CPW-Fed Wide Band Micro-machined Fractal Antenna with Band-notched Function

Ashwini Kumar and Amar Partap Singh Pharwaha

Department of Electronics and Communication Engineering
Sant Longowal Institute of Engineering and Technology, Longowal, Sangrur, Punjab, India
ashwiniarya15@gmail.com, aps.aps67@gmail.com

Abstract **─** In this paper, a straightforward yet effective design methodology to design wideband antenna with band notched characteristics has been proposed. Sierpinski carpet fractal geometry has been used to realize the antenna structure. Co-planar waveguide feed is used with a novel structure to achieve larger impedance bandwidth and band notching characteristics. Proposed antenna is designed using High Frequency Structure Simulator (HFSS) on a low cost FR4 substrate (ε_r=4.4) which resonates at three frequencies 1.51 GHz (1.19-2.06GHz), 6.53 GHz and 8.99 GHz (4.44-9.54 GHz) while a band is notched at 10.46 GHz (9.32-11.92 GHz). The proposed antenna has an electrical dimension of 0.36 $\lambda_m\times$ 0.24 λ_m, here λ_m is the wavelength with respect to lowest resonating frequency of the antenna. The resonating and radiation characteristics of the antenna are verified experimentally. Further, investigations are made to achieve easy integration of the antenna to the monolithic microwave integrated circuits. For that the antenna has been designed on micro-machined high index Silicon substrate which improve matching and gain of the antenna. The results of the micro-machined Sierpinski carpet fractal antenna are highly convincing over the conventional FR4 based antenna.

Index Terms **─** Gain, micro-machining, Sierpinski fractal, silicon, wideband.

I. INTRODUCTION

Wideband antennas are potent solution for reducing the number of onboard antennas for such kind of applications which operate in different bands. Design of wideband, compact, light weight antennas with acceptable performance become a more complicated and challenging task for the researcher. Therefore this work is aimed to develop a low profile antenna with wideband performance. Wide bandwidth of antenna is a desirable characteristic to meet the challenges like: high data rate, capacity and multi-functionality etc. There are various techniques to improve the bandwidth like the use of frequency selective surface, multiple resonators, thicker substrate, parasitic patch, folded and self-complementary structures, use of stacked configuration, shorting pins, presenting of U-openings, cavity-backed slot antenna, utilizing of high permittivity substrates, slots, and fractal geometry [1-5], developed by researcher and scientist to meet these challenges. The primary objective of this research is to develop a low profile wideband fractal antenna. Therefore a review of various wideband fractal antennas adopted. Fractal antennas have gained a lot of popularity in comparison of ordinary patch antennas. Many Fractal radiators were used to achieve wideband characteristics like: an effort was made in [6]. Similarly various antennas were proposed using fractal geometries [7-11]. To achieve band-notched function various techniques have been applied in literature like: embedding of slots [12-15] on the patch or ground, and utilizing parasitic elements near the radiator [16]. All these techniques require more space and difficult to implement because of structural complexity, but the proposed technique is very simple to implement and does not consume extra space. Microstrip patch antenna performance predominantly decided by the selection of substrate material and shape of the patch. At high frequency surface wave and substrate losses are more significant in case of substrates which have higher value of dielectric constant like: Silicon and GaAs in comparison to substrates which low dielectric constant [17,18]. In this work, a special method known as micro-machining has been exercised to win over the limitations of the high resistive Silicon substrate. In micro-machining an air cavity is created by etching out a specific portion of the substrate to avoid the surface wave and substrate losses. Micro-machining reduce the dielectric constant of the substrate thus improving the performance [19,20]. Although the antennas reported in literature were wideband in nature, certain limitation exist in terms of design complexity, size and presence of undesired bands/complicated techniques for band notching. Thus from the literature, it is perceptible that there is still a huge possibility of development of micro-machined fractal antenna.

In this paper, a common but proved fractal structure has been used from [21]. The work intends to provide a

Submitted On: January 19, 2020
Accepted On: May 25, 2020
https://doi.org/10.47037/2020.ACES.J.350812
1054-4887 © ACES

simple yet effective design methodology to design multiband antenna with wide band and band notched characteristics. Proposed fractal antenna covers the frequency bands for fixed satellite services (FSS) in L-Band, C-Band and X-Band. The novelty of the work is twofold as follow: (i) Modified CPW-feed has been utilized to get larger impedance bandwidth (S_{11}<=-10 dB) approximately of 5 GHz and at the same time the undesired frequency band has been notched with only simple structural modification in comparison of the techniques used in literature. (ii) Proposed antenna is designed on high index micro-machined silicon substrate with an additive feature of easy integration of antenna to the Monolithic Microwave Integrated Circuits (MMIC). This specially featured antenna also provides higher order of impedance matching and higher gain than Sierpinski Carpet Fractal Antenna (SCFA) designed on FR4 substrate. The results of the micro- machined SCFA are highly convincing over the conventional FR4 based antenna.

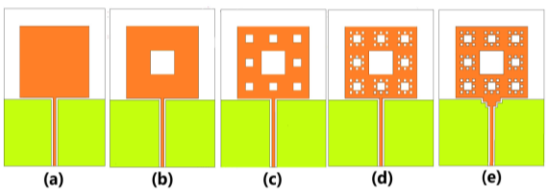

Fig. 1. All iterations of SCFA: (a) 0th Iteration, (b) 1st Iteration, (c) 2nd Iteration, (d) 3rd Iteration, and (e) final design.

The rest of the work is divided in three sections as follow: Section II contains the design procedure and performances of the proposed antenna, Section III discusses the results, Section IV discusses the experimental validation, Section V the micro-machined SCFA is discussed which is followed by Section VI containing conclusion.

II. ANTENNA DESIGN

The antenna design procedure begins by designing a square patch antenna on low index FR4 substrate with a loss tangent of 0.02 and a dielectric constant of 4.4 having a size of The antenna dimensions are simply calculated using the standard equation given in [22]. After designing a square patch antenna of side length 41.08 mm fed by CPW-feed, the Sierpinski carpet fractal geometry has been etched out. Sierpinski Carpet fractal geometry is considered in this work to design the proposed antenna which has been extensively used in literature for designing multiband antenna. For 1st iteration Initial Square is scaled with a factor of 1/3 in both x-axis and y-axis and subtracted from 0th iteration structure as shown in Fig. 1 (b). Same procedure is used to generate further two iterations. In last step CPW-feed is modified to step feed to enhance the bandwidth of the antenna as shown in Fig. 1 (e). Figures 1 (a) to 1 (d) show transformation of the antenna design from basic square patch to 3rd iteration of Sierpinski carper fractal structure, and Fig. 1 (e) shows the final proposed antenna with modified CPW-feed. Figure 2 shows the dimensional details of the proposed antenna which are tabulated in Table 1. The overall size of the proposed antenna is 0.36 λ_m× 0.24 λ_m × 0.0064 λ_m, here λ_m is the wavelength with respect to lowest resonating frequency of the antenna.

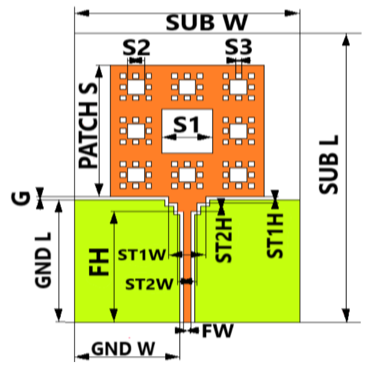

Fig. 2. Dimensional details of SCFA.

Table 1: Dimensional details of SCFA

Parameter	Value (mm)	Parameter	Value (mm)
SUB L	90	GND L	38.05
SUB W	60	GND W	28
PATCH S	41.08	FL	34.55
S1	13.69	FW	1.8
S2	4.56	ST1H	2
S3	1.52	ST1W	10
G	1	ST2H	2.5
		ST2W	5

III. RESULT AND DISCUSSION

High frequency structure simulator (HFSS) is used to design and simulate the proposed antenna. Proposed SCFA is characterized using characteristics like reflection coefficient (S_{11}), radiation pattern, gain and bandwidth. Figure 3 shows the reflection coefficient values for all iterations which have been also tabulated in Table 2 [21]. In iteration 3rd there is a little improvement in performance of antenna in comparison of 2nd iteration therefore the analysis is done up to 3rd iteration only. It is noticed from the Fig. 3 [21] that after changing CPW-feed in CPW-feed with two steps the bandwidth of the antenna is significantly improved and also band notching is achieved for the band 9.32-11.92 GHz which is not useful for desired applications. Without modification the maximum bandwidth of antenna is only 2.6 GHz whereas after feed modification and optimization the antenna resonates at 1.51 GHz (1.19-2.04 GHz), 6.53 GHz and 8.99 GHz (4.44-9.54 GHz) with a maximum bandwidth of 5.09 GHz in the required frequency band for the desired application. From Fig. 3, it can be seen that the antenna at 3rd iteration is operating at 10.46 GHz whereas for final design with modified CPW-feed the band is notched at 10.46 GHz.

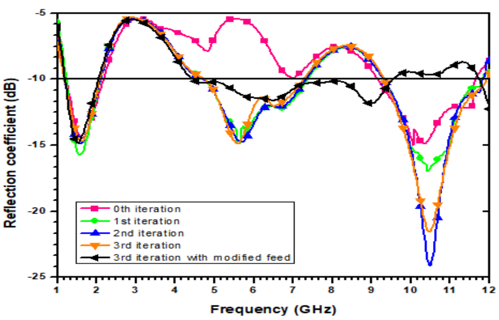

Fig. 3. Simulated reflection coefficient (S_{11}) values of all iterations of SCFA.

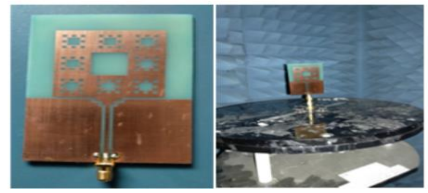

Fig. 4. Fabricated antenna in anechoic chamber.

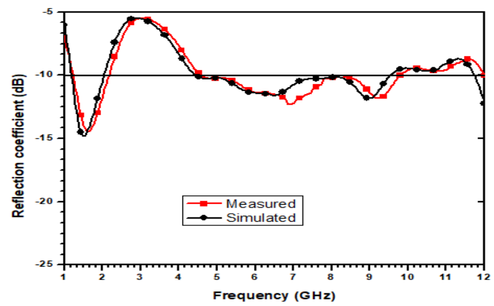

Fig. 5. Simulated and measured reflection coefficient of proposed SCFA.

Table 2: Performance parameters of the proposed antenna

Iterations	Resonating Frequency (GHz)	Reflection Coefficient (dB)	VSWR	Bandwidth (MHz)	Gain (dB)
Zeroth	1.62	-14.4	1.46	900	0.2
	10.35	-14.8	1.21	2450	4.1
First	1.58	-15.7	1.39	870	0.2
	5.62	-14.8	1.40	2650	1.4
	10.42	-16.9	1.14	2490	2.2
Second	1.58	-14.9	1.43	880	-0.4
	5.65	-14.8	1.44	2560	1.4
	10.49	-24.1	1.13	2500	3.2
Third	1.62	-14.7	1.45	820	0.07
	5.58	-14.8	1.43	2470	1.3
	10.46	-21.6	1.16	2600	4.2
Proposed Antenna Design	1.51	-14.8	1.44	850	0.08
	6.53	-11.6	1.71	5100	1.3
	8.99	-11.8	1.68		3.6
Proposed Micro-machined Antenna	1.99	-42	1.02	1320	3.78
	8.07	-31.7	1.05	4690	2.96

IV. EXPERIMENTAL VALIDATION

A. Reflection coefficient

Prototype of the proposed antenna has been fabricated on FR4 substrate as shown in Fig. 4. Measurement of reflection coefficient has been done using Anritsu (Model No. MS46322A) Vector Network Analyzer. Measured and simulated reflection coefficient versus frequency plot is shown in Fig. 5. Measured and simulated results show higher degree of matching for the proposed antenna. The proposed antenna resonates at 1.51 GHz, 6.53 GHz and 8.99 GHz. The frequency bands of interest for FSS are (1.24-1.35 GHz), (1.559-1.626 GHz), (4.5-4.8 GHz), (5-5.65 GHz), (5.725-8.4 GHz) and (8.75-9.5 GHz). The proposed antenna covers desired frequency bands in L-Band, C-Band and X-Band.

B. Radiation pattern

Figure 6 shows the simulated and measured radiation characteristics of the proposed SCFA at 1.51 GHz, 6.53 GHz and 8.99 GHz. Radiation pattern has been measured in receiving mode in anechoic chamber. Experimental measured pattern are shown with simulated radiation pattern to verify the radiation characteristics of the fractal antenna. Measured and simulated results show the higher degree of matching. It can be observed that, at all frequencies, the antenna has nearly omnidirectional radiation pattern in the H-Plane, while in the E-Plane the radiation pattern at 1.51 GHz is bidirectional, 6.53 GHz and 8.99 GHz patterns are broadside.

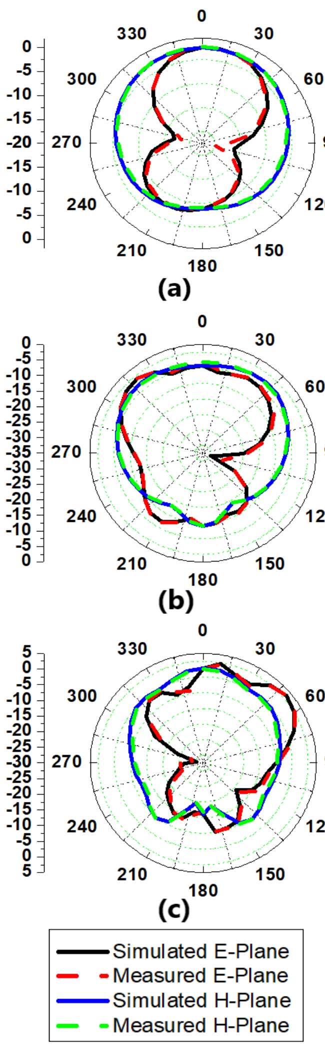

Fig. 6. Radiation pattern proposed SCFA: (a) at 1.51 GHz, (b) at 6.53 GHz, and (c) at 8.99 GHz.

V. MICROMACHINED SCFA

A Monolithic Microwave Integrated Circuit (MMIC) is an integrated circuit that works at microwave frequencies. These circuits are generally fabricated using High Index substrate like: Silicon (ε_r=11.9) or GaAs (ε_r=12.9) to work at high frequencies. To integrate patch antenna over these high index substrate, the limitation of surface wave losses and dielectric losses of these substrate should be avoided. To avoid these losses a process of micromachining is done. In this process selective portion of the high index substrate is removed and an air cavity is created beneath the patch to make a low index conditions. By creating a low index environment in high index substrate performance of the patch antenna can be improved [19,20]. Micro-machining process is of two types: 1) Bulk Micro-machining and 2) Surface micro-machining. When selective bulk material from substrate is removed by etching then it is known as bulk micro-machining. In this work, process of bulk micro-machining is used to design a fractal antenna on low index environment as shown in the Fig. 7. The overall effective dielectric constant has been calculated from the Equations (1-3) [19]:

$$\varepsilon_c = \frac{\varepsilon_a \varepsilon_s}{\varepsilon_a + (\varepsilon_s - \varepsilon_a)k_a}, \tag{1}$$

$$\frac{\varepsilon_f}{\varepsilon_c} = \frac{\varepsilon_a + (\varepsilon_s - \varepsilon_a)k_a}{\varepsilon_a + (\varepsilon_s - \varepsilon_a)k_f}, \tag{2}$$

$$\varepsilon_{reff} = \varepsilon_c \left(\frac{L + 2\Delta L \frac{\varepsilon_f}{\varepsilon_c}}{L + 2\Delta L} \right). \tag{3}$$

Here, ε_s is dielectric constant of substrate. ε_a air dielectric height in the mixed field region. k_f represents ratio of air cavity height to substrate height in the fringing field region. L represents side length of the design.

Proposed SCFA has been designed on high index silicon (ε_r=11.9) substrate having height of 1.6 mm. An air cavity (shown in light blue color underneath the patch) has been created by etching off 43 mm × 49 mm × 1.5 mm substrate volume underneath the patch leaving a 0.1 mm thick membrane under the patch. Figure 8 illustrates comparison of the simulated reflection coefficient of the proposed fractal antenna on FR4 and micro-machined silicon substrate. Micro-machined antenna resonates at1.99 GHz and 8.07 GHz. The best value of reflection coefficient for FR4 antenna is -14.8 dB whereas for micro-machined antenna it is -42 dB. The value of reflection coefficient got improved by nearly -28 dB in case of micro-machined antenna. The performance parameters of micro-machined antenna are tabulated in Table 2. However, the proposed micro-machined antenna has better performance and approximately equal bandwidth to the conventional FR4 antenna but there is a small deviation in the resonating characteristics of the micro- machined antenna which may be due to change in substrate properties. To get deeper physical insight into the behavior of antenna and band rejection, the proposed micro-machined antenna is modeled in terms of lumped components by estimating the value of R, L, and C from the input impedance of the antenna using foster's network synthesis [23-25]. Figure 9 illustrates the impedance versus frequency plot for the micro-machined silicon antenna. It can be observed from the Fig. 9 that the real part of the impedance fluctuate around the 50 ohm value while the imaginary part is nearly zero for both of the resonating bands. The value of real and imaginary part of impedance at 10.46 GHz (Band Notched) is nearly 35 ohm and -28 respectively. It is observed that at the notch frequencies of 10.46 GHz, input impedances are akin to that of the series RLC circuit, because the imaginary graph is going towards positive (Inductive) value from a negative (Capacitive) value while the real part is falling towards the zero value. The lumped component model with complex input impedance Z_c in Fig. 10 shows the equivalent model of the proposed antenna. Each parallel RLC circuit shown in Fig. 10 signifies the corresponding operating band like: R_1, L_1, and C_1 are corresponding to first operating band, R_2, L_2, C_2 for second operating band and series RLC circuit of R_3, L_3, C_3 signify the rejected band. Figure 11 shows the gain versus frequency plot for the FR4 and micro-machined antenna. It can be seen from the gain plot that the gain of the micro-machined antenna is far better than the FR4 antenna. The gain at 1.51 GHz got improved by nearly more than 4 dB; similarly a significant improvement in gain for second operating band can be seen from the plot. In addition to the above-discussed characteristics, the proposed SCFA on FR4 and Micro-machined silicon substrate has been compared with the existing antennas in Table 3. The proposed fractal antenna on FR4 has multiband performance with wide bandwidth, good gain and better matching as compared to antenna proposed in literature. Moreover, the antenna has been designed successfully on micro-machined silicon substrate for MMIC circuits with enhanced parameters like impedance matching, bandwidth and gain.

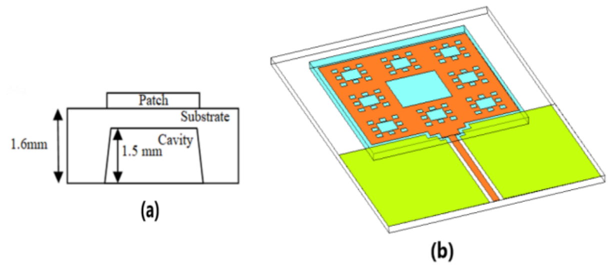

Fig. 7. (a) Micro-machined substrate and (b) 3D view of the proposed antenna.

Table 3: Comparison of the proposed antenna with existing antenna

Reference	Resonating Frequency (GHz)	Reflection Coefficient (dB)	Band Rejected	Bandwidth Improved (MHz)	Max. Gain (dB)	Electrical Dimension	Technique/ Inferences
[1]	2.45	-32	--	10.3	--	$0.3\ \lambda_m \times 0.34\ \lambda_m$	Substrate removal/ difficult and complex process
[2]	2.45	--	--	40	5	$0.45\ \lambda_m \times 0.51\ \lambda_m$	Using via hole/Increase structural complexity
[3]	1.3	-30	--	2600	2	$0.65\ \lambda_m \times 0.65\ \lambda_m$	Folded and self-complementary structures/Increased dimensions by 13%
[4]	1.5, 2.5, 2.8	--	--	11.5	8.9	$0.93\ \lambda_m \times 0.93\ \lambda_m$	Closed resonant slot pair/Small improvement in bandwidth
[5]	UWB	-15	3	--	3	$0.31\ \lambda_m \times 0.30\ \lambda_m$	Quarter-wavelength band-rejected elements/ Complicated design
[15]	UWB	-35	1	--	6	$0.41\ \lambda_m \times 0.51\ \lambda_m$	λ/4 short stub/Increase Structural complexity
Proposed antenna on FR4 substrate	1.51	-14.8	1	2630	4	$0.36\ \lambda_m \times 0.24\ \lambda_m$	Modification in feed completed both requirements of bandwidth enhancement and band rejection
	6.53	-11.6					
	8.99	-11.8					
Proposed Micro-machined Antenna	1.99	-42	1	2220	6	$0.36\ \lambda_m \times 0.24\ \lambda_m$	MMIC compatible antenna with enhanced bandwidth, Impedance matching and band rejection characteristics
	8.07	-31.7					

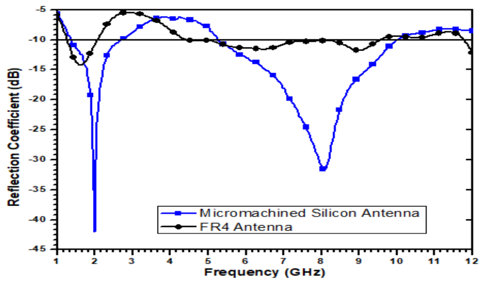

Fig. 8. Comparison of simulated reflection coefficients of the proposed antenna for two different substrates.

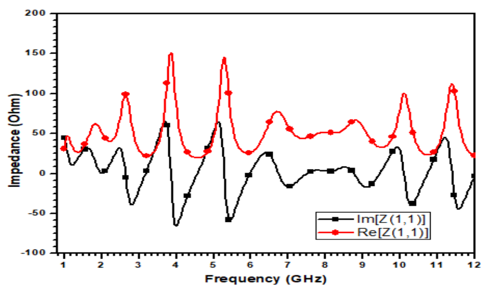

Fig. 9. Simulated impedance versus frequency plot for micro-machined antenna.

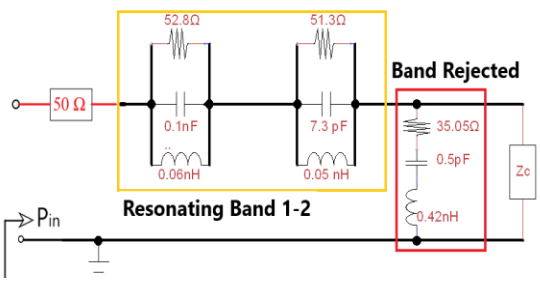

Fig. 10. Equivalent circuit of the proposed antenna.

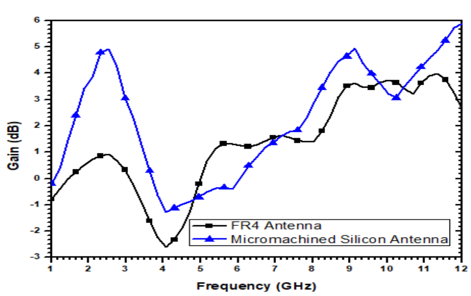

Fig. 11. Comparison of gain of the proposed antenna for two different substrates.

VI. CONCLUSION

A wideband Sierpinski carpet fractal antenna fed with a novel modified CPW feed has been presented here. The modification in CPW feed structure successfully increased the impedance bandwidth of the antenna by 107% and also notched an undesirable frequency band. The antenna has been designed and parametrically optimized to operate at 1.51 GHz (1.19-2.06GHz), 6.53 GHz and 8.99 GHz (4.44-9.54 GHz) covering fixed satellite services in L-Band, C-Band and X-Band. The radiation patterns are stable and approximately omnidirectional in H-plane at all three operating bands and antenna exhibits satisfactory gain at different bands. The measured reflection coefficient and radiation characteristics indicate high degree of matching with the simulated. Further, the proposed antenna has been designed on micro-machined Silicon substrate. Improvement in the crucial parameters like: Gain and Reflection coefficient, of the proposed SCFA has been achieved successfully using micro-machined Silicon substrate. MMIC compatible fractal antenna with very simple structure utilizing a small space has been proposed with effective radiation and resonance characteristics.

ACKNOWLEDGMENT

The authors are immensely thankful to the Department of Electronics and Communication Engineering of Sant Longowal Institute of Engineering & Technology, Punjab, India for providing kindly support and excellent lab facilities.

REFERENCES

[1] S. Yun, D.-Y. Kim, and S. Nam, "Bandwidth and efficiency enhancement of cavity-backed slot antenna using a substrate removal," *IEEE Antennas Wirel. Propag. Lett*., vol. 11, pp. 1458-1461, 2012.

[2] S. Yun, D.-Y. Kim, and S. Nam, "Bandwidth enhancement of cavity-backed slot antenna using a via-hole above the slot," *IEEE Antennas Wirel. Propag. Lett*., vol. 11, pp. 1092-1095, 2012.

[3] R. Azadegan and K. Sarabandi, "Bandwidth enhancement of miniaturized slot antennas using folded, complementary, and self-complementary realizations," *IEEE Trans. Antennas Propag*., vol. 55, no. 9, pp. 2435-2444, Sep. 2007.

[4] S. Fu, Z. Cao, P. Chen, D. Gao, and X. Quan, "A novel bandwidth-enhanced dual-polarized antenna with symmetrical closed-resonant-slot pairs," *IEEE Access*, vol. 7, pp. 87943-87950, 2019.

[5] F. Zhu, S. Gao, A. T. S. Ho, R. A. Abd-Alhameed, C. H. See, T. W. C. Brown, J. Li, G. Wei, and J. Xu, "Multiple band-notched UWB antenna with band-rejected elements integrated in the feed line," *IEEE Trans. Antennas Propag*., vol. 61, no. 8, pp. 3952-3960, Aug. 2013.

[6] A. Amini, H. Oraizi, and M. A. Chaychi Zadeh, "Miniaturized UWB log-periodic square fractal antenna," *IEEE Antennas Wirel. Propag. Lett*., vol. 14, pp. 1322-1325, 2015.

[7] A. Kumar and A. P. S. Pharwaha, "Triple band

fractal antenna for radio navigation and fixed satellite services using dragonfly optimization," *Adv. Electromagn*., vol. 8, no. 3, pp. 43-49, June 2019.
[8] M. A. Dorostkar, R. Azim, M. T. Islam, and Z. H. Firouzeh, "Wideband hexagonal fractal antenna on epoxy reinforced woven glass material," *Appl. Comput. Electromagn. Soc. J*., vol. 30, no. 6, pp. 645-652, 2015.
[9] G. Singh and A. P. Singh, "On the design of planar antenna using Fibonacci word fractal geometry in support of public safety," *Int. J. RF Microw. Comput. Eng*., vol. 29, no. 2, p. e21554, Feb. 2019.
[10] X. Bai, J. W. Zhang, L. J. Xu, and B. H. Zhao, "A broadband CPW fractal antenna for RF energy harvesting," *Appl. Comput. Electromagn. Soc. J*., vol. 33, no. 5, pp. 482-487, 2018.
[11] Y. Zehforoosh and M. Naser-Moghadasi, "CPW-fed fractal monopole antenna for UWB communication applications," *Appl. Comput. Electromagn. Soc. J*., vol. 29, no. 9, pp. 748-754, 2014.
[12] J.-Y. Sze and J.-Y. Shiu, "Design of band-notched ultrawideband square aperture antenna with a hat-shaped back-patch," *IEEE Trans. Antennas Propag*., vol. 56, no. 10, pp. 3311-3314, Oct. 2008.
[13] Y.-C. Lin and K.-J. Hung, "Compact ultra-wideband rectangular aperture antenna and band-notched designs," *IEEE Trans. Antennas Propag*., vol. 54, no. 11, pp. 3075-3081, Nov. 2006.
[14] A. M. Abbosh, M. E. Bialkowski, J. Mazierska, and M. V. Jacob, "A planar UWB antenna with signal rejection capability in the 4-6 GHz band," *IEEE Microw. Wirel. Components Lett*., vol. 16, no. 5, pp. 278-280, May 2006.
[15] I.-J. Yoon, H. Kim, H. K. Yoon, Y. J. Yoon, and Y.-H. Kim, "Ultra-wideband tapered slot antenna with band cutoff characteristic," *Electron. Lett*., vol. 41, no. 11, p. 629, 2005.
[16] K.-H. Kim, Y.-J. Cho, S.-H. Hwang, and S.-O. Park, "Band-notched UWB planar monopole antenna with two parasitic patches," *Electron. Lett*., vol. 41, no. 14, p. 783, 2005.
[17] A. Kumar and A. P. Singh, "Design and optimization of slotted micro-machined patch antenna using composite substrate," *Appl. Comput. Electromagn. Soc. J*., vol. 34, no. 1, pp. 128-134, 2019.
[18] S. B. Yeap and Z. N. Chen, "Microstrip patch antennas with enhanced gain by partial substrate removal," *IEEE Trans. Antennas Propag*., vol. 58, no. 9, pp. 2811-2816, Sep. 2010.
[19] A. Kumar and A. P. Singh, "Design of micro-machined modified Sierpinski gasket fractal antenna for satellite communications," *Int. J. RF Microw. Comput. Eng*., vol. 29, no. 8, Aug. 2019.
[20] I. Papapolymerou, R. Franklin Drayton, and L. P. B. Katehi, "Micromachined patch antennas," *IEEE Trans. Antennas Propag*., vol. 46, no. 2, pp. 275-283, 1998.
[21] A. Kumar and A. P. Singh Pharwaha, "On the design of wideband Sierpinski carpet fractal antenna for radio navigation and fixed satellite services," in *2019 6th International Conference on Signal Processing and Integrated Networks (SPIN)*, pp. 736-738, 2019.
[22] C. Balanis, *Antenna Theory - Analysis and Design*. 3rd ed., New York, USA: John Wiley & Sons Inc., 2005.
[23] T. Ali, K. D. Prasad, and R. C. Biradar, "A miniaturized slotted multiband antenna for wireless applications," *J. Comput. Electron*., vol. 17, no. 3, pp. 1056-1070, 2018.
[24] D. Caratelli, R. Cicchetti, G. Bit-Babik, and A. Faraone, "Circuit model and near-field behavior of a novel patch antenna for WWLAN applications," *Microw. Opt. Technol. Lett*., vol. 49, no. 1, pp. 97-100, Jan. 2007.
[25] G. Sami, M. Mohanna, and M. L. Rabeh, "Tri-band microstrip antenna design for wireless communication applications," *NRIAG J. Astron. Geophys*., vol. 2, no. 1, pp. 39-44, June 2013.

Ashwini Kumar is pursuing his Ph.D degree in the field of Microstrip Patch Antennas from Sant Longowal Institute of Engineering and Technology (SLIET), Longowal, Sangrur, Punjab, India. His research includes Microstrip patch antennas and Fractal antennas Design.

Amar Partap Singh Pharwaha is a Professor of ECE at SLIET, Longowal. Singh is credited with a professional experience of more than 24 years. He has guided seven Ph.D. thesis and published more than 180 research papers in various national and international journals/ conferences.