A LABORATORY COURSE ON ANTENNA MEASUREMENT

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ABSTRACT

This paper presents background information and experiment procedures for an antenna measurement laboratory course to be held in a new anechoic chamber at California Polytechnic State University. The lab consists of five experiments and one design project intended to give students practical experience with antenna measurement techniques and to creatively apply analytical skills to design, construct, and test antennas that meet given specifications. The experiments reinforce antenna principles including E-field polarization, antenna gain, radiation patterns, image theory, and frequency response.

In addition to the experiment procedures, this paper presents the design and characterization of Helical Beam (RHCP and LHCP) and Discone antennas, a Dipole Antenna near Planar and Corner Reflectors, and Dipoles with and without a balun. These antennas demonstrate polarization, antenna gain, broadband matching characteristics, image theory, and feedline radiation due to unbalanced currents. Measured radiation patterns, gain, and axial ratio (helical only) show excellent correlation to theoretical predictions.

Keywords: Anechoic chamber, Antenna Education, Antenna measurements, Discone Antenna, Helical Antenna, Instrumentation.

1.0 Introduction

Many antenna systems courses introduce theory and systems characteristics without a laboratory component. Since the development of antenna systems benefits from a physical understanding of wave propagation and competent measurement techniques, laboratory experiments should be an integral part of the lecture course. To address this issue, a complete laboratory course involving antenna measurements using Cal Poly's anechoic chamber and antenna measurement system has been developed and is described in this paper. Section 2 contains background information and procedures for five antenna measurement experiments. Antenna system parameters and components, theorems in electromagnetic theory as applied to antenna systems, and the specifications for a final design project are addressed in the experiment set. Section 3 of this paper contains detailed information on the design and measured performance of antennas used in the experiments.

2.0 Experiment Background and Procedures

The laboratory course, outlined in Table 1, is designed to complement topics covered in a lecture course on antenna theory. During the first week of the term, a tour and demonstration of the antenna measurement facility will be given. The five experiments will be conducted during the second through the seventh weeks. The design project will be the emphasis during the final three weeks of the term.

Table 1. Schedule of Experiments

Week 1	Introduction and Overview of Laboratory Course
Week 2	Antenna Polarization
Week 3	Gain Transfer Measurement
Weeks 4-5	Radiation Pattern Measurement
Week 6	Image Theory for Planar and Corner Reflectors
Week 7	Frequency Response and Baluns
Weeks 8-10	Design Project

Calibration procedures are included at the beginning of each laboratory experiment to ensure accurate measurements and to establish proficient RF measurement techniques in students.

2.1 Antenna Polarization (Week 2)

This experiment demonstrates the significance of polarization in antenna systems. The experiment description includes an explanation of general elliptical polarization, the special cases of linear and circular polarization (both left- and right-hand: LHCP and RHCP), and their importance to communications systems. The Poincaré sphere is introduced and used to graphically illustrate several polarization states and to transform measured parameters to those that quantify antenna performance. Axial ratio is introduced to quantify the elliptical properties of radiated electromagnetic waves.

The first part of the experiment involves the placement of two linearly polarized antennas (one transmit, one receive) inside the anechoic chamber (Fig. 1).

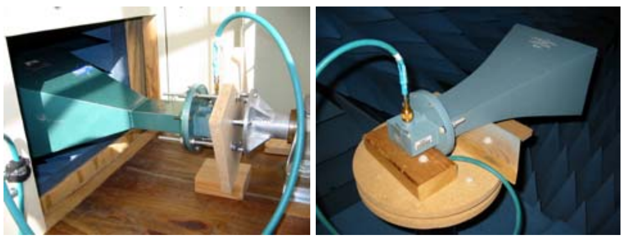

Fig. 1 Mounting of Linearly Polarized Antenna Pair

Mounting fixtures and calibration devices were designed and built to enable the measurement of the polarization matching factor *F*. This parameter quantifies the coupling between antennas based on their relative orientation (polarization). The matching factor is measured between the antenna pair while varying the polarization tilt angle of the transmit antenna. The experimental outcome also introduces the idea of co- and cross-pol directions in antenna systems.

In part two, a linearly polarized transmit antenna and a circularly polarized receive antenna (helical antenna, Fig. 2) are used to demonstrate the advantages and disadvantages of this system configuration.

The polarization matching factor between the linearly and circularly polarized antenna and the axial ratio for the circularly polarized antenna are measured. The representation of a circularly polarized wave as the summation of two phase-shifted linearly polarized waves is used to explain the value of the polarization matching factor for a linearly and circularly polarized pair of antennas.

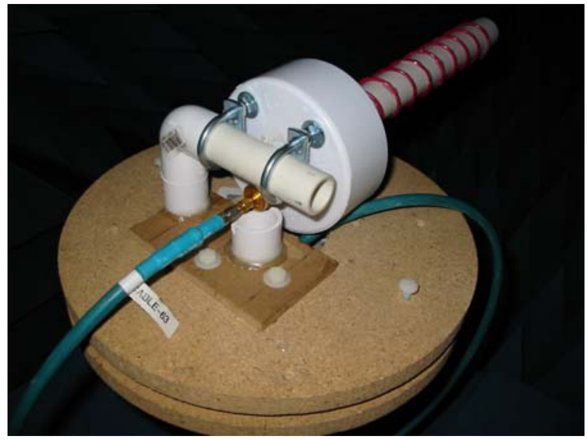

Fig. 2 Mounting of Helical Antenna

The third configuration is composed of two circularly polarized antennas (one transmit, one receive; both helicals) – first with aligned polarizations (RHCP to RHCP) followed by opposing polarizations (RHCP to LHCP). The polarization matching factor will be measured for the latter case relative to the former.

2.2 Gain Measurement (Week 3)

The second experiment involves the gain characterization of various antennas using the gain transfer method. The concept of gain, as the amount of received power in the optimum direction relative to a nondirective (isotropic) antenna, is described in the experiment procedure. The received signal power from the antenna under test (AUT) is measured relative to levels detected by a standard gain horn (see Fig. 1). This allows the gain of the AUT to be calculated based on the known gain of the standard. The gain of a linearly polarized antenna and the gain and axial ratio of a circularly polarized antenna are measured.

The linearly polarized antenna to be measured is a commercial Yagi antenna (Fig. 3).

Fig. 3 Mounting of Linearly Polarized (Yagi) Antenna

This antenna is first aligned to the beam peak and polarization direction. The received power is then measured to compute the gain relative to the gain standard.

The circularly polarized antenna to be measured is a student-built helical antenna mounted in both the horizontal and vertical orientations (Fig. 4).

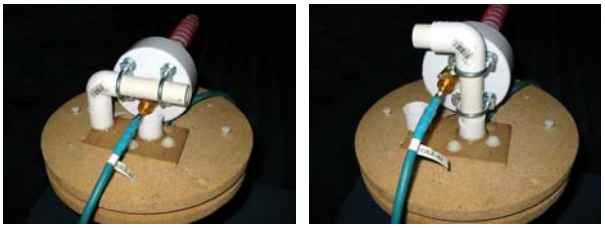

Fig. 4 Mounting of a Circularly Polarized Helical Antenna: Horizontal and Vertical Orientations

The overall gain for the helical antenna is calculated from the summation of gain magnitudes measured in both the horizontal and vertical orientations.

2.3 Radiation Pattern Measurements (Weeks 4 and 5)

This experiment introduces students to antenna radiation patterns. The spherical coordinate system (applied to antenna structures), E and H planes for an AUT, and the radiation pattern's polar representation of radiated power as a function of directional angle are defined in the experiment description. Diagrams such as Fig. 5 are used to help define these parameters and to show the positioner rotation axis and aperture E field direction.

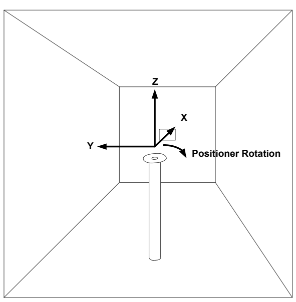

Fig. 5 Example Coordinate Definition for Radiation Patterns

Coordinate systems relative to the AUT are first applied to define scan polar angles in the E and H planes. This establishes the coordinate reference for radiation patterns taken for both linearly and circularly polarized antennas.

Radiation patterns for two antenna types are measured in this experiment: a commercial Yagi antenna (Fig. 3) and the student-built helical antenna (Fig. 4). Measured front-back ratios are compared to the datasheet for the Yagi antenna and the analytically-based pattern for an array of loop antennas is compared to patterns measured for the helical antenna. The loop array has been shown to closely approximate the radiation characteristics of the helical antenna [1].

Radiation pattern plotting routines were developed in MATLAB to help visualize the spatial relation between E and H plane patterns (see Fig. 6).

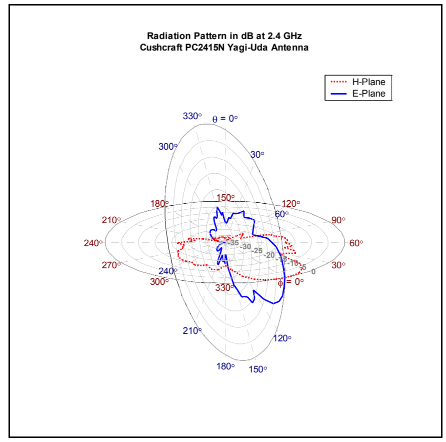

Fig. 6 Example 3D Radiation Pattern

2.4 Image Theory (Week 6)

The image theory experiment demonstrates the effect of a large ground plane in the vicinity of a radiator. The location and polarity of images in an equivalent configuration are explained in the experiment description. Image theory is used to predict the radiation pattern of a dipole antenna located a specified distance from a planar and 90º corner planar perfect electrical conductor approximated by the structure shown in Fig. 7.

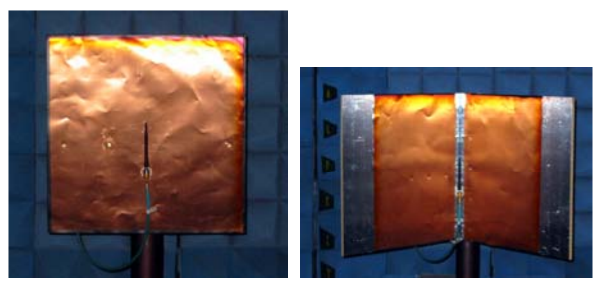

Fig. 7 Dipole Near Planar and Corner Reflectors

The measured results are compared to theoretical patterns calculated in MATLAB by applying Image Theory to the reflector configurations and analyzing the resultant linear or planar arrays.

2.5 Frequency Response and Baluns (Week 7)

In the frequency response experiment, the input voltage standing wave ratio (VSWR) for various antennas is measured to find the resonant frequencies and to evaluate impedance matching characteristics to a 50Ω transmission line. Radiation patterns, gain, axial ratio, and VSWR performance are evaluated to determine the useful bandwidth for each antenna. Broadband antennas, which maintain acceptable performance over a wide frequency range, are also explored. The above mentioned antenna parameters are measured for a student-built discone antenna (Fig. 8) as well as the Yagi and helical antennas used in previous experiments.

Fig. 8 Discone (Broadband) Antenna

The importance of baluns to match unbalanced transmission lines to balanced antenna ports is also explained in the experiment description. To illustrate the effect, radiation patterns for dipoles both with and without baluns (Fig. 9) are measured and compared (Figs. 10 and 11).

The absence of a null in the radiation pattern for the dipole without the balun shows the effect of radiation from currents flowing on the outside of the coax outer conductor.

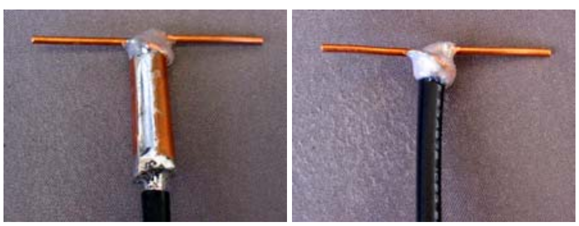

Fig. 9 Dipole with and without Sleeve Balun

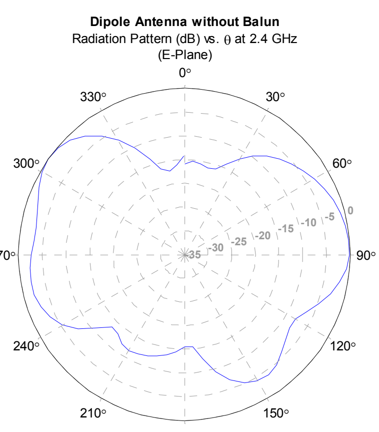

Fig. 10 Radiation Pattern for Dipole without Balun

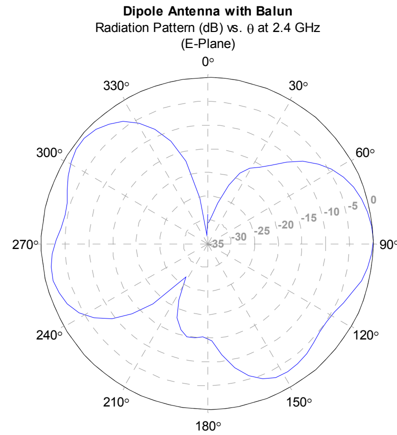

Fig. 11 Radiation Pattern for Dipole with Balun

2.6 Design Project (Weeks 8-10)

The final three weeks of the term will be devoted to a creative design project intended to require students to combine and/or develop new radiating structures to satisfy a set of given design specifications. The project includes simulations of candidate antenna geometries to identify and refine the design, and developing parameter tradeoffs among the most promising alternatives. simulations can be accomplished using modeling software or analytical formulations programmed in MATLAB. Finally, one or more prototypes are fabricated and tested to show attainment of the design requirements.

3. Antenna Designs

Two antenna types were designed and built for use in the experiments as part of this project. Section 3 describes the design and measured performance of a 2.4-2.5GHz Helical Beam Antenna and a 2.5GHz Discone Antenna.

The Helical Beam Antenna produces circularly polarized waves and high gain over a relatively wide bandwidth (~40%). The three helical antennas constructed from this design are the backbone of the antenna polarization experiment and are also integral to the gain transfer, radiation pattern, and frequency response experiments.

Critical dimensions for the helical including turn spacing, pitch angle, number of turns, and the end cap ground plane are described in [1], while construction details involving the selection of inexpensive components to realize the antenna are described in [2]. For instance, a 1" PVC pipe was used as the coil form onto which the helical antenna is wound (see Fig. 12).

Fig. 12 Helical Antenna on Coil Form and End Cap Ground Plane

The matching section is critical in achieving broadband performance. Guidelines on the empirical adjustment of a copper strip (Fig. 13) on the first quarter wavelength (at midband) are given in [3].

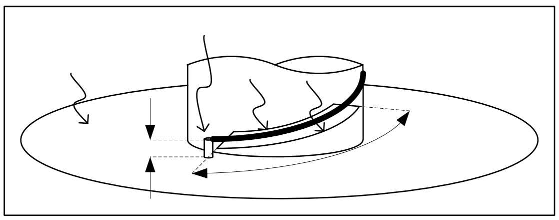

Fig. 13 Matching Section on Helical Antenna Feed

The effective feed point is at the end of the copper strip. This location sets the pattern null formed on the axis in the plane of the 1λ diameter loops 90^o offset from the feed point.

Through refinements in the matching section, VSWR values remained below 2.0 over the band 1.55GHz to 3.20GHz. Fig. 14 shows the VSWR frequency response for Helical Antenna #1, one of three prototypes built for the lab experiments. Gain and axial ratio were also measured, but have been omitted for brevity. Predictions of the radiation patterns using a 1λ diameter loop array were plotted and compared to the measured patterns. For the configuration shown in Fig. 15, calculated and measured radiation patterns are compared in the xz- and xy-planes; Figs. 16 and 17, respectively. The xz-plane pattern shows the loop element pattern nulls at θ=0 and θ=180^o.

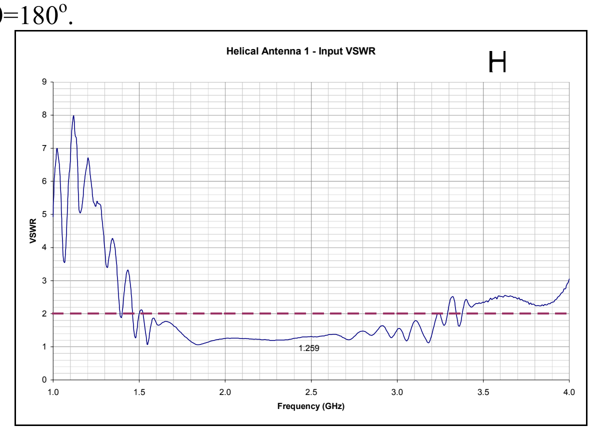

Fig. 14 VSWR Response for Helical Antenna #1

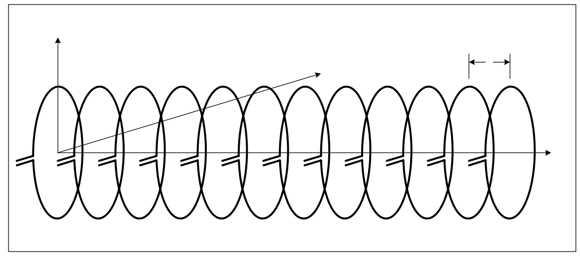

Fig. 15 Coordinate System for Helical Antenna Model

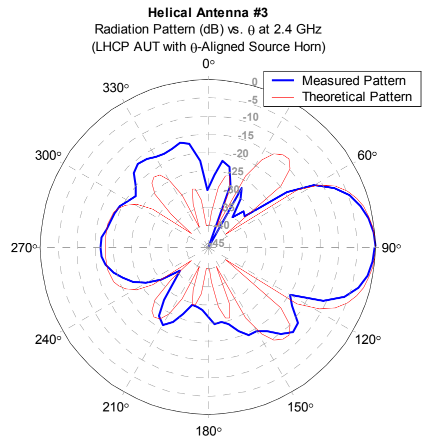

Fig. 16 XZ-Plane Radiation Pattern, Helical Antenna

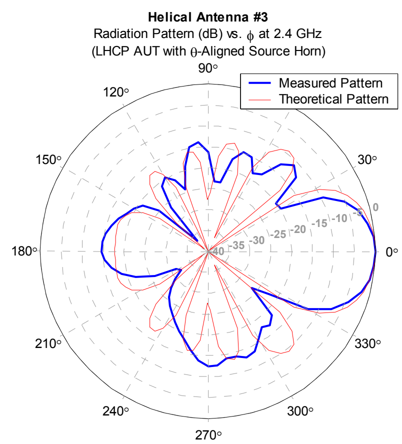

Fig. 17 XY-Plane Radiation Pattern, Helical Antenna

The "Discone" Antenna ('disk' + 'cone') used in the frequency response experiment (see Fig. 8) operates at frequencies greater than 2GHz. This design was first described by Kandoian in 1946 [4].

Dimensional parameters (Fig. 18) and design guidelines for their selection are given in [1]. The discone antenna provides excellent impedance matching to a 50Ω transmission line over a broad frequency range as illustrated in Fig. 19. VSWR values remain below 1.6 over the band 0.6GHz to 11.5GHz. It should be noted that these results were obtained using a 'hand-made' prototype. This attests to the relative insensitivity of this design to dimensional tolerances.

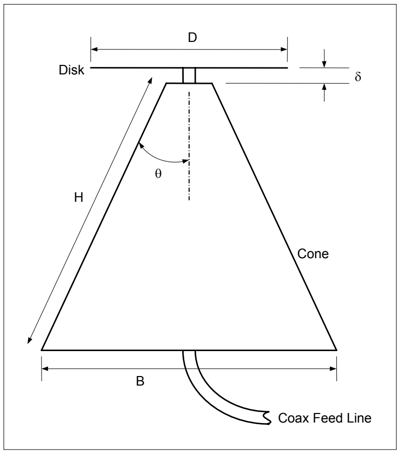

Fig. 18 Discone Antenna Dimensional Parameters

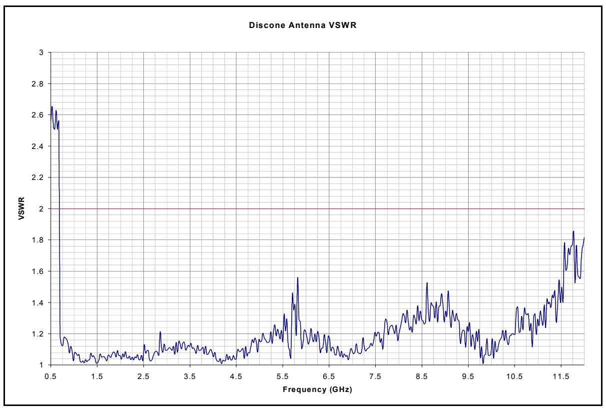

Fig. 19 VSWR Response for Discone Antenna

4. Conclusions

This paper has presented a set of experiments to accompany a lecture course on antenna theory. The procedures for each experiment are outlined and concepts important to antenna theory and design are highlighted. Student-built antenna designs are also presented including construction details and test results. Predictions derived from approximate analytical models are compared to measured results; close correlation is illustrated.

It is believed that this set of antenna measurement experiments will lead to an improved understanding of electromagnetic wave propagation and illustrate antenna design and measurement techniques. It should also provide confirmation of the theory presented in lecture courses and help set a foundation toward accomplished measurement skills.

5. REFERENCES

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6. ACKNOWLEDGMENTS

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