Session #: ___________

ANTENNA FOXHUNT LABORATORY

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ABSTRACT

Antenna theory is one of the most challenging subjects to study in electrical engineering. Conversely, the implementation of the theory can be fairly straightforward in certain scenarios. In a recent offering of a wireless communications systems course, students took part in a unique two-part laboratory on antenna basics covering antenna design and construction along with a competitive "foxhunt". The antenna design portion of the laboratory had the students choosing an antenna topology from a range of choices including dipole, inverted-V dipole, folded dipole, 2 or 3 element Yagi and diamond or square quad antennas. Constructing these antennas using pegs and pegboard, the students then used an SWR meter to tune to their specific frequency in the FM band. The students further built the proper balun to match and drive their antennas. Since low-power FM transmission is unregulated, the students were then able to measure the radiation pattern of their antennas in order to predict directivity. Taking place in a large open room with minimal obstruction in the near field, the students transmitted across the room to a receiving monopole antenna, measuring both bandwidth and radiation pattern. With this knowledge in hand, the students then constructed a frequency-scaled (hence, spatially-scaled) version of their antenna to operate at the HAM radio band near 450 MHz in order to participate in the foxhunt. Using the known directivity and sensitivity of their antennas, the students participated in a competition to locate a hidden HAM radio transmitter. Those students who had chosen the more directive antennas and did the best job in construction and testing were the most successful in the foxhunt, earning bragging rights amongst their peers. Finally, this paper concludes with assessment that was performed via a survey of the student population as to the effectiveness of the laboratory exercise.

1. INTRODUCTION

As part of a new course on wireless systems (Dunne and Wilson, 2011), a unique sequence of laboratories intended to allow students to design, implement and test an antenna was performed. A key feature of these exercises is the “foxhunt” competition, where students compete against each other to find a hidden transmitter using antennas of their own construction, with the best locator antenna declared the winner. Along the way, students learn about various antenna configurations and their respective directivity, which will be a key feature in their success in the foxhunt. Furthermore, students have the opportunity to design and build support modules for their antennas, including impedance matching transformers and RF field strength meters. In so doing, students work with several key pieces of equipment including function generators, spectrum analyzers and VSWR meters.

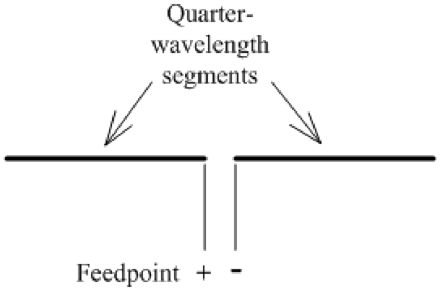
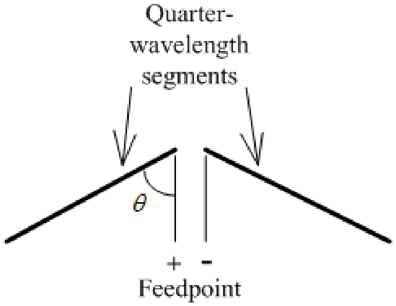
This paper begins with Part I of the lab, where students build and characterize an antenna of their own choosing for the FM band. Following this exercise is Part II, where the students rework their antenna to operate in the UHF band for the actual foxhunt competition. Finally, the results of a student survey on this laboratory are presented.

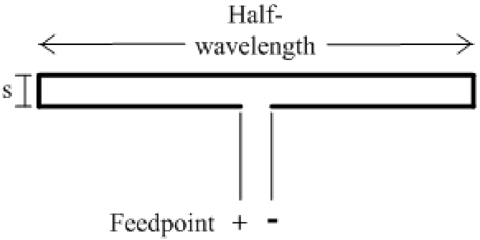
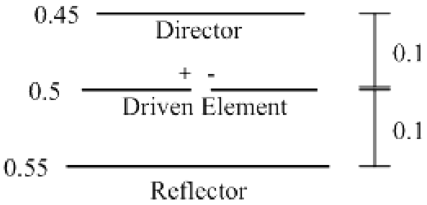
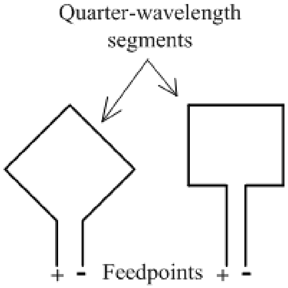
2. PART I: FM ANTENNA

2.1 Strategy

In the first part of the laboratory, students are asked to design and build an FM-band (roughly 88-108 MHz) directional antenna of their own choosing from a variety of available configurations (see Table 1). Constructing and testing these antenna designs at FM frequencies was an ideal choice for several reasons. First of all, low-power FM transmission is unregulated (Low Power Signal Licensing), allowing students to experiment and transmit in the FM band, up to a range of 200 feet. Secondly, the sizes of the antennas, while somewhat large, are still manageable. Lastly, being the FM band, the antennas can be used to receive local radio stations or generate FM over commonly available FM transmitters.

Table 1: Antenna types.

Type	Topology
Center Fed Dipole	
Center Fed Inverted V Dipole	

Type	Topology
Center Fed Folded Dipole	
3-Element Yagi	
Diamond or Square Quad	

The students construct these antennas and supporting circuitry as described below. The radiation pattern of their antenna is then measured in order to predict directivity for the later competition. Students were encouraged to choose an antenna with high directivity, as well as one with nulls as these are particularly useful for directionally locating a hidden transmitter.

2.2 Implementation

The students were required to choose an antenna type for their assigned FM band center frequency f_c (each group was assigned a different center frequency that coincidently did not correspond to any local FM broadcasting station). Coarse design equations used by students are listed in Table 2 (corresponding to the physical description shown in Table 1). The students applied these equations under the assumption that they yield an antenna that is typically too long, allowing for some trimming to achieve final tuning.

To physically build the antennas, students wound 24GA insulated wire over pegs mounted on pegboard, as secured with masking tape. Wire lengths were determined by the formulas of Table 2, with care taken to correctly follow the specified shape with precise corners and straight sections. Since antennas are typically driven by a differential signal, the students were required to convert from the single-ended function generator to the antenna differential feedpoint. To achieve this conversion, students constructed a transmission line transformer style “balun” (i.e., the joining of the words **bal**anced and **un**balanced), shown schematically in Figure 1, where the primary side is single-ended and the secondary side is differential. As an added benefit, the balun also serves to match impedance between the source and the antenna's resonant resistance. Assuming a source impedance of 50Ω (typical function generator), additional secondary windings can convert the source impedance to the antenna feedpoint resistance. For example, for the Diamond Quad antenna, a ratio of 1:2 might be employed to improve power transfer from source to load. Actual implementation of a 1:4 balun is shown below in Figure 2.

Table 2: Antenna design summary.

Antenna Design	Design Equation (antenna length based on f_c MHz) (m)	Feedpoint Resonant Input Resistance (Ω)
Center Fed Dipole	$L \approx 142.6 / f_c$ (end-end)	~73
Center Fed Inverted V Dipole	trim 2% to 5% off dipole L for $22° \le \theta \le 45°$	~73
Center Fed Folded Dipole	same as dipole (end-end); choose side $s \approx \lambda_c / 64$	~292
2-Element Yagi	omit either Director or Reflector driven element $L \approx \lambda_c / 2$ with ratios shown in Table 1	< 50
3-Element Yagi	driven element $L \approx \lambda_c / 2$ with ratios shown in Table 1	< 40
Diamond or Square Quad	circumference $L \approx \lambda_c$	~120

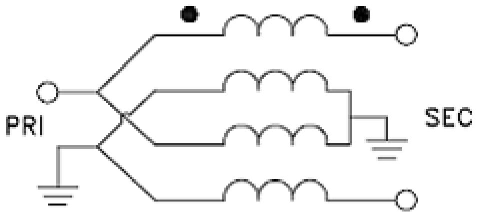


Figure 1: Balun schematic.

As is well known, antennas exhibit polarization. For the antennas chosen for this experiment, linear polarization is in effect (polarization is either vertical or horizontal). Students need to be aware of their particular polarization when using their antenna for characterization or the eventual foxhunt.

To tune their antennas, the students employed a VSWR meter, such as the MFJ-269 (MFJ Enterprises Inc.). Ideally, at resonance, the VSWR would read 1:1 at the selected frequency, corresponding to the students' desired frequency of operation. This particular meter employs a 50 Ω source impedance, and the 1:1 VSWR would mean that the corresponding feedpoint input impedance (again, at the desired f_c) is also 50 Ω, implying that the antenna is resonating and the total of the applied power is radiating into the atmosphere. A VSWR reading other than 1:1 indicates a mismatch; fortunately, the MFJ-269 also registers load impedance allowing the students the opportunity to adjust the antenna length or tweak other elements (such as their balun). An inductive load impedance (positive reactance) indicates that the antenna length is too long, and needs to be trimmed, while the opposite is true if the reactance is negative. Since the VSWR source resistance is 50 Ω, it will not be possible to quite reach a reading of 1:1; students were encouraged to tweak their designs until they reached a VSWR of 1.8:1 or better (the more complicated designs were also more difficult to tune).

Figure 2: Balun implementation.

The laboratory tuning setup is shown below in Figure 3. Shown is a student-built implementation of an inverted-V dipole mounted on the pegboard along with a 1:1 balun. Other laboratory equipment includes the MFJ-269 VSWR meter, spectrum analyzer, oscilloscope and function generator.

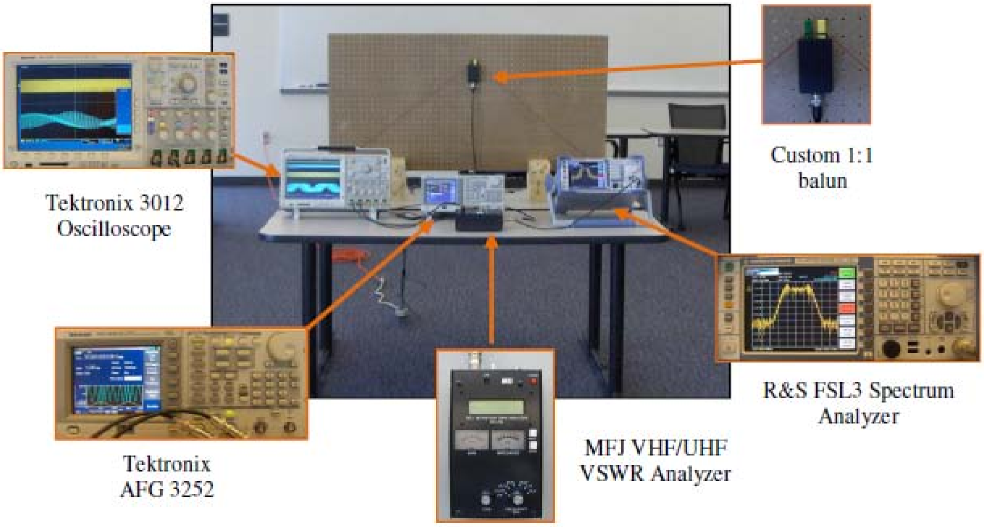


Figure 3: FM antenna build workbench.

2.3 Characterization

Since the goal of the antenna construction is to eventually use a similar design in a foxhunt competition, the radiation pattern of the antenna needs to be determined. To do so, the students tested their antennas in the largest space available (a large classroom), cognizant of the non-ideal situation and potential issues from reflections and ground surfaces. Across the room (well in the far field), a fixed quarter wavelength monopole with ground plane, polarized to the antenna under test and connected to a spectrum analyzer, was made available. The students' antenna, acting as a transmitter sending a single tone at the center frequency, was rotated while the resulting signal level at the far receiver was noted as the rotation angle was varied. Despite the non-ideal conditions, most students were able to measure a radiation pattern that had at least a recognizable similarity to the expected theoretical radiation pattern for that design. The laboratory configuration at the student transmitter side is shown below in Figure 4.

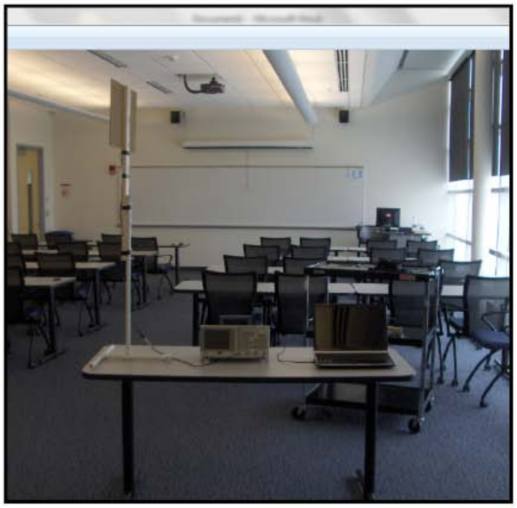


Figure 4: Characterizing the antenna radiation pattern.

In addition to the radiation pattern, the students also swept the input frequency of the function generator in order to estimate the frequency response of their antenna. Most antennas exhibited a fairly wide frequency response, generally peaking at or near the desired resonance. Finally, the students were able to take advantage of the external FM modulation input of the function generator (the Tektronix AFG 3252) to connect some sort of audio signal. On the receiving end, the spectrum analyzer in use (the Rhode & Schwarz FSL3), equipped with internal FM demodulation, was used to demodulate the received signal. In this way, the students were able to demonstrate the use of their antennas for FM transmission.

The next step in the process is to use what they have learned in this experiment to assist them in the foxhunt competition.

3. PART II: UHF ANTENNA AND FOXHUNT

3.1 Concept

In Part I, the students constructed and characterized their antennas at an FM frequency. For the foxhunt portion of the experiment, it was decided to use a HAM radio transmitter operating at the center frequency of 445 MHz as the hidden source. The HAM radio choice is preferred since it can yield a higher power transmission in a compact form (i.e., a handheld radio) while allowing a smaller, easier-to-transport student antenna. Furthermore, there will be decidedly less in-band interference from distracting sources (such as FM radio) in this UHF range. Thus, in part II, the students were required to physically scale their antennas to work at this new frequency, where the dimensions shrink proportionally to the change of frequency ratio. Furthermore, applying the principle of reciprocity (Carr, 1989), the expected receiver directivity of their antennas will match that as measured as a transmitter from Part I.

3.2 Implementation

As mentioned above, the students were required to scale down their antennas to work at the specified UHF frequency of 445 MHz. Students were free to continue with using the pegboard based antennas or switch to a material of their own choosing. For the more complicated antennas, some students switched to using tubing material.

To sense the RF energy, students constructed hand-held, battery-powered RF meters based on a simple design found in a radio handbook (Wilson and Ford 2009). These basic meters included a simple filter to pass the 445 MHz and assist in attenuating out-of-band energy. The meter, along with a student-built multiple director element Yagi antenna is shown below in Figure 5.

3.3 Foxhunt Competition

The competition was the last phase of the combined laboratory. While the students are sequestered in the classroom, a (licensed) HAM radio operator hides somewhere in the building. The students are released, antenna and RF meter in hand, to seek out and find the hidden radio. The radio operator alternates 30 second periods of on/off transmission in order for the students to calibrate to the signal (as well as to avoid continually “squawking”). Additionally, the radio operator varies the polarization of the radio to cover the possible polarizations of the student antennas.

Because too many students at once may allow poor performing groups to “follow the crowd” and get lucky once the target is in close range, a series of rounds with no more than three groups at a time was run. Unfortunately, due to undesirable reflections and the like in the close quarters, it was not always skill that won out; luck played an important role in determining the winner. Furthermore, it was necessary that the hidden transmitter remain on the same building floor to keep the searching process from becoming unwieldy. Despite the difficulties of the interior search, in general, the superior directional antennas tended to do better in the competition and the hidden transmitter was typically found in a matter of several minutes.

In the event of better weather and a daylight hour's laboratory, it would be preferred to conduct the foxhunt laboratory outside in an appropriately open area, mostly free from reflections.

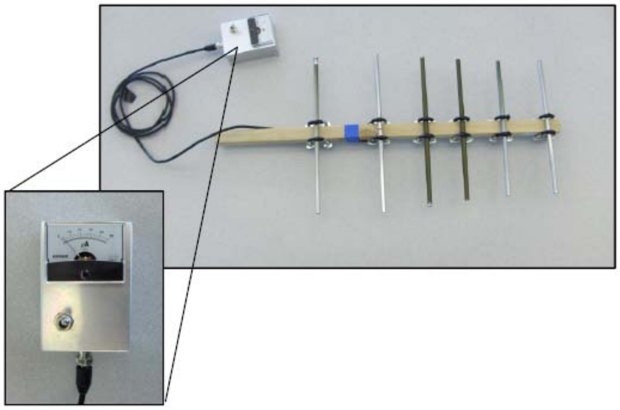


Figure 5: RF Field Strength Meter and student-built Yagi antenna.

4. STUDENT SURVEY AND FEEDBACK

In an effort towards continuous improvement, the students were anonymously surveyed in order to solicit feedback on the appropriateness and completeness of the two part foxhunt laboratory. The following questions were asked of the students (set of 11 students in the pilot offering of the course):

Q1: This experiment was a good introduction to the challenges of antenna design.

Q2: I have gained a good understanding of the methods and techniques of qualifying antenna performance.

Q3: I have a good understanding of the common antenna types and their respective performance tradeoffs.

Q4: List suggestions for improving the antenna experiment.

The results of the first three questions (mean and standard deviation) are displayed below in Figure 8 (key: 5: strongly agree; 4: mostly agree; 3: somewhat agree; 2: disagree; 1: strongly disagree).

The survey results indicate that the students felt that the laboratory was clearly adequate as an introduction to antenna design and implementation. Slightly less strong was their feeling that they knew how to measure and tune antennas, but a result still seen as acceptable. For the third question, clearly there was some minor amount of doubt in the students' minds that they had been properly exposed to the range of antennas and their associated tradeoffs. Given the nature of the experiment in which the students work with at most two antenna types, this is understandable. It is proposed that in the next offering, the students have the opportunity to test and experiment with antennas from other groups in order to gain a better exposure to the performance of other antenna types. Furthermore, a wider range of antenna types should be offered to the students and the students should be encouraged to select the more “exotic” variants for their experiments.

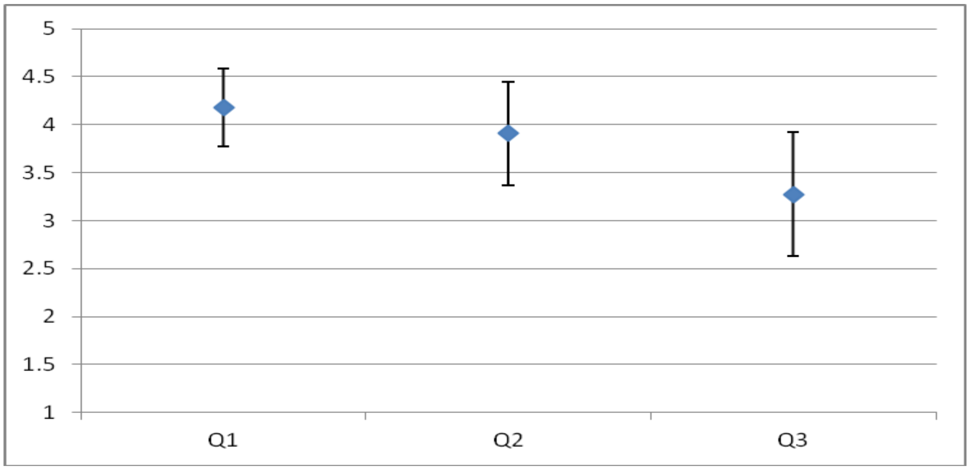


Figure 6: Student survey results.

The fourth question solicited student comments. A selection of insightful comments is given below:

1. *It might be insightful to additionally experiment with professionally built antennas.*
2. *Include material concerning PCB-based antenna design.*
3. *Room geometry affects antenna performance; need less interference to properly test and characterize antennas. The testing environment needs to be carefully controlled.*
4. *My previous experience with anything RF has been very intimidating and difficult; this lab increased my confidence in this area of EE.*
5. *Minor changes to antenna construction/testing seemed to have huge performance effects.*

The student responses were insightful and valuable. Comment #1 is a good idea, and a selection of these antennas will be used for comparison in the future. Comment #2 is a good point and an important aspect of antenna design for these students, although it may be beyond the scope of the exercise. Comment #3 has already been addressed in this paper, and issue that is not easily remedied. Comment #4 is gratifying; it was certainly appreciated that the students were able to gain some experience in the difficult area of RF. Comment #5 reflects some of the frustration that the students experienced in characterizing their antennas.

CONCLUSION

A two part laboratory that had students design, construct and test an antenna of their own choosing was described. Students then used these antennas in a foxhunt competition. Overall, this novel set of experiments served as a good primer for the issues of RF and antenna design as demonstrated by the positive student response.

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