2.45GHz Yagi Antenna

EET499C Group Project

Professor Honchell

Group Members:
Troy Brown
Mike Brown
Eric DeBolt
Mark Fernandes
Adam Gohn

April 2002

Introduction

The purpose of this project is to design an antenna for use in the 802.11b wireless protocol. The protocol allows for wireless Ethernet in the 2.4 GHz open band. The antenna was developed to increase the signal strength received when using a wireless LAN card on a laptop computer, therefore increasing the range over which the connection could be used. The corrugated rod antenna design was chosen to accomplish the task of developing an antenna with a simple design and a good gain. The corrugated rod, or cigar, antenna uses the same concepts as a Yagi antenna. The antenna was created from a waveguide set to 2.45 GHz and a disc on rod method also set to 2.45 GHz. The disc on rod method set into the waveguide gives excellent directivity. The antenna was tested using various software programs and a wireless LAN card in a laptop computer. The performance of the antenna was measured in several ways to show how well it truly worked. The antenna works very well, allowing the user to connect to a wireless network from quite a distance. The design and construction process for the antenna was very thorough to allow the best gain possible. The testing of the antenna was also very thorough to show the effect the antenna had on signal strengths. The design, construction, and testing was critical to producing an antenna that works well.

Design

The antenna was designed to operate in the middle of the 2.4-2.5 GHz band. The frequency of operation was 2.45 GHz. Since the signal will be traveling in free air, the velocity of propagation is $3x10^8$ m/s. The calculation of the wavelength appears below.

$$\lambda = \frac{v}{f} = \frac{3\times10^8\,m/s}{2.45GHz} = 122449mm$$

Once the wavelength was known, the length of the rod could now be calculated. The length of the rod can be any multiple of half the wavelength. The length that was used was 3.5 wavelengths. The calculation for the length appears below.

$$L = 3.5\lambda = 3.5(122449mm) = 428.572mm$$

The next step of the design process is to determine the low cutoff frequency of the antenna. This calculation depends solely on the diameter of the waveguide that is chosen. The diameter of the circular waveguide for a 2.45 GHz antenna must be between 90mm and 110mm. The diameter of the waveguide chosen was 110 mm. The calculation of the cutoff wavelength appears below.

$$\lambda_c = 1.706D = 1.706(110mm) = 187.66mm$$

Once the cutoff wavelength was known, the standing wavelength could be determined. This is a function of both the high frequency wavelength and cutoff wavelength. The calculation for the standing wavelength appears below. Figure 1 shows the standing wavelength inside the waveguide and the properties of the quarter-wavelength effect.

$$\lambda_g = \frac{1}{\sqrt{\left(\frac{1}{\lambda}\right)^2 - \left(\frac{1}{\lambda_c}\right)^2}} = \frac{1}{\sqrt{\left(\frac{1}{122449mm}\right)^2 - \left(\frac{1}{187.66mm}\right)^2}} = 161.588mm$$

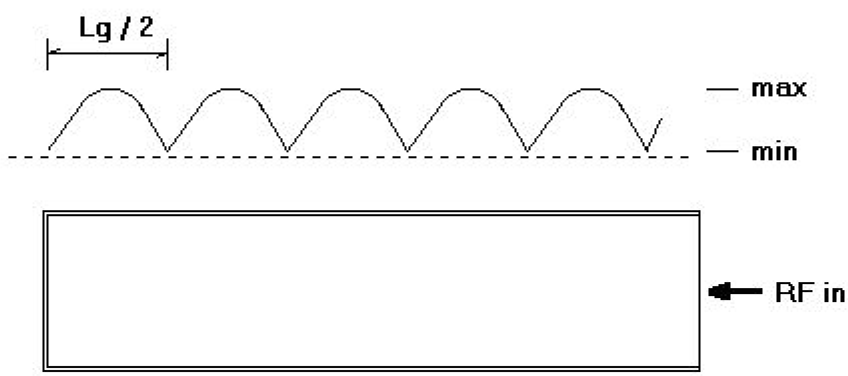

Figure 1: Standing Wavelength (Quarter-Wavelength Effect)

The calculations above are used to determine the dimensions of the waveguide and the rod. The placement of the driven element in the waveguide is also calculated using these values. The driven element should be placed one-quarter of the standing wavelength back from the reflector of the waveguide. This distance was calculated and found to be 40.397 mm. The height of the driven element is found using the wavelength of the signal in free air. It is one-quarter of this value, which equals 30.612 mm. The length of the waveguide is determined using the standing wavelength. It is three-quarters of this value, which is 121.191 mm. The dimensioning of the waveguide is summed up in Figure 2.

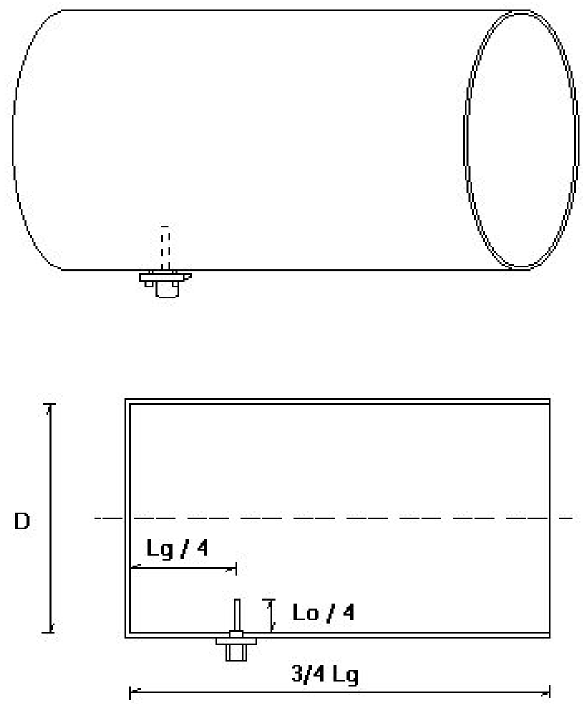

Figure 2: Waveguide Dimensions

The rod is made from a piece of all-thread. The rod consisted of washers that were equally spaced. The dimensions of the washers and all-thread appear below.

• Washer diameter - D	1 ¾"
• Spacing between washers	29.612 mm
• Center-to-center spacing of washers - S	30.612 mm
• Washer thickness - t	1 mm
• Length of rod	428.572 mm
• Diameter of rod – d	½”

The dimensioning of the rod appears in Figure 3.

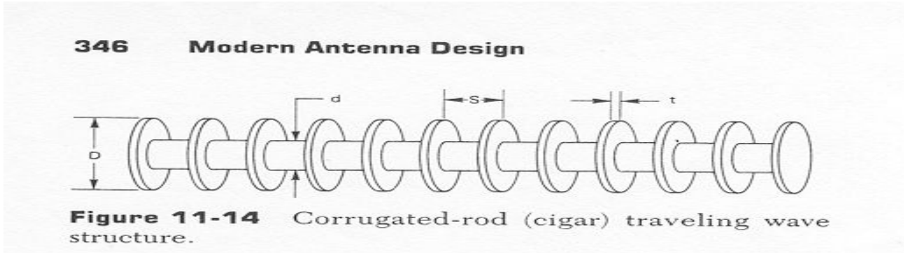

Figure 3: Rod Dimensions

Once the dimensioning of the rod and waveguide were complete, the theoretical directivity was calculated. Table 1 and figure 4 work hand in hand to determine the directivity. First, a P value must be calculated based on the washer diameter, rod diameter, and wavelength. This calculation appears below.

$$\lambda = 122449 mm = 4.821 in.$$

$$\frac{(D-d)}{\lambda} = \frac{(1.75 in. - 0.5 in.)}{4.821 in.} = 0.259$$

Once this value was known, the table could be used to determine the P value. This value, from Table 1, was found to be about 1.16. The graph of the directivity based on the P value and length of the rod could now be used to determine the theoretical directivity. From the chart in Figure 4, the directivity was found to be 13.5 dB.

TABLE 11-16 Measured Relative Propagation Constant on Corrugated-Rod (Cigar) Antenna [26]

$(D-d)/\lambda$	P	$(D-d)/\lambda$
0.15	1.03	0.275
0.175	1.05	0.30
0.20	1.08	0.325
0.225	1.12	0.35
0.25	1.16	0.375

$0.15 \leq$ disk spacing/$\lambda \leq 0.21$
$0.15 \leq$ central rod diameter/$\lambda \leq 0.21$
$0.018 \leq$ disk thickness/$\lambda \leq 0.025$

Table 1: P values for the corrugated rod method

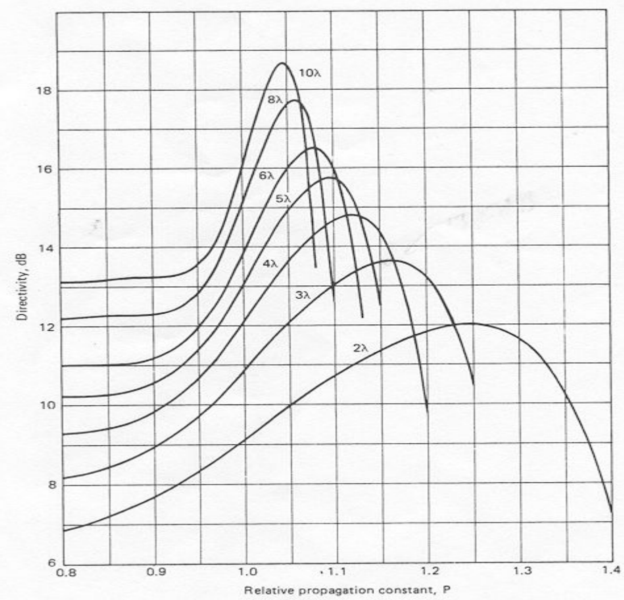

Figure 11-1 Directivity of axisymmetrical uniform distribution traveling wave.

Figure 4: Plots of directivity

Construction

The construction portion of this project took more effort than initially predicted. It was important to keep our actual antenna as close to the design as possible. It was apparent that the closer the antenna was to the specifications the greater the gain would be. The inside diameter of 4½" EMT is 110mm. This was perfect for the waveguide portion of the antenna. The length of the waveguide needed to be as close as possible to 122mm. A lathe in the ME lab was used to cut the pipe down to a length of 122.007mm. Because the tube needs to have a back plate that is completely electrically connected, a steel plate was welded to back of the tubing. A ½" hole was drilled into the tubing exactly ¼ wavelength from the back for the N-type connector to be placed through. The ½" diameter tubing was then cut using a hacksaw into 13 separate ¼ wave sections. To hold these pieces into place a piece of all-thread was cut to the total length of these assembled sections using a hacksaw. A nut was placed on one end on the all-thread. Alternating pieces of the cut tubing and washers were placed on the all-thread until the end was reached. Another nut was placed on the end to secure the tubing and washers onto the all-thread.

To secure the element rod into to correct place on the waveguide it was decided to use Plexiglas. To ensure that the Plexiglas would not attenuate the incoming signal the microwave test was performed. A piece of the material was placed in a microwave next to a cup of water. The microwave was run on high power until the water boiled. The Plexiglas was then touched to ensure that it did not get hot. This proved that microwaves would pass through the material. Three circles of Plexiglas were cut, using a rotozip tool, to ensure perfect circles were formed. These circles were placed over three sections of the element rod and slid into the waveguide portion. The back washer was placed lined up with the N-type connector. This concluded the construction process of the antenna. A picture of the completely assembled antenna can be seen at top of next page.

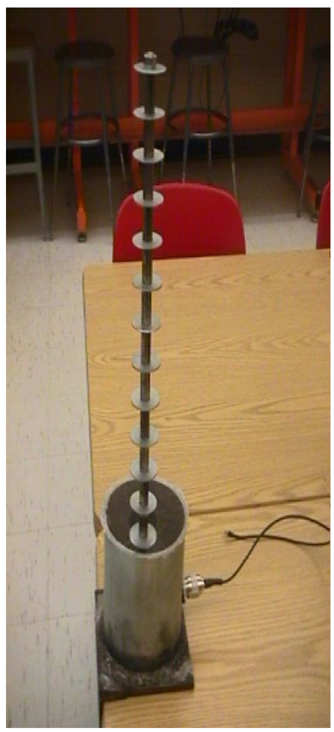

Figure 5: Completely Assembled Antenna

Testing & Performance

Once the antenna had been constructed, the testing phase of the project was executed. Testing of the antenna would be accomplished using the following setup. First, the antenna would be connected to an Orinoco 802.11b wireless network card. This connection required a special “pigtail” cable, allowing the signal to travel from our

N-type connector on the antenna to the Orinoco's proprietary MC connector. (See Figure 6) With the pigtail secured, our antenna functioned as an external antenna connected to the wireless card.

Figure 6. Type N to Orinoco MC Pigtail connector

Next, a software program called Netstumbler was used to measure the signal strength, gain, and other characteristics of our antenna. Netstumbler will automatically search for active wireless networks in the vicinity of the network card. For our test to succeed, we would have to first use Netstumbler to find a network. A brisk walk across Purdue's engineering mall was all Netstumbler needed to acquire 12 wireless access points, as seen in Figure 7. In order to calculate distance, we decided it would be best if the physical location of the access point was known. Lucky for us, Netstumbler was able to decode the access point description. We chose an access point with the description of EE246. (Electrical Engineering Building room 246) This gave us the exact physical location of the access point, and provided with a reasonable estimate of distance and direction. We estimated the distance to be approximately 70 yards to the room inside the building, and the direction was estimated to be 120 degrees SW.

With our target, the EE building, in clear site, we were able to devise a testing algorithm. We would first connect our antenna, point it towards our target, and monitor the signal strength, gain, and signal to noise ration using the software. We would next disconnect our antenna, forcing the card to rely on its internal omnidirectional antenna, and monitor the difference in signal strength, gain, and signal to noise ratio. Finally, we would test the directional properties of the antenna by varying the angle at which the antenna was pointed at the target. If there was any noticeable decline in signal strength, we would prove that the antenna was indeed directional as designed.

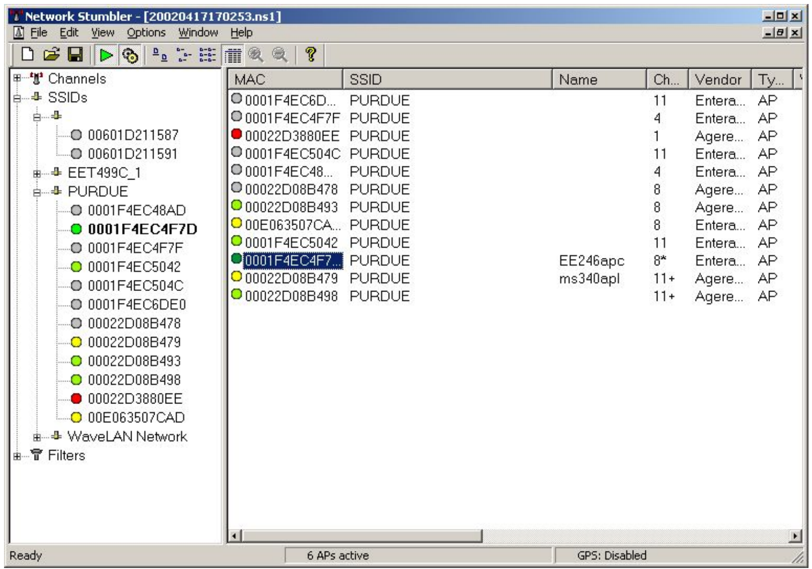

Figure 7. Detected Access Points

With the antenna pointed at our target, we began taking measurements. As seen in Figure 8, we first pointed our antenna toward the target until maximum gain was achieved. We next moved the antenna approximately 45 degrees horizontally, and then 90 degrees vertically, to test the directional properties. We saw that during a 45 degree horizontal shift, the gain decreased by approximately 25dBm. During the 90 degree vertical shift, the antenna was pointed towards the ground, with the end of the rod about three feet from the ground. The gain again dropped by a value of 27dBm. Next, we disconnected our antenna from the wireless card, forcing the card to use only its internal omnidirectional antenna, and looked for differences. We were happy and surprised to see a drop of approximately 20dBm when our antenna was disconnected. When we reconnected our antenna, the gain quickly jumped 20dBm from -79dBm to -59dBm. This proves that our antenna is performing as designed, with a gain of approximately 20dBm. Our signal to noise ratio remained constant while our antenna was connected, and increased slightly when the card’s internal antenna was being used.

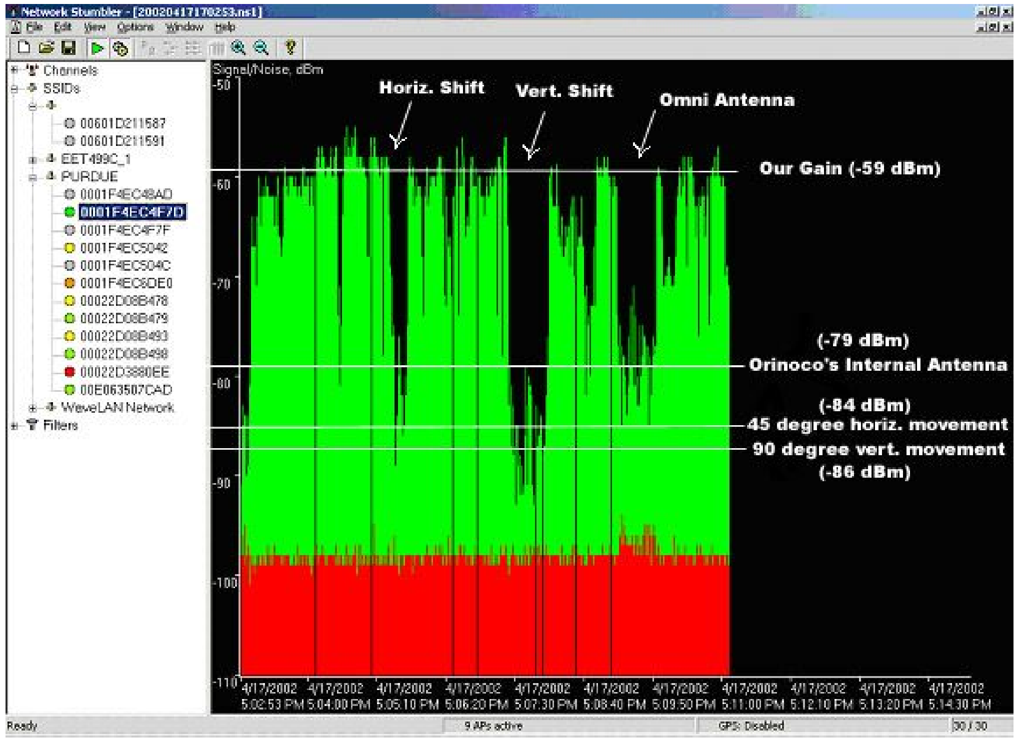

Figure 8. Actual Performance Results

Conclusion

Following the calculations and construction methods above, an efficient and highly directional disc-on-rod antenna may be constructed.