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RESEARCH ARTICLE

Compact wideband tapered-fed printed bow-tie antenna with rectangular edge extension

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Abstract

In this article, a wideband printed bow-tie antenna is designed entire band of GPS (L5), PCS, IMT-2000, Bluetooth, Wi-Fi, WiMAX bands, and the most of frequency range of UWB. Apart from the traditional designs, the proposed antenna includes tapered printed line with a feeding point patch and triangular bows with rectangular edge extensions, which makes the antenna more compact. The antenna realized at the frequency band of 1.49-9.5 GHz (more than 6.3:1 ratio bandwidth) has the dimensions of 122 mm × 56 mm ($0.61\lambda_0 \times 0.28\lambda_0$). According to measurement results, the realized gain varies between almost 1 and 6.5 dBi with 4.44 dBi average, which are in good agreement with simulation results. Radiation patterns at the lower frequencies of operating band show dipole like radiation pattern with higher cross-pol discrimination levels while they degrade at the higher frequencies due to increase in gain.

KEYWORDS

bow-tie antenna, microstrip antenna, tapered feeding, wideband antenna

1 | INTRODUCTION

In recent years, the growth in communication technologies has led to development of various wireless systems such as Global System for Mobile communications (GSM), Bluetooth, WLAN, WiMAX, and UWB. Additionally, they have been generally used in different applications such as radar and biomedical. For this reason, today's space and weight limited, and low cost portable or wearable devices must be compatible with the above systems according to the purpose, and hence they require wideband antennas.

Biconical antennas are one of the very well-known antenna types and they have been employing in Very High Frequency (VHF)/Ultra High Frequency (UHF) band applications and electromagnetic compatibility (EMC) measurements for a long time. However, their massive, physically large and heavy structures degrade their convenience. Planar versions of them, which are mechanically lighter and more functional are developed in order to take advantage of their electrical characteristics as much as possible.[1] They are generally named as bow-tie antennas (BA) consisting of two metallic sheets and fed on the contact point of them. BAs are linearly polarized and they have bidirectional radiation pattern with broad main beam perpendicular to the plane of the antenna. As currents are abruptly terminated at the ends of the bows, BAs have limited bandwidth in common. Traditional printed bow-tie antennas (PBA) with triangular bows and straight feeding line do not offer wideband characteristics, too. On the other hand, printed antennas exhibit very low profile, small size, light, weight, low cost, high efficiency, and ease of fabrication and implementation. Furthermore, they are readily adaptable to hybrid and monolithic microwave integrated circuits' fabrication techniques at RF and microwave frequencies.[2]

In the literature, there are many studies about PBAs for very wide range of specific applications such as ground penetrating radar, synthetic aperture radar (SAR) imaging, cancer detection, medical sensors, radio astronomy, wireless communication, direction finding, 5G communications, antenna measurements, UHF and digital video broadcasting (DVB) reception, GPS, RFID, millimeter wave, and pulse-based systems.[3–9] Single-sided and double-sided PBAs can be counted as two main types of them. Employment of coplanar waveguide (CPW) feeding is the most practical way to realize single-sided PBAs,[9,10] when parallel transmission and microstrip lines are frequently used in double-sided PBAs. According to the needs of these specific applications, performances of PBAs have been tried to be improved. There are many useful methodologies such as implementations of metamaterials,[7,9,11] feeding line modifications,[8,10–12] employment of slots,[9,13,14] different ground plane[15,16] variations, matching stubs[7] and lumped elements,[17] fractal[18] and array[15,19] structures, parasitic directors,[10,12,20] reflectors[14,21] and additional bow

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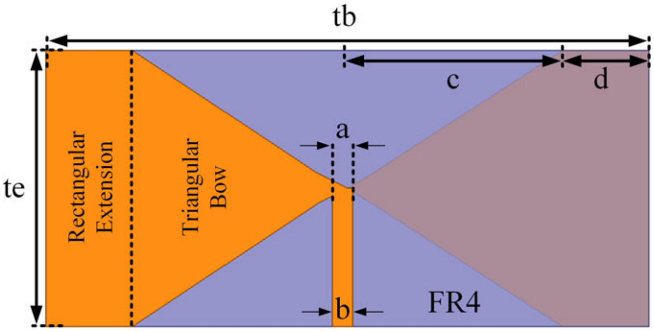

FIGURE 1 Printed bow-tie antenna with rectangular extensions [Color figure can be viewed at wileyonlinelibrary.com]

extensions[10,11] are suggested in order to improve the performances of PBA in terms of radiation pattern, gain, and bandwidth. However, relatively smaller structures have comparably narrower bandwidths[7,8,13] while the ones with relatively wider bandwidth have larger dimensions.[17] In this article, a novel compact PBA design is introduced for wideband applications including GPS, GSM, Wi-Fi, WiMAX, and UWB. Wideband characteristics are obtained by employing additional rectangular extensions at bows and tapered printed line with a small patch at feeding line. In this study, comprehensive numerical studies with parametric analysis are performed by using HFSS and CST, and their results are validated by the measurements.

2 | PBA DESIGN

Although design procedures are suggested for some of the special kinds of PBAs, there is no exact formulation for the design of PBA in the literature.[22] These antennas are generally designed and optimized by using several numerical methodologies. As depicted in Figure 1, the antenna in this study consists of two identical bows located at the both sides of the dielectric substrate. To determine the shape of the bows, triangular and exponentially tapered geometries are investigated. Apart from the traditional bow design, the antenna has bows with rectangular extensions, which results in the reduction of antenna dimensions and makes the antenna operate at lower frequency band. These bows are fed by a parallel tapered line having a feeding point patch (FPP) at the termination of SMA connector.[23]

A low cost FR4 substrate with thickness of 1.52 mm, dielectric constant of 4.4, and tangent loss of 0.02 is used for the mentioned design. Parametric studies are realized by HFSS in this study in order to perform a wideband antenna in GHz region with compact structure as much as possible. For this purpose, different geometries for feeding lines and bow tapering are investigated to understand their effects on operating frequency bandwidth by considering the structure in Figure 1. The design is aimed to have minimum frequency

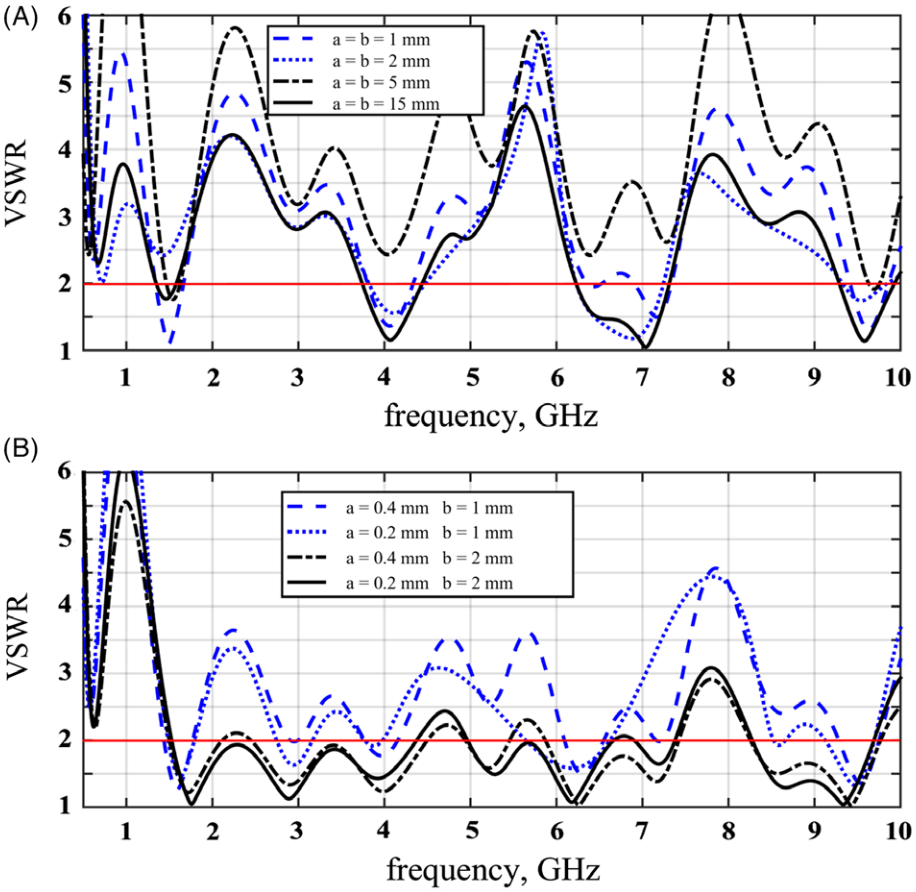

FIGURE 2 Simulated VSWR results: A, straight feeding line; and B, tapered feeding line [Color figure can be viewed at wileyonlinelibrary.com]

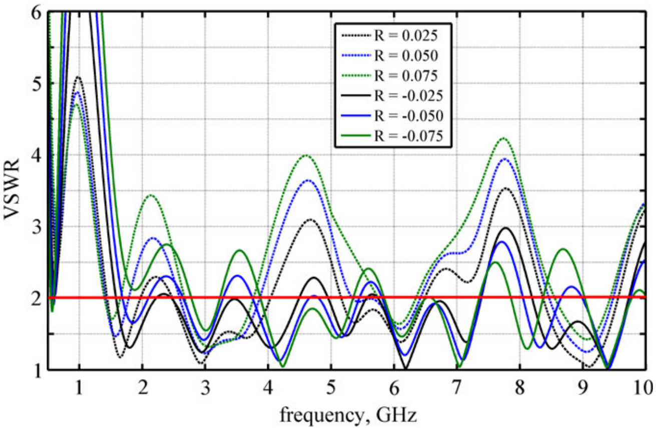

FIGURE 3 Simulated VSWR results of exponentially tapered bows for $a = 0.2$ mm and $b = 2$ mm [Color figure can be viewed at wileyonlinelibrary.com]

of around 1.5 GHz. The initial optimization studies are carried out by considering the mentioned minimum frequency and the structure in Figure 1 with triangular tapered bows. Here, inclined straight edges of triangular tapered bows obey the mathematical expression of where y and z are horizontal and vertical distance values from the upper end of the feeding line in Figure 1 (center point of Figure 1), respectively. From the optimization studies, the values of $tb = 122$ mm, $te = 56$ mm, $c = 43.5$ mm and $d = 17.5$ mm are obtained to make the antenna electrically small as possible, these

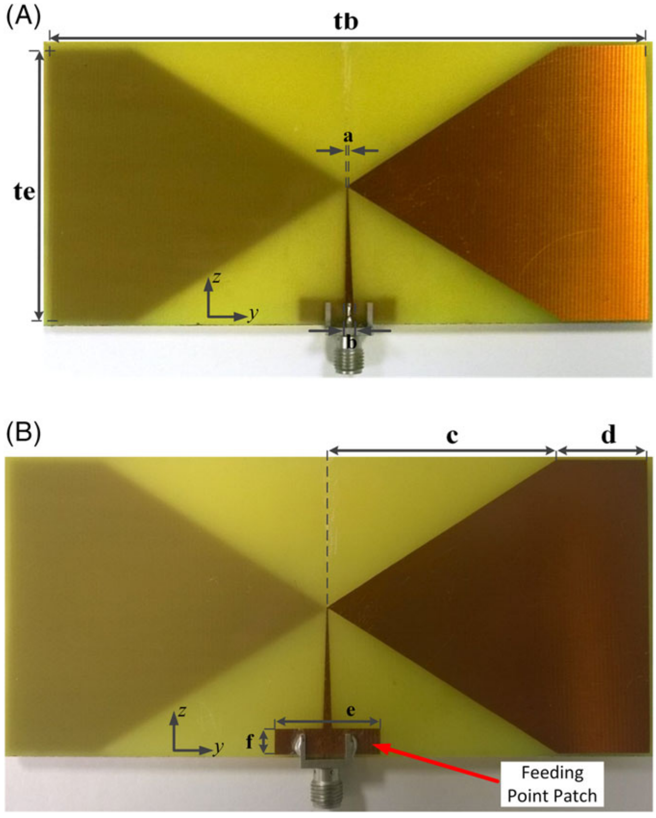

FIGURE 4 Fabricated proposed printed bow-tie antenna: A, front side; and B, back side [Color figure can be viewed at wileyonlinelibrary.com]

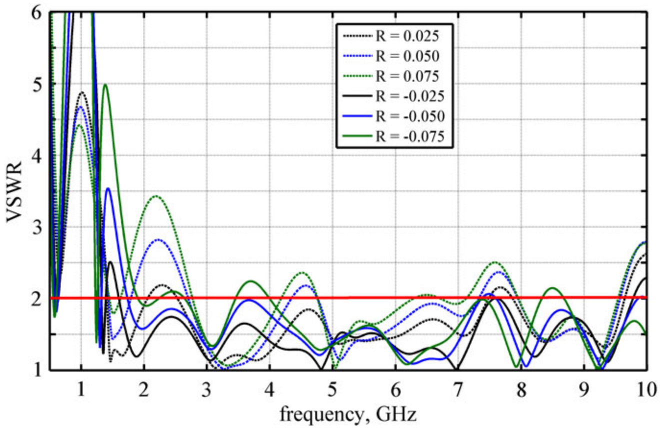

FIGURE 5 Simulated VSWR results of exponentially tapered bows with feeding point patch [Color figure can be viewed at wileyonlinelibrary.com]

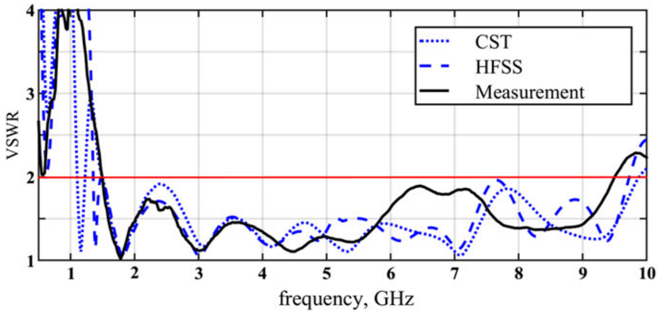

FIGURE 6 Comparison of simulated and measured VSWR for designed printed bow-tie antenna [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Comparison of proposed printed bow-tie antenna with the antennas in literature

Reference	Frequency band (GHz)	Bandwidth (%)	Dimensions	Peak gain (dBi)
7	2.48-3.80	42	$0.58\lambda_0 \times 0.33\lambda_0$	7.94
8	8.70-17.7	68	$0.87\lambda_0 \times 0.87\lambda_0$	No data
10	3.62-11.0	101	$0.36\lambda_0 \times 0.33\lambda_0$	7.90
13	2.88-10.8	116	$0.62\lambda_0 \times 0.29\lambda_0$	5.20
16	3.30-15.2	128	$0.37\lambda_0 \times 0.37\lambda_0$	6.60
17	0.50-5.10	164	$0.83\lambda_0 \times 0.64\lambda_0$	No data
Proposed	1.49-9.50	146	$0.61\lambda_0 \times 0.28\lambda_0$	6.50

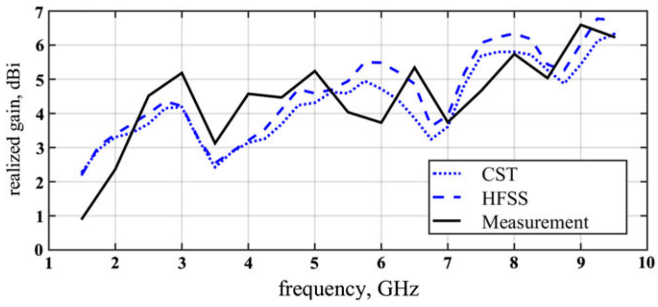

FIGURE 7 Realized gains of proposed printed bow-tie antenna [Color figure can be viewed at wileyonlinelibrary.com]

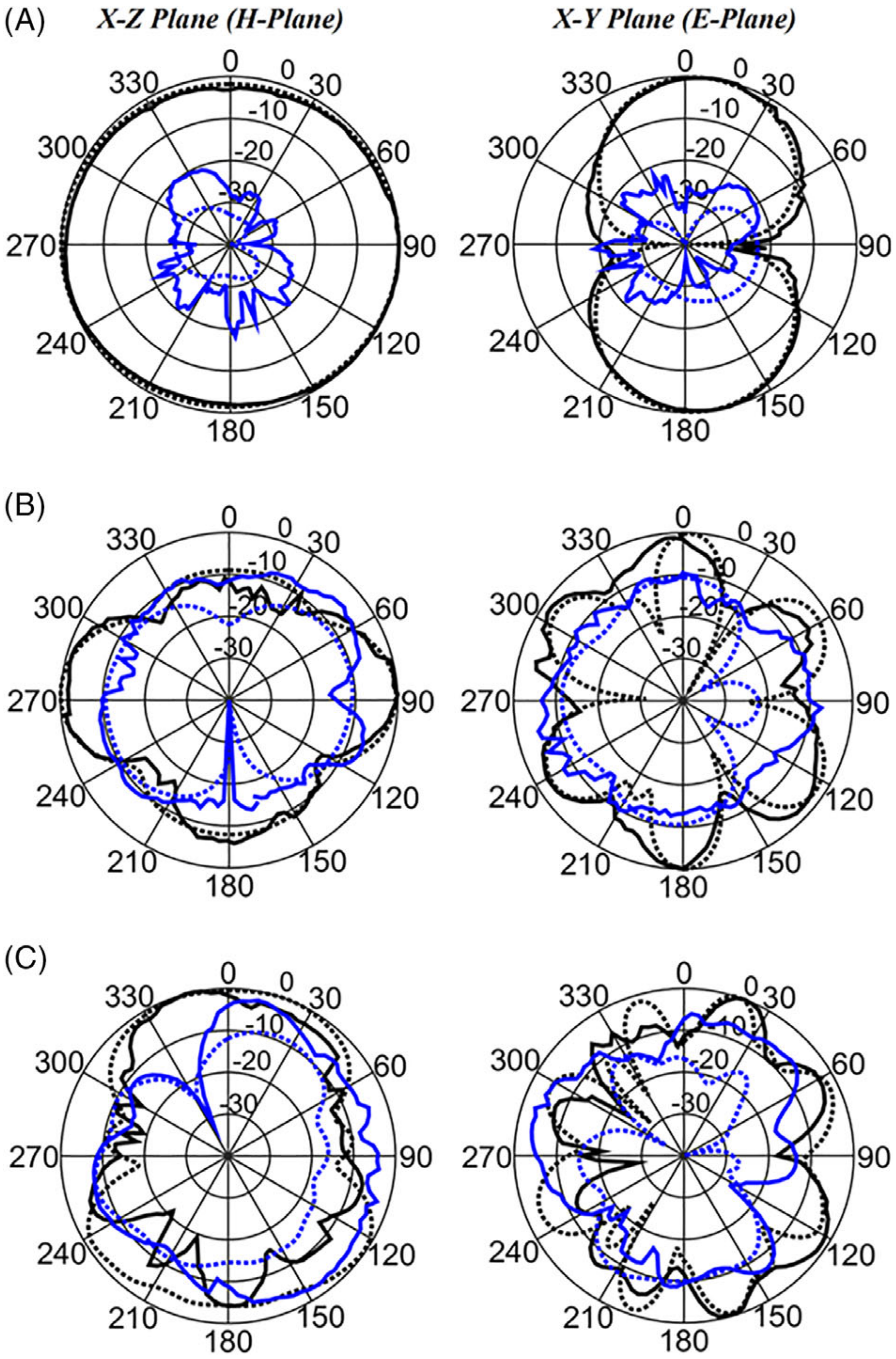

FIGURE 8 Normalized radiation patterns of proposed printed bow-tie antenna at: A, 2.5 GHz; B, 5.8 GHz; and C, 8 GHz (black: co-pol, blue: cross-pol, dotted: simulated, and solid: measured) [Color figure can be viewed at wileyonlinelibrary.com]

values are kept constant throughout the following parametric studies. The simulated VSWR results shown in Figure 2 are obtained for the different values of a and b in straight ($a = b$) and linearly tapered ($a < b$) parallel lines by keeping their lengths constant. It can be obviously seen from Figure 2A, PBA with straight feeding lines gives multiple narrow band characteristics. On the other hand, the results in Figure 2B with tapered lines have wider bandwidth and improved VSWR performance. Despite the acquired improvement on VSWR, it is still above 2 at the frequency bands of 4.5-5 GHz and 7.5-8.5 GHz even for $a = 0.2$ mm and $b = 2$ mm. As the next parametric and geometrical studies, exponentially tapered bows instead of triangular tapered bows are examined in order to make VSWR levels below 2 at the mentioned frequency bands. Here, the curved edges of the exponentially tapered bows are formed with a mathematical expression of $z = f(y) = \frac{te(e^{Ry}-1)}{2(e^{Rc}-1)}$, where R can be called as curvature parameter. The lengths of these bows are kept as same as the triangular ones, and tapered feeding line with $a = 0.2$ mm and $b = 2$ mm is chosen due to the results presenting in Figure 2. Then, bandwidth performances of

PBA are investigated for the values of $R = \pm 0.025$, ± 0.05, ± 0.075 and the corresponding results are shown in Figure 3. Although exponentially tapered bows with $R = -0.025$ gives very promising VSWR levels around 7 GHz, they are still above 2 in 4-6 GHz bands. To improve the bandwidth performance of the antenna, a small FPP which is located at the end of tapered feeding line and shown in Figure 4 is used. The dimensions of FPP are optimized and found as $e = 20$ mm and $f = 5$ mm. Then, the performances of bows are investigated again for the proposed tapered feeding line with FPP. Exponentially tapered bows' results are compared in Figure 5. It can be stated from the figure that, employing FPP significantly decrease VSWR values for all of values of R. PBA employing exponentially tapered bows for $R = -0.025$ has 6.1 bandwidth ratio, which is highly satisfied when it is compared to the ones in the literature, for the frequencies between 1.6 and 9.76 GHz. On the other hand, the antenna with triangular bows and FPP has better bandwidth performance with 7.2 bandwidth ratio for the frequencies between 1.35 and 9.75 GHz according to simulated results shown in Figure 6. Therefore, the overall dimensions of the proposed antenna shown in Figure 4 are finalized as $a = 0.2$ mm, $b = 2$ mm, $c = 43.5$ mm, $d = 17.5$ mm, $e = 20$ mm, $f = 5$ mm, $tb = 122$ mm and $te = 56$ mm.

3 | FABRICATION AND MEASUREMENT

VSWR, gain, and radiation patterns of the fabricated PBA prototype in Figure 4 with the obtained dimensions are measured. In Figure 6, the results of measured VSWR with HP 8720D and simulated VSWRs by CST and HFSS are presented and compared. As it seen from the figure, measured and simulated results are in good agreement. According to measurement results, the proposed PBA operates between 1.49 and 9.5 GHz, which corresponds to more than 6.3:1 ratio bandwidth or 146% bandwidth. The length and width of the proposed antenna are 122 mm ($0.61\lambda_0$ for minimum operating frequency) and 56 mm ($0.28\lambda_0$), respectively. The proposed PBA is compared with the state-of-the-art broadside PBA realizations from the literature in Table 1. It can be easily observed that the proposed PBA provides a highly competitive trade-off between bandwidth and compactness compared with the other designs such as all studies except Reference 17 have smaller bandwidth in percentage where Reference 17 has slightly higher bandwidth but significantly larger electrical area (almost four times larger than proposed PBA). Although References 21 and 24 have very compact dimensions with quite wide band characteristics and high gain, their multilayer structure degrades its planarity and degrades its usage convenience. In Figure 7, simulated and measured realized gains are presented. According to measurements, the gain values within the frequency band vary between 1 and 6.5 dBi. The average realized gains are 4.27, 4.61, and 4.44 dBi for CST, HFSS, and measurements, respectively. Simulated and measured radiation patterns at 2, 5.8, and 8 GHz for co-pol and cross-pol are presented in Figure 8. They are in very good agreement especially the ones for co-polarization. As it is seen from the figure that the antenna has a dipole like radiation pattern with more than 20 dB co-polarization and cross-polarization discrimination level at 2 GHz. However, both dipole like radiation pattern and high discrimination levels degrade at higher frequencies.

4 | CONCLUSION

In this article, a wideband PBA is presented. The proposed antenna has two bows consisting of triangular structures with rectangular edge extensions, and it is fed by a tapered printed line with an FPP to improve the bandwidth. The antenna has 146% bandwidth at 1.49-9.5 GHz band that corresponds to entire band of GPS (L5), PCS, IMT-2000, Bluetooth, Wi-Fi, WiMAX bands, and the most of frequency range of UWB. The antenna is sufficiently compact with the size of $0.61\lambda_0 \times 0.28\lambda_0$ compared to ones in the literature, and it reaches the maximum 6.5 dBi realized gain at 9 GHz. As a result, the proposed antenna is a very good candidate for wideband and multipurpose applications.

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