A Flexible Dual-Band Metasurface Antenna for Biomedical Applications

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Abstract

Abstract — **In this report, a low-profile, flexible, efficient, and directive metasurface antenna (MSA) has been proposed for biomedical applications. The MSA has been formed by incorporating the CPW-fed square spiral patch and a 7×7 order MS. The spiral patch and the MS have been designed over poly-lactic acid (PLA) dielectric in a stacked manner. The proposed antenna has fractional bandwidths of 7.1 % and 11.3 % at 6.86 GHz and 10.99 GHz, respectively. The antenna achieves the realized gain of 2.2 dBi at 10.99 GHz. The antenna provides directional radiation characteristics in both the E- and H-planes. This MSA may be applicable in biomedical activities such as post-operative blood flow monitoring after reconstructive surgery.**

Keywords—Metasurfaces, Antenna, Biomedical applications.

1. Introduction

Flexible antennas are growing due to the increasing demand for Internet of Things (IoT) frameworks, wearable devices, customized medical platforms, 5G technology, wireless sensor networks, smaller form factor communication devices, etc. [1-4]. The design of non-rigid antennas depends on the substrate, materials, processing techniques, antenna performance, and the surrounding environment [1-4]. Biodegradable polymers and plastics are good for the environment because they reduce pollution, save resources, and minimize non-recyclable wastes [2-5]. Polylactic acid (PLA) is a plant-based polymer that can be decomposed. PLA possesses unique features such as biodegradability, biocompatibility, excellent electrical and mechanical qualities and has been thereby employed in biomedical and tissue engineering applications [4-7].

Flexible antennas are commonly used in biomedical equipment for wireless operation and bidirectional data communication [6-10]. Biomedical antennas are essential components for implantable medical devices (IMD) that exchange body anatomy data with installed base stations [6-10]. Several distinct prototypes of implantable patch antennas have been presented till date; however, they suffer from multiple features such as the radiation efficiency, gain, impedance bandwidth, axial ratio bandwidth, large antenna footprint for implantation [7-11]. According to some reports, the antenna dimensions are significantly reduced, making them suitable prototypes for implantation; but they are prone to multipath fading due to their omnidirectional linearly polarized radiations [7-11]. For wide impedance and axial ratio bandwidth, several forms of antennas with defective ground, slotted, spiral, fractal shape, and PIFA have been proposed in the literatures; however, they are not low profile, making them unsuitable for implantable applications [12-13]. The primary requirement of antenna design for biomedical applications is that the physical size of the prototype must be small with excellent radiation characteristics.

A portable, flexible, efficient, directional, and dual-band metasurface antenna (MSA) has been proposed in this paper for biomedical applications. The MSA has been integrated with a CPW-fed spiral patch and a 7×7 order metasurface (MS). The MSA operates over two different frequencies, 6.86 GHz and 10.99 GHz, with a maximum return loss of 29 dB at 10.99 GHz. This antenna yields fractional bandwidths of 7.1 % and 11.3% at the operational frequencies, with a maximum achievable gain of 2.2 dBi at 10.99 GHz. The prototype exhibits directional radiation features in both the E- and H-planes.

2. Design of the structure

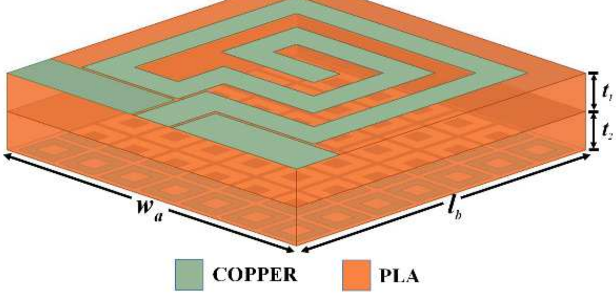

Figure 1. The 3D view of the proposed MS structure [Designed parameters: $w_a = l_a = 10$ mm, $t_1 = t_2 = 0.1$ mm].

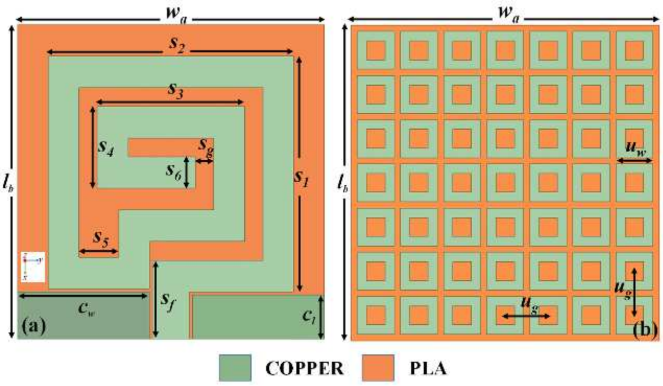

Figure 2. Schematic view of the proposed MSA with (a) top and (b) bottom views [Designed parameters: $w_a = l_b = 10$ mm, $s_1 = 7.4$ mm, $s_2 = 8$ mm, $s_3 = 4.8$ mm, $s_4 = 2.6$ mm, $s_5 = 1.5$ mm, $s_6 = 0.9$ mm, $s_g = 0.7$ mm, $c_l = 1.5$ mm, $c_w = 4.3$ mm, $u_w = 1.2$ mm, $u_g = 1.4$ mm].

The proposed MSA comprises a CPW-fed spiral square patch as the radiating element and a 7×7 order MSA. The spiral patch and the MS are designed on two separate PLA substrates (relative permittivity of 3.549 and loss tangent of 0.001) of thickness 0.1 mm each. The spiral patch is positioned on top of the first dielectric, while the MS layer is arranged on the backside of the second dielectric. A 3D schematic representation of the proposed MS structure is shown in Fig. 1. In addition, Figs. 2(a) and 2(b) show the top and bottom perspectives of the proposed prototype, respectively. The proposed prototype has been analyzed and optimized using Ansys HFSS [14].

3. Simulation Results

The conventional patch design steps with their respective return loss characteristics are depicted in Fig. 3. Initially, a spiral patch with a simple ground surface has been analyzed in CASE-I of Fig. 3, in which the return loss characteristics are not perfectly matched. Next, in CASE-II, the CPW feeding has been introduced with the spiral patch to improve the impedance characteristics. This antenna operates at 9.67 GHz with a fractional bandwidth of 16.9%, and it has been considered as a conventional patch. Later, the 7×7 order MS has been incorporated with the spiral patch for further improvements in the impedance characteristics that have been depicted in Fig. 3.

The MS unit cell is made of a square annular ring. The electromagnetic behaviour of the effective permittivity and permeability of the MS unit cell has been

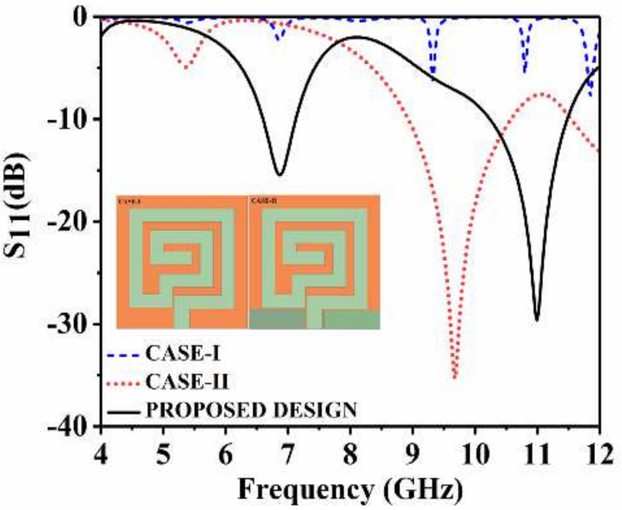

Figure 3. The plot of S_{11} (dB) with respect to the frequency of the different antenna configurations.

investigated by analyzing the reflection and transmission properties of the periodic unit cell. The homogeneity properties of the metasurface have been taken into consideration when designing the MS unit cells. The designed prototype operates in two distinct frequency bands viz., 6.61-7.1 GHz and 10.23-11.48 GHz with the fractional bandwidths of 7.1% and 11.3%, respectively. The maximum return loss of 29 dB has been achieved at 10.99 GHz.

The surface current distributions at 6.86 GHz and 10.99 GHz for the top surface of the spiral patch and the bottom MS layer have also been studied and are shown in Figs.

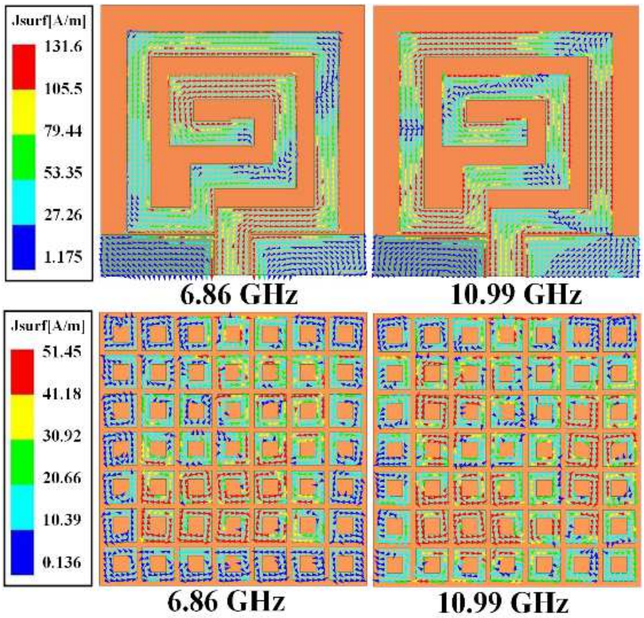

Figure 4. The surface current of the proposed prototype at 6.86 GHz and 10.99 GHz.

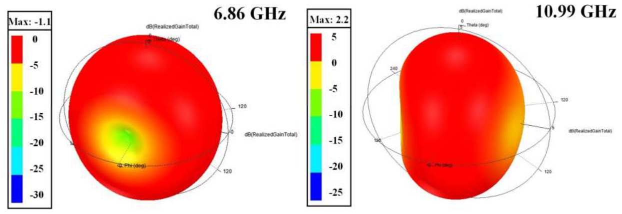

Figure 5. **P**lot of the realized gain (dBi) of the proposed prototype at different operating frequencies.

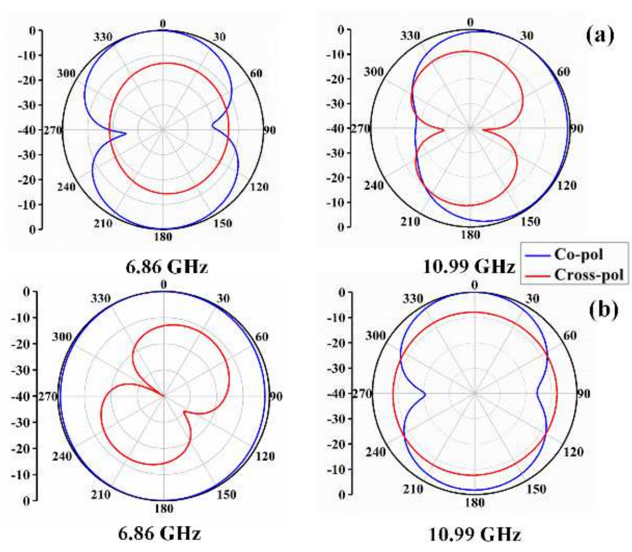

Figure 6. Radiation patterns of the proposed antenna prototype in the (a) E-plane and (b) H-plane at frequencies of 6.86 GHz and 10.99 GHz.

4(a) and 4(b), respectively. They are denser between the spiral surface interface and the CPW feed. The directions of surface currents at the interface of the unit cells are parallel, forming a magnetic coupling between the adjacent unit cells, as shown in Fig. 4(b). The study of realized gain characteristics at 6.86 GHz and 10.99 GHz have been illustrated in Fig. 5. A maximum gain of 2.2 dBi has been attained at 10.99 GHz. The co-polarized and cross-polarized radiation characteristics of the proposed MS antenna along with the E- and H-planes at 6.86 GHz and 10.99 GHz, respectively, are shown in Figs. 6(a) and 6(b). It is observed that the antenna radiates along the boresight direction both in the E-and H-planes. At all operational frequencies, the cross-polarized radiated powers are found to be considerably lower than co-polarized ones.

4. Conclusion

This paper presents a low-profile, flexible, directive, and efficient MSA for biomedical applications. A spiral patch and a 7×7 array of periodic MS are arranged in a stacked manner for performance improvement. The antenna operates at dual frequencies, with fractional bandwidths of 7.1 % and 11.3 % at 6.86 GHz, and 10.99 GHz, respectively. The antenna exhibits directional radiation characteristics in the E- and H-planes, with a maximum realized gain of 2.2 dBi at 10.99 GHz. This antenna can be used in medical supervision or wearable applications.

5. Acknowledgment

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6. References

[1] Boutry CM, Beker L, Kaizawa Y, et al., "Biodegradable and flexible arterial-pulse sensor for the wireless monitoring of blood flow," *Nature Biomedical Engineering*, vol. 3, no. 1, pp. 47-57, Jan 2019.

[2] Giorgio Mattana, Danick Briand, Alexis Marette, Andrés Vásquez Quintero, Nico F. de Rooij, "Polylactic acid as a biodegradable material for all-solution-processed organic electronic devices," *Organic Electronics*, vol. 17, pp. 77-86, 2015.

[3] W. Groot, J. van Krieken, O. Sliekersl, and S. de Vos, "Production and purification of lactic acid and lactide," in Poly Lactic Acid: Synthesis, Structures, Properties, Processing, and Applications. New York, NY, USA: Wiley, 2010.

[4] M. Haroon, S. Ullah, and J.-A. Flint, "Electro-textile based wearable patch antenna on biodegradable poly lactic acid (PLA) plastic substrate for 2.45 GHz, ISM band applications," in *Proc. IEEE Int. Conf. Emerg. Technol.*, pp. 158–163, Dec. 2014.

[5] J. M. Felício, C. A. Fernandes, and J. R. Costa, "Complex permittivity and anisotropy measurement of 3D-printed PLA at microwaves and millimeter-waves," in *Proc. 22nd Int. Conf. Appl. Electromagn. Commun.,* pp. 1–6, Sep. 2016

[6] P.-Y. Cresson *et al.*, "1 to 220 GHz complex permittivity behavior of flexible polydimethyl siloxane substrate," *IEEE Microw. Wireless Compon. Lett.*, vol. 24, no. 4, pp. 278–280, Apr. 2014.

[7] Y.-H. Su, P.-C. Chiang, L.-J. Cheng, C.-H. Lee, N. Swami, and C.-F. Chou, "High aspect ratio nanoimprinted grooves of poly (lactic co-glycolic acid) control the length and direction of retraction fibers during fibroblast cell division," *Biointerphases*, vol. 10, no. 4, p. 041008, Dec. 2015.

[8] Roy, S.; Chakraborty, U. Metamaterial Based Dual Wideband Wearable Antenna for Wireless Applications, *Wirel. Pers. Commun*. vol. 106, pp. 1117–1133, 2019.

[9] H. -N. Morales-Lovera, J. -L. Olvera-Cervantes, A. Corona-Chavez, and T. K. Kataria, "Dielectric Characterization of Anisotropic 3D-Printed Biodegradable Substrates Based on Polylactic Acid [Application Notes]," in *IEEE Microwave Magazine*, vol. 22, no. 9, pp. 18-100, Sept. 2021.

[10] Kirtania, Sharadindu G., Alan W. Elger, Md. R. Hasan, Anna Wisniewska, Karthik Sekhar, Tutku Karacolak, and Praveen K. Sekhar. "Flexible Antennas: A Review" *Micromachines* 11, no. 9: 847, 2020.

[11] D. Samantaray, S. Bhattacharyya, "A Metasurface Based Gain Enhanced Dual Band Patch Antenna Using SRRs With Defected Ground Structure," Radio Science, vol. 56, issue 2, article no. 2020RS007192, Feb. 2021.

[12] Stuardo, Pablo, Francisco Pizarro, and Eva Rajo-Iglesias, "3D Printed Sievenpiper Metasurface Using Conductive Filaments" *Materials* 13, no. 11: 2614, 2020.

[13] O. Yurduseven, et al., "Computational microwave imaging using 3D printed conductive polymer frequency-diverse metasurface antennas," *IET Microwaves, Antennas & Propagation*, vol. 11, no. 14, pp. 1962-1969, 2017.

[14] Ansys Electronics Desktop, R1, 2019, ANSYS Corporation.