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Design of a Non-Pyramidal Modeled Waveguide Horn Antenna for WLAN 2.4 GHz Communication System

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***Abstract*—The indoor antenna characteristic measurement is usually affected by electromagnetic wave reflection and other signals interference which cause the strength of a received signal decreased or sometimes increased. With a standard scientific methodology i.e., literature review, analysis for antenna measurement, and design, we suggest a method for using a *Non-Pyramidal Modeled Waveguide Horn Antenna* as a transmission antenna or receiving antenna to reduce the effect of reflected waves and other signals interference in order to get a good received signal strength. Based on our research in Electrical Engineering Telecommunication Laboratory, in azimuth field the proposed antenna has a "power pattern" of -3.15 dB at 340^0 and of -2.48 dB at 20^0, so the HPBW is 40^0. In elevation field this antenna also has a "power pattern" of -3.59 dB at 340^0 and of -2.08 dB at 20^0, so the HPBW 40^0. These unidirectional radiation pattern characteristics give best output for WLAN 2.4 GHz communication system especially better design of transmission antenna and receiving antenna for internet network. A reliable internet network with wisely used parameters will support high quality communication and targeted information transfer that mainly contributes on improving people quality of life and the sustainability of environment.**

***Keywords*—Electromagnetic wave reflection, interference, horn antenna, power pattern, unidirectional**

I. Introduction

For a period of time the measurement of indoor antenna in Electrical Engineering Telecommunication Laboratory Universitas Katolik De La Salle Manado (Unika De La Salle Manado) was conducted using *λ/4 monopole antenna*. The antenna radiation pattern was *omnidirectional* which radiated the *multipath reflection* from everything that have conductive characteristic in that room or could be also the reflection from the laboratory walls (phenomena from *small-scale fading*) [11], so the result of signal measurement at receiver antenna did not appropriate with the signal strength that came directly from the transmitter antenna (*Line-of-Sight*).

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In addition, our laboratory does not have an anechoic chamber capable of absorbing electromagnetic waves on its walls so that no reflection occurs. A room like this is very expensive. That is why in this research we try to design a *Non-Pyramidal Modeled Waveguide Horn Antenna* that has a *unidirectional* radiation pattern to minimize the effect of electromagnetic wave reflection signals [9][10].

This *Horn* Antenna was made from aluminum sheet material that being formed into a rectangle shape which one of its front sides was emptied (no wall side), so it was formed a 'tunnel'. Driver for this antenna used *monopole λ/4* antenna that injected at the bottom side, *λ/2* distance from the back wall, as shown in figure 1. We purposely only used a waveguide, and did not use a 'tunnel' like a typical *Horn* Antenna. We did this to get the smallest possible antenna space angel beam. This *Horn* Antenna can be used as a transmitter antenna or receiver antenna for antenna characteristic measurement operates in WLAN 2.4 GHz communication system.

This proposed antenna has *Half Power Beam-Width* (HPBW) radiation pattern in 40^0 azimuth field and HPBW in 40^0 elevation field, which refers to *unidirectional* radiation pattern.

In communication system, signal strength of a received antenna is one of the important parameters that helps people around the world to communicate smoothly and uninterruptedly. So, with this great signal strength output and wise properly implementation, areas that usually have difficulty receiving internet signals have better expectation to receive reliable signals to support them in communication, learning process, and getting updated information.

II. Literature Study

Horn Antenna has been used in many applications as a *feed element* in parabolic antenna with wide diameter that usually used in radio astronomy, satellite tracking, and communication system found in all over the world [8][9]. Its wide applications were caused by its simple construction, easy to extracted, multi-function, high *antenna gain*, and the whole performance is preferred [9].

This designed *Horn* Antenna has a quite narrow HPBW (40^0), narrower from previous HPBW research (90^0) conducted by Mahendra Singh Meena and Ved Prakash [1], and narrower from HPBW (60^0) conducted by Stefania Diana, Danilo Brizi, and Agostino Monorchio [2].

A. *Waveguide*

Above 2 GHz, waveguides are short enough to allow practical and efficient energy transfer in different ways [3]. A waveguide is a conduction tube through which energy is emitted in the form of electromagnetic waves. The tube acts as a boundary that confines the waves in an enclosed space. Figure 1 below shows the waveguide.

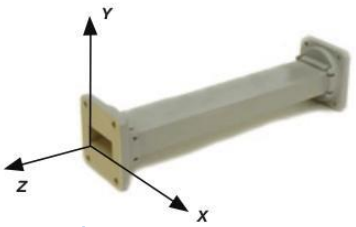

Figure 1. Dimension X, Y, and Z at a Rectangular Waveguide

The Faraday cage effect prevents electromagnetic effects from appearing outside the guide. The electromagnetic field is propagated through the waveguide by reflection against its inner wall, which is considered to be a perfect conductor. The field intensity is very large at the center along the *X* dimension, and must decrease to zero at the end of the wall because the presence of any field parallel to the wall at the surface can cause an infinite current to flow in a perfect conductor.

There are many ways for the electric and magnetic fields to regulate themselves in a waveguide for frequencies above the low cut-off frequency. Each field configuration is called a mode. These modes can be separated into two groups. The first, called TM (Transverse Magnetic), has a magnetic field that is completely transverse to the direction of propagation, but has an electric field component in the direction of propagation. The other type, called TE (Transverse Electric), has an electric field that is completely transverse, but has a magnetic field component in the direction of propagation.

The mode of propagation is identified by a group of letters followed by two numbers located below the line. For example, TE10 TM11, etc. The number of possible modes increases with frequency for a given waveguide size, and there is only one possible way, called dominant mode, for the lowest frequency to be transmitted. On a rectangular wavefront, the critical dimension is *X*. This dimension must be more than 0.5 at the lowest frequency to be transmitted. In practice, the *Y* dimension is usually made nearly equal to 0.5 *X* to avoid the possibility of operating at frequencies other than the dominant mode. In this study we used the TE10 mode.

If the waveguide is left open at one end, the waveguide will radiate energy so that the waveguide can be used as an antenna [5], not as a transmission path. This radiation can be increased by forming a pyramid at the open end of the waveguide so that it is in the form of a 'tunnel', therefore this antenna is called a 'tunnel' antenna or better known as a *Horn* Antenna which has a unidirectional radiation pattern [6]. But in this study, we did not use a pyramidal 'tunnel'. We do this to get a radiation pattern that has a narrow HPBW.

B. *Theoretical Basis*

The wavelength of (λ) *Electromagnetic* that propagates in free space can be calculated using the following equation 1 [10]:

$$\lambda = \frac{c}{f} \qquad (1)$$

where:
c: speed of light in free space ($3\text{x}10^8$ m/sec)
f: operation frequency (2.4 GHz)
λ: wavelength in free space (m)

For rectangular waveguide in this research, we used TE_{10} mode. *Cut-off* frequency can be calculated using the following equation 2 [9][10]:

$$f_c = \frac{1}{2a\sqrt{\mu_o \varepsilon_o}} \qquad (2)$$

where:
μ_o: air permeability
ε_o: air permittivity
α: length dimension *waveguide* (*X*)
f_c: *cut-off* frequency
The wavelength in *waveguide* can be calculated using equation 3 [9][10]:

$$\lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{\lambda}{\lambda_o}\right)^2}} \qquad (3)$$

where:
λ: wavelength in free space
λ_o: *cut-off* wavelength ($\lambda_o = 2X$)
λ_g: wavelength in *waveguide*

C. *Antenna Measurement*

There is an electromagnetic wave radiation pattern difference between outside of the antenna which divided into two regions, the field near the antenna, called the "near field" [4], or the Fresnel region, and the field at a distance from the antenna, called the "far field", or Fraunhofer region, as shown in figure 2 below:

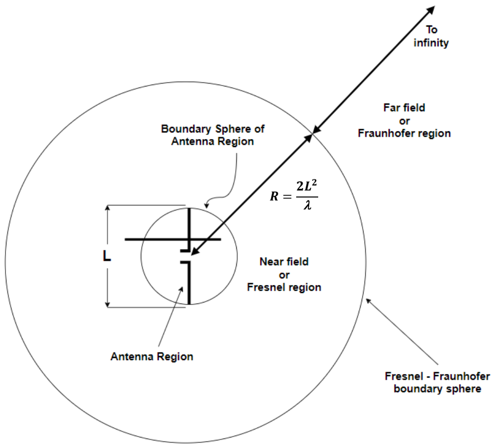

Figure 2. Antenna Regions: Fresnel region and Fraunhofer region

The boundary between these two regions is spherical with a radius in equation 4 [10]:

$$R = \frac{2\,L^2}{\lambda} \qquad (4)$$

where:

L: *boundary sphere of antenna region*
λ: wavelength in free space
R: Fresnel and Fraunhofer border radius

In Fraunhofer region, the components of the electric field (*E*) and magnetic field (*H*) are perpendicular to each other (transverse), and the shape of the field pattern is independent of the radius (radius) at which the measurement is taken. In the Fresnel region the field components *E* and *H* change considerably depending on the radius, and the shape of the field pattern is a function of the radius [10].

III. RESEARCH METHOD

Our research to design a non-Pyramidal modeled waveguide *Horn* antenna for WLAN 2.4 GHz communication system is based on a standard scientific methodology:

3.1. Literature Review

A literature study was conducted to collect related reading materials from textbooks and journal articles which can be used for theory and analysis. There were old textbooks had been used as reference because of their main contribution to the basic antenna measurement theories [9][10][11].

3.2. Analysis for Antenna Measurement

Analysis was carried out using formula of *Electromagnetic* wavelength, Cut-off frequency, and Waveguide wavelength. Then an electromagnetic wave radiation pattern difference between outside of the antenna (“near field” or Fresnel region and “far field” or Fraunhofer region) was calculated and set-up before measurement.

The antenna measurement used in this research is a radiation pattern measurement to measure the *Half-Power Beamwidth* (HPBW)

3.3. Antenna Design

Based on literature study and analysis, we designed a Non-Pyramidal Waveguide *Horn* Antenna that form a rectangular shape. To get the measurement result, we use supporting device: smartphone and spectrum analyzer. We did several observations for received power (dBm) and normalized (dB).

IV. RESULT AND DISCUSSION

The designed *Horn* antenna is very simple, has a rectangular shape made from aluminum where one of its front sides was open (no wall) and formed a ‘tunnel’ as described in the following figure 3:

The *Horn* Antenna has length (dimension *Z*) 20 cm, width (dimension *X*) 10 cm, and height (dimension *Y*) 5 cm. Based on (1) we could calculate the wavelength in free space λ = 12.5 cm, while the *cut-off* wavelength (λ_o = 2*X*) was 2 x 10 cm = 20 cm. Then refers to (3) we had wavelength in *waveguide* λ_g = 16 cm. This means that the length of the designed antenna (20 cm) is 1.25 λ_g. It was concluded that this length of our designed antenna was enough for electromagnetic wave propagation in *waveguide*.

Figure 3. *Horn* Antenna

The antenna measurement we used in this research is a radiation pattern measurement to measure the *Half-Power Beamwidth* (HPBW) because the goal for using this antenna is to avoid the reflection wave from the laboratory walls and devices inside the laboratory [7]. The radiation pattern measurement configuration can be seen in this following figure 4:

Figure 4. Radiation Pattern Measurement Configuration

We chose 2 meters for the distance between transmitter antenna and receiver, while the boundary between the Fresnel and Fraunhofer regions was based on equation (4), where L = 25 cm (the length of the antenna diagonal) and the wavelength in free space = 12.5 cm, the radius *R* = 1 m will be obtained. So, our measurements are already in the "far field" of the antenna, in the Fraunhofer region, where the components of the electric (*E*) and magnetic (*H*) fields are perpendicular to each other (transverse), and the shape of the field pattern is independent of radius again.

As a transmitter we used TP-Link TL-MR3420 access point, and as a receiver we used Rohde & Schwarz Spectrum Analyzer FSL18 to measure the received signal power.

Measurement has been done by rotating the *Horn* Antenna in 0^0, 10^0, 20^0, ….. , 360^0 angles at two polarization fields, i.e. azimuth field and elevation field [9][10].

The measurement results for the received signal power in azimuth field and elevation field are shown in table 1:

Table 1: *Power Pattern* in Azimuth Field and Elevation Field

Azimuth			Elevation		
Direction [°]	**Received Power [dBm]**	**Normalized [dB]**	**Direction [°]**	**Received Power [dBm]**	**Normalized [dB]**
0°	-62.16	0	0°	-61.87	0.00
10°	-62.71	-0.55	10°	-62.18	-0.31
20°	-64.64	-2.48	20°	-63.95	-2.08
30°	-68.35	-6.19	30°	-66.77	-4.90
40°	-70.85	-8.69	40°	-70.70	-8.83
50°	-72.23	-10.07	50°	-65.97	-4.10
60°	-71.36	-9.2	60°	-65.39	-3.52
70°	-71.3	-9.14	70°	-68.23	-6.36
80°	-70.9	-8.74	80°	-68.51	-6.64
90°	-70.45	-8.29	90°	-69.88	-8.01
100°	-66.68	-4.52	100°	-64.99	-3.12
110°	-65.56	-3.4	110°	-64.15	-2.28
120°	-66.14	-3.98	120°	-66.06	-4.19
130°	-71.55	-9.39	130°	-69.40	-7.53
140°	-66.82	-4.66	140°	-66.52	-4.65
150°	-66.4	-4.24	150°	-64.95	-3.08
160°	-65.06	-2.9	160°	-64.82	-2.95
170°	-67.69	-5.53	170°	-68.65	-6.78
180°	-65.23	-3.07	180°	-70.02	-8.15
190°	-65.38	-3.22	190°	-67.58	-5.71
200°	-65.23	-3.07	200°	-65.37	-3.50
210°	-65.18	-3.02	210°	-63.36	-1.49
220°	-66.56	-4.4	220°	-64.35	-2.48
230°	-71.33	-9.17	230°	-68.13	-6.26
240°	-68.8	-6.64	240°	-70.77	-8.90
250°	-65.72	-3.56	250°	-70.96	-9.09
260°	-65.4	-3.24	260°	-68.98	-7.11
270°	-69.08	-6.92	270°	-67.98	-6.11
280°	-68.13	-5.97	280°	-68.79	-6.92
290°	-70.14	-7.98	290°	-73.54	-11.67
300°	-68.02	-5.86	300°	-70.09	-8.22
310°	-67.81	-5.65	310°	-65.85	-3.98
320°	-71.03	-8.87	320°	-66.82	-4.95
330°	-67.25	-5.09	330°	-74.22	-12.35
340°	-65.31	-3.15	340°	-65.46	-3.59
350°	-63.98	-1.82	350°	-61.97	-0.10

The *Half-Power Beamwidth* (HPBW) measured in normalized received signal power was half of the received maximum power, or -3 dB [9][10]. From table 1 it is seen that in azimuth field, angle 20^0 and 340^0, the received signal power approaches -3 dB, so we concluded that the antenna HPBW in azimuth field is 40^0.

The radiation pattern in azimuth field is described in this following figure 5:

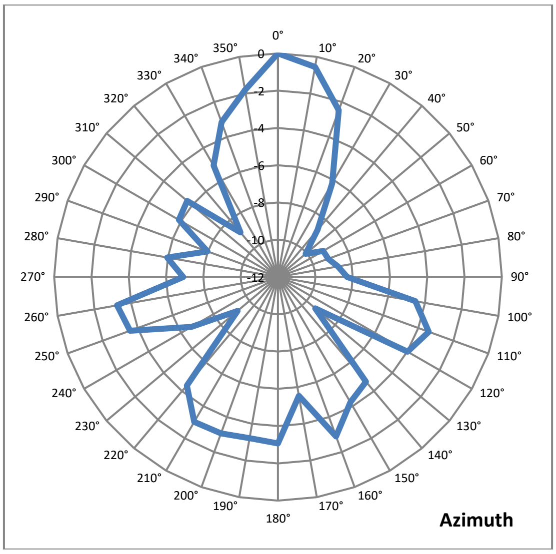

Figure 5. Radiation Pattern in Azimuth Field

Figure 5 shows the *Main Lobe* is occurred in 0 dB maximum received power, in 0^0 angle. *Side Lobe* is occurred in 110^0, 160^0, 210^0, and 260^0 angles that caused by *multi-reflections* from walls and devices inside the laboratory room, that is also occurred for *Back Lobe* in 180^0 angle.

In elevation field, angle 20^0 and 340^0, the received signal power approaches -3 dB, so we concluded that antenna HPBW in elevation field is 40^0.

The radiation pattern in elevation field can be seen in this figure 6:

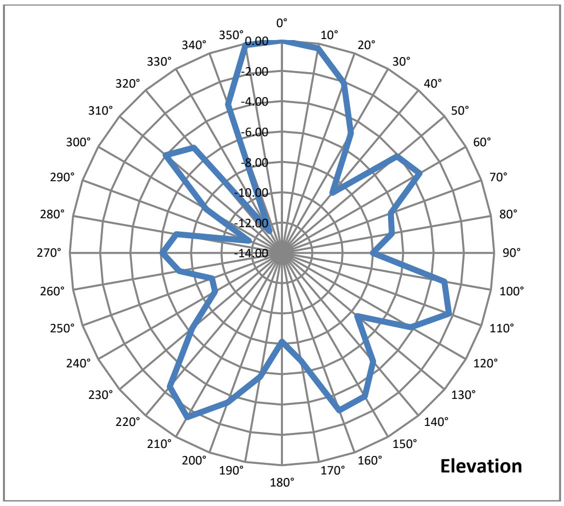

Figure 6. Radiation Pattern in Elevation Field

Figure 6 shows that *Main Lobe* is occurred in 0^0 angle. *Side Lobe* is occurred in 60^0, 110^0, 160^0, 210^0, 270^0, and 310^0 angles caused by *multi-reflections* from walls and devices inside the laboratory room.

The measurement results confirm that our designed *Horn* Antenna has better performance of HPBW (40^0), narrower from previous HPBW research (90^0) conducted by Mahendra Singh Meena and Ved Prakash [1], and narrower from HPBW (60^0) conducted by Stefania Diana, Danilo Brizi, and Agostino Monorchio [2].

V. Conclusion

The new waveguide *Horn* antenna with non-Pyramidal model can be proposed for WLAN 2.4 GHz communication system, which is applicable as a transmitter antenna or receiver antenna.

The measurement results and antenna prototype have been informed in this research and the effect of *Horn* Antenna parameter in the received radiation pattern also has been analyzed and suitable for *unidirectional* antenna application for WLAN system antenna measurement.

Both in azimuth field or elevation field, the radiation pattern of the proposed antenna fulfills the requirement of 2.4 GHz for WLAN operation. This *Horn* Antenna has HPBW 40^0 in azimuth field and HPBW 40^0 in elevation field that can overcome the occurring of small-scale fading caused by reflections of walls and devices inside Telecommunication laboratory room.

The usage of this *Horn* antenna in WLAN system antenna measurement can be used as an alternative replacement for the usage of anechoic chamber that usually costly, and also alternative design for reliable communication system.

Future works can be conducted for designing a long 'tunnel' rectangular shape to achieve narrower HPBW and just very few *reflections* that perfectly generate a strong signal strength.

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