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Analysis of Improvement in Bandwidth and Multiband Behavior of Metamaterial Based Microstrip Patch Antenna

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ABSTRACT: This paper presents the analysis of latest advancement achieved by researchers in the development of improving the parameters of microstrip patch antenna. The main focus of paper is on metamaterials as this material is used to extend the capability of microstrip patch antenna and ultimately antenna can be improved for its utilization in different applications which were not earlier due to limitations of size, bandwidth, gain and efficiency of microstrip patch antenna.

Keywords: Metamaterials, Artificial magneto-dielectric substrate, Impedance bandwidth

1. Introduction

Dechamps first proposed the concept of the microstrip patch antenna (MSA) in 1953 and antenna first practically developed by Munson and Howell in 1970s. MSAs were developed using different arrangements and shapes as many researchers were taking interest because of the benefits that MSAs are offering. Generally MSAs are called as per the shape of its radiating patch mostly they are either rectangular of circular. MSAs are having advantage of being small size, light weight, planar structure, conformal and low cost device. Radiation in MSA is due to the fringing fields between the periphery of the patch and ground plane. As given in figure 1 below the various affecting factors in radiation of MSA are height of dielectric, permittivity of dielectric medium, shape of radiating patch, loss tangent of the material and some other factors also. We should also understand the effect of feeding technique used to apply to microstrip antenna as it also has great effects on performance parameters of antenna.

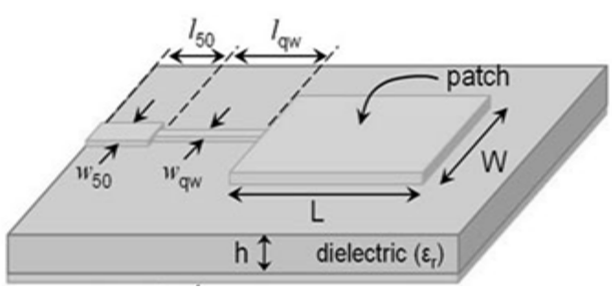

Fig. 1 Basic microstrip patch antenna [1]

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Researchers are trying to enhance the performance MSAs in terms of bandwidth, efficiency, power handling capacity and smaller size to widen the applications of MSAs. Various techniques exist to simulate the performance of MSAs namely cavity model, FDTD method, FEM method and MOM method. HFSS is software widely used to accurately observe the operation of MSAs and its parameters [2].

Metamaterials are used in MSAs to improve their bandwidth, gain to a great extent. As MSAs are suffering from low gain it became limitation for the applications of MSAs. As metamaterial has the property to interact with the field and generate resonating effect due to its artificial structure specially designed by manufacturer.

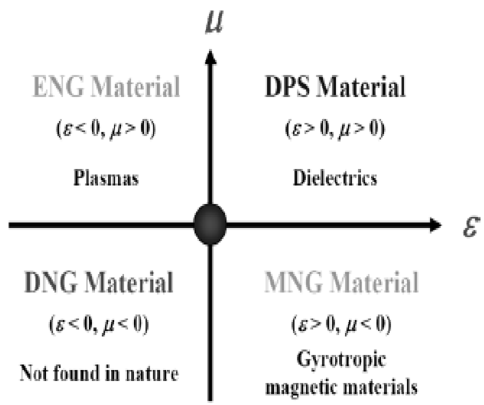


Fig. 2 Classification of metamaterials by real parts of their constitutive parameters [3]

As shown in fig 2, four different quadrants are shown for four different characteristics of metamaterials. Materials are classified on the basis of permittivity and permeability values they have. As per the Maxwell's equations permittivity and permeability of material are important as this will have effect when electromagnetic wave will interact to them.

1. Various parameters affecting the performance of Microstrip patch antenna and its results

2.1.1 Increasing the height (h) of the Patch

With the increase in h, the fringing fields from the edges increase, which increases extension in length L and so, the effective length decreasing resonance frequency? On the other side with the increase in value of h, the W/h ratio is reduces so it decreases εr and hence increases the resonance frequency. However, the effect of the increase in L is dominant all over the decrease in εr . So, the total net effect is to decrease the resonance frequency.

The Input Impedance and VSWR plot for two different height of patch is shown in Fig. 3.as shown in Fig. as we increase the height VSWR is close to 1 which is increase BW from 64 MHz to 124 MHz [1]

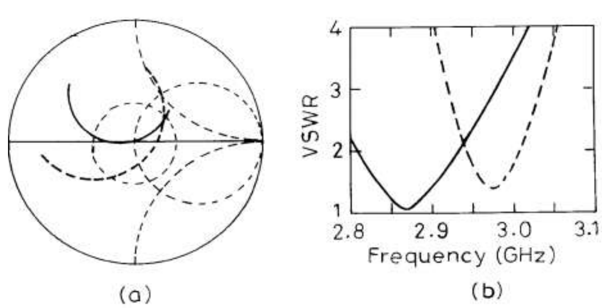


Fig.3. Input impedance (b) VSWR plots of the RMSA for two different values of h: (- - -) 0.159 and (——) 0.318 cm.[2]

2.1.2 Increasing the Width (W) of the Patch

The width W of the RMSA has been significant effect on BW and input impedance and also gain of the antenna. 4 different values of parameters W are 2, 3, 4, and 5 cm, the input impedance. VSWR plots for x = 0.65 cm are given in Fig 4.

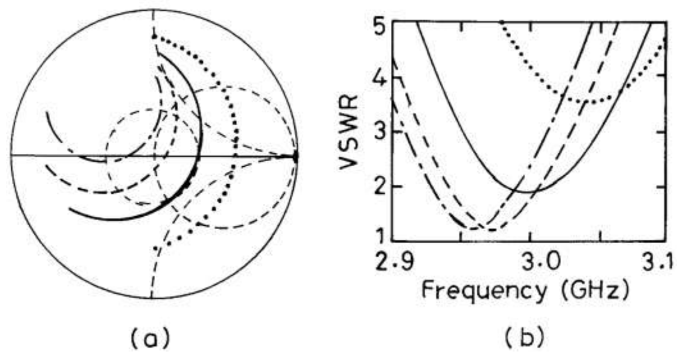


Fig. 4 Input impedance (b) VSWR plots of the RMSA for four different W :(. . .) 2, (——) 3, (- - -) 4 and (– – –), 5 cm. [2]

With an increase parameter W, input impedance is decreases, so the feed point is moved toward the edge. Input resistance Rin in the range of 50V to 65V. As W increases from 2 cm to 5 cm, the value of x is increased from 0.35 cm to 0.75 cm, and the BW increases from 42 MHz to 73 MHz the HPBW in the E-plane remains around 105°, but in the H-plane, it decreases from 86° to 70°. The gain of the RMSA increases from 6.2 dB to 7.0 dB. [2]

2.2.3 Decreasing the value of εr

For RMSA with L = 3 cm, W = 4 cm, and h = 0.159 cm, when εr is decreased to 1, the resonance frequency increases to 4.541 GHz. The BW of the antenna is 167 MHz for the feed at x = 0.7 cm. This increase in BW is due to a decrease in εr and an increase in h/l 0, because the resonance frequency has increased the dimensions of the patch for four different values of εr (1, 2.55, 4.3, and 9.8) are shown in Table I

TABLE-I

Effect of ε_r on the Performance of RMSA[2]

(ε_r)	**L Cm**	**W Cm**	**X Cm**	**fo (Ghz)**	**BW (Mhz)**	**Gain (dB)**
1	4.65	6.2	1.00	2.997	74	10.0
2.55	3.0	4.0	0.65	2.974	64	6.8
4.3	2.3	3.1	0.40	2.986	49	5.6
9.8	1.51	2.0	0.20	3.02	30	4.4

2. Planar and multilayer structure of Microstrip patch antenna and its results

3.1 Planar Multiresonator Configurations

When the parasitic patches are placed along all the four edges of the RMSA as shown in fig 5, as the fringing field of radiation element will mutually couple to parasitic patches, both bandwidth and gain increase. However, the patches along the two orthogonal edges are taken to be unequal lengths, so that their resonance frequency is different but close to each other to yield broad bandwidth.

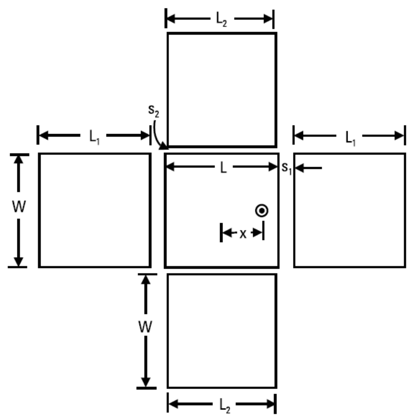


Fig. 5 Four-edge gap-coupled RMSA.[2]

For L=3CM, W=3cm, L1=2.9cm, s1=0.15cm, L2= 2.85cm, s2= 0.05cm, r = 2.55, h=0159cm and x=1.2cm the input impedance and VSWR plots are shown in fig 6. the bandwidth achieved is 569MHz at the operating frequency 3.03GHz and the gain is 9.9dB.

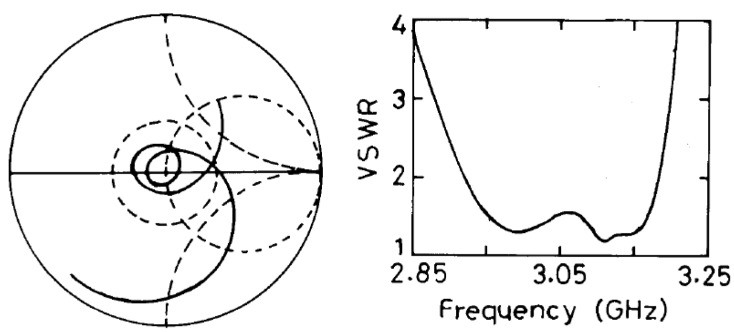


Fig. 6 Input impedance and VSWR plots for h=0.159cm

3.2 Multilayer Configurations

Multilayer aperture coupled MSA are a stack of patches in which all the patches receives radiation of feed line through aperture. The dimension of aperture is also important to decide parameters of antenna. As shown in fig 7 Dual-stacked rectangular MSA are coupled through an aperture. Feedline is on the ground plane and its radiation through feeds two patches sent on it.

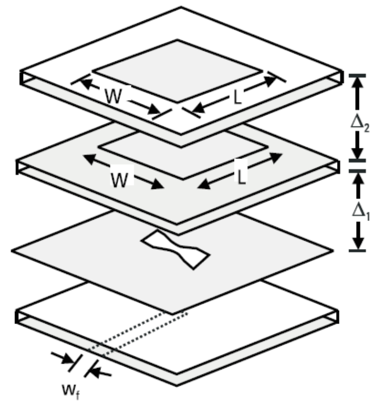


Fig. 7 Dual-stacked ACMSA[2]

The rectangular patch dimensions are L=4cm, W=5cm., r=4.3, h=0.16 and tanδ=0.02 are used. The air gap spacing are provided by using dielectric spacers at the edges. The measured bandwidth for VSWR≤ 2 is 501 MHz that is 24.9%. The measured input impedance and VSWR plots are shown in fig 8.

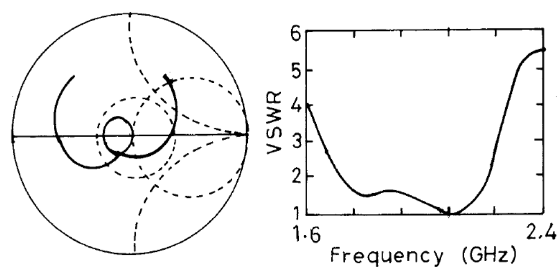


Fig. 8 Input impedance and VSWR plots of stacked rectangular ACMSA.

3. Material Based Antenna

4.1 Metamaterial based antenna to miniaturize the patch antenna

Ouedraogo, R.O.; Rothwell, E.J.; Diaz, A.R.; Fuchi, K.; Temme, A. [9] have proposed method of split ring resonator to achieve miniaturization up to 1/16 reduction in patch area. Consider a traditional patch antenna consisting of a circular copper patch of radius 23.1 mm etched on top of a circular Rogers RT/duroid 5870 substrate of thickness 2.34 mm and radius 46.2 mm, backed by a copper ground plane also of radius 46.2 mm. The dielectric constant of the substrate is εr=2.33 and the dielectric loss tangent is tan δ =0.0012.

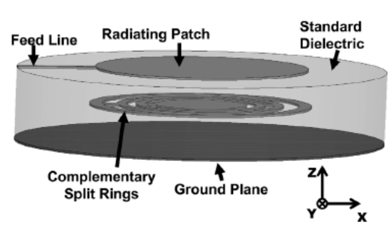


Fig.8 Geometry of miniaturized patch antenna

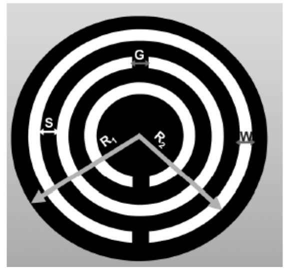


Fig.9 Geometry of the disk containing CSRR

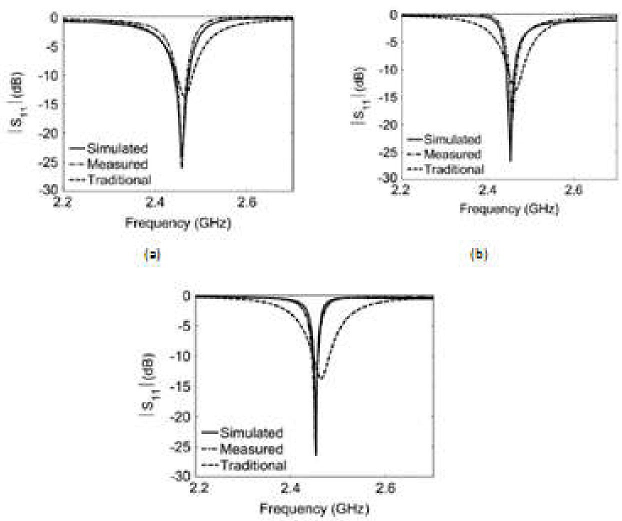


Fig. 10 Reflection coefficient of the patch antenna (a) miniaturized to ¼ (b) miniaturized to 1/9 (c) miniaturized to 1/16

From the simulations, the bandwidths of the antennas with area reductions to 1/4, 1/9 and 1/16of the traditional patch antenna are 1.2%, 0.81% and 0.4%, respectively, compared to 1.3% for the traditional patch antenna; the corresponding efficiencies are 84.7%, 49.8% and 28.1% respectively, compared to 94% for the traditional patch antenna.

The MTM structure can be convenient to get different medium characteristics by changing its structure parameters. Radius and length of via, length of the unit cells, and distance between the cells in multiple cells at propagation sides can be changed to get the desired electromagnetic characteristics for the working frequency band. Sayed amir and Zahra [10] have proposed U-shaped and inverted U-shaped metamaterial loaded substrate antenna to achieve 35% miniaturization compared to folded monopole antenna.

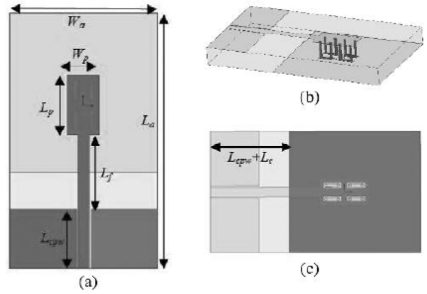


Fig. 11 Minaturized CPW-fed antenna loaded with U-shaped MTM and its parameters. (a) Top-view (b) overview, and (c) bottom view.

Table II

Antenna Structure Dimensions

	U-shaped MTM loaded antenna	Inverted U-shaped MTM loaded antenna
W_a	20	20
L_a	34.5	37
W_p	4.4	4.8
L_p	8	8
L_f	10	10
L_{cpw}	8	8
L_c	5	5

4.2 MTM loading for improved bandwidth

Tong Cai; Guang-Ming Wang; Xiao-Fei Zhang; Ya-Wei Wang; Bin-Feng Zong; He-Xiu Xu [8] have proposed MTM loaded antenna having improved bandwidth. As an important divarication of MTMs, the artificial magneto-dielectric substrate has been verified to be a promising avenue to realize antenna size reduction and impedance BW improvement.

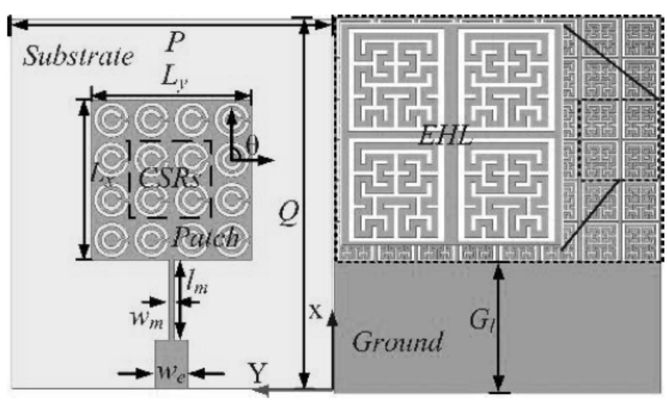


Fig. 12 Schematic of the proposed antenna with MED-WG-MTM loading[8]

The geometrical parameters of the proposed patch antenna are as: P=40mm, Q=45mm, Lx=Ly=20mm, Gl=15mm, lm=10mm,Wm=0.8mm, and Wc=4.1mm. the final geometrical parameters of CSRs ar r1=2.1mm, d=0.5mm, c=0.3mm and g=0.5mm. The fabricated antenna of above dimensions and their result when compared to reference is shown in fig. 13 and Table III

Table III

Comparison of the reference and proposed antenna

Type	Size(mm^2)	BW (MHz(%))
Reference	25.4 × 27.4	43 (1.23%)
Prototype	20 × 20	115 (3.29%)

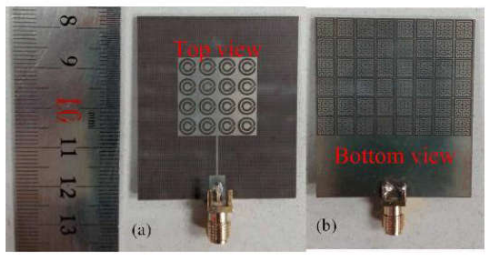
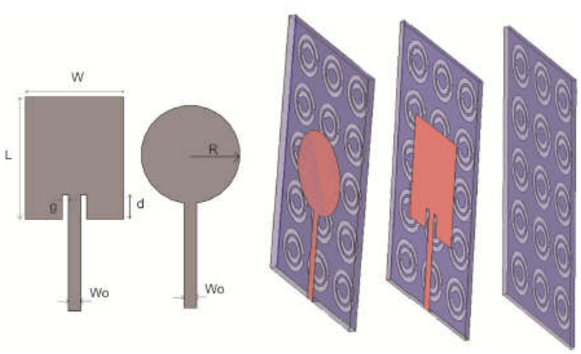


Fig. 13 Photograph of the fabricated antenna. (a) Top view (b) Bottom View.

4.3 MTM loading for Multiband behavior

The paper proposed by D. R. Luna, V. P. Silva Neto, C. F. L. Vasconcelos and A. G. D'Assunção [11] is about to investigate the performance of microstrip patch antenna geometry composed of a metamaterial substrate (grounded by an array of CSRRs) with a superstrate (with another array of CSRRs.) as shown in figure 14. The SRR is an artificial structure which is used to achieve the metamaterial properties. The SRR works as small magnetics dipoles, increasing the magnetic response. The SRR can be seen as a LC circuit. Then effective magnetic permeability can be found. As per the figure 14 of prototype antennas, the first two are MPA with solid GP , the next two figures are of circular and rectangular patch antenna with CSRR in the ground plane and next to it is rectangular patch antenna with superstrate with a CSRR array.



(a) (b) (c) (d) (e)

Fig. 14 Proposed antenna geometries (a) rectangular patch, (b) circular patch, (c) circular patch with CSRR array in the ground plane, (d) rectangular patch with CSRR array in the ground plane, and (e) superstrate with CSRR array [11].

The prototype of the antenna when fabricated of above mentioned different configurations are shown in figure 15. Five different types of microstrip antenna are made using metamaterial loading.

Fig 15 Photographs of the antenna prototypes [11].

When we discuss about rectangular patch antenna with CSRR in the ground plane, we can observe the multiband behavior in the VSWR plot shown in the figure 16. Patch antenna with solid GP has the resonance at 1.7GHz whereas the rectangular patch antenna with CSRR in the ground plane has the potential resonance at 1.3GHz and 2.4GHz. This multiband property can also widen the application of microstrip patch antenna.

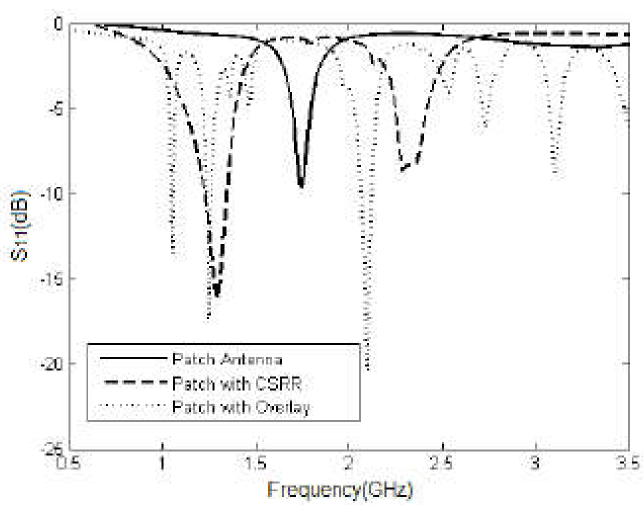


Fig 16 Simulated return loss results for the proposed microstrip antenna geometries with rectangular patch elements [11].

As per the paper of S. Lamari, and R. Kubacki [12], they used sierpinski method etched on the microstip patch antenna to obtain reasonable bandwidth with multiband behavior.

A simple patch antenna was designed and simulated having dimension 28× 32× 0.787 mm^3 to serve as a reference. The patch is 12×16 mm^2 and the feeding line is 2.46×8.0mm^2. ur proposed antenna is 31.87× 27.74× 0.787 mm^3 , feeding line is , the geometry is depicted in figure 17 it was constructed on the Rogers RT5880 substrate of 2.2 permittivity and 0.787mm thickness.

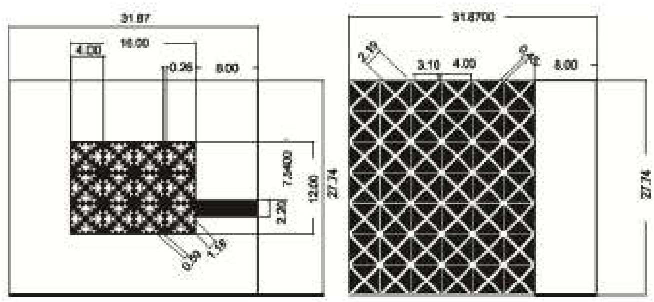


Fig 17 The antenna configuration [12].

The metamaterial patterned structure applied on the metal parts of the antenna. On the patch Sierpinski gasket is etched on every quarter of a square cell. On the ground plane, four isosceles triangles are formed by etching two diagonal slots on the cell. the picture of fabricated antenna shown in figure 18. The left handed characteristics is impelled by the whole configuration which drives a coupling between the patch and ground plane, thus favoring better characteristics of antenna.

Fig 18 Picture of fabricated antenna [12].

Simulation in CST MWS 2011 environment is shown in figure 19 for reference antenna and figure 20 for proposed antenna. Proposed antenna shows potential resonance around 7.89GHz and other at 11.9GHz in its results, whereas the reference antenna shows the resonance at only 7.9GHz. so multiband behavior of antenna achieved using metamaterial.

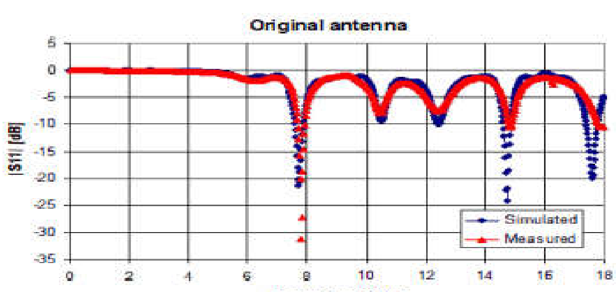


Fig. 19 The simulated and measured return loss of the original antenna. [12].

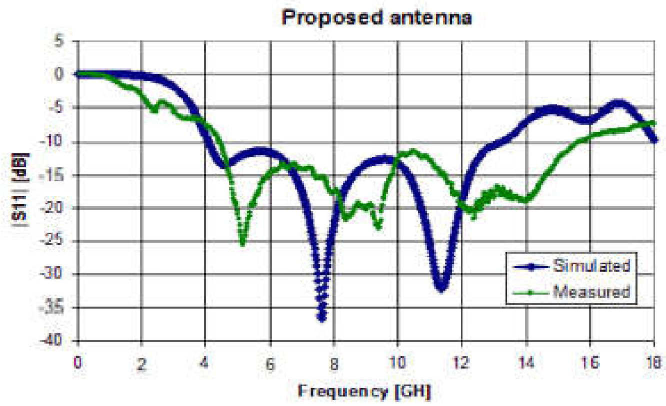


Fig. 20 The simulated and measured return loss of the proposed antenna [12].

Conclusion

As the metamaterial is not directly available in nature but it is composed artificially, various characteristics of microstrip patch antenna are addressed using metamaterials. Enhanced bandwidth, smaller size and multiband behavior are few issues addressed using metamaterials. In fact, antenna efficiency and gain are also improved using metamaterials. So it has been a strong hope and latest subject of research in the field of microstrip patch antenna.

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