A New Design of a Compact Metamaterial Antenna for RFID Handheld Applications

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ABSTRACT:
The development of miniature antennas is the key requirement for radio frequency identification applications in various fields. In this paper, a new design of a compact metamaterial microstrip antenna based CSRR resonators is proposed. The proposed metamaterial antenna has a simple structure. It is formed by a rectangular patch embedded a T-shaped slot in one side, and a two metamaterial unit cells formed by CSRR etched from the ground plane in the other side. The designed antenna is printed on an epoxy Frame Resistant 4 substrate by using CST Microwave Studio. It operates at two RFID bands around 5.8GHz and 2.45GHz. The designed antenna is fabricated by using an LPKF machine. The simulation results have been justified by measuring the parameters, respectively.

KEYWORDS: Antenna, Radio Frequency Identification, Metamaterial, ISM Band, Dual Band Antenna, Split Ring Resonator, CST.

1. INTRODUCTION

In the last years, radio frequency identification technology (RFID) have become very popular due to its exponential growing applications in many fields like, manufacturing companies, logistics, distribution, goods, flow systems, electronic toll collection, retail item management, asset identification, animal tracking, access control, and vehicle security [1-2]. A typical RFID system consists of three components: a transponder, a reader and databases. The transponder is a device that has a microchip to store data and tag antenna to provide communication with the reader, each tag has a unique identification information of the tagged object. The reader is a device that can read and write information to the RFID chip and it has an antenna for communication purpose [3]. The host system associates arbitrary records with the tag identifying data. These records may contain tracking logs, product information, expiration dates or sales data [4]. Fig.1 illustrates the basic components of an RFID system.

Many operating frequencies have been assigned to the RFID systems, there are the low-frequency (LF) around 125KHz, the high-frequency (HF) around 13.56MHz, the ultra-high-frequency (UHF) from 860MHz to 960MHz and the microwave band (MW) around 2.45GHz or 5.8GHz [5].

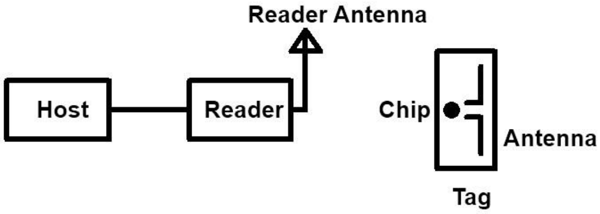


Fig. 1. The basic architecture of an RFID system.

The most important component in the RFID system is the reader and tag antenna and its capability will determine the performance of the whole system. RFID technologies require antennas with small size and high performances such as large bandwidth, multiband operation and, high gain. Many techniques such as metamaterial, defected ground structure (DGS) slot, and fractal methods are used for size reduction and antenna performances enhancement.

This paper discusses and analysis a new design of dual band patch antenna-based metamaterial for RFID handheld applications. It is organized according to the following plan: Section 2 gives an overview of metamaterial, section 3 explains the antenna design, section 4 gives the results and discussion and, section 5 discusses the experimental results.

2. OVERVIEW OF METAMATERIAL

Metamaterials are artificially manufactured structures or materials which have some electromagnetic properties not available in natural materials. The basic parameters which describe the electromagnetic proprieties of such materials are the magnetic permeability and the electric permittivity. A systematic study of this kind of medium was originally made by Victor Veselago, whose paper was published in 1967 in Russian, and a year later in English [6]. Pendry and his group introduced the first realization of a negative permittivity structure, which consists of a periodic array of metallic wires [7]. Three years later, Pendry and his colleagues proposed a negative permeability structure which is formed by a periodic array of SRR (Split Ring Resonators) [8]. An arrangement of split ring resonator and thin wires can exhibit a negative permittivity and negative permeability simultaneously.

In literature, there are many structures that have the metamaterial effect such as square, circular, triangular, Ω-shaped, and others [9-11]. However, SRR and its negative image the complimentary SRR are the basic elements of metamaterials that can exhibits a negative permittivity, it received a growing interest recently in many applications like filters [12-13], antennas [14-15] and other circuits. In the present work, we have used a two-cell network composed of complementary split ring resonators as shown in Fig. 2.

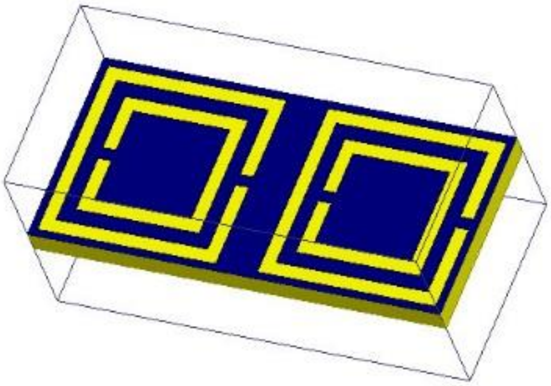


Fig. 2. Geometry of the proposed unit cells.

To extract the permittivity and the permeability from the S-parameters, the metamaterial network was embedded into an electromagnetic waveguide and the Nicolson Ross Weir method [16] was used which starts by using the following equations:

$$S11 = \frac{i}{2}\left(\frac{1}{z} - z\right)\sin(nkd) \qquad (1)$$

$$S21 = \frac{1}{\cos(nkd) - \frac{i}{2}\left(z + \frac{1}{z}\right)\sin(nkd)} \qquad (2)$$

Where n is the refractive index, d is the thickness of the metamaterial unit cell, z and k are the wave impedance and number respectively. The wave impedance and the refractive index are calculated by:

$$z = \sqrt{\frac{(1+S_{11})^2 - S_{21}{}^2}{(1-S_{11})^2 - S_{21}{}^2}} \qquad (3)$$

$$n = \frac{1}{kd}\cos^{-1}\left[\frac{1}{2S_{21}}\left(1 - S_{11}{}^2 + S_{21}{}^2\right)\right] \qquad (4)$$

The permeability μ and the permittivity ε are calculated by the following equations:

$$\varepsilon = \frac{n}{z} \qquad (5)$$

$$\mu = n.z \qquad (6)$$

The results in term of permittivity against frequency are reported in Fig. 3. We can clearly observe that the proposed metamaterial network presents a negative region around the first RFID frequency band around 2.45GHz which proves the metamaterial effect of the proposed structure.

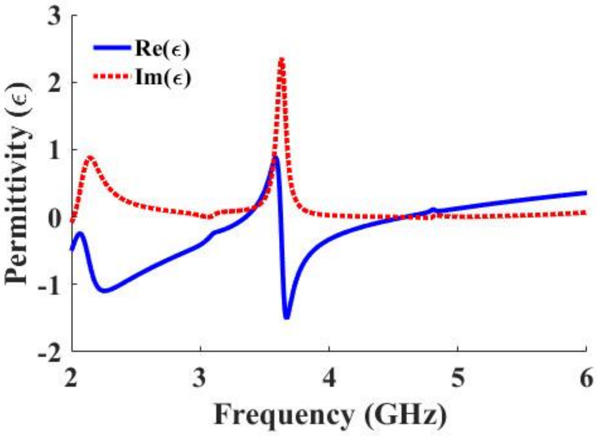
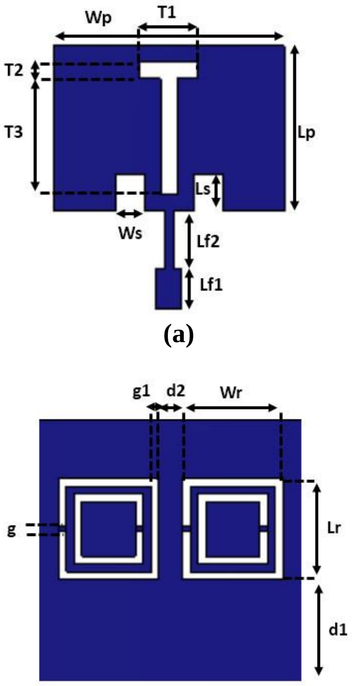


Fig. 3. Geometry of the split ring resonator.

3. ANTENNA DESIGN

3.1. Antenna geometry

The geometry of the designed metamaterial antenna is presented in Fig. 4. It consists of a rectangular conducting patch embedded with T-shaped slot on the front side of the Frame Resistant substrate having relative permittivity of 4.4, tangent loss of 0.025, the substrate thickness is 1.6mm and, the conductor thickness is 0.035mm. In order to reduce the antenna size, two metamaterial unit cells formed by square CSRR are etched from the ground plane. The designed antenna has a small and compact size of 34 mm x 34 mm and it is excited by a microstrip line with characteristic impedance of 50Ω. The antenna is optimized by using the tuning method integrated into CST Microwave Studio and the final dimensions are illustrated in Table. 1.



(a)

(a)

Fig. 4. Geometry of the proposed antenna (a) front view (b) back view.

Table 1. Dimensions of the proposed antenna.

Parameter	Value (mm)	Parameter	Value (mm)
Wp	28	Lf1	5
Lp	20	Lf2	7
Ws	3.5	T1	7
Ls	4.5	T2	2
Wf	3	T3	14
Wr	13	Wr1	1
G1	1	D2	3
G	0.8	D1	13.5

3.2. Design procedure

Firstly, the initial dimensions of the designed antenna were calculated from the following equations [17]:

$$W = \frac{c}{2 f_0 \sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{7}$$

$$L = L_{eff} + 2\Delta L \tag{8}$$

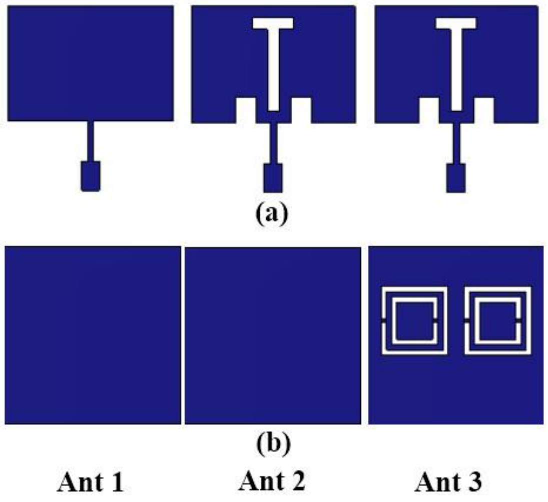
$$L_{eff} = \frac{c}{2 f_0 \sqrt{\varepsilon_{reff}}} \tag{9}$$

$$\Delta L = 0.412h \frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} + 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{10}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12h/W\right]^{-1/2} \tag{11}$$

Where, W is the width of the conventional patch antenna, c is the speed of light, L is the antenna length, L_{eff} is the effective length of the antenna, ε_{reff} is the effective dielectric constant, ΔL is the length extension and, ε_{eff} is the dielectric constant of the epoxy

Secondly, a T-shaped slot is inserted in the patch to attain the first resonant frequency around 5.8GHz. Then, in order to attain the second resonant frequency around 2.45GHz, two metamaterial unit cells are inserted from the ground plane. By adjusting the position and the dimensions of the metamaterial unit cells and the T-shaped slot, we can easily obtain the two RFID bands. The design steps are reported in Fig. 5 and the return loss for each antenna is illustrated in Fig. 6.



(a)

(b)

Fig. 5. Proposed antenna (a) front view (b) back view.

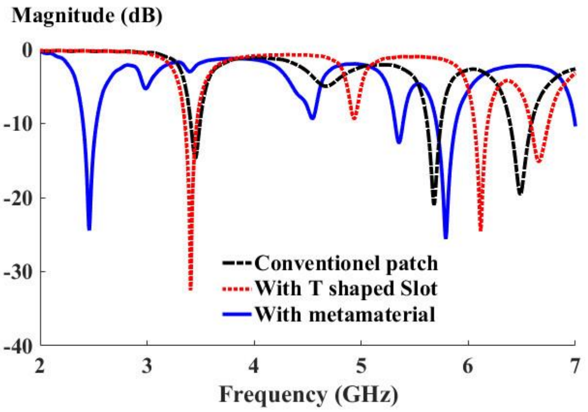


Fig. 6. Different S11 for each antenna.

4. RESULTS AND DISCUSSION

The numerical results in term of reflection coefficient of the proposed metamaterial antenna are reported in Fig. 7. From this result, we can show that the designed antenna covers two RFID frequency band 2.45 GHz and 5.8 GHz. The antenna has an impedance bandwidth of 180 MHz (from 5.70 GHz to 5.88 GHz) at 5.8 GHz and 124 MHz (from 2.402 GHz to 2.526 GHz) at 2.45GHz and the reflection coefficient is about -22.05dB at 2.45GHz and -23.54dB at 5.8GHz.

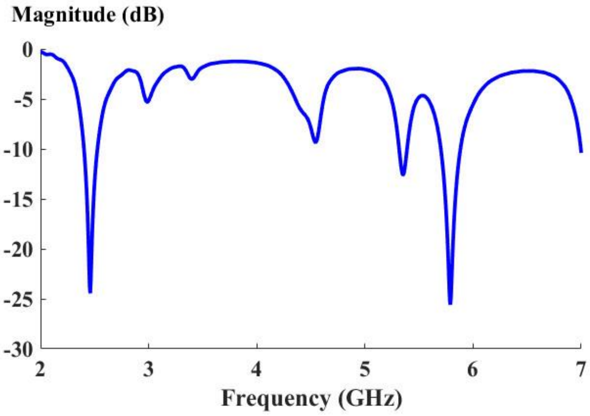


Fig. 7. Simulated return loss of the proposed antenna.

To validate this result, other simulations were done by using another 3D electromagnetic solver HFSS based on Finite Element Method. Fig. 8 illustrates the comparison results obtained by both simulators. We can observe that there is a good agreement between the simulated results.

The computed results of gain versus frequency are shown in Fig. 9. From this result, we can observe that the peak gain is about 2.44dB at 2.45GHz and 2.02dB at 5.8 GHz.

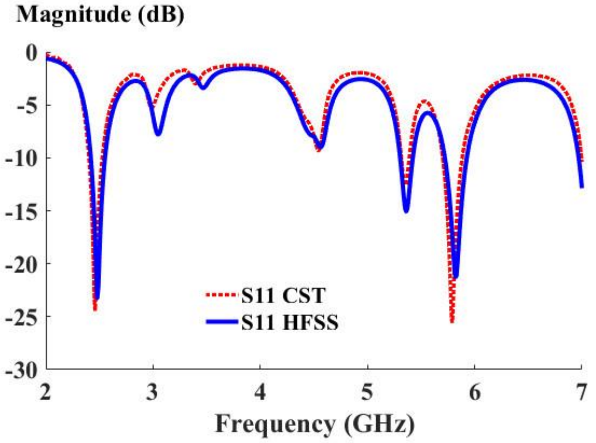


Fig. 8. Comparison between the S11 obtained by CST and HFSS.

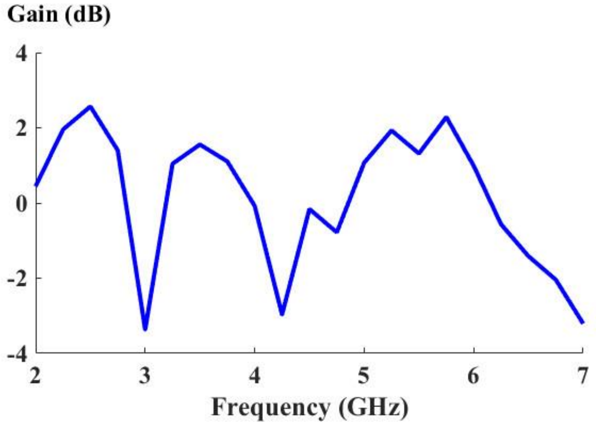
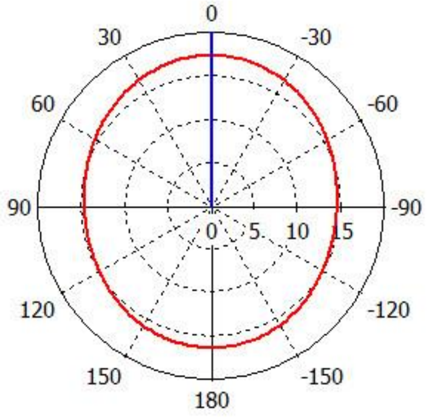


Fig. 9. Gain against frequency of the antenna.

The 2D radiation pattern at E and H planes for 2.45GHz and 5.8GHz is illustrated in Fig. 10 and Fig. 11. It is clearly observed that the designed antenna has a bidirectional radiation at 2.45GHz in both H and E planes.



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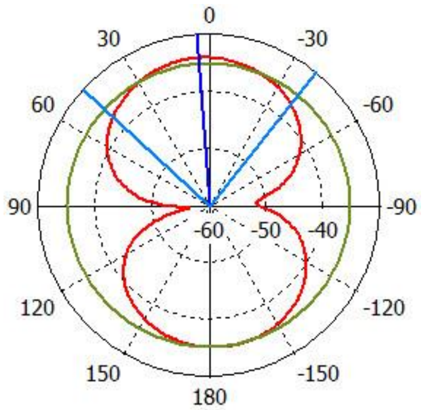
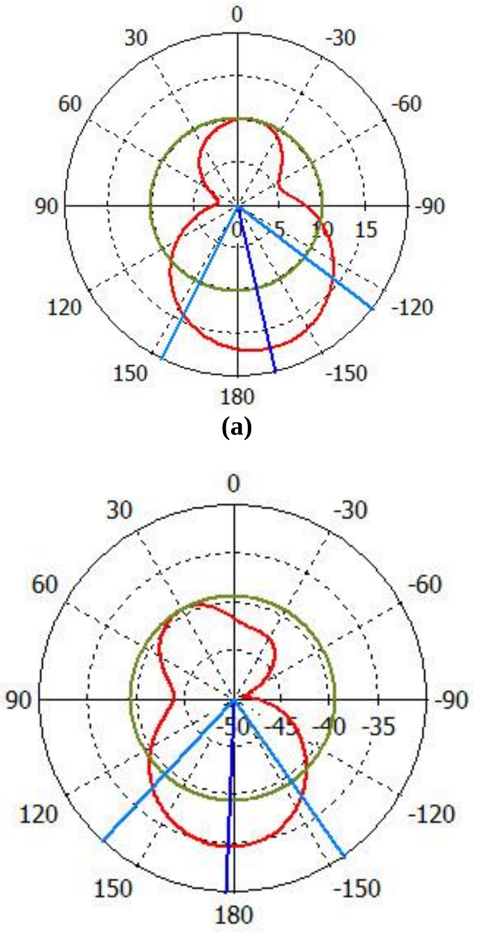


(b)

Fig. 10. Radiation patterns for the proposed reader antenna at 2.45GHz. (a) E-plane (b) H-plane.



(a)

(b)

Fig. 11. Radiation patterns for the proposed reader antenna at 5.8GHz. (a) E-plane (b) H-plane.

For further understanding the antenna behavior, the surface current distribution on the antenna has been reported in Fig. 12. As can be seen in the figure, the surface current is concentrated along the CSRRs, the microstrip line feed and the T slot for both frequencies.

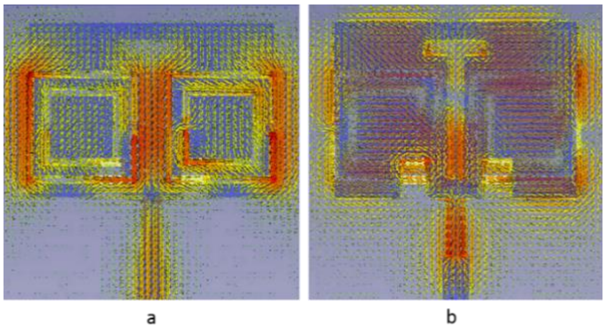


Fig. 12. Current distribution of the RFID handheld antenna.

5. EXPERIMENTAL RESULTS

After optimization of the proposed antenna parameters and validation of the simulated results by using another electromagnetic solver, a prototype of the proposed antenna has been fabricated on the FR-4 substrate having dielectric constant of 4.4 and dielectric thickness of 1.6mm by using LPKF machine. Fig. 13 illustrates the manufactured prototype. As can be seen in the figure, the structure of this antenna is relatively simple as it can be fabricated on a single layer. The fabricated antenna presents an area of 34mm x34mm and a SMA connector soldered to the edge of the antenna was used as a feeding port.

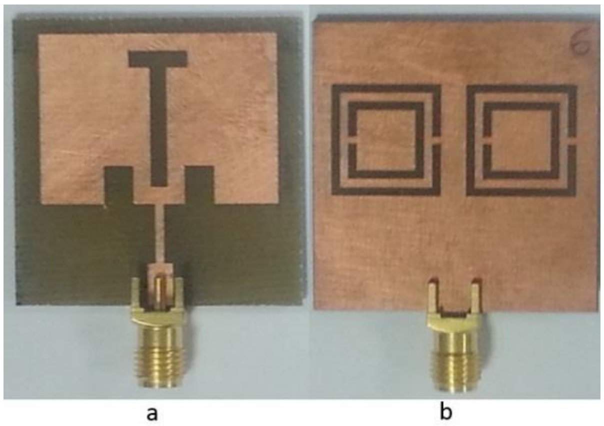


Fig. 13. Manufactured antenna.

Fig. 14 reports the comparison results of the reflection coefficient obtained from the simulation and the measurement. The measured result is performed by using a VNA (HP 8719ES) “vector network analyzer”. From the comparison between the numerical and the measured results, we can observe that there is a close agreement between them. The slight difference between the numerical results and measurement is due to the fabrication error, the SMA connector and uncertainty in substrate thickness and dielectric constant.

Table 2 presents a comparison of the obtained results with some published works in the literature in terms of size, impedance matching and gain. From this table, we can notice that the proposed antenna is smaller than the cited works and has a good gain compared to its size.

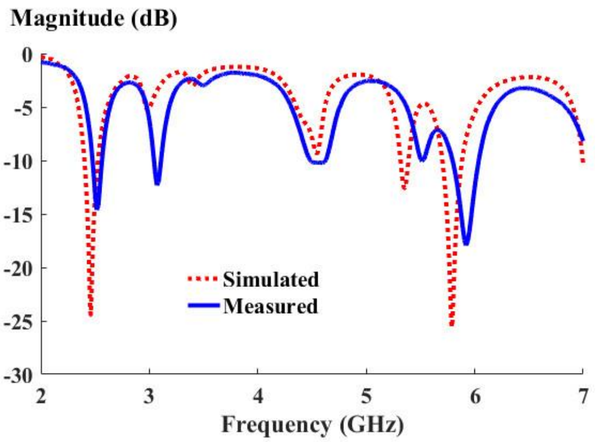


Fig. 14. Simulation and measurement of the reflection coefficient against frequency.

Table 2. Comparison of the obtained results with some published works in the literature.

Ref		[18]	[19]	[20]	This work
Dimensions (mm^2)		47.3x 38.8	38 x 35	52 x 52	34 x 34
Resonance Frequency (GHz)	**F1**	2.45	2.45	2.45	2.45
	F2		5.8		5.8
Return loss (dB)	**F1**	-55	-16	-41	-22
	F2		-29		-23.5
Gain (dB)	**F1**	3.5	1.5	3.6	2.44
	F2		2.4		2.02

6. CONCLUSION

A novel design of dual band compact antenna based on metamaterial for RFID handheld applications is presented in this paper. The proposed antenna has a small and compact size (34mm x 34mm). By using the complimentary split ring resonator, the antenna can cover two RFID band 2.45 GHz and 5.8 GHz with an impedance bandwidth of 2.402-2.526 GHz and 5.70-5.88 GHz. In addition, the designed antenna presents good radiation characteristics. The proposed antenna was simulated by using CST and the numerical results were validated by a second 3D electromagnetic solver HFSS. A prototype of the antenna was manufactured and the simulated results were compared to the measurement and the comparison results shows good agreement.

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REFERENCES

[1] F. Al-Naima and H. Ameen, **“Design of an RFID based Students/Employee Attendance System”,** *Majlesi Journal of Electrical Engineering*, vVol. 10, No. 1, Mar. 2016.

[2] El Hamraoui, E. Abdelmounim, J. Zbitou, A. Errkik, H. Bennis, M. Latrach, **“A Dual-Band Microstrip Slot Antenna Reader for UHF and Microwave RFID Applications,”** *TELKOMNIKA*, Vol.16, No.1, pp. 94-101, Feb. 2018.

[3] A. Hashemi, A. H. Sarhaddi, and H. Emami, **“A Review on Chipless RFID Tag Design”,** *Majlesi Journal of Electrical Engineering*, Vol. 7, No. 2, pp. 68-75, Jun. 2013.

[4] Ennajih, J. Zbitou, M. Latrach, A. Errkik, A. Tajmouati, L. El Abdellaoui, **“A New Design of UHF RFID Tag Antenna using Double Negative Metamaterial Based on Fractal SRR,”** *International Review on Modelling and Simulations*, Vol. 10, No. 6, pp. 392-398, Dec. 2017.

[5] Ennajih, J. Zbitou, M. Latrach, A. Errkik, L. El Abdellaoui, A. Tajmouati, **“Dual Band Metamaterial Printed Antenna Based on CSRR for RFID Applications,”** *International Journal of Microwave and Optical Technology*, Vol. 12, No. 2, pp. 106-113, Mar. 2017.

[6] V. G. Veselago, **“The Electrodynamics of Substances with Simultaneously Negative Values of Epsilon and μ,”** *Soviet Physics Uspekhi*, Vol. 10, No. 4, pp. 509-514, Apr. 1968.

[7] J. B. Pendry, **“Extremely Low Frequency Plasmons in Metallic Mesostructures,”** *Physical Review Letters*, Vol. 76, No. 25, pp. 4773-4776, Jun 1996.

[8] J. B. Pendry, A. J. Holden, D. J. Robbins, and W. J. Stewart, **“Magnetism from Conductors and Enhanced Nonlinear Phenomena,”** *IEEE Transactions on Microwave Theory and Techniques*, Vol. 47, No. 11, pp. 2075-2084, Nov. 1999.

[9] He Y Wang X Ingram W Ai B Zhao Y, **“Optimized Fan-Shaped Chiral Metamaterial as an Ultrathin Narrow-Band Circular Polarizer at Visible Frequencies,”** *Nanotechnology*, Vol. 29, No. 16, pp. 165301, Feb. 2018.

[10] S. Bhattacharjee, R. Saha and S. Maity, **"Metamaterial based Patch Antenna with Omega Shaped Slot for RFID System,"** *in proc. 2014 International Conference on Advances in Engineering & Technology Research, Unnao*, pp. 1-5.

[11] Nasiri, A. Errkik, J. Zbitou, A.Tajmouati, L. El Abdellaoui, M. Latrach, **“A New Compact Microstrip Band-stop Filter by using Square Split Ring Resonator”,** *International Journal of Microwave and Optical Technology*, Vol. 12, No. 5, pp. 367-373, Sep. 2017.

[12] M. Hasan, M. Faruque, M. Islam, **“Dual Band Metamaterial Antenna for**

LTE/Bluetooth/WiMAX System," *Scientific Reports*, Vol. 8, No. 1, pp. 1-17, Jan. 2018.

[13] W. Abd Ellatif, and A. Boutejdar, **"Design of Low-Pass Filter Using Meander Inductor and U-Form Hi-Lo Topology with High Compactness Factor for L-Band Applications",** *Progress in Electromagnetics Research M,* Vol. 55, pp. 95-107, Mar. 2017.

[14] N. Gupta, J. Saxena, K. S. Bhatia, N. Dadwal, **"Design of Metamaterial-Loaded Rectangular Patch Antenna for Satellite Communication Applications",** *Iranian Journal of Science and Technology, Transactions of Electrical Engineering* (2018). https://doi.org/10.1007/s40998-018-0118-9

[15] G. Varamini, A. Keshtkar, M. Naser-Moghadasi**, "Compact and Miniaturized Microstrip Antenna Based on Fractal and Metamaterial Loads with Reconfigurable Qualification,"** *AEU - International Journal of Electronics and Communications*, Vol. 83, pp. 213-221, Jan. 2018.

[16] Nasiri, A. Errkik, J. Zbitou, A. Tajmouati, L. El Abdellaoui, M. Latrach, **"A Miniature Microstrip BSF Using Complementary Split Ring Resonator,"** *International Journal of Intelligent Engineering and Systems*, Vol. 11, No. 3, pp. 29-36, Jan. 2018

[17] Constantine A. Balanis, **"Antenna Theory and Design",** *John Wiley & Sons*, Inc., 1997.

[18] K. P. Vinay, B. Ramesh, L. B. Prasad, D. V. Rama Koti Reddy, **"Design of Microstrip Patch Antenna for RFID Reader Applications,"** *In proc. 2018 2nd International Conference on Micro-Electronics, Electromagnetics and Telecommunications. Lecture Notes in Electrical Engineerin*g, Vol 434. Springer, Singapore.

[19] A. El Hamraoui, E. Abdelmounim, J. Zbitou, H. Bennis, M. Latrach, **"A New Design of a CPW-Fed Dual-Band Monopole Antenna for RFID Readers,"** *International Journal of Electrical and Computer Engineering*, Vol. 8, No. 2, pp. 1040-1047, Apr. 2018.

[20] A. K. Verma, D. Dubey, Y. Kumar and A. K. D. Dwivedi, **"Defective Ground Structure For Circularly Polarized Microstrip Antenna with an Irregular Slot for 2.45 GHz RFID Reader,"** *in proc. 2017 3rd International Conference on Advances in Computing, Communication & Automation*, Dehradun, pp. 1-4.