COAXIAL-FEED MULTI-BAND PATCH ANTENNA

Dr. Leelavathi H P[1], Dr. Imran Khan[2], Dr. Raveendra K[3], Dr. Nataraj Urs H.D[4*], Priyadarshini M H[5], Sathish Kumar B G[6]

[1]Professor, Dept. of Electronics & Communication Engineering, Global Academy of Technology Bangalore, India.

[2,3]Associate Professor, Dept. of Electronics & Communication Engineering, Government Engineering College Chamarajanagar, India.

[4]Associate Professor, School of Electronics & Communication Engineering, REVA University, Bangalore, India.

[5,6]Student, Dept. of Electronics & Communication Engineering, Government Engineering College Ramanagara, India.

***Corresponding Author:** natarajurs.hd@reva.edu.in

Abstract—This paper presents the design and analysis of a multiband MSP antenna with coaxial feeding, multiband achieved through strategically incorporating slots on the patch surface. The presented antenna operates efficiently across multiple frequency bands, making it compatible for various wireless communication applications. Introducing specific slot geometries alters the antenna's resonance characteristics, enabling it to support multiple frequency ranges while maintaining a compact form factor. The design process involves optimizing slot dimensions and placements to enhance bandwidth, improve gain, and achieve optimal impedance matching across the desired frequency bands. Simulation results demonstrate the antenna's performance, showcasing its capability for multiband operation, low return loss, and stable radiation patterns. This approach offers a practical solution for contemporary communication systems that require compact, cost-effective, and multi-functional antennas.

Keywords—coaxial feeding, multiband, MSP, slots.

1. INTRODUCTION

The demand for compact, efficient, and versatile antennas is ever-increasing in modern wireless communication systems. Microstrip patch (MSP) antennas have emerged as a popular choice due to their low profile, lightweight, and ease of fabrication[1]. This study presents the design and simulation of an MSP antenna utilizing the Rogers RT duroid 5880 substrate, renowned for its low dielectric constant and low loss tangent, which makes it ideal for high-frequency applications[2]. To improve the effectiveness of the MSP antenna and achieve multiband frequencies, the patch plane is integrated with slots. Slotting techniques are employed to create additional resonant paths allowing the antenna to operate at multiple frequency bands. This functionality offers significant advantages for applications that necessitate simultaneous support for diverse frequency ranges[3-7], such as modern communication devices that need to support various standards and protocols simultaneously. The design process involves meticulous selection of the antenna geometry, including the length, width, and thickness of the patch and the substrate. The positioning and geomentry of the slots are also optimized to achieve multiband performance. CST Simulation tool is utilized to analyze the antenna's performance, including return loss, radiation pattern, and gain across the targeted frequency bands[8]. This paper provides the design methodology, simulation results, and analysis of the MSP antenna with slots on its patch. The objective is to demonstrate the feasibility and effectiveness of using the Rogers RT 5880 substrate and slotting techniques to achieve multiband frequencies, thereby contributing to the advancement of MSP antenna technology for modern wireless communication systems.

This paper details a systematic approach to designing a multiband MSPA using the Rogers RT 5880 substrate. The design process is divided into 4 stages, starting with a simple rectangular patch and incrementally introducing slots on the patch to achieve the desired multiband frequencies. Coaxial feeding is a commonly employed technique for feeding MSP antennas. This technique involves connecting the inner conductor of a coaxial cable to the radiating patch and the outer conductor to the ground plane[9].

2. ANTENNA DESIGN

2.1 STAGE 1: Rectangular Patch Antenna

The initial design values for the rectangular-shaped antenna patch for the frequency of 6GHz were determined utilizing the formulas outlined in the Table I below [10]. And to determining the radius of both inner and outer cable of the coaxial cable the CST software impedance calculator is utilized and position of coaxial feed is given at the center of the patch.

TABLE I. FORMULAS FOR THE DETERMINATION OF DIMENSION ANTENNA'S PATCH

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Width of the patch:	**Length of the patch:**
$W = \frac{c}{2f\sqrt{\frac{\varepsilon_{r+1}}{2}}}$	$L = \frac{c}{2f\sqrt{\varepsilon_{reff}}} - 2\Delta L$
$\Delta L = 0.412h \frac{(\varepsilon_{reff}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{w}{h}+0.8)}$ $\varepsilon_{reff} = \varepsilon_{reff} \frac{\varepsilon_{r+1}}{2}+\frac{\varepsilon_{r-1}}{2}(\frac{1}{\sqrt{1+12h/w}})$	

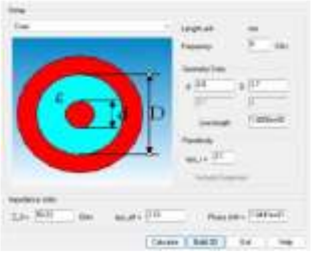


Fig.1. CST impedance calculator

TABLE II. DESIGN VALUES FOR PATCH ANTENNA IN MM

Ground	W1XL1XH1	30 x 40x0.035
Substrate	W1XL1XH1	30 x 40 x 0.8
Patch	PwxPL	16.3 x 19.7
Outer cable Radius	R1(d/2)	0.4
Inner cable Radius	R2(D/2)	1.35

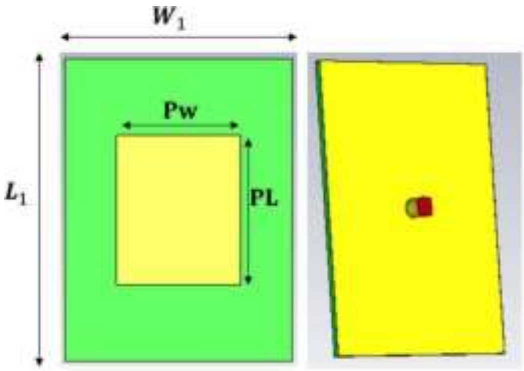


Fig .2. Design of rectangular patch antenna at stage 1

After the design and simulation of the antenna in CST, results indicate that, for the Rogers RT 5880 Substrate the following resonant frequencies and their corresponding S_{11}values were recorded at 9.911 GHz with S_{11}= -11.44 dB, 11.745 GHz with S_{11}= -19.12 dB, 15.82 GHz with S_{11}= -6.86 dB, and 19.56 GHz with S_{11} = -18.89 dB as shown in Fig. 3, there is a peak at 15.82 GHz however, the S_{11} value at this peak is not up to standards. This suggests that while the frequency is resonant, the antenna's performance at this frequency is suboptimal. The next design stage will involve adding slots to the patch to address this issue. These adjustments aim to shift the resonance and bring the S_{11} value below -10 dB, thus improving the antenna's efficiency and achieving optimal multiband performance.

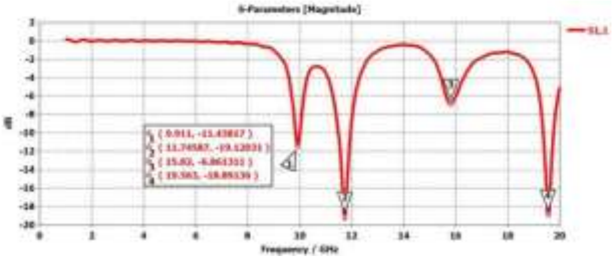


Fig. 3. S_{11} parameter for the simple rectangular patch

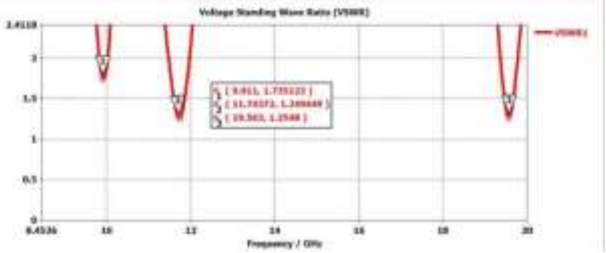


Fig.4. VSWR

TABLE III. PARAMETERS OF ANTENNA AT STAGE 1

Frequencies (GHz)	S_{11}	VSWR	Gain (dBi)	%ɳ	Directivity (dBi)	Bandwidth (MHz)
9.911	**-11.4**	**1.73**	**7.45**	**91.26**	**7.85**	**169**
11.745	**-20.1**	**1.24**	**8.32**	**96.12**	**8.500**	**462**
19.563	**-18.8**	**1.25**	**10.25**	**94.08**	**10.52**	**387**

The simulation results presented in Table III reveal that the antenna resonates at 9.911 GHz, 11.745 GHz, and 19.563 GHz, with corresponding gains of 7.45 dBi, 8.32 dBi, and 10.25 dBi, respectively. These gains indicate a progressive improvement in directional energy concentration, making the antenna suitable for high-frequency applications like radar systems and point-to-point communication. The antenna's efficiency is exceptional across all frequencies, with minimal power losses. At 9.911 GHz, the efficiency is 91.26%, which increases to 96.12% at 11.745 GHz, demonstrating excellent power conversion. The efficiency remains high at 94.08% at 19.563 GHz, ensuring effective radiation of input power.The directivity aligns closely with the gain at each frequency, indicating well-focused radiation patterns. The directivity values are 7.45 dBi, 8.5 dBi, and 10.52 dBi at 9.911 GHz, 11.745 GHz, and 19.563 GHz, respectively, highlighting the antenna's ability to radiate energy in a narrow direction.The bandwidth performance varies across frequencies, with a moderate 169 MHz at 9.911 GHz, a significant increase to 462 MHz at 11.745 GHz, and a relatively wide 387 MHz at 19.563 GHz. This enable fast data transfer and enables operation over multiple frequency channels, making it suitable for satellite communication or high-frequency radar.In the next design stage, additional slots will be introduced to the patch to further optimize these parameters, potentially introducing new resonant frequencies and enhancing overall performance.

2.2 STAGE 2: L-SHAPED SLOT ON PATCH

In this stage, an L-shaped slot was introduced to the antenna's patch. This modification generated additional resonant frequency bands. The L-shaped slot effectively altered the current distribution and extended the patch's electrical path, enabling the antenna to support multiple frequency bands. This approach offers a simple yet efficient way to achieve multiband operation, enhancing the antenna's versatility for various wireless communication applications.

TABLE IV: SLOT DIMENSIONS

L-shaped slot's dimensions(mm)			
a-1.8	b-15.8	c-14	d-1.6

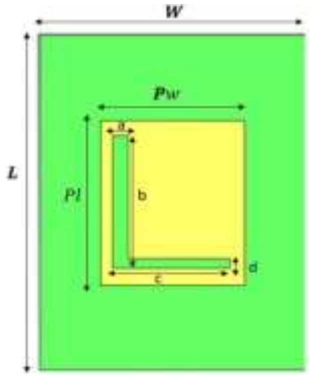


Fig .5. An L-shaped slot is created on the patch

In this design, after introducing an L-shaped slot, a total of nine frequency peaks are observed in the S_{11} plot, with six of them showing a return loss below -10 dB. This indicates significantly improved performance compared to the initial design, which had only three operating frequencies.

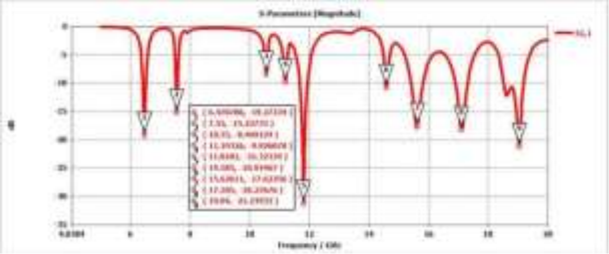


Fig. 6. S_{11} parameter (stage 2)

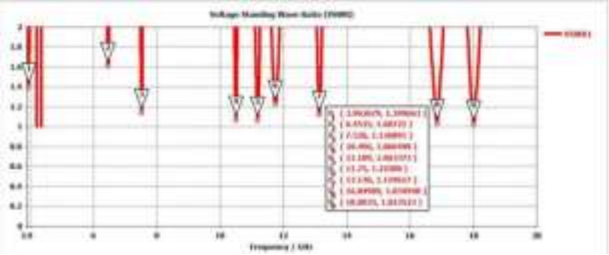


Fig .7. VSWR

TABLE V. PARAMETERS OF ANTENNA AT STAGE

Frequencies (GHz)	S_{11}	VSWR	Gain (dB)	%η	Directivity	Bandwidth (MHz)
6.470	-19.27	1.245	7.467	91.4	7.853	104
7.55	-15.22	1.435	4.913	82.4	5.735	58
11.810	-31.32	1.087	7.551	94.1	7.811	256
15.626	-17.62	1.291	6.624	94.2	6.882	398
17.105	-18.27	1.275	8.122	94.8	8.354	416
19.04	-21.23	1.190	8.037	92.3	8.385	671

Table V presents the antenna parameters the design exhibits six distinct resonant peaks, as illustrated in Figure 6, demonstrating excellent matching at various frequencies. Notably, the peaks at 6.470 GHz (-19.27 dB) and 11.810 GHz (-31.32 dB) showcase impressive results. The introduction of the L-shaped slot has enabled the antenna to achieve multiband performance across six different frequencies, boasting high gain, efficiency, and sufficient bandwidth. The antenna's features support versatile multiband operations. The design's compatibility with multiple frequencies is a significant advantage, particularly at higher frequencies like 15.626 GHz, 17.105 GHz, and 19.04 GHz, where the bandwidth is notably wide. This allows the antenna to handle a range of frequencies around these points. Future design stages will focus on incorporating additional slots of varying sizes to further enhance the antenna's performance, optimize key parameters, and study the effects of slots on its behavior

2.3 STAGE 3: ADDITION OF RECTANGULAR SLOT ALONGSIDE OF L-SHAPED SLOT

A rectangular slot has been added alongside the existing L-shaped slot. This combination of slots aims to optimize the antenna's impedance matching and bandwidth across the desired frequency bands. The careful design and placement of these slots play a vital role in achieving efficient multi-band functionality and the coaxial feeding position is the same as stage 1.

TABLE VI: SLOT DIMENSIONS

Rectangular slot dimensions(mm)	
e-1.6	f-14

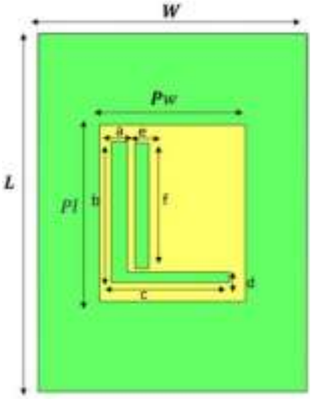


Fig .8. Addition of rectangular slot along side of L shaped slot

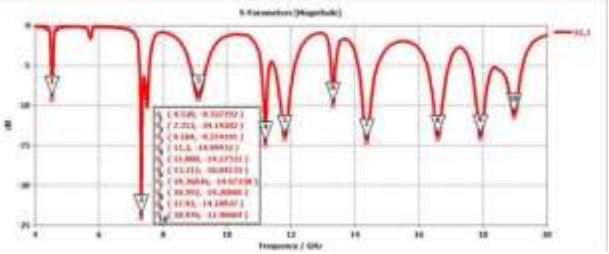


Fig .9. S_{11} of stage 3 design

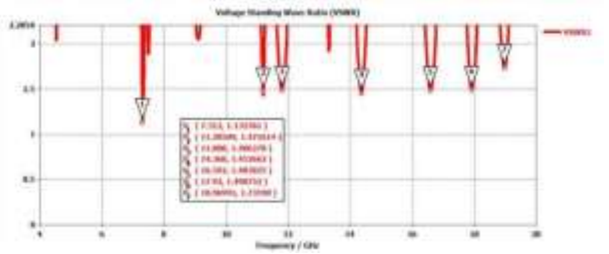


Fig .10. VSWR

TABLE VII. PARAMETERS OF ANTENNA AT STAGE 3

Frequencies (GHz)	S_{11}	VSWR	Gain (dB)	%η	Directivity	Bandwidth (MHz)
7.312	-24.14	1.13	4.173	70.72	5.677	72
11.2	-14.99	1.47	7.263	88.75	7.782	97
11.808	-14.17	1.48	7.282	93.95	7.555	259
14.368	-14.67	1.45	7.995	92.40	8.338	245
16.592	-14.2	1.48	7.478	94.34	7.731	273
17.96	-14.1	1.49	6.260	93.23	6.564	252
18.976	-11.46	1.73	7.505	92.40	7.848	168

The stage 3 antenna design operates at seven different frequency bands 7.312 GHz, 11.2 GHz, 11.808 GHz, 14.368 GHz, 16.592 GHz, 17.96 GHz, and 18.976 GHz as illustrated in Fig 9. At 7.312 GHz, the antenna shows a strong return loss (S_{11}) of -24.14 dB, with a gain of 4.173 dB and 70.72% efficiency. For the higher frequencies, such as 11.2 GHz and 11.808 GHz, the gain improves to around 7.26-7.28 dB, with efficiency reaching as high as 94%. The VSWR remains close to 1.5, indicating good impedance matching across most frequencies, figure 10. The bandwidth ranges from 72 to 273 MHz, showing that the antenna covers a broad spectrum, particularly at higher frequencies like 16.592 GHz and 11.808 GHz. The performance metrics indicate a well-balanced design, though there is room for further optimization, especially in the lower gain observed at 7.312 GHz. Comparing this design to its Stage 2 predecessor, which showcased substantial enhancements in antenna parameters, reveals limited improvements. The introduction of a rectangular slot alongside the existing L-shaped slot has not significantly boosted key performance metrics, despite expanding to seven operating frequency bands. This suggests the modified design may have introduced intricate resonances requiring further refinement. Future iterations should focus on optimizing slot geometry and positioning to strike a balance between resonant frequencies and overall antenna performance.

2.4 STAGE 4:- VARIATIONS IN THE DIMENSIONS OF SLOTS

In the final iteration of the MSP antenna, targeted design enhancements were integrated to boost performance. Leveraging the existing L-shaped and rectangular slots, the refinements concentrated on fine-tuning key parameters, including resonant frequencies, bandwidth, gain, and efficiency. Following an iterative optimization process, critical adjustments were made to the slot . To further refine the antenna's multiband characteristics, an innovative technique was employed. A slender divider, designed from the same material and thickness as the patch, was strategically positioned to bifurcate the slots into two distinct segments. This novel configuration enabled a more sophisticated current distribution, substantially enhancing the antenna's multiband functionality.

TABLE VIII: SLOT DIMENSIONS

Rectangular shaped separator dimensions(mm)	
h-4.8	g-1.6

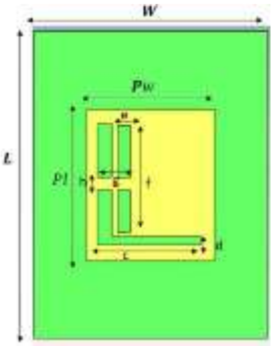


Fig .11. Separation of slots by adding small patch on pre existing slots

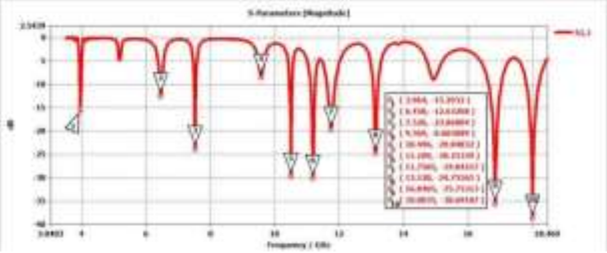


Fig .12.S_{11} of final stage design

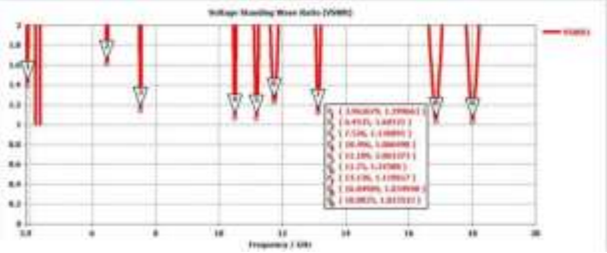
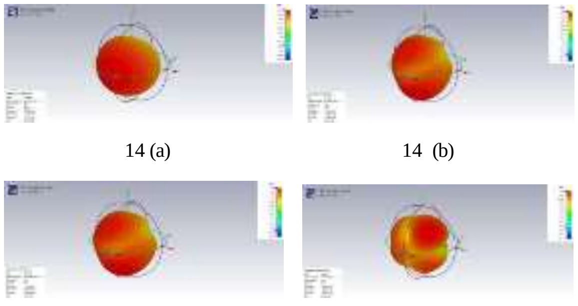


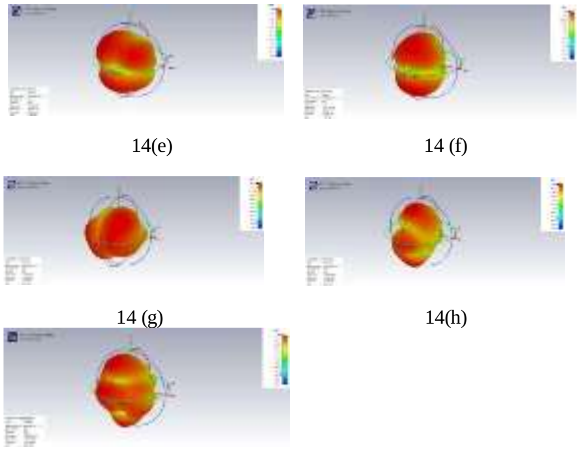
Fig .13.VSWR

Optimization efforts have yielded remarkable enhancements in the antenna's performance. The S_{11} parameter now showcases nine distinct resonant frequencies with acceptable return losses


14 (a) 14 (b)

14 (c) 14 (d)

Fig. 14. Gain results at different frequencies(a) 3.962, (b) 6.47, (c) 7.526, (d)10.496,

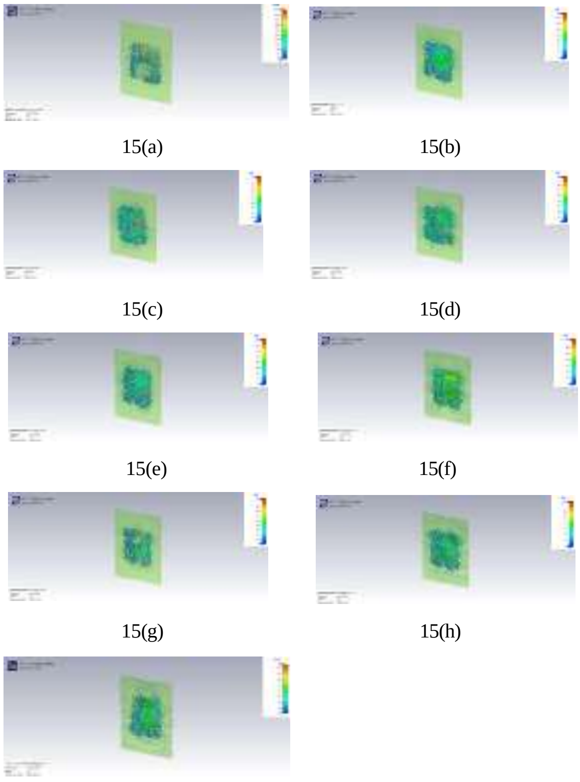


14(e) 14 (f)

14 (g) 14(h)

14 (i)

Fig. 14. Gain results at different frequencies(continued)(e) 11.189, (f) 11.752, (g) 13.128, (h) 16.848, (i) 18.003.



15(a) 15(b)

15(c) 15(d)

15(e) 15(f)

15(g) 15(h)

15(i)

Fig. 15. Surface current distributions at different frequencies(a) 3.962, (b) 6.47, (c) 7.526, (d)10.496, (e) 11.189, (f) 11.752, (g) 13.126, (h) 16.848, (i) 18.003,

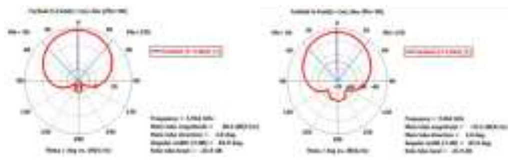


Fig. 16. Radiation patterns

Radiation pattern details for other frequencies are summarized in Tables IX and X."

TABLE IX. RADIATION PATTERN DETAILS OF E FIELD

Frequency (GHz)	Main lobe magnitude (dB (V\m)	Main lobe direction (deg)	Angular width(3dB) (deg)	Side lobe level (dB)
3.964	18.4	2.0	82.9	-21.9dB
6.458	19.3	39.0	50.6	-16.6
7.526	19.3	39.0	50.6	-16.6
10.496	15.9	55.0	49.4	-3.5
11.189	19.5	34.0	47.7	-2.1
11.175	19.6	34.0	47.6	-1.8
13.128	18.3	3.0	98.1	-12.2
16.848	22.4	58.0	35.4	-1.8
18.003	21.2	63.0	38.0	-1.0

TABLE IX. RADIATION PATTERN DETAILS OF H FIELD

Frequency (GHz)	Main lobe magnitude (dB (V\m))	Main lobe direction (deg)	Angular width(3db) (deg)	Side lobe level(dB)
3.964	-33.2	2.0	82.9	-21.9
6.458	-32.2	39.0	50.6	-16.6
7.526	-32.2	39.0	50.6	-16.6
10.496	-35.6	55.0	49.4	-3.5
11.189	-32.1	34.0	47.7	-2.1
11.175	-31.9	34.0	47.6	-1.8
13.128	-33.3	3.0	98.1	-12.2
16.848	-29.1	58.0	35.4	-1.8
18.003	-30.3	63.0	38.0	-1.0

At lower frequencies, the E-field shows a wide radiation pattern with a strong main lobe and low side lobes. The H-field is significantly weaker but follows the same general direction. At higher frequencies, the E-field becomes more focused, with narrower beams and stronger main lobes. However, side lobes become more prominent, especially at frequencies like 11.189 GHz, where side lobes are only slightly weaker than the main lobe

TABLE XI. PARAMETERS OF ANTENNA

Frequencies (GHz)	S_{11}	**VSWR**	**Gain (dB)**	**%η**	**Directivity**	**Bandwidth (MHz)**
3.964	-15.29	1.39	3.775	50.0	6.732	36
6.458	-12.63	1.60	5.490	81.4	6.380	65
7.526	-23.86	1.13	5.490	81.4	6.380	67
10.496	-29.84	1.06	6.670	81.1	7.579	84
11.189	-30.25	1.06	6.094	89.7	6.562	146
11.75	-19.84	1.22	7.191	93.4	7.484	256
13.128	-24.75	1.11	6.534	89.6	7.038	161
16.848	-35.75	1.03	7.841	93.9	8.111	395
18.003	-38.69	1.02	6.877	93.4	7.172	387

Table XI indicates that this MSP antenna operates across a wide range of frequencies, from 3.964 GHz to 18.003 GHz. At the lower frequencies, such as 3.964 GHz, the return loss is -15.29 dB, indicating moderate signal reflection, with a gain of 3.775 dB and 50% efficiency. As the frequency increases to 6.458 GHz and 7.526 GHz, the antenna shows better impedance matching (VSWR around 1.13 to 1.60), with higher gains of around 5.49 dB and efficiency improving to 81.4%. At higher frequencies, such as 10.496 GHz and 11.189 GHz, the S_{11} improves significantly (as low as -30.25 dB), with gains reaching up to 7.191 dB and efficiencies peaking at 93.4%. The bandwidth becomes much broader at frequencies like 16.848 GHz and 18.003 GHz, where the antenna offers very low reflection (S_{11} around -35 to -38 dB), excellent gain around 6.877 to 7.841 dB, and high efficiency (around 93.4% to 93.9%). These higher frequencies also provide large bandwidths, reaching up to 395 MHz and 387 MHz, making the antenna suitable for wideband applications at these frequencies.

2. COMPARATIVE STUDY

The MSP antenna design evolves through four stages, with a constant feed position. Stages 2 and 4 demonstrate enhanced performance merits, making them i for multiband usage. Our analysis reveals that Rogers RT/Duroid 5880 substrate is an excellent material choice for MSP antennas, offering superior performance in multiband configurations.

TABLE XII. NUMBER FREQUENCIES AT EACH STAGE

Stages	No of frequencies
1st stage	3
2nd stage	9
3rd stage	7
4th stage	9

3. CONCLUSION

This paper presents the design and simulation of a probe-fed multiband MSP antenna using CST Studio. The process of achieving multiband operation through slotting is demonstrated, highlighting its potential across a wide range of applications, including communication, biomedical imaging, satellite communication, IoT, and modern warfare. The performance parameters of various antenna designs were meticulously analyzed and compared to develop a low-cost, simple-structure antenna with superior performance. Through careful selection and optimization of substrate materials and dimensions, enhanced impedance matching and radiation efficiency were achieved. The simulated results provide valuable insights into the most effective configurations, paving the way for practical implementations in diverse fields. This research emphasizes the significant role of microstrip patch antennas in advancing technology, offering a versatile, efficient, and cost-effective solution for modern communication and biomedical applications. The findings underscore the importance of continued innovation in antenna design to meet the growing demands of various industries.

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