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Slotted Stepped Patch Antenna for Ka Band Applications

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Abstract

The need for efficient antennas for satellite communication is increasing day by day. This paper presents the design analysis of two slotted patch antennas operating in the Ka band. The two antennas were designed using an FR-4 epoxy substrate having dielectric permittivity 4.4. The first design is a slotted patch antenna operating at 26.76 GHz and 36 GHz having gain 4.19 dB and 6.60 dB. The second antenna is an enhanced version of the first antenna by introducing steps and optimizing the dimension of the slot. With the enhancement in the antenna design, the antenna could provide a gain of 4.98 dB and 8.55 dB at 27.03 GHz and 37.09 GHz frequencies respectively. Enhancement of results is observed, covering the wideband frequencies within the Ka-band.

***Keywords—Wideband, Ka band, satellite communication, mobile communication*.**

1. Introduction

The significant need for satellite communication is increasing day by day. Ka band is considered as an efficient band within the electromagnetic spectrum because of its characteristics such as high data transmission and enhanced connectivity in remote locations for efficient antennas operating at various frequency bands to enhance the communication systems efficiency and data transmission rates [1]. Ka band in wireless communication plays a major role in communication applications like satellite communication and mobile communication systems. The Ka band frequency extends from 26.5 GHz to 40 GHz. Ka band has many applications in the area of communication, spacecraft, radars, vehicle speed detection, aircraft, drone, mobile, and satellite communication systems [2].

The major component of every wireless communication system is the antennas. Antennas can be wire antenna, reflector antenna, lens antenna, planar antennas, dielectric antennas, and so on [3 - 5]. Out of the different types of antennas, planar antennas have many advantages such as low cost, lightweight, ease of fabrication and flexibility to be integrated with the PCB board [6]. The commonly used type of planar antenna is the Microstrip Patch Antenna (MPA). Hence, MPAs became an attractive choice for researchers for use in wireless communication. Jeong-Wook Kim et al. analyzed the signal feed Ku/Ka dual band shared aperture planner antenna array design he used a method where he sequentially rotated the array antenna and got a gain of the antenna design as 15.6 dBi for ka band and 13.7 dBi for Ku band fabricated and compared with the simulated results got good agreement [7]. Zixi Wing et al. advocated the design by creating the novel wideband monopulse array antenna design for Ka band application. The authors performed a comparison of the antenna design and the modification for enhancement in the total efficiency of the fabricated design and got a good agreement with the simulated results [8]. M Kamesh et al. discussed the antenna design of a reconfigurable Microstrip patch antenna and did a comparative analysis for 5G communication for Ka band [9]. Akash Rawat et al. advocated the antenna design for the wide band and gained enhancement from 8.28 dBi to 12.2 dBi by considering the total operating Band [10].

Ming -An Chung et al. discussed the antenna for Ka band and introduced the slot. The antenna was developed by using the CMOS technology process and got satisfactory results [11]. V Nagaraju et al. presented the antenna design with five band MPA of square shape with slot and got satisfactory results [12]. Jian Ren et al. advocated the antenna design for Ka band and Ku band where he proposed dual-band shared aperture antenna array technology with FSS technology between Ku and Ka band and found a reduction of blockage between both bands. The simulated and fabricated antenna arrays are in good agreement with each other. [13]. Showrajit Saha et al. advocate the antenna design with a modified D-shaped MPA with two slots got efficient results after doing parametric analysis [14]. Touko et al. discussed the U slotted wideband MPA for Ka band and got satisfactory results S_{11} as -22.31 dB and gain as 6.08 dBi suitable for 5G communication [15]. Ribhu et al. discussed the mathematical analysis for the resonant frequency of the patch for 60 GHz frequency useful for applications like WLAN and Wi-Fi [16]. Ribhu et al. advocated the plano concave patch antenna design with substrate material as RT Duriod is simulated and got satisfactory results that can be utilized for applications like 5G communications[17]. T.S.S. Apoova et al. discussed high gain dual band antenna design for 5G communication operating at 28/38 GHz improved performance of results observed after doing structure changes in the design [18].

The work presented in this paper discusses a slotted step patch antenna for Ka band applications. The details about the design, optimization, and analysis of the slotted multiband antenna starting from a simple patch antenna is presented in this paper.

2. Antenna design

The antenna is designed using FR-4 epoxy, having a dielectric constant of 4.4, loss tangent of 0.02 with substrate height of 1.6 mm. The design is initiated from a rectangular microstrip patch antenna (RMPA).

The first design is by adding a slot at the center point of RMPA, where the electric field concentration is negligible. The second design is by adding a slot onto the stepped RMPA in the same location. For both antenna designs, parametric analysis is carried out to optimize the dimension of the slot. All simulation of designs is done using the High Frequency Simulation Software (HFSS) in Ansys Electronics Suite 2023. The details about the antenna designs are discussed in the next subsections.

A. Slotted Rectangular Microstrip Patch Antenna (S-RMPA)

Rectangular slot is introduced to the standard RMPA to increase the efficiency of the antenna. The final design obtained is the Slotted Rectangular Microstrip Patch Antenna (S-RMPA) which is shown in Figure 1.

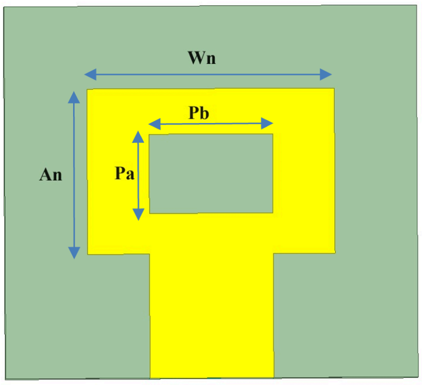


Figure 1: Slotted Rectangular Microstrip Patch Antenna

The dimensions of the designed S-RMPA antenna is 4 mm x 6 mm and the dimensions of the feed line is 3 mm x 3 mm. The dimension of the substrate is 9 mm x 10 mm x 1.6 mm. The dimensions of the patch are optimized by running a parametric analysis using the simulation software. In this antenna design, the optimized dimension of the slot is 1.91 mm x 3 mm. The various optimized design parameters used in the design of S-RMPA are shown in Table I.

Table I: Design parameters for S-RMPA

Design Parameters	**Value(mm)**
Patch length (An)	4
Patch width (Wn)	6
Slot width (Pb)	1.91
Slot length (Pa)	3

B. Slotted Stepped Rectangular Microstrip Patch Antenna (SS-RMPA)

A rectangular slot with dimensions 0.75 mm x 3 mm and one step to the patch with dimensions 0.5 mm x 4.2 mm is introduced into the S-RMPA design. The final design obtained is a Slotted Stepped Rectangular Microstrip Patch Antenna (SS-RMPA) which is shown in Figure 2. The step size and slot dimension are optimized based on parametric analysis done using the simulation software. The optimized design parameters of the SS-RMPA are mentioned below in Table II.

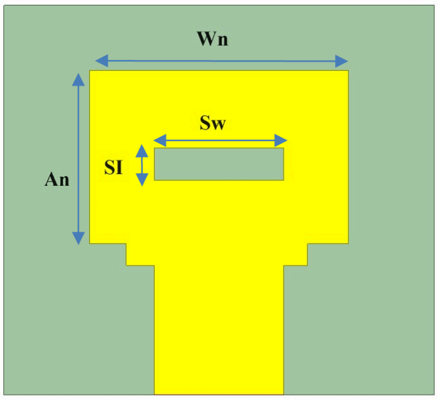


Figure 2: Slotted Stepped Rectangular Microstrip Patch Antenna

Table II: Design parameters for Antenna SS-RMPA

Design parameters	**Values (mm)**
Patch length (An)	4
Patch width (Wn)	6
Slot width (Sw)	0.75
Slot length (Sl)	3

3. Results and Analysis

The optimized antennas are analyzed using the simulation software Ansys Electronics Suite. The S-RMPA is found to operate in two frequencies, 26.76

GHz and 36 GHz. The return loss characteristics of the antenna is shown in Figure 3.

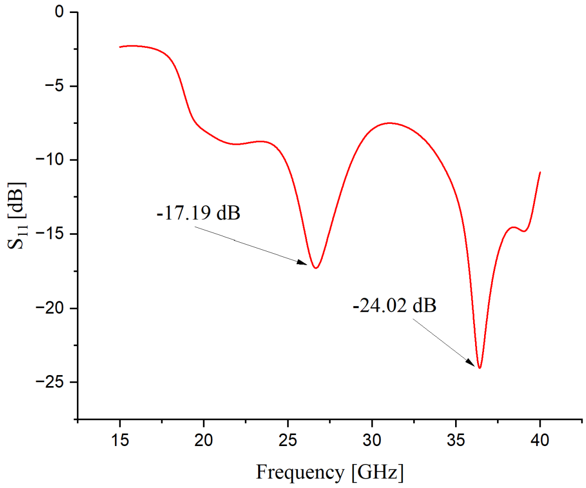
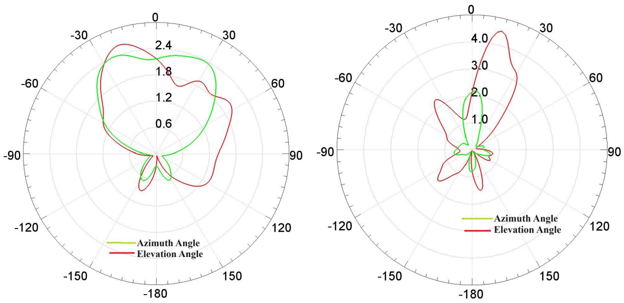


Figure 3: Return loss of S-RMPA

The performance of the antenna is analyzed for the two operating frequency bands and found that the first band at 26.76 GHz has a bandwidth of 3.97 GHz and a gain of 4.19 dB. The second frequency at 36 GHz has a wide operational band of 5.88 GHz with a higher gain of 6.6 dB. The radiation pattern at the operational frequencies is shown in Figure 4.



(a) (b)

Figure 4: Radiation pattern of S-RMPA at (a) 26.76 GHz (b) 36 GHz

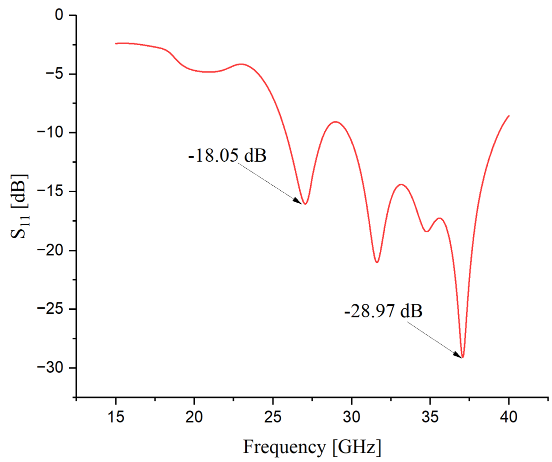
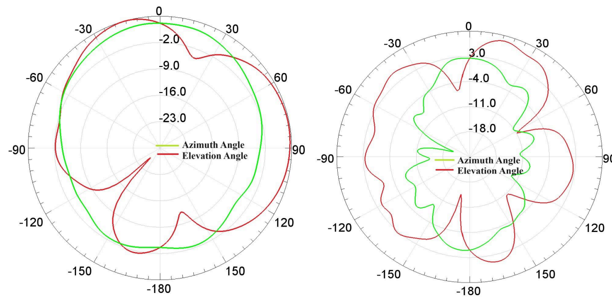


Figure 5: Return loss of SS-RMPA

In a similar way, the second antenna, SS-RMPA, is analyzed using the same software. The return loss characteristics of SS-RMPA is shown in Figure 5. The antenna is dual band, operating at 27.03 GHz and 37.09 GHz. The radiation pattern and bandwidth is analyzed in the same way. The bandwidth at the first frequency, 27.03 GHz, is 2.45 GHz, whereas the second at 37.09 GHz is a wide band of 9.18 GHz. The observed gain at 27.03 GHz is 4.98 dB whereas at 37.09 GHz is 8.55 dB.



(a) (b)

Figure 6: Radiation pattern of S-RMPA at (a) 27.03 GHz (b) 37.09 GHz

The detailed comparison of the two antennas, S-RMPA and SS-RMPA is shown in Table III. From the results, it is observed that for both the S-RMPA and SS-RMPA, the second operating frequency gives a high gain with a wider bandwidth.

Table III: Comparison of results of the S-RMPA and SS-RMPA

Design	Operating frequency (GHz)	S11 (dB)	Bandwidth (GHz)	Gain (dB)
S-RMPA	26.76	-17.19	3.979	4.19
	36	-24.02	5.8808	6.6
SS-RMPA	27.03	-18.05	2.4525	4.98
	37.09	-28.97	9.1842	8.55
Ref [15]	35GHz	-22.31	3	7.61

On comparing the two designed antennas and ref [15], SS-RMPA provided better characteristics in terms of return loss, bandwidth, and gain compared to S-RMPA. The designed two antennas can be used for different satellite and mobile communication-based applications whose operating frequencies are within the Ka band.

4. Conclusion

The design of two antennas operating in the Ka band is presented in this work. The designs are S-RMPA and SS-RMPA simulated and analyzed using Ansys Electronics Suite in FR4 Epoxy substrate. For S-RMPA, operating at frequencies 26.72 GHz and 36 GHz with S_{11} is -17.19 dB and -24.02 dB, a gain of 4.19 dB and 6.6 dB is obtained. For SS-RMPA, operating at frequencies 27.03 GHz and 37.09 GHz, and S_{11} of -18.05dB and -28.97 dB and with a peak gain of 4.98 dB and 8.55 dB respectively is achieved. Improvement in the antenna performance of SS-RMPA design makes it considerable for Ka band applications including satellite and mobile communications.

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