A UNIDIRECTIONAL ANTENNA USING A PROBE EXCITED CIRCULAR RING ABOVE CYLINDRICAL REFLECTOR

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หัวข้อวิทยานิพนธ์	สายอากาศทิศทางเดียวที่ใช้วงแหวนวงกลมกระตุ้นด้วยโพรบวางเหนือแผ่นสะท้อนทรงกระบอก
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บทคัดย่อ

วิทยานิพนธ์นี้นำเสนอสายอากาศที่มีการแพร่กระจายคลื่นทิศทางเดียวที่มีโครงสร้างประกอบด้วยวงแหวนวงกลมล้อมรอบโพรบที่ป้อนสัญญาณเหนือแผ่นสะท้อนทรงกระบอก การประยุกต์ใช้งานสายอากาศชนิดนี้ได้แก่การประยุกต์ใช้เป็นสายอากาศสำหรับการสื่อสารไร้สายแบบจุดต่อจุดระหว่างอาคาร ที่ความถี่ 2.45 GHz ระยะห่างระหว่างแผ่นสะท้อนทรงกระบอกและโพรบ ความยาวของโพรบและค่าพารามิเตอร์ต่างๆที่ใช้สำหรับออกแบบและคำนวณเพื่อให้ได้สายอากาศทิศทางเดียวนั้นใช้ซอฟต์แวร์ CST® (Microwave Studio) เพื่อจำลองคุณลักษณะของสายอากาศ นอกจากนั้นยังออกแบบสายอากาศทิศทางเดียวภายใต้เงื่อนไขที่มีโพลาไรซ์เป็นแบบวงกลมซึ่งมีความสำคัญสำหรับการปรับปรุงคุณภาพของสัญญาณ โดยวงแหวนวงกลมด้านในได้ใช้สตับเพื่อปรับการแมตชิ่งอิมพีแดนซ์ส่วนโพรบนั้นถูกครอบด้วยแท่งไดอิเล็กตริกและส่วนด้านปลายของโพรบที่ป้อนสัญญาณถูกปรับให้โค้งงอ เพื่อให้การแพร่กระจายคลื่นของสายอากาศนั้นเป็นโพลาไรซ์แบบวงกลม นอกเหนือจากนั้นเพื่อขยายช่วงกว้างแถบความถี่ตลอดช่วงกว้างความถี่ที่ใช้งานตั้งแต่ 3.1 – 10.6 GHz สำหรับการให้บริการในช่วงความถี่กว้างยิ่งยวด (Ultra wideband-UWB) ดังนั้นจึงได้นำเสนอสายอากาศวงแหวนวงกลมที่ป้อนด้วยโมโนโพลแผ่นวงกลมวางเหนือแผ่นสะท้อนทรงกระบอกที่มีแบบรูปการแพร่กระจายคลื่นทิศทางเดียวเพื่อประยุกต์ใช้ในช่วงกว้างแถบความถี่กว้างยิ่งยวด

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ABSTRACT

This thesis concerns about a unidirectional antenna from a probe that is used to excite circular ring above the cylindrical reflector. One application of this antenna is for the point to point wireless Local Area Network communication systems between the buildings. The operating frequency of this antenna is 2.45 GHz. The distance between the cylindrical reflector and probe, the probe length, and the design parameters obtaining a unidirectional pattern can be determined by using the CST® (Microwave Studio) Software for investigating the antenna characteristics. In addition, the unidirectional beam antenna with the circular polarization is significant to improve the signal quality. For impedance matching, the circular ring contains the stub, and the probe has been shielded by the dielectric rod. At the end of probe, it has been bent for identical magnitude with quadrature phase excitation for circularly polarized radiation. Furthermore, to enhance the bandwidth, the frequency range 3.1-10.6 GHz is of interest for UWB service, and thus a UWB antenna will be employed in this band using a circular ring antenna excited by circular disc monopole above cylindrical reflector whose radius is the same as that structure is also proposed. The configuration can be constructed using that the same exterior as the circular ring antenna excited by linear probe above the cylindrical reflector. Finally, a prototype of the antenna is shown.

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Souphanna Vongsack

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continue)

Page

TABLE OF CONTENTS (Continue)

TABLE OF CONTENTS (Continue)

LIST OF TABLES

Table Page

LIST OF FIGURES

Fig. Page

LIST OF FIGURES (Continue)

LIST OF FIGURES (Continue)

Chapter 1

Introduction

1.1 Rationale

Nowadays, the wireless communications have grown rapidly. It plays a vital role, and it has become an important part of the daily life [1]. It is well-known that the antenna is a significant part of wireless system to make the communication successfully. In microcell communication systems, when base stations are placed in urban areas, many of these base stations are set up in locations lower than the surrounding buildings. In this situation, cells are located along the street and are called "street cell" [2]. The conventional antenna for the wireless Local Area Network (WLAN) communication system radiates the omnidirectional beam. However, on the long and narrow path service areas such as the communication between the buildings the unidirectional antenna is more suitable. If the antenna pattern can be restricted to the narrow path, the coverage area can be enhanced. The directional radiation pattern along the street is suitable for the street cell [3]. Particularly from literature review, we found that the directional antenna for WLAN communication system is necessary. The investigation of unidirectional antenna with high gain for point-to-point communication is very useful. The conventional unidirectional antennas are made by a probe excited circular ring antenna above reflector. Moreover, many researches and developments on unidirectional antenna have been continuously conducted. Some of works are cited as the following literature.

Generally, it is desirable for the antenna to possess the high gain, low side lobe level and narrow beamwidth. Hence, many researches and continuous developments of these antennas published in literature [4]. The unidirectional beam is obtained by using microstrip antenna with fundamental mode [5], horn antenna [6], reflector antenna [7], and others. Moreover, the unidirectional antenna can be achieved by using some specific antenna that is arranged to form the array configuration [8]-[9].

Historically, the probe excited circular ring is designed to radiate the bidirectional pattern [10]-[12]. On the other hand, the unidirectional pattern is carried out by placing the antenna above the reflector or ground plane. To realize the unidirectional beam, the reflector should be placed near one side of the ring aperture [13]-[14], which is easily fabricated and has low production cost. Unfortunately, it was found that the front-to-back ratio is not sufficient, and the directivity is not so high. Another development of a unidirectional antenna by using a probe excited circular ring antenna above cylindrical reflector can be made. However, this thesis proposes to improve the directivity and reduce the back lobe and use the low cost material available in the market to make more feasibly of the mass production.

Most unidirectional antenna has complicated structure that makes it expensive. According to requirement of low-cost unidirectional antenna, the use of probe excited circular ring above cylindrical reflector is proposed. In this regard, it is expected that a bidirectional pattern can be modified to a unidirectional one. However, it is necessary to know the appropriate dimensions of the ring that provides the desirable characteristics, i.e., maximum gain, low side lobe, narrow beamwidth, compact structure and especially low cost. Therefore, a unidirectional antenna using a probe excited circular ring above cylindrical reflector was modeled to investigate its characteristics by using CST® (Microwave Studio). Once the radiated field from this structure is obtained, the radiation patterns can be analyzed. Then, the optimum dimension that provides the maximum gain with compact size is achieved. Furthermore, impedance characteristic is investigated to match the antenna with the transmission line. Although the unidirectional antenna using a probe excited circular ring above cylindrical reflector is simple for modeling, practically it is found that the unidirectional antenna with circular polarization is interesting to improve the signal quality from polarization change. It can be mass produced conveniently. The circular ring uses the stub for impedance matching, and the probe is also shielded by dielectric rod. At the end of probe, it was bent for identical magnitude with quadrature phase excitation for circularly polarized radiation. Moreover, the second approach on the development of the circular ring antenna with unidirectional beam and circular polarization is proposed. In this way, we proposes a bent probe excited circular ring antenna above the cylindrical reflector radiating circular polarization for the point-to-point wireless LAN communication system. It is evident that the unidirectional antenna using a probe excited circular ring above cylindrical reflector can be designed and it provides the satisfactory characteristics, both technically and economically. Especially the structure of a circular ring antenna above cylindrical reflector with ultra-wideband is more interesting. Furthermore, to enlarge the bandwidth covering the frequency range of 3.1-10.6 GHz for ultra-wideband applications by using circular disc monopole excited circular ring antenna above cylindrical reflector. The configuration can be constructed using that the similar procedure as the circular ring antenna excited by linear probe. The feeding surface dipole is suitable structure to enhance the bandwidth but radiate omnidirectional pattern [15]-[19]. This antenna type can radiate unidirectional beam with simple feeder and low cost components. The antenna design is described in detail and investigated in terms of return loss/impedance bandwidth and radiation pattern. Computer Simulation Technology (CST®) was used for design and simulation.

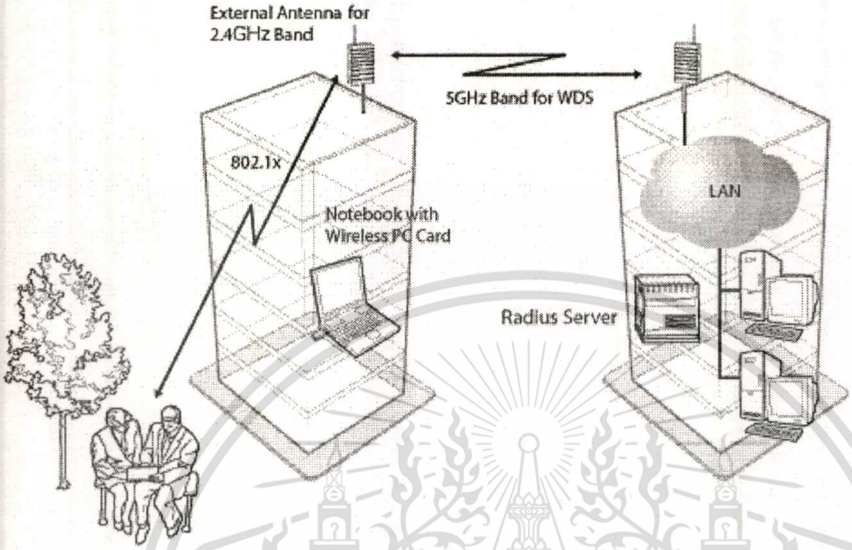


Fig. 1.1 (a) The wireless communication between the buildings

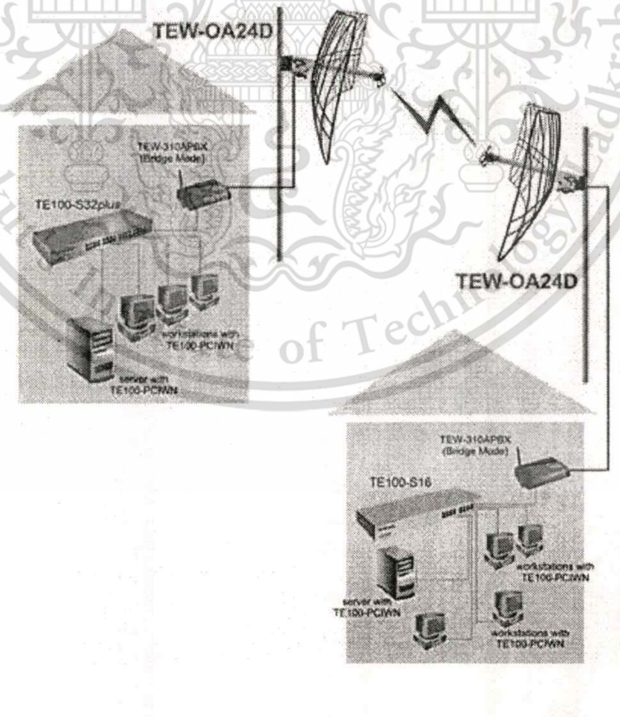


Fig. 1.1 (b) Point-to-point communications

Fig. 1.1 Wireless Local Area Network (WLAN) communication systems

1.2 The Objective and Scope of the Thesis

To fulfill the purpose of this thesis, numerous works must be carried out both theoretically and experimentally. They are summarized as follow:

Chapter 2 introduces the model of the unidirectional antenna using a probe excited circular ring above cylindrical reflector.

Chapter 3 presents the simulation of a unidirectional antenna using a probe excited circular ring above cylindrical reflector. The field in a circular ring, radiation pattern, directivity and impedance bandwidth is analyzed in terms of antenna parameters, such as radius and length of circular ring, radius and length of cylindrical reflector, probe length and distance between probe and reflector. These results are shown in figures and variations of their characteristics on frequency are also discussed. For this chapter the proposed antenna are divided into three models. The first model is a unidirectional antenna using a probe excited circular ring above the cylindrical reflector. It is expected that a bidirectional pattern can be modified to a unidirectional one. The structures are designed by using CST$^{(R)}$ (Microwave Studio) for investigating the antenna characteristics. The proposed antenna is operated at the frequency of 2.45 GHz for point-to-point communication system. Moreover, the good radiation characteristics of the proposed antenna have been obtained that is vertical polarization, front-to-back ratio in both in E-plane and H-plane and large bandwidth of better than 20 dB. Moreover, the unidirectional beam antenna that provides the circular polarization is interesting to improve the signal quality from polarization change. Hence, the second model, the development of the circular ring antenna with unidirectional beam and circular polarization is proposed. In this way, this chapter proposes a bent probe excited circular ring antenna above the cylindrical reflector radiating circular polarization for the point-to-point wireless LAN communication system. Moreover, the third model, to enlarge the bandwidth the frequency range 3.1-10.6 GHz is of interest for ultra-wideband service, and thus a ultra-wideband antenna will be employed in this band. A unidirectional antenna using circular disc monopole excited circular ring above cylindrical reflector is presented. The configuration can be constructed using the similar procedure as a unidirectional antenna using a probe excited circular ring above cylindrical reflector.

Chapter 4 applies the analysis results in chapter 3 to fabricate a unidirectional antenna using a probe excited circular ring above cylindrical reflector. The antenna structure can be fabricated easily and straightforwardly by choosing the appropriate parameters. Validation of the model of the antenna was conducted by comparing the simulated with measured results.

Experimental results such as radiation patterns, impedance bandwidth, gain and axial ratio are illustrated.

Chapter 5 the bandwidth enhancement will be realized by using circular disc monopole excitation. This chapter presents the simulation of a unidirectional antenna using a circular disc monopole excited circular ring antenna above cylindrical reflector. The content of this chapter is presented in five sections such as antenna structure that described about the configuration of antenna. Then, the parametric study and summary of the antenna parameters, radiation pattern, directivity, and impedance bandwidth are analyzed. Ultimately, the final section is concluded.

Chapter 6 summarizes the consequence of the preceding chapters with the discussion of the future studies.

Chapter 2

Principle of a Unidirectional Antenna Using a Probe Excited Circular Ring above Cylindrical Reflector

2.1 Introduction

To describe the performance of an antenna, definitions of various parameters are necessary. Some of parameters are interrelated and not all of them need to be specified for completed description of the antenna performance. Radiation characteristics such as radiation pattern and directivity are important in wireless communication.

2.2 Principle of Antenna

2.2.1 Fundamental Parameters of Antenna

2.2.1.1 Radiation Pattern

An antenna radiation pattern or antenna pattern is defined as "a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. In most cases, the radiation pattern is determined in the far-field region and is represented as a function of the directional coordinates. Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization." The radiation property of most concern is the two- or three- dimensional spatial distribution of radiated energy as a function of the observer's position along a path or surface of constant radius. A trace of the received electric (magnetic) field at a constant radius is called the amplitude field pattern. On the other hand, a graph of the spatial variation of the power density along a constant radius is called an amplitude power pattern. Often the field and power patterns are normalized with respect to their maximum value, yielding normalized field and power patterns.

A major lobe (also called main beam) is defined as "the radiation lobe containing the direction of maximum radiation." The major lobe is pointing in the $\theta = 0$ direction. In some antennas, such as split-beam antennas, there may exist more than one major lobe.

A minor lobe is any lobe except a major lobe and all the lobes with the exception of the major can be classified as minor lobes.

A side lobe is "a radiation lobe in any direction other than the intended lobe." (Usually a side lobe is adjacent to the main lobe and occupies the hemisphere in the direction of the main beam.)

A back lobe is "a radiation lobe whose axis makes an angle of approximately 180° with respect to the beam of an antenna". Usually it refers to a minor lobe that occupies the hemisphere in a direction opposite to that of the major (main) lobe.

Minor lobes usually represent radiation in undesired directions, and they should be minimized. Side lobes are normally the largest of the minor lobes. The level of minor lobes is usually expressed as a ratio of the power density in the lobe in question to that of the major lobe. This ratio is often termed the side lobe ratio or side lobe level. Side lobe levels of -20 dB or smaller are usually not desirable in most applications.

2.2.1.2 Field Regions

The space surrounding an antenna is usually subdivided into three regions:

1. Reactive near-field region
2. Radiating near-field (Fresnel) region
3. Far-field (Fraunhofer) region

Reactive near-field region is defined as "that portion of the near-field region immediately surrounding the antenna wherein the reactive field predominates." For most antennas, the outer boundary of this region is commonly taken to exist at a distance $R < 0.62\sqrt{D^3/\lambda}$ from the antenna surface, where λ is wavelength and D is the largest dimension of the antenna.

Radiating near-field (Fresnel) region is defined as "that region of the field of an antenna between the reactive near-field region and the far-field region wherein radiation fields predominate and wherein the angular field distribution is dependent upon the distance from the antenna. If the antenna has a maximum dimension that is not large compared to the wavelength, this region may not exist. For an antenna focused at infinity, the radiating near-field region is sometimes referred to as the Fresnel region on the basis of analogy to optical terminology. If the antenna has a maximum overall dimension which is very small compared to the wavelength, this field region may not exist." The inner boundary is taken to be the distance $R \geq 0.62\sqrt{D^3 / \lambda}$ and the outer boundary the distance $R < 2D^2 / \lambda$ where D is the largest (to valid, D must also be large compared to the wavelength ($D > \lambda$)) dimension of the antenna.

Far-field (Fraunhofer) region is defined as "that region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna. If the antenna has a maximum (to be valid, D must also be large compared to the wavelength ($D > \lambda$)) overall dimension D, the far-field region is commonly taken to exist at distances greater than $2D^2/\lambda$ from the antenna, λ being the wavelength. In this region, the field components are essentially transverse and the angular distribution is dependent of the radial distance where the measurements are made. The inner boundary is taken to be the radial distance $R = 2D^2/\lambda$ and the outer one at infinity.

2.2.1.3 Radiation intensity

Radiation intensity in a given direction is defined as "the power radiated from an antenna per unit solid angle." The radiation intensity is a far-field parameter, and it can be obtained by simply multiplying the radiation density by the square of the distance. In mathematical form it is expressed as

$$U = r^2 W_{\text{rad}} \tag{2.1}$$

Where

U = radiation intensity (W/unit solid angle)

W_{rad} = radiation power density (W/m^2)

The radiation intensity is also related to the far-zone electric field of an antenna by

$$\begin{aligned} U(\theta,\phi) &= \left(r^2/2\eta\right)\left|E(r,\theta,\phi)\right|^2 \\ &= \left(r^2/2\eta\right)\left[\left|E_\theta(r,\theta,\phi)\right|^2 + \left|E_\phi(r,\theta,\phi)\right|^2\right] \end{aligned} \tag{2.1a}$$

Where

$E(r, \theta, \phi)$ = far-zone electric-field intensity of the antenna

E_θ, E_ϕ = far-zone electric-field components of the antenna

η = intrinsic impedance of the medium

The radial electric-field component (E_r) is assumed, if present, to be small in the far-zone. Thus the power pattern is also a measure of the radiation intensity.

The total power is obtained by integrating the radiation intensity, as given by (2.2), over the entire solid angle of 4π. Thus

$$P_{rad} = \oiint_{\Omega} U d\Omega = \int_{0}^{2\pi}\int_{0}^{\pi} U \sin\theta d\theta d\phi \tag{2.2}$$

Where $d\Omega$ = element of solid angle = $\sin\theta d\theta d\phi$.

2.2.1.4 Directivity

Basically the term directivity in the new 1983 version has been used to replace the term directive gain of the old 1973 version. In the new 1983 version the term directive gain has been deprecated. Therefore directivity of an antenna defined as "the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. The average radiation intensity is equal to the total power radiated by the antenna divided by 4π. If the directional is not specified, the directivity of a nonisotropic source is equal to the ratio of its radiation intensity in a given direction over that of an isotropic source.

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}} \tag{2.3}$$

If the direction is not specified, it implies the direction of maximum radiation intensity (maximum directivity) expressed as

$$D_{\max} = D_0 = \frac{U|_{\max}}{U_0} = \frac{U_{\max}}{U_0} \frac{4\pi U_{\max}}{P_{rad}} \tag{2.3a}$$

D = directivity (dimensionless)

D_0 = maximum directivity (dimensionless)

U = radiation intensity (W / unit solid angle)

$U_{\max}$ = maximum radiation intensity (W / unit solid angle)

U_0 = radiation intensity of isotropic source (W / unit solid angle)

P_{rad} = total radiated power (W)

For an isotropic source, it is very obvious from (2.3) or (2.3a) that the directivity is unity since U, $U_{\max}$, and U_0 are all equal to each other.

For antennas with orthogonal polarization components, we define the partial directivity of an antenna for a given polarization in a given direction as "that part of the radiation intensity corresponding to a given polarization divided by the total radiation intensity averaged over all directions." With this definition for the partial directivity, then in a given direction "the total directivity is the sum of the partial directivities for any two orthogonal polarizations." For a spherical coordinate system, the total maximum directivity D_0 for the orthogonal θ and ϕ components of an antenna can be written as

$$D_0 = D_\theta + D_\phi \tag{2.4}$$

While the partial directivities D_θ and D_ϕ are expressed as

$$D_\theta = \frac{4\pi U_\theta}{(P_{rad})_\theta + (P_{rad})_\theta} \tag{2.4a}$$

$$D_\phi = \frac{4\pi U_\theta}{(P_{rad})_\theta + (P_{rad})_\theta} \tag{2.4b}$$

Where

U_θ = radiation intensity in a given direction contained in θ field component

U_ϕ = radiation intensity in a given direction contained in ϕ field component

$(P_{\text{rad}})_\theta$ = radiated power in all directions contained in θ field component

$(P_{\text{rad}})_\phi$ = radiated power in all directions contained in ϕ field component

These can also be used for design purposes. For antennas with one narrow major lobe and very negligible minor lobes, the beam solid angle is approximately equal to the product of the half-power beamwidths in two perpendicular planes

$$D_0 = \frac{4\pi}{\Omega_A} \cong \frac{4\pi}{\Theta_{1r}\Theta_{2r}} \tag{2.5}$$

The beam solid angle Ω_A has been approximated by

$$\Omega_A = \Theta_{1r} = \Theta_{2r} \tag{2.5a}$$

Where

Θ_{1r} = Half-power beamwidth in one plane (rad)

Θ_{2r} = Half-power beamwidth in a plane at a right angle to the other (rad)

If the beamwidths are known in degrees, (2.5) can be written as

$$D_0 = \frac{4\pi(180/\pi)^2}{\Theta_{1r}\Theta_{2r}} \tag{2.6}$$

Θ_{1d} = Half-power beamwidth in one plane (degrees)

Θ_{2d} = Half-power beamwidth in a plane at a right angle to the other (degrees)

2.2.1.5 Gain

Another useful measure describing the performance of an antenna is the gain. Although the gain of the antenna is closely related to the directivity, it is a measure that takes into account the efficiency of the antenna as well as its directional capabilities. Remember that directivity is a measure that describes only the directional properties of the antenna, and it is therefore controlled only by the pattern.

Gain of an antenna (in a given direction) is defined as "the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically. The radiation intensity corresponding to the isotropically radiated power is equal to the power accepted (input) by the antenna divided by 4π." From this definition it can be expressed as

$$G = 4\pi \frac{U(\theta,\phi)}{P_{in}} \qquad \text{(dimensionless)} \tag{2.7}$$

In most cases we deal with relative gain, which is defined as "the ratio of the power gain in a given direction to the power gain of a reference antenna in its referenced direction." The power input must be the same for both antennas. The reference antenna is usually a dipole, horn, or any other antenna whose gain can be calculated or it is known. In most cases, however, the reference antenna is a lossless isotropic source. Thus

$$G = \frac{4\pi U(\theta,\phi)}{p_{in}} \qquad \text{(dimensionless)} \tag{2.8}$$

The total radiated power (P_{rad}) is related to the total input power (P_{in}) by

$$P_{rad} = e_t P_{in} \tag{2.9}$$

Where e_t is the antenna radiation efficiency (dimensionless) which is defined as

$$G(\theta,\phi) = e_t\left[\frac{4\pi U(\theta,\phi)}{p_{rad}}\right] \tag{2.10}$$

This is related to the directivity by

$$G(\theta,\phi) = e_t D(\theta,\phi) \tag{2.11}$$

In the similar manner, the maximum value of the gain is related to the maximum directivity by

$$G_0 = G(\theta,\phi)\big|_{\max} = e_t D(\theta,\phi)\big|_{\max} = e_t D_0 \tag{2.11a}$$

For many practical antennas an approximate formula for the gain is

$$G_o \cong \frac{30{,}000}{\Theta_{1d}\Theta_{2d}} \tag{2.12}$$

2.2.1.6 Antenna Efficiency

The total antenna efficiency e_0 is used to take into account the losses at the input terminals and within the structure of the antenna. In general, the overall efficiency can be written as

$$e_0 = e_r e_c e_d \tag{2.13}$$

Where

e_0 = total efficiency (dimensionless)

e_r = reflection (mismatch) efficiency = $(1 - |\Gamma|^2)$ (dimensionless)

e_c = conduction efficiency (dimensionless)

e_d = dielectric efficiency (dimensionless)

Γ = voltage reflection coefficient at the input terminals of the antenna

[$\Gamma = \dfrac{Z_{in} - Z_0}{Z_{in} + Z_0}$ Where Z_{in} = antenna input impedance,

Z_0 = characteristic impedance of the transmission line]

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|}$$

Usually e_c and e_d are very difficult to compute, but they can be determined experimentally. Even by measurements they cannot be separated, and it is usually more convenient to write as

$$e_t = e_r e_{cd} = e_{cd}(1-|\Gamma|^2) \tag{2.14}$$

Where $e_{cd} = e_c e_d$ = antenna radiation efficiency, which is used to relate the gain and directivity.

2.3 Circular Polarization Realization

According to the total field radiated by this antenna, the resultant electric field can be expressed as

$$E_x(x,y,z) = -\frac{\omega\mu J_m}{ab} \sum_{m=0,1,\ldots}^{\infty} \sum_{n=0,1,\ldots}^{\infty} \frac{e^{-jk_z|z-z'|}}{k_z} \cos\left(\frac{m\pi}{2}\right) \cos\left(\frac{m\pi(x+a/2)}{a}\right) \sin\left(\frac{n\pi(y+b/2)}{b}\right)$$
$$\times \left\{ \frac{1}{X}\left[\sin\left(\frac{n\pi l}{b}\right) - \sin(kl)\right] + \frac{1}{Y}\left[\sin\left(\frac{n\pi l}{b}\right) + \sin(kl)\right]\right\} \tag{2.14a}$$

$$E_y(x,y,z) = -\frac{\omega\mu J_m}{ab}\sum_{m=0,1,\ldots}^{\infty}\sum_{n=0,1,\ldots}^{\infty}\frac{e^{-jk_z|z-z'|}}{k_z}\sin\left(\frac{m\pi}{2}\right)\sin\left(\frac{m\pi(x+a/2)}{a}\right)\cos\left(\frac{n\pi(y+b/2)}{b}\right)$$
$$\times\left\{\frac{1}{X}\left[\cos\left(\frac{n\pi l}{b}\right)-\cos\left(kl\right)\right]+\frac{1}{Y}\left[\cos\left(\frac{n\pi l}{b}\right)+\cos\left(kl\right)\right]\right\}$$

(2.14b)

$$E_z(x,y,z) = -\frac{\omega\mu J_m}{ab}\sum_{m=0,1,\ldots}^{\infty}\sum_{n=0,1,\ldots}^{\infty}\frac{e^{-jk_z|z-z'|}}{k_z}\sin\left(\frac{m\pi}{2}\right)\sin\left(\frac{m\pi(x+a/2)}{a}\right)\sin\left(\frac{n\pi(y+b/2)}{b}\right)$$
$$\times\left\{\frac{1}{X}\left[\sin\left(\frac{n\pi l}{b}\right)-\sin\left(kl\right)\right]+\frac{1}{Y}\left[\sin\left(\frac{n\pi l}{b}\right)+\sin\left(kl\right)\right]\right\}$$

(2.14c)

$$\overline{E} = E_x\hat{a}_x + E_y\hat{a}_y + E_z\hat{a}_z \qquad (2.14d)$$

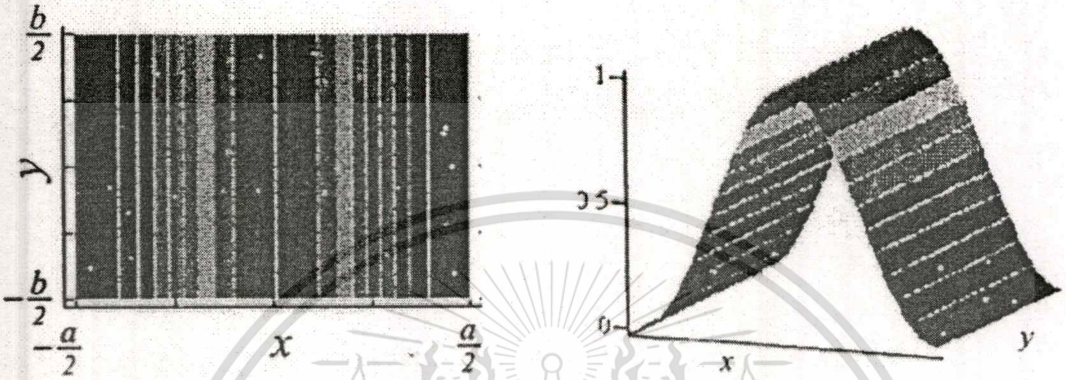
Where $X = k - \frac{n\pi}{b}$ and $Y = k + \frac{n\pi}{b}$

It should be pointed out that the proposed structure has E_x and E_y which contribute to the radiation, but E_x has very low coefficient compared to E_y. Hence, it is obvious that only E_y is the component that radiates. E_z does not contribute to the radiation since direction is normal to the aperture.

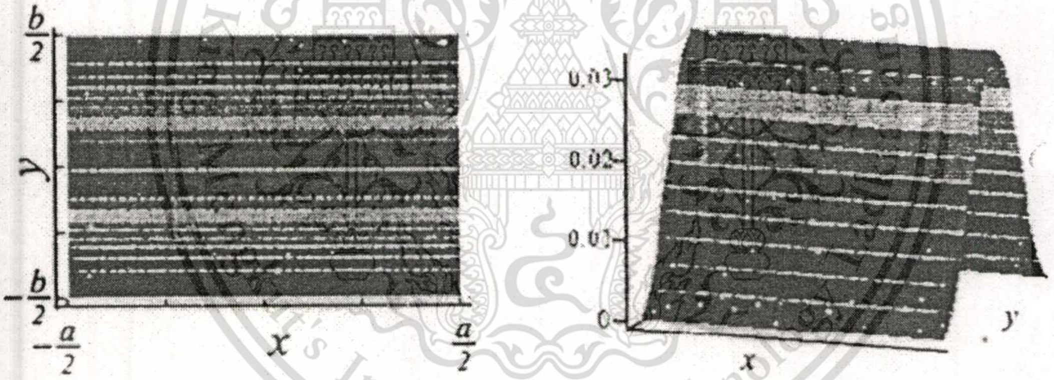
The far field pattern of the antenna can be expressed by neglecting mutual coupling, as a superposition of the fields from these two apertures. Since the fields radiated from the two apertures have the same phase but in opposite directions; therefore, as they are combined, the resultant field can be written as

$$\overline{E}(\overline{r}) = \overline{E}(\overline{r})\cdot 2\sin\left[\frac{1}{2}\left(kc\cos\theta + k_z c\right)\right] \qquad (2.15)$$

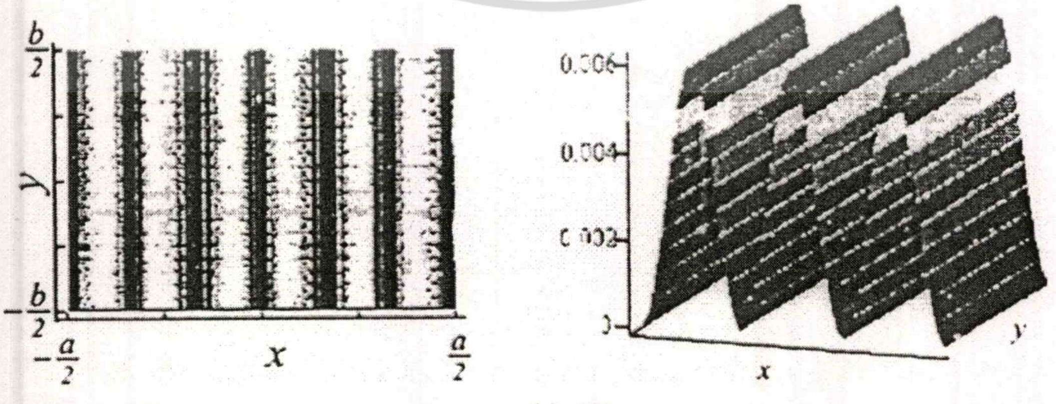
According to the total field radiated by this antenna as shown in (2.14)-(2.15), it is obvious that the radiation characteristics of the antenna depend on the following parameters, i.e., the probe length (*l*), the ring width (*a*), the ring height (*b*) and the ring length (*c*). Since the antenna structure is the same as a rectangular waveguide, in this circumstance the width and the height of the ring are chosen to be the dimension of a standard waveguide operating at a dominant TE_{10} mode. However, if the ring length is short, the field at the aperture which is close to the probe will consist of several modes and the evanescent wave of the higher order modes near the probe still have a significant level. Therefore, they contribute to the aperture field and, consequently, the radiated field. For the waveguide dimension of $a = 0.69\lambda$, $b = 0.35\lambda$, $l = 0.28\lambda$, the aperture field distribution of TE_{10} (E_y component), TE_{01} (E_x component) and TE_{30} (E_y component) wave are illustrated in Fig. 2.1 (a) – (c) respectively.



(a) TE_{10}



(b) TE_{01}



(c) TE_{30}

Fig. 2.1 Aperture power distribution

2.3.1 Polarization

Polarization of an antenna in a given direction is defined as "the polarization of the wave transmitted (radiated) by the antenna. When the direction is not stated, the polarization is taken to be the polarization in the direction of maximum gain." In practice, polarization of the radiated energy varies with the direction from the center of the antenna, so that different parts of the pattern may have different polarizations. The necessary and sufficient conditions that the wave must have in order to possess linear, circular or elliptical polarization are as following.

2.3.1.1 Linear Polarization

A time-harmonic wave is linearly polarized at a given point in space if the electric-field (or magnetic-field) vector at that point is always oriented along the same straight line at every instant of time. This is accomplished if the field vector (electric or magnetic) possesses:

a. Only one component, or

b. Two orthogonal linear components that are in time phase or 180° (or multiples of 180°) out-of-phase.

2.3.1.2 Circular Polarization

A time-harmonic wave is circularly polarized at a given point in space if the electric (or magnetic) field vector at that point traces a circle as a function of time. The necessary and sufficient to accomplish this are if the field vector (electric or magnetic) possesses all of the following:

a. The field must have two orthogonal linear components, and

b. The two components must have the same magnitude, and

c. The two components must have a time-phase difference of odd multiples of 90°.

2.3.1.3 Elliptical Polarization

A wave is elliptically polarized if it is not linearly or circularly polarized. Although linear and circular polarizations are special cases of elliptical, usually in practice elliptical polarization refers to other than linear or circular. The necessary and sufficient conditions to accomplish this are if the field vector (electric or magnetic) possesses all of the following:

a. The field must have two orthogonal linear components, and

b. The two components can be of the same or different magnitude.

c. (1) If the two components are not of the same magnitude, the time-phase difference between the two components must not be 0° or multiples of 180° (because it will then be linear).

(2) If the two components are of the same magnitude, the time-phase difference between the two components must not be odd multiples of 90° (because it will then be circular).

2.4 Summary

This chapter introduces the fundamental of a unidirectional antenna using a probe excited circular ring above cylindrical reflector. The ring length must be appropriately chosen to let only a single mode appear at the apertures. Radiation characteristics such as radiation pattern and directivity are important in wireless communication. The former is used in antenna installation whereas the latter contributes to the communication range. To investigate radiation characteristics of a unidirectional antenna using a probe excited circular ring above cylindrical reflector can radiate both linearly and circularly polarized unidirectional beam.

Chapter 3

Simulation of a Unidirectional Antenna Using a Probe Excited Circular Ring above Cylindrical Reflector

3.1 Introduction

Based on the principle of antenna in chapter 2, this chapter describes characteristics of a unidirectional antenna using a probe excited circular ring above cylindrical reflector. Simulated results to be discussed in this chapter are impedance bandwidth, directivity, front-to-back ratio and field radiation. From these characteristics, it is possible to find appropriated parameters such as radius and length of inner ring, radius and length of cylindrical reflector, distance between probe and reflector, probe length, and so on in order to design and fabricate this antenna.

3.2 A unidirectional Antenna Using a Probe Excited Circular Ring above Cylindrical Reflector

The structure of a unidirectional antenna using a probe excited circular ring above cylindrical reflector is simple and cost-effective. The structure of the antenna is easy and straightforward as shown in Fig. 3.1. For the specified operating frequency, only the dominant mode can be propagated inside the cylindrical waveguide. The structure of a unidirectional antenna using a probe excited circular ring above cylindrical reflector for high gain application consists of a linear electric probe of the length l aligned along the y axis, and the distance from probe and reflector is h, and it is surrounded by an circular ring radius and length a and t, respectively. The radius and length of cylindrical reflector are b and d, respectively. It is noted that the probe is shielded by dielectric rod of the length $l/2$. The wave travels along z axis, which is accomplished by using an electric probe fed in the radial direction as shown in Fig. 3.1

The ensemble of the antenna was made using 2 material types, i.e. the circular ring is made of brass and the cylindrical reflector is made of aluminum. The antenna can be fabricated using low-cost material that is easy to find in the market. Table 3.1 shows the initial of parameters used in this section.

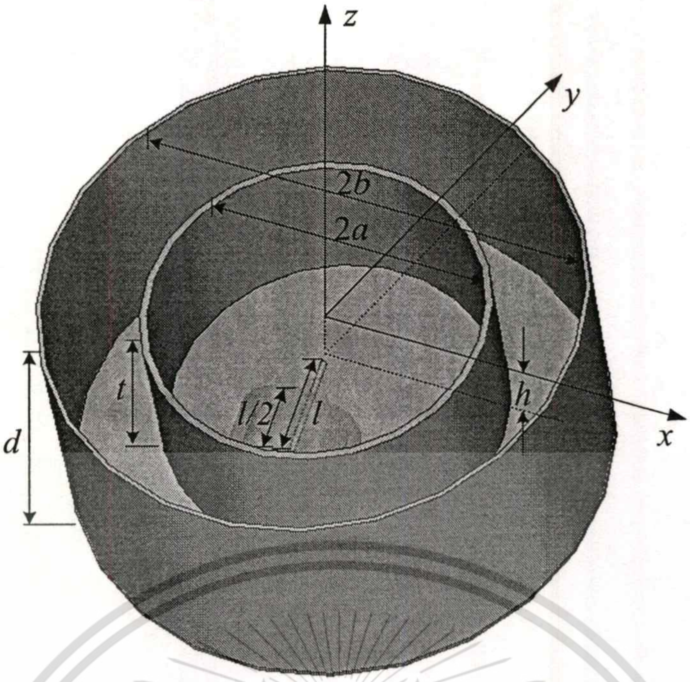


Fig. 3.1 A circular ring antenna above the cylindrical reflector

3.2.1 Parametric Study

Table 3.1 Initial Parameters

Parameters	Electrical Size	Physical Size (mm)
a	0.29λ	36
b	0.47λ	58
l	0.26λ	33
h	0.26λ	32
t	0.29λ	36
d	0.43λ	53
ε_r (dielectric constant)	10	
Location of the probe	$\rho = a$, $\phi = 90^{\circ}$, $z = 0$	

3.2.1.1 Variation of Radius and Length of Circular Ring

According to the design criterion (1), a unidirectional antenna using a probe excited circular ring above circular reflector is designed to operate at frequency of 2.45 GHz. The simulation is performed to study the influence of six parameters being investigated such as the circular ring radius and length (a) and (t), radius and length of cylindrical reflector (b) and (d), the distance from probe and reflector (h), and probe length (l) respectively.

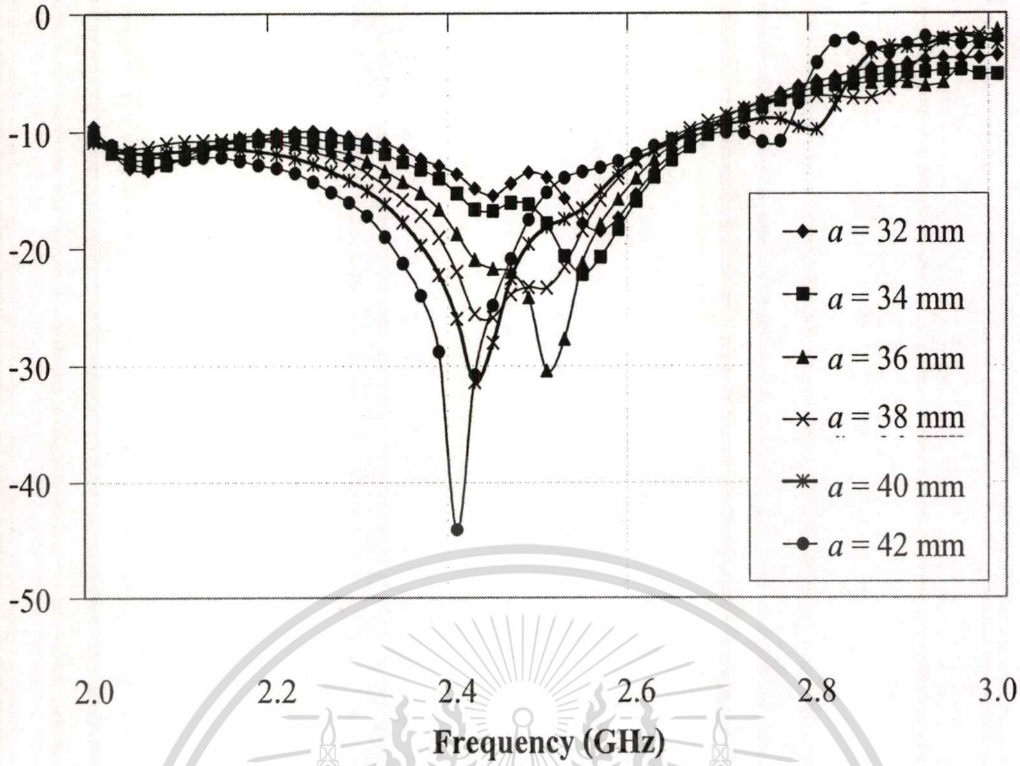


Fig. 3.2 Frequency response of return loss as a function of circular ring radius

Fig. 3.2 shows the frequency response of return loss as a function of circular ring radius, there are different radii of circular ring to be analyzed. It consists of *a*=32 mm, *a*=34 mm, *a*=36 mm, *a*=38 mm, *a*=40 mm and *a*=42 mm whereas all other parameters are fixed following Table 3.1. From the simulated results we found that the circular ring radius is not affected to the directivity but affected to return loss, bandwidth and front-to-back ratio, as illustrated in Fig. 3.3 and Fig. 3.4, respectively. From the verified results it is obvious that *a*=40 mm is suitable value for the circular ring radius. The reason why we chose this value because it is provides the optimum front-to-back ratio and high directivity. The simulation is performed to study the influence of the circular ring radius for impedance matching; the results are shown in Fig. 3.2. We found that the circular ring radius of 40 mm is suitable value for the operating frequency of 2.45 GHz.

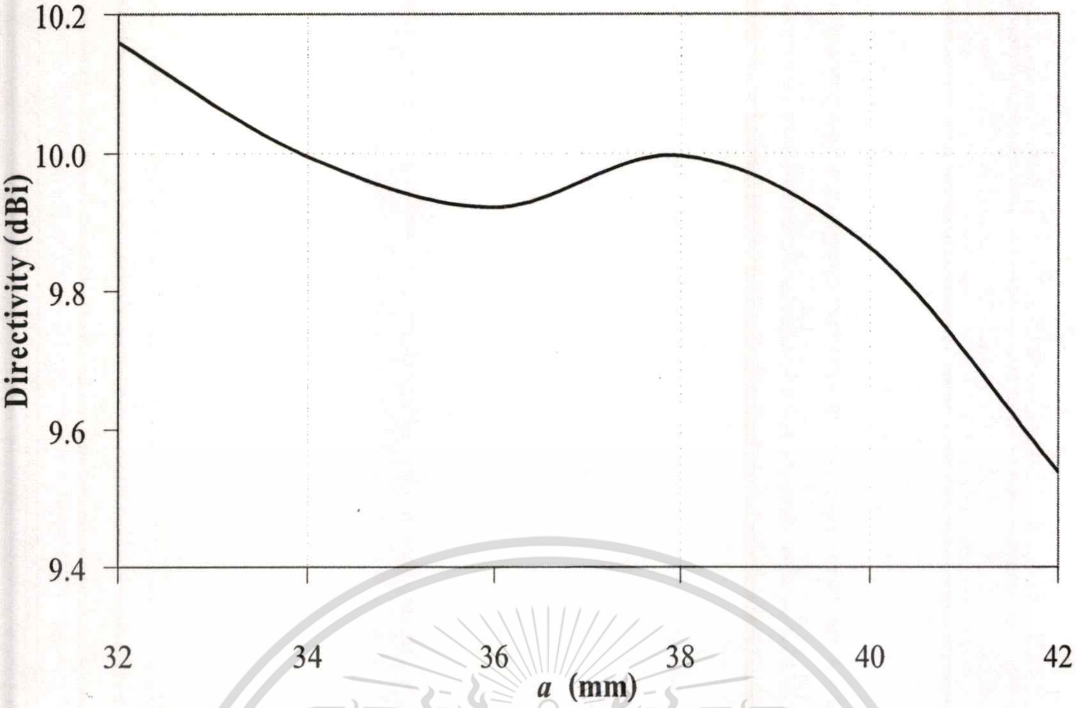


Fig. 3.3 Directivity versus circular ring radius

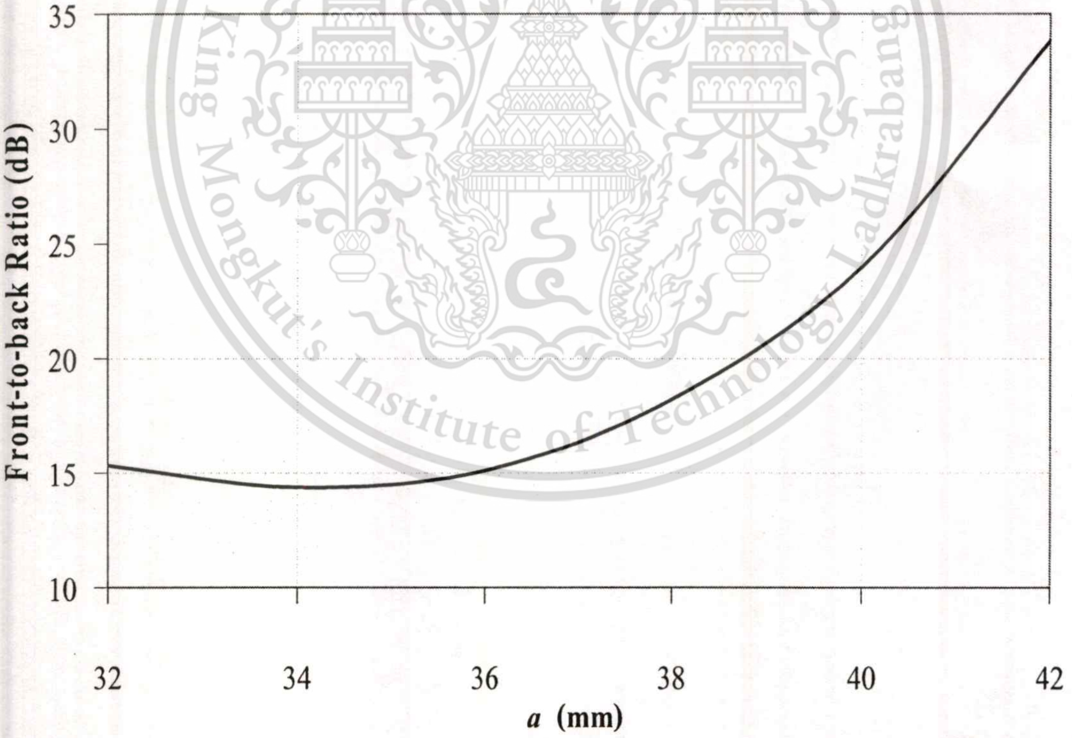


Fig. 3.4 Front-to-back ratio versus circular ring radius

The simulation is performed to study the influence of the length of circular ring (*t*) by fixing the radius of circular ring at 40 mm. There are different lengths of circular ring to be analyzed. It consists of t=32 mm, t=34 mm, t=36 mm, t=38 mm and t=40 mm. From the results, we found that the length of circular ring is not affected to return loss but affected to directivity and front-to-back ratio as shows in Fig. 3.5 and Fig. 3.6, respectively. From the verification of simulated results it is obvious that the circular ring length (*t*) equal to 36 mm is suitable for the antenna design.

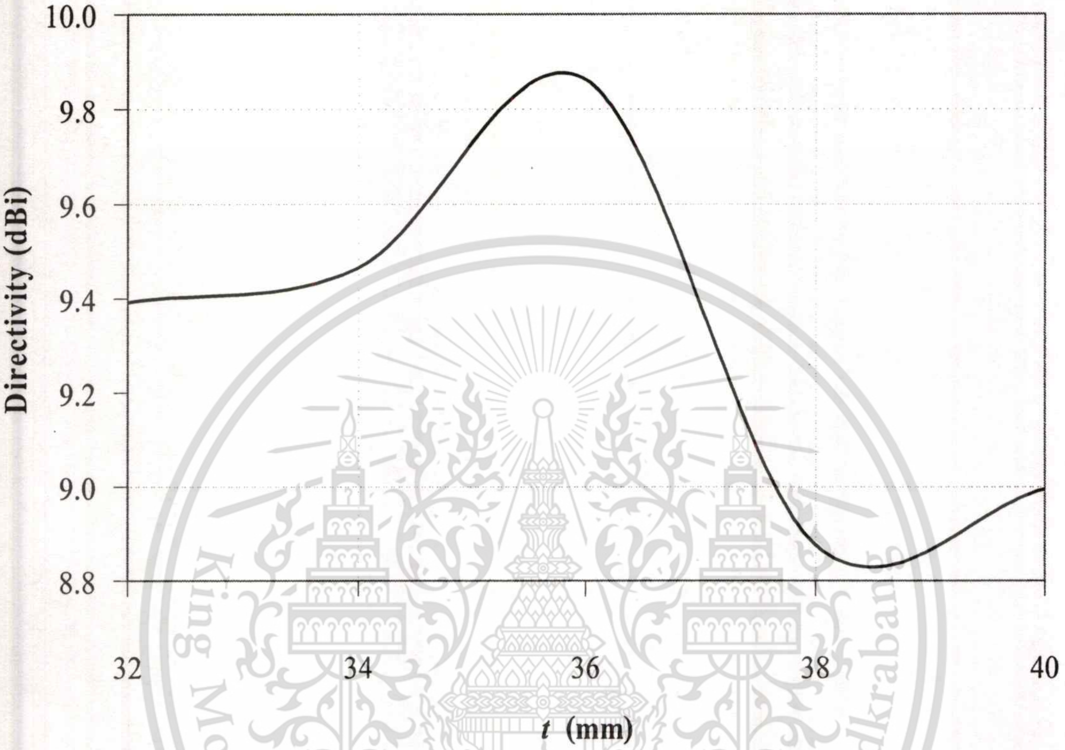


Fig. 3.5 Directivity versus circular ring length

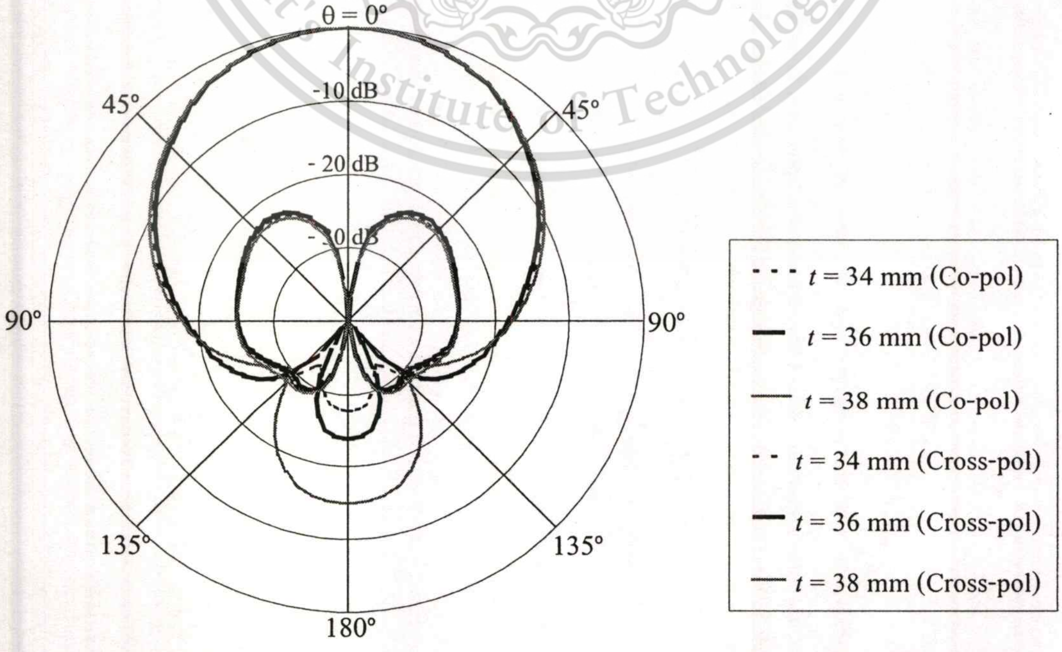


Fig. 3.6 The comparison between co and cross polarization in XZ-plane

3.2.1.2 Variation of Radius and Length of Cylindrical Reflector

The simulation is performed to study the influence of the radius of cylindrical reflector. There are different radii of cylindrical reflector to be analyzed. It consists of *b*=54 mm, *b*=56 mm, *b*=58 mm, *b*=60 mm and *b*=62 mm by fixing the radius and length of circular ring at 40 mm and 36 mm, respectively. From the results we found that the outer ring radius is not affected to return loss and directivity but affected to front-to-back ratio as shows in Fig. 3.7 and Fig. 3.8, respectively. From the verified results it is obvious that the radius of cylindrical reflector (*b*) equal to 58 mm is suitable for the antenna design.

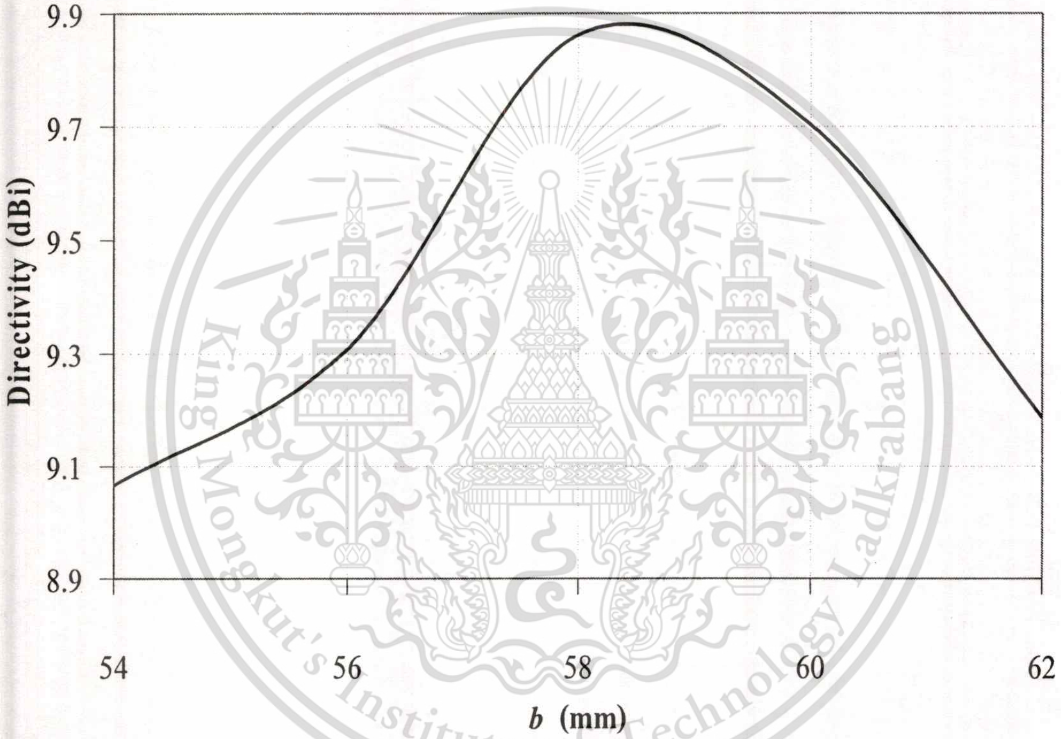


Fig. 3.7 Directivity versus radius of cylindrical reflector

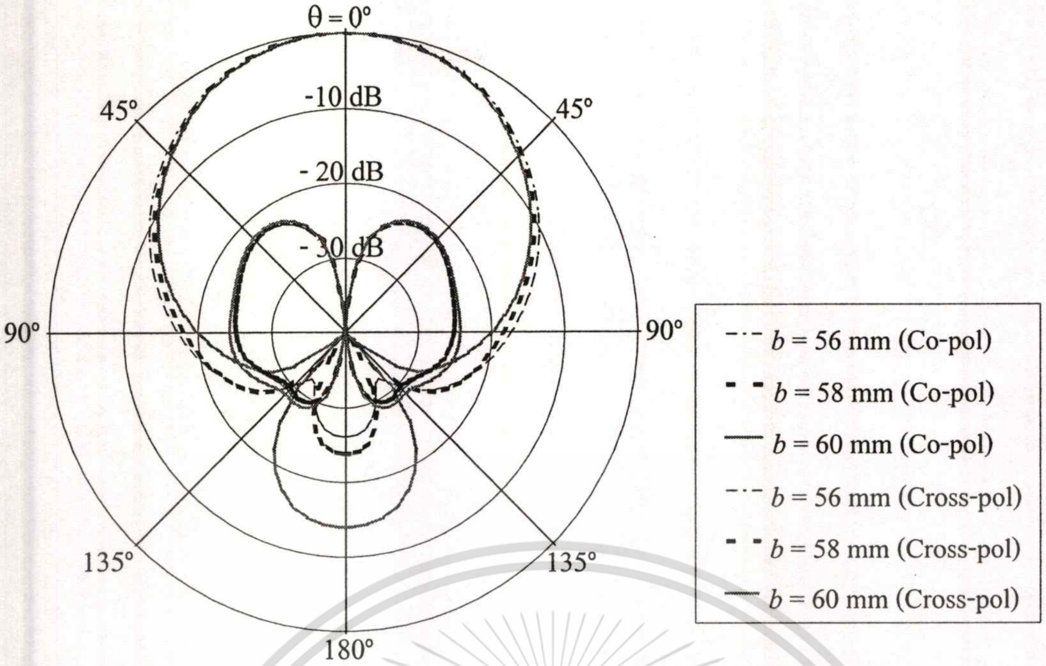


Fig. 3.8 The comparison between co and cross polarization in XZ-plane

From several values of the radius of cylindrical reflector, we found that the front-to-back ratio is better at 58 mm and directivity is approximately 9.862 dBi. Thus, the simulation is performed to study the influence of the length of cylindrical reflector by fixing *a*=40 mm, *t*=36 mm and *b*=58 mm. While the lengths of cylindrical reflector are varied from 49 to 59 mm. By varying the lengths of cylindrical reflector it is obvious that the length of cylindrical reflector (*d*) equal to 57 mm is the suitable value for the antenna design. From simulation the length of cylindrical reflector is not affected to the return loss but affected to directivity as shown in Fig. 3.9, we found that when the increment of length of cylindrical reflector makes the higher directivity, but the longer length of cylindrical reflector makes the reduced front-to-back ratio as shown in Fig. 3.10.

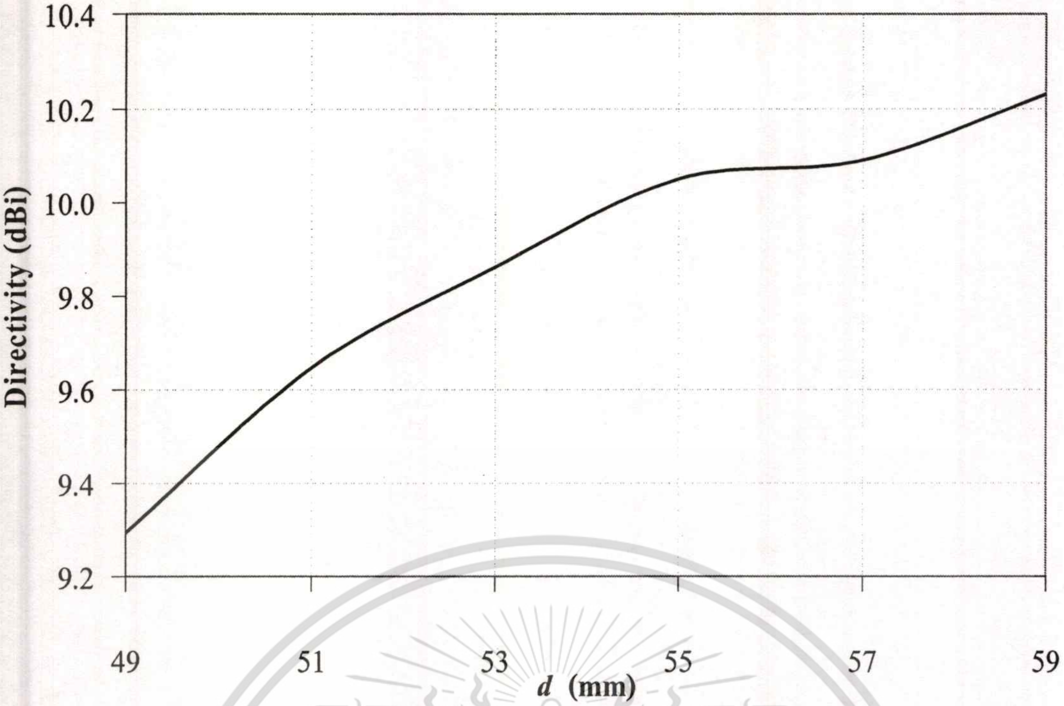


Fig. 3.9 Directivity versus the length of cylindrical reflector

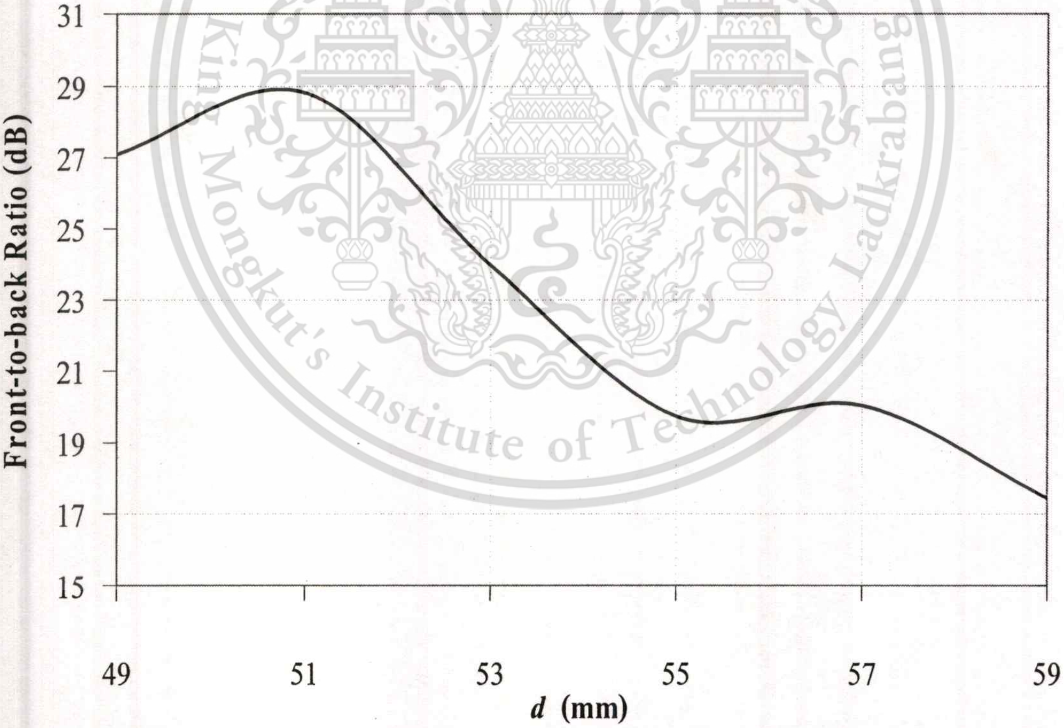


Fig. 3.10 Front-to-back ratio versus the length of cylindrical reflector

3.2.1.3 Variation of Distance between Probe and Reflector

The simulation is performed to study the influence of the distance between probe and reflector by fixing *a*=40 mm, *t*=36 mm, *b*=58 mm and *d*=57 mm. The distance between probe and reflector consists of *h*=28 mm, *h*=30 mm, *h*=32 mm, *h*=34 mm and *h*=36 mm. From the results it is found that the distance between probe and reflector affect the return loss, directivity and front-to-back ratio as illustrated in Fig. 3.11, 3.12 and Fig. 3.13, respectively. From the simulated results it is obvious that the distance between probe and reflector (*h*) equal to 32 mm is suitable value for the antenna design.

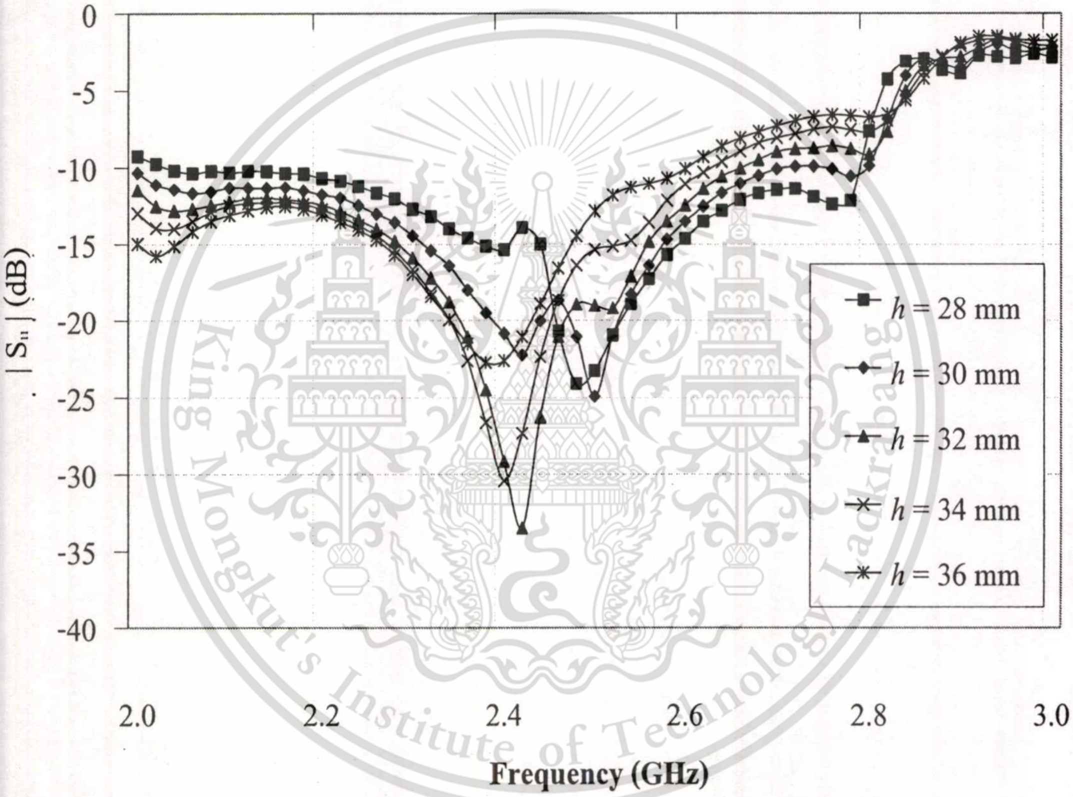


Fig. 3.11 Frequency response of return loss as a function of distance between probe and reflector

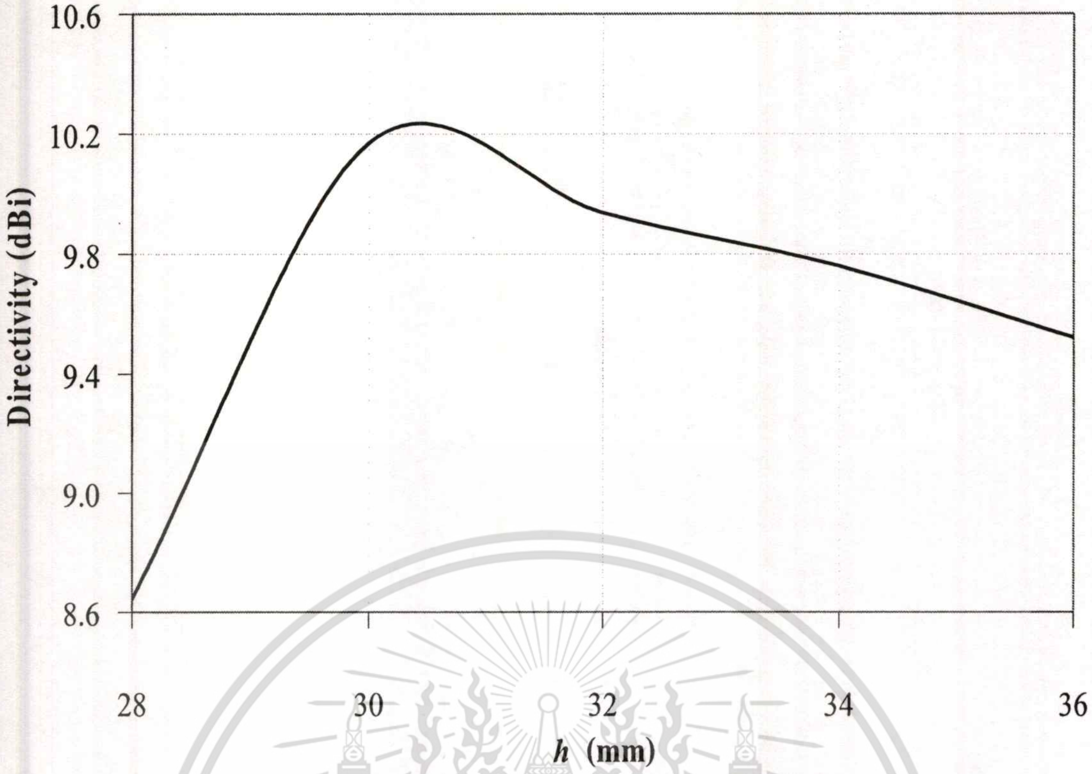


Fig. 3.12 Directivity versus distance between probe and reflector

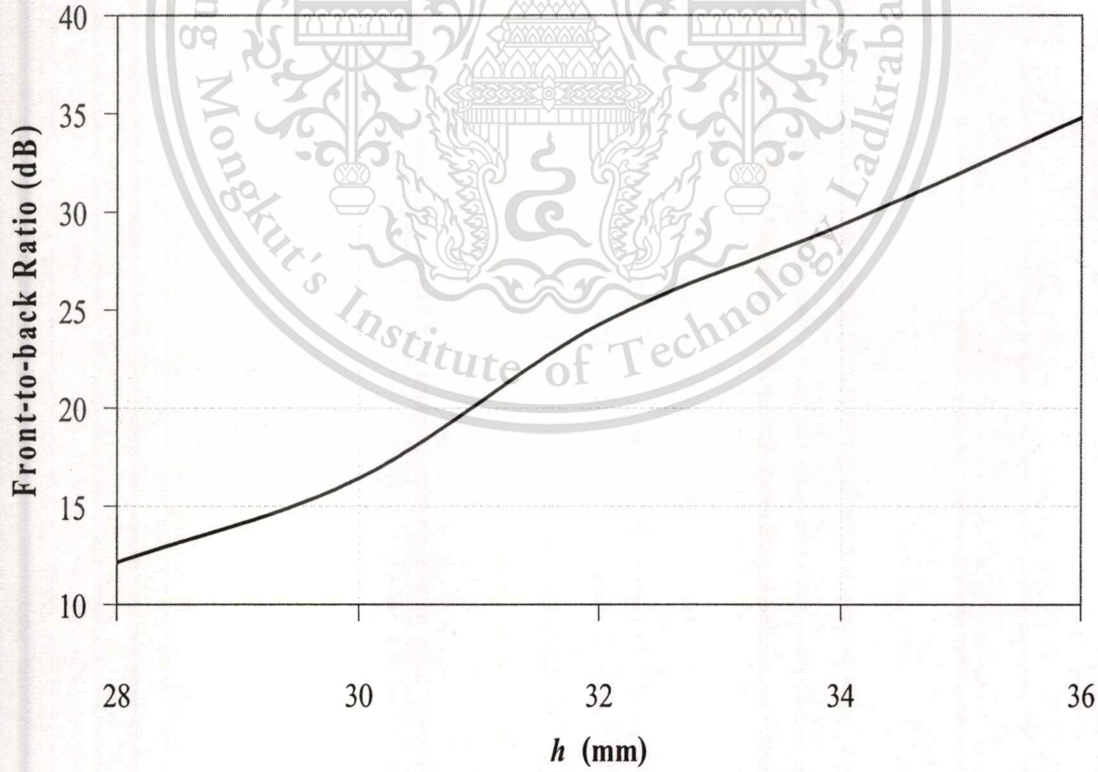


Fig. 3.13 Front-to-back ratio versus distance between probe and reflector

3.2.1.4 Variation of Probe Length

The simulation is performed to study the influence of the probe length (*l*) by fixing *a*=40 mm, *t*=36 mm, *b*=58 mm, *d*=57 mm and *h*=32 mm. While the probe lengths are varied from 29 to 37 mm. From verification of simulated results we found that the probe length (*l*) influence the return loss as illustrated in Fig. 3.14. But it is not impact to main lobe in both in E- and H-plane as shown in Fig. 3.15. Thus, from the simulated results it is obvious that the probe length which is suitable value for the antenna design is equal to 33 mm.

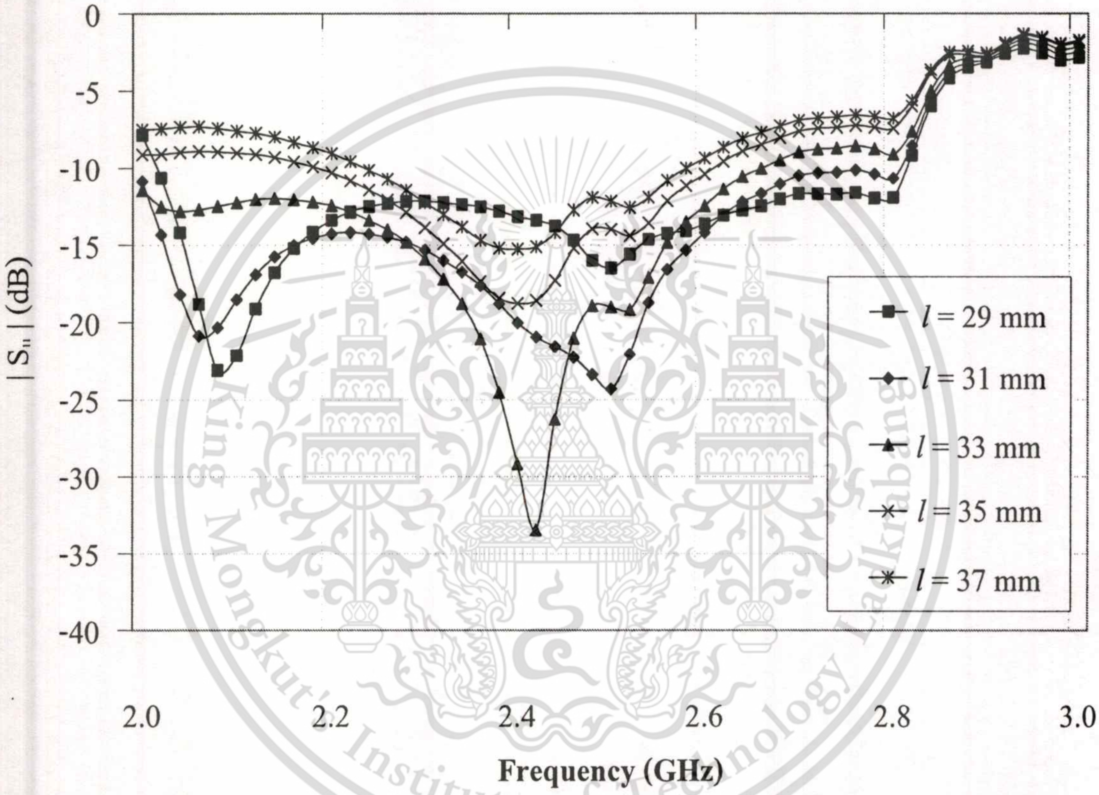


Fig. 3.14 Frequency response of return loss as a function of probe length

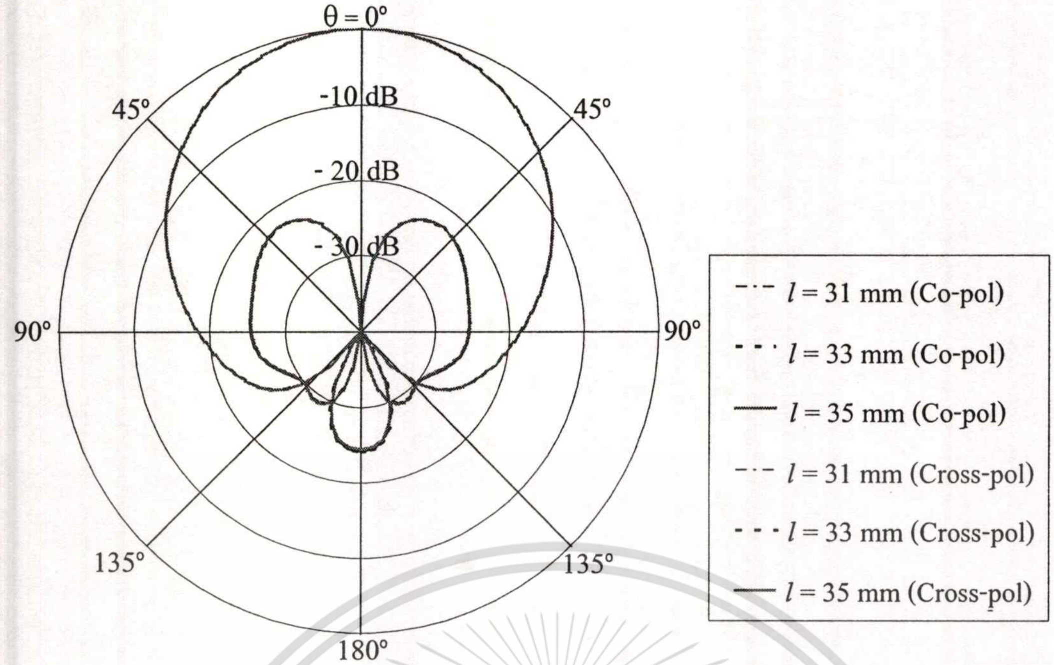
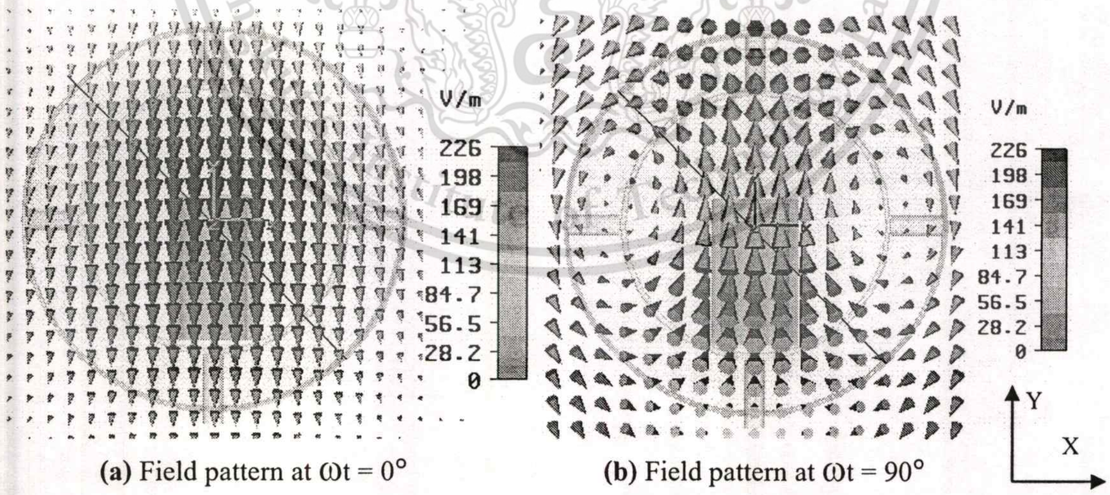


Fig. 3.15 The comparison between co and cross polarization in XZ-plane

3.2.2 Electric Field inside a Circular Ring

According to the antenna structure shown in Fig. 3.1, the electric field radiate from the aperture distribution in a circular ring is shown in Fig. 3.16. It is seen that the polarization is vertical.



(a) Field pattern at ωt = 0°

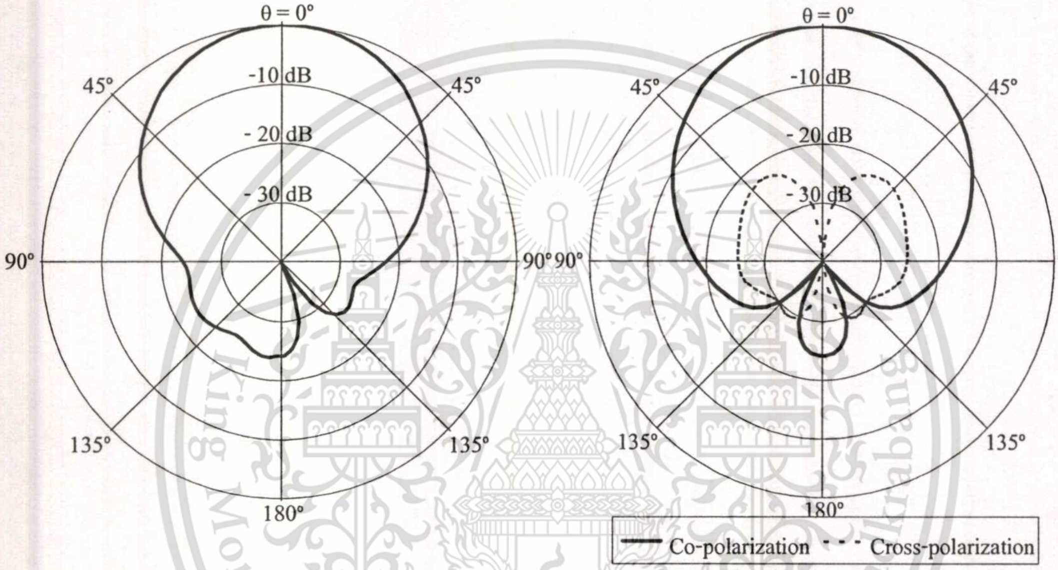
(b) Field pattern at ωt = 90°

Fig. 3.16 Field pattern in XY-plane

3.2.3 Radiation Pattern

The simulation has been performed for the influence of antenna parameters. We can choose the optimum parameters such as circular ring radius (a) of 40 mm, circular ring length (t)

of 36 mm, the radius of cylindrical reflector (*b*) of 58 mm, the length of cylindrical reflector (*d*) of 57 mm, the distance between probe and reflector (*h*) of 32 mm, and probe length (*l*) of 33 mm, respectively. This structure radiates the unidirectional beam with the vertical linear polarization. The half-power beamwidth (HWBW) in both in E- and H-plane is 50° and 55°, respectively. The front-to-back ratio (F/B) in both planes of better than 20 dB. Fig. 3.17 shows the radiation pattern from simulation at angle ϕ of 90° and 0° in E-plane and H-plane, respectively. The simulation of the return loss as illustrated in Fig. 3.18. The center frequency is 2.45 GHz and the frequency range is 2.30-2.64 GHz.



(a) E-plane **(b)** H-plane

Fig. 3.17 Radiation pattern

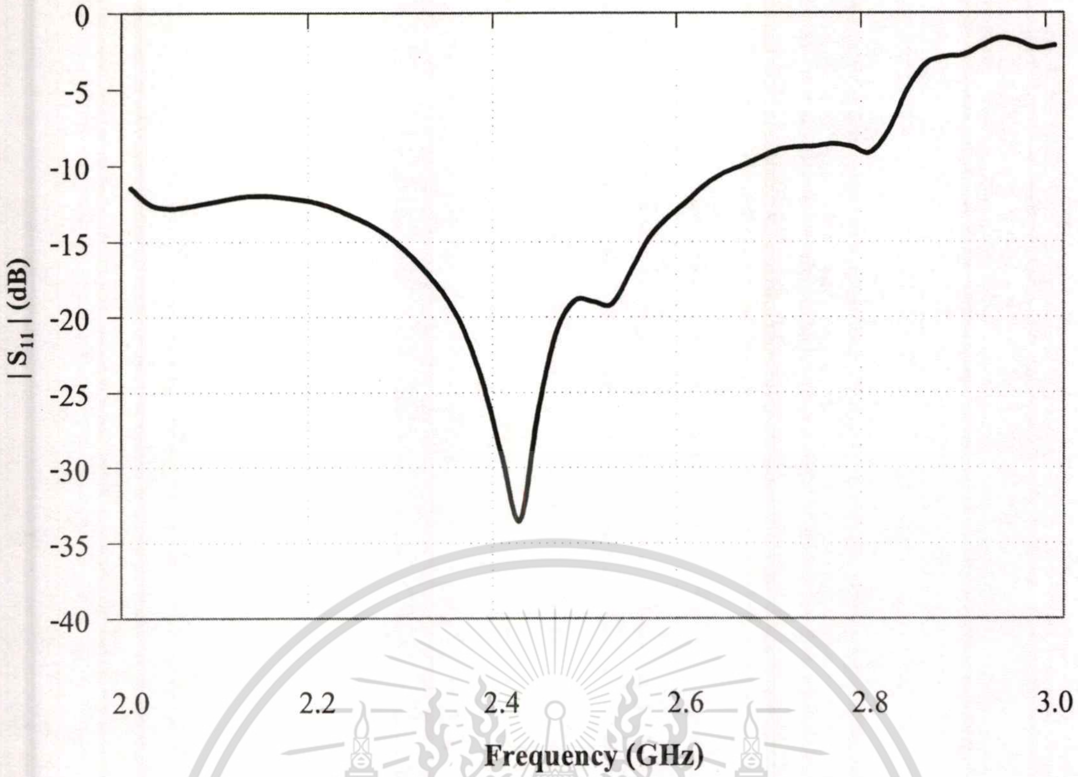


Fig. 3.18 The return loss versus frequency

3.2.4 Directivity

The directivity is 9.92 dBi at the frequency 2.45 GHz and the average gain along the frequency range of 2-3 GHz is 9.46 dBi from the simulation illustrated in Fig. 3.19.

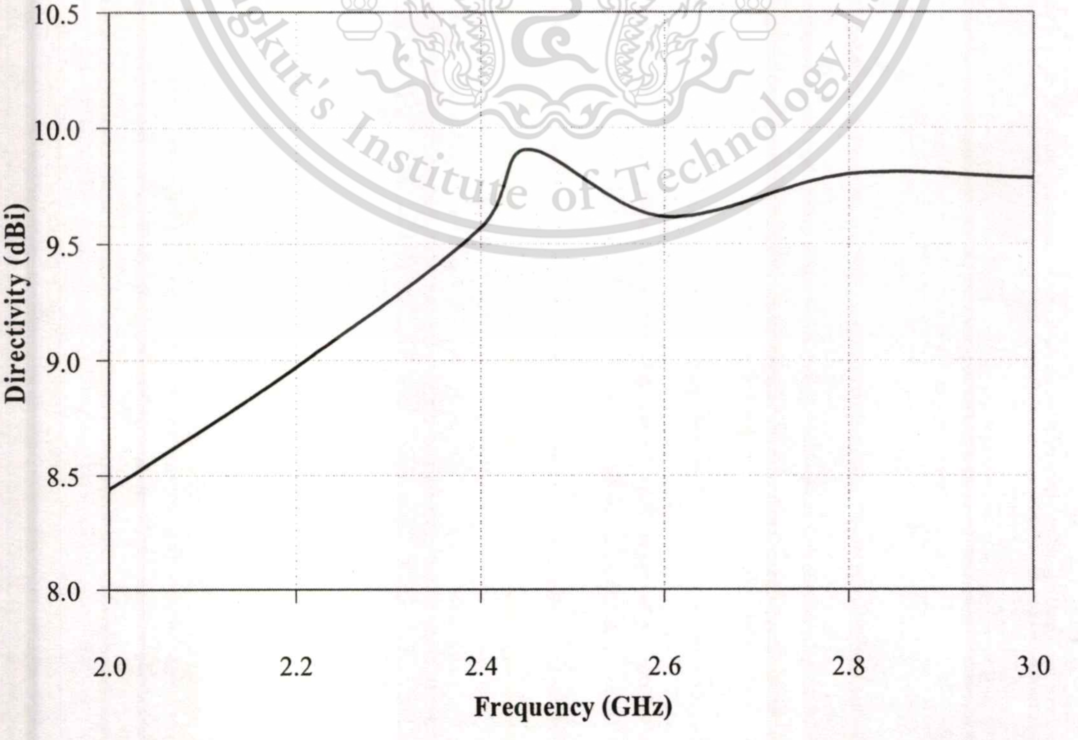


Fig. 3.19 Directivity versus frequency

3.3 A Bent Probe Excited Circular Ring Antenna above Cylindrical Reflector

For the specified operating frequency, a choice of the ring radius is first chosen to achieve the condition that only the dominant mode can be propagated inside the cylindrical waveguide. The structure of circular ring antenna excited by a probe above the cylindrical reflector consist of a linear electric probe of the length l aligned along the y axis as shown in Fig. 3.20. At the end of probe, it was bent with the length g aligned along the x axis. The distance between probe and the reflector is h. The probe is surrounded by the circular ring of a circular radius a and length t. The radius and length of the cylindrical reflector is b and d, respectively. It is noted that the probe is shielded by dielectric rod of the height e. The stub of the length s is aligned along the x axis. The antenna structure is depicted in Fig. 3.20.

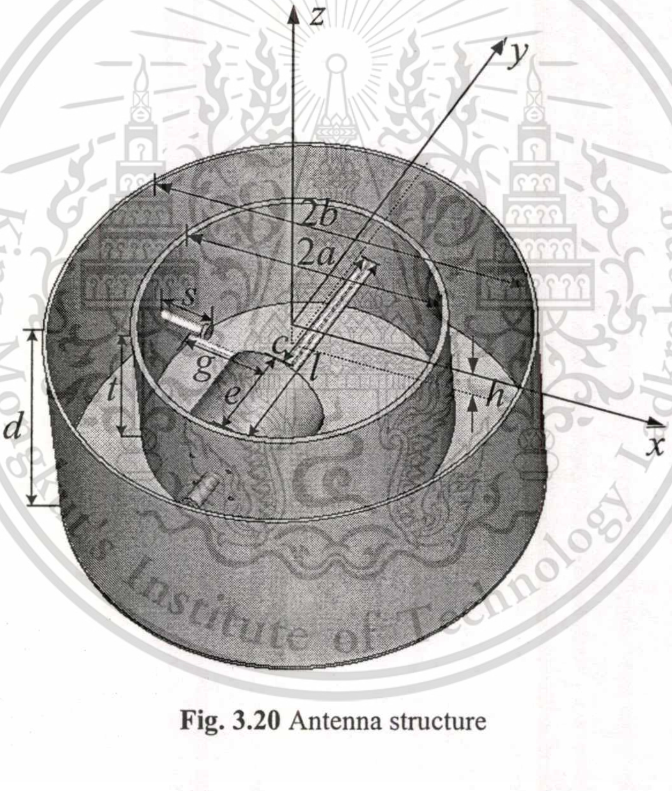


Fig. 3.20 Antenna structure

3.3.1 Parametric Study

In order to design the antenna, the circular ring radius is first chosen to operate at the desired frequency. In this topic, the desired operating frequency is 2.45 GHz. The ensemble of the antenna was made using 2 material types, i.e. the cylindrical reflector is made of aluminum and circular ring is made of brass. The antenna can be easily designed with the low production cost material that is suitable for installing at the base station in the street cell. The other initial parameters used in this structure are tabulated in Table. 3.2

Table 3.2 Initial Parameters

Parameters	**Electrical Size**	**Physical Size (mm)**
a	0.29λ	36.00
b	0.45λ	56.00
l	0.69λ	85.00
c	0.33λ	41.00
g	0.21λ	26.00
h	0.27λ	34.00
t	0.28λ	35.00
d	0.40λ	49.00
e	0.13λ	17.00
r_d	0.11λ	13.50
s	0.10λ	13.00
ε_r (dielectric constant)	10	
Location of the Probe	$\rho = a$, $\phi = 90^{\circ}$, $z = 0$	

3.3.1.1 Effect of Radius and Length of Inner Ring

In order to accomplish the circular polarization, the antenna parameters are varied to minimize the axial ratio. The varied parameters are the radius and length of circular ring (a) and (t), respectively. The radius of cylindrical reflector (b), and length of cylindrical reflector (d), distance between probe and reflector (h), probe length (g), stub length (s) and radius of dielectric (r_d). Moreover, the unidirectional beam antenna that provides the circular polarization is interesting to improve the signal quality from polarization change. The circular ring uses the stub for impedance matching and the probe is also shielded by dielectric rod. At the end of probe, it was bent for identical magnitude with quadrature phase excitation for circularly polarized radiation. From these antenna parameters, simulated results are carried out.

From the result in Fig. 3.21, it shows the response of return loss as a function of circular ring radius. The different radii of circular ring are analyzed whereas all other parameters are fixed following Table 3.2. It consists of a=32 mm, a=34 mm, a=36 mm, a=38 mm and a=40 mm. Radius of circular ring is significantly affected to return loss and axial ratio as illustrated in Fig.

3.21 and Fig. 3.22, respectively. From the results, it is obvious that *a*=36 mm is suitable for the radius of circular ring because it provides the optimum return loss and axial ratio.

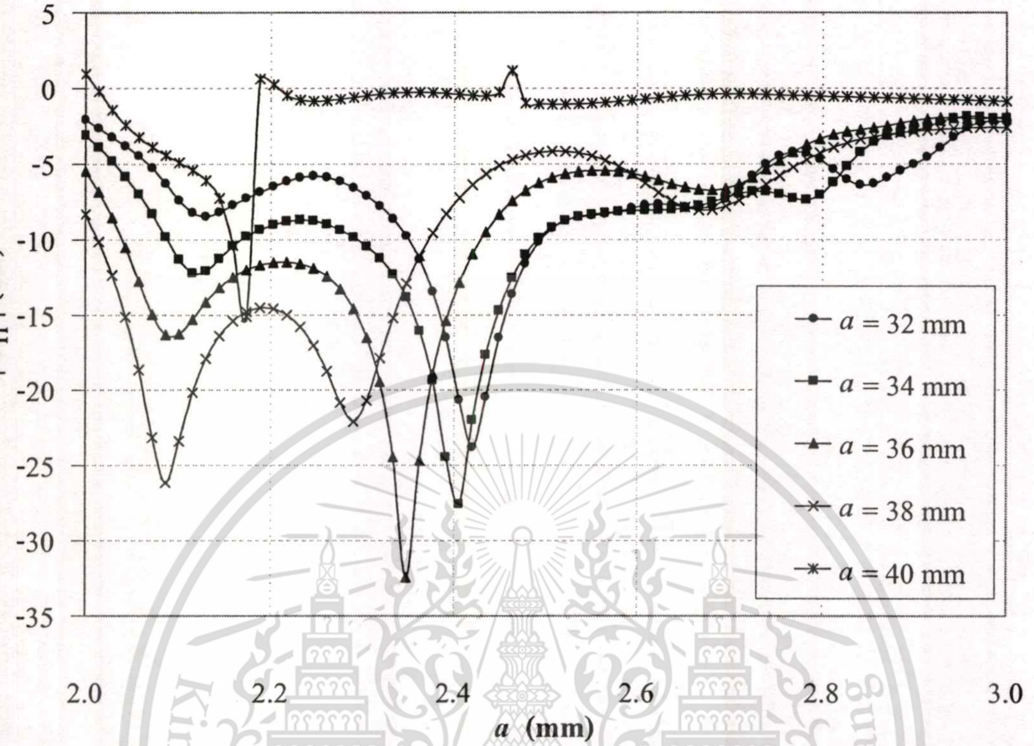


Fig. 3.21 Frequency response of return loss as a function of circular ring radius

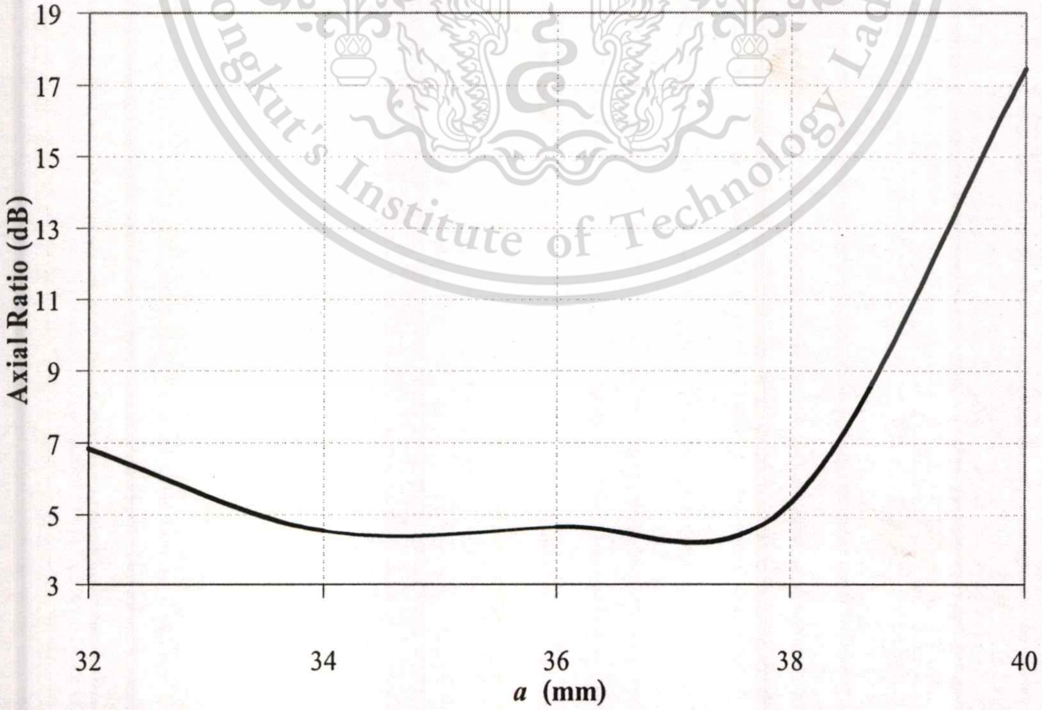


Fig. 3.22 Axial ratio versus circular ring radius

Moreover, the simulation is performed to study the influence of the length of circular ring by fixing the radius of circular ring at 36 mm. There are different lengths of circular ring to be analyzed. It is consist of *t*=28 mm, *t*=32 mm, *t*=36 mm, *t*=40 mm and *t*=44 mm. From the results, we found that the length of circular ring is not strongly affected to return loss and front-to-back ratio but it is affected to axial ratio as illustrated in Fig. 3.23, 3.24 and 3.25, respectively. From the result it is obvious that the length of circular ring equal to 36 mm is suitable for the antenna design.

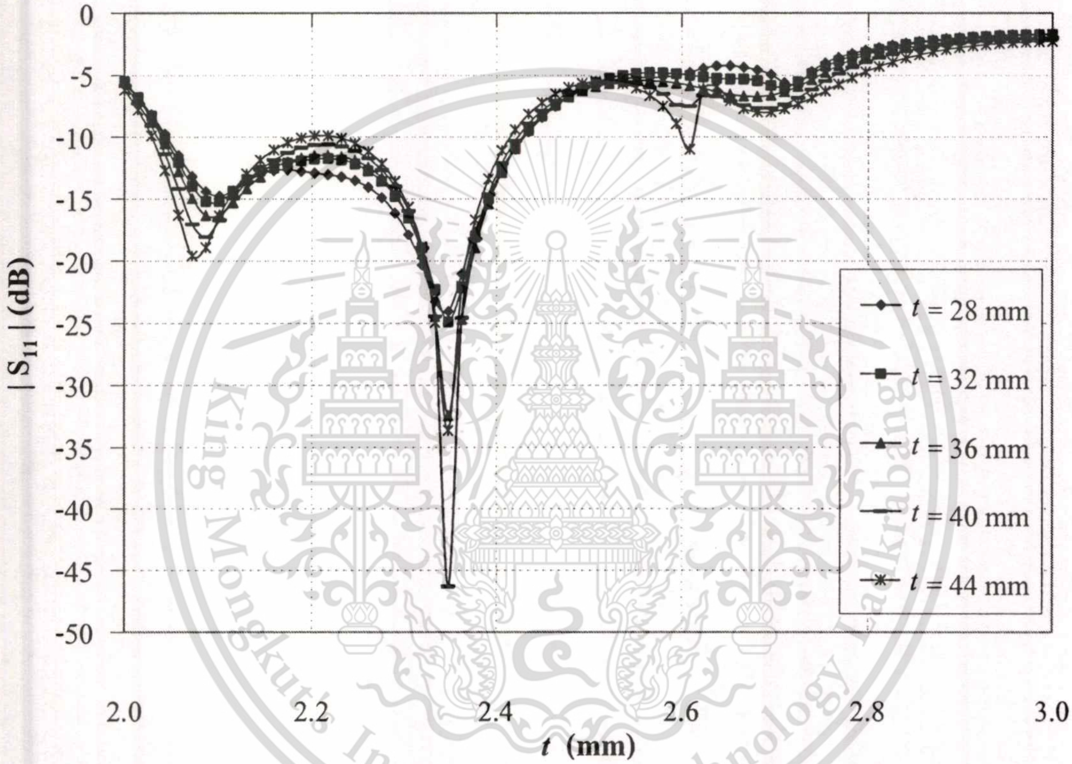


Fig. 3.23 Frequency response of return loss as a function of circular ring length

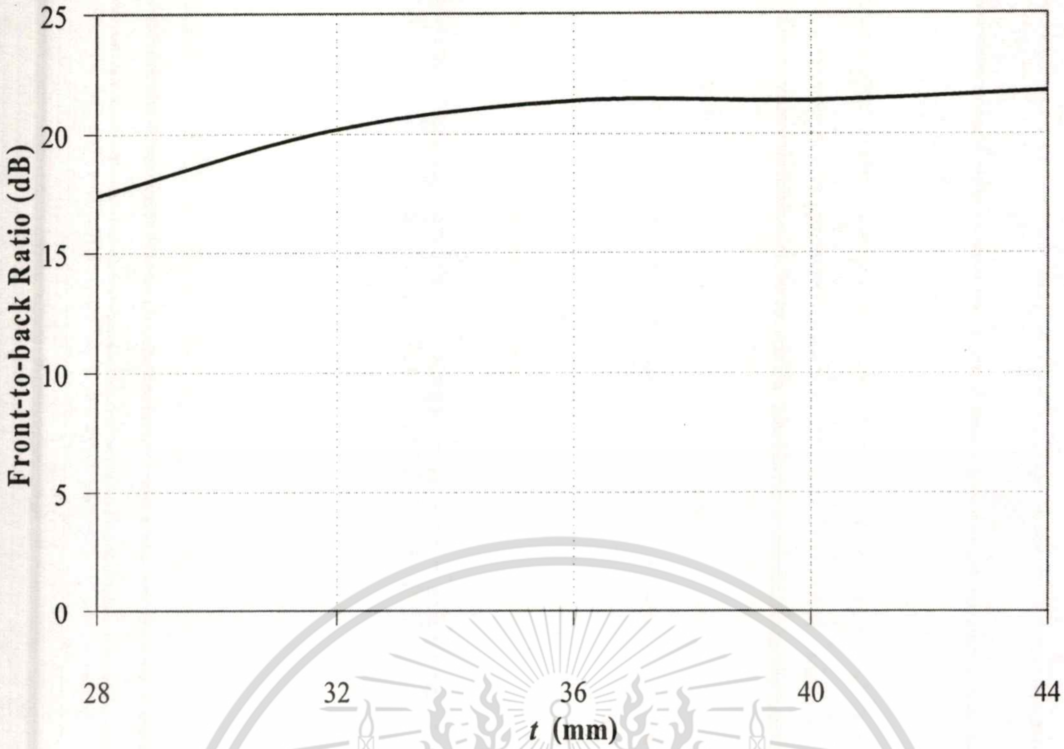


Fig. 3.24 Front-to-back ratio versus circular ring length

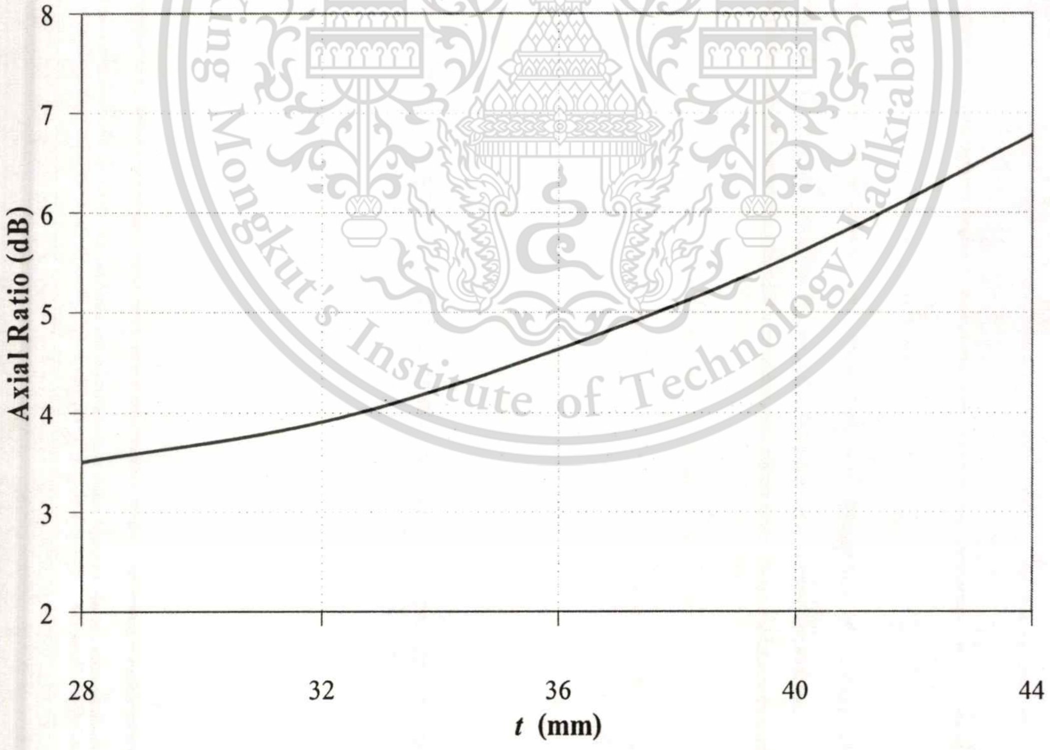


Fig. 3.25 Axial ratio versus circular ring length

3.3.1.2 Effect of Radius and Length of Cylindrical Reflector

The different radii of cylindrical reflector are analyzed by fixing radius and lengths of circular ring at 36 mm and 36 mm, respectively. There are different radii of cylindrical reflector to be analyzed. It is consist of *b*=52 mm, *b*=54 mm, *b*=56 mm, *b*=58 mm and *b*=60 mm. The radius of cylindrical reflector is not significantly affected to return loss but affected to axial ratio as shown in Fig. 3.26 and 3.27, respectively. From the simulated result it is obvious that *b* of 58 mm yields lowest axial ratio.

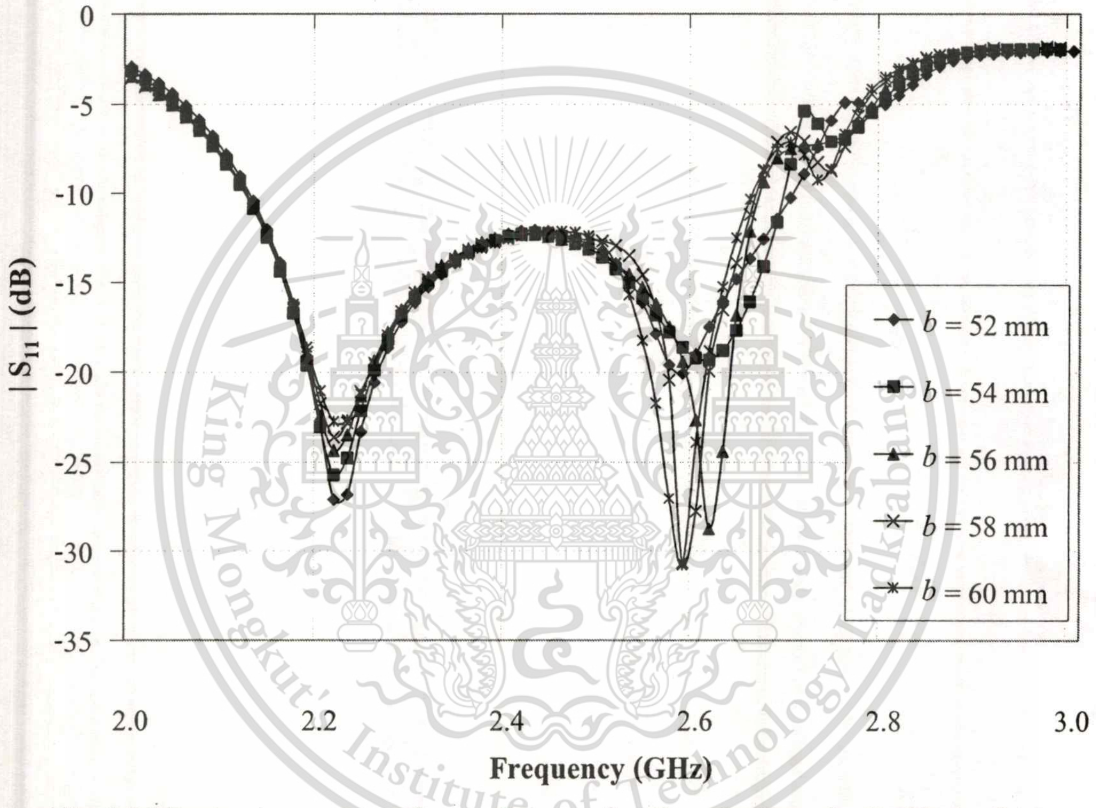


Fig. 3.26 Frequency response of return loss as a function of radius of cylindrical reflector

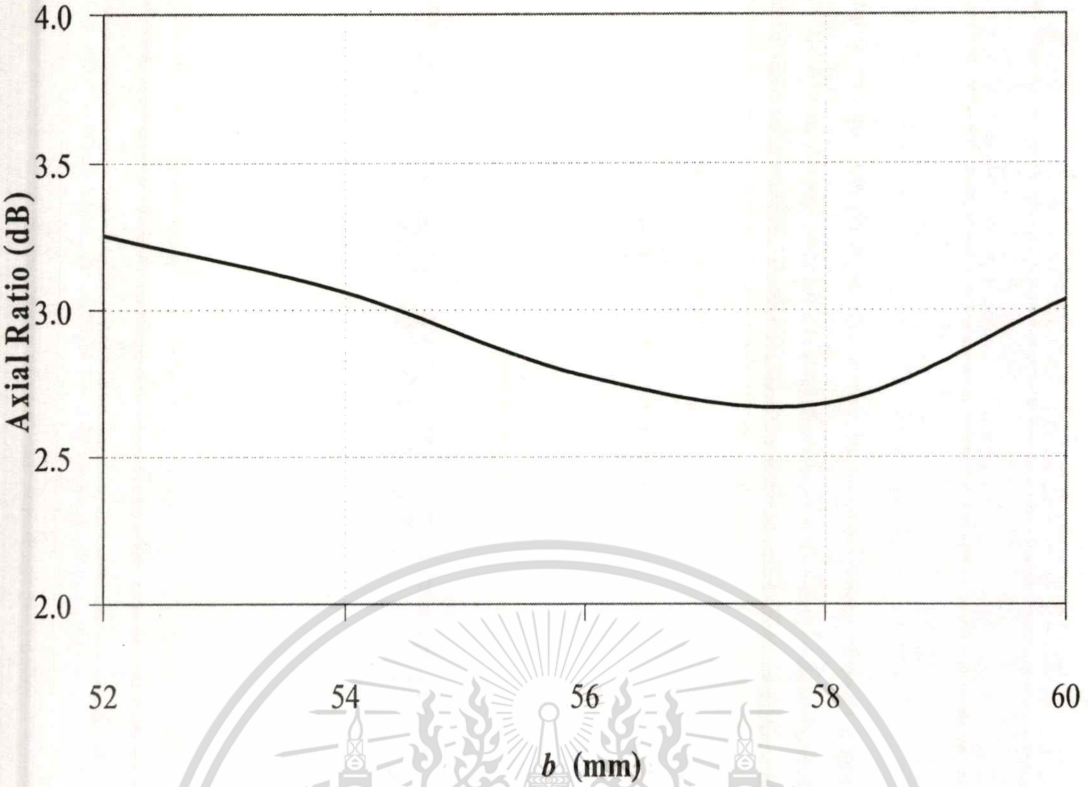


Fig. 3.27 Axial ratio versus radius of cylindrical reflector

Moreover, the simulation is performed to study the influence of the length of cylindrical reflector by fixing a=36 mm, t=36 mm and b=58 mm. There are different lengths to be analyzed. It is consist of d=45 mm, d=47 mm, d=49 mm, d=51 mm, d=53 mm and d=55 mm. From the results we found that the length of cylindrical reflector is not really affected to return loss as shown in Fig 3.28 and Fig 3.29, respectively. From the result it is obvious that the proper length of cylindrical reflector (d) is equal to 53 mm. Therefore, this length is employed as a design parameter.

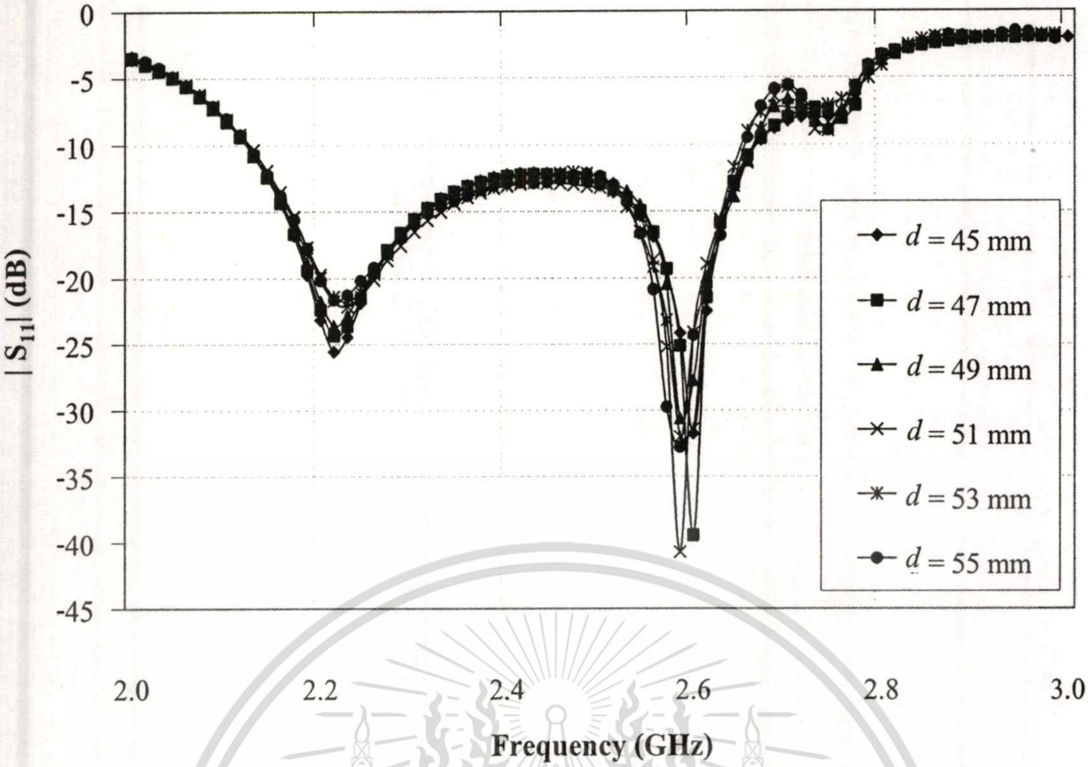


Fig. 3.28 Frequency response of return loss as a function length of cylindrical reflector

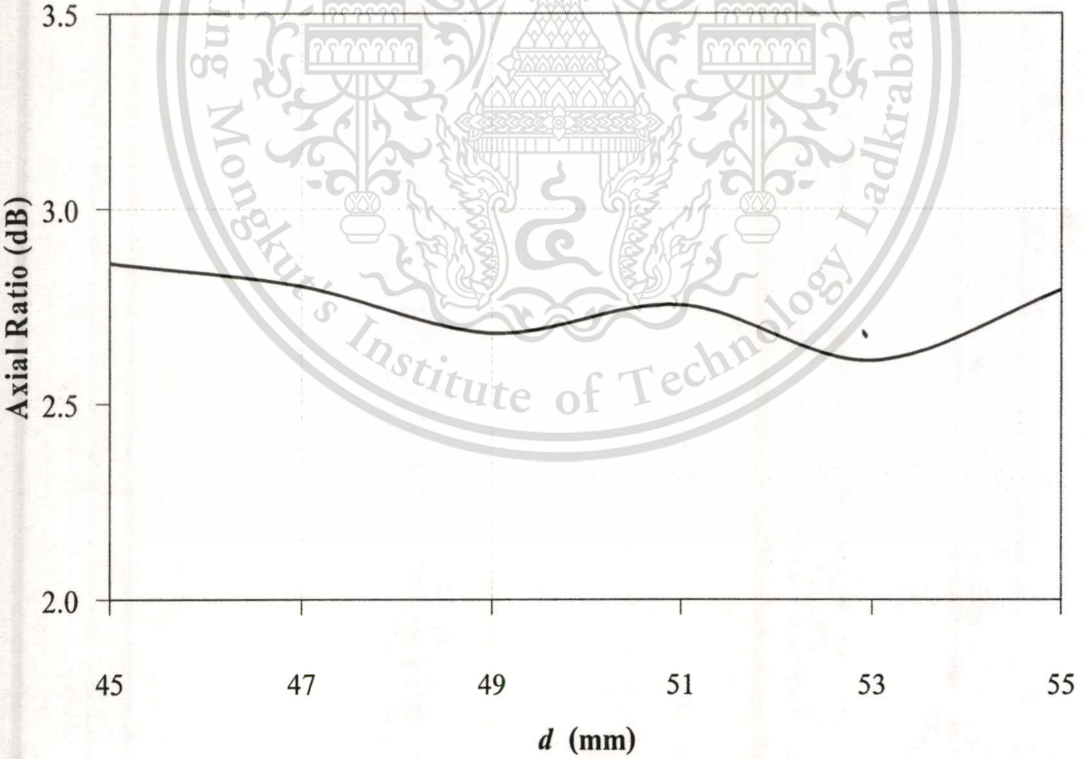


Fig. 3.29 Axial ratio versus length of cylindrical reflector

3.3.1.3 Effect of Distance between probe and Reflector

The axial ratio can be further improved by varying the distance between probe and reflector (*h*). The effects of distance between probe and reflector are investigated from 32 mm to 42 mm while the radius and length of circular ring are fixed at 36 mm and 36 mm, respectively. And the radius and length of cylindrical reflector are fixed at 58 mm and 53 mm, respectively. From the results, we found that the distance between probe and reflector is not affected to return loss but it is affected to the axial ratio as shown in Fig. 3.30 and Fig. 3.31, respectively. It is obvious that the axial ratio is equal to 1.68 dB at the distance between probe and reflector (*h*) of 40 mm, which is the suitable value for the antenna design.

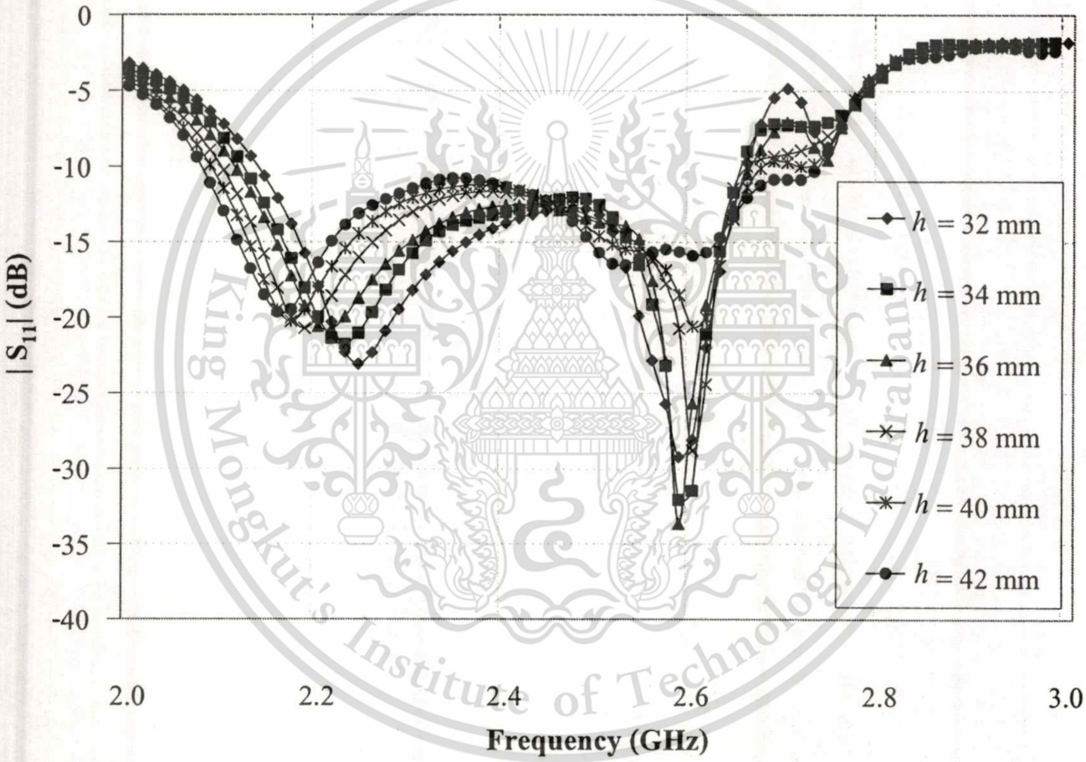


Fig. 3.30 Frequency response of return loss as a function of distance between probe and reflector

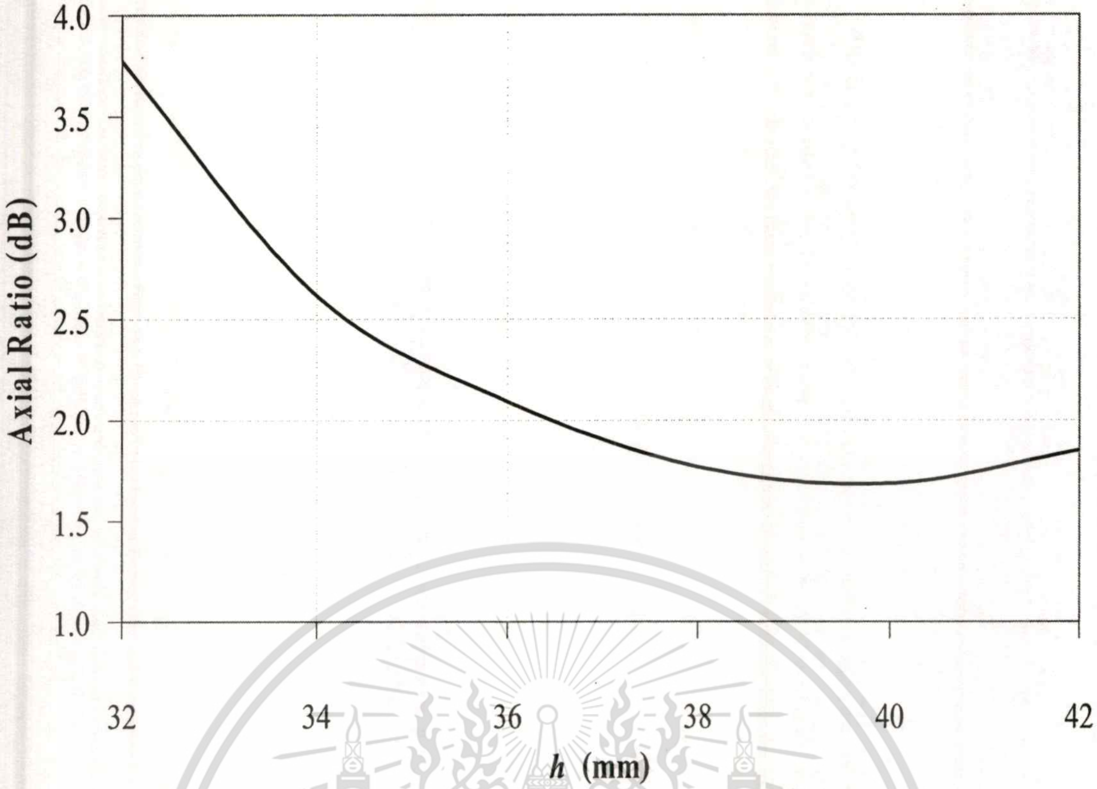


Fig. 3.31 Axial ratio versus distance between probe and reflector

3.3.1.4 Effect of Probe Length and Stub Length

In this section, the simulation is conducted to study the influence of the probe length (*g*) by fixing *a*=36 mm, *t*=36 mm, *b*=58 mm, *d*=53 mm and *h*=40 mm. The probe lengths are investigated from 22 mm to 30 mm. From various parameters of simulated results, we found that the probe length (*g*) is affected to return loss but not affected to axial ratio as illustrated in Fig. 3.32 and Fig. 3.33, respectively. However, the axial ratio cannot be further reduced. Thus, from the result it is obvious that the probe length (*g*) which is suitable for the antenna design is equal to 26 mm.

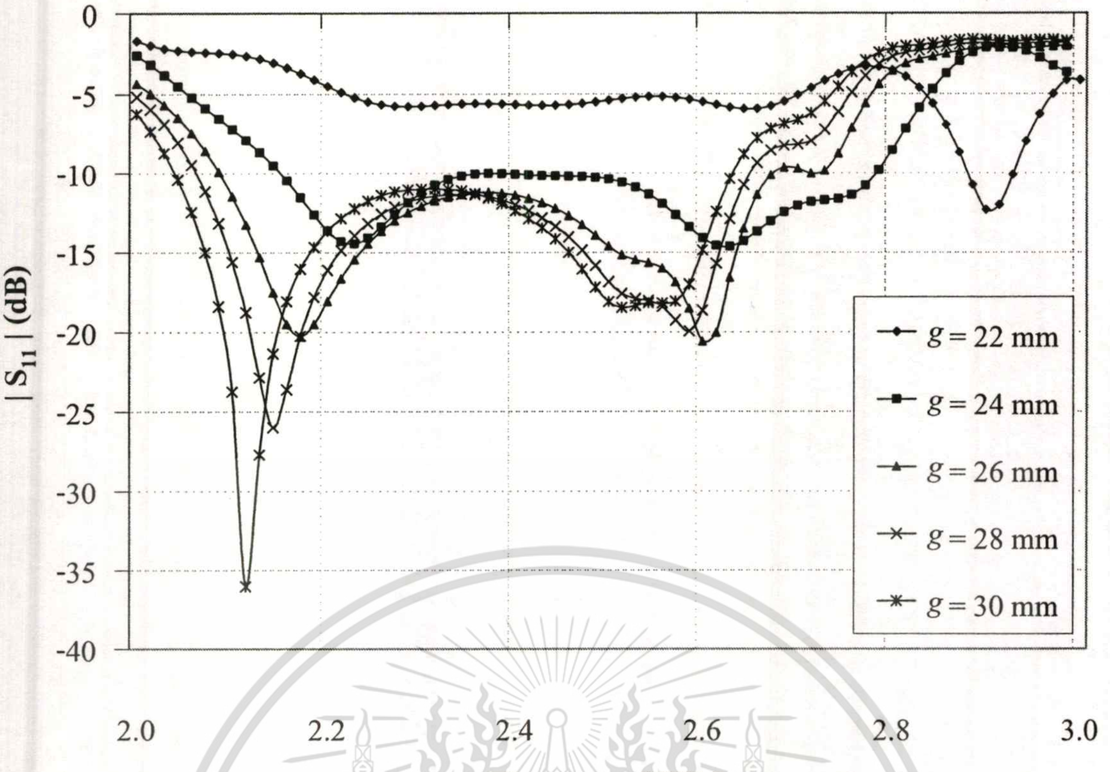


Fig. 3.32 Frequency response of return loss as a function of probe length

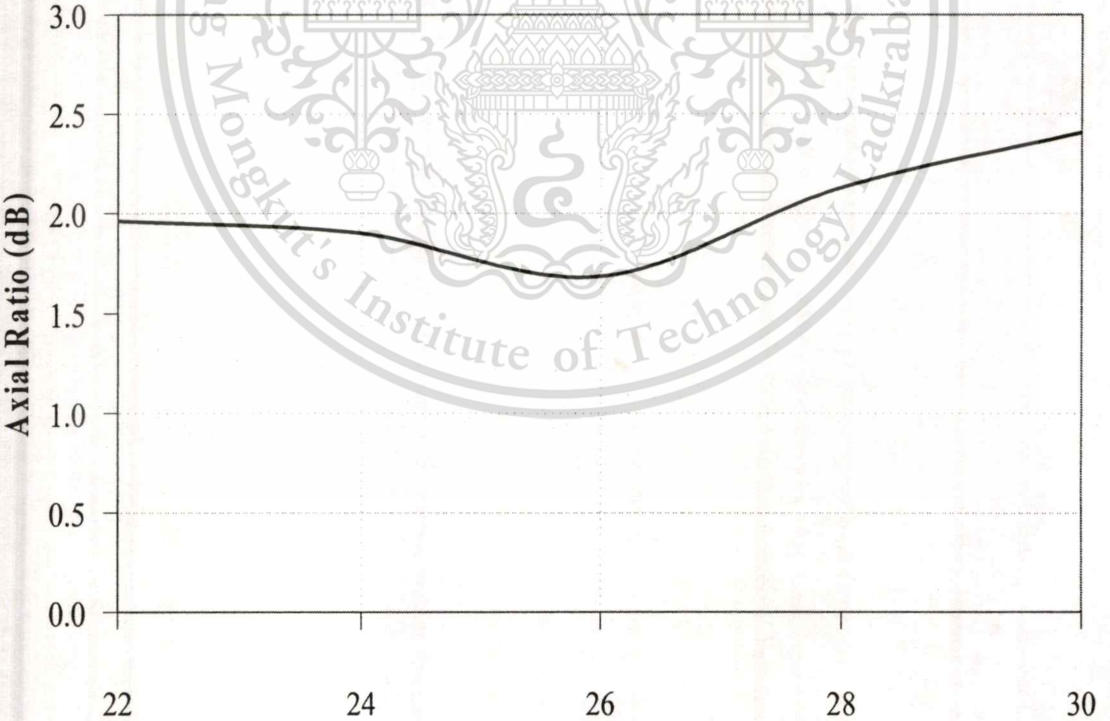


Fig. 3.33 Axial ratio versus probe length

Furthermore, the study of influence of stub length (*s*) is done by fixing *a*=36mm, *t*=36 mm, *b*=58 mm, *d*=53 mm, *h*=40 mm and *g*=26 mm while the stub length are varied from 9 mm to 17 mm. From simulated results, we found that the stub length is affected to return but not affected to axial ratio as shown in Fig. 3.34 and Fig. 3.35, respectively. It is obvious that the stub length (*s*) of 13 mm is suitable for the antenna design because the best axial ratio is obtained.

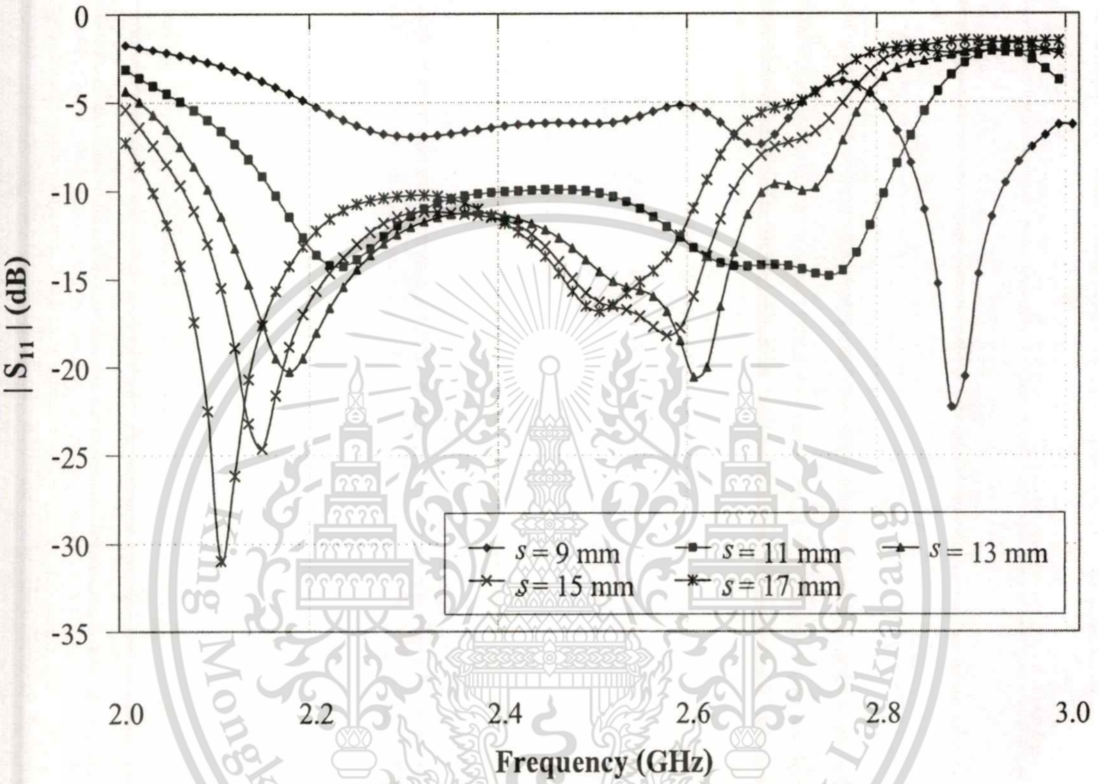


Fig. 3.34 Frequency response of return loss as a function of stub length

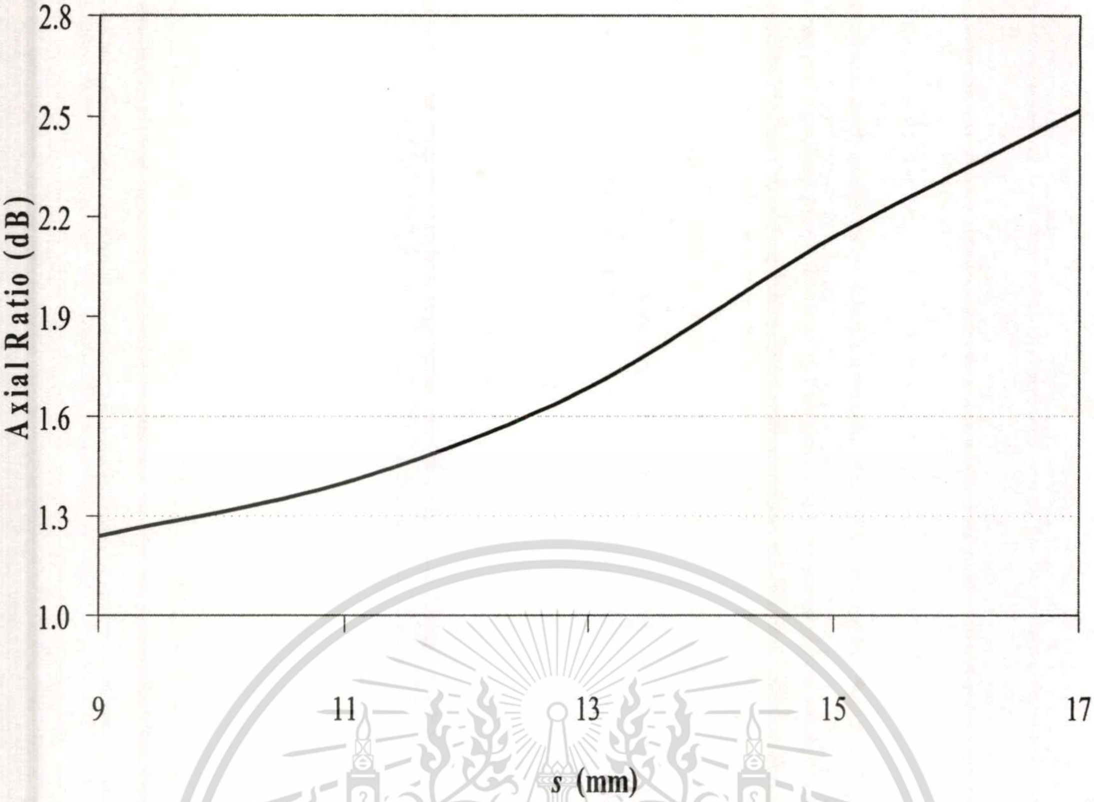


Fig. 3.35 Axial ratio versus stub length

3.3.1.5 Effect of Radius of Dielectric Rod

Moreover, the simulation is performed to study the influence of dielectric rod radius. There are different radii of dielectric rod to be analyzed whereas all other parameters are fixed. The radii of dielectric rod (r_d) are investigated from 5.5 mm to 13.5 mm. From the verification simulated results, we found that the dielectric rod radius is affected to frequency resonant and affected to axial ratio as shown in Fig. 3.36 and Fig. 3.37, respectively. It is obvious that the radius of dielectric rod equal to 13.5 mm is suitable for the antenna design because the best axial ratio is obtained. Finally, the probe length, stub length and radius of dielectric rod are used to achieve the optimum matching condition.

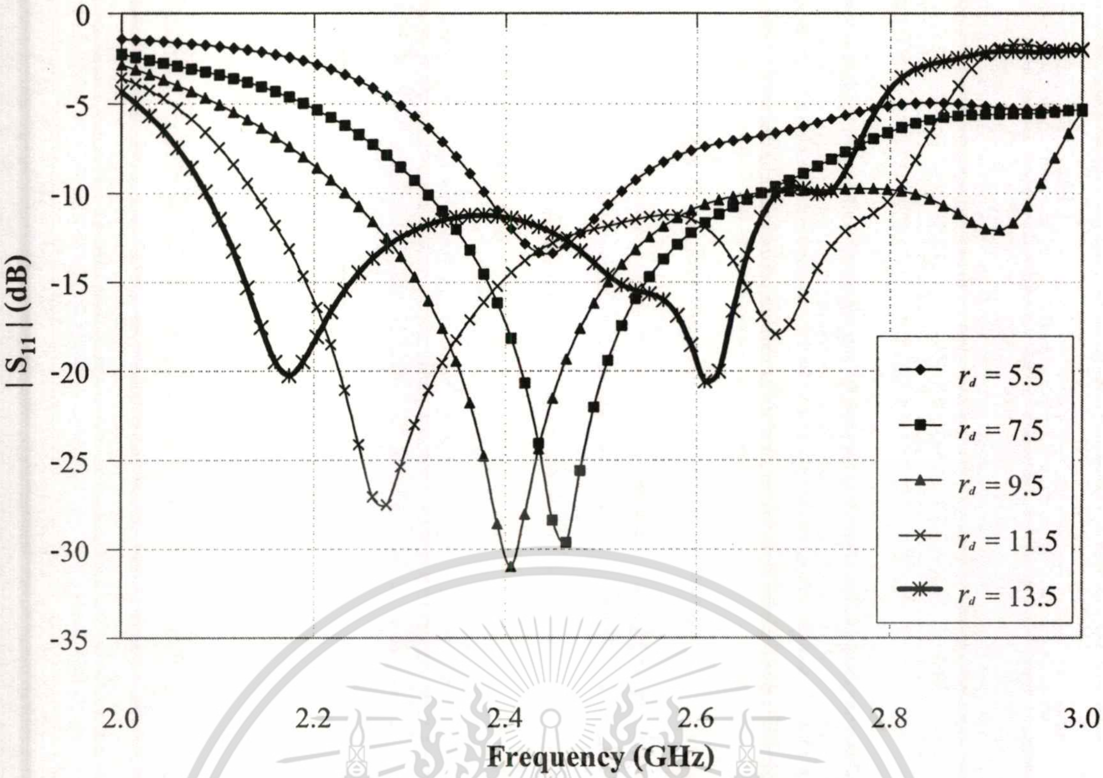


Fig. 3.36 Frequency response of return loss as a function of radius of dielectric rod

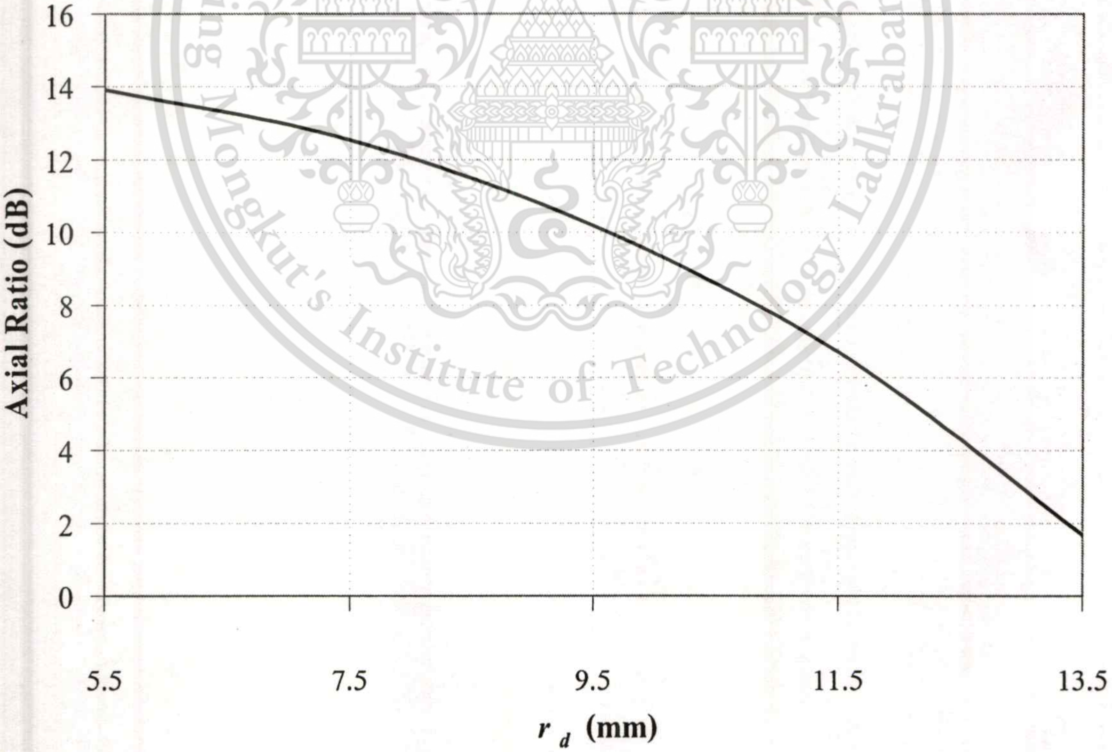
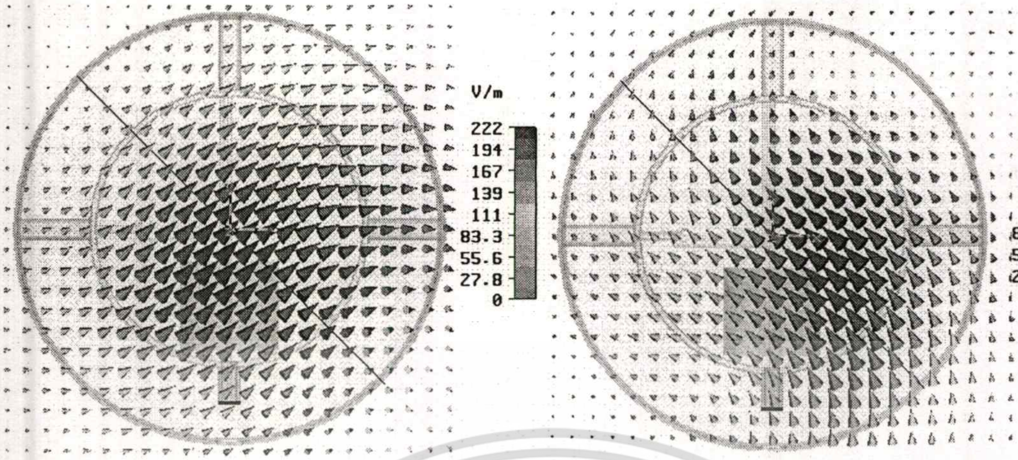
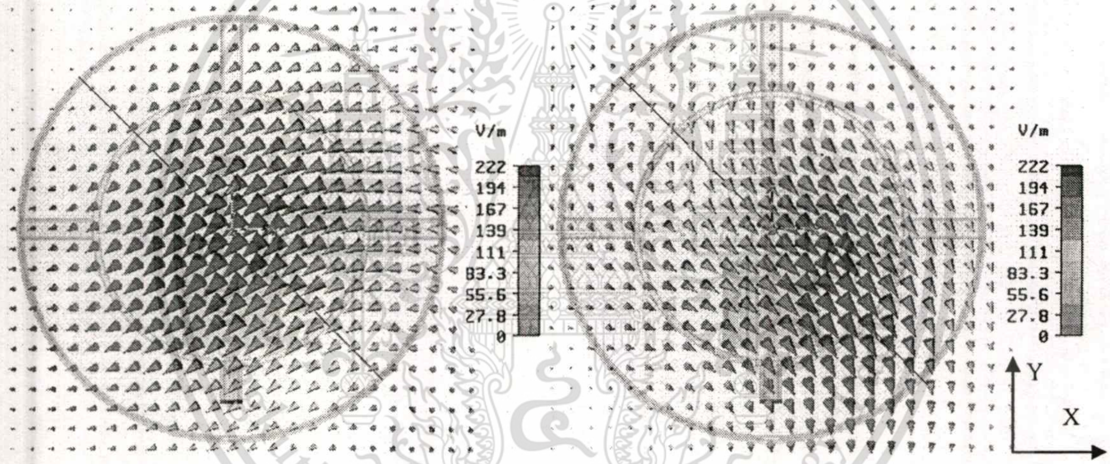


Fig. 3.37 Axial ratio versus radius of dielectric rod

3.3.2 Electric Field inside a Circular Ring



(a) Field pattern in 0° **(b)** Field pattern in 90°



(c) Field pattern in 180° **(d)** Field pattern in 270°

Fig. 3.38 Field pattern in XY-plane

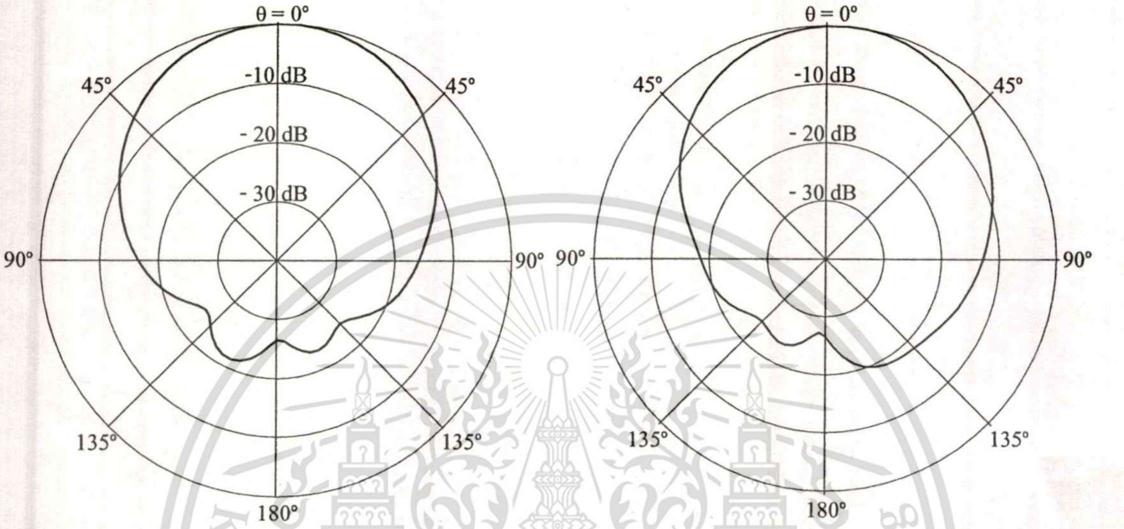
From Fig. 3.38, it is obvious that the antenna radiates circular polarization.

3.3.3 Radiation Pattern

From the previous section, the appropriate parameters were selected such as radius of circular ring (*a*) of 36 mm, length of circular ring (*t*) of 36 mm, radius of cylindrical reflector (*b*) of 58 mm, length of cylindrical reflector (*d*) of 53 mm, distance between probe and reflector (*h*) of 40 mm, probe length (*g*) of 26 mm, stub length (*s*) of 13 mm and radius of dielectric rod (r_d) of 13.5 mm, respectively.

Fig. 3.39 shows the radiation pattern in both planes i.e. E- and H-plane at angle ϕ of 90° and 0°, respectively. This antenna structure radiates the unidirectional beam with the circular polarization. The half-power beamwidth (HPBW) in E- and H-plane are 65.7° and 65.5°, respectively. The front-to-back ratio (F/B) in both planes is better than 20 dB.

The return loss for various frequencies is shown in Fig. 3.40 and the antenna has an impedance bandwidth (return loss <-10 dB) of 24.93% is observed. The frequency range covers 2.089 – 2.684 GHz.



(a) E-plane **(b)** H-plane

Fig. 3.39 Radiation pattern

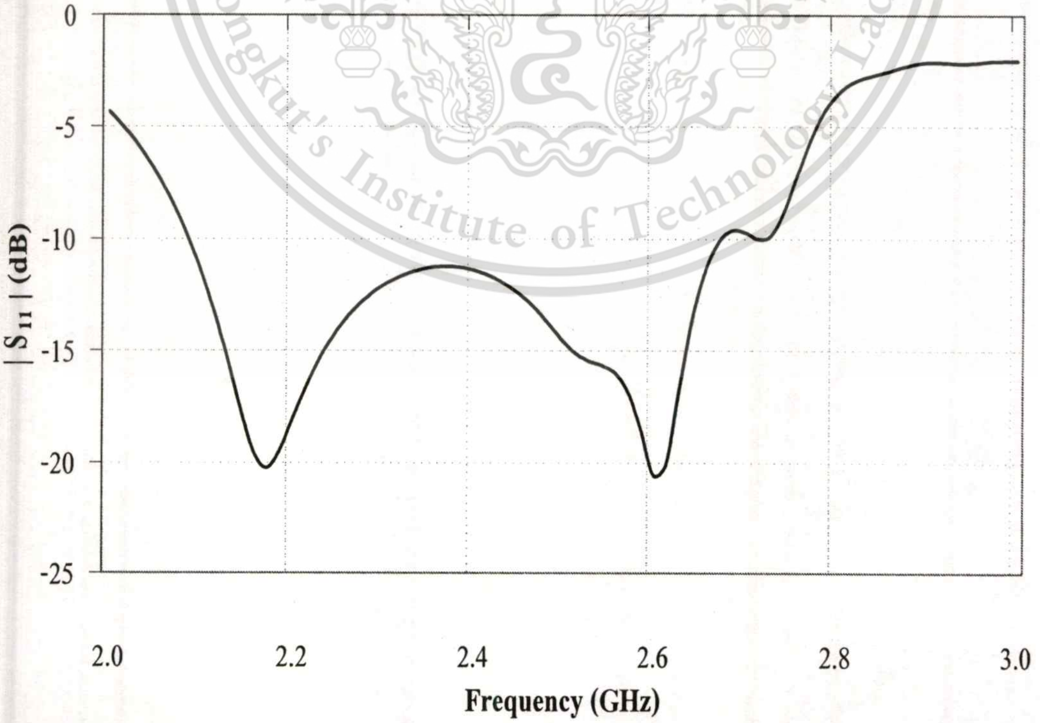


Fig. 3.40 Frequency versus return loss

3.3.4 Directivity

The maximum directivity for various frequencies is shown in Fig. 3.41 and the directivity is 9.009 dBi at the frequency 2.45 GHz.

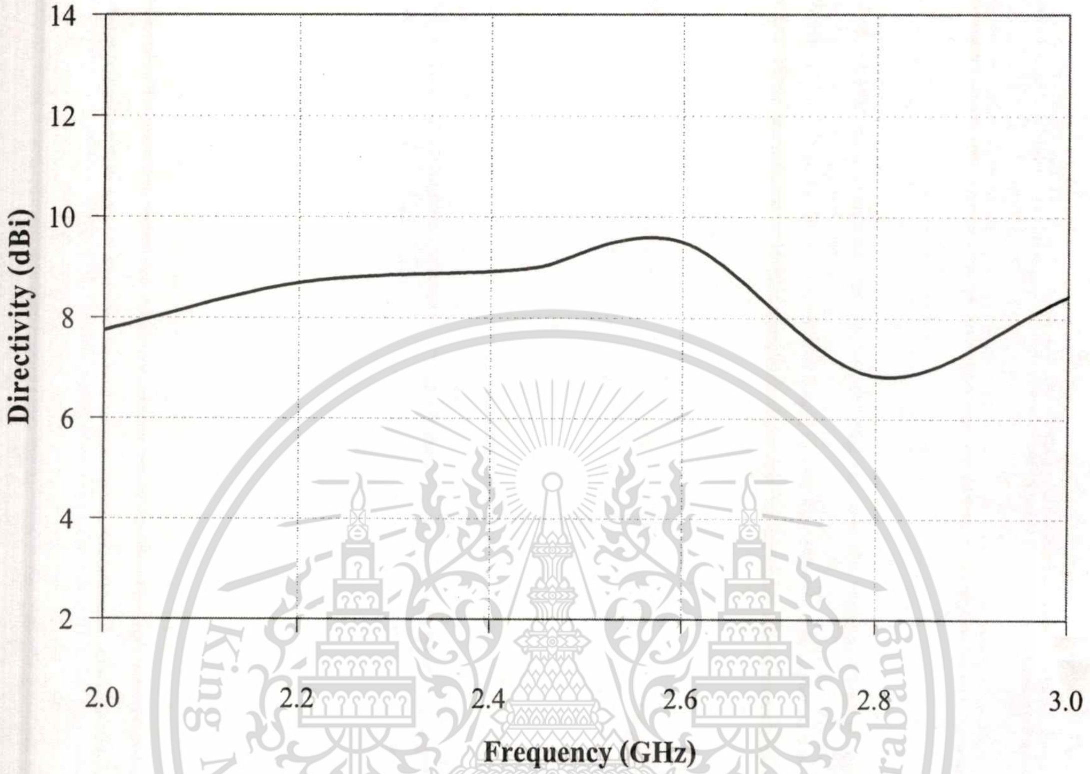


Fig. 3.41 Directivity versus frequency

3.4 Summary

This chapter shows the simulation of a unidirectional antenna using a probe excited circular ring above cylindrical reflector. We have proposed a simple structure unidirectional antenna, which can be designed easily and straightforwardly by choosing the optimum parameters that provide the maximum directivity. The cylindrical reflector is designed to achieve the high gain and low side lobe level. Moreover, the antenna can be designed to radiate both linear and circular polarizations. The cylindrical reflector dimensions are varied to achieve the minimum axial ratio of 1.68 dB. The probe length, stub length and radius of dielectric rod are also adjusted. Ultimately, the probe length (g) of 0.21λ, stub length of 0.10λ, and radius of dielectric rod of 0.11λ are used to achieve the optimum matching condition. This antenna has a unidirectional beam radiation with circular polarization. The results of the investigations are very useful for the design of the high gain unidirectional beam antenna. Therefore, this antenna is suitable for the access point of the Wireless Local Area Network (WLAN) communication system. The ring length must be appropriately chosen to let only a single mode appear at the apertures. It is equal to 0.29λ.

Chapter 4

Fabrication and Performance Test of a Unidirectional Antenna Using a Probe Excited Circular Ring above Cylindrical Reflector

4.1 Introduction

In this chapter the fabrication and performance test of a unidirectional antenna using a probe excited circular ring above cylindrical reflector are described. The experiment is performed to confirm the theoretical principle. The prototype antenna was fabricated according to appropriate antenna parameters to obtain maximum directivity and matched impedance. Characteristics of the antennas are measured and compared with simulated results.

4.2 Design Procedure

4.2.1 A Unidirectional Antenna Using a Probe Excited Circular Ring Antenna above Cylindrical Reflector

Design criteria have already been presented in Chapter 4. The parameters are appropriately selected so that maximum directivity and matched impedance can be obtained. In addition, a smallest dimension is restricted. To carry out this requirement, simulation results as illustrated in chapter 3 must be obtained. The radius and length of the circular ring are firstly chosen to let the dominant wave propagated in this ring. It can be made from either standard waveguide or circular tube available in the market. It should be pointed that this antenna can be easily designed.

Since the ring length and radius are desired to be as small as possible, although we choose the smallest radius that cutoff all the higher modes but dominant mode TE_{11}, the field near the probe is still consisting of composite modes. Generally, the higher modes are evanescent and their amplitudes are decreased rapidly as the distance from the probe is increased. The distance is chosen such that the amplitudes of the higher modes are negligible at the apertures. Hence, the apertures radiate the fields according to only the dominant made. To let only the dominant mode accommodated in the ring, the radius is chosen such that the lowest cutoff frequency is the dominant mode TE_{11}. The adjacent mode TE_{21} is cutoff. Therefore [12]-[14]

$$0.293\lambda < a < 0.486\lambda \tag{4.1}$$

Where λ is the wavelength at the operating frequency.

Since the structure of the antenna is a part of the circular waveguide, in this circumstance the radius and the width of the ring can be either standard waveguide or waveguide available in the market that is operating in a dominant TE_{11} mode.

The experiment is performed to confirm the theoretical principle using fabricated prototype antenna. The ensemble of the antenna was made using 2 material types, i.e. the cylindrical reflector is made of aluminum and the circular ring is made of brass. The antenna can be easily designed with the low production cost material and available in the market. Therefore, this antenna is suitable for installing at the base station in the street cell. The photograph of the fabricated antenna is shown in Fig. 4.1

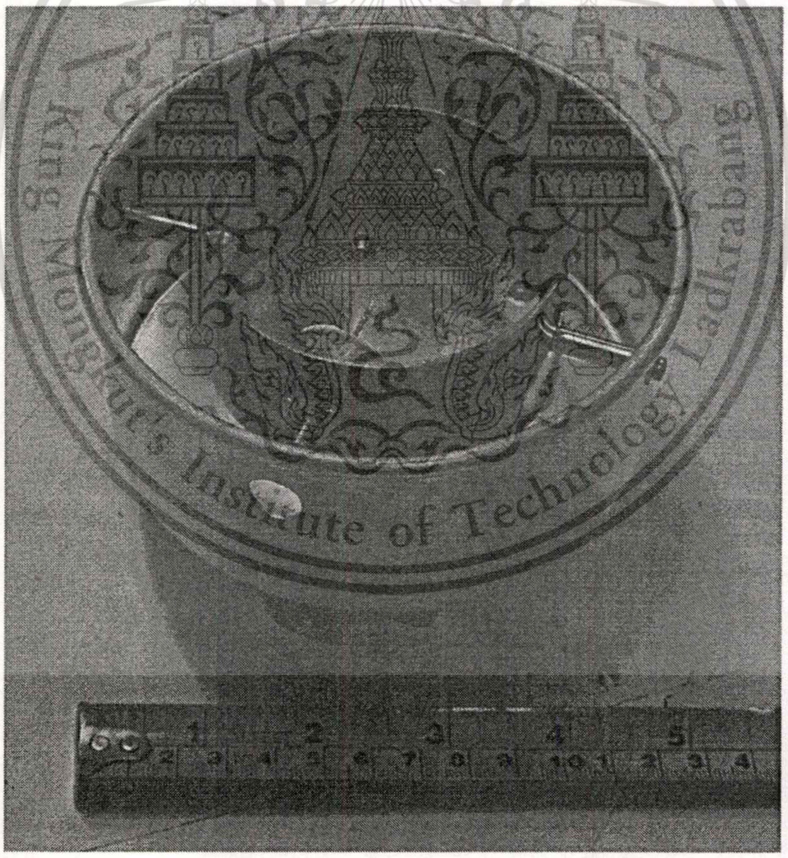
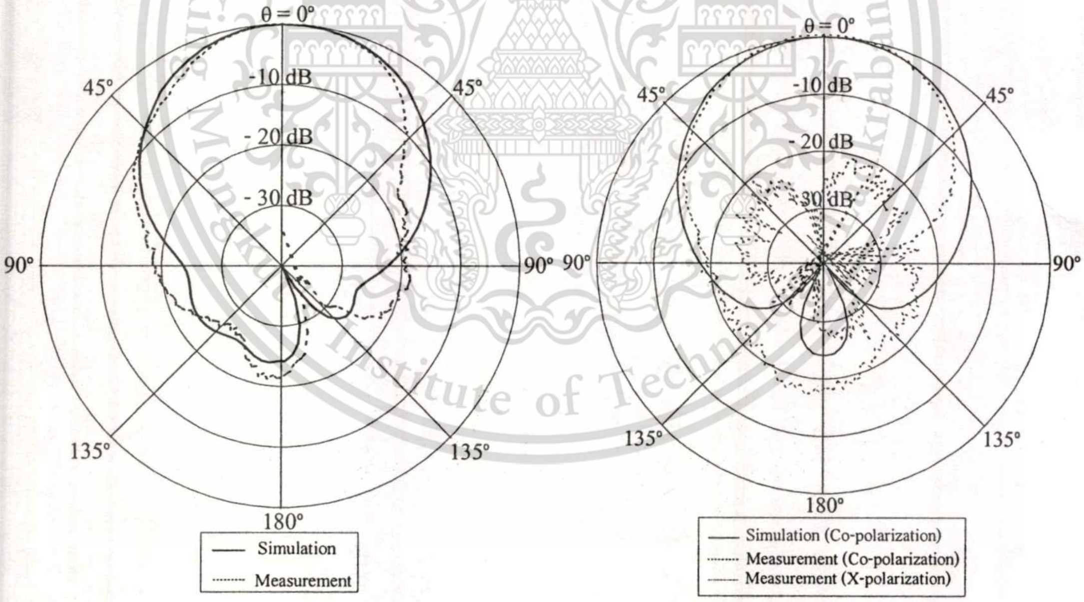


Fig. 4.1 Photograph of the fabricated antenna

4.2.1.1 Experimental Results

To verify the theoretical results, a unidirectional antenna excited circular ring above cylindrical reflector was fabricated to operate at the frequency of 2.45 GHz. The dimensions are as follows: a equals 40 mm, b equals 58 mm, l equals 33 mm, h equals 32 mm, t equals 36 mm and d equals 57 mm, respectively. The fabricated antenna is shown in Fig. 4.1. The radiation patterns were measured and plotted on the same graph with the simulated results in Fig. 4.2 (a) and (b). It is obvious that this structure radiates the unidirectional beam with the vertical linear polarization. The half-power beamwidth (HPBW) in both in E- and H-plane is 50° and 55°, respectively. The front-to-back ratio (F/B) in both planes is better than 20 dB. Fig. 4.2 (a) has shown the comparison between the radiation pattern from simulation and measurement at angle ϕ of 90° in E-plane. Fig. 4.2 (b) shows the comparison between the radiation pattern from simulation and measurement angle ϕ of 0° in H-plane. The radiation pattern of the simulation agrees well with the measurement.

4.2.1.1.1 Radiation Pattern



(a) E-plane

(b) H-plane

Fig. 4.2 The comparison between simulated and measured results

4.2.1.1.2 Impedance characteristics

For the impedance characteristics, the antenna was measured by using a Network Analyzer and compared with the simulated results. The simulation and experiment of the return loss has been compared as illustrated in Fig. 4.3. The results are in good agreement. The measured return loss has the impedance bandwidth (VSWR<2) of 13.76%. The center frequency is 2.45 GHz, and the frequency range is 2.30-2.64 GHz.

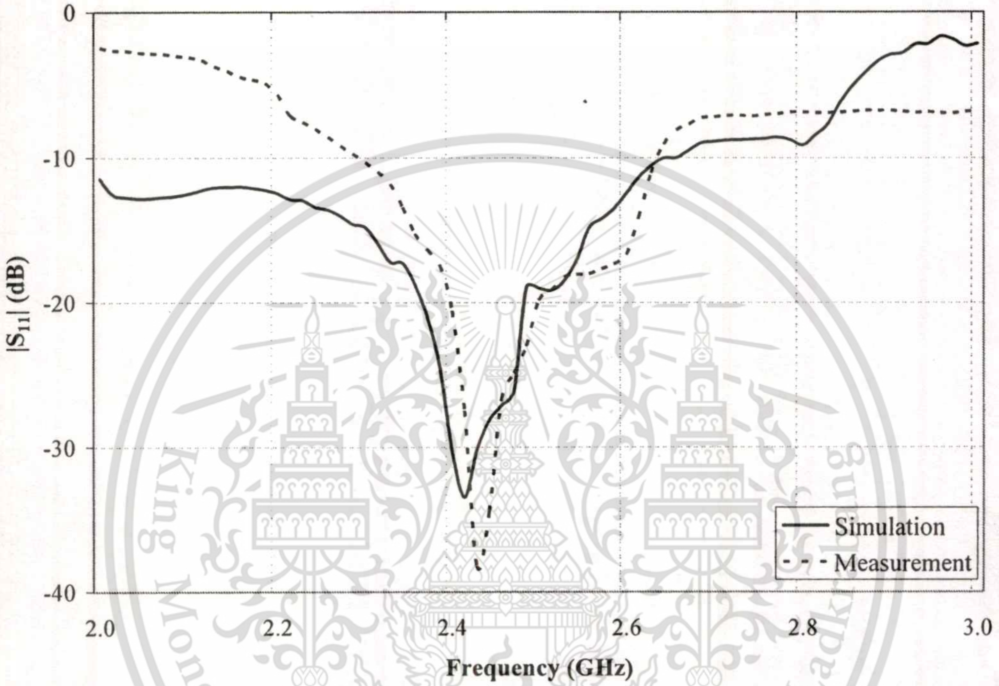


Fig. 4.3 The comparison of return loss between the simulated and measured results

4.2.2 A Bent Probe Excited Circular Ring Antenna above Cylindrical Reflector

Although the unidirectional antenna using a probe excited circular ring above cylindrical reflector with linear polarization is simple for modeling, practically it is found that the unidirectional antenna with circular polarization is more interesting. Moreover, the unidirectional beam antenna that provides circular polarization can improve the signal quality from the polarization change. Hence, it is of interest to investigate a unidirectional antenna using a bent probe excited circular ring above cylindrical reflector, which is simple, cost-effective and easy to fabricate, for circular polarization. It can be mass produced conveniently. Radiation pattern, impedance characteristics and gain of the antenna are measurement, and their results are discussed.

A unidirectional antenna using a bent probe excited circular ring above cylindrical reflector consists of a linear electric probe of length l aligned along y axis protruded from a coaxial transmission line into a circular ring and at the end of probe, it was bent with the length g aligned along the x axis. The distance between probe and reflector is h. The probe is surrounded by the circular ring of radius a and length t, respectively. The radius and length of cylindrical reflector is b and d, respectively. It is noted that the probe is shielded by dielectric rod of the height e. The stub length s is aligned along the x axis, and radius of dielectric rod is r_d. The structure of antenna is shown in Fig. 4.4.

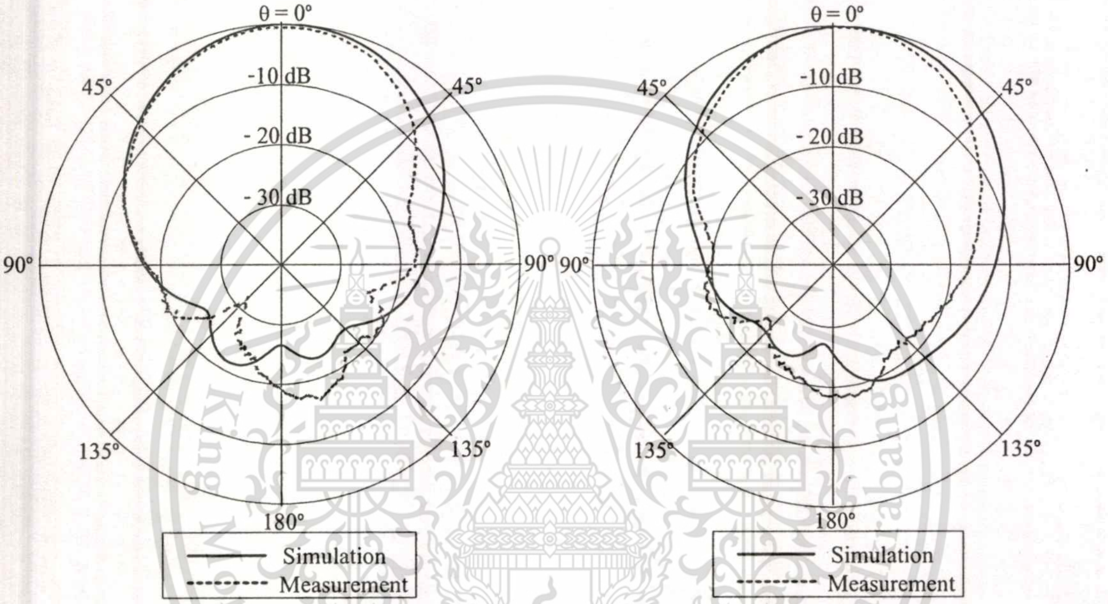
Fig. 4.4 Prototype antenna

4.2.2.1 Experimental Results

The experiment is performed to confirm the theoretical principle. The prototype antenna was fabricated from the selected parameters based on the simulation performed to study the influence of parameters in chapter 3. These parameters are as follows: radius of circular ring (a) is 36 mm, length of circular ring (t) is 36 mm, radius of cylindrical reflector (b) is 58 mm, length of cylindrical reflector (d) is 53 mm, distance between probe and the reflector (h) is 40 mm, probe length (g) is 26 mm, stub length (s) is 13 mm, and radius of dielectric (r_d) is 13.5 mm, respectively.

4.2.2.1.1 Radiation Pattern

Radiation characteristics of the antenna are reported in this section. This structure radiates the unidirectional beam with circular polarization as shown in Fig. 4.5. The half-power beamwidths (HPBW) in E-plane is 65.7° as shown in Fig. 4.5 (a) and the radiation pattern in H-plane as shown in Fig. 4.5 (b) with half-power beamwidth (HPBW) of 65.5°, respectively. The front-to-back ratio (F/B) in both planes is better than 20 dB. From Fig. 4.5 we found that the radiation pattern from simulation is agree with that of the measurement.



(a) E-plane **(b)** H-plane

Fig. 4.5 The comparison between simulated and measured results

4.2.2.1.2 Impedance Bandwidth

The impedance bandwidth for various frequencies is shown in Fig. 4.6. The impedance bandwidth (return loss < -10 dB) of 8.5% from measurement is observed. The frequency range covers 2.365-2.575 GHz. The maximum gain of a unidirectional antenna using a bent probe excited circular ring above cylindrical reflector is shown in Fig. 4.7. It is obvious that the maximum gain equal to 9.11 dBi at the frequency 2.45 GHz.

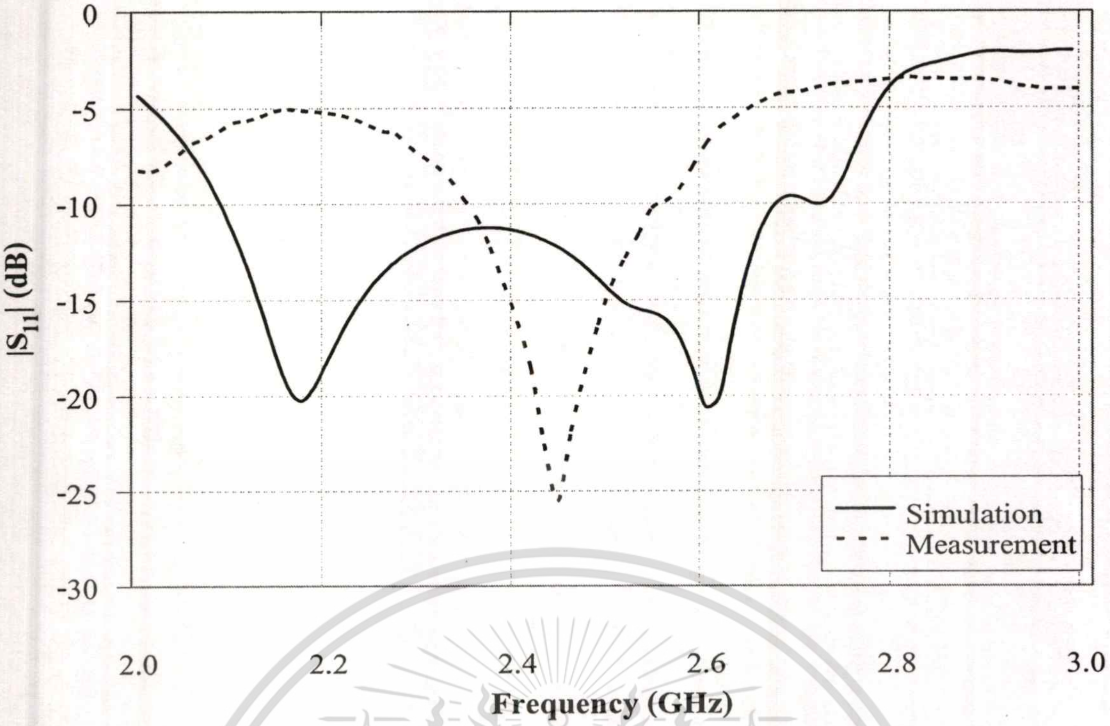


Fig. 4.6 The comparison of return loss between the simulated and measured results

4.2.2.1.3 Gain

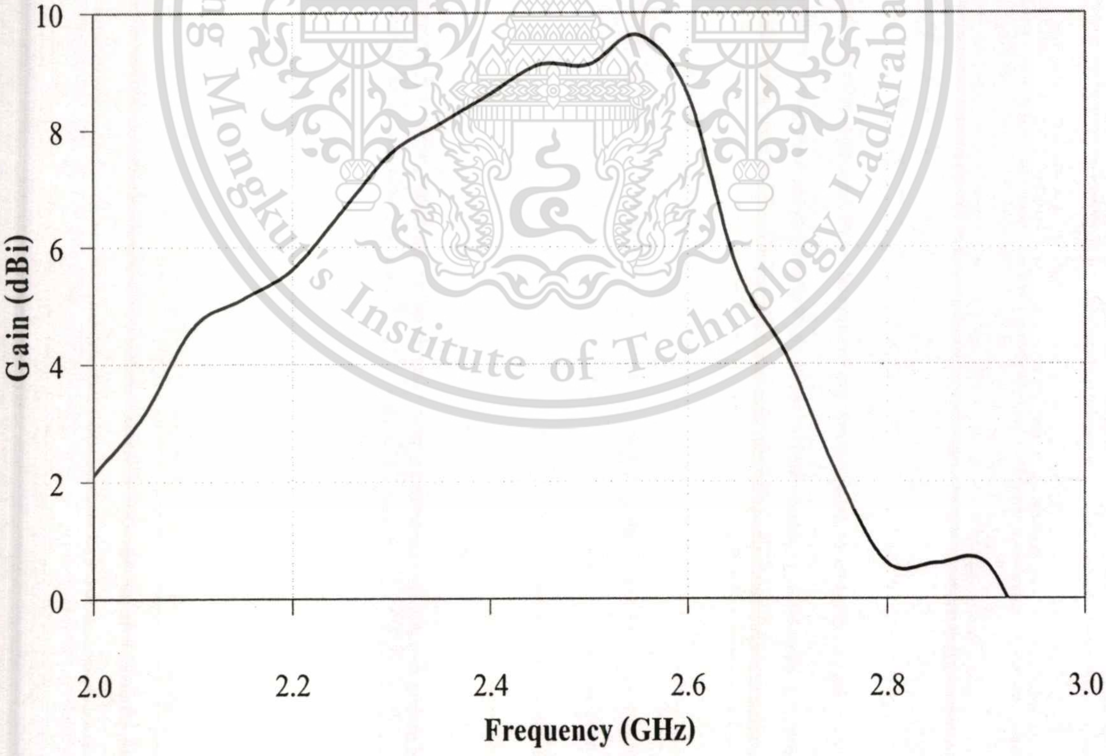


Fig. 4.7 Gain versus frequency

4.3 Summary

A unidirectional antenna using a probe excited circular ring has the same principle as that of the circular one. However, the simulation of the length of cylindrical reflector can be achieved, by using attenuation property of wave at various modes. This results in a simple task. We proposed a circular ring antenna excited by a probe above the cylindrical reflector. The antenna can be designed to radiate both linear and circular polarizations. The optimum parameters that provide the maximum gain, low side lobe level is obtained from the simulation. The cylindrical reflector dimensions are varied to achieve the minimum axial ratio. The minimum axial ratio is 1.68 dB. The probe length, stub length and radius of dielectric are also adjusted. Ultimately, the probe length (g) of 0.21λ, stub length is 0.10λ, and radius of dielectric is 0.11λ are used to achieve the optimum matching condition. This antenna possesses a gain of 9.11 dBi over the bandwidth of 8.5% at the centre frequency of 2.45 GHz. The front-to-back ratios (F/B) in both E- and H-plane are better than 20 dB. This antenna has a unidirectional beam radiation with the circular polarization. The results of the investigations are very useful for the design of the high gain unidirectional beam antenna. Therefore, this antenna is suitable for the access point of the Wireless Local Area Network (WLAN) communication system.

Chapter 5

Improvement of Unidirectional Antenna Using Circular Disc Monopole Excited Circular Ring above Cylindrical Reflector

5.1 Introduction

Recently considerable attention has been given to the ultra-wideband (UWB) technology. However, for some specific applications that we need the long range service such as the communication between the buildings, the unidirectional antenna is more suitable then omnidirectional one. Therefore, in this chapter we present a unidirectional antenna using circular disc monopole excited circular ring antenna above cylindrical reflector to cover the frequency of 3.1-10.6 GHz for ultra-wideband applications. Simulated results to be discussed in this chapter are impedance bandwidth, directivity and front-to-back ratio. The simulated results are presented ultra-wideband performance of this antenna by using Computer Simulation Technology (CST®). The return loss of better than 10 dB covers the frequency range from 2.46 to 12.41 GHz. The unidirectional antenna using circular disc monopole excited circular ring above cylindrical reflector has a unidirectional pattern with gain of 9.98 dBi at 3 GHz, 11.56 dBi at 7 GHz and 11.59 dBi at 11 GHz from the simulated results. Moreover, the design of this antenna is simple. Therefore, the unidirectional radiation pattern is desirable for many applications in long and narrow path service cell.

5.2 A Unidirectional Antenna Using a Circular Disc Monopole Excited Circular Ring above Cylindrical Reflector

The structure of a unidirectional antenna using circular disc monopole excited circular ring above cylindrical reflector to cover the frequency of 3.1-10.6 GHz for ultra-wideband applications. The structure of unidirectional antenna excited by circular disc monopole above cylindrical reflector consists of a radius of circular disc monopole of a_c. The circular disc monopole is surrounded by the circular ring radius a and length t, respectively. The distance between the circular disc monopole and reflector is h. The radius and length of the cylindrical reflector is b and d, respectively. The structure of antenna and its design is easy and straightforward, as shown in Fig. 5.1. This antenna is proposed for installing at the base station in the street cell. Table 1 shows the initial parameters of the antenna used in this chapter.

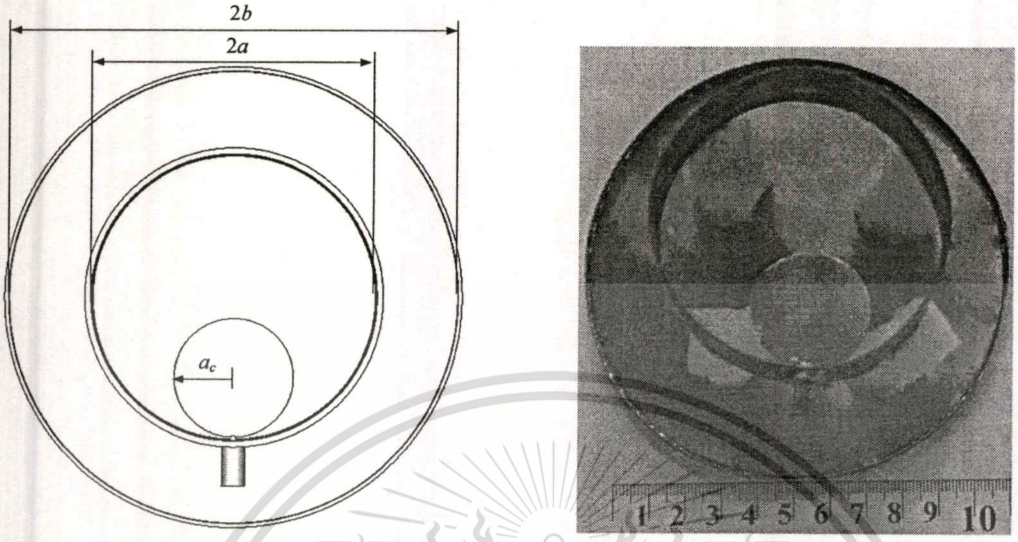


Fig. 5.1 Antenna structure

5.2.1 Parametric Study

Table 5.1 Initial Parameters

Parameters	Electrical Size	Physical size (mm)
a_c	0.25λ	25
a	0.36λ	36
t	0.25λ	25
b	0.50λ	50
h	0.25λ	25
d	0.05λ	5

5.2.1.1 Variation of Radius of Circular Ring and Circular Disc Monopole

The unidirectional antenna using circular disc monopole excited the circular ring above cylindrical reflector is designed to operate at the frequency covering 3.1-10.6 GHz. The radiation patterns of the proposed antenna various frequencies are studied. The antenna parameters are varied to study the influence of six parameters such as the radius of circular disc monopole (a_c), radius of circular ring (a) and length (t), respectively. Then, radius of cylindrical reflector (b), distance from circular disc monopole to cylindrical reflector (*h*) and length of cylindrical reflector (*d*), respectively.

In this section, the antenna impedance characteristics are investigated for various the combination radius of circular disc monopole and radius of circular ring. There are different radii of circular ring to be analyzed. It consists of a=32 mm, a=36 mm, a=40 mm, a=44 mm, a=48 mm and a=52 mm. There are different radii of circular disc monopole to be analyzed. It consist of a_c=5 mm, a_c=10 mm, a_c=15 mm, a_c=20 mm, a_c=25 mm, a_c=30 mm and a_c=35 mm whereas the other parameters are fixed as tabulated in Table 5.1. From the simulation, we found that the radius of circular disc monopole (a_c) affected to lower edge frequency (f_L) and higher edge frequency (f_H) when the radius of circular ring is small and the radius of circular disc monopole becomes larger as shown in Fig. 5.2 and Fig. 5.3, respectively.

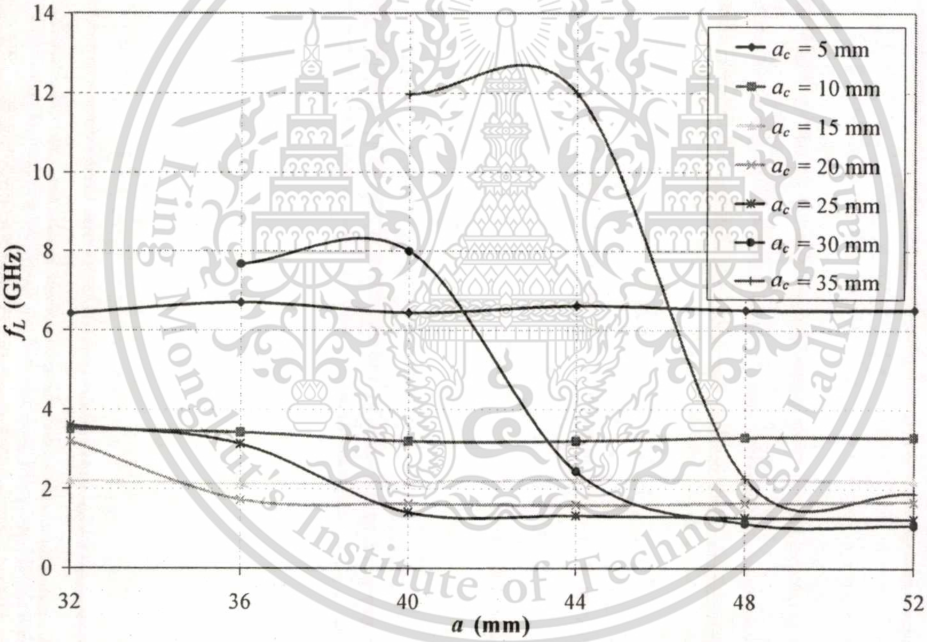


Fig. 5.2 Lower edge frequency as a function of ring radius for various a_c

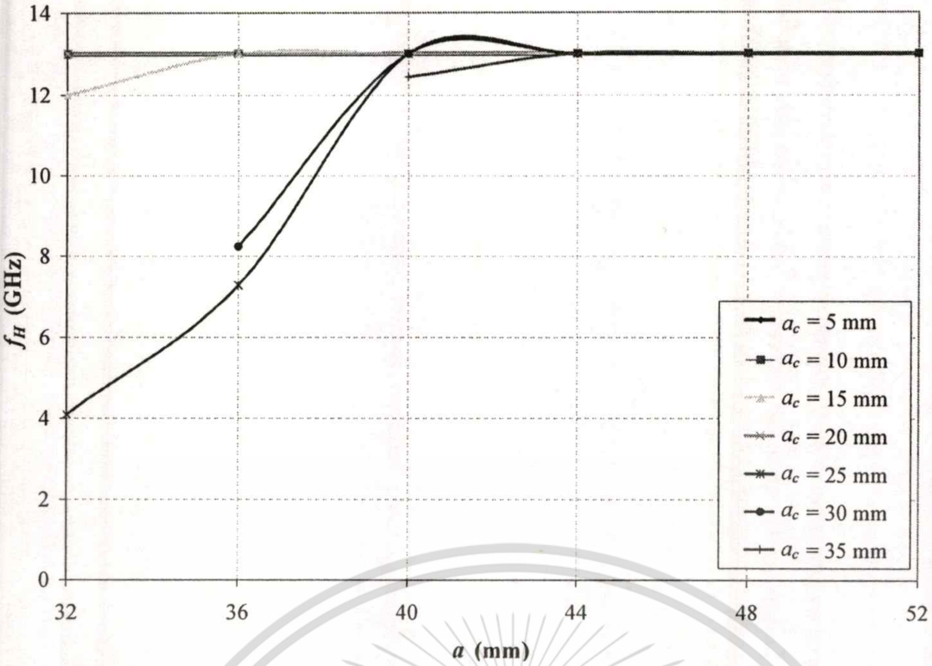


Fig. 5.3 Higher edge frequency as a function of ring radius for various a_c

From the simulated results from Fig. 5.2 and Fig. 5.3, the optimum impedance bandwidth was obtained that the circular disc monopole equal to 15 mm, and circular ring equal to 36 mm is suitable for antenna design because the proposed antenna has the return loss is better than 10 dB and cover the frequency range from 3 GHz to 11 GHz as illustrate in Fig. 5.4. On the other hand, the proposed of this antenna structure and design is compact and small size.

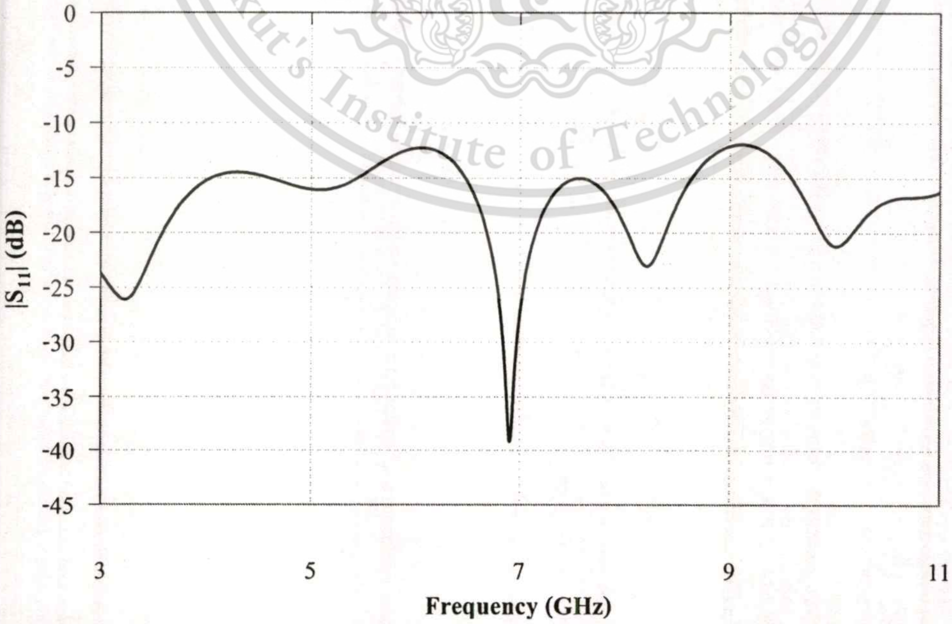


Fig. 5.4 Return loss versus frequency

5.2.1.2 Variation of Length of Circular Ring

The simulation is performed to study the influence of the length of circular ring (*t*) by fixing the circular disc monopole and radius of circular ring are 15 mm and 36 mm, respectively. There are various lengths of circular ring to be analyzed. It consists of *t*=15 mm, *t*=20 mm, *t*=25 mm, *t*=30 mm, *t*=35 mm, *t*=40 mm and *t*=45 mm. From the results, we found that the length of circular ring not affected to return loss as shown in Fig. 5.5. From the simulated results it is obvious the length of circular ring (*t*) of equal to 35 mm is suitable for antenna design. The proposed antenna has the bandwidth from 3 GHz to 11 GHz.

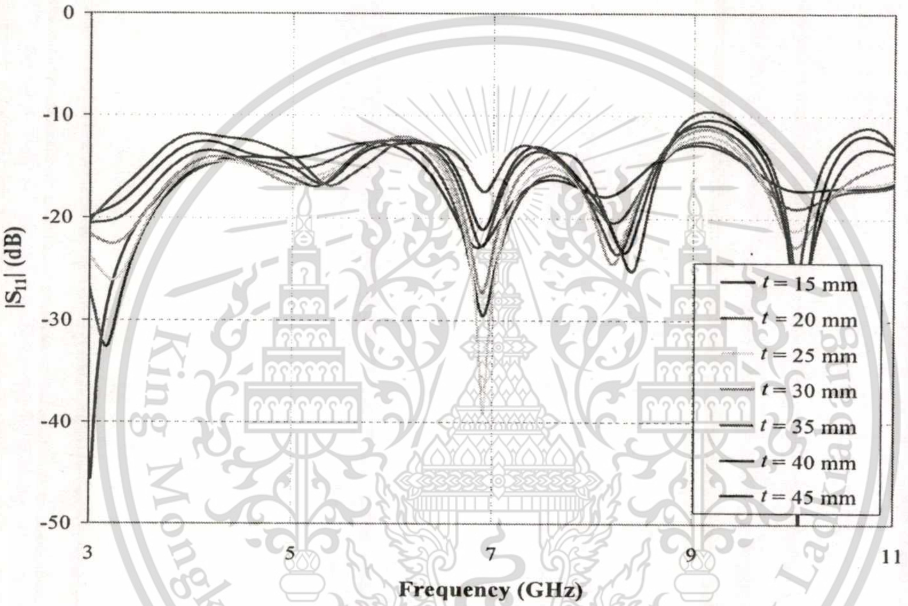


Fig. 5.5 Return loss versus frequency for various *t*

5.2.1.3 Variation of Radius of Cylindrical Reflector

From the simulated results in the previous sections, the proposed antenna has the bandwidth from 3 GHz to 11 GHz, the optimum bandwidth with bidirectional pattern was obtain by using circular disc monopole excited circular ring. To realize the unidirectional pattern with ultra-wideband, the reflector should be placed near one side of the ring aperture. Thus, in this section to determine flat reflector has the radius of 50 mm, and distance from circular disc monopole of *h* is equal to 25 mm. the radius of flat reflector are investigated from 42 mm to 62 mm. From the simulated results we found that the radius of flat reflector influenced to return loss but radiation pattern can not cover frequency range from 3.1 GHz to 10.6 GHz as illustrated in Fig. 5.6. Thus, it is obvious the radius of flat reflector is equal to 58 mm.

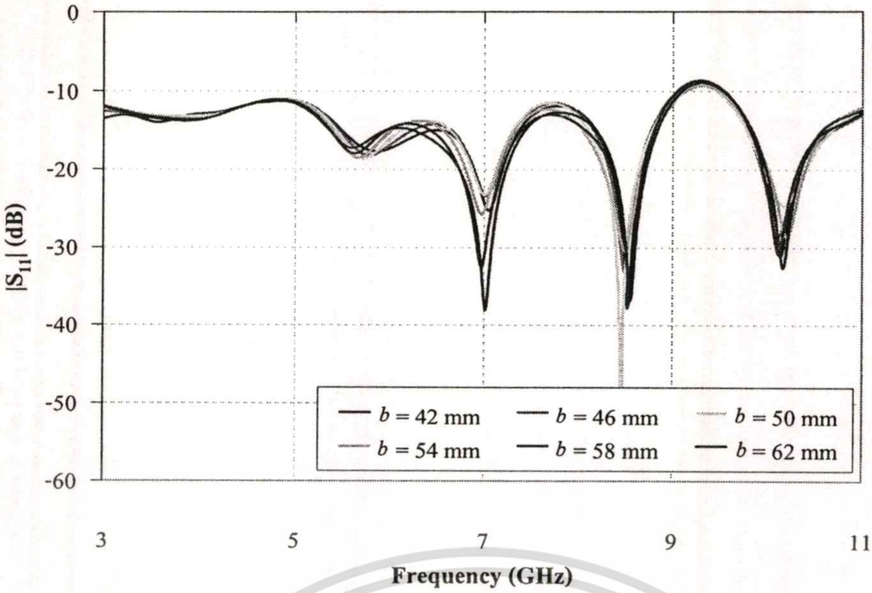


Fig. 5.6 Return loss versus frequency for various *b*

5.2.1.4 Variation of Distance between Circular Disc Monopole and Reflector

Moreover, the frequency range can be further enhanced by varying the distance from circular disc monopole to reflector. The simulation is performed to study the influence of distance from circular disc monopole and reflector by fixing a, a_c, t and b while the distance from circular disc monopole to reflector (h) are varied from 20 mm to 45 mm. From the simulated results the distance from circular disc monopole to reflector (h) impacted to the return loss as shown in Fig. 5.7. From the verification simulated results it is obvious that the distance from circular disc monopole to reflector of equal to 40 mm is suitable for the antenna design.

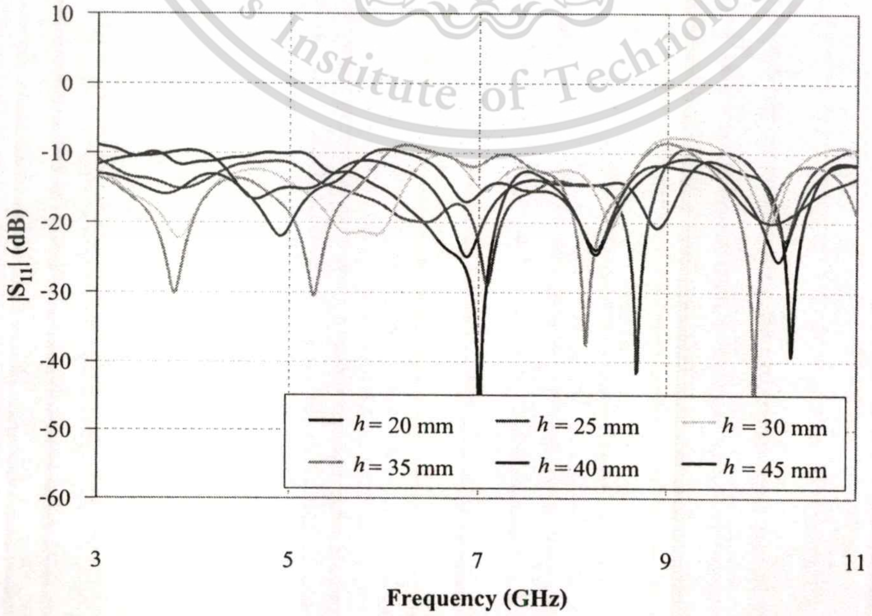


Fig. 5.7 Return loss versus frequency for various *h*

5.2.1.5 Variation of Length of Cylindrical Reflector

Furthermore, the frequency range can be further improved by varying length of cylindrical reflector. The simulation is conducted to study the influence of the length of cylindrical reflector (*d*) by fixing a=36 mm, a_c=15 mm, t=35 mm, b=58 mm and h=40 mm. The lengths of cylindrical reflector are investigated from 3 mm to 15 mm. From various parameters of simulated results, we found that the length of cylindrical reflector (*d*) influenced to return loss but radiation pattern can not cover frequency range from 3.1 GHz to 10.6 GHz as shown in Fig. 5.8. Thus, it is obvious that the length of cylindrical reflector is equal to 7 mm is suitable for antenna design because the return loss is better than 10 dB and cover the frequency range from 3.1 GHz to 10.6 GHz.

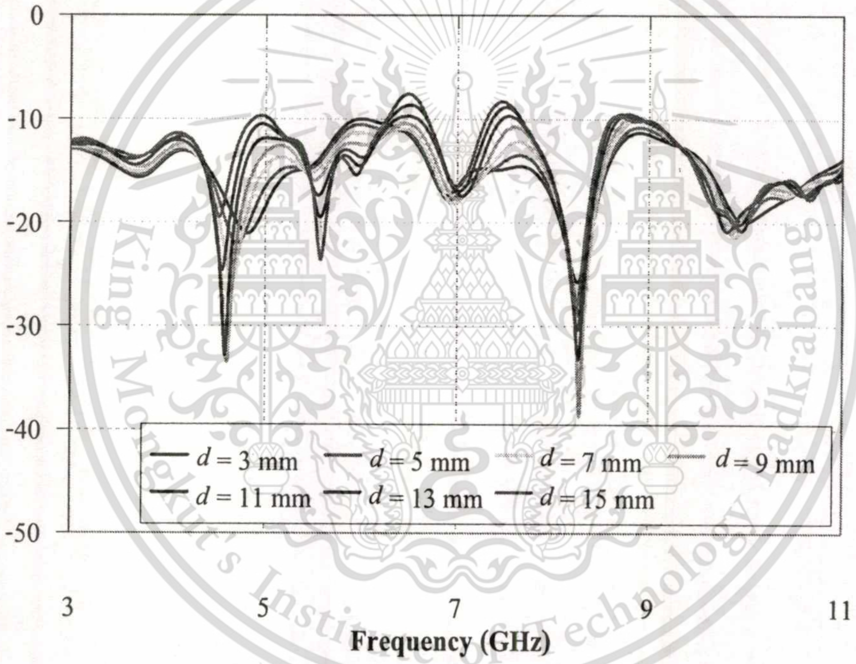


Fig. 5.8 Return loss versus frequency for various *d*

5.3 Radiation and Impedance Characteristics

The simulation is performed to study the influence of antenna parameters. We can choose the optimum parameters such as the circular disc monopole (a_c) of 15 mm, the radius and length of circular ring (a) and (t) of 36 mm and 35 mm, respectively. The radius of cylindrical reflector (b) and 58 mm, length of cylindrical reflector (d) of 7 mm and the distance between circular disc monopole and reflector (h) of 40 mm, respectively. The radiation patterns of the proposed antenna from various frequencies at 3 GHz, 7 GHz and 11 GHz. The circular disc monopole excited circular ring above cylindrical reflector has the unidirectional radiation characteristics and the front-to-back ratio (F/B) as illustrated in Fig. 5.9. It is observed that the main beam direction will tilt upward when the frequency becomes higher. Therefore, the unidirectional pattern is degraded at the frequency higher than 11 GHz. The frequency range covers 2.98-12.76 GHz from measurement and from the simulation is 2.46-12.41 GHz, as shown in Fig. 5.10. The proposed antenna has the bandwidth from simulation from 2.46 GHz to 12.41 GHz. The half-power beamwidths (HPBW) in E-plane and H-plane are 81.5° and 87.4° at the frequency of 3 GHz, 20.6° and 22.2° at the frequency of 7 GHz, 11.9° and 13.8° at the frequency of 11 GHz, as shown in Fig. 5.11 and 5.12, respectively. However, the beampeak angle in E-plane tilt upward around $\theta = 57°$ at the frequency of 11 GHz, as shown in Fig. 5.13. Therefore, from the simulated results; the proposed antenna could have good unidirectional ultra-wideband characteristics.

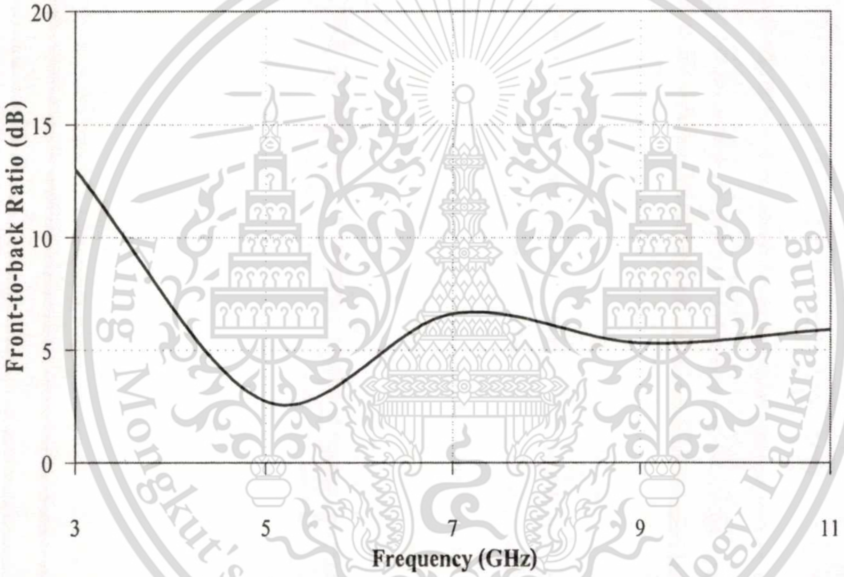


Fig. 5.9 Front-to-back ratio versus frequency

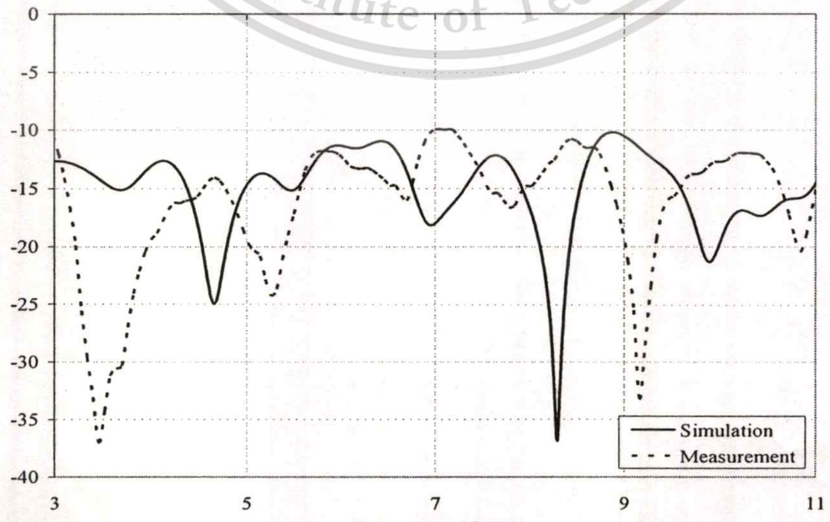
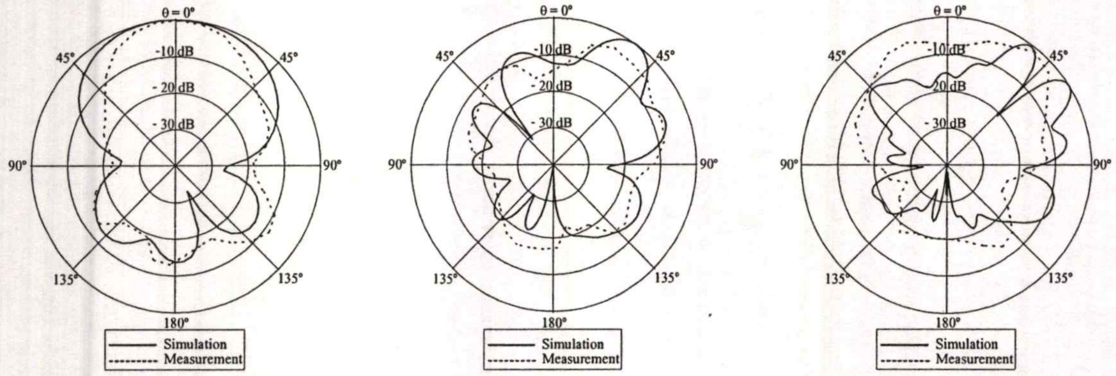
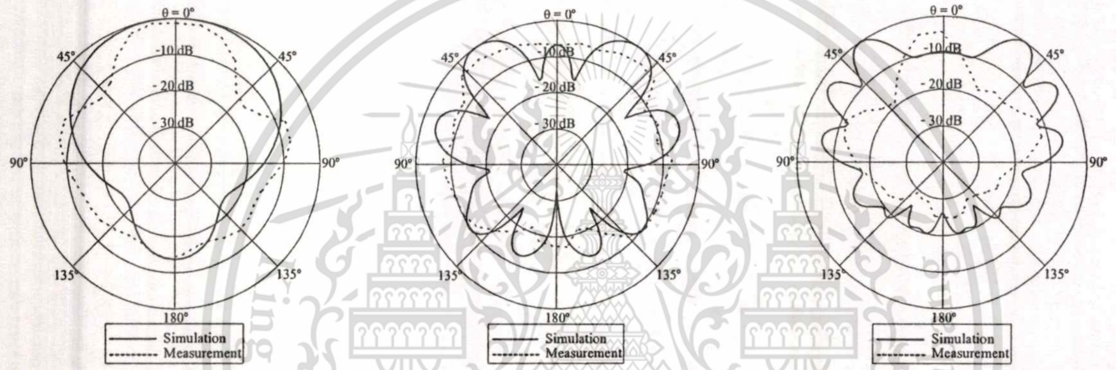


Fig. 5.10 The comparison of return loss between the simulated and measured results



(a) 3 GHz (b) 7 GHz (c) 11 GHz

Fig. 5.11 The comparison between simulated and measured results in E-plane (YZ-plane)



(a) 3 GHz (b) 7 GHz (c) 11 GHz

Fig. 5.12 The comparison between simulated and measured results in H-plane (XZ-plane)

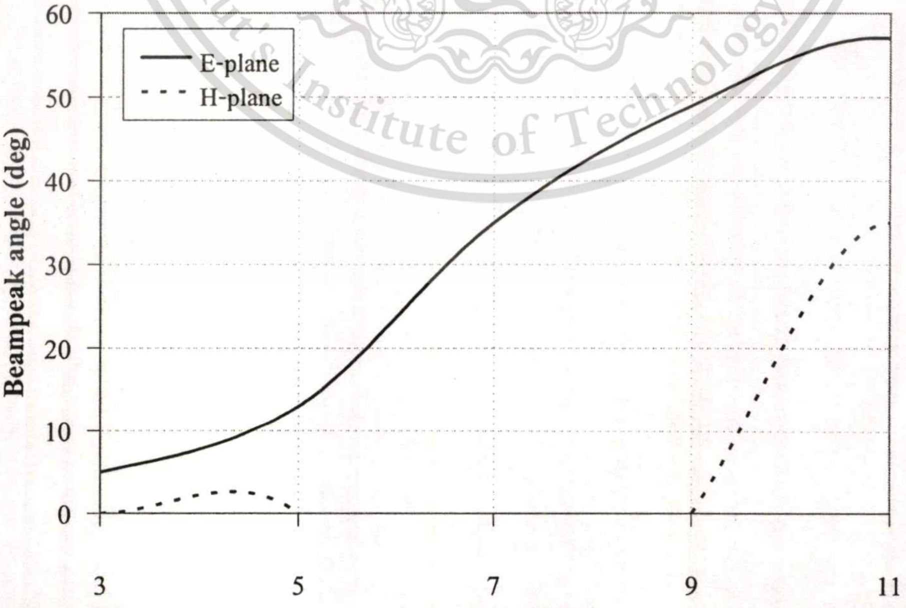


Fig. 5.13 Beampeak angles in E-plane and H-plane

5.4 Directivity

The simulation is also performed to study the characteristic of maximum gain. The maximum gain is 9.98 dBi at the frequency 3 GHz, 11.56 dBi at 7 GHz and 11.59 dBi at 11 GHz as illustrated in Fig. 5.14

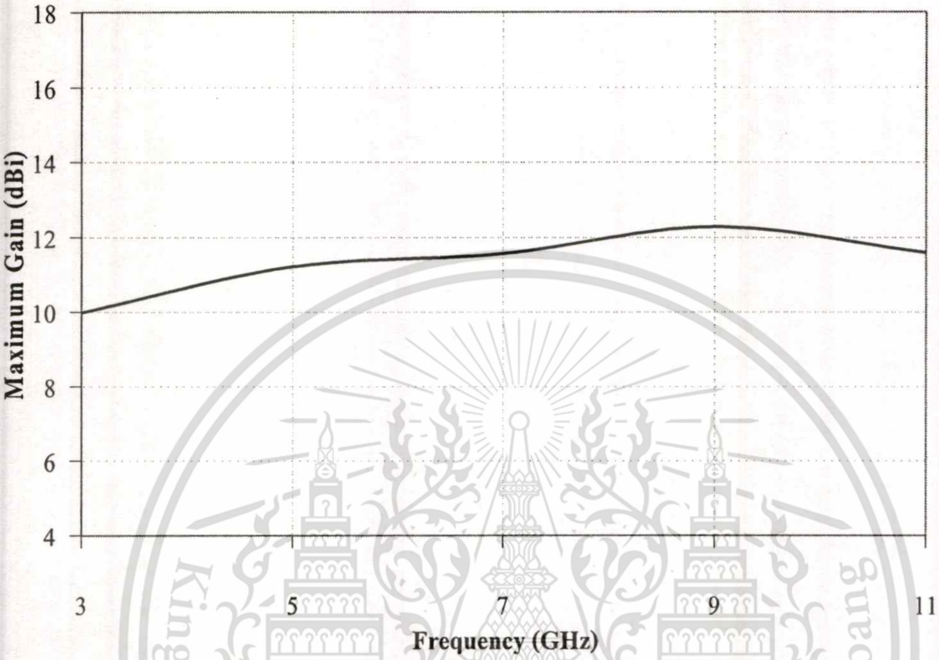


Fig. 5.14 Maximum gain versus frequency

5.5 Summary

An ultra-wideband unidirectional antenna with using circular disc monopole excited circular ring above cylindrical reflector. The proposed antenna has a simple structure unidirectional antenna, which can be design easily and straightforwardly by choosing the optimum parameters that provide the maximum gain. To obtain the ultra-wideband range, the impedance characteristics and radiation patterns of these antennas are optimized by parametric study. The designed antenna is well-matched from 2.98 GHz to 12.76 GHz over the ultra-wideband requirement and provides the unidirectional patterns. The results of antenna are very useful for long range and narrow path service area, for the ultra-wideband applications.

Chapter 6

Conclusions and Discussions

The author proposed a unidirectional antenna using a probe excited circular ring above cylindrical reflector. It is evident that development of a bidirectional antenna that has suitable characteristics for a particular application is desired. It is initially described theoretically in term of a unidirectional antenna using a probe excited circular ring above cylindrical reflector. Radiation characteristics of the antenna can be considered from the simulation which was modeled to investigate its characteristics by using CST® (Microwave Studio). To describe the performance of antenna, definitions of various parameters are necessary. Some of parameters are interrelated and not all of them need be specified for complete description of the antenna performance. Radiation characteristics such as radiation pattern and directivity are important in wireless communication. Moreover, cost effectiveness must be considered since the numbers of cells are very large. This principle of unidirectional antenna using a probe excited circular ring above cylindrical reflector is summarized in chapter 2.

We have proposed a simple structure unidirectional antenna, which can be designed easily and straightforwardly by choosing the optimum parameters that provide the maximum directivity. The cylindrical reflector is designed to achieve the high gain, and low side lobe level from the simulation. The ring length must be appropriately chosen to let only a single mode appear at the apertures. Moreover, the antenna can be designed to radiate both linear and circular polarization with the configuration that can be constructed using the similar procedure of a probe excited circular ring above cylindrical reflector. Numerical results describing the simulation of a unidirectional antenna using a probe excited circular ring above cylindrical reflector are addressed in chapter 3. They confirm that the unidirectional pattern can be achieved simply when the appropriate antenna dimensions are chosen.

Chapter 4 mentions about the fabrication and test of a unidirectional antenna using a probe excited circular ring above cylindrical reflector. Characteristics of a prototype antenna are illustrated and proved to be satisfactory. However, in a viewpoint of manufacturing process, a circular ring can be easier fabricated. Therefore, it is significant to further investigate a unidirectional antenna using a probe excited circular ring above cylindrical reflector. To carry out this investigation, a principle of a unidirectional antenna using a bent probe excited circular ring above cylindrical reflector is applied. The configuration can be constructed using the similar procedure as the circular ring antenna excited by linear probe.

This thesis proposes the antennas that are divided into three models. The design and prototype fabrication at the frequency of 2.45 GHz (the operating frequency of the Wireless Local Area Network communication system) are shown. The first model is a unidirectional antenna using a probe excited circular ring above cylindrical reflector. From the results, the antenna bandwidth, frequency range and gain are 13.76%, 2.30-2.64 GHz and 9.92 dBi, respectively. Moreover, good radiation characteristics with vertical linear polarization and the front-to-back ratio better than 20 dB in both E- and H-plane are obtained. Moreover, the antenna radiates circular polarization is also necessary to mitigate the polarization degradation. Hence, the second model, the development of the circular ring antenna with unidirectional beam and circular polarization is proposed. In this model, this thesis proposes a bent probe excited circular ring antenna above cylindrical reflector radiating circular polarization for the point-to-point wireless LAN communication system. The antenna has an impedance bandwidth (return loss < -10 dB) of 8.5% can be obtained. The frequency range covers 2.365-2.575 GHz and maximum gain is 8.88 dBi at the frequency of 2.45 GHz. Moreover, to enlarge the bandwidth the frequency range 3.1-10.6 GHz is of interesting for ultra-wideband service, and thus a ultra-wideband antenna will be employed in this band. A unidirectional antenna using a circular disc monopole excited circular ring above cylindrical reflector is presented. The configuration can be constructed using that the similar procedure as a unidirectional antenna excited by linear probe above cylindrical reflector. The designed antenna is well-matched from 2.46 GHz to 12.41 GHz over the ultra-wideband requirement and provides the unidirectional patterns. The results of antenna are very useful for long range and narrow path service area for the ultra-wideband applications. Furthermore, to obtain the ultra-wideband range the impedance characteristics and radiation patterns of these antennas are optimized by parametric study. The simulated results of these antenna parameters are shown in chapter 5.

As the aforementioned earlier, it is obvious that a unidirectional antenna using a probe excited circular ring above cylindrical reflector is satisfactorily developed. It is well-known that the antenna is a significant part of wireless system to make the communication successfully. However, on the long and narrow path service areas such as the point-to-point communication between the buildings, highway, tunnel and corridor, the unidirectional antenna is preferred.

However, there are many interesting topic to be considered such as development of polarization diversity of this antenna, increase its gain and enhance bandwidth, etc.

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Related Publications:

1. S. Vongsack, C. Phongcharoenpanich, S. Kosulvit, T. Wakabayashi, "A Unidirectional Antenna Using a Probe Excited Concentric Circular Ring above the Reflector," *Proceedings of the 2006 International Symposium on Antennas and Propagation (ISAP 2006)*, Singapore, p.conf99a350_r269. 4 pages, Nov. 2006.
2. S.Vongsack, C.Phongcharoenpanich, S.Kosulvit and T.Wakabayashi, "Parametric Study of a Vertically Polarized Concentric Circular Ring Antenna above the Reflector for High Gain Applications," *Proceedings of the 2007 Electrical Engineering/Electronics, Computer, Telecommunications, and Information Technology (ECTI) International Conference*, p.837-840, May 2007.
3. S.Vongsack, C.Phongcharoenpanich, S.Kosulvit and T.Wakabayashi, "A Circularly Polarized Unidirectional Antenna Using a Bent Probe Excited Circular Ring above Cylindrical Reflector," *Proceedings of the 2007 International Symposium on Antennas and Propagation (ISAP 2007)*, pp.49-52, Aug 2007.
4. S.Vongsack, C.Phongcharoenpanich, S.Kosulvit and T.Wakabayashi, "A Bent Probe Excited Circular Ring Antenna above Cylindrical Reflector Radiating Circular Polarization," *Proceedings of the 2007 Asia-Pacific Microwave Conference (APMC 2007)*, Bangkok, vol.3, pp.1637-1640, Dec 2007.

5. S.Vongsack, C.Phongcharoenpanich, S.Kosulvit and T.Wakabayashi, "Realization of UWB Unidirectional Antenna Using Surface Dipole Fed Circular Reflector," *Proceeding of the* 1^{st} *Joint International Conference on Information Communication Technology (JICT-2007)*, Vientiane Lao PDR, pp.300-303, Dec 2007.