

Self Complementary Frequency Independent Triple Band Sinuous Antenna Array for Wireless Applications

Indumathi Ganesan^{*}, Kavitha Kaliyappan, and Paulkani Iyampalam

Abstract—In this article, a self complementary frequency independent triple band Sinuous Antenna Array (SAA) is designed for wireless applications such as Mobile Satellite Service (MSS), Global Positioning System (GPS) and Global System for Mobile communications (GSM). Four Sinuous elements are connected to the nearest one in such a way to form an array structure. A prototype of a Sinuous Antenna Array (SAA) is embedded into a flame retardant-4 (FR-4) dielectric material. The performance of the proposed antenna array has been analyzed by using Ansys High Frequency Structure Simulator (HFSS). The suggested antenna is fabricated and tested. From the measured results, the proposed antenna array can be operated at the frequencies of 1.54 GHz for GPS, 1.76 GHz for GSM and 2 GHz for MSS with a reflection coefficient of below -10 dB. It has good reflection coefficient characteristics, Voltage Standing Wave Ratio, impedance bandwidth, axial ratio, surface current distribution and radiation characteristics.

1. INTRODUCTION

In modern communication systems, low profile and multiband antennas play an indispensable role for wireless applications [1–3]. Furthermore, there is a demand for a single antenna to support multiband operation, including GPS, GSM and MSS. Many approaches have been developed in the design of antenna to achieve multi-frequency operation [4–6]. In recent days, all the commercial transport vehicles and cell phones are furnished with GSM and GPS antenna for location finding service. The linear polarization antenna is used for GSM operation while the GPS antenna requires circular polarization [7]. Mobile Satellite Service (MSS) is also a telecommunication service which uses the satellite for voice and data communications. Sinuous antenna is a convincing choice to achieve both linear and circular polarizations for GSM and GPS operation. Raymond H. DuHamel formulated a dual-polarized antenna, called as Sinuous [8]. It possesses properties of a planar structure, capability of PCB printing, dual polarizations and low cost fabrication. Sinuous antenna is classified under the category of frequency-independent antennas because the shape of the antenna is defined only by angles rather than lengths [9, 10]. It is also known as self-complementary antenna, where the geometry of the antenna does not change while interchanging the metallic and dielectric parts of the radiating element. Most of the Sinuous antenna research work has been proposed for L-band and high frequencies [11–15]. Many researchers have reported Sinuous antennas with two [11] or four arms [12, 13]. Four-arm Sinuous antenna is designed for the frequency range from 1 GHz to 5 GHz for reflector based searching system and phased focal plane array applications in [14]. In [15], a modified four-arm sinuous antenna is presented for ultra-wideband (UWB) radar applications. Sinuous antenna phased array for millimeter wavelength is presented in [16].

Received 6 June 2018, Accepted 1 August 2018, Scheduled 7 September 2018

^{*} Corresponding author: Indumathi Ganesan (gindhu@mepcoeng.ac.in).

The authors are with the Department of Electronics and Communication Engineering, Mepco Schlenk Engineering College, Sivakasi, Tamil Nadu, India.

In our work, a Sinuous Antenna Array (SAA) is designed for L and S band frequencies such as 1.54 GHz for GPS (L1 band), 1.76 GHz for GSM 1800 uplink (1710–1784 GHz) and 2 GHz for MSS (1980–2010 MHz) applications. Section 2 presents the design methodology of the proposed antenna. Experimental and simulated results are discussed in Section 3. Some important antenna parameters such as reflection coefficient, Voltage Standing Wave Ratio (VSWR), impedance bandwidth, radiation pattern, surface current distribution, axial ratio and gain are analyzed in that section. Section 4 consists of conclusion, acknowledgments and references.

2. PROPOSED ANTENNA DESIGN METHODOLOGY

This section deals with two-stage design of the Sinuous Antenna Array. HFSS v-17 software is used for the simulation. The Sinuous antenna comprises an even number of N arms. At the first stage, the Sinuous curve is built up for the development of a single Sinuous element. The second stage provides the design of SAA by using the Sinuous element which is constructed at the first stage.

2.1. Formation of Sinuous Curve and Sinuous Element

The Sinuous curve is generated to construct the arm of the Sinuous antenna. There are s cells in the curve numbered from 1 to k which are generated by using the expression provided by DuHamel [8].

$$\phi = (-1)^s \alpha_s \sin \left[\frac{\ln \left(\frac{r}{R_s} \right)}{\ln(\tau_s)} \right]; \quad R_s + 1 \leq r \leq R_s, \quad s = 1, 2, \dots, k \quad (1)$$

where r and ϕ are the polar coordinates of the curve; s is the number of repetition cells; R_s and α_s are the cell radius and angular width; τ_s is the growth rate, which is defined by the ratio between inner and outer radii of each cell which is given by [8].

$$\tau_s = \frac{R_s + 1}{R_s} \quad (2)$$

Parameters α_s and τ_s define the log-periodic structure, and these parameters are independent of cells. The single arm of the Sinuous antenna is formed by sweeping the curve as in Equation (1) over an angle $\pm\delta$ (angular spacing). The complete four arms of the Sinuous antenna are obtained by duplication and rotation of single arm by 90° , 180° , 270° , 360° ($360^\circ/N$) about its central point. The arms are placed on the substrate, and they are not touching each other. The default value for δ is 22.5° for four arms. Figures 1(a) and (b) display the formation of a Sinuous curve and single Sinuous element. In Sinuous structure, the operating frequency is related to the radius of the cell, angular width and angular spacing which is given by

$$f_c = \frac{c}{4R_s(\alpha_s + \delta)} \quad (3)$$

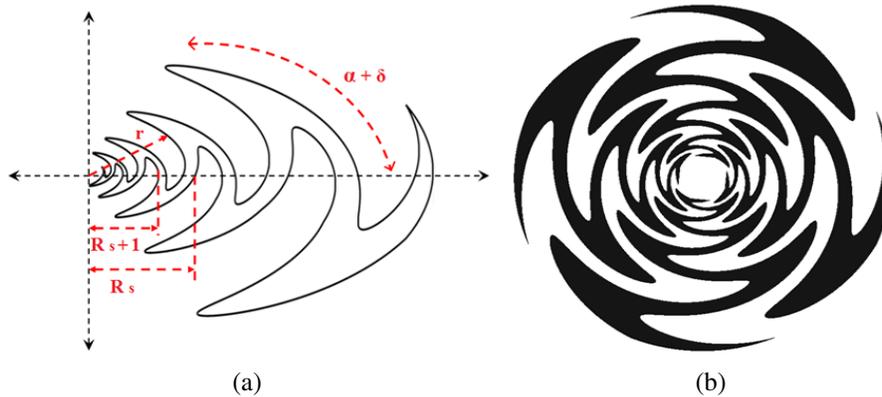


Figure 1. (a) Formation of Sinuous curve. (b) Single Sinuous element.

By varying the radius of the cell, angular width and angular spacing in Sinuous structure, the resonant frequency of the designed antenna can be controlled.

2.2. Design of Sinuous Antenna Array

The design evolution of the proposed antenna to achieve three bands is presented in Figure 2. Antenna 1 is the single Sinuous element with microstrip feeding structure. In the second step, Antenna 2 is designed by arranging the four Sinuous elements in the array form as shown in Figure 2(b). The distance between the adjacent Sinuous elements is 17.5 mm. As seen in Figure 2(c), the tail of each Sinuous arm is connected to the neighboring arm by connecting traces. The geometry of the proposed antenna array is demonstrated in Figure 3. The proposed antenna is assembled on an FR-4 dielectric material with the thickness of 0.8 mm, relative dielectric constant of 4.4 and loss tangent of 0.02. Figures 3(a) and (b) show the top view and the fabricated antenna array. The specifications of the proposed SAA are listed in Table 1. The novelty of the proposed design lies in the self complementary structure with the frequency independent concept, which is used to construct an antenna array for L and S band applications.

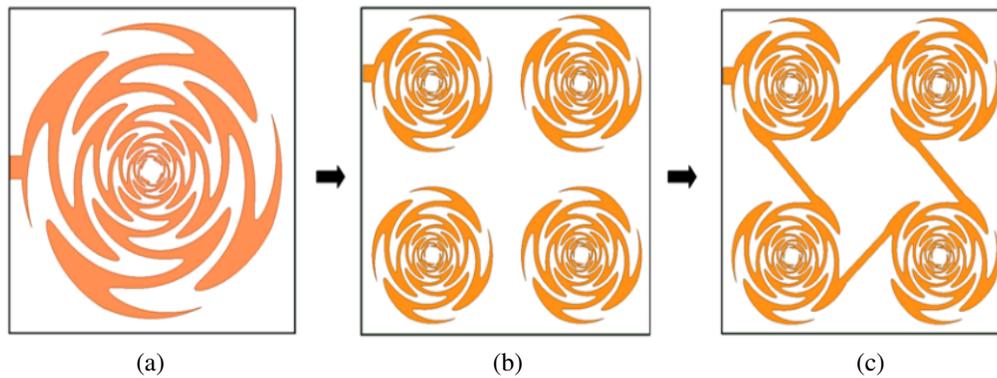


Figure 2. Evolution of the proposed antenna. (a) Antenna I. (b) Antenna II. (c) Proposed antenna.

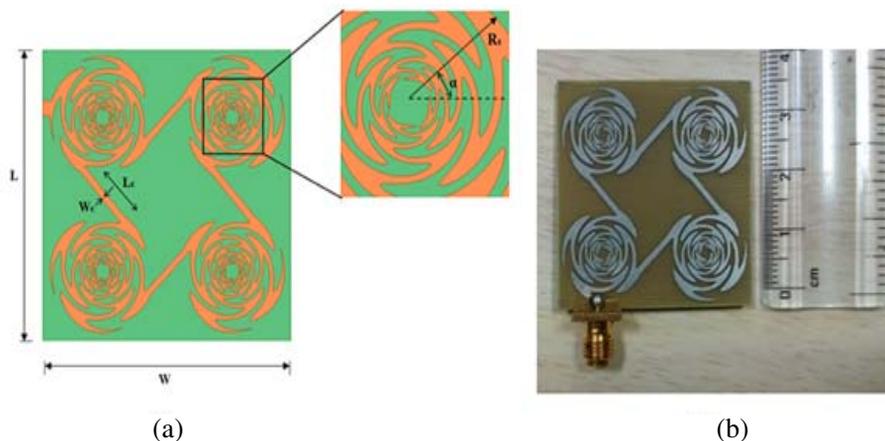


Figure 3. Configuration of sinuous antenna array. (a) Top view. (b) Fabricated SAA.

3. EXPERIMENTAL RESULT AND DISCUSSION

In this section, some important parameters of the antenna are analyzed in order to illustrate the performance of the antenna. In order to validate the simulation results, the fabricated SAA is measured

Table 1. Specifications of sinuous antenna array.

Number of arms (N)	Growth rate (τ)	Angular width (α)	Angular spacing (δ)	Outer radius (R) mm	Substrate Length (L) mm	Substrate Width (W) mm	Connecting Line length (L_c) mm	Connecting Line width (W_c) mm
4	0.75	45°	22.5°	1.5	38	38	17	2

by using Agilent E5071C Network Analyzer which supports the frequency range from 300 kHz to 20 GHz. The measured and simulated reflection coefficient characteristics of the SAA are depicted in Figure 4.

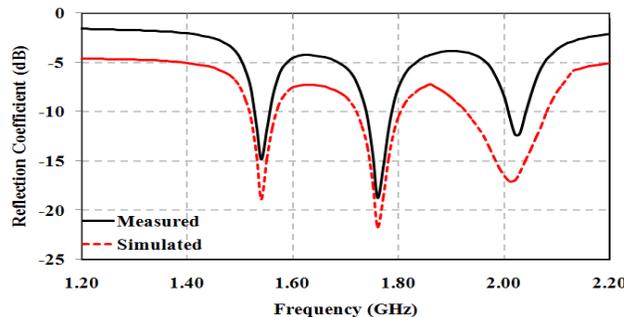
The fabricated prototype exhibits a triple-band with a reflection coefficient of -14.75 dB at 1.54 GHz, -18.93 dB at 1.76 GHz and -12.06 dB at 2.03 GHz, whereas in the simulation, antenna reveals the reflection coefficients of -18.75 at 1.52 GHz, -21.98 dB at 1.76 GHz and -17.09 dB at 2.02 GHz. The value of measured VSWR is 1.52 at 1.54 GHz, 1.31 at 1.76 GHz and 1.72 at 2.03 GHz. In the simulation, the SAA has a VSWR of 1.57, 1.33 and 1.75 at the three resonant frequencies, respectively. Experimental results are very close to the simulated data, but there is a small discrimination between the measured and simulated results that could be due to some misalignment during the fabrication process or during soldering of the SMA connector.

The measured bandwidths of the SAA for $S_{11} \leq 10$ dB are about 30 MHz or 1.95% (1.52 GHz to 1.55 GHz) centered at 1.54 GHz, 60 MHz or 3.41% (1.73 GHz to 1.79 GHz) centered at 1.76 GHz and 40 MHz or 1.97% (2 GHz to 2.04 GHz) centered at 2.03 GHz. In the case of simulation, the antenna exhibits 60 MHz or 3.95% bandwidth in the first band (1.51 GHz to 1.57 GHz) resonant at 1.52 GHz, 90 MHz or 5.11% in the second band (1.72 GHz to 1.81 GHz) resonant at 1.76 GHz and 160 MHz or 7.92% in the third band (1.92 GHz to 2.08 GHz) resonant at 2.02 GHz.

Simulated radiation patterns of E -plane ($\phi = 90^\circ$) and H -plane ($\phi = 0^\circ$) by varying the θ from -180° to $+180^\circ$ are shown in Figure 5 for the resonant frequencies of 1.52 GHz, 1.76 GHz and 2.02 GHz. In the x - z plane (H -plane), the proposed SAA exhibits omnidirectional radiation pattern at the said resonant frequencies. Symmetric pattern is observed in the y - z plane (E -plane) at 2.02 GHz. The radiation pattern is somewhat symmetrical at 1.52 GHz and 1.76 GHz.

Surface current distribution behaviors of the proposed antenna at the above said resonant frequencies are presented in Figures 6(a), (b) and (c), respectively. From Figure 6(a), it is clear that the maximum current flow occurs in the feeding arm and the connecting traces of the neighbor Sinuous element. The current is flowing outward from the feeding arm to the adjacent arm via the connecting traces. For 1.76 GHz, the maximum current distribution is observed only at the feeding of an array which is depicted in Figure 6(b). As seen in Figure 6(c), for the MSS frequency band, current density is high at all the four arms of the SAA.

Theoretically, circularly polarized antenna should have Axial Ratio of 1 (0 dB), but practically it is not possible to achieve it. So, an axial ratio up to 3 dB can be acceptable for circular polarization. Axial Ratio (AR) plot is shown in Figure 7(a). It is inferred that the antenna exhibits axial ratio

**Figure 4.** Simulated and measured reflection coefficient characteristics.

of 2 dB at 1.52 GHz, 4 dB at 1.76 GHz and 3.8 dB at 2.02 GHz. The antenna is required to possess circular polarization for GPS application and linear polarization for GSM and MSS applications. Dual polarizations are achieved by using the proposed Sinuous structure. The simulated gain of the proposed antenna array is shown in Figure 7(b). It is found that the antenna has the gain of -1.68 dB at 1.52 GHz, 1.08 dB at 1.76 GHz and 2.52 dB at 2.02 GHz. The comparison between simulated and fabricated designs is listed in Table 2.

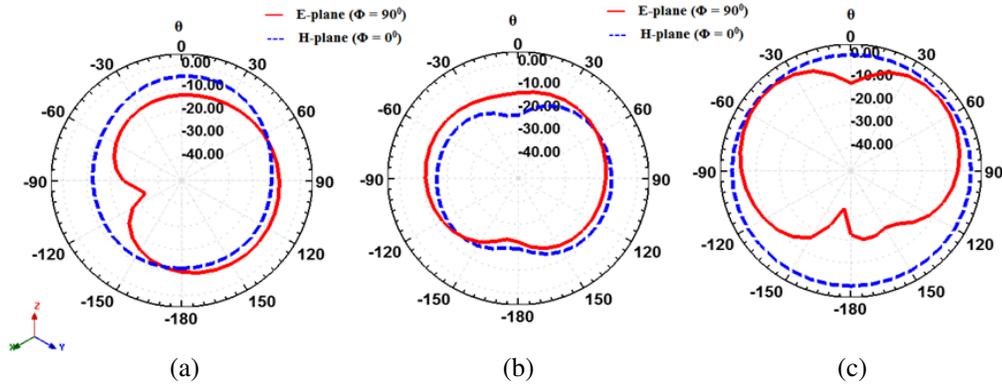


Figure 5. Radiation pattern of SAA in *E*-plane and *H*-plane at (a) 1.52 GHz, (b) 1.76 GHz, (c) 2.02 GHz.

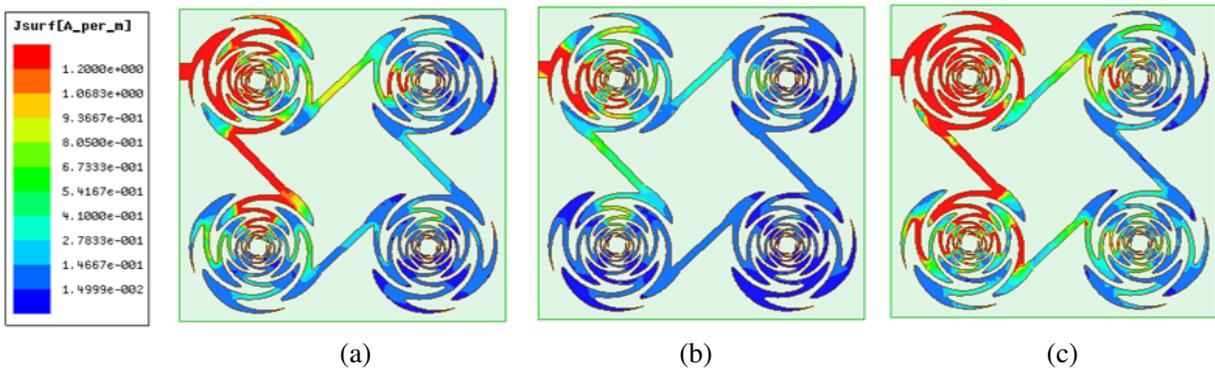


Figure 6. Surface current distribution of SAA at (a) 1.52 GHz, (b) 1.76 GHz, (c) 2.02 GHz.

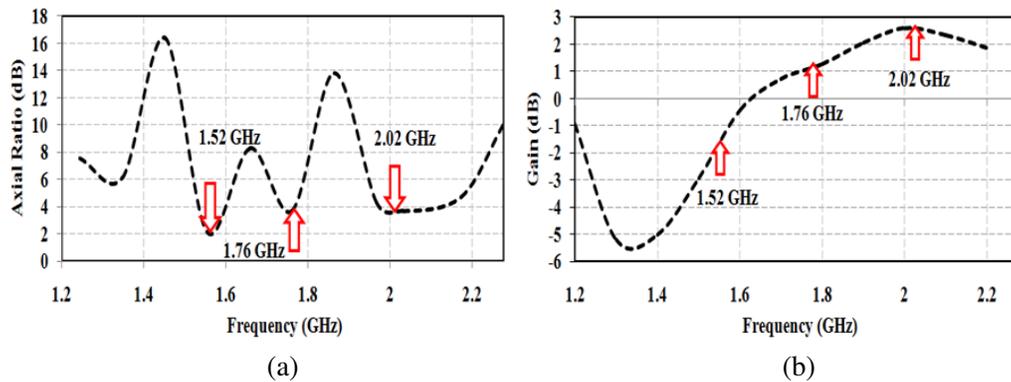


Figure 7. (a) Axial ratio. (b) Gain of SAA.

Table 2. Comparison between simulated and fabricated design

Design	Number of bands	Resonant frequency (GHz)	Reflection coefficient (dB)	VSWR	Bandwidth (MHz)
Simulation	Triple band	$F_1 = 1.52$	-18.75	1.57	60 or 3.95%
		$F_2 = 1.76$	-21.98	1.33	90 or 5.11%
		$F_3 = 2.02$	-17.09	1.75	160 or 7.92%
Fabrication	Triple band	$F_a = 1.54$	-14.754	1.52	30 or 1.95 %
		$F_b = 1.76$	-18.93	1.31	60 or 3.41 %
		$F_c = 2.03$	-12.06	1.72	40 or 1.97%

4. CONCLUSION

In this work, a triple band self complementary frequency independent Sinuous Antenna Array (SAA) is proposed for wireless applications. The various parameters of the proposed antenna such as reflection coefficient, Voltage Standing Wave Ratio (VSWR), impedance bandwidth, radiation pattern, surface current distribution, axial ratio and gain have been analyzed using Ansys HFSS V17. The prototype of the SAA is fabricated on an FR4 substrate and tested using Agilent E5071C Network Analyzer. It can be observed from the measurement results that the antenna exhibits three resonant frequencies at 1.54 GHz for GPS, 1.76 GHz for GSM and 2.03 GHz for MSS with the small size of $38 \times 38 \times 0.8 \text{ mm}^3$. It is observed that the proposed SAA has a reflection coefficient of less than -10 dB and smaller VSWR (≤ 2) over the operating band. The simulation results of Ansys HFSS are in good agreement with the experimental ones. Fabricated antenna has acceptable bandwidths for GPS, GSM and MSS applications, and a compact size and low manufacturing cost also make the antenna suitable for mobile phone devices.

ACKNOWLEDGMENT

This work was supported by the ISRO under RESPOND Scheme (Grant No.: ISRO/RES/3/711/16-17). The authors express their sincere gratitude to Shri. B. V. Subba Rao, DGM, RIS, Department of Space, ISRO, for providing technical support.

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