A closed modified V-shaped uniplanar triple band ACS fed antenna for wireless applications

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ABSTRACT

In the proposed paper, a uniplanar asymmetric coplanar strip (ACS) fed antenna with closed V-shaped radiating patch of size $26 \times 15 \times 1.6 \text{ mm}^3$ printed on FR4 substrate with loss tangent ($\delta$)=0.02, height (h)=1.6mm, and dielectric constant of 4.4 covering WiMAX, X-band and WLAN applications is presented. The closed V-shaped radiating patch is formed by joining two rectangular stubs. The remaining radiating part is obtained by adding rectangular strips to feed to obtain multi-band operation. The advantage of this structure is that it forms simple configuration as well as helps the antenna attaining three distinct useful frequency band with good impedance matching for $S_{11} < -10 \text{ dB}$ criteria. The proposed antenna operates at 3.1 (WiMAX), 5.0 (WLAN) and 9.9 (X-band) GHz in simulation. Under measurement the proposed antenna shows multiband phenomenon at 3.2, 5.3 and 9.7 GHz, respectively. The antenna exhibits simulated gain of 2.51, 1.18 and 1.96 dB at 3.1, 5.0 and 9.9 GHz. The key parameters of the antenna like length and width of the multi-branched strips are optimized to get the multiband operation. The evolution and optimization process is dealt in detail with the help of $S_{11}$, VSWR, current distributions, radiation patterns and gain.

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1. INTRODUCTION

The recent advancements in the field of wireless communications has led to the development of different types of antennas. There is a necessity for integrating the various communication devices such as WLAN, WiMAX and LTE in a single wireless gadget (i.e. smart phones) [1-5]. Due to this, multiband antennas are being widely used in order to cover multiple frequency bands. Different types of antennas designed to cover the wireless applications are monopole, dipole, metamaterial, dielectric resonator antenna etc. Multi band antennas not only cover various applications but also display features like compact size, low costand high datarates [6-10].

The asymmetric coplanar strip (ACS) fed antennas has recently gained tremendous popularity to the antenna design engineers due to their size reduction techniques along with its wide impedance bandwidth, desired radiation properties (gain and efficiency) and simple structures [11-13]. ACS method provides a compact and uniplanar antenna since it has a single ground plane compared to other techniques [14, 15].

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In order to decrease the overall size of the patch antenna, designs are proposed using the concept of asymmetric coplanar strip fed technique [16-18]. In comparison to a coplanar waveguide (CPW) antenna, an ACS fed antenna will reportedly consume only 50% of area due to only half of the ground plane of coplanar waveguide fed structure [19, 20].

Recently numerous ACS fed multiband antenna are proposed in this regard [16-25]. An ACS fed antenna of size $14 \times 20 \times 1.6$ mm$^3$ operating at 2.35, 3.5 and 5.25 GHz is proposed in [16]. The radiating element is made up of Y-shaped patch with rectangular feed. Brijesh Mishra et al. [17] proposed a microstrip patch antenna for WLAN/WiMax applications, operating at frequencies 3.6 and 5.4 GHz of size $60 \times 36 \times 1.6$ mm$^3$. The antenna comprises of a single slot and inverted L-shaped slot. Samson et al. [18], proposed a dual band monopole antenna having a size of $19.1 \times 22.6 \times 1.6$ mm$^3$ and resonant frequencies of 2, 3 and 5.2 GHz. An ACS fed antenna loaded with mirrored S and L-shaped strips of size $11.5 \times 26 \times 1.6$ mm$^3$, with resonant frequencies of 2.35, 3.45 and 5.2 GHz is proposed in [19].

The proposed antenna consists of a meandered mirrored S-shaped strip and an electrical L-shaped radiating patch. Ansal et al. [20], proposed a novel CB (conductor backed) ACS-fed dual band antenna operating at frequencies 2.45 and 5 GHz of size $25 \times 17.5 \times 1.6$ mm$^3$. The antenna consists of a radiating L-shaped strip, ground plane and a modified truncated ground plane.

Arvind Kumar et al. [21] proposed a compact uniplanar ACS fed antenna operating at bandwidths 2.3 to 2.5 GHz, 3.4 to 3.6 and 4.25 to 6.85 GHz of size $14 \times 20.5 \times 1.6$ mm$^3$. It consists of multiple branches of L-shape and the asymmetric rectangular ground plane comprises of the ACS fed antenna. A Compact ACS-fed MIMO antenna operating at frequencies 5, 5.8 and 6.3 GHz of size $46 \times 26$ mm$^2$ is proposed in [22]. The antenna consists of meandered radiating patch with rectangular feed line. Similarly, a triple band ACS fed antenna with M and rectangular shaped radiating branches operating with bandwidths 2.41 to 2.55 GHz, 3.45 to 3.65 GHz and 4.6 to 6.3 GHz having a size of $12.5 \times 18 \times 1.6$ mm$^3$ is proposed in [23]. Praveen V. Naidu et al. [24] designed a printed V-shaped ACS fed compact dual band antenna of size $14.75 \times 26 \times 1.6$ mm$^3$ having resonant frequency of 2.48 and 3.6 GHz. A strip of V-shape and a vertical rectangular feedline is used as radiating elements for this antenna. Rajkumar et al. [25] proposed mirrored L-shaped monopole antenna with ACS feed operating at frequencies 2.44, 5.3 and 8.2 GHz having size of $22 \times 16.08 \times 0.8$ mm$^3$. Mirrored L-shaped branches and a split ring resonator is taken as the radiating patch. The antenna is designed using M and L-shaped strips. A rectangular-shaped CSRRs with offset-fed microstrip line is proposed to achieve this operating frequencies.

The above mentioned antennas are compact and are multiband in nature. However, the proposed ACS fed antenna in this research work has the advantage of more degree compactness, higher gain, simple configuration, stable radiation pattern and better impedance matching as compared to [16-25]. In the proposed paper, a V-shaped uniplanar triple-band ACS fed antenna has been designed with a size of $26 \times 15 \times 1.6$ mm$^3$ at frequencies 3.15 and 9.9 GHz with corresponding gains of 2.51, 1.18 and 1.96 dB. The resultant shape of the radiating patch is obtained by adding rectangular strips to feed line until desired results are obtained. The fabricated prototype of this antenna operates at 3, 5.2 and 9.7 GHz, thereby closely mimicking the simulated results.

2. ACS FED ANTENNA DESIGN
2.1. Design equation

The initial dimensions for an monopole antenna with resonant frequency ($f_1$) is calculated as [6]:

$$L = \frac{\lambda_0}{4} = \frac{c}{4f_r \sqrt{\varepsilon_{eff}}}$$  \hspace{1cm} (1)

where $L$=Length and $\varepsilon_r$=4.4. The equations mentioned below are used for the calculation of impedance:

$$Z_0 = \frac{60\pi \cdot k(k)}{\sqrt{\varepsilon_{eff}} \cdot k'(k')}$$  \hspace{1cm} (2)

$$\frac{k(k)}{k'(k')} = \begin{cases} \frac{\pi}{2} & 0 \leq k \leq \frac{1}{\sqrt{2}} \\ \frac{ln(1+k)}{ln(1-k)} & \frac{1}{\sqrt{2}} \leq k \leq 1 \\ \frac{1}{\pi ln(2\sqrt{k'}+\sqrt{1-k'})} & \frac{1}{\sqrt{2}} \leq k \leq 1 \end{cases}$$  \hspace{1cm} (3)

where $\varepsilon_r$ is the dielectric constant of the material, $k=a/b$ (Length of major axis/Length of Minor axis).
2.2. Design evolution

An ACS fed antenna for lower frequency ranges, covering WiMAX and WLAN applications, is proposed by evolving the basic structure (configuration “T1”) as shown in Figure 1(a). Configuration “T1” corresponds to a basic design consisting of only rectangular ground plane and rectangular feedline in the front plane (uniplanar). For this design two operating frequencies are obtained as depicted in Figure 1(b). To incorporate more number of operating bands “T1” is evolved by adding rectangular strips as shown in configuration “T2” of Figure 1(a). After adding four more strips to configuration “T1” strips (“T2-T5”) again dual band is achieved but with higher $S_{11}$ (Figure 1(b)) and gain values resulting in an open V-shaped radiating patch (configuration “T5”) in the front plane. The optimization process is carried out for “T5” configuration which leads to closed V-shaped radiating patch hence resulting in proposed structure (configuration “T7”). The proposed ACS fed antenna gives three operating bands at 3.1 (WiMAX), 5.0 (WLAN) and 9.9 GHz (X-band) for $S_{11}<-10$dB criteria as illustrated in Figure 1(b). The proposed configuration “T7” is further characterized by conducting parametric analysis in order to achieve stable radiation performances.

![Evolution stages of corresponding to “T7”](image1)

![Evolution stage $S_{11}$ results](image2)

Figure 1. (a) Evolution stages of corresponding to “T7”, (b) Evolution stage $S_{11}$ results

The overall design of the proposed uniplanar triple band ACS fed antenna covering WiMAX, WLAN along with X-band is outlined in Figure 2. The antenna consists of closed V-shaped radiating patch with rectangular ground plane in the radiating plane. The antenna is fed using rectangular ACS feed line to achieve an impedance matching of 50 ohm.

![Proposed “T7” configuration](image3)

Figure 2. Proposed “T7” configuration. (a) Front view, (b) Backview

2.3. Parameteric analysis

The operational characteristics is observed by performing parametric analysis where the antenna dimensions have been optimized by keeping one dimension constant and varying the other dimension. For operational characteristics optimum values of S1, S2, S3, S4 and F (as shown in Figure 2) are calculated with varying factor as 0.5mm. The first analysis is carried out by optimizing width of strip 1 (S1) of
the antenna. Its width is first decreased by 0.5mm and then increased by 0.5mm. The $S_{11}$ and gain plots of these analysis is depicted in Figure 3(a) and 3(b) respectively. For the $S_{11}$ plot the output is similar for all the three dimensions of of S1. Whereas, from the gain plot it can be observed that for S1=1mm the gain is more compared to other two values. Thus in this case S1=1mm is taken as the proposed dimension. Similarly, optimization of width of of strip 2 (S2) and strip 3 (S3) is carried out wherein the width is again increased and decreased by 0.5mm. The $S_{11}$ and gain plots are depicted in Figure 4 and Figure 5 respectively. In this case also the outputs are similar to that of S1. There is negligible variation for different dimensions of S2 and S3 in the $S_{11}$ plot, as depicted in Figure 4 and 5(a). On the other hand, the gain plot gives better result when S2=1mm and S3=1mm, as illustrated in Figure 4(b) and 5(b), respectively. Hence S2=S3=1mm is taken in the proposed structure as the final dimension. In the next step shown in Figure 6 modification in the width of strip 4 (S4) is done, in which the length is again kept constant and width is first increased by 0.5mm and then decreased by 0.5mm to analyse the results. From the $S_{11}$ and gain plots (Figure 6(a) and 6(b)) it is concluded that S4=1.05mm is chosen for the proposed design because it gives minimum return loss while maintaining the acceptable gain. Feed width of the antenna (F) is optimized in the similar manner by increasing and decreasing its width by 0.5mm. $S_{11}$ and gain plots are observed in Figure7 from where it is observed that the proposed dimension gives acceptable results for F=3.325mm. Thus, the final dimensions (mm) of these five important parameters in the proposed structure are: S1=S2=S3=1, S4=1.05 and F=93.325.

Figure 3. (a) Impedance bandwidth ($S_{11}$) vs. frequency, (b) Gain vs. frequency for variation in strip 1 (S1)

Figure 4. (a) Impedance bandwidth ($S_{11}$) vs. frequency, (b) Gain vs. frequency for variation in strip 2 (S2)

Figure 5. (a) Impedance bandwidth ($S_{11}$) vs. frequency, (b) Gain vs. frequency for variation in strip 3 (S3)
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3. RESULTS AND DISCUSSION

The proposed configuration “T7” is fabricated using photolithographic etching process and the fabricated prototype is depicted in Figure 8. In the simulated and measured $S_{11}$ result illustrated in Figure 9, it is seen that the antenna shows operation at 3.1, 5 and 9.9 GHz in simulation whereas in measured the fabricated antenna exhibits operation at 3.2, 5.3 and 9.7 GHz. The designed antenna has an impedance bandwidth of 1200 MHz (2.7-3.9 GHz, WiMAX), 1100 MHz (4.4-5.5 GHz, WLAN) and 800 MHz (9.5-10.3 GHz, X-band) in simulation. Under measurement the antenna shows a bandwidth of about 900 MHz (2.8-3.7 GHz), 800 MHz (4.6-5.4 GHz) and 600 MHz (9.4-10 GHz). The simulated results complies best with the measured results, however, slight differences in the results may be due to fabrication process, substrate loss and soldering of connectors. The obtained bandwidth is sufficient which can easily meet the demand of WiMAX, WLAN and X-band applications. The detailed results are summarized in Table 1.

![Figure 8. Fabricated prototype of the antenna](image8.png)

![Figure 9. Simulated and measured $S_{11}$ results](image9.png)
Table 1. Simulated and measured results of the designed antenna

| Sl. No. | PARAMETER          | SIMULATED RESULTS | MEASURED RESULTS |
|---------|--------------------|-------------------|------------------|
| 1.      | Frequency (GHz)    | 3.1               | 5                | 9.9               | 3.2               | 5.3               | 9.7               |
| 2.      | S_{11} (dB)        | -30.8             | -19.2            | -13.1            | -22               | -25.8             | -13.8             |
| 3.      | Bandwidth (MHz)    | 1200              | 1100             | 800              | 900 MHz           | 800 MHz           | 600 MHz           |
| 4.      | Applications       | WiMAX             | WLAN             | X-band           | WiMAX             | WLAN             | X-band           |

The simulated 3D gain plot of the designed antenna is illustrated in Figure 10. It can be seen that the antenna has a total gain of 2.5 dB, 1.18 dB and 1.96 dB at the operating frequency of 3.1 GHz, 5.0 GHz and 9.9 GHz, respectively.

![Figure 10. Gain at the operating frequencies of (a) 3.1, (b) 5, (c) 9.9 GHz](image)

The Figure 11 shows the surface current distribution at the three operating frequencies 3.1, 5.0 and 9.9 GHz. The scale shows the different colors which are arranged in descending order of the value of current. The regions depicted by red color shows a better current distribution as compared to the ones depicted by yellow, green and so on. It can be analysed for 3.1 GHz the current around strip length 1, 2 and 5 is more concentrated. For 5.0 GHz, the current is denser around the length of strip 2, 3 and 5. For 9.9 GHz the current covers the entire closed V-shaped path. The simulated radiation patterns of the proposed antenna at the three operating frequencies 3.1, 5 and 9.9 GHz is illustrated in Figure 12. The antenna has bi-directional radiation pattern and omnidirectional pattern in E (φ=0°) and H-plane (φ=90°) respectively.

![Figure 11. Current distribution at the operating frequencies of (a) 3.1, (b) 5, (c) 9.9 GHz](image)

![Figure 12. Simulated radiation patterns at (a) 3.1, (b) 5, (c) 9.9 GHz (blue line-φ=0°and red line-φ=90°)](image)
A comparative analysis is done between the proposed antenna and the similar type present in the literature. The Table 2 exhibits that the proposed ACS fed antenna has several advantages over its counterparts.

Table 2. Comparative analysis of the proposed ACS fed antennas with the similar types in the literature

| Ref. | Patch Size(mm²) | No. of bands | Operating Frequencies (GHz) | Operating Bandwidth (GHz) | Applications |
|------|-----------------|--------------|----------------------------|---------------------------|--------------|
| [16] | 14 × 20         | 3            | 2.35/3.5/5.25              | 2.3-2.4/3.4-3.55/4.15-6.6 | WLAN/WiMAX  |
| [17] | 60 × 36         | 2            | 3.5/4.5                    | 3.4-3.85/5.15-5.6         | WLAN/WiMAX  |
| [18] | 19.1 × 22.6     | 3            | 2/5.5                      | 1.86-1.91/2.89-2.98/4.96-6.78 | WLAN/WiMAX |
| [19] | 11.5 × 26       | 3            | 2.35/3.5/5.2               | 2.28-2.46/3.33-3.6/5.05-5.4 | WLAN/WiMAX  |
| [20] | 25 × 17.5       | 2            | 2.45/5                     | 2.30-2.55/4.06-6.65      | Bluetooth/WLAN |
| [21] | 14 × 20.5       | 3            | 2.4/3.5/5.5                | 2.3-2.53/4.3-6.25/6.85   | WLAN/WiMAX  |
| [22] | 46 × 26         | 3            | 5.8/6.3                    | 4.75-5.25/5.76-6.83/7.26-7.63 | WLAN/WiMAX |
| [23] | 12.5 × 16       | 3            | 2.45/3.5/5.5               | 2.41-2.55/3.45/3.65/4.65-6.5 | WLAN/WiMAX |
| [24] | 1475 × 26       | 2            | 2.48/3.06                 | 2.38-3.95/3.3-4.2        | WiMAX/WLAN |
| [25] | 22 × 16.08      | 3            | 2.44/3.5/8.2              | 2.3-2.53/5.18-5.85/8.53  | WiMAX/WLAN |
| Prop. | 19 × 10         | 3            | 5.6/2.12/6.6              | 5.2-6.2/7.52-8.69/4.13-13.5 | WLAN/X-Band |

4. CONCLUSION

A triple band ACS fed antenna of size $26 \times 15 \times 1.6$ mm$^3$ is simulated and fabricated which shows operation at 3.2, 5.3 and 9.7 GHz, thus covering WiMAX, WLAN and X-band applications. The simulated $S_{11}$ and field parameters of the antenna closely mimics the fabricated prototype results which are evaluated using VNA (vector network analyzer). All the three bands exhibit good impedance matching and acceptable gains. The designed antenna has the advantage of compact size, uniplanar simple structure and exhibits good radiational performance which can easily meet the demand of the aforementioned applications.

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