A Fun Hidden Transmitter Hunt Offers an Inexpensive Hands-On Antenna Experiment Rich with Insight for the Students

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Abstract

This paper describes an antenna design project that adds a great deal of hands-on insight into antennas and propagation. The testing of antennas in done under the guise of a game, where students use their antennas to locate a hidden transmitter. The required equipment consists of basic amateur radio equipment along with very inexpensive construction material.

1 Introduction

The abstract concepts of antenna theory make this subject difficult to grasp by many students. Practical hands-on experiments do not always provide a great deal of insight into electromagnetic propagation, because sometimes the measurement results are almost as difficult to visualize as the original theory. This is especially true when an antenna under test is enclosed in an anechoic chamber, thus out of students' view when performing the experiments. In this case, students must rely on their ability to assimilate power and position readings along with abstract theory in order to visualize radiation patterns and find real meaning in the experiment. Students are even more removed from the experiment when the data-collecting equipment is automated. Furthermore, some departments may not be able to afford these costly antenna-measurement facilities and equipment. As a result, some electrical-engineering programs may decide to forgo hands-on antenna experiments, or even applied electromagnetics courses altogether.

The Electrical Engineering Department at the United States Air Force Academy does have antenna measurement facilities, including an anechoic chamber, suitable for antenna measurements at microwave frequencies. However, in the Fall 1999 semester this facility was unavailable due to building construction. The unavailability of this facility created a dilemma for the antenna design course: EE444, Applied Field Theory. All the labs had previously been conducted in the anechoic chamber using an HP8510 Network Analyzer and Flam and

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Russell positioning and data-collection equipment. The instructor relied on these labs to give students the hands-on experience required to make the abstract electromagnetics theory real. However, with this facility out of commission, students could not conduct these lab experiments. This left the instructor with a dilemma.

The instructor of this course, along with two other instructors in the department, happened to be licensed amateur radio operators who had their own hand-held radio transceivers that operated in the popular 2-meter amateur-radio band. (The term "2 meters" refers to the wavelength of the VHF amateur frequency band from 144 MHz to 148 MHz.) Due to the availability of these radios (five in total), the instructor decided to use them in place of more sophisticated, yet unavailable microwave measurement equipment. This solved the problem of test equipment; however, it left the question unanswered as to where to test antennas.

Since the purpose of an anechoic chamber is to simulate free space, the antenna experiments needed to be conducted outside in an open field free from reflecting objects. Anyone who has visited the US Air Force Academy knows that an open-field free-space environment is nearly impossible to obtain. Most of the buildings in the cadet area are constructed from glass and steel with the Rampart Range of the Rocky Mountains as a backdrop. These gigantic reflectors create a multipath environment that is anything but anechoic or free space. Nevertheless, multipath is a very real ingredient in the operation of antennas and propagation, so the instructor had to make an attitude adjustment. Rather than attempting to eliminate multipath, the instructor had no choice but to incorporate it as part of the students' learning experience.

Therefore, as a substitute for the usual microwave antenna experiments conducted in the anechoic chamber, students designed and built antenna arrays operational in the 2-meter VHF amateur-radio band that would be tested outdoors. Since the students only used the radios as receivers, they did not need licenses. Only the instructor, who has an amateur radio license, actually transmitted a signals, thus complying with FCC rules.

One benefit of designing and constructing antennas at lower VHF frequencies, rather than at higher microwave frequencies, is that the larger antenna dimensions require less precision in construction. In fact, students built their antennas out of ordinary materials, such as heavy-gauge copper wire, wooden broom-stick type stock, and common coax cable found in any electronics lab. The simplified construction techniques refocused attention to concepts, rather than technology.

2 Project Description

The project consisted of designing, simulating, and building antennas suitable for direction finding. To make the experiment fun as well as insightful, there was also an operational element to the project. The students had to use their antennas to locate a 500-mW hidden transmitter, operating at a frequency near 146 MHz, in less than fifty minutes. The trans-

Figure 1: Parade Field at the USAF Academy.

mitter was a dual-band hand-held transceiver (2-way radio) that was capable of operating as a cross-band repeater, i.e, the radio receives a signal on one frequency in the UHF band, while simultaneously transmitting on another frequency in the VHF band, which the students' receivers detected. This hand-held unit was placed in a zip-lock bag and hidden along the edge of the parade field at the USAF Academy, shown in Figure 1. It was not necessary to use a repeater, but without it the instructor would have had to hide outside in the cold wind in December. Instead, the repeater allowed the instructor to transmit from his warm vehicle while watching the show. This added an extra element of challenge, as some students initially thought they would be able to see the instructor at the transmitting site. However, the students' receivers were tuned to the repeater's transmit frequency, and the instructor was transmitting on the repeater's receive frequency, so the students only detected the signal transmitted from the hidden repeater's location, not the instructor's location.

As previously mentioned, multipath from the transmitted signal reflecting off of steel buildings and granite mountains poses a problem for direction finding. A receiver with only a simple signal-strength meter has no way of knowing if the received signal is from the direct path or a reflected path. Therefore, it behooved the students to work cooperatively and design different types of antennas that were not fooled by multipath In the same manner. By working cooperatively, they could triangulate on suspected signal paths while ruling out reflected signals.

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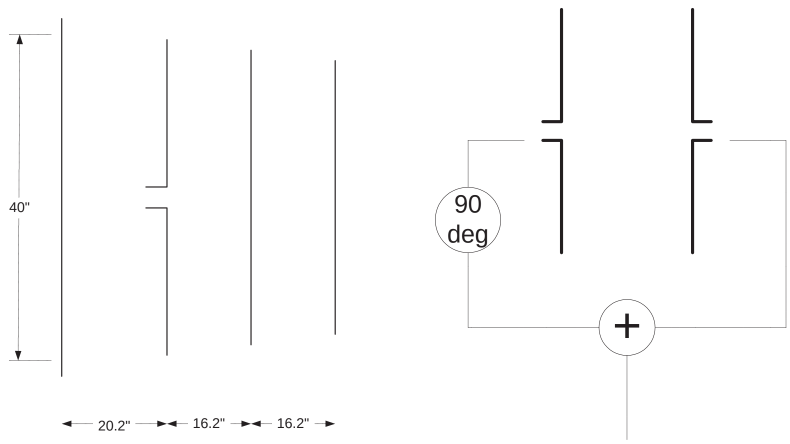


(a) 4-element Yagi-Uda (b) 2-element array

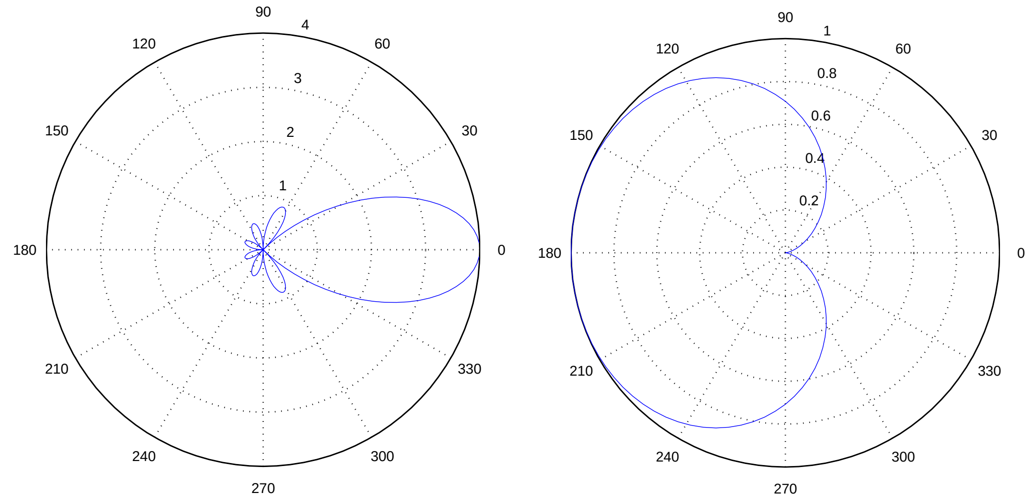
Figure 2: Two types of antennas proposed for direction finding.

3 Antenna Designs

The class proposed two types of antennas. One was a Yagi-Uda antenna and the other was a two-element phased array antenna. These two antennas operate by two entirely different principles.

The Yagi-Uda antenna illustrated in Figure 2(a) is a parasitic array, common in VHF/UHF television applications.[1] The Yagi-Uda consists of a half-wavelength center-fed dipole antenna and passive elements forming a parasitic linear array. The center-fed dipole is called the driven element, and is the only active element physically connected to the receiver, usually through a coaxial cable. If the passive element to the left of the driven element in Figure 2(a) is placed in proximity to the driven element (usually within a quarter of a wavelength), it will re-radiate energy.[2] This re-radiation comes from current induced on it from the incident field radiated by the driven element (the dipole antenna). If it is slightly longer than the driven element, it has an inductive reactance, and its induced current lags its induced voltage. This phase relationship tends to reflect the signal back toward the driven element. Therefore, this element is called a reflector. The reflector provides gain or directivity. If the passive element to the right of the driven element is slightly shorter than the driven element, it will have a capacitive reactance. The leading current will tend to reinforce radiation in that direction. Since this parasitic element directs radiation, it is called a director. Combined with the active driven element, the passive reflector and directors form a parasitic array creating a radiation pattern much like that illustrated in Figure 3(a).

Both active elements in the 2-element phased array are center-fed half-wave dipole antennas, shown in Figure 2(b). The designs used in this project consisted of two elements spaced one quarter of a wavelength apart and fed 90^o out of phase. A signal incident from the right in Figure 2(b) will cause the signals to combine 180^o out of phase, while signals from the left



(a) Yagi-Uda (b) Cardioid

Figure 3: Radiation patterns from the two antenna types.

will combine in phase. This phase relationship can be seen by the normalized array factor,

$$f(\theta) = \cos\left[\frac{\pi}{4}(\cos\theta - 1)\right]$$

The resulting radiation pattern has the cardioid shape plotted in Figure 3(b).

The characteristically different patterns of Figure 3 allow for completely different operational techniques for direction finding. The Yagi-Uda antenna uses its main beam to locate the transmitter, while the two-element array uses the deep narrow null of its cardioid pattern. The Yagi-Uda tends to be less confused by multipath than the cardioid array. However, the Yagi-Uda must be attenuated when in close proximity to differentiate between a signal received by the main lobe versus the back or side lobes. Without attenuation, the receiver would easily become saturated, thus losing the direction-finding ability. Attenuation was provided by a series of four T-networks, each providing 20-dB of attenuation, that could be switched in and out as needed. These cascaded circuits were encased in a shielded box with BNC connectors for insertion between the antenna and receiver. This attenuation box measured only 1.5 by 4 inches, so it could easily mount to the antenna. In contrast, the deep null of the cardioid allowed the user to approach quite closely to the transmitter, while still maintaining its null. Both types of antennas were connected to amateur radio receivers with built-in signal-strength meters. As previously stated, students made the antennas out of very crude and inexpensive material to emphasize the concepts rather than construction techniques. Figure 4 shows two of the antennas used for the transmitter hunt.

Figure 4: Two USAF Academy cadets holding their antennas. Antenna on the left is a 2-element phased array. Antenna on the right is a Yagi-Uda antenna.

4 Operational Phase

The instructor chose the transmitter site so the students would not initially receive a direct signal. Otherwise, assuming their antenna designs functioned properly, the exercise would have lasted only minutes. Therefore, the students initially only received multipath signals reflected off of nearby buildings, bleachers, and mountains. This necessitated them working cooperatively to resolve the ambiguous results created by multiple reflections. As they proceeded in their search, they eventually cleared the corner of the large wall in the upper right of Figure 1, around which the transmitter was hidden. At that point, they all received the direct signal path, but still had to resolve some multipath signals as well. They soon realized that the direct path was the one giving them the most consistent signal direction between the different antennas, allowing them to exclude the reflected signals. At that point, they quickly zeroed in on the transmitter. This exercise reinforced the cooperative learning style in which the instructor conducted the class.[3]

5 Educational Results

This exercise not only provided a substitute for the more elaborate labs conducted in the anechoic chamber, it provided a hands-on insight that students did not get in the more sophisticated automated microwave experiments. In fact, this project was so successful in reinforcing antenna and propagation concepts that it was repeated in the Fall of 2000, even though the microwave lab equipment was back in service. In this latest offering of the course, students performed several antenna experiments in the microwave lab, but they still enjoyed the lower-tech transmitter hunt added at the end of the semester. The transmitter hunt provided further intuition under the guise of a fun game. Students unanimously praised this project. In fact, in his end-of-course critique, one student wrote:

"The project served a valuable role in reinforcing the theory learned in lecture by applying it in a hands-on manner. The construction and testing technique helped make the reasons for certain design parameters stick to memory better. Because the construction is simple in design, the project increased confidence in the lab environment, and with the knowledge remembered better, the theory became less of an intangible."

Even though the anechoic chamber and test equipment in the microwave lab is currently fully functional, EE444 will continue to use this transmitter hunt as one of the course's lab exercises. This is not only due to the project's success in reinforcing abstract concepts, but is also due to its operational aspect making it a fun exercise for students as well as the instructor. When this instructor stumbles upon a vehicle to make electromagnetic principles fun for students, he takes notice.

6 Conclusion

A transmitter hunt that was used to test antenna-designs was initially intended as a short-term substitute for more elaborate microwave antenna experiments. This exercise occurred when the microwave lab at the USAF Academy was unavailable due to construction. However, this exercise turned out to be such a hit with students, that even though the lab facility is available again, the instructor continues to supplement the students' learning experience with this exercise. The transmitter hunt adds an insightful hands-on element making it an invaluable supplement for the more sophisticated, yet automated and less visible microwave experiments. Besides the ease with which this project was executed, an added benefit was that students gained additional insight into concepts that would otherwise be hidden by more automated test equipment. Furthermore, they and the instructor just had fun doing it.

The transmitter hunt required students to design, simulate, and construct antenna arrays operating at VHF frequencies so common amateur radio equipment could be used as the hidden transmitter and the receivers. Since the transmitter hunt was conducted outdoors and required basic amateur radios, this project provided an inexpensive alternative for the more elaborate antenna experiments usually conducted in the anechoic chamber with a very expensive network analyzer and positioning equipment. Schools that are looking for antenna experiments, but do not have funds to purchase sophisticated measurement equipment can use the transmitter hunt to interest students and provide a great deal of concrete insight into electromagnetics and antenna theory.

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