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RESEARCH ARTICLE

Gain Enhancement of Fractal Shape Antenna using Metamaterial Cover

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Abstract

Gain enhancement has attracted a great amount of attention in literatures. There were many ways, which were published to improve antenna gain. One of these ways is using Metamaterials. Materials that have negative refractive index are used to achieve this goal. These materials are artificial structures that exhibit characteristics not found in nature. Microstrip antennas covered by metamaterial are one of the interesting areas of study. Fractal shapes are used to improve antenna characteristics. Among these characteristics is antenna gain. In this paper fractal shape antenna is proposed and covered by new design of ring resonator to get enhancement in gain. The calculated result shows an enhancement in efficiency, gain, directivity and far field shapes. There is big agreement between simulation and measurements.

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Introduction

Gain enhancement is one of the most important parameters that attracted researchers in antenna design. Antenna design with fractal shapes, improves antenna parameters. Metamaterials are artificial materials that provide electromagnetic properties not found in natural materials (Veselago et al., 2006). Negative refractive index over certain frequency range is the most important property of interest. This type of materials has been studied by (Veselago, 1968), he mentioned to some unique properties like negative refractive index and backward waves. One of the most known designs to get negative permeability is Split ring resonator. Different shapes of split rings are published in literatures to achieve this property (Wu et al., 2006).

Classical microstrip patch antennas are most popular antennas because of several advantages such as low profile, lightweight and low cost of fabrication. Adding cover of split ring resonator over microstrip patch antenna has been reported to enhance antenna gain and radiation efficiency (Sarkar et al., 2013), (Garg et al., 2011), (Wu et al., 2005). Several configurations of superstrates were used to improve antenna radiation properties, such as artificial magnetic superstrates (Attia et al., 2009), dielectric slabs (Vettikalladi et al., 2009), highly-reflective surfaces (Feroozesh et al., 2010) and electromagnetic band gap (EBG) structures (Attia et al., 2008).

In this paper we introduce modified ring design by adding more spaces to the open side and use it as a cover over fractal Quadruple Koch antenna shape. This configuration is shown in Fig 1. HFSS software code which is based on finite element method was used to calculate S - parameters. Notable enhancement of gain and directivity obtained of this model of fractal antenna shape. This model is also constructed and measured using vector network analyzer. Big agreement obtained with calculated results.

Antenna design

In the present model the dimensions of the ring are $L=W=3.3$ mm, $g_1=g_2=t=s=0.4$ mm. Arrangements of two different unit cells are simulate in a waveguide to calculate scattering parameters. Two models of ring design is proposed, we call it model (a) and (b) this is shown in Fig 2. Unit cells are etched on FR4 substrate ($\epsilon_r = 4.4$) of

0.25 mm thickness. Unit cells are separated by 1.4 mm. 144 cells are distributed to cover the area above the fractal shape antenna. The starting shape of the antenna is a square of 20 mm side length. The generator is a second iteration of Koch curve applied to each side as shown in Fig 3. Details of Koch curve generation can be found in (Puente et al., 1998). Patch antenna etched on substrate of dimensions 65 mm x 65 mm x 1.6 mm. Material of substrate is FR4.

Results and Discussion

Relative permittivity, relative permeability and refractive index of meta- cover are determined using Nicolson-Ross-Weir approach (Ziolkowski, 2003).

$$\epsilon_r = \frac{2}{jkd} \frac{1-v_1}{1+v_1} \quad (1)$$

$$\mu_r = \frac{2}{jkd} \frac{1-v_2}{1+v_2} \quad (2)$$

$$n = \pm \sqrt{\epsilon_r \mu_r} \quad (3)$$

Where

$$v_1 = S_{21} + S_{11} \quad (4)$$

$$v_2 = S_{21} - S_{11} \quad (5)$$

$$k = \omega/c \quad (6)$$

Where (ω) is radian frequency, (d) is Substrate thickness, and (n) is refractive index

Fig 4 shows the resonance frequency of each model of the rings. Relative permittivity and relative permeability of model (a) and (b) cells are shown in Fig 5. Refractive index versus frequency of the two cells is shown in Fig 6. From these figures, we can see the resonances and negative refractive index lies in the same range of frequency. The refractive index can have negative values without the simultaneous negative values of real permeability and permittivity (μ' and ϵ'). The condition in (Ziolkowski et al., 2011) is utilized to get negative refractive index as seen in relation (7).

$$\mu' \epsilon'' + \mu'' \epsilon' < 0 \quad (7)$$

Where μ' , ϵ' are real part of permeability and permittivity and μ'' , ϵ'' are imaginary part of permeability and permittivity. This condition is plotted versus frequency in Fig 7.

The starting shape of this model is square antenna its side length is 20 mm. By adding the second iteration of Koch curve generator to the square antenna, we get Fractal Quadruple Koch antenna. As a second step to make enhancement to the square antenna parameters, we add a metamaterial cover over the antenna plane. We get best enhancement to the antenna parameters at distance 30 mm over patch antenna.

This model is studied experimentally. The picture of constructed antenna and its cover is shown in Fig 8. Fig 9 shows simulated S- parameters of classical square and fractal Koch antenna. Measured S- parameters and impedance of fractal Koch is shown in Fig 10. From these figures we can see that square antenna resonate at 4.15 Ghz and fractal Koch antenna resonate at 3.6 Ghz, 9.9 Ghz and 11.1 Ghz. Applying meta-cover do not affect the resonance point locations of the antenna.

Fig 11 shows far field of square and fractal antenna. Fig 12 shows far field shape after applying meta-cover to the antenna. From these figures we can see far field become more directive. To get more understanding to far field shape, current distribution over antenna body is calculated. This is shown in Fig 13. Antenna parameters are listed in table 1. From this table we can see the gain of the antenna is improve and reach to 13 dB in the range of frequencies located at X-band after applying meta-cover. Metamaterial cells have no effect in the area of S-band. Efficiency of the antenna improved too and reaches to 74%. More visualization to the improvement of gain and directivity, three-dimensional far field is plotted in Fig 14.

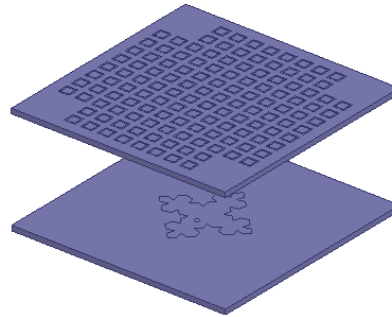


Fig 1: Meta-cover over fractal Quadruple Koch antenna shape

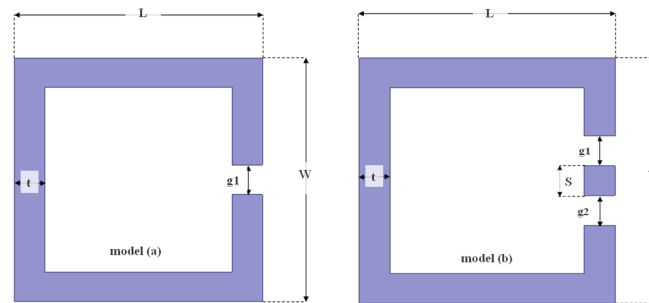


Fig 2: Unit cell shape of meta-cover

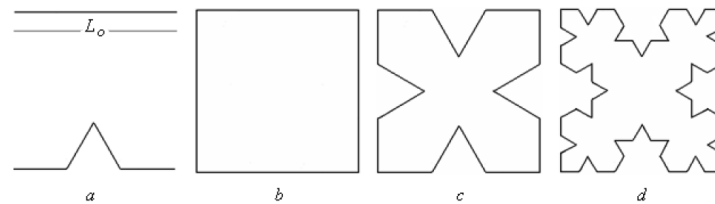


Fig 3: Generation process of Quadruple Koch structure, (a) the generator, (b) classical square (zero iteration), (c) first iteration, (d) second iteration

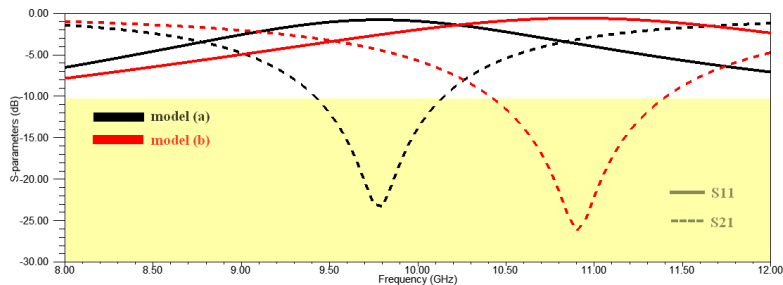


Fig 4: Resonance frequencies of the unit cells of meta-cover

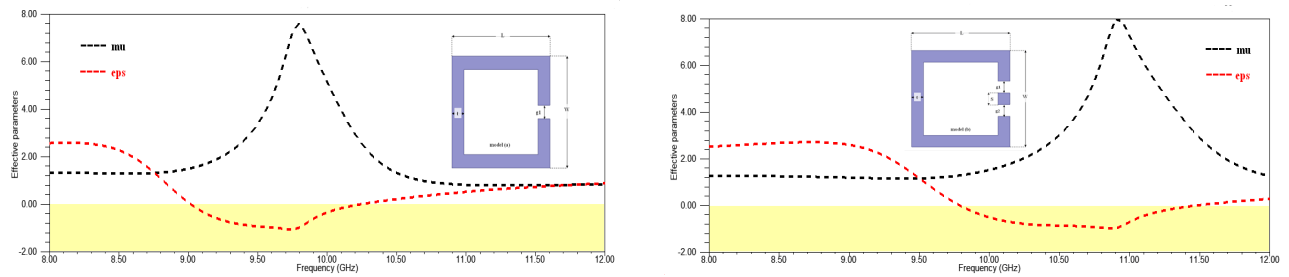


Fig 5: Relative permeability (μ) and relative permittivity (ϵ) of unit cells of meta-cover

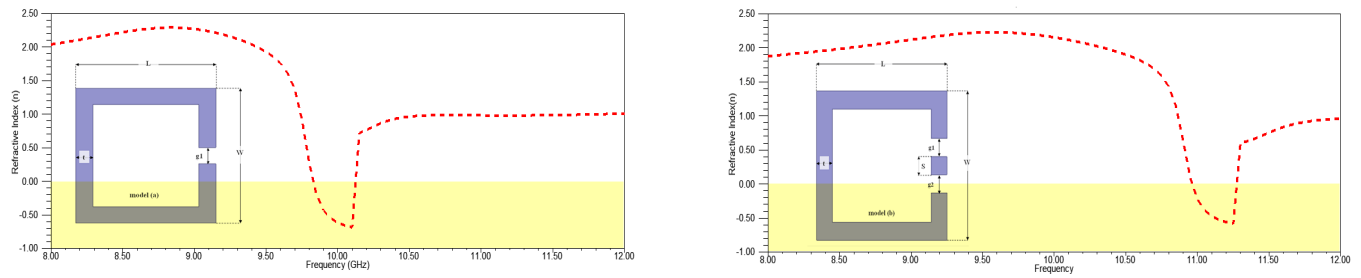


Fig 6: Refractive index of unit cells of meta-cover

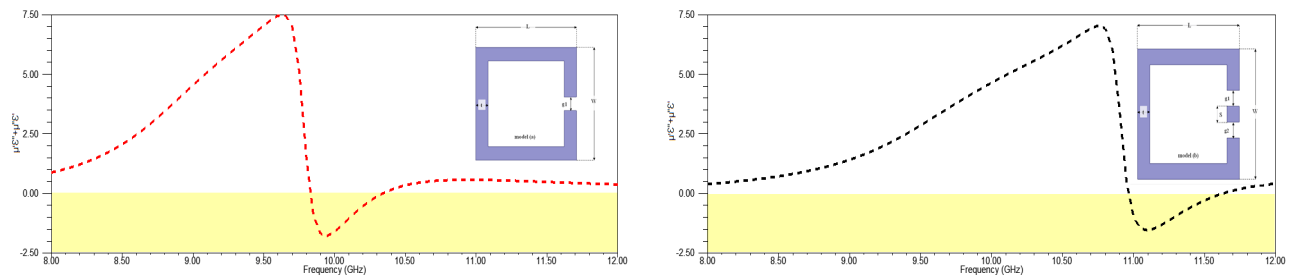


Fig 7: Relation of $\mu' \epsilon'' + \mu'' \epsilon' < 0$ versus frequency to indicate negative index region

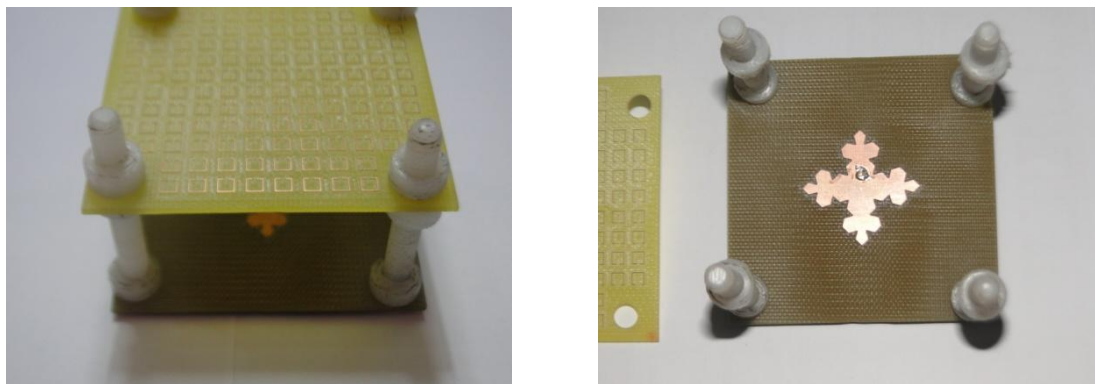


Fig 8: Constructed antenna pictures

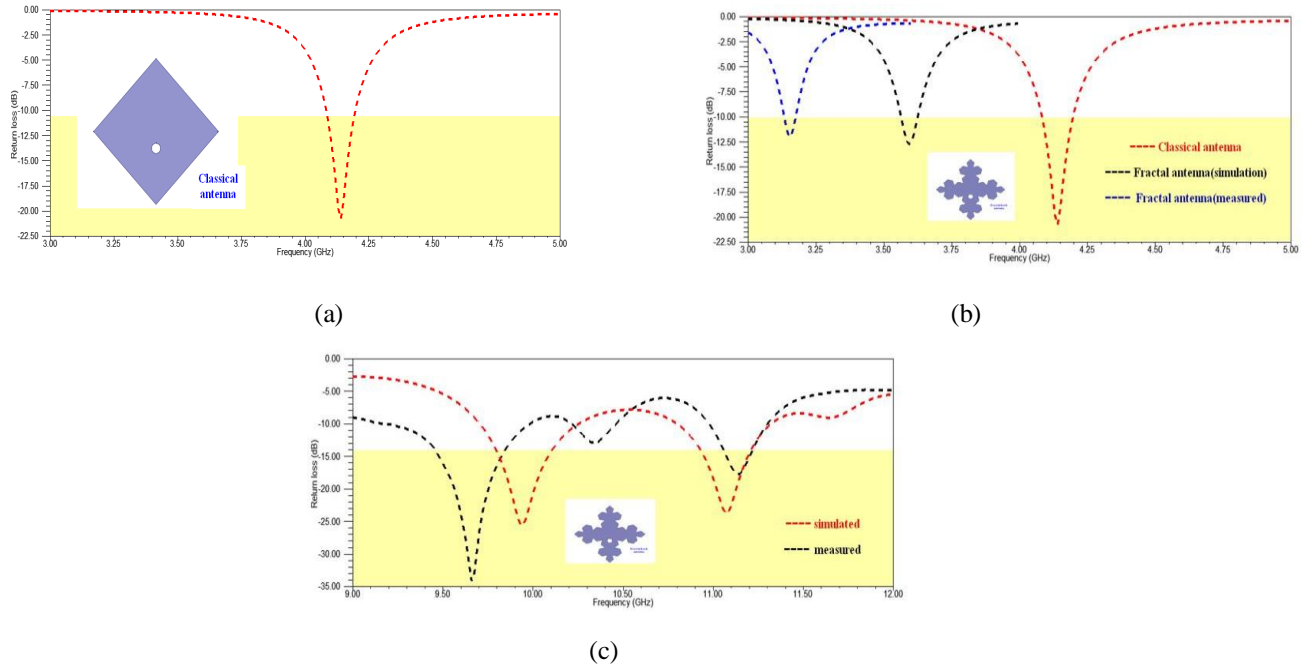
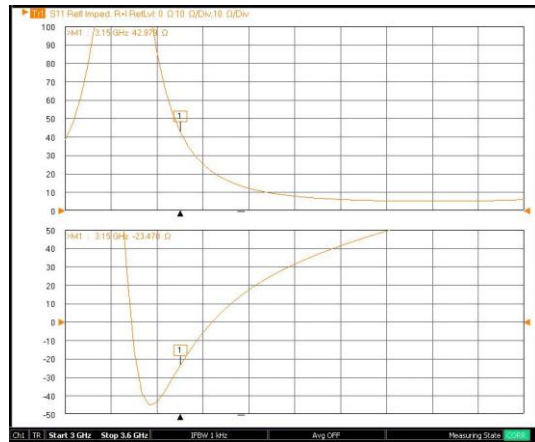
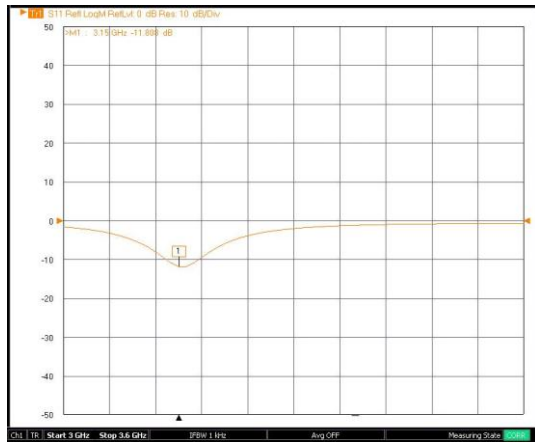
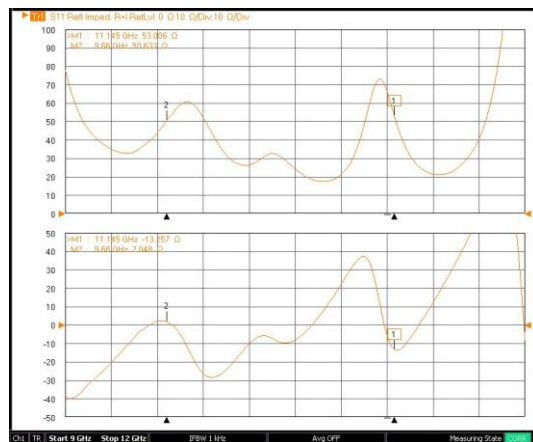
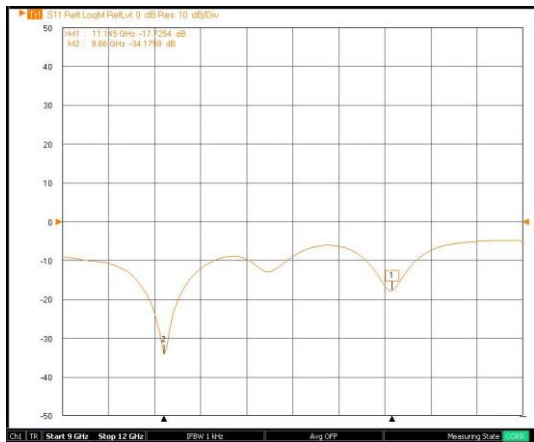


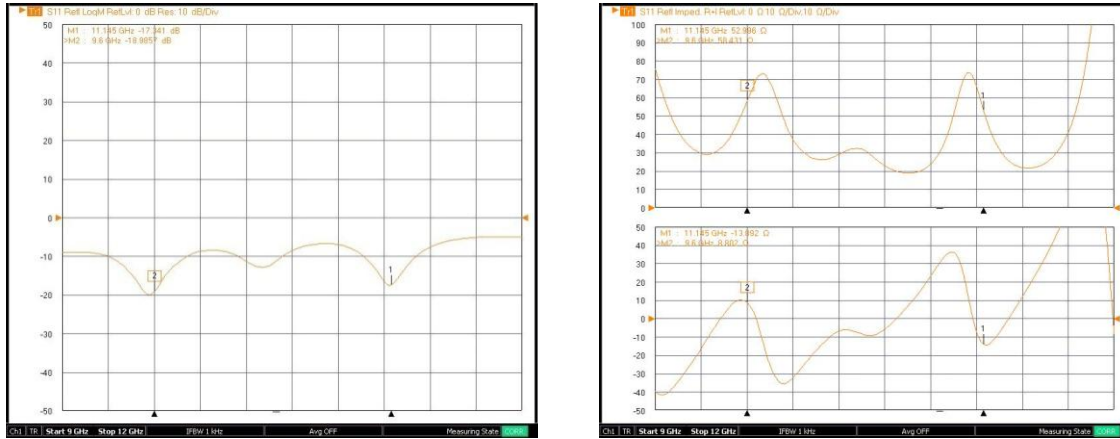
Fig 9: Resonance frequencies of (a) classical square antenna, (b) fractal Koch antenna at S-band, (c) fractal Koch antenna at X-band



(a): Resonance point (s_{11}) and impedance of fractal antenna at S-band



(b): Resonance point (s_{11}) and impedance of fractal antenna at X-band



(c): Resonance point (S_{11}) and impedance of fractal antenna at X-band after applying meta-cover
 Fig 10: Measured results of fractal Koch antenna using vector network analyzer

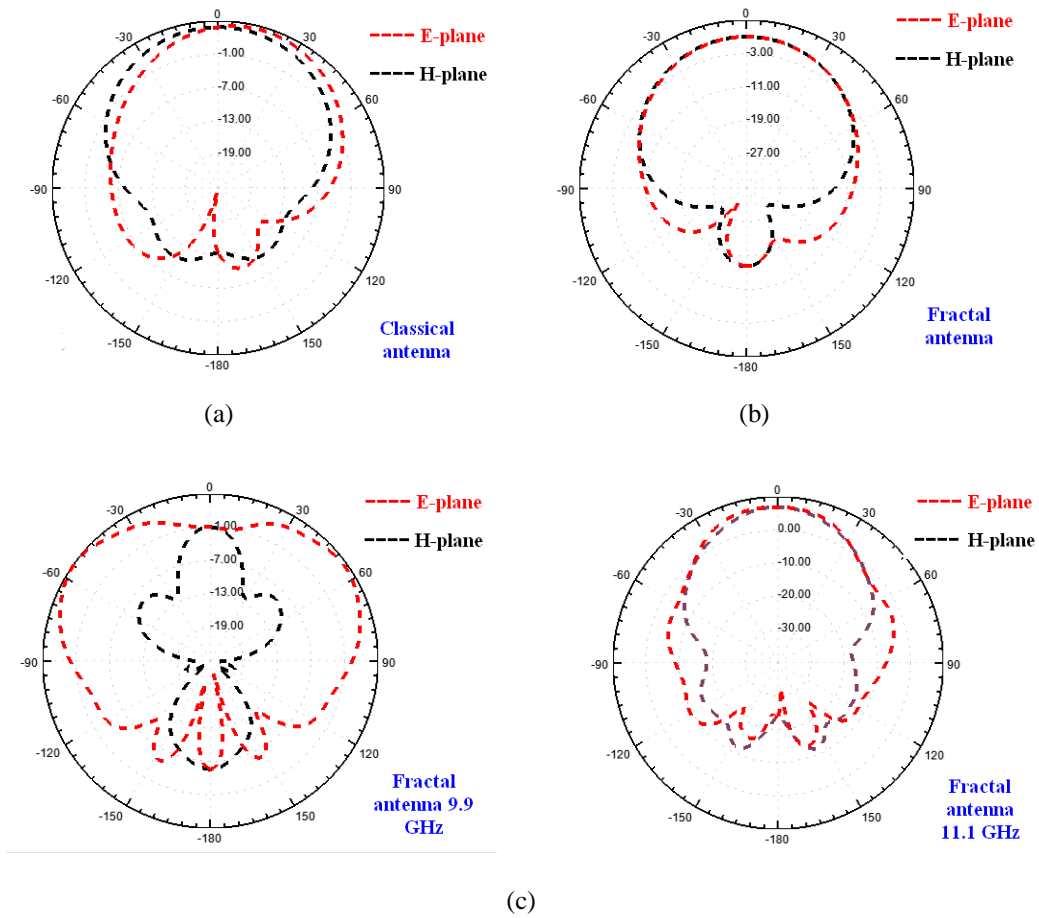


Fig 11: Far field of (a) classical square antenna, (b) fractal Koch antenna at S-band, (c) fractal Koch antenna at X-band

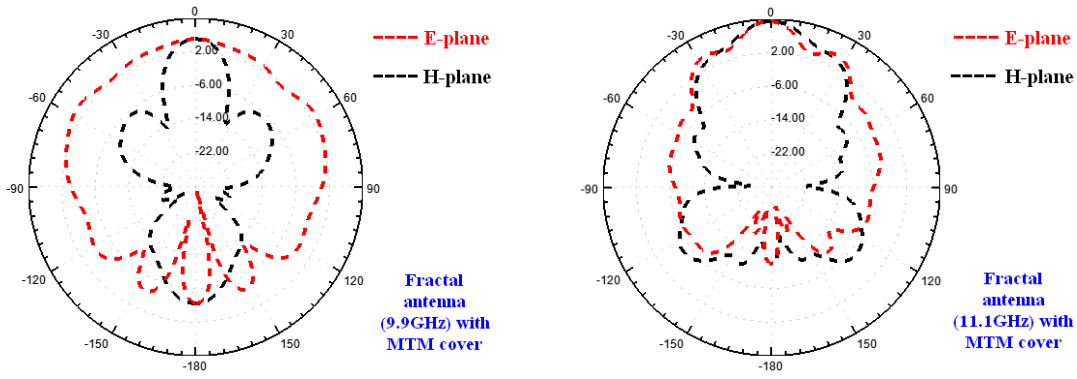


Fig 12: Far field of fractal Koch antenna after applying meta-cover

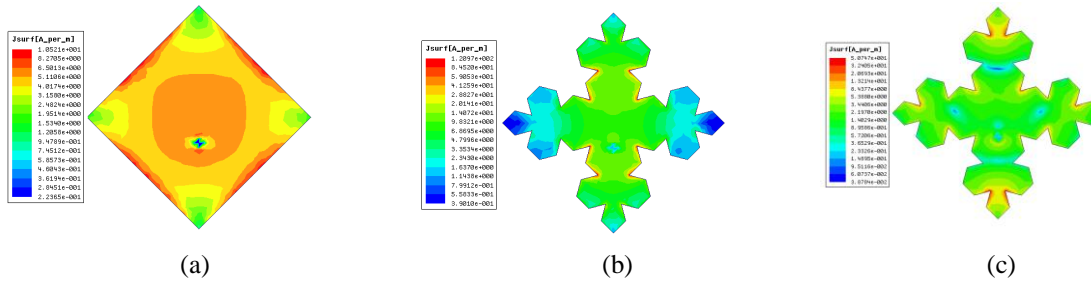


Fig 13: Current distribution over antenna body (a) square antenna, (b) fractal Koch at S-band, (c) fractal Koch at X-band

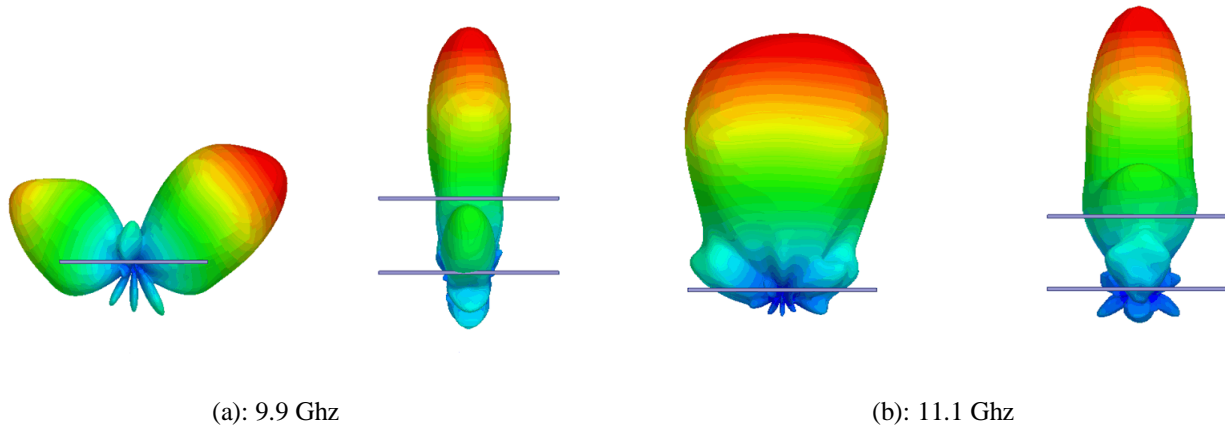


Fig 14: Three-dimensional far field of fractal Koch antenna with and without meta-cover at X-band

Table 1: Antenna parameters

Fractal antenna parameters						
without MTM	Frequency (GHz)	Return loss (dB)	VSWR	Gain (dB)	Directivity (dB)	Efficiency %
	9.9	-25	1.11	7.2	8.6	70
	11.1	-23	1.13	9.2	10.8	68
with MTM h(30 mm)	9.9	-19.5	1.2	11.5	12	74
	11.1	-17	1.3	13	14.2	74

Conclusion

In this paper we use modified rings as meta-cover over fractal Quadruple Koch shape antenna. Distance between antenna and cover is 30 mm. although fractal shape enhances antenna gain and directivity, adding metamaterial cover to the antenna will cause additional enhancement to the gain and directivity. Enhancement limited to X- band region because metamaterial unit cells are not effective in lower bands. Efficiency of the antenna is improved too because it is related to directivity and gain. Meta-cover cause enhancement to the shape of far field of fractal antenna as seen in Fig 14. This model is constructed and measurement done using vector network analyzer, there is big agreement in results between simulation and measurement. This model is very useful in point-to-point communication and meta-cover can protect the antenna from environment hazards in addition to enhance antenna parameters. Two other models are currently under investigation and will be discuss in future publications.

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