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RESEARCH PAPER

Compact hybrid fractal antenna for wideband wireless applications

YOGESH KUMAR CHOUKIKER AND JAGADISH CHANDRA MUDIGANTI

A compact size hybrid fractal antenna is proposed for the application in wideband frequency range. The proposed antenna structure is the combination of Koch curve and self-affine fractal geometries. The Koch curve and self-affine geometries are optimized to achieve a wide bandwidth. The feed circuit is a microstrip line with a matching section over a rectangular ground plane. The measured impedance matching fractal bandwidth ($S_{11} \leq -10$ dB) is 72.37% from 1.6 to 3.4 GHz. An acceptable agreement is obtained from the simulated and measured antenna performance parameters.

Keywords: Antenna design, Modeling and measurements, Antennas and propagation for wireless systems

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I. INTRODUCTION

Owing to the progress in wireless communication systems and increase in their application, small size and wideband antennas are in great demands. These have recently received a great deal of attention from researcher creating new antenna structures. One such structure is the fractal shape. The fractal concept was introduced in antenna field to design new innovative and competitive antennas for modern communication system technology [1]. Fractal shaped antennas show some interesting properties such as self-similarity and scale-invariance. This can be carried out by applying the infinite number of iteration using multiple reduction copy machine (MRCM) algorithm. In the last decade, researches on fractal antennas were performed especially on deterministic structures where exact mathematic relationships are well defined to describe the fractal structures [2–4]. The space filling property, when applied to an antenna element, leads to an increase of the electrical length. The more convoluted and longer surface currents result in lowering the antenna resonant frequency for a given overall extension of the resonator. The fractal miniaturization technique has already been applied to Koch wire monopole [4], combination of fractal geometries [5–10], and the Sierpinski fractal-shape antennas [11]. Although the essence of this technique falls into the inductive loading, the radiation patterns of the antennas derived from this technique are maintained because of the self-similarities of the fractals.

In this paper, we have proposed a compact hybrid fractal antenna as a radiating element for the wideband applications. It is a combination of Koch curve and self-affine fractals with compact size of 11.60×25.4 mm^2. It covers several wireless bands like DCS-1800 (1.71–1.88 GHz), PCS-1800 (1.80–1.99 GHz), UMTS (1.92–2.17 GHz), IMT-2000 (1.9–2.2 GHz), WiBro (2.3–2.4 GHz), Bluetooth (2.4–2.48 GHz), WLAN 802.11b/g/a (2.4–2.5 GHz), and Wi-Fi. This antenna provides the omnidirectional radiation patterns and gain is more than 2 dBi for the wide frequency band.

Department of Communication Engineering, School of Electronics Engineering, VIT University, TN, India
Corresponding author:
Y.K. Choukiker
Email: yogesh.ku.84@gmail.com

II. ANTENNA GEOMETRY AND SIMULATION RESULTS

A) Antenna geometry

The recursive procedure of the Koch and self-affine fractal curves are shown in Fig. 1. To obtain the self-similarity dimensions, the geometry is scaled down, but with identical copies of itself. If there are n such copies of original geometry scaled down by a function S, the similarity dimension D is defined as described in equation (1).

$$D = \frac{\log n}{\log 1/s}. \tag{1}$$

For example, a square can be divided into four copies of 1/2 scale, nine copies of 1/3 scale, 16 copies of 1/4 scale, or n^2 copies of $1/n$ scale. Substituting in the above formula, the dimension of the geometry is ascertained to be 2. This approach can be followed in determining the dimension of fractal geometries. For construction of Koch and self-affine fractal curves, one can start with a straight-line (l) called initiator and it is divided into three equal parts ($l/3$). This is the first iterated version of geometry and is called "generator" for higher iterations, as shown in Figs 1(a) and 1(b). This procedure is iterated recursively to result in self-similar fractal geometry by taking the order of iteration n and the dimension D (equation (1)) as the input parameters. Basically, individual

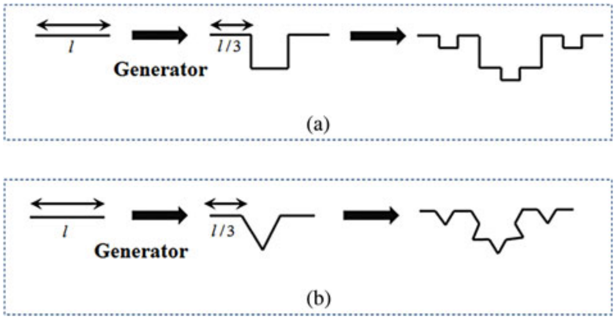

Fig. 1. Three initial stages of generation: (a) self-affine curve fractal and (b) Koch curve fractal geometries.

iterations are applied to both the Koch and self-affine fractal curves, which are then combined to get hybrid fractal geometry. For further optimizations, dimension "D" for both fractals are varied simultaneously.

The structure of the proposed hybrid fractal antenna for wideband operation is shown in Fig. 2 with corresponding optimized parameters are listed in Table 1. The proposed geometry is constructed using Koch curve and self-affine fractals. Koch curve is applied to the lower edge of rectangular patch with iteration factor of 3. The upper edge of rectangular microstrip is replaced by the self-affine fractal, which is constructed by a factor of 3 and 2 in the horizontal and vertical directions, respectively. The motivation of such geometry is to improve space filling, a feature that translates it into reduced antenna physical size and to increase the bandwidth. Also, fractal antennas have an increased number of resonant frequency bands, a valuable feature that can be advantageous for multi-functional and multi-standard wireless devices. The benefit of combining of Koch curve and self-affine fractal geometries is that it is having plane filling property. Self-affine geometry leads to curves that electrically very long, but can fit in a compact physical area. There are several benefits for choosing such self-affine. The first benefit is that the increased electrical length leads to lower resonant frequency, which effectively provides miniaturized antenna. The second benefit is that the increased electrical length can raise the input resistance of the antenna when it is used in a small antenna. Choosing Koch fractal curve is to understand the behavior of the resonant frequency of fractal antenna as a function of the antenna geometry. The proposed antenna is fed by a 50 Ω microstrip line of width, W_f, which is built on one side of a FR-4 dielectric substrate (thickness h_s and relative permittivity, $\varepsilon_r = 4.4$) of 66 × 27 mm². On the other side of the substrate, a rectangular ground plane of length 39 mm and width 27 mm is used as reflector element.

B) Simulations results

Figure 3 shows the simulated reflection coefficients of proposed hybrid fractal antenna for different iteration levels. It is observed that with increase in number of iteration, the average electrical length of the patch also increases just like the inductive loading and slot-loading techniques reported in [12]. Thus, it can be lowered the resonant frequency of the proposed patch antenna. However, for more than second iterations, the reduction of operating frequency is not achievable and the antenna design becomes quite complicated as well as its fabrication becomes difficult. Figure 4 shows the simulated reflection coefficient of the proposed antenna for the gap (g) between radiating element and ground plane. It is observed that for $g = 1$ mm the antenna

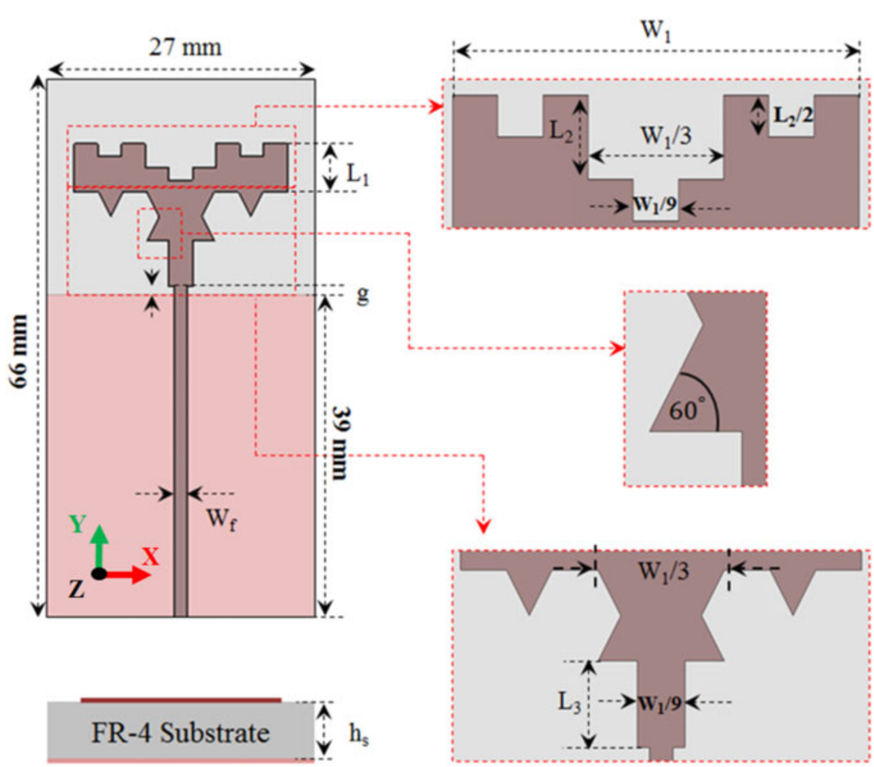

Fig. 2. Geometry of proposed hybrid fractal planar monopole antenna.

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Table 1. Dimensions of proposed hybrid fractal antenna (All the dimensions in mm).

L1	L2	L3	W1	W_f	g	h_s
5.8	2.9	5.5	25.4	1.5	1.0	1.58

has the desired bandwidth. Although at different values of gap (g) show a frequency shift at the higher band. In addition, the reflection coefficient has high value at $g = 1$ mm compared with other values of g. Figure 5 shows the reflection coefficient of the proposed antenna for width (W_1) of radiating element. It is found that at $W_1 = 25.4$ mm the antenna has the desired bandwidth. For the other values of W_1 the operating band is low compared with W1 = 25.4 mm. Here, also the reflection coefficient is high compared to other values of W_1. Figure 6 shows the reflection coefficient of proposed antenna for length (L_3) of lower edge of radiating element. It is observed that the reflection coefficient is quite well at $L_3 = 5.5$ mm. Although, when we increase or decrease the length (L_3), frequency shift is observed at higher-frequency band. Figure 7 shows the simulated reflection coefficients for different sizes of the radiating element (L_1). It is found that when the size of the radiating element (L_1) decreases, the impedance matching at the lower frequencies improves. For, $L_1 = 5.8$ mm the bandwidth of hybrid fractal antenna is 72.37% over 1.6–3.4 GHz frequency range. Optimum performance is obtained in terms of compact size and broad bandwidth of the proposed antenna, keeping other parameters fixed. Figure 8 shows the simulated three-dimensional (3D) radiation pattern and surface current distribution at 1.9 and 3.07 GHz for the proposed hybrid fractal antenna. It is observed from the proposed antenna having omnidirectional radiation property for wide frequency band. In addition, the surface current distribution of current in lower frequency covers feed line and edges of the radiating element besides for higher frequency current moves toward the tip as well as it covers radiating element.

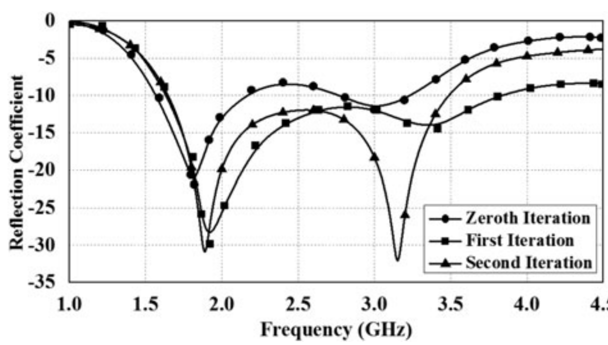

Fig. 3. Reflection coefficient of proposed hybrid fractal antenna for different iteration levels.

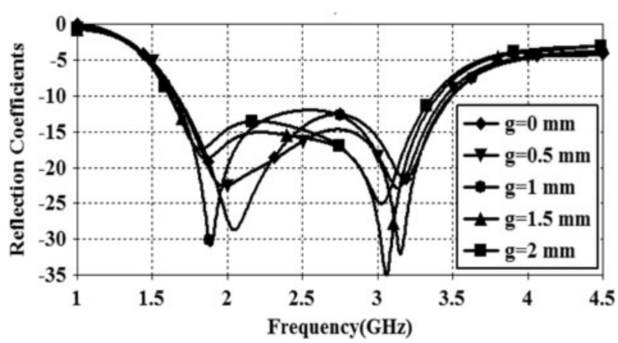

Fig. 4. Reflection coefficient of proposed hybrid fractal antenna for gap (g) between radiating element and ground plane.

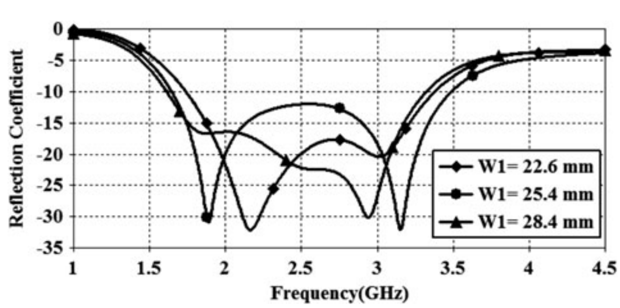

Fig. 5. Reflection coefficient of proposed hybrid fractal antenna for width (W_1) of radiating element.

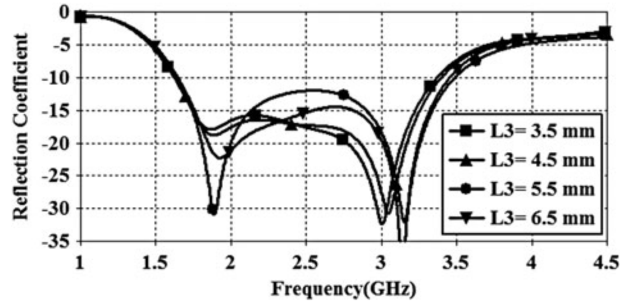

Fig. 6. Reflection coefficient of proposed hybrid fractal antenna for length (L_3) for radiation element.

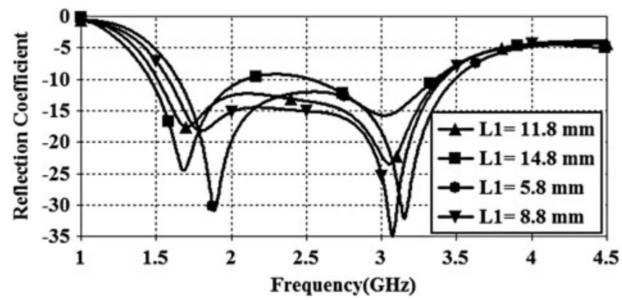

Fig. 7. Reflection coefficient of proposed hybrid fractal antenna for length (L_1) for radiating element.

III. EXPERIMENTAL VERIFICATIONS

Proposed hybrid fractal antenna is milled on the copper side of FR-4 substrate using LPKF-42 Protomat milling machine. Photographs of fabricated antenna are shown in Fig. 9. Measured and simulated values of the reflection coefficient magnitude are plotted in Fig. 10. These results exhibit reasonable agreement although there is a frequency shift that can be

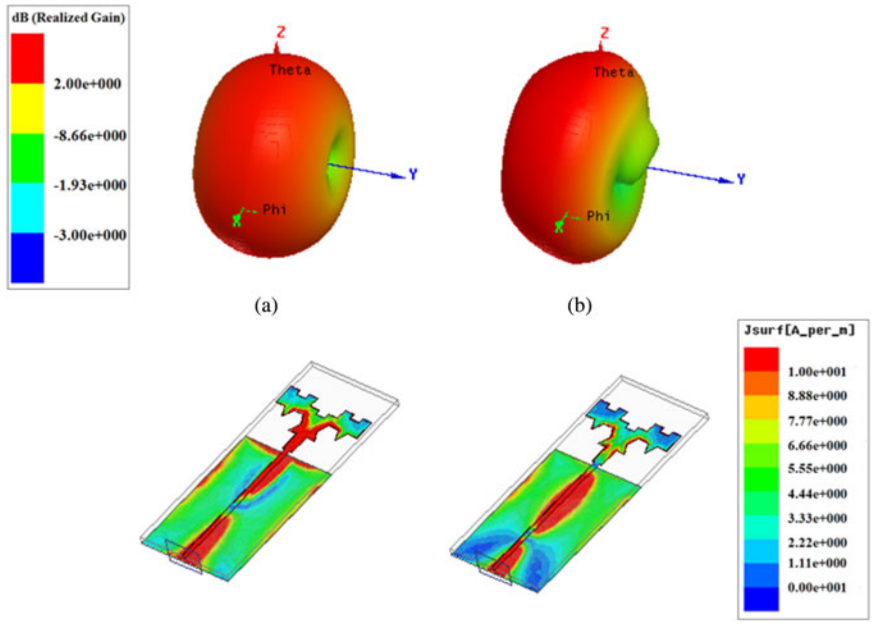

Fig. 8. 3D radiation patterns and surface current distribution of the proposed antenna at (a) 1.9 GHz and (b) 3.07 GHz.

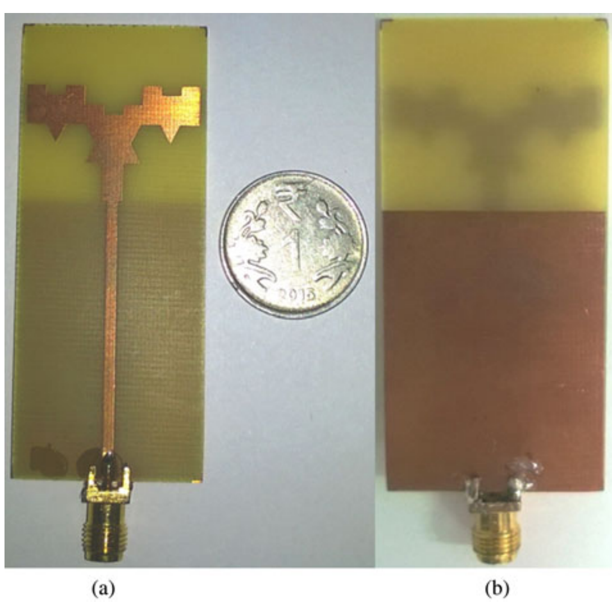

Fig. 9. Photograph of proposed hybrid fractal planar monopole antenna.

attributed to reflection from SMA (SubMiniature version A) connector and some uncertainty in the electrical properties of the substrate. The −10 dB impedance bandwidth is 72.37%, which is achieved from 1.6 to 3.4 GHz with resonances at 1.9 and 3.07 GHz. Therefore, the antenna covers wireless band such as DCS-1800 (1.71–1.88 GHz), PCS-1800 (1.80–1.99 GHz), UMTS (1.92–2.17 GHz), IMT-2000 (1.9–2.2 GHz), WiBro (2.3–2.4 GHz), Bluetooth (2.4–2.48 GHz), WLAN 802.11b/g/a (2.4–2.485 GHz), and Wi-Fi. The measured *E*- and *H*-plane radiation patterns at 1.9 and 3.07 GHz are shown in Fig. 11. The proposed antenna radiation patterns are stable like monopole, which are almost omnidirectional in the *XZ* (co-pol. and cross-pol.) and *YZ* (co-pol. and cross-pol.) planes. It may be noted that there is a slight discrepancy in the measured radiation pattern at 0° and 180° in the *XZ* and *YZ* planes although they correspond to the same point in radiation pattern. This may be attributed to the impedance mismatch between cable and antenna that could have arisen during measurement, while the antenna was rotated on the turn-table. Table 2 shows the measured gain and total antenna efficiency at different frequencies. We can observe that, some variation in measured and simulated gain occurs but the difference is not consistent in

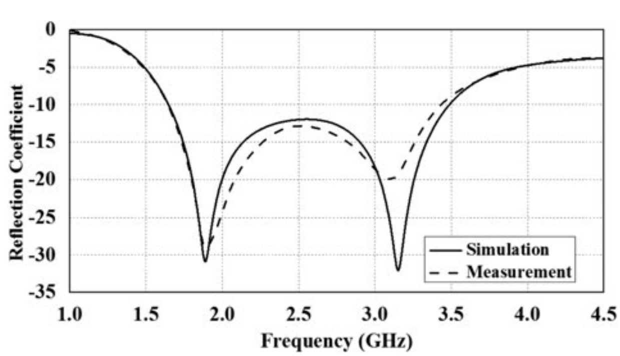

Fig. 10. Simulated and measured reflection coefficient of proposed hybrid fractal planar monopole antenna.

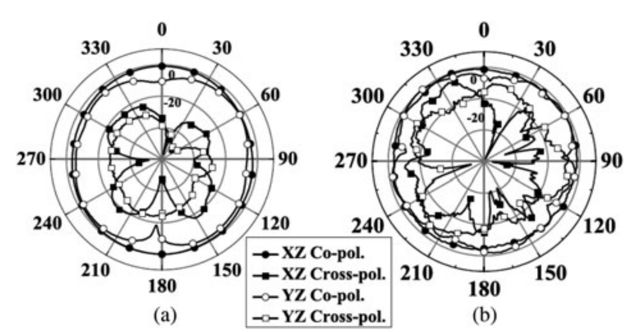

Fig. 11. Measured radiation patterns for proposed antenna: (a) at 1.90 GHz and (b) at 3.07 GHz.

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Table 2. Gains and total antenna efficiency of proposed hybrid fractal antenna.

Frequency (GHz)	Simulated gain (dBi)	Measured gain (dBi)	Simulated antenna efficiency (%)
1.6	1.29	0.97	75.20
1.9	1.76	1.74	89.56
2.5	2.04	2.63	87.90
3.07	4.12	4.37	86.34
3.5	3.60	4.35	84.26

nature. This may be attributed to fabrication tolerances associated with fractal shape, when simulation expected sharp edges, but fabrication provided rounded corners. The maximum peak realized gains in the two resonant frequencies are 2.58 dBi (at 1.9 GHz) and 4.18 dBi (at 3.07 GHz). The simulated total antenna efficiency is found to be more than 75% throughout the band.

IV. CONCLUSIONS

A compact hybrid fractal planar monopole antenna has been investigated. By incorporating the Koch curve and self-affine curve fractals, it is found that the operating frequency of the fractal antenna is lowered greatly. The measured impedance bandwidth is 72.37% for frequency band 1.6–3.4 GHz, which is suitable for several wireless communication band such as DCS-1800 (1.71–1.88 GHz), PCS-1800 (1.80–1.99 GHz), UMTS (1.92–2.17 GHz), IMT-2000 (1.9–2.2 GHz), WiBro2.3–2.4 GHz), Bluetooth (2.4–2.48 GHz), WLAN 802.11b/g/a (2.4–2.485 GHz), and Wi-Fi. The measured radiation patterns are stable throughout the operational band. Therefore, the proposed antenna is feasible for the use as a low profile and low-cost wideband antenna and supporting wireless communication systems.

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Y.K. Choukiker received the M.Tech. and Ph.D. degrees in Electronics and Communication Engineering from National Institute of Technology, Rourkela, India in 2009 and 2014, respectively. He specialized in Antenna and wave propagation. In particular, his research interest is Microstrip antenna (Fractal antennas) in the area of wireless application, MIMO environment, UWB, reconfigurable fractal, etc. He completed the ISRO Respond project in the year of 2013, which is based on the optimization techniques. In January 2014, he joined Vellore Institute of Technology (VIT), Vellore, TN, India, as an Assistant Professor with School of Electronic Science (SENSE) in Microwave and Optics Division. Currently, he is an Associate Professor in VIT, University. He is a Member of IEEE, USA. He acts/acted also as a reviewer for various journals (e.g., IEEE Transactions on Antenna and Propagation, IEEE Antenna and Wireless propagation letter, Wireless Personal Communications, IET Microwave and Antenna, etc.) and several conference papers.

J.C. Mudiganti obtained his bachelor and Master of Science degrees in applied electronics from Osmania University, India, in 1996 and 1998, respectively. He joined Central Electronics Engineering Research Institute, Pilani, India, as a project scientist in 1999. Later in 2000, He joined Institut Theorie Electromagnetischer Felder under Technical University of Darmstadt, Germany, as research assistant which

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resulted in a Ph.D. in 2006. He had joined Indian Institute of Technology Roorkee, India in 2008 as a research associate, where he worked toward design and development of high power gyrotrons for fusion reactors. In 2010, he joined Research Center for Development of Far-Infrared Region, University of Fukui, Japan as a post-doctoral fellow. He worked in the design and development of a sub-Terahertz source for NMR spectroscopy. In 2014, he joined VIT University, India, where he is currently an Associate Professor in the school of electronics engineering. He specializes in areas of computational electromagnetics, high-power microwave sources, and antennas.