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THE DESIGN OF A DUAL-POLARIZED SMALL BASE STATION ANTENNA WITH HIGH ISOLATION HAVING DIELECTRIC FEEDING STRUCTURE

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Abstract—A dual-polarized small base station antenna with a dielectric feeding structure is presented. The proposed antenna is composed of a micro-strip feed line board, eight metallic shorting plates, four dielectric feed substrates, four metallic radiators, a metallic cube, and a radome. A wide impedance bandwidth of 20% (2.45 to 3.0 GHz) is achieved. The proposed antenna has an isolation of greater than 50 dB over the operating bandwidth. Details of the proposed antenna design, and the simulated and measured results are presented and discussed.

1. INTRODUCTION

As a variety of wireless communication technologies such as 2G, 3G, and 4G are developed, the number of base stations (BS) and antennas is increasing with the development of such wireless communication technologies, with increasing sizes and costs of the radio frequency (RF) and antennas. Beyond 4G (B4G) mobile communication technology effectively provides a variety of services, including high-quality mobile multimedia and M2M services. In addition, the space-time traffic variation is flexibly accommodated. B4G mobile communication technology is an energy-efficient next-generation mobile communication technology providing a high transmission capacity of more than 10 times greater than in 4G mobile communication.

B4G mobile communication technology is required by a single base station, as well as by a micro-miniature base station in which small

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size and economic and environmental friendly concept are considered. Since a micro-miniature base station does not require the existing base station which is complicated and in which the volume is large, an installation area is not required, power loss caused by a transmission line minimized, and low power consumption and application of the coordinated multi-points are achieved. In addition, owing to its small size, the micro-miniature base station may be installed anywhere power sources and the Internet are connected with each other, such as the fronts of buildings, and at bus-stops, and telephone poles, and street lights. The core technology of a micro-miniature base station is RF technology, and the antennas are built in a single small cube to thereby miniaturize the base station [1]. In particular, miniaturization of the antenna is the most important element.

Recently, many researchers have developed base station antenna with dual-polarization [2–20]. However, the size of the published base station antenna is large, and it is impossible to mount it on a metallic cube. Dual-polarized antenna that uses an electric and magnetic field to increase the channel capacity is used, but it is difficult to configure two antennas within a metallic cube having spatial constraints instead of free space. When the antenna is inserted into a metallic cube, the boundary conditions cause changes in antenna features. There are problems in which the bandwidth becomes narrower, and the gain and efficiency are lowered. In this paper, we modify a dual polarized dipole antenna with dielectric loading [2]. The proposed BS antenna uses a printed dielectric substrate instead of dielectric filling, and manufacture is easier than another published antenna in [2]. In addition, the size of the antenna is smaller, and the proposed base station antenna may obtain the most excellent isolation feature.

In this article, we propose a method to reduce the size of a BS antenna and improve the matching using a dielectric feeding structure. The design procedure is as follows. First, we design a single-element linearly polarized antenna with a metallic cube. Second, based on a single-element linearly polarized antenna, a dual-polarized antenna with a metallic cube is designed and implemented. The antenna is operated from 2.45–3.08 GHz with a bandwidth of 23% ($|S_{11}| < -10\,\text{dB}$) and from 2.45 –3.0 GHz with a bandwidth of 20% ($|S_{11}| < -10\,\text{dB}$) for ports-1 and 2, respectively. The measured isolation of the proposed antenna is better than 50 dB over the operating bandwidth. Although the small BS antenna is inserted inside a metallic cube, the antenna obtains a wide bandwidth and isolation and high gain.

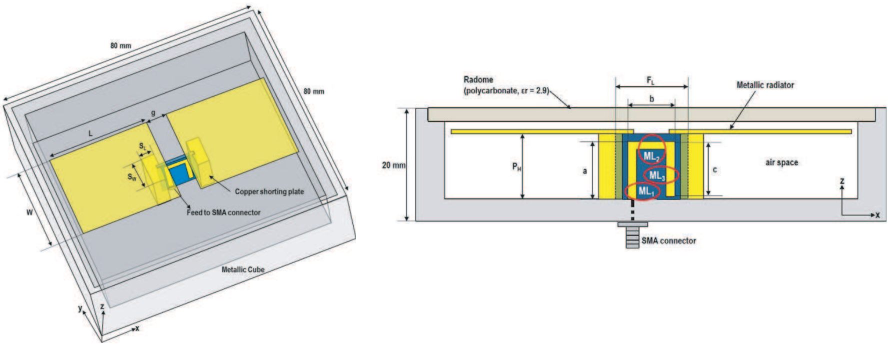
2. SINGLE ELEMENT LINEARLY POLARIZED ANTENNA

2.1. Geometry of a Single-element Linearly Polarized Antenna

The geometry of a single-element linearly polarized antenna operated at 2.6 GHz and its detailed dimensions are shown in Figure 1. The proposed antenna is composed of two metallic radiators (dipole element), two metallic shorting plates, a dielectric feed substrate, a metallic cube, and a radome. A dielectric feed substrate used FR-4 ($\varepsilon r = 4.4$; $\tan\delta = 0.025$) with a thickness of 0.8 mm.

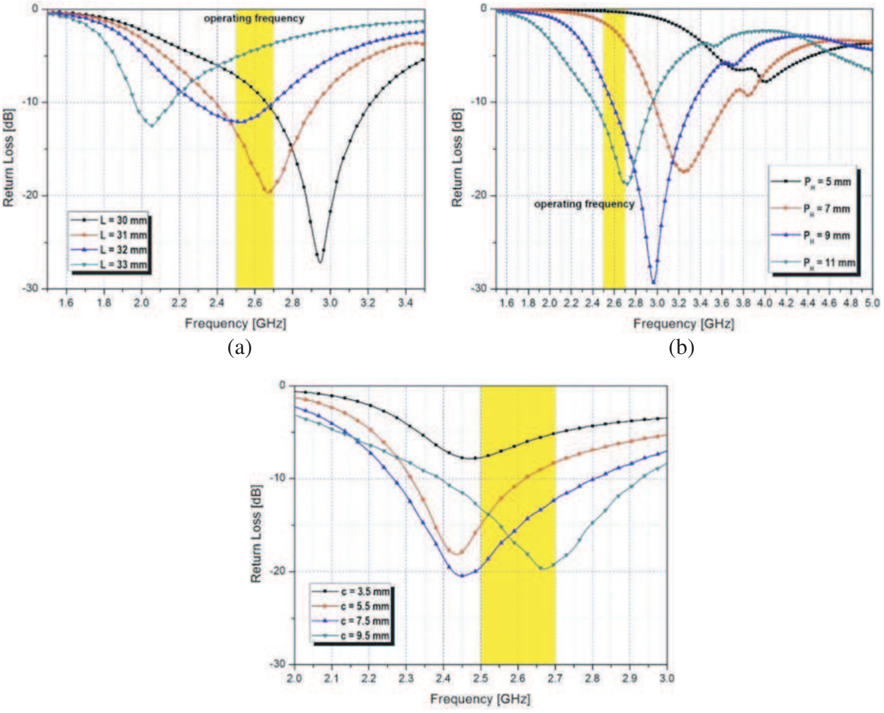
Each metallic radiator is connected to a metallic shorting plate. To fix the dielectric feed substrate, we cut a groove into a metallic shorting plate. The two metallic radiators operate as a dipole element. ML_1 of a micro-strip feed line is vertically connected to an SMA connector. The electrical energy is transmitted from the SMA connector to $\mathrm{ML}_{1,\,2}$ and $_3$. ML_2 is oriented horizontally and has one end connected to ML_3. A dipole element is excited by ML_2 of the dielectric feed substrate. The proposed antenna induces the coupling feature of the dipole element and dielectric feed substrate and expands the bandwidth. The radome uses a polycarbonate ($\varepsilon r = 2.9$, $\tan\delta = 0.009$). The optimal parameters can be chosen as $W = 31\,\mathrm{mm}$, $L = 31\,\mathrm{mm}$, $S_L = 4\,\mathrm{mm}$, $S_W = 10\,\mathrm{mm}$, $P_H = 11\,\mathrm{mm}$, $g = 6\,\mathrm{mm}$, $a = 10\,\mathrm{mm}$, $b = 8\,\mathrm{mm}$, $c = 9.5\,\mathrm{mm}$, and $F_L = 12\,\mathrm{mm}$ based on an extensive simulation using Ansys HFSS.

We study the effects of the antenna geometry (L, P_H, and c). The



(a) (b)

Figure 1. Geometry of a single-element linearly polarized antenna: (a) 3D and (b) side views.



(a) (b)

(c)

Figure 2. The effects of a geometry change: (a) L, (b) P_H, and (c) c.

effects of a horizontal metallic patch size (L) on the return loss are shown in Figure 2(a). From the figure, as the length of the metallic patch size increases, the operating frequency band moves to a lower frequency band, and the degree of impedance matching worsens. The effects of the antenna height (P_H) and feed length (c) of the dielectric feed substrate on the return loss are shown in Figures 2(b) and 2(c), respectively. As the antenna height (P_H) increases, the operating frequency band moves to a lower frequency. The feed length (c) of the dielectric feed substrate is related to the frequency band shift and antenna matching.

2.2. Experimental Results of a Single-element Linearly Polarized Antenna

Figure 3 shows the measured return losses. The proposed antenna was measured using an Anritsu Vector Network Analyzer (37397C) in an anechoic chamber.

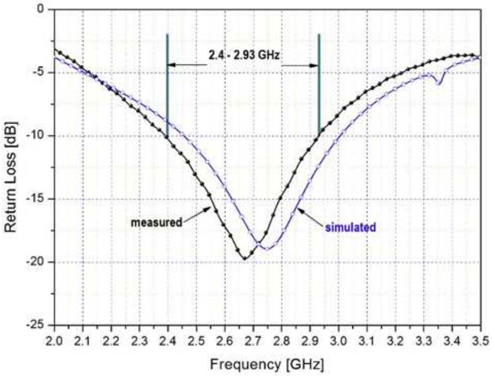


Figure 3. Measured and simulated return losses of the proposed antenna.

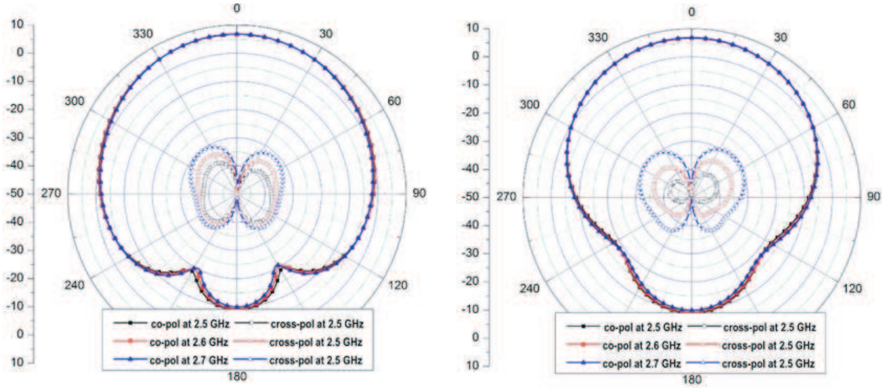
The antenna is operated from 2.4 to 2.93 GHz with a bandwidth of about 19.8%. The measured and simulated results are slightly different. In the simulation, the dimension of the antenna structure was ideal, and the loss of the coaxial feed cable was not considered.

Figure 4 shows the measured radiation patterns of the proposed antenna. The antenna gain and radiation patterns were measured in the middle range using an Agilent E5071C antenna measurement system. The measured radiation patterns at 2.5, 2.6, and 2.7 GHz are shown in Figure 4. Stable measured peak with antenna gains of about 6.5 dBi at 2.5 GHz, 6.6 dBi at 2.6 GHz, and 6.7 dBi at 2.7 GHz were obtained. The antenna is radiated towards the broadside with symmetrical radiation patterns in the xz and yz-planes. The cross polarization levels are less than -30 dB across the operating frequency range. The measured 3 dB beam-widths in the xz-plane are 91° at 2.5 GHz, 87° at 2.6 GHz, and 83° at 2.7 GHz. The measured 3 dB beam-widths in the yz-plane are 76.8° at 2.5 GHz, 76.8° at 2.6 GHz, and 76.2° at 2.7 GHz.

3. DUAL-POLARIZED ANTENNA WITH A DIELECTRIC FEED STRUCTURE

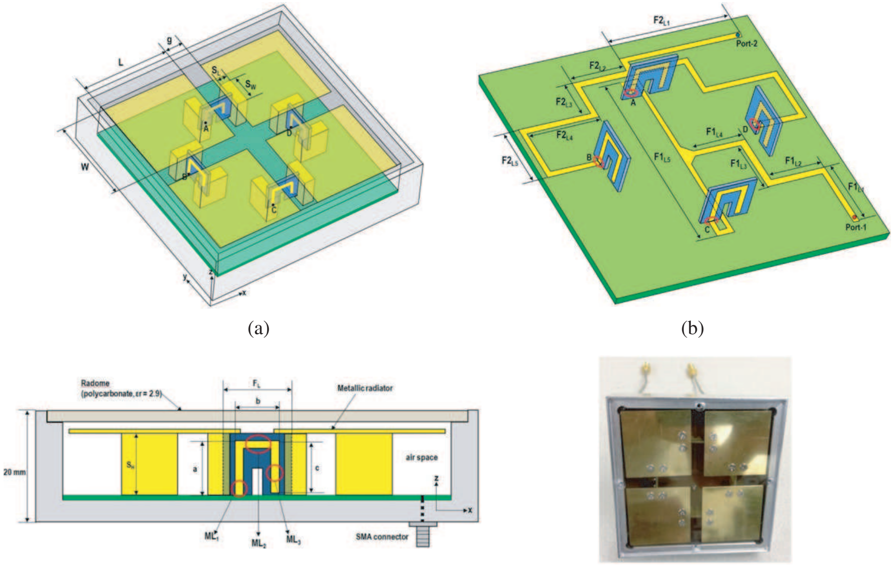
3.1. Geometry of a Dual-polarized Antenna with a Dielectric Feed Structure

Based on the previous linearly polarized antenna design, a dual-polarized antenna operated at 2.6 GHz was designed and implemented. Figure 5 shows a dual-polarized antenna with a dielectric feed



(a) (b)

Figure 4. Radiation patterns of the proposed antenna: (a) xz-plane and (b) yz-plane.



(a) (b) (c) (d)

Figure 5. The proposed base station antenna: (a) a 3D view, (b) feed structure, (c) side view, and (d) photograph.

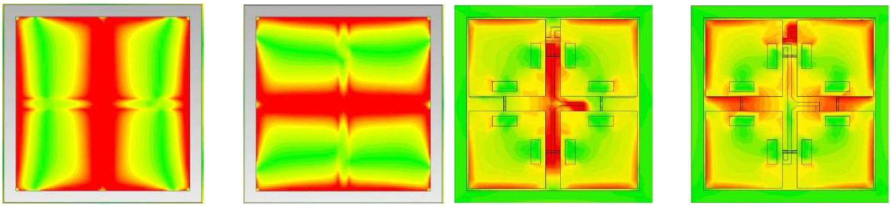
substrate. The size of the metallic cube is $70 \times 70 \times 20\,\text{mm}^3$, and the four metallic radiators placed orthogonal to each other are positioned inside the metallic cube.

The proposed antenna is composed of four metallic radiators and a dielectric feed substrate, eight metallic shorting plates, a micro-strip feed line board (FR-4, $\varepsilon r = 4.4$; $\tan\delta = 0.025$), a metallic cube, and a radome (Polycarbonate, $\varepsilon r = 2.8$; $\tan\delta = 0.009$). The antenna is located symmetrically with respect to the center and mounted into a metallic cube. The metallic cube with a thickness of 5 mm improves the radiation pattern of the proposed antenna. The bottom of the antenna is fully filled with the dielectric substrate. All micro-strip feed lines (width = 1.5 mm) are designed to have an input impedance of 50 Ω. A micro-strip feed network, printed on a printed feed line board with a thickness of 0.8 mm, is located on the surface of the metallic cube. Points A, B, C, and D, shown in Figures 5(a) and 5(b), are the connection points between the dual-polarized antenna and micro-strip feed line network. Four dielectric feeds are directly connected to the microstrip feed line network. The dielectric feeds at points A and C are excited with the same phase by the micro-strip feed line network, which is connected to a SMA connector (port-1). The dielectric feeds at points B and D are excited with the same phase by another micro-strip feed line network, which is connected to another SMA connector (port-2). Each metallic radiator is connected by a metallic shorting plate. To fix the dielectric feed substrate, we cut a groove into the metallic shorting plate. A pair of metallic radiators operates as a two-dipole element (vertical yz-plane and horizontal xz-plane). The excited energy from the SMA connector is transmitted to ML$_{1,2}$ and $_3$. ML$_2$ is oriented horizontally and has one end connected to ML$_3$. Dipole elements are excited by ML$_2$ of the dielectric feed substrates. The proposed antenna induces the coupling feature of the dipole element and dielectric feed substrate and expands the bandwidth. The detailed design dimensions of the antenna are given in Table 1.

To elucidate if the orthogonal radiations are emitted mainly from the metallic patch, the electric field and current distribution for both feeding ports at 2.6 GHz are shown in Figure 6. Ignoring the feeding line of both ports and the coupled radiation found at the center of the metallic cube, the radiating metallic patch is the main resonator for the orthogonal radiations at boresight direction.

Table 1. The dimensions of the proposed antenna [mm].

L	W	g	S_L	S_W	$F1_{L1}$	$F1_{L2}$	$F1_{L3}$	$F1_{L4}$	$F1_{L5}$
31	31	6	4	10	18.5	18	11.5	9.5	48
$F2_{L1}$	$F2_{L2}$	$F2_{L3}$	$F2_{L4}$	$F2_{L5}$	a	b	c	F_L	S_H
30	14.1	9.5	18.5	15	10	8	9.5	12	11



(a) (b) (c) (d)

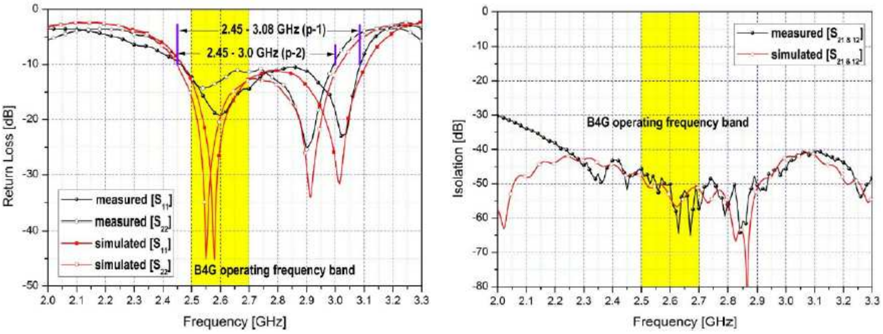
Figure 6. Simulated electric field and current distribution at 2.6 GHz for port-1 and port-2: (a) electric field (port-1), (b) electric field (port-2), (c) current distribution (port-1), and (d) current distribution (port-2).

3.2. Experimental Results of a Dual-polarized Antenna with a Dielectric Feed Structure

The measured return loss, isolation, radiation patterns, and gain of the proposed antenna are shown in Figures 7, 8, and 9, respectively.

Figure 7 shows the measured and simulated results of the return loss and isolation. The antenna is operated from 2.45 to 3.08 GHz with a bandwidth of 23% ($|S_{11}| < -10\,\text{dB}$), and from 2.45 to 3.0 GHz with a bandwidth of 20% ($|S_{11}| < -10\,\text{dB}$) for ports 1 and 2, respectively. Agreement between the simulation and measurement is achieved. The impedance bandwidth obtained is wide enough to cover B4G systems. The measured isolation between the two ports of the proposed antenna is better than 50 dB over the frequency band.

The measured and simulated radiation patterns of the proposed antenna for ports 1 and 2 at 2.5, 2.6, and 2.7 GHz are shown in Figures 8 and 9, respectively. The proposed antenna was measured

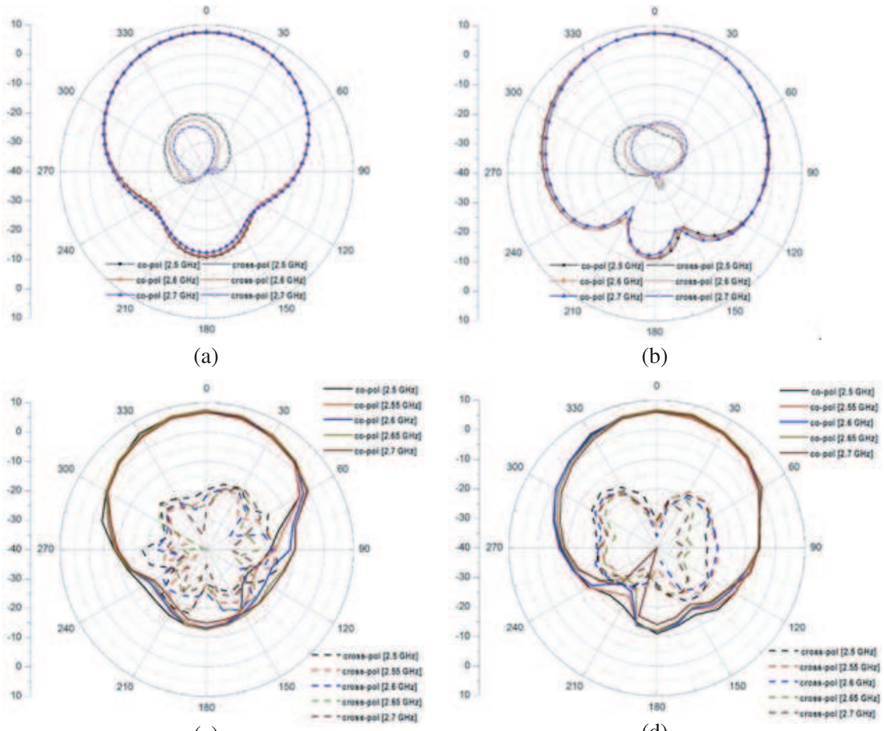


(a) (b)

Figure 7. Measured and simulated results of the proposed antenna: (a) return loss, and (b) isolation.

radiation patterns in the frequency band of B4G systems. The antenna gain and 3-dB beam-width of the proposed antenna are provided in Figure 10, Tables 2, and 3.

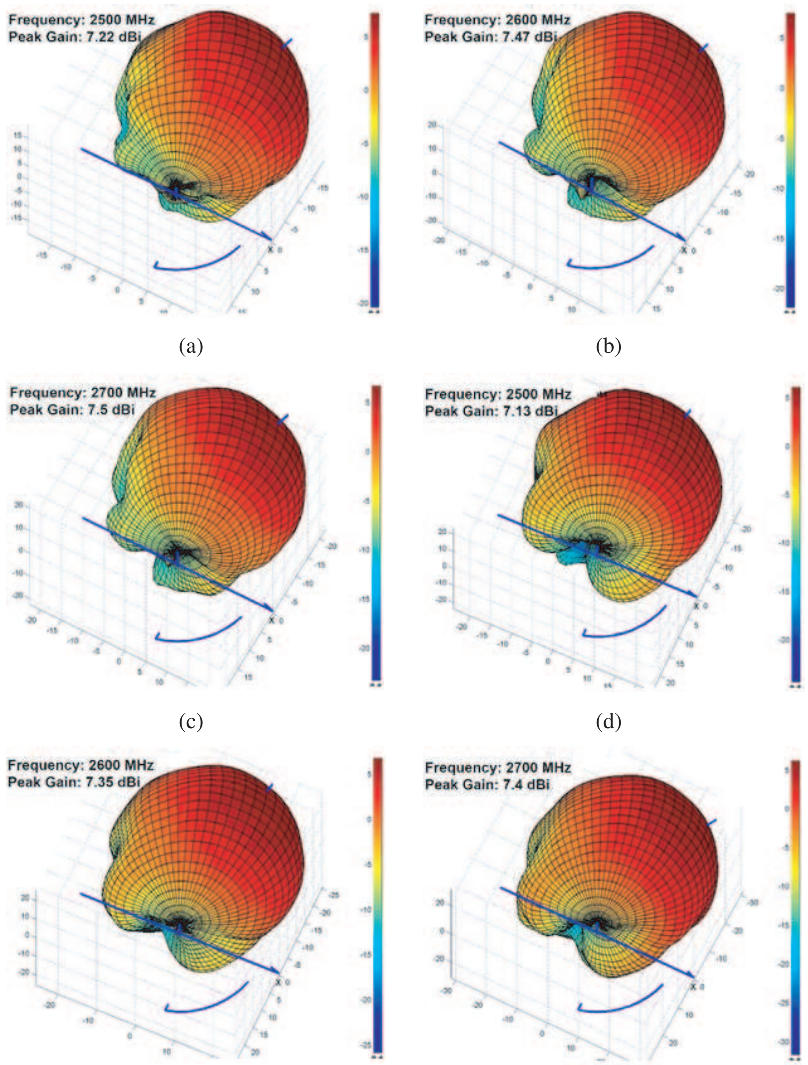
Figure 8 shows the measured and simulated radiation patterns of the proposed antenna for ports 1 and 2. The measured 3-D patterns of the antenna for ports 1 and 2 are shown in Figure 9. Experimental results of the radiation patterns were obtained in an anechoic chamber (7 m) at the Daedeok Radio Engineering Center, Daejeon, Korea. The antenna gain and radiation patterns were measured in the middle range using an Agilent E5071C antenna measurement system. The simulated and measured results show a reasonable agreement. The antenna has stable radiation patterns and low back lobes across the entire bandwidth.



(a) (b)

(c) (d)

Figure 8. Simulated and measured radiation patterns of the proposed antenna: (a) simulated yz-plane at port-1, (b) simulated yz-plane at port-2, (c) measured yz-plane at port-1, and (d) measured yz-plane at port-2.



(a) (b)

(c) (d)

(e) (f)

Figure 9. Measured 3-D patterns of the proposed antenna: (a) port-1 at 2.5 GHz, (b) port-1 at 2.6 GHz, (c) port-1 at 2.7 GHz, (d) port-2 at 2.5 GHz, (e) port-2 at 2.6 GHz, and (f) port-2 at 2.7 GHz.

Figure 10 shows the measured base station gain and efficiency. From the figure, the measured gain varies from 7.22 to 7.5 dBi at port-1 and from 7.13 to 7.3 dBi at port-2 over the operating frequency range for B4G systems. The measured antenna efficiency varies from 85 to

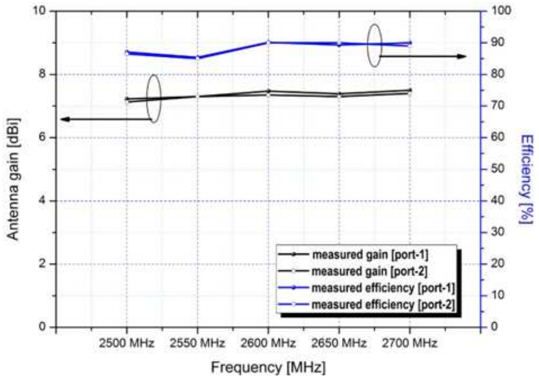


Figure 10. Measured antenna gain and efficiency.

90% over the operating frequency range.

As shown in Table 4, in spite of existing inside the metallic cube, the proposed antenna size is much smaller than that in [2]. The proposed base station antenna has a wider bandwidth than that in [2], and isolation feature is very high.

Table 2. Simulated 3-dB beam-width and gain.

Freq. [GHz]	*yz*-plane				*xz*-plane			
	beamwidth		Gain [dBi]		beamwidth		Gain [dBi]	
	P-1	P-2	P-1	P-2	P-1	P-2	P-1	P-2
2.5	73°	83°	6.5	6.6	84°	73°	6.5	6.6
2.6	72°	80°	6.7	6.7	80°	72°	6.7	6.7
2.7	72°	76°	6.9	6.9	75°	72°	6.9	6.9

Table 3. Measured 3-dB beam-width and gain.

Freq. [GHz]	*yz*-plane				*xz*-plane			
	beamwidth		Gain [dBi]		beamwidth		Gain [dBi]	
	P-1	P-2	P-1	P-2	P-1	P-2	P-1	P-2
2.5	76°	85°	7.22	7.13	85°	76°	7.22	7.13
2.6	75°	83°	7.47	7.35	83°	75°	7.47	7.35
2.7	75°	80°	7.5	7.4	80°	75°	7.5	7.4

Table 4. Comparing proposed antenna with reference [2].

	Modified proposed antenna	Ref. [2]
Antenna size	70 mm × 70 mm × 12 mm	130 mm × 130 mm × 24 mm
Antenna bandwidth	2.45 – 3.0 GHz (BW = 550 MHz)	1.65 – 2.12 GHz (BW = 470 MHz)
Antenna isolation	50 dB	30 dB
Antenna peak gain	7.47 dBi	8.2 dBi
Feed structure	Printed dielectric substrate	Filled dielectric

4. CONCLUSION

A dual-polarized small base station antenna with a dielectric feed structure for B4G systems has been designed and experimented upon. A wide bandwidth, high isolation, low cross polarization level, and stable antenna gain over the operating frequency band were achieved. The antenna is operated from 2.45 to 3.08 GHz with a bandwidth of 23% ($|S_{11}| < -10\,\text{dB}$) and from 2.45 to 3.0 GHz with a bandwidth of 20% ($|S_{11}| < -10\,\text{dB}$) for ports 1 and 2, respectively. The measured isolation between the two ports of the proposed antenna is better than 50 dB over the frequency band. The measured average gain is 7.4 for port-1, and 7.3 dBi for port-2.

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