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BROADBAND SERIES-FED DIPOLE PAIR ANTENNA WITH PARASITIC STRIP PAIR DIRECTOR

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Abstract—A method to increase the bandwidth of a series-fed dipole pair (SDP) antenna by using a parasitic strip pair director is presented in this paper. A conventional SDP antenna consists of two dipole elements having different lengths and a ground reflector, which are serially connected with a transmission line. In the proposed antenna, a parasitic strip pair director is appended to the conventional SDP antenna. Initially, a conventional SDP antenna that operates in a frequency range of 1.7–2.7 GHz is designed by optimizing the lengths of the elements (two dipoles and ground reflector) and the distances between these elements. Subsequently, a parasitic director containing a pair of strips is placed near the top dipole element to improve the bandwidth and gain of the conventional SDP antenna. Then, the effects of the location and size of the director on the impedance bandwidth and realized gain are investigated. A prototype of the proposed antenna is fabricated on an FR4 substrate, and its performance is compared with that of the conventional SDP antenna. The experimental results show that the proposed antenna has an enhanced bandwidth of 1.63–2.97 GHz (58.26%) and an increased gain of 5.6–6.8 dBi.

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1. INTRODUCTION

Recently, printed antennas have been widely used for various wireless communication applications because of features such as low profile, low weight, low cost, ease of fabrication, and suitability for integration with microwave-integrated circuit modules [1–3]. To increase the bandwidth, several printed antennas such as a printed dipole antenna with an integrated balun [4], series-fed printed dipole pair [5], double-dipole antenna [6], planar quasi-Yagi antenna [7], double-layered printed dipole [8], and trapezoidal patch dipole antenna [9] have been designed.

Among the different broadband printed antennas, a series-fed dipole pair (SDP) antenna or a double-dipole antenna has been widely used in many mobile communication applications, such as base-station antennas and wideband phased-array antennas, because of its broad bandwidth, stable gain, and simple structure [5, 6]. It consists of two dipoles having different lengths and a truncated ground plane, which are serially connected with a transmission line. Generally, the lengths of the long and short dipoles control the lower and upper operating frequencies, respectively, and the distance between the two dipoles as well as the distance between the first dipole and truncated ground plane control the input reflection coefficient level between the two main resonances.

Recently, a wideband double-dipole Yagi-Uda antenna containing a microstrip (MS)-to-coplanar strip (CPS) transition feed, a pair of reflectors, two parallel printed dipoles, and a director has been introduced [10]. In this case, the bandwidth of the antenna is increased to approximately 80% (3.48–8.16 GHz). However, the feed structure containing an MS-to-CPS transition is very long and the size of the ground plane used as a reflector is large.

In this paper, we present a method for enhancing the bandwidth of an SDP antenna by using a parasitic strip pair director. Initially, a conventional SDP antenna is designed for a frequency range of 1.7–2.7 GHz by optimizing the lengths of and distances between the elements (two dipoles and ground reflector) [11]. The elements of the SDP antenna are serially connected with a CPS line. Moreover, a modified integrated balun consisting of an MS line and a CPS line is employed to match the input impedance of the antenna with the 50 Ω MS feed line. Because the integrated balun does not require any additional space, this type of SDP antenna is compact when compared with other antennas that have long feed structures. Next, a parasitic director consisting of two separated strips is positioned near the top dipole element to improve the bandwidth and gain of the conventional

SDP antenna. Further, the effects of the location and size of the director on the impedance bandwidth and realized gain characteristics are investigated.

In this study, the results are obtained with a commercial electromagnetic simulator, CST Microwave Studio (MWS), on a Dell OptiPlex 960 (Intel® Core^{TM} 2 Quad CPU Q9400 @ 2.66 GHz and 8 GB of RAM), and the measurements of the input VSWR, gain, and radiation patterns, tested in an anechoic chamber, are used to validate these results.

2. ANTENNA GEOMETRIES AND DESIGN

The geometries of a conventional SDP antenna and the proposed SDP antenna with a parasitic director are illustrated in Figure 1. The conventional SDP antenna consists of two strip dipole elements, dipole 1 (D_1) and dipole 2 (D_2), having different lengths, and a ground reflector (R_0). The length and width of D_1 are l_1 and w_1, respectively, and those of D_2 are l_2 and w_2, respectively. The length and width of R_0 are l_g and w_g, respectively. The distance between R_0 and D_1 is s_1, and that between D_1 and D_2 is s_2. In the proposed antenna, a parasitic strip pair director (D_r) is appended to the conventional SDP antenna at a distance d_p from D_2. The length and width of each strip are l_d and w_d, respectively, and the gap between the two strips is g_d.

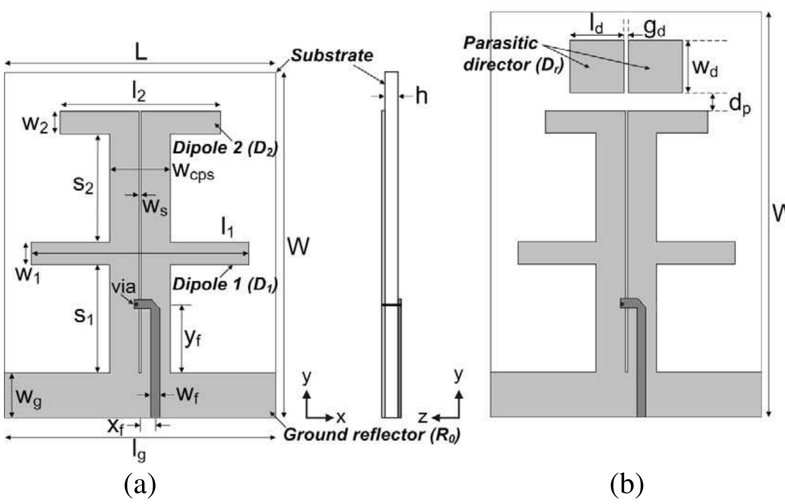


Figure 1. Geometries of (a) a conventional SDP antenna and (b) the proposed SDP antenna having a parasitic director.

An integrated balun between the MS and CPS lines is implemented on the CPS line to match the input impedance of the antenna with the $50\,\Omega$ feed line, and the end of the MS line is shorted with a shorting pin at the feed point. The widths of the CPS line and slot line are denoted as w_{cps} and w_s, respectively. The width of the MS feed line is w_f, and the MS feed is offset from the center at a distance of x_f. The antenna is printed on an FR4 substrate having a dielectric constant of 4.4 and a thickness $h = 1.6\,\text{mm}$ (loss tangent = 0.025). The length and width of the substrate are L and W, respectively.

In the conventional printed 3-element quasi-Yagi antennas, the distance between the driver and director is in the range of 0.15–0.35λ (λ is the free-space wavelength at the center frequency of the frequency band) for effective operation, and the resulting bandwidth usually decreases when a director is appended to the driver [12]. However, in the proposed antenna, a parasitic director is placed close to the second dipole at a distance of $d_p = 0.05\lambda$ to obtain a broad bandwidth and an increased gain. In order to increase the bandwidth and gain, the width w_d of the parasitic director is set to be much greater than that of the conventional director.

2.1. Design of Conventional SDP Antenna

We begin by designing an SDP antenna without a parasitic director (D_r), which will be used as a reference antenna, for operation in a frequency range of 1.7–2.7 GHz, as shown in Figure 1(a). To obtain an SDP antenna having an optimum bandwidth and a stable gain in the band, the effects of several design parameters on the antenna performance such as input VSWR and realized gain are investigated. The considered design parameters are as follows: length ratio $r_1 = l_2/l_1$, spacing ratio $r_2 = s_2/s_1$, length of the ground reflector (l_g), and feed point (y_f).

Figure 2(a) shows the input VSWR and realized gain characteristics of the SDP antenna for a varying length ratio (r_1) with l_1 and l_g fixed at 72 mm and 90 mm, respectively. The other design parameters are as follows: $s_1 = s_2 = 36\,\text{mm}$, $w_{cps} = 20\,\text{mm}$, $w_1 = w_2 = 7.5\,\text{mm}$, $w_f = 3\,\text{mm}$, $w_g = 15\,\text{mm}$, $w_s = 0.7\,\text{mm}$, $L = 90\,\text{mm}$, $W = 115\,\text{mm}$, $x_f = 5\,\text{mm}$, $h = 1.6\,\text{mm}$, and $y_f = 23\,\text{mm}$. When $r_1 = 0.7$, the impedance bandwidth is about 49.09% (1.66–2.74 GHz) for a VSWR < 2, and the range of the gain in the band is 4.6–6.1 dBi. When r_1 is increased to 0.75, the bandwidth slightly increases to 50.80% (1.63–2.74 GHz), and the range of the gain is 4.5–6.7 dBi. Further, the input VSWR and gain characteristics decrease as r_1 decreases. When r_1 is increased to 0.8, the frequency band shifts toward a lower frequency, and in the low band, the gain increases.

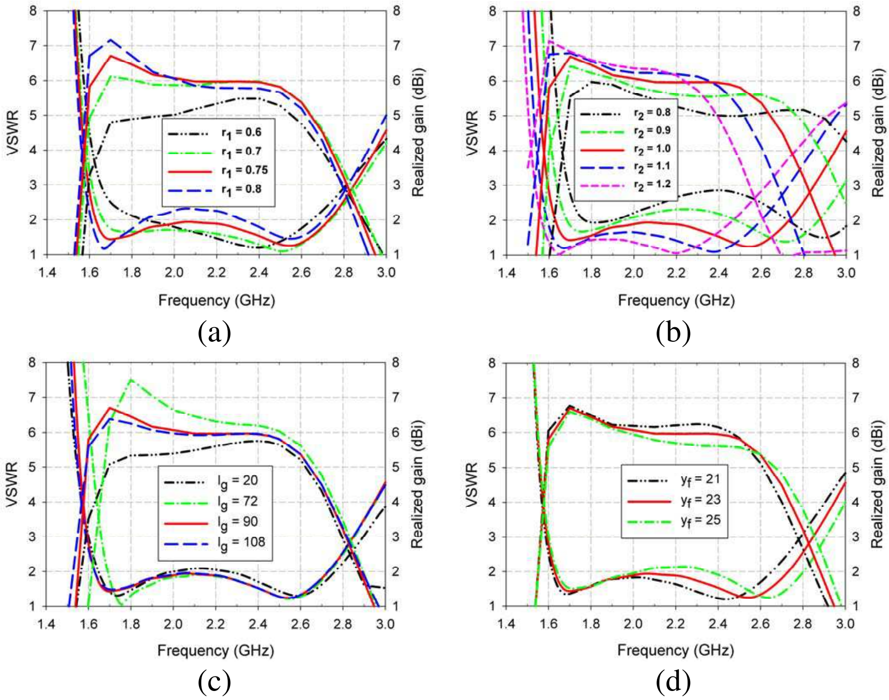


Figure 2. Effects of the (a) length ratio (r_1), (b) spacing ratio (r_2), (c) length of ground reflector (l_g), and (d) feed point (y_f) on the input VSWR and realized gain of the SDP antenna.

However, in the middle band, the impedance matching deteriorates. Therefore, the optimum length ratio that satisfies the maximum bandwidth and stable gain requirements is $r_1 = 0.75$.

Figure 2(b) shows the input VSWR and realized gain characteristics of the SDP antenna for a varying spacing ratio r_2 with r_1, l_1, and l_g fixed at 0.75, 72 mm, and 90 mm, respectively. The other parameters remain the same. Here, the maximum bandwidth and a stable gain within the band can be achieved when $r_2 = 1.0$ implying that $s_1 = s_2$. When r_2 is reduced, the frequency band moves toward a higher frequency, and the input VSWR deteriorates. As r_2 increases, the impedance matching improves, but the bandwidth decreases.

Another parameter that is considered is the length of ground reflector (l_g). From Figure 2(c), we can see that when there is no ground reflector ($l_g = 20$ mm), the impedance matching varies slightly, but the gain decreases in the low frequency region. The optimal length of the ground reflector satisfying the maximum bandwidth and stable gain within the band requirements is 90 mm. Moreover, the antenna characteristics do not change much as l_g is further increased. For $l_g = 90$ mm, the length ratio between the first dipole and the ground reflector is 0.8. It should be noted that the substrate length (L) is fixed at 90 mm for $l_g < 90$ mm but increased to $L = l_g$ for $l_g > 90$ mm.

Figure 2(d) shows the input VSWR and realized gain characteristics of the SDP antenna for a varying feed point (y_f). In this case, r_1, r_2, and l_g are fixed at 0.75, 1.0, and 90 mm, respectively. We can observe that when $y_f = 21$ mm, the frequency band shifts toward a lower frequency, and the upper limit of the band falls below 2.7 GHz. As y_f is increased to 25 mm, the frequency band moves toward a higher frequency, but the impedance matching deteriorates in the middle band. Moreover, the gain is reduced in the middle and high bands. Therefore, $y_f = 23$ mm can be chosen as the optimal position for the feed point.

The final optimized design parameters obtained from Figures 2(a)–2(d) are as follows: $l_1 = 72$ mm, $l_2 = 54$ mm, $l_g = 90$ mm, $s_1 = s_2 = 36$ mm, $w_{cps} = 20$ mm, $w_1 = w_2 = 7.5$ mm, $w_f = 3$ mm, $w_g = 15$ mm, $w_s = 0.7$ mm, $L = 90$ mm, $W = 115$ mm, $x_f = 5$ mm, $h = 1.6$ mm, and $y_f = 23$ mm.

2.2. Design of SDP Antenna with Parasitic Director

In this section, the effects of the principal design parameters on antenna performance are examined to provide the guidelines for designing a parasitic director of a strip pair to achieve the maximum bandwidth and a stable gain in the band. The five design parameters that determine the input VSWR and realized gain characteristics of the SDP antenna having the parasitic director are as follows: length of the director (l_d), director width (w_d), distance between D_2 and $D_r (d_p)$, gap between the two strips (g_d), and the length ratio (r_1). It is noted that the substrate width (W_1) of the proposed antennas is increased slightly to 135 mm to accommodate the parasitic director.

First, the length of each strip of the director (l_d) is considered. Figure 3(a) shows the input VSWR and realized gain characteristics for varying values of l_d when d_p and w_d are fixed at 6 mm and 17.5 mm, respectively. In this case, the gap between the two strips (g_d) is set to be 1.4 mm. We observe that for a VSWR < 2, the upper limit of the frequency band and its bandwidth increase until $l_d = 18$ mm and decrease when l_d is further increased to 22 mm. For example, when $l_d = 10$ mm, the frequency band ranges from 1.63 GHz to 2.78 GHz (52.15%) whereas the band extends from 1.63 GHz to 2.98 GHz (58.57%) when l_d is increased to 18 mm. The level and bandwidth of the realized gain increase accordingly. In the band, the range of the gain is 4.4–6.8 dBi for $l_d = 10$ mm whereas for $l_d = 18$ mm, it ranges from 5.7 dBi to 6.9 dBi. When l_d is increased to 22 mm, the level of the realized gain increases when compared with that of $l_d = 18$ mm, but the gain variation in the band is increased. Moreover, the impedance matching deteriorates at approximately 2.55 GHz.

Second, the width of each director strip (w_d) is considered. The input VSWR and realized gain characteristics for a varying w_d are shown in Figure 3(b) where d_p and l_d are fixed at 6 mm and 18 mm, respectively. As can be seen from Figure 3(b), the upper limit and bandwidth of both the input VSWR and realized gain increase until $w_d = 17.5$ mm. When w_d is further increased to 22.5 mm, the input VSWR and gain improve in the high frequency region but their bandwidths decrease. Therefore, w_d can be selected to be 17.5 mm for achieving impedance matching and stable gain over a wide frequency band.

Third, the distance d_p between D_2 and D_r is considered. In this case, l_d and w_d are fixed at 18 mm and 17.5 mm, respectively. As shown in Figure 3(c), when $d_p = 2$ mm, the lower limit of the frequency band decreases slightly, and the impedance matching improves in the low frequency region (less than 2.35 GHz) but deteriorates in the high frequency region (above 2.35 GHz). As d_p is increased, in the high frequency region, the input VSWR and gain increase with a reduction in bandwidth. Thus, to obtain the maximum bandwidth and a stable gain within the band, the distance between D_2 and D_r (d_p) is selected to be 6 mm.

Fourth, the gap between the two strips (g_d) is considered, as shown in Figure 3(d). Here, d_p, l_d, and w_d are fixed at 6 mm, 18 mm, and 17.5 mm, respectively. We can see that as g_d is reduced, both the upper limit of the frequency band and its bandwidth increase for a VSWR < 2. Further, the level and bandwidth of the realized gain increase accordingly. However, in the high frequency region, the impedance matching deteriorates and the bandwidth decreases when the gap becomes zero, i.e., the two strips are connected to each other.

Finally, the effect of the length ratio (r_1) on the input VSWR and realized gain characteristics are investigated, as shown in Figure 3(e). In this case, l_d, w_d, d_p, and g_d are fixed at 18 mm, 17.5 mm, 6 mm, and 1.4 mm, respectively. Here, the input VSWR and gain characteristics deteriorate when $r_1 < 0.75$. When $r_1 = 0.75$, for a VSWR < 2, the impedance bandwidth is approximately 58.57% (1.63–2.98 GHz), and the range of the gain is 5.7–6.9 dBi in the band. However, for $r_1 =$ 0.7, both the impedance bandwidth and range of the gain decrease to 58.12% (1.66–3.02 GHz) and 6.1–6.7 dBi, respectively. As r_1 is further increased to 0.8, the frequency band shifts toward a lower frequency,

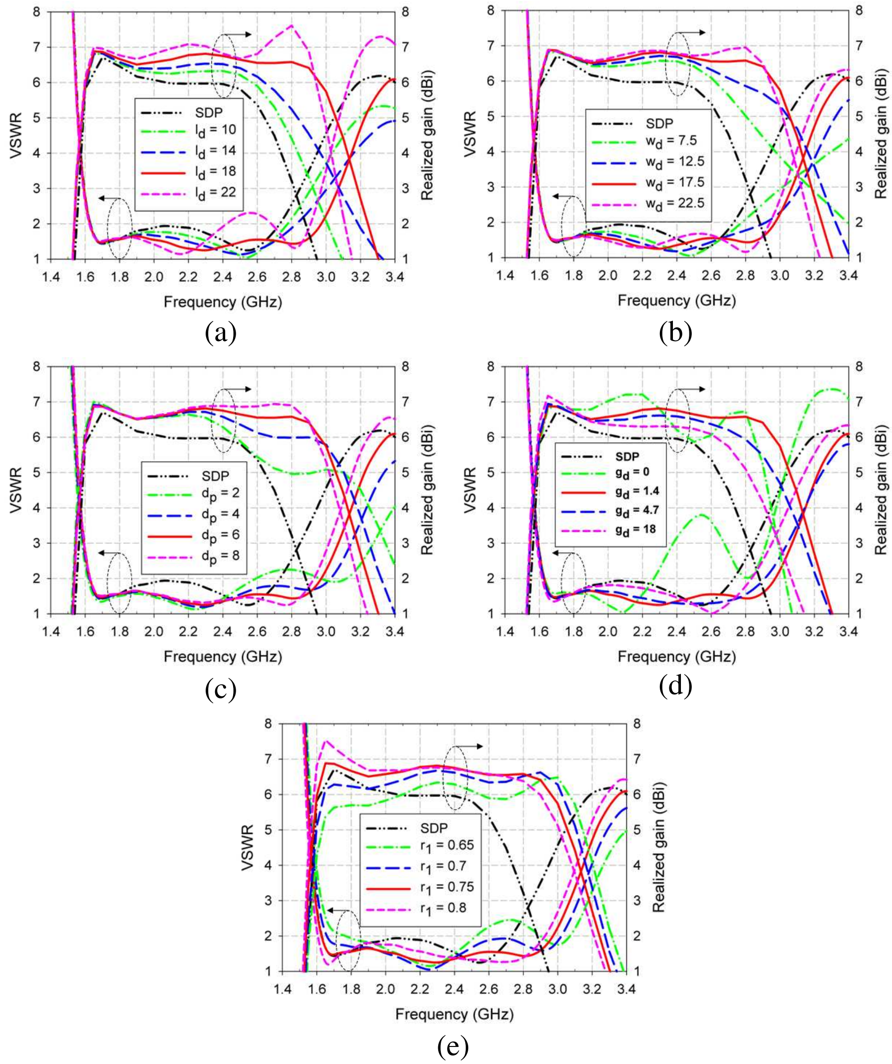


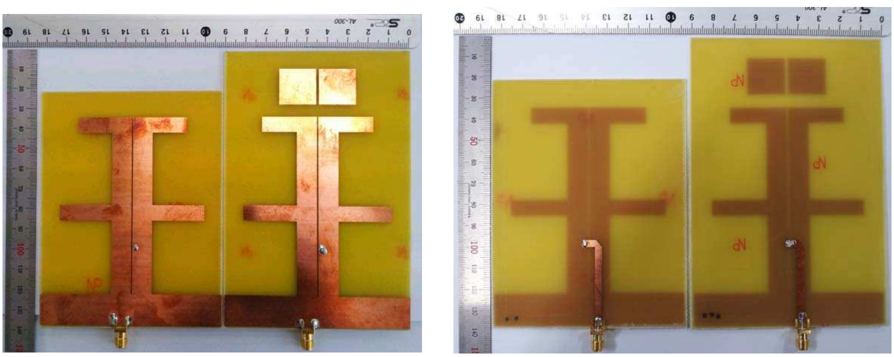
Figure 3. Effects of the (a) director length (l_d), (b) director width (w_d), (c) distance between dipole 2 and parasitic director (d_p), (d) gap between two strips (g_d), and (e) length ratio (r_1) on the input VSWR and realized gain of the SDP antenna having the parasitic director.

and the gain is enhanced at the low frequency. In this case, the impedance bandwidth is approximately 58.15% (1.61–2.93 GHz), and the gain ranges from 5.7 dBi to 7.5 dBi in the band with a relatively large variation. Therefore, a length ratio (r_1) of 0.75 is chosen as the optimal design parameter.

For the proposed antenna, the final optimized design parameters are as follows: $l_1 = 72\,\text{mm}$, $l_2 = 54\,\text{mm}$, $l_g = 90\,\text{mm}$, $s_1 = s_2 = 36\,\text{mm}$, $w_{cps} = 20\,\text{mm}$, $w_1 = w_2 = 7.5\,\text{mm}$, $w_f = 3\,\text{mm}$, $w_g = 15\,\text{mm}$, $w_s = 0.7\,\text{mm}$, $L = 90\,\text{mm}$, $W = 135\,\text{mm}$, $x_f = 5\,\text{mm}$, $h = 1.6\,\text{mm}$, $y_f = 23\,\text{mm}$, $l_d = 18\,\text{mm}$, $w_d = 17.5\,\text{mm}$, $d_p = 6\,\text{mm}$, and $g_d = 1.4\,\text{mm}$.

3. EXPERIMENTAL RESULTS AND DISCUSSION

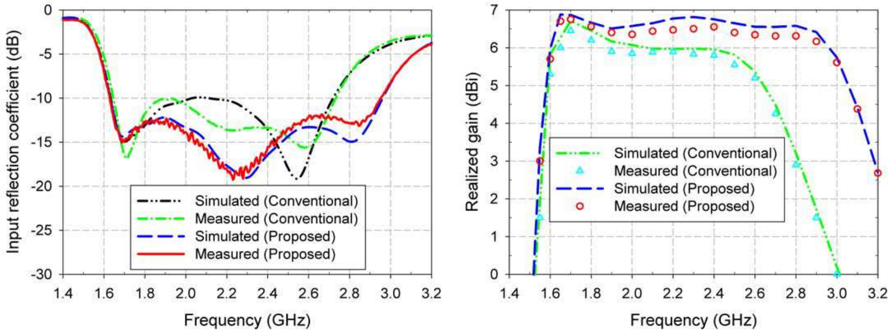
A prototype of the proposed antenna is fabricated on an FR4 substrate using the optimal geometrical parameters of the parasitic director obtained in the previous section. In addition, its performance is compared with that of the conventional SDP antenna. The photographs of the fabricated antennas are illustrated in Figure 4.



(a) (b)

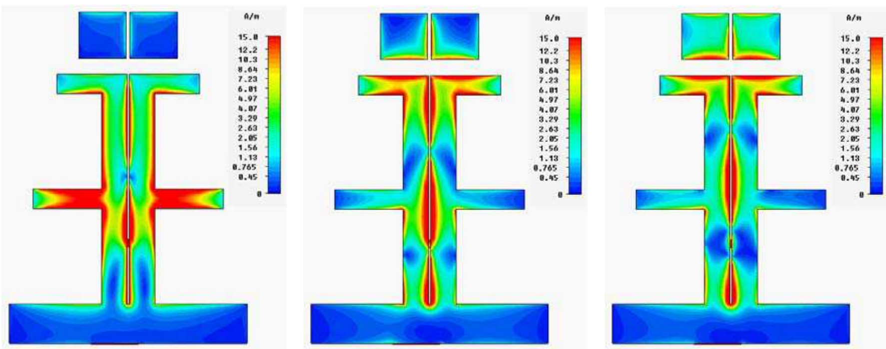
Figure 4. Photographs of the fabricated antennas: (a) front view and (b) back view.

Figure 5 illustrates the simulated and measured input reflection coefficients and realized gain characteristics of the fabricated conventional and proposed SDP antennas. The measured results agree well with the simulated data. For a VSWR < 2, the simulated impedance bandwidths are approximately 50.80% (1.63–2.74 GHz) and 58.57% (1.63–2.98 GHz) for the conventional and proposed SDP antennas, respectively, and the measured bandwidths are approximately 50.57% (1.64–2.75 GHz) and 58.26% (1.63–2.97 GHz), respectively. The measured gain ranges from 4.3 dBi to 6.5 dBi for the conventional SDP antenna whereas for the proposed antenna, it ranges from 5.6 dBi to 6.8 dBi. The averaged peak gains in the band are 5.7 dBi and 6.4 dBi for the conventional and proposed SDP antennas,



(a) (b)

Figure 5. Comparison of performance of the fabricated antennas: (a) input reflection coefficient and (b) realized gain.



(a) (b) (c)

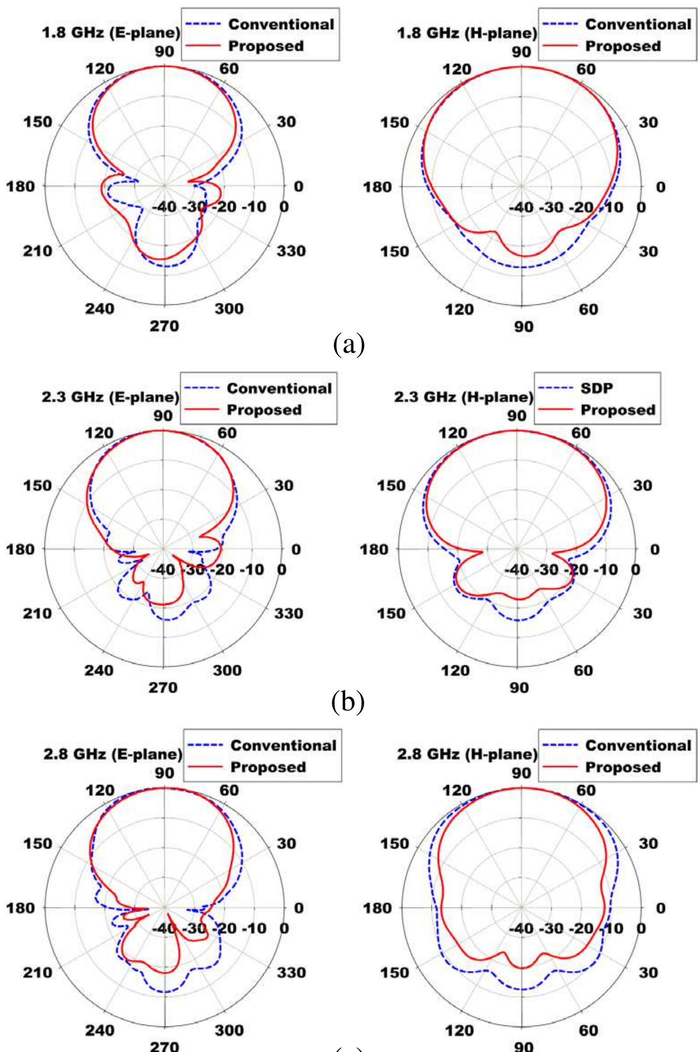
Figure 6. Surface current distributions of the proposed antenna at (a) 1.69 GHz, (b) 2.3 GHz, and (c) 2.8 GHz.

respectively. Therefore, the gain variation of the proposed antenna is reduced from 2.2 dB to 1.2 dB and the averaged peak gain in the band is increased by 0.7 dB compared to the conventional SDP antenna.

In the frequency band, the simulated total efficiencies of the conventional and proposed SDP antennas for a VSWR < 2 are 64.6–87.4% and 64.0–86.9%, respectively, which are very similar. In the antennas, the loss is mainly due to the FR4 substrate, so the efficiency can be improved by using a lower-loss dielectric substrate.

Figure 5(a) shows that the conventional SDP antenna has two resonances at 1.82 GHz and 2.61 GHz whereas the proposed SDP antenna with the director has three resonances at 1.69 GHz, 2.3 GHz, and 2.8 GHz. Figure 6 shows the surface current distributions of the proposed antenna at the three resonance frequencies, $f = 1.69$ GHz, 2.3 GHz, and 2.8 GHz. The first resonance at 1.69 GHz corresponds to D_1, and D_2 resonates at 2.3 GHz. These two resonances are similar to those of the conventional SDP antenna. The new third resonance at 2.8 GHz is due to a slot in the CPS line [13].

The measured radiation patterns of the fabricated conventional



(a)

(b)

(c)

Figure 7. Measured radiation patterns of the fabricated antennas in the E- and H-planes at (a) 1.8 GHz, (b) 2.3 GHz, and (c) 2.8 GHz.

and proposed SDP antennas in the E-plane (x-y plane) and H-plane (y-z plane) at 1.8 GHz, 2.3 GHz, and 2.8 GHz are plotted in Figure 7. We can see that the half-power beamwidths of the proposed antennas range from 62° to 63° and from 82° to 111° in the E- and H-planes, respectively, which are 3°–8° and 5°–32° narrower than those of the conventional SDP antenna. The proposed antenna has front-to-back ratios in the range of 15.46–21.11 dB and 16.69–22.91 dB in the E- and H-planes, respectively, which are better than those of the conventional SDP antenna by 2.43–6.37 dB and 3.79–7.10 dB.

4. CONCLUSION

In this paper, we have presented an SDP antenna having a parasitic strip pair director for bandwidth enhancement. In order to improve the bandwidth characteristics of the conventional SDP antenna, a parasitic director having a pair of strips was placed near the upper dipole element of the SDP antenna. Additionally, the effects of the location and size of the parasitic director on the impedance bandwidth and realized gain characteristics were investigated.

A prototype of the proposed antenna having the director with optimal parameters was fabricated on an FR4 substrate, and its performance was compared with that of the conventional SDP antenna operating in a frequency band of 1.7–2.7 GHz. In the case of the conventional SDP antenna, for a VSWR < 2, the measured impedance bandwidth is 1.64–2.75 GHz (50.57%) and the measured gain ranges from 4.3 dBi to 6.5 dBi. The proposed antenna presents an enhanced bandwidth of 1.63–2.97 GHz (58.26%) and an increased gain of 5.6–6.8 dBi over the conventional SDP antenna

Thus, the proposed antenna can be used in low-power (indoor) repeaters for integrating various mobile communication systems (PCS, IMT-2000, LTE) and wireless services (WiBro, WLAN, Bluetooth, WiMAX) and as an element in a wideband high-gain base-station antenna for mobile communications.

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