# Compact Design of Modified Pentagon-shaped Monopole Antenna for UWB Applications

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***Abstract*—In this work detailed analysis of a modified, pentagon-shaped planar antenna is presented for ultra-wide bandwidth (UWB) applications. The proposed antenna was designed on an FR-4 substrate and has a compact size of 12 × 22 × 1.6 mm$^3$. It achieves an impedance bandwidth of 8.73 GHz (3.8–12.53 GHz) in the UWB range. The design has a uniform gain and stable radiation pattern in the operating bandwidth.**

***Index Terms*—Golden angle, pentagram, pentagon, star-shaped antenna**

## I. Introduction

Nowadays, wireless communications and their high-speed data rate are becoming increasingly popular. The research in the field of microstrip antennas has also been conducted at higher speeds to achieve a higher data rate. Since the declaration of the ultra-wide bandwidth (UWB) band (3.1-10.6 GHz) by the Federal Communication Commission in 2002 for commercial use, research on UWB antennas has reached new heights [1]. The UWB monopole antennas have become one of the most emerging fields of research to acquire ultra-wide bandwidth and high data rate for wireless communication.

Recently, many wideband UWB monopole antennas with different shapes have been proposed [2]-[4]. Many star-shaped and pentagon-shaped antennas are also presented and reported [5]-[8]. Many similar modified UWB configurations for wider bandwidth, multi-band response, and notch characteristics have been investigated using slots in the radiating patch, ground plane, or feed line [9]-[12]. Many of the reported antennas are very large in size and have complex structures. The star-shaped antennas presented are not regular star-shaped pentagrams but have more than five angles.

The presented antenna is of a very compact size when compared to the previously investigated structures. The unique feature of a golden ratio is incorporated to design the pentagram star-shaped patch geometry. The initial design of the pentagram star-shaped monopole was modified to another pentagon monopole for enhanced radiation performance. Both geometries retain the concept of a golden ratio in their structures. The paper is organized into three sections. Section I consists of the introduction, and in Section II the initial antenna geometry is presented and discussed. In the preceding section, the modified pentagon-shaped antenna is elaborated and the results are discussed.

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## II. Antenna Geometry

### A. Initial Pentagram Star-shaped Antenna

The antenna presented in this paper was designed on a FR-4 substrate, which was a partial ground on one side and a conducting patch on the opposite side. The antenna design is initially started with a pentagram star shape and then the shape was modified into a pentagon shape. The pentagram is also called a pentangle, i.e., 5-pointed star [13]. The geometry of the microstrip line fed star-shaped monopole antenna is shown in Fig. 1. The width and length of the presented antenna are 12 mm and 22 mm, respectively. The star (pentagram)-shaped patch was printed on one side of the FR-4 substrate. The overall side length of the pentagram is $a$ = 10.47 mm. The full ground was optimized to a partial ground for improved results. The overall dimensions of the antenna are 12 × 22 × 1.6 mm$^3$.

The pentagram considered in this paper is a regular five angle star [13]. The pentagram star has one unique quality or number hidden inside its geometry called the golden ratio, which is approximately equal to 1.618 and denoted by the letter Phi ($\Phi$ =1.618). The golden ratio is also known as the golden mean or divine proportion. The unique characteristic of the golden ratio is that it differs from its reciprocal by unity [14], given by

$$\Phi - 1/\Phi = 1 \tag{1}$$

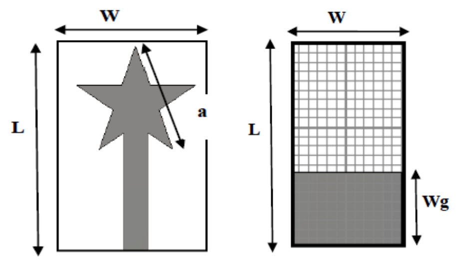


Figure 1. The geometry of the pentagram star-shaped monopole antenna: (a) Front-view and (b) back-view.

The concept of the golden ratio was utilized for the design of the patch geometry. The golden ratio for the




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proposed pentagram patch is described below. The concerned geometrical parameters and the patch geometry for the same are shown in Fig. 2, where $a$ = 10.472 mm and the total length of the side length of the star were $b$ = 6.472 mm, $c$ = 4 mm and $d$ = 2.472 mm. Thus we have

$$a/b = 1.618 = \text{Golden ratio}$$

$$b/c = 1.618 = \text{Golden ratio}$$

$$c/d = 1.618 = \text{Golden ratio}$$

The pentagram star-shaped antenna with a golden ratio makes an antenna unique from the other antennas presented [5], [6]. The characteristic results obtained for the novel prototype are presented in the succeeding sections.

The impedance bandwidth defined for a return loss ($S_{11}$) of −10 dB is shown in Fig. 3. The return loss characteristics presented show an impedance bandwidth of 7.9 GHz (3.8-11.7 GHz) in the UWB range.

The resonating frequencies are at 4.34, 7.24, and 10.81 GHz in the obtained range. The VSWR curve for the same is presented in Fig. 4. A VSWR <2 is obtained for the operating range.

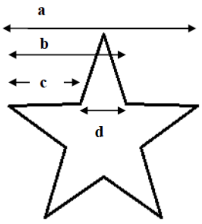



Figure 2. The design of the pentagon patch with a golden ratio.

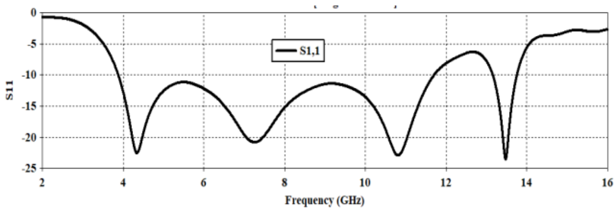



Figure 3. The variation in the return loss ($S_{11}$) with frequency.

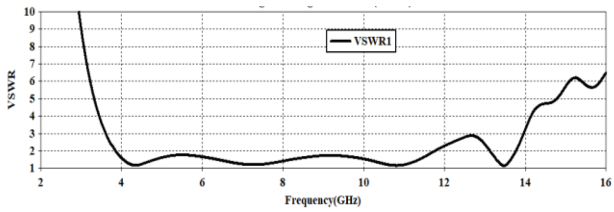



Figure 4. The variation in the VSWR with frequency.

## III. Modified Pentagon Monopole Geometry

The presented pentangle or pentagram geometry was modified to a regular pentagon-shaped antenna. The design was modified by connecting the five corner vertices of the star pentagram and the as-obtained geometry is a pentagon monopole with each side 6.47 mm in length. The ratio of the pentagon side length $l_p$ to the inner star side length $l_s$ (4 mm) was equal to the golden ratio (1.618), as shown in Fig. 5. Note that

$$l_p/l_s = 6.47 \text{ mm}/4 \text{ mm} = 1.618 = \text{Golden ratio}$$

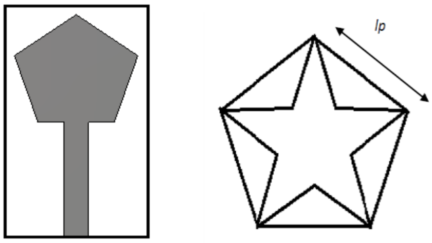



Figure 5. The modified pentagon monopole formed by connecting the five corners of the pentagram star.

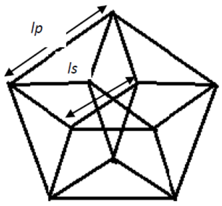



Figure 6. The pentagon, pentagram and inner star.

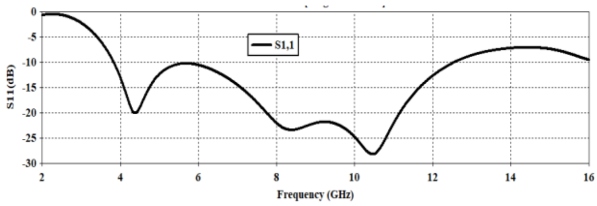



Figure 7. The variation in the return loss ($S_{11}$) with frequency.

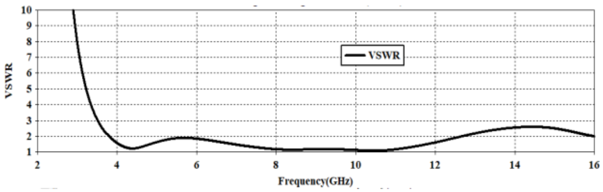



Figure 8. The variation in the VSWR with frequency.

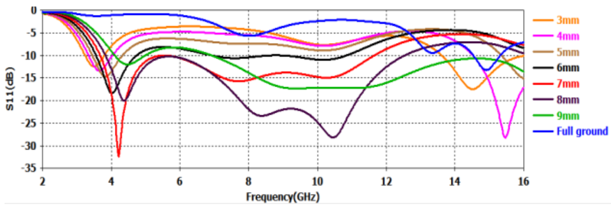



Figure 9. The variation in the return loss ($S_{11}$) for the different ground size.

The resulting antenna shape acquired after the modification is depicted in Fig. 6, which is a regular pentagon monopole fed with a microstrip line. The other parameters of the antenna remain the same as it was in the star-shaped pentagram design.

The return loss and VSWR characteristics are shown in Fig. 7 and Fig. 8, respectively. The achieved bandwidth of 8.73 GHz (3.8–12.53 GHz) for the antenna was improved when compared to the previous star-shaped antenna. The proposed antenna resonates at 4.4, 8.4, and 10.4 GHz.

A ground size of 8 mm was selected after parametric analysis of the various ground sizes. The initial design was considered with a full ground size of 22 mm. However, the return loss obtained was not satisfactory. The impedance bandwidths observed for the various ground sizes are presented in Fig. 9. The widest impedance bandwidth was acquired when the ground size was 8 mm.

The current distributions at the resonating frequencies were evaluated and presented in Fig. 10. The maximum current was accumulated at the feed line, and a very small current was accumulated at the lower portion of the pentagon patch at 4.4 GHz i.e., at the lower resonating frequency. The current starts flowing at the lower half part of the patch and contributed to the resonating frequency of 8.4 GHz. As the resonating frequency is higher at 10.4 GHz, the current was concentrated in the full patch. The current flows in the outer perimeter of the patch and results in the higher resonating frequency.

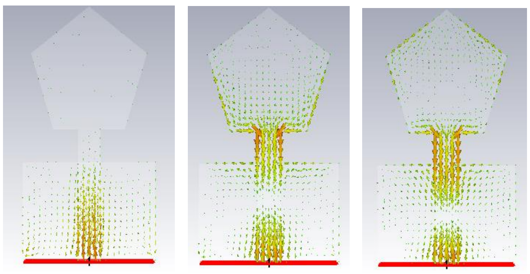


Figure 10. The surface current distribution at resonant frequencies of (a) 4.4 GHz, (b) 8.4 GHz, and (c) 10.4 GHz.

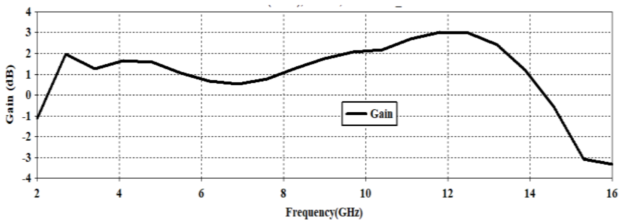
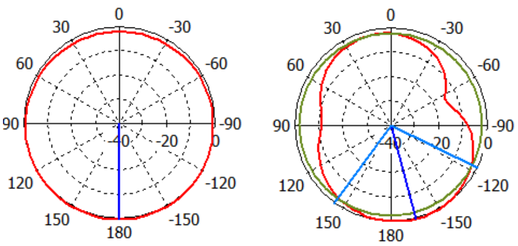
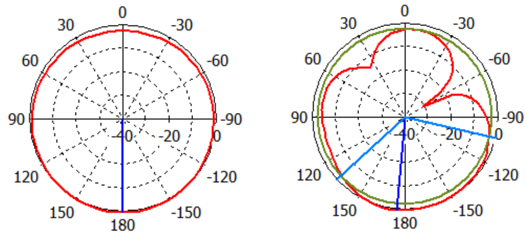



Figure 11. The variation in the gain with frequency (GHz).

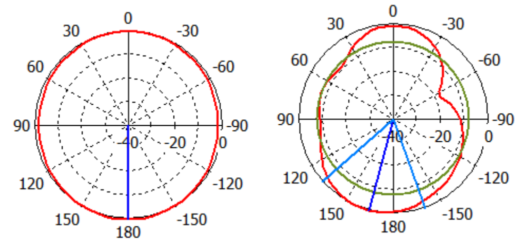
The variation in gain is shown in Fig. 11. It was observed that the gain is enhanced when compared to the initial star-shaped antenna. The radiation pattern for the E field and H-field are shown in Fig. 12. The E-plane radiation pattern at 4.4, 8.4, and 10.4 GHz are omnidirectional in nature. At 4.4 GHz the H-field is tilted by nearly 20° and at 8.4 and 10.4 the H-field is bidirectional in nature.



(a)



(b)



(c)

Figure 12. The elevation pattern at the resonant frequencies of (a) 4.4 GHz, (b) 8.4 GHz, and (c) 10.4 GHz.

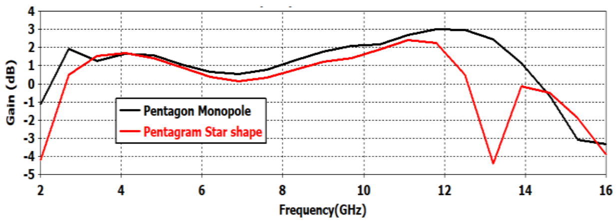



Figure 13. The gain comparison of the pentagon and pentagram star-shaped antenna.

TABLE I. A COMPARISON OF THE PREVIOUSLY REPORTED WORK WITH THE PROPOSED WORK

| Antenna design | Parameter | | | |
|---|---|---|---|---|
| | Size (mm$^2$) | Maximum Gain (dBi) | Bandwidth (GHz) | Remarks |
| Pentagram star | 12 × 22 | 2.8 | 3.8–11.7 | Simple structure with concept of Golden ratio |
| Pentagon | 12 × 22 | 3.02 | 3.8–12.53 | Simple geometry derived from Pentagram |
| Pentagon [3] | 25 × 30 | 3.05 (Without ground slot) | 3.6–14.7 | Large size |
| Hexagram star [5] | 20 × 19.5 | 6.36 | 13.32-13.75 | Slotted ground, small bandwidth |
| Octagram star [6] | 52 × 52 | 10.21 | 16 | Only one resonating frequency and large size |
| Irregular pentagon [7] | 33 × 30 | −0.95–4.4 | 2.6–20 | Large size and negative gain in some range |

A comparison of the gain observed for the pentagram star-shaped and pentagon monopole antennas is depicted in Fig. 13. The graph clearly shows the gain for the pentagon monopole was slightly higher than that for the star-shaped antenna. A comparison of the previously reported work with the proposed geometry is shown in Table I, considering the radiation performance parameters of the antenna.

## IV. CONCLUSIONS

A novel golden ratio pentagram star-shaped antenna was modified to a pentagon monopole for UWB applications. The initial antenna is constructed by incorporating the golden ratio in the star pentagram geometry and then modified into a pentagon monopole by connecting the corners of the five vertices of the pentagram shape. Both the prototypes have a very compact size of $12 \times 22 \times 1.6$ mm$^3$ and positive gain in the UWB range. The modified geometry resulted in an improved bandwidth i.e., from 7.9 GHz to 8.73 GHz and enhanced gain from 2.45 dBi for the star-shaped pentagram to 3.1 dBi for the pentagon monopole antenna. The enhanced gain and bandwidth makes the proposed antenna a better option for UWB applications.

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