PAPER • **OPEN ACCESS**

Miniaturized cpw-fed conformal antenna for guided missiles

Miniaturized cpw-fed conformal antenna for guided missiles

Dattatreya Gopi[1]*, A R G Chandra Mouli K[2], V Janardhan Reddy[3], G K Chaitanya[4], S Ramu[5]

[1,3,4,5]Raghu Engineering College, Department of Electronics and Communication Engineering,Visakhapatnam, A.P, India.
[2] Research and Development Engineer, Avantel Limited, Visakhapatnam, A.P, India.

***E-mail:** dattatreya.gopi@gmail.com

Abstract. A conformal wing-shaped patch (WSP) antenna is designed and investigated in this paper. Coplanar waveguide (CPW) feed is used to get high impedance matching and better radiation pattern. The WSP antenna is designed on Kapton polyimide substrate material measuring 20 × 30 × 0.1 mm^3. It offers the impedance bandwidth of 630 MHz (6.55 GHz -7.18 GHz), 560 MHz (9.80 GHz -10.36 GHz), 560 MHz (9.80 GHz -10.36 GHz) at resonant frequencies 6.97 GHz, 10.12GHz, 15.78GHz respectively. The reflection coefficients are obtained at -17.42 dB, -16.39dB, -18.23dB for the resonant frequencies. To analyze the conformability of the WSP antenna, the model is tested by mounting on the guided missile. The performance of the antenna is good and small deviations are observed with a shift of 30 MHz, 120MHz, 380MHz in the reflection coefficient. The compactness and conformal design with multi-band support proves the antenna suitable for future military applications.

Keywords: Coplanar waveguide (CPW), Conformal antenna, kapton polyimide, Multi-band antenna.

1. Introduction

New technological advances in antenna design have been developed in aircraft and navigation communications. Traditional antennas are not suitable for aircraft fuselages. Earlier, the aircraft were used the conventional antenna systems. These antenna systems might occupy more space for limited services. In spite of occupying more space, these antenna systems might get damaged easily. This results in communication loss and misses functioning. As the antennas vary in size, the placement of the antenna on the curved surfaces like aircraft and missiles is a challenge. Placing at wrong areas may result in communication loss or unbalance in aircraft/missile. Thus, to overcome these problems, conformal antennas are preferred to place on reentry vehicles like aircraft and missiles [1], [2]. Conformal antennas are more attracted and easily adapts to the object's surface. Optimized antenna characteristics improve overall performance with proper aerodynamics and size reduction. In recent years, research has grown in the field of flexible antennas. Integrating a conformal antenna into the outer surface of the object has several advantages over traditional antennas. This provides more options for locating antennas, increasing the field of view, and reducing aircraft/missile radar signatures.

Flexible antenna design with good performance has received much attention. Increasingly reported enablement components and antennas[3], [4], [5] for future requirements of low profile, flexible communication systems compatible with the substrate materials such as paper, textile and polymers and plastics [6], [7]. In addition to the trends of the flexible antenna[8], [9], [10], multi-band support is required in many cases. Different antenna designs are proposed, depending on the application and the required specifications. However, the printed monopoles antenna structures [11]-[12] have received the most attention due to their compact size and good radiation characteristics. The substrate deformation may cause performance degradation of the antenna. So, it is also important to study and analyze the conformal characteristics of an antenna. In order to reduce the complexity in the design and fabrication of antenna coplanar waveguide (CPW), feeding is [13], [14], [15] preferred.

In this paper, the antenna is designed to suitable for different logos of the Indian airforce. So, that the structure is adapted to the surface of the aircraft or missile, this design is selected such that there is no requirement of a separate place that is to be reserved for placing the antenna. The antenna performance is analyzed with both planar and conformal characteristics. The reflection coefficient, radiation pattern, and antenna gains are simulated with the antenna held flat and bent positions on a guided missile. The results of flat and bent designs are compared and studied.

2. Antenna Design

The simulated model of the wing-shaped patch (WSP) antenna is shown in 'figure 1'. To achieve conformability, the WSP antenna is designed on a Kapton Polyimide film with a dielectric constant (ε_r) of 3.5 and loss tangent (δ) of 0.008, Polyimide film has been used successfully in applications at temperatures 23 to 200°C (73 to 392°F) range, and it has excellent chemical and temperature resistance. The proposed patch designed to operate at multi-band frequency and is shown in 'figure 1'. The length and width of the substrate are Ls × Ws with 0.1mm thickness. The widths of each wing are denoted by W_1, W_2, W_3, and the gap between wings is denoted by L_2. The circular-shaped patch with a circular slot is designed to resonate at the desired band of communications. The optimized design parameters of the WSP antenna are tabulated in table 1. The simulations of the WSP antenna is done by using CST (computer simulation technology) software [17].

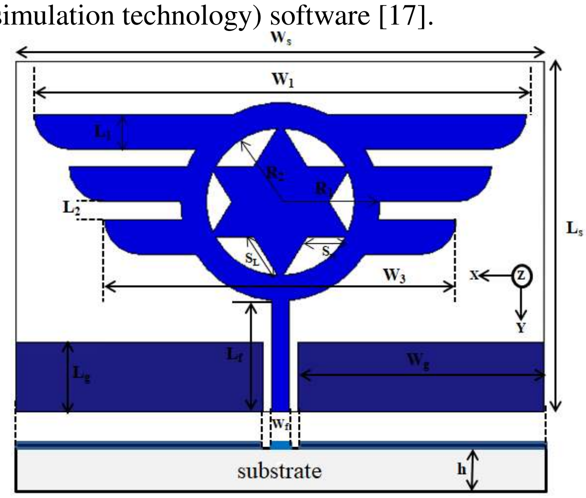


Figure 1. The geometry of the wing-shaped patch (WSP) antenna.

$$R_{effective} = \frac{8.79 \times 10^9}{f_{resonant1,2}\sqrt{\varepsilon_r}} \quad (1)$$

$$R_{1,2} = \frac{R_{effective}}{\left(1 + \frac{2h}{\pi \varepsilon_r R_{effective}}\left[ln\left(\frac{1.57 R_{effective}}{h}\right) + 1.78\right]\right)^{\frac{1}{2}}} \quad (2)$$

The resonant frequencies vary with the respective radius of the circular rings. The radius 'R_1'and 'R_2' (equation (2)) of the circular ring patch is calculated by using effective radius $R_{effective}$ (equation (1)) [16].Where $f_{resonant1,2}$ is the first and second resonant frequency, ε_r is the dielectric constant of the substrate material.

Table 1. Design parameters of WSP antenna.

Parameter	Value(mm)	Parameter	Value(mm)
L_s	20	W_s	30
L_g	4	W_g	14
L_1	2	W_1	28
L_2	1	W_3	20
L_f	6.4	W_f	1
R_1	5.5	S_L	2.6
R_2	4.2	S_W	2.1

3. Results and discussions

The reflection coefficient response (S_{11}) of the simulated WSP antenna is shown in 'figure 2'. From the 'figure 2' three operating frequencies 6.97 GHz, 10.12GHz, 15.78GHz are resonated with -17.42 dB, -16.39dB, -18.23dB reflection coefficients and a bandwidths of 630 MHz (6.55 GHz -7.18 GHz), 560 MHz (9.80 GHz -10.36 GHz), 560 MHz (9.80 GHz -10.36 GHz) respectively.

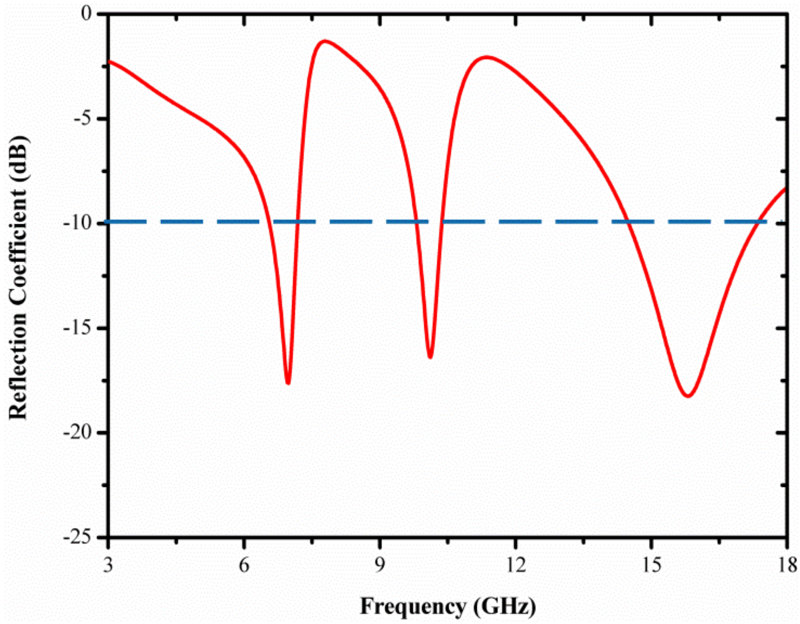
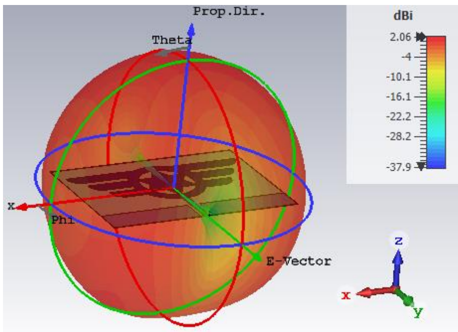
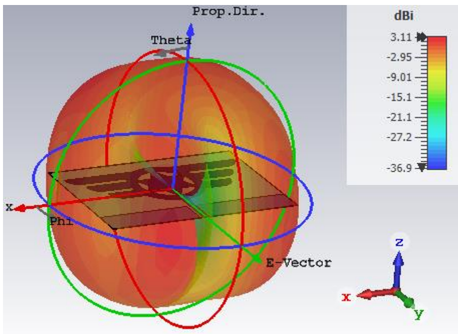


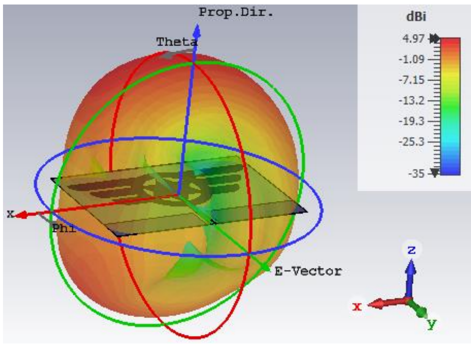
Figure 2. $S_{11}$of wing-shaped patch (WSP) antenna.



(a)



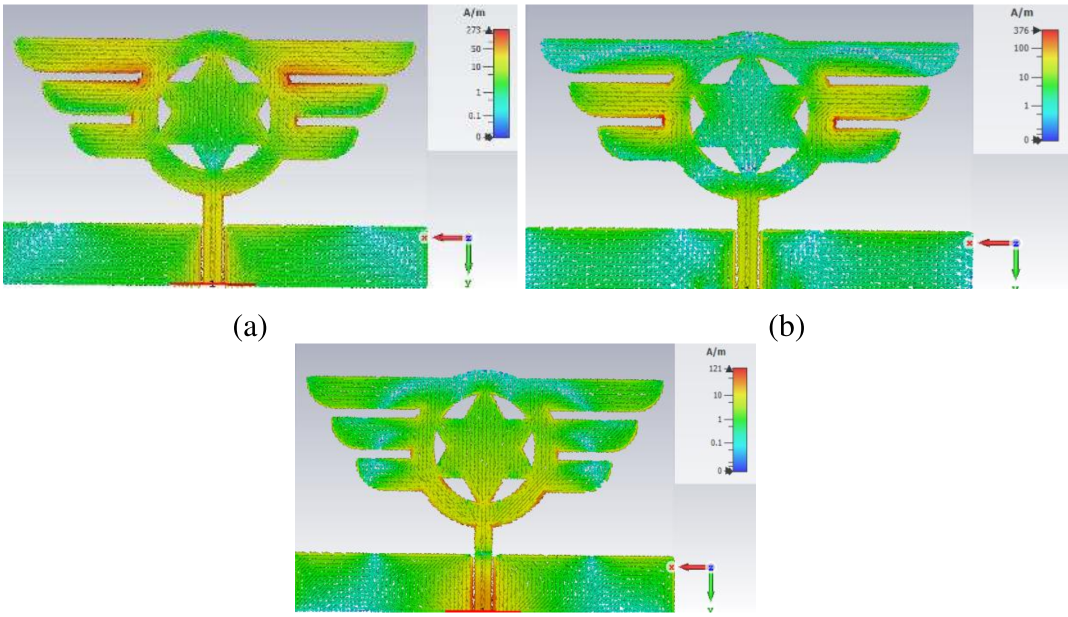
(b)



(c)

Figure 3. 3D-Gain plot of proposed wing-shaped patch (WSP) antenna at (a) 6.97 GHz, (b) 10.12GHz, (c) 15.78GHz frequencies.

The 3D-gain plots of the WSP antenna are shown in figure 3. The maximum gain of 4.97dBi is observed at 15.78GHz frequency. The gain is observed moderate at 10.12GHz and 2.06dBi for 6.97 GHz frequency.



(a) (b)

(c)

Figure 4. Surface current distribution of WSP antenna at (a) 6.97 GHz, (b) 10.12GHz, (c) 15.78GHz frequencies.

The distribution of surface currents of the WSP antenna at each operating frequencies is shown in figure 4. The current distribution of 273 A/m is measured at 6.97 GHz frequency. It is observed that for the first resonant frequency, the maximum surface current intensity is focused in between first and second wings. The remaining resonant frequency surface currents are intensified at second and third wings, and the lower sections of the circular rings and the values are 376 A/m, 121 A/m observed at 10.12GHz, 15.78GHz frequencies.

The radiation characteristics of both E, H-fields of the proposed antenna are shown in figure 5. As shown in figure 5 (a) the E-field and H-field radiation characteristics are observed as semi-omnidirectional and bi-directional. The angular width is 175.2deg, and the main lobe direction is 180deg for E-Field, and for H-Field, the angular width is 77.9deg, and the main lobe direction is 200deg. Figure 5 (b) shows the E-Field and H-field radiation characteristics of 10.12GHz frequency. The main lobe direction is 137deg for E-field, and for H-field, the angular width is 66.2deg, and the main lobe direction is 339deg. Figure 5 (c) shows the E-field and H-field radiation patterns of 15.78GHz frequency, and it is observed as semi-omnidirectional and butterfly-shaped patterns. The angular width is 149deg, and the main lobe direction is 221deg for E-field, and for H-field, the angular width is 52.6deg, and the main lobe direction is 336deg.

Journal of Physics: Conference Series **1706** (2020) 012073 doi:10.1088/1742-6596/1706/1/012073

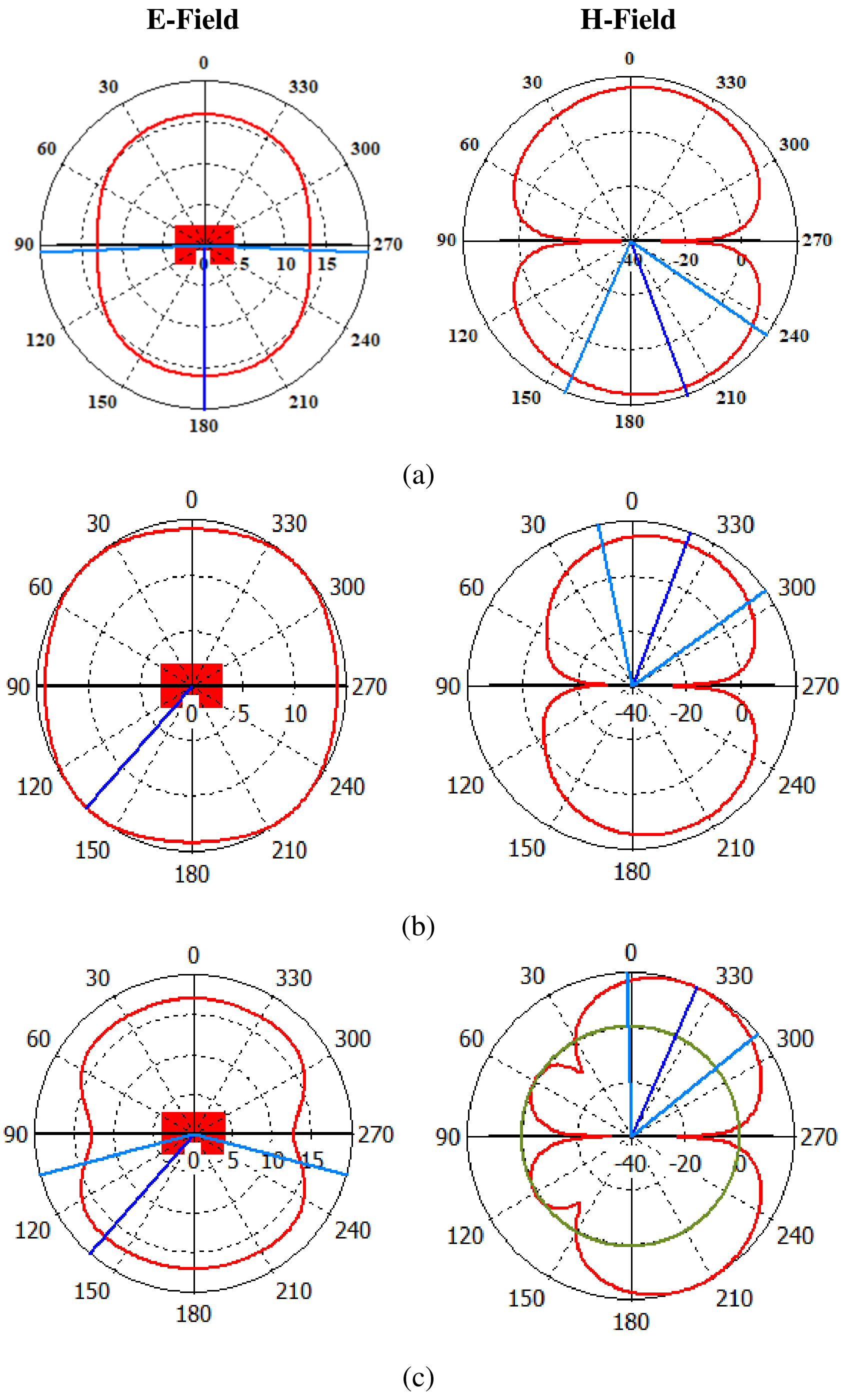
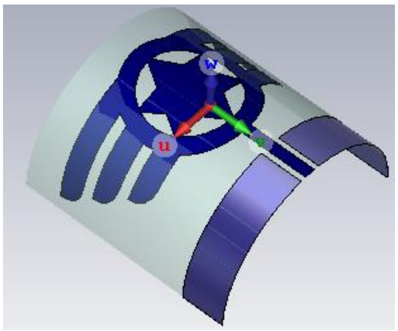


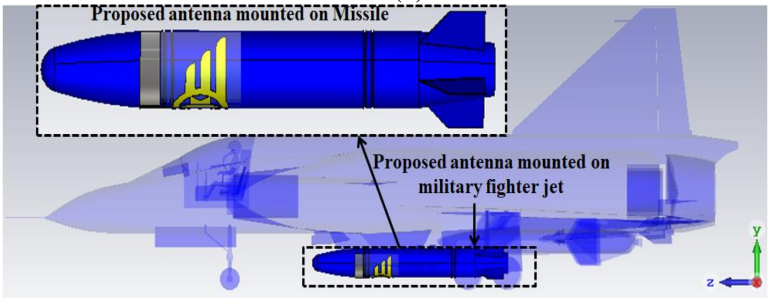
Figure 5. E-field and H-field radiation patterns of WSP antenna at (a) 6.97 GHz, (b) 10.12GHz, (c) 15.78GHz frequencies

4. Bending analysis

The WSP antenna is designed to suitable for guided missiles. As shown in figure 6, the WSP antenna is mounted on a guided missile, which conforms to the surface of the missile and doesn't need extra space. So, the antenna is characterized in a bending position to check the antenna performance.



(a)



(b)

Figure 6. The geometry of (a) conformal WSP antenna, (b) WSP antenna mounted on aircraft with a guided missile.

The reflection coefficient of the conformal WSP antenna for an 80mm radii cylinder (missile) is shown in figure 7. It is observed that the performance of the antenna mounted on the missile will not be affected much. The resonant frequencies are slightly shifted towards high, and the bandwidths are slightly varied. The conformal antenna resonates at 7 GHz, 10.24GHz, 16.16GHz frequencies with -17.71 dB, -21.89dB, -15.71dB reflection coefficients respectively.

The 3D-gain plots of the conformal WSP antenna are shown in figure 8. The maximum gain of 4.94dBi, 4.89dBi, is observed at 16.16GHz, 10.24GHz frequencies. The gain is observed low at 7GHz frequency.

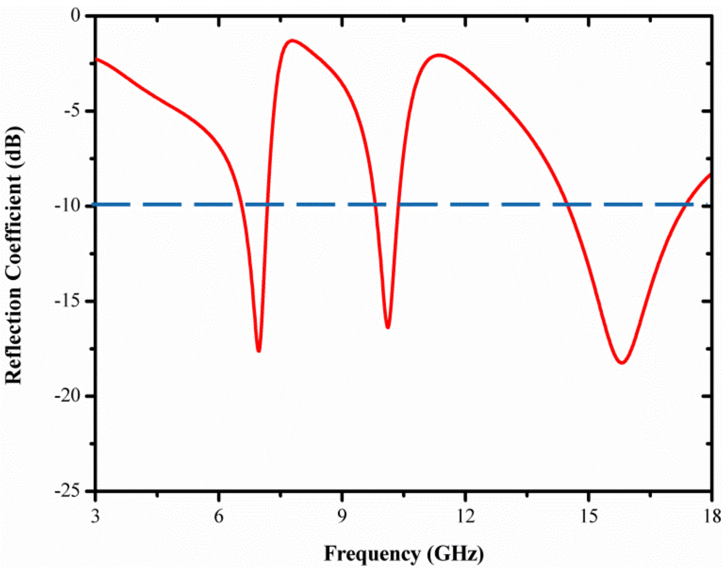
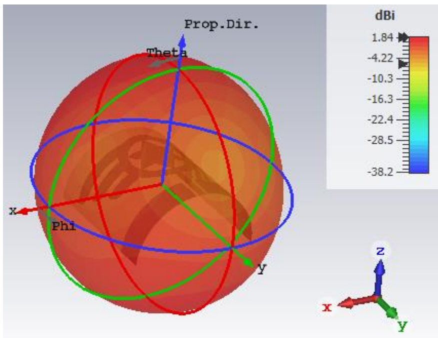
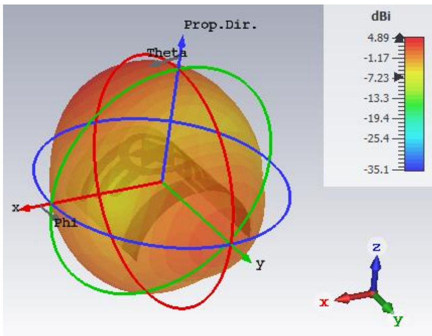


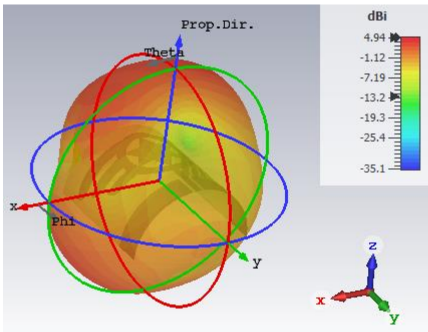
Figure 7. S11 of conformal WSP antenna mounted on a missile.



(a)



(b)



(c)

Figure 8. 3D-Gain plot of conformal WSP antenna at (a) 7 GHz, (b) 10.24GHz, (c) 16.16GHz frequencies.

As shown in figure 9(a) the E-field and H-field radiation patterns are observed as omnidirectional and semi-omnidirectional. The main lobe direction is 180deg for E-Field, and for H-field, the angular width is 90.3deg, and the main lobe direction is 323deg. Figure 9(b) shows the E-Field and H-field radiation patterns of 10.12GHz frequency, and it is observed as semi-omnidirectional and flower-shaped patterns. The angular width is 108.4deg, and the main lobe direction is 180deg for E-field, and for H-field, the angular width is 70.8deg, and the main lobe direction is 297deg. Figure 9(c) shows the E-Field and H-field radiation patterns of 15.78GHz frequency, and it is observed as semi-omnidirectional and directional shaped patterns. The angular width is 113deg, and the main lobe direction is 180deg for E-field, and for H-field, the angular width is 45.9deg, and the main lobe direction is 192deg.

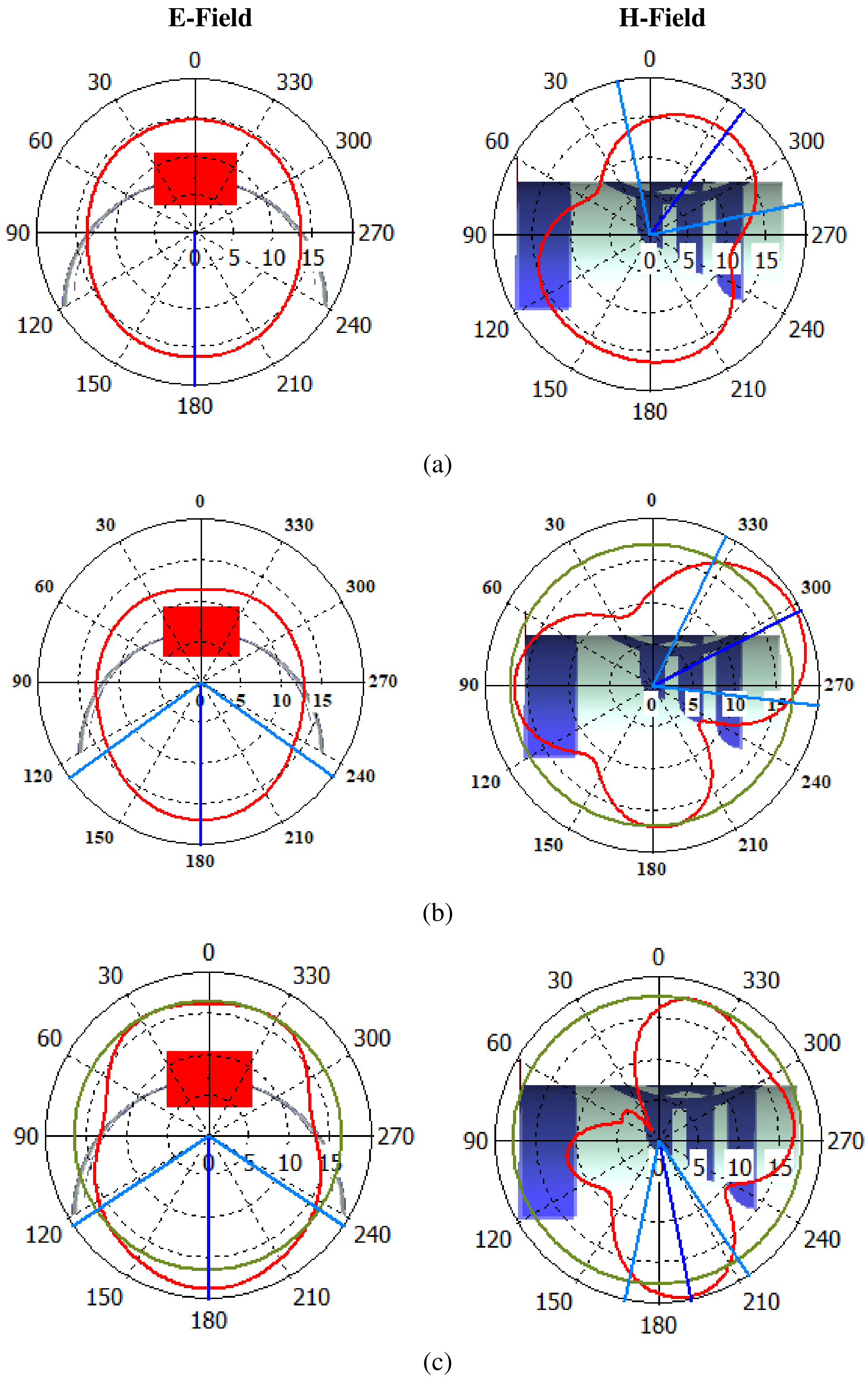


Figure 9. E-field and H-field radiation patterns of conformal WSP antenna (a) 7 GHz, (b) 10.24GHz, (c) 16.16GHz frequencies.

5. Conclusion

A conformal wing-shaped patch (WSP) antenna is proposed for military applications. The proposed antenna operates at 6.97 GHz, 10.12GHz, 15.78GHz frequencies with an impedance bandwidth of 630 MHz (6.55 GHz -7.18 GHz), 560 MHz (9.80 GHz -10.36 GHz), 560 MHz (9.80 GHz -10.36 GHz) respectively. The simulated results showed the gain of 2.06dBi, 3.11dBi, 4.97dBi for respective frequencies. The proposed antenna achieves semi-omnidirectional, bi-directional patterns. Bending analysis is done by mounting the antenna on a missile, and conformability will not degrade the antenna performance. The proposed antenna finds applications in long-distance communications, terrestrial broadband, radars, and satellite communications for the guided missiles.

References

[1] R Bridgelall and M Corcoran 2019 Conformal antennas for unmanned and piloted vehicles and method of antenna operation *ed: Google Patents*
[2] A Patrovsky and R Sekora 2010 Structural integration of a thin conformal annular slot antenna for UAV applications *Loughborough Antennas & Propagation Conference* 229-232
[3] C L Li, X W Shi, H H Wang and X Li 2018 A compact missile-borne conformal array antenna with off-axis radiation *Microwave and Optical Technology Letters* **60(4)** 1010-1013
[4] K Saraswat and A R Harish 2019 Flexible dual-band dual-polarised CPW-fed monopole antenna with discrete-frequency reconfigurability *IET Microwaves, Antennas & Propagation* **13(12)** 2053-2060
[5] L Desclos, Y Mahe, S Reed, G Poilasne and S Toutain 2001 Patch antenna size reduction by combining inductive loading and short-points technique *Microwave and Optical Technology Letters* **30(6)**, 385-386
[6] K Z Rajab, R Mittra and M T Lanagan 2007 Size reduction of microstrip patch antennas with left-handed transmission line loading *IET microwaves, antennas & propagation* **1(1)** 39-44
[7] X Cheng, D E Senior, C Kim, and Y -K Yoon 2011 A compact omnidirectional self-packaged patch antenna with complementary split-ring resonator loading for wireless endoscope applications *IEEE Antennas and Wireless Propagation Letters* **10** 1532-1535
[8] A S Alqadami, N Nguyen-Trong, B Mohammed, A E Stancombe, M T Heitzmann and A Abbosh 2020Compact Unidirectional Conformal Antenna Based on Flexible High Permittivity Custom-made Substrate for Wearable Wideband Electromagnetic Head Imaging System *IEEE Transactions on Antennas and Propagation* **68(1)** 183-194
[9] G Dattatreya and K KNaik 2019 A low volume flexible CPW-fed elliptical-ring with split-triangular patch dual-band antenna *International Journal of RF and Microwave Computer-Aided Engineering* **29(8)** p. e21766
[10] Y Dong, H Toyao and T Itoh 2011 Design and characterization of miniaturized patch antennas loaded with complementary split-ring resonators *IEEE Transactions on antennas and propagation* **60(2)** 772-785
[11] A Hachi, H Lebbar and M Himdi 2017 Flexible and conformal printed monopoles antennas *Progress In Electromagnetics Research* **67** 89-95
[12] A Hachi, H Lebbar and M Himdi 2018 Mutual Coupling Reduction Using Two Flexible monopoles Antennas *Revue Méditerranéenne des Télécommunications* **8(2)**1-4
[13] K N Ketavath, DattatreyaGopi and S S Rani 2019 In-Vitro Test of Miniaturized CPW-Fed Implantable Conformal Patch Antenna at ISM Band for Biomedical Applications *IEEE Access* **7**43547-43554
[14] K Kumar Naik and D Gopi 2018 Flexible CPW-fed split-triangular shaped patch antenna for WiMAX applications *Progress In Electromagnetics Research* **70**157-166
[15] H R Khaleel, H M Al-Rizzo, A I Abbosh and A Kishk 2013 Design, fabrication, and testing of flexible antennas *Advancement in Microstrip Antennas With Recent Applications: InTech Vienna, Austria*
[16] C A Balanis 2016 Antenna theory: analysis and design*John wiley& sons*
[17] CST Microwave Studio [Online]*Available: http/www.cst.com*