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AMELIORATE OF BANDWIDTH AND RETURN LOSS OF RECTANGULAR PATCH ANTENNA USING METAMATERIAL STRUCTURE FOR RFID TECHNOLOGY

RAJESH SAHA*, SANTANU MAITY

Electronics and Communication Engineering, National Institute of Technology,
Arunachal Pradesh, India
*Corresponding Author: rajeshsaha93@gmail.com

Abstract

Radio Frequency Identification is an emerging research topic to identify any object automatically and it has applications in many fields like manufacture industry, business, animal tracking, vehicle tracking etc. In automatic identification system, the main role of radio frequency identification system is radiation and detection. The reader and the tag are the important components in radio frequency identification technology. In radio frequency identification system, antenna plays very significant role to transmit and receive data in both direction (i.e., from reader to tag and vice versa). An antenna with high gain, high directivity, high bandwidth and more down in negative S11 (dB) value works as an effective antenna. So design and optimization of an effective antenna is very necessary for any application. In this paper, firstly itdesigned a rectangular patch antenna and simulated through High Frequency Structure Simulator. In next step, itdesigned a metamaterial structure having U shape Split Ring Resonator with both one and two port, on the rectangular patch antenna to improve the return loss and bandwidth of patch antenna; so that the performance of the tag can be increased for the radio frequency identification system. By simulation it has been seen that, two port antenna provides maximum return loss and bandwidth of -41.2dB and 870MHz respectively. Finally, the output parameters such as return loss, gain, directivity that are obtained from simulation of the metamaterial Split Ring Resonator structure antenna are compared with the network output of Artificial Neural Network to find the Mean Square Error between the simulated output and Artificial Neural Network output.

Keywords:RFID, ANN, SRR, Metamaterial, Return loss.

1. Introduction

RFID is one of the most promising and widely used technologies that make effective traceability at reasonable costs [1]. Any basic RFID system is a combination of three

Nomenclatures

D	Directivity
f_r	Resonant frequency(Hz)
G	Gain
S11	Return Loss

Greek Symbols

ε_{eff}	Effective value of permittivity
μ_{eff}	Effective value of permeability
ω	Frequency in radian

Abbreviations

ANN	Artificial Neural Network
HFSS	High Frequency Structure Simulator
MSE	Mean Square Error
RFID	Radio Frequency Identification
SRR	Split Ring Resonator

main components: a tag that carry an identification code containing an Application Specific Integrated Circuit (ASIC) on it and a tag antenna; a reader and its antenna to communicate with the tag; and a host computer equipped with a middleware in which software are installed for reading and writing to or from the tags [2-4]. RFID technology means collecting information about an object, without touching or seeing the object through the use of inductive coupling or electromagnetic waves. The tag can be passive or active [5]. The active tag activates its chip by using the internal battery of it. The passive tag gets its functioning energy from theelectromagnetic waves transmitted by the reader.

In order to collect data from the tag, the reader sends an electromagnetic wave to that particular tag with identity code. The tag modulates this electromagnetic wave and sends two backscattered signal: one correspond to logic 0 and another one correspond to logic 1. Because timing information is associated with this backscattered wave, so these waves are demodulated and received properly by the reader without any interference [6-8]. The advantages of RFID technology include: line of sight is not required, tag can have read/write capability, and more information can be stored by the tag, eliminates human error and simultaneously many tag can be read [9]. Depending on frequency band, RFID system operates on: Low Frequency (LF) band (30-500) KHz, High Frequency (HF) band (10-15) MHz, Ultra High Frequency (UHF) band (850-950MHz,2.4-2.5GHz) and in microwave band (more than 3 GHz)[10]. In general, the reader antenna is circularly polarized and the polarization of the tag antenna is linear. The polarization of reader antenna is circular, as it does not know the location of the tag which may be fixed or movable. The polarization of the reader antenna is circular so that it can track the tag wirelessly, without any line of sight communication and hence no polarizations will loss [11-12]. The performance of any wireless communication depends on performance parameters of antenna and channel characteristic. Therefore optimization of important antenna characteristics are return loss, gain, bandwidth, axial ratio etc. and channel properties like fading, path loss are necessary [13]. So designs of such effective antenna with such characteristic are demanding, to increase the reading range of the reader by manifolds. In this paper, our main objective is to design a metamaterial structure having U-shape SRR on the rectangular patch to improve the performance of this patch antenna. After that the results obtained through simulation are also verified in ANN.

2. Brief Concept of Metamaterial and Neural Network

Metamaterial is one of the new technologies to improve the performance of an antenna. Theoretical concept of metamaterial was given by Vesalago in 1968, but practically the existence of such material has been proved by Dr. Smith from Duke University after the year of 2005. Dr. Smith and his group proved that, the metamaterial structure can be created by periodically arranging Split Ring Resonators (SRRs) and metal thin wires. Metamaterial possess some electromagnetic properties which are not found in naturally occurring material [14-15]. Metamaterial has properties like negative value of permeability (μ) and permittivity (ε), negative refraction index and the phase velocity moves in opposite direction of group velocity. Since the metamaterial is composition of material, so permeability (μ) and permittivity (ε) can be calculate by taking effective value of them [16]. Nicolson-Ross-Weir (NRW) has approach the following equations to calculate the value of effective permeability (μ_{eff}) and permittivity (ε_{eff}) of the metamaterial [17].

$$\mu_{eff} = \frac{2}{jkd}\left(\frac{1-V_2}{1+V_2}\right) = \frac{2c}{\omega dj}\left(\frac{1-V_2}{1+V_2}\right) \tag{1}$$

$$\varepsilon_{eff} = \frac{2}{jkd}\left(\frac{1-V_1}{1+V_1}\right) = \frac{2c}{\omega dj}\left(\frac{1-V_1}{1+V_1}\right)$$

(2)

where, k is the wave number and $k = \frac{2\pi}{\lambda} = \frac{2\pi f}{c} = \frac{\omega}{c}$, ε_{eff} =effective value of permittivity, μ_{eff} = effective value of permeability, c = Speed of Light, ω = frequency in Radian, d = thickness of the substrate.

V_1 = Voltage Maxima = $S_{21} + S_{11}$

V_2 = Voltage Minima = $S_{21} - S_{11}$

Artificial neural networks (ANNs) is one of the popular intelligent techniques in solving engineering problems. ANN is information processing system and a large number of interconnected processing element working together to solve a specific problem. An ANN has large numbers of input and one output [18]. A neural network has three layers: input layer, hidden layer and output layer. The first layer called input layer and the activity of input layer is to feed the information to the network. The layer between input and output layer is called hidden layer. The input layer without any processing distributes the input to the hidden layer. The activity of hidden layer depends on the activity of input layer and this layer process the information from the input layer in such a way that the signal reach to the output layer [19]. ANN is used to train the network and therefore before train a network, the input data and the target data (or desired output data) are given to the network. The input data and target data are called learning data. When a network is trained to perform some task, itmust adjust the weight of each unit so that the error between the desired output and actual output is reduced and this error is called mean square error (MSE) [20].The MSE is the cumulative error between the network output and target output. The MSE, i.e., performance index [21] is given by

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left[y_i - F_{ANN}\left(x_i\right)\right]^2 \tag{3}$$

where n = number of sample, y_i = desired output,$F_{ANN}(x_i)$= *ANN* output.

In this work, itused feed forward back propagation algorithm to learn the neuron. The feed forward network allow data to flow only one way i.e., from input to output. Back propagation is one of the optimization methods of weight and bias to its original value by an amount equal to proportional to partial derivative of the error with respect to initial weight. The expression used for adjustment is given below [22]

$$W_{ij}\left(t+1\right) = W_{ij}\left(t\right) - \rho\frac{\partial E}{\partial W_{ij}} \tag{4}$$

where η is the learning rate, $w(t+1)$ and $w(t)$ are connecting weights at present and just previous time. E is the mean square error of overall neurons of the output layers.

3. Design of Antennas and Simulation

Initially, a rectangular patch antenna is designed having substrate Roger RT/Duroid5880(tm) with dielectric constant ε_r=2.2 and this antenna resonant at frequency of 10.004GHz. The substrate having dimension of 28.1mm×32mm is placed between the ground and the patch. The ground and patch are made of same PEC material. The patch itdesigned having length (L) = 16mm and width (W) = 12.45mm. In next step, itdesigned a metamaterial structure of U-shape Split Ring Resonator (SRR) on the normal patch antenna having dimension of 8.46mm×4mm, thickness 2.1mm and the ring gap 4mm. The resonance frequency of this U-shape SRR structure shifted to the value of 15.3707GHz. In order to improve the return loss and bandwidth, another port has been designed on the antenna loaded with U-shape SRR. Because of change in parasitic elements the resonance frequency shifted to 12.2144GHz. The various simulated parameters of all the antennas like return loss, smith chart, gain, directivity, VSWR, permeability and permittivity are depicted in this paper. Top view of patch antenna loaded with U-shape SRR metamaterial for both one port and two ports are shown in Fig. 1 and Fig. 2 respectively.

4. ANN Model for Analysis of Performance Parameter of Rectangular SRR Structure Antenna

The ANN model has been developed for the rectangular SRR antenna. For the given value of substrate dielectric constant (ε_r), height of the substrate (h), resonance frequency (f_r) and width of the patch (W), itcan analyse the performance of return loss (*S11*), gain (*G*) and directivity (*D*) of the SRR antenna. The block diagram of ANN is shown in Fig.3.

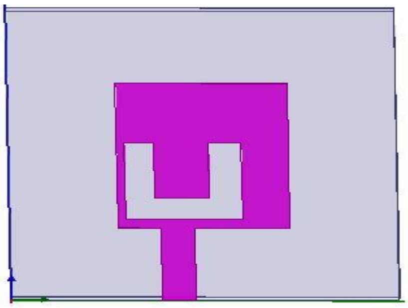

Fig. 1. Model of U-shape SRR antenna with one port.

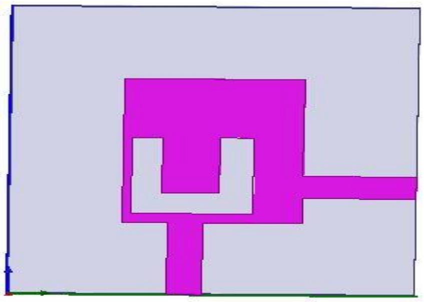

Fig. 2. Model of U-shape SRR antenna with two port.

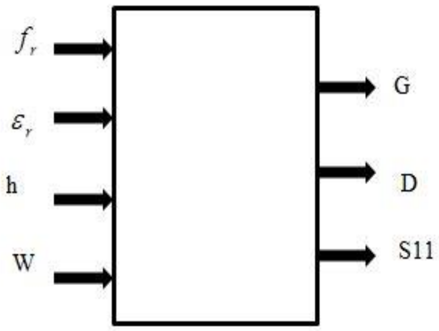

Fig.3. ANN Model for the proposed antenna.

An Artificial Neural Network (ANN) is human made system and it operates in the same way as the human brain. To find the performance of rectangular SRR structure antenna have taken 7 numbers of samples and 15 number of neuron in the hidden layer. The comparison between simulated output and ANN output shown in next section and Mean Square Error (MSE) are also shown in the following section of the consecutive parameter.

5. Result and Discussion

Metamaterial provides an effective solution to improve the performance of the antenna. The comparison of S parameters for the different antennas shown in Fig.4. For normal rectangular patch antenna the S11 parameter and bandwidth values are -25dB and 200.7MHz respectively. Simulation of metamaterial based U – shape SRR antenna with one port display that the S11 parameter and bandwidth reaches to the value -35.7397dB and 702.3MHz respectively. But the S11 and bandwidth value are maximum for the U-shape SRR antenna with two port and these values are -41.26dB and 869.5MHz respectively.

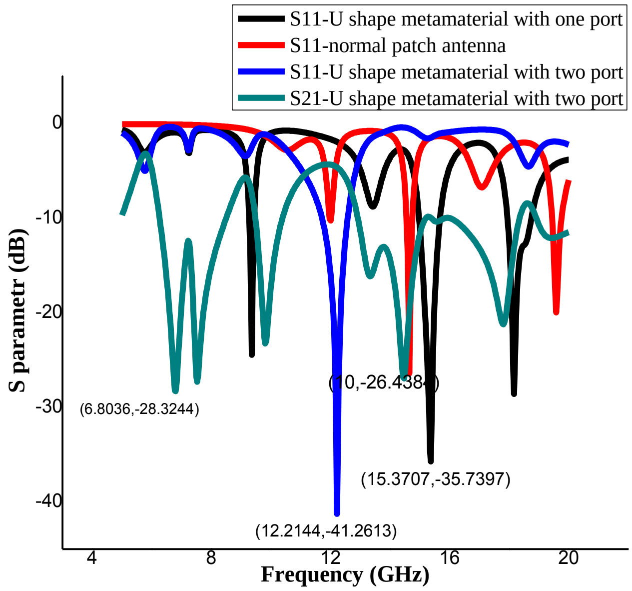

Fig. 4. Comparison of S-parameters (dB) vs. frequency (GHz) of all antennas.

Gain and directivity performance degrades for the metamaterial based antenna compared to normal patch antenna shown in Fig. 5 and Fig. 6 respectively. The gain and directivity also shows better performance for all the antennas. The plot voltage standing wave ratio (VSWR) versus frequency shown in Fig. 7 and the U-shape SRR with two port antenna shows good matching as the value is more close of VSWR to one near the resonance frequency. Figure 8 and 9 shows the plot of permeability and permittivity versus frequency plot for the antenna with metamaterial structure for both single and two ports respectively.

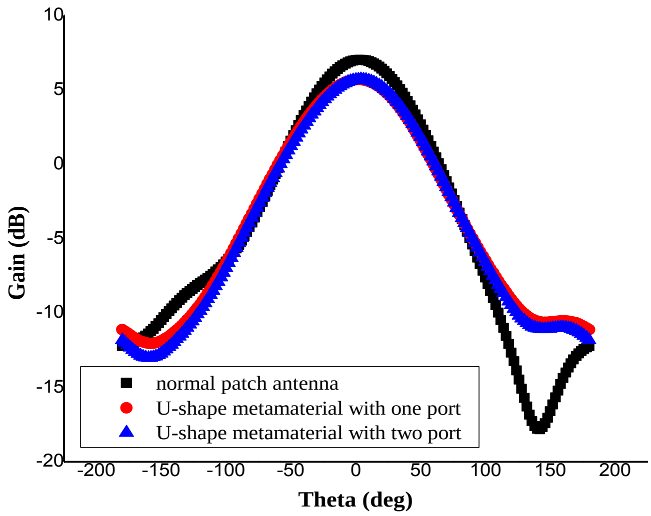

Fig. 5. Comparison of gain (dB) vs. theta (deg) for all antennas.

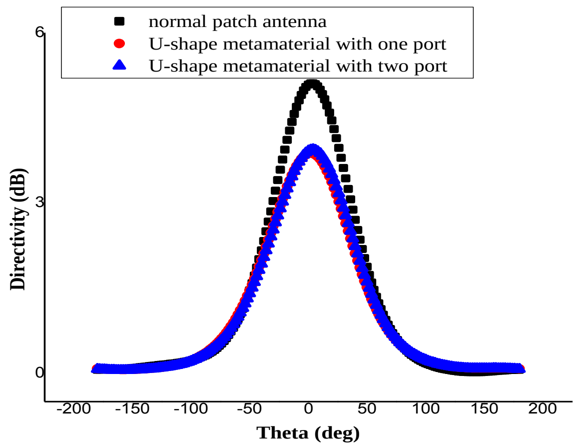

Fig. 6. Comparison of directivity (dB) vs. theta (deg) for all antennas.

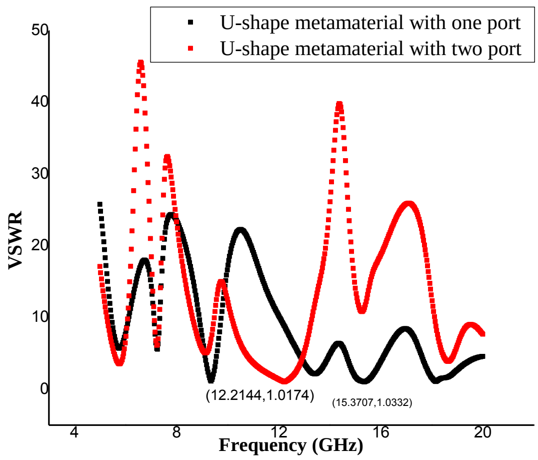

Fig. 7. VSWR vs. frequency (GHz) of the metamaterial antennas.

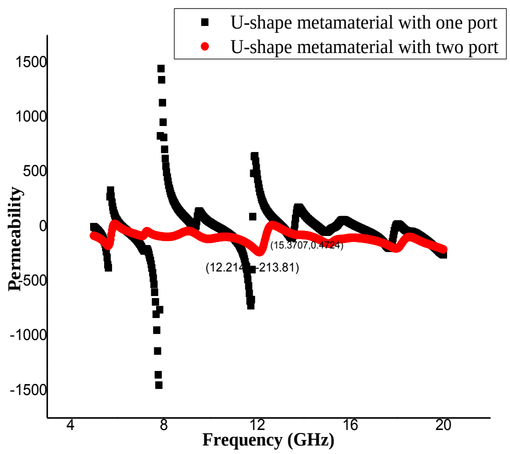

Fig. 8. Permeability vs. frequency (GHz) of the metamaterial antennas.

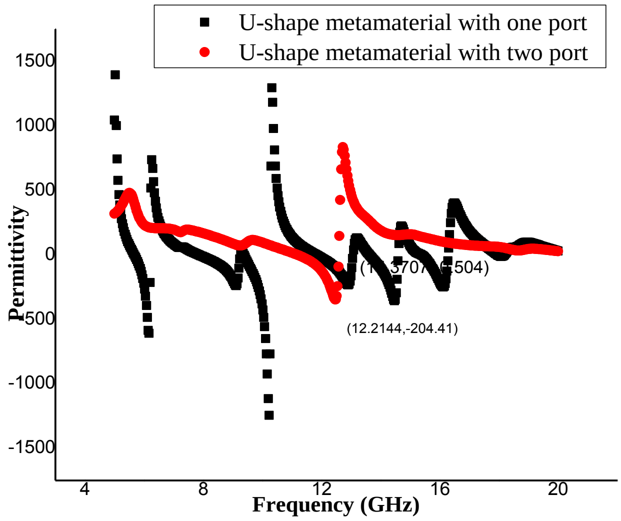

Fig. 9. Permittivity vs. frequency (GHz) of the metamaterial antennas.

The comparison of parameter of different structures antenna shown in Table 1. Patch antenna with U-shape SRR having two ports shows better performance in terms of return loss and bandwidth compared to antenna with one port. Antenna with two ports gives high gain and directivity compared to one port antenna but less than normal patch antenna. So, antenna with two ports has shown better performance than one port antenna.

Table1. Comparison of parameters of the different Structure.

Type of Antenna *	Resonance Frequency (f_r)(GHz)	Return loss (dB)	Band-width (MHz)	Permeability (μ_r) At f_r	Permittivity (ϵ_r) At f_r
NP	10.004	-25	200.7	1	2.2
MOP	15.3707	-35.739	702.3	0.4724	-0.504
MTP	12.2144	-41.26	869.5	-213.81	-204.41

*NP-Normal Patch antenna, MOP- Metamaterial of U-shape SRR on patch with one port, MTP-Metamaterial of U-shape SRR on patch with two ports.

The comparison of proposed metamaterial based antenna with some published works which are also based on metamaterial has shown in table 2. The published works has metamaterial structure of rhombic or rectangular on the patch and return loss, bandwidth of such antenna is reported in above table. But our proposed model having a metamaterial slot of SRR U-shape for both one port and two ports provides better performance in terms of return loss and bandwidth in comparison to reference work.

Table 2. Comparison of proposed work with published work.

Antenna Type	Resonant Freq. (GHz)	Return Loss (dB)	Bandwidth (MHz)
Metamaterial based SRR Antenna [23]	2.45	-20	80
Normal Patch [24]	2.4	-32.84	51
Rhombic Patch [24]	2.42	-24.09	53
Normal Patch [2]	7.5	-24.09	120
Loaded with Metamaterial[2]	8.7	-13.15	220
Model with SRR [25]	12.37	-21.26	460
Normal Patch	10	-25	200.7
Metamaterial of U-shape SRR on patch with one port	15.37	-35.74	702.3
Metamaterial of U-shape SRR on patch with two ports	12.21	-41.26	869.5

The return loss, gain and directivity were obtained by trained the ANN and their MSE value shown in Tables 3, 4 and 5 respectively. The return loss completes its training in 138 epochs and gives the best validation performance of value 2.6714at epoch 138 as shown in Fig.10. The training performance of the gain is depicted in Fig.11 with minimum MSE of value 0.0012744 at epoch 20. The directivity also completes its training within 27 epochs and gives minimum MSE at 27 epoch of value 0.034354 as depicted in Fig.12. The similar model of antenna with one port and two ports can be verified through ANN model. As the model is similar in nature for both the cases, so in this paper antenna with one port has been described.

Table 3. Comparison of HFSS output and ANN output for the analysis of return loss of rectangular SRR patch antenna with one port.

Substrate Dielectric Constant (ε_r)	Resonance frequency (f_r)	Return loss(dB) using HFSS (S11)	Return loss (dB) using ANN (S11)	MSE
1.6	17.6253	-28.3011	-28.7666	0.21669
1.7	17.2044	-31.3357	-31.3357	0
1.8	16.8136	-36.2919	-35.6575	0.40246
1.9	16.4529	-35.3418	-35.3414	0
2	16.0922	-35.3059	-35.3059	0
2.1	15.7615	-38.7422	-38.7419	0.00258
2.2	15.3707	-35.7397	-35.7397	0.00000073

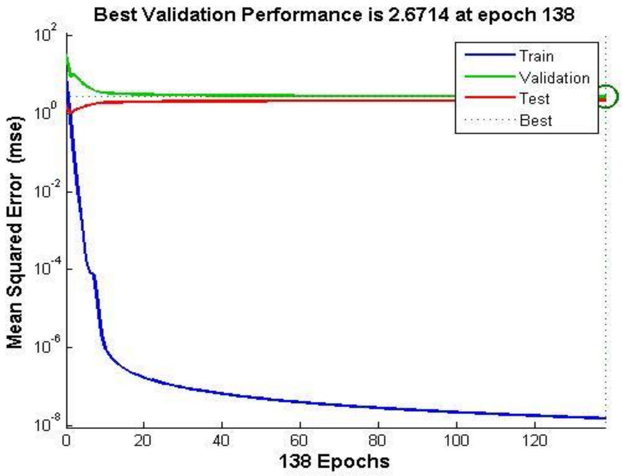

Fig. 10. Training Performance of return loss and number of epoch to achieve mean square error.

Table 4. Comparison of HFSS output and ANN output for the analysis of gain of rectangular SRR patch antenna with one port.

Substrate Dielectric Constant(ε_r)	Resonance frequency (f_r)	Gain (dB) using HFSS (G)	Gain (dB) using ANN (G)	MSE
1.6	17.6253	6.1749	6.1749	0
1.7	17.2044	5.8695	5.8695	0
1.8	16.8136	5.5223	5.5006	0.000471
1.9	16.4529	5.5006	5.5006	0
2	16.0922	5.7865	6.1672	0.14493
2.1	15.7615	6.0937	6.0937	0
2.2	15.3707	5.6929	5.7286	0.000127

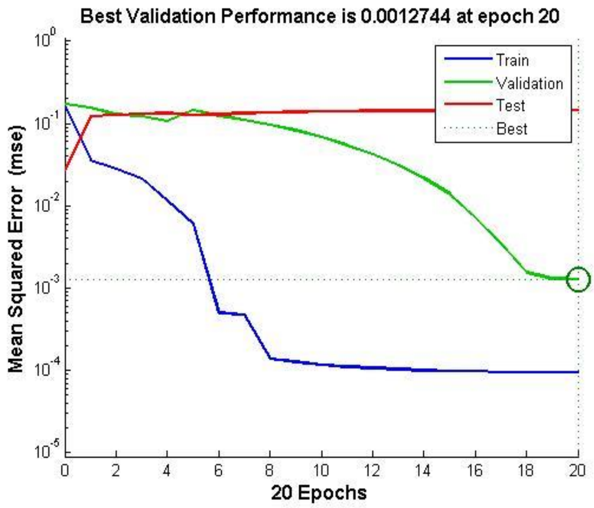

Fig. 11. Training Performance of gain and number of epoch to achieve mean square error.

Table 5. Comparison of HFSS output and ANN output for the analysis of directivity of rectangular SRR patch antenna with one port.

Substrate Dielectric Constant (ε_r)	Resonance frequency (f_r)	Directivity (dB) Using HFSS	Directivity (dB)using ANN	MSE
1.6	17.6253	4.2970	4.2970	0
1.7	17.2044	4.0213	4.2066	0.03434
1.8	16.8136	3.7631	3.7631	0
1.9	16.4529	3.6950	3.6950	0
2	16.0922	3.9290	3.9240	0.000025
2.1	15.7615	4.3273	4.3270	0.00000009
2.2	15.3707	3.8799	4.3273	0.200166

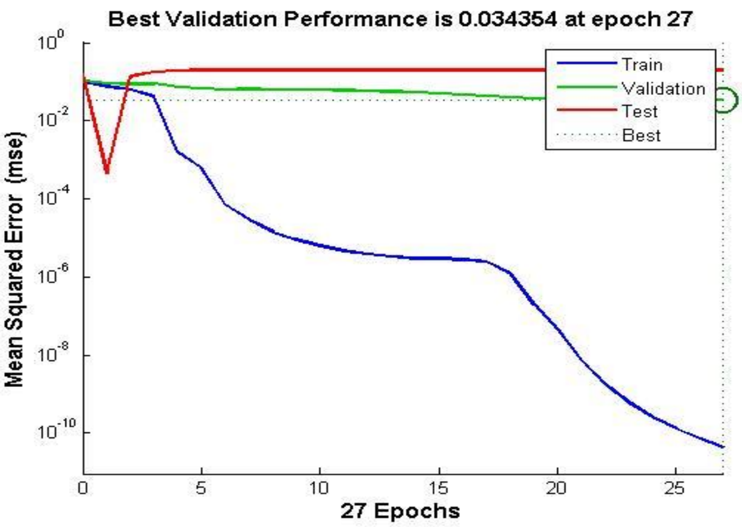

Fig. 12. Training Performance of directivity and number of epoch to achieve mean square error.

6. Conclusion

In this paper, introduction to RFID technology, concept behind metamaterial and neural network were discussed. Then, proposed metamaterial structure U-shape SRR on rectangular patch antenna for RFID system. Simulation of the antennas has done through HFSS and verified by ANN also. Some concluding observations made from the simulation are described below.

- By designing a U-shape SRR structure on the rectangular patch, the resonance frequency shifted to the value 15.3707GHz from the value 10.004GHz of the normal patch antenna.
- For antenna with one port shows return loss is -35.74dB and bandwidth is 702.3MHz. Antenna with two ports provides return loss and bandwidth of -

41.26dB and 869.2 MHz respectively. Therefore, both antenna provides ameliorate in return loss and bandwidth compared two normal patch antenna.

- Due to having better performance, antenna with two ports works more effectively than one port antenna and results in increase of reading range of the tag. Simulated output is also verified in ANN.
- Since both the permeability and permittivity value is negative for two port antenna, so this composite structure poses the properties of left handed material.
- Because of the mentioned features like high bandwidth, high return loss, high gain and high directivity the metamaterial structure of U shape SRR antenna can be used for RFID application.

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