Low-Profile Broadband Top-Loaded Triangular Antenna with Folded Rim

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Abstract **—** This paper presents the impedance matching technique and the bandwidth characteristics of a low-profile top-loaded triangular antenna with oblique shorting pins. The folded rim is arranged at the edge of the finite ground plane. The bandwidth diagrams for various antenna heights, finite sizes of the ground plane, and the widths of the folded rim are obtained through the moment-method simulation. The maximum bandwidth of 43 % is achieved with 0.05 λ height. For the low-profile configuration, the bandwidth of 17 % is obtained with 0.03 λ height.

Index Terms – Broadband, folded rim, low profile, moment method, and top-loaded triangular antenna.

I. INTRODUCTION

A radio-on-fiber system has been developed for enabling cellular mobile communication in radio-blind areas, such as highway tunnels and underground shopping malls [1]. A distributed antenna system consisting of coaxial cables and couplers has been specifically designed for use in the aforementioned radio-blind areas [2]. In an in-building antenna distribution system, the antenna is installed on the ceiling, and hence a low-profile antenna is preferred.

A top-loaded monopole antenna (TLMA) has been developed for use as a low-profile antenna. The TLMA that is arranged with a shorting cylinder or pins has a feature of low profile and vertical polarization antenna by exciting TM_{01} mode [3]. In typical example for the application of mobile communication, a disc-loaded monopole array antenna with electrically steerable beam has been proposed for diversity technique and reducing multipath or interference [4]. For bandwidth enhancement of the low-profile antenna, a triple-ellipse inverted-hat antenna has been proposed [5]. The bandwidth over 160 % can be achieved at an antenna height of 0.1 λ at the lowest frequency. For obtaining the TM_{01} mode with low-profile configuration, a disc-ring dielectric resonator antenna has been presented [6]. A 47 % bandwidth is achieved at an antenna height of 0.2 λ.

For achieving simple configuration, triangular or trapezoidal plates are used as the radiating elements for the TLMA [7]. Based on them, the TLMA was designed with clarified impedance-matching techniques showing the bandwidth characteristics of the TLMA with oblique shorting pins [8]. Moreover, the effects of a folded rim at the edge of a finite ground plane are also clarified to reduce the antenna height for the low-profile TLMA [9]. However, the optimum width of the folded rim has not been obtained at each size of the ground plane when the antenna height is less than 0.05 λ.

This paper presents the impedance matching and bandwidth characteristics of the low-profile top-loaded triangular antenna (TLTA) on a finite ground plane. To clarify the effect of the folded rim to the bandwidth enhancement at various antenna heights, the moment-method simulation is employed. And, the bandwidth diagrams for various sizes of the ground plane and the widths of the folded rim are investigated when the antenna height is less than 0.05 λ.

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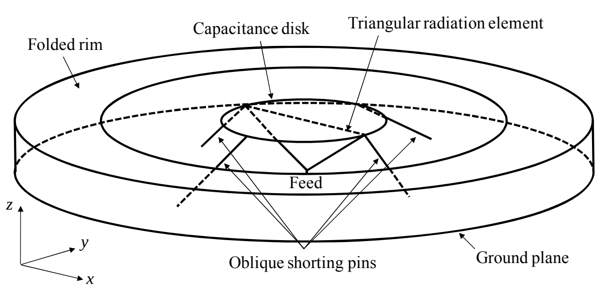
II. IMPEDANCE MATCHING TECHNIQUE USING OBLIQUE SHORTING PINS

Figure 1 shows the configuration and structural parameters of the TLTA with the folded rim. The TLTA comprises a triangular radiation element, a top-loaded capacitance disk, and oblique shorting pins on a finite ground plane as shown in Fig. 1 (a). Since the proposed antenna is fed against a ground plane at a center feed point, the antenna is operated as a monopole [10]. The antenna model has been designed using the electromagnetic simulation based on the moment method. The TLTA is designed to operate at a frequency of 2 GHz. The conductor thicknesses of the finite ground plane and side walls are 1.0 mm and 0.2 mm, respectively. The conductor thicknesses of the disk and the radiation element are 0.6 mm each. Wires of radius 0.5 mm are used as shorting pins. R_g is the radius of the finite ground plane and h is the height of antenna. The height of the rim is equal to h, while L_{ring} is the width of the upper part of the folded rim.

Figure 2 shows the optimum parameters for the impedance matching of the TLTA with four shoring pins. Usually, the location of the arrangement of the shorting pins affects the impedance matching of the TLTA. The oblique angle of the shorting pins is added as the structural parameters for impedance matching of the low-profile TLTA. D_x and D_y are the oblique angles that are inclined to x and y axes, respectively. R_g, D_x and D_y increase as h decreases and, D_x and D_y are separately tuned.



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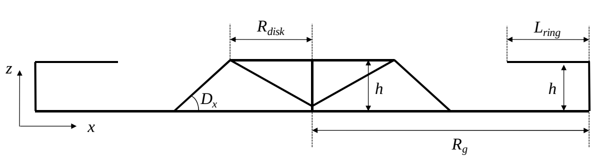

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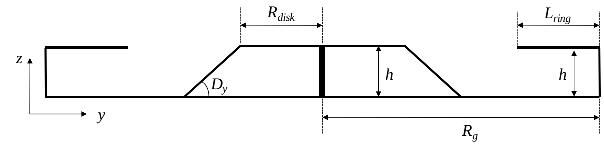

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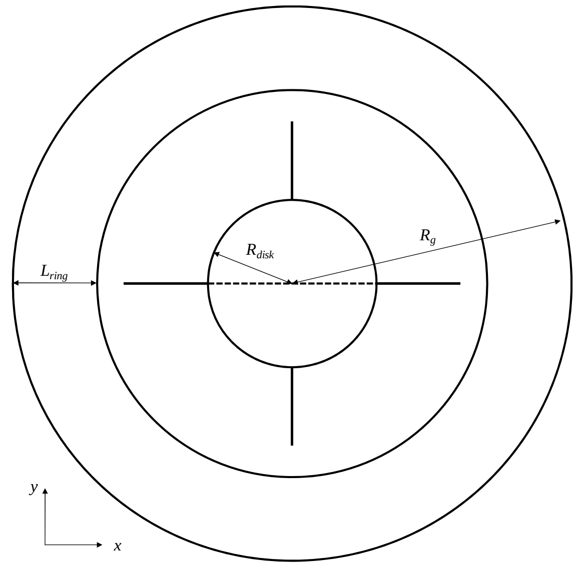

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Fig. 1. Configuration of a top-loaded triangular antenna with folded rim from a (a) perspective view, (b) side view in the *ZX* plane, (c) side view in *YZ* plane, and (d) top view in *XY* plane.

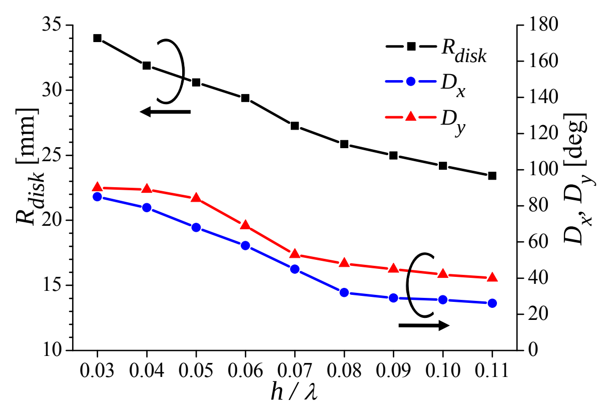


Fig. 2. Optimum parameters for impedance matching of the top-loaded triangular antenna without a folded rim.

III. LIMITATION OF BANDWIDTH ENHANCEMENT USING SIDE RIM

The side rim installed at the edge of the finite ground plane is designed for broadband at the low profile. The folded rim is eliminated from the configuration of the TLTA model as shown in Fig. 1. Figure 3 shows the S_{11} characteristics of the TLTA with/without the side rim at $h = 0.1\lambda$ and $R_g = 0.55\lambda$. The resonant frequency of the TLTA without the side rim is 1.8 GHz. When the side rim is installed, dual resonance is observed at 1.7 GHz and 2.1 GHz, and is expected to achieve broadband characteristics.

Figure 4 shows the bandwidth diagrams for various heights of the side rim and radius of the finite ground plane. The bandwidth is calculated for VSWR $\leq$ 2. The effect of the side rim is pronounced at $R_g = 0.44\lambda$. A sharp variation in the bandwidth is observed when $h = 0.04$-0.1λ, and this variation becomes maximum at $h = 0.07\lambda$. However, the variation in the bandwidth observed at $R_g = 0.48\lambda$ is less than that observed at $R_g = 0.44\lambda$. The maximum bandwidth appears at $h = 0.1\lambda$. Moreover, it shows little effect when $R_g = 0.56\lambda$. In other words, the effect of the side rim is suppressed with an increase in the size of the finite ground plane. Therefore, the bandwidth more than 45 % is observed at $0.07\ \lambda < h < 0.1\ \lambda$. When the antenna height is less than 0.04 λ, impedance matching cannot be achieved.

Figure 5 shows the maximum bandwidth characteristics of the TLTA with/without the side rim when h is varied. Both maximum bandwidth increases as h increases. The maximum bandwidth of the TLTA with the side rim becomes 13 % broader than that without the side rim at around $h = 0.1\lambda$. The arrangement of the side rim becomes less effective as h decreases and has no effect at $h < 0.04\ \lambda$.

IV. BANDWIDTH ENHANCEMENT FOR LOW-PROFILE ANTENNA USING FOLDED RIM

To achieve the broadband characteristics at $h \leq 0.05\ \lambda$, the folded rim is arranged at the edge of the TLTA, and its effect is examined. Figure 6 shows the S_{11} characteristics at $h = 0.05\ \lambda$. The first resonant frequency at around 1.7 GHz becomes the lower frequency as L_{ring} increases. And L_{ring} affects the impedance matching for the second resonant frequency at around 2.3 GHz. Since the maximum bandwidth can be obtained from the optimum radius of the finite ground plane as shown in Fig. 5, R_g and L_{ring} are adjusted to achieve broadband characteristics for the TLTA with folded rim.

Figure 7 shows the current distributions of the TLTA with the folded rim at $h = 0.05\ \lambda$ and $L_{ring} = 0.14\ \lambda$. The currents at the feeding triangular element and the folded rim flow in phase at the lower resonant frequency of 1.85 GHz and out of phase at the higher resonant frequency of 2.45 GHz, respectively.

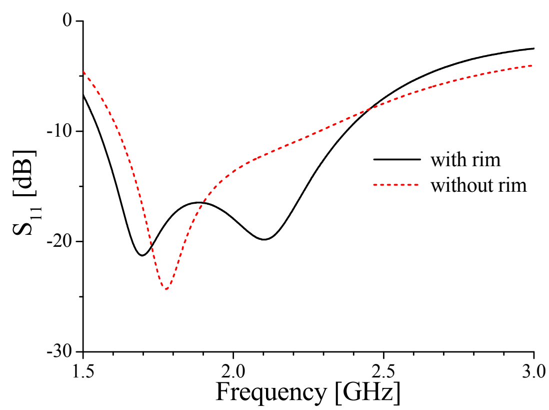


Fig. 3. The S_{11} characteristics of top-loaded triangular antenna with/without side rim.

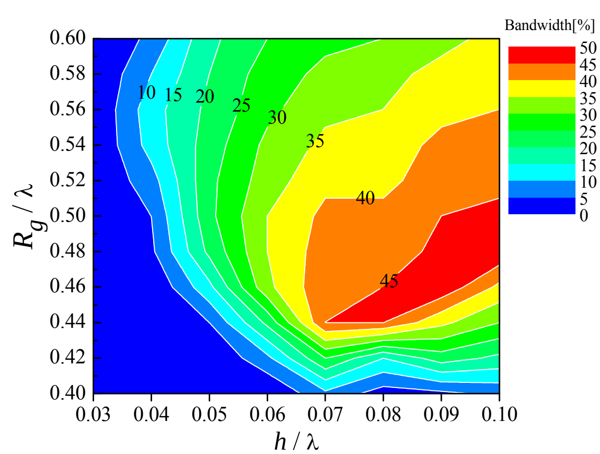


Fig. 4. Bandwidth characteristics of the top-loaded triangular antenna with side rim, when h and R_g are varied.

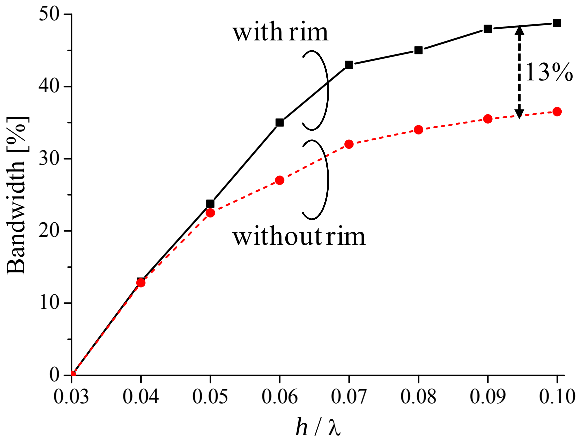


Fig. 5. Maximum bandwidth characteristics of the top-loaded triangular antenna with side rim when h is varied.

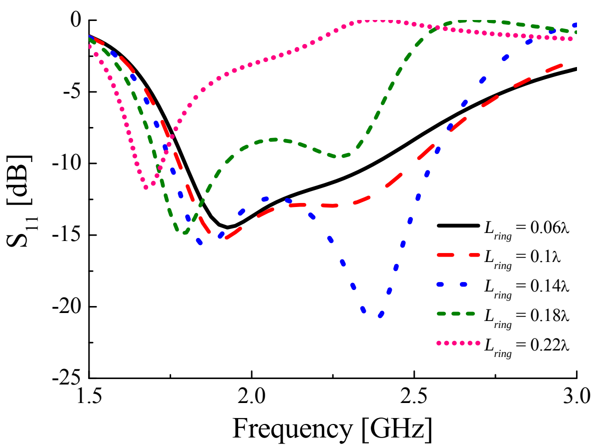
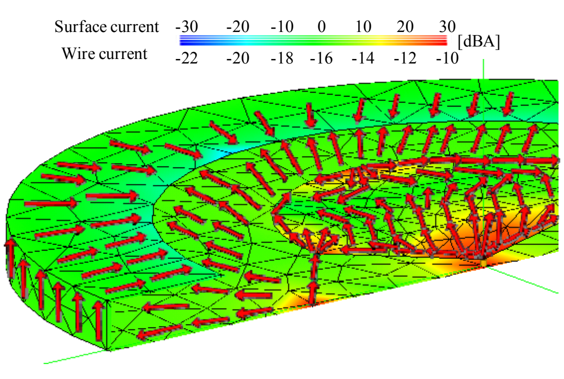


Fig. 6. The S_{11} characteristics of the top-loaded triangular antenna with folded rim at h = 0.05 λ.



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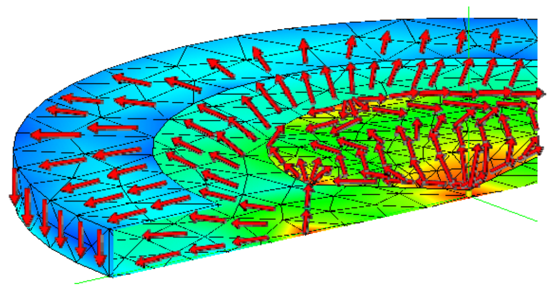
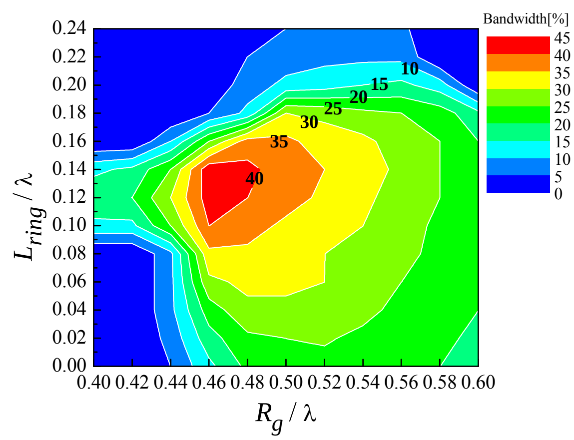


(b)

Fig. 7. Current distributions of the top-loaded triangular antenna with a folded rim at h = 0.05λ for (a) 1.85 GHz and (b) 2.45 GHz.

Figure 8 shows the bandwidth characteristics for the variable R_g, L_{ring}, and h. After adjusting R_g and L_{ring} at each h, the maximum values of the bandwidth are 43 %, 31 %, and 17 % at h = 0.05λ, 0.04 λ, and 0.03 λ, respectively. In addition, optimum values of L_{ring} can be selected only on a narrow range when R_g is small. The effect of L_{ring} becomes insensitive as R_g increases.



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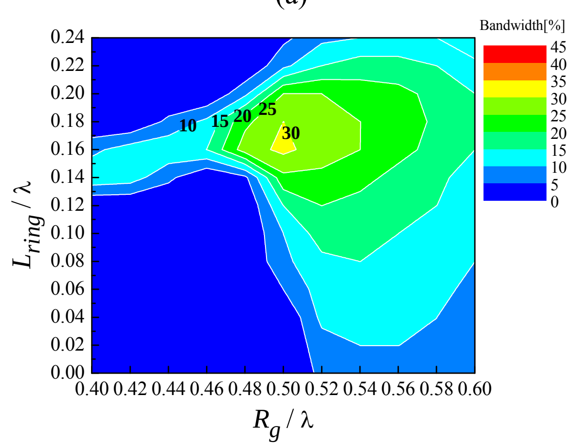

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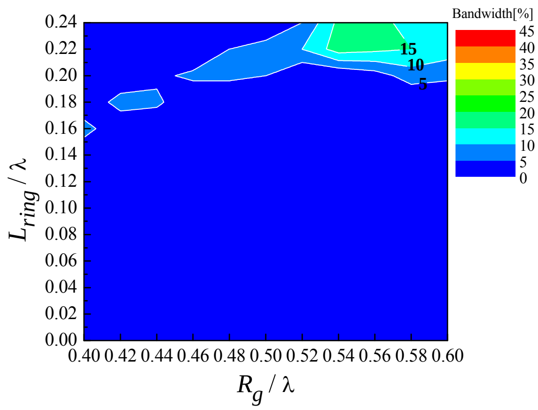

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Fig. 8. Bandwidth characteristics of the top-loaded triangular antenna with folded rim when R_g and L_{ring} are varied at (a) h = 0.05 λ, (b) h = 0.04 λ, and (c) h = 0.03 λ.

V. EXPERIMENT

Figure 9 shows the photograph of the fabricated TLTA with folded rim at h = 0.03λ. Figure 10 shows the simulated and measured VSWR characteristics of the TLTA with folded rim at h = 0.05 λ, 0.04 λ, and 0.03 λ. Measured bandwidths are 42.75 %, 29.25 %, and 18.75 % at h = 0.05 λ, 0.04 λ, and 0.03 λ, respectively. The simulated and measured results agree well. Figures 11 and 12 show the simulated and measured radiation patterns of the TLTA with the folded rim on the vertical (ZX) and horizontal (XY) planes. Radiation pattern is similar to the monopolar radiation with small sized ground plane. The maximum measured gain at the center frequency are 4.25 dBi and 3.17 dBi at h = 0.05λ and 0.03λ, respectively. The omni-directional pattern is confirmed on the horizontal plane. The simulated and measured results agree well.

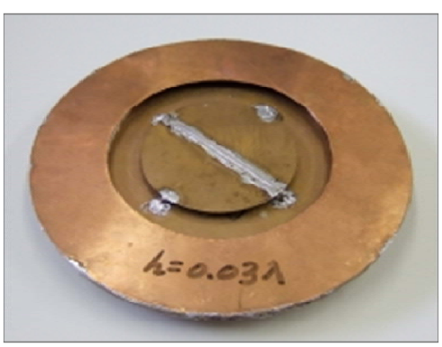


Fig. 9. Photograph of the fabricated top-loaded triangular antenna with folded rim at h = 0.03λ.

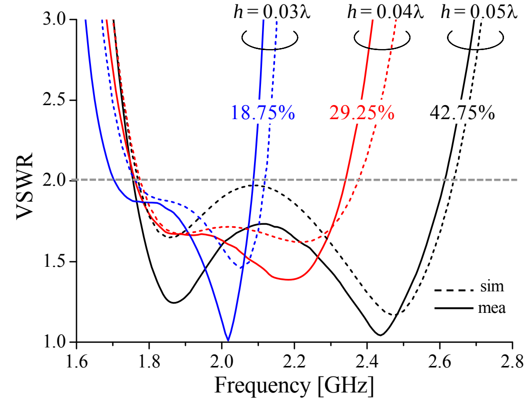
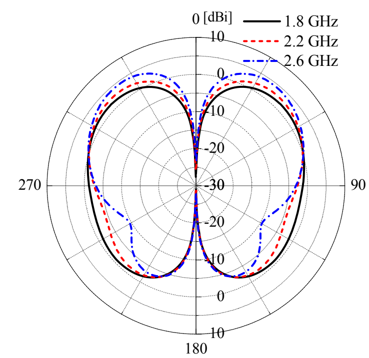


Fig. 10. Simulated and measured VSWR characteristics of the TLTA with folded rim at h = 0.05 λ, 0.04 λ, and 0.03 λ.



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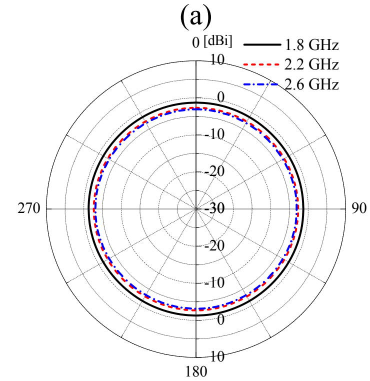

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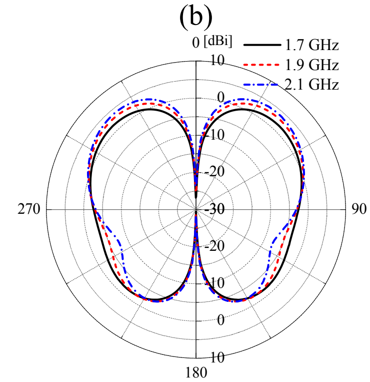

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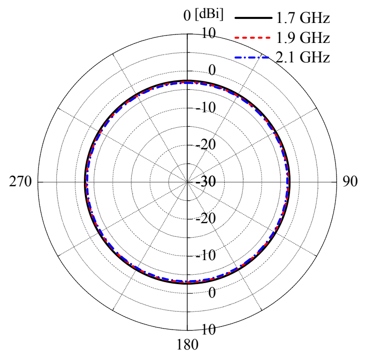
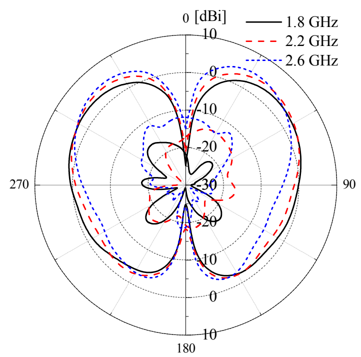


(d)

Fig. 11. Simulated radiation patterns of the top-loaded triangular antenna with folded rim on the (a) vertical and (b) horizontal planes at $h = 0.05\ \lambda$ and on the (c) vertical and (d) horizontal planes at $h = 0.03\ \lambda$.



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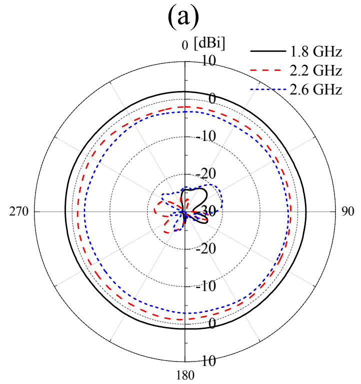

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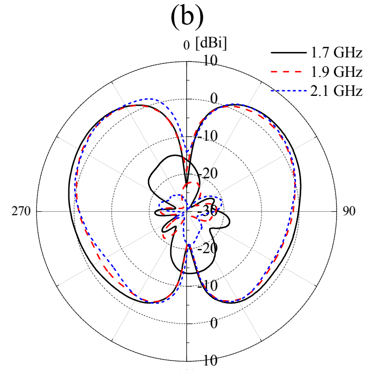

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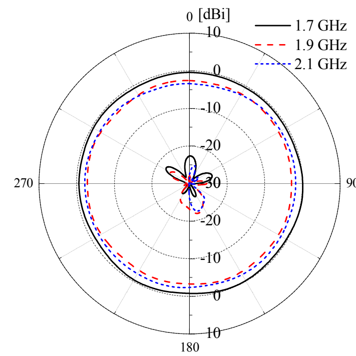

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Fig. 12. Measured radiation patterns of the top-loaded triangular antenna with folded rim on the (a) vertical and (b) horizontal planes at $h = 0.05\ \lambda$ and on the (c) vertical and (d) horizontal planes at $h = 0.03\ \lambda$.

VI. CONCLUSION

This paper presents the impedance matching technique and the bandwidth characteristics of the low-profile TLTA with the folded rim. The impedance matching can be achieved by selecting the optimum parameters of the capacitance disk and the oblique shorting pins. When the folded rim is arranged, the maximum bandwidth of 43 %, 31 %, and 17 % can be achieved at $h = 0.05\ \lambda$, $0.04\ \lambda$, and $0.03\ \lambda$, respectively.

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