Design of Microstrip Antennas with Folded Structure

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Abstract

In this paper, methods to miniaturize the linear polarization and the circular polarization microstrip antennas were studied, where the two ends in the resonance length direction or all the four-ends were folded.
For the linear polarization microstrip antenna, the visible length reduction rate was 73.9% and the gain was 5.12dBd. -10dB bandwidth was 64MHz(4.1%) and E-plane and H-plane HPBW were 151° and 79.2°, respectively.
For the circular polarization microstrip antenna, the folded structure of the linear polarization antenna was applied to all the four directions. In case of a triangular shape, the visible area reduction rate was 71.5% and the gain was 3.96dBd. -10dB bandwidth was 84MHz(5.3%) and HPBW were 81° and 82° in horizontal polarization of the z-x plane and the z-y plane, respectively. In case of a rectangular shape, the visible area reduction rate was 79.5% and the gain was 2.56dBd. -10dB bandwidth was 80MHz(5.1%) and HPBW were 91° and 124° in horizontal polarization of the z-x plane and the z-y plane, respectively. These results indicate that the 3-dimensional structure with the folded structure is adequate for the miniaturization of microstrip antennas.

1. Introduction

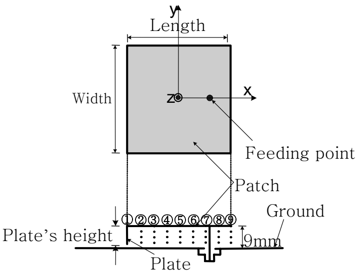
Recent trends of the miniaturization of wireless devices have led to the increasing demand for the miniaturization of antennas. Its miniaturization is becoming particularly important due to the development of the personal wireless communication. The size of antennas, however, increases in proportion to the wavelength of the center frequency, so the miniaturization of microstrip patch antennas(MPA) at the same frequency has been actively investigated.
In general, the characteristics of MPA are light weight, low volume, low profile and easy to manufacture, and it has the compatibility with the MMIC design process[1]. For the miniaturization of MPA, ceramic material with the dielectric constant is 20 ~ 50 is commonly used, but this method has a limit since it shows a low radiation efficiency due to its high dielectric constant.
For these reasons, a new way of miniaturization by three-dimensional Corrugated and folded structure is proposed[2], [3], [4], [5], [8]. The dielectric substance is the foam with a relative dielectric constant of 1.06.
In this paper, to miniaturize the linear polarization and the circular polarization microstrip antennas, methods, where the two ends in the resonance length direction or all the four-ends of microstrip antennas were folded, were studied and the characteristics of the folded microstrip antennas designed, fabricated and measured at 1.575GHz.

2. Linear and Circular Polarization Folded Microstrip Antennas

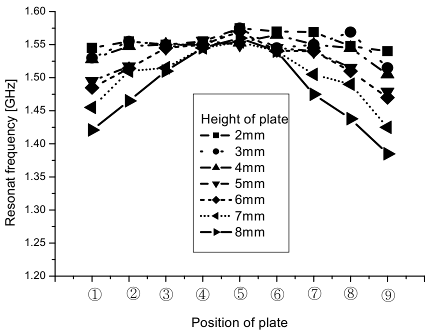
A. Basic principle

Prior to the investigation on the characteristics of the three-dimensional, plate-attached MPA that we propose in this work, we have fabricated a plane MPA with a height of 9mm which served as a reference. Since the proposed structure is three-dimensional, foam(ε_r = 1.06) was selected as the dielectric for the convenience of fabrication. The height of the patch was chosen to be 9mm in order to elucidate the effect of the height of plate at the GPS frequency(1.575 GHz).
The return loss at the center frequency was -37.3 dB and the -10dB bandwidth was 6.3%(99MHz), which are the characteristics of a typical MPA. The plate was to be attached beneath the patch in the perpendicular direction. The size of the patch was 80.5mm and 90mm, in length and width, respectively. A plate was attached beneath the reference, rectangular patch of 1.575GHz. The characteristics of the resonance frequency with respect to the changes of the attachment position and height of the plate, respectively, are displayed in Fig. 1. The attachment position of the plate was moved equidistantly by 10.2mm(0.05 λ, λ : wavelength, 190.5 mm) or one-eighth of the distance from the position ① to the position ⑨, which are at the far edge and near edge from the feed point of the reference patch, respectively. At each position, the resonance frequencies were measured as plate height was varied by 1 mm from 2mm to 8mm.
The measurement results showed that at each fixed position, the resonance frequency was decreased as the plate height was increased. We attribute it to the increase of current path beneath the patch due to the increase of the height of plate attached beneath the patch. When the height of the plate is fixed, the resonance frequency should be decreased by the same amount regardless of the attachment positions, because

the current path beneath the patch has increased by an equal distance.
However, the measurement results showed that the decline rate of the resonance frequency varied depending on the attachment position of the plate. The characteristic can be explained by the perturbation method[6], [7].



a. Structure



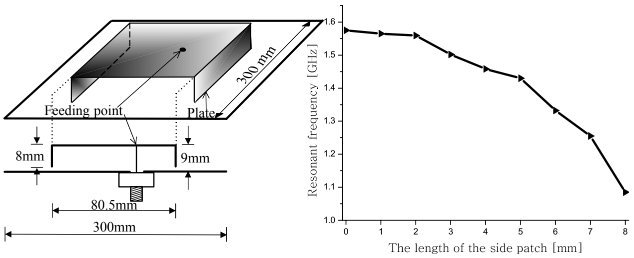
b. Measurement

Fig. 1: Variation of resonant frequency for various value of attached position(①~⑨) and height of plate

At positions ① and ⑨ where the electric fields are strong, the patch internally deforms more greatly by the increase of the plate height, resulting in a larger decline of the resonance frequency. At position ⑨(1.385GHz) near the feed point, the strong electric-field feed effect led to a larger decline of the resonance frequency compared to that at position ①(1.421 GHz). But, at position ⑤(1.56GHz) where the magnetic field is strong, a relatively smaller decline of the resonance frequency was observed, because the effect of the internal deformation by the magnetic field is combined with the effect of the elongation of the current path, where the resonance frequency is increased by the former while it is decreased by the latter as the plate height is increased.

B. Linear polarization folded microstrip antenna(LPFMA)

The commonly-used planar microstrip patch antennas have been fabricated, in order to make the comparison with the folded microstrip antenna that we proposed in this paper. The microstrip patch antenna was designed for 1.575GHz, using the 9mm foam as the dielectric with its dielectric constant =1.06, which is close to the dielectric constant of air.
The size of the ground surface was limited to 300mm × 300mm(1.575λ × 1.575λ) and the probe feeding was used. The area of the patch surface was 80.5mm(length) × 90mm(width). Return loss at the center frequency(1.575GHz) was measured to be -21dB, which showed a good impedance match characteristic, and -10dB bandwidth was 87MHz(5.5%).



a. Structure b. Variation of resonant frequency

Fig. 2: Variation of resonant frequency by the length of two plates on patch edges(measurement)

Based on the principles of Section **2-*A***, two plates are placed on both ends and the height(=h) of plates is increased their length up to 8mm by 1mm. And the change of the resonance frequency is measured. As a result, resonance frequency is reduced from 1.575GHz to 1.21GHz as the length of plates increases(Fig. 2).

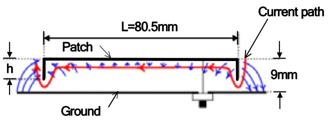
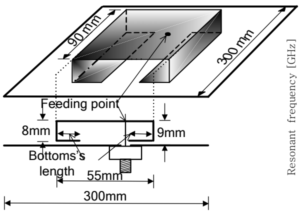


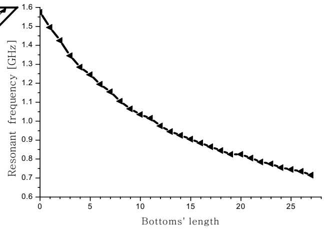
Fig. 3: The current path and electric field distribution

As shown in Fig. 3, the current path along the bottom surface of the antenna was increased by 4h(2h by each of the plate of height h), which enabled the reduction of the visible length.
In this structure, when the antenna is optimized by 1.575GHz, the antenna size(length 55mm × width 90mm × height 9mm) is reduced 31.7% to resonant length direction as shown in Fig. 4. Return loss is –30dB and –10dB bandwidth is 108MHz (6.86%). It is thought that this size reduction is resulted from the increase of the current path, fringing and perturbation effect by plates of both ends where the electric field is strong.
As shown in Fig. 4, for more effective miniaturization, the lower sides of two plates are outstretched toward the center of antenna, which is optimized(1.575GHz) above. Both bottoms are outstretched up to 27mm by 1mm, and the resonant frequency is measured, and the result is shown in Fig. 4, b.

When the lengths of two bottoms are 27mm, resonance frequency is reduced from 1.575GHz to 0.715GHz.
This characteristic can be also explained by the increase of the current path. The current length in this case is twice the length of the bottom surface. When the length of the bottom surface was 27mm, the increase of the current path was 108mm(27mm × 2 × 2), resulting in the 54.6% frequency reduction.

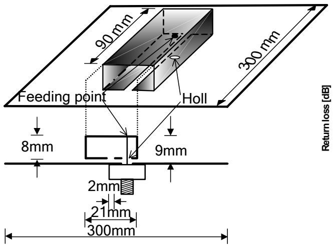


a. Structure

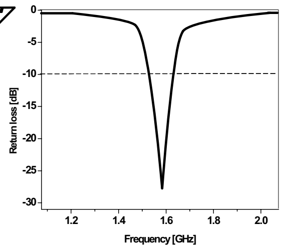


b. Variation of resonant frequency

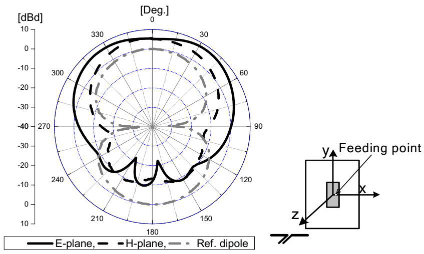
Fig. 4: Variation of resonant frequency by outstretching of bottoms' length(measurement)



a. Structure



b. Return loss



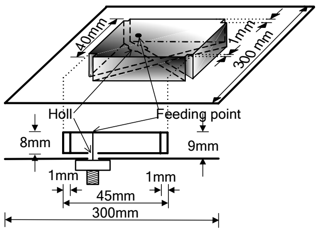
c. Radiation pattern

Fig. 5: LPFMA(measurement, 1.575GHz)

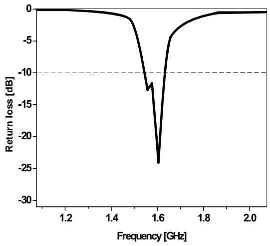
The finally designed LPFMA's structure and radiation pattern are shown in Fig. 5.
When this antenna is optimized by the same structure, the antenna size(length 21mm × width 90mm × height 9mm) shows a 73.9% reduction in the visible resonant length, and return loss is -27.6dB in the designed frequency. This antenna has a gain 5.12dBd, -10dB bandwidth is 64MHz(4%) and the HPBWs in the E-plane and H-plane are each 151°, 79.2°. The wider beam width in the E-plane compared with the planar antenna seems to be originated from the widening of the beam angle by the close-up of the two radiation ports caused by the shortening of the resonance length.

C. Triangle-shaped bottom circular polarization folded microstrip antenna(TSBCPFMA)

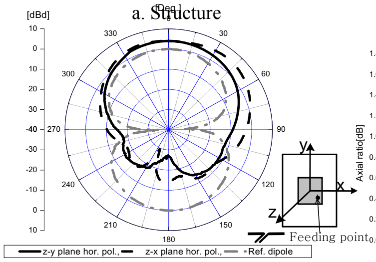
In this section, circular polarization folded microstrip antenna is designed and fabricated(at 1.575GHz). Fig. 6 shows the structure, return loss, radiation pattern and axial ratio of CPFMA.
To make the miniaturization of antenna, the triangle-shaped bottoms of the antenna are outstretched toward the center in four directions. The height from top to ground is 9mm, and the height from bottom to ground is 1mm. The antenna size (45mm × 40mm × height 9mm) is reduced by 71.5% when compared with the plane-type MPA(83mm × 76mm × height 9mm), and -10dB bandwidth of return loss is 84MHz(5.3%) at designed frequency of 1.575GHz, and the gain is 3.96dBd. HPBW is 80.6° in the horizontal polarization of the z-x plane, and 82.1° in the horizontal polarization of the z-y plane. The axial ratio is 1.2dB(1.575GHz) and 2dB axial ratio bandwidth is 8MHz.



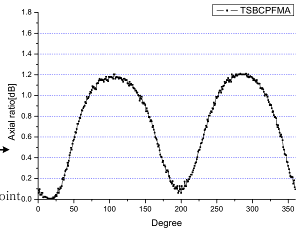
a. Structure



b. Return loss



c. Radiation pattern



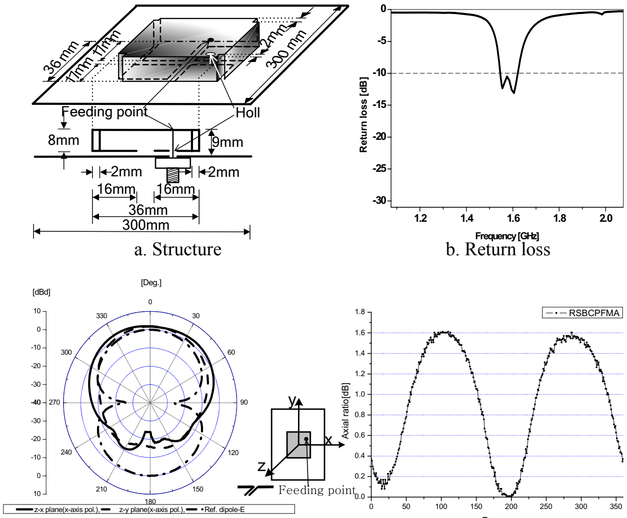
d. Axial ratio

Fig. 6: TSBCPFMA(measurement)

D. Rectangle-shaped bottom circular polarization folded microstrip antenna(RSBCPFMA)

Finally, circular polarization folded microstrip antenna is designed and fabricated(at 1.575GHz) by the same method. The rectangle-shaped bottoms of the antenna are used instead of the triangle-shaped bottoms to make the miniaturization of antenna more effective.

The antenna size(36mm × 36mm × height 9mm) is reduced by 79.5% as compared with the plane-type MPA(83mm × 76mm × height 9mm). -10dB bandwidth of return loss is 80MHz(5.1%, at 1.575GHz), and the gain is 2.56dBd. HPBW is 91° in the horizontal polarization of the z-x plane, and 124° in the horizontal polarization of the z-y plane.
The axial ratio is 1.61dB(1.575GHz) and 2dB axial ratio bandwidth is 10MHz.
For the clear comparison, both LPFMA and CPFMA (TSBCPFMA and RSBCPFMA) are compared with the plane type MPA, and all the characteristics are listed in Table 1.



a. Structure b. Return loss

c. Radiation pattern d. Axial ratio

Fig. 7: RSBCPFMA(measurement)

3. CONCLUSIONS

In order to miniaturize the rectangular MPA(1.575GHz), we dropped bending both end sides of the MPA and folded to the center of the antenna again. The LPFMA has a 73.9% reduction in the visible resonant length, and the triangle-shaped and rectangle-shaped CPFMA have 71.5% and 79.5% reductions in the visible size, respectively.
It is expected that the similar reduction rate as above is gained when a dielectric substance, such as ceramic which has a high dielectric constant, is adopted in the designed structure. Therefore, it has been confirmed that the folded microstrip antenna(FMA) is appropriate in miniaturization of microstrip antenna while it is keeping the fringing effect.

Table 1: The characteristics of MPA and FMA

		General MPA		FMA		
		Linear polarization	Circular polarization	LPFMA	CPFMA	
					TSBCPFMA	RSBCPFMA
Designed frequency		1.575 GHz				
Size [mm×mm]		80.5×90	76×83	21×90	40×45	36×36
Reduction ratio		Reference	Reference	73% (length)	71.5% (size)	79.5% (size)
Return loss		-28.3	-10.1	-27.6	-12.1	-10.5
-10 dB Bandwidth (MHz)		87(5.5%)	85(5.4 %)	64(4%)	84(5.3 %)	80(5.1%)
Gain(dBd)		8	4.2	5.12	3.96	2.56
-3 dB Beam-width (Deg.)	E-plane / z-x plane	E-plane	z-x plane (Hor. pol.)	E-plane	z-x plane (Hor. pol.)	z-x plane (Hor. pol.)
		57.6	56.2	151	80.6	91
	H-plane / z-y plane	H-plane	z-y plane (Hor. pol.)	H-plane	z-y plane (Hor. pol.)	z-y plane (Hor. pol.)
		67.7	66.2	79.2	82.1	124
Axial ratio(dB)			2.8		1.2	1.61
2 dB axial ratio Bandwidth (MHz)			25		8	10

Acknowledgments

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