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A H-shaped Slotted Circular Patch Antenna for Sub-6 GHz Applications

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Abstract— **The main focus is to represent a H-shaped slotted circular patch antenna (SCPA) for sub-6 GHz. The antenna resonates at 4.02 GHz and covers a large bandwidth of 2640.8 MHz (3.3198 GHz to 5. 9606GHz). It also exhibits very good reflection coefficient profile (-34.749 at 4.02 GHZ), VSWR (1.0373 at 4.02 GHz) and radiation efficiency (average=94%) which ensures the antenna would be practically usable within the intended Sub-6 GHz operating band. The proposed SCPA is printed on low dielectric material Rogers RT5880 having thickness of 0.79 mm. The area of the SCPA is 34×30 mm². It possesses an impedance of (50.651-j1.7257) Ω which is close to 50 Ω. The current distribution and gain of the SCPA is also good. Therefore, the designed SCPA can be considered as a good competitor for Sub-6 GHz applications.**

Index Terms—5G; Circular Patch antenna; Partial ground plane; H-shaped slot; High efficiency; CST.

I. INTRODUCTION

In the 20th century, development of wireless systems has attained a new dimension and attention due to its massive involvement in every aspect of modern life style all over the world. Researchers are continuously trying to develop high speed and user-friendly wireless systems. In the last few decades, wireless mobile communication technology has flourished through some evolutionary steps like 1G, 2G, 3G, 4G, and 5G. The 1st generation (1G) technology was introduced in early 1980s for voice communication only. After the invention of 5G technology, internet of things (IoT) and enhanced mobile broadband (eMBB) services have been added [1-2]. Basically, Sub-6 GHz band refers to the frequency band below 6 GHz (2.1, 2.6, 3.5 and 4.8 GHz), which plays a key role in research purposes due to the applications of Bluetooth, WLAN, LTE, WiMAX, and WiFi which involve many handy commodities such as smart-phones, computers, speakers, media players, handheld devices, robotic systems, laptops, headphones, watches, live streaming video players, modems and routers [3-4]. The 5G Sub-6 GHz band is able to provide more speed than 4G technology. Though microstrip patch antennas (MPAs) have some disadvantages like small power handling capability and low gain etc, one of the major positive sides of using MPAs is light weight which make it more suitable to use in any portable small wireless handy devices [5-7]. In [8], a wide and tri-band flexible patch antennas have been presented for Sub-6 GHz with dimension of 32×25×.064 mm^3 by using the Rogers RO4835T substrate. The wideband antenna exhibits frequency range from 2.85 GHz to 5.35 GHz and triple band. Both CST and HFSS are used to analyse the Sub-6 GHz antennas. A UWB circular patch sub-6 GHz antenna is introduced in [9] Though it covers the frequency 3.05-5.82 GHz, it's gain and efficiency suffers badly up to 4.5 GHz. A notch slotted circular monopole antenna is reported in [10]. A 47×37×1.6 mm^3 FR4 substrate (4.3) is used in the antenna. The antenna operates within 2-6 GHz having gain between 2.04- 4.67 dBi. A low profile microstrip patch antenna (20 ×35× 0.8mm^3) operating from 2.99 GHz to 5.89 GHz has been introduced. The average gain was 2.5 dBi and maximum gain was 3.75dBi at 3GHz. It gives an Omni-directional radiation pattern [11]. The authors in [12] developed a nearly Omni-directional antenna for the lower 5G band having bandwidth of 2.46 GHz. The partial ground plane technique has been deployed to reduce antenna size in the design. It's peak gain is 79.54 % and average gain is only 67.22 % within the operating 5G band. The antenna faces higher loss due to the use of lossy FR4 substrate material. Gunaram et al. [13] design and fabricated an elliptical microstrip patch antenna for Sub-6 GHz application. The antenna shows comparatively larger bandwidth (3.24GHz) but it suffers in gain which is only almost 1 dB at 3.24 GHz. The elliptical patch antenna also has a comparatively higher volume (55 ×30 ×1.6). They used lossy FR-4 material as substrate of the elliptical patch antenna.

In the interest of achieving high performance, the main contribution of this work is efficiency enhancement and good gain though a wide operating band (2640.8 MHz). The substrate size of the proposed antenna plays a significant role for stable gain as well as radiation characteristics throughout the entire operating Sub-6 GHz band. The dimension of the H-slotted circular patch antenna is 34×30×0.79 mm^3.The rest orientation of the paper is placed as follows: The structure of the H-shaped slotted circular patch antenna is narrated in section II. Then, the required simulated results and the performance estimation with analysis are discussed in section III. Conclusion and discussion are presented in section IV.

II. H-SHAPED SLOTTED ANTENNA

The analysis of H-shaped slotted circular patch antenna has been performed by CST-MWS suite 2018. A very low loss dielectric substrate, Rogers RT 5880 (2.2, 0.0009), is used in the design which helps to uplift the efficiency of the SCPA. The copper (thickness 0.035 mm) is used as metallic layers. The antenna made of a circular patch with H-shaped slot and a

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50 Ω microstrip feeder as presented (3D view) in Fig. 1(a). The width of the feeder is 2.4 mm which influences to get matched with 50 Ω and length of it is 15.20 mm. The area of the Rogers RT 5880 substrate is 34×30 mm^2. The radius of the patch is 7 mm as shown in Fig. 1(b). The horizontal space between the edge of the circular patch and the edge of the substrate (A) is 8 mm and the vertical space between the edge of the patch and the edge of the substrate (B) is 5 mm.

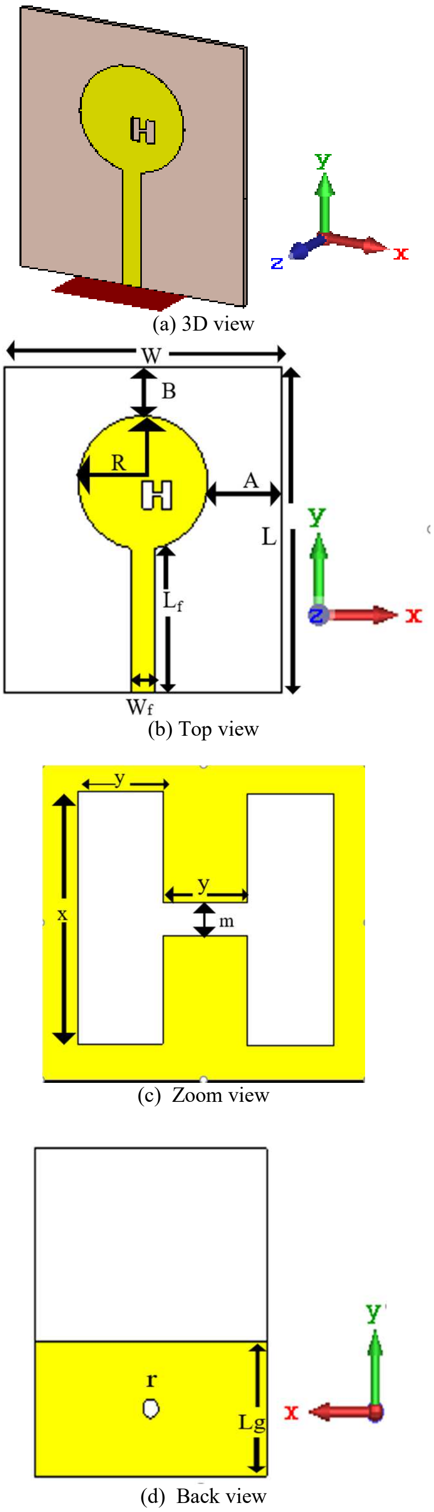


Fig. 1. H-shaped circular slotted patch antenna (SCPA).

The size of the H-shaped slot is 3 mm × 1 mm and width of the connecting slot is 0.4 mm as shown in Fig. 1(c). The area of the partial circular slotted ground plane is 14×30 mm^2as depicted in Fig. 1(d). The radius of the small circular slot (r) on the modified ground plane is 1 mm. The partial ground plane influences to enhance bandwidth, reduce antenna volume as well as good impedance matching of the proposed H-shaped slotted circular patch antenna. Table I provides a complete list of the design parameters of the proposed SCPA.

TABLE I PARAMETER'S LIST OF H-SHAPED SCPA.

Title	Symbol	Weight (mm)
Length	L	34
Width	W	30
Radius of circular patch	R	7
Ground length plane's length	L_g	14
Horizontal distance between edge of circular patch and edge of substrate	A	8
Vertical distance between edge of circular patch and edge of substrate	B	5
Length of legs of H-shaped slot	x	3
Width of legs of H-shaped slot	y	1
Width of connecting slot	m	0.4
Substrate thickness	h	0.79
Feeder length	L_f	15.20
Feeder width	W_f	2.4
Radius of circular slot on ground plane	r	1

III. RESULTS

From the estimated reflection coefficient curve as in Fig. 2, the designed H-shaped slotted circular patch antenna with modified ground structure shows a large bandwidth of 2640.8 MHz ranging from 5960.6 MHz - 3319.8 MHz. This operating band completely covers the commonly used 3.33-4.2 GHz Sub-6 GHz 5G band. It also shows a very good reflection coefficient profile (-34.749 dB at 4.02 GHz) within the entire coverage frequency range. The impact of H-shaped slot is also presented in Fig. 2. The reflection coefficient enhances with deploying the H-shaped slot on the circular patch. The 3D and linear gain and directivity graphs of H-shaped SCPA are depicted in Fig. 3. At 4.02 GHz, the gain and the directivity are 2.636 dB and 2.976 dBi. The gain and directivity are differing from 2.38 dB to 2.41 dB and 2.65 dBi to 3.741dBi within 3.3198 GHz - 5.9606 GHz. From Fig. 3(c), the antenna also has an acceptable gain and directivity profile.

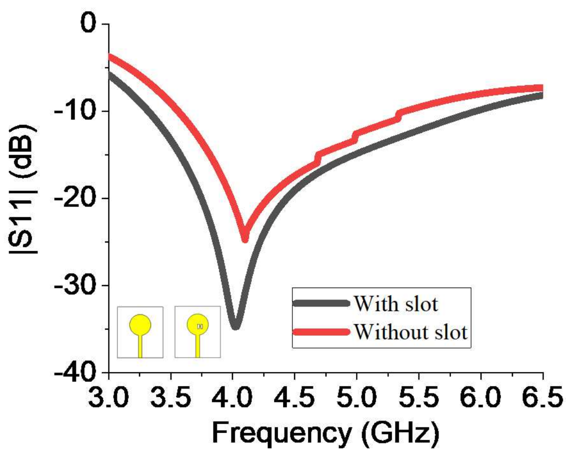
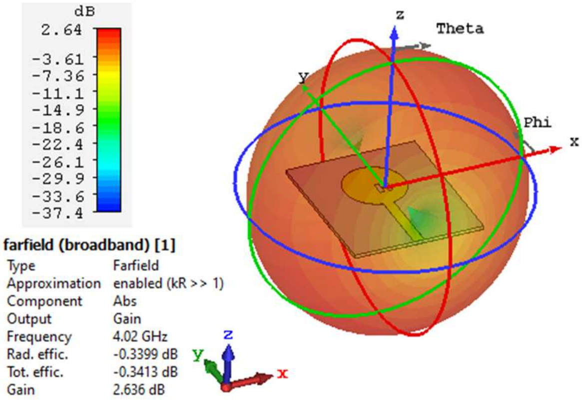
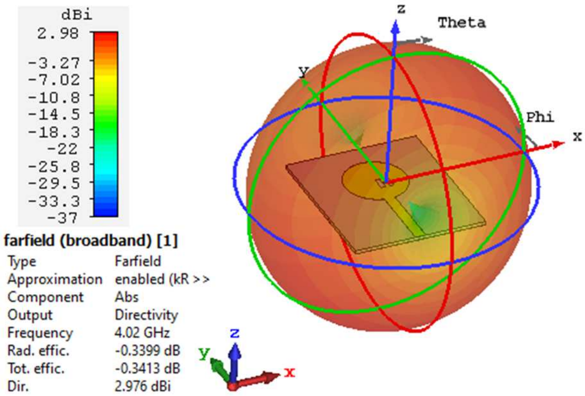


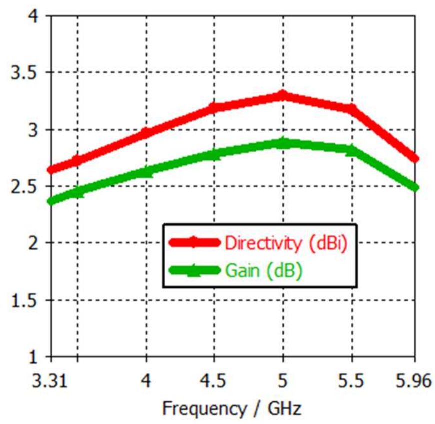
Fig. 2. Reflection Coefficient of the SCPA



(a) Gain at 4.02 GHz



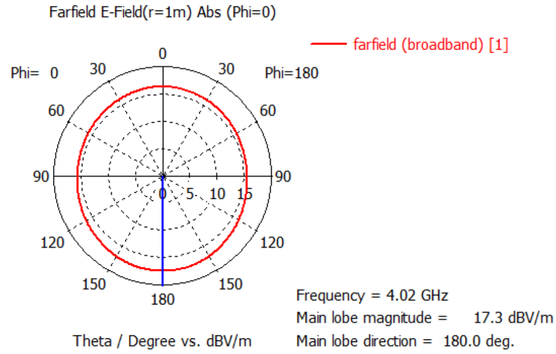
(b) Directivity at 4.02 GHz



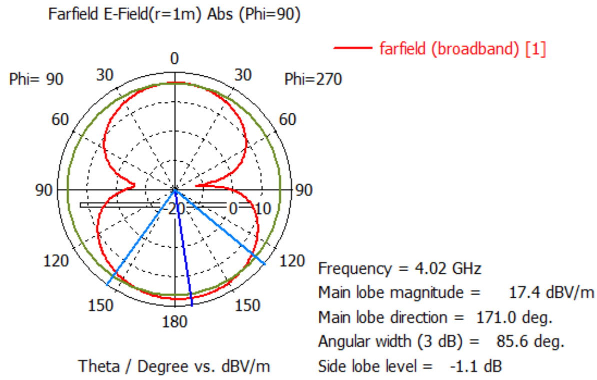
(c) Gain and directivity vs. frequency of the proposed SCPA.

Fig. 3. Gain and Directivity of the SCPA.

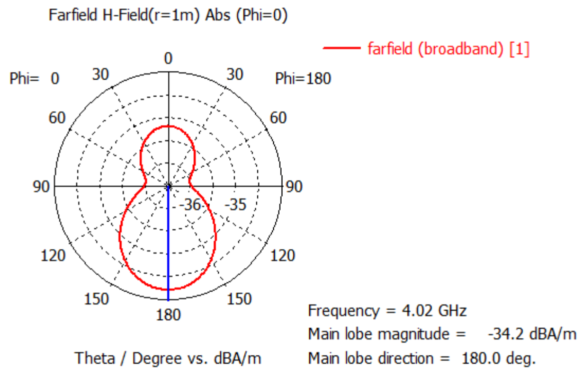
For E-field, the major lobe magnitude is 17.3 dBV/m for ϕ=0˚and 17.4 dBV/m for ϕ=90˚whereas for the H-field it is -34.2 dBA/m for ϕ=0˚and -34.1 dBA/m for ϕ=90˚. The major lobe is focussed at 180˚ for ϕ=0˚ and 171˚ for ϕ=90˚. The 3 dB angular beamwidth is 85.6˚ for ϕ=90˚ and the side lobe level is -1.1 dB at ϕ=90˚for both fields. The VSWR of the SCPA is 1.0373 at 4.02 GHz and it varies within 1-2 (Fig. 5).



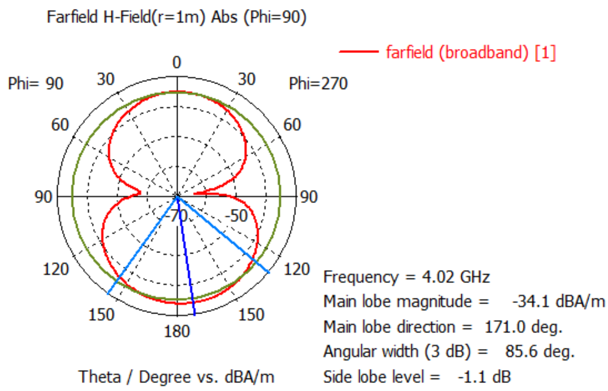
(a) E-Field at (phi =0º, 4.02 GHz)



(b) E-Field at (phi =90º, 4.02 GHz)



(c) H-Field at (phi =0º, 4.02 GHz)



(d) H-Field at (phi =90º, 4.02 GHz)

Fig. 4. Fields of the SCPA.

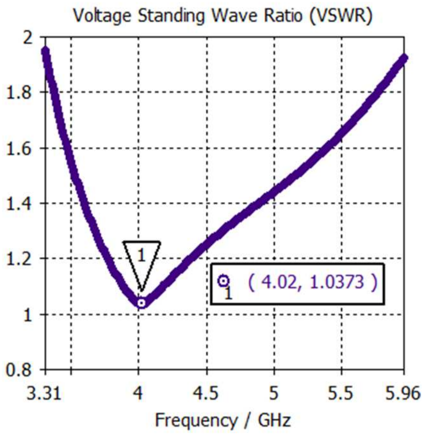


Fig. 5. VSWR of the proposed SCPA.

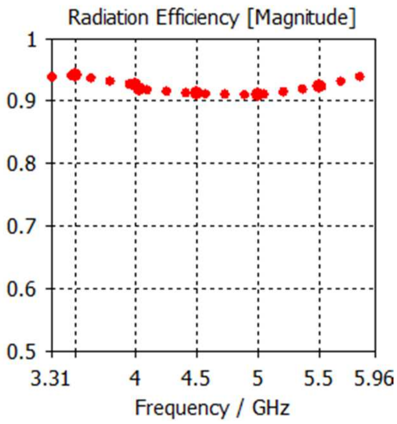


Fig. 6. Efficiency of SCPA.

Due to the use of low loss material Roger RT 5880 and proper impedance matching, the design SCPA shows excellent radiation efficiency. It always holds 91% or more as illustrated in Fig. 6. Radiation efficiency is 92% at 4.02 GHz which indicates the SCPA is capable of radiating the most of received power perfectly. The surface current distribution is presented in Fig. 7 at 4.02 GHz. It is 81.9941 A/m at centre frequency 4.02 GHz. Maximum is obtained at the edge of the slotted circular patch and microstrip feed as per color indicator. The impedance profile of the SCPA is depicted in Fig. 8. The impedance of the SCPA is (50.651-j1.7257) Ω which is very close to 50 Ω pure resistive at 4.02 GHz. The results summary of the designed SCPA is presented in Table II.

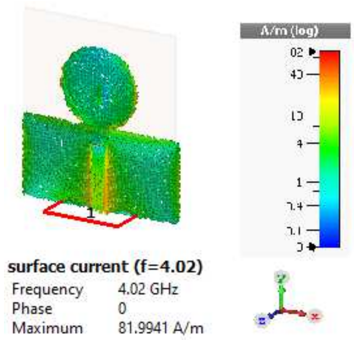
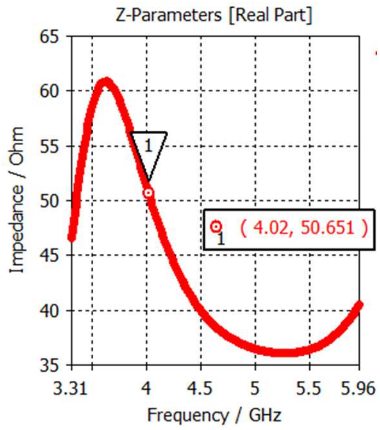
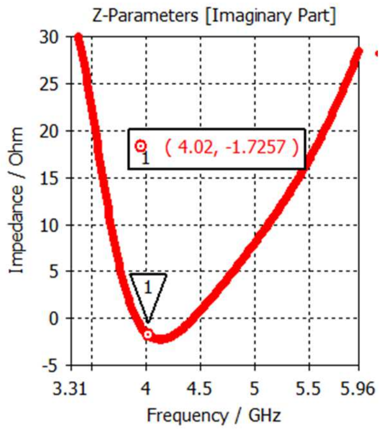


Fig. 7. Surface current at 4.02 GHz



(a) Real part



(b) Imaginary part

Fig. 8. Z-parameters of the SCPA.

TABLE II KEY FINDINGS OF THE SCPA.

Description	Weight (mm)
Lower cut off (dB)	3.3198
Upper cut off (dB)	5.9606
Bandwidth (GHz)	2.6408
Resonant frequency	4.02
Return loss (dB)	-34.749
VSWR	1.0373
Gain(dB) at 4.02 GHz	2.636
Directivity (dBi) at 4.02 GHz	2.976
Average radiation efficiency (%)	94
Impedance (Z) at 4.02 GHz	50.651-j1.7257

The following Table III presents a comparative picture of our designed H-shaped slotted circular patch Sub-6 GHz antenna with some recently published Sub-6 GHz antennas. The thickness of our antenna low (0.79 mm) and we have chosen Rogers RT 5880 due to its low loss property. Our proposed SCPA shows comparatively standard gain with a single wide band which covers all n77, n78 and n79 bands.

TABLE III COMPARISON.

Parameter	Ref. Number				Our work
	[12]	[13]	[14]	[15]	
Size (L×W×h) mm^3	30× 24× 1.5	55× 30× 1.6	35×33 ×0.76	30.2 ×36.4 ×1.6	34×30 ×0.79

Substrate material	FR4	FR4	Rogers Duroid RO3003	FR4	Rogers RT 5880
Operating Frequency Range (GHz)	3.15-5.61	2.26-5.50	2.48 - 2.55, 4.23-5.42	3.43-3.80	3.3198-5.9606
Centre frequency	4.80	3.24	≈ 2.5, 4.5	3.5	4.02
Reflection coefficient (dB)	-41	≈-38	-25, -22	-30.77	-34.749
Gain (dB) at centre frequency	≈2.36	≈1	5, 5.5	5	2.636
BW (GHz)	2.46	3.24	1.07, 1.19	0.37	2.6408
VSWR	<2	-	-	1.05	1.0373
Average Efficiency (%)	67.22	-	≈ 93.3	95	94

IV. CONCLUSION

A compact H-shaped slotted circular patch antenna (SCPA) for Sub-6 GHz has been designed and observed in this work. The designed SCPA consists of a H-shaped slotted circular metallic patch, a low loss Roger RT 5880 dielectric substrate, a modified ground plane with a circular slot and a feed line. The antenna shows very good gain and directivity over the large operating band. It covers WLAN, n77 (f= 3700 MHz, 3300 – 4200 MHz, most European and Asian countries), n78 (f=3500MHz, 3300 – 3800 MHz, USA) and n79 (4700MHz, 4400 – 5000, China, Hong Kong, Japan, Russia). The average radiation efficiency is very high (94%). Thus, the designed H-shaped SCPA could be deployed in the Sub-6 GHz applications.

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