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Broadband Magneto-Electric Dipole Antenna using Circular Quadrants with SIW Technique

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Ku (12-18 GHz) band is prominently utilized for application related to satellite communications. In the proposed work, the essential characteristics of Magneto electric dipole antenna has fruitfully been designed by printing L shaped probe feed and four circular quadrants embedding shorted metallic vias. Wideband impedance bandwidth of 2.53 GHz (12.40-14.93 GHz) is offered by the antenna, which is around 19.26 % at center frequency. Moreover, it exhibits good gain and radiation characteristics. An extensive simulation and optimization have been performed using CST-MW-2019. The fabricated antenna has been verified with VNA and anechoic chamber

Keywords: Vector network analyzer (VNA), Magneto-electric dipole antenna, Low-profile, Substrate integrated waveguide (SIW)

1 Introduction

There are eternal technologies and wide bandwidth with broadside radiation characteristics and gain stability. In recent times, specific investigations related to magneto electric dipole antennas pertinent to wireless satellite transmissions have been accomplished. The characterization of these types of dipole antennas could be represented using radiation patterns having symmetry, minimum cross-polarization, enough bandwidth, and extraordinarily consistent performance of radiation gain. A novel broadband antenna was developed in[1], named magneto-electric dipole antenna (MEDA)[2], which comprises a patch antenna of quarter wavelength and a λ/2 electric dipole aerial. This encouraged the growth of enhanced bandwidth characteristics of MEDA.MEDA antennas with improved bandwidth have been proposed in[3].

Next, in differential-feed topology[4-5], such as underlying techniques that deploy two ports for its excitation, has appropriately been explained. It elongates the operating bandwidth of the MEDA[7-8], but they have complicated structures. Digital handheld devices require low-profile antennas for purposes of planar addition. Moreover, certain studies[9,10] have been done about the substrate-integrated waveguide (SIW)[11] technology. The conversion of three-dimensional construction into planar description[12] is provided by the SIW. It endorses similar merits to its planar counterparts. It has substandard unsolicited losses as compared to that incurred in microstrip, which has been deployed meticulously to design high-performance millimeter-wave[13-14] and microwave RF circuitry[15,16,17]. These antennas suffer from the constraints of complicated design along with feeding regime[18-19], chiefly at a frequency range of millimeter wave. Some investigations have been accomplished related to the enhancement of the bandwidth[20-21]. Afterward, high-profile broadband magneto-electric dipole antennas were elaborated with limited bandwidths of operation as 56, 95.2, and 110 %[22-23]. However, their three-dimensional composite metallic structures in terms of volume make them unfit for several applications[24].

2 Materials and Methods

2.1 Antenna design and mechanism

The detailed configuration of the projected design is shown in Fig.1(a) plan view and (b) perspective outlook. The proposed design has appropriately been accomplished from a circular patch of radius 'Rad' centered on the substrate. Subsequently, two narrow thin strips were etched out along the center of the

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circular patch whose dimensions were (2Rad × (W_{50}+2g)) and (2Rad × W), one horizontally and one vertically. This process divided the patch into four equal quadrants. Meanwhile, four metallic posts of radii 0.6mm were embedded along one edge of the quadrant. The posts were placed at a distance of 0.9 mm from each other. Followed by this, an L-shaped feed line emerging from the ground surface was introduced at the centre of the circular patch whose dimensions were l_{ms} × W_{50} , coaxial line was used as feed line of 50 Ω. The back side of the substrate was fully grounded. To summarize, the radiating element comprised of a L-shaped probe feed encircled by four quadrants of a circular patch embedded with four metallic posts along each quadrant edges and a ground plane. The quadrants were parasitically attached to the feed line due to the narrow slots. The length of the feed line was approximately 1/2 of the guided wavelength $l=\lambda_g/2$ at the lower operating frequency of 13.3 GHz, which acted as an electric dipole. The metallic posts loaded along the quadrants acted as magnetic dipoles of approximately $\lambda_g/4$ at 14 GHz (higher operating frequency). Effectively, these posts served as vertical metallic walls. The feed excited the electric and magnetic dipoles at the same time. Bandwidth was increased, since two dipoles (electric and magnetic) resonated at nearest frequencies. This aerial was designed and optimized using CST Microwave Studio, a commercially available electromagnetic simulator tool. The optimized antenna parameters have been shown in Table 1. The proposed MEDA exhibited dual resonance at 13.13 GHz (lower) and 14.04 GHz (Upper) due to the simultaneous excitation of magnetic and electric dipoles.

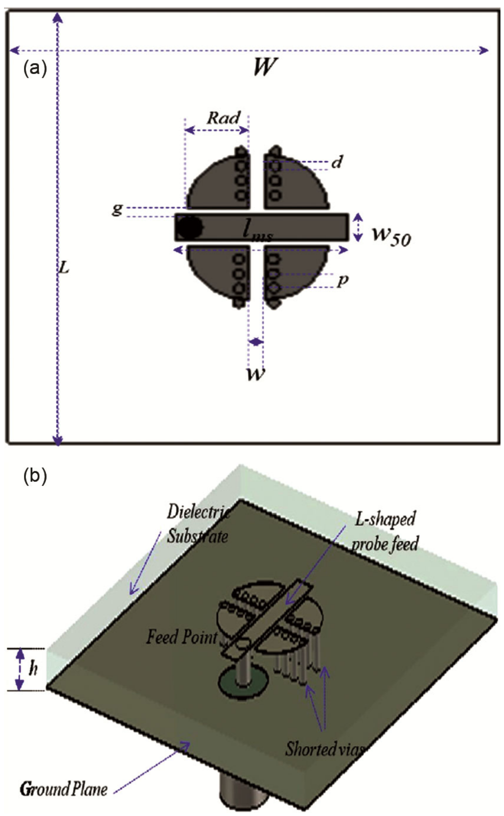

Fig. 1 — Detailed antenna design (a) the plan outlook, & (b) perspective outlook.

These two near resonances coupled each other by properly tuning parameters to yield a broad impedance bandwidth. To understand the matching factor of the projected antenna, real (Re Z_{11}) and imaginary (Im Z_{11}) parts of the input impedance are exposed in Fig. 2. It was analyzed that the Real Z_{11}

Table 1 —Dimensions of the proposed design

Parameters	Values(mm)	Parameters	Values(mm)
Rad	3.1	H	1.57
W	27	G	0.35
L	27	l_{ms}	9.4
W_{50}	1.6	d	0.3

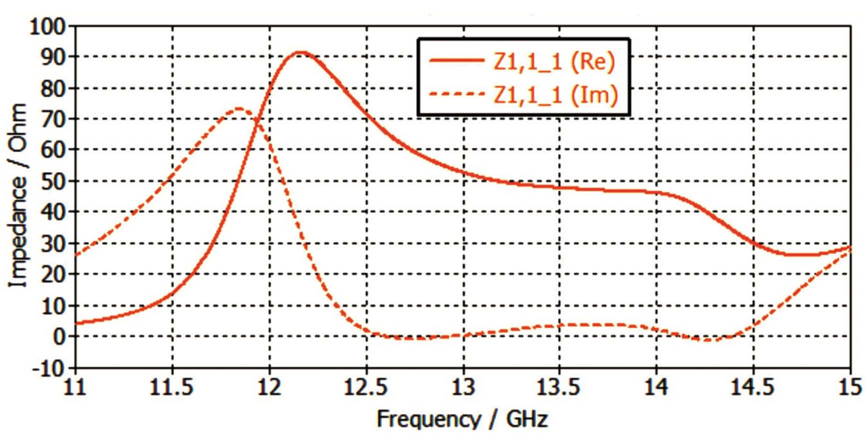

Fig. 2 — Impedance matching characteristics (real and imaginary impedance).

parameter was around 50 Ω in the frequency range of 12.40 and 14.93 GHz. It showed an operating bandwidth of 2.53 GHz (19.26 %). At the same instant, the input impedance (imaginary part) was approaching zero. Input impedance matching characteristics are shown in the Fig. 2, the radius of the circular patch was taken as 3.0 mm. Figure 3 shows the result of the radius of the round patch on the working bandwidth of the projected design. Further, with the increment in the radius (parameter *rad*) of circular quadrants, the bandwidth shifted towards the lower frequency ranges and vice-versa. The antenna provided a broad flexibility in shifting the bandwidth by merely changing the '*rad*' parameter of the antenna.

Table 2 shows the investigations related to number of vias and the spacing between them. Moreover, the gain, directivity, frequency range and efficiency of antenna were affected due to the number of vias & spacing between vias is shown in Table 2. According to satellite component requirements we could change number of vias and spacing between them.

3 Results and Discussion

3.1 Fabrication and experimental validations

The proposed work comprises a wideband magneto-electric dipole aerial for Ku-band using PCB with the help of MITS Lab 11 milling machine. The antenna includes an L-shaped feed, four circular quadrants and three or four metallic posts along the edges of the circular quadrants. The antenna design, mechanism, fabrication and measurement results (S_{11} and Gain) have suitably been described in the subsequent. To authenticate our proposal, the above design was produced on Rogers 5880 dielectric substrate of dielectric constant (ε_r) is 2.2, depth was 1.57 mm, and loss tangent-0.0009. Various views of a prototype are shown after fabrication in Figure 4. The antenna reflection coefficients (S_{11}) were characterized by Vector Network Analyzer (VNA). The measured and simulated reflection coefficient characteristics are compared in Fig. 5. There was a fair amount of agreement in between the measured and simulated outcomes. It was observed that the simulated S_{11}

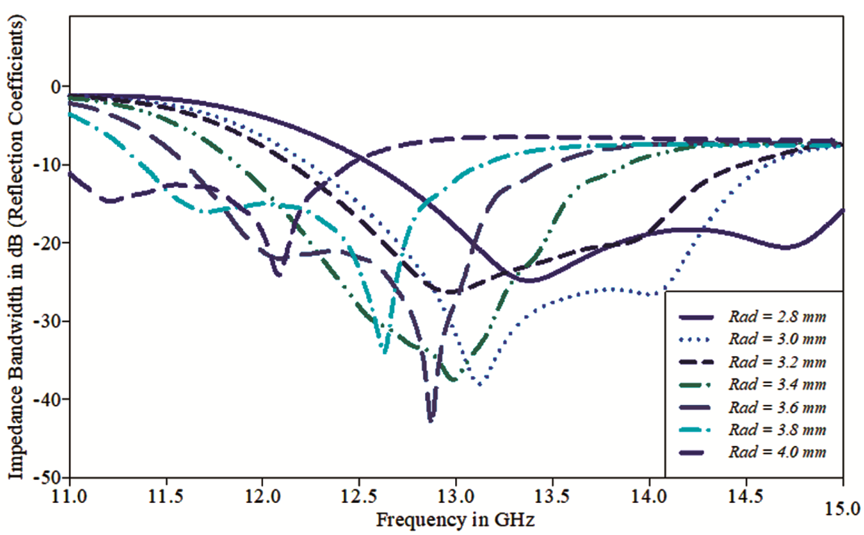

Fig. 3 — Impedance bandwidth performance of the aerial for changed values parameter 'rad'.

Table 2 — Effect of variations in values of vias

No of Vias	Spacing between vias in mm	Directivity in dBi (at 13GHz)	Gain in dBi (at 13GHz)	Bandwidth in GHz with range	Efficiency in % (G=ήD)
4	0.9	4.814	4.724	2.368 (12.246-14.614)	98.13
4	1.0	4.90	4.82	2.48(12.31-14.79)	98.36
4	1.1	5.01	4.93	2.53(12.40-14.93)	98.40
4	1.2	5.07	4.99	2.52(12.43-14.95)	98.42
3	0.9	4.81	4.73	2.44 (12.20 14.64)	98.33
3	1	4.893	4.80	2.54 (12.286-14.826)	98.2
3	1.1	4.998	4.92	2.55(12.38 to 14.936)	98.43
3	1.2	5.06	4.97	2.54(12.42 -14.96)	98.22

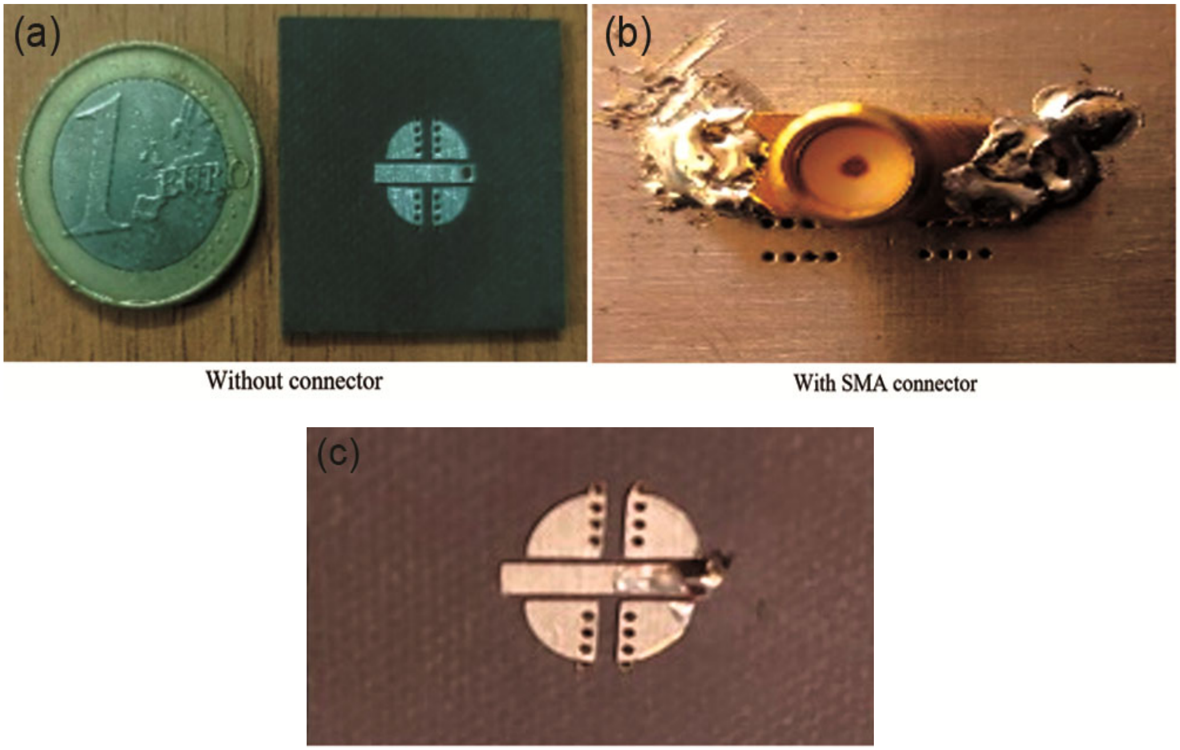

Fig. 4 — Fabricated antenna prototype. (a) without connector, (b) with SMA connector, & (c).

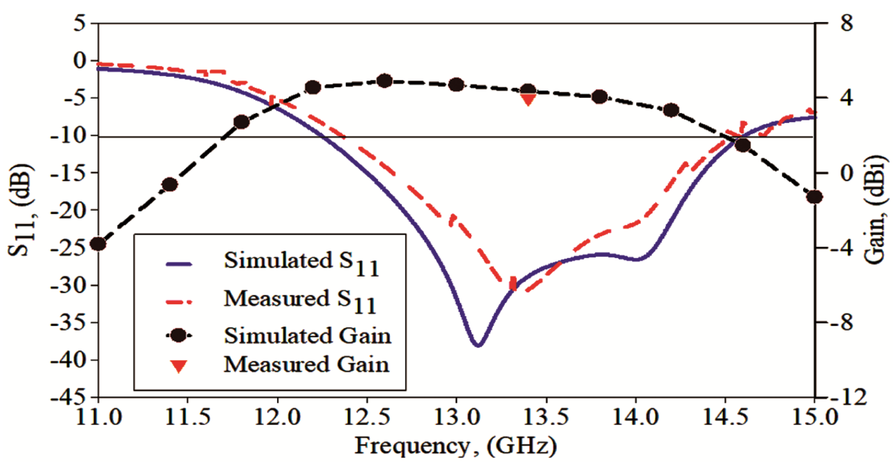

Fig. 5 — The operating bandwidth and gain characterization of the projected design.

parameters span from 12.40 and 14.93 GHz showing a bandwidth of 2.53 GHz (19.26 %), when the spacing between vias was 1.0 mm. Whereas the measured bandwidth characteristics were 16.46% (2.14 GHz), which ranges from 12.38 to 14.52 GHz. The simulated S_{11} shows two resonant dips at 13.13 GHz (lower) and 14.04 GHz (Upper).These dips offer perfect impedance matching between radiating patch and coaxial probe feeding.

It was conjectured that the lower and upper resonant frequencies appeared due to the excitations of electric and magnetic dipoles. The measured resonant frequency dips appeared around 13.33 and 13.95 GHz frequencies. A slight deviation in the measured and simulated bandwidths was anticipated due to the tolerance effects in the fabrication and soldering processes. The antenna gain characteristics were also analyzed and studied in Fig. 5. The design displays consistent, uniform and unchanging radiation characteristics similar to a conventional three-dimension metallic MEDA. The average simulated gain of the proposed MEDA was 4.93 dBi. The antenna gain at 13.4 GHz was measured using a standard horn antenna, and it was 3.91 dBi. The measured gain value was near the average gain value in the operating frequency range. Also, the total efficiency and radiation efficiency of the projected aerial are shown in Fig. 6. The antenna displays 98% and 95% radiation efficiencies at the two operating bands, respectively.

The measured and simulated radiation styles in terms of co-polar and cross-polar radiations in two principles cut plane of 0 degrees and 90 degrees at the resonant of 13.30 GHz are plotted in Fig. 7. The simulated results of the radiation style show a satisfactory accord with the measured results.

The antenna revealed unidirectional and practically steady radiation characteristics in the main direction. The cross-polar levels in principle cut-planes of 0 degrees and 90 degrees at the resonant frequency of 13.30 GHz were below 14 and 16 dB correspondingly. As the antenna pertained to unidirectional radiation styles, thus FBR is better than 15 dB in every case.

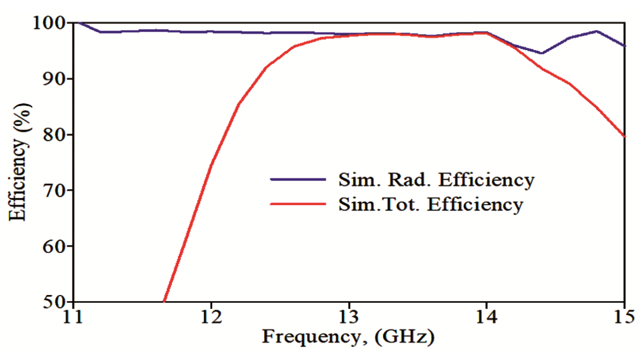

Fig. 6 — The antenna efficiencies: radiation and total.

Additionally, the design was rescaled at another center frequency, even in the millimeter or THz range. The antenna design could be a promising candidate for compact handheld devices functioning in the Ku band, principally for broadband claims.

The presentation between this work and a few beforehand testified SIW based wideband antennas are described in Table 3. It shows comparatively larger bandwidth though the complete performance is modest.

Table 4 shows the comparison among simulated antenna (four vias), simulated antenna (three vias) and, fabricated antenna (four vias) electrical properties.

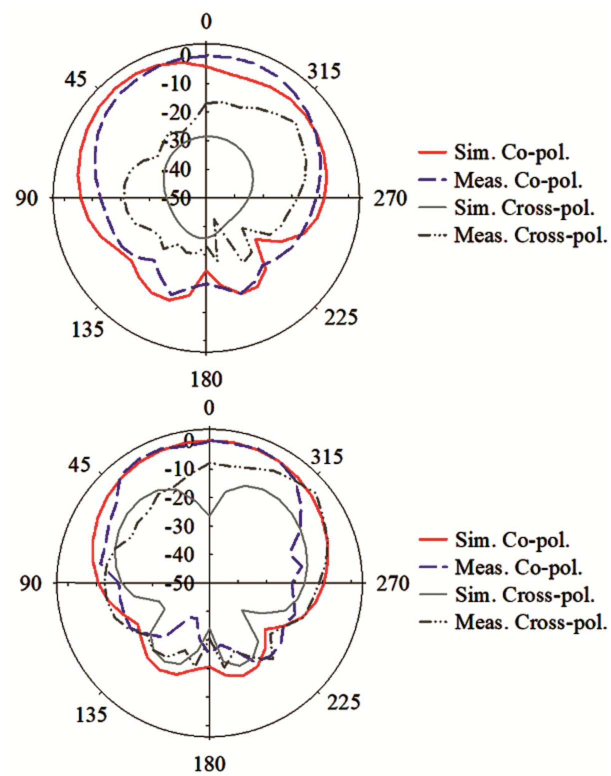

Fig. 7 — Radiation patterns at 13.30 GHz: (a) ϕ=0 , & (b) ϕ=90°.

Table 3 — A comparative study -previous reported and proposed work

Ref.	Frequency range	Substrate Thickness (mm)	Antenna Size (in term of operating frequency)	Dielectric constant	Bandwidth(%)	Remark(s)
Present study	12.38-14.52 (fabricated)	1.57	$2\,\lambda_o \times 2\lambda_o$	2.2 (Rogers 5880)	16.46	L shaped probe with circular quardrants, single layer planar structure
	12.40 -14.93 (simulated)	1.57	$2\,\lambda_o \times 2\lambda_o$	2.2 (Rogers 5880)	19.26	
[4]	13.3-16.7	1.57	2.2λ ×2.2λ	3.55 Rogers RO 4003C	11.56	Single layered planar structure, L-Shaped Probe
[18]	5.63-5.88	2.4-3.3	2.55 λ ×0.459 λ	2.2(Rogers 5880)	4.3	Plannar,high thickness ,L shaped probe
[22]	1.62-2.87	45.7	2.18 λ ×2.18 λ	1(Air)	56	3D metallic structure,feed by microstrip line
[25]	13.3-16.7	1.5	$2\,\lambda_o \times 2\lambda_o$	2.2(Rogers 5880)	11.56	L shaped probe

Table 4 — Comparisons between simulated and fabricated results of antenna

Electrical property	Simulated (CST) when four vias	Simulated(CST) when three vias	Fabricated
Frequency range (GHz)	12.40 -14.93	12.286-14.826	12.38 -14.52
S_{11} peak(dB)	-40	-65	-30
Bandwidth (GHz)	2.53	2.54	2.14
% bandwidth	19.26	19.28	16.46
Max Gain in dBi	5.07	5.06	3.91
Spacing in vias in mm	1	1	1

4 Conclusion

A planar magneto-electric dipole antenna is designed on RT/Duroid 5880 substrate. Wideband response of 19.26 % from 12.40 to 14.93 GHz is exhibited by antenna. Whereas, gain (4.7 to 4.97 dBi), directivity (4.81 to 5.07dBi), and efficiency (above 98%) of antenna is found to vary with quadrants size, vias size and distance between vias etc. a unidirectional pattern of radiation with a small cross-polarization level is sustained by the antenna. Small size, simple design structure and low manufacturing cost are some merits of this antenna. Single feed and a scalable assembly corresponding to THz and millimetre waves are comprised by the antenna.

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