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RESEARCH ARTICLE

Design and realization of dual band stacked antenna via three-dimensional printing technology

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Abstract

With the ever-increasing demands for high-performance wireless communication systems, the need of fast and low-cost realization of antenna stages had also become more crucial for wireless communication industry. Herein, design and low-cost realization of a three-dimensional (3D) printed dual band Stacked Microstrip Patch Array (SMPA) antenna has been studied. A 3D electromagnetic-based simulation model of the proposed SMPA antenna has been created in CST Microwave Studio. The antenna achieves a simulated gain level of almost 8.3 dBi at 5.2 and 10.4 GHz frequencies. Then, the antenna design with optimally selected parameters has been prototyped via the use of 3D printing technology. The prototyped antenna has a measured gain level of 7.2 dBi at the operation frequencies. Furthermore, the experimental results of the prototyped antenna have been compared with the simulated results. From the compared results, it can be concluded that not only the proposed antenna design has achieved high-performance measures compared with counterpart designs in the literature but also it is possible to achieve an accurate, fast, and low-cost realization via the use of 3D printing technology.

KEYWORDS

3D printer, dual band, microstrip antenna, novel prototyping methods, stacked antenna

1 | INTRODUCTION

With the increase in the needs of wireless communications systems, design of antenna models with properties such as low cost, low profile, light-weight, compact, and broadband or multiresonant frequency has attracted increasing attention of many researchers.[1-4] For the last decades, many studies have been done on improving the performance of microstrip patch antennas such as capacitive compensation,[5,6] usage of reactive matching networks,[7] or thicker substrates.[8] However, each methods would either increase the cost of the design or might deteriorate the radiation pattern and cause a considerable amount of decrease in the radiation efficiency. Another technique for performance improvement of microstrip antennas is stacking.[9-17] It is possible to design an antenna with high gain and wide operation band by stacking a parasitic patch. The performance of the stacked design is based on the material (dielectric constant) and the distance of parasitic patch and the feeding patch, which would affect the gain and bandwidth of the antenna.

As mentioned, another important of antenna design is its realization cost and durability. One of the novel techniques for fast, cost efficient, and accurate prototyping of microwave antenna designs is three-dimensional (3D) printing technology. With the recent development in the 3D printing technology and decreases in its cost, this method has now become a commonly used technique in many research field for fast, low cost, and precise prototyping.[18] Thanks to unique features of 3D printers, manufacturing of antenna designs that were not feasible or would have a considerable amount of cost has become feasible and easy to prototype. Recently, one of the fields that extensively use 3D printed based manufacturing process, is microwave circuits. Prototyping of complex microwave designs such as reflectarray antennas,[19,20] realization of flexible antennas,[21,22] multilayered dielectric loaded antenna,[23] Quasi-Yagi antenna,[24] microstrip patch antenna,[25] prototyping of horn antennas for X band applications,[26] and dielectric loaded horn antenna designs.[27-29]

Herein, fast and low-cost realization of a 3D printed dual band Stacked Microstrip Patch Array (SMPA) antenna has been studied. For this mean, first, a 3D electromagnetic-based simulation model of the proposed antenna has been created in CST Microwave Studio. The effect of the geometrical design parameters of the proposed SMPA on the performance measures of the antenna

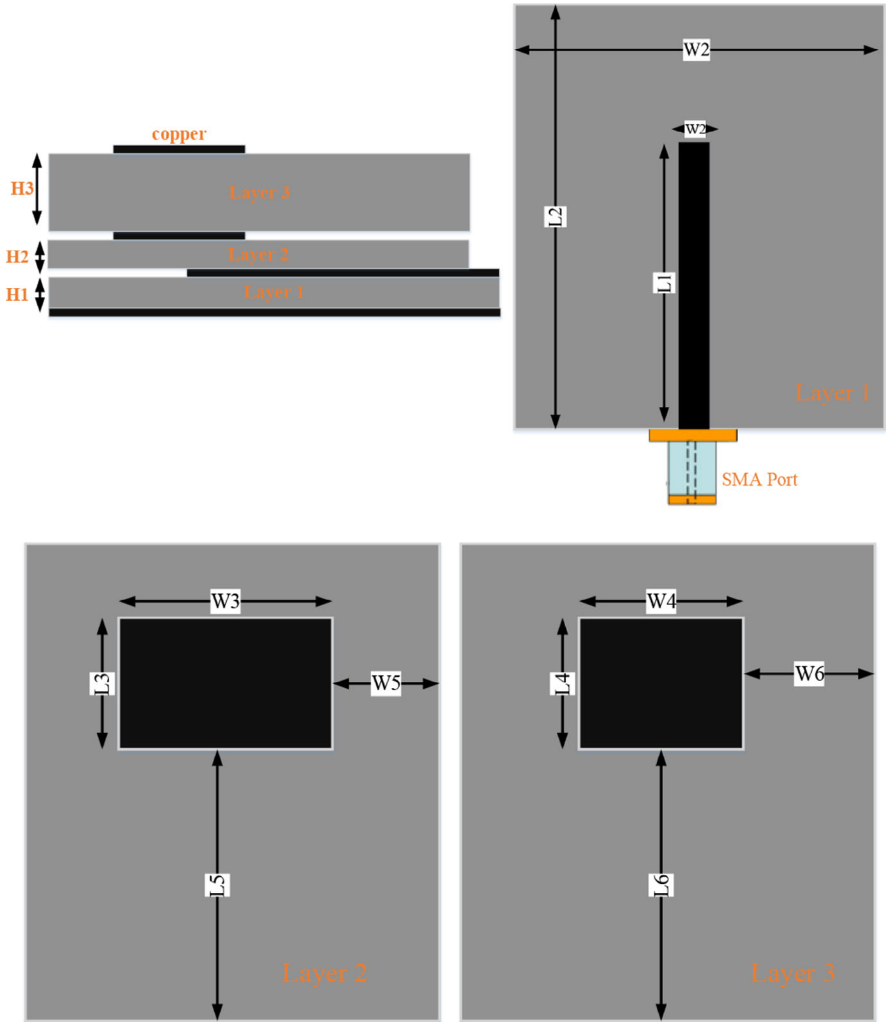

FIGURE 1 Design schematic of the Stacked Microstrip Patch Array antenna [Color figure can be viewed at wileyonlinelibrary.com]

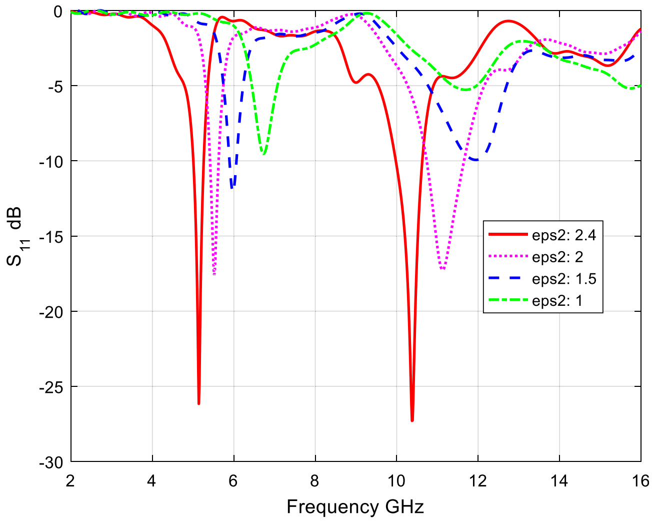

FIGURE 2 Parametric analysis of dielectric constant of secondary layer [Color figure can be viewed at wileyonlinelibrary.com]

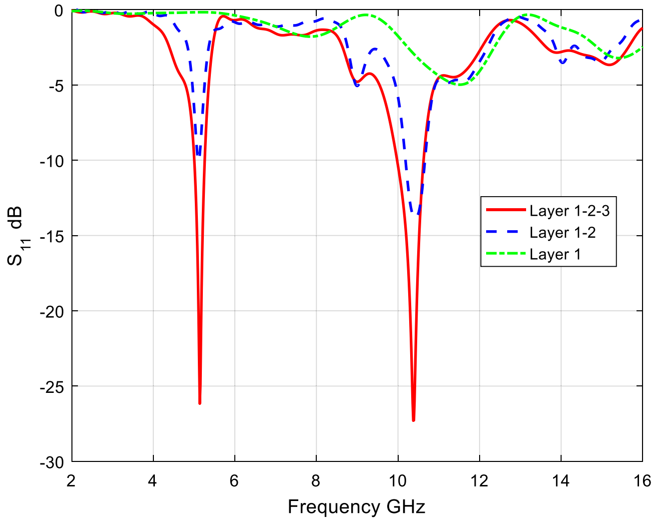

FIGURE 3 Parametric analysis of layer number [Color figure can be viewed at wileyonlinelibrary.com]

has been studied. Then an antenna design with optimally selected parameters has been prototyped via the use of 3D printing technology. The experimental results of the prototyped antenna have been compared with the simulated and counterpart design performance results in the literature. From the compared results, it can be concluded

TABLE 1 Parametric analysis of the proposed antenna design[a]

	S_{11} (dB)	Gain (dBi)
	5.2 GHz/10.4 GHz	5.2 GHz/10.4 GHz
Layer 1	−0.5/−3	−9.1/2.6
Layer 1–2	−9/−13	5.7/7.6
Layer 1–2–3	−27/−27	8/8.3
H3: 1 mm	−15/−14	5.9/6.4
H3: 2 mm	−22/−15.5	6.1/8
H3: 3 mm	−31/−15	6.25/8.1
H3: 4 mm	−25/−14.5	6.5/8.15
H3: 5 mm	−20/−13.5	6.9/8.2
H3: 6 mm	−18/−12.5	7.2/8.3
H3: 8 mm	−27/−27	8/8.3
ε_2: 1	0/−2	−5/2.7
ε_2: 1.5	−1/−3	−1/3.6
ε_2: 2	−4/−8	5/6.1
ε_2: 2.4	−27/−26	8/8.3
ε_3: 1	−10/−9	6.25/7.1
ε_3: 1.4	−15/−12	6.7/7.8
ε_3: 1.7	−27/−27	8/8.3
ε_3: 2.2	−7/−9	5.8/7.5

[a] All other design parameters are taken equal to the values given in Table 2.

TABLE 2 Design values of the Stacked Microstrip Patch Array antenna (lengths in millimeter)

L1	25	W1	2.4	H1	0.8
L2	45	W2	40	H2	0.5
L3	17.1	W3	19.7	H3	8
L4	16	W4	16.6	ε_1	2.5
L5	19.45	W5	9.85	ε_2	2.4
L6	19	W6	8	ε_3	1.7

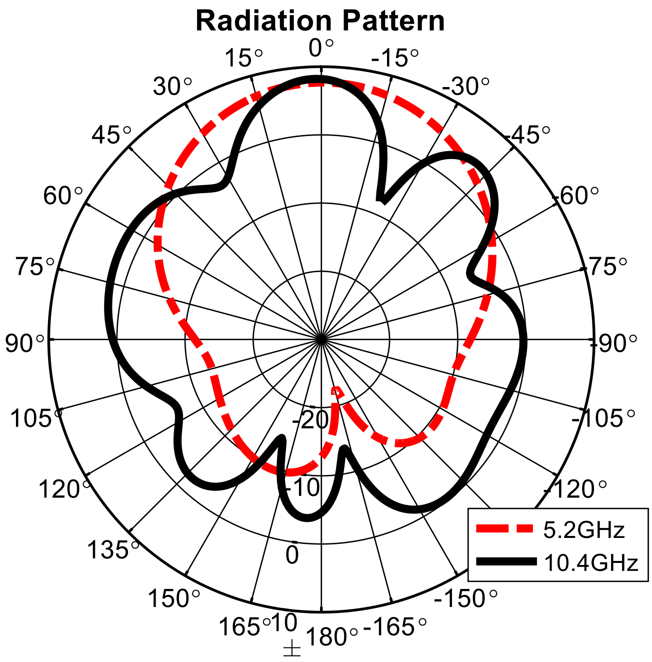

FIGURE 4 Simulated 3D radiation pattern of Stacked Microstrip Patch Array antenna at 5.2 and 10.4 GHz [Color figure can be viewed at wileyonlinelibrary.com]

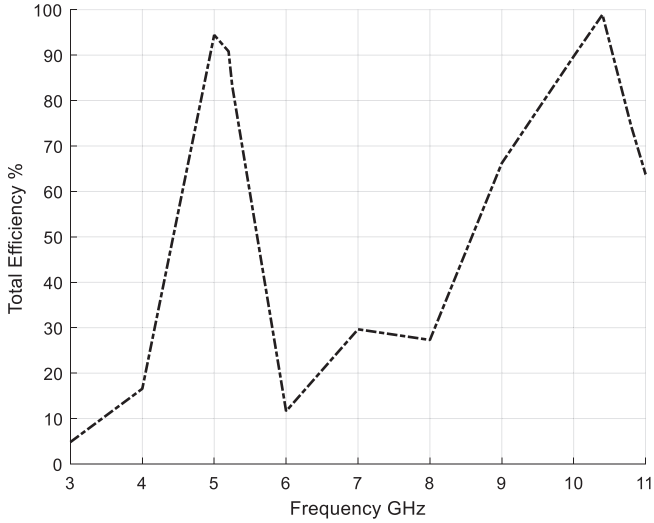

FIGURE 5 Simulated total efficiency on the Stacked Microstrip Patch Array [Color figure can be viewed at wileyonlinelibrary.com]

that not only the proposed antenna design has achieved high-performance measures compared with counterpart designs in the literature but also it is possible to achieve an accurate, fast, and low-cost realization via the use of 3D printing technology.

2 | SMP ANTENNA DESIGN

Impedance matching, radiation pattern, array design, and low manufacturing cost are the most important design aspects of the proposed SMPA antenna. In this section, design of a dual band SMPA antenna for applications on 5.2 and 10.4 GHz has been presented. The schematic view of the proposed antenna is given in Figure 1. The proposed SMPA antenna is made of 3 layers where first layer consists of a radiating element, second and third layers have parasitic patches, which are separated by dielectric layers. Here, it should be noted that the variation in the length of the radiation element would shift the resonant frequency, the gain, and the bandwidth of the design can be changed via the design parameters of the stacked arrays. The material that is used for dielectric layers are taken as polylactic acid (PLA), which has a variant dielectric constant of 1.24–2.72.[30] This variant dielectric constant value of PLA had been define by using equation (1) with a simple expression that calculates the dielectric constant value of a material with respect to the infill rate of the material.[25]

$$\varepsilon_r = -1.3x10^{-6}x^3 + 0.0374x + \frac{6.42}{x} + 0.217. \qquad (1)$$

Here x represents the infill rate of the material in percentage.

A parametric analysis of the proposed antenna with respect to some of its design parameters are given in Figures 2 and 3 and Table 1. As it can be seen from Figure 2, with the variation of dielectric constant of secondary layer, it is possible to shift the operation frequency between 5.2 to 6 GHz and 10.4 to 12 GHz in lower and upper operation band, respectively. The effect of layer number over the performance measures of the SMPA has been given in Figure 3. As it can be observed with addition of secondary layer the resonant frequency of the SMPA is adjust to the requested band. Furthermore, with the placement of third layer, the

TABLE 3 Simulated main lob radiation performance of the Stacked Microstrip Patch Array antenna at (ϕ, θ) = (0^0, 0^0)

Frequency (GHz)	Gain (dB)	3 dB angular width	Side lobe level (dB)
5.2	8	64.2°	−17.1
5.25	7.69	63.8°	−16.9
10	7.87	29.4°	−4.2
10.4	8.3	26.2°	−4.5

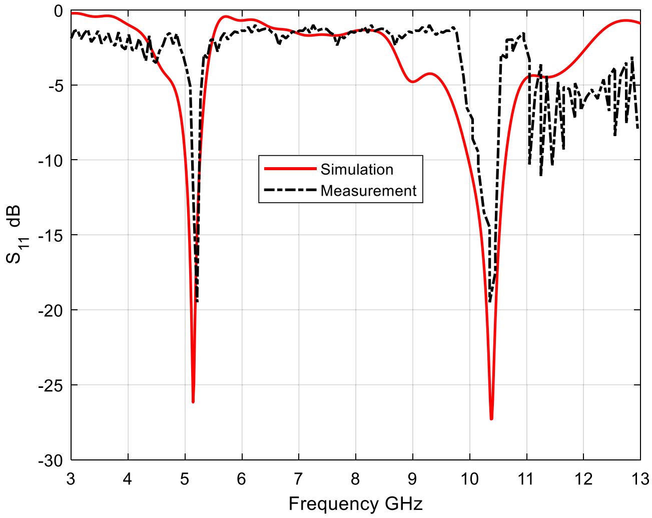

FIGURE 7 Simulated and measured return loss characteristic of Stacked Microstrip Patch Array Antenna [Color figure can be viewed at wileyonlinelibrary.com]

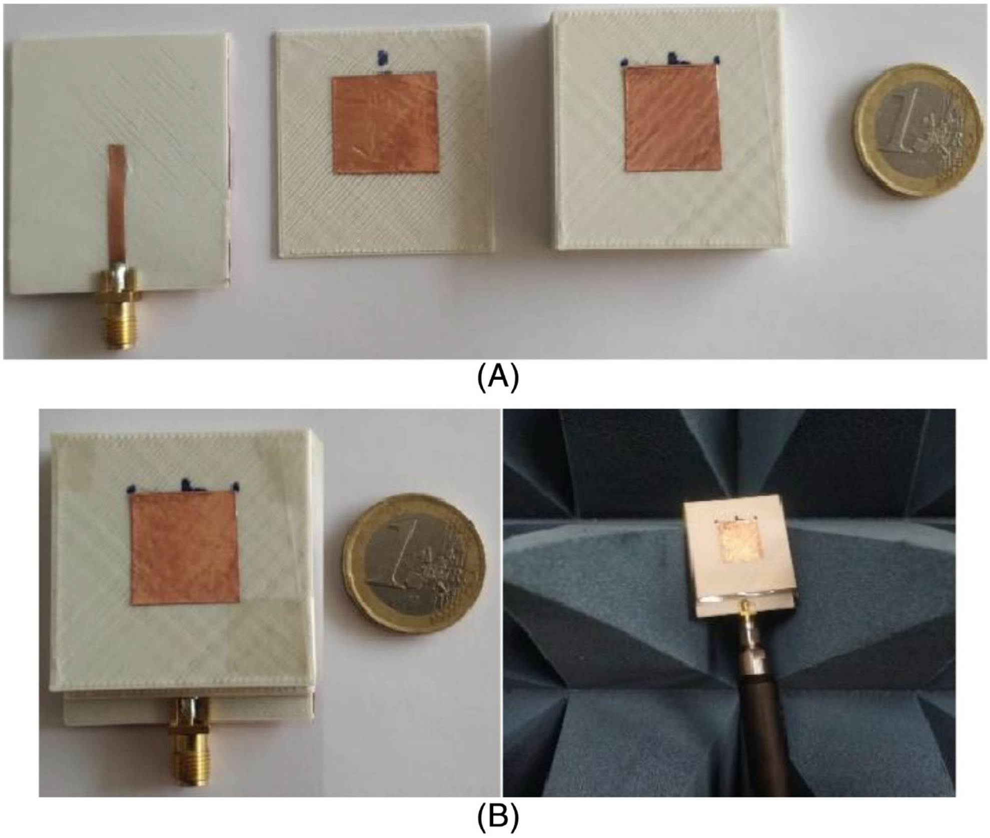

FIGURE 6 (A) Top view of each layer, (B) view of the ready to measure 3D printed Stacked Microstrip Patch Array antenna [Color figure can be viewed at wileyonlinelibrary.com]

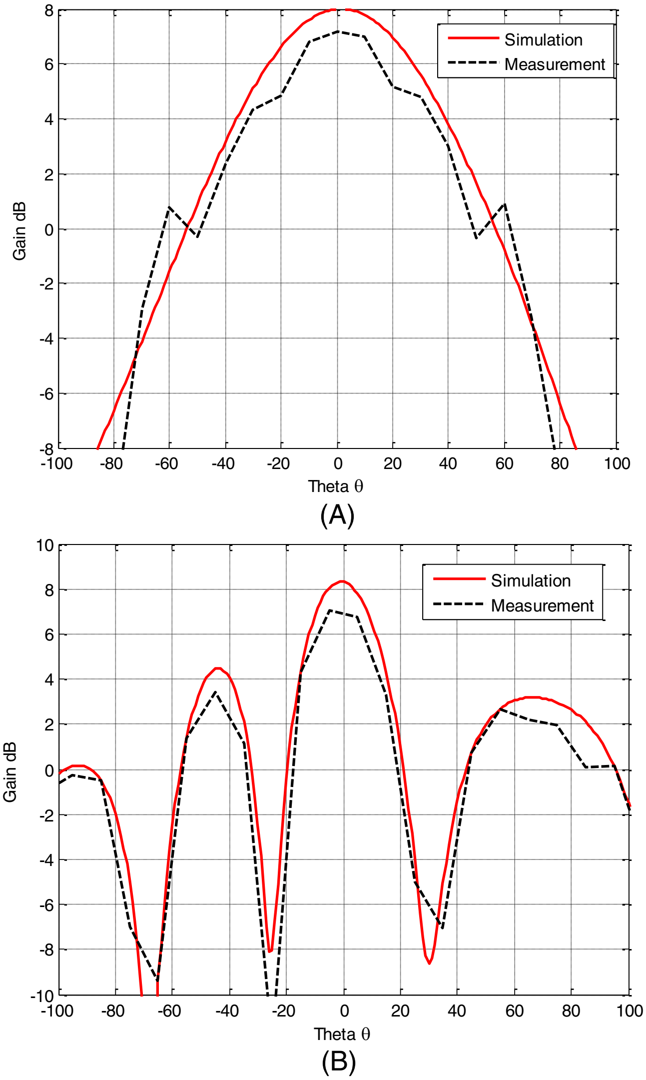

FIGURE 8 Measured and simulation radiation patterns of the Stacked Microstrip Patch Array Antenna @ (A) 5.2 and (B) 10.4 GHz [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 4 Simulated and measured performance characteristics of Stacked Microstrip Patch Array antenna (dB)

Measurement		Simulation	
f	Gain/S_{11}	f	Gain/S_{11}
5.2 GHz	7.2/−18	5.2 GHz	8/−26
10.4 GHz	7.1/−19	10.4 GHz	8.3/−27

return loss and gain characteristic of the antenna is also improved. A more detailed parametric analysis of the SMPA is given in Table 1.

With respect to the parametric analysis, in Table 2, the optimally selected design values of the SMPA, for operation frequencies of 5.2 and 10.4 GHz, are given. The simulated 3D radiation pattern and total efficiency of the SMPA are also given in Figures 4 and 5 and Table 3. As it can be seen, the antenna achieves a simulated gain value of almost 8 dBi over the request operation frequencies. In the next section of the work, the optimally selected design values had been used for prototyping of SMPA using 3D printing technology.

3 | 3D FABRICATION AND EXPERIMENTAL RESULTS OF SMP ANTENNA

In this section, 3D printing technology[31] has been used for prototyping of the 3D modeled SMPA antenna via the comparison of the simulated and experimental results. In Figure 6, the 3D printed SMPA antenna has been presented.

A Network Analyzer with a measurement bandwidth of 9 kHz to 13.5 GHz, and 2 identical antennas “Rohde—Schwarz RS Zvl13 and LB8180 0.8 to 18 GHz” (https://www.rohde-schwarz.com/sg/product/zvl-productstartpage_63493-9014.html)[32] have been used for measurement of the 3D printed SMPA antenna. The measured performance characteristics of the 3D printed antenna are given in Figures 7 and 8 and Table 4. As it can be seen from both simulated and measured results, it is possible to realize an antenna design with high-performance measures using 3D printed stacked layers.

Furthermore, performance comparison of the proposed SMPA antenna with counterpart design in the literature[16,33-38] has been presented in Table 5. As it can be seen from the table, the SMPA antenna design not only achieves better radiation performance but also has smaller size to its counterpart design in the literature.

TABLE 5 Comparison of the literature

References	Frequency (GHz)	S_{11} (dB)	Gain (dBi)	Size (mm)	Material
16	2.4	−19	11.3	142 × 168 × 7.3	ABS $\varepsilon_r = 2.5$
33	1.57	−15	6.5	87 × 95.2 × 24.8	FR4
34	2.4	−13	11	227 × 164 × 22	
35	5.2	−20	7	42 × 55 × 4.8	
36	5.2	−18	7	35 × 35 × 37	$\varepsilon_{r1} = 3.6$; Rogers 4350 B $\varepsilon_{r2} = 2.2$; Rogers 5800
37	4.8	−10	4.4	22 × 31	Kapton polyimide substrate
38	2.4/5.2	−25/−20	5/6	130 × 130 × 6	$\varepsilon_r = 2.2$
This study	5.2/10.4	−18/−19	7.2/7.1	40 × 45 × 9.4	ABS $\varepsilon_r = 2.5$

4 | CONCLUSION

Herein, design and low-cost realization of a 3D printed dual band SMPA antenna has been achieved. The proposed SMPA antenna achieves a measured gain level of 7.2 dB at the operation frequencies. Furthermore, the experimental results of the prototyped antenna have been compared with counterpart design in the literature. From the compared results, it can be concluded that not only the proposed antenna design has achieved high-performance measures compared with counterpart designs in the literature, but also it is possible to achieve an accurate, fast, and low-cost realization via the use of 3D printing technology. The proposed antenna can be used in many applications where communications at 2 frequencies with arbitrary separation are required. The measured characteristics of the 3D printed SMPA antenna and its extremely low profile and ease of fabrication makes this design a good candidate for micro base station antenna applications.

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