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Series-fed two dipole array antenna using bow-tie elements with enhanced gain and front-to-back ratio

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In this paper, a miniaturized series-fed two dipole array antenna with bow-tie elements (STBDA) for mobile communication applications is presented. In the proposed antenna, two bow-tie-shaped dipole elements of different lengths, which are serially connected through a coplanar strip line, are used instead of conventional straight strip dipole elements in a series-fed two dipole array (STDA) antenna. In addition, a planar ground reflector is replaced by a V-shaped one. A modified integrated balun consisting of a microstrip line and slot line is used to match the input impedance of the antenna to the 50 Ω feed line. As the flare angle of the bow-tie dipole elements increases, the lowest operating frequency of the antenna is shifted toward the low frequency and the average gain is lowered. To validate the proposed approach, an STBDA antenna with a flare angle of 10° covering a frequency band ranging from 1.7 to 2.7 GHz and with a gain >5 dBi is designed and fabricated on an FR4 substrate. Its performance is compared with that of the STDA antenna. Experimental results show that the proposed antenna presents a 48.8% bandwidth in the range of 1.69–2.78 GHz, a stable gain of 5.8 to 6.3 dBi, and a front-to-back ratio (FBR) of 14–17 dB with a 10% size reduction in total width of the antenna. In fact, the characteristics of the half-power beam width and FBR of the STBDA are improved compared to those of the STDA.

1. Introduction

With rapid advances in wireless communication systems, there has been increasing interest in planar antennas because of features such as low profile, light weight, low cost, ease of fabrication, and suitability for integration with microwave integrated circuit modules [1–3]. Printed monopole and dipole antennas etched on a dielectric substrate might be one of the simplest types of planar antennas and have been widely used for various applications. Printed monopole antennas have been employed for multiband and broadband applications such as wireless communications and ultra wideband (UWB) applications because of simple structure, small size and omnidirectional radiation pattern [4–6]. Printed dipole antennas have similar properties such as low profile and small size, but can be used as building blocks in various array applications [7–9]. However, the bandwidth of the conventional printed dipole is not wide enough to meet the requirements of the applications based on broadband operations, such as antennas for integrating various wireless communication systems.

To increase the bandwidth, several different approaches such as a printed dipole with an integrated balun, a series-fed printed dipole pair, a double-dipole antenna, a planar quasi-Yagi

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antenna, a double-layered printed dipole, and trapezoidal patch dipole antenna have been attempted [8–13]. A broadband printed dipole antenna with an integrated balun consisting of a microstrip (MS) line and a slot line with a bandwidth of more than 40% was analyzed by using an equivalent circuit [8]. A design of a broadband series-fed two dipole array (STDA) antenna fed by an MS-to-parallel strip (PS) line with a bandwidth greater than 30% for a voltage standing wave ratio (VSWR)<1.5 operating near 2.0 GHz was investigated [9]. A double-dipole antenna consisting of two parallel dipoles of different lengths was presented to achieve a wide bandwidth of more than 84% [10]. An optimized broadband planar quasi-Yagi antenna with a bandwidth of 48% for a (VSWR)<2, a front-to-back ratio (FBR) better than 12 dB, a gain of 3–5 dB, and a nominal radiation efficiency of 93% was demonstrated [11]. A broadband double-layered printed dipole antenna with a bandwidth of more than 50% and low cross-polarization was also proposed [12]. Recently, a double-printed trapezoidal patch dipole antenna suitable for UWB applications was proposed [13].

In this paper, a design of a series-fed two bow-tie dipole array (STBDA) antenna with a reduced size for mobile communication applications is proposed. The proposed STBDA antenna consists of two bow-tie-shaped dipole elements of different lengths instead of conventional straight strip dipole elements in the STDA antenna. To match the input impedance of the antenna to the 50 Ω feed line, a modified integrated balun consisting of an MS line and slot line is employed. The effects of varying a flare angle of the bow-tie dipole elements on the antenna performances, such as the input reflection coefficient and the realized gain, are investigated. From the knowledge obtained from the simulation, an STBDA antenna with a flare angle of 10° covering a frequency band ranging from 1.7 to 2.7 GHz and with a gain >5 dBi is designed and fabricated on an FR4 substrate, and its performance is compared with that of the STDA. All simulation results are obtained using commercial EM software CST Microwave Studio.

2. Antenna structure and design

The geometries of STDA and STBDA antennas are presented in Figure 1. Both STDA and STBDA antennas are composed of two printed strip dipole elements, drivers 1 (D_1) and 2 (D_2) with different lengths, and a ground reflector (R_0). We first design an STDA antenna, as shown in Figure 1(a), which will be used as a reference antenna, operating in the frequency range between 1.7 and 2.7 GHz by optimizing the lengths and widths of the elements (two dipoles and ground reflector) and the spacings between these elements. An integrated balun between the MS line and the coplanar strip (CPS) line is implemented on the CPS line to match the input impedance of the antenna to the 50 Ω feed line, and the end of the MS line is shorted using a shorting pin at the feeding point. The dimensions of the first dipole element and the ground reflector, which can be considered as a printed quasi-Yagi antenna, are first designed. Next, the distance between the first and the second dipoles and the length of the second dipole are adjusted to obtain the desired frequency band of 1.7–2.7 GHz and to achieve stable gain when the CPS line and the second dipole element are added. The input reflection coefficient characteristics of the STDA antenna for varying the lengths of the second dipole and the CPS line between the two dipoles are shown in Figure 2. Note that the length of the second dipole is represented by the ratio to the first dipole as $r_1 = l_2/l_1$, and that of the CPS line between the two dipoles is denoted by the ratio to the CPS line between the first dipole and the ground reflector as $r_2 = s_2/s_1$, respectively. From Figure 2, the optimized design parameters to maximize both bandwidth and gain are as follows: $l_1 = 72\,\text{mm}$, $l_2 = 50.4\,\text{mm}$, $l_g = 100\,\text{mm}$, $s_1 = s_2 = 36\,\text{mm}$, $w_{cps} = 20\,\text{mm}$, $w_1 = w_2 = 7.5\,\text{mm}$,

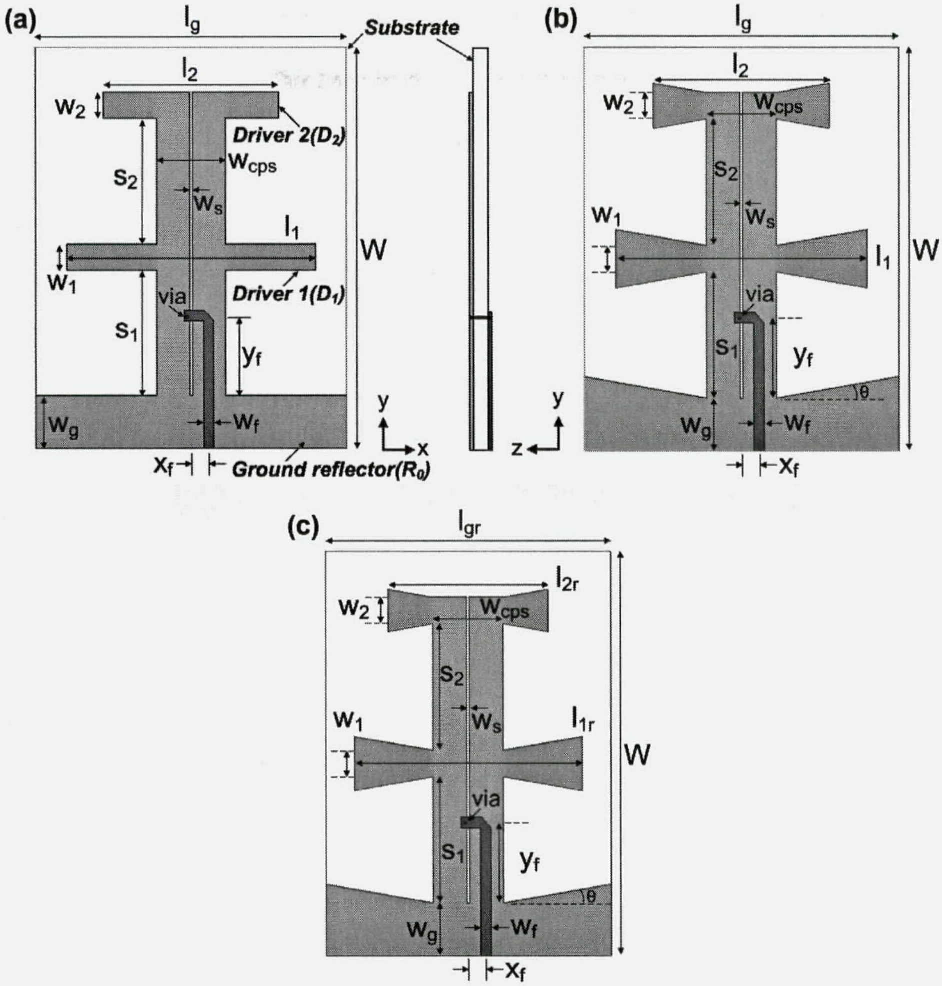

Figure 1. Geometries of proposed antennas: (a) STDA, (b) STBDA, and (c) STBDA with reduced dipoles and ground reflector.

$w_f = 3\,\mathrm{mm}$, $w_g = 15\,\mathrm{mm}$, $w_s = 0.7\,\mathrm{mm}$, $W = 115\,\mathrm{mm}$, $x_f = 5\,\mathrm{mm}$, and $y_f = 23\,\mathrm{mm}$. In the optimized STDA antenna, the length ratio of the second dipole to the first one is $r_1 = 0.7$, and that of the first dipole to the ground reflector is $l_1/l_g = 0.8$. The antenna is printed on an FR4 substrate with a dielectric constant of 4.4 and a thickness of 1.6 mm (loss tangent = 0.025).

Next, the proposed STBDA antenna, which has two bow-tie-shaped dipole elements instead of straight strip dipole elements in the STDA antenna, is designed as shown in Figure 1(b), and the effects of a flare angle θ of the bow-tie dipole elements on the antenna performances are investigated. Half of the bow-tie shape, i.e., a V-shaped patch, is also employed in the ground reflector. Figure 1(c) shows an STBDA antenna with reduced dipoles and ground reflectors. The reduced lengths of the first and second dipoles and the ground reflector are $l_{1r} = 64.8\,\mathrm{mm}$, $l_{2r} = 45.36\,\mathrm{mm}$, and $l_{gr} = 81\,\mathrm{mm}$, respectively. The detailed explanation for Figure 1(b) and (c) will be discussed in the next section.

Figure 3 compares the input reflection coefficient and the realized gain characteristics of the STBDA antenna with those of the STDA antenna for different flare angles of the bow-tie elements. As can be seen from Figure 3, the frequency band of the STBDA antenna extends

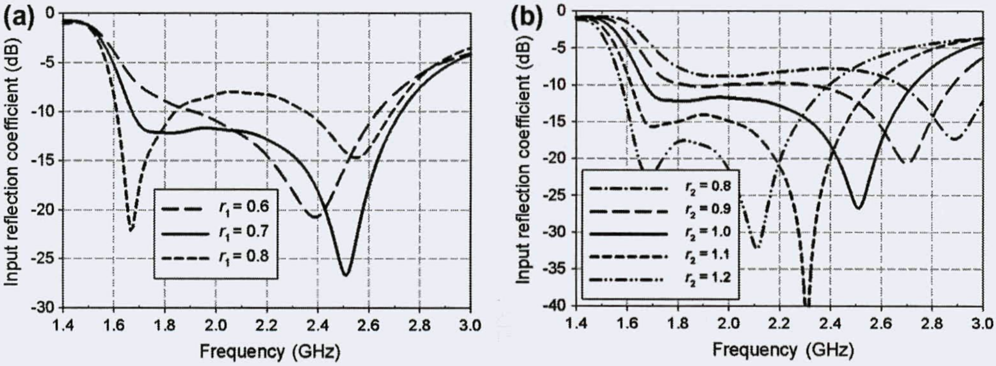

Figure 2. Input reflection coefficient characteristics of STDA antenna for varying (a) $r_1 = l_2/l_1$ (l_1 is fixed as 72 mm and $s_1 = s_2 = 36$ mm) and (b) $r_2 = s_2/s_1$ (s_1 is fixed as 36 mm and $r_1 = 0.7$).

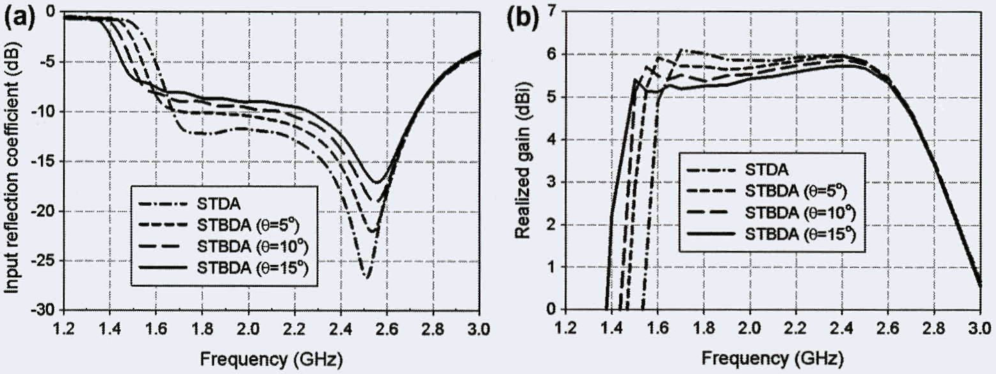

Figure 3. Effects of flare angle of bow-tie elements: (a) input reflection coefficient and (b) realized gain.

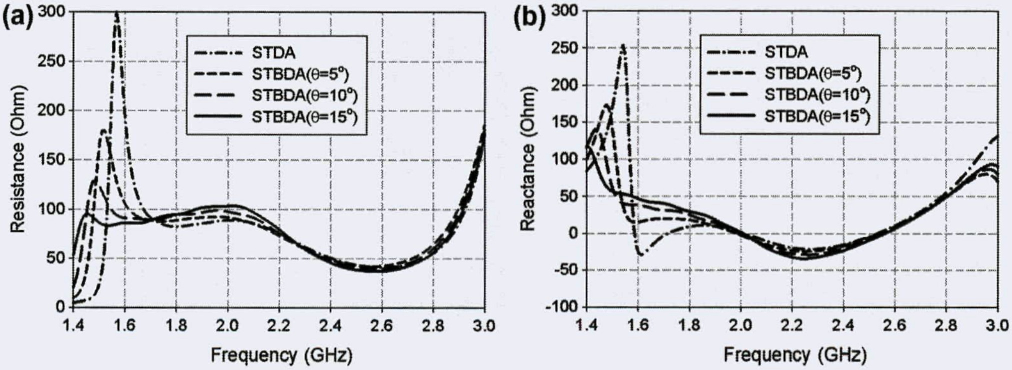

Figure 4. Input impedance characteristics of STBDA antenna for different flare angle of bow-tie elements: (a) resistance and (b) reactance.

in the lower frequency region as the flare angle increases, but the average gain decreases due to impedance mismatching. The input impedance characteristics of the STBDA antenna for different flare angles of the bow-tie elements are also plotted in Figure 4. It is observed that the input resistance and reactance values in the lower frequency band (1.45–1.7 GHz) decrease compared to those of the STDA antenna, and this makes the frequency band shift toward the lower frequency.

3. Experimental results and discussion

Based on the study on the effects of the flare angle of the bow-tie elements, an STBDA antenna with a flare angle $\theta = 10°$ is chosen for the performance comparison with the STDA antenna. For this purpose, the design parameters of this STBDA antenna ($\theta = 10°$) are optimized to maximize the bandwidth and gain. As the frequency band of the STBDA shifted toward the lower frequency according to Figures 3 and 4, we first increase the spacing between the elements to improve input impedance matching. The optimized spacing is found to be $s_1 = s_2 = 40$ mm, and the input reflection coefficient and realized gain of the STBDA with this spacing are compared with the STDA antenna in Figure 5.

Next, to shift the operating frequency band of the STBDA antenna to that of the STDA (1.7–2.7 GHz), the lengths and spacings of the elements are reduced 10% with the other parameters kept identical to those of the STDA. Therefore, the lengths of the two bow-tie dipole elements of the STBDA antenna are $l_{1r} = 64.8$ mm and $l_{2r} = 45.36$ mm, respectively, and the length of the V-shaped ground reflector becomes $l_{gr} = 81$ mm as well. The spacing between the elements becomes $s_1 = s_2 = 36$ mm, which is the same as that of the STDA. The only differences between the STDA and the STBDA antennas are the shapes and lengths of the dipole elements and the ground reflector, as shown in Figure 1(c).

To validate the proposed approach, an STDA antenna and an STBDA antenna with a flare angle $\theta = 10°$ with reduced dipoles and ground reflector are fabricated on an FR4 substrate as shown in Figure 6, and their performance characteristics are compared.

Figure 7 presents the simulated and measured input reflection coefficients and realized gain characteristics of the fabricated STDA and STBDA antennas. The bandwidths for a VSWR<2 are about 47.3% (1.68–2.72 GHz) and 47.96% (1.68–2.74 GHz), respectively, for the simulation, and about 47.8% (1.72–2.8 GHz) and 48.8% (1.69–2.78 GHz), respectively, for the measurement. In the band from 1.7 to 2.6 GHz, the measured gains of the STDA and

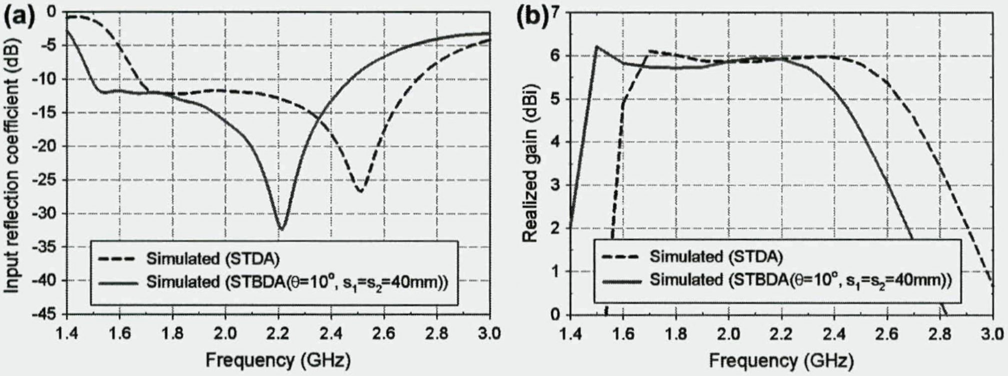

Figure 5. Input reflection coefficient and realized gain characteristics of STBDA antenna $\theta = 10°$ with spacing $s_1 = s_2 = 40$ mm: (a) input reflection coefficient and (b) realized gain.

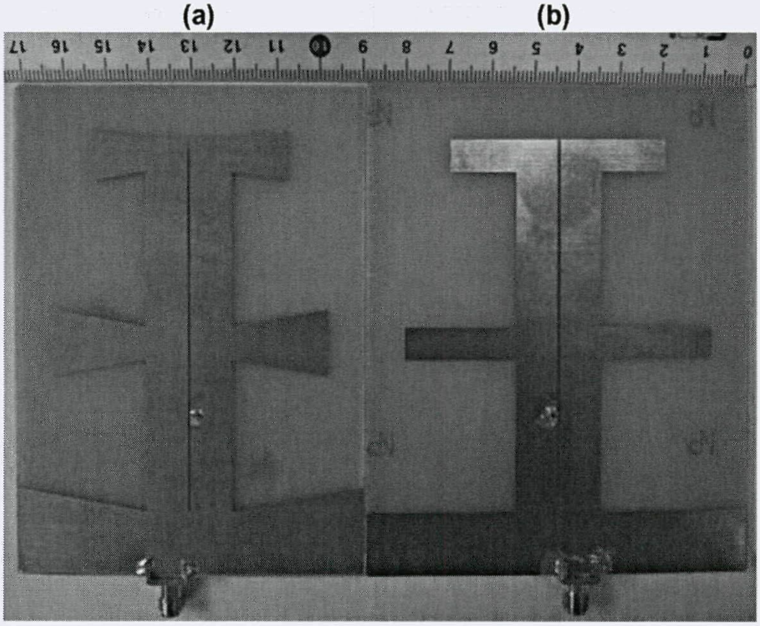

Figure 6. Photographs of fabricated STBDA (a) and (b) STDA antennas.

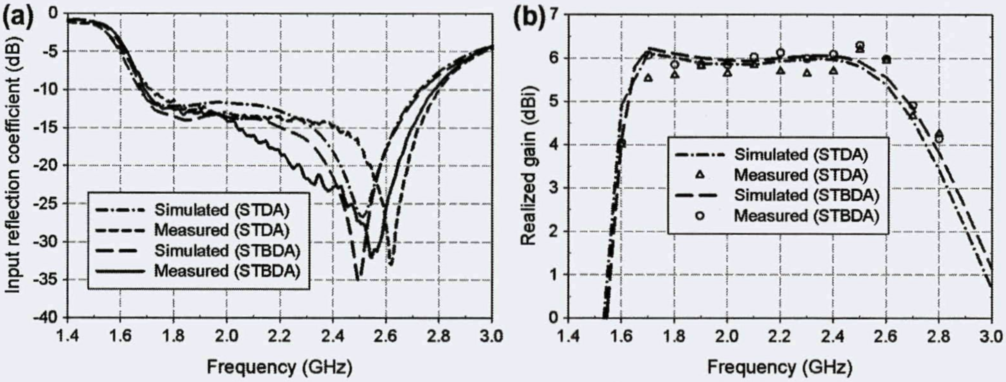

Figure 7. Performance comparison of fabricated STDA and STBDA antennas: (a) input reflection coefficient and (b) realized gain.

STBDA antennas are 5.5–6.2 and 5.8–6.3 dBi, respectively. As can be observed, the performance characteristics of the proposed STBDA antenna with a size reduction of 10% are better than those of the STDA antenna. We note that both STDA and STBDA antennas show stable gain with small variation and gain enhancement of more than 2 dB compared to the conventional broadband planar antenna (3–5 dBi) [11].

The radiation patterns of the fabricated STDA and STBDA antennas in two principal cut planes, E-plane (*x*-*y* plane) and H-plane (*y*-*z* plane), at 1.8, 2.35, and 2.6 GHz are compared in Figure 8. Table 1 summarizes the measured half-power beam width (HPBW) in the E- and H-planes and the FBR at 1.8, 2.35, and 2.6 GHz. From Table 1, we observe that the HPBW

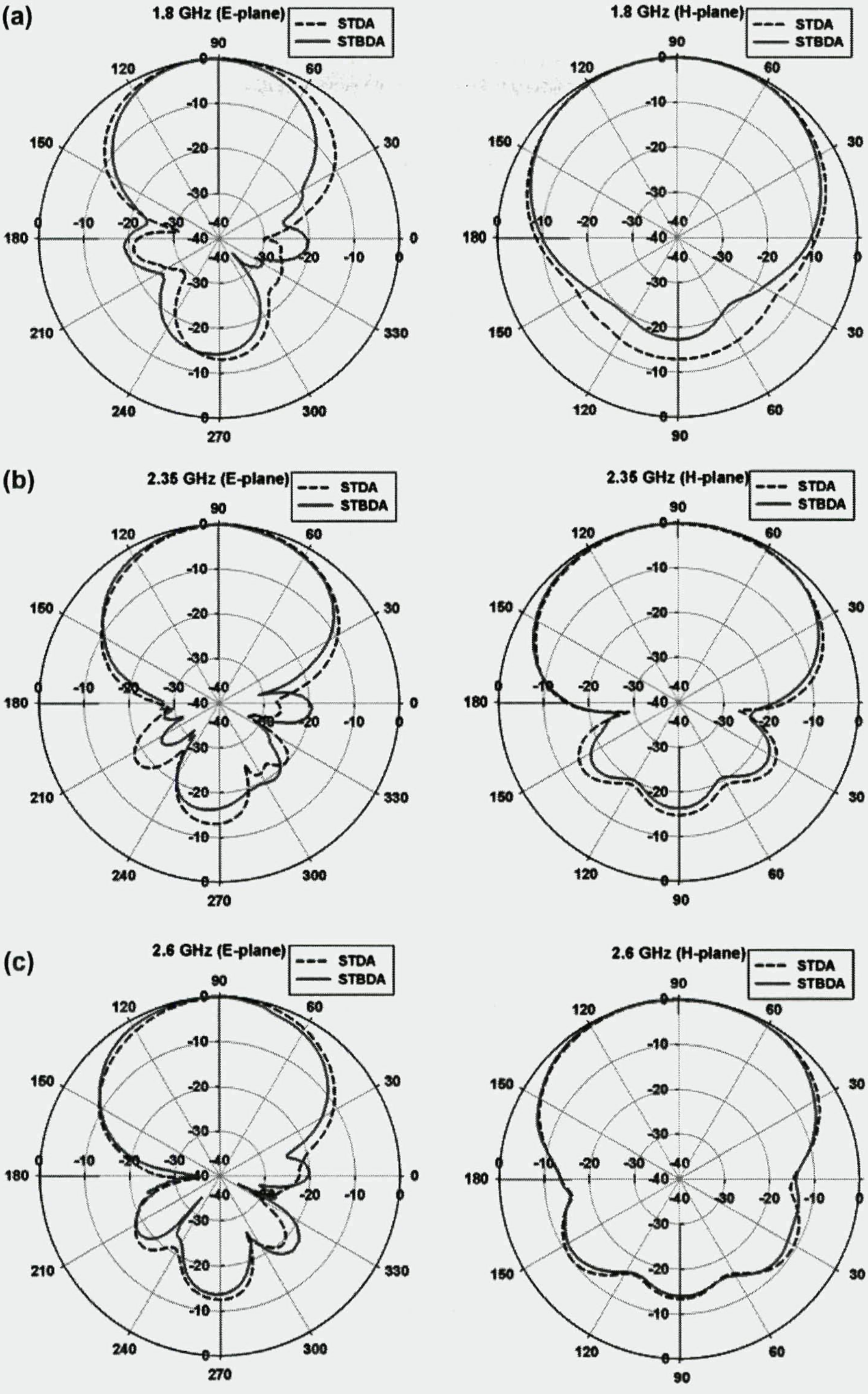

Figure 8. Comparison of measured half-power beamwidth in E- and H-planes and FBR at (a) 1.8, (b) 2.35, and (c) 2.6 GHz.

Table 1. Comparison of measured half-power beamwidth in E- and H-planes and FBR at 1.8, 2.35, and 2.6 GHz.

	E-plane				H-plane			
	HPBW (degree)		FBR (dB)		HPBW (degree)		FBR (dB)	
Frequency (GHz)	STDA	STBDA	STDA	STBDA	STDA	STBDA	STDA	STBDA
1.8	71	57	13.03	14.17	116	107	12.9	17.31
2.35	67	69	13.09	16.44	111	110	14.78	16.41
2.6	68	67	12.48	13.72	106	102	13.31	14.0

and FBR of the STBDA are enhanced compared to those of the STDA, and these results comply well with the measured gain results shown in Figure 7(b).

4. Conclusions

We have proposed a broadband STBDA antenna for mobile communication applications. In the proposed antenna, two bow-tie-shaped dipole elements of different lengths, serially connected through a CPS line, are used instead of the conventional straight strip dipole elements in a STDA antenna. A modified integrated balun consisting of a MS line and slot line is used to match the input impedance of the antenna to the 50 Ω feed line. It turns out that the lowest operating frequency of the antenna moves toward the low frequency as the flare angle of the bow-tie dipole elements increases.

An STBDA antenna with a flare angle of 10° covering a frequency band ranging from 1.7 to 2.7 GHz and with a gain >5 dBi is designed and fabricated on an FR4 substrate, and its performance is compared with that of the STDA. Experimental results show that the proposed antenna presents a 48.8% bandwidth in the range of 1.69–2.78 GHz, a stable gain of 5.8–6.3 dBi, and an FBR of 14–17 dB with a 10% size reduction in total width of the antenna. Furthermore, the characteristics of the HPBW and FBR of the STBDA are improved compared to those of the STDA.

It is expected that the proposed broadband STBDA antenna can be used as antennas for low-power (indoor) repeaters integrating various mobile communication systems (PCS, IMT2000, and LTE) and wireless services (WiBro, WLAN, Bluetooth, and WiMAX) or as an element antenna of a wideband high-gain base-station antenna for mobile communications.

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