Doctoral Dissertation

A Study of Highly Functional Hybrid Antenna

(複合型アンテナの高機能化に関する研究)

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Under the Supervision of

Professor Hiroyuki Arai

Presented by

Yuko Rikuta

Division of Electrical and Computer Engineering,
Faculty of Engineering,
Yokohama National University, Japan

Abstract

Some functions are required for hybrid antenna for the installation. Not only the achievement of required antenna characteristics but also considering about high function is required for examined. This dissertation described hybrid antenna to achieve highly functional antenna. Three different functions are discussed in this dissertation.

In chapter 2, we proposed two types of the stacked antenna which are improved on easy manufacturing from using ring patch which has shorted part. One is the two-layer antenna using a rectangular patch antenna with a hole. Another one is the stacked antenna using slitted patch antenna with one or two slit(s). We simulated the S parameter characteristics and radiation pattern. Our proposed antenna structure suppresses the mutual coupling between upper and lower antenna and the cross polarization level. When this antenna has circular polarization, it can be used for self-diplexing antenna.

In chapter 3, we presented the two-layered antenna which consists of a rectangular or loop element as the upper layer antenna and a low profile top loaded monopole antenna as the lower antenna which has matching structure. We simulated the S parameter characteristics and radiation pattern of this antenna by using FDTD method. This antenna has two resonant frequencies at about 1.5[GHz] and 2.0[GHz], and the radiation pattern of this antenna is similar to that of the monopole antenna at each resonant frequencies.

In chapter 4, the antenna characteristics of dipole antenna and patch antenna due to the shape of reflector or ground plane are presented. High level of FB ratio can be achieved instead of using large reflector (ground plane). A miniaturization of reflector can be achieved by selecting the size parameters of each reflector shape. By using the reflector with high FB ratio, the mutual coupling characteristics between two dipole antennas back to back in parallel are examined. The level of mutual coupling between two antennas is suppressed with small distance by using the reflector with high FB ratio.

Dual polarized antenna (linear polarization, circular polarization) and dual frequency antenna using stacked patch antenna is proposed. Propose antenna can be achieved the required antenna characteristics (high performance, multi function). The miniaturization of proposed antenna is also considered by using simple antenna model.

Contents

Chapter 1

Introduction

In recent years, mobile communication systems are being successfully developed all over the world. To accommodate the remarkable increase in the numbers of mobile phone subscribers, plural systems and functional antennas have been studied.

Wire antenna widely used for mobile communication systems has a simple construction. One of the wire antennas is monopole antenna. However, the need for smaller antenna systems has been increasing because the space of antenna installation is limited. One of the methods to miniaturize the antenna systems is the miniaturization of the antenna, and one is hybrid antenna.

To achieve the miniaturization of antenna, several types of antennas have been examined instead of wire antenna, and one of them is planer antenna, for example, the patch antenna and the top loaded monopole antenna. The planer antenna has some characteristics such as simple, small, light, low profile, and so on.

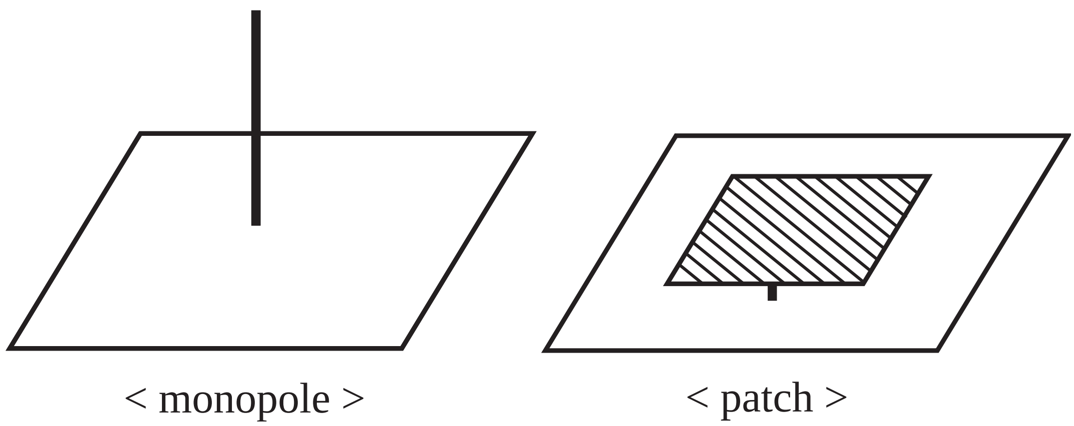


Figure 1.1: Wire antenna and planer antenna.

Reducing the number of antennas has been strongly required because of the physical limits for installation space. Hybrid antenna has been studied instead of using one antenna because it acts one characteristic or a few characteristics. For example, stacked antenna which is one of the hybrid antennas consists of each layer antenna. Hybrid antenna has high function or multi function, such as the characteristics of plural antennas.

For the mobile communication antenna, it has been required and examined several functional characteristics. For example, wide bandwidth, circular polarization, dual frequency, dual polarization, low side lobe, other high function, and so on. Antenna characteristics required for mobile communications are also required for hybrid antenna. In addition to the requirement for antenna, more functions are required for hybrid antenna for the installation. Not only the achievement of required antenna characteristics but considering about high function is required for examined.

To achieve the miniaturization of antenna system, not only the antenna itself but also the around part of antenna is required to be smaller.

In this paper, we consider about high function adding for hybrid antenna, such as dual polarization and dual frequency from above characteristics. High performance for hybrid antenna is examined by using dual polarized stacked antenna, and multi function for hybrid antenna is examined by using two-layer antenna with dual frequency. After the examination of high performance and multi function, the miniaturization of the antenna for installation is also considered in this dissertation.

1.1 Hybrid Antenna for Mobile Communication System

1.1.1 Dual Polarized Antenna

For the dual polarized antenna which has transmitting part and receiving part, several types of antenna using microstrip antenna are examined [1]-[12]. For the feed of microstrip antenna, electro magnetic coupling is widely used. Some of the dual polarized antenna is using triplet structure and fed by aperture coupled as shown in Figure 1.2 [2]-[4]. First layer is for the slot of upper receiving layer, second layer is receiving microstrip antenna, third layer is for the slot of lower transmitting layer, forth layer is transmitting microstrip antenna, and the last layer is ground plane. There are two types of dual polarized antenna, such as circular polarized antenna and liner polarized antenna. By changing the shape of aperture of the layer in Figure 1.2, circular polarization can be achieved.

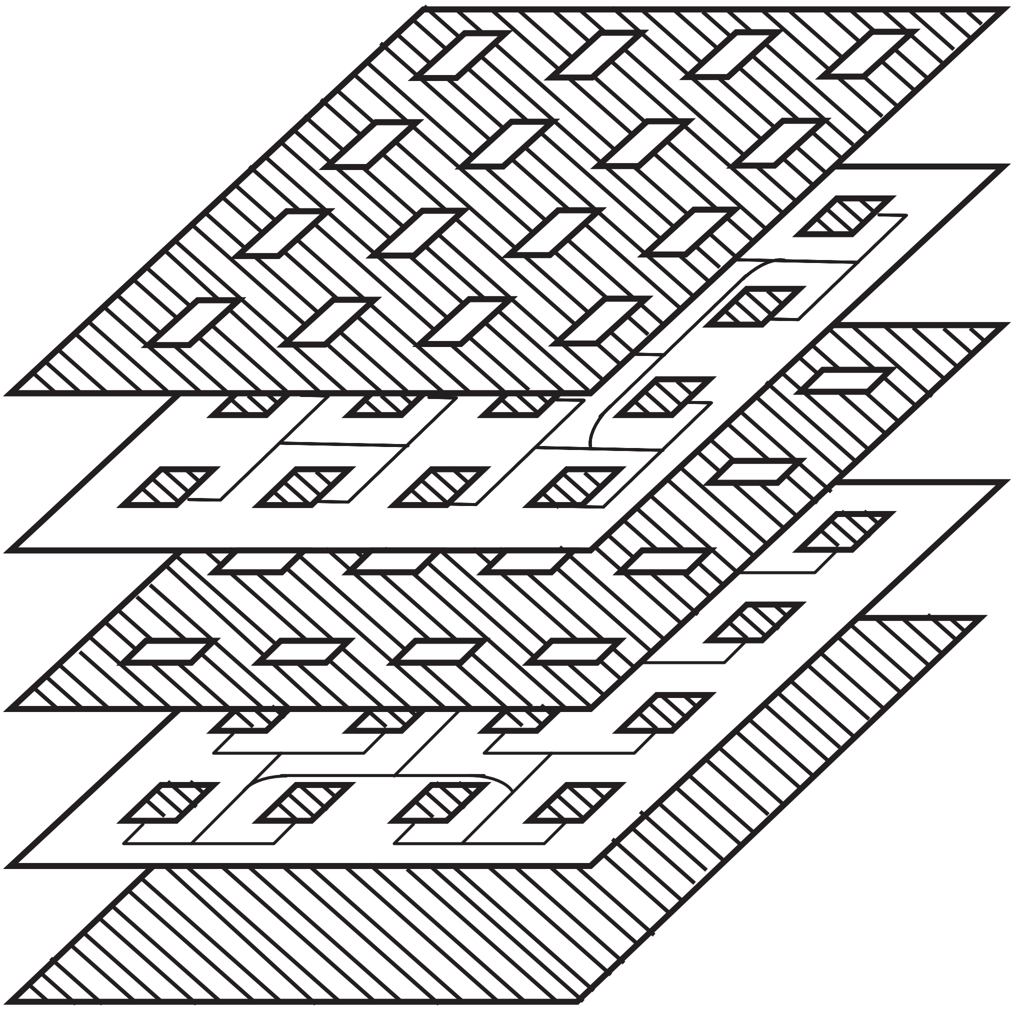


Figure 1.2: Dual-polarized aperture coupled planer antenna.

One of the dual polarized antennas with circular polarization is shown in Figure 1.3 [9]. This two-layer self-diplexing antenna consists of an upper circular microstrip patch antenna and a lower ring patch antenna. Considering a functional hybrid antenna consists of two antennas, mutual coupling between each antenna at the resonant frequency of both antenna is important. Mutual coupling between two antennas must be suppressed to act independently and also act as a filter. Self-diplexing antenna is the one of hybrid antenna and considered in this dissertation.

The ring patch antenna has a shorted ring structure to separate physically the feed circuit of the upper antenna and lower one. So, the high isolation between both antennas can be achieved. However, the shorted ring made by through holes is not easy for manufacturing. In order to make the manufacturing easier than using ring patch antenna, the patch antenna with a hole which doesn't have shorted part is considered and examined for dual polarized antenna in this dissertation.

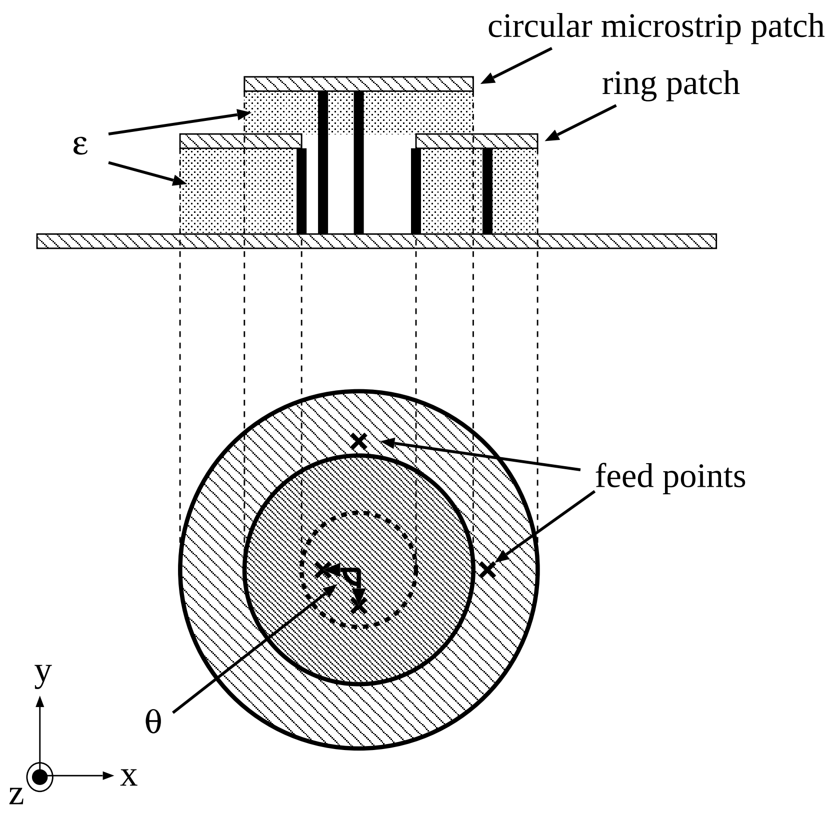


Figure 1.3: A two-layer self-diplexing antenna using a circular microstrip antenna and ring patch antenna.

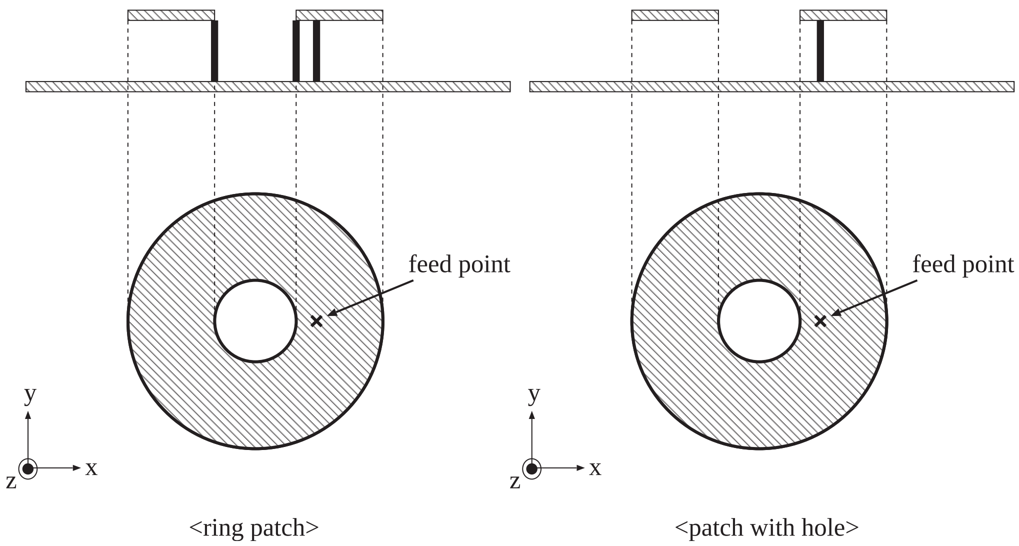


Figure 1.4: Ring patch antenna and patch antenna with a hole.

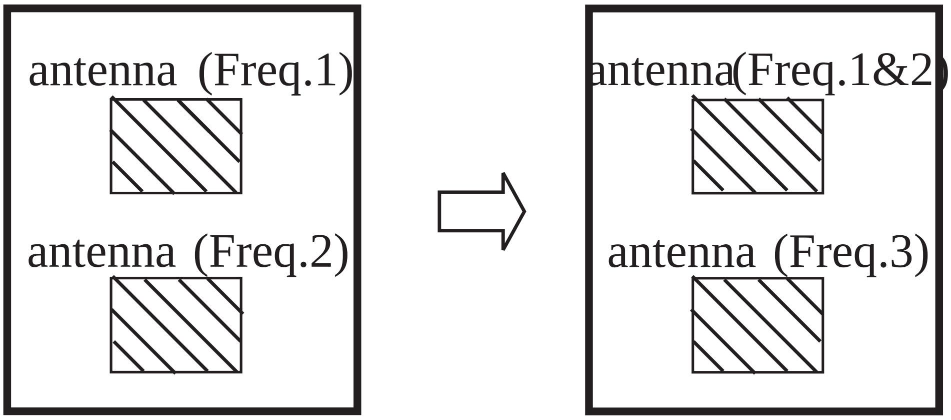


Figure 1.5: Antenna installation in limited space.

1.1.2 Dual Frequency Antenna

In Japan, the mobile system operated frequency bands of 900[MHz] and 1500[MHz] and 2[GHz] (IMT-2000). In the base station tower, each base station antennas are installed. Reducing the number of antennas has been strongly required because of the physical limits for the installation space. To minimize the size of indoor base station antenna, a dual frequency antenna is necessary [17]. If the antenna has dual frequency, one more antenna operated for another frequency can be installed in the space as shown in Figure 1.5.

Installed base station is consists of four antennas for frequency bands of 900[MHz] and 1.5[GHz]. If the dual frequency antenna, for example 1.5[GHz] and 2[GHz], is almost same size of the antennas for 1.5[GHz], it can be used instead of the antennas for 1.5[GHz] without changing the size of base station antenna.

One of the method to make the antenna with dual frequencies is using the parasitic element in front of the radiation element as shown in Figure 1.7. By using a parasitic element, another resonance is occured on the parasitic element, so, it can obtain dual frequencies or multi frequencies [18]. However, the radiation pattern at both resonant frequencies is not similar because the distance from the reflector isn't same.

For the base station antenna, the radiation characteristics of antenna are required to be similar to monopole antenna. However, the height of the monopole antenna is problem to install in base station antenna. To achieve the miniaturization of the monopole antenna's height, several types of antenna have been studied, for example, inverted F antenna, low profile top loaded monopole antenna, and so on [19]-[24]. The characteristics of top loaded monopole antenna with short pin for impedance matching are also examined [20].

In order to make dual frequency antenna with radiation pattern similar to monopole, top loaded monopole antenna is examined in this dissertation.

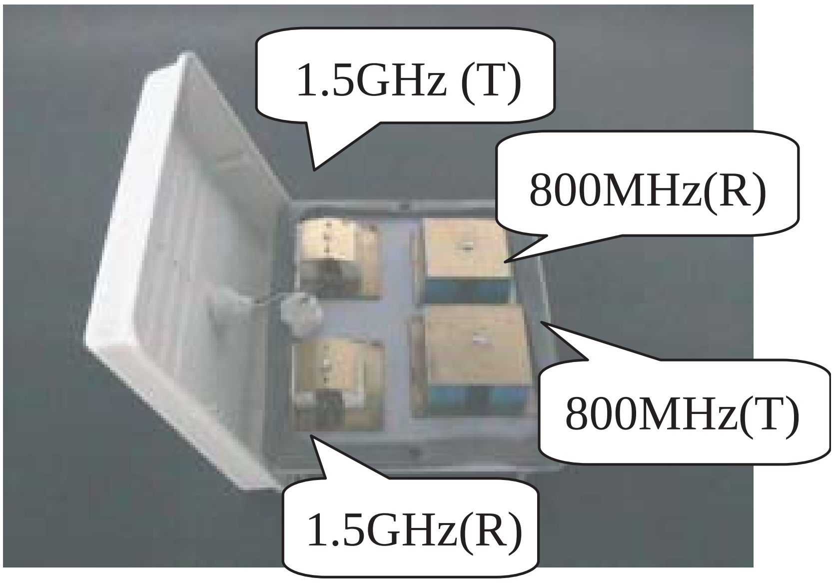


Figure 1.6: Installed base station for the cellular system.

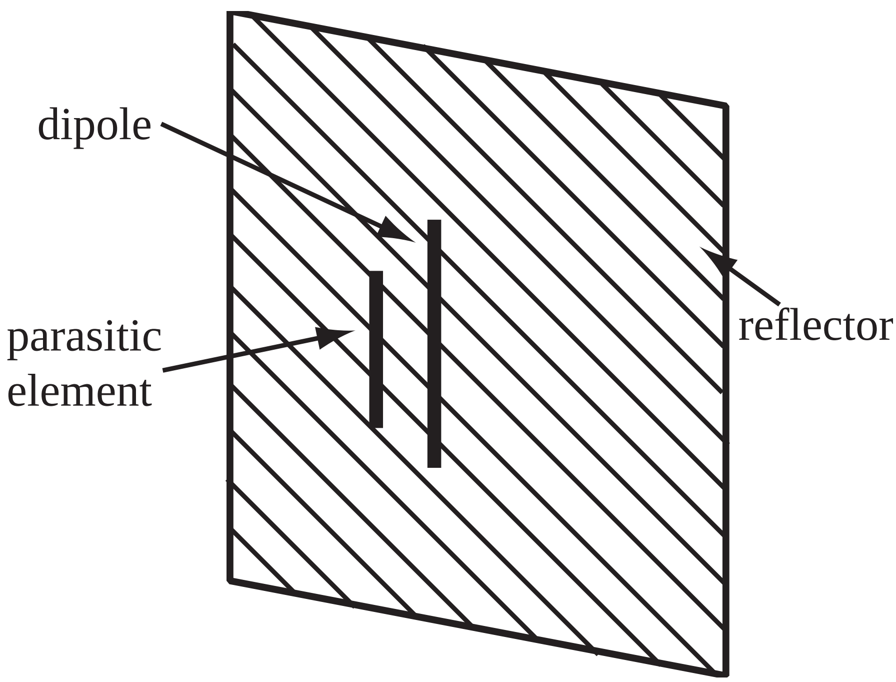


Figure 1.7: Dipole antenna backed by reflector with parasitic element.

1.1.3 Miniaturization of Antenna

In this dissertation, dual polarized antenna (which has linear polarization or circular polarization) and dual frequency antenna are considered to make high function. However, to make the antenna system for actual situation, smaller antenna is required with required antenna characteristics.

The miniaturization of the antenna can be achieved by using planer antenna like microstrip antenna instead of using wire antennas. However for actual situation for using antenna, there is ground plane under the planer antenna. For the antenna which is wanted to suppress the radiation backward has reflector backed of the antenna. For the base station antenna, the reflector or ground plane in radome is needed to consider about miniaturization. By adding the function, for example, dual polarization and dual frequency, to the antenna for reducing the installation space or achieving the suppression of mutual coupling between antennas, miniaturization of antenna can be only achieved. If the reflector and ground plane backed of the antenna is large, miniaturization of whole antenna system cannot be achieved. Considering not only the antenna but the around part of the antenna is needed for miniaturization.

In order to make the antenna miniaturization, the characteristics of antenna backed by reflector due to reflector shape are examined in this dissertation.

1.2 Summary of Remaining Chapters

The objective of this study is to propose highly functional hybrid antennas for mobile communications. Three different functions are discussed in this dissertation

- For high performance, dual polarized antenna using stacked antenna is proposed.
- For multi function, novel two-layer antenna with dual frequency is proposed.
- For antenna miniaturization, around of antenna is considered.

In chapter 2, we proposed two types of the stacked antenna which are improved on easy manufacturing from using ring patch which has shorted part. One is the two-layer antenna using a rectangular patch antenna with a hole. Another one is the stacked antenna using slitted patch antenna with one or two slit(s). The S parameter characteristics and radiation patterns of each antenna are examined.

In chapter 3, we presented the two-layered antenna which consists of a rectangular or loop element as the upper layer and a low profile top loaded monopole antenna as the lower antenna which has matching structure. The S parameter characteristics and radiation pattern of this antenna are examined by using FDTD method.

In chapter 4, the antenna characteristics of dipole antenna and patch antenna due to the shape of reflector and ground plane are presented. FB ratio characteristics of dipole antenna by the size of reflector and that of patch antenna by the size of ground plane are examined. By using the reflector with high FB ratio, the mutual coupling characteristics between two dipole antennas back to back in parallel are examined.

Finally, in chapter 5, summarize of these study are presented.

Chapter 2

Dual Polarized Antenna using Stacked Antenna

2.1 Introduction

Up to now, for the hybrid antenna, the ring patch antenna is used because of a shorted ring structure to separate physically the feed circuit of the upper antenna and lower one. However, the shorted ring made by through holes is not easy for manufacturing.

In this chapter, we present the characteristics of patch with a hole instead of ring patch antenna by using FDTD method and examined the hybrid antenna using patch with a hole. The S parameter characteristics of hybrid antenna are compared between patch with shorted hole like ring antenna and patch with a hole.

The characteristics of patch with a hole have been examined by experiment. For the rectangular ring microstrip antenna (that is rectangular patch with a hole), it has been already presented that, when the length of outer ring is a and inner is b, length of resonance a/λ becomes smaller by increasing the ratio of length b/a which is main parameter for miniaturization of microstrip antenna, the same as ring patch antenna [14]. For the rectangular patch antenna with a circular hole, the influence on the resonant frequency by changing the diameter of hole is measured in the case of patch with a shorted hole and with a hole. The case of hybrid antenna consists of patch with a hole and monopole placed in that center is also measured. When the size of hole becomes larger, the resonant frequency shifts higher when the hole is shorted and it shifts lower when the hole isn't shorted. It has already shown that the mutual coupling between V/UHF monopole and patch is about -30[dB] when the hole is shorted, and it's suppressed about -40[dB] when the hole isn't shorted at the resonant frequency 406[GHz] [13].

From the characteristics of hybrid antenna using patch with a hole, we consider the two-layer antenna which has dual polarization for the application of self-diplexing antenna.

2.2 Hybrid Antenna using Rectangular Patch with a Hole

2.2.1 Characteristics of Patch Antenna with a Hole

First, the input characteristics of rectangular patch antenna with a square hole as shown in Figure 2.1 is examined. The rectangular patch antenna (24×24[mm]) has a square hole ($D \times D$) at the center. The characteristics of patch antenna by changing the size of hole ($D \times D$) is examined by FDTD method.

The analysis parameter of FDTD method is shown in Table 2.1.

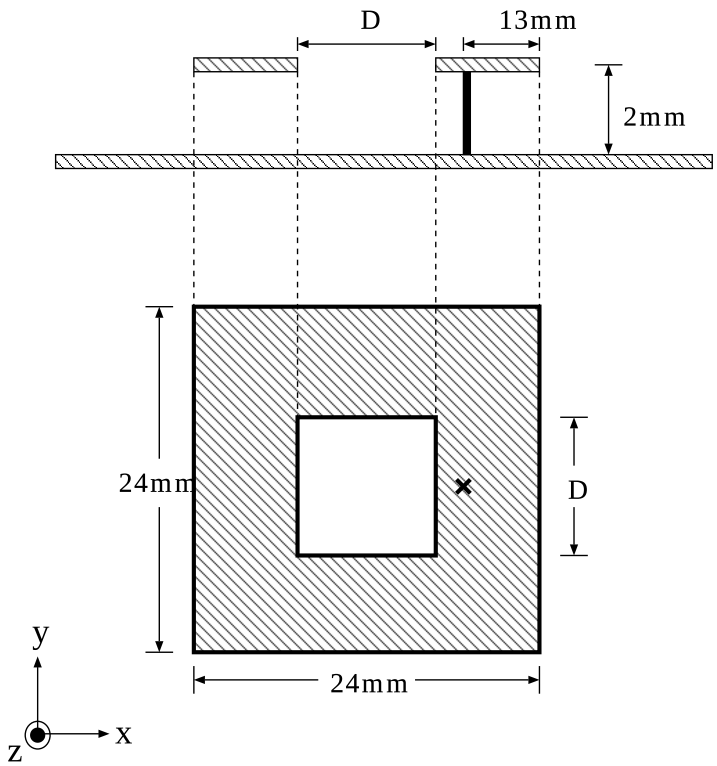


Figure 2.1: Geometry of patch with a hole.

Table 2.1: Parameters for FDTD analysis.

Computation space	$150 \times 150 \times 50$[cell]
Cell size	$\Delta x = \Delta y = \Delta z$=1[mm]
Iteration	5000
Incident wave	Gaussian pulse
Absorbing Boundary Condition	Mur's 2nd approx.

The return loss characteristics by FDTD method is shown in Figure 2.2. When the hole size of rectangular patch becomes larger, the resonant frequency shifts to lower frequency. For example, when the hole length is D=0[mm], that is equal to without hole, the resonant frequency of patch is about 4[GHz], and it shifts to lower 5.1[GHz] when the length is D=8[mm]. This is because the resonance length of patch antenna becomes longer by the existence of hole, and the resonant frequency shifts lower. The level of return loss is suppressed about -27[dB] at D=0[mm], and it's level increased to -9[dB] at D=8[mm]. This is because the impedance of patch is changed by the hole size. By changing the hole size of ring patch antenna, the resonant frequency shifts lower, the same as patch with a hole, and this characteristics agree to the presented experimental result [9].

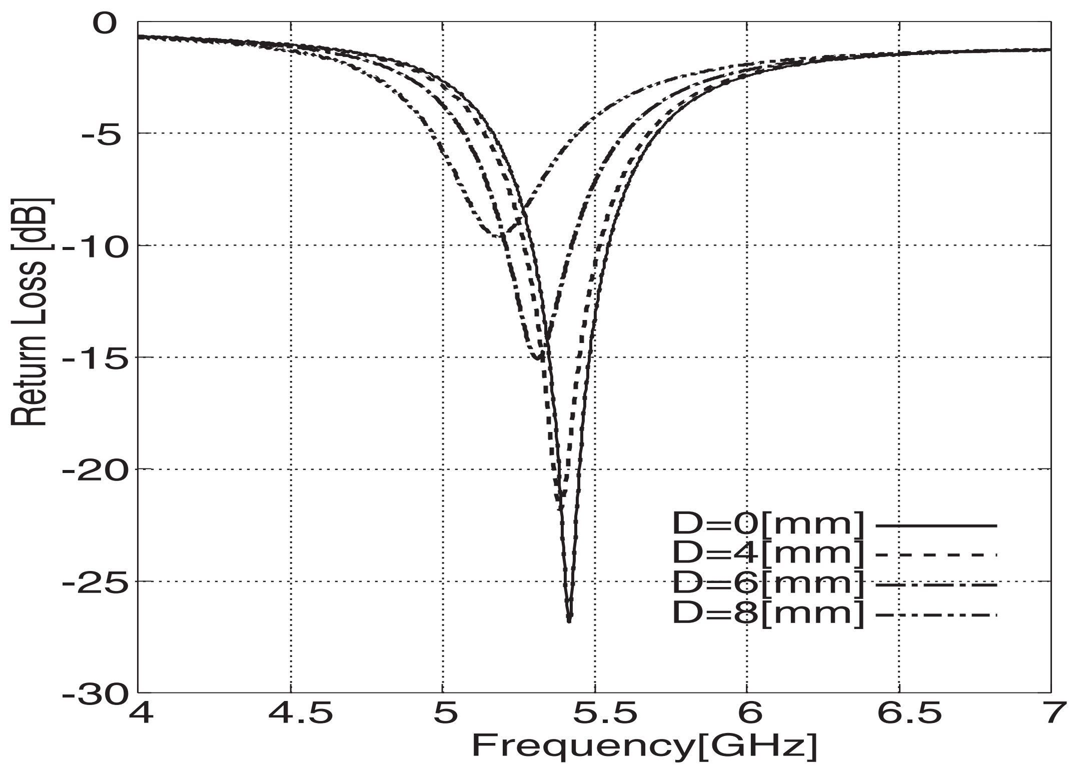


Figure 2.2: Return loss characteristics due to hole size.

2.2.2 Hybrid Antenna using Patch with a Hole and Monopole Antenna

In this section, hybrid antenna which consists of a rectangular patch antenna (50 × 50[mm]) with a hole (8 × 8[mm]) and monopole antenna (35[mm]) placed in that center is considered as shown in Figure 2.3. The mutual coupling between both antennas is examined by FDTD method.

Figure 2.4 shows the S parameter characteristics of this hybrid antenna. The resonant frequency of monopole antenna is about 2.0[GHz] from the return loss characteristics (S_{11}), and that of patch with a hole is about 2.5[GHz] from the return loss characteristics (S_{22}). The level of mutual coupling (S_{21}) is about −16[dB] at the resonant frequency of monopole antenna and about −20[dB] at that of patch with a hole.

The mutual coupling between patch with a hole and monopole antenna is suppressed and both antennas act independently by this configuration.

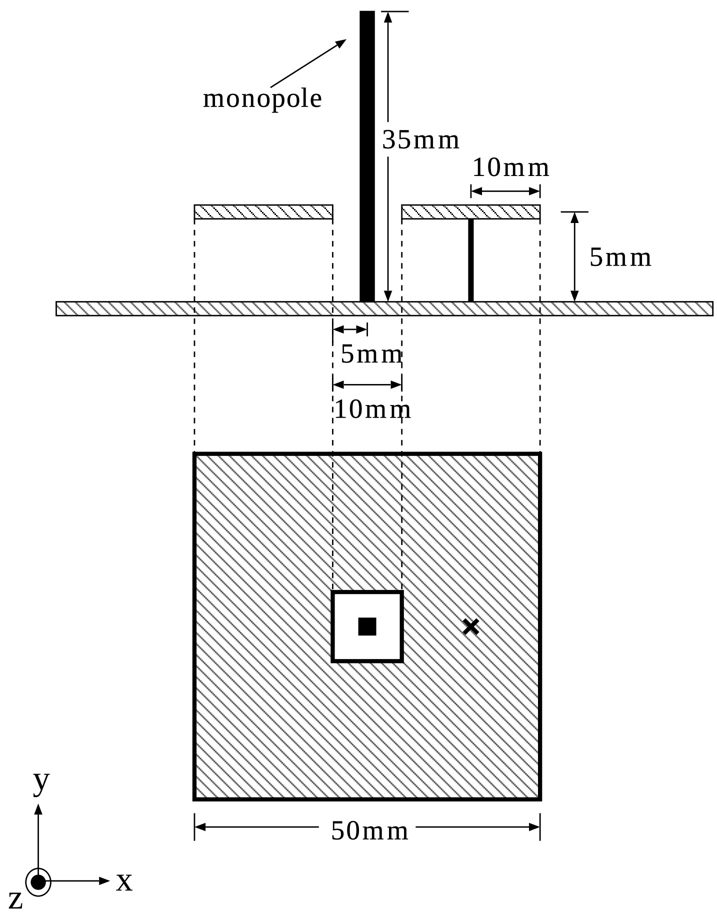


Figure 2.3: Geometry of hybrid antenna using patch with a hole and monopole antenna.

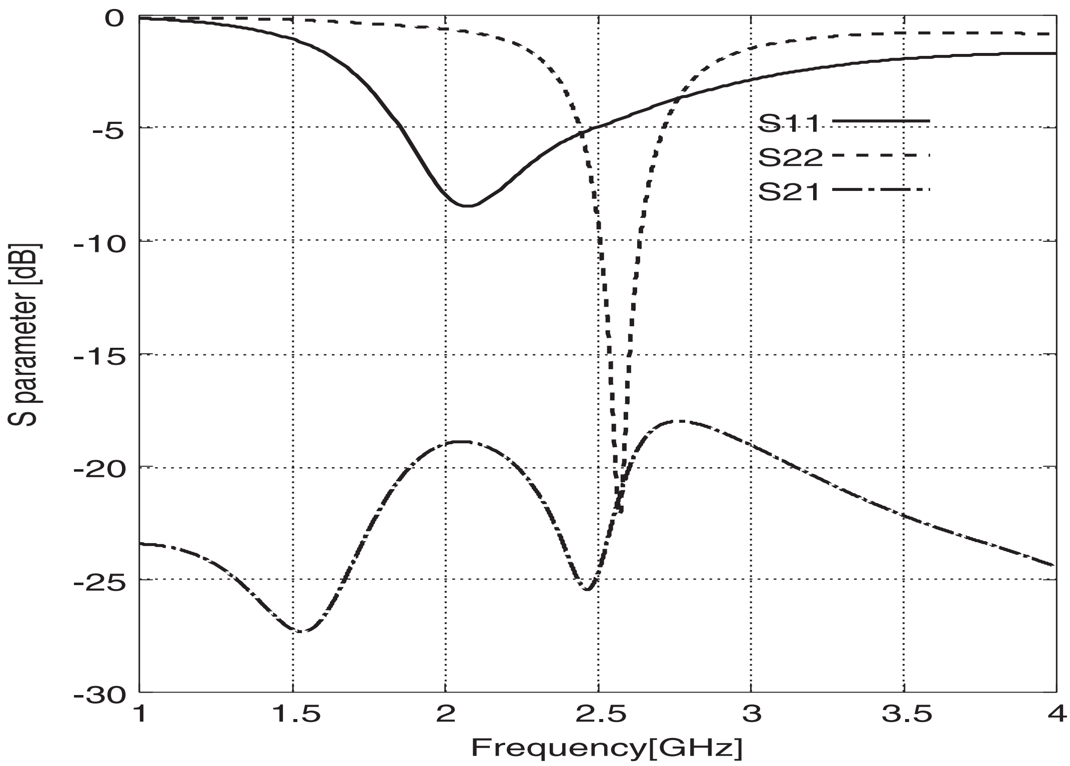


Figure 2.4: S parameter characteristics.

2.2.3 Input Characteristics due to Shorted Hole of Patch

Next, the influence on mutual coupling characteristics of hybrid antenna consists of patch with a hole and monopole antenna is examined by using rectangular patch with shorted hole. As a short circuit for the patch antenna, we use two types of configuration. One is using short pins at four corners of square hole as shown in Figure 2.5 and another one is shorted all edges of square hole as shown in Figure 2.6.

From Figure 2.7 to 2.9 show the S parameter characteristics versus frequency of this hybrid antenna by using FDTD method. The return loss characteristic of the patch antenna without a shorted hole (S_{22}) has a resonant frequency at 2.5[GHz], and that of the patch with a shorted hole, both using short pin and shorted edges, has two resonant frequency at 2.6[GHz] and lower frequency about 1.5[GHz] by TM01 mode excitation as shown in Figure 2.8. The resonant frequency of the monopole antenna (S_{11}) is about 2.0[GHz].

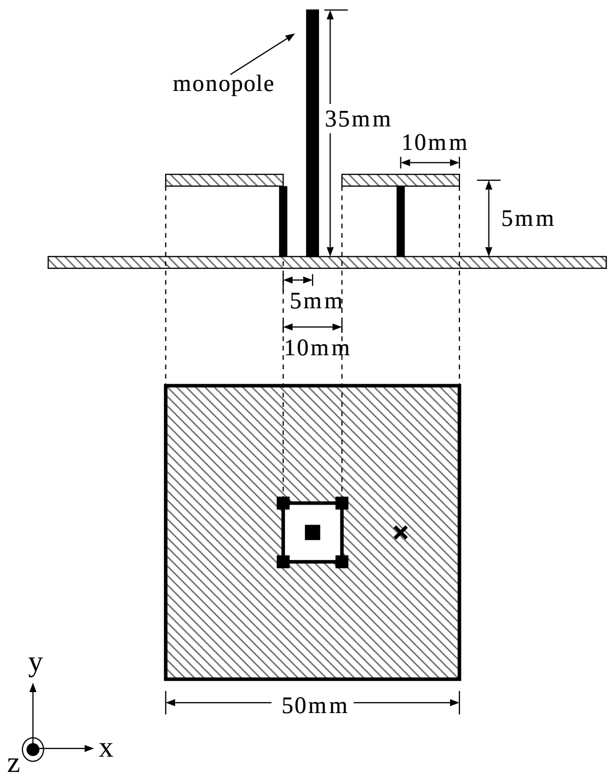


Figure 2.5: Geometry of hybrid antenna using patch with a hole when all corners of hole are shorted.

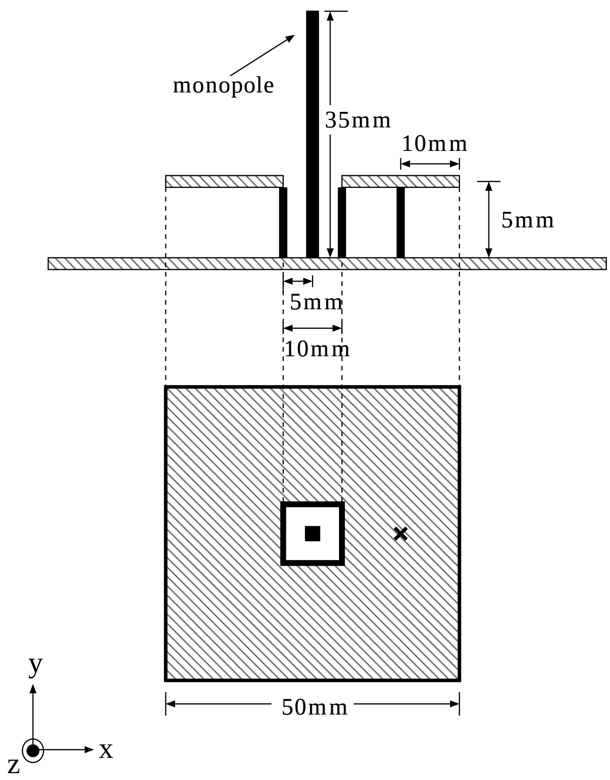


Figure 2.6: Geometry of hybrid antenna using patch with a hole when all edges of hole are shorted.

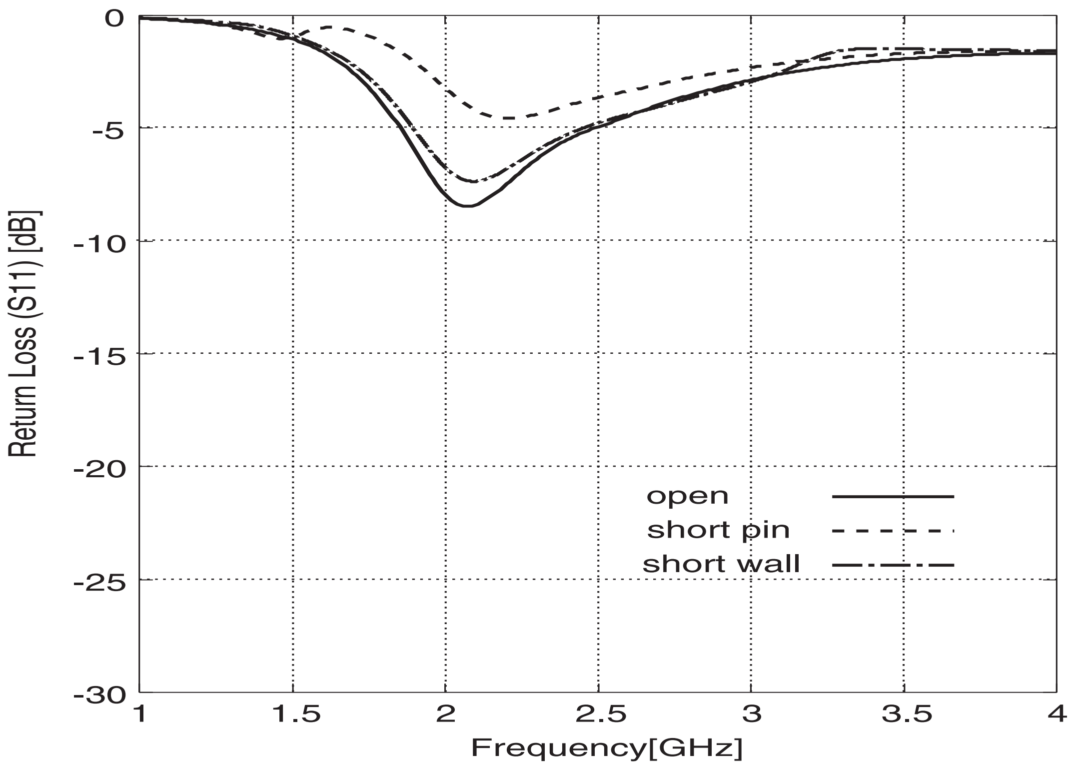


Figure 2.7: Return loss characteristics of monopole antenna due to shorted hole.

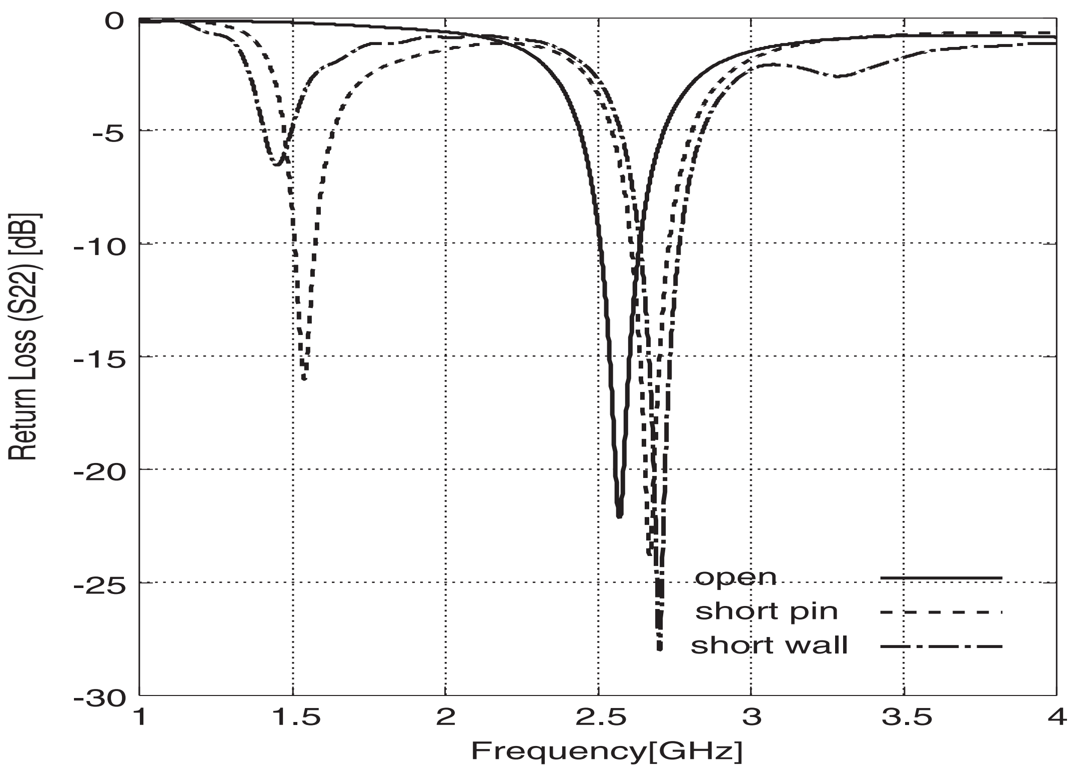


Figure 2.8: Return loss characteristics of patch with a hole due to shorted hole.

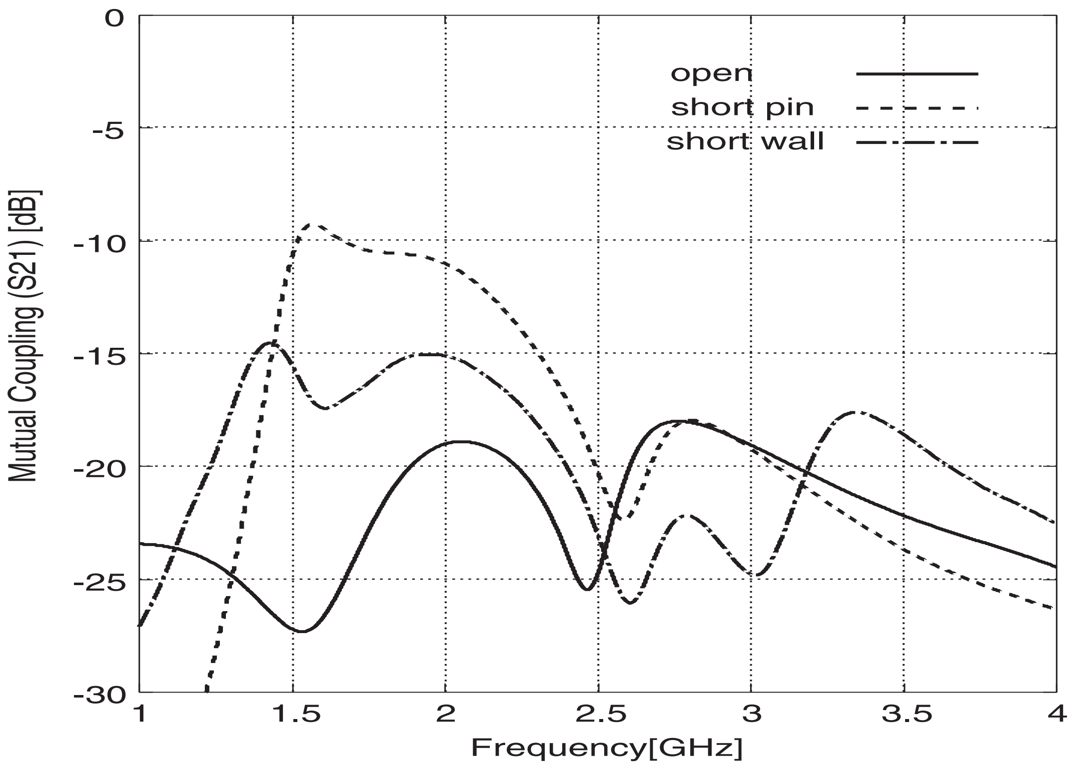


Figure 2.9: Mutual coupling characteristics due to shorted hole.

The mutual coupling characteristics of this hybrid antenna is shown in Figure 2.9. By using the patch with a shorted hole, both using short pin and shorted edges, the mutual coupling characteristics (S_{21}) is suppressed about -20[dB] at the resonant frequency of patch with a hole (2.5[GHz]) and both antennas act independently. In the case of using the patch shorted all edges of square hole, mutual coupling is suppressed about -22[dB]. By using shorted pin at square corner, mutual coupling is also suppressed about -20[dB]. Both antennas act independently by using short pin at square hole without short all edges of square hole. The mutual coupling is increased up to -10[dB] in the case of using short pin at the corner, and up to -15[dB] using shorted edges of square at the frequency 1.5[GHz] by the excitation of TM_{01} mode. At the resonant frequency of the monopole (2.0[GHz]), the mutual coupling characteristic is suppressed about -13[dB].

On the other hand, when the corners of the hole are not shorted, the level of mutual coupling is suppressed about -20[dB] at the resonant frequency of patch with a hole (2.5[GHz]) and suppressed about -15[dB] at the resonant frequency of monopole antenna (2.0[GHz]).

Therefore, using shorted hole of rectangular patch can suppress the mutual coupling of hybrid antenna; the same as ring patch; but according to the antenna geometry, without shorted hole also achieve the small mutual coupling and almost same level with using shorted hole. The patch antenna with no short circuit structure is very easy for manufacturing, and then we use this structure in the following stacked antenna.

2.2.4 Conclusion

In this section, we presented the characteristics of rectangular patch antenna with a hole. We simulated the S parameter characteristics by FDTD method. The resonant frequency is affected by the size of square hole, and the characteristics are similar to ring patch antenna.

By using hybrid antenna consists of patch with a hole and monopole antenna, we show the mutual coupling between both antennas is small and they act independently. Mutual coupling characteristics are compared between patch with shorted hole and patch with a hole, and we find that both level of mutual coupling are almost same.

Therefore, patch antenna with no short circuit structure can be used instead of ring patch antenna.

2.3 Two-Layer Antenna using Rectangular Patch with a Hole

2.3.1 Introduction

In the previous section, the characteristics of patch with a hole, which is easier for manufacturing than ring patch antenna, are shown. Using patch with a hole for hybrid antenna can suppress the mutual coupling between both antennas and they act independently.

Therefore, we consider using patch with a hole instead of using ring patch, which is used for suppress the mutual coupling, for the two-layer antenna.

In this section, we propose the novel two-layer antenna using rectangular patch with a hole and show the antenna characteristics.

2.3.2 Antenna Characteristics of Two-Layer Antenna

Geometry of Two-Layer Antenna

We propose novel two-layer patch antenna as shown in Figure 2.10. The antenna consists of a upper rectangular patch antenna (32 $\times$ 32[mm]) and a lower rectangular patch antenna (50 $\times$ 50[mm]) with a hole ($D \times D$). The upper layer antenna is fed through the hole of lower layer antenna. The coordinates of the feed point is considered when the center of two-layer antenna is (x, y)=(0, 0).

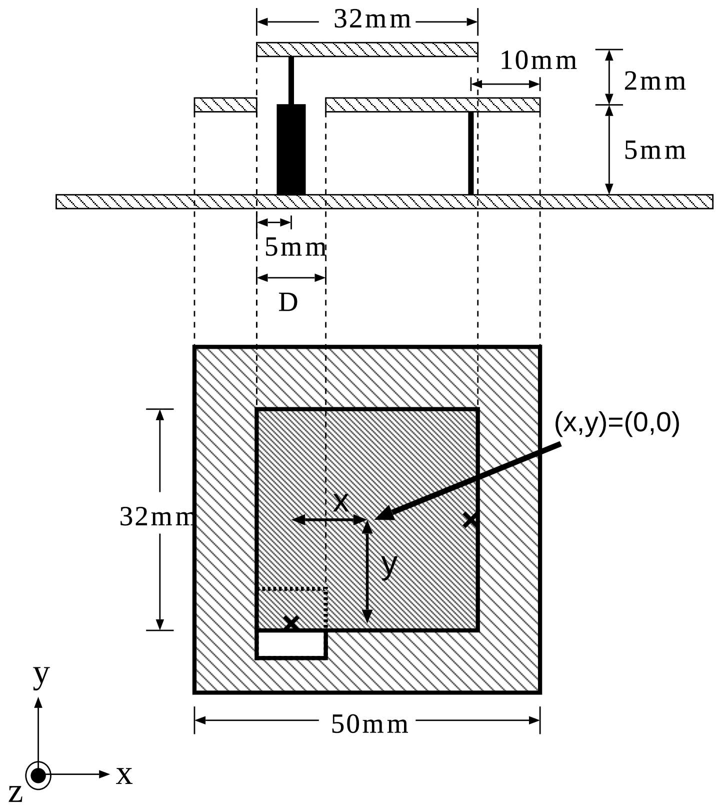
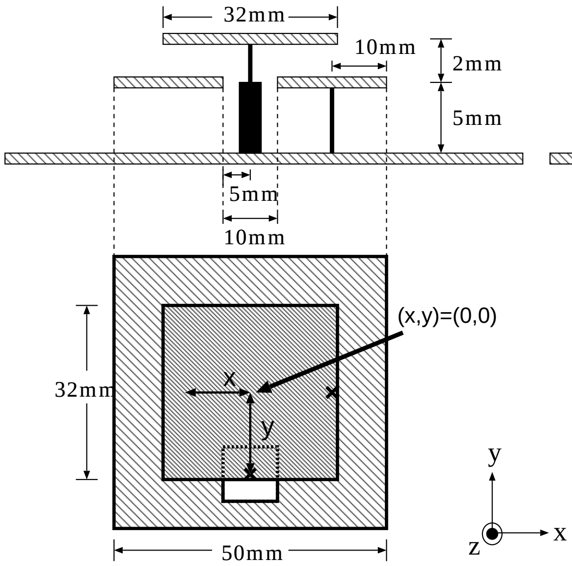


Figure 2.10: Geometry of two-layer patch antenna using patch with a hole.

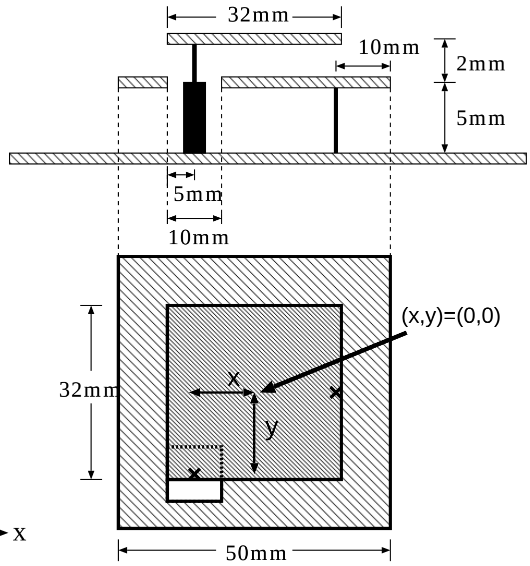
Characteristics due to the Location of Feeding Point

To find parameter suppressing the mutual coupling in high level, we changed the location of feed point of the upper patch antenna. The feed point of the upper antenna is through the center hole of the lower antenna, so, when the location of feed point of the upper patch is moved, the hole of the lower patch also moved. This is the case when the size of hole of the rectangular patch is 10 × 10[mm]. (D=10[mm])

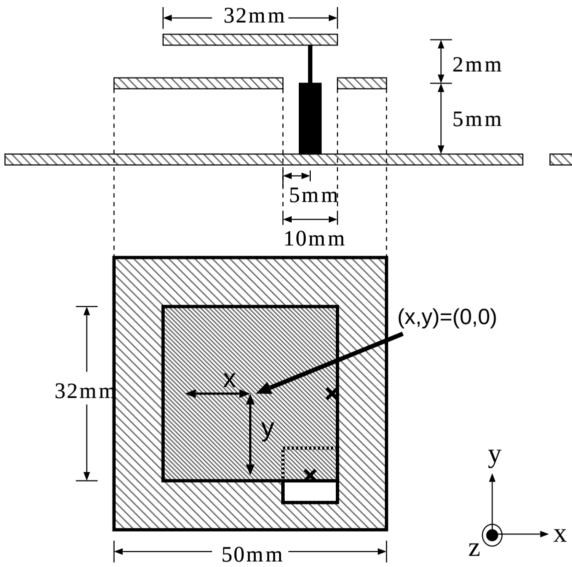
Figure 2.11 shows four types of antenna geometry when moving the feed point of upper antenna. In this figure, the coordinates of the feed point is considered when the center of two-layer antenna is (x, y)=(0, 0). The case (a) is when the feed point location of upper antenna is (x, y)=(0, −15). The case (b) is when the feed point location is (x, y)=(−11, −15). The case (c) is when the feed point location is (x, y)=(11, −15). The case (d) is when the feed point location is (x, y)=(−11, −5). The feed point location of lower antenna is (x, y)=(15, 0) in this coordinate.



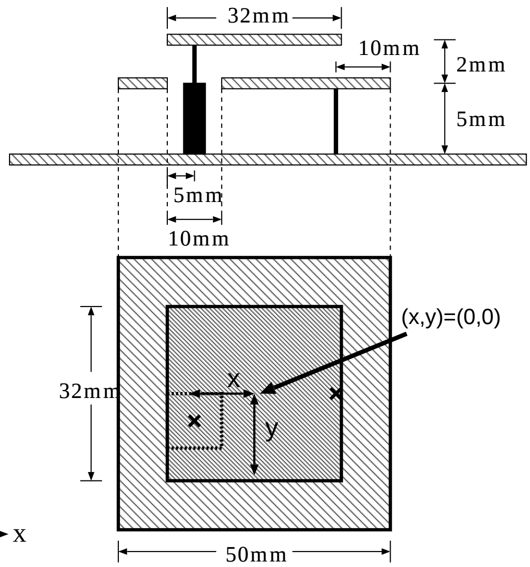
(a) (x,y)=(0,-15)



(b) (x,y)=(-11,-15)



(c) (x,y)=(11,-15)



(d) (x,y)=(-11,-5)

Figure 2.11: Antenna geometry due to feed point location for upper patch antenna.

From Figure 2.12 to 2.14 show the S parameter characteristics calculated by FDTD method. When the feed point of the upper antenna is moved, the resonant frequencies of the upper and lower antenna are not changed. The resonant frequencies of the both antenna are around 2.5[GHz]. The return loss level is affected by the feed point location of upper antenna because of impedance matching.

Figure 2.14 shows the mutual coupling characteristic versus frequency when the location of feed point is changed. At the resonant frequencies of the upper and lower antenna, the mutual coupling is suppressed less than -30[dB] when the hole center of the lower layer is located (x, y)=(0, -15). It is because the current resonance of upper antenna is in the direction of Y axis and that of lower antenna is in the direction of X axis, cross from the upper antenna. Therefore, mutual coupling (S_{21}) is suppressed less than -30[dB] at the resonant frequency of both upper and lower antenna. Both antennas are operated independently at both resonant frequencies. Its level is increased up to -7[dB] when the hole center is located (x, y)=(-11, -5), (11, -15), (-11, -5), because the cross current becomes smaller and parallel current becomes larger.

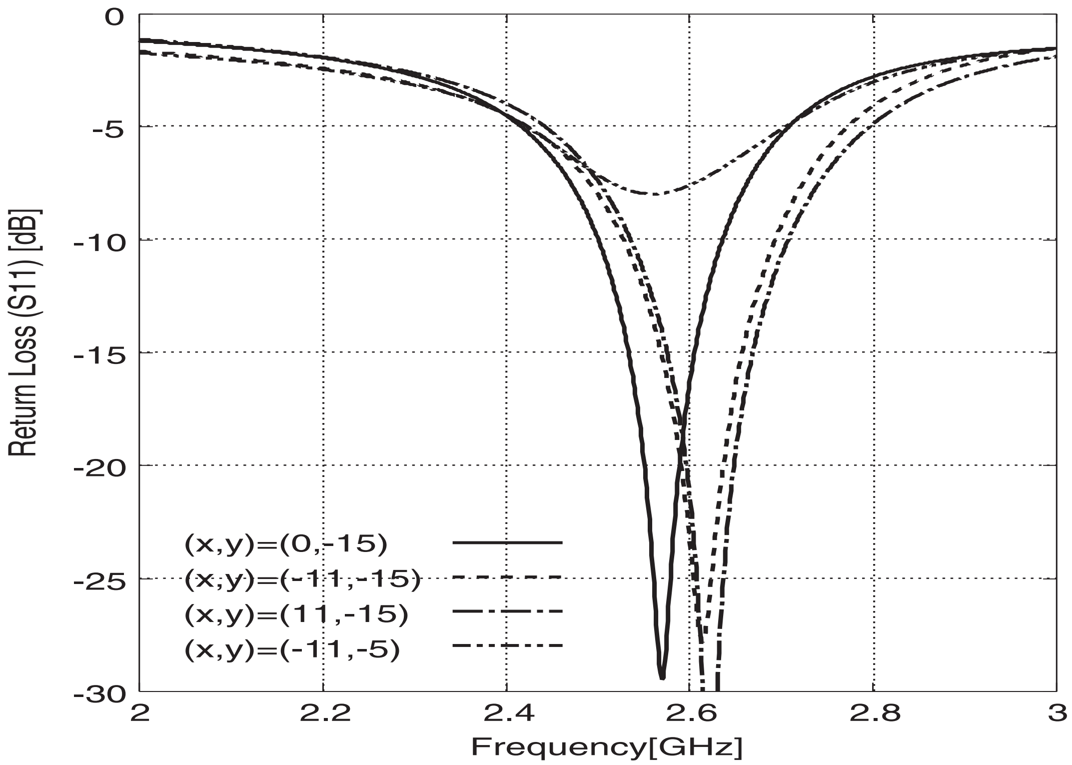


Figure 2.12: Return loss characteristics of upper antenna due to feed point location.

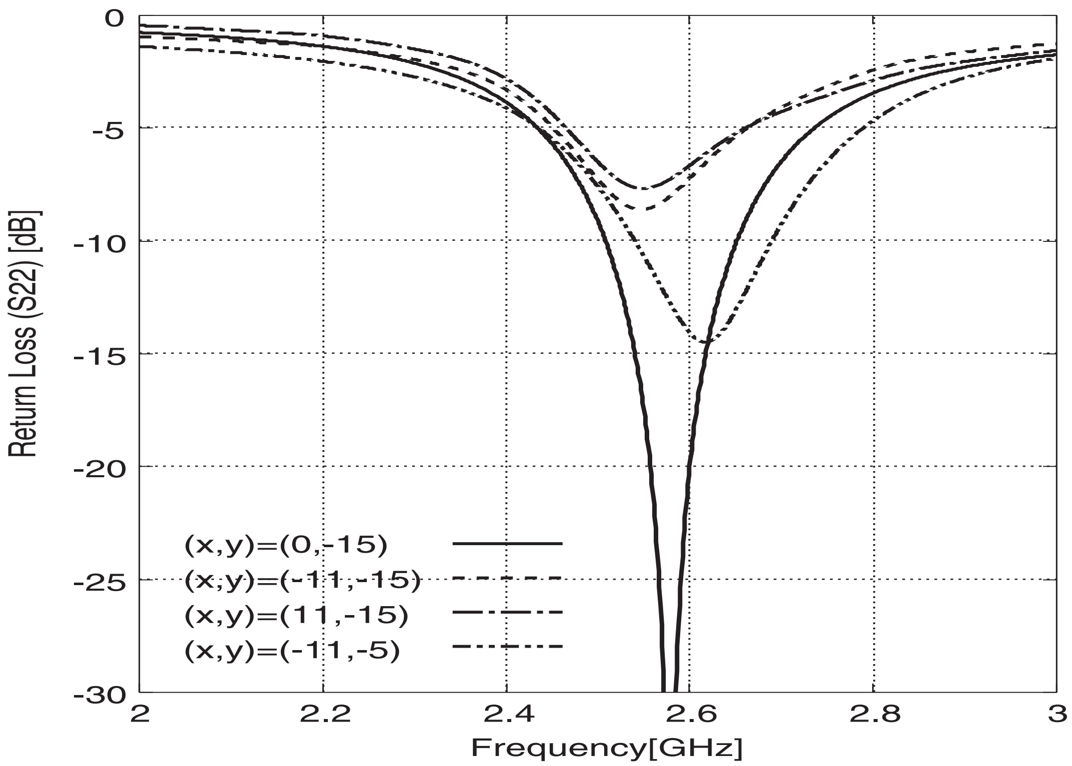


Figure 2.13: Return loss characteristics of lower antenna due to feed point location.

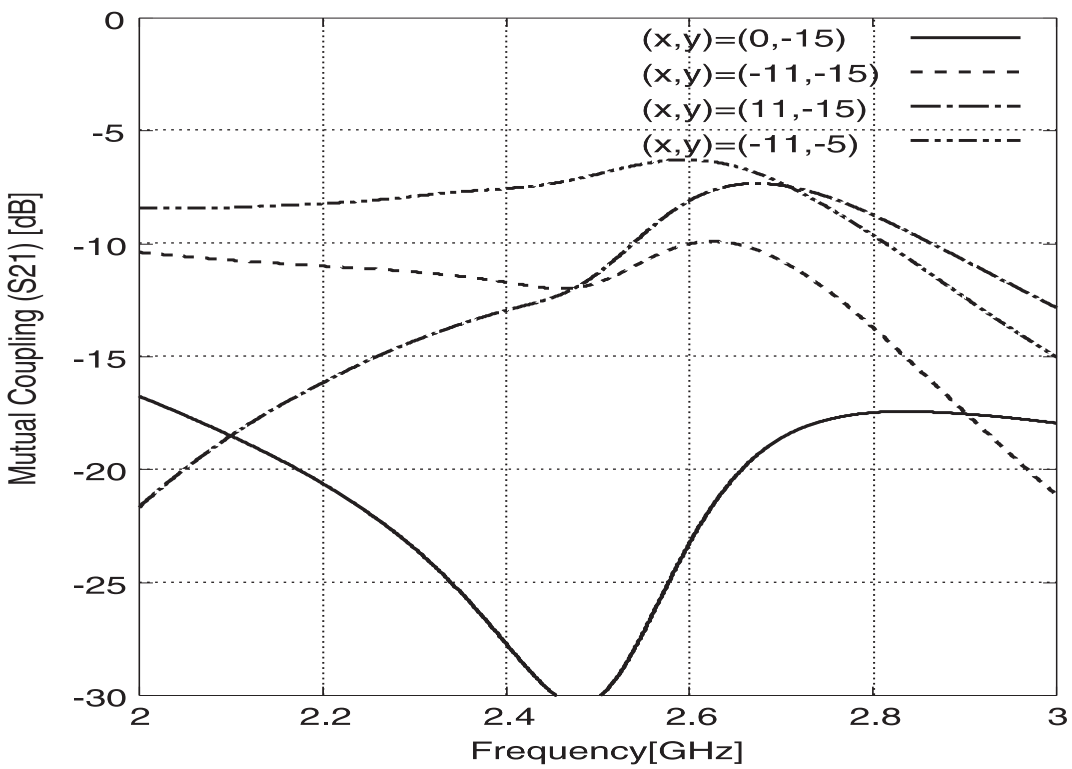


Figure 2.14: Mutual coupling characteristics due to feed point location.

Analysis model of two-layer antenna

From the previous part, the level of mutual coupling suppressed by using the antenna geometry whose upper and lower current is cross as shown in Figure 2.15. The S parameter characteristics and radiation pattern of this two-layer antenna is examined. The antenna consists of a upper rectangular patch antenna (32 $\times$ 32[mm]) and a lower rectangular patch antenna (50 $\times$ 50[mm]) with a hole ($D \times D$). The feed point location of upper antenna is (x, y)=(0, -15). The hole size of lower patch is D=10[mm].

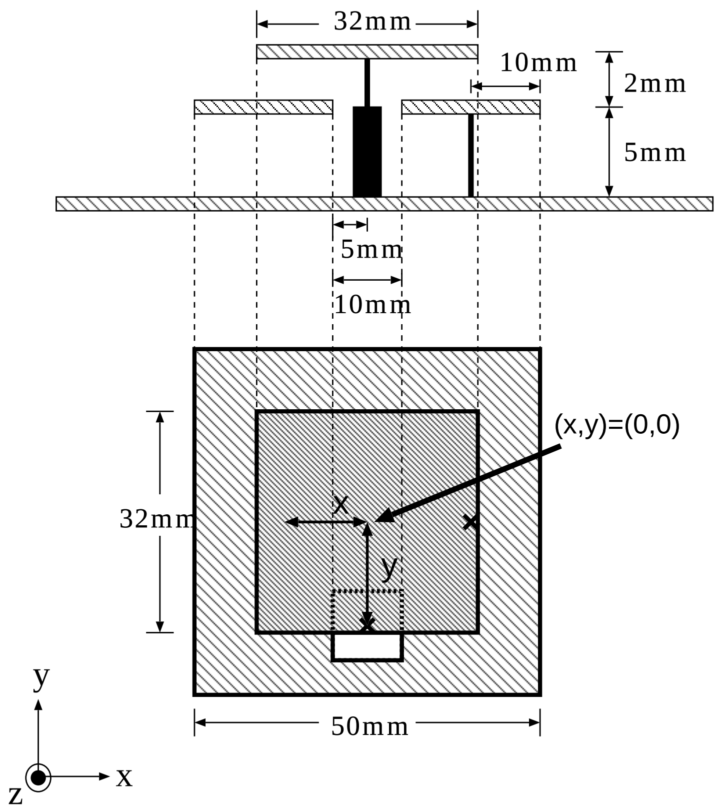


Figure 2.15: Geometry of two-layer patch antenna using patch with a hole.

Influence of Antenna Geometry on Input Characteristics

Influence of antenna geometry on input characteristics is examined. Influence of feed part of upper antenna and the existence of upper antenna is examined and compared with lower patch with a hole.

Each antenna geometry is shown in Figure 2.16. The case (a) is the lower antenna only. The case (b) is the lower antenna with feed pin located in center hole. The case (c) is the two-layer antenna consists of lower and upper antenna and feed pin for upper antenna. The return loss characteristic of lower antenna versus frequency is shown in Figure 2.17. The return loss characteristics of patch antenna are not affected by these feeding structure.

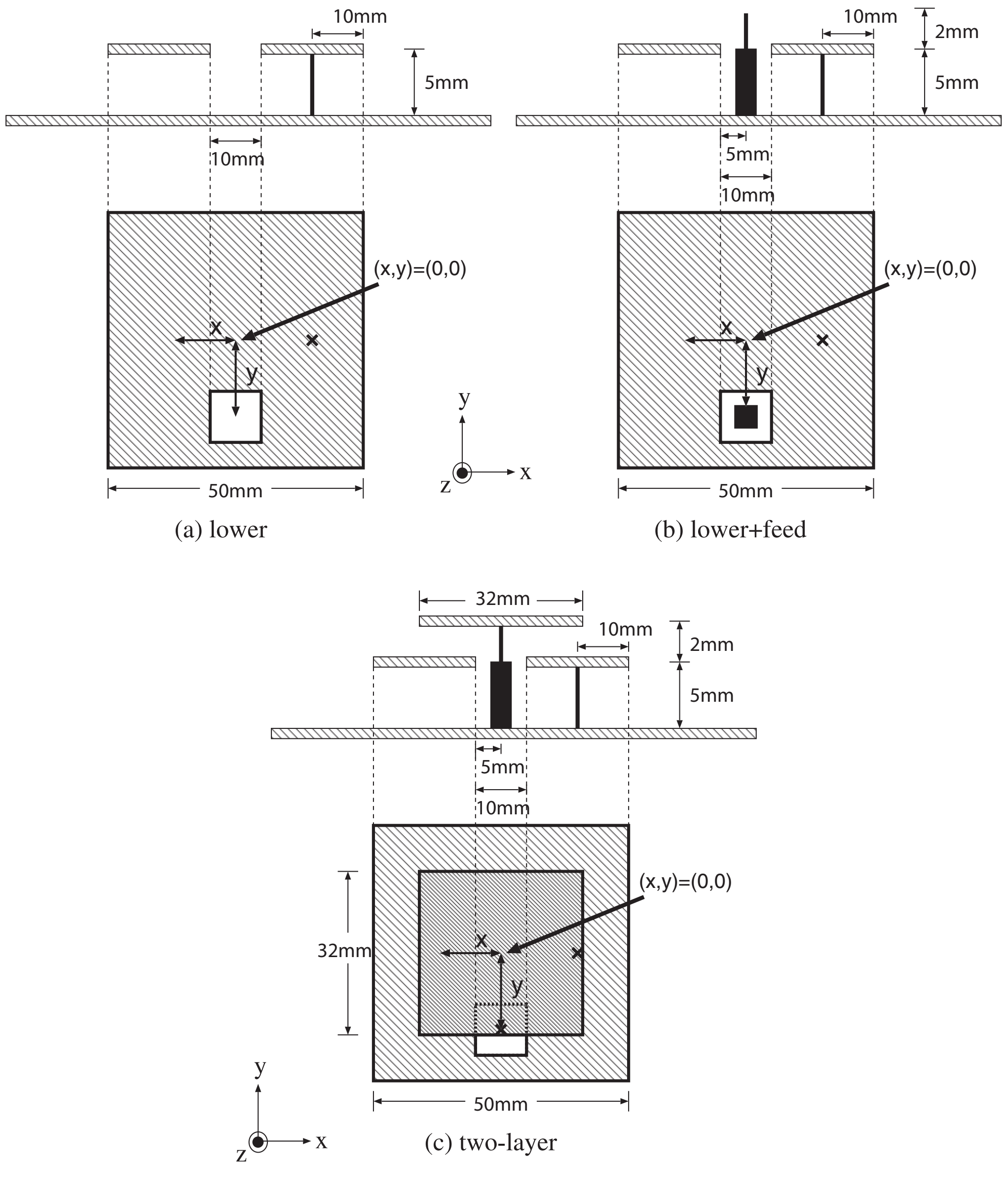


Figure 2.16: Geometry of patch with a hole and considered antenna model

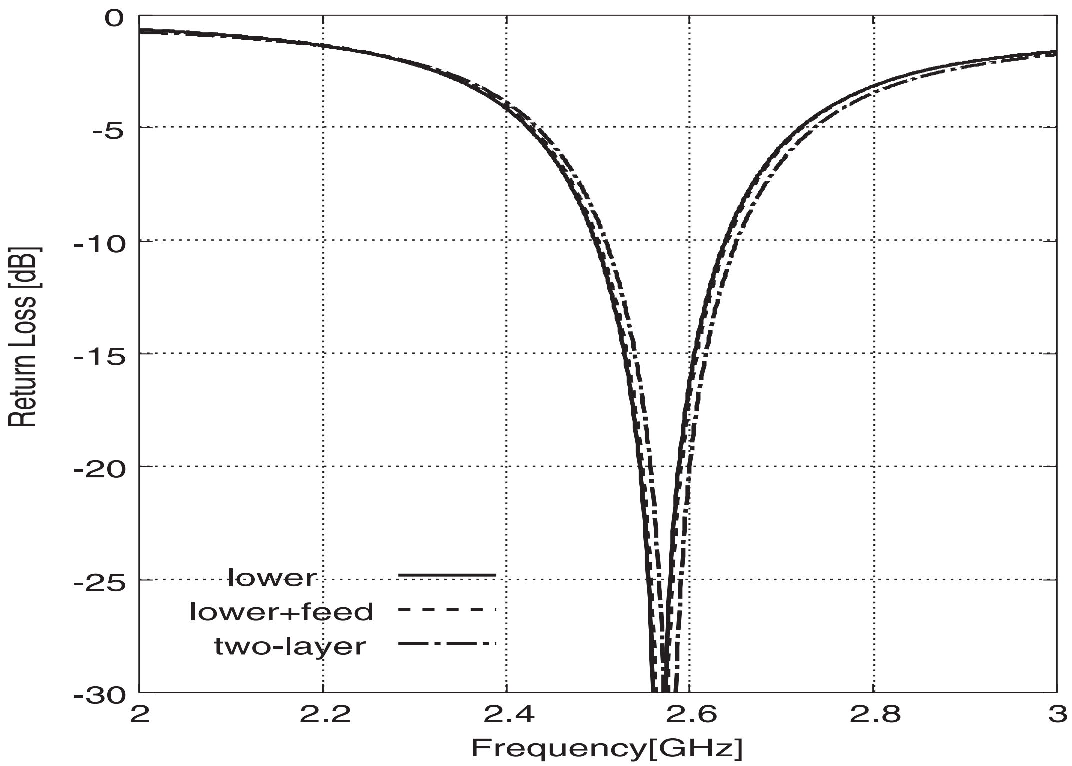


Figure 2.17: Return Loss characteristics due to antenna geometry

Input characteristics due to shorted hole

Next, the influence on mutual coupling characteristics of two-layer antenna is examined by using rectangular patch with shorted hole. The feed point location of upper antenna is (x, y)=(0, -15). As a short circuit for the patch antenna, we use two types of configuration. One is using short pins at four corners of square hole as shown in Figure 2.18 and another one is shorted all edges of square hole as shown in Figure 2.19. Antenna parameter is same with Figure 2.15. The feed point location of lower antenna is (x, y)=(15, 0) when using patch with a hole and (x, y)=(18, 0) when using patch with shorted hole for impedance matching.

From Figure 2.20 to 2.22 show the S parameter characteristics versus frequency of this two-layer antenna by using FDTD method.

The return loss characteristic of the lower patch antenna without a shorted hole (S_{22}) has a resonant frequency at 2.6[GHz], and that of the patch with a shorted hole, both using short pin and shorted edges, has two resonant frequency at 2.7[GHz] and lower frequency about 1.5[GHz] by TM01 mode excitation as shown in Figure 2.21. The resonant frequency of the upper patch antenna (S_{11}) is about 2.5[GHz].

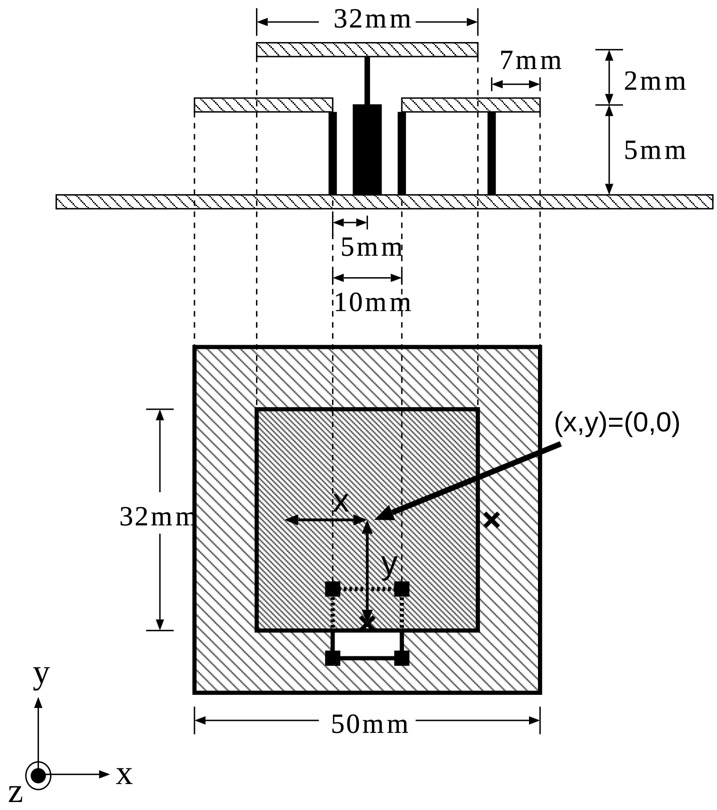


Figure 2.18: Geometry of two-layer patch antenna when all corners of hole are shorted.

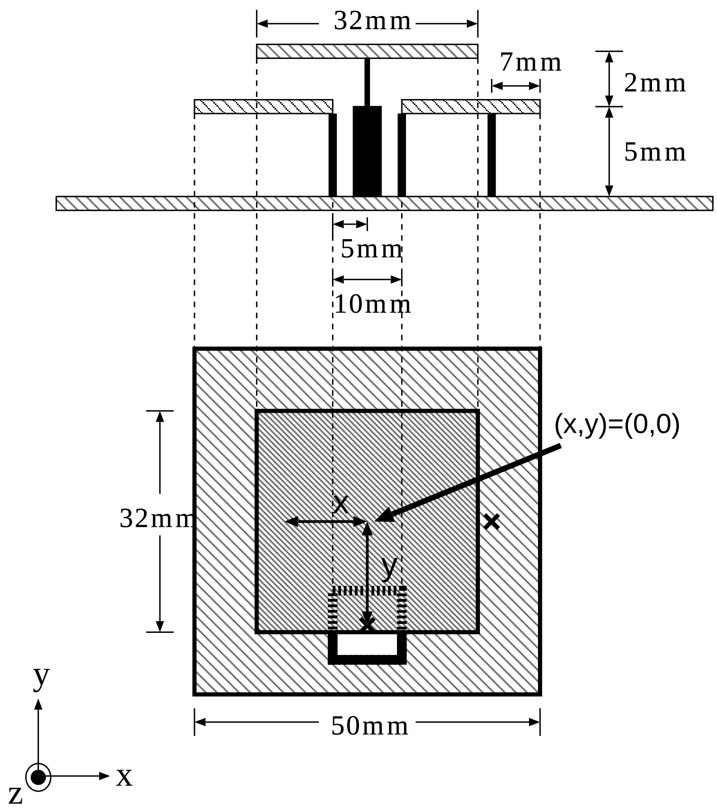


Figure 2.19: Geometry of two-layer patch antenna when all edges of hole are shorted.

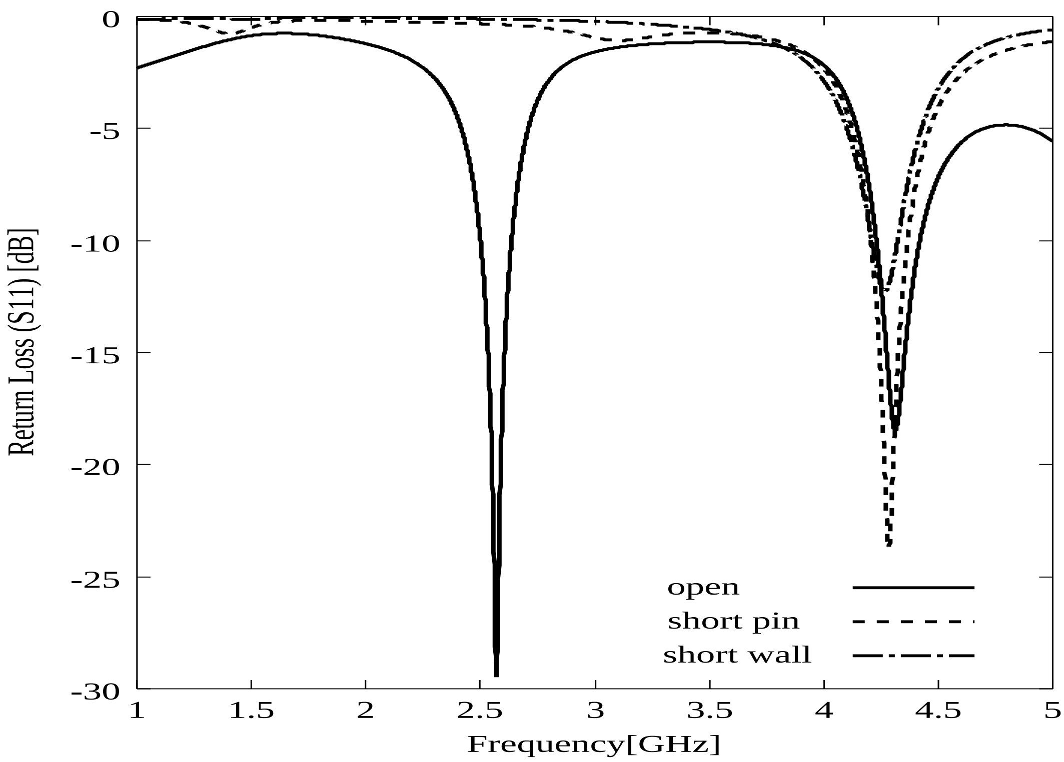


Figure 2.20: Return loss characteristics of upper antenna due to shorted hole.

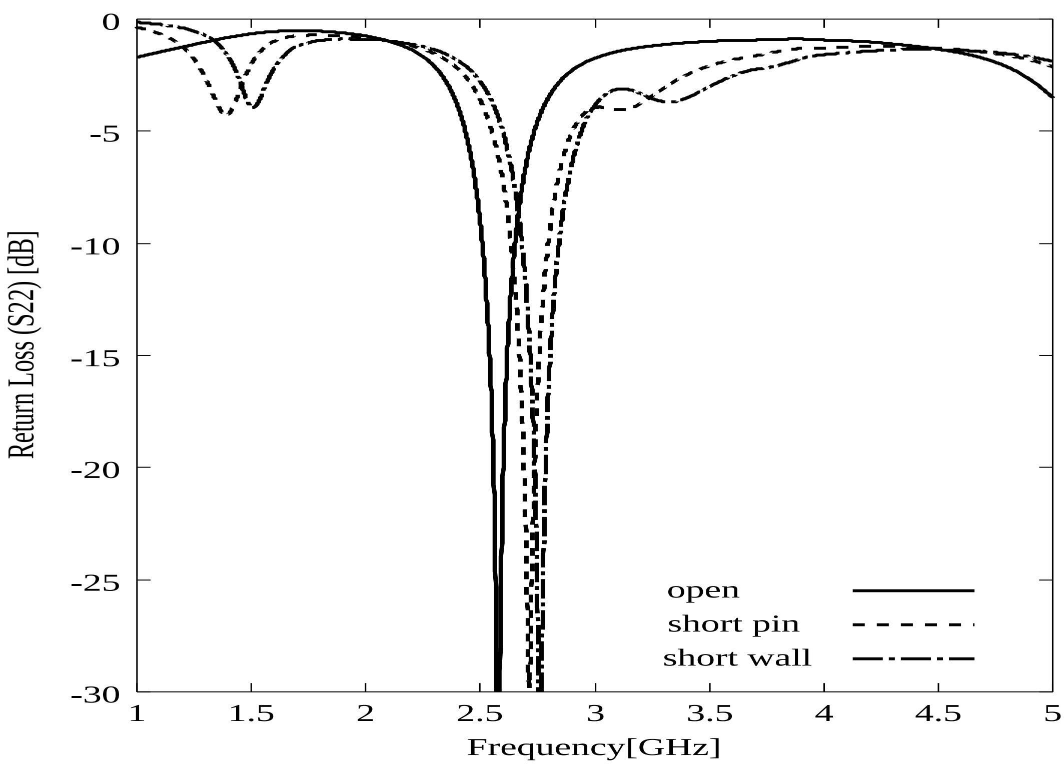


Figure 2.21: Return loss characteristics of lower antenna due to shorted hole.

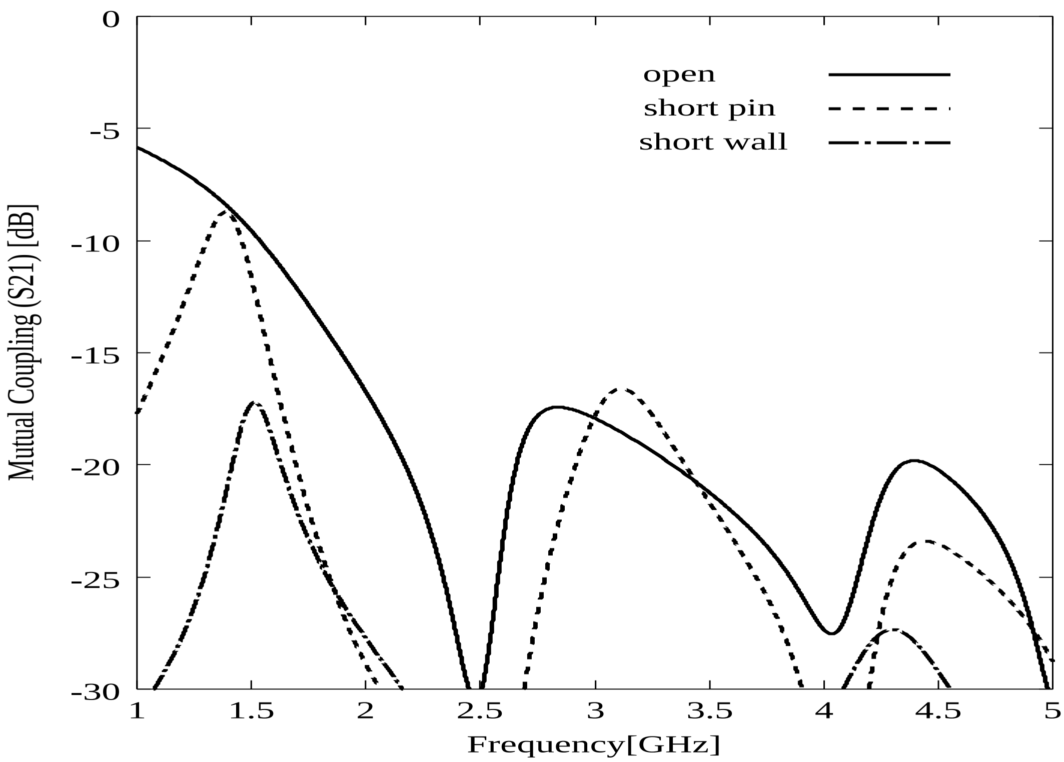


Figure 2.22: Mutual coupling characteristics due to shorted hole.

The mutual coupling characteristics of this two-layer antenna is shown in Figure 2.22. By using the patch with a shorted hole, both using short pin and shorted edges, the mutual coupling characteristics (S_{21}) is suppressed about -25[dB] at the resonant frequency of patch with a hole (2.7[GHz]) and both antennas is operated independently. In the case of using the patch shorted all edges of square hole, mutual coupling is suppressed than -30[dB]. By using shorted pin at square corner, mutual coupling is also suppressed about -30[dB]. Both antennas are operated independently by using short pin a t square hole without short all edges of square hole. The mutual coupling is increased up to -10[dB] in the case of using short pin at the corner, and up to -15[dB] using shorted edges of square at the frequency 1.5[GHz]. On the other hand, when the corners of the hole are not shorted, the level of mutual coupling is suppress about -20[dB] at the resonant frequency 2.6[GHz].

Therefore, using shorted hole of rectangular patch can suppress the mutual coupling of two-layer antenna, but according to the antenna geometry, without shorted hole also achieve the small mutual coupling less than -20[dB]. The patch antenna with no short circuit structure is very easy for manufacturing, and it is no need to use shorted part.

Input characteristics due to hole size of patch

Figures 2.24 and 2.25 show the input characteristics of two-layer antenna as shown in Figure 2.23 by changing the hole size ($D \times D$) of lower patch. The feed point location of upper antenna is (x, y)=(0, -15) and that of lower antenna is (x, y)=(12, 0).

When the hole size of the lower patch becomes larger, the impedance characteristic is changed, and the resonant frequency of the lower antenna shifts lower as shown in Figure 2.25 For example, when the square hole size D is 6[mm], the resonant frequency is 2.57[GHz] and the return loss level is -11[dB], and when the hole size D is 18[mm], the resonant frequency shifts lower to 2.40[GHz] and the return loss level is suppressed -30[dB].

The return loss level of the upper antenna shifts lower and the return loss level increase when the hole size of the lower patch becomes larger as shown in Figure 2.24. For example, when the square hole size D is 6[mm], the return loss level is -30[dB], and when the hole size D is 18[mm], the return loss level goes up to -16[dB].

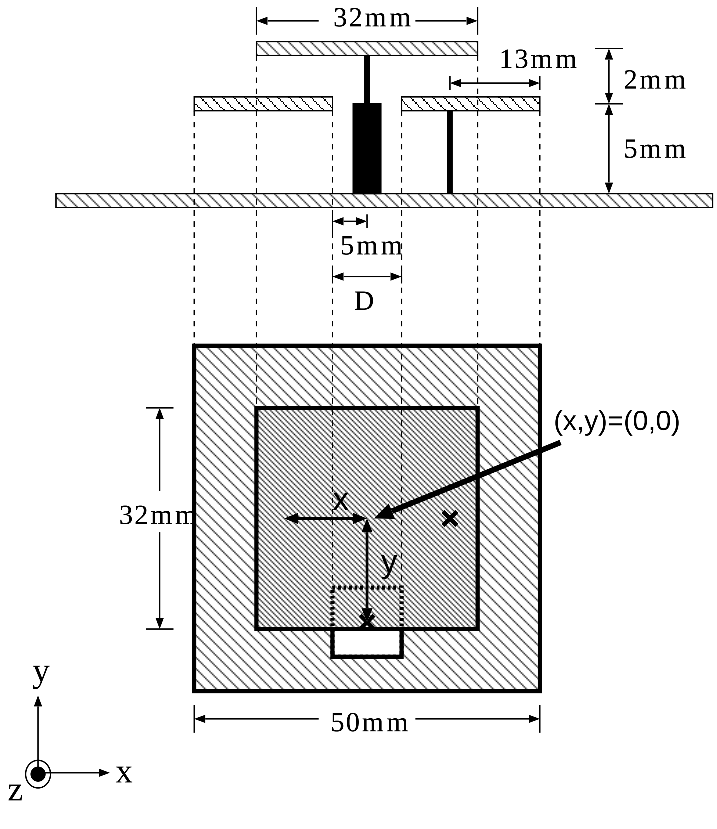


Figure 2.23: Geometry of two-layer patch antenna using patch with a hole.

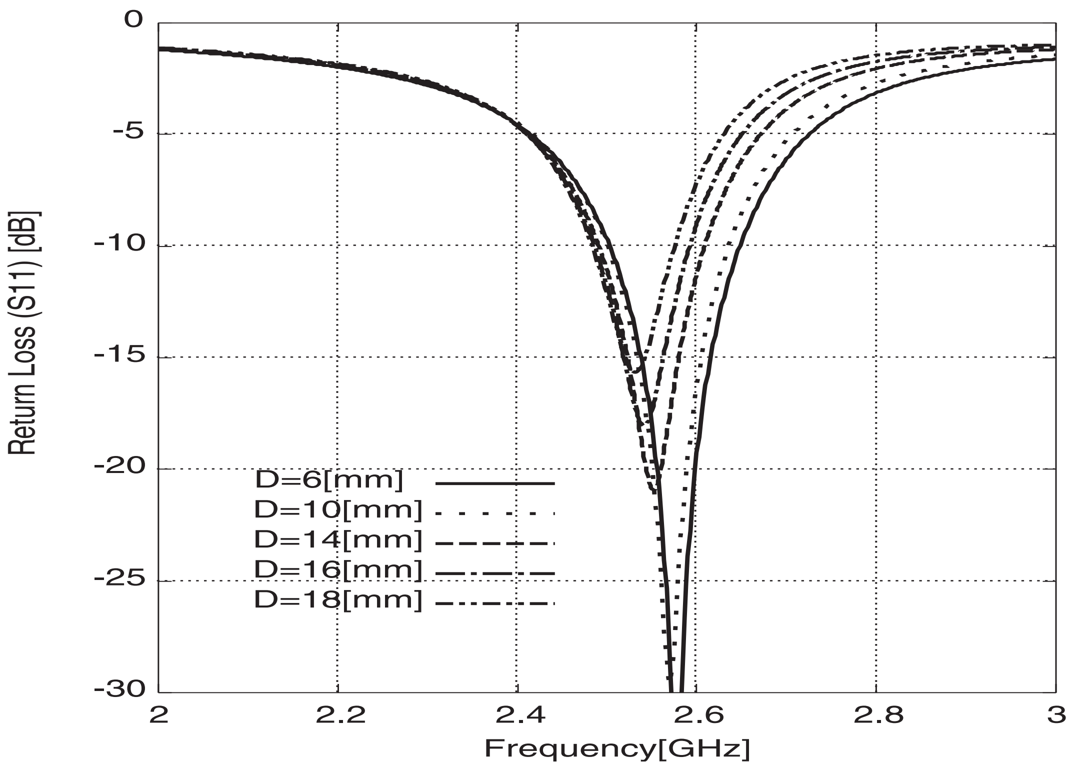


Figure 2.24: Return loss characteristics of upper antenna due to hole size.

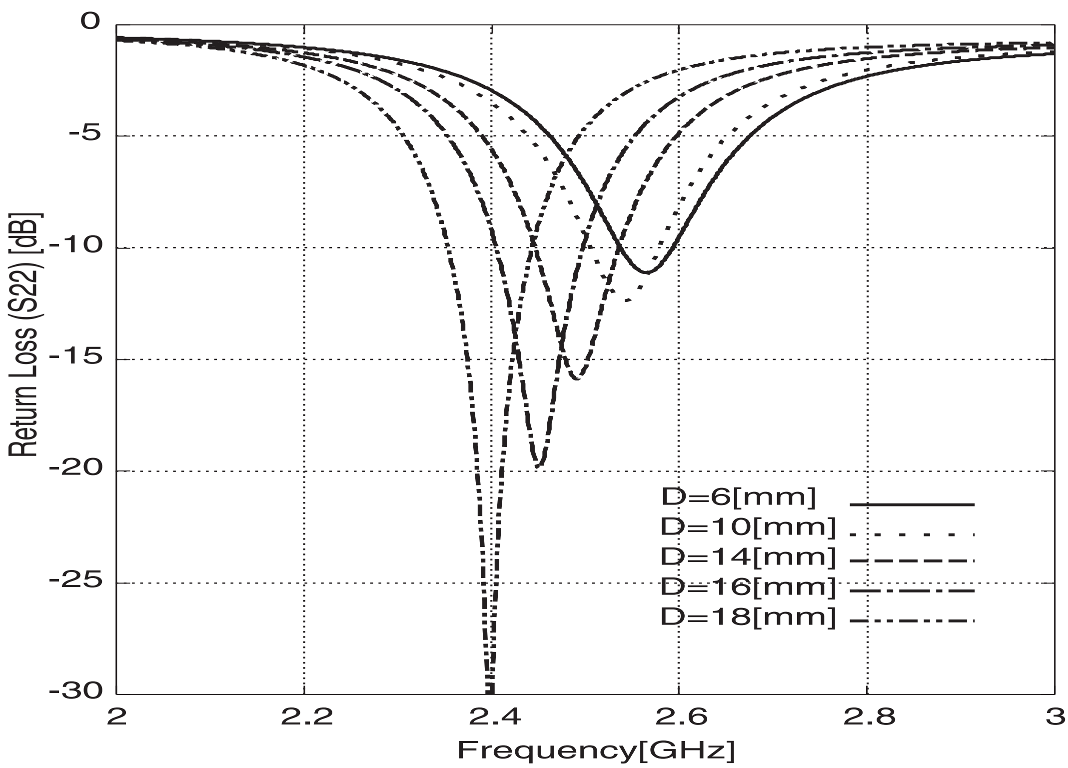


Figure 2.25: Return loss characteristics of lower antenna due to hole size.

The return loss level of lower antenna is due to the impedance matching. By changing the hole size of lower antenna, antenna impedance is changed. The resonant frequency is shift by the hole size because the resonance length of patch antenna becomes longer by the existence of hole. By changing the hole size of ring patch antenna, the resonant frequency shifts lower, the same as patch with a hole. We find that patch with a hole can be used instead of ring patch antenna. The return loss characteristics of the upper antenna are due to lower antenna because it seems as ground plane of upper antenna. When the hole size of the lower patch becomes larger, it means making hole at ground plane larger.

2.3.3 Example Model of Two-Layer Antenna using Patch with a Hole

Figure 2.26 shows the example model of two-layer antenna using patch with a hole. This antenna consists of a upper rectangular patch antenna (32 $\times$ 32[mm]) and a lower rectangular patch antenna (50 $\times$ 50[mm]) with a hole ($D \times D$). The coordinates of the feed point is considered when the center of two-layer antenna is (x, y)=(0, 0). The feed point location of upper antenna is (x, y)=(0, -15) and that of lower antenna is (x, y)=(12, 0). The hole size of lower patch is D=16[mm]. The S parameter characteristics of this antenna is shown in Figure 2.27. The radiation patterns are also shown in Figures 2.28 and 2.29.

From Figure 2.27, the resonant frequency of upper rectangular patch (S_{11}) is about 2.54[GHz] and that of lower patch with a hole (S_{22}) is about 2.45[GHz]. The level of return loss is suppressed about -20[dB] and that of mutual coupling at each resonant frequency is suppressed less than-30[dB]. This is because the polarization plane of upper and lower antenna is cross (Y-Z plane and Z-X plane) by the geometry.

The radiation patterns in E plane at the resonant frequency of upper and lower antenna are shown in Figures 2.28(a) and 2.29(a). The radiation patterns in H plane are shown in Figures 2.28(b) and 2.29(b). The resonant frequency of the upper antenna is 2.54[GHz], and that of the lower antenna is 2.45[GHz].

At the resonant frequencies of the upper and lower antenna, we find no distortion in both radiation patterns. The cross polarization level is suppressed when the hole center of lower antenna is located (x, y)=(0, -15). The level of mutual coupling is also suppressed as shown in Figure 2.27. The cross polarization is excited by the existence of lower hole, but the radiation characteristics are almost same with rectangular patch antenna. By using this antenna geometry, the cross polarization is about -20[dB] and the influence of lower hole can be neglected.

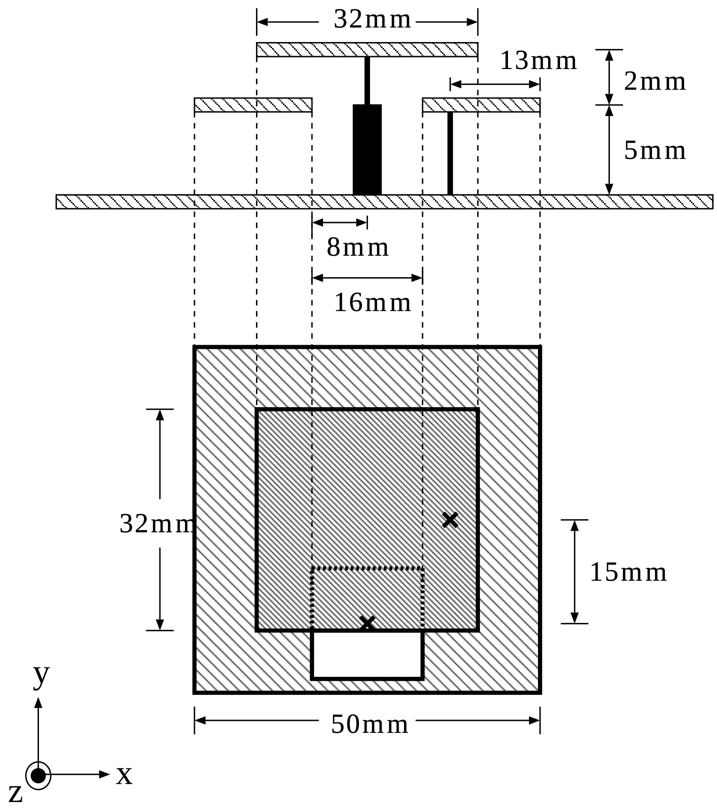


Figure 2.26: Example geometry of two-layer patch antenna using patch with a hole.

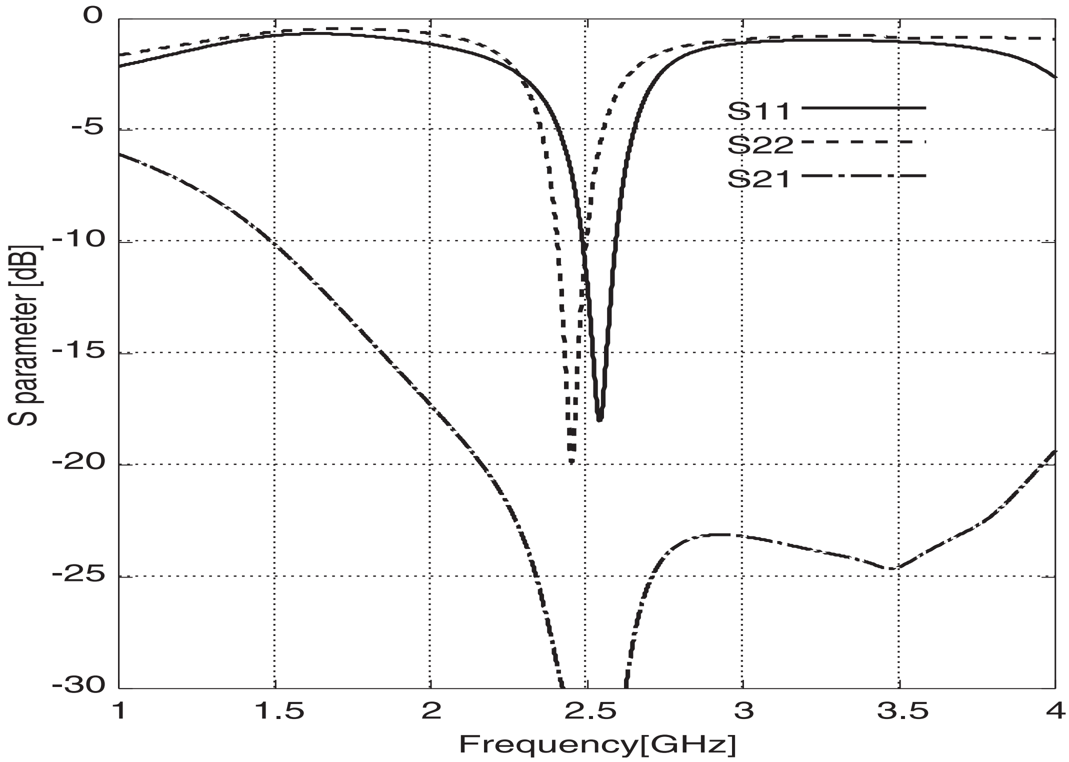
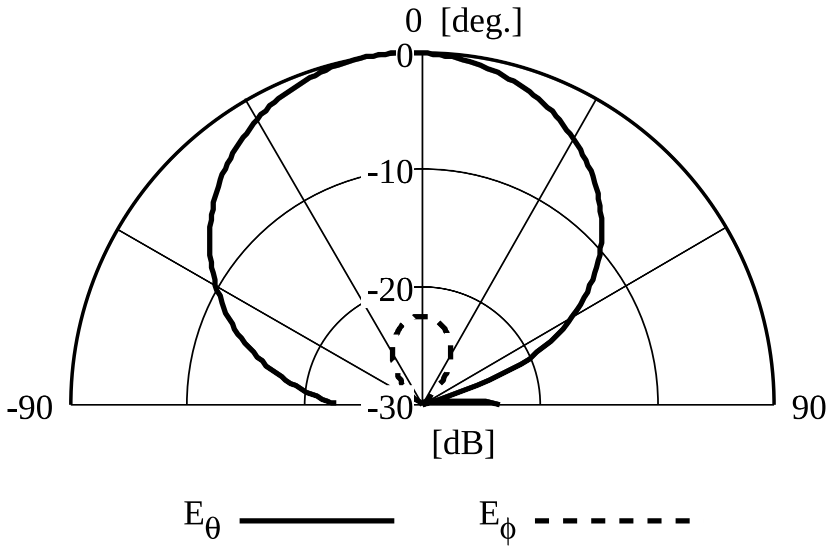
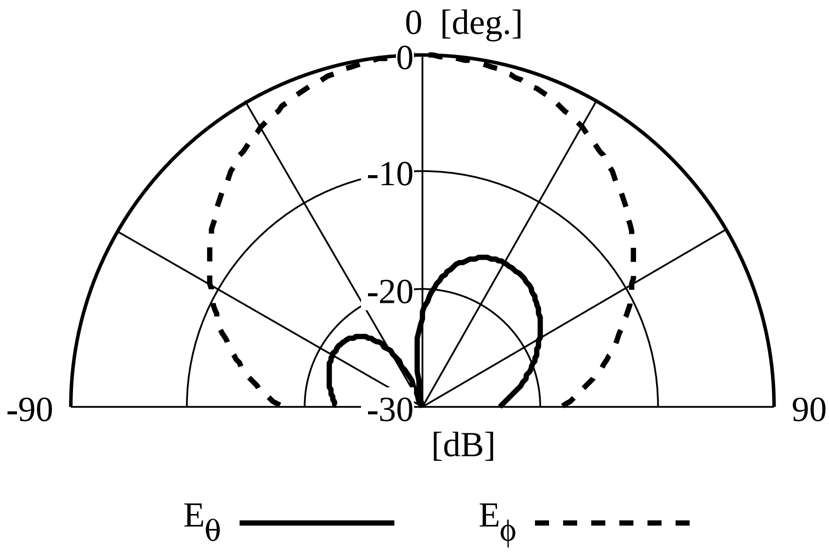


Figure 2.27: S parameter characteristics.

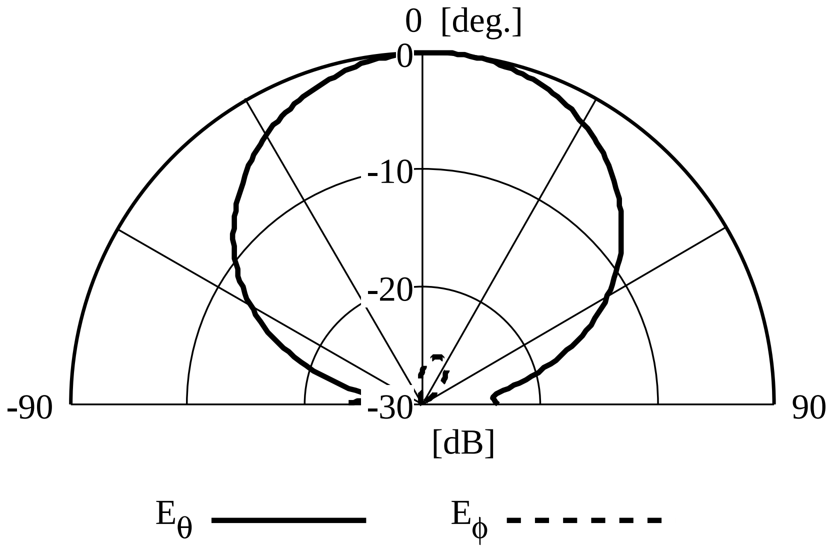


（a）E-Plane （Y-Z Plane）

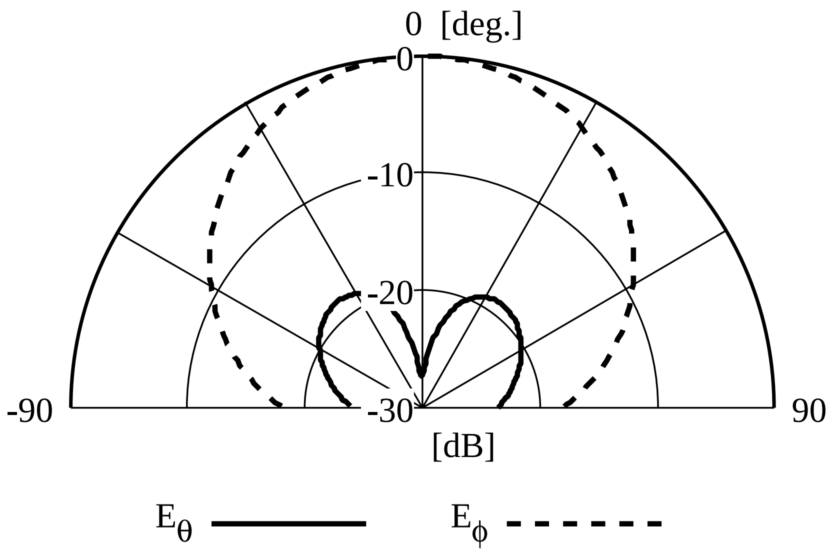


（b）H-Plane （Z-X Plane）

Figure 2.28: Radiation characteristics of upper antenna at the resonant frequency Freq.=2.54[GHz].



（a）E-Plane （Z-X Plane）



（b）H-Plane （Y-Z Plane）

Figure 2.29: Radiation characteristics of lower antenna at the resonant frequency Freq.=2.45[GHz].

2.3.4 Comparison between Analysis and Measurement

To check the analysis result of the antenna model proposed for the foregoing section, next, comparison examination with a measurement is presented. The measurement model of two-layer antenna is shown in Figure 2.30. This antenna model consists of the rectangle patch antenna 32[mm] around as a lower antenna and the rectangle patch antenna 50[mm] around with a hole D[mm] around as an upper antenna. The hole center of the lower antenna, that is the feed point location of the upper antenna, is located at (x, y)=(-15, 0) where the mutual coupling is most suppressed when changing the location. Moreover, although one side length of the lower hole was set to D=16[mm] in Figure 2.26, the length is changed into D=10[mm] on manufacture of an antenna

Figures 2.31 and 2.32 show the analysis and measurement result of S parameter characteristics, respectively. Figures 2.33 and 2.34 are that of radiation pattern. The resonant frequency of upper antenna is about 2.5[GHz] from upper return loss characteristics (S_{11}) and that of lower antenna is about 2.6[GHz] from lower characteristics (S_{22}) as shown in Figure 2.31. In addition, though upper patch is fed from the edge, the hole of lower layer adjusted the upper input impedance, and impedance matching can be taken. The isolation characteristics shown in Figure 2.32 is less than -20[dB] at both resonant frequencies. Comparing the analysis and measurement results, the S parameter characteristics agree well, respectively.

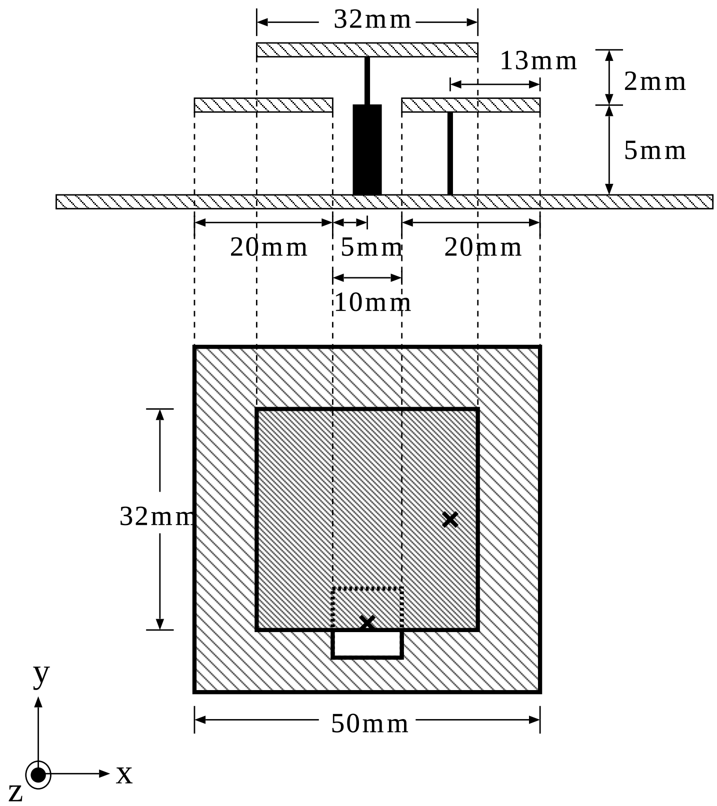


Figure 2.30: Geometry of stacked antenna using patch with a hole for measurement.

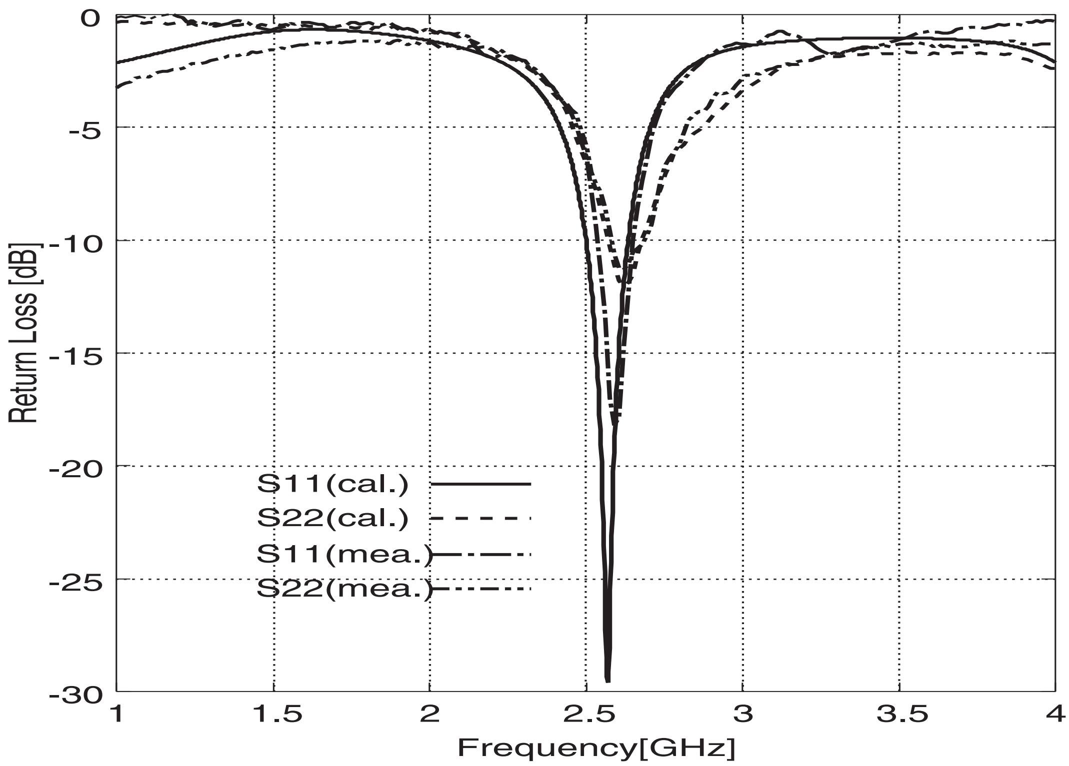


Figure 2.31: Return loss characteristics.

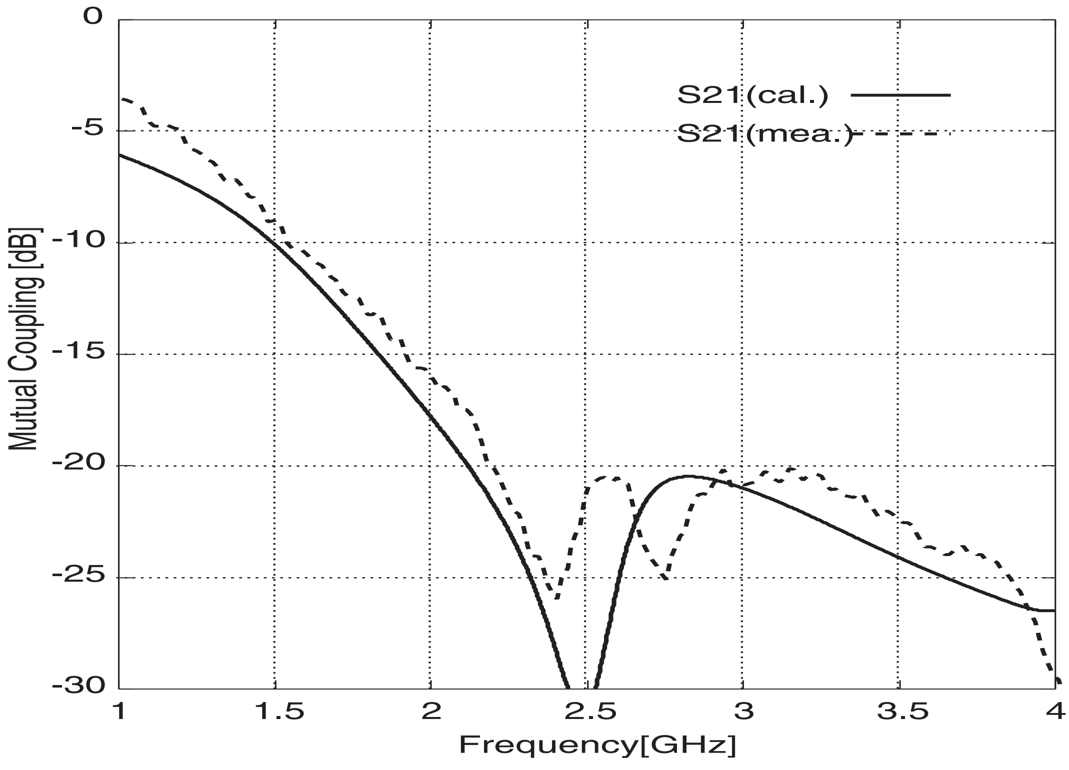


Figure 2.32: Mutual coupling characteristics.

The radiation patterns in E plane at the resonant frequency of upper and lower antenna are shown in Figures 2.33(a) and 2.34(a). The radiation patterns in H plane are shown in Figures 2.33(b) and 2.34(b). The resonant frequency of the upper antenna is about 2.5[GHz], and that of the lower antenna is about 2.6[GHz].

At the resonant frequencies of the upper and lower antenna, we find no distortion in both radiation pattern. The cross polarization level is suppressed when the hole center of lower antenna is located (x, y)=(0, -15). The level of mutual coupling is also suppressed as shown in Figure 2.32. Comparing the FDTD simulation and the measurement results, the radiation pattern agree well, respectively by considering the ground plane of simulation is infinite and that of measurement is finite.

The cross polarization is excited by the existence of lower hole, but the radiation characteristics are almost same with rectangular patch antenna. By using this antenna geometry, the cross polarization is about -20[dB] and the influence of lower hole can be neglected.

2.3.5 Conclusion

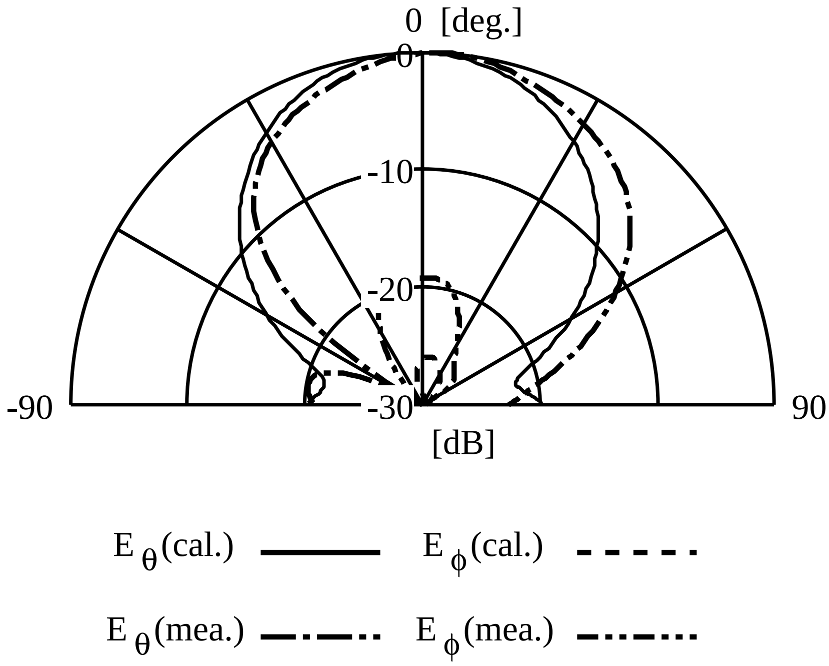
In this section, we propose two-layer antenna which consists of rectangular patch as an upper antenna and patch with a hole as lower antenna. S parameter characteristics and radiation pattern are examine by FDTD simulation and experiment.

First, the influence on input characteristics of two-layer antenna by changing the feed point location is examined. By the antenna geometry, who's upper and lower current resonance is cross, mutual coupling between upper and lower antenna is suppressed and both antenna is operated independently.

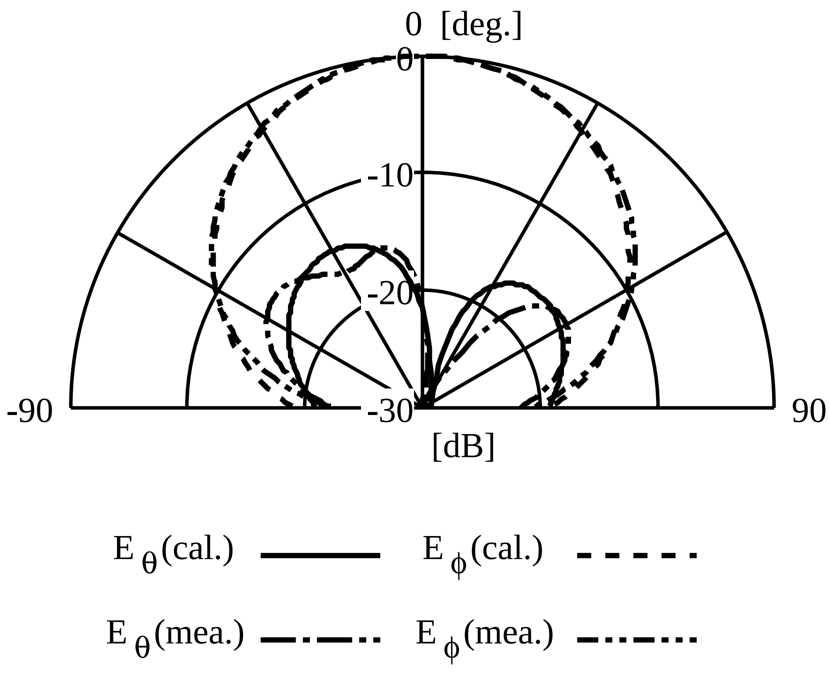
Next, the influence of antenna geometry compared with lower patch with a hole is examined. The case of using patch with a shorted hole and patch with a hole are also examines. These geometries have few influence on the input characteristics.

By changing the hole size of lower antenna, S parameter characteristics are also presented.

Last, example model of two-layer antenna using patch with a hole is presented. This antenna geometry suppresses the mutual coupling between upper and lower antenna.

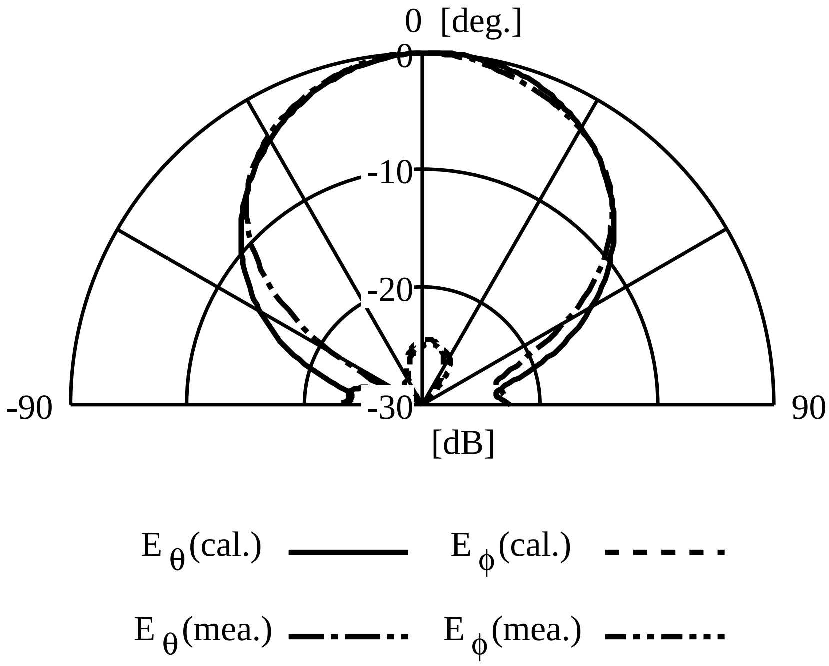


(a) E-Plane (Y-Z Plane)

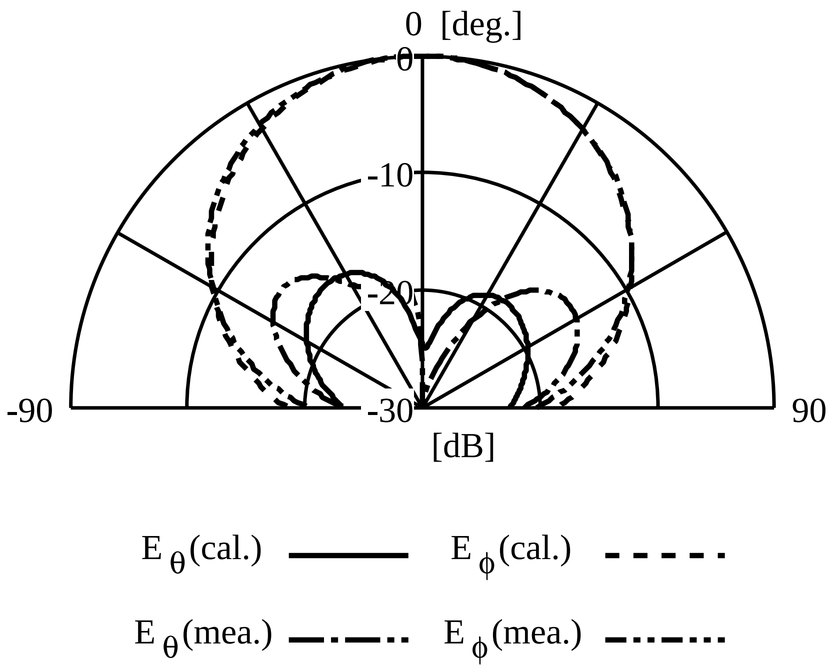


(b) H-Plane (Z-X Plane)

Figure 2.33: Radiation pattern of upper antenna at the resonant frequency Freq.=2.5[GHz].



（a）E-Plane（Z-X Plane）



（b）H-Plane（Y-Z Plane）

Figure 2.34: Radiation pattern of lower antenna at the resonant frequency Freq.=2.6[GHz].

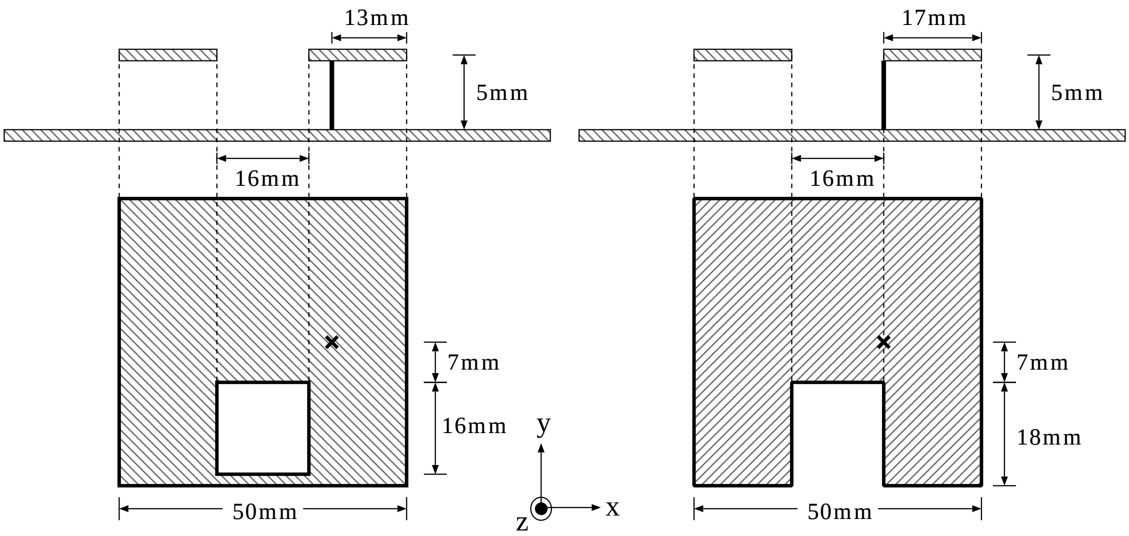
2.4 Two-Layer Antenna using Slitted Patch and Electromagnetic Coupling Patch

2.4.1 Introduction

From the previous section, we propose the dual polarized two-layer antenna which consists of patch antenna as upper antenna and patch with a hole as lower antenna. From the structure of the lower antenna with a hole, we noticed that the spacing between the hole edge and that of the lower antenna is very small. If we remove this part of patch with a hole like concave shaped patch, we considered that there is few influence on antenna characteristics. And we can use concave part to excite the upper patch antenna by electromagnetic coupling. It is easier for manufacturing than using patch antenna with a hole. In this section, we propose stacked antenna which consists of concave shaped patch (that is patch with one slit) as lower antenna and electromagnetic couple patch as upper antenna.

2.4.2 Patch with a Hole and Concave Shaped Patch

First, we consider the rectangular patch (50 $\times$ 50[mm]) which has (a) a hole (16 $\times$ 16[mm]) that is patch with a hole and (b) a concave part (16 $\times$ 18[mm]) that is concave shaped patch as shown in Figure 2.35. The S parameter characteristics of these two models are calculated by FDTD analysis. Figure 2.36 shows the return loss characteristics. The resonant frequency of the rectangular patch is 2.42[GHz], and that of concave shaped patch (CSP) is 1.98[GHz]. The resonant frequency of concave shaped patch shifts to lower side because the length of resonance changed by the difference of geometry, but the impedance matching is good and the return loss level is less than -25[dB] at both resonant frequencies.



（a） Patch with a hole （b） Concave shaped patch

Figure 2.35: Geometry of patch with a hole and concave shaped patch.

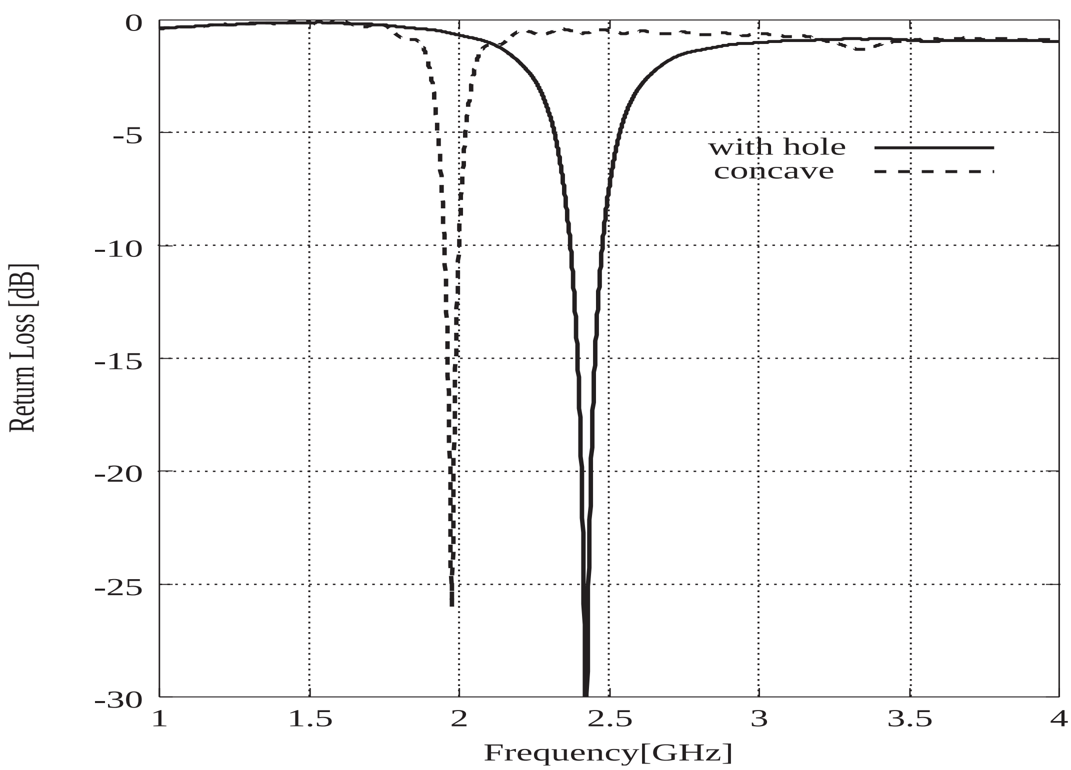


Figure 2.36: Return Loss characteristics of patch with a hole and concave shaped patch.

The radiation patterns of E-plane for each antenna are shown in Figures 2.37 and 2.38. At the resonant frequencies of each antenna, the principle radiation pattern agrees well each other. However, the cross polarization level of concave shaped patch is increased to −15[dB]. The cross polarization is excited by bent current on the concave part of the patch, but its level is about −15[dB] which can be neglected for the self-diplexing antenna. Therefore, we use concave shaped patch instead of using patch with a hole.

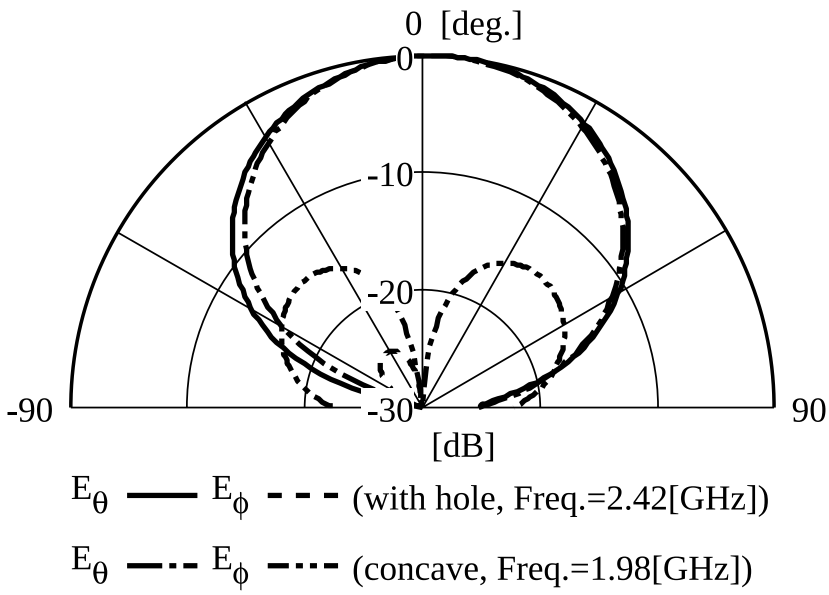


Figure 2.37: Radiation pattern. (E-plane)

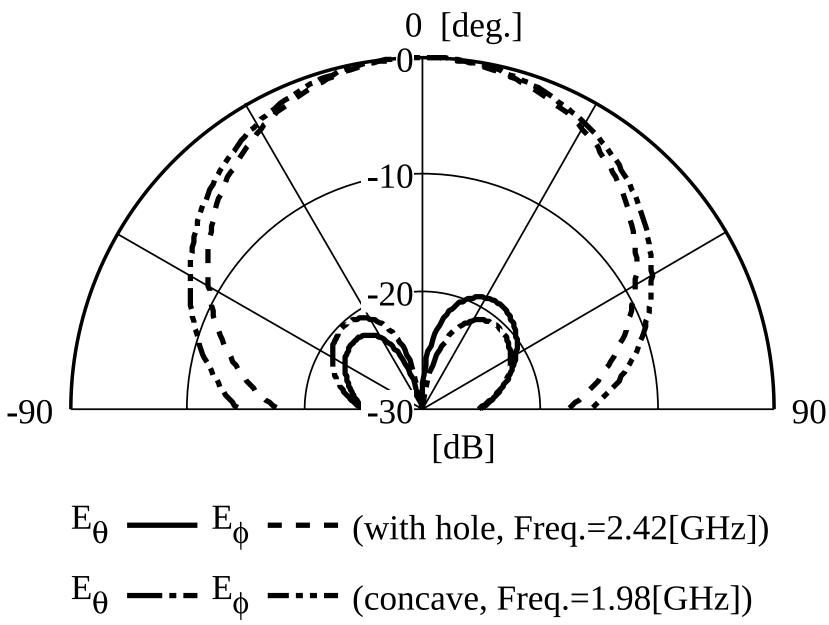


Figure 2.38: Radiation pattern. (H-plane)

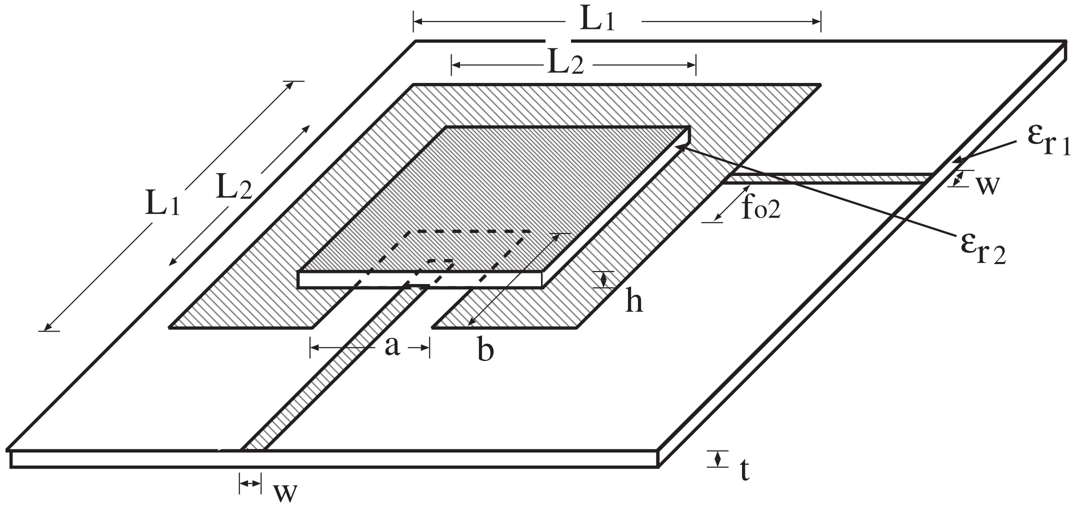
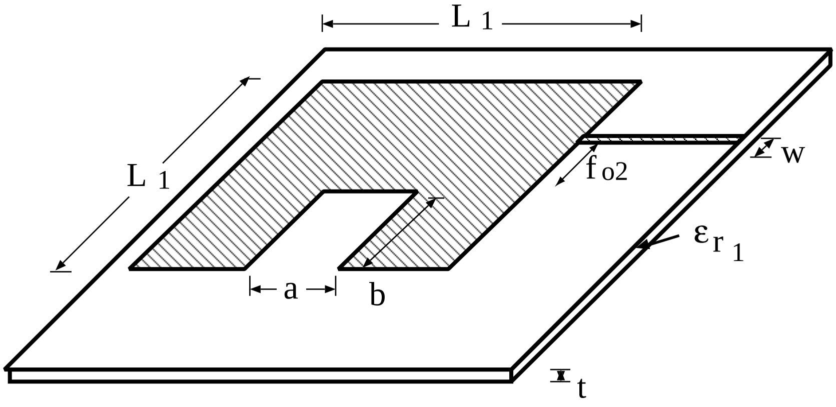


Figure 2.39: Geometry of stacked patch antenna using concave shaped patch and electormagnetic coupled patch.

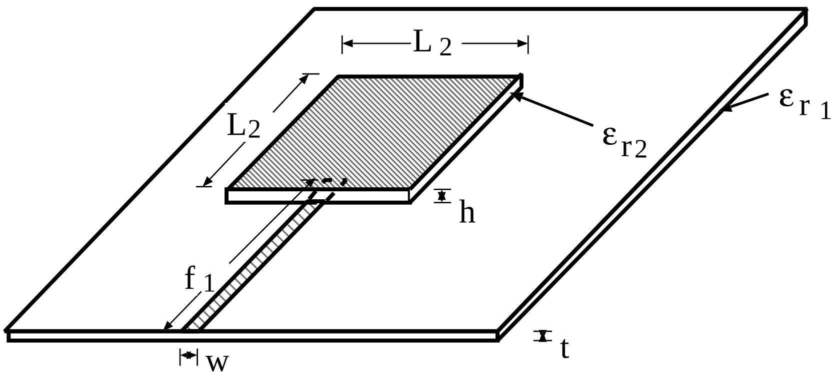
2.4.3 Antenna Characteristics of Stacked Antenna consist of Concave Shaped Patch and Electromagnetic Coupled Patch

Geometry of Stacked Patch Antenna

We propose the stacked patch antenna consisting of the rectangular patch antenna as the upper layer antenna and the rectangular patch antenna with concave part as the lower antenna as shown in Figure 2.39. The lower concave shaped patch ($L_1 \times L_1$) is on the dielectric substrate (thickness T, dielectric constant ε_{r1}), and it has concave part ($a \times b$). On the lower layer antenna, there is dielectric substrate (thickness T, dielectric constant ε_{r2}, $L_2 \times L_2$) and rectangular patch antenna ($L_2 \times L_2$). The upper patch antenna excited by electromagnetic coupling by using concave part of the lower antenna. The width of both microstrip lines for feeding upper and lower antenna are w. The offset length of feeding point for lower antenna is f_{o2} from the corner of the patch.



(a) Concave shaped patch



(b) Electromagnetic coupled patch

Figure 2.40: Geometry of concave shaped patch and electromagnetic coupled patch

Input Characteristics due to Stacked Antenna Model

First, we examined the influence of concave shaped patch and electromagnetic coupled patch on the each other antenna. The geometry of the antenna is shown in Figures 2.39 and 2.40. Figure 2.40 shows the antenna geometry when the antenna is not stacked. The case (a) is the lower concave shaped patch only. The case (b) is the upper electromagnetic coupled patch only. Figure 2.39 is the stacked antenna consists of upper and lower antenna.

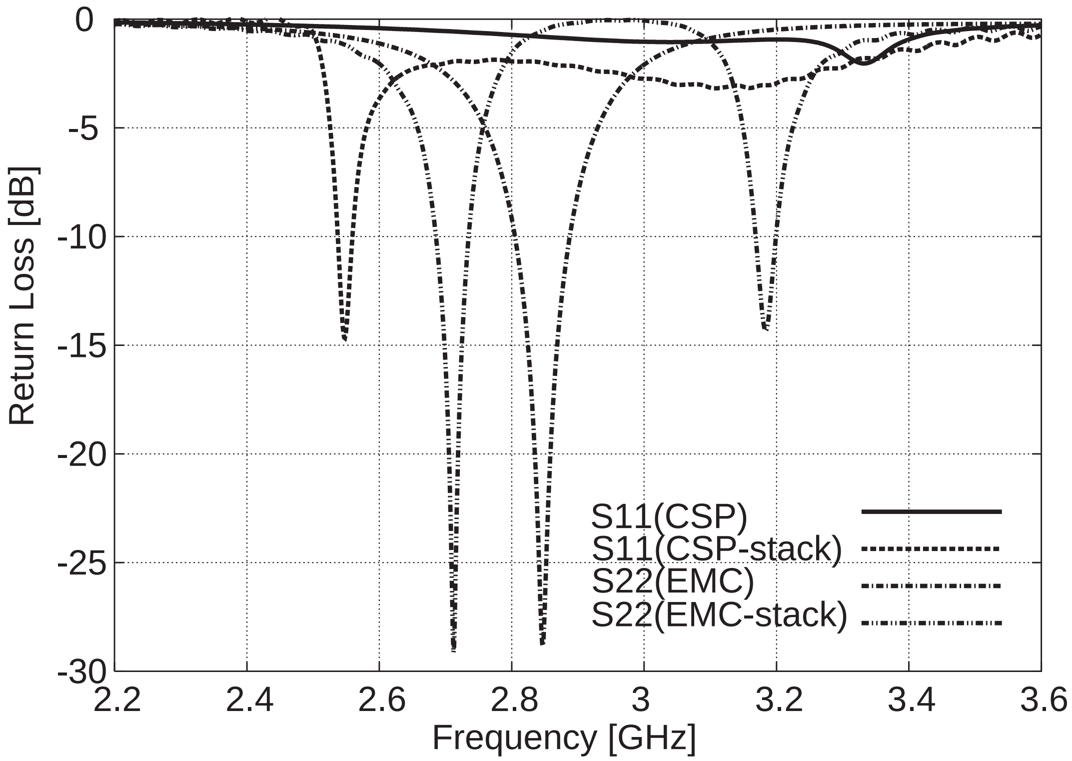


Figure 2.41: S parameter characteristics per antenna structure.

(L_1=27, L_2=27, f_{o2}=0, a=13.5, b=4.5, w=4.5, t=h=1.6[mm], ε_{r1}=2.6, ε_{r2}=4.0)

Figure 2.41 shows the S parameter characteristics of the stacked antenna versus antenna structure. From the S parameter characteristics of the concave shaped patch (S_{11}), the resonant frequency of the patch is 3.04[GHz], and when it becomes stacked patch, the resonant frequency shift lower to 2.55[GHz]. From the S parameter characteristics of the electromagnetic coupled patch (S_{22}), the resonant frequency of the patch is 2.85[GHz], and when it is stacked patch, the resonant frequency also shifts lower to 2.71[GHz]. It is because there is mutual coupling between upper electromagnetic coupled patch and lower concave shaped patch. The upper electromagnetic coupled patch is excited not only from the microstrip line but also from lower concave shaped patch. The lower concave shaped patch has influence on upper electromagnetic coupled patch.

Input Characteristics due to Size of Concave Part

Next, the influence of input characteristics of stacked patch antenna due to the size of lower concave part is examined. The S parameter characteristics of this antenna are shown in Figure 2.42 to 2.47.

From Figure 2.42, the resonant frequency of lower concave shaped patch (S_{11}) is almost same by changing the concave width a, but the return loss level is changed because the antenna impedance is also changed by the concave part size. From Figure 2.43, the return loss characteristics of upper electromagnetic coupled patch (S_{22}) is affected by changing the concave width a. The input characteristics of upper antenna is affected by the mutual coupling from lower antenna as shown in Figure 2.41. When the concave width a becomes larger, overlapped part of upper and lower antenna becomes smaller, and the influence from the lower antenna also becomes smaller. From Figure 2.44, mutual coupling at the resonant frequency of lower antenna (2.35[GHz]) increase when the concave width a becomes larger.

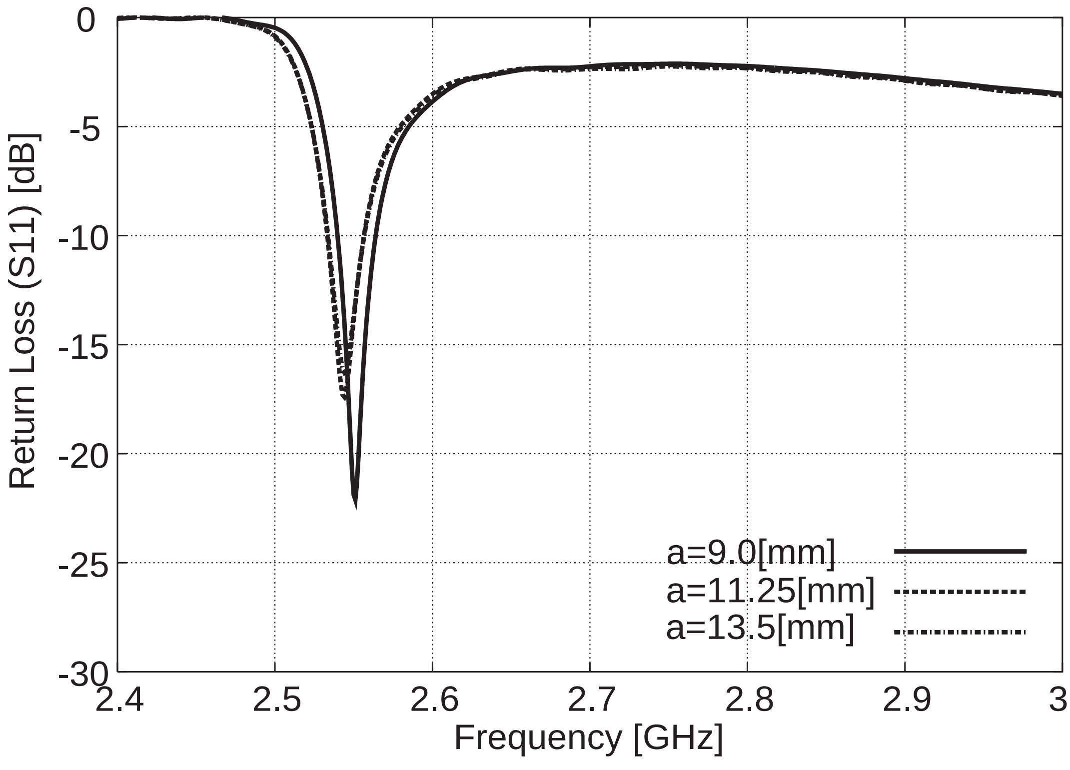


Figure 2.42: Return loss characteristics of lower patch due to length of concave part a.

(L_1=27, L_2=27, f_{o2}=0, b=4.5, w=4.5, t=h=1.6[mm], ε_{r1}=2.6, ε_{r2}=4.0)

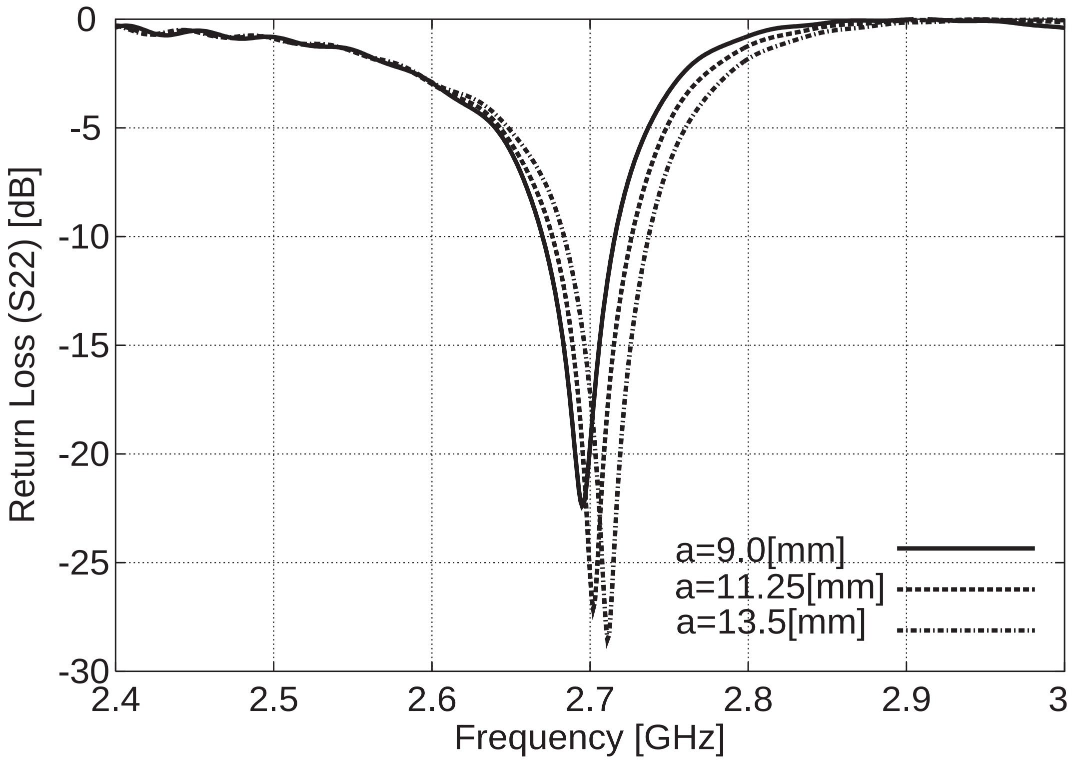


Figure 2.43: Return loss characteristics of upper patch due to length of concave part a.

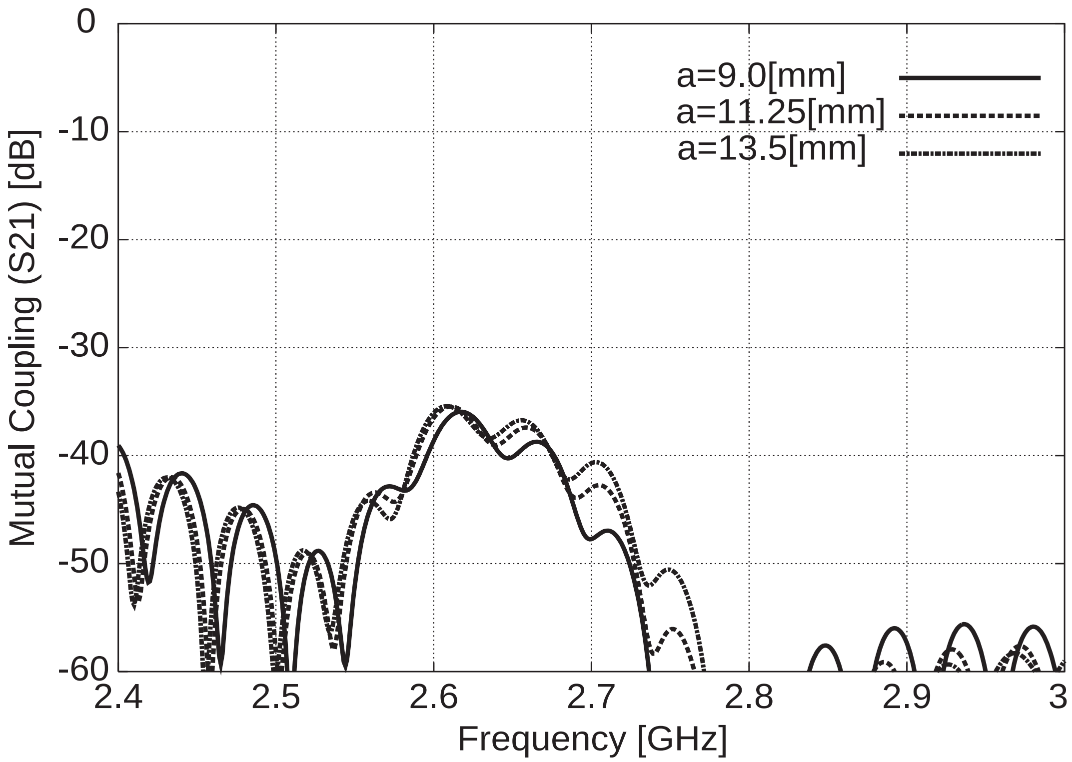


Figure 2.44: Mutual coupling characteristics due to length of concave part a.

(L_1=27, L_2=27, f_{o2}=0, b=4.5, w=4.5, t=h=1.6[mm], ε_{r1}=2.6, ε_{r2}=4.0)

From Figure 2.45, the resonant frequency and return loss level of lower concave shaped patch (S_{11}) is affected by changing the concave length b. This is because the antenna impedance is changed by the concave part size. Compared with Figure 2.42, concave length b has bigger influence on antenna impedance and resonant length than concave width a.

From Figure 2.46, the return loss characteristics of upper electromagnetic coupled patch (S_{22}) is affected by changing the concave length b. When the concave length b becomes larger, overlapped part of upper and lower antenna becomes smaller, and the influence from the lower antenna also becomes smaller. From Figure 2.44, mutual coupling at the resonant frequency of increase when the concave length b becomes larger.

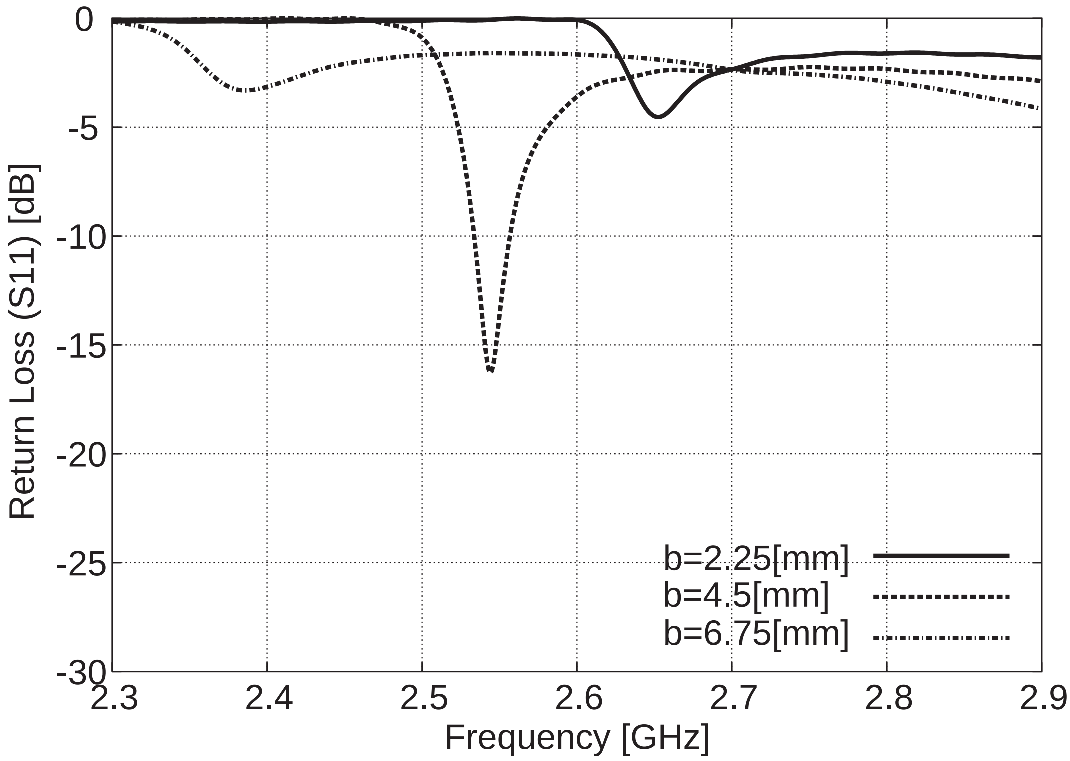


Figure 2.45: Return loss characteristics of lower patch due to length of concave part b.

(L_1=27, L_2=27, f_{o2}=0, a=13.5, w=4.5, t=h=1.6[mm], ε_{r1}=2.6, ε_{r2}=4.0)

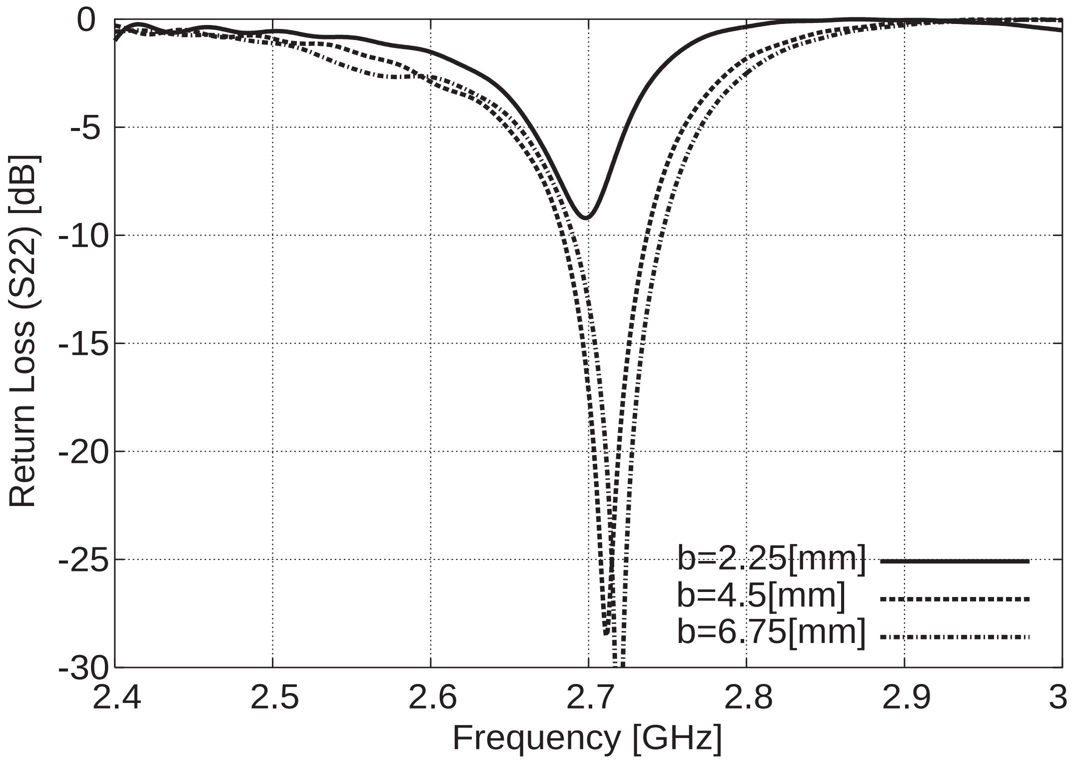


Figure 2.46: Return loss characteristics of upper patch due to length of concave part b.

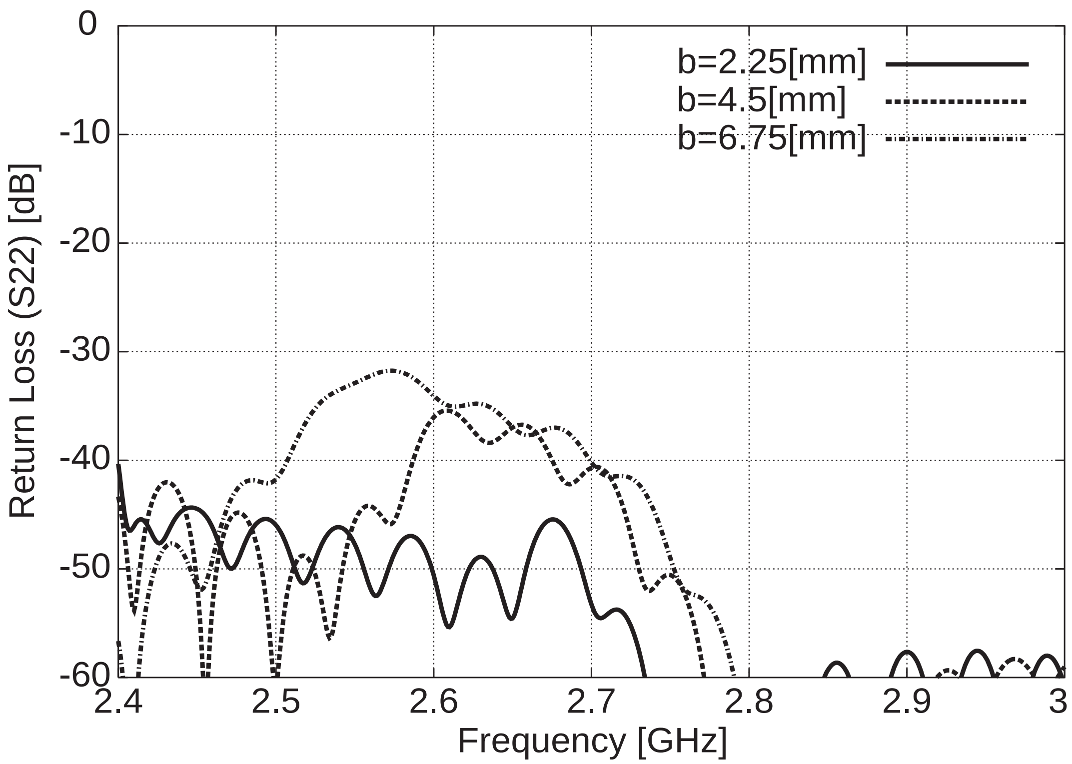


Figure 2.47: Mutual coupling characteristics due to length of concave part b.

(L_1=27, L_2=27, f_{o2}=0, a=13.5, w=4.5, t=h=1.6[mm], ε_{r1}=2.6, ε_{r2}=4.0)

Input Characteristics due to Size of Electromagnetic Coupled Patch

The influence of input characteristics of stacked patch antenna due to the size of upper electromagnetic coupled patch is examined. The S parameter characteristics of this antenna are shown in Figure 2.48 to 2.50.

From Figure 2.48, the resonant frequency of lower concave shaped patch (S_{11}) shifts lower by changing the upper antenna size because there is mutual coupling between upper and lower antenna by the overlapped part becomes larger. From Figure 2.49, the resonant frequency of upper electromagnetic coupled patch (S_{22}) shifts lower when the upper antenna size becomes larger because the resonant length also becomes longer.

From Figure 2.50, mutual coupling at the resonant frequency of lower antenna (2.35[GHz]) increase when the upper antenna size becomes larger.

By changing the dielectric constant between upper and lower antenna, the influence on input characteristics is the same with changing the size of upper layer, because changing dielectric constant is meaning changing the electrical antenna size of upper antenna.

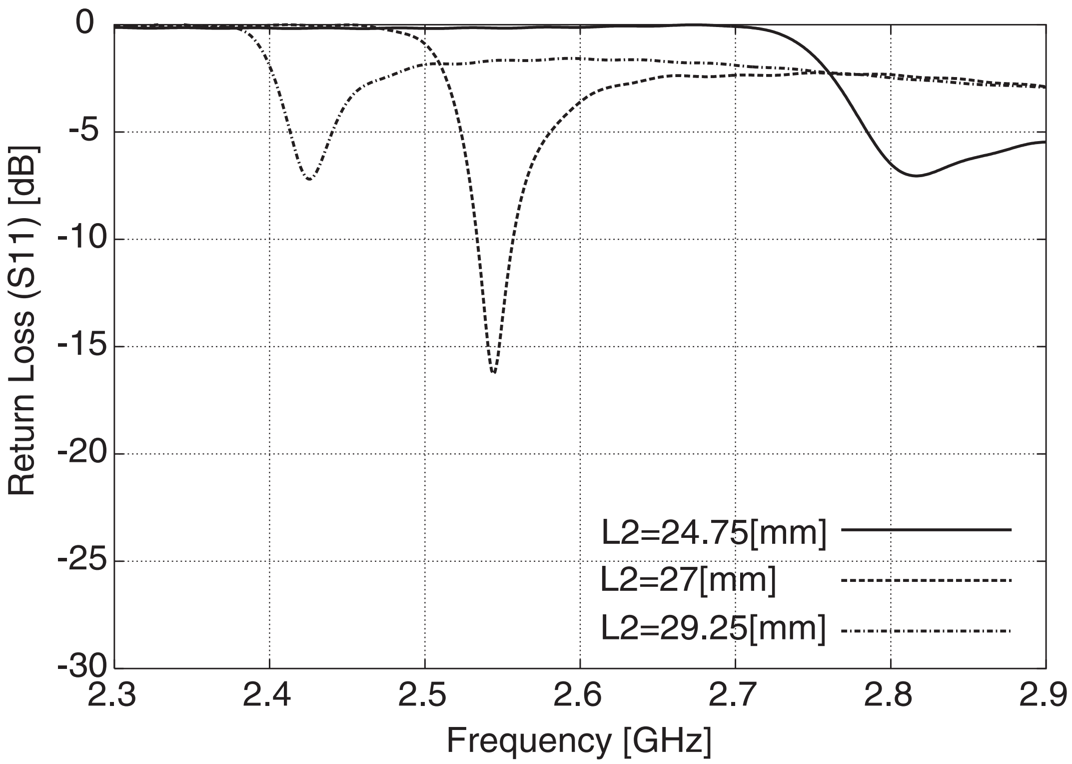


Figure 2.48: Return loss characteristics of upper antenna due to size of upper patch L_2. (L_1=27, f_{o2}=0, a=13.5, b=4.5, w=4.5, t=h=1.6[mm], ε_{r1}=2.6, ε_{r2}=4.0)

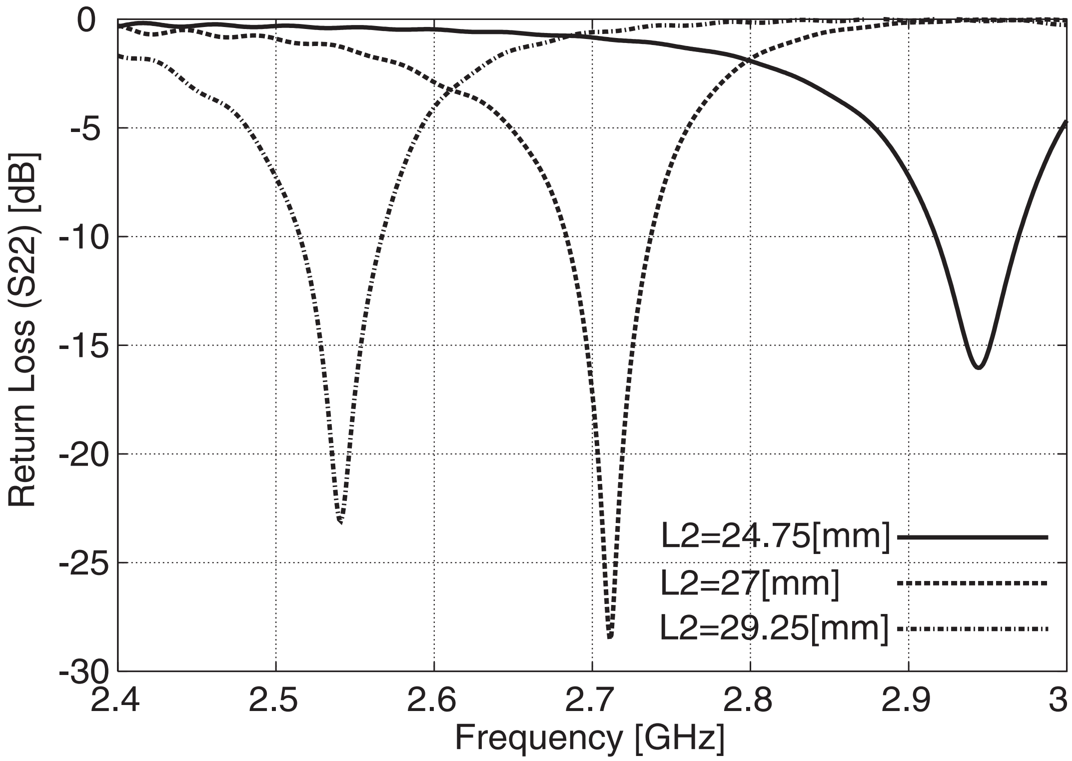


Figure 2.49: Return loss characteristics of lower antenna due to size of upper patch L_2

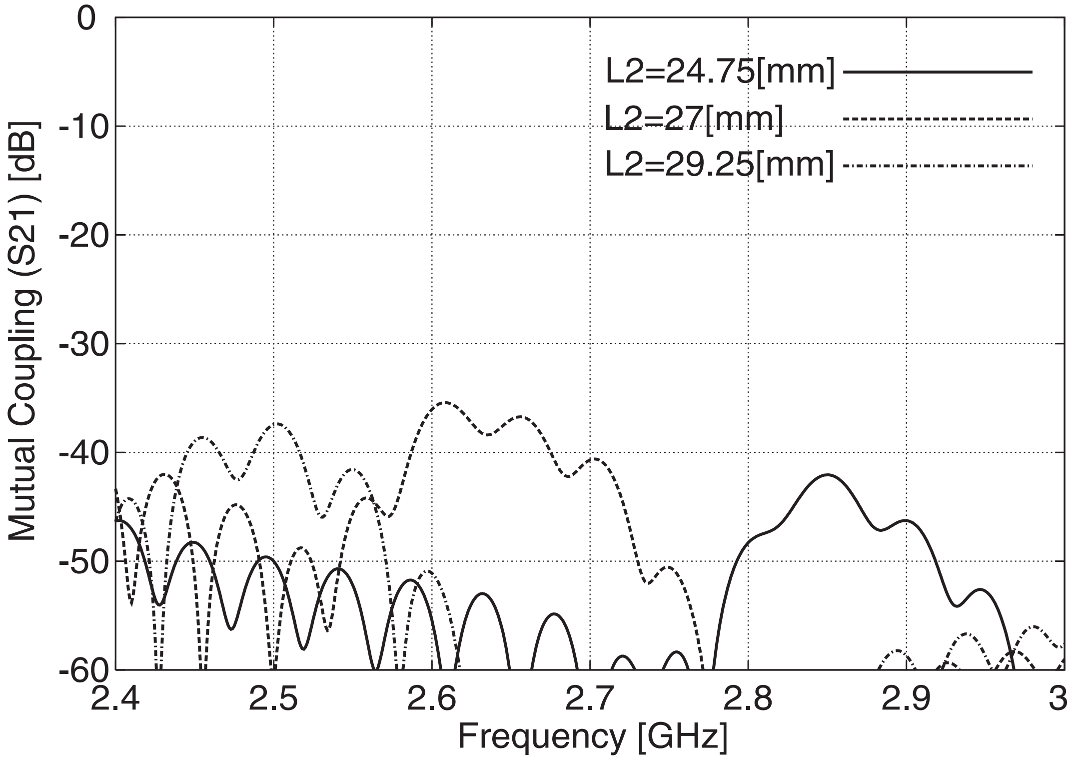


Figure 2.50: Mutual coupling characteristics due to size of upper patch L_2.

(L_1=27, f_{o2}=0, a=13.5, b=4.5, w=4.5, t=h=1.6[mm], ε_{r1}=2.6, ε_{r2}=4.0)

Example Model of Stacked Antenna using Concave Shaped Patch

From the previous calculation finding the concave part size of lower antenna and the electrical size of upper patch antenna, we will introduce the example structure of the stacked patch antenna for dual polarization antenna. The S parameter characteristics versus frequency of this model are shown in Figure 2.51. The resonant frequency of the upper electromagnetic coupled patch is 2.71[GHz] and that of lower concave shaped patch is 2.54[GHz]. At the resonant frequencies of the upper layer and lower layer antenna, both return loss level is suppressed less than -15[dB], and the mutual coupling is suppressed less than -40[dB].

The radiation pattern of the stacked patch antenna at each upper and lower resonant frequencies are shown in Figures 2.52 and 2.53. Both radiation patterns are in E-plane and H-plane for each layer. The resonant frequency of the lower concave shaped patch is 2.54[GHz] and that of the upper electromagnetic coupled patch is 2.71[GHz]. At the resonant frequencies of the upper and lower antenna, we find no distortion in both radiation patterns. The level of cross polarization of lower concave shaped patch is suppressed about -30[dB]. The cross polarization level of upper patch is about -15[dB].

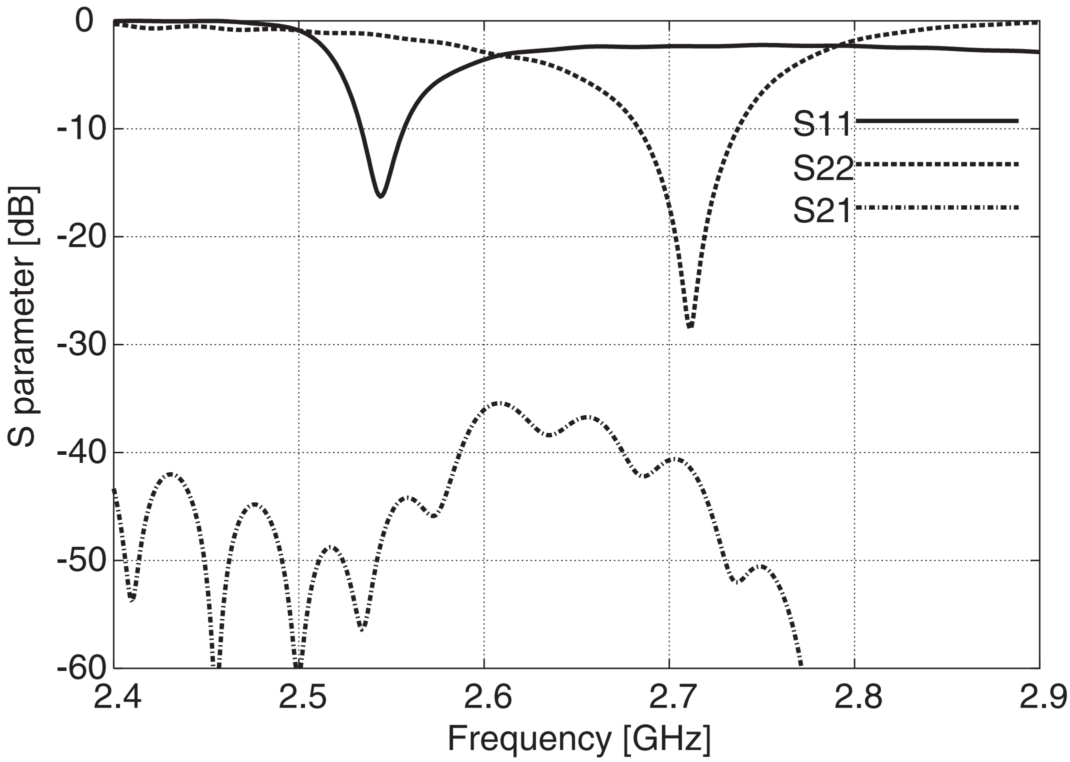
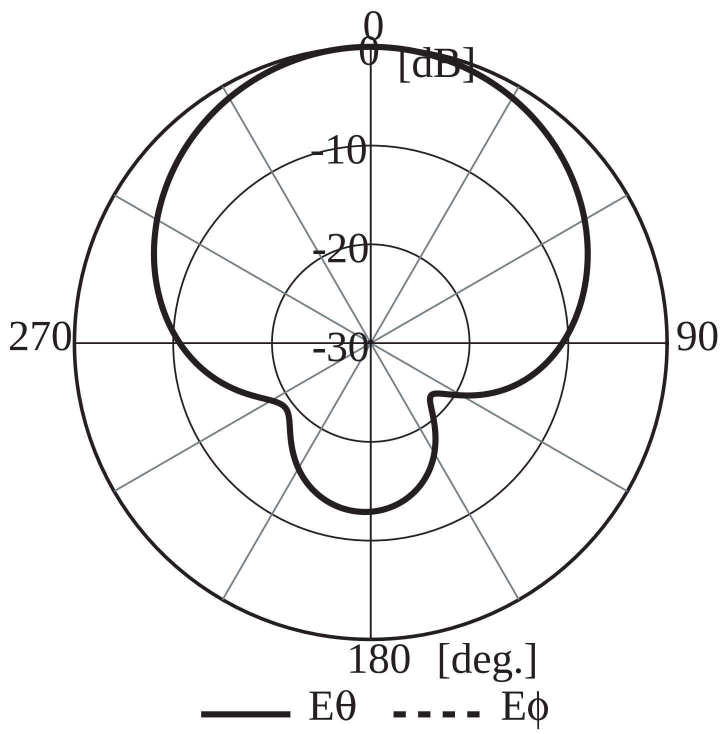
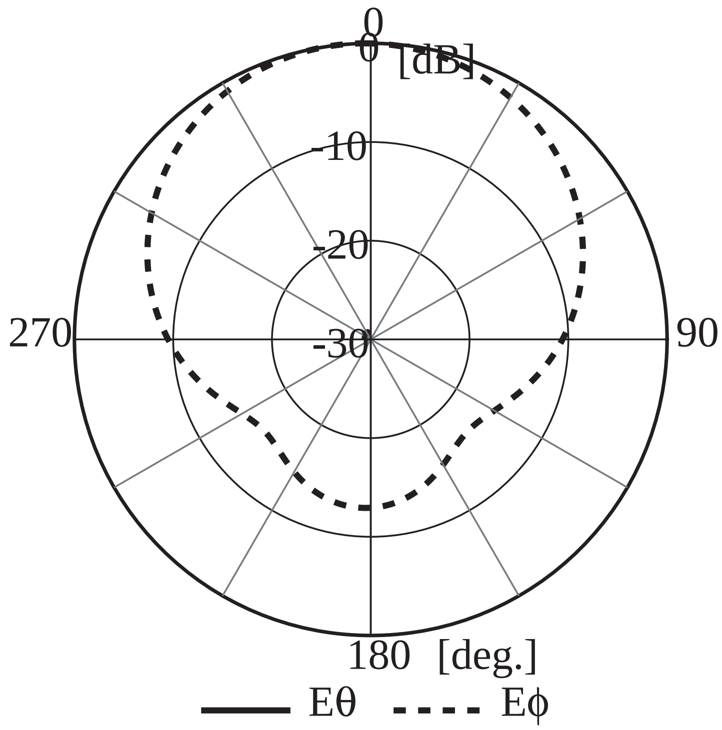


Figure 2.51: S parameter characteristics of the example stacked patch antenna model.

(L_1=27, L_2=27, f_{o2}=0, a=13.5, b=4.5, w=4.5, t=h=1.6[mm], ε_{r1}=2.6, ε_{r2}=4.0)

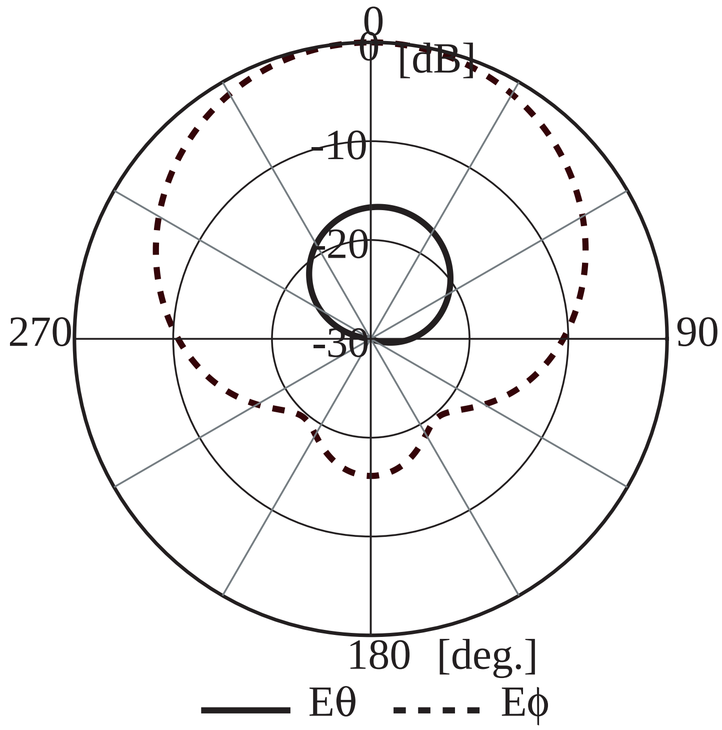


(a) E-Plane (Z-X Plane)

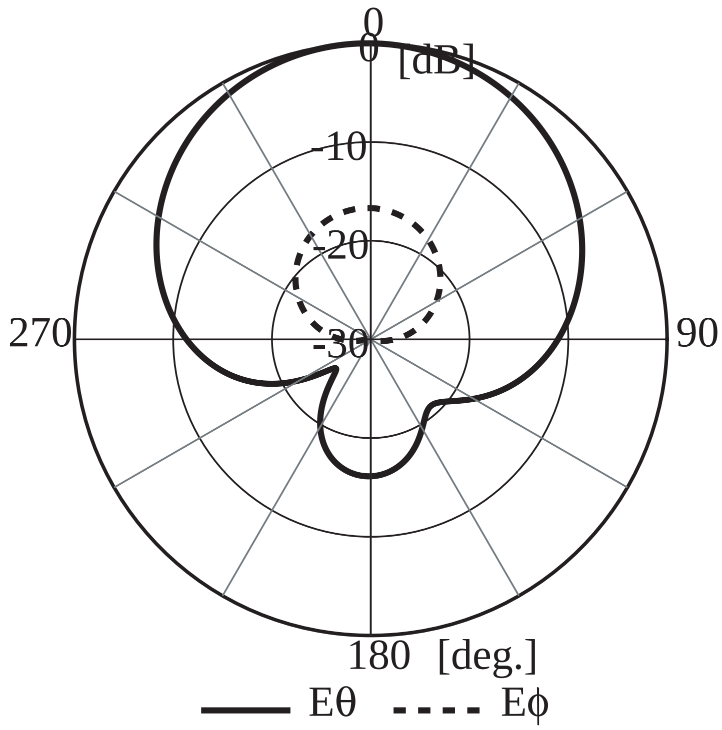


(b) H-Plane (Y-Z Plane)

Figure 2.52: Radiation pattern of the lower concave shaped patch antenna at the resonant frequency Freq.=2.54[GHz].



（a）E-Plane（Y-Z Plane）



（b）H-Plane（Z-X Plane）

Figure 2.53: Radiation pattern of the upper electromagnetic coupled patch antenna at the resonant frequency Freq.=2.71[GHz].

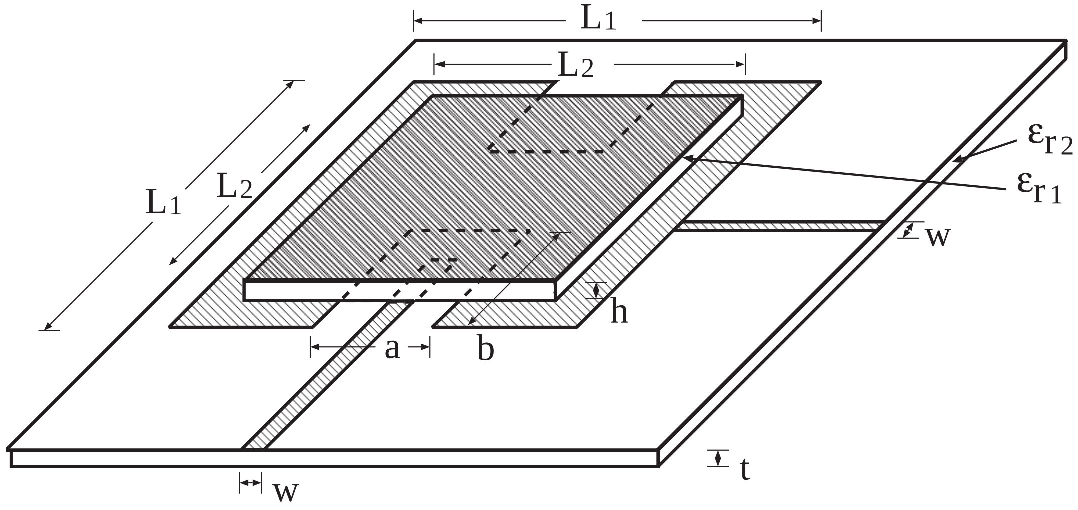


Figure 2.54: Geometry of stacked patch antenna using slitted patch and electromagnetic coupled patch.

(L_1=27, L_2=27, f_{o2}=0, a=13.5, b=4.5, w=4.5, t=h=1.6[mm], ε_{r1}=2.6, ε_{r2}=4.0)

2.4.4 Stacked Patch Antenna using Patch with Two Slit and Electromagnetic Coupled Patch

Geometry of Stacked Patch Antenna

From the previous section, using stacked antenna shown in Figure 2.39, both resonant frequencies are around 2.6[GHz] and have a difference about 150 to 300[MHz]. The resonant frequency of the upper electromagnetic coupled patch is 2.71[GHz] and that of lower concave shaped patch is 2.54[GHz] . Both return loss levels at the resonant frequency are suppressed less than −15[dB]. Mutual coupling level at the resonant frequency can be achieved to suppressed less than −40[dB]. However the cross polarization level of upper patch is about −15[dB].

By using the concave shaped patch, the cross polarization level of the antenna is increased up because of the current distribution. The current is strong not only at top edge and bottom edge but also at both side edges. In order to cancel the current of side edge and suppress the level of cross polarization, one more slit opposite side of concave slit is considered.

Figure 2.54 shows novel stacked patch antenna. This stacked antenna consists of an upper patch and a lower patch with two slits. The upper patch antenna is excited by electromagnetic coupling by using slit part of the lower patch. The size of upper patch antenna is 27 × 27[mm] and that of lower patch antenna is the same size with two slit. The dielectric constant of lower layer is ε_{r1}=2.6 and that of upper layer is ε_{r2}=4.0.

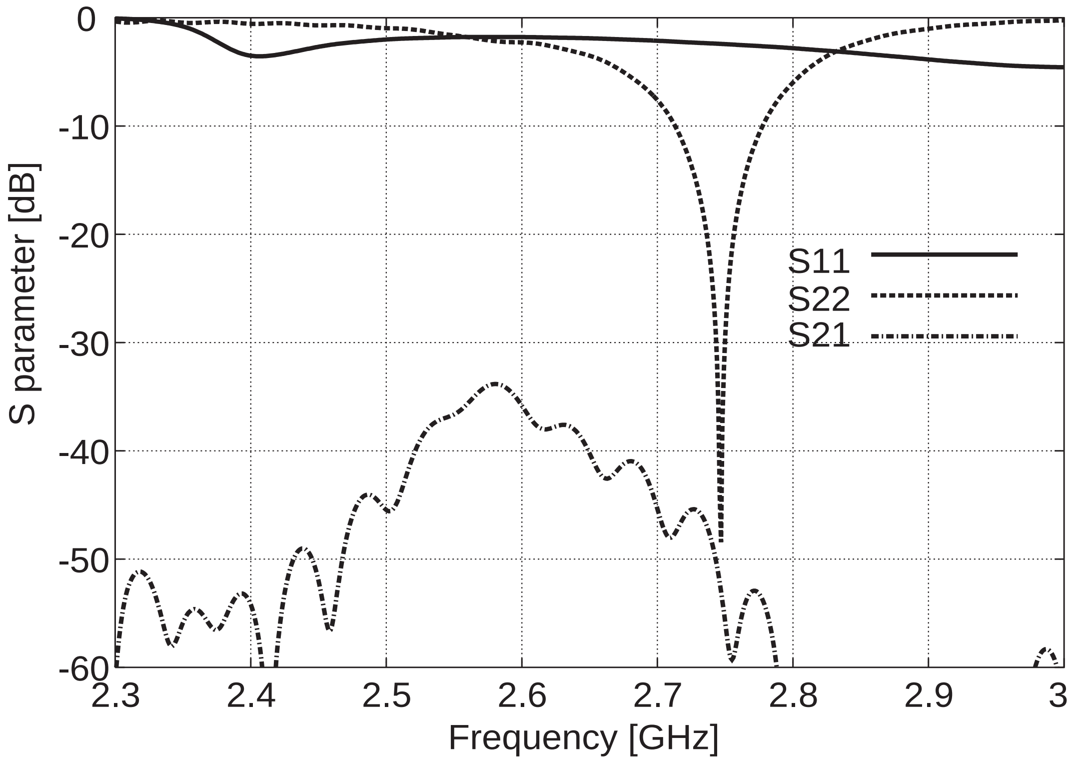


Figure 2.55: S parameter characteristics of stacked antenna.

(L_1=27, L_2=27, f_{o2}=0, a=13.5, b=4.5, w=4.8, t=h=1.6[mm], ε_{r1}=2.6, ε_{r2}=4.0)

First, we examine the influence of two slit part on the characteristics of stacked antenna. The antenna of Figure 2.39 has one slit and that of Figure 2.54 has two slits on the lower patch antenna. Second slit of Figure 2.54 is just added the same size slit opposite side of concave part of Figure 2.39. The feed location of the lower patch antenna is at the middle of the edge because the feed location is wanted to make at the middle of two slits not to make distortion of current distribution for suppressing cross polarization.

The S parameter characteristics versus frequency of this two slitted antenna are shown in Figure 2.55. The resonant frequency of the upper electromagnetic coupled patch is 2.75[GHz] and that of lower concave shaped patch is 2.41[GHz] . Comparing with Figure 2.51 that is a case of one slitted antenna, the resonant frequency of lower slitted antenna shifts to lower frequency and the return loss level at the resonant frequency becomes larger because the antenna impedance is changed by the antenna size adding slit. At the resonant frequencies of the upper layer antenna, the return loss level of upper antenna is suppressed less than -20[dB]. The level of mutual coupling is suppressed less than -40[dB] at both resonant frequencies of upper and lower antenna. This is almost the same as the case of using one slitted patch for lower antenna. Both antennas are operated independently at both resonant frequencies.

The radiation pattern of the stacked patch antenna with two slits at each upper and lower resonant frequencies are shown in Figures 2.56 and 2.57. Both radiation patterns are in E-plane for each layer antenna. The resonant frequency of the lower concave shaped patch is 2.41[GHz] and that of the lower electromagnetic coupled patch is 2.75[GHz]. At the resonant frequencies of the upper and lower antenna, we find no distortion in both radiation patterns. The level of cross polarization of lower concave shaped patch is suppressed about -30[dB]. And by using two slitted patch, the cross polarization level of upper patch is suppressed about 3[dB] from the case using one slit. The level is suppressed less than -18[dB]. Therefore, we use the patch antenna with two slits for lower antenna.

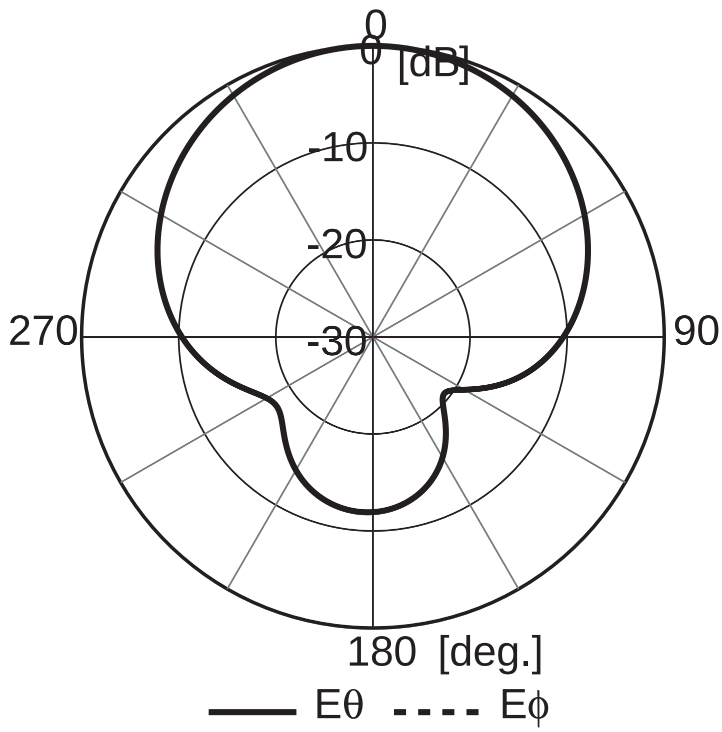


Figure 2.56: Radiation pattern of the lower concave shaped patch antenna at the resonant frequency Freq.=2.41[GHz]. (E-Plane)

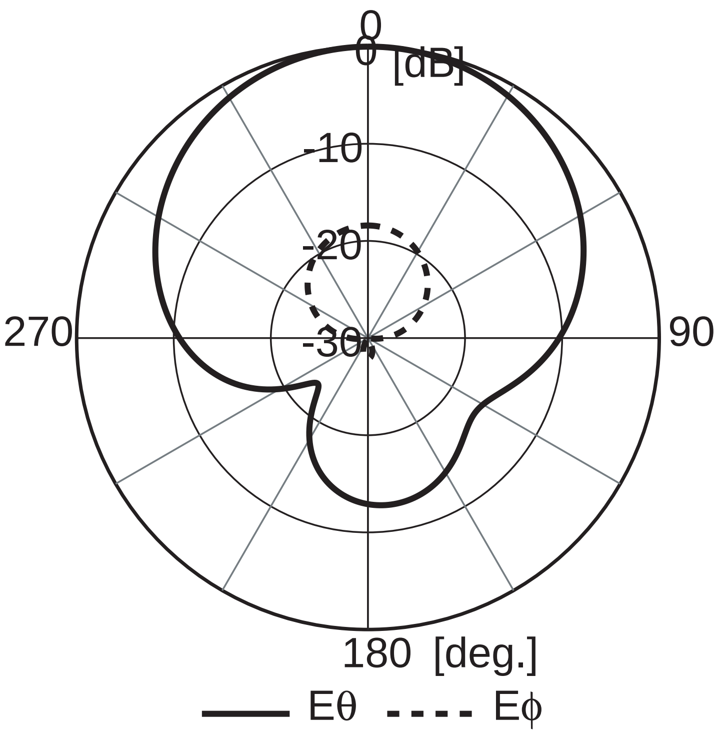


Figure 2.57: Radiation pattern of the upper electromagnetic coupled patch antenna at the resonant frequency Freq.=2.75[GHz]. (E-Plane)

S Parameter Characteristics and Radiation Pattern

As shown in Figure 2.55, the resonant frequency of the upper electromagnetic coupled patch is 2.75[GHz] and that of lower concave shaped patch is 2.41[GHz] . The difference of both resonant frequencies is about 300[MHz]. However, the return loss level of lower concave shaped patch at resonant frequency is not suppressed less than -20[dB]. To make impedance matching for lower slitted antenna, feed point is moved to enter from the edge of patch (parameter f). And the width of microstrip line is also changed to affect the impedance of strip line.

By making the impedance matching by changing the feed point location and finding the antenna size, we will introduce the example structure of the stacked patch antenna using double slitted patch for lower antenna. The S parameter characteristics versus frequency of this model are shown in Figure 2.58. The resonant frequency of the upper electromagnetic coupled patch is 2.64[GHz] and that of lower concave shaped patch is 2.43[GHz]. At the resonant frequencies of the upper layer antenna, return loss level is suppressed less than -20[dB] and that of lower layer antenna is suppressed less than -15[dB]. The level of mutual coupling is suppressed less than -50[dB] at both resonant frequencies.

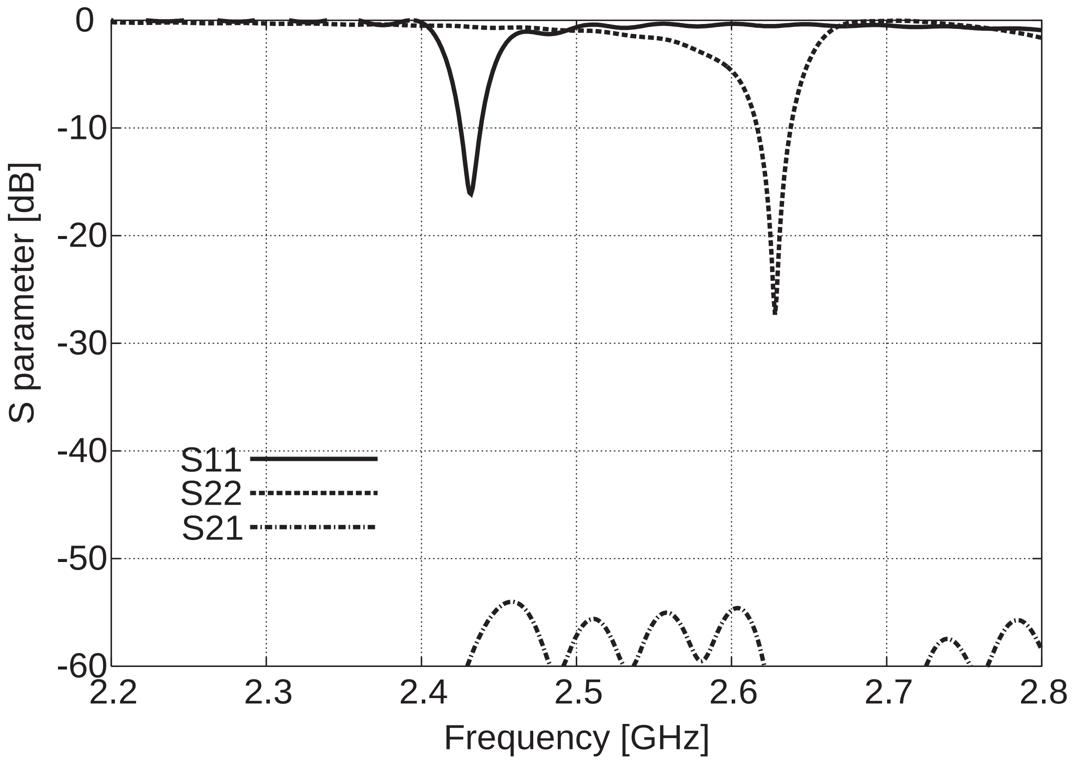


Figure 2.58: S parameter characteristics of the example stacked patch antenna model.

(L_1=27, L_2=27, f_{o2}=0, f=4.5, a=13.5, b=4.5, w=2.25, t=h=1.6[mm], ε_{r1}=2.6, ε_{r2}=4.0)

The radiation pattern of the stacked patch antenna at each resonant frequencies are shown in Figures 2.59 and 2.60. The resonant frequency of the lower concave shaped patch is 2.43[GHz] and that of the upper electromagnetic coupled patch is 2.64[GHz]. At the resonant frequencies of the upper and lower antenna, we find no distortion in both radiation patterns. The level of cross polarization of both antenna is suppressed less than -20[dB].

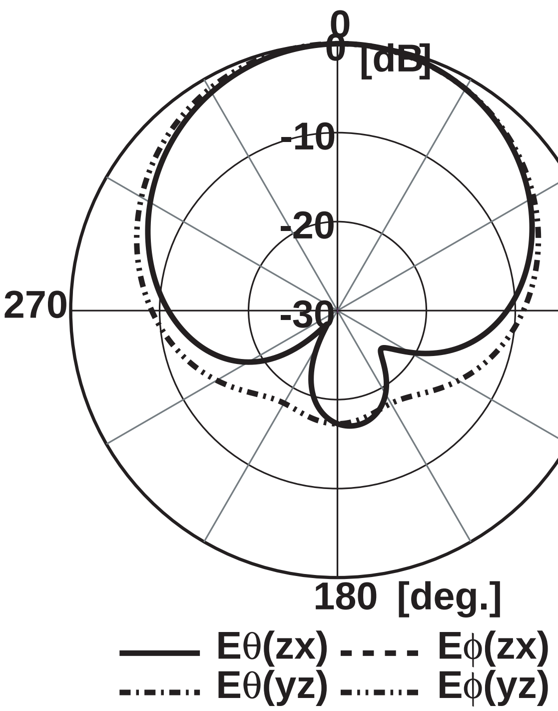


Figure 2.59: Radiation pattern of the lower concave shaped patch antenna at the resonant frequency Freq.=2.43[GHz]. (E-Plane : zx-plane, H-Plane : yz-plane)

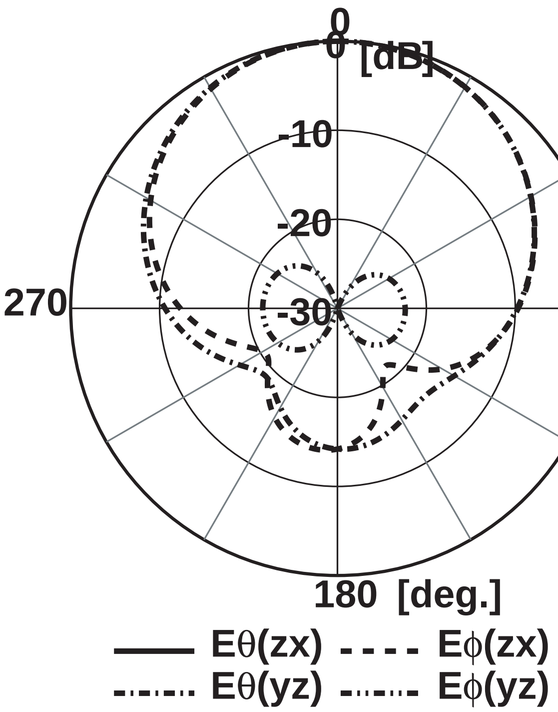


Figure 2.60: Radiation pattern of the upper electromagnetic coupled patch antenna at the resonant frequency Freq.=2.64[GHz]. (E-Plane : yz-plane, H-Plane : zx-plane)

2.4.5 Conclusion

In this section, we presented two types of stacked antenna which consists of an electromagnetic coupled patch as the upper antenna and a slitted patch antenna as the lower antenna. The upper patch antenna is excited by electromagnetic coupling by using slit part of the lower patch. We simulated the S parameter characteristics and radiation pattern by FDTD method.

First, we make a comparison between the characteristics of stacked antenna using patch with a hole and concave shaped patch. The level of mutual coupling and cross polarization becomes larger by using concave shaped patch than by using patch with a hole. However, the mutual coupling level at resonant frequency is almost -20[dB] and the cross polarization is suppressed less than -15[dB]. The concave shaped patch can be used instead of patch with a hole for two-layer antenna.

We proposed stacked antenna which consists of concave shaped patch as the lower antenna and rectangular patch as the upper antenna. There is an influence between upper electromagnetic coupled patch and lower concave shaped patch on each other. The characteristics are affected by the overlapped part between upper and lower layer antenna. Proposed antenna structure suppress the mutual coupling between upper and lower antenna less than -40[dB]. The level of cross polarization is about -15[dB].

Next, we examine the influence of two slit part on the characteristics of stacked antenna. The level of mutual coupling is almost the same as the case of using one slitted patch for lower antenna.

We proposed stacked antenna which consists of patch antenna with two slits as the lower antenna and electromagnetic couple patch as the upper antenna. We make impedance matching for lower slitted antenna, and show the influence on resonant characteristics. Our proposed antenna structure suppress the mutual coupling between upper and lower antenna less than -50[dB]. By using patch with two slits, the cross polarization level is suppressed less than -20[dB].

2.5 Stacked Self-Diplexing Patch Antenna

In the previous sections, several types of stacked antenna with dual polarization are proposed. Our proposed stacked antennas in previous sections have linear polarization. Suppression of mutual coupling between two antennas can be achieved by using proposed antenna structure. However, for the application of self-diplexing antenna, the characteristic of circular polarization is required. In this section, for the next step, stacked antenna with circular polarization is considered.

2.5.1 Antenna Characteristics Due to Offset Length of Lower Feed Location

From the previous section, using stacked antenna shown in Figure 2.61, both resonant frequencies are around 2.6[GHz] and have a difference about 150 to 300[MHz]. The resonant frequency of the upper electromagnetic coupled patch is 2.71[GHz] and that of lower concave shaped patch is 2.54[GHz] . Both return loss levels at the resonant frequency are suppressed less than −15[dB]. Mutual coupling level at the resonant frequency can be achieved to suppressed less than −40[dB]. The cross polarization level of upper patch is about −15[dB].

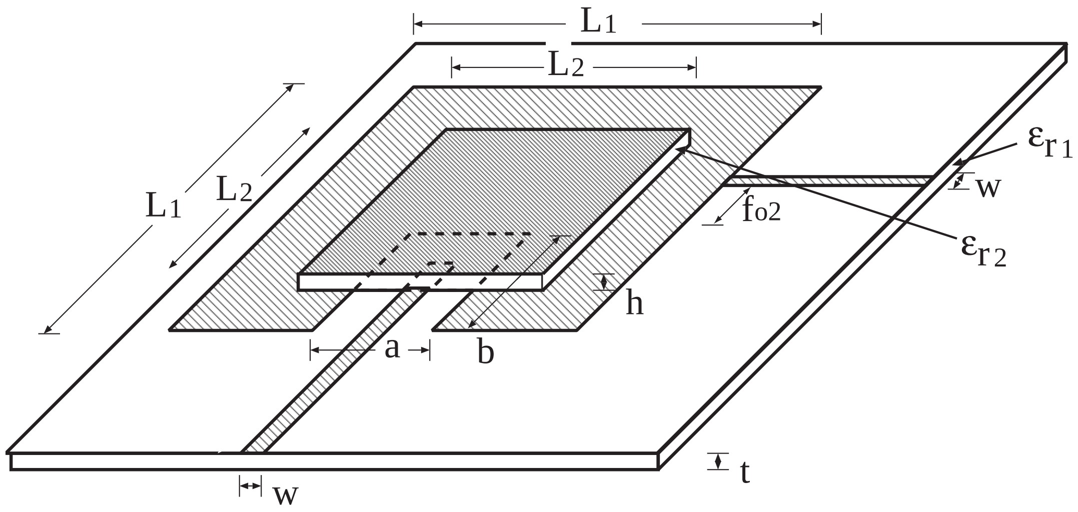


Figure 2.61: Geometry of stacked patch antenna using concave shaped patch and electormagnetic coupled patch.

(L_1=27, L_2=27, f_{o2}=0, a=13.5, b=4.5, w=4.5, t=h=1.6[mm], ε_{r1}=2.6, ε_{r2}=4.0)

To make impedance matching and also make circular polarization for the stacked antenna whose S parameter characteristics shown in Figure 2.51, offset length of feed point location for lower concave shaped patch is moved. The S parameter characteristics due to the offset length f_{o2} are shown in Figure 2.62 to 2.64. The offset length is changed from f_{o2}=0[mm] that is the middle of the lower patch edge to side of the edge.

From Figure 2.62, return loss characteristics of lower concave shaped patch (S_{11}) is affected by the offset length because of the impedance matching. The level of return loss at the resonant frequency is changed from −15[dB] to −25[dB]. The return loss characteristics of upper electromagnetic coupled patch (S_{22}) is almost same by changing the offset length as shown in Figure 2.63. The resonant frequencies of the upper and lower antenna are not changed when the offset length of lower antenna is moved.

The mutual coupling characteristics versus frequency when the offset length of lower concave shaped patch is changed is shown in Figure 2.64. The mutual coupling characteristics are few changed at the resonant frequencies of both antennas. The mutual coupling is suppressed less than −40[dB] at each offset length.

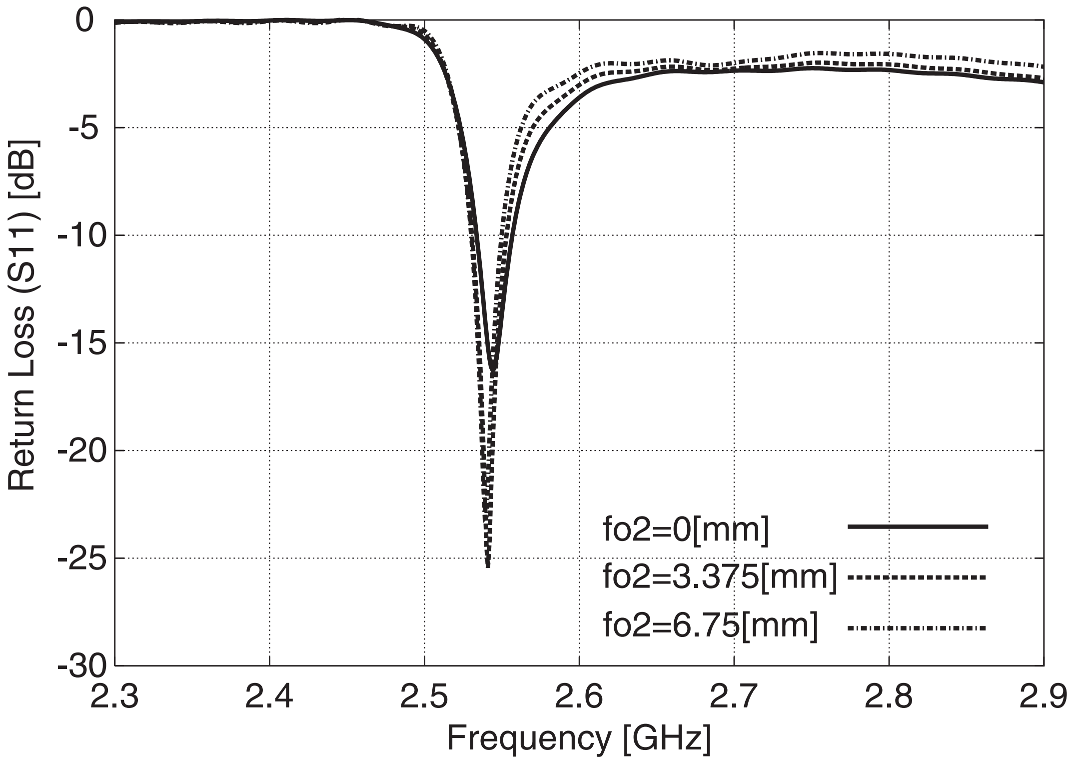


Figure 2.62: Return loss characteristics of lower antenna due to offset length f_{o2}.

(L_1=27, L_2=27, a=13.5, b=4.5, w=4.5, t=h=1.6[mm], ε_{r1}=2.6, ε_{r2}=4.0)

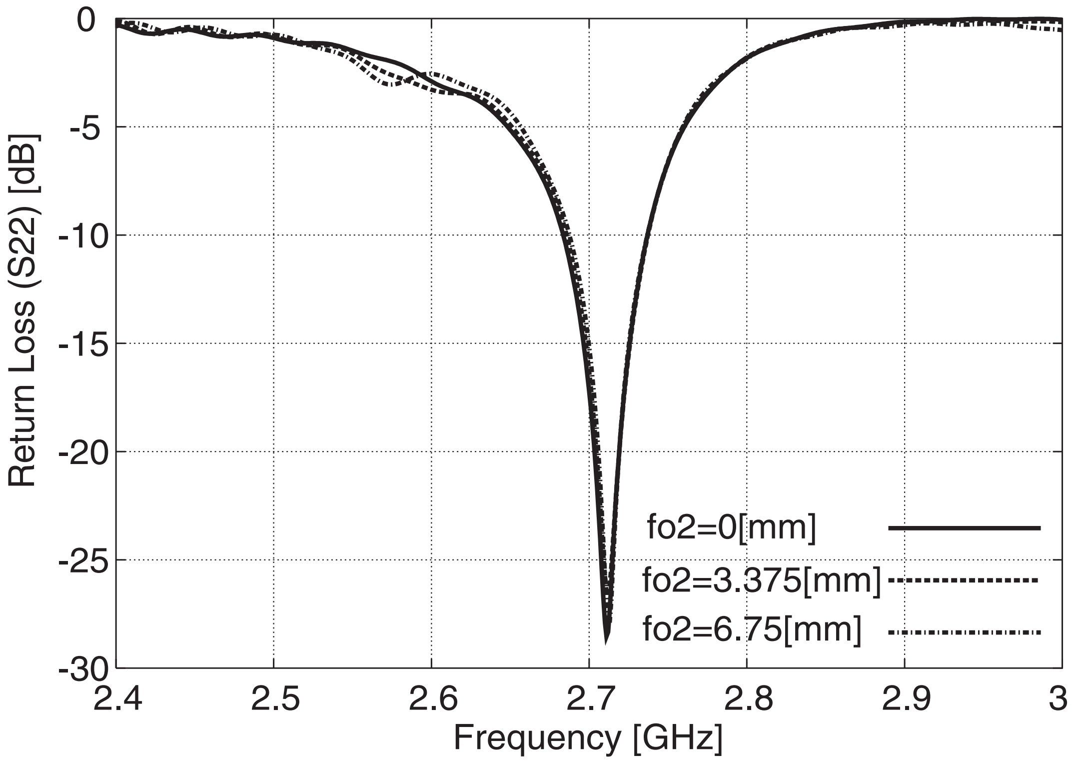


Figure 2.63: Return loss characteristics of upper antenna due to offset length f_{o2}.

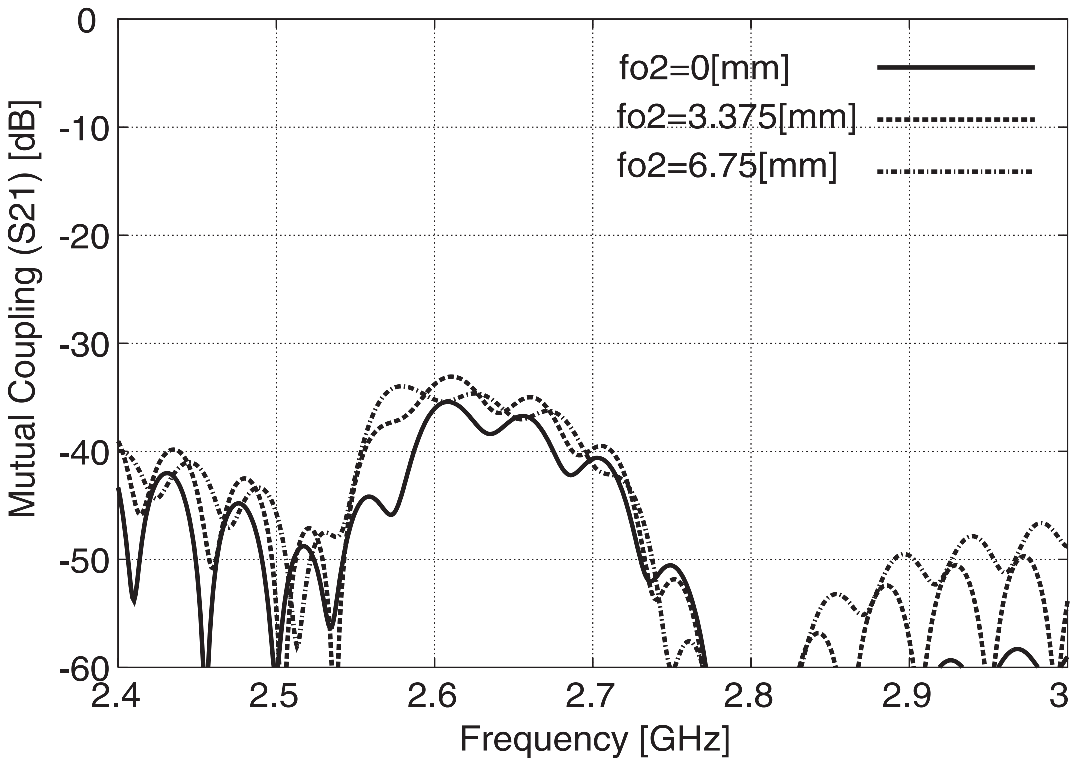


Figure 2.64: Mutual coupling characteristics due to offset length f_{o2}.

(L_1=27, L_2=27, a=13.5, b=4.5, w=4.5, t=h=1.6[mm], ε_{r1}=2.6, ε_{r2}=4.0)

The radiation pattern of the stacked patch antenna at each upper and lower resonant frequencies are shown in Figures 2.65 and 2.66. Both radiation patterns are in E-plane of each layer. The resonant frequency of the lower concave shaped patch is 2.54[GHz] and that of the upper electromagnetic coupled patch is 2.71[GHz]. At the resonant frequencies of the upper and lower antenna, we find no distortion in both radiation patterns. The level of cross polarization of lower concave shaped patch is suppressed about −30[dB] when the offset length of lower feed point location is f_{o2}=0[mm]. The cross polarization level is increase up to −18[dB] when the offset length is f_{o2}=6.75[mm]. The cross polarization level of upper patch is about −15[dB] and it's not affected by the feed point location of lower antenna. By moving the feed point location of lower antenna, current direction on the lower antenna is changed but that of upper is few influenced. However, for the radiation pattern of lower concave shaped patch, we consider that circular polarization can be achieved by the offset length of lower feed point location.

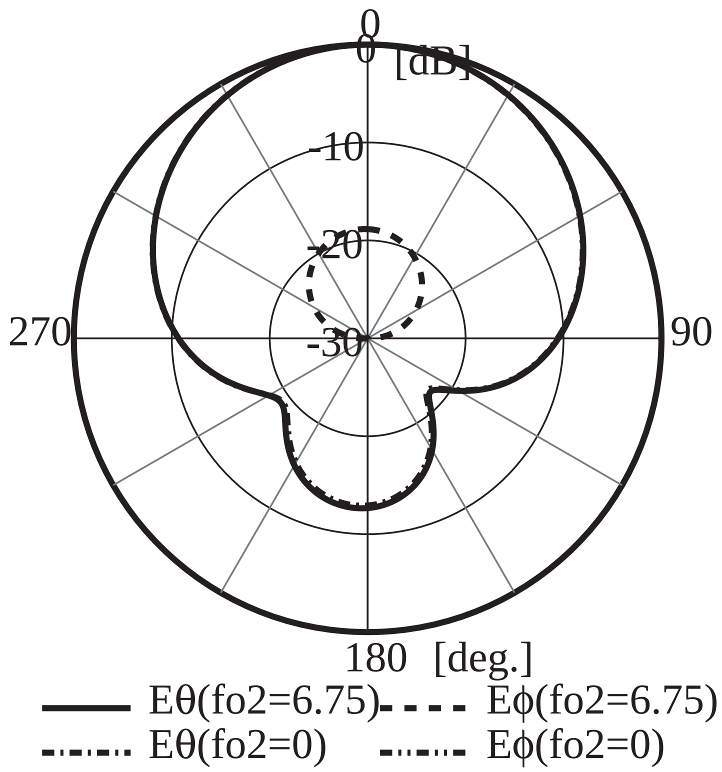


Figure 2.65: Radiation pattern of the lower concave shaped patch antenna at the resonant frequency Freq.=2.54[GHz]. (E-Plane)

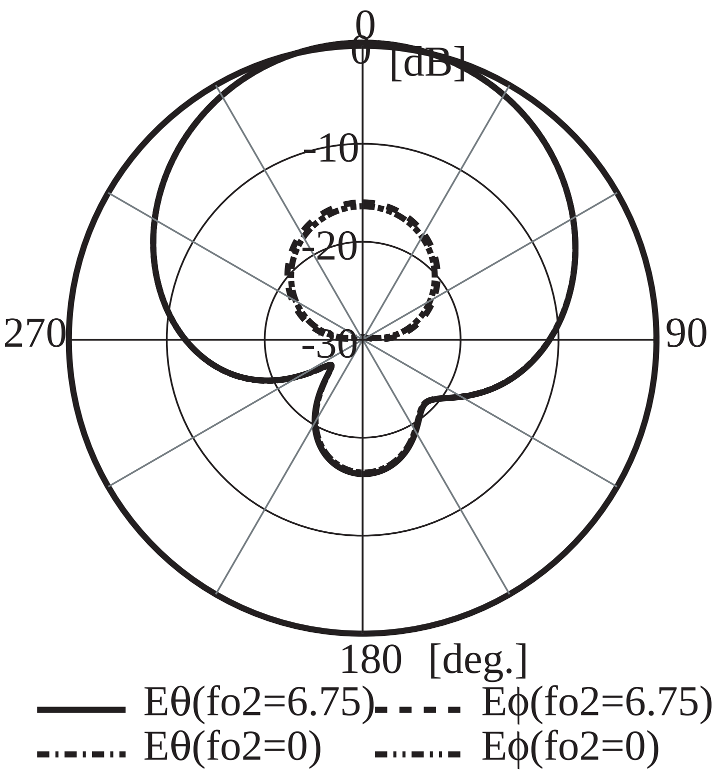


Figure 2.66: Radiation pattern of the upper electromagnetic coupled patch antenna at the resonant frequency Freq.=2.71[GHz]. (E-Plane)

2.5.2 Antenna Characteristics Due to perturbation of Upper Antenna

To make circular polarization for the stacked antenna whose S parameter characteristics shown in Figure 2.51, perturbation of upper electromagnetic couple patch is examined as shown in Figure 2.67. The S parameter characteristics due to the perturbation size p are shown in Figure 2.68 to 2.70. The perturbation size is changed from p=0[mm] that is rectangular patch.

From Figure 2.68, return loss characteristics of lower concave shaped patch (S_{11}) is affected by the perturbation size of upper antenna. The return loss characteristics of upper electromagnetic coupled patch (S_{22}) is also affected by changing the perturbation size as shown in Figure 2.69. There is a mutual coupling between both antennas, so perturbation has influence on not only upper antenna but also lower antenna.

The mutual coupling characteristics versus frequency when the perturbation size of upper patch is changed is shown in Figure 2.70. The mutual coupling at the resonant frequency of upper antenna is increase by the perturbation. However, the level of mutual coupling is suppressed less than -30[dB]. The mutual coupling at the resonant frequency of lower antenna is suppressed less than -40[dB].

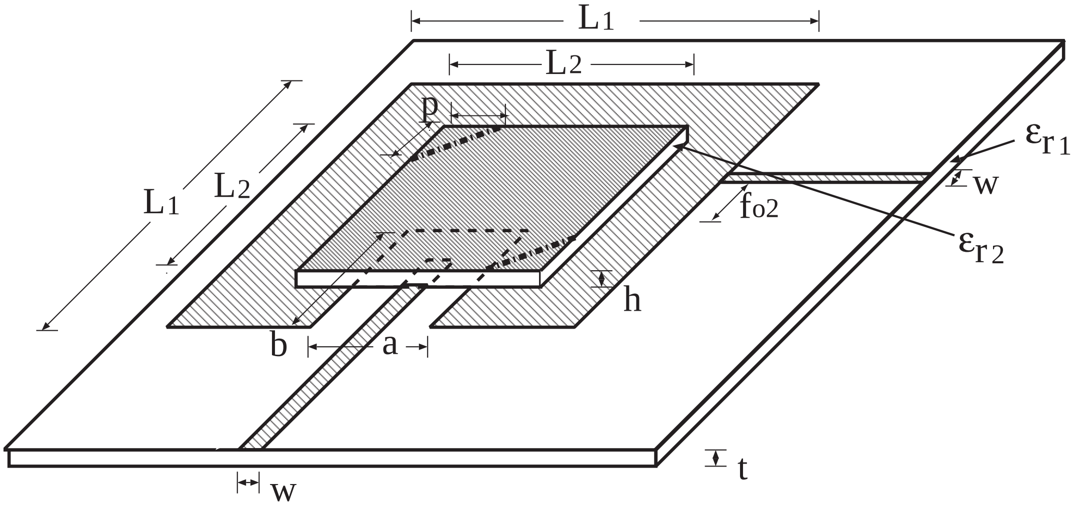


Figure 2.67: Geometry of stacked patch antenna using concave shaped patch and electormagnetic coupled patch.

(L_1=27, L_2=27, f_{o2}=0, a=13.5, b=4.5, w=4.5, t=h=1.6[mm], ε_{r1}=2.6, ε_{r2}=4.0)

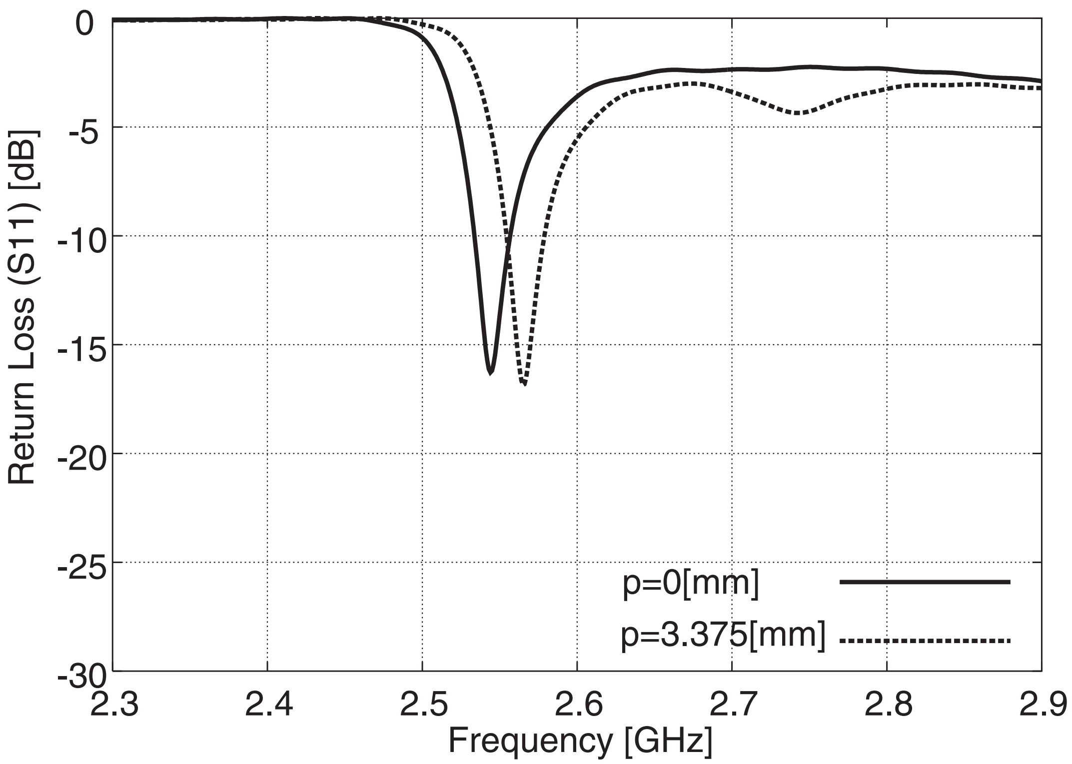


Figure 2.68: Return loss characteristics of lower antenna due to perturbation size p.

(L_1=27, L_2=27, f_{o2}=0, a=13.5, b=4.5, w=4.5, t=h=1.6[mm], ε_{r1}=2.6, ε_{r2}=4.0)

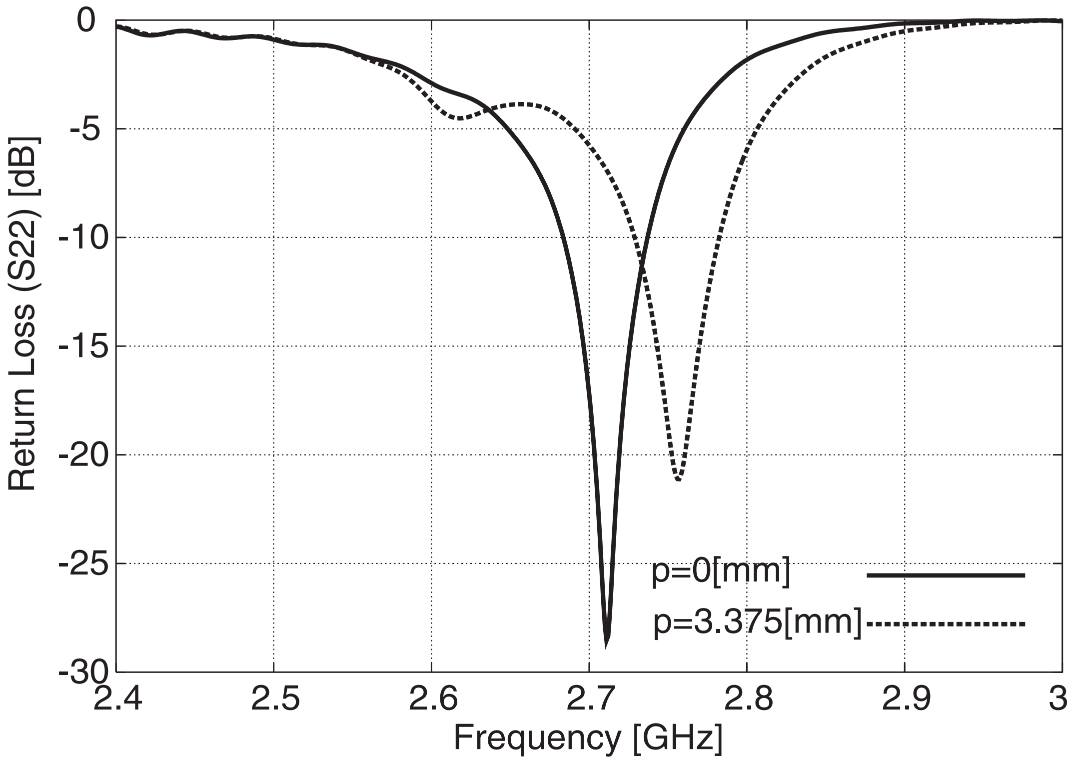


Figure 2.69: Return loss characteristics of upper antenna due to perturbation size p.

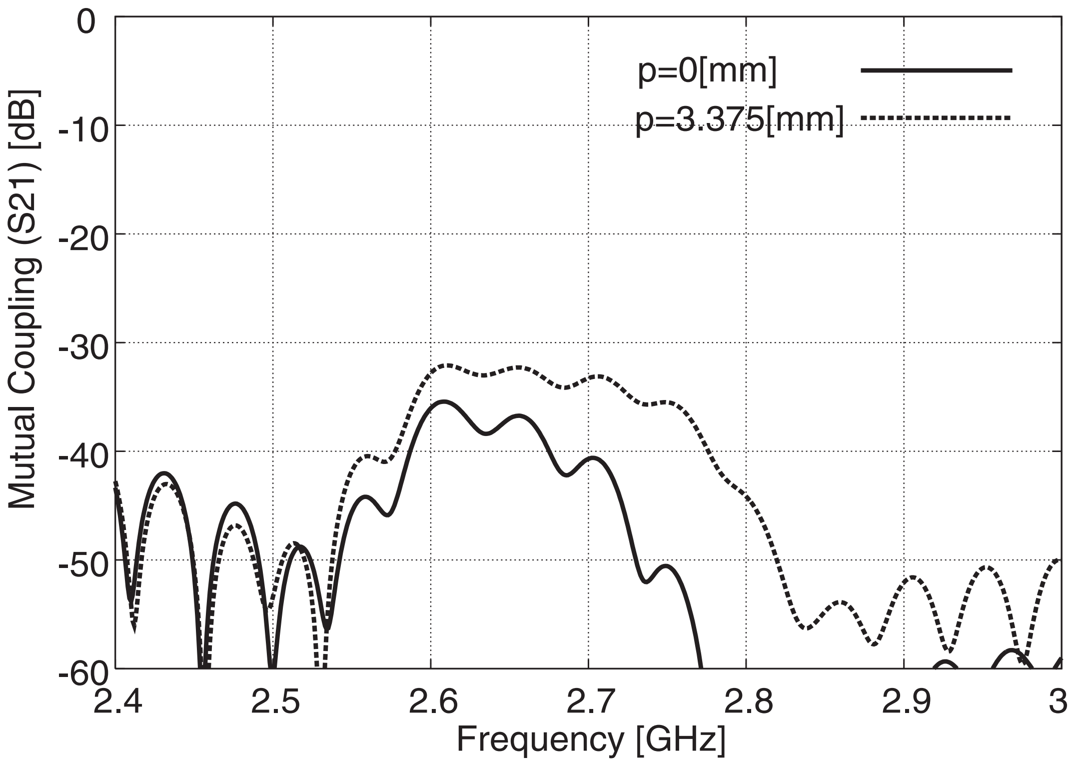


Figure 2.70: Mutual coupling characteristics due to perturbation size p.

(L_1=27, L_2=27, f_{o2}=0, a=13.5, b=4.5, w=4.5, t=h=1.6[mm], ε_{r1}=2.6, ε_{r2}=4.0)

The radiation pattern of the stacked patch antenna at each upper and lower resonant frequencies are shown in Figures 2.71 and 2.72. Both radiation patterns are in E-plane of each layer. At the resonant frequencies of the upper and lower antenna, we find no distortion in both radiation patterns. The level of cross polarization of lower concave shaped patch is suppressed about −30[dB] when the perturbation size of upper patch is p=0[mm]. The cross polarization level is increase up to −11[dB] when the perturbation size is p=3.375[mm]. The cross polarization level of upper patch is about −15[dB] when the perturbation size p=0[mm], and the level is increased up to −5[dB] when the perturbation size is p=3.375[mm]. By making the perturbation of upper antenna, resonance of current is changed. The cross polarization goes up about 10[dB]. By choosing the perturbation parameter of this antenna, circular polarization at both resonant frequencies can be achieved.

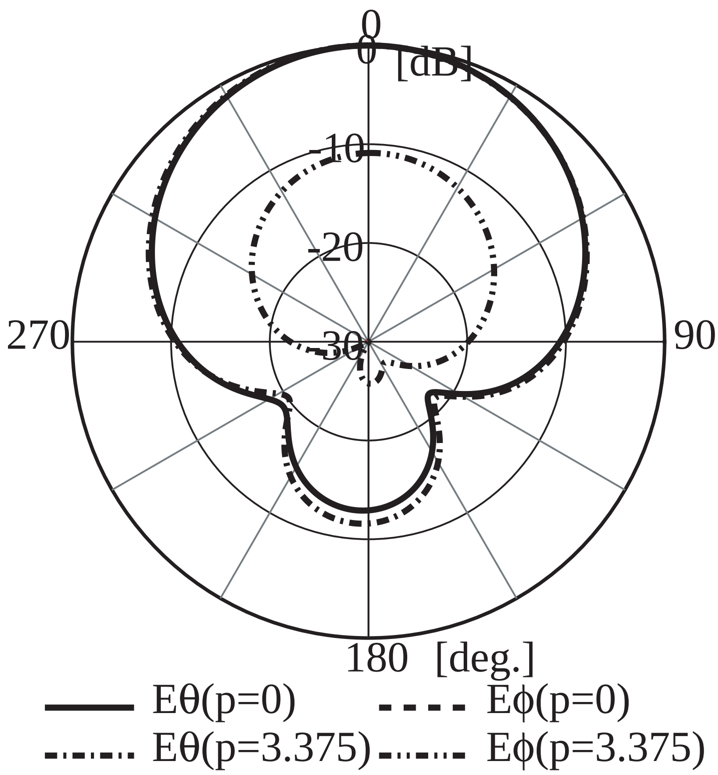


Figure 2.71: Radiation pattern of the lower concave shaped patch antenna at the lower resonant frequency. (E-Plane)

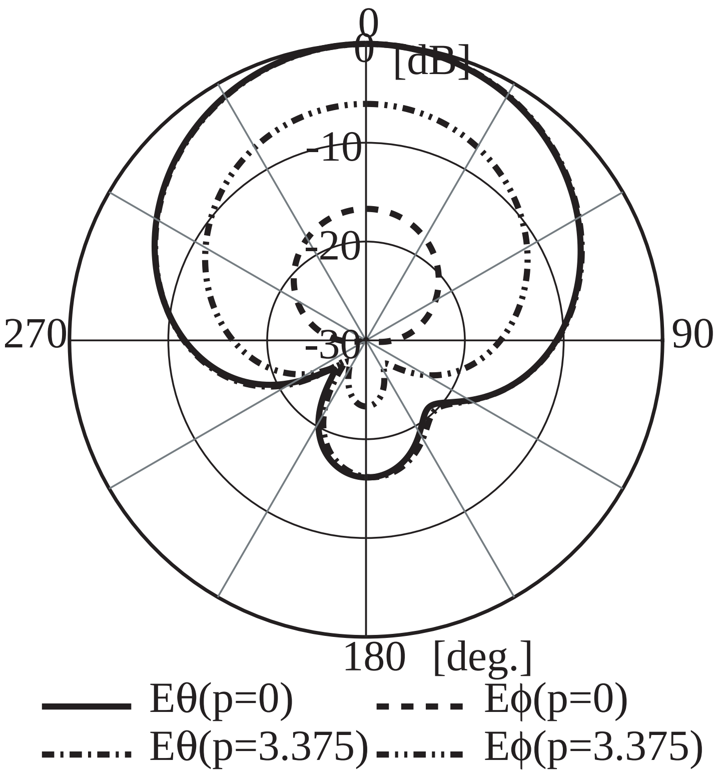


Figure 2.72: Radiation pattern of the upper electromagnetic coupled patch antenna at the higher resonant frequency. (E-Plane)

2.5.3 Conclusion

In this section, we presented stacked antenna which consists of an electromagnetic coupled patch as the upper antenna and a concave shaped patch antenna as the lower antenna. The upper patch antenna is excited by electromagnetic coupling by using slit part of the lower patch. We simulated the S parameter characteristics and radiation pattern by FDTD method.

By moving the feed point location of lower antenna and making perturbation on the upper antenna, antenna characteristics are examined. Proposed antenna structure suppress the mutual coupling between upper and lower antenna less than −30[dB] at each resonant frequency. This antenna can be circular polarized.

2.6 Conclusion

In this chapter, we proposed two types of the stacked antenna which are improved on easy manufacturing from using ring patch which has shorted part.

One is the two-layer antenna which consists of a patch as the upper antenna and a rectangular patch antenna with a hole as the lower antenna. Another one is the stacked antenna which consists of an electromagnetic coupled patch as the upper antenna and a patch antenna with one or two slit(s) as the lower antenna. We simulated the S parameter characteristics and radiation pattern.

First, we presented the patch antenna with a hole instead of ring patch, and the hybrid antenna using rectangular patch with a hole is examined. From the mutual coupling characteristics, both antennas are operated independently at both resonant frequencies by using patch with a hole. Patch with a hole can be used instead of ring patch by the antenna structure.

Next, we proposed the two-layer antenna which consists of a patch as the upper antenna and a rectangular patch antenna with a hole as the lower antenna. Our proposed self-diplexing antenna structure suppress the mutual coupling between upper and lower antenna less than -25[dB] by using patch with a hole. The cross polarization level is suppressed less than -20[dB].

And, we proposed the stacked antenna which consists of an electromagnetic coupled patch as the upper antenna and a patch antenna with one or two slit(s) as the lower antenna. Our proposed antenna structure suppress the mutual coupling between upper and lower antenna less than -40[dB]. By using patch with two slits, the cross polarization level is suppressed less than -20[dB].

In the Last, for the application of self-diplexing antenna, circular polarization is considered for the previous proposed two-layer dual polarized antenna which has linear polarization. By making perturbation on the upper patch and moving the feed point location of lower antenna, circular polarization can be achieved.

Chapter 3

Two-Layer Antenna with Dual Frequency

This chapter presents a two-layered antenna with dual frequency for indoor micro cellular system. It consists of an upper rectangular or loop element and a lower center feed rectangular patch antenna, that is low profile top loaded monopole antenna. FDTD analysis shows that this antenna has two resonant frequencies and the radiation patterns are similar to monopole antenna.

3.1 Introduction

For IMT-2000, the mobile telephone should also be available for the blind area from the terrestrial base stations. Inside large building and underground shopping center, a booster system or the micro cellular system supplements the terrestrial service. The frequency in Japanese cellular syster are 800[MHz] and 1.5[GHz], and the frequency for IMT-2000 is 2.0[GHz]. To minimize the size of indoor base station antenna or exchange the present system, a dual frequency antenna is necessary.

To achieve the miniaturization of the antenna, not only the additional function, like dual frequency, but also the smaller size of included antenna is effective. To reduce the antenna size, one parameter is the height. Instead of using monopole antenna, it has already considered inverted L antenna, inverted F antenna, disc loaded monopole antenna, and so on for miniatuarizing the antenna's height. From the impedance characteristics, top loaded monopole antenna has matching element for impedance matching.

Since the antenna for the indoor system is installed on the ceiling, the radiation pattern like monopole antenna is required. Therefore, this chapter proposes a novel two-layered dual frequency antenna which consists of rectangular of loop element and top loaded monopole antenna for each layer and presents FDTD simulation results of the proposed antenna.

3.2 Antenna Geometry

Figure 3.1 shows the two-layered antenna which has two resonant frequencies. This antenna consists of an upper rectangular element and a lower rectangular patch antenna with center feed probe and two bent matching posts instead of using short pin for miniaturized. This antenna is mounted on the ground plane whose size is 50 $\times$ 50[mm]. The size of upper rectangular element is $L \times L$. This upper element is connected to the lower patch antenna by a short pin at the center like center feed probe. For the FDTD analysis, stairs approximation is used to configure the upper layer. The size of lower rectangular patch antenna is $R \times R$. The lower rectangular patch antenna is also considered as a low profile disk loaded monopole antenna. Figure 3.2 shows the geometry of only lower antenna which is low profile top loaded antenna.

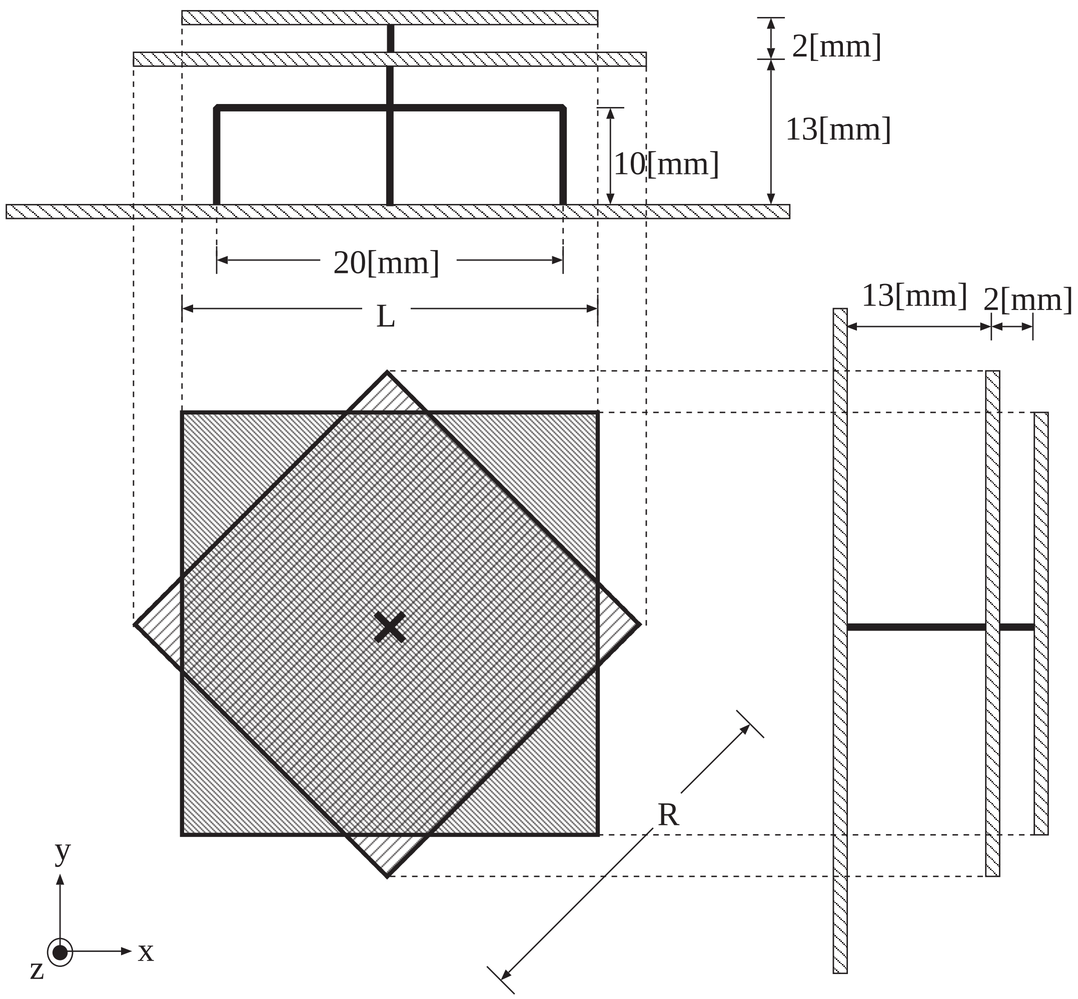


Figure 3.1: Geometry of two-layered antenna with dual frequency. (upper layer : rectangular element, lower layer : patch)

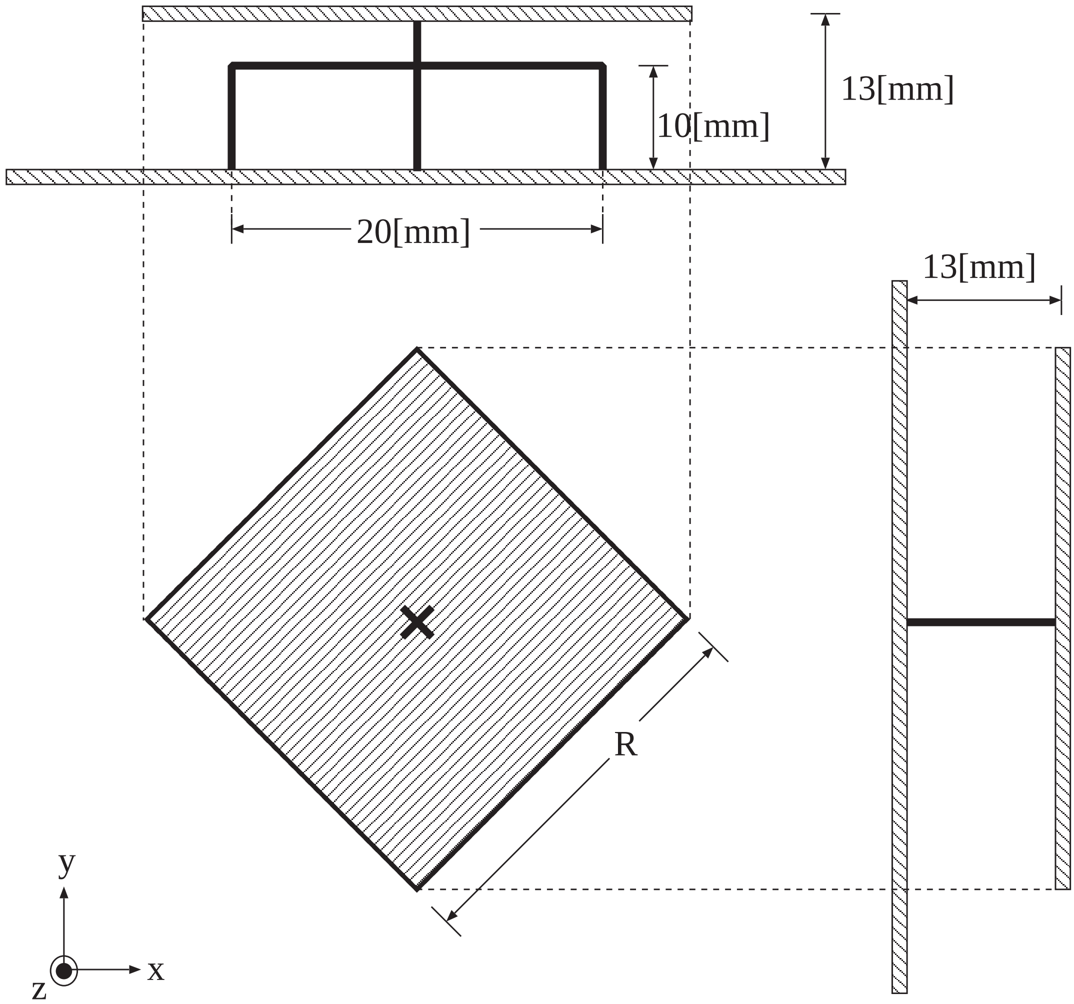


Figure 3.2: Geometry of low profile disk loaded monopole antenna.

Table 3.1: Parameters for FDTD analysis.

Computation space	80 × 80 × 55[cell]
Cell size (uniform mesh)	$\Delta x = \Delta y = \Delta z$=1[mm]
Iteration	12000 steps
Incident wave	Gaussian pulse
Absorbing Boundary Condition	PML A.B.C. 8layer

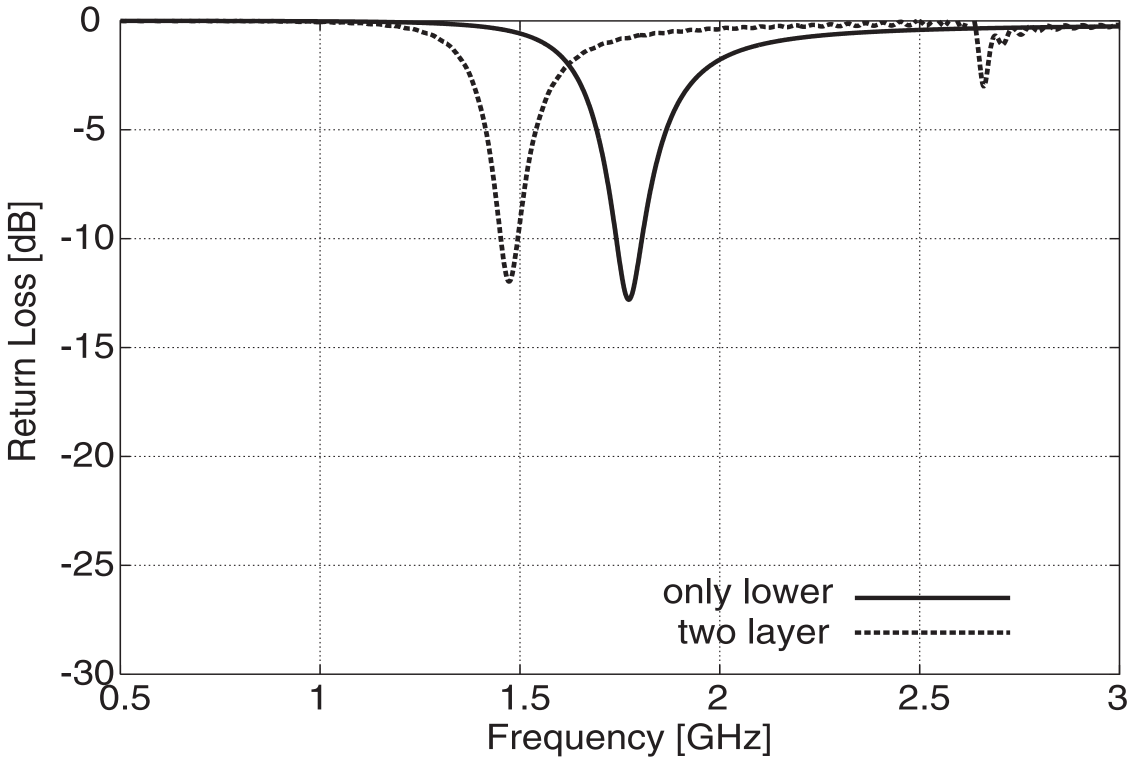
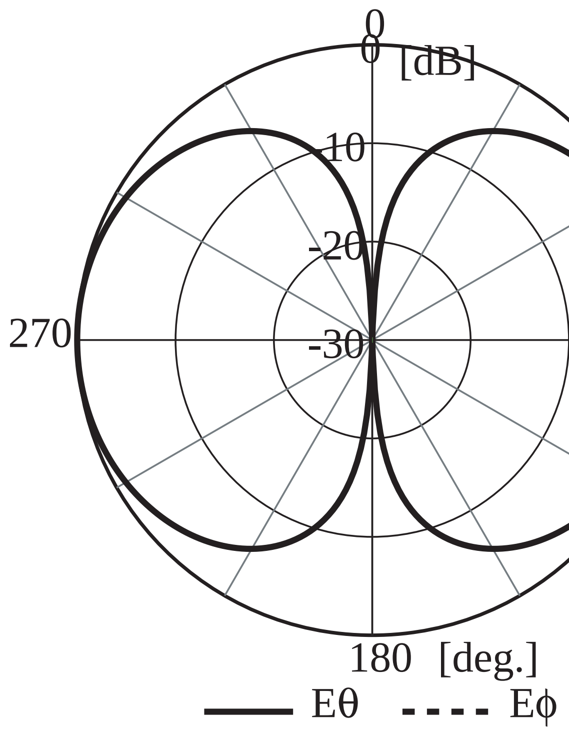


Figure 3.3: Return loss characteristics per structure. (size of upper rectangle is L=24 × 24[mm] and that of lower patch is R=21 × 21[mm])

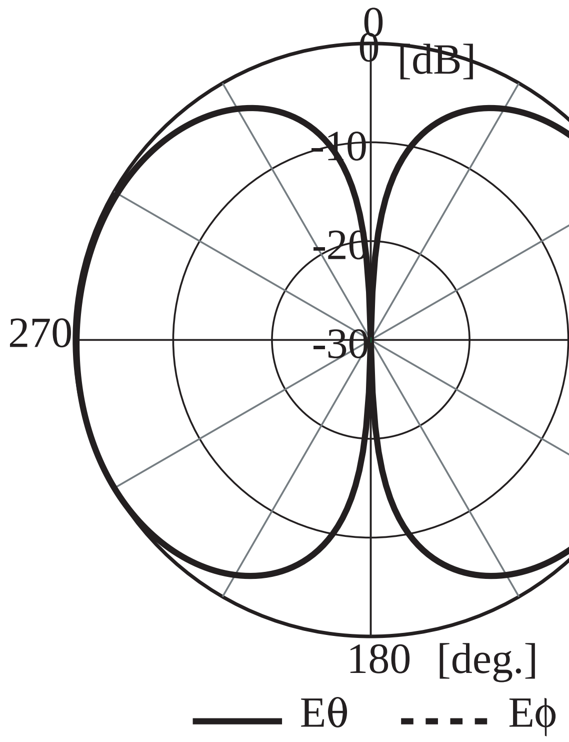
In the first step, we simulated the two-layered antenna and the lower rectangular patch only to find the effect of upper rectangular element. We simulated this two-layered antenna by using FDTD method. In this FDTD simulation, we used the analysis parameters as shown in Table 3.1.

Figure 3.3 shows the return loss characteristics per antenna structure by the FDTD simulation. The resonant frequency of the lower patch only is 1.77[GHz], however, the two-layered antenna has two resonant frequencies of 1.47[GHz] and 2.66[GHz].

Figures 3.5 and 3.4 show the FDTD simulation results of the radiation patterns of vertical plane (zx-plane) at each resonant frequencies of low profile disk loaded monopole antenna and two-layered antenna. From these figures, we find that the radiation patterns at each resonant frequency are similar to monopole antenna. The cross polarizations are suppressed less than -30[dB] at each resonant frequencies.



(a) Freq. = 1.47[GHz]



(b) Freq. = 2.66[GHz]

Figure 3.4: Radiation pattern of two-layered antenna. (zx-plane. size of upper patch is L=24 × 24[mm] and that of lower patch is R=21 × 21[mm])

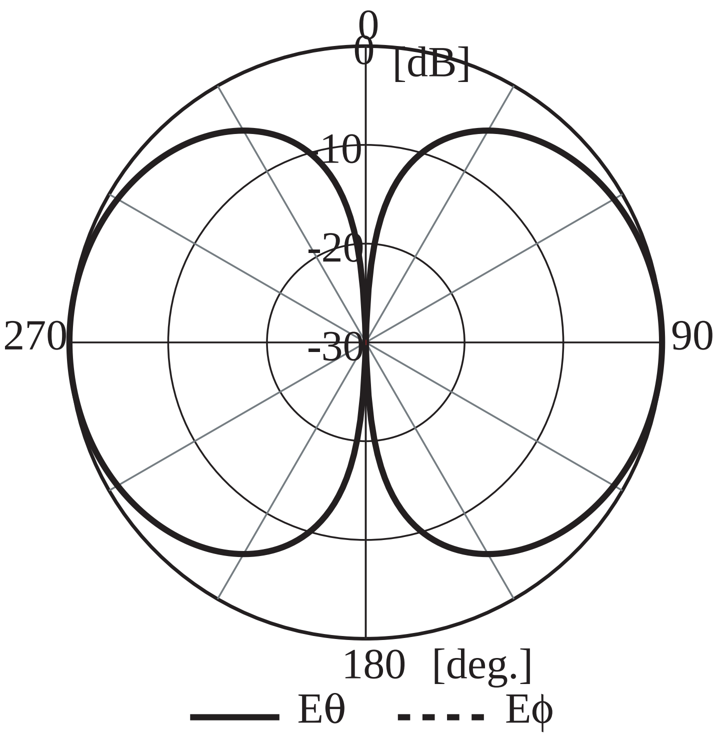
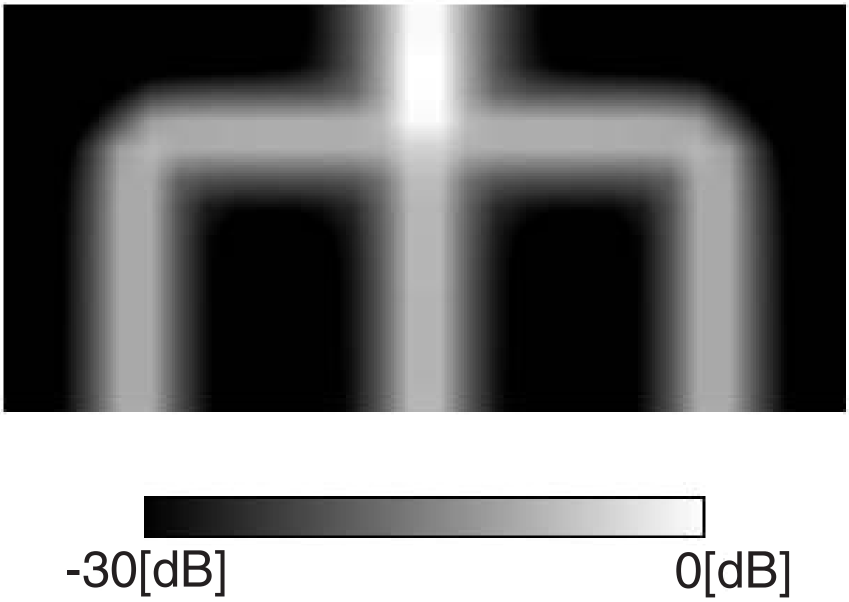
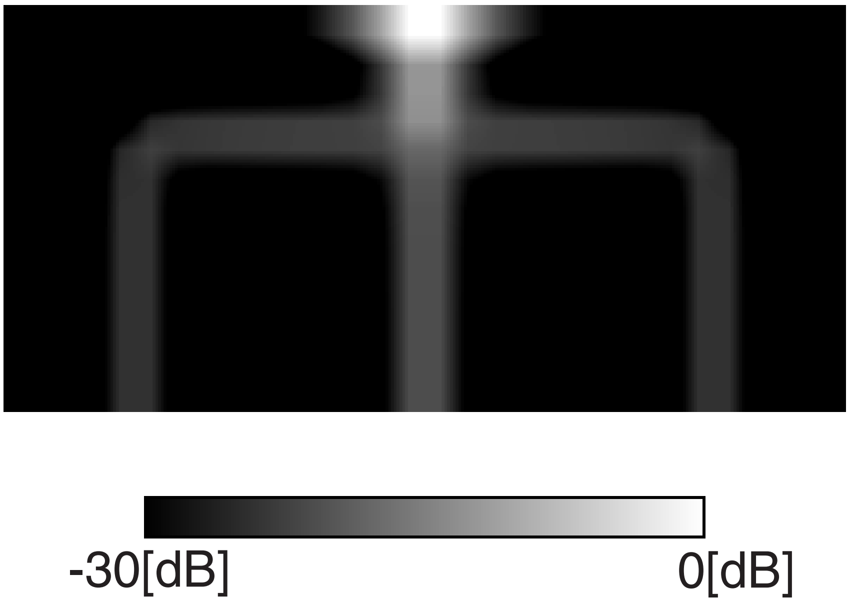


Figure 3.5: Radiation pattern of low profile disk loaded monopole antenna. (zx-plane. size of patch is R=21 × 21[mm])

The current distribution on the feed probe and matching posts are shown in Figures 3.6 and 3.7. From Figure 3.7, the strong current can be seen at the feed probe of disk loaded monopole antenna. Then this antenna has radiation characteristics like monopole antenna. When the resonant frequency of two-layered antenna is 1.47[GHz], the strong current can be seen at the feed probe and the connection pin between upper and lower layer as shown in Figure 3.6. The current is strong at the connection pin when the resonant frequency is 2.66[GHz]. The length of strong current is changed by the geometry, so the resonant frequency of the antenna is changed to higher or lower frequency. And this antenna also has radiation characteristics like monopole antenna.



(a) Freq. = 1.47[GHz]



(b) Freq. = 2.66[GHz]

Figure 3.6: Current distribution of two-layered antenna. (zx-plane. size of upper layer is L=24 × 24[mm] and that of lower layer is R=21 × 21[mm])

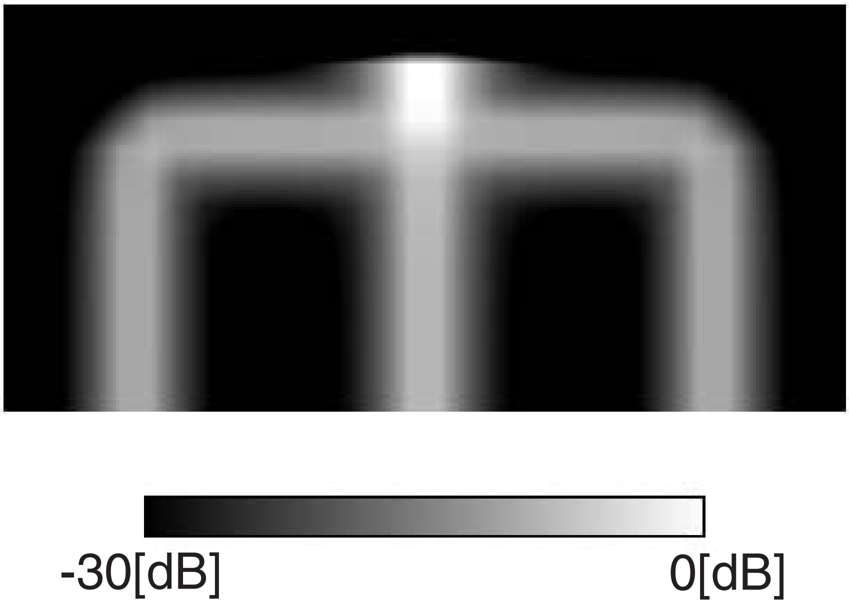


Figure 3.7: Current distribution of low profile disk loaded monopole antenna. (zx-plane. size of patch is R=21 $\times$ 21[mm])

By using rectangular element for upper layer of the two-layered antenna, the resonant frequencies are 1.47[GHz] and 2.66[GHz] as shown in Figure 3.3. However, the required resonant frequencies of this dual frequency antenna are around 1.5[GHz] and 2.0[GHz]. To make the second resonant frequency to lower frequency, the geometry of this antenna is changed. From the current distribution of second resonant frequency shown in Figure 3.6, the current is only strong at the connection between upper and lower layer. It seems as one of low profile disk loaded monopole antenna. By changing the electrical size of upper rectangle bigger, the second resonant frequency will be moved lower frequency.

Figure 3.8 shows the two-layered antenna which has two resonant frequencies. This antenna consists of an upper loop element instead of using rectangular element for miniaturization and a lower rectangular patch antenna with center feed probe and two bent matching posts. This antenna is mounted on the ground plane whose size is 50 $\times$ 50[mm]. The size of upper loop element is $L \times L$ and the width of loop is 2[mm]. This upper element is connected to the lower patch antenna by a short pin. The size of lower rectangular patch antenna is $R \times R$.

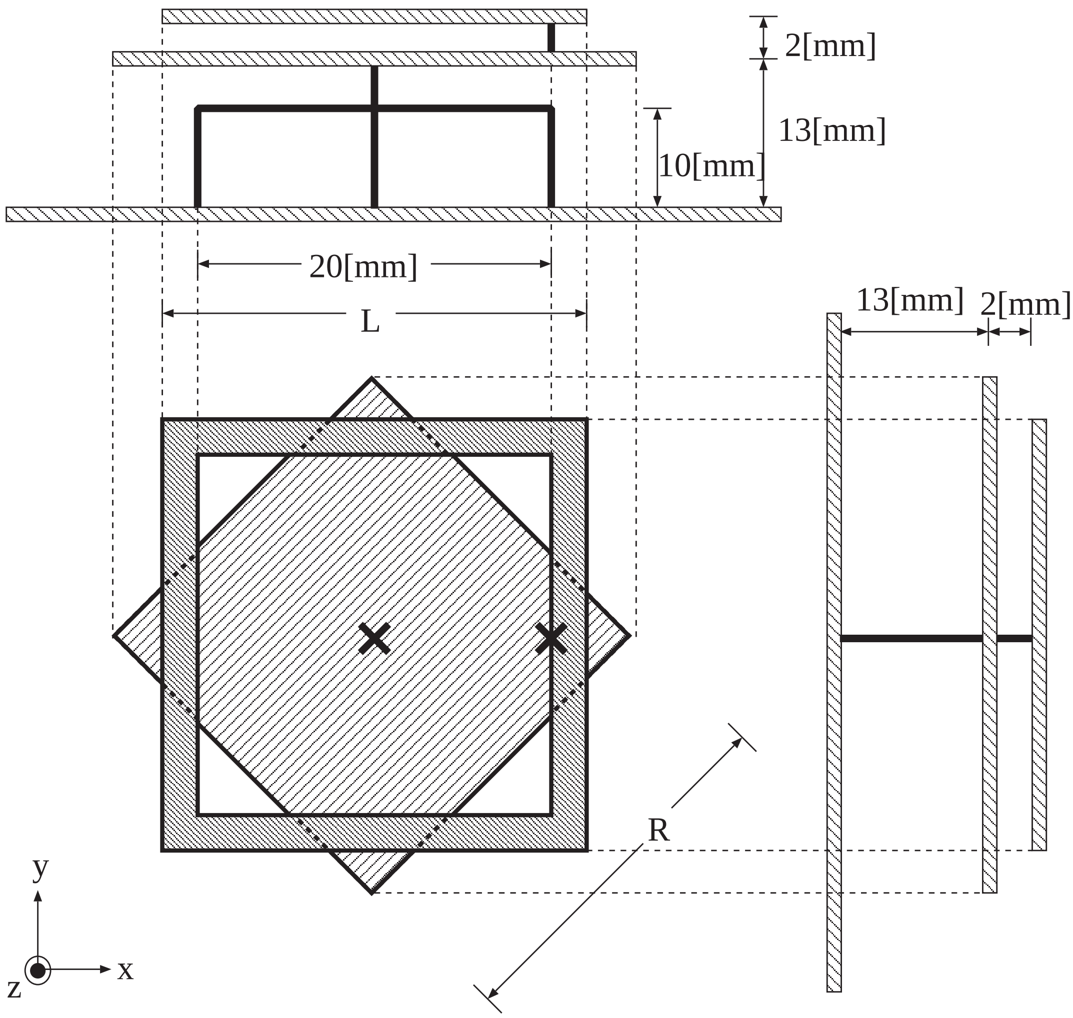


Figure 3.8: Geometry of two-layered antenna with dual frequency. (upper layer : loop element, lower layer : patch)

Figure 3.9 shows the return loss characteristics per upper antenna structure by the FDTD simulation. The resonant frequencies of the two-layered antenna using rectangular element for upper layer are 1.47[GHz] and 2.66[GHz]. On the other hand, the two-layered antenna using loop for upper layer has two resonant frequencies of 1.36[GHz] and 2.05[GHz]. By using loop element instead of patch antenna for upper layer, the length of current resonance becomes longer and the resonant frequency move to lower frequency.

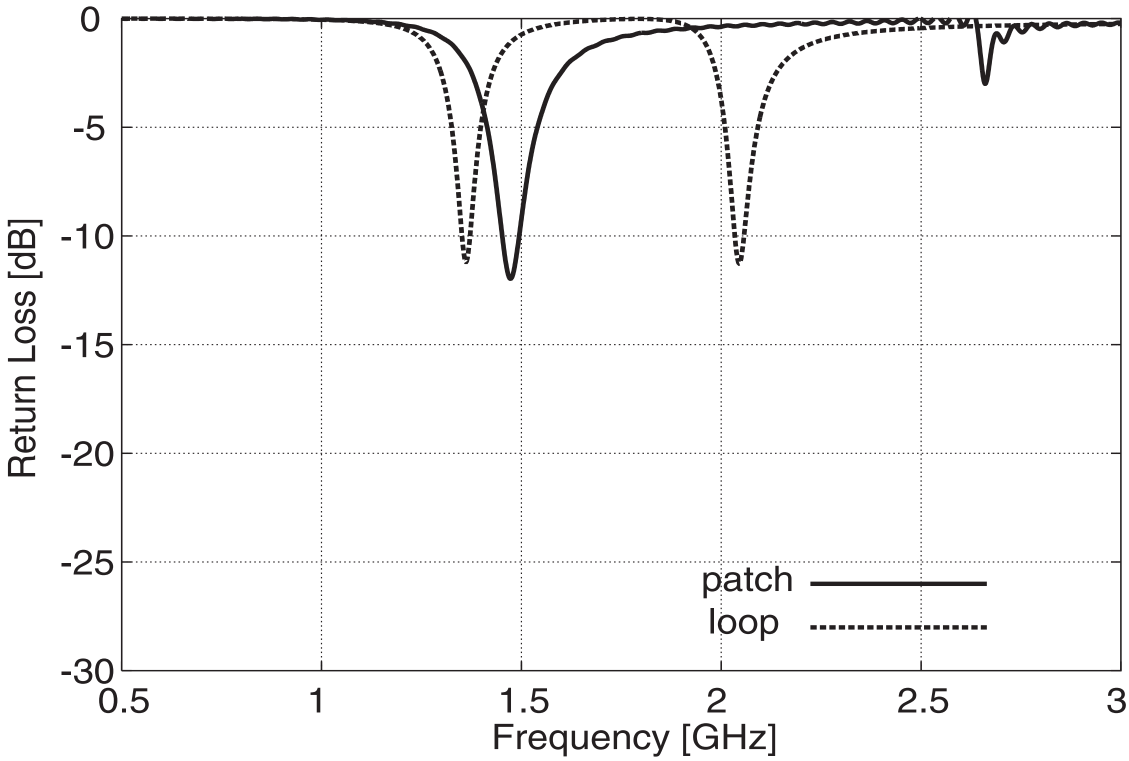
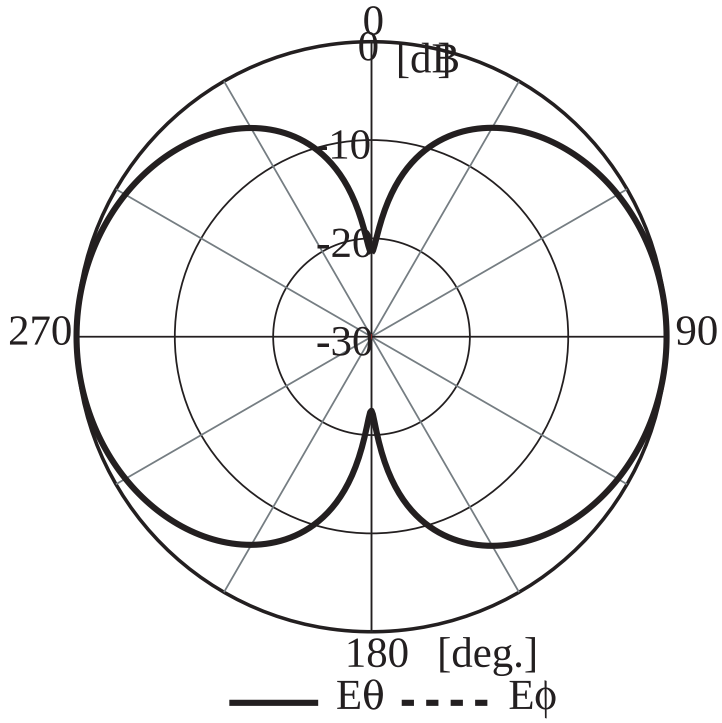


Figure 3.9: Return loss characteristics per structure of upper antenna. (size of upper loop is L=24 × 24[mm] and that of lower patch is R=21 × 21[mm])

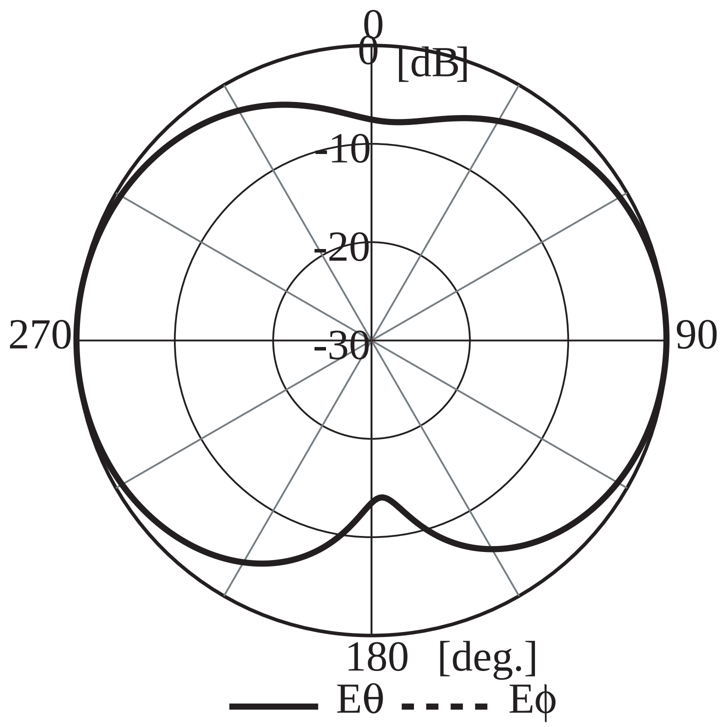
Figure 3.10 shows the FDTD simulation results of the radiation patterns of vertical plane (zx-plane) at two resonant frequencies of two-layered antenna using loop for upper layer. From these figures, we find that the radiation pattern at first resonant frequency is similar to monopole antenna. The cross polarizations are suppressed less than -30[dB] at each resonant frequencies.

On the other hand, the radiation pattern at the second resonant frequency is changed from the pattern of monopole antenna. This is because the connection pin can not be made at the center of upper antenna when using loop element instead of rectangular element. So, the current distribution on the upper layer is changed and the radiation pattern becomes similar to patch antenna from monopole antenna. This radiation pattern is similar when using rectangular element for upper layer and moving the connection pin at the same location of using loop element. However, the radiation pattern at the second resonant frequency is still similar to monopole antenna.

The current distribution on the feed probe and matching posts of two-layered antenna using loop element for upper antenna are shown in Figure 3.11. From Figure 3.11, the strong current can be seen at the feed probe and the connection pin between upper and lower layer.

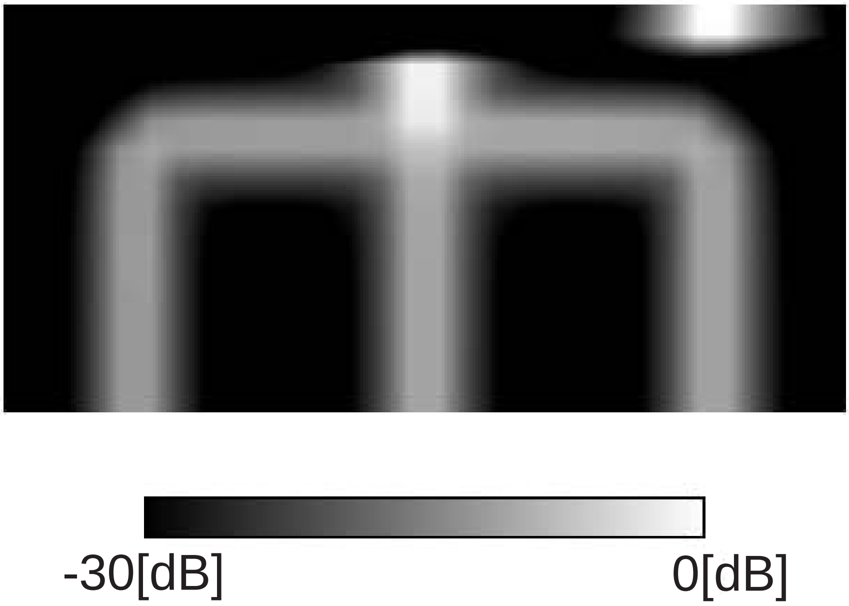


(a) Freq. = 1.36[GHz]

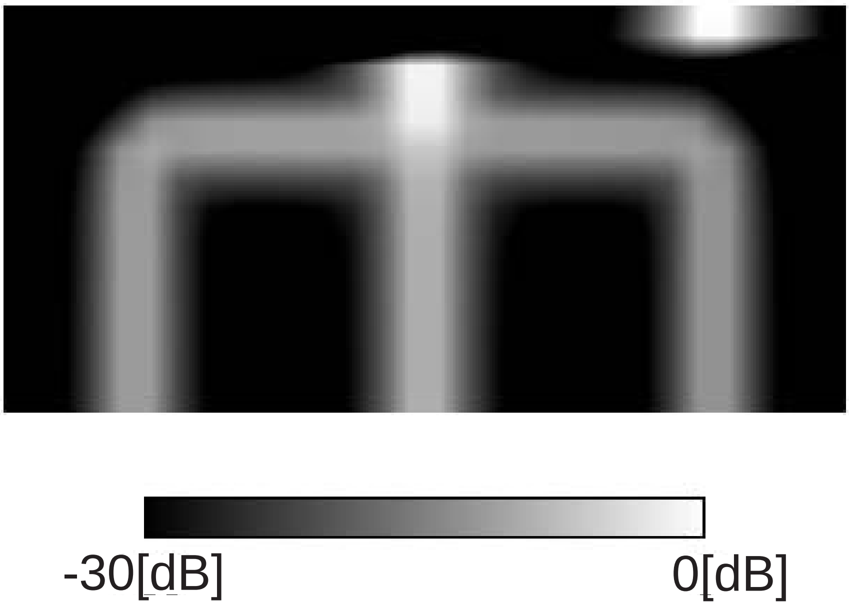


(b) Freq. = 2.05[GHz]

Figure 3.10: Radiation pattern of two-layered antenna. (zx-plane. size of upper loop is L=24 × 24[mm] and that of lower patch is R=21 × 21[mm])



(a) Freq. = 1.36[GHz]



(b) Freq. = 2.05[GHz]

Figure 3.11: Current distribution of two-layered antenna. (zx-plane. size of upper loop is L=24 × 24[mm] and that of lower patch is R=21 × 21[mm])

3.3 Antenna Characteristics of Two-Layered Antenna

3.3.1 Input Characteristics Due to Upper Loop Element

Figure 3.12 shows the Return Loss characteristics by varying the loop length L. When the size of upper loop element ($L \times L$) becomes larger, the first and second resonant frequencies go down to lower frequency. For example, when the loop element length L is 20[mm], the first resonant frequency is 1.56[GHz] and the second resonant frequency is 2.21[GHz]. The first resonant frequency is 1.18[GHz] and the second resonant frequency is 1.98[GHz] for loop length L of 28[mm]. The loop length L changes the both resonant modes. When the width of loop element is changed, that is when the hole size of loop is changed, both resonant frequencies is also changed, because the current length is changed, same as changing the loop size. This loop element is assumed to give a perturbation to separate the degenerated mode.

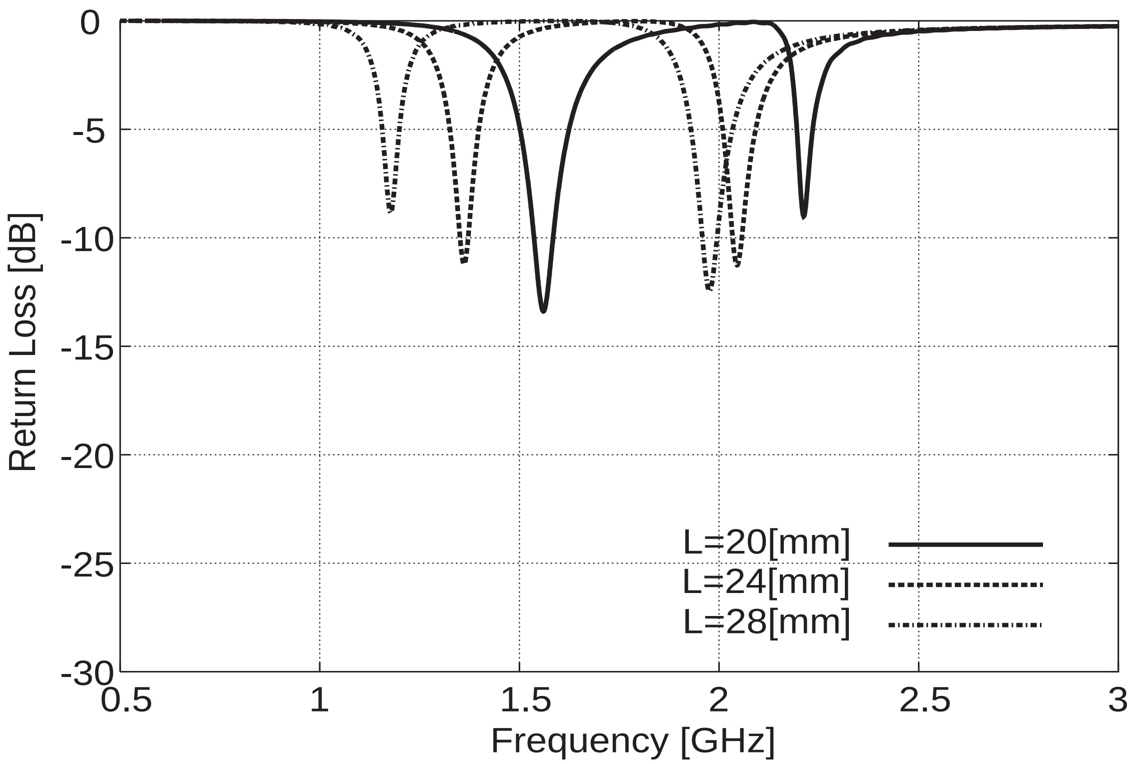


Figure 3.12: Return loss characteristics per loop element length L. (size of lower patch is R=21 $\times$ 21[mm])

3.3.2 Input Characteristics Due to Lower Patch Antenna

Figure 3.13 shows the Return Loss characteristics by varying the patch size R. When the size of lower rectangular patch antenna ($R \times R$) becomes larger, the first resonant frequency is not changed. On the other hand, for the large lower patch, the second resonant frequency goes down and the return loss level is also changed. For example, when the rectangular patch length R is 18[mm], the second resonant frequency is 2.26[GHz] and the return loss level is -16.5[dB]. And when the patch length R is 24[mm], the second resonant frequency goes down to 1.89[GHz] and the return loss level is -8.4[dB]. Therefore, we find that the lower rectangular patch antenna dominates the second resonant frequency.

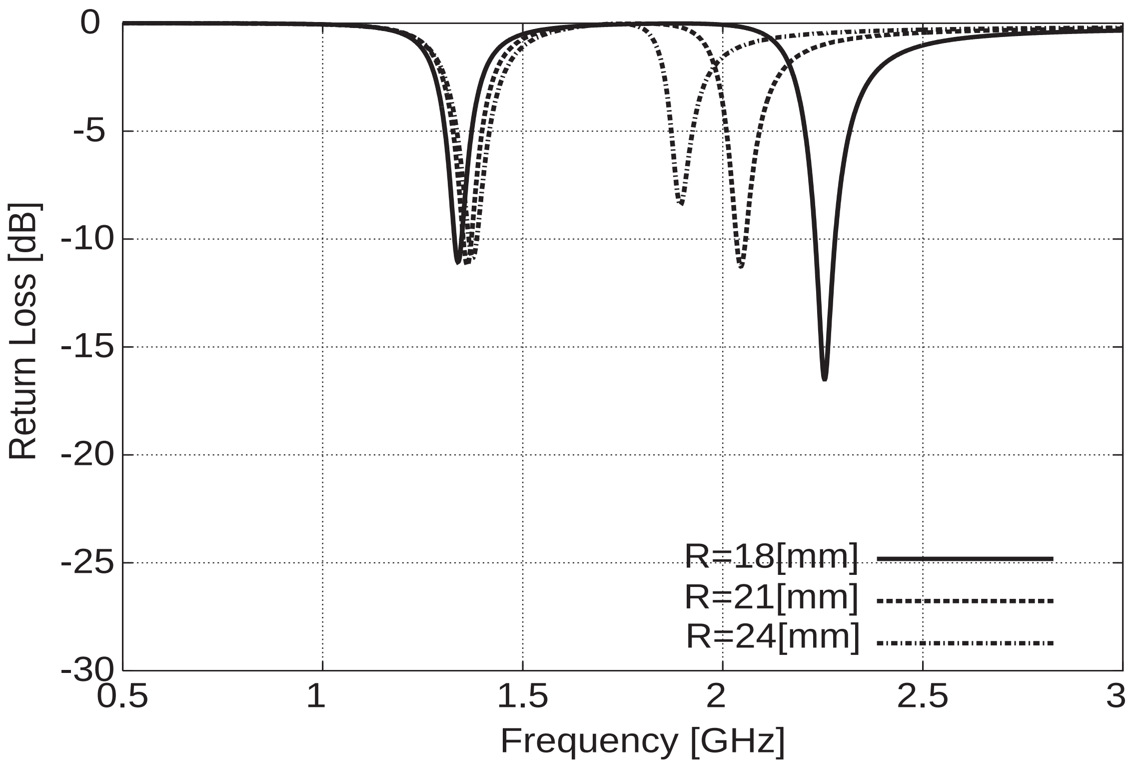


Figure 3.13: Return loss characteristics per rectangular patch length R. (size of upper loop is L=24 $\times$ 24[mm])

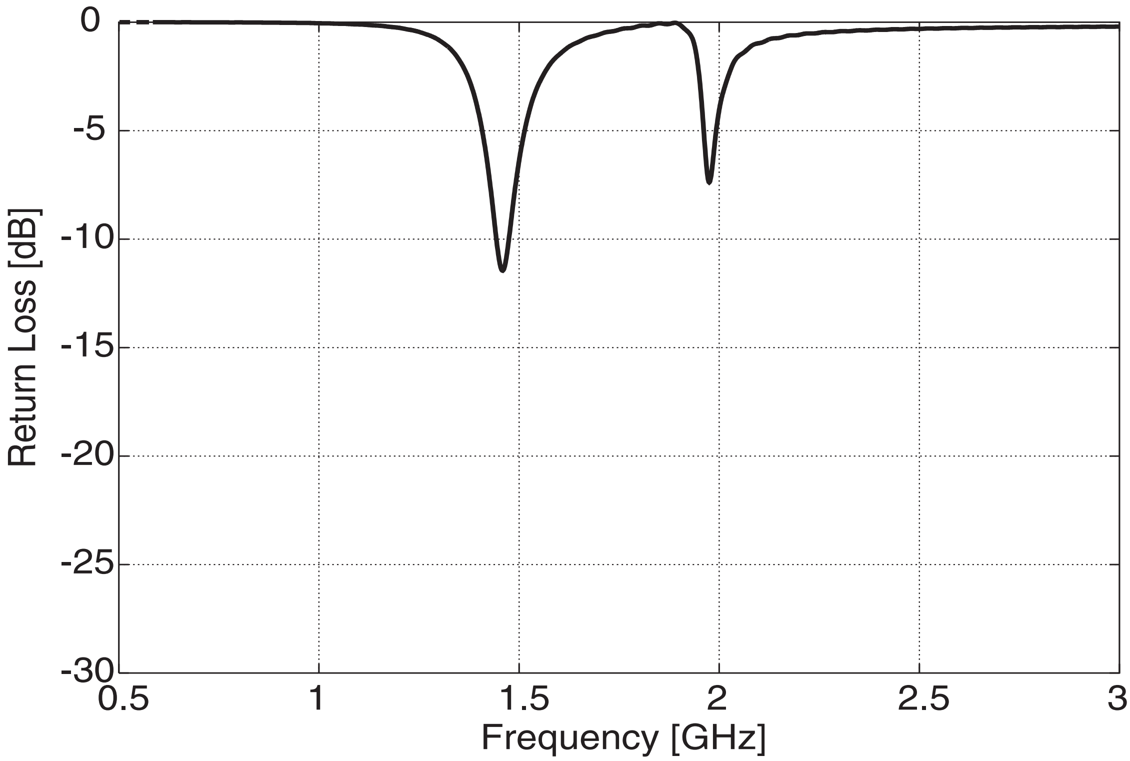


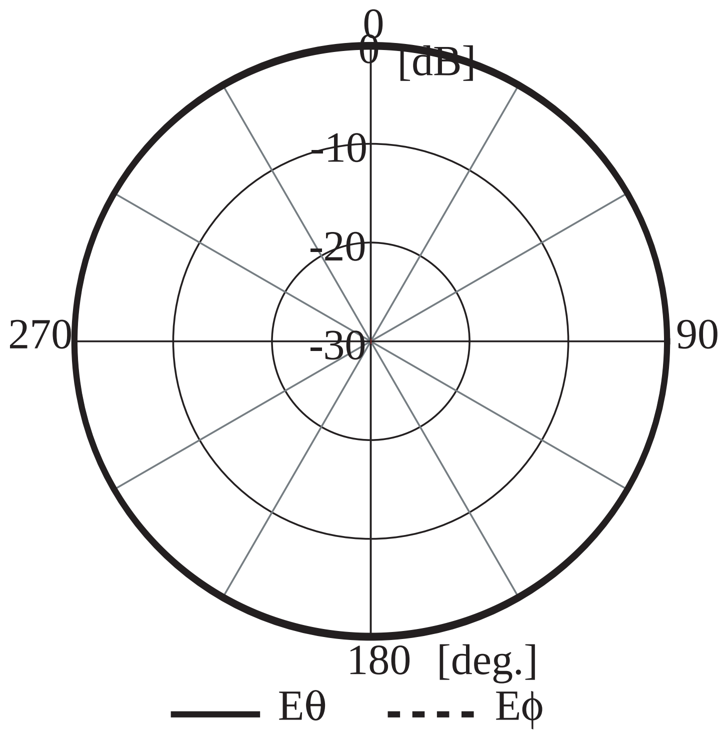
Figure 3.14: Return loss characteristics of two-layered antenna. (size of upper loop is L=22 × 22[mm] and that of lower patch is R=24 × 24[mm])

3.3.3 Example Model of Two-Layered Antenna

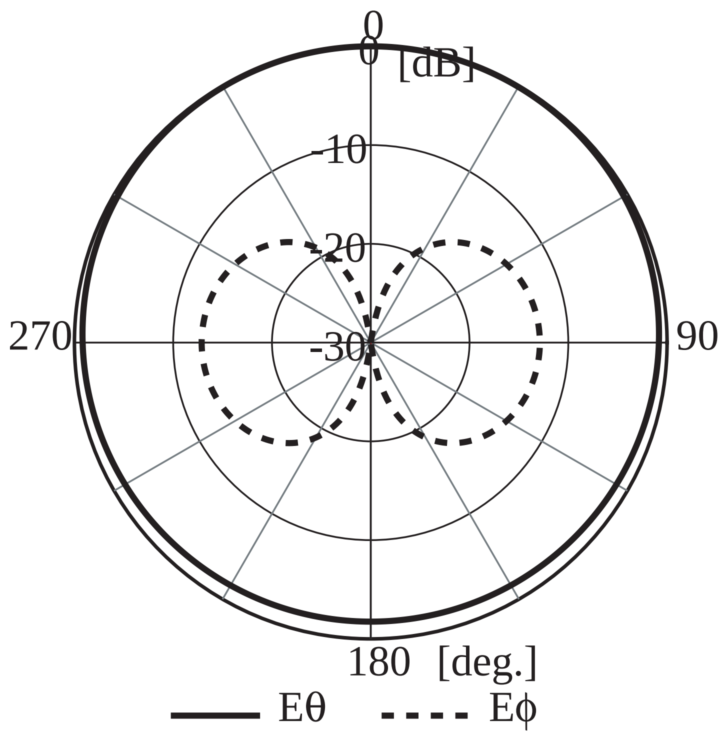
Figure 3.14 shows the Return Loss characteristics of example two-layered antenna model consists of an upper loop element and a lower rectangular patch antenna with center feed probe. This antenna is mounted on the ground plane (50 × 50[mm]). The size of upper loop element ($L \times L$) is L=22[mm] and the width of loop is 2[mm]. This upper layer is connected to the lower patch antenna by a short pin. The size of lower rectangular patch antenna ($R \times R$) is R=24[mm].

This two-layered antenna has two resonant frequencies of 1.46[GHz] and 1.98[GHz]. Each return loss level is −11.5[dB] and −7.4[dB]. By making the impedance matching, the level of return loss will be achieved more suppression.

Figures 3.15 and 3.16 show the FDTD simulation results of the radiation patterns in the xy, zx, and yz-plane at both resonant frequencies. From these figures, we find that the radiation patterns at each resonant frequency are similar to monopole antenna. The cross polarizations are less than −20[dB] at xy (horizontal) plane, zx and yz (vertical) plane at the first resonant frequency, but it is less than −10[dB] in the xy and yz-plane at the second resonant frequency.

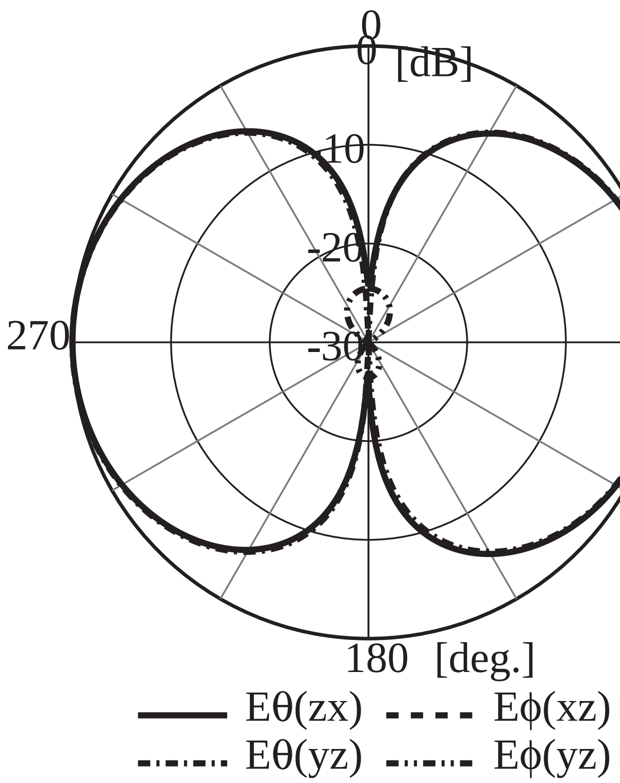


(a) Freq. = 1.46[GHz]

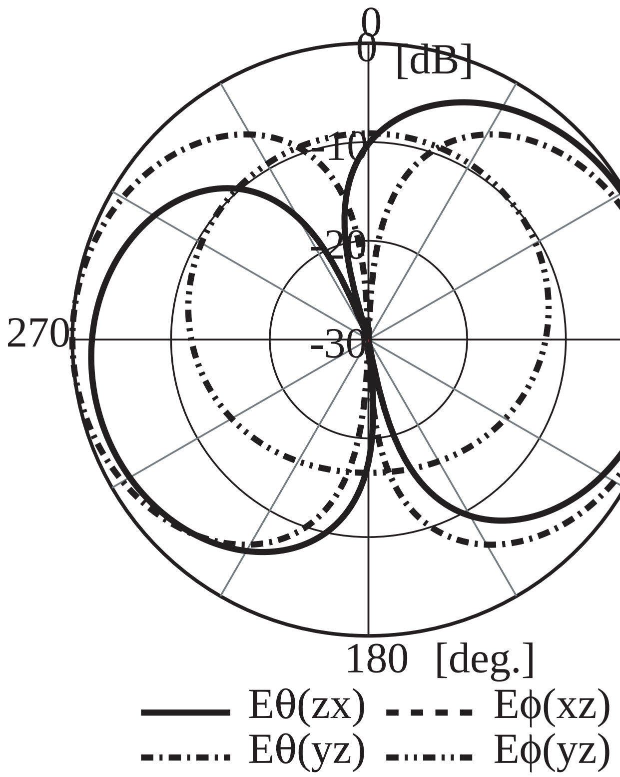


(b) Freq. = 1.98[GHz]

Figure 3.15: Radiation pattern of two-layered antenna. (xy-plane. size of upper loop is L=22 × 22[mm] and that of lower patch is R=24 × 24[mm])



(a) Freq. = 1.46[GHz]



(b) Freq. = 1.98[GHz]

Figure 3.16: Radiation pattern of two-layered antenna. (zx, yz-plane. size of upper loop is L=22 × 22[mm] and that of lower patch is R=24 × 24[mm])

We already presented that the return loss level at the second resonant frequency is changed by the size of lower top loaded monopole antenna as shown in Figure 3.13. Then the cross polarization radiation is caused by the resonance of lower antenna, however, these levels are not too large for the application of dual frequency.

3.4 Comparison between Analysis and Measurement

Figure 3.17 shows comparison between calculation and measurement of the return loss characteristics of measured two-layered antenna model consists of an upper loop element and a lower rectangular patch antenna with center feed probe. This antenna is mounted on the ground plane. The size of upper loop element ($L \times L$) is L=24[mm] and the width of loop is 2[mm]. This upper layer is connected to the lower patch antenna by a short pin. The size of lower rectangular patch antenna ($R \times R$) is R=21[mm].

This two-layered antenna has two resonant frequencies of 1.49[GHz] and 2.17[GHz] at the measurement. Comparing the FDTD simulation and the measurement results, the return loss characteristics agree well, respectively.

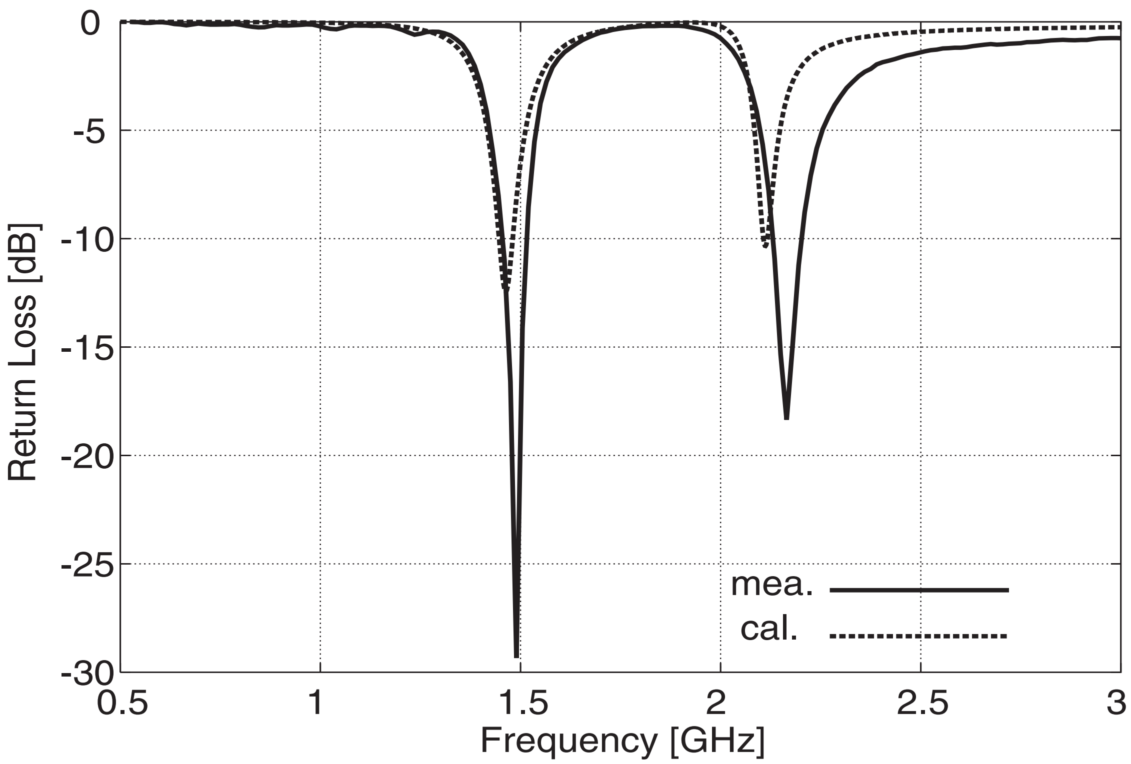


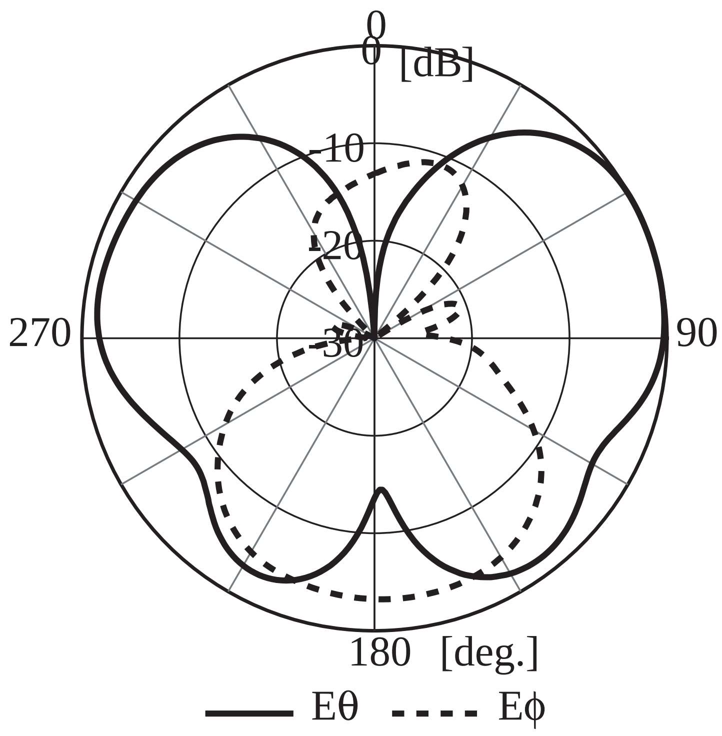
Figure 3.17: Return loss characteristics of measured two-layered antenna. (size of upper loop is L=24 $\times$ 24[mm] and that of lower patch is R=21 $\times$ 21[mm])

Figures 3.18 and 3.19 show the measurement and FDTD simulation results of the radiation patterns in the zx (vertical) plane at both resonant frequencies. From these figures, we find that the radiation patterns at each resonant frequency are similar to monopole antenna. Comparing the FDTD simulation and the measurement results, the principal radiation characteristics agree well, respectively. The difference of backward direction is because of the ground plane. The cross polarizations of the measurement are increased because of experimental error.

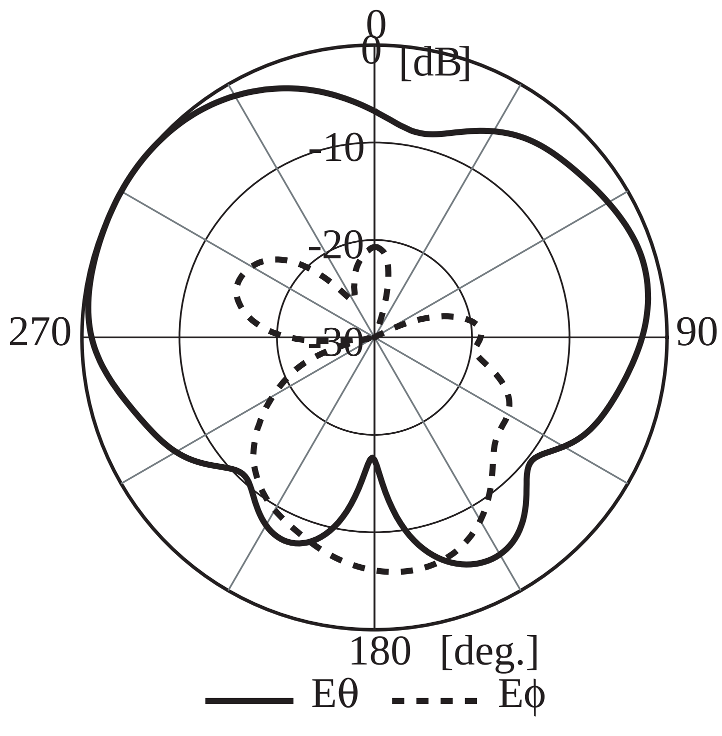
3.5 Conclusion

In this chapter, we presented the novel two-layered antenna which consists of a rectangular or loop element as the upper layer and a low profile top loaded monopole antenna as the lower antenna which has matching posts. We simulated the input characteristics and radiation pattern of this antenna by using FDTD method.

This antenna has two resonant frequencies at about 1.5[GHz] and 2.0[GHz], and the radiation patterns of this antenna are similar to that of the monopole antenna at each resonant frequencies.

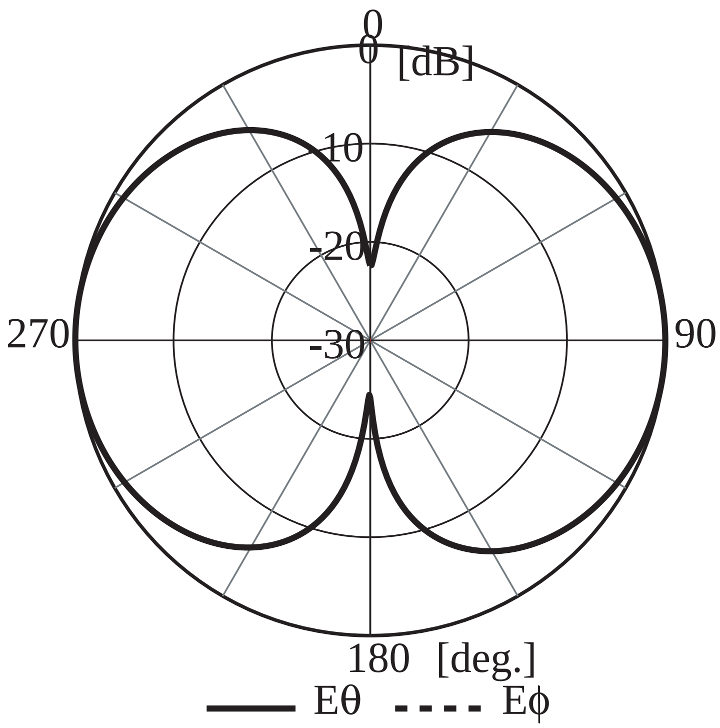


(a) Freq. = 1.49[GHz]

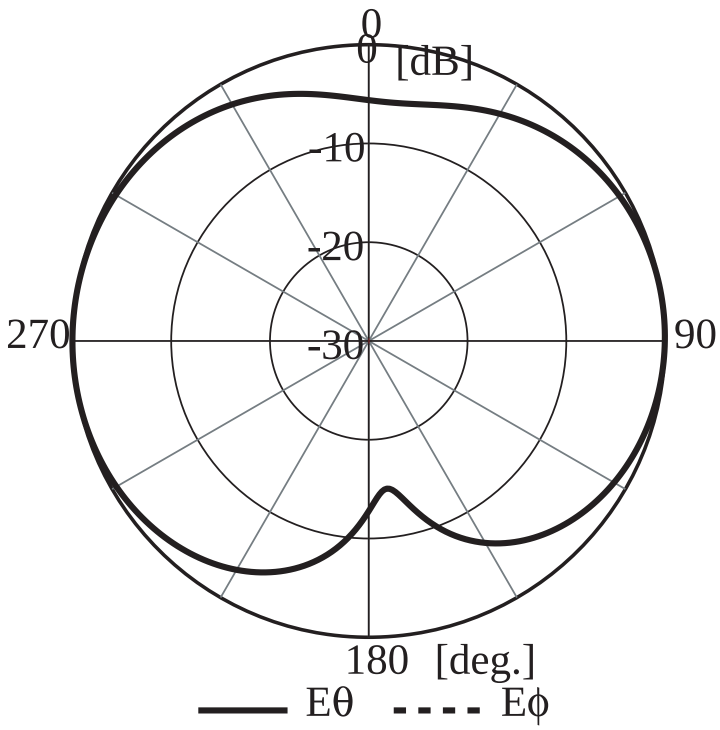


(b) Freq. = 2.17[GHz]

Figure 3.18: Radiation pattern of two-layered antenna in measurement. (size of upper loop is L=24 × 24[mm] and that of lower patch is R=21 × 21[mm])



(a) Freq. = 1.46[GHz]



(b) Freq. = 2.11[GHz]

Figure 3.19: Radiation pattern of two-layered antenna in calculation. (size of upper loop is L=24 × 24[mm] and that of lower patch is R=21 × 21[mm])

Chapter 4

Antenna Characteristics due to Ground Plane Shape

4.1 Introduction

One of the requirement for the antenna system is to reduce the size of the whole antenna system for antenna installation with required characteristics of antennas. In this chapter, the characteristics of FB ratio (front-to-back ratio) and mutual coupling between two antennas are particularly noticed and examined for reducing the size of antenna backed by reflector.

The number of subscribers is rapidly on the increase in Japanese cellular phone market. Therefore, an increase of the subscriber capacity for one base station antenna is required instead of building new base stations in the present cellular system. A method for increasing capacity of the converge area using sectoral pattern antenna is the enhancement of FB ratio to reduce the overlapping converge areas between adjusting cells for suppressing the influence on each radiation. In order to increase the capacity of the subscribers, it is required that the base station antenna has the characteristics of FB ratio more than 20[dB] [26]. The base station antenna widely used in the cellular system consists of radiation element backed by reflector. If the reflector size is infinite, there is no radiation to the backward direction. An infinite sized reflector is not possible, and small reflector is necessary for base station antenna installation.

On the other hand, in a repeater antenna for wireless communications, suppression of mutual coupling between transmitting and reception antenna is required to reduce the weight and size of the antenna system even if the separation between two antennas is very small. The repeater antenna consists of radiation element backed by reflector. If the reflector size is infinite or the distance between two antennas is infinite, there is no mutual coupling between two antennas located back to back in parallel. An infinite sized reflector and distance are not possible and not only small distance between two antennas but also small reflector is necessary for antenna system.

This paper presents the enhancement of FB ratio by optimizing the several types of reflector shape backed of dipole antenna, for example, rectangular reflector, dual rectangular reflector in parallel, box shaped reflector, dual box reflector, and so on. We calculate the characteristics of FB ratio by using FDTD method and compare with measurement. Then, the suppression of mutual coupling with small distance between antennas by using two dipole antennas with high FB ratio back to back in parallel is presented. The characteristics of mutual coupling between these antennas are also calculated by FDTD analysis.

4.2 FB Ratio Characteristics of Monopole Antenna backed by Reflector

The radiation elements of base station antenna are dipole, printed dipole, microstrip antenna and etc. For the simplicity of the analysis model, we select the dipole antenna backed by conducting reflector as shown in Figure 4.5. The resonant frequency of dipole antenna is about 2.0[GHz] for the application of IMT-2000. The distance between dipole antenna and the reflector is fixed to be $\lambda/4$ throughout this paper. FB ratio is defined between $\pm$ 30 degrees about the backward direction.

4.2.1 FB Ratio and Rectangular Reflector

First, we consider the influence of reflector size on the radiation characteristics of dipole antenna. The geometry of reflector is shown in Figure 4.1, single rectangular reflector. The parameters of this reflector are width (W) and height (H).

The characteristics of FB ratio of dipole antenna by changing the width and height of single rectangular reflector are shown in Figure 4.2. The radiation pattern of dipole antenna when the width is fixed to be 0.5λ are shown in Figure 4.3.

When the width of rectangular reflector is constant at W=0.5λ, the characteristics of FB ratio are changed by the reflector height. The level of FB ratio goes up more than 10[dB] as the reflector height becomes larger from 0.5λ to 1.5λ, and the level becomes peak level. However, when the reflector height becomes larger than 1.5λ, the level of FB ratio goes down and becomes converge near 17[dB].

When the height of rectangular reflector is constant at H=0.5λ, the characteristics of FB ratio are slightly changed by the reflector width. The level of FB ratio rises by 3[dB] at W=λ, but the level is decreased over W=λ and becomes close to 9[dB]. The return loss level of dipole antenna at the resonant frequency is not affected by the reflector size. If the FB ratio is required more than 20[dB], large reflector is not need and just using the rectangular reflector whose height is about H=1.5λ when the reflector width

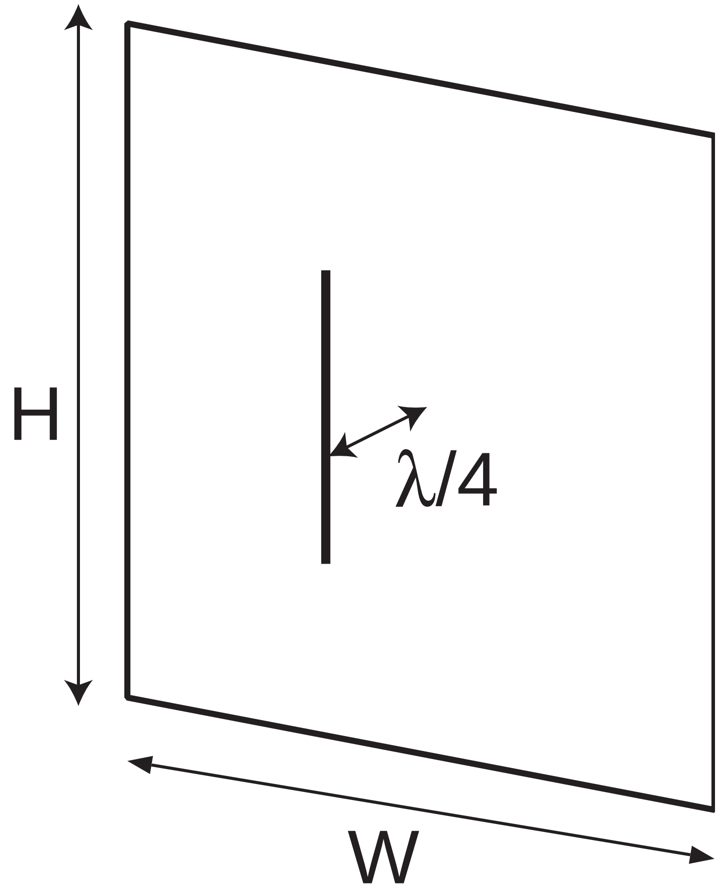


Figure 4.1: Geometry of dipole antenna and rectangular reflector.

is W=0.5λ. By selecting the reflector height, required FB ratio can be achieved in stead of using large reflector.

The measurement results when the reflector height is parameter and the reflector width is fixed to be W=0.5λ are also shown in Figure 4.2. The geometry of antenna is monopole antenna backed by rectangular reflector by using the image method. The ground plane of measurement model is finite. If the ground plane is infinite, this model corresponds to the analysis model. The radiation pattern of dipole antenna when the width is fixed to be 0.5λ in measurement are shown in Figure 4.4. When the reflector height becomes larger, the level of FB ratio goes up and it has a peak value at H=1.25λ. From the reflector height H=1.25λ to 4λ, the level of FB ratio becomes goes down. Comparing the FDTD simulation and the measurement results, the FB ratio characteristics agree well, respectively.

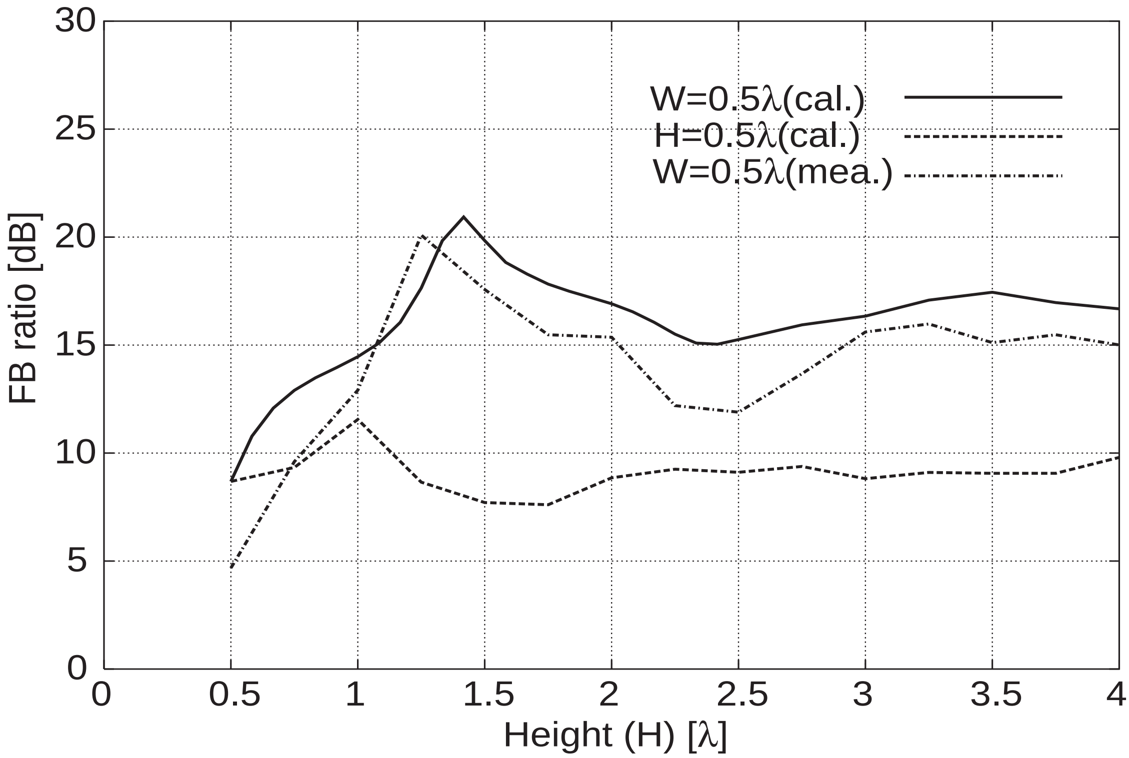


Figure 4.2: FB ratio characteristics of dipole antenna due to size of single rectangular reflector. (width or height of reflector is fixed to be 0.5λ in calculation. width is fixed to be 0.5λ in measurement.)

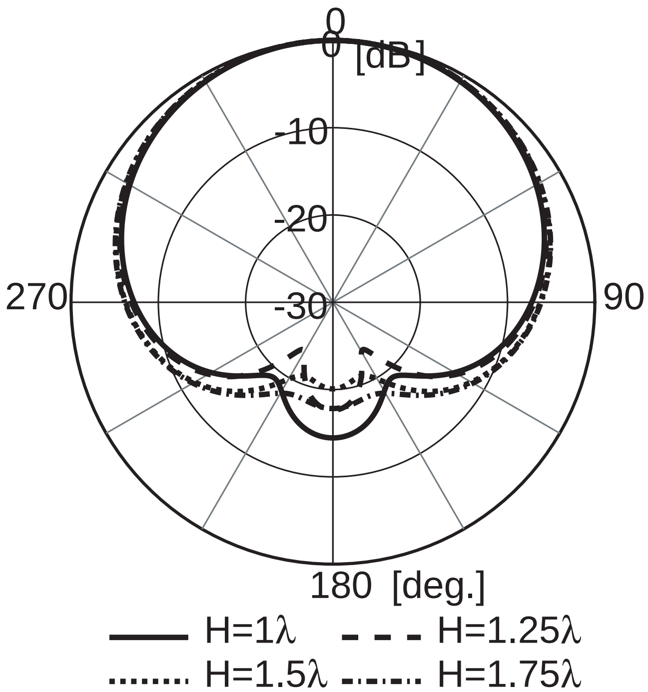


Figure 4.3: Radiation pattern of dipole antenna backed by single rectangular reflector. (reflector width is fixed to be W=0.5λ)

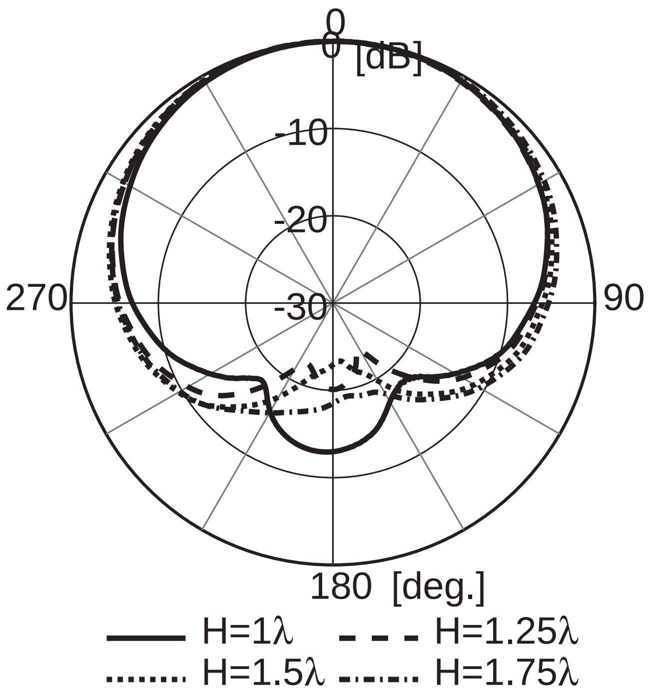


Figure 4.4: Measurement radiation pattern of dipole antenna backed by single rectangular reflector. (reflector width is W=0.5λ)

There is an optimum size for single rectangular reflector when the reflector width is constant, and high FB ratio can be achieved by selecting height without using large reflector. A miniaturization of reflector can be achieved by using optimum size. From the next section, several types of reflectors are examined to enhance the level of FB ratio.

4.2.2 Reflector Shapes

Several types of reflector shape are considered in this paper, such as single rectangular reflector (Figure 4.5(a)), dual rectangular reflector in parallel (Figure 4.5(b)), half cylindrical reflector (Figure 4.5(c)), rectangular reflector with flanges in horizontal edge and vertical edge backward as shown in Figure 4.5(d), thick reflector (Figure 4.5(e)), box shaped reflector which is equivalent to the rectangular reflector with flanges in both horizontal and vertical edges forward (Figure 4.5(f)), and dual box reflector which is equivalent to the box shaped reflector with flanges in horizontal and vertical edges (Figure 4.5(g)).

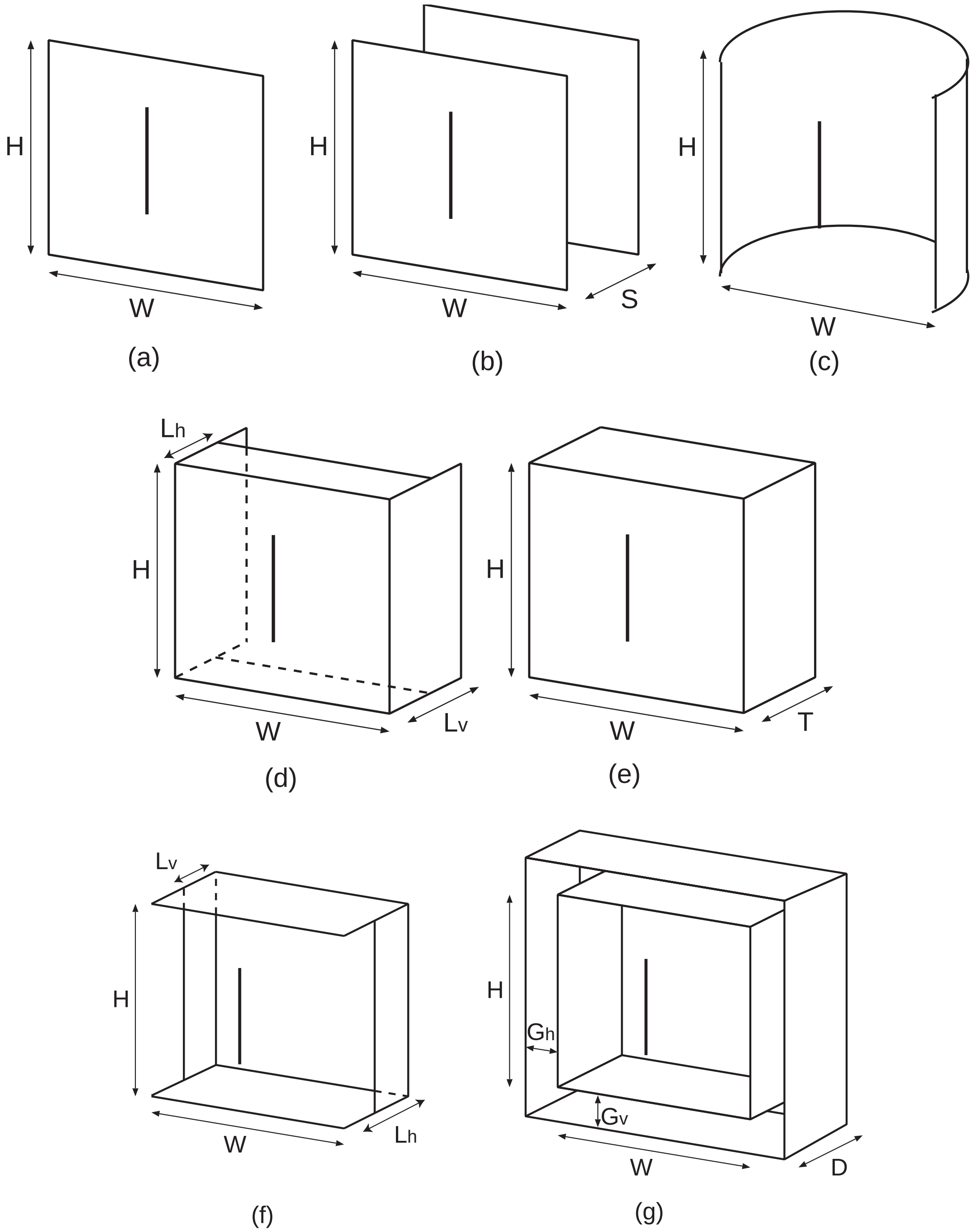


Figure 4.5: Geometry of dipole antenna and several types of reflector shape which are (a) rectangular reflector, (b) dual rectangular reflector in parallel, (c) half cylindrical reflector, (d) rectangular reflector with flanges in both horizontal and vertical edges backward, (e) thick reflector. (f) box shaped reflector which is equal to rectangular reflector with flanges in both horizontal and vertical edges forward, (g) dual box reflector which is equal to box shaped reflector with flanges in both horizontal and vertical edges. (from (b) to (g), width and height of each reflector are fixed to be W=0.5λ and H=1.5λ.)

By changing the parameter of each reflector, we examine the characteristics of FB ratio which is defined between ± 30 degrees about the backward direction. The parameters of the reflector are height (H) and width (W) for every reflector, spacing (S) for dual rectangular reflector in parallel, length (L) for flanged reflector, thickness (T) for thick reflector, depth (D) for box shaped reflector, and gap (G) for dual box reflector. When the flanged length of vertical edge and horizontal edge are different, the parameter L_v is for the length of vertical flanges and L_h is for the length of horizontal flanges. For dual boxing reflector, when the gap between two flanges in vertical edges and horizontal edges are different, the parameter G_v is for the gap between two flanges in vertical edge and G_h is for the gap between flanges in horizontal edge.

4.2.3 FB Ratio Characteristics due to Reflector Shape

First, we examine the characteristics of FB ratio of dipole antenna by changing the size of rectangular reflector (Figure 4.5(a)) as shown in Figures 4.6 and 4.7. When the height of rectangular reflector is fixed to be 0.5λ, the level of FB ratio is almost unchangeable near 9[dB] by changing the reflector width from 0.5λ to 6.0λ. When the height of rectangular reflector is fixed to be 1.0λ, the level of FB ratio is increased up about 5[dB] by changing the reflector width from 0.5λ to 6.0λ, but the level is almost stable over W=4.0λ. When the height of rectangular reflector is 1.5λ, the level of FB ratio is almost unchangeable close to 22[dB] by changing the reflector width from 0.5λ to 6.0λ. When the height of rectangular reflector is fixed, the characteristics of FB ratio are not affected by changing the reflector width as shown in Figure 4.6.

On the other hand, when the width of rectangular reflector is fixed to be 0.5λ, the characteristics of FB ratio are changed by the reflector height. The level of FB ratio is dramatically increased more than 10[dB] as the height of reflector becomes larger, and the FB ratio becomes the maximum value for H=1.42λ. The level is more than 20[dB] around H=1.5λ. However, when the reflector height becomes larger than 1.5λ, the level of FB ratio is decreased and becomes converge. When the width of rectangular reflector is fixed to be 1.0λ or 1.5λ, the characteristics of FB ratio are also changed by the reflector height in the same way. The level of FB ratio is dramatically increased more than 15[dB] to the peak value for each reflector width, which is about 28[dB]. When the width of rectangular reflector is fixed, the characteristics of FB ratio are affected by changing the reflector height, and there is a maximum level as shown in Figure 4.7. High FB ratio, for example 20[dB], can be achieved by selecting the reflector size, width W=0.5λ and height H=1.5λ, instead of using large reflector.

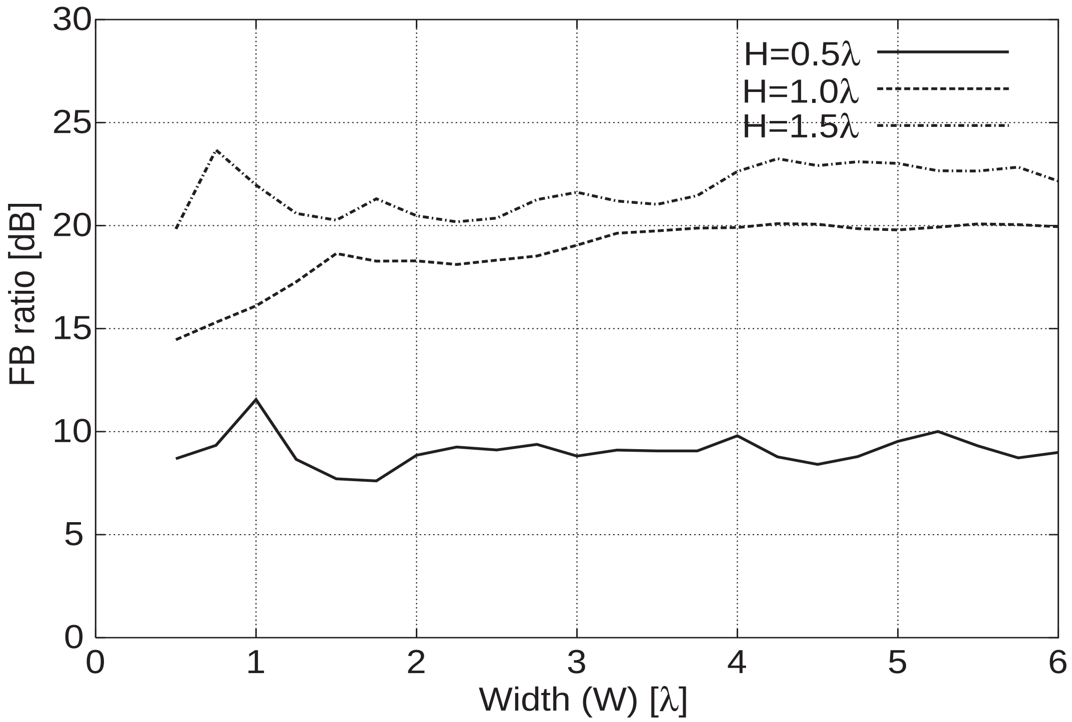


Figure 4.6: FB ratio characteristics of dipole antenna due to width of single rectangular reflector. (height of reflector is fixed to be H=0.5λ, 1.0λ, 1.5λ)

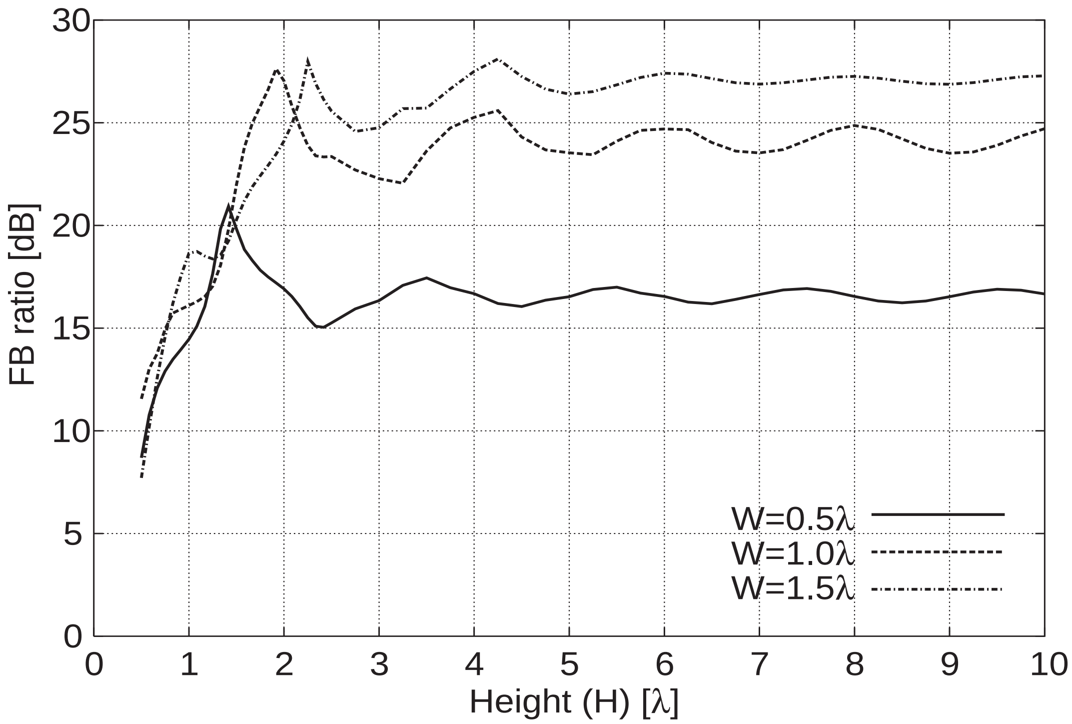


Figure 4.7: FB ratio characteristics of dipole antenna due to height of single rectangular reflector. (width of reflector is fixed to be W=0.5λ, 1.0λ, 1.5λ)

From next, the enhancement of FB ratio is examined when the reflector height is equal to H=1.5λ and width is equal to W=0.5λ in order to achieved the level of FB ratio more than 20[dB] by adding or changing the single rectangular reflector shape.

When using the half cylindrical reflector (Figure 4.5(c)), the characteristics of FB ratio are also changed by changing the reflector height as shown in Figure 4.8. The level of FB ratio is increased as the reflector height becomes larger, and FB ratio has also the maximum value. There is an optimum size for half cylindrical reflector when the reflector diameter is constant, and high FB ratio can be achieved by selecting the reflector height without using large reflector as well as when using rectangular reflector. When the diameter of reflector is fixed to be W=0.5λ, the peak level of FB ratio is about 28[dB] at H=1.75λ. When the width of rectangular reflector is fixed to be W=0.5λ, the peak level of FB ratio is about 21[dB] at H=1.42λ. The level of FB ratio using half cylindrical reflector can be achieved higher level than using rectangular reflector when the reflector height is more than 0.75λ.

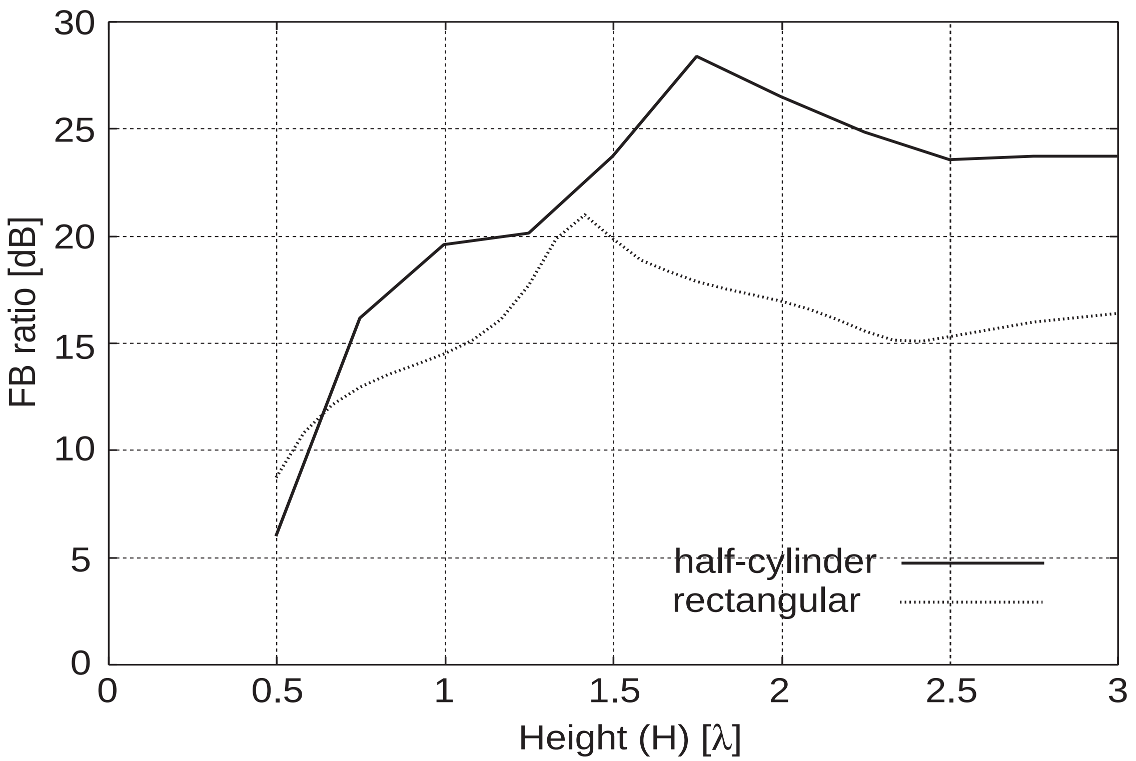


Figure 4.8: FB ratio characteristics of dipole antenna due to height of half cylindrical reflector or rectangular reflector. (reflector diameter or width is fixed to be W=0.5λ)

Figure 4.9 shows the FB ratio of dipole antenna by changing the spacing (S) of dual rectangular reflector in parallel (Figure 4.5(b)), by changing the thickness (T) of thick reflector (Figure 4.5(e)), and by changing the length (L) of flanged reflector in both horizontal edges or vertical edges backward (Figure 4.5(d)). The spacing S=0, length L=0, and thickness T=0 are equivalent to rectangular reflector. The reflector width and height of each reflector are fixed to be W=0.5λ, H=1.5λ. By using dual rectangular reflector, thick reflector, and flanged reflector in vertical edge (L_h=0) or in both vertical and horizontal edges (L_h=L_v), the level of FB ratio becomes larger than single rectangular reflector by the spacing, thickness and flanged length, for example, about 2[dB] to 4[dB] up from the level of rectangular reflector. When using the flanged reflector in horizontal edge (L_v=0), the characteristics of FB ratio are not affected by changing the flanged length. The characteristics of FB ratio by using thick reflector and flanged reflector in both vertical and horizontal edges (L_h=L_v) or in vertical edge (L_h=0) are almost same. The characteristics of FB ratio are affected by the flanged length in vertical edge (L_v) of rectangular reflector. The return loss level of dipole antenna at the resonant frequency is almost same by changing these parameters.

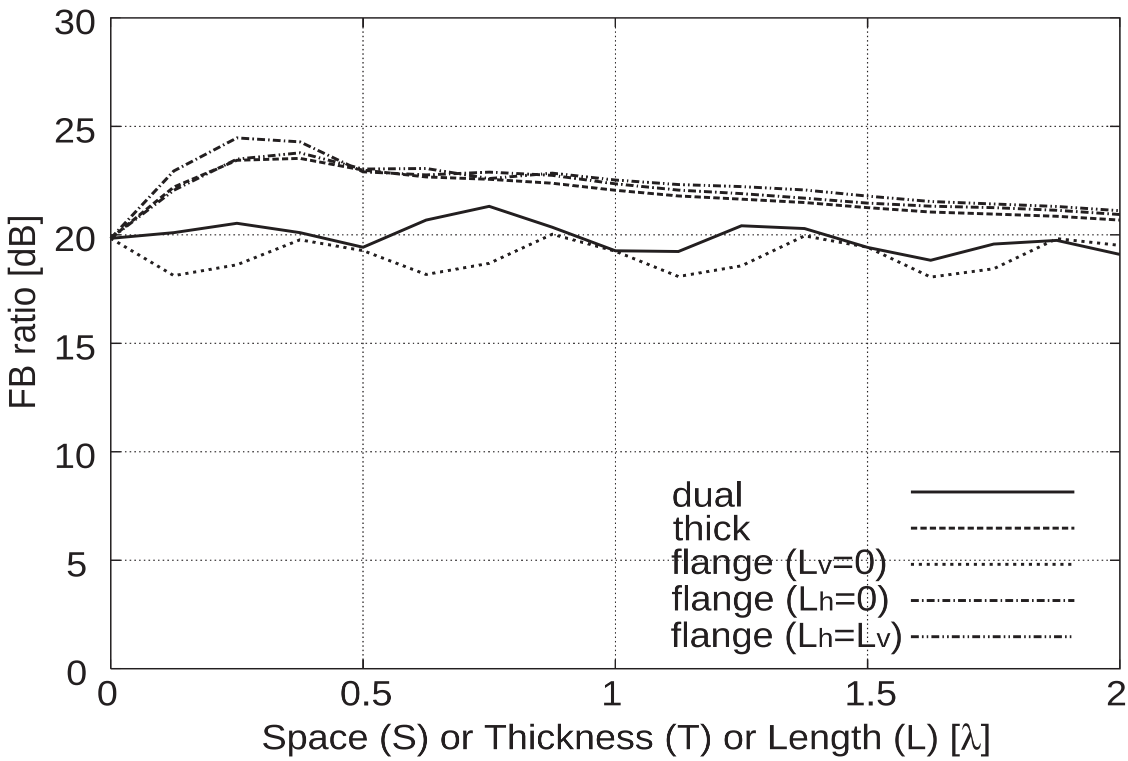


Figure 4.9: FB ratio of dipole antenna per size of dual or thick or flanged reflector. (reflector width and height is fixed to be W=0.5λ, H=1.5λ)

4.2.4 FB Ratio Characteristics due to Box Shaped Reflector

Next, we examine the characteristics of FB ratio by using box shaped reflector which is adding the vertical and horizontal flanges forward at the both edges of rectangular reflector (Figure 4.5(f)). The reflector width and height of each reflector are fixed to be W=0.5λ, H=1.5λ.

Figure 4.10 shows the FB ratio of dipole antenna by changing the length (L) of reflector flanges in horizontal edges and vertical edges forward. The flanged length L=0 is equivalent to rectangular reflector. By using the flanged reflector in vertical edges (L_h=0) and box shaped reflector (L_v=L_h), the level of FB ratio becomes larger than single rectangular reflector by the flanged length, for example, about 5[dB] up from the level of rectangular reflector at L=0.25λ. However, the impedance matching is not good when the flanged length becomes larger because of the influence between dipole antenna and reflector flanges. The return loss level becomes more than −5[dB] when the flanged length is over L_h=0.25λ.

When using the flanged reflector in horizontal edges (L_v=0), the level of FB ratio decrease by changing the flanged length. The characteristics of FB ratio by using the flanged reflector in vertical edges are nearly equal to that of FB ratio by using the box shaped reflector. The characteristics of FB ratio are affected by the flanged length in vertical edges (L_v) of rectangular reflector. When the flanged length is 0.25λ, the level of FB ratio by using box shaped reflector can be achieved more than 25[dB].

By adding the vertical and horizontal flanges at the each edge of box shaped reflector, we consider dual box reflector (two concentric boxes) as shown in Figure 4.11. The reflector width (W), height (H), and depth (D) is fixed to be W=0.5λ, H=1.5λ, and D=0.25λ. Figure 4.12 shows the FB ratio of dipole antenna by changing the gap (G) between two flanges at the edge of box shaped reflector. The gap G=0 is equivalent to box shaped reflector. By using dual box reflector (G_v=G_h), the level of FB ratio becomes larger than box shaped reflector by the gap, for example, about 2[dB] up from the level of box shaped reflector at G=0.25λ. This dual box reflector has plate between two flanges as shown in Figure 4.11. When there is no plate at the gap between two flanges, the characteristics of FB ratio has a maximum value at G=0.125λ as shown in Figure 4.12 line "dual-box2". On the other hand, when using the box shaped reflector with flanges in horizontal edges (L_v=0) or vertical edges (L_h=0), the level of FB ratio decrease. When the reflector gap is 0.25λ, the level of FB ratio by using dual box reflector can be achieved more than 28[dB], higher than using box shaped reflector.

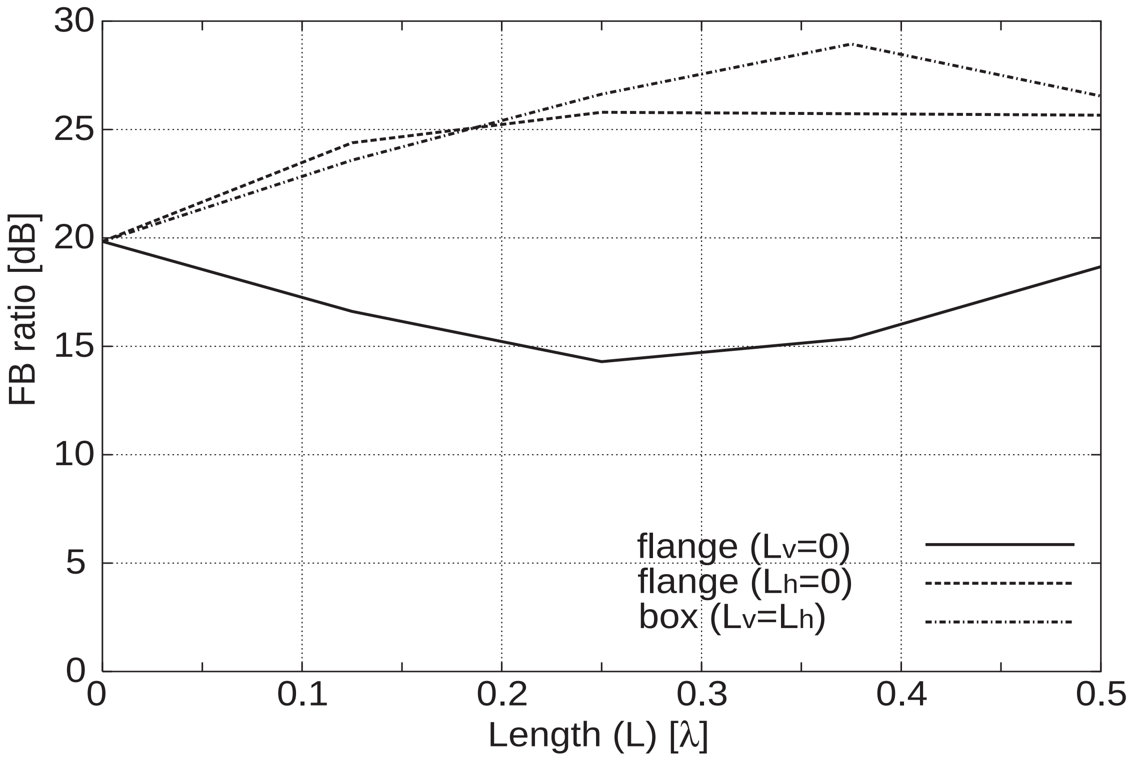


Figure 4.10: FB ratio of dipole antenna per size of flanged or box shaped reflector. (reflector width and height is fixed to be W=0.5λ, H=1.5λ)

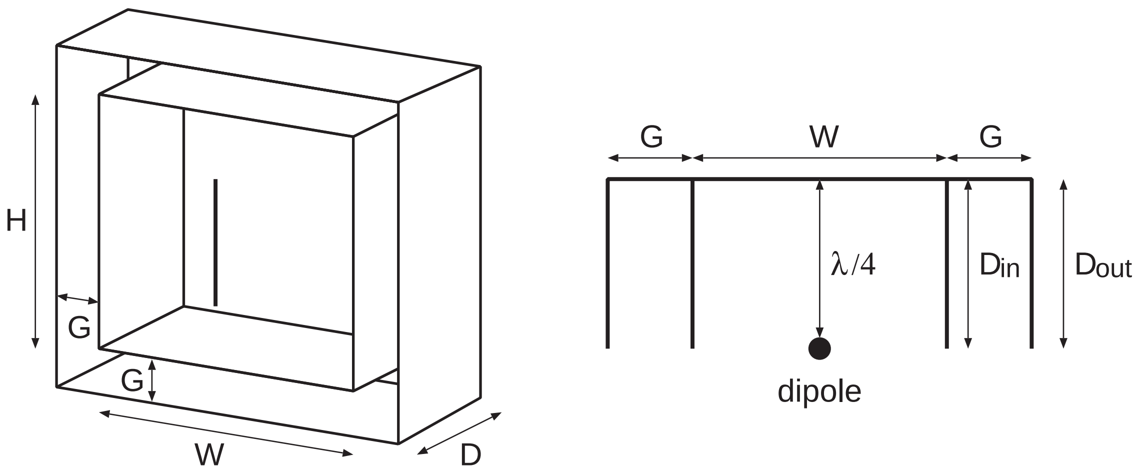


Figure 4.11: Geometry of dipole antenna and dual boxing reflector. (reflector width, height and depth is fixed to be W=0.5λ, H=1.5λ, D=0.25λ)

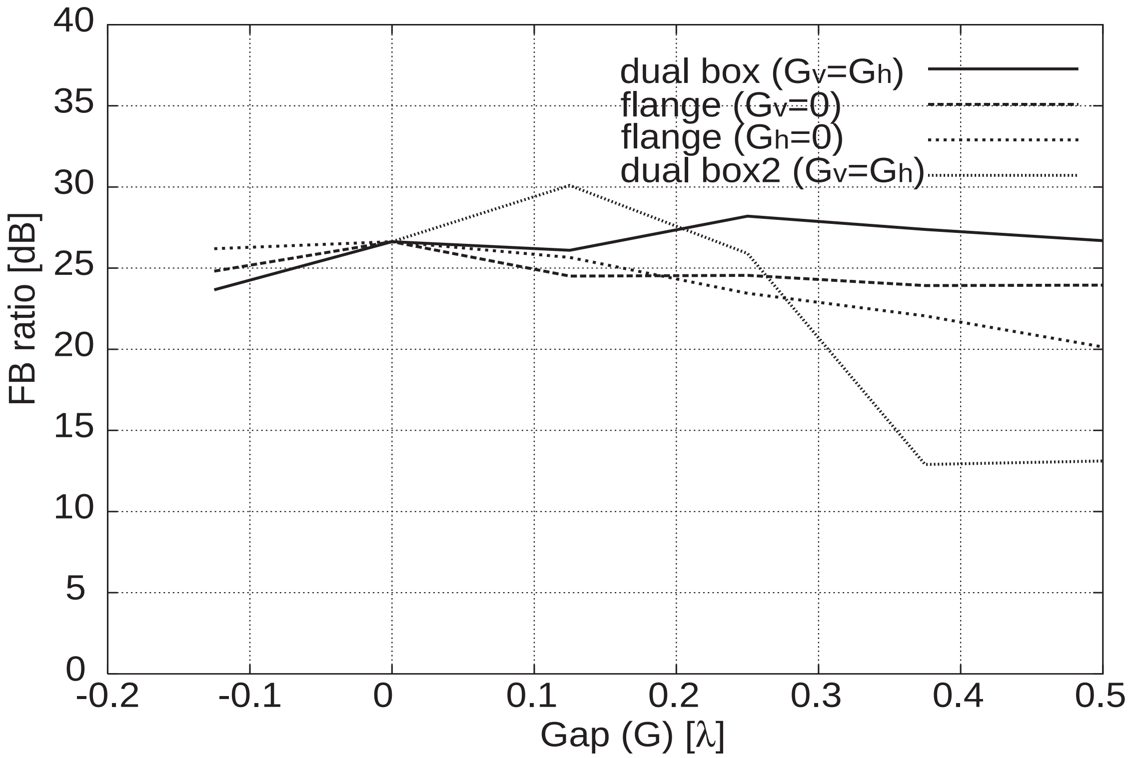


Figure 4.12: FB ratio of dipole antenna per gap of box shaped reflector with flanges or dual box reflector. (reflector width, height and depth is fixed to be W=0.5λ, H=1.5λ, D=0.25λ)

The characteristics of FB ratio by changing the depth of dual box reflector are shown in Figure 4.13. There are two parameters of depth, which are D_{in} for the inner flanges and D_{out} for the outside flanges as shown in Figure 4.11. The gap of dual box reflector is constant (G=0.25λ). By changing only D_{out} (D_{in} is fixed to 0.25λ) or changing both D_{out} and D_{in}, the level of FB ratio becomes increase over D=0.25λ. However, the impedance matching is not good when the depth becomes larger because of the influence between dipole antenna and reflector flanges. The return loss level becomes more than -5[dB] when the depth is over D_{out}=0.25λ. On the other hand, when changing only D_{in} (D_{out} is fixed to 0.25λ), the level of FB ratio is increased but the impedance matching is not affected by changing the depth over 0.25λ. The level of FB ratio can be achieved more than 30[dB], higher than using box shaped reflector. A dual box makes a $\lambda/4$ choke at the reflector edges.

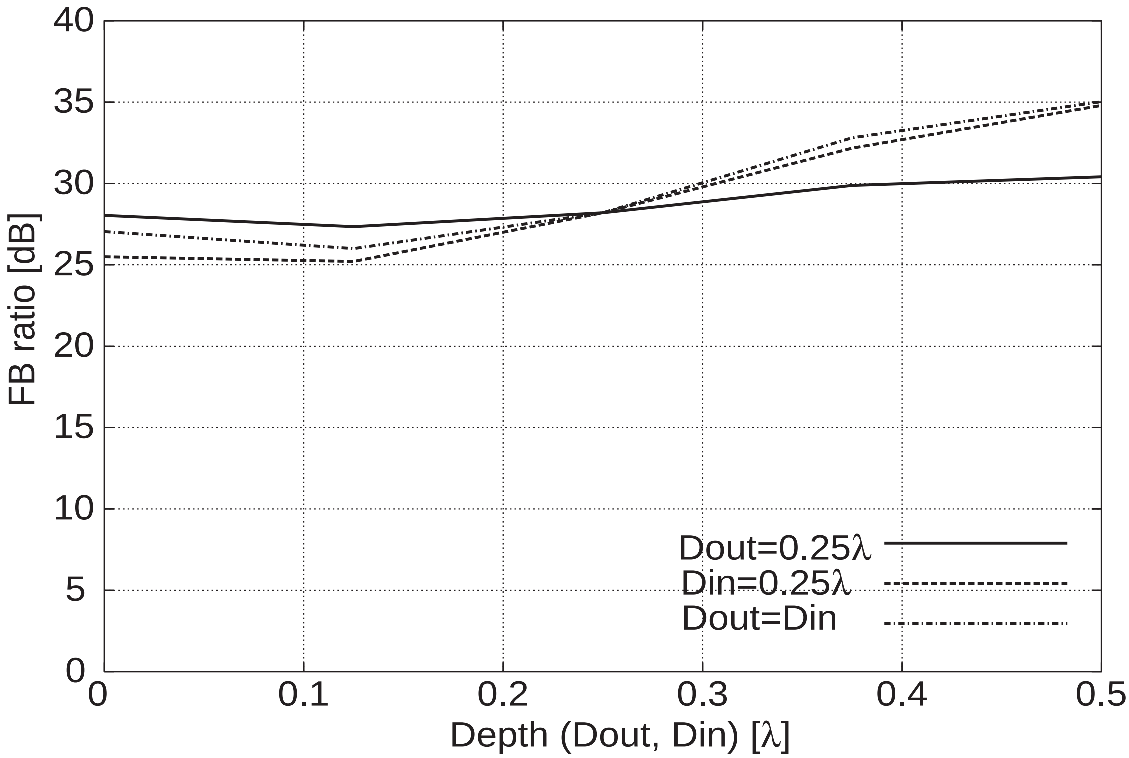


Figure 4.13: FB ratio of dipole antenna per depth of dual box reflector. (reflector width, height and gap is fixed to be W=0.5λ, H=1.5λ, G=0.25λ)

The radiation pattern of dipole antenna inside dual box reflector is shown in Figure 4.14. Each size parameters of dual box reflector are width W=0.5λ, height H=1.5λ, gap G_v=G_h=0.125λ, and depth D_{out}=D_{in}=0.25λ. When using this dual box reflector, the level of FB ratio is more than 28[dB].

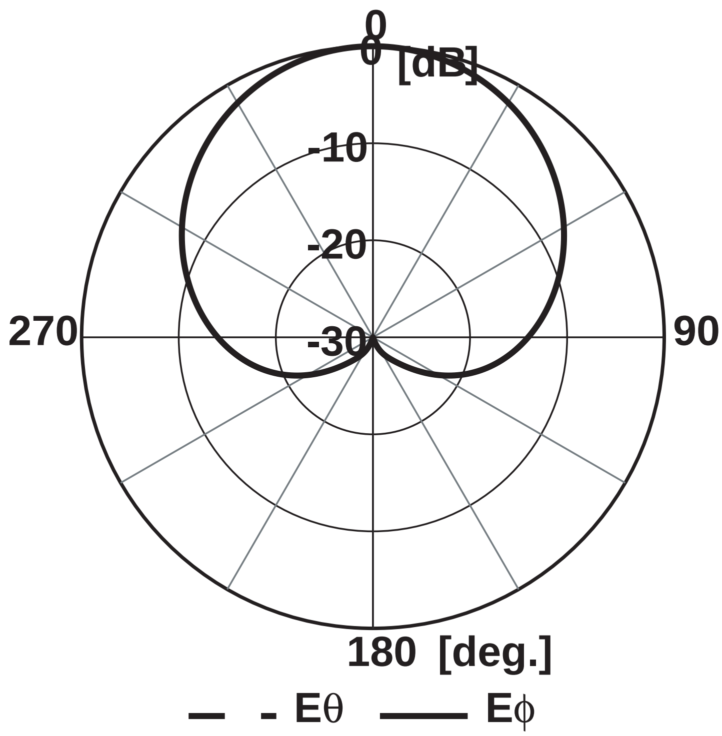


Figure 4.14: Radiation pattern of dipole antenna backed by dual box reflector. (reflector width is W=0.5λ, height is H=1.5λ, gap is G=0.25λ, and depth is D=0.25λ.)

4.2.5 Conclusion

The summary of the FB ratio for main reflectors is shown in Table 4.1. Each reflector width is fixed to be W=0.5λ and height is fixed to be H=1.5λ. By using these parameters of reflector, each level of FB ratio is about more than 20[dB]. And dual box reflector has the maximum level of FB ratio. There is an optimum size for each shapes of reflector when the size is limited, and FB ratio of dipole antenna is increased up more than 20[dB]. A miniaturization of reflector can be achieved by selecting the parameter of each reflector instead of using large reflector. Comparing each shapes of reflector when the width and height is constant, using dual box reflector has the highest FB ratio of dipole antenna more than 30[dB].

Table 4.1: Construction of reflector and FB ratio at reflector width is fixed to be W=0.5λ and height is fixed to be H=1.5λ. Each parameters are width W, height H, spacing S, depth D, inner depth D_{in}, outer depth D_{out}, and gap G.

Reflector construction	Size of Object [$\times\lambda$]	F/B
Rectangular ref.	W=0.5, H=1.5	19.8[dB]
Dual rectangular ref.	S=0.75	21.3[dB]
Box shaped ref.	D=0.25	26.6[dB]
Dual box ref.	G=D_{out}=0.25, D_{in}=0.5	30.4[dB]

4.3 FB Ratio Characteristics of Patch Antenna

In the previous section, we presented the FB ratio characteristics of monopole antenna due to the reflector shape. And, a miniaturization of reflector can be achieved by selecting the parameter of each reflector instead of using large reflector.

One of the other radiation elements of antenna is patch antenna. In this section, next of monopole antenna, the patch antenna is selected to examine the FB ratio characteristics. In this case, the influence of ground plane size is considered instead of reflector size.

For the simplicity of the analysis model, we select the patch antenna with rectangular ground plane. The resonant frequency of patch antenna is about 2.0[GHz]. FB ratio is defined between ± 30 degrees about the backward direction.

4.3.1 FB Ratio Due to Ground Plane

We consider the influence of ground plane size on the radiation characteristics of patch antenna. The geometry of patch and ground plane is shown in Figure 4.15. The parameters of this ground plane are length (X) for x-axis which is the direction of H plane and (Y) for y-axis, the direction of E plane for patch antenna.

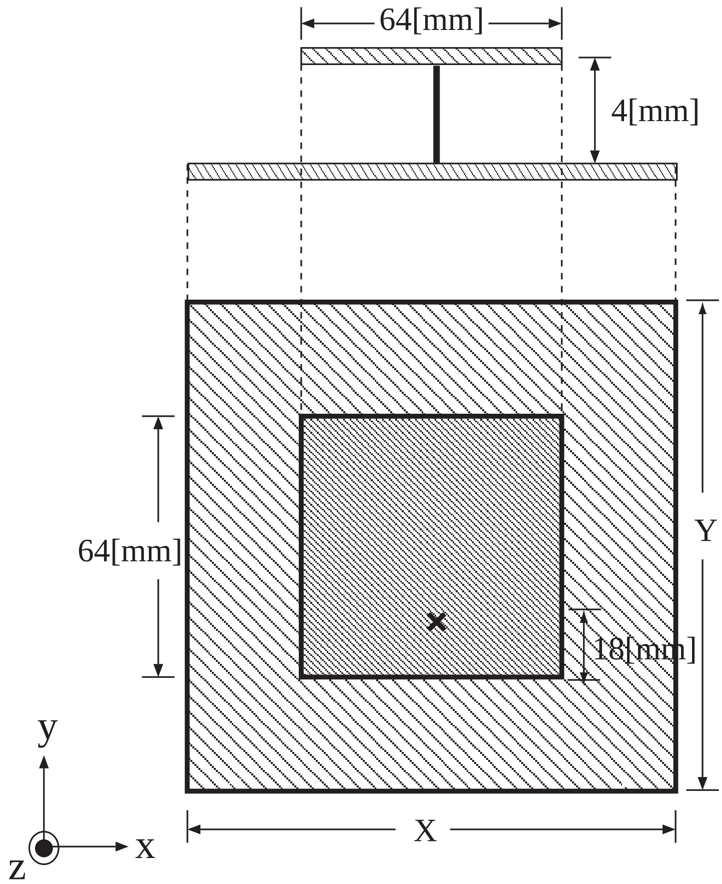


Figure 4.15: Geometry of patch antenna and ground plane.

The characteristics of FB ratio of patch antenna by changing the size of gound plane are shown in Figures 4.16 and 4.17.

When the length (Y) of ground plane is constant at Y=λ, the characteristics of FB ratio are not influenced by the length X. The level of FB ratio is almost 20[dB] in both E plane (yz-plane) and H plane (zx-plane) as shown in Figure 4.16.

When the length (X) of ground plane is constant at X=λ, the characteristics of FB ratio increased up more than 10[dB] as the length Y becomes larger from 0.75λ to 2λ. The level of FB ratio rises to almost 25[dB] in E plane and 30[dB] in H plane as shown in Figure 4.17.

The length (X) of ground plane which is the direction of H plane for patch doesn't affected to the radiation pattern in both E and H plane. On the other hand, the length (Y) which is the direction of E plane has influence on the radiation pattern.

There is an optimum size for ground plane when the length X is constant, and high FB ratio can be achieved by selecting length Y without using large ground plane. A miniaturization of ground plane can be achieved by using optimum size. This is the same as monopole antenna backed by reflector.

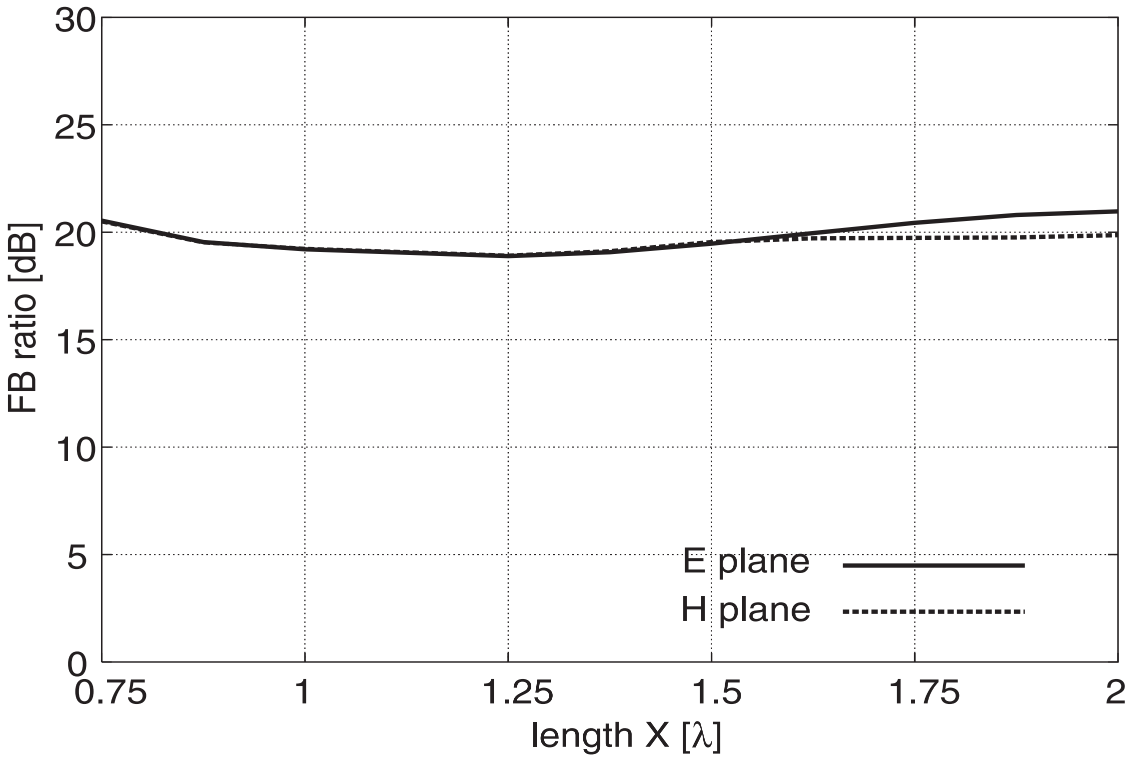


Figure 4.16: FB ratio characteristics of patch antenna due to size of ground plane. (length Y of ground plane is fixed to be λ in calculation.)

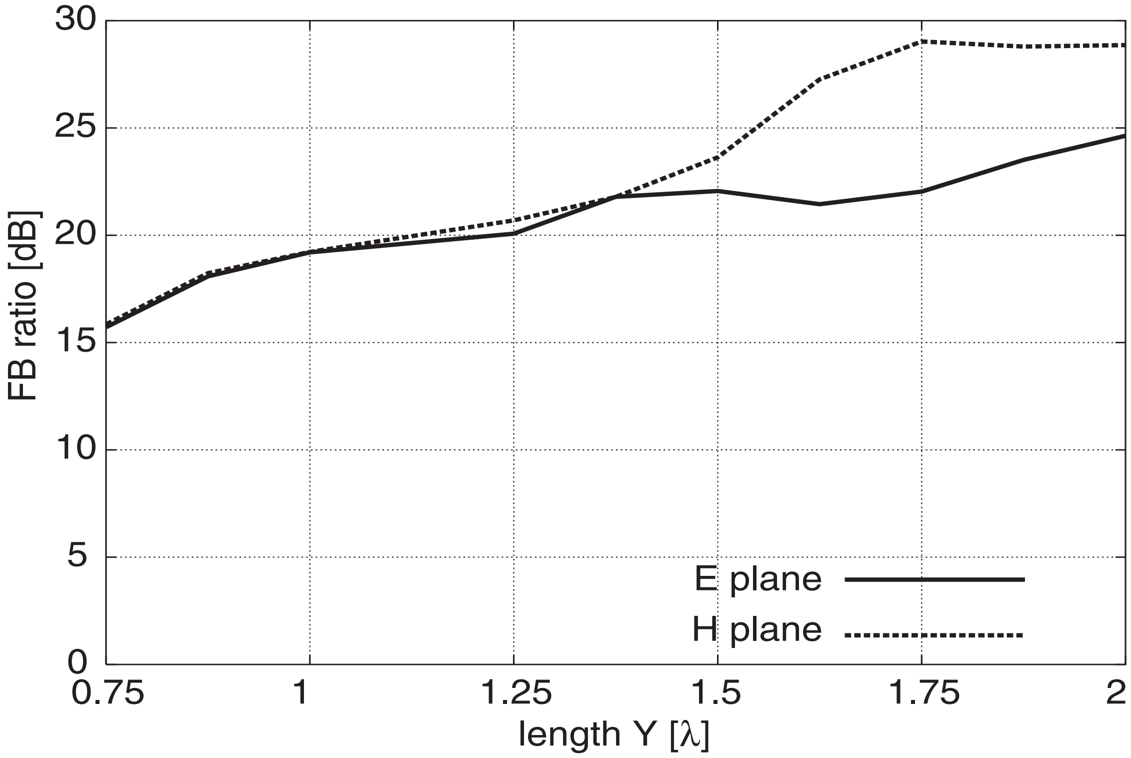


Figure 4.17: FB ratio characteristics of patch antenna due to size of ground plane. (length X of ground plane is fixed to be λ in calculation.)

4.3.2 Conclusion

In this section, the FB ratio characteristics of patch antenna is examined by changing the size of ground plane. The radiation pattern is affected by the size of ground plane. There is an optimum size for ground plane when the size is limited, and FB ratio of patch antenna is increased up more than 25[dB]. A miniaturization of ground plane can be achieved by selecting the parameter of size instead of using large ground plane.

4.4 Suppression of Mutual Coupling Characteristics of Monopole Antenna backed by Reflector

4.4.1 Mutual Coupling due to Reflector Shape

The radiation elements of repeater antenna is patch antenna and printed dipole antenna. For the simplicity of the analysis model, we select the dipole antenna backed by two types of conducting reflector. The rectangular reflector shape is selected for FB ratio when the reflector width is fixed from the previous section. The FB ratio becomes about 20[dB] for the height of reflector H=1.5λ when the width W is fixed to be 0.5λ. By using dual boxing reflector, higher FB ratio than using rectangular reflector can be achieved.

Two identical antennas backed by two types of reflector are located back to back in parallel by using rectangular reflector as shown in Figure 4.18 and by using dual boxing reflector in Figure 4.19. The resonant frequency of dipole antenna is about 2.0[GHz]. The distance between dipole antenna and the reflector is fixed to be 0.25λ. The width of rectangular reflector is W=0.5λ, height is H=1.5λ. The width of dual box reflector is W=0.5λ, height is H=1.5λ, gap is G=0.25λ, and depth is D=0.25λ. By changing the distance (S) of two reflectors, we examined the characteristics of mutual coupling.

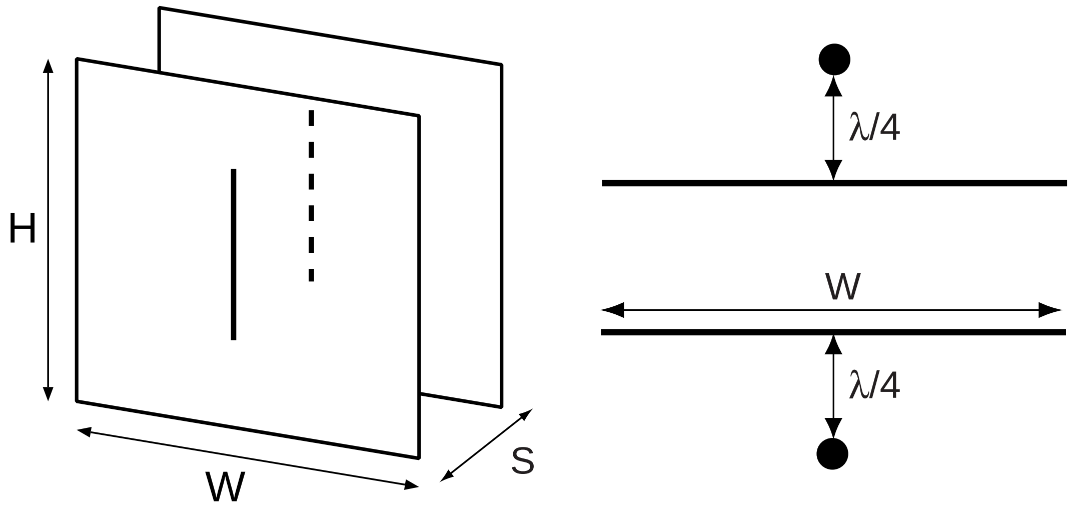


Figure 4.18: Geometry of two dipole antennas and rectangular reflector. (reflector width is W=0.5λ, height is H=1.5λ.)

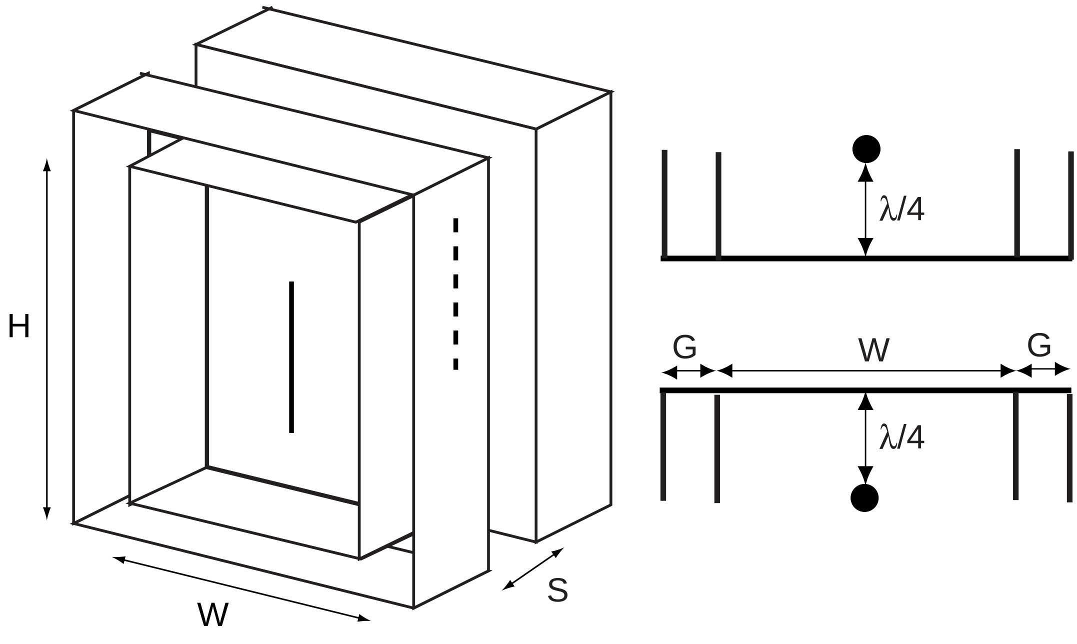


Figure 4.19: Geometry of two dipole antennas and dual boxing reflector. (reflector width is W=0.5λ, height is H=1.5λ, gap is G=0.25λ, and depth is D=0.25λ.)

First, we examine the characteristics of mutual coupling between two dipole antennas backed by rectangular reflector shape, where the reflector height is calculation parameter. When the width of rectangular reflector is fixed to be W=0.5λ and the distance between two reflectors is fixed to be S=2λ, the characteristics of mutual coupling between two dipole antennas by changing the height of rectangular reflectors from H=0.5λ to 2λ are shown in Figure 4.20. The level of mutual coupling is suppressed when the reflector height is equal to 1.5λ. The level of FB ratio has the peak value for height is H=1.5λ when the width is fixed to be 0.5λ as shown in Figure 4.7. The antenna with high FB ratio back to back has few influences on the backward direction, so, each other antenna suppresses the mutual coupling. So, we used the optimized rectangular reflector and dual boxing reflector with high FB ratio when the reflector size is limited to examine the characteristics of mutual coupling.

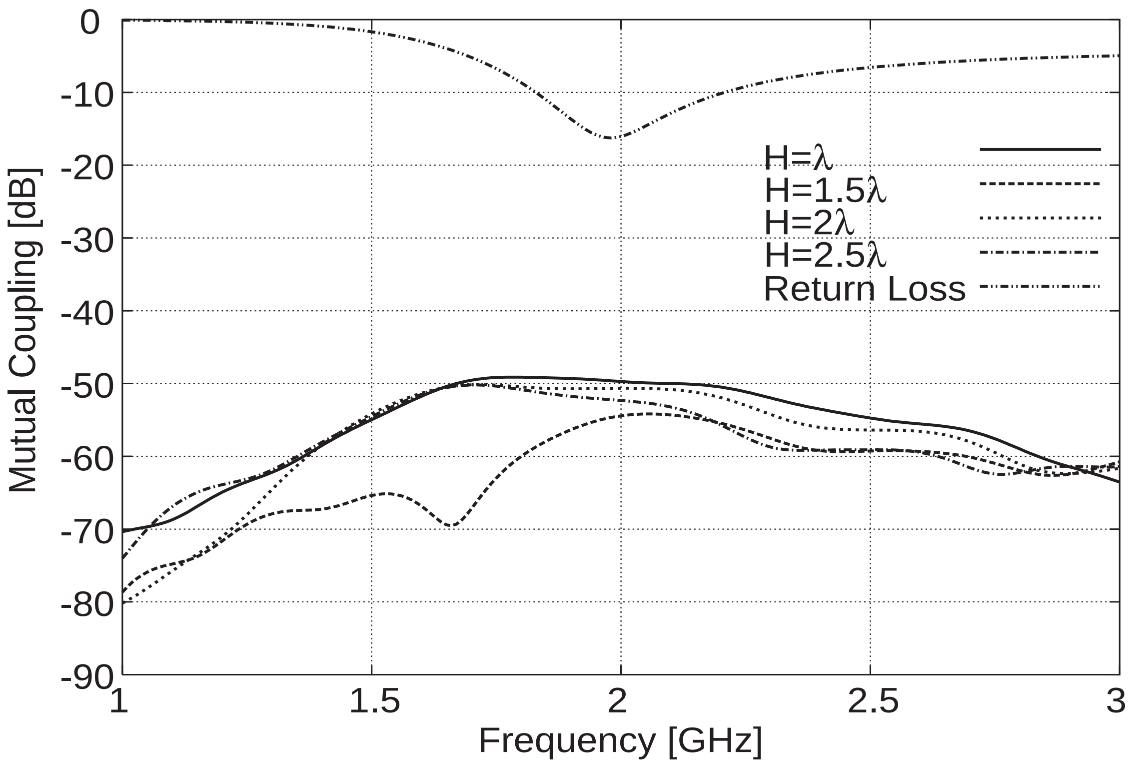


Figure 4.20: Mutual coupling of two antennas per height of rectangular reflector. (reflector width is W=0.5λ, and distance is S=2λ.)

4.4.2 Mutual Coupling Characteristics

Next, we examine the characteristics of mutual coupling between two dipole antennas by changing the distance (S) of two types of reflector, that is rectangular reflector and dual boxing reflector. When the width of rectangular reflector is fixed to be W=0.5λ and the height of reflector is fixed to be H=1.5λ, the characteristics of mutual coupling by changing the distance of two reflectors are shown in Figure 4.21. The level of mutual coupling is suppressed more than 20[dB] as the distance between two reflectors becomes larger. When the distance of two reflector is 4.0λ, the level of mutual coupling is suppressed less than −60[dB].

By using two dipole antennas backed by dual boxing reflector, the characteristics of mutual coupling by changing the distance of two reflectors from S=0.2λ to λ are shown in Figure 4.22 when the width of dual boxing reflector is fixed to be W=0.5λ, height is fixed to be H=1.5λ, depth is fixed to be D=0.25λ, and gap is fixed to be G=0.25λ. The level of mutual coupling is suppressed as the distance between two reflector becomes larger. When the distance of two reflector is 0.5λ, the level of mutual coupling is suppressed less than −60[dB]. The level of FB ratio by using dual boxing reflector is higher than by using rectangular reflector when the reflector width is fixed to be W=0.5λ and the height is fixed to be H=1.5λ, such as about 20[dB] for rectangular reflector and about 30[dB] for dual box reflector, this is 10[dB] higher level of FB ratio. So the level of mutual coupling suppressed less than −60[dB] can be achieved by small distance.

4.4.3 Conclusion

From the previous sections, the characteristics of FB ratio are examined by changing the shape and size of reflector, and we find that there is an optimum size for each reflector shapes when the size is limited. By using the reflector with high FB ratio, the mutual coupling characteristics between two dipole antennas back to back in parallel are examined. The level of mutual coupling between two antennas is suppressed less than −60[dB] with small distance by using the reflector with high FB ratio.

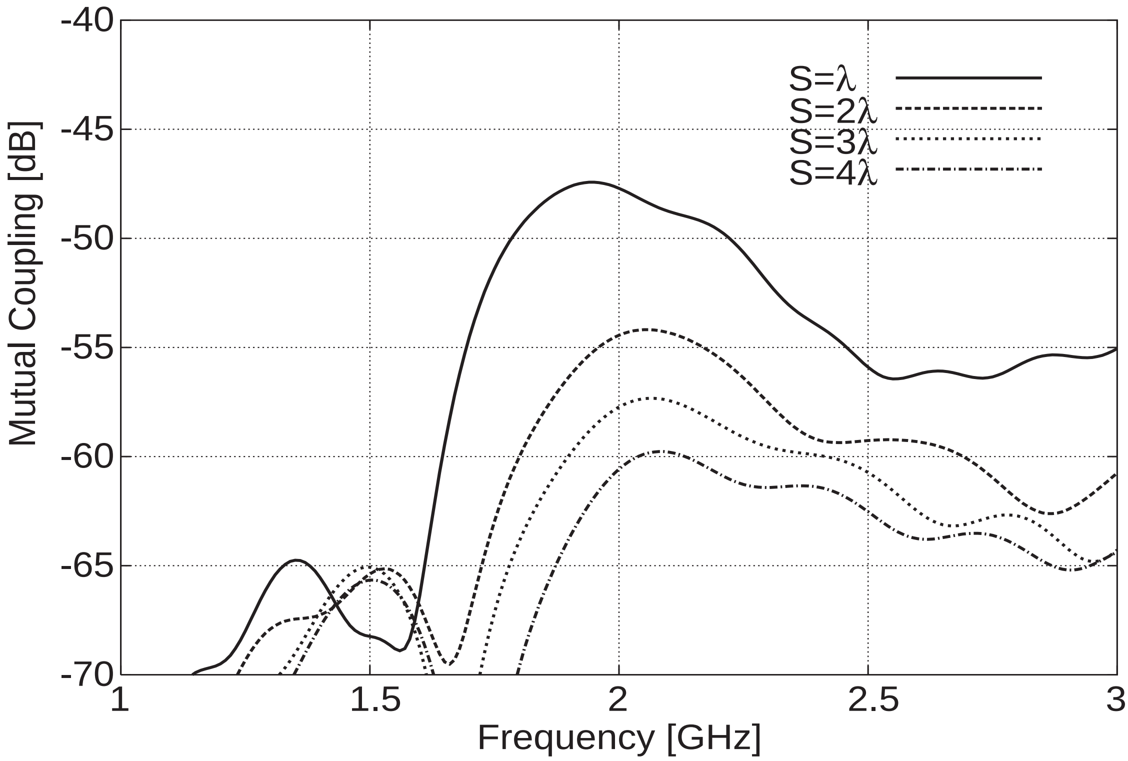


Figure 4.21: Mutual coupling of two antennas per distance of rectangular reflector. (reflector width is W=0.5λ, and height is H=1.5λ.)

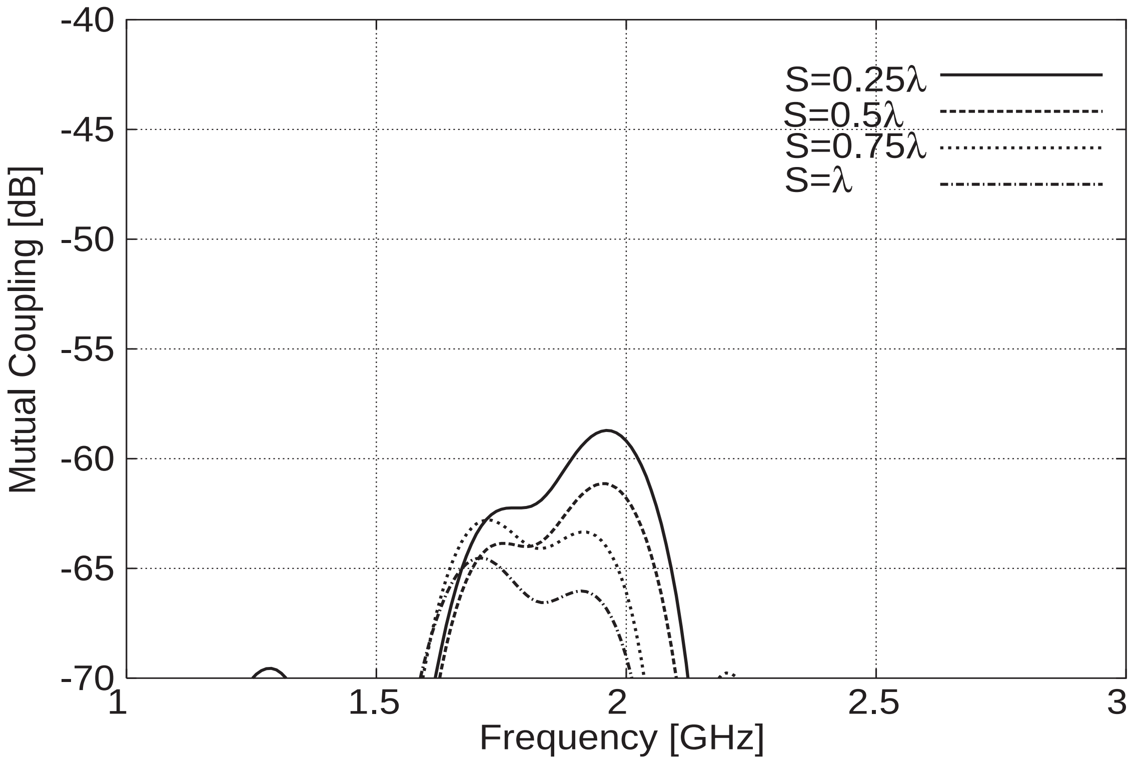


Figure 4.22: Mutual coupling of two antennas per distance of dual boxing reflector. (reflector width is W=0.5λ, height is H=1.5λ, depth is D=0.25λ, and gap is G=0.25λ.)

4.5 Conclusion

The antenna characteristics of dipole antenna and patch antenna due to the shape of reflector or ground plane are presented in this section.

The characteristics of FB ratio of monopole antenna are examined by changing the shape and size of reflector, and we find that there is an optimum size for each reflector shapes when the size is limited. High level of FB ratio can be achieved instead of using large reflector. A miniaturization of reflector can be achieved by selecting the parameters of each reflector shape.

FB ratio characteristics of patch antenna due to the size of ground plane is also examined. The ground plane size has influence on radiation pattern, the same as monopole antenna. A miniaturization of ground plane can be achieved by selecting the parameters of size.

By using the reflector with high FB ratio, the mutual coupling characteristics between two dipole antennas back to back in parallel are examined. The level of mutual coupling between two antennas is suppressed less than -60[dB] with small distance by using the reflector with high FB ratio.

Chapter 5

Conclusion

This dissertation described hybrid antenna to achieve highly functional and performance antenna. Three different functions are discussed in this dissertation as follows.

- High performance for dual polarized antenna using stacked antenna.
- Multi function for two-layer antenna with dual frequency
- Miniaturization for antenna due to ground plane shape

In chapter 2, we proposed two types of the stacked antenna which are improved on easy manufacturing from using ring patch which has shorted part. We simulated the S parameter characteristics and radiation pattern. First, we presented the patch antenna with a hole instead of ring patch, and the hybrid antenna using rectangular patch with a hole is examined. From the mutual coupling characteristics, both antennas are operated independently at both resonant frequencies by using patch with a hole. Patch with a hole can be used instead of ring patch by the antenna structure. Next, we proposed the two-layer antenna which consists of a patch as the upper antenna and a rectangular patch antenna with a hole as the lower antenna. Our proposed self-diplexing antenna structure suppress the mutual coupling between upper and lower antenna less than -25[dB] by using patch with a hole. The cross polarization level is suppressed less than -20[dB]. And, we proposed the stacked antenna which consists of an electromagnetic coupled patch as the upper antenna and a patch antenna with one or two slit(s) as the lower antenna. Our proposed antenna structure suppress the mutual coupling between upper and lower antenna less than -40[dB]. By using patch with two slits, the cross polarization level is suppressed less than -20[dB]. Last, for the application of self-diplexing antenna, circular polarization is examined by making perturbation and moving feed location.

In chapter 3, we presented the two-layered antenna which consists of a rectangular or loop element as the upper layer and a low profile top loaded monopole antenna as the lower antenna which has matching structure. We simulated the S parameter characteristics and radiation pattern of this antenna by using FDTD method. This antenna has two resonant frequencies at about 1.5[GHz] and 2.0[GHz], and the radiation pattern of this antenna is similar to that of the monopole antenna at each resonant frequencies.

In chapter 4, the antenna characteristics of dipole antenna and patch antenna due to the shape of reflector or ground plane are presented. The characteristics of FB ratio of monopole antenna are examined by changing the shape and size of reflector, and we find that there is an optimum size for each reflector shapes when the size is limited. High level of FB ratio can be achieved instead of using large reflector. A miniaturization of reflector can be achieved by selecting the parameters of each reflector shape. FB ratio characteristics of patch antenna due to ground plane size is also examined. The ground plane size has influence on radiation pattern, the same as monopole antenna. By using the reflector with high FB ratio, the mutual coupling characteristics between two dipole antennas back to back in parallel are examined. The level of mutual coupling between two antennas is suppressed less than -60[dB] with small distance by using the reflector with high FB ratio.

Dual polarized antenna (linear polarization, circular polarization) and dual frequency antenna using stacked patch antenna is proposed. Propose antenna can be achieved the required antenna characteristics (high performance, high function). The miniturization of proposed antenna is also considered by using simple antenna model.

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Publication List

Following lists contain the related publications of this dissertation.

Papers

1. Yuko Rikuta, Hiroyuki Arai (Yokohama Natl. Univ.), *"Self-Diplexing Antenna Using Patch Antenna With a Hole"*
   IEICEJ Transaction B Vol.J83-B, No.8, pp.1178-1185, August 2000 (in Japanese).

2. Yuko Rikuta, Hiroyuki Arai (Yokohama Natl. Univ.), Yoshio Ebine (NTT DoCoMo Inc.), *"Two-Layer Antenna with Dual Frequency"*
   IEICEJ Transaction B (in Japanese, submitted in 2003).

3. Yuko Rikuta, Hiroyuki Arai (Yokohama Natl. Univ.), Yoshio Ebine (NTT DoCoMo Inc.), *"Antenna Charactristics due to Ground Plane Shape"*
   IEICE Transactions on Communications (submitted in 2003)

International Conferences

1. Yuko Rikuta, Hiroyuki Arai (Yokohama Natl. Univ.), *"A Two-Layer Self-Diplexing Patch Antenna With A Hole"*
   1999 Asia-Pacific Microwave Conference, A-5-4, pp.154-157, December 1999, Singapore.

2. Yuko Rikuta, Hiroyuki Arai (Yokohama Natl. Univ.), *"A Self-Diplexing Antenna Using Stacked Patch Antennas"*
   2000 IEEE International Symposium on Antennas and Propagation and USNC/URSI National Radio Science Meeting, pp.2208-2211, July 2000, Salt Lake City, U.S.A.

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   2000 Asia-Pacific Microwave Conference, pp.1493-1496, December 2000, Sydney, Australia.

4. Yuko Rikuta, Hiroyuki Arai (Yokohama Natl. Univ.), Yoshio Ebine (NTT DoCoMo Inc.), *"Enhancement of FB ratio for Cellular Base Station Antenna by Optimizing Reflector Shape"*
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7. Yuko Rikuta, Hiroyuki Arai (Yokohama Natl. Univ.), *"A Self-Diplexing Antenna Using Slitted Patch Antenna"*
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1998 General Conference of IEICE, C-2-78, March 1998, Kanagawa.

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