Liquid crystal polymer substrate based wideband tapered step antenna

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Abstract

Performance study of wideband tapered step antenna on liquid crystal polymer substrate material is presented. Bandwidth enhancement is achieved by adding step serrated ground on the front side of the model along with the radiating patch. The radiating patch seems to be the intersection of two half circles connected back to back. The lower half circle radius is more than upper half circle radius. Wideband tapered step antenna is designed on the liquid crystal polymer substrate (Ultralam 3850, ε_r = 2.9) with dimensions of 20×20×0.5 mm. Coplanar waveguide feeding is used in this model with feed line width of 2.6 mm and gap between feed line to ground plane of 0.5 mm.

Keywords

Coplanar waveguide feeding (CPW); Liquid crystal polymer (LCP); Ultralam 3850; Bandwidth; Serrated ground

Introduction

In recent years, wireless communication systems related applications are increasing in different fields [1]. In order to fulfil the future requirements, an antenna should be operative in multiband and wideband according to their usage in the corresponding domain. Antennas are going to play the major role in the coming future with their number of advantages like low profile, light weight, low cost and ease of integration with microwave devices etc. One of the major challenges in the modern antennas is the design of small size antenna with omni directional radiation pattern, wide bandwidth and stable gain [2]. Generally microstrip antennas suffer with narrow bandwidth problem and researchers proposed different techniques to overcome this problem with their novel designs.

An efficient technique to improve the bandwidth of the antenna is to use modified shape of monopole [3]. This can be implemented with coplanar waveguide feeding or microstrip feeding technologies. Along with the improvement in the bandwidth, the radiation characteristics and the associated gain parameter also should be considered up to the satisfactory values. There is a challenge to the researchers to design antennas which can be adoptable to the surface without any degradation in the performance. Conformal antennas have great demand in the fields of military and domestic applications. The conformal antenna should mount on any surface and it should have the flexible structural characteristics.

A simple structure of tapered step ground plane [4-5] is used in the proposed model. The special ground plane is providing additional path to the current and enhancing the bandwidth. A performance study of wideband tapered step antenna on liquid crystal polymer substrate material was carried out. The current design is fabricated on the flexible liquid crystal polymer substrate material Ultralam 3850 with dielectric constant of 2.9 and loss tangent of 0.0025.

Material and Method

Liquid Crystal Polymer

Liquid Crystal Polymer (LCP) has drawn much attention for its outstanding packaging characteristics [6-8]. LCP is low-cost material with the best packing characteristics of any polymer has generated great interest in using it as a substrate material for mm-wave applications. A comparison of these packing characteristics Vs all other polymers are shown in Fig 1. Low water absorption should be there for microwave substrate materials for better stability and reliability. Generally for organic materials the range of water absorption characteristics is from 0.02% to 0.25% or more.

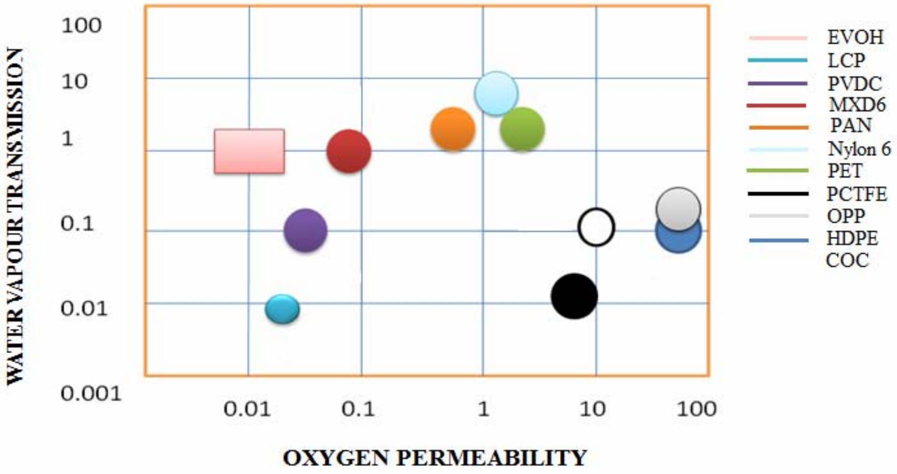

Figure 1. *Water and oxygen permeability of different polymers*

Figure 1 shows the water and oxygen permeability of different polymers, in which liquid crystal polymer is having low water vapour transition. Not only for less water absorption characteristic, but also for several reasons LCP material will be used in the design of RF and microwave modules [9-14]. Some of the key features are

- LCP is having excellent high-frequency electrical properties, stable ε_r and low loss tangent 0.002-0.004 for frequency < 35GHz.
- Quasi-hermetic
- Low coefficient of thermal expansion(CTE)
- Recyclable
- Cost is less
- Naturally Non-flammable(Environmentally Friendly)
- Flexible
- Multilayer all LCP laminations capabilities to create multilayer LCP RF modules
- Relatively low lamination processing temperature(=285 0°C)
- Low dielectric constant for use as an efficient antenna substrate.

Traditionally with high dielectric constant materials, introducing air cavities inside of multilayer RF modules for embedding chips or other elements creates impedance discontinuities that cause reflections and can destroy RF performance. In addition many package cavities rely on metal bonding rings around the cavity interface, which necessitates more difficult feed through solutions such as re-routing and tapering the transmission line underneath the seal. A unique possibility with LCP, because of its low dielectric constant and multilayer lamination capabilities, is to form cavities in the substrate before lamination to provide sandwiched all LCP constructions that can pass transmission lines directly through the package interface with negligible effects on the RF performance with different behaviour at different ° C (Figure 2).

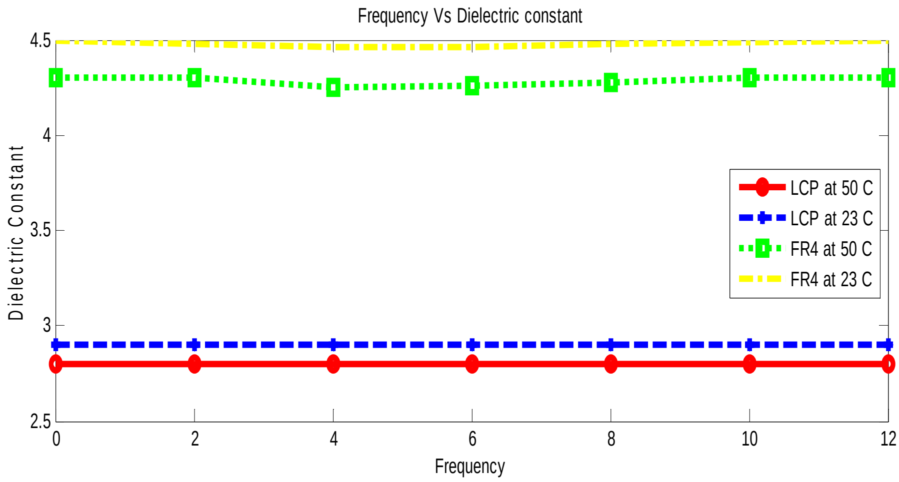

Figure 2. *Frequency vs Dielectric constant of LCP and FR4 at 23° C and 50° C*

The LCP low dielectric constant would enable the superstrate packing to accommodate chips, MEMS and other devices without any concern for the parasitic packing effects. Because of the flexibility [15] and low cost, the LCP can be used in conformal antenna designs.

Ultralam ® 3850 (Liquid Crystal Polymer Substrate Material)

Ultralam ® 3850 is the emerging liquid crystal polymer circuit material from Rogers Corporation. The features like excellent high frequency properties, good dimensional stability, and external low moisture absorption and flame resistant makes this as one of the potential substrate material for RF circuit design. So many benefits are associated with this material, which are listed below

- Excellent and stable electrical properties for impedance matching
- Uniformity in the thickness for maximum signal integrity
- Flexible material for conformal applications [16-18] i.e. bends easily
- In humid environment it maintains the stable mechanical, electrical and dimensional properties.

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The applications includes high speed switches and routers, chip packing, MEM's, military satellites, radar sensors, hybrid substrates, handheld RF devices and in the design of antennas.

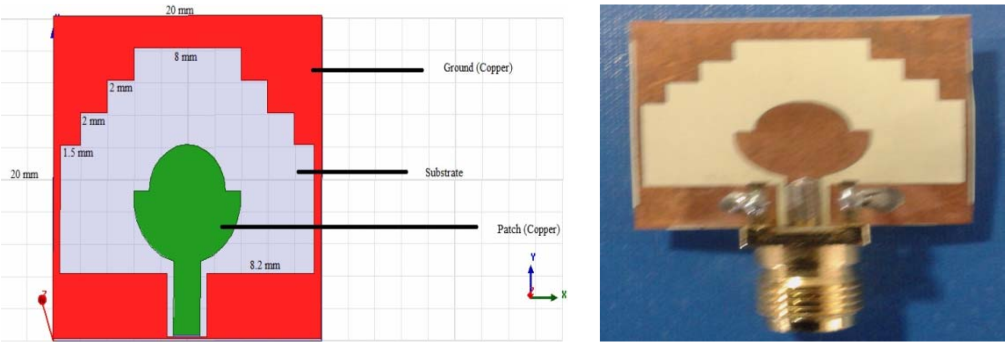
The electrical and environmental properties of Ultralam ® 3850 at 10 GHz, 23°C are tabulated as shown in Table 1.

Table 1. Electrical and Environmental Properties of Ultralam ® 3000 LCP material

No.	Parameter	Value
1	Dielectric Constant	2.9
2	Dissipation Factor	0.0025
3	Surface Resistivity	$1x10^{10}$ Mohm
4	Volume Resistivity	$1x10^{12}$ Mohm cm
5	Dielectric Breakdown Strength	1378(3500) KV/cm(v/mil)
6	Water Absorption (23° C, 24 hrs)	0.04%

Antenna description

Wideband tapered step antenna is designed on the liquid crystal polymer substrate (Ultralam 3850, ε_r = 2.9) with dimensions of 20×20×0.5 mm. Coplanar waveguide feeding is used in this model with feed line width of 2.6 mm and gap between feed line to ground plane of 0.5 mm.



(a) (b)

***Figure 3.** Wideband tapered step antenna on LCP Substrate, (a) HFSS design, (b) Fabricated prototype*

Detailed methodology and algorithm

The design of the antenna based on the dimensional characteristics will be carried out on the commercial electromagnetic tool HFSS. The detailed procedure is presented here in a sequential order

a) Initially liquid crystal polymer substrate material characteristics are studied and their dielectric properties are paced in the simulated design model.

b) The simulation results using commercial Electromagnetic tool HFSS is analysed before the fabrication.

c) The fabricated prototype antenna is tested with ZNB20 Vector Network Analyser for S-parameters.

d) Measured results are compared with simulated results and analysed for the validation of the designed antenna model.

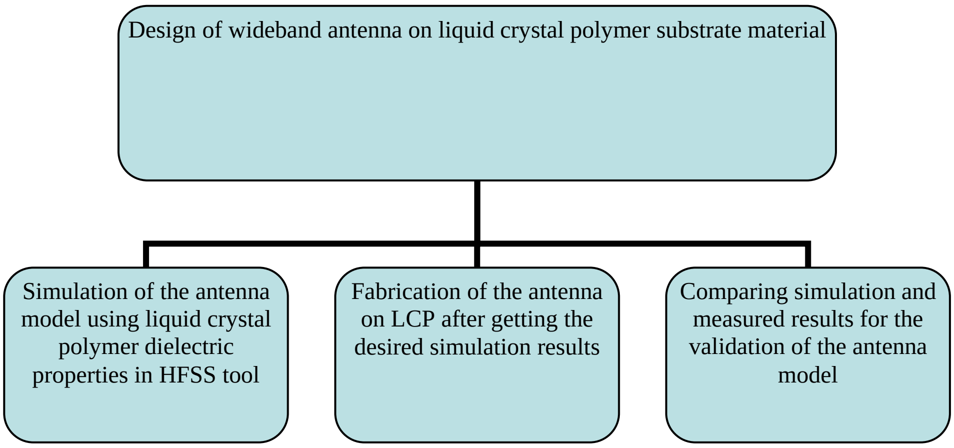


Figure 4. *Procedural steps for LCP antenna design*

In the design of the model and in the simulation, there is a possibility to optimize the model before going to fabrication. Once the optimized model is fixed for the fabrication then there should be no other modifications in the model. After getting fabrication results from vector network analyser, then comparison for validation with simulation results is carried out.

Results and Discussion

Figure 5 shows the return loss curve for the LCP based wideband tapered step antenna. Antenna is resonating between 5.2 to 16.6 GHz with bandwidth of 11.4

GHz in the simulation and Figure 6 show the measured result from network analyser from 4.8-15.5 GHz with bandwidth of 10.7 GHz. There is a small difference of 0.7 GHz in bandwidth is observed from simulate results due to poor quality in the SMA connector with

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feed line and ground plane.

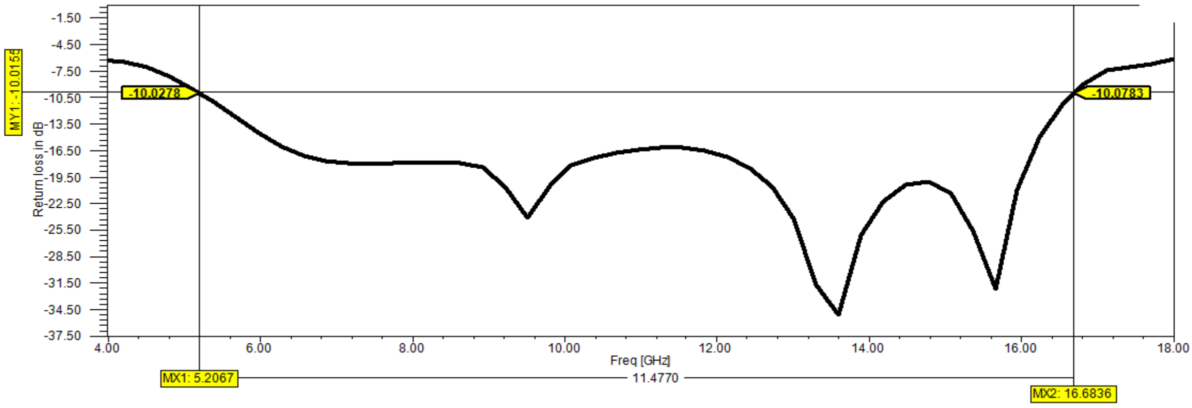

Figure 5. *Simulated return loss Vs frequency of wideband tapered step antenna on LCP Substrate*

Figure 7 shows the antenna three dimensional radiation view at 13.6 GHz. Radiation pattern of Omni directional in E-plane and quasi Omni directional in H-plane with low cross polarization levels can be observed from Figure 8.

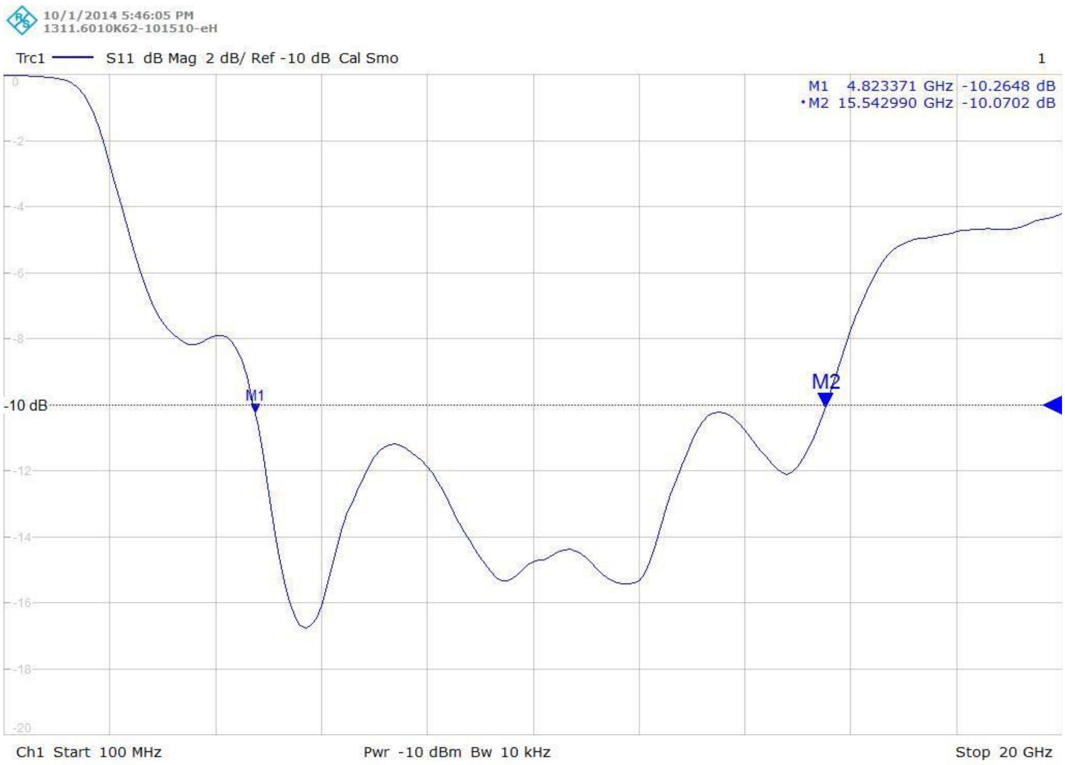

Figure 6. *Measured return loss Vs frequency of wideband step serrated antenna on LCP substrate*

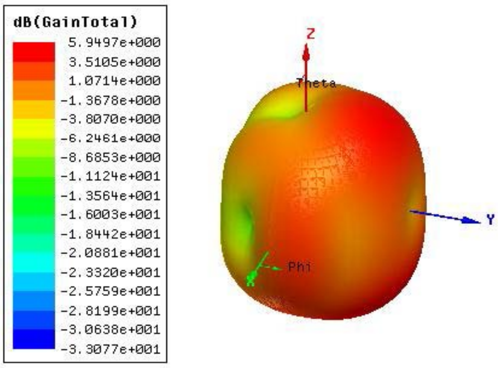

Figure 7. *Three dimensional view of radiation for wideband tapered step antenna at 13.6 GHz*

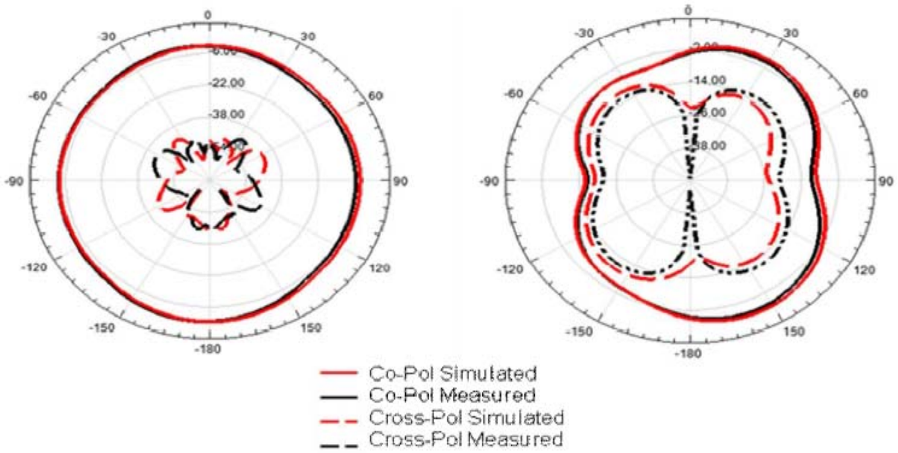

Figure 8. *Radiation pattern in E and H-plane of wideband tapered step antenna at 13.6 GHz*

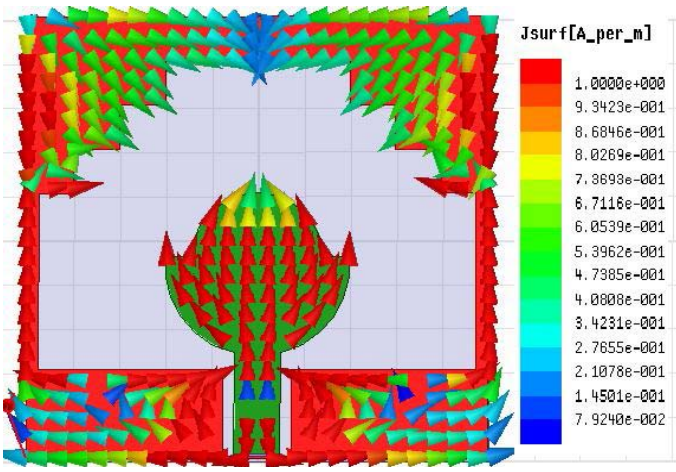

Figure 9. *Current distribution of wideband tapered step antenna at 13.6 GHz*

Figure 9 shows the simulated current distribution of the antenna at 13.6 GHz. The current intensity is maximum at radiating element and feed line towards x-direction with equal magnitude but opposite in polarity. Figure 10 shows the frequency Vs gain plot for the liquid crystal polymer antenna. From this result we can observe that gain is increasing up to 14 GHz and after reaching to the peak gain of 4 dB, the gain is decreased at higher frequency.

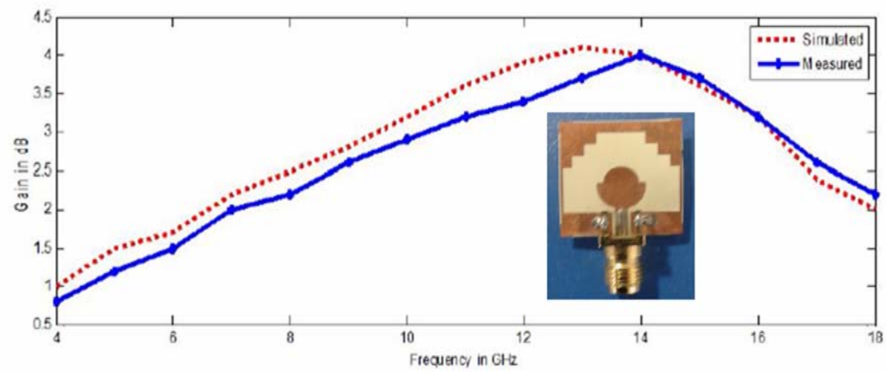

Figure 10. *Gain vs frequency of wideband tapered step antenna*

Flexibility consideration

Flexibility is one of the key factors for LCP materials usage in the design of conformal antennas. Test was performed on the mechanical flexibility and the effects of bending on antenna performance. The procedure for performing the antenna testing in real time mode is included here in a systematic manner by considering all the precautions like repeatability, flexibility and potential strength.

1. Ensuring measurement repeatability when connecting/disconnecting antenna in the default flat state
2. Performing flexure testing on the antenna, rolling it on to tubes with various diameters
3. Re-measuring and observing once again the potential differences in measurement or visual structural changes

In this procedure we observed that there are very minute changes in the reflection coefficient of antenna at resonating frequency and in all the cases, almost no frequency shift is observed.

Actual reason for choosing LCP material in the design is to have a flexible model, which should not produce odd results when it is placed on different surfaces. The ability of this model is also tested by bending the antenna in different angles and in each case the reflection coefficient result is noted. The current model is placed in different tubes with various diameters for this testing.

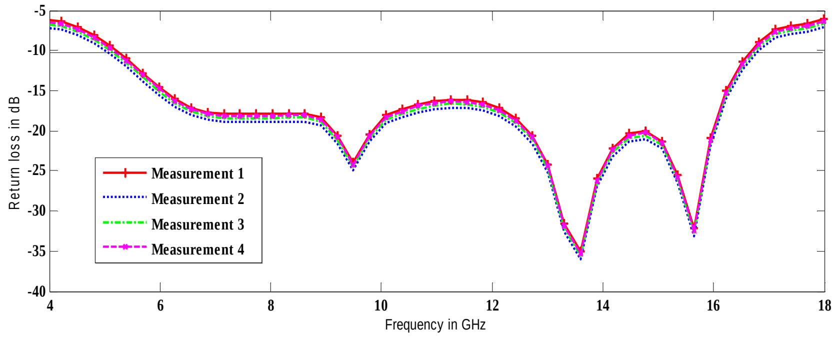

Figure 11. *Flexibility testing of LCP antenna with different angles*

By consolidating all these cases of testing we observed not much variation in the frequency of operation rather than a small shift in the frequency, which gives the potential of the LCP material in the conformal applications. Fig. 11 shows the testing result of the antenna with different bending angles.

Conclusion

Wideband tapered step liquid crystal polymer material based antenna is designed to operate between 4.8 to 15.5 GHz with bandwidth of more than 10.7 GHz. Omni directional radiation with peak realized gain of 4 dB is attained from this model. Flexibility of the antenna is tested by placing the model in different tubes with different diameters and observed the constant reflection coefficient results over the frequency range. The proposed model is providing excellent flexible characteristics with large bandwidth and maximum gain of 4 dB in the desired band.

Acknowledgements

Authors would like to express their deep gratitude towards the department of ECE and management of K. L. University for their continuous support and encouragement during this work.

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