AC 2008-820: BUILDING THE LARGEST CANTENNA IN KANSAS: AN INTERDISCIPLINARY COLLABORATION BETWEEN ENGINEERING TECHNOLOGY PROGRAMS

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“Building the Largest Cantenna in Kansas: An Interdisciplinary Collaboration between Engineering Technology Programs”

Abstract:

This paper describes the design and development of a large 20 dBi (decibels isotropic) Wi-Fi antenna for a class project in the Communication Circuit Design course. This large antenna is based on smaller Wi-Fi antennas commonly referred to as cantennas (gain of about 10 dBi). The smaller version is made with a single can (3-4 inches) in diameter and an appropriately placed feed probe. Our version consists of several progressively larger cylindrical sections connected together by 34 degree flared sections (3 inches long). The first cylindrical section has a diameter of 4 inches and the last flared section has a diameter of about 36 inches. The overall length of the antenna is about 5 feet long. While the antenna was designed by electronic and computer engineering technology (ECET) students, mechanical engineering technology (MET) students took charge of building it under the supervision of their MET instructor. The structure was built by spot welding laser-cut pieces of sheet metal. ECET students made experimental measurements to verify the predicted gain and functionality.

Motivation:

The design of the large Cantenna (Figure 1) was taken up by students as a class project for the Communication Circuit Design (ECET 420) course. Chief among the motivational factors influencing their choice seemed to be a desire to learn more about cantennas that could potentially help them share internet access with their friends that lived reasonably close. In the early part of the research cycle we came upon the world record[1] for "unamplified" Wi-Fi distance (125 miles). This feat was accomplished by linking two dish antennas (10 feet and 11 feet) in diameter. Each antenna was attached to a Zcom PCMCIA card with a built in power of 300mW. This record influenced the design team to start thinking about building a high-gain Wi-Fi antenna that would be able to communicate over several miles.

Our design did not attempt to match the records for distance. We were interested in building the largest known antenna based on the standard cantenna[2] design, using some of the same methodologies.

From the point of view of a communication design course, the construction of any antenna is a good way to learn about impedance matching, guided wave propagation and the radiation characteristics of antennas. Furthermore, the building of a high gain antenna with real world application and record dimensions appealed to all involved. The paper will also comment on student enthusiasm and teamwork in this interdisciplinary endeavor. The sections to follow cover all aspects of antenna development, including design, simulation, construction, measurement and testing. A discussion of the learning outcomes is presented just before the concluding remarks.

Figure 1. Students and Instructors pose with Large Cantenna.

Design:

We employed design principles to those of the standard cantenna[2] combined with the "Theory of Small Reflections[3]." The standard cantenna is essentially a cylindrical waveguide that permits only the dominant TE_{11} mode[4] (or electromagnetic field distribution) to propagate at the 2.4 GHz Wi-Fi frequency. The can should have a length that exceeds ¾ of the guide wavelength for the TE_{11} mode at 2.4 GHz. The feed is placed at ¼ of a guide wavelength from the back wall of the can. This assures that the reflected wave from the back wall and the wave traveling toward the opening are in phase and do not destructively interfere with one another.

In designing the first section of the large antenna, we followed the design guidelines of the standard cantenna[2]. With the exception of the first section (smallest of sections), all other sections carry multiple modes and the number of modes in any section is proportional to the diameter. The large number of modes in the last section allows a field distribution that permits highly directive radiation patterns. Our version consists of six different cylindrical sections connected together by six 3-inch 34° flared or conical sections (Figure 2). Flared sections were used to minimize reflections at the junctions.

The "Theory of Small Reflections[3]" suggests that a gradual change in waveguide dimensions will keep the reflections small at their junctions. When we make the transition between two cylinders the intermediary conical section keeps the reflections at a minimum. Indeed the conical section itself can be seen to be composed of many progressively larger cylindrical sections having infinitesimal lengths with no reflections at their junctions. The first cylindrical section has a diameter of 4 inches and the last flared section has a diameter of about 36 inches. The overall length of the antenna is about 5 feet long.

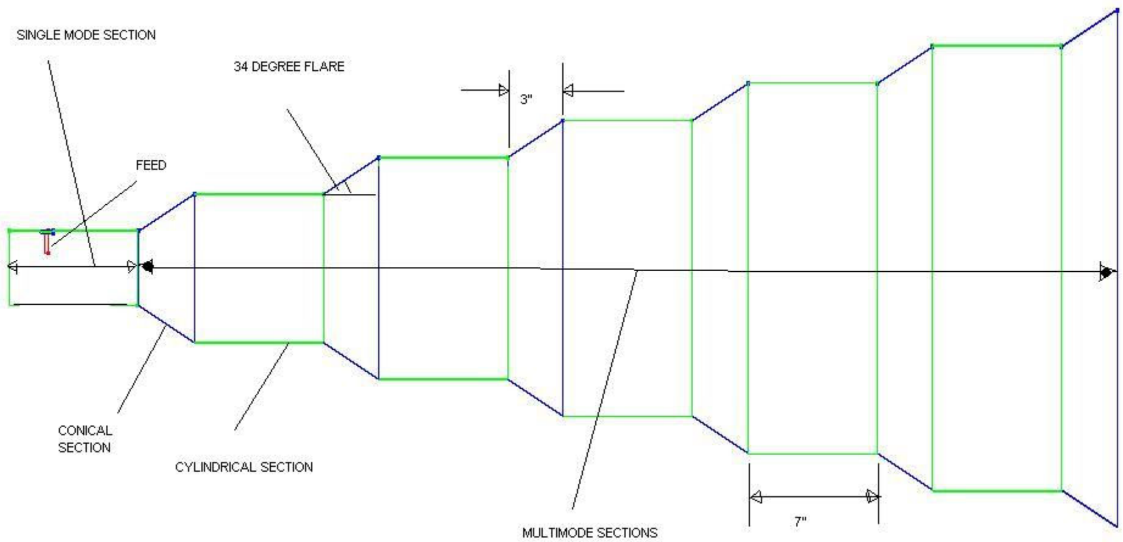

Figure 2. The figure shows the side view of the antenna.

Simulation:

A simulation of the above design was performed using MicroStripes[5], a 3-D EM solver. The results of simulation seemed to indicate a gain of almost 21 dBi (decibels isotropic). The antenna is highly directive and has a 3-dB beamwidth of about 14 degrees (Figure 3). There are no noticeable side lobes or back radiation to speak of. Figure 4 indicates the antenna has a very large bandwidth (630 MHz).

Construction:

While the antenna was designed by electronic and computer engineering technology (ECET) students, mechanical engineering technology (MET) students took charge of building it under the supervision of their MET instructor. The structure was built by spot welding laser-cut pieces of sheet metal. The back wall of the feed section was made tunable by using a piston like device that can move back and forth. The antenna was placed in a frame on a cart in a manner that

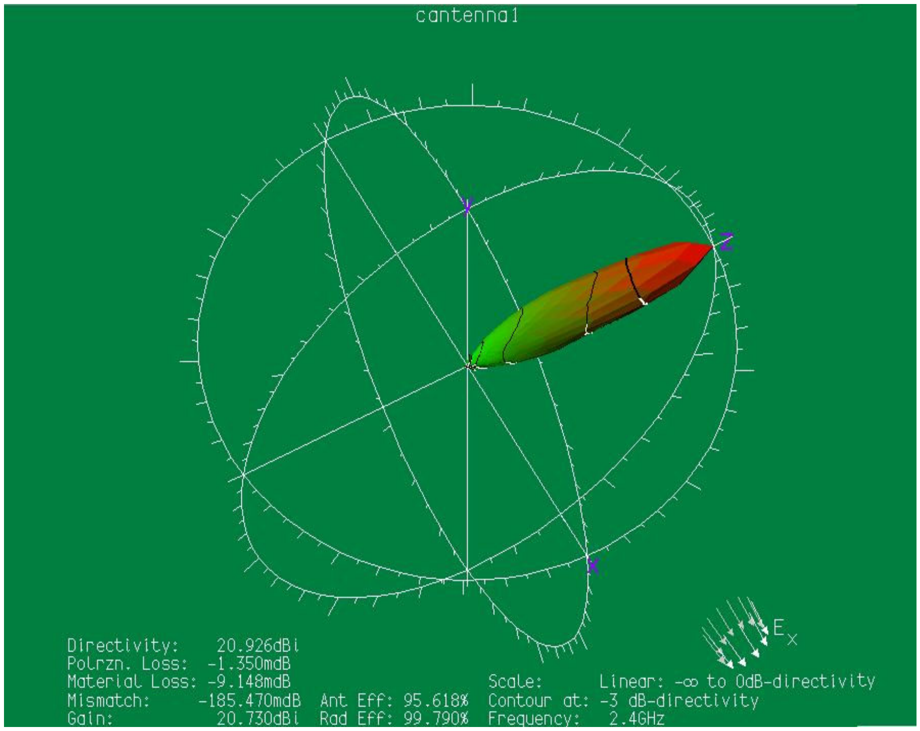

Figure 3. The figure shows the simulated radiation pattern for the design.

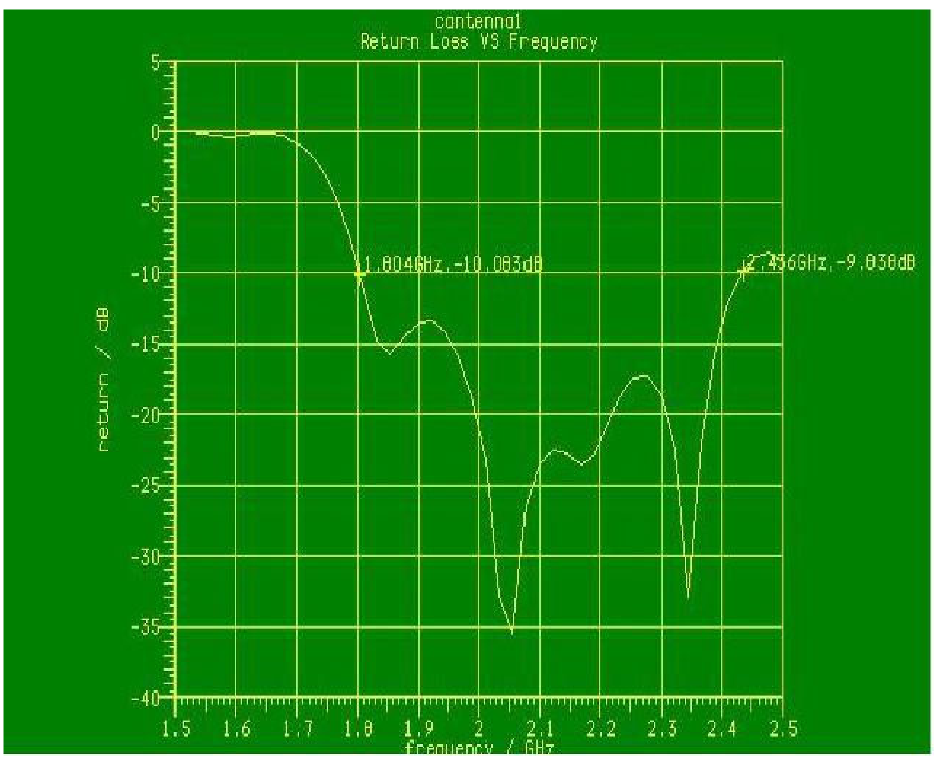

Figure 4. The graph above shows the simulation results of the return loss of our antenna in the 1.5 to 2.0 GHz range.

allows it to rotate around the axis to minimize polarization mismatch[6]. The dimensional specifications seemed to be quite closely followed.

Measurements:

Bandwidth: After constructing the antenna, the bandwidth was measured by using a spectrum analyzer in combination with a directional coupler. The tracking generator of the spectrum analyzer inputs power into the directional coupler. The input power propagates to the antenna hook up and is reflected. The directional coupler separates the returned signal from the source and passes it to the input of the spectrum analyzer. Lower levels of return loss, means that more energy is being coupled to the antenna. When the return loss is lower than -10 dB we are considered to be in the operational part of the bandwidth. The onset of the pass band at around 1800 MHz was verified by the spectrum analyzer. The upper bound cannot be accurately established due to the operational limitations of the directional coupler, which is around 2 GHz. Measurements of gain and passively picked signals (shown later) corroborate the simulation result of 600+ MHz bandwidth.

Gain: To determine the radiation pattern of our antenna, one would normally require a fairly large range; alternatively one could use a smaller range with a scaled model. Our approach was to use a software package called Network Stumbler[7] running on a computer which receives its Wi-Fi signal from an external antenna and a 2511 PLUS EXT2 Wireless Card. These cards are available from Jefatech[8]. Network Stumbler is capable of picking out the signal and noise levels of different Wi-Fi sources. The following procedure was followed in figuring out the gain of a large antenna.

1. A standard cantenna (Figure 6) of known gain (10 dBi) was placed in a location directly in front of an access point. The signal and noise levels from this access point were recorded.
2. The test antenna was placed at the same position in front of the same access point.
3. Take readings of power and noise levels of this particular antenna.
4. The difference of the readings of the signal level in step 3 and step 1 plus the gain of the known antenna was calculated to be the gain of the device being tested (the large cantenna).

Using the procedure outlined above, the gain was calculated to be about 21 dBi. It should be noted that the gain was only measured at the maximum direction and this result validates the maximum simulated pattern gain. The maximum gain conveys a great deal of information for highly directive antennas with narrow beamwidths.

Testing:

Spectrum Analyzer Test: When the large antenna was hooked up directly to a spectrum analyzer it was able to pick up the distinct Wi-Fi signals in its environment without any amplification. Figure 7 shows the recorded maximum signal strengths centering around 2.41 GHz. Notice that channel 1 signal (2.412 GHz) possesses the most strength. We had previously identified the channel 1 and 6 to be the two strongest channels in that vicinity using an omni-directional antenna, a 2511 PLUS EXT2 wireless card and the Net Stumbler software for that room. The fact that channel 6 did not show up is not surprising considering the directional nature of the antenna.

Outdoor Signal Test: We rolled the large Cantenna to a distance of about 200 yards from our building (Technology Center) and hooked it up through 2511 PLUS EXT2 wireless card to a laptop which was running Net Stumbler. We then turned the antenna to face the Tech Center. Using our antenna we were able to pick up 8 access points with 4 of them having a signal to noise ratio (S/N) greater than or equal to 20 dB (a threshold required for proper access). We then replaced the large cantenna with a smaller one and we were then able to pick up 7 access points with 2 of them having S/N ratio that is greater than the threshold. Figure 8 shows location of our measurements with a white star.

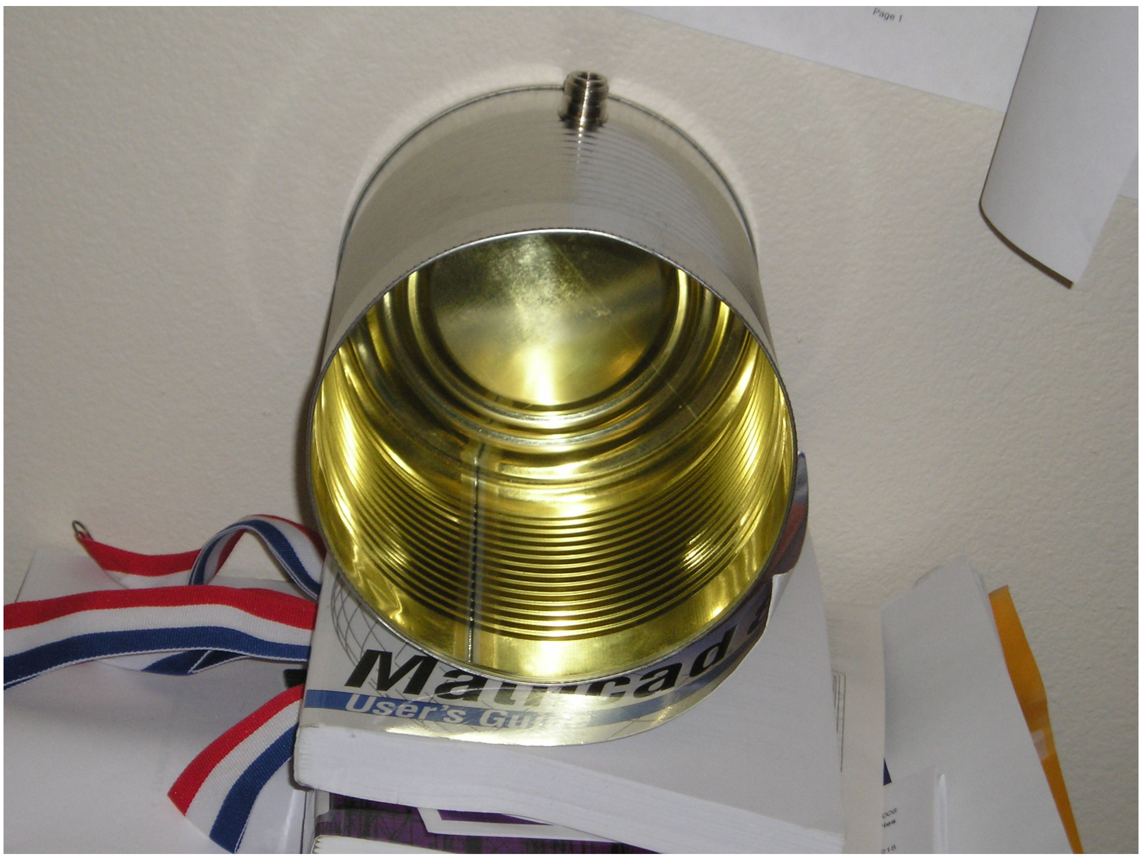

Figure 6. A view of the reference antenna is shown above.

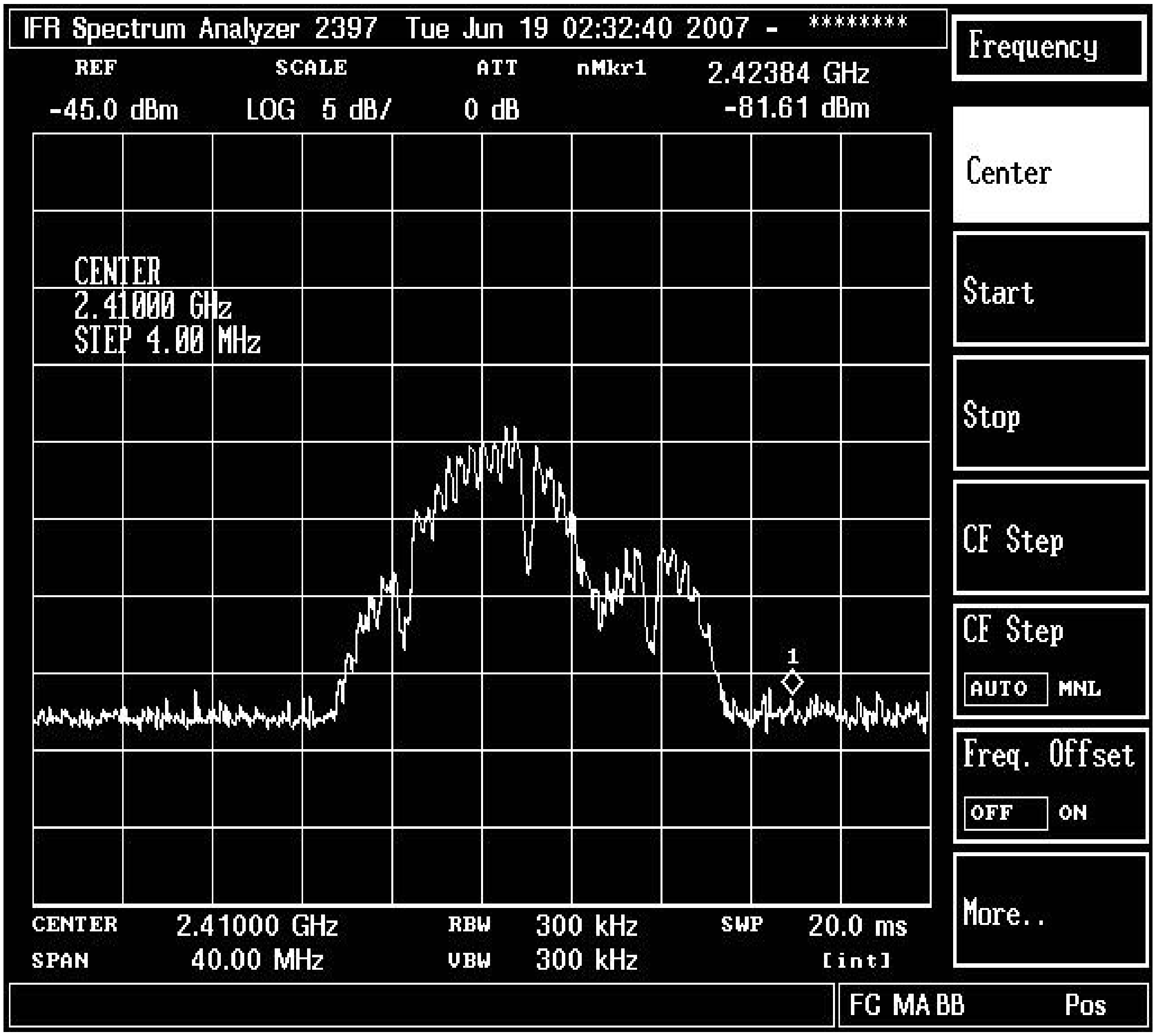

Figure 7. The figure shows the recorded maximum signal strengths centering around 2.41 GHz.

Learning outcomes and assessment:

The course outcomes for the Communication Circuits Design course are listed in column 1 of table 1. Column 2 shows which of these areas were directly impacted by the project; column 3 shows the aspect of the project that relates to the course objective and column 4 shows TAC of ABET outcomes that have been touched upon by the activity in column 3. Apart from addressing outcomes shown in table 1 the students have successfully completed an interdisciplinary team project (TAC of ABET criteria e). While a complete assessment of all direct and indirect data for the course have not yet been completed, teaching evaluation data seem to indicate a significant improvement in the desire to learn from the previous year.

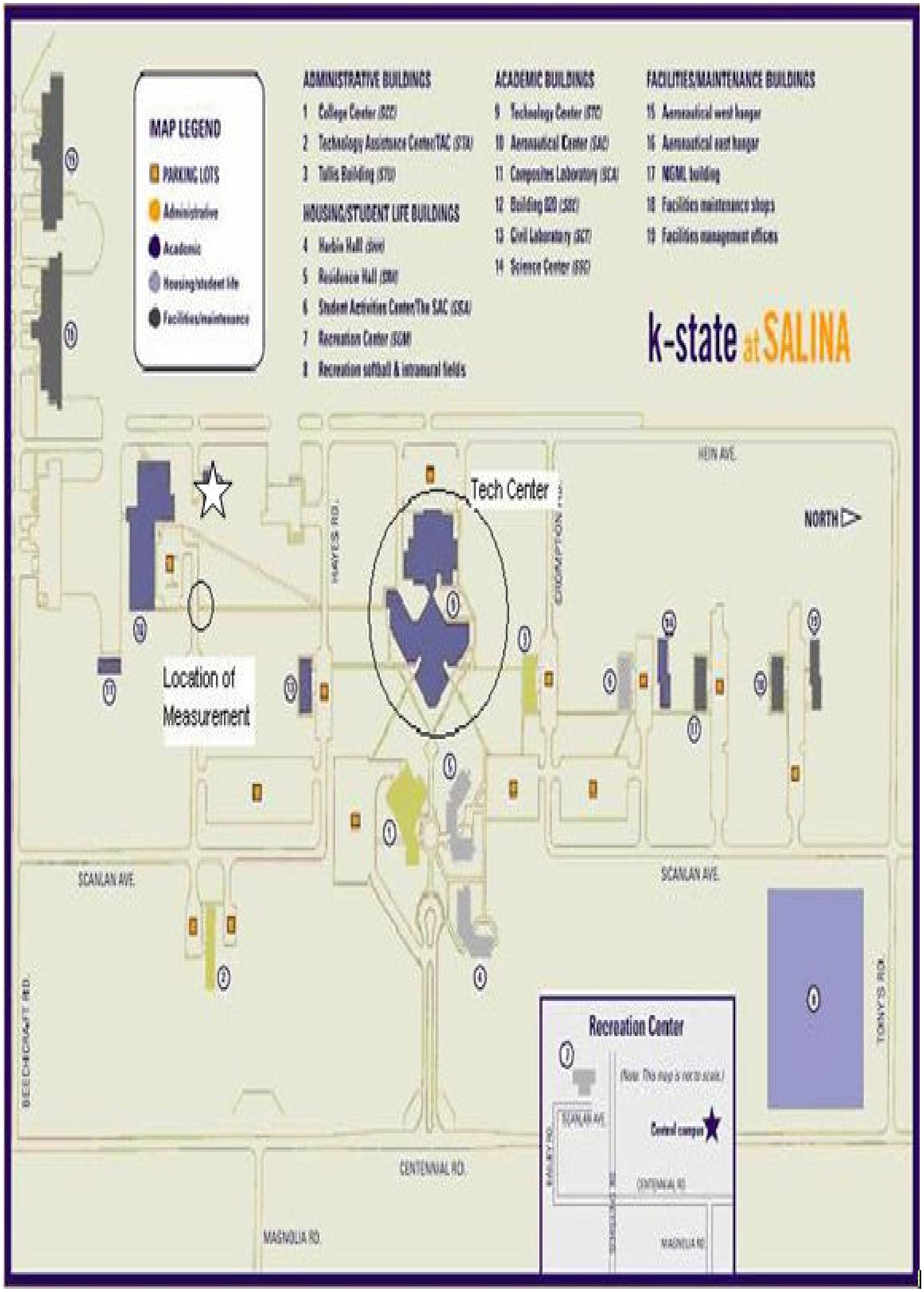

Figure 8. Measurement location is marked with a red circle in the above map.

TABLE 1
Impact of project on ECET 420 course outcomes

Course Outcome	Impacted by Project Yes/No	Related Activity	TAC of ABET General Criteria a thru i
Understanding the different components of an RF communication System	no		
Design and build RF amplifiers	no		
Design and build an impedance matching network	yes	The design of the tuning piston arrangement	d. an ability to apply creativity in the design of systems, components or processes appropriate to program objectives
Design and build a communication antenna	yes	The design and building of the Large Cantenna	d. an ability to apply creativity in the design of systems, components or processes appropriate to program objectives
Understand the role of software in modern wireless design	yes	1. Simulation using Microstripes 2. Use of Net Stumbler to study access point signals.	b. an ability to apply current knowledge and adapt to emerging applications of mathematics, science, engineering and technology.
Understand the role of transmission lines in wireless design	yes	Understanding the quarter-wave feed probe using transmission line theory	a. an appropriate mastery of the knowledge, techniques, skills, and modern tools of their disciplines.
Study of a complete wireless receiver	yes	Study of the Wi-Fi system	a. an appropriate mastery of the knowledge, techniques, skills, and modern tools of their disciplines.

Conclusions:

We started the project with the intention of building a standard cantenna for Wi-Fi purposes and ended up building a high-gain cantenna with record dimensions. So what brought about this level of overachievement? Student enthusiasm regarding cantennas was high, for one, but the interdisciplinary nature of the project was also a big factor. One cannot but stop and admire the synergistic relationship that had formed between ECET and MET students. Even non-participating students from the two disciplines were excited and eager to learn about the project during the development process. From the instructor's point of view, it was the question of finding common ground between course objectives and student interest during a time of the dreaded "senioritis."

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