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Planar UWB Antenna with Enriched Gain and Band-Notch Characteristics

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ABSTRACT

The design of a compact planar monopole antenna featuring ultra-wideband characteristics and simultaneous signal rejection in the 6.5-8.5 GHz band is presented here. Five different antenna configurations have been proposed with the same RF performance and radiation characteristics. Co-Planar Waveguide(CPW) is used to feed the radiating element. The presented results depict that the prototype antenna of 47×47 mm^2 dimension has a bandwidth from 3 GHz to more than 10.6 GHz excluding the rejection band. Measured peak gain of the fabricated prototype antenna varies from 1.5 dBi to 5.5 dBi except the notch band. This gain can be improved by 3 dB (avg.) implementing honeycomb superstrate along with metallic shield.

Keywords: Band–notching, CPW feed, Gain enhancement, Honeycomb structure and UWB antenna

INTRODUCTION

In modern age wireless communication, broadband monopole antennas are gaining prime importance due to their attractive features, such as ultra-wide frequency band, simple structure and ease of realization [1-8]. These monopole antennas require ground plane which is perpendicular to the radiator. As a result, whole structure becomes bulky, non-planar and finally incompatible for integration with printed circuit technology. To alleviate these problems, planar versions of the UWB monopoles have been realized by several researchers from the last decade either by using the microstrip-line [9] or CPW feeds [10-12].

After the assignment of 3.1-10.6 GHz frequency band as unlicensed ultra-wideband (UWB) range in the year 2002 by Federal Communication Commission (FCC)-USA, tremendous efforts in research have been put together by microwave engineers till date. The UWB system has been popular because of its inherent characteristics, such as extremely high data-rates, low power consumption, low fabrication cost and above all simple hardware configuration. This paper demonstrates five different shaped CPW-fed printed monopole antennas showing potential performance throughout the entire FCC-standard unlicensed UWB frequency range [13]. Overall fabrication cost in minimized by reducing the metallization area in these prototypes without changing the cross-sectional area and antenna performance parameters. However, frequency interference between existing narrow-band wireless systems and upcoming UWB system has become a major concern due to large operating bandwidth for UWB communication. Most notable among them is 6-8.5 GHz (Fixed Satellite Service, FSS) used for satellite communication. To reject this unwanted sub band in UWB domain, easiest method is to use a band-stop filter. This method not only increase circuit dimension but also introduces extra complexities. So, people have approached to achieve this band-notching by implementing half-wavelength slots or quarter-wavelength open-ended slits either on the radiating patch or in the ground plane.

In this work, unwanted frequency interference in the already existed satellite communication (FSS) is avoided by implementing open-ended rectangular slits in the ground-planes of the proposed antenna. Further, the antenna is embedded with some composite structures suitable for aerospace applications. Composite structure is built with quartz-made honeycomb core and metallic cover on it. Honeycomb superstrate along with metallic face sheet is used to improve the gain of the antenna by 3 dB. Also, the entire structure becomes more suitable to handle various dynamic loads because of its inherent structural benefits.

ANTENNA DESIGN AND ANALYSIS

The geometry of the reference antenna is shown in Fig.1. The radiating disc shaped patch and the feed mechanism are printed on the top side of the substrate. Patch is excited by 50 Ω coplanar waveguide line of dimension 0.33/4/0.33 (mm). The antenna has a cross-sectional area of 47 ×47 mm^2. It is designed for standard 1.6 mm thick FR-4 substrate of relative permittivity of 4.4 and loss tangent of 0.02. The simulations were performed using the Ansys HFSS suite, which utilises finite element method (FEM) for electromagnetic computations [14]. It has been observed during simulations that, the operating bandwidth of these CPW-fed monopole antennas is critically dependent on the feed-gap (h), width of the ground plane (W) and radius of the disc (r). Hence, all of these parameters are tuned carefully to optimize the antenna performance.

Observing the surface current profiles of this monopole (Fig.2), it can be inferred that the whole disc is containing lowest density currents, which dictate the lower band-edge frequency of the antenna. Removal of the few portion of the upper-half shouldn't affect the overall antenna results. Hence, it results in a *'Wine-glass'* shaped radiator. Current density plot also depicts that, the current flowing through the peripheral regions are only responsible for antenna radiation not from the central zone. So, central zone area elimination can't hamper antenna merits, and thus *'Annular ring (Half and full)'* structure evolves. In addition to this, if an open-ended stub is incorporated at the juncture of the signal line of the feed-section and annular ring-shaped radiator, then good impedance matching can be achieved at the cost of suitable length and width of the stub-line. Finally, it gives a shape of *'Tri-shul'* type radiating element. All the derived antenna shapes are schematically explained in Fig.3.Changes in the current densities in various shaped radiators are shown elaborately in Fig.4.

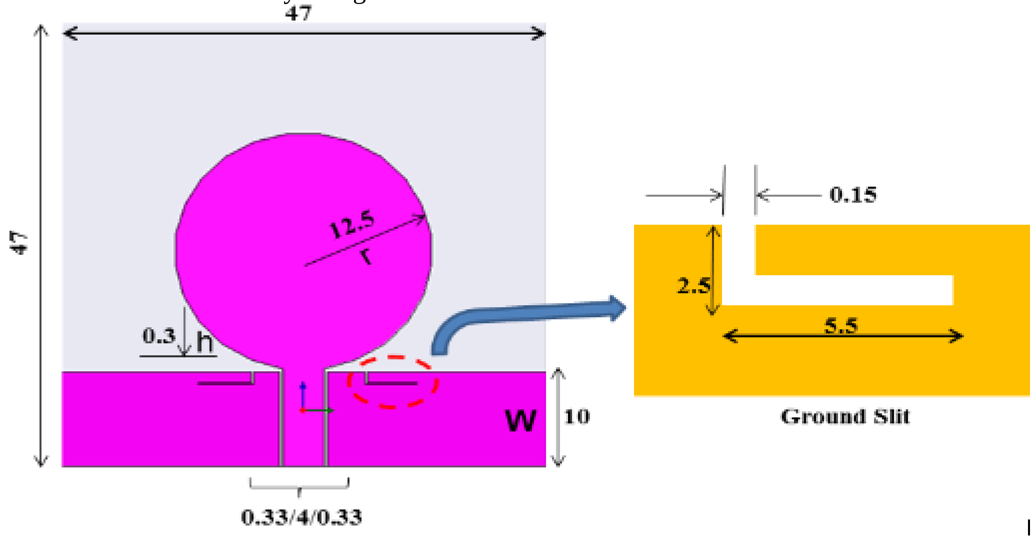


Fig. 1 Geometry of reference Antenna [*All dimensions are in mm]

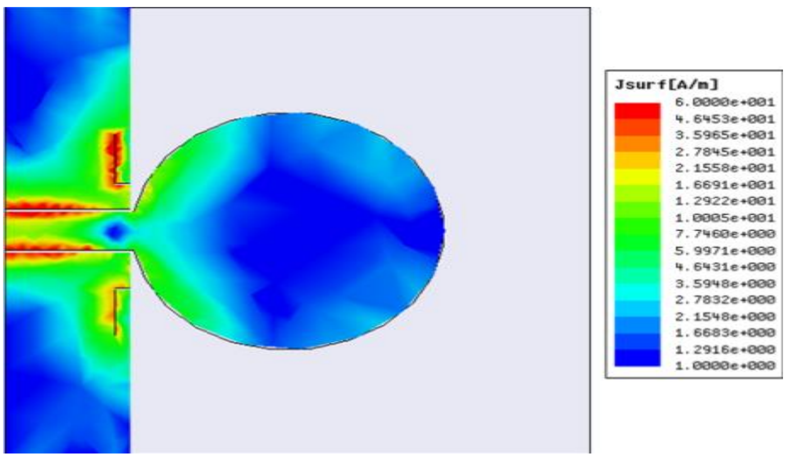
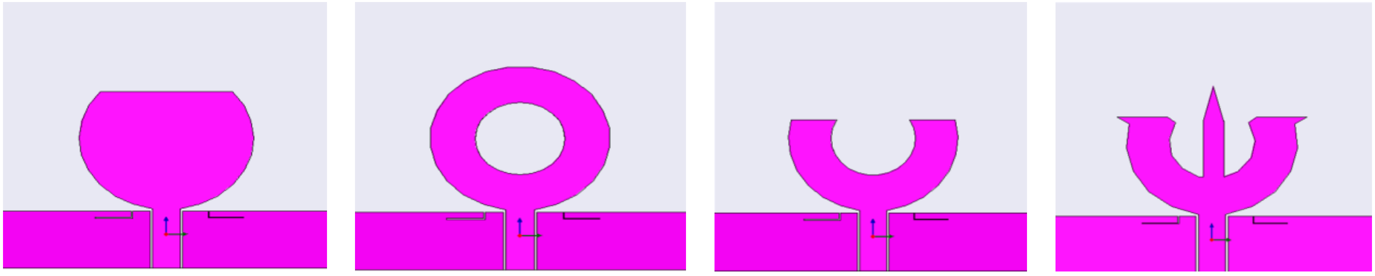


Fig. 2 Current distribution of reference antenna structure



(a) (b) (c) (d)

Fig. 3 Geometry of (a) Wine glass (b) Annular Ring (Full) (c) Annular ring (Half) and (d) Trishul Antenna

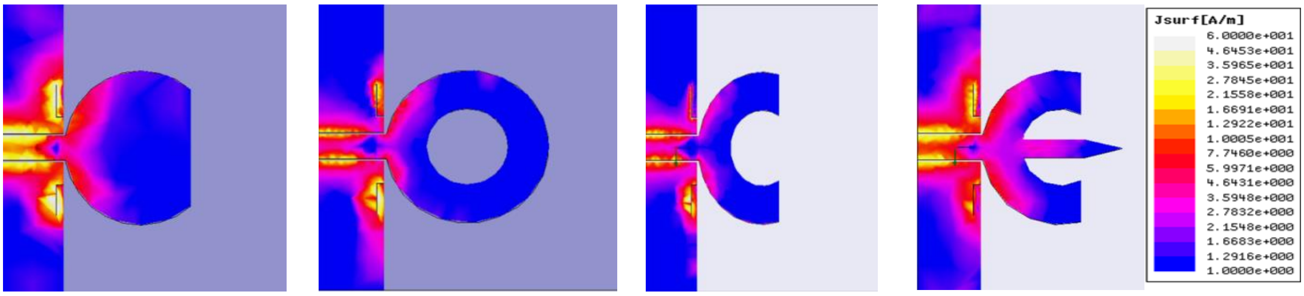
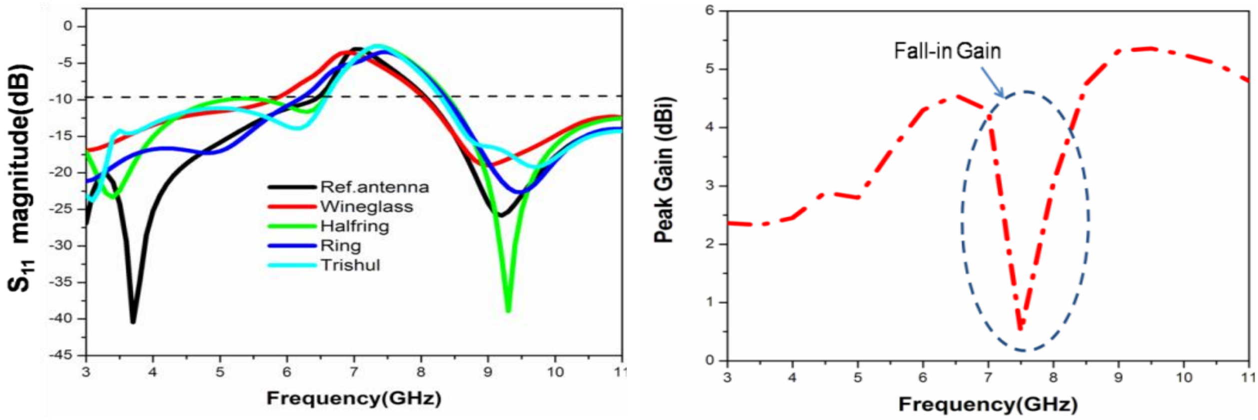


Fig. 4 Changes of current densities in the various antenna structures



(a) (b)

Fig. 5 Simulated (a) Return loss of the band-notched antenna structure with different configurations (b) Peak gain of the ref. antenna.

Band-notching of the antenna is achieved by incorporating rectangular shaped open-ended slits in the ground plans of the CPW-feed line. These slits have a signal rejection capability in the range of 6.5-8.5 GHz band. The length of the slit is kept as half-wavelength ($\lambda_g/2$) at the mid-band frequency of the notch-band. And, the width determines the notch bandwidth. Slit provides strong radiation attenuation at the corresponding rejection band [15]. Basically, it works as band-stop filter, which removes unwanted frequencies. Placement of these slits is very crucial. Usually, they are placed at the densely populated E-filed/magnetic current zones, so that these structures can alter the direction of electric field or magnetic current vectors and resulting in signal rejection at desired frequencies.

Antenna performances after 3D-simulations are shown in Fig.5. It depicts that, the '*Tri-shul'* has the highest signal rejection capability, whereas the '*Wine-glass'* shaped antenna poses the wideband signal notch characteristics. Simulated peak gain of the reference structure varies from 2.4 dBi to 5.4 dBi except the notch band.

EFFECT OF SUPERSTRATE

In this work, a stack of honeycomb core and metallic facesheet have been used as a superstrate of the antenna, as shown in Fig.6. This composite structure basically acts as an aperture antenna and increases the effective aperture size, and hence it enhances the directivity beyond that of original primary antenna.

Honeycomb core is load-bearing structure; used specially in aerospace applications [16-17]. Table-1 details the properties of the honeycomb material used in this work. The constituent materials of the honeycomb give it superior mechanical strength, toughness and chemical resistance. The cell shape is hexagonal in nature for obtaining optimum mechanical properties. These cells have perforated side-walls. The honeycomb has an air-like dielectric properties (ε_r = 1.04 to 1.06), which is almost transparent to radio and radar waves.

Facesheet of the antenna is metallic in nature, placed at the quarter-wavelength ($\lambda_0/4$) apart from the main radiating element. Face sheet carries bending –induced axial loads; and core sustains shear stresses as well as compressive stresses normal to the metal plate. Equivalent model of the composite antenna structure can be thought as shown in Fig.7. The top metallic cover is acting as a short circuit placed at quarter-wavelength away from the resonating antenna element. From antenna view point, it is nothing but an open circuit or equivalent free-space environment.

Table -1 Properties of Honeycomb Material used in this Work

Parameter	Values/Attributes
Construction material	Astroquartz/Cyanate Ester
Compressive strength (psi)	250
Compressive Modulus (ksi)	26.5
Shear strength in L-direction (psi)	225
Shear modulus in L-direction (ksi)	18.0
Shear strength in W-direction (psi)	105
Shear modulus in W-direction (ksi)	10.6
Dielectric constant along ribbon	1.042
Loss tangent along ribbon	0.00083
Dielectric constant across ribbon	1.06
Loss tangent across ribbon	0.00036
Average frequency(GHz)	9.5
Coefficient of Thermal Expansion, CTE (min/In/°F)	2.5

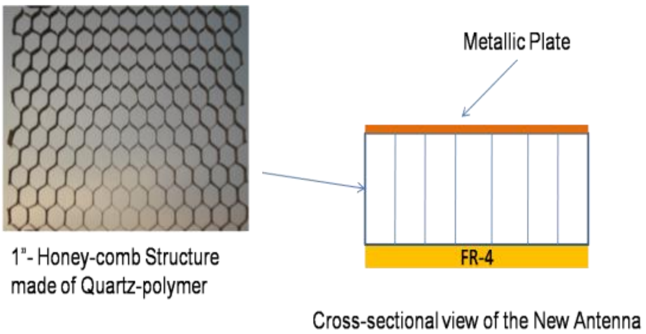


Fig. 6 Proposed composite antenna structure (a) schematic view

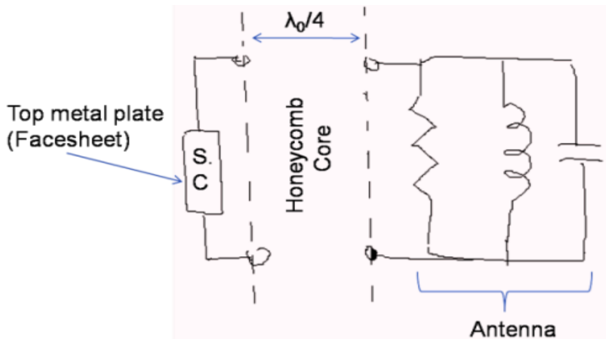


Fig. 7 Equivalent model of the composite antenna structure

FABRICATION & MEASURED RESULTS

Prototype structures have been fabricated on standard 1.6 mm thick FR-4 (ε_r =4.4, tan δ =0.02) PCB substrate, as shown in Fig.8. SMA-type RF connector is attached to the input port for signal excitation. The critical dimension of the design is 0.15 mm (slit width). Metallization thickness is kept as 0.2 mm considering the skin-depth at the operating band. For the composite structure (Fig.9), Quartz-made honeycomb core (courtesy to M/s Ultracor Inc, USA) of sample number *UQF-314-3/8-3.0* is used, which has a thickness of 25.4 mm. This height is equivalent to the one quarter-wavelength at the mid-frequency of the rejection band. Above the core, 0.2 mm thick copper made metallic facesheet is placed, acting as a reflector for EM-wave. Overall volume of the composite antenna structure is coming around 47 mm (L) × 47 mm (W) × 27.2 (1.6+25.4+0.2) mm (H).

Return loss of the antenna is measured by using the Vector Network Analyzer (R&S make ZVA-40). Magnitude of the S_{11} is coming better than -10 dB throughout the entire UWB domain excluding the rejection band (6.5-8.5 GHz). Fig. 10(a) compares the measured data with the simulated values for the reference antenna, where a close relevance is observed. Slight variation is attributed to the tolerances in resistivity and fabrication. Sometimes, during assembly of the RF connector at the feed portion of the antenna, unexpected spreading of the solder materials can happen. It can lead to change in gap dimension of the CPW line. And, the characteristics impedance value may deviate from 50 Ω arbitrarily over this wide range of frequencies. Measured peak gain of the reference antenna with and without top-side cover is depicted in Fig. 10(b). The peak gain of the reference antenna varies from 1 dBi to 5.4 dBi, whereas the antenna with honeycomb structure shows a variation of 4 to 8 dBi. It can be inferred that there is a clear signature of gain enrichment unaltering its band-notch behaviour with the implementation of composite superstrates.

Fig. 8 Fabricated reference antenna structure

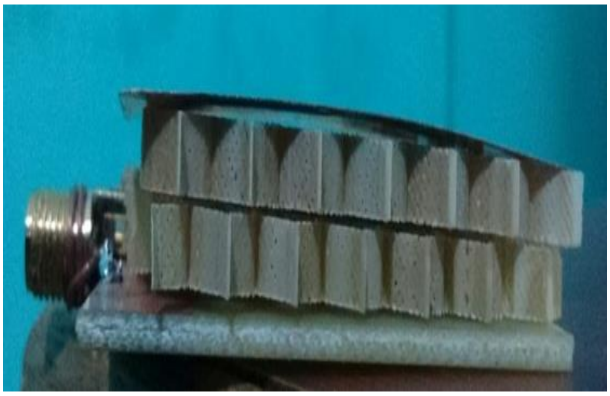


Fig. 9 C/S view of the antenna with superstrate materials

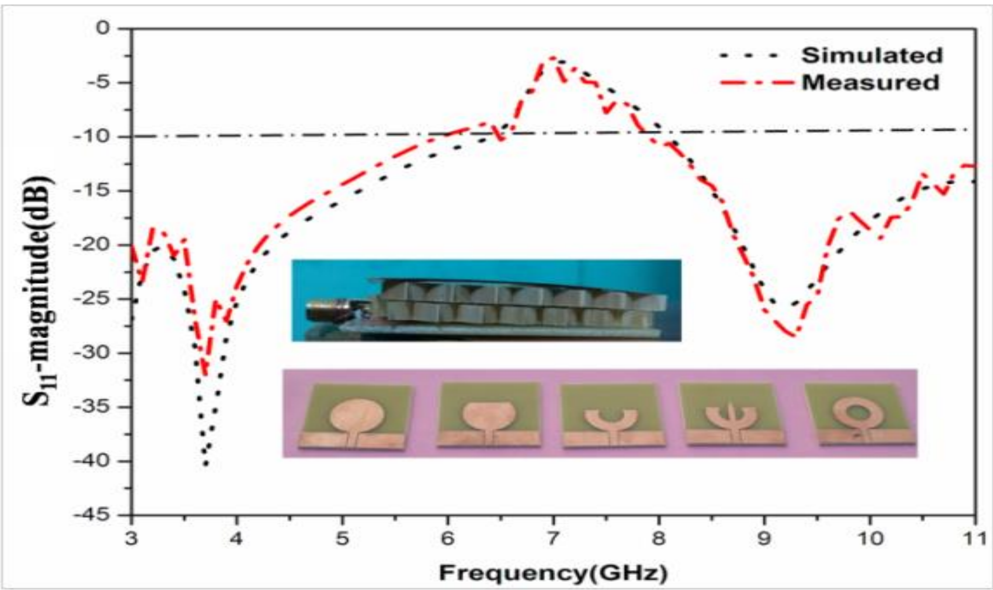


Fig. 10 (a) Simulated Return loss of the band-notched antenna structure with different configurations

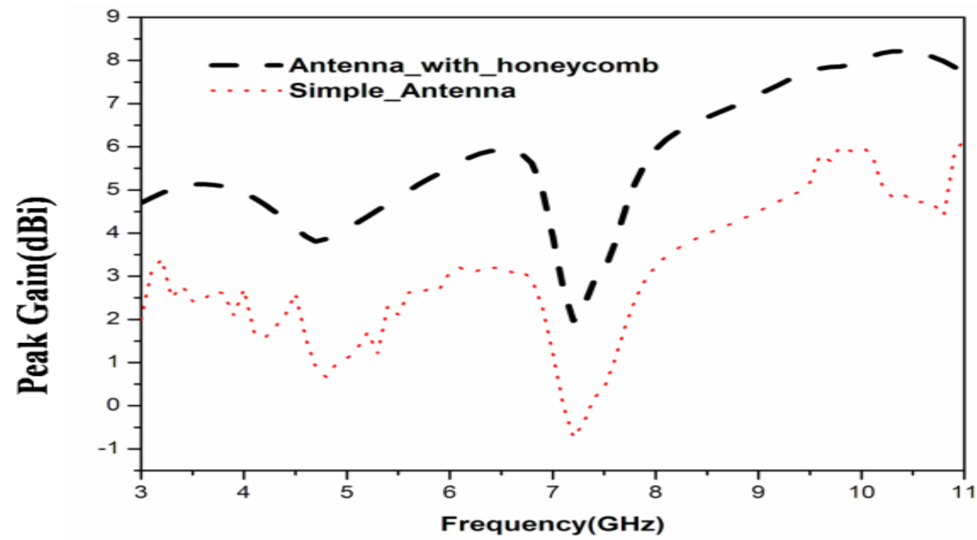
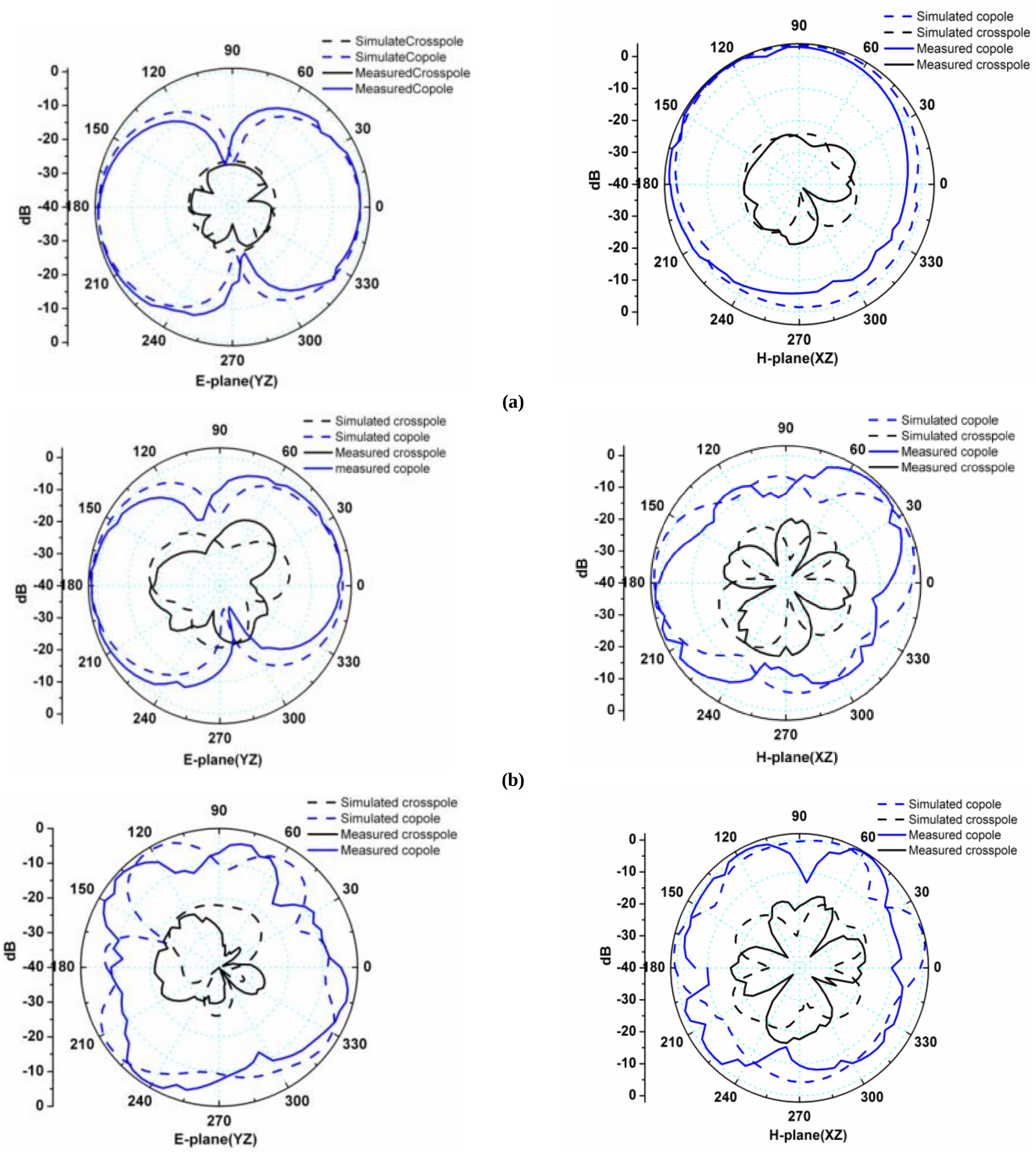


Fig. 10(b) Simulated Peak gain of the reference antenna

Far-field radiation patterns at three distinct frequencies, such as 3.1 GHz, 5.4 GHz and 10.5 GHz are shown in Fig.11. At the lower frequency side, the patterns are very similar to omni-directional type; but it becomes distorted at high frequency ranges. This is because of unwanted enhancement `of cross-polarization levels.

CONCLUSION

This article presents the planar design and implementations of monopole antenna with ultra-wide frequency band. Simple open-ended slits are embedded in the design itself to achieve the band-stop behaviour of this antenna. Maximum peak gain of the single antenna structure is coming around 5 dBi. Further, it can be enhanced by 3 dB (avg.) with the implementation of composite structure made of honeycomb core and metallic facesheet. Use of load-bearing honeycomb structure makes the new antenna a suitable candidate for aerospace applications. Equivalent circuit modelling makes ease of understanding the composite antenna structure. Easiest band-notch approach adopted in the current work makes the use of the proposed structure in the UWB domain without interfering the fixed satellite services. Performance parameters of this antenna show a very good agreement with its predicted (simulated) values. Main attraction of the present work is the simplicity of the structure, which can be implemented very easily.



(c)

Fig. 11 Measured radiation patterns of the proposed antenna at (a) 3.1 GHz (b) 5.4GHz and (c) 10.5 GHz

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