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스트립이 추가된 소형 UWB 대수 주기 직각 삼각형-모양 다이폴 배열 안테나

Compact UWB Log Periodic Right Triangle-Shaped Dipole Array Antenna Appended With Strips

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[요 약]

UWB 응용을 위해 스트립이 추가된 직각 삼각형-모양의 다이폴 소자로 구성된 소형 대수 주기 다이폴 배열 (LPDA; log periodic dipole array) 안테나를 제안하였다. 첫째, LPDA 안테나의 폭을 줄이기 위해 기존의 스트립 다이폴 소자 대신에 직각 삼각형-모양 다이폴 소자를 사용하였다. 둘째, 소자 사이의 간격을 줄여 LPDA 안테나의 길이를 줄였다. 마지막으로, 안테나의 폭을 더 줄이기 위해 직각 삼각형-모양 다이폴 소자의 양 팔의 끝에 스트립을 추가하였다. 16개의 다이폴 소자와 4 dBi 이상의 이득을 가지도록 제안된 안테나의 시제품을 FR4 기판에 44mm×30mm 크기로 제작하였다. 제작된 안테나의 전압 정재파비가 (VSWR; voltage standing wave ratio) 2 이하인 주파수 대역은 2.99-14.76 GHz로 UWB 대역을 만족하며, 측정된 이득은 4.0-5.5dBi이고 전후방비는 10 dB 이상이다. 제안된 소형 LPDA 안테나의 길이와 너비는 기존 LPDA에 비해 각각 40.9%와 20.6% 감소하였다.

[Abstract]

A compact LPDA antenna consisting of right triangle-shaped dipole elements appended with strips is proposed for UWB applications. First, right triangle-shaped dipole elements are used instead of conventional strip dipole elements to reduce the width of the LPDA antenna. Second, the spacing between the LPDA elements is decreased to reduce the length of the LPDA antenna. Finally, strips are appended at the ends of the right triangle-shaped dipole elements in order to further reduce the width of the antenna. A prototype of the proposed antenna with 16 elements and gain > 4 dBi is fabricated on an FR4 substrate with dimensions of 44 mm×30 mm. Measured frequency band of the fabricated antenna is 2.99-14.76 GHz for a VSWR < 2, which ensures UWB operation, and measured gain range is 4.0-5.5 dBi with a front-to-back ratio larger than 10 dB. The length and width of the proposed compact LPDA antenna are reduced by 40.9% and 20.6%, respectively, compared to the conventional LPDA.

Key word : Right triangle-shaped dipoles, Appended strips, Compact, Log periodic dipole array (LPDA), UWB.

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Ⅰ. Introduction

Since their introduction by DuHamel and Isbell in the 1960s, log periodic dipole array (LPDA) antennas have been widely used for various applications, such as long-distance radio communications, terrestrial broadcasting television reception, electromagnetic compatibility measurement, and high-resolution radar systems because of their relatively uniform input impedance, voltage standing wave ratio (VSWR), radiation pattern, and gain characteristics over a wide range of frequencies[1]. LPDA antennas consist of a number of half-wavelength dipole-driven elements with gradually increasing length, which are connected in parallel to the feed transmission line with an alternating phase. Planar or printed versions of the LPDA antenna have also been extensively investigated for various applications due to advantages such as low cost, low profile, and light weight[2].

Ultra-wideband (UWB) technology with the 3.1-10.6 GHz frequency band has been widely researched in many fields, such as short-range wireless communications, distance measurement, radar, and imaging systems, because of its high-speed transmission, wide bandwidth, and very low spectral power density[3]. A printed series-fed LPDA antenna with dimensions of 80 mm×60 mm×1.6 mm using trapezoidal toothed dipole elements and a microstrip-to-coplanar strip line transition operating in the 4-11 GHz band was introduced with a large gain variation of 3-7 dBi[4]. A simple LPDA antenna using strip dipoles and a strip feed line with an input reflection coefficient better than -10 dB over the band from 4.2-10.6 GHz and a gain of 5-10 dBi was presented[5]. The dimensions of this LPDA antenna are 200 mm×50 mm×1.02 mm. A printed UWB LPDA antenna operating in the 4-18 GHz frequency range to cover C, X, and Ku bands with dimensions of 70 mm×40 mm×0.51 mm and simulated gain of 6.5-8.5 dBi was proposed[6]. An eight-element LPDA antenna covering 1.4-12 GHz with an average gain of 4.51 dBi was presented for WLAN/LTE/UWB applications[7]. The dimensions are 115 mm×72.2 mm. A coplanar waveguide-fed UWB LPDA antenna using U-shaped dipole elements was proposed with operating frequency band of 1.85-11 GHz, dimensions of 50 mm×50 mm×0.8 mm, and an average gain of 5.5 dBi[8]. In order to extend the lowest operating frequency, the longest strip dipoles of the LPDA antenna were replaced by triangular dipole elements to cover 0.4-8 GHz with dimensions of 270 mm×278 mm×1 mm and gain of 2-6 dBi[9]. A compact LPDA antenna with twelve biconial dipole elements was proposed for operating in the frequency band from 0.5 GHz to 6 GHz[10]. The dimensions are 170 mm×160 mm×1.6 mm and gain ranges from 4.6 dBi to 7 dBi.

A design method for a compact LPDA antenna fully covering the UWB band by employing right triangle-shaped dipole elements appended with strips is presented in this paper. Note that although the original UWB band is 3.1 to 10.6 GHz, it is designed for 3 to 18 GHz band to give a sufficient margin in the high frequency band. First, a reference 16-element LPDA antenna using strip dipole elements to operate in the 3-18 GHz range with 8 dBi gain was designed. In order to reduce the width of the LPDA antenna, right triangle-shaped dipole elements were applied, instead of the strip dipole elements of the reference antenna, and the frequency band for a VSWR < 2 and gain in the band were investigated. Next, considering the shift toward a low frequency when the right triangle-shaped dipole elements were used, the length of the longest dipole was shortened to cover the 3-18 GHz band. The spacing between the dipole elements was then decreased to reduce the length of the LPDA antenna. Finally, strips were appended at the ends of the right triangle-shaped dipole elements in order to further reduce the width. The commercial electromagnetic simulator CST Microwave Studio was used to obtain full-wave simulation results of the antenna.

Ⅱ. Compact LPDA Antenna Geometry and Design Method

Figure 1 shows the geometries of the conventional planar LPDA antenna with strip dipole elements and the proposed compact LPDA antenna with right triangle-shaped dipole elements appended with strips.

In general, scale factor τ and spacing factor σ of the LPDA antenna are given by the following equations [1].

$$\tau = \frac{l_{n-1}}{l_n} = \frac{w_{n-1}}{w_n} = \frac{d_{n-1}}{d_n} \tag{1}$$

$$\sigma = \frac{d_{n-1}}{2l_n} = \frac{1-\tau}{4\tan(\alpha)} \tag{2}$$

where l_n is the length of the n-th dipole element, w_n is the width of the n-th dipole element, d_{n-1} is the spacing between the n-th and (n-1)-th dipole elements, b_n is the length of the strip for the n-th dipole element, and α is the apex angle. For the proposed compact LPDA antenna, right triangle-shaped dipole elements are used instead of the conventional strip dipole elements to reduce the width of the LPDA antenna, and flare angle θ determines the shape of the right triangle-shaped dipole elements.

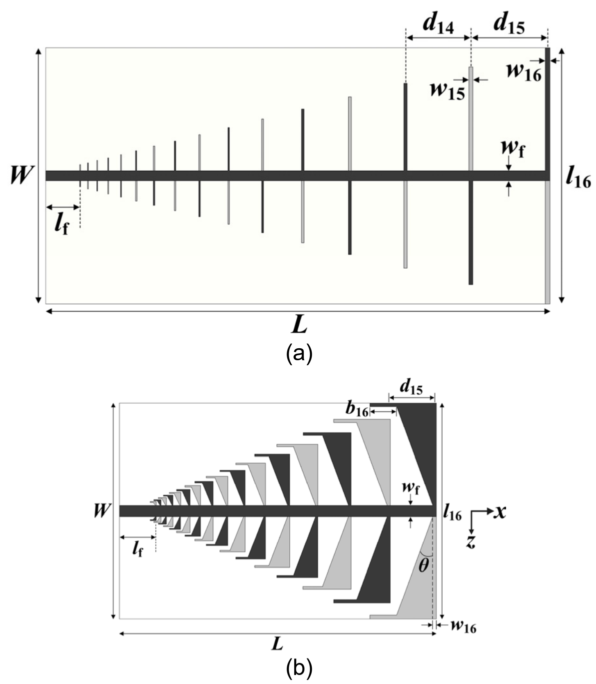


그림 1. LPDA 안테나 구조: (a) 기존 LPDA 안테나, (b) 제안된 스트립이 추가된 직각 삼각형-모양 다이폴 소자를 사용한 소형 LPDA 안테나

Fig. 1. Geometries of LPDA antennas: (a) conventional LPDA antenna and (b) proposed compact LPDA antenna using right triangle-shaped dipole elements appended with strips.

The spacing factor of the proposed compact LPDA antenna is decreased, compared to that of the conventional LPDA, in order to reduce the length of the antenna. To further reduce the width, strips are appended at the ends of the right triangle-shaped dipole elements, as shown in Figure 1(b).

To help understand the design procedure for a compact LPDA antenna, four antenna structures were considered for performance comparison, and are shown in Figure 2. The corresponding simulated input VSWR and gain characteristics for the four antenna structures are presented in Figure 3.

Figure 2(a) shows the reference conventional LPDA with 16 strip dipole elements, and Figure 2(b) depicts the reference LPDA replaced by the right triangle-shaped dipole elements. Figure 2(c) is the miniaturized LPDA using the right triangle-shaped dipole elements and reduced spacing factor, whereas Figure 2(d) is the proposed compact LPDA using the right triangle-shaped dipole elements, reduced spacing factor, and the strips.

First, the reference LPDA antenna with strip dipole elements was designed based on the design procedure for a planar LPDA described in the literature[2]. In order to achieve a directivity of 8 dBi over the 3-18 GHz frequency band (1:6 frequency ratio), a scale factor, τ = 0.85 and a spacing factor, σ = 0.150 were selected accordingly. The number of dipole array elements needed was calculated to be 16. The length of the longest dipole element (l_{16}) is a little less than a half-wavelength of the lower frequency limit of 3 GHz.

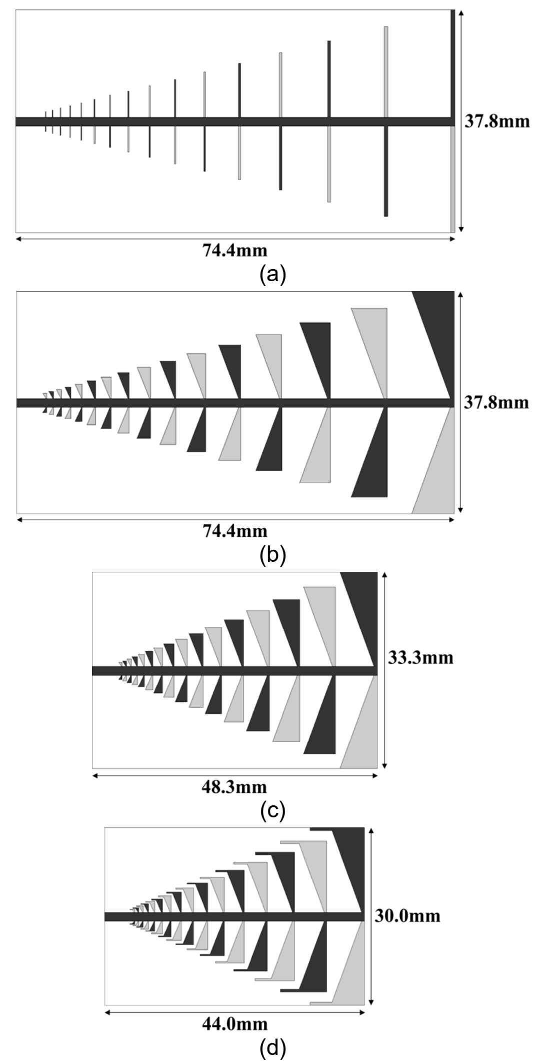


그림 2. 성능 비교를 위한 4가지 안테나 구조: (a) 스트립 다이폴 소자로 구성된 기존 LPDA 안테나, (b) 직각 삼각형-모양 다이폴 소자로 구성된 LPDA 안테나, (c) 감소된 간격 인자를 사용하여 소형화된 직각 삼각형-모양 다이폴 소자로 구성된 LPDA 안테나, (d) 제안된 직각 삼각형-모양 다이폴 소자, 감소된 간격 인자, 스트립을 사용한 소형 LPDA 안테나

Fig. 2. Four antenna structures for performance comparison: (a) a conventional LPDA antenna with strip dipole elements, (b) an LPDA antenna with right triangle-shaped dipole elements, (c) a miniaturized LPDA antenna using right triangle-shaped dipole elements and a reduced spacing factor, and (d) the proposed compact LPDA antenna using right triangle-shaped dipole elements, a reduced spacing factor, and strips.

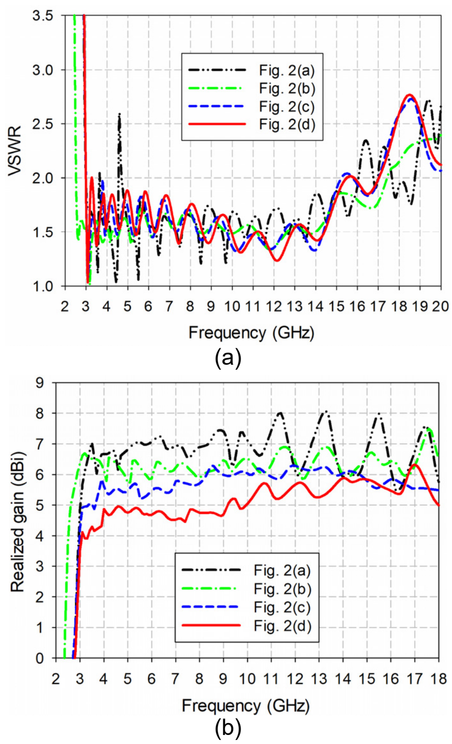


그림 3. 그림 2의 안테나 구조에 대한 입력 VSWR과 이득 특성 비교: (a) 입력 VSWR, (b) 이득

Fig. 3. Comparison of input VSWR and gain characteristics for the antenna structures in Figure 2: (a) input VSWR and (b) gain.

표 1. 그림 2의 기준 및 제안된 LPDA 안테나의 설계 변수

Table 1. Design parameters of the reference and proposed LPDA antennas in Figure 2. (all units are in millimeters.).

	reference LPDA antenna (Fig. 2(a))			proposed LPDA antenna (Fig. 2(d))			
dipole number	length (l_n)	width (w_n)	spacing (l_n)	length (l_n)	width (w_n)	spacing (l_n)	strip length (b_n)
1	3.3	0.10	1.2	2.6	0.10	0.7	0.33
2	3.9	0.10	1.4	3.1	0.10	0.8	0.38
3	4.6	0.10	1.6	3.6	0.10	0.9	0.45
4	5.4	0.10	1.9	4.3	0.10	1.1	0.53
5	6.3	0.10	2.2	5.0	0.10	1.3	0.62
6	7.4	0.20	2.6	5.9	0.20	1.5	0.73
7	8.8	0.20	3.1	6.9	0.20	1.7	0.86
8	10.3	0.20	3.6	8.2	0.20	2.0	1.02
9	12.1	0.20	4.3	9.6	0.20	2.4	1.20
10	14.3	0.25	5.0	11.3	0.20	2.8	1.41
11	16.8	0.29	5.9	13.3	0.23	3.3	1.66
12	19.7	0.34	7.0	15.7	0.27	3.9	1.95
13	23.2	0.40	8.2	18.4	0.32	4.6	2.29
14	27.3	0.47	9.6	21.7	0.38	5.4	2.70
15	32.1	0.56	11.3	25.5	0.44	6.4	3.17
16	37.8	0.65		30.0	0.52		3.73

l_{16} was determined to be l_{16} = 37.8 mm, considering the effective dielectric constant of the substrate[2]. The LPDA antenna is assumed to be printed on an FR4 substrate with a dielectric constant of 4.4 and a thickness of h = 0.8 mm (loss tangent = 0.025). The width of l_{16} was calculated using the relationship between the average characteristic impedance of the dipole element and the length and width of the dipole[11]. The lengths and widths of the remaining dipole elements, and the spacing between the elements can be calculated by using equations (1) and (2). The designed geometric parameters of the reference LPDA antenna are shown in Table 1. The overall length, L, of the reference LPDA is 74.4 mm. The width of the feed line is w_f = 1.5 mm. The frequency band for a VSWR < 2 is 2.99-16.06 GHz, and gain in the band is 4.8-8.0 dBi with an average of 6.9 dBi. It is worthwhile to note that impedance mismatch exists in the frequency ranges of 3.63-3.65 GHz, 4.55-4.70 GHz, and 16.06-17.65 GHz with maximum VSWR of 2.6, and the frequency band can be extended to 19.20 GHz for a VSWR < 2.6, which satisfies the desired frequency band of 3-18 GHz. In addition, gain in the band fluctuates a lot because of the large variation in input VSWR. Average gain reduction compared to the requirement of 8 dBi might have resulted from the loss tangent of the substrate, and this can be avoided by using a low-loss substrate.

Second, the right triangle-shaped patches were appended to the left side (feed or apex direction) of the strip dipole elements, as shown in Figure 2(b). In this case, a flare angle of θ = 20° was chosen. The length and width of the LPDA antenna are the same as those in Figure 2(b). The frequency band for a VSWR < 2 is 2.52-17.42 GHz (1:6.9) and the frequency bandwidth increased, compared to the reference LPDA antenna. In addition, the lower-limit frequency shifted from 2.99 GHz to 2.52 GHz, which confirms the size reduction of the antenna. Gain in the band is 4.0-7.2 dBi with an average of 6.3 dBi. Although the average gain slightly decreased, the fluctuation of gain in the high-frequency region was greatly reduced.

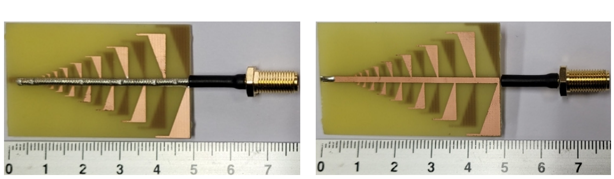
Third, the length of the longest dipole was shortened to l_{16} = 33.3 mm to cover the 3-18 GHz band, considering the frequency shift toward the low frequency in Figure 2(b) when the right triangle-shaped dipole elements are used. In addition, the spacing between the dipole elements decreased by modifying the spacing factor to σ = 0.106 in order to reduce the length of the LPDA antenna. Therefore, total length L of the LPDA with a 5 mm feed line was reduced to 48.3 mm, as shown in Figure 2(c). The frequency band for a VSWR < 2 is 2.99-15.24 GHz, and gain in the band is 4.2-6.3 dBi with an average of 5.8 dBi. We can see that a slight impedance mismatch exists in the frequency range 15.24-15.74 GHz, with a maximum VSWR of 2.04, and the frequency band can be extended to 17.02 GHz to meet the VSWR < 2.04 criterion.

Finally, strips were appended at the ends of the right triangle-shaped dipole elements, and the length of the longest dipole was shortened to l_{16} = 30.0 mm to cover the 3-18 GHz band, considering the frequency shift toward the low frequency owing to the size-reduction effect from addition of the strips. The length of the strip on l_{16} is b_{16} = 3.73 mm, and its width is the same as w_{16}. The lengths and widths of the strips on the remaining right triangle-shaped dipole elements can be calculated by using equation (1). As shown in Figure 2(d), the overall length, L, of the LPDA including a 5 mm feed line extension (= l_f) was reduced to 44.0 mm. The designed geometric parameters of the proposed compact LPDA antenna are shown in Table 1. The frequency band for a VSWR < 2 is 2.99-17.04 GHz, and gain in the band is 4.1-6.3 dBi with an average of 5.2 dBi. We note that the length of the proposed compact LPDA antenna in Figure 2(d) is reduced by 40.9%, compared to the conventional LPDA antenna in Figure 2(a), whereas the width is reduced by 20.6%.

Ⅲ. Experiment Results

A prototype of the proposed compact LPDA antenna using right triangle-shaped dipole elements with a reduced scaling factor and strips was fabricated as shown in Figure 4. A coaxial cable soldered along the top-side transmission line is used to feed the antenna, and its center conductor is connected to the bottom-side transmission line through a hole at the end of the feedline.

The performance of the fabricated antenna was measured by using an Agilent N5230A network analyzer and anechoic chamber, and the results are compared in Figure 5. The measured frequency band for a VSWR < 2 is 2.99-14.76 GHz. The upper limit frequency decreased, compared to the simulated antenna. The simulated gain in the UWB band is 4.1-5.7 dBi, whereas the gain measured was 4.0–4.8 dBi. The difference between simulated and measured results in the high frequency region might be related to the impedance mismatch and the loss caused by the coaxial cable. This problem can be improved by adjusting the lengths and spacings of the dipoles in the high frequency band.



(a) (b)

그림 4. 제작된 안테나 사진: (a) 앞면, (b) 뒷면

Fig. 4. Photograph of the fabricated antenna: (a) front side and (b) back side.

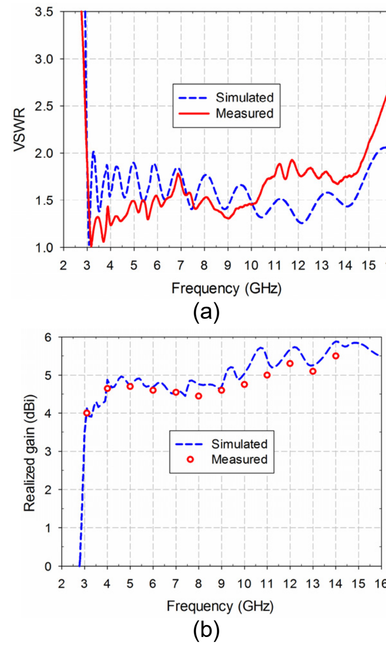


그림 5. 제작된 LPDA 안테나의 성능: (a) 입력 VSWR, (b) 이득

Fig. 5. Performance of the fabricated LPDA antenna: (a) input VSWR and (b) gain.

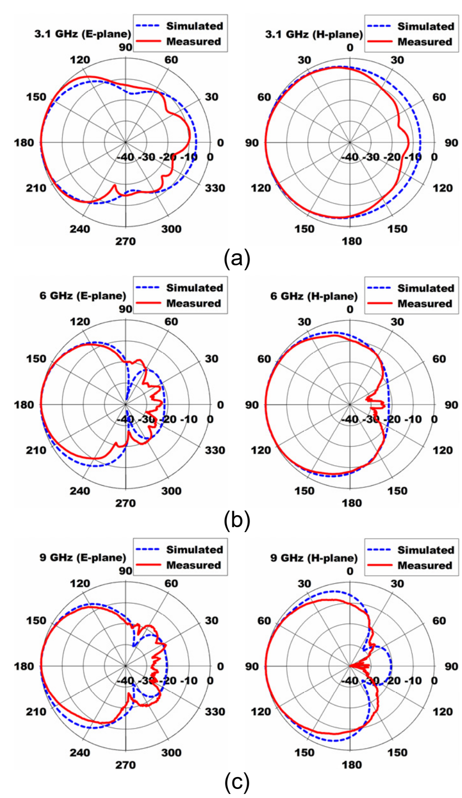


그림 6. 제작된 LPDA 안테나의 E- 및 H-평면 측정 복사 패턴: (a) 3.1 GHz, (b) 6 GHz, (c) 9 GHz

Fig. 6. Measured radiation patterns of the fabricated LPDA antenna in the E- and H-planes at (a) 3.1 GHz, (b) 6 GHz, and (c) 9 GHz.

The radiation patterns of the fabricated antenna in the E-plane (z-x plane) and the H-plane (x-y plane) at 3.1 GHz, 6 GHz, and 9 GHz are plotted in Figure 6, in which the measured patterns for both planes agree well with the simulated results. The proposed antenna has end-fire beam patterns with a measured front-to-back ratio > 10 dB.

Ⅳ. Conclusions

A compact LPDA antenna operating in the 2.99-14.76 GHz frequency range was designed using right triangle-shaped dipole elements with a reduced scaling factor and appended strips.

The fabricated prototype shows a frequency band of 2.99-14.76 GHz for a VSWR < 2 with gain of 4.0-5.5 dBi and a front-to-back ratio > 10 dB. The reduction in the length of the proposed LPDA antenna (compared to a conventional LPDA) is 40.9%, whereas the reduction in the width is 20.6%.

The proposed antenna can be used for wideband directional antennas for UWB communication applications.

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