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DUAL RESONANT MICROSTRIP PATCH ANTENNA USING METAMATERIAL PLANAR STRUCTURES FOR S BAND AND C BAND APPLICATIONS

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Abstract

In this paper a dual band antenna operating in S band and C band is designed and developed with the help of metamaterial planar structure. Incorporating metamaterials in the conventional microstrip patch antenna improves the performance and reduce the size of the antenna. The proposed antenna has the dimension of 21.7mm X 20.4mm which is designed on FR4 substrate with microstrip line feeding. Further, the performance of the antenna is analyzed by varying substrate thickness. From the analysis, it is noticed that the proposed antenna has better performance when the substrate thickness is 1.6mm. It resonates at 2.7GHz, 7.5GHz with the return loss of -17.27dB, -29.63dB, respectively. It can be used for space communication (2.025GHz–2.110GHz) and for RADAR applications.

Keywords:

Metamaterial, CSRR, C Band and S Band

1. INTRODUCTION

In the recent years, the development in communication systems requires the development of low cost, minimal weight, low profile antennas that are capable of maintaining high performance over a wide spectrum of frequencies. The future development of the personal communication devices will aim to provide image, speech and data communications at any time, and anywhere around the world.

Nowadays microwave components with high performance and small size are needed for modern communication systems, so compact antennas such as printed antennas are required [1-3]. Hence researchers are showing interest in designing low profile antennas with multiple operating frequencies. It is a well-known factthat printed microstrip antennas present really appealing physical features [4]. Microstrip antennas are becoming very widespread within the mobile phone market. The printed antenna such as microstrip patch antenna has advantages of low profile, low cost, good radiator, easy integration with microwave integrated circuits and support linear and circular polarization. Microstrip antennas are used in aviation, space communication, satellite, missile and various government and commercial applications, because of their small size, weight, cost, performance and ease of installation [2-3]. However, the main drawbacks of such antennas are narrow bandwidth and low gain hence it could not accommodate with all those systems [5].

A direct technique to widen the bandwidth can be done by achieving a good impedance matching between the feeding line and the radiating element [6]. Another technique is adding parasitic elements and cutting slots on the patch. However, the aforementioned techniques could not provide better performance. Hence, a new attempt is made to design patch antenna on metamaterial surface in order to enhance the performance of an antenna for real time on-demand applications.

Metamaterial is an artificial material which has negative dielectric constant. These materials are periodic in which is not obtained from nature. The Metamaterial or Left Handed Material (LHM) is a combination of thin wires and Split Ring Resonators (SRR).Many new structures have been proposed for LHM such as Omega shape, spiral multi-split, fishnet and S-shape which exhibits the properties of a LHM [7-10]. In metamaterials, the values of permittivity (μ), permeability (ξ) or both of them are negative [11-14]. For double-negative metamaterials (DNMs), there is an enhanced electromagnetic radiation compared to the existing slow wave structures [15-16]. Antenna designs incorporating metamaterials can step-up the antenna's radiated power. The wider bandwidth antenna can be designed by using artificial engineered material called metamaterial in the antenna substrate. By means of this material antenna miniaturization, bandwidth enhancement can be achieved. The negative refractive index of this material supports backward waves [17-18]. Knowing the phases and amplitudes of the waves transmitted and reflected from the slab, we can retrieve values for the complex refractive index, *n* and wave impedance, *z* [19]. Waves in general DNG media focus in a paraxial sense along the propagation axis [20].

Many researchers are aiming to design a multiband antenna with preferable performance. The bandwidth and gain of the antenna are closely related to the structure and size of the antenna. Reducing the size of the antenna will reduce the efficiency and bandwidth of the antenna.

Generally, in conventional microstrip patch antenna design, the relative permittivity (ξ_r) and height of the dielectric substrate plays a major role. The height of the substrate should be much smaller than the operating wavelength. Also the relative permittivity (ξ_r) should be small in order to produce more fringing effect. Based on the dielectric constant and thickness of the substrate, the dimensions (Length and Width) of the radiating patch can be calculated. Length of the patch determines the resonating frequency of the antenna.

In this paper, rectangular patch antenna with a slot of 1×5mm is proposed, designed and developed on the metamaterial substrate with the operating frequency of 2.8GHz and 7.5GHz. The functional parameters such as resonant frequency, VSWR, return loss, radiation pattern and gain are analyzed through simulation. Further, the variation in operating frequency and return loss while varying the substrate thickness are analyzed.

The paper is organized as follows. In section 2, the related work is discussed. In section 3, the metamaterial structure and design of CSRR are discussed. In section 4, the design of microstrip patch antenna on metamaterial substrate is discussed. The results are presented in section 5 and their features are analyzed and discussed. The conclusion is made in the section 6.

2. RELATED WORK

Richard W. Ziolkowski at al. explained that the double negative materials are having negative relative permittivity and negative permeability over the operating frequency range of antenna. They provided the method of extracting effective permittivity and permeability from reflection and transmission coefficients [20].

Smith et al. proposed a new method called as standard retrieval method to validate the dielectric parameters of the metamaterial structures. They analyzed the method for both symmetric and non-symmetric structures. From the results it seems that the theoretical results are having good agreement simulated results [19].

Wu at al. proposed split ring resonator to enhance the bandwidth. They investigated different shapes such as 1-D, 2-D, omega and S structures at operating frequency of 14.5GHz. 1-D unit cell produced a bandwidth of 12-12.3GHz, 2-D unit cell produced a bandwidth of 16.1-18GHz, omega structure produced a bandwidth of 13.7-14.1GHz and 15.6-17.2GHz and S structures produced a bandwidth of 10.7-10.8GHz. From this analysis the 2-D unit cell resonated with wider bandwidth of 1.9GHz [9].

Alici et al. proposed fishnet metameterial structure operating at 100GHz with dimensions of 2mm×2mm on a dielectric substrate Rogers RT/Duroid (5880). By using standard retrieval method the double negative properties were analyzed. It seems that the simulation and experimental results are in good agreement [11].

A modified square rectangular split ring resonator with a capacitive loaded strip for the performance improvement is discussed by Majid et al. They achieved a bandwidth of 4.98% with a gain of 4dB [8].

Duan et al. proposed a new double negative material composed of square split ring resonator with two strip lines. The proposed antenna was designed on Teflon with a dimension of 2.2mm for THz communication [16].

Han Xiong et al. proposed an improved metamaterial rectangular patch antenna operating at 13.5GHz for UWB application. The antenna was designed in F4BM-2 substrate and it's produced broad bandwidth of 11.77 with an average gain of 5.42dB. From the results it seems that the proposed antenna has wider bandwidth with the dimension of 27.6×31.8mm^2. [5].

So while increasing the performance of the antenna miniaturization is the major fact. In this paper the proposed circular shape split ring resonator is designed on FR4 material with antenna size of 21.7×20.4mm^2 with improved gain. Antenna miniaturization is achieved. The proposed antenna resonates at 3.27GHz produces a bandwidth about 6.8GHz and average gain 5.82dB.

3. METAMATERIAL STRUCTURE

The unit cell is the basic of the periodic structure. One of the famous metamaterial structures is CSRR. It is composed of two concentric metallic ring slots with slits etched in each ring at its opposite sides [19]. In SRR external magnetic field penetrates through the rings and currents are induced. The gap between the rings prevents flow of current around the rings which considerably increase the resonance frequency of the structure. With adjustment of the size and geometric parameters of the CSRR, the resonant frequency can be easily tuned to the desired value [20].

The Fig.1 shows the complementary split ring resonator, which consist of two concentric rings of copper with thickness 2mm patterned on FR4 substrate of dielectric constant = 4.4. The other structural parameters of proposed split ring resonator are listed in Table.1.

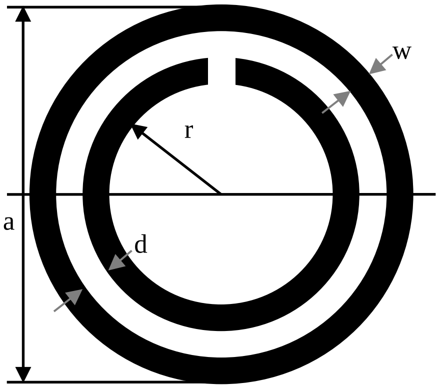


Fig.1. Schematic representation of Complimentary Split Ring Resonator

Table.1. Structural parameters of SSR

Dimensions of SSR	Values (mm)
Width of ring	2
Radius of outer ring	5
Gap between inner and outer ring	1
Side of the ring	14

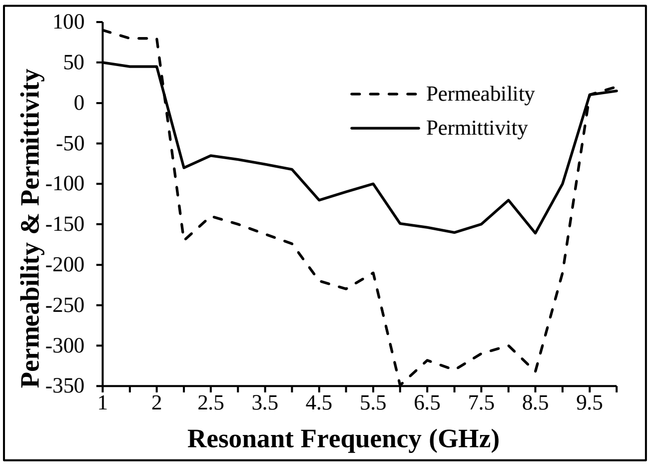


Fig.2. Values of Permittivity and Permeability

The Fig.2 shows that the impact of permittivity/permeability while varying the frequency. It seems that the proposed SRR accord negative permittivity/permeability which is essential to ensure the desirable performance. The equations used in direct retrieval method to find the dielectric constant of the proposed unit cell is given as,

$$\xi = \frac{n}{Z}; \mu = nZ \quad (1)$$

$$n = \frac{1}{kd}\cos^{-1}\left(\frac{1}{2S_{21}}\left(1 - S^2{}_{11} + S^2{}_{21}\right)\right) \quad (2)$$

$$Z = \sqrt{\frac{\left(1+S_{11}\right)^2 - S^2{}_{21}}{\left(1-S_{11}\right)^2 - S^2{}_{21}}} \quad (3)$$

The proposed circular geometry metamaterial is incorporated on the ground plane. The C shaped complementary split ring resonator produces negative permittivity and negative permeability simultaneously.

4. DESIGN AND ANALYSIS OF CONVENTIONAL PATCH ANTENNA

4.1 DESIGN SPECIFICATION

- *Operating frequency*: The operating frequency of the proposed antenna is 3.27GHz.
- *Dielectric constant of the substrate*: FR4 material is selected as a substrate which has dielectric constant of 4.4.
- *Height of the substrate*: The height of the substrate is selected as 1.6mm.

The conventional microstrip antenna parameters are calculated as follows:

$$W = \frac{C}{2 f_0 \sqrt{\frac{(\xi_r + 1)}{2}}} \quad (4)$$

$$\xi_{reff} = \frac{(\xi_r + 1)}{2} + \frac{(\xi_r - 1)}{2}\left(1 + 12\frac{h}{w}\right)^{\frac{1}{2}} \quad (5)$$

$$\Delta L = 0.412h \frac{\left(\xi_{reff} + 0.3\right)\left(\frac{w}{h} + 0.264\right)}{\left(\xi_{reff} - 0.264\right)\left(\frac{w}{h} + 0.8\right)} \quad (6)$$

$$L_{eff} = \frac{C}{2 f_0 \sqrt{\xi_{reff}}}; L_{eff} = L + 2\Delta L \quad (7)$$

$$L_g = 6h + L; W_g = 6h + W \quad (8)$$

Length of patch	-	21.7mm
Width of patch	-	20.4mm
Length of Substrate	-	45.0mm
Width of Substrate	-	26.0mm

A proposed microstrip antenna has a size of $21.7 \times 20.4 mm^2$ with a slot opening of $1 \times 5 mm^2$ is designed on a Flame Retardant 4 (FR-4) substrate has size of $45 \times 26 \times 1.6 mm^3$, relative permittivity of 4.4 and loss tangent of 0.02.

The proposed antenna has microstrip line feeding with 12mm length. The Fig.3 shows the front and bottom view of the proposed antenna. The CSRR structure is introduced on the ground plane.

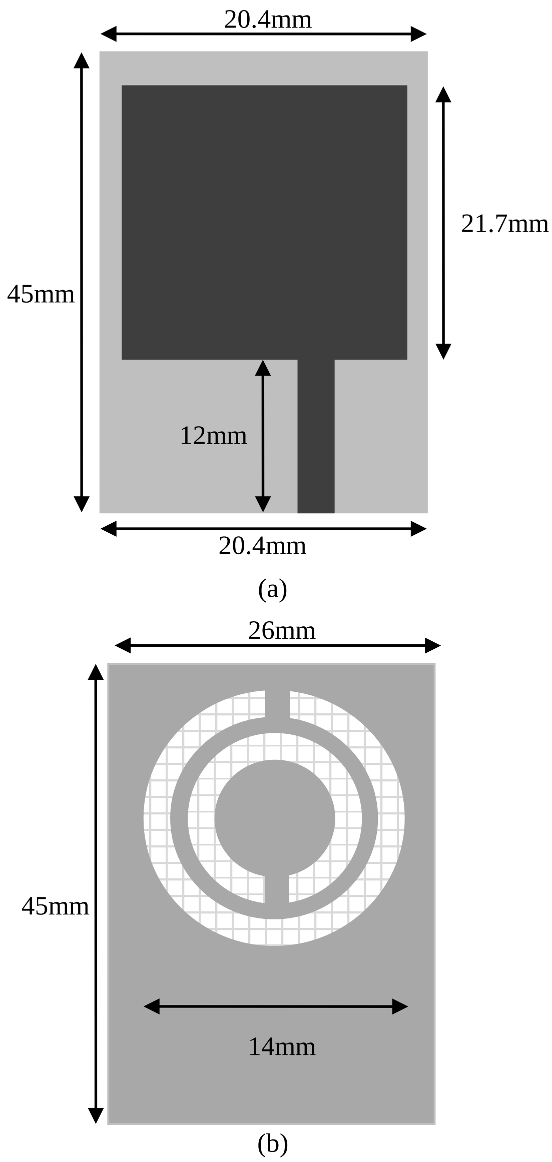


Fig.3. Proposed antenna (a) Front view (b) Bottom view

5. RESULTS AND DISCUSSION

The proposed antenna is studied and simulated by HFSS software which is Finite Element Method based simulation software. From the simulation results it is observed that the proposed antenna resonates at two frequencies and it produces better return loss at the resonant frequencies. The Fig.4 shows that the return loss of -17.27dB and -29.63dB is arrived at 2.7GHz and 7.5GHz, respectively. It seems that with the help of metamaterial structure on ground and a patch with slot produces dual operating bands. The Fig.5 shows that VSWR of the antenna at 2.7GHz and 7.5GHz is closer to unity which dictates the perfect impedance matching and maximum radiation. The values of return loss and VSWR at resonant frequency are listed in Table.2.

Also the proposed antenna has a wider bandwidth over a frequency range of 2.2GHz-9GHz which represents 6.8GHz bandwidth. So this patch is suitable for S band (2GHz-4GHz) and C band (4GHz-8GHz) applications.

The simulated far field radiation pattern in E plane with phi=0 of the proposed antenna at 2.7GHz and 7.5GHz are shown in Fig.6(a) and Fig.6(b), respectively. It seems that the antenna has high gain at 7.5GHz as 6.20dB. Also, it shows that the antenna produces stable radiation and average gain of 5.82 dB.

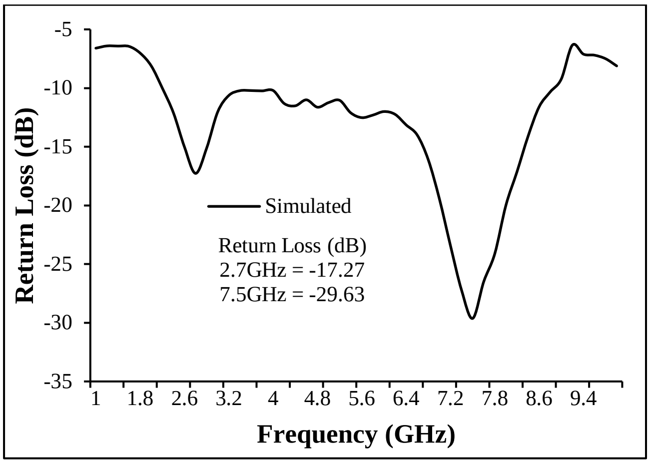


Fig.4. Return loss of proposed antenna

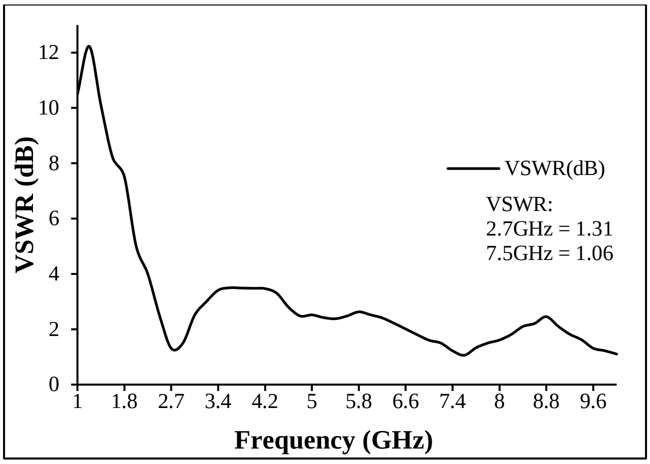
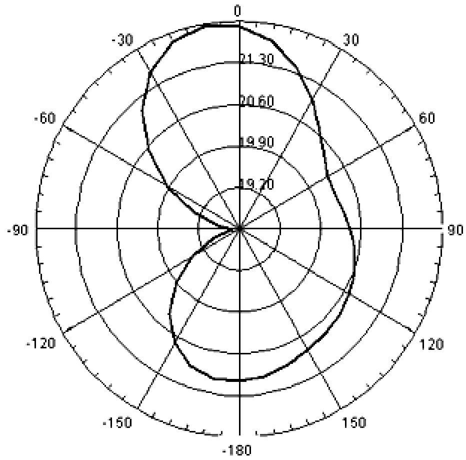


Fig.5. VSWR of proposed antenna

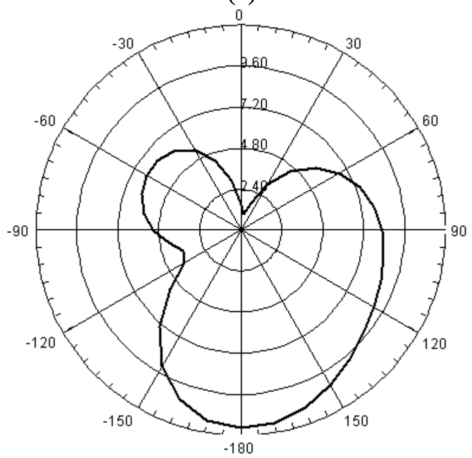
Table.2. Simulation results

Frequency (GHz)	Return Loss (dB)	VSWR
2.7	-17.27	1.31
7.5	-29.63	1.06

The proposed antenna is fabricated on FR-4 dielectric substrate with the thickness of 1.6mm. Front and bottom view of the fabricated antenna is shown in Fig.7(a) and Fig.7(b), respectively. The fabricated antenna is fed through the SMA connector. The Fig.8 shows the values of measured and simulated return loss. It seems that the fabricated antenna also has dual resonating frequencies, and it has a good agreement with the simulated results. From the measured results, it is observed that that fabricated antenna has low return loss as -27.8dB and -21.03dB at a frequency of 2.8GHz and 7.5GHz, respectively. The value of return loss and resonant frequency of simulated and fabricated antenna is listed in Table.3.



(a)



(b)

Fig.6. Radiation Pattern of proposed antenna at (a) 2.7GHz and (b) 7.5GHz

(a)

(b)

Fig.7. Fabricated antenna (a) Front View (b) Bottom View

The fabricated antenna has -10dB and below -10dB of return loss ranging from 2.2GHz-9GHz which represents 6.8GHz of bandwidth. From Table.3, it is noticed that there is a minor change in performance parameters owing to SMA connector.

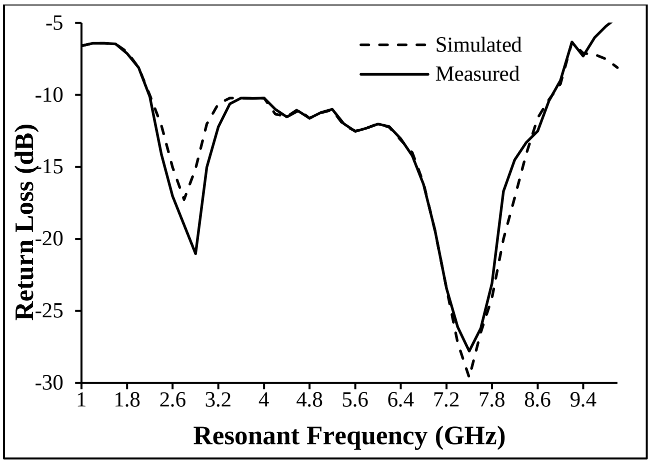


Fig.8. Return loss of fabricated antenna

Table.3. Comparison of simulated results and fabricated results

Simulated results			Fabricated results		
Frequency (GHz)	**Return Loss (dB)**	**VSWR**	**Frequency (GHz)**	**Return Loss (dB)**	**VSWR**
2.7	-17.27	1.31	2.8	-21.03	1.41
7.5	-29.63	1.06	7.5	-27.8	1.04

The variation in resonant frequency and return loss while varying substrate thickness is listed in Table.4. The Fig.9 shows the variation on operating frequency and return loss while varying the thickness of the substrate as 0.8mm, 1.6mm and 3.2mm. It indicates that substrate with thickness of 1.6mm is having dual resonant frequencies and minimum return loss of -17.27 and -29.63dB at 2.7GHz and 7.5 GHz, respectively.

Table.4. Variation in operating frequency, return loss and VSWR proposed antenna with different substrate thickness

Substrate Thickness (mm)	Operating Frequency (GHz)	Return Loss (dB)	VSWR
0.8	7.5	-24.56	1.65
1.6	2.7	-17.27	1.31
	7.5	-29.63	1.08
3.2	4.9	-22.32	1.75

6. CONCLUSION

A compact dual band antenna has the dimension of $45\times26\times1.6mm^3$ which operates in S band (2GHz-4GHz) and C band (4GHz-8GHz) is proposed, designed and developed with the help of metamaterial planar structure on the ground. It has double resonant frequency at 2.8GHz and 7.5GHz with the return loss of -21.03 and -27.8, respectively. It allows a wider bandwidth of about 6.8GHz and average gain of 5.82dB. The proposed antenna could be incorporated for S band and C band applications.

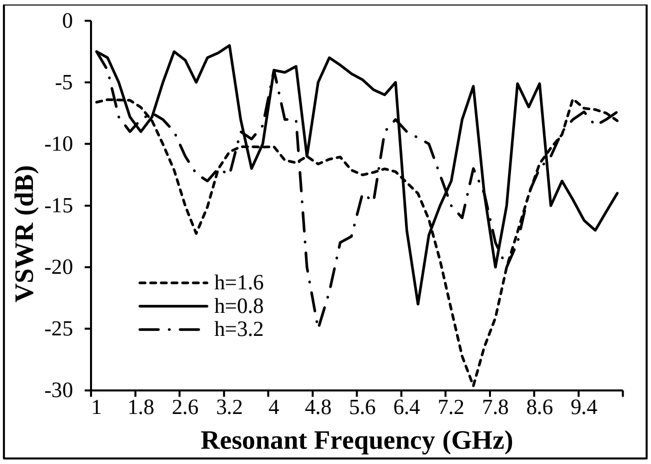


Fig.9. Return loss of proposed antenna with different substrate thickness

REFERENCES

[1] Maryam Rahimi, Ferdows B. Zarrabi, RaheleAhmadian, Zahra Mansouri and Asghar Keshtkar, “Miniaturization of Antenna for Wireless Application with Difference Metamaterial Structures”, *Progress in Electromagnetics Research*, Vol. 145, pp. 19-29, 2014.

[2] N.H. Ramli, M.R. Kamarudin, N.A. Samsuri, E.N. Ahyat, A.Y. Abdulrahman and M.F.B. Jamlos, “A 6.0 GHz Small Printed Monopole Antenna for Wireless Implantable Body Area Network (WiBAN) Applications”, *Progress In Electromagnetics Research C*, Vol. 41, pp. 189-200, 2013.

[3] Y. Hu, Y.J. Zhang and J. Fan, “Equivalent Circuit Model of Coaxial Probes for Patch Antennas”, *Progress In Electromagnetics Research B*, Vol. 38, pp. 28-296, 2012.

[4] Han Xiong, Jing-Song Hong and Yue-Hong Peng, “Impedance Bandwidth and Gain Improvement for Microstrip Antenna Using Metamaterials”, *RadioEngineering*, Vol. 21, No. 4, pp. 993-998, 2012.

[5] Salim Lamari, Roman Kubacki and Miroslaw Czyzewski, “Bandwidth Enhancement of a Microstrip Patch Antenna Using the Metamaterial Planar Periodic Structure”, *Proceedings of Progress in Electromagnetics Research Symposium*, pp. 6-9, 2015.

[6] H.F. Pues and A.R. Van de Capelle, “An Impedance Matching Technique for Increasing the Bandwidth of Microstrip Antennas”, *IEEE Transactions on Antennas and Propagation*, Vol. 37, No. 11, pp. 1345-1354, 1989.

[7] H.A. Majid, M.K. Abd Rahim and T. Masri, “Microstrip Antenna's Gain Enhancement using Left-Handed Metamaterial Structure”, *Progress In Electromagnetics Research M*, Vol. 8, pp. 235-247, 2009.

[8] B.I. Wu, W. Wang, J. Pacheco, X. Chen, T. Grzegorczyk and J.A. Kong, “A Study of using Metamaterials as Antenna Substrate to Enhance Gain”, *Progress In Electromagnetics Research*, Vol. 51, pp. 295-328, 2005.

[9] Kamil Boratay Alici, Filiberto Bilotti, Lucio Vegni and Ekmel Ozbay, “Optimization and Tunability of Deep Subwavelength Resonators for Metamaterial Application: Complete Enhanced Transmission through A Sub

Wavelength Aperture", *Optic Express*, Vol. 17, No. 8, pp. 5933-5943, 2009.

[10] Kamil Boratay Alici and Ekmel Ozbay, "Characterization and Tilted Response of a Fishnet Metamaterial Operating at 100 GHz", *Journal of Physics D: Applied Physics*, Vol. 41, No. 13, pp. 135011-135015, 2008.

[11] M. Li, H.L. Yang, X.W. Hou, Y. Tian and D.Y. Hou, "Perfect Metamaterial Absorber with Dualbands", *Progress In Electromagnetics Research*, Vol. 108, pp. 37-49, 2010.

[12] K. Buell, H. Mosallaei and K. Sarabandi, "A Substrate for Small Patch Antennas providing Tunable Miniaturization Factors", *IEEE Transactions on Microwave Theory and Techniques*, Vol. 54, No. 1, pp. 135-146, 2006.

[13] F. Bilotti, A. Alu and L. Vegni, "Design of Miniaturized Metamaterial Patch Antennas with μ-Negative Loading", *IEEE Transactions on Antennas and Propagation*, Vol. 56, No. 6, pp. 1640-1647, 2008.

[14] L. Gurel, A. Unal and T. Malas, "Fast and Accurate Analysis of large Metamaterial Structures using the Multilevel Fast Multipole Algorithm", *Progress In Electromagnetics Research*, Vol. 95, pp. 179-198, 2009.

[15] Z.Y. Duan, Y.S. Wang1, X.T. Mao, W.X. Wang and M. Chen, "Experimental Demonstration Of Double Negative Metamaterials Partially Filled In A Circular Waveguide", *Progress In Electromagnetics Research*, Vol. 121, pp. 215-224, 2011.

[16] D.L. Barker and W.R. Owens, "Smith-Purcell Radiation Source using Negative Metamaterial (NIM)", United States Patent, 2008.

[17] J. Chen, W. Chen, J. Yen, L. Chen and C. Wang, "Comparative Analysis of Split-Ring Resonators for Tunable Negative Permeability Metamaterial based on Anisotropic Dielectric Substrates", *Progress In Electromagnetics Research M*, Vol. 10, pp. 25-38, 2009.

[18] D.R. Smith, D.C. Vier, Th. Koschny and C.M. Soukoulis, "Electromagnetic Parameter Retrieval from in Homogeneous Metamaterials", *Physical Review E*, Vol. 71, No. 3, pp. 1-11, 2005.

[19] R.W. Ziolkowski, "Design Fabricating and Fabrication and Testing of Double Negative Metamaterials", *IEEE Transactions on Antennas and Propagation*, Vol. 51, No.7, pp. 1516-1529, 2005.

[20] H.A. Jang, D.O. Kim and C.Y. Kim, "Size Reduction of Patch Antenna Array using CSRRs Loaded Ground Plane", *Proceedings on Progress in Electromagnetics Research Symposium*, pp. 1487-1489, 2012.