Bandwidth Enhancement of Cross-Shaped Fractal Antenna Using Lanthanum Doped Ba-Sr Hexagonal Ferrite As Substrate Material For X-Band Applications

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Abstract

This paper analyzes and compares the performance of a proposed cross-shaped fractal antenna design with two different substrate materials FR4 epoxy and lanthanum doped Ba-Sr hexagonal ferrite in X-band, where the lanthanum doped Ba-Sr hexagonal ferrite substrate is synthesized based on solid-state reaction method. The proposed antenna design is simulated using HFSS (High frequency structure simulator) version 15. The antenna is intended to work at 10 GHz frequency and involves four iterations. The antenna design is optimized for significant performance parameters viz. return loss, bandwidth, and gain. It provides better results with ferrite substrate as compared to FR4 epoxy substrate and provides –10 dB broad bandwidth in three frequency regions 6.2969-6.4 GHz, 7.8702-9.44 GHz, and 9.68-9.7746 GHz. The prototype of proposed antenna with FR4 epoxy substrate is fabricated and tested to attain experimental results. The measured results are in good liaison with simulated results. This antenna structure can be considered suitable for RADAR, satellite, microwave communication, and weather forecasting applications in X-Band.

Introduction

In the present communication system, a high bit rate is a rigorous necessity to assist high-speed multimedia services. Thus, a large bandwidth is acquired by maximum data providers. In the meantime, the lesser size of antennas is essential at the transmitter and receiver side in addition to the large amount of bandwidth [1, 2]. The foremost requirement of MPA (microstrip patch antenna) is to obtain broad bandwidth whereas maintaining reduced size. Several methods are existing in earlier research papers that focus on the growth of multiband/broadband antennas, which comprise parasitic patch, electromagnetic bandgap materials (EBG), dual feed, the addition of slots, stacking of patch antennas, defective ground structure (DGS), low permittivity substrate materials, and use of fractal structures [3-5]. The present research paper is related to the fractal design that keeps up all these prerequisites of a high-speed communication system. Fractal structures are preferred because of their main properties such as self-correlated, space-filling, and fractional ratios. Thus, fractal antennas are more beneficial over conventional microstrip patch antennas because they provide multiband/broadband behavior along with size miniaturization [6-13].

Depending upon the literature survey prepared in this concern; it is perceived that there are many shapes of fractal structures that are used in antenna designs such as Koch snowflake, Sierpinski carpet, Sierpinski gasket, Minkowski fractals, Moore, and Hilbert curve along with some different shapes over a period of time [7-13]. In addition, various researchers have presented some ideas related to cross, plus-shape, and Chaucer shape fractal antennas due to their simple geometries. As S. Jagadeesha et al. designed multiband fractal antenna with a plus-shaped patch and FR4 substrate and examined bandwidth of 12.92% along with broadside radiation properties [14]. B.S. Dhaliwal et al. proposed the design of multiband fractal antenna using FR4 substrate with a cross-stitch structure of patch and obtained enhanced gain and bandwidth in three bands. The radiation pattern of antenna can produce directivity up to 10.8 dbi [15]. R.K. Yadav et al. designed a Chaucer fractal antenna using FR4 substrate with the insertion of the split ring at center and observed return loss values of -24 dB, -14.62 dB, and -10.50 dB along with omnidirectional radiation patterns at frequencies 6.58, 8.62, and 9.60 GHz [16]. N. Kaur and A. Kaur developed a plus-shaped carpet form fractal antenna, which is operated in C/X/UWB/WIBAN band. The antenna is designed with two FR4 substrate layers, I-shaped DGS, and aperture coupled feed. It is observed that a maximum gain of 4 dB at 7.95 GHz, and multi bands in frequency regions 5.2-5.45 GHz, 5.65-5.85 GHz, 6.5-6.9 GHz, and 7.2-10.3 GHz are examined in the analysis of designed antenna [17]. Though some researchers have proposed the plus/cross/chaucer shaped fractal antenna designs in the past [14-17], however it was observed that in the previous published articles, plus/cross shape patch material is added in the outer area of basic patch instead of reducing copper material from basic patch which increases the metal size on the front side of substrate, consequently increasing the fabrication cost. In this paper, a cross-shaped fractal antenna is proposed where copper material is truncated from the basic patch to acquire the proposed design which provided the add-on benefit of reduced size, which is another significant requirement of modern antenna structures. Furthermore, two types of substrates can be used for antenna designing. The first type is conventional dielectric material with permittivity>1 but permeability=1. The second type is ferrite substrate with permittivity as well as permeability greater than one [18]. According to previous literature, earlier only limited conventional dielectric materials have been used in fractal antenna designs and among them FR4 is used in maximum antenna designs as it is easily available in market and inexpensive. However, there are some disadvantages of FR4 substrate such as with increase in frequency, the losses in FR4 substrate are increased; along with variation in dielectric constant at high frequencies [19]. To overcome disadvantages and limitations of earlier used dielectric substrates, some research work is started with composed/synthesized ferrite substrates. Ferrite materials attracted microwave specialists for two causes. Firstly, they provide two degrees of freedom in changing the material properties which are relative permittivity (ε_r) and relative permeability (μ_r), so providing enhanced flexibility. Secondly, they provide great dielectric strength at the high range of frequencies such that the eddy current losses are negligible and thus highly applicable for high-frequency range applications. Thus, these materials are highly suitable for microwave applications [20-22].

Despite all of the above merits, yet only few researches have been performed on the conventional microstrip patch antenna designs using ferrite substrates and good results are achieved by optimizing different constituents of materials, synthesis method, doping and sintering temperature of antenna substrate [23-27]. W. Lee et. al. designed a miniaturized multiband antenna using air-core and $BaCo_{1.4}Zn_{0.6}Fe_{16}O_{27}$ hexagonal ferrite, with different loading configurations of ferrite, four slots, connecting lines, six shorting pins along with specific dynamic properties of ferrite material such as μ_r=2, ε_r=7.3, $\tan\delta_\varepsilon$=0.005, and $\tan\delta_\mu$=0.035 at frequency 1 GHz and provides good impedance matching, broad bandwidth, omnidirectional radiation pattern, good gain, and miniaturization [23]. I.H. Hasan et al. proposed MPA design with thick ferrite film of Yttrium iron garnet on FR4 substrate at 5.8 GHz frequency and examined improvement in return loss and bandwidth [24]. S.R. Bhongale et al. designed an MPA using magnesium-doped cadmium ferrite substrate in the X-band region and investigated maximum return loss of -29.05 dB, -10dB percentage bandwidth of 87.1, VSWR of 1.04, and beamwidth of 95^o [25].

Then, S.R. Bhongale prepared the spinel ferrite Mg/Nd/Cd and used as a substrate in X-band MPA and obtained better performance in the form of return loss, bandwidth, and VSWR [26]. Later, R.K. Paulraj and R. Kalidass designed a patch antenna using a dielectric substrate of magnesium ferrite doped with lanthanum material, which is synthesized using the sol-gel method and obtained return loss, gain, and directivity of -12.85 dB, 7.67 dB, and 7.47 dB respectively at resonant frequency 2.4 GHz [27]. It is observed from above literature that ferrite substrate provides flexibility to microstrip patch antenna designs with different compositions of materials. Also, it is examined from earlier discussion that fractal geometries offer many advantages as compared to simple microstrip patch antennas [6-13].

Nonetheless, no significant research has been reported to enhance the performance of fractal antennas using ferrite substrates. Henceforth, the favorable results obtained in the literature for conventional microstrip antenna designs with ferrite substrate has led an inspiration to perform research on proposed fractal antenna design and improve its performance with novel composed ferrite substrate. In this paper, a new cross-shaped fractal antenna is proposed due to its simple geometry and this design is compared by using FR4 substrate and innovative ferrite substrate. This antenna operates in X-band frequency region and the microstrip feed line is used in this design to provide an input signal to the antenna. It involves four iterations from iteration 0 (basic design) to iteration 3. This design provides multiband and broad bandwidth with ferrite substrate as compared to FR4 substrate. The simulated design covers frequency region of 8.7617 - 9.5750 GHz with FR-4 epoxy substrate in iteration 3 whereas it covers frequency regions of 6.2969-6.4 GHz, 7.8702-9.44 GHz, and 9.68-9.7746 GHz using lanthanum doped Ba-Sr hexagonal ferrite substrate in iteration 3. Thus, the proposed antenna has some advantages such as low profile, multiband, and broad bandwidth in the desired band using ferrite substrate. After the introduction, the following contents of the paper are discussed as proposed design of the antenna and its layout, then the proposed design is simulated and simulation results are discussed. Afterward, proposed design of the antenna with FR4-epoxy substrate is fabricated, and results are measured. Then conclusion is given related to this design analysis in next part. In last, future scope is presented.

Proposed Design Of The Antenna And Its Layout

The major requirement of this proposed antenna is to design a broadband fractal antenna that can assist a high bit rate to encourage the present wireless communication system in X-band. Therefore, this cross-shaped fractal antenna is designed with a wideband approach for X-band applications including defense, satellite, RADAR, and weather forecasting. The proposed antenna is designed for four iterations (iteration 0 to iteration 3). Initially, an anticipated antenna structure is designed on commercially available FR4 epoxy substrate material having dielectric loss i.e., tan δ of 0.02 and permittivity of 4.4. The dimensions of substrate are considered 19 mm × 19 mm × 1.575 mm.Also, dimensions of the ground are taken as 19mm × 19 mm. The microstrip feed line is used to deliver input to the proposed antenna. In all iterations, the same feeding point is used. The dimensions of feed line are 4.11mm × 3mm. Optimum values of different parameters are taken to attain a wide bandwidth through parametric analysis. To design iteration 0, two rectangular stripes of dimensions 17mm and 8.5mm are taken and joined to make a cross shape radiating patch. Further, iteration 1 is considered by taking one more cross joined with two rectangular stripes, each having size 10.5mm × 3.5mm and this cross is cut from the base cross taken in iteration 0. Thus the metallic area of patch is reduced and the perimeter of radiation patch is increased. This is one of the important characteristics of the fractal antenna. Next, another four crosses, each made by two rectangular stripes of dimensions 1mm × 2.5mm are cut symmetrically from the metallic area of iteration 1 to obtain iteration 2. Again, to design iteration 3, four slots each made by two rectangular stripes of dimensions 0.35mm × 1.7mm are cut symmetrically from the remaining metallic patch of iteration 2. Then, SMA (Sub Miniature version A) connector with 50Ω value is attached to deliver the input signal through the terminal point of the feed line. Table 1 represents the dimensions of the designed antenna.

Table 1 Dimensions of the designed cross-shaped fractal Antenna

Elements	Scale	Dimensions (mm)
Substrate	Length L_s	19
	Width W_s	19
	Height	1.6
Patch	Length	17
	Width	17
Feed Line	Length F_L	4.11
	Width F_w	3
Ground	Length	19
	Width	19
Fractal Patch Metal	Length L1	17
	Width W1	8.5
	Length L2	8.5
	Width W2	17
	Length L3	4.25
	Width W3	4.25
	Length L4	4.25
	Width W4	2.75
Slots	Length L5	10.5
	Width W5	10.5
	Length L6	3.5
	Width W6	3.5
	Length L7	3.5
	Width W7	3.5
	Length L8	0.755
	Width W8	1
	Length L9	0.675
	Width W9	0.35

Fig. 1(a)-(d) shows all iterations of the proposed fractal antenna. This is represented as self-similar cross-shaped iterations (0 to 3) to design a final fractal antenna. The black portion in Fig. 1(a)-(d) represents the metal portion and white portion signifies the removed metal from the patch of antenna.

The novelty of this research is that the proposed design is also simulated with synthesized/composed lanthanum substituted Ba-Sr hexagonal ferrite substrate which is presented by chemical formula $Ba_{0.5}Sr_{0.5}Co_xLa_xFe_{(12-2x)}O_{19}$, Where ($0.0 \leq x \leq 1.0$ with steps of x=0.2). This ferrite substrate is composed based on solid-state reaction (standard ceramic) method which is arranged using typical ceramic technique and sintered in a microwave furnace at a temperature of 1100 ^oC.

According to literature survey, there are various advantages of composed ferrite substrates. Moreover, these materials can be used to enhance the bandwidth of patch antenna. Also, the zero-order bandwidth is reliant on permittivity/permeability as suggested by Hansen and Burke is represented by equation (1).

$$BW \approx \frac{96\sqrt{\frac{\mu_r}{\varepsilon_r}}}{\sqrt{2}\ [4 + 17\sqrt{\mu_r \varepsilon_r}\,]}\frac{h}{\lambda_o} \qquad (1)$$

where *h*, *μr*, *εr* are known as thickness of ferrite substrate, relative permeability and relative permittivity [28]. In [29], H. Kaur et al. have already synthesized M-type Ba-Sr hexagonal ferrite with addition of doping ions Co2+ and La3+ ions and validated properties of composed material as ferrite which can be used as substrate for various applications in X-band. It is observed that reflection loss of -43.33 dB is obtained. Thus, ferrite material is recommended as a suitable substrate material for the proposed fractal antenna design, which provides more bandwidth as compared to FR4 epoxy substrate in X-band.

Simulation Results

The cross-shaped fractal antenna design is simulated initially with FR4 substrate and after that simulated with synthesized lanthanum substituted Ba-Sr hexagonal ferrite substrate material in (6-12) GHz band. Then, the performance of intended antenna is analyzed for both substrates with the investigation of certain important parameters such as return loss, bandwidth, and gain. The return loss represents how much energy is going from the feeding point to the designed antenna. If there is impedance mismatch, then the signal can be reflected back from the feed point and will not be radiated by antenna. The return loss of less than -10 dB at a resonant frequency is admissible. The radiation pattern of antenna represents the directional strength of electromagnetic waves from the prototype antenna. It presents the radiation of signal strength by designed antenna corresponding to azimuth and elevation angles at a particular resonant frequency. It is presented as far-field radiation pattern for two main planes referred to as E plane (phi=90 deg) and H plane (phi=0 deg) at observed resonant frequencies [4]. Simulation results of the proposed antenna with FR-4 glass epoxy material and lanthanum substituted Ba-Sr hexagonal ferrite substrates are given below.

FR4 Glass Epoxy Material

FR4 is a flame-resistant (called flame retardant) composite material which is composed of woven fiberglass cloth by an epoxy resin binder. The material FR4 has dielectric loss value i.e., tan δ of 0.02 and permittivity of 4.4 [2]. The important parameters of designed cross-shaped antenna with FR4 substrate material are explained in this section. The performance of different parameters is observed in the (8-12) GHz frequency region. The simulation results of return loss, and bandwidth for all iterations using FR4 substrate material are given in Table no 2.

Table 2 Results of the simulated cross-shaped fractal antenna design using FR4 substrate material

Iteration No	Resonant frequency (GHz)	Return loss (dB)	Bandwidth
0	8.9710, 10.0599	-23.1478, -12.0282	(9.17-8.6898) GHz =480.2 MHz, (10.17-9.8604) GHz =309.6 MHz
1	9.3916	-30.7699	(9.82-8.9439) GHz =876.1 MHz
2	9.1789	-21.4309	(9.6093-8.8005) GHz =808.8 MHz
3	9.1789	-22.2827	(9.5750-8.7617) GHz =813.3 MHz

Fig. 2 shows the comparison of simulated return loss for all iterations using FR4 substrate. It is perceived from the figure that two values of return loss -23.1478 dB and -12.0282 dB are examined at resonant frequencies 8.9710 GHz and 10.0599 GHz in iteration 0, also return loss of -30.7699 dB, -21.4309 dB and -22.2827 dB are obtained at resonant frequencies 9.3916 GHz, 9.1789 GHz, and 9.1789 GHz in iterations 1, 2 and 3 respectively. There is another specific parameter called impedance bandwidth which is a range of frequencies where antenna represents good impedance matching. It can be examined that antenna covers frequency regions 8.6898-9.17 GHz and 9.8604- 10.17 GHz with corresponding bandwidths of 480.2 MHz and 309.6 MHz in iteration 0, also antenna covers frequency regions of 8.9439-9.82 GHz, 8.8005-9.6093 GHz, and 8.7617-9.5750 GHz having bandwidths of 876.1 MHz, 808.8 MHz and 813.3 MHz in iterations 1, 2 and 3 respectively.

It is observed that resonant frequency is reduced with increasing iterations from iteration 1 to iteration 3. Moreover next iterations are not preferred because there is no further reduction of resonant frequency. Additionally, complexity is increased in the design for the iteration 4 that makes it difficult to get it fabricate with required precision (the slot width of cross used in iteration 3 is already 0.35mm). Hence, only four iterations (iteration 0 to iteration 3) are included in the final design. Therefore, iteration 3 is considered to finalize the design of fractal antenna.

Lanthanum doped Ba-Sr Hexagonal Ferrite as a Substrate

Lanthanum substituted Ba-Sr hexagonal ferrite substrate is prepared based on solid-state reaction (standard ceramic) method. There are some steps that are to be followed to compose a substrate using this method. These are named as weighing, mixing, grinding, drying, pre-sintering, crushing of powder in a pestle mortar and sieving of powder using sieves with a mesh size of 220 B.S.S. Moreover, the filtered powder is mixed with PVA binder and then the pallet is prepared using a hydraulic press of 75 KN/m^2 uniaxial pressure [29,30]. The final sintering is done at a temperature of 1100 ^oC. Then, some characterization techniques are used to investigate the structural, electric and magnetic properties of the designed substrate to observe its suitability in X-band.

The S-parameters are analyzed using VNA (Vector Network Analyszer) to find complex permittivity and complex permeability of material compositions in X-band.

Complex permittivity; $\varepsilon_r = \varepsilon' - \varepsilon''$ (2)

Complex permeability; $\mu_r = \mu' - j\mu'$ (3)

ε', μ', ε'', and μ'' are called as permittivity, permeability, dielectric loss, and magnetic loss [29].

Moreover, tangent loss and magnetic loss are expressed as

$tan\delta\ \varepsilon = \varepsilon''/\varepsilon'$ (4)

$tan\delta\ \mu = \mu''/\mu'$ (5)

ε_r, μ_r, $tan\delta_\varepsilon$, and $tan\delta_\mu$ are required parameters of ferrite substrate which are used to increase performance of fractal antenna design. Figs. 3 and 4 represent variations of ferrite parameters with respect to frequency. Because of variations of these parameters versus frequency is achieved as desired so we used this ferrite material as antenna substrate in the present research based on our earlier research.

Comparison of simulated antenna using Fr4 Epoxy substrate material and lanthanum substituted Ba-Sr hexagonal ferrite substrate material

After the preparation of lanthanum doped Ba-Sr hexagonal ferrite, it is used as a substrate of proposed antenna. This proposed design is simulated with ferrite substrate and its results are analyzed. It is observed that the simulated antenna using ferrite substrate covers the frequency region of 7.8702-9.44 GHz with lower cut-off frequency (-10 dB) existing below the X-band region. Also, the antenna covers another frequency region i.e. 9.68-9.7746 GHz at resonant frequency 9.74 GHz, therefore antenna is simulated in frequency region 6-12 GHz to observe its behavior in this frequency range. Then, it covers one more frequency region 6.2969-6.4 GHz at resonant frequency of 6.36 GHz. Further, various performance parameters of the proposed antenna are compared for both substrate materials in frequency region 6-12 GHz, as represented by Table 3. It is cleared from Table 3 that the proposed antenna designed with FR-4 epoxy resonates at frequency 9.1789 GHz and provides return loss, bandwidth, and gain of -22.2827 dB, 813.3 MHz, and 5.7928 dB respectively. On the contrary, the proposed antenna designed with lanthanum doped Ba-Sr hexagonal ferrite substrate material resonates at 6.36 GHz, 9GHz, and 9.74 GHz and provides return loss of -21.8962 dB, -21.0406 dB, and -11.1134 dB. It also provides bandwidths of 103.1 MHz, 1.5698 GHz, and 101.1 MHz along with gain of 9.2927 dB, 4.4306 dB, and 2.0587 dB at resonant frequencies 6.36 GHz, 9 GHz, and 9.74 GHz respectively.

Table 3 Comparison of simulated design using FR4 epoxy and Lanthanum doped Ba-Sr hexagonal ferrite substrate

materials

FR4 Epoxy				Lanthanum doped Ba-Sr hexagonal ferrite as a substrate			
Resonant Frequency (GHz)	Return loss (dB)	Bandwidth	Gain (dB)	Resonant Frequency (GHz)	Return loss (dB)	Bandwidth	Gain (dB)
9.1789	-22.2827	(9.5750-8.7617) GHz =813.3 MHz	5.7928	6.36	-21.8962	(6.4-6.2969) GHz =103.1 MHz	9.2927
				9	-21.0406	(9.44-7.8702) GHz =1.5698 GHz	4.4306
				9.74	-11.1134	(9.7746-9.68) GHz =101.1 MHz	2.0587

Fig. 5 represents a comparison of return loss using both substrate materials. Fig. 6 represents 3D polar plot gain of the designed antenna using FR4 substrate at resonant frequency 9.1789 GHz, Where figs. 7(a)-(c) represent 3D polar plots of designed antenna using ferrite substrate at resonant frequencies 6.36 GHz, 9 GHz, and 9.74 GHz respectively.

Also, the radiation pattern is one of the specific parameter of antenna, which represents power directing capacity of an antenna in a particular direction. Figure 8 (a) represents E plane (phi=90 deg)/H plane (phi=0 deg) simulated normalized far field radiation patterns of designed antenna using Ferrite substrate at 6.36 GHz which are directional approximately toward 330^o-30^o, fig. 8 (b) represents E/H plane radiation pattern at 9 GHz, where E plane is directional near 30^o and H plane shows omnidirectional radiation pattern and fig. 8 (c) represents E/H plane radiation patterns at 9.74 GHz where E plane is directional pattern towards 30^o including some distortions and H plane shows bidirectional characteristics nearly towards 90^o and 270^o. Thus E plane represent directional pattern at frequencies 6.36 GHz, 9 GHz and 9.74 GHz with slight distortions at high frequencies and H plane depicts directional characteristics at low frequency and bidirectional characteristics at high frequency.

Fabrication And Measurements

The model of cross-shaped fractal antenna design is fabricated with FR4 substrate and measured to verify the results of simulated antenna. Fig. 9 (a) represents the measurement of fabricated antenna using VNA. In measurements, benchtop VNA with frequency range 10 MHz-20 GHz is used to measure the return loss plot. Fig. 9 (b) provides a comparison of return loss of simulated and fabricated antenna using FR4 substrate. It is observed from the figure that return loss is -22.2827 dB is obtained at resonant frequency 9.1789 GHz (which is near to 9 GHz) for simulated design using FR4 substrate, So VNA is adjusted to frequency region 8-12 GHz for measurement of fabricated antenna. It is investigated that the return loss of -22.6246 dB is seen at resonant frequency of 9.5 GHz for fabricated antenna. Also, simulated antenna with FR4 substrate provides bandwidth of 813.3 MHz in frequency region 8.7617-9.5750 GHz whereas fabricated antenna provides bandwidth of 1.1136 GHz in frequency region 8.8089-9.9225 GHz. Even if the resonant frequency of fabricated design is shifted slightly to upper end in comparison to simulated design it may be due to fabrication inaccuracies and also due to the soldering process of SMA connector to the fabricated antenna [4,17,31].

Also, comparison between simulated/measured results of designed antenna using FR4 substrate is represented by Table no. 4. Figure 10 (a) represents an anechoic chamber setup for the investigation of fabricated antenna with FR4 substrate. It is used to measure 2D radiation patterns of the main two planes E plane as well as H plane. It is observed that both simulated as well as measured results are in reasonable agreement with each other. Figures 10 (b) and (c) represent comparison of E-plane (phi=90 deg)/H-Plane (phi=0 deg), simulated (8.7617 GHz)/measured (8.8089 GHz) normalized far-field radiation patterns using FR4 substrate. Where E-plane (sim. 8.7617 GHz)/(meas. 8.8089 GHz) radiation patterns are directional patterns with maximum radiation near 30^o-60^o. Also, H-plane (sim. 8.7617 GHz) radiation pattern is directional towards 30^o-330^o and H-plane (meas. 8.8089 GHz) radiation pattern is also nearly directional pattern particularly toward 30^o-60^o. Also, figs. 10 (d) and (e) represent comparison of E-plane (phi=90 deg)/H-Plane (phi=0 deg), sim. (9.5750 GHz)/meas. (9.9225 GHz) normalized far-field radiation patterns. E-plane sim. (9.5750 GHz)/meas.(9.9225 GHz) radiation patterns are directional with maximum radiation toward 30^o and 330^o having some distortions due to higher-order mode generation [13],[32]. However H-plane sim.(9.5750 GHz)/meas.(9.9225 GHz) radiation patterns present bidirectional radiation characteristics toward 90^o and 270^o. Thus almost directional patterns in E plane at low/high frequency are obtained and in H plane directional pattern at low frequency and bidirectional pattern at high frequency are perceived. Simulated and measured radiation patterns are nearly similar for low and high Frequencies. Some discrepancy between simulated and measured radiation patterns is generally accredited by unpredicted tolerance in fabrication as well as in measurement, as often occurred [33].

Table 4. Comparison of simulated/measured results of proposed design using FR4 substrate

Simulated Results			Measured Results		
Resonant Freq (GHz)	Return loss (dB)	Bandwidth	Resonant Freq (GHz)	Return loss (dB)	Bandwidth
9.1789	-22.2827	=(9.5750-8.7617) GHz =813.3 MHz	9.5	-22.6246	=(9.9225-8.8089) GHz =1.1136 GHz

Conclusion

This paper illustrates a cross-shaped fractal antenna design with two different substrate materials viz. FR4 and lanthanum substituted Ba-Sr hexagonal ferrite in the X frequency band. The hexagonal ferrite is prepared using a solid-state reaction method and its properties are examined using different characterization techniques to check its suitability in X-band. The fractal structure is beneficial because it provides reduced antenna size along with broadband characteristics. Different performance parameters of the proposed antenna are analyzed using both substrates. It is interpreted that the antenna designed using lanthanum substituted Ba-Sr hexagonal ferrite offers superior performance as compared to an antenna designed using FR4 epoxy substrate material as it results in larger bandwidth with lower resonant frequency. The designed antenna covers frequency regions 6.2969-6.4 GHz, 7.8702-9.44 GHz, 9.68-9.7746 GHz and provide bandwidths of 103.1 MHz, 1.5698 GHz, and 101.1 MHz in 6-12 GHz frequency range, which covers the broadband region in X band along with some frequency region in C band as well. Broadband coverage and reduced size permit the antenna designed with lanthanum doped Ba-Sr hexagonal ferrite to be used for the required application areas. Moreover, the reduced size of antenna permits the antenna to be implemented in handheld devices in numerous wireless applications. The performance of proposed antenna design with FR4-epoxy substrate is experimentally verified with the simulated results that are in close agreement. This antenna can be used in numerous X band applications such as RADAR, satellite, microwave communication and, weather forecasting along with few C band application areas.

Future Scope

The recommended ferrite substrate is prepared using solid state reaction method (also called ceramic method) but presently no facility is available for etching of required fractal pattern on ferrite substrate.

However, the authors are planning to find suitable technique for fabrication of proposed antenna with ferrite substrate in the future.

Declarations

On behalf of all authors it is hereby to confirm that

1. There was not funding available from any agencies to impart this research work.
2. There is no any Conflicts of interest/Competing interests (include appropriate disclosures) by any authors or external sources
3. Authors are ready to provide related data for this research article as and when desired.
4. There is no any code availability for this work
5. All authors included in the research article have contributed directly or indirectly for this work

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Figures

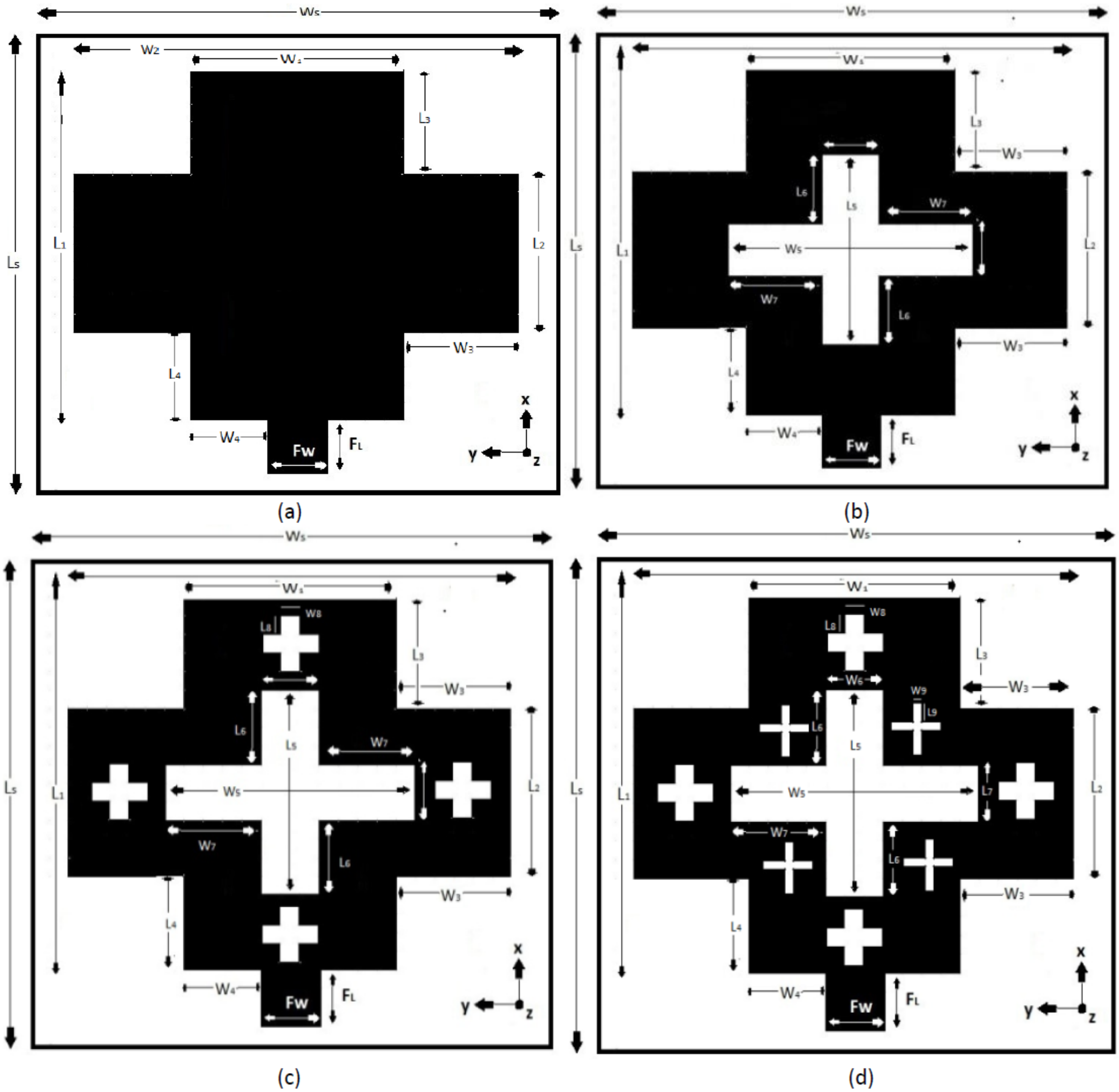


Figure 1

Stages of suggested cross-shaped fractal antenna design (a) Iteration 0, (b) Iteration 1, (c) Iteration 2 and (d) Iteration 3

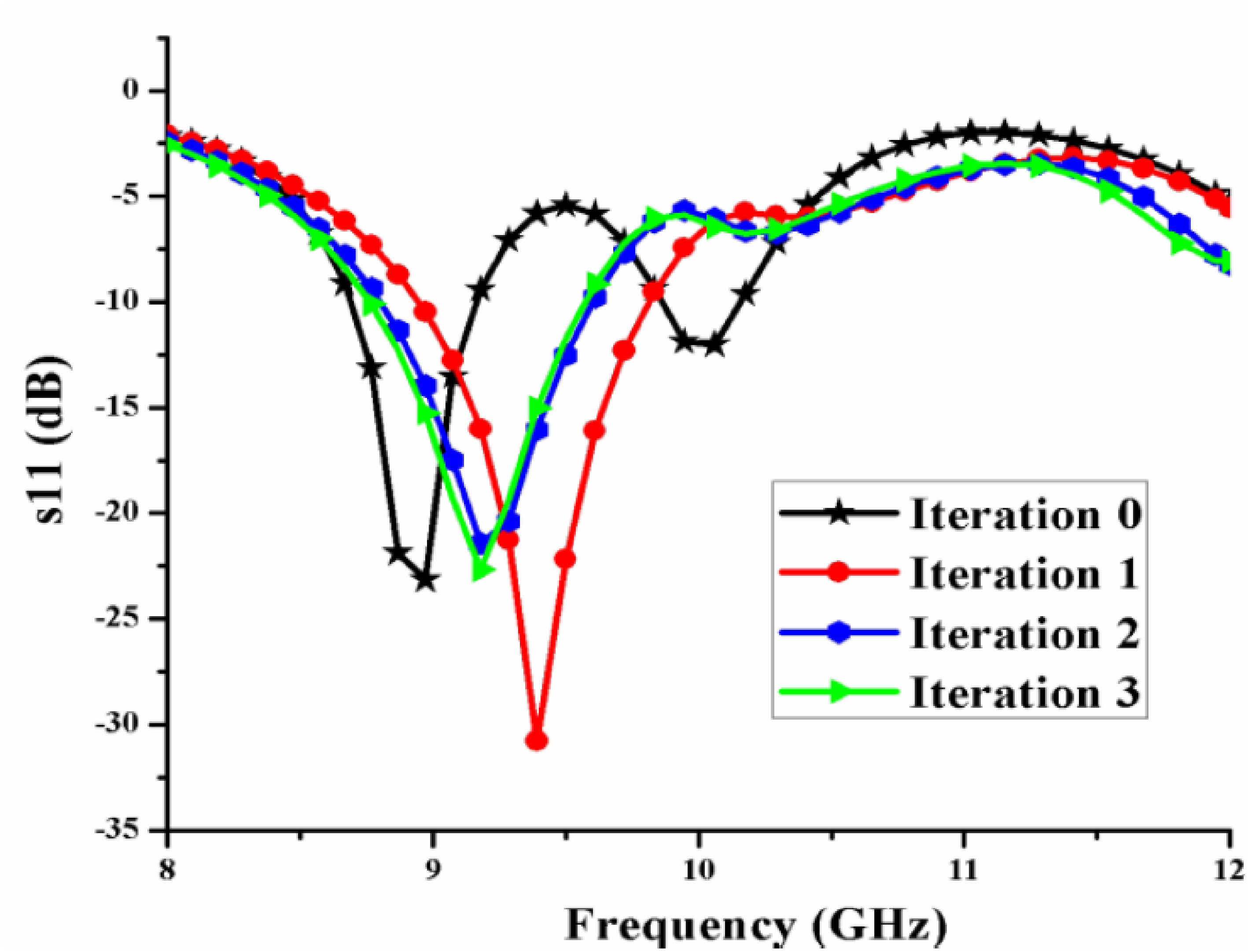


Figure 2

Represents plot of return loss w.r.t. frequency for different iterations of the simulated cross-shaped fractal antenna using FR4 substrate material

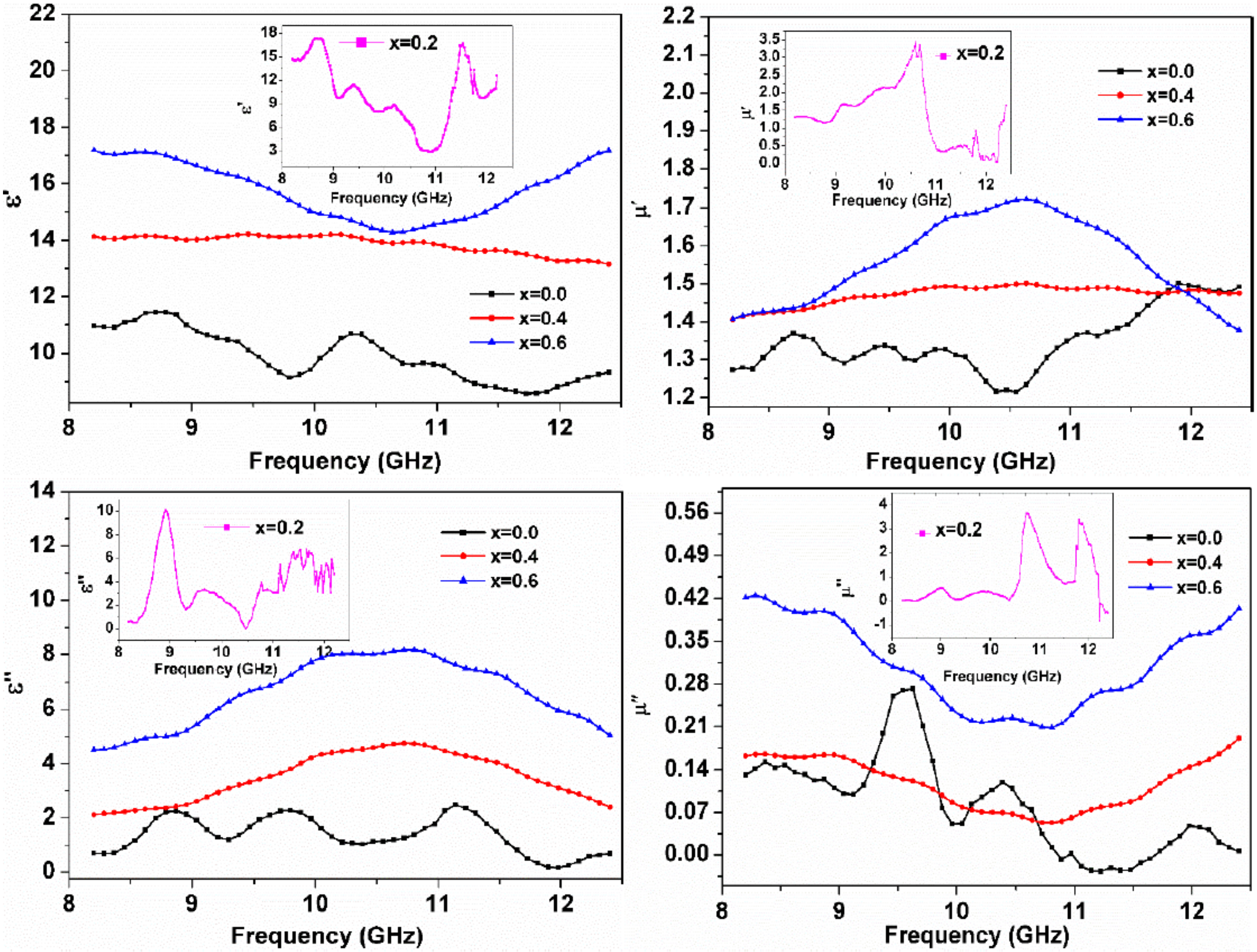


Figure 3

Variations in complex permittivity, permeability, dielectric and magnetic loss for different samples of ferrite $Ba_{0.5}Sr_{0.5}Co_xLa_xFe_{12-2x}O_{19}$ with compositions ($0.0 \leq x \leq 0.6$ with steps of x=0.2)

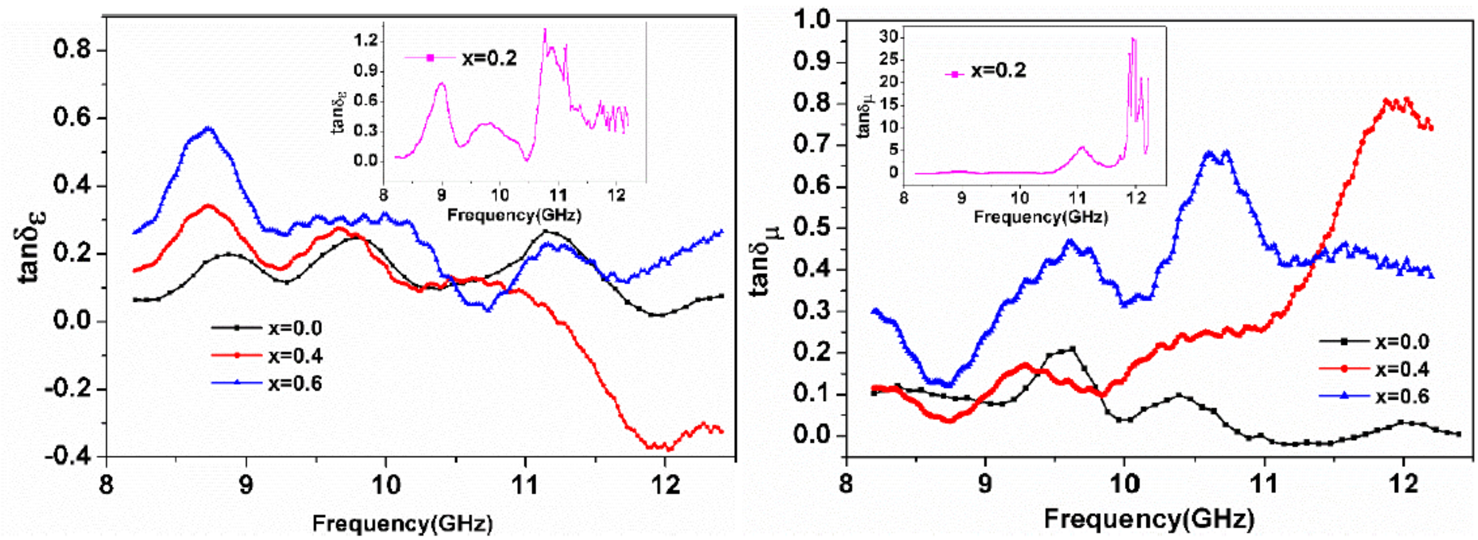


Figure 4

Variations in dielectric & magnetic loss tangent for different samples of ferrite Ba0.5Sr0.5CoxLaxFe12−2xO19 with compositions (0.0 ≤ x ≤ 0.6 with steps of x=0.2)

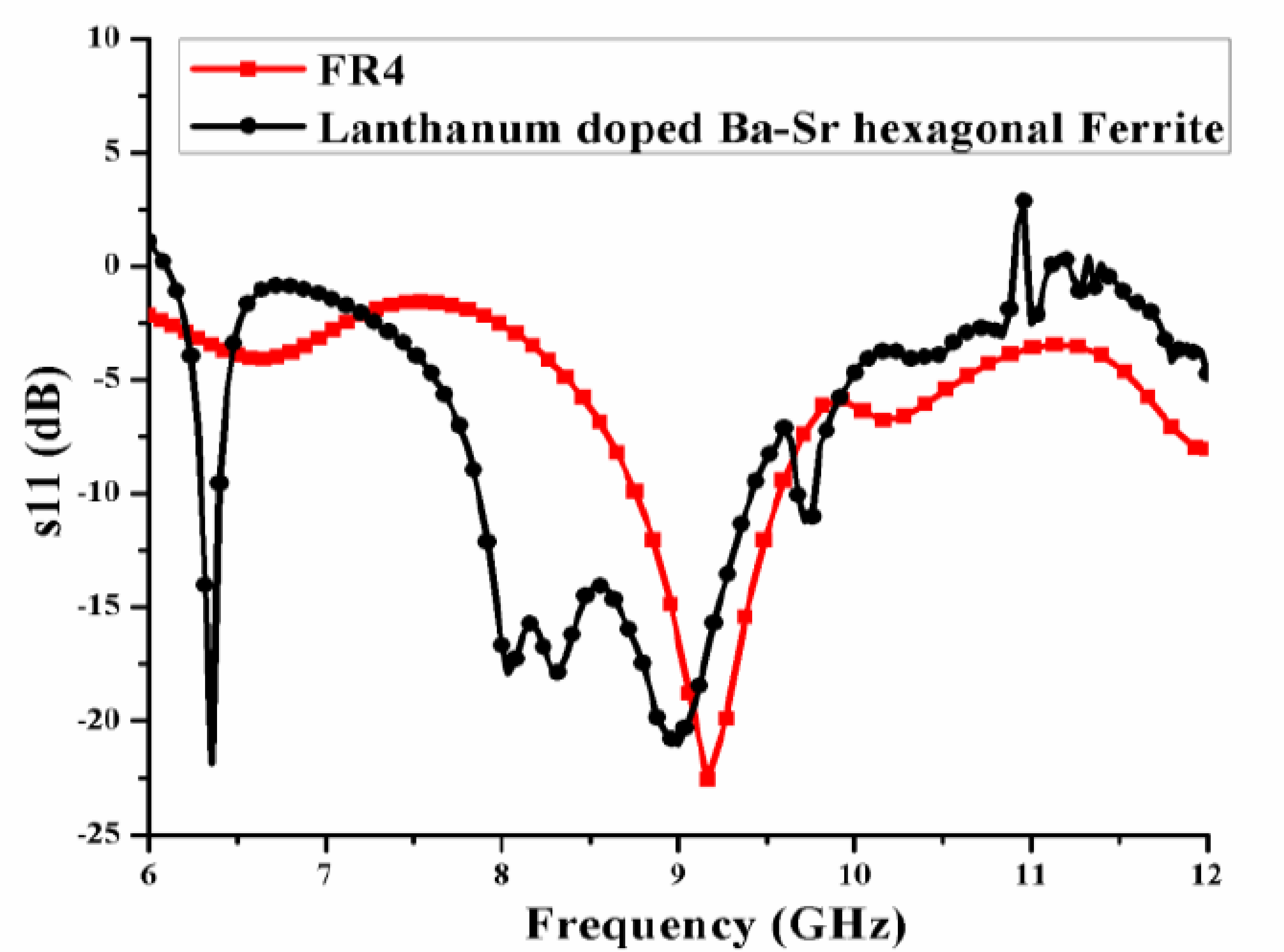


Figure 5

Comparison of return loss plot of simulated design with FR4 epoxy and Lanthanum doped Ba-Sr hexagonal ferrite substrate materials at resonant frequency 9.1789 GHz

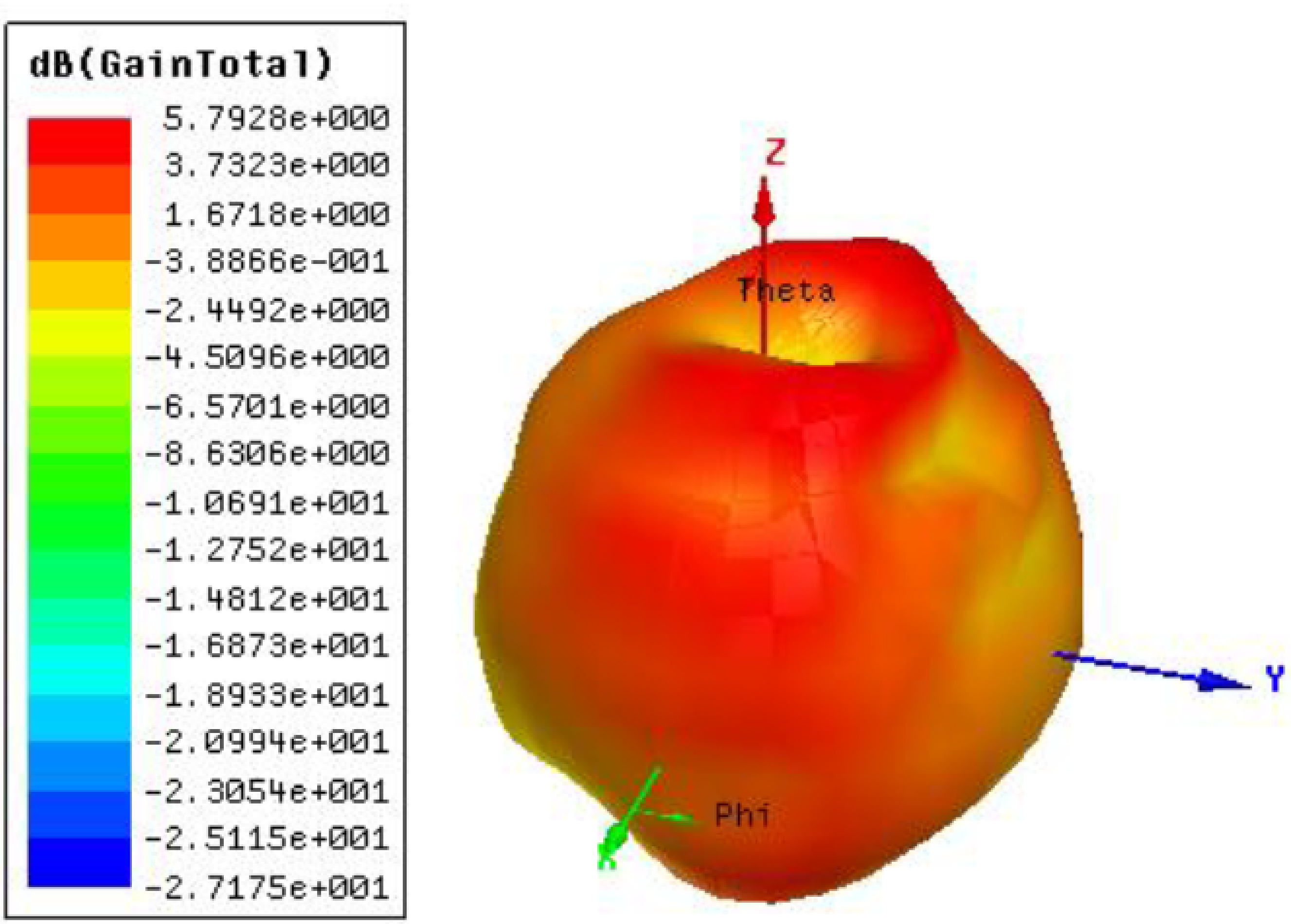


Figure 6

Gain of simulated antenna design using 3D polar plot with FR4 epoxy substrate material at resonant frequency 9.1789 GHz

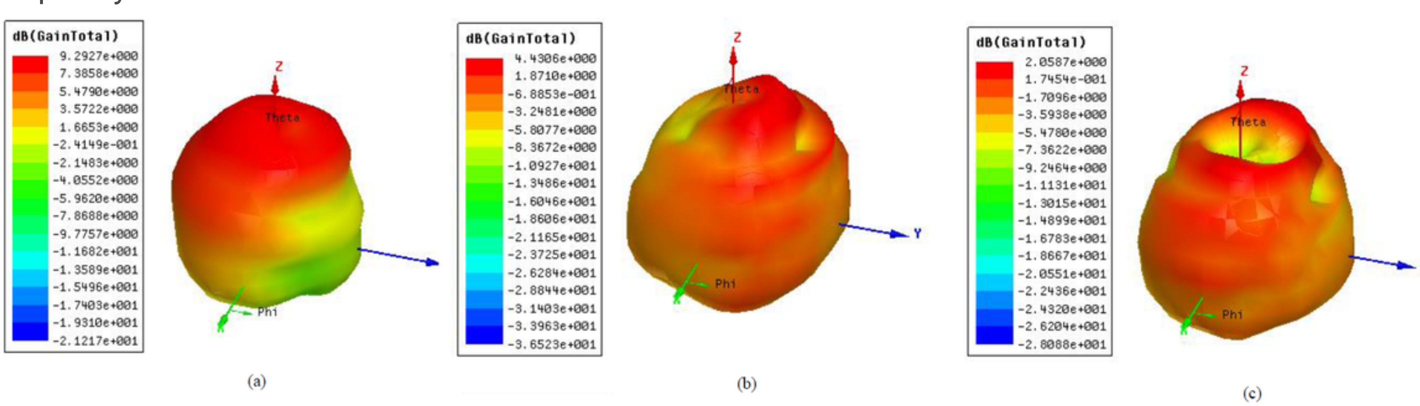


Figure 7

Gain of simulated antenna design using 3D Polar plot at resonant Frequencies (a) 6.36GHz, (b) 9GHz, and (c) 9.74GHz using Lanthanum doped Ba-Sr Hexagonal Ferrite substrate

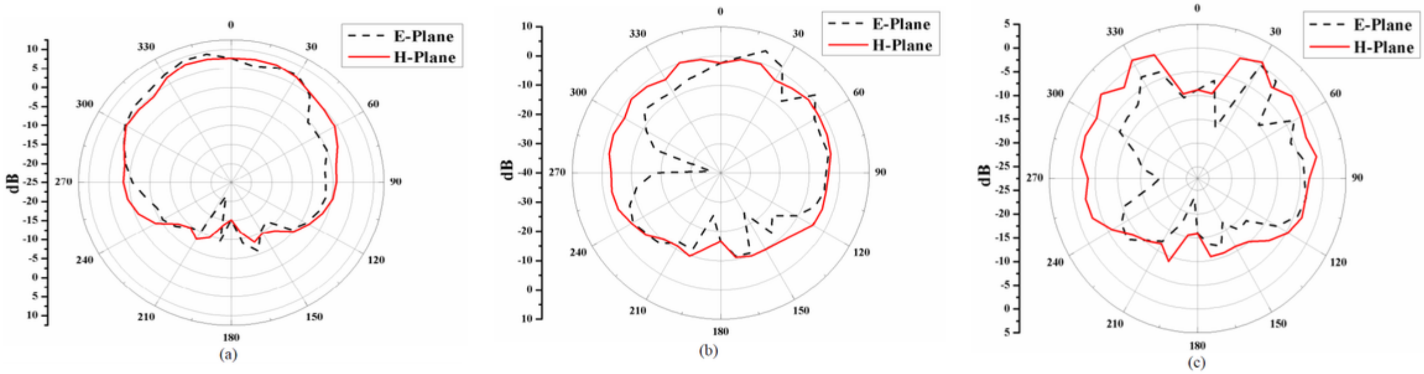
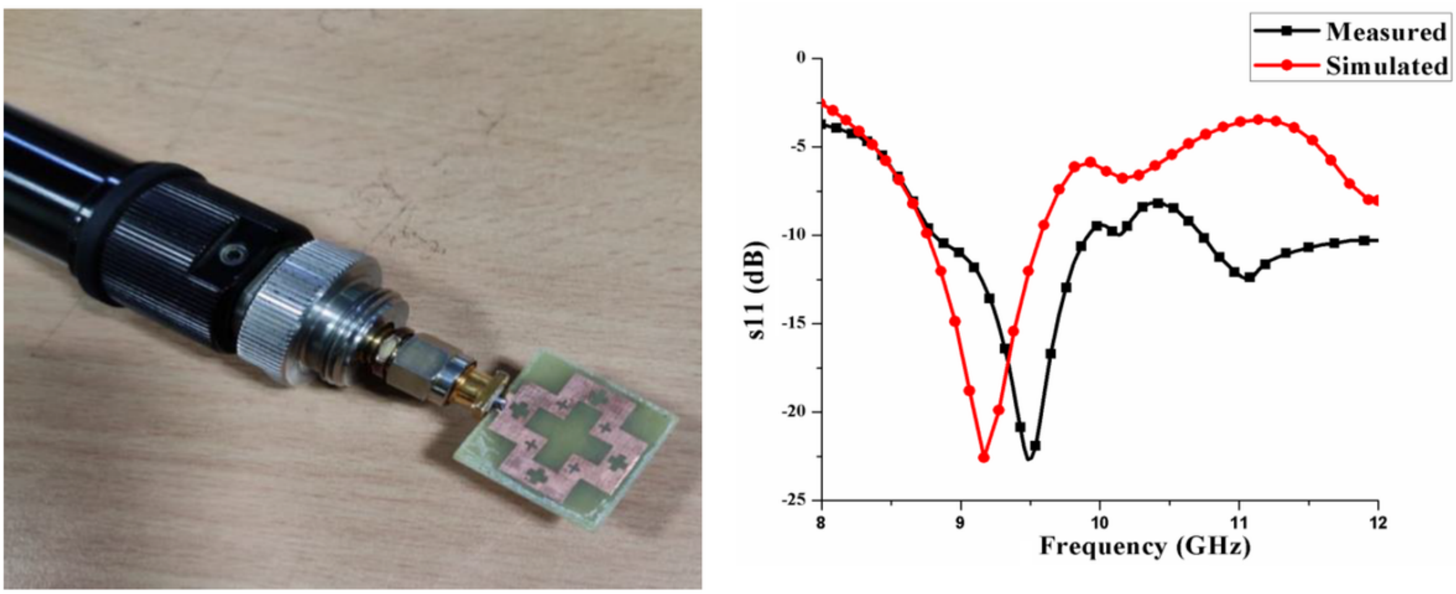


Figure 8

E-plane/H-plane simulated radiation patterns at resonant Frequencies (a) 6.36GHz, (b) 9GHz, and (c) 9.74GHz using Lanthanum doped Ba-Sr Hexagonal Ferrite substrate



(a) (b)

Figure 9

(a) Represents fabricated antenna (FR4 epoxy substrate) measurement using VNA (b) Represents comparison of simulated/measured return loss versus Frequency plot of designed antenna using FR4 substrate

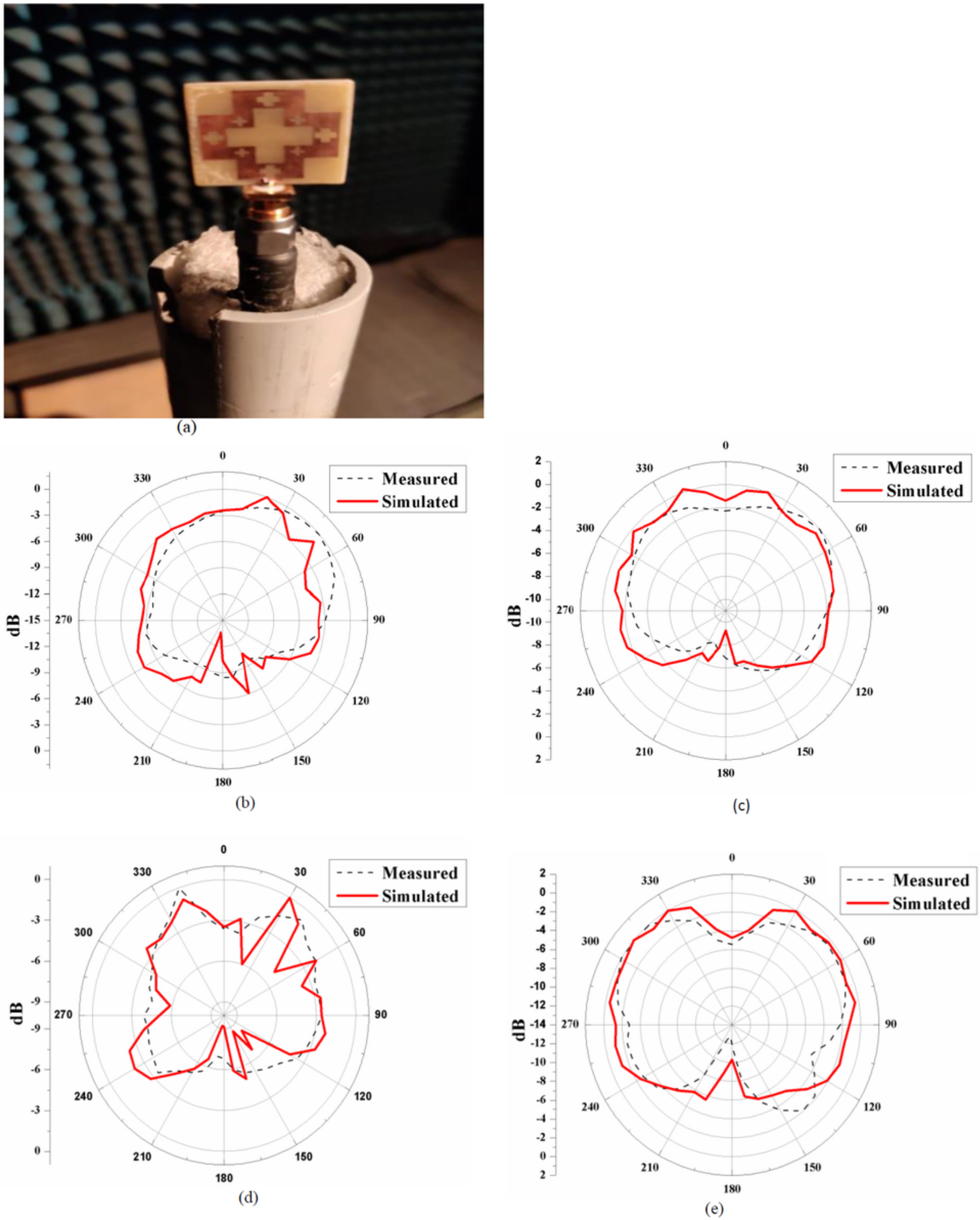


Figure 10

(a) Anechoic chamber measurement setup of the fabricated antenna using FR4 substrate (b) E-plane & (c) H-plane radiation patterns at sim.(8.7617 GHz)/meas.(8.8089 GHz) frequencies. Also Fig. 10 (d) E-plane & (e) H-plane radiation patterns at sim.(9.5750 GHz)/meas.(9.9225 GHz) frequencies.