be done in one of two ways. The first is to use a highly directional antenna such as a Yagi or phased array such that we get the signal source's bearing when the antenna is pointed in the direction that yields the maximum response on the SA. This is the basis for our fox hunting exercise. Because of practical antenna dimensions, this DF method is only feasible at frequencies above 100 MHz. This method works when the directional antenna has a narrow spatial lobe.

The second method of DFing is to use a loop antenna. Note that a loop antenna in the forward and backward direction has a relatively broad spatial lobe and thus would not be suitable for

DFing with respect to maximum intensity. However, in the perpendicular direction, it exhibits an extremely sharp null and thus we locate the source based on the bearing that yields the minimum SA response. Figure 2 shows the setup for a loop antenna to DF on AM broadcast stations. Using triangulation, students have been able to pinpoint a local 980 kHz AM station within less than a km.

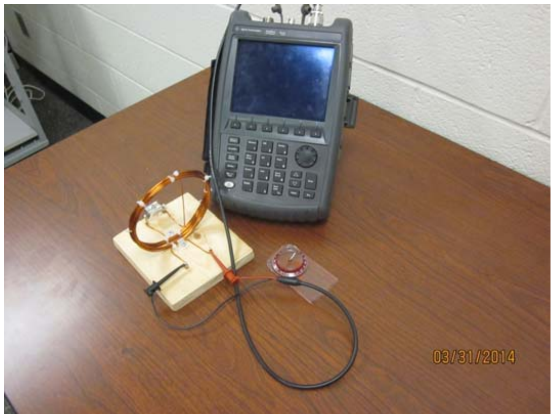

Figure 3. Loop antenna to direction find on frequencies below 2 MHz.

C. Time Domain Reflectometry

Using the time domain reflectometry capability of the 9912A, we can do the following experiments: (1) given a random length of coaxial cable, accurately determine its length, (2) measure the loss of a given length of coax, and (3) determine the location of a fault (e.g. the fault being a nail inserted at some point in the cable to short the inner and outer conductors). These experiments also force the student to think about how the conductor size and dielectric type affects cable losses and transit times (i.e. velocity factor).

D. Signal Source and Slotted Line Experiments

We use a slotted line in conjunction with the signal source to illustrate transmission line behavior in the presence of various loads including opens $(Z_L = \infty)$, shorts $(Z_L = 0)$, perfectly matched $(Z_L = 50\Omega)$, and otherwise $(Z_L = 150\Omega)$. Figure 4 shows the test setup. Because the 9912A's has a maximum output frequency in the GHz range, we have the opportunity to demonstrate that seemingly pure resistive loads whose lead lengths exceed 1 mm will show significant parasitic reactance at frequencies above 200 MHz and thus what we thought was a resistor is really an inductor + resistor.

E. Antenna Feed Matching

The 9912A's ability to easily measure SWR provides the student a great deal of flexibility in their antenna designs as well as facilitating the adjustment of the gamma or T match networks.

F. Dipole types, pattern and SWR

The antennas course starts out with the development of the basic center fed half-wave dipole antenna. Initially we present its voltage-current profile and show that the feed impedance is 70 ohms. We then we extend the voltage-current profile to illustrate that the feed impedance is still 70 ohms for odd harmonics of the original half wave frequency. To confirm this, we do an experiment using the 9912A in SWR mode to show that for a half-wave dipole at 7 MHz, the SWR is nearly unity at 7, 21, 35...147 MHz. Similarly the student can verify the even harmonics yield an extremely high SWR as predicted by the dipole's voltage-current profile for even wavelengths. Similarly, the analyzer allows us to develop a multiband off center fed dipole with minimal SWR.

Figure 4. Test setup for slotted line experiment.

Conclusions

We have described several ways in which a portable RF analyzer can be used to augment the laboratory experience for a course on antennas and propagation. The source side of the RF analyzer gives us the ability to measure SWR, cable lengths, losses, fault locations and generate antenna test signals. In SA mode, we can characterize patterns of various types of antennas. The portable analyzer can be useful in any capstone courses that require the design of an antenna or other RF component. Presumably, if the student were to try implementing an antenna using any piece of metal, even a bedspring, the analyzer could be used to help design a matching network for minimal SWR and then characterize the radiation pattern.

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