

CPW Fed Antenna for Wideband Applications based on Tapered Step Ground and EBG Structure

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Abstract

A combination of tapered step ground plane with electromagnetic band gap structured CPW fed antenna is proposed for wideband applications. Bandwidth is enhanced by adding tapered steps on the ground plane and by placing EBG structure in the design. Elliptical and rectangular monopole antennas are designed and discussed in detail with respect to their performance characteristics. The proposed models are printed on FR4 substrate of dielectric constant 4.4 with dimension of 20X20X1.6 mm. The parametric analysis with change in substrate permittivity is recorded and presented in this work for better understanding of the antenna behaviour with different substrate materials. The proposed models exhibiting excellent wideband characteristics in the communication applications with stable gain and efficiency.

Keywords: Bandwidth Enhancement, Coplanar Wave Guide Feeding (CPW), Electromagnetic Bandgap Structure (EBG), Tapered Step Ground Plane, Wideband antenna

1. Introduction

Surface wave propagation is a serious problem in microstrip antennas¹. Surface waves reduce antenna efficiency and gain, limit bandwidth, increase end-fire radiation, increase cross-polarization levels, and limit the applicable frequency range of microstrip antennas². Additionally, miniaturization of micro strip antennas and their integration with micro strip circuits are hindered because high dielectric constant substrates are required to achieve these objectives³. Few designs are proposed by the researchers to increase the bandwidth by using CPW fed monopole designs and gain improvement by using array designs⁴⁻⁶.

To overcome these problems, we have two wonderful techniques. First one is based on the micromachining technology in which a part of substrate beneath the radiating element is removed to realize a low effective dielectric constant environment for antenna⁷. The second method is to place the slots on the ground plane which will reduce the surface wave loss problem⁸. This process of placing

slots on the ground plane and removing certain portion from substrate are called with the name electromagnetic band gap structures.

Electromagnetic bandgap structures are a new class of periodic dielectric, which are the photonic analogy of semiconductor. Early attempts involved drilling a periodic pattern of holes in substrate or etching a periodic pattern of circles in the ground plane. Next, a periodic pattern of metallic pads was shorted to the ground plane⁹. The current study deals with the design and implementation of two antennas with tapered ground plane¹⁰⁻¹³ and EBG structure in the substrate. Harmonic suppression and mutual coupling reduction can be achieved by employing EBG structures in the microstrip arrays. Not only suppression of mutual coupling, but also reduces the side lobe levels in the arrays compared to the conventional design methods. Initially elliptical and rectangular monopole antennas with tapered step ground are designed and after that EBG structures are introduced in to these designs. By placing tapered step ground on the ground plane, the bandwidth of the antenna can be increased. Tapered steps

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on the surface of the antenna ground plane with EBG structure in the substrate material is been used in the current designs. The combinations of these two techniques are giving a novel concept with respect to the improvement in antenna characteristics. The proposed methodology is giving rise to the new concept of combinational design and their related advantages in the antenna applications. The detail description of these models and geometry are discussed in the presiding sections.

2. Antenna Geometry

Figure 1(a) shows the elliptical monopole antenna with patch on top side and ground plane on same side of the substrate material. The radius of the elliptical patch and feed line length are calculated from standard equations. Figure 1(b) shows the tapered step coplanar fed rectangular monopole antenna.

Both these models are printed on FR4 substrate with dielectric constant of 4.4 and loss tangent 0.002. The thickness of the substrate is maintained 1.6 mm. The overall dimension of the antenna is 20x20x1.6 mm. Width of the rectangular patch $W_p = 5.64$ mm and length of the patch $L_p = 5.65$ mm. Table 1 shows the dimensions of the models selected in this work. By taking radiating elements of elliptical, rectangular patches and the ground plane on same side, the fabrication become easy and cost is also decreased. Cylindrical shaped PEC materials are inserted into the substrate material to form EBG structure in this model. The feed line width in these models and the separation between ground plane and feed are chosen according with 50 ohm impedance. By adding the EBG structure with tapered step ground, the bandwidth enhancement is achieved and the tapered steps on the ground plane created a new

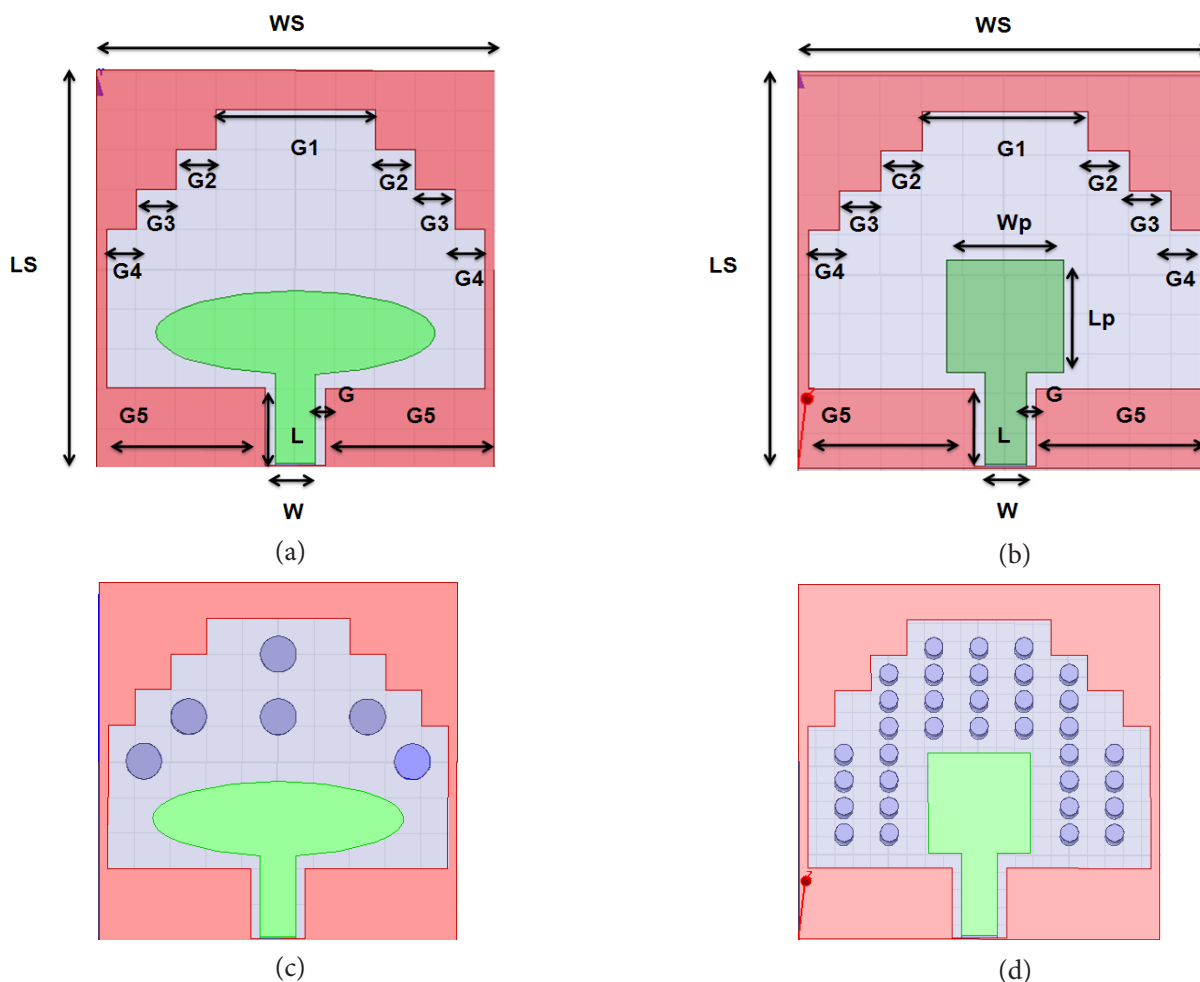


Figure 1. (a) Tapered step ground elliptical monopole antenna. (b) Tapered step rectangular monopole antenna. (c) Tapered step elliptical monopole with EBG substrate. (d) Tapered step rectangular monopole antenna with EBG substrate.

Table 1. Antenna dimensional Characteristics

Parameters	h	ϵ_r	ϵ_{eff}	W	G	Ws	Ls	G1	G2	G3	G4	G5	L
Elliptical Monopole	1.6	2.2	1.6	2	0.5	20	20	8	2	2	1.5	8.5	10.9
Rectangular Monopole	1.6	2.2	1.6	2.54	0.5	20	20	8	2	2	1.5	8.5	10.9

path for the current. The flow of current through this path leads to the improvement in impedance matching and bandwidth. While taking EBG substrate first, we removed certain portion in cylindrical form from substrate material and then filled that etched portion with PEC material. Detail description of the design considerations are discussed with simple equations with respect to wavelength.

3. Design Steps of the Elliptical Monopole with Tapered Step Ground

a) Design of elliptical monopole patch
For the ellipse with major axis 'a' and minor axis 'b', the perimeter

$$P = 2aE(e) \text{ ----- (1)}$$

Where E (e) is a complete Elliptic integral of the second kind with elliptic modulus 'e'.

$$e = \sqrt{1 - (b/a)^2} \text{ ----- (2)}$$

If the lowest frequency in the impedance bandwidth of the antenna is f_L (GHz) and the effective permittivity of the medium of radiation can be approximated by

$$\epsilon_{eff} \approx (\epsilon_r + 1)/2, f_L = 300/p\sqrt{\epsilon_{eff}} \text{ (3)}$$

Where perimeter unit is in the mm.

Frequency of operating band is taken into account, while deriving the design equations. Step by step procedure for the design of the antenna is paraphrased.

- Design a 50Ω CPW line on a substrate with permittivity ϵ_r . calculate ϵ_{eff} using $\epsilon_{eff} = (\epsilon_r + 1)/2$ where ϵ_{eff} is the effective permittivity of the substrate.
- Width of the substrate W_s and Length of the substrate $L_s = 1.13 \lambda_c$
- Tapered step ground plane dimensions $G_1 = 0.45 \lambda_c$
 $G_2 = G_3 = 0.11 \lambda_c$
 $G_4 = 0.08 \lambda_c$
 $G_5 = 0.48 \lambda_c$
- Length of the feed line $L = 0.61 \lambda_c$

- Gap between feed line and ground plane $G = 0.02 \lambda_c$
- Width of the feed line $W = 0.11 \lambda_c$

4. Design Steps of the Rectangular Monopole with Tapered Step Ground

- Design a 50Ω CPW line on a substrate with permittivity ϵ_r . Calculate ϵ_{eff} using $\epsilon_{eff} = (\epsilon_r + 1)/2$ where ϵ_{eff} is the effective permittivity of the substrate.
- Width of the substrate W_s and Length of the substrate $L_s = 1.005 \lambda_c$
- Tapered step ground plane dimensions $G_1 = 0.45 \lambda_c$
 Second and third stage tapered step ground $G_2 = G_3 = 0.11 \lambda_c$
 $G_4 = 0.08 \lambda_c$
 $G_5 = 0.48 \lambda_c$
- Length of the feed line $L = 0.54 \lambda_c$
- Gap between feed line and ground plane $G = 0.02 \lambda_c$
- Width of the feed line $W = 0.11 \lambda_c$
- Width of the patch $W_p = 0.28 \lambda_c$
- Length of the patch $L_p = 0.28 \lambda_c$

5. Results and Discussion

Figure 2 shows the return loss curve for the elliptical monopole antenna with tapered step ground and with EBG structure. The result shows that by incorporating EBG structure in the tapered step ground model, the bandwidth is enhanced by 600 MHz. Antenna is showing a wide bandwidth (11.6 to 16.4 GHz) of 4.8 GHz, with tapered step ground arrangement. By incorporating EBG structure in the substrate the bandwidth (11.6 to 17GHz) of 5.4 GHz is obtained for the elliptical monopole antenna.

Figure 3 shows the return loss curve for a rectangular monopole antenna with and without EBG structure in the substrate. With tapered step ground a bandwidth of (6 to 13.5 GHz) 7.5 GHz is attained. By placing EBG structure in the substrate, bandwidth of (6 to 15 GHz) 9 GHz is

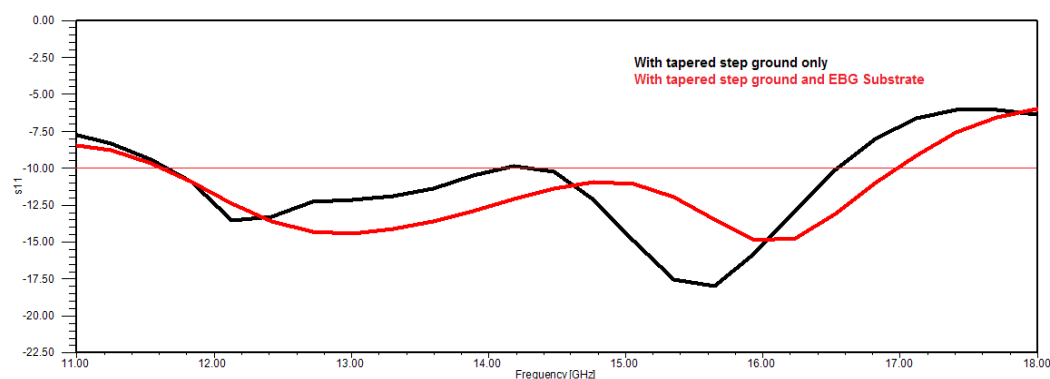


Figure 2. Reflection coefficient of Elliptical monopole antenna with and without tapered step ground.

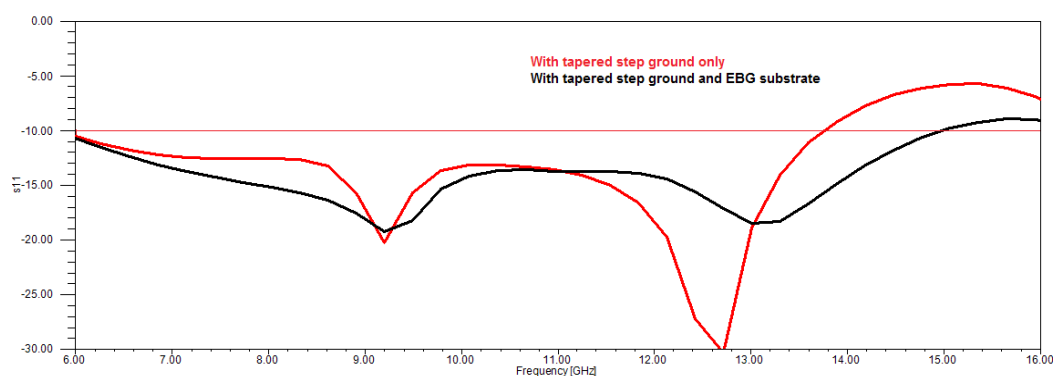


Figure 3. Reflection coefficient of Rectangular monopole antenna with and without tapered step ground.

obtained, which shows enhancement in the bandwidth of 1.5 GHz.

The proposed models three dimensional radiation can be observed from Figure 4(a) and 4(b). From Figure 4(a) we can observe a quasi-omni directional radiation pattern and from Figure 4(b) we can observe the radiation focused in the XZ plane.

The current distribution of the tapered step models and EBG structured substrate models are presented in Figure 5 and 6. From elliptical monopole with tapered step ground model we can observe that most of the current intensity is focused on the radiating element and feed line. In the case of rectangular monopole with tapered step ground the current intensity can be observed on tapered step ground plane also along with the radiating element and feed line. From Figure 6 we can observe the current distribution of elliptical monopole with a tapered step ground and EBG structure. The current intensity is focused on the radiating element and on the ground

plane is focused towards X direction on the edges. The current distribution of rectangular monopole antenna with tapered step ground and EBG structure presented in Figure 6(b), which shows the current density focused on feed line directing towards x-direction and on the edges of the ground plane with same magnitude but opposite in direction.

Figure 7 shows the gain and efficiency curve of the elliptical monopole antenna with tapered step ground and EBG structure. From this result, we realized an average gain of 2.5 dB in the operating band and the efficiency of more than 80%. Figure 8 shows gain and efficiency curve for rectangular monopole antenna with a tapered step ground and EBG structure. An average gain of 2.5 dB and efficiency more than 75% is attained in the operating band for the rectangular monopole antenna.

Simulated and measured radiation pattern in E and H plane for elliptical monopole and rectangular monopole with a tapered step ground is presented in Figure 9

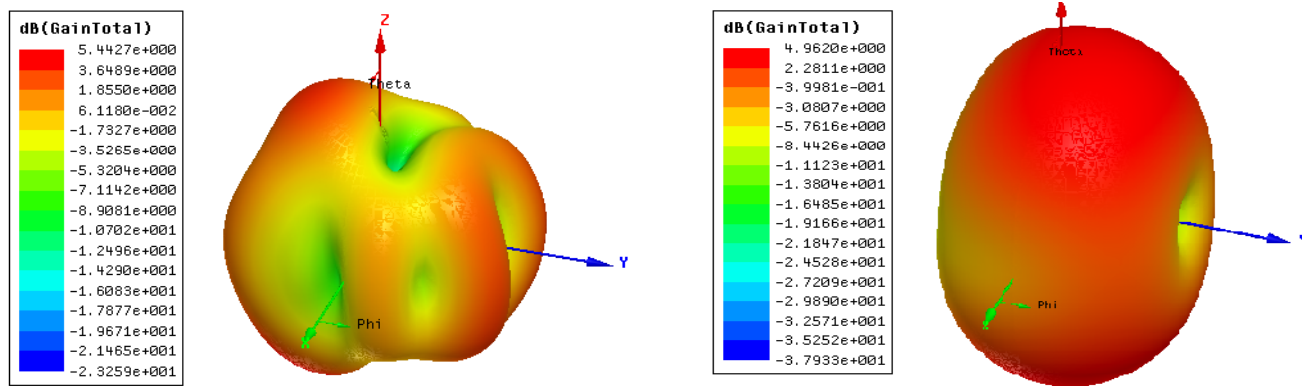


Figure 4. (a) 3D Radiation view for elliptical monopole with EBG substrate. (b) 3D Radiation view for rectangular monopole with EBG substrate.

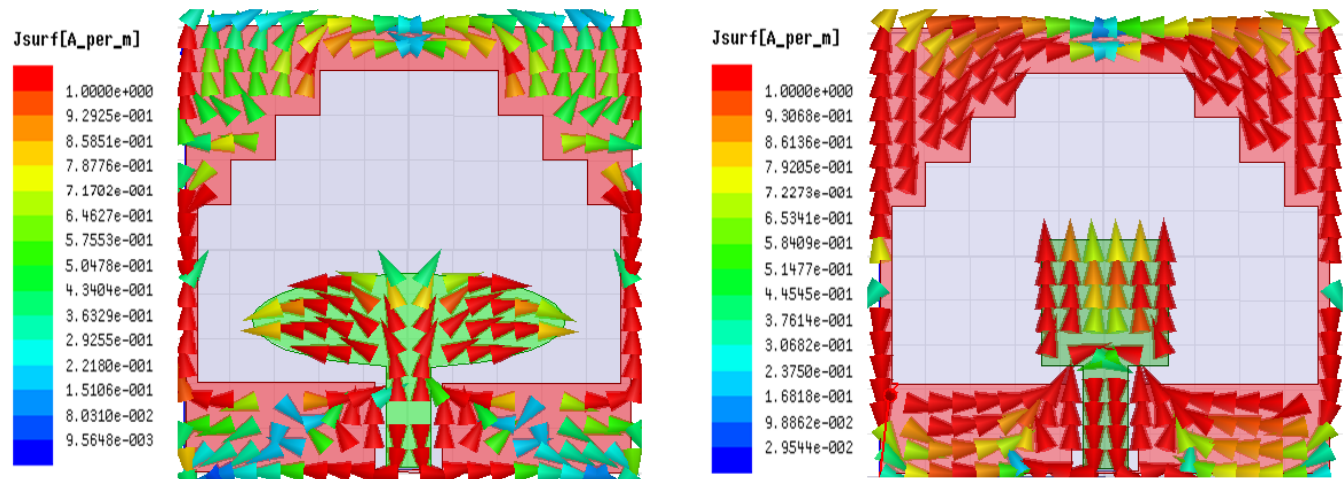


Figure 5. (a) Current distribution of Elliptical monopole antenna with tapered step ground at 13 GHz. (b) Current distribution of rectangular monopole antenna with tapered step ground at 9.2 GHz.

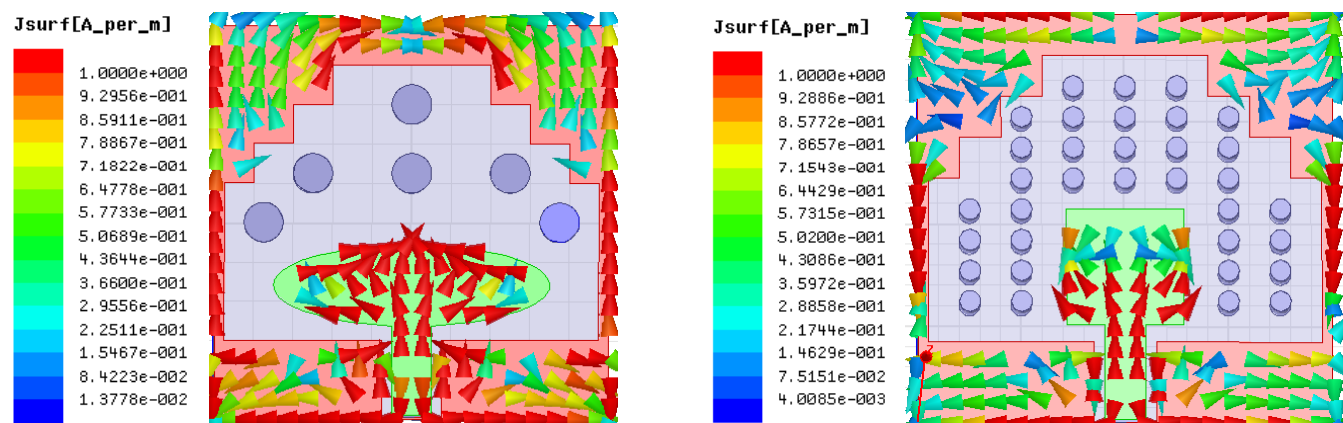


Figure 6. (a) Current distribution of Elliptical monopole antenna with tapered step ground and EBG substrate at 13 GHz. (b) Current distribution of rectangular monopole antenna with tapered step ground and EBG substrate at 9.2 GHz.

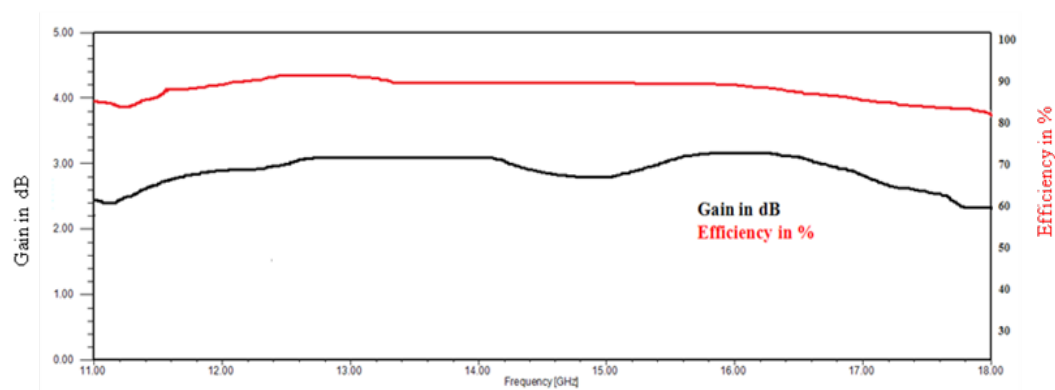


Figure 7. Gain and efficiency of Elliptical monopole antenna with tapered step ground and EBG.

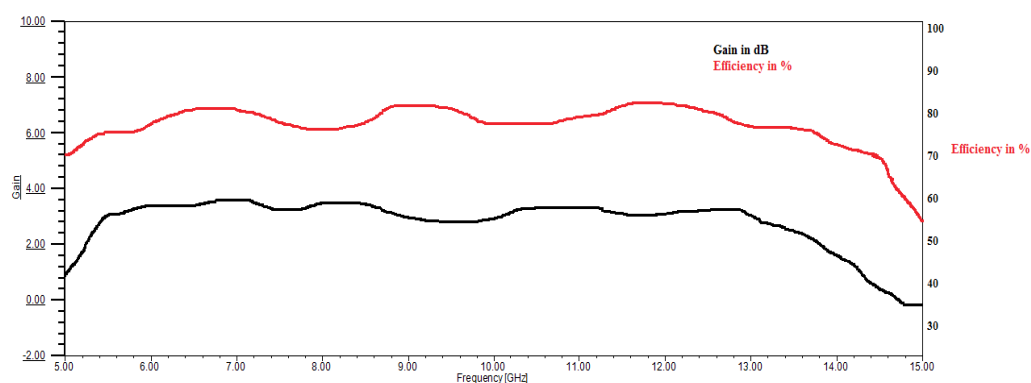


Figure 8. Gain and Efficiency of Rectangular monopole antenna with tapered step ground and EBG.

and 10. Figure 11 shows the simulated radiation pattern of elliptical monopole tapered step ground with EBG substrate. A parametric analysis is presented here with change in substrate permittivity^{14, 15} and observed that for different substrate materials the cross polarization is less than -34dB in the E plane and less than -6dB in H-plane. Figure 12 shows simulated radiation pattern of rectangular monopole with tapered step ground and EBG structure. Parametric analysis with change in substrate permittivity is carried out and the result shows cross polarization level less than -40dB in E-plane and less than -20 dB in the H-plane from the radiation pattern curve of Figure 12. Solid lines indicates the co-polarization and dotted lines indicates the cross polarization in the radiation plots.

Seven substrate materials are chosen in this work to examine the performance of the antenna. RT-duroid, Arlon, Ultralam 3850 (LCP), Polyester, plexiglass, FR4

and Alumina are selected for this study, whose permittivity values are from 2.2 to 9.2.

Step serrated antennas are fabricated on FR4 substrate and presented in Figure 13. Coplanar wave guide feeding is used with 50 ohm impedance at the port of the antenna.

6. Parametric Analysis of Elliptical Monopole with Tapered Step Ground and EBG with Change in Substrate Permittivity

Table 2 and 3 shows the dimensional characteristics of the elliptical and rectangular monopole tapered step ground EBG antenna on different substrate materials ranging from $\epsilon_r = 2.2$ to 10.2. The design of the antenna can be

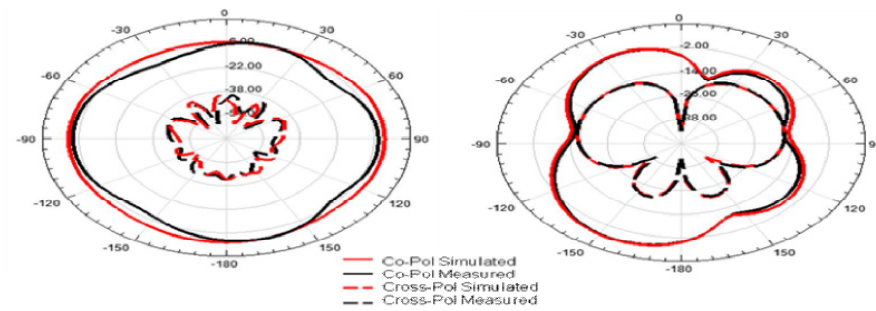


Figure 9. Radiation Pattern of Elliptical monopole antenna with tapered step ground at 13 GHz.

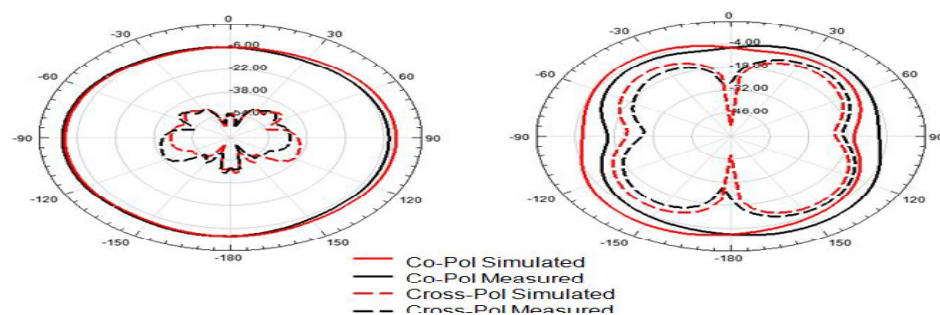


Figure 10. Radiation pattern of Rectangular monopole antenna with tapered step ground in E and H-plane at 9.2 GHz.

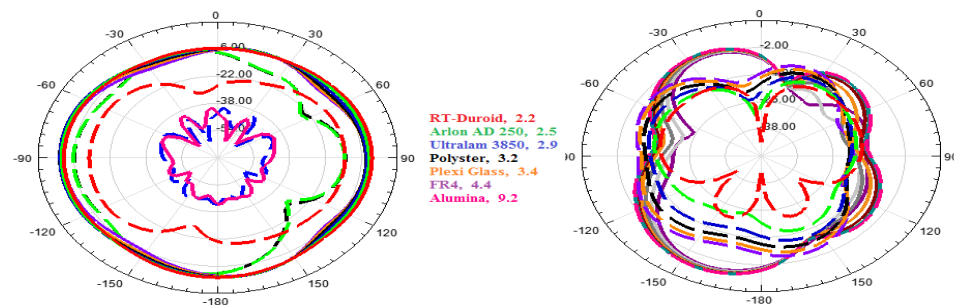


Figure 11. Simulated radiation pattern in E and H-Plane for elliptical monopole with tapered step ground and EBG on different substrates.

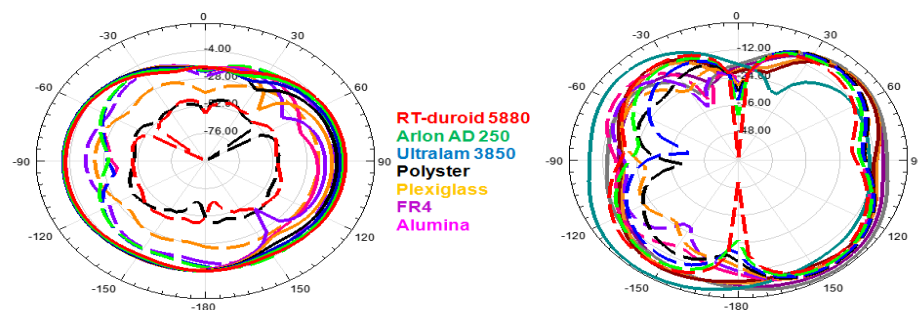


Figure 12. Simulated radiation pattern in E and H-Plane for rectangular monopole with tapered step ground and EBG on different substrates.

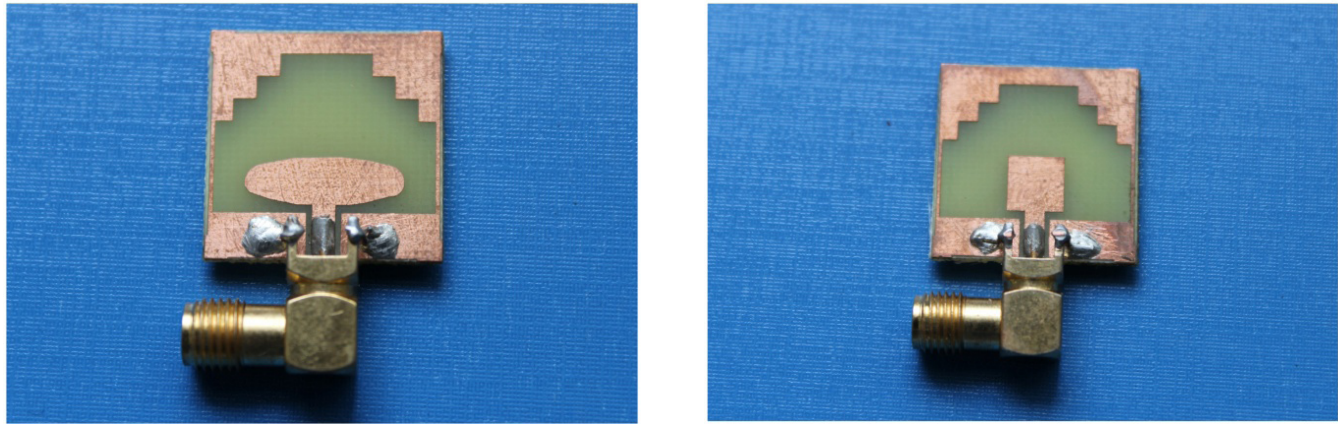


Figure 13. Fabricated Prototypes of Elliptical and Rectangular Monopole Antennas with Tapered Step Ground.

Table 2. Elliptical monopole with tapered step ground EBG antenna dimensions (in mm) for different substrate materials

Substrate material	RT-duroid 5880	Arlon AD 250A	Ultralam 3850	Polyester	Plexiglass	FR4	Alumina
h	1.57	1.6	1.6	1.6	1.6	1.57	1.6
ϵ_r	2.2	2.5	2.9	3.2	3.4	4.4	9.2
ϵ_{eff}	1.6	1.75	1.95	2.1	2.2	2.7	5.1
W	2.36	2.27	2.19	2.13	2.06	2	1.83
G	0.53	0.525	0.517	0.511	0.505	0.5	0.45
Ws	21.25	21.02	20.68	20.45	20.22	20	18.18
LS	21.25	21.02	20.68	20.45	20.22	20	18.18
G ₁	8.5	8.40	8.27	8.18	8.09	8	7.27
G ₂	2.12	2.10	2.06	2.04	2.02	2	1.81
G ₃	2.12	2.10	2.06	2.04	2.02	2	1.81
G ₄	1.59	1.57	1.55	1.53	1.51	1.5	1.36
G ₅	9.03	8.93	8.78	8.69	8.59	8.5	7.72
L	11.5	11.45	11.27	11.14	11.02	10.9	9.9

Table 3. Rectangular monopole with tapered step ground EBG antenna dimensions (in mm) for different substrate materials

Substrate material	RT-duroid 5880	Arlon AD 250A	Ultralam 3850	Polyester	Plexiglass	FR4	Alumina
h	1.57	1.6	1.6	1.6	1.6	1.57	1.6
ϵ_r	2.2	2.5	2.9	3.2	3.4	4.4	9.2
ϵ_{eff}	1.6	1.75	1.95	2.1	2.2	2.7	5.1
W	4	3.8	3.55	3.35	3.2	2.54	1.23
G	0.58	0.54	0.53	0.52	0.51	0.5	0.46
Ws	23.5	21.8	21.5	21.0	20.4	20	18.7
LS	23.5	21.8	21.5	21.0	20.4	20	18.7
G1	9.4	8.72	8.6	8.4	8.6	8	7.51
G2	2.35	2.18	2.15	2.1	2.04	2	1.87
G3	2.35	2.18	2.15	2.1	2.04	2	1.87
G4	1.76	1.63	1.61	1.57	1.53	1.5	1.4
G5	9.99	9.26	9.14	8.92	8.67	8.5	7.98
Wp	6.63	6.15	6.06	5.92	5.75	5.64	5.29
Lp	6.64	6.16	6.07	5.93	5.76	5.65	5.30
L	12.81	11.88	11.72	11.44	11.11	10.9	10.24

taken on any of these materials based on the availability and application. Among all these materials, low dielectric constant material based antenna size is more compared to the high dielectric constant substrate materials as shown in the tables.

7. Conclusion

Two novel designs of wideband antennas are proposed on EBG structures. A tapered step ground with the combination of EBG is providing enhancement in the bandwidth and stable gain. The proposed models consisting of simple structure with total dimension of 20x20x1.6 mm. Wide impedance bandwidth of 35.5% from elliptical monopole antenna and 37.5% from rectangular monopole is attained. Average gain of 2.5 dB and efficiency of 80% and 75% is obtained from elliptical and rectangular monopole antennas with EBG structure. Simple and small sizes, low cost of fabrication, good radiation characteristics with wide operating bandwidth are making these antennas suitable for microwave communication applications.

8. Acknowledgement

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