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# Resonant Frequency Analysis Of Circular Microstrip Patch Antenna Design with U-Slot Using Artificial Neural Networks

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**Abstract- The paper proposes an efficient design methodology for Circular Microstrip Patch Antenna with U-slot. The effect of variation in the width of U-slot on the resonant frequency has been reported. It was observed that increment in U-slot width leads to decrease in the resonant frequency of the antenna. The comparative analysis has been made using three different types of ANN(Artificial Neural networks) namely Feed Forward and Backpropagation Network, Cascade Forward Backpropagation, and Layer Recurrent Network. A strong compliance has been observed between the results obtained from ANN and the simulation software-CST(Computer Simulation Technology) used in the study. The results have been obtained from the three ANNs using LMA(Levenberg Marquardt Training) algorithm and the Cascade Forward Back Propagation Network outperforms other networks as indicated by the least MSE(Mean Square Error) value.**

**Keywords: Artificial Neural Networks(ANN), Circular Microstrip Patch Antenna, U-slot, CST, Feed Forward Back Propagation Network, Resonant Frequency.**

## I . INTRODUCTION

With the rise in demand for handheld wireless communication equipment, the antenna can be realized as a microstrip structure and its realization is becoming and overall system design requirement[1]. Microstrip patch antennas are becoming increasingly useful as they can be printed directly on a circuit board. They are becoming popular in recent times for use in wireless applications due to their small size, light weight, easy reproduction, have simple geometries and moreover, have integrability with the circuitry [2]. The two most advantages of the antenna are light weight construction and the suitability for integration with the component mounted on the surface. In high-performance applications like aircraft, spacecraft, missile and satellite, where size, weight, cost, performance, and ease of installation are constraints, low profile antennas may be required. At present, mobile radio and wireless communication have similar specifications. To meet these requirements, microstrip antenna can be used[3].Microstrip antennas are popular at frequencies above 100 MHz [4].

In the past decade, lots of studies have been conducted by researchers to analyze the resonant frequency, input impedance, and radiation efficiency of circular microstrip patch antenna. **Lu**(2003) analyzed a circular patch antenna and its arrays with a pair of L-shaped slots for broadband dual frequency operation. **Wong and Hsu**(1997) incorporated a U-shaped slot in an equilateral triangular microstrip antenna to make it a broadband structure. The concept used in calculating resonant frequency are the effective radius and dynamic dielectric constants and were developed by **Wolff and Knoppik**(1974). The resonant frequency formula was proposed by **Watkins**(1969) and also used by Howell(1975). The resonant frequency was
obtained by **Borkar and Yang**(1975) by solving a dual integral equation. **Guo**(1999) reported the performance of U-shaped circular patch antenna with L-probe feeding to improve its bandwidth and gain. **Luk et al**.(1997) reported the performance of a circular U-slot patch with dielectric superstrate. **Sharma et al**(2009) observed that modified antenna resonates at two different frequencies allotted by IEEE 802.16.

From the careful analysis of the art, it can be observed that a detailed study on circular microstrip patch antenna with U-slot for resonant frequency analysis is lacking. Therefore, this paper seeks to address the research gap identified. ANN are suitable models for microwave circuit optimization and statistical design[5]. They are actually computational tools that learn from training(experience), generalize from previous examples to new ones, and abstract essential characteristics from the input which is containing irrelevant data. In this paper, circular microstrip patch antenna has been designed with U-slot and the effect of variation in the width of U-slot on the resonant frequency has been reported. The increase in the width of U-slot leads to decrease in the resonant frequency of the antenna.

In the designing of circular microstrip patch antenna, it is important to determine the resonant frequency of the antenna accurately, as the antenna has narrow bandwidth and can only operate in the vicinity of the resonant frequency[6]. In this paper, an attempt has been made to exploit the capability of ANN to calculate the resonant frequency of center feed circular microstrip patch antenna with U-slot.

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## II. GENERATION OF DATA DICTIONARY

In this work, data dictionary for the design of circular microstrip patch antenna is generated by using CST software for the training and validation of the proposed ANN model[7]. The design of circular microstrip antenna includes the specified information of the dielectric constant of the substrate(Є), the resonant frequency(fr) and height of the substrate(h) for dominant mode. Here for the center feed, circular microstrip patch antenna results of return losses versus frequency are shown in fig.1

As the performance of ANN majorly depends on the training, validation, and testing, the network is trained rigorously in order to improve its performance. Hence, in the process of designing of theantenna, a collection of data is the first step. The data collected should be in ample amount so that the ANN is properly trained, validated and tested.Here,we have collected nearly 80 different values from the CST software and used them for training, validating and testing of ANN.

## III.DESIGN OF CIRCULAR MICROSTRIP ANTENNA WITH U-SLOT

For designing a circular microstrip patch antenna, the calculations are done as below [9]:

$$a = \frac{F}{\sqrt{1 + \left(\frac{2h}{\pi \varepsilon F}\right)\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]}}$$

$$F = \frac{8.791 \times 10^9}{f_r\sqrt{\in \varepsilon}}$$

Where,

- a=radius of the circular patch
- *h*=height of dielectric substrate
- $\epsilon_r$=dielectric constant
- $f_r$=resonating frequency of antenna

Geometry and center feed arrangement of a circular patch antenna with theU-shaped slot are shown in fig.2. The circular patch antenna with a=20mm is designed on FR-4(lossy) substrate having thickness h=1.6mm, $\epsilon_r$ = 4.3 and loss tangent δ=0.025.

When a U-shaped slot with dimensions L1, W1, L2, W2 (L1=9mm, W1=8mm, L2, and W2 are varied) is introduced in a circular patch antenna,the resonating frequency of antenna starts decreasing. So, we can say as the width of U-slot increases, resonating frequency of the antenna decreases.

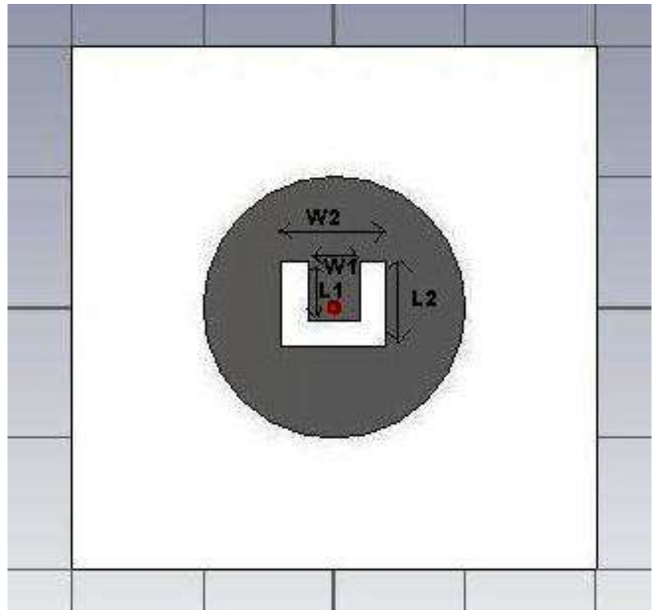


Figure 1. The Designed Antenna Geometry.

Here,in this paper, we have kept the values of the height of the substrate and dielectric constant constant and have varied the width of the U-slot for collecting different values of the data(resonating frequency)[8]. The values of the width of the U-slot was varied from 0.1mm to 8mm with an interval of 0.1mm in between two successive values resulting in 80 values which are later used as data for ANN training, validating and testing.

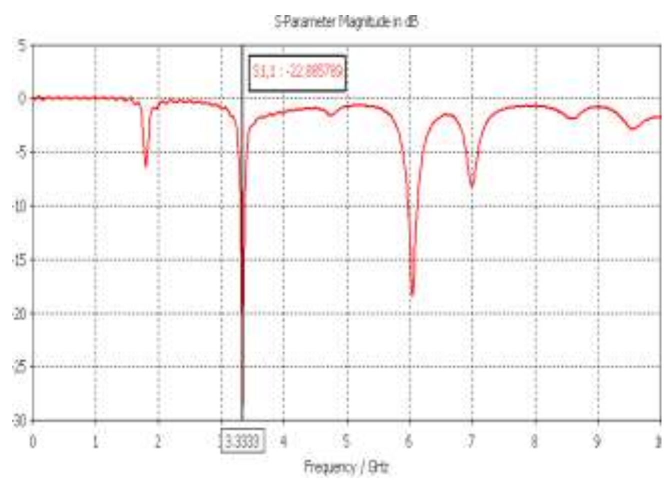


Figure 2. Return loss in dB vs Resonating frequency

## IV.NETWORK ARCHITECTURE

The ANN model has been developed for circular microstrip patch antenna using Matlab as shown in figure3[9].

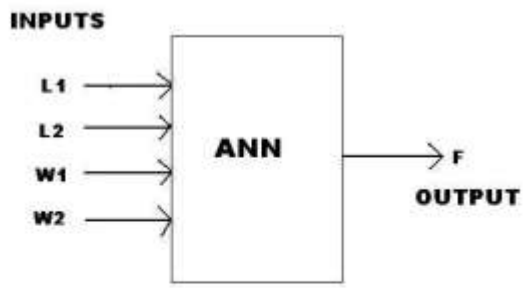


figure 3.ANN model for the design of circular antenna with U-slot

Among the various available algorithms Levenberg-Marquardt training algorithm(LMA) has been used here. The number of neurons is kept 10 in all the networks.

To get more accurate and comparable results, three neural networks are used namely Feed Forward Back Propagation Network(FFBP), Cascade Forward Back Propagation (CFBP) and Layer Recurrent Network.

A.FEED FORWARD BACK PROPAGATION(FFBP)

An FFBP is a feed forward network that just happened to be trained with a back propagation training algorithm. Here, connections do not form a cycle and information goes in one direction only, forward. It has been utilized to calculate the outputs as resonance frequency by putting different values of the dimensions. This model is trained with 80 sets of inputs/output data, which is obtained by CST software.

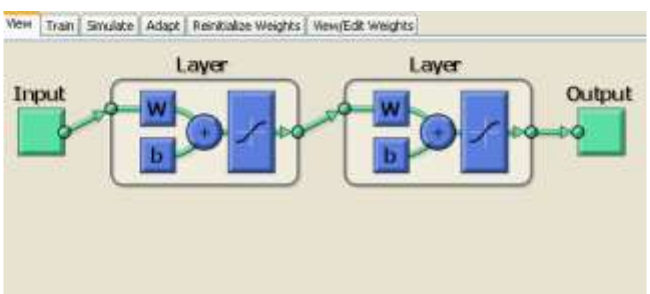


Figure 4. FFBP Network

B. CASCADE FORWARD BACKPROPAGATION(CFBP)

These are similar to feed forward networks but include a connection from the input and every previous layer to the following layer. As with feed forward networks, a two or more layer cascade-network can learn any finite input-output relationship arbitrarily well given enough hidden neurons.

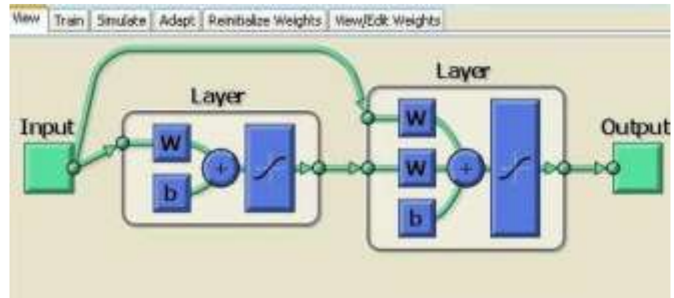


Figure 5. CFBP Network

C. LAYER RECURRENT NETWORK

A layer recurrent is a class of ANN where connections between units form a directed cycle. This creates an internal state of the network which allows it to exhibit dynamic temporal behavior. Each layer has a recurrent connection with a tap delay associated with it. This network is similar to time delay and distributed delay neural networks.

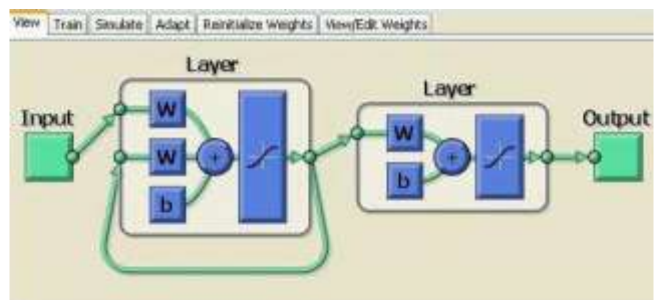


Figure 6. Layer Recurrent Network

V. RESULTS AND ANALYSIS

A . NEURAL NETWORKS TRAINING

In order to evaluate the performance of proposed FFBP,CFBP and Layer Recurrent ANN based model for the design of circular microstrip antenna,simulated results are obtained using CST software.
Following are the tables showing the comparison of CST software outputs and ANN outputs resulting in a square error which later helps in calculating Mean Square Error (MSE).

$$Error = CST\ Simulated\ output - ANN\ output$$

Table I Comparison of results of CST software and FFBP ANN for resonant frequency calculation

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| S.No. | INPUT (U-slot Width in mm) | TARGET/OUTPUT(Resonant Frequency) | | Square Error |
|---|---|---|---|---|
| | | Resonant frequency in GHz calculated using CST software | Resonant frequency in GHz calculated using FFBP ANN | |
| 1. | 2.0 | 3.3333 | 3.3322 | 0.000121 |
| 2. | 2.1 | 3.3333 | 3.3284 | 0.0002401 |
| 3. | 2.2 | 3.3322 | 3.3254 | 0.00004624 |
| 4. | 2.3 | 3.3223 | 3.3230 | 0.00000049 |
| 5. | 2.4 | 3.3213 | 3.3208 | 0.00000025 |
| 6. | 2.5 | 3.3213 | 3.3185 | 0.0000784 |
| 7. | 2.6 | 3.3094 | 3.3159 | 0.00004225 |
| 8. | 2.7 | 3.3094 | 3.3127 | 0.00001089 |
| 9. | 2.8 | 3.3094 | 3.3088 | 0.00000036 |
| 10. | 2.9 | 3.2974 | 3.3041 | 0.00004489 |

Table II  Comparison of results ofCST software and CFBP ANN for resonant frequency calculation

| S.No. | INPUT (U-slot Width in mm) | TARGET/OUTPUT(Resonant Frequency) | | Square Error |
|---|---|---|---|---|
| | | Resonant frequency in GHz calculated using CST software | Resonant frequency in GHz calculated using FFBP ANN | |
| 1. | 2.0 | 3.3333 | 3.3374 | 0.00001681 |
| 2. | 2.1 | 3.3333 | 3.3341 | 0.00000064 |
| 3. | 2.2 | 3.3322 | 3.3306 | 0.0000256 |
| 4. | 2.3 | 3.3223 | 3.3269 | 0.00002116 |
| 5. | 2.4 | 3.3213 | 3.3230 | 0.0000289 |
| 6. | 2.5 | 3.3213 | 3.3190 | 0.0000529 |
| 7. | 2.6 | 3.3094 | 3.3148 | 0.00002916 |
| 8. | 2.7 | 3.3094 | 3.3104 | 0.00001 |
| 9. | 2.8 | 3.3094 | 3.3057 | 0.00001369 |
| 10. | 2.9 | 3.2974 | 3.3009 | 0.00001225 |

Table III Comparison of results of CST software and Layer Recurrent ANN for resonant frequency calculation

| S.No. | INPUT (U-slot Width in mm) | TARGET/OUTPUT(Resonant Frequency) | | Square Error |
|---|---|---|---|---|
| | | Resonant frequency in GHz calculated using CST software | Resonant frequency in GHz calculated using FFBP ANN | |
| 1. | 2.0 | 3.3333 | 3.3348 | 0.0000225 |
| 2. | 2.1 | 3.3333 | 3.3319 | 0.0000196 |
| 3. | 2.2 | 3.3322 | 3.3287 | 0.00001225 |
| 4. | 2.3 | 3.3223 | 3.3255 | 0.00001024 |
| 5. | 2.4 | 3.3213 | 3.3223 | 0.0000100 |
| 6. | 2.5 | 3.3213 | 3.3183 | 0.0000900 |
| 7. | 2.6 | 3.3094 | 3.3144 | 0.0000250 |
| 8. | 2.7 | 3.3094 | 3.3102 | 0.00000064 |
| 9. | 2.8 | 3.3094 | 3.3058 | 0.00001296 |
| 10. | 2.9 | 3.2974 | 3.3011 | 0.00001369 |

The MSE is calculated by averaging the total sum of all the square errors of the respective network.

Table IV  Comparison of the MSE of all the three networks

| Name of the ANN | FFBP | CFBP | Layer recurrent |
|---|---|---|---|
| MSE | 0.000058487 | 0.000021111 | 0.000021688 |

B. RESULTS

It has been established from these tables that the Levenberg-Marquardt algorithm (LMA) is the optimal model to achieve the optimal values of MSE and accuracy achieved.Achievement of such a low value of MSE indicates that ANN model is an accurate model for designing of microstrip patch antenna. Resonant frequency values obtained using ANNs are in a very good agreement with simulated values calculated by CST software.

Figure number 7, 8 and 9 shows the training plots of the three networks and figure number 10, 11 and 12 shows the performance plots of the three networks.

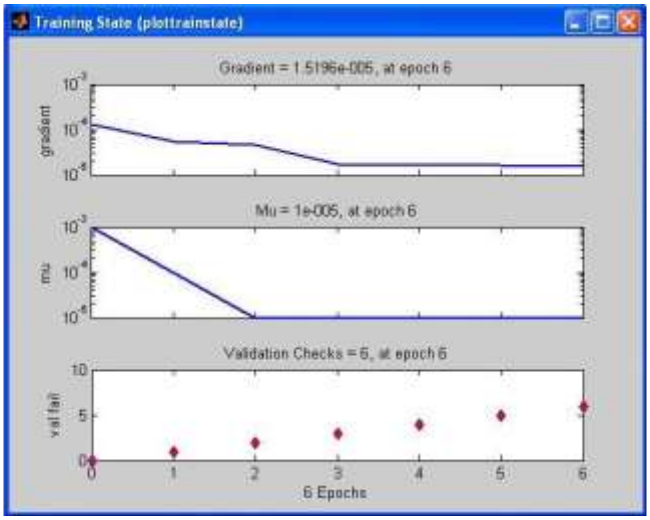


Figure 7.Training plot of FFBP Network

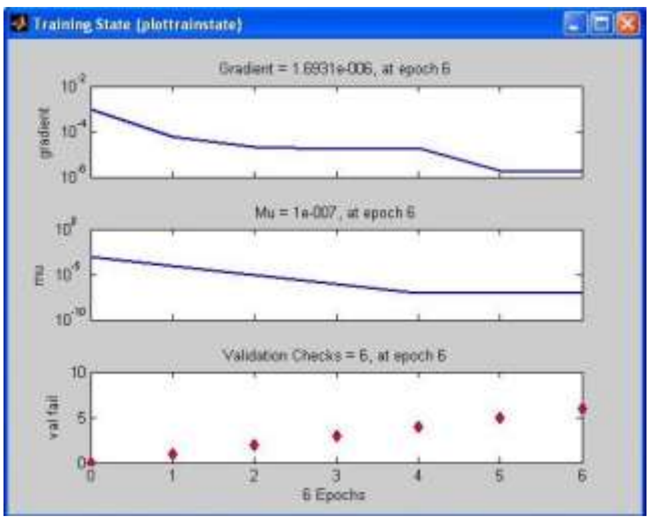


Figure 8.Training plot of CFBP Network

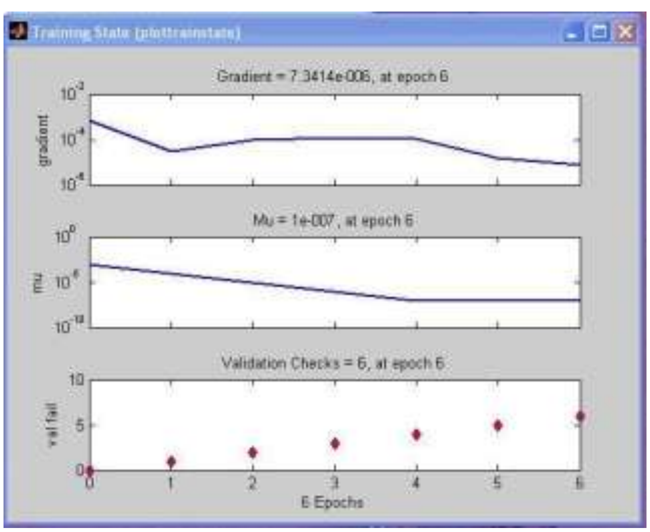


Figure 9.Training plot of Layer Recurrent Network

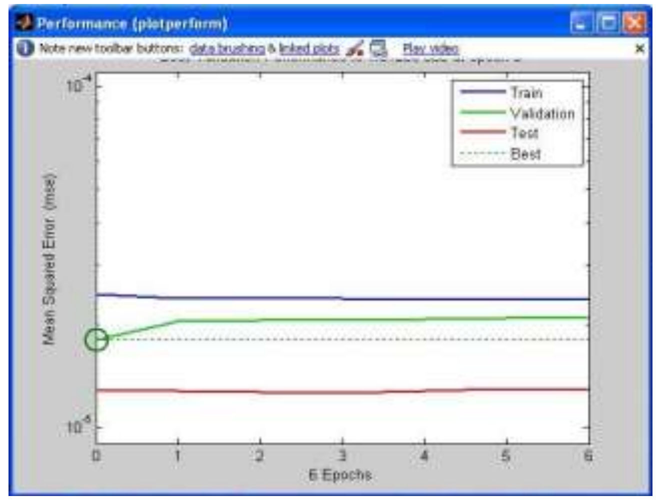


Figure 10.Performance plot of FFBP Network

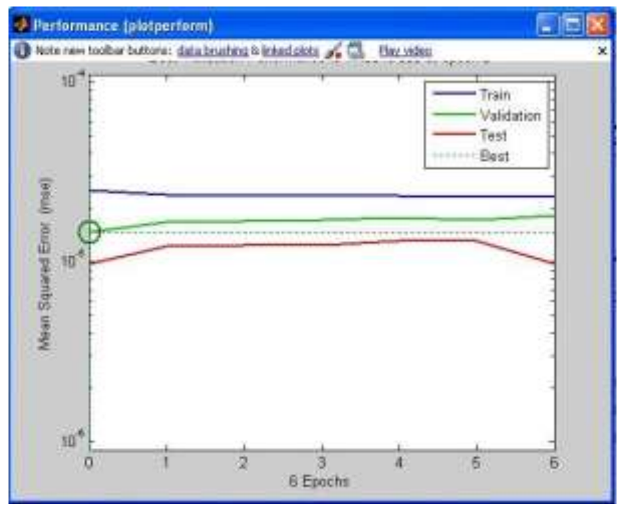


Figure 11.Performance plot of CFBP Network

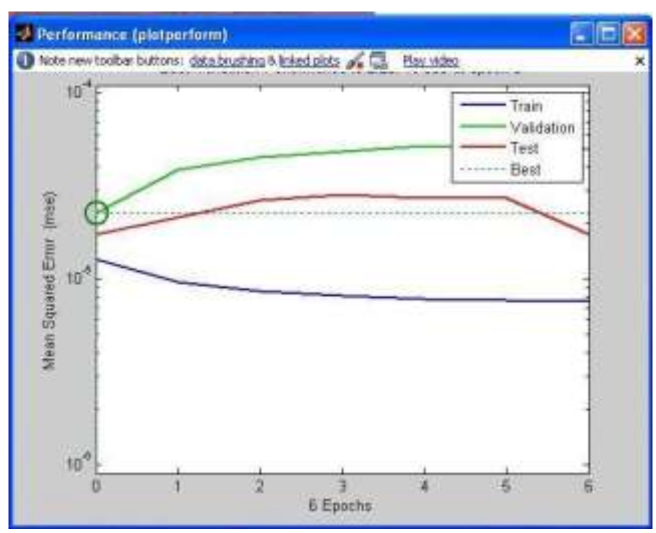


Figure 12.Performance plot of Layer Recurrent network

## VI. CONCLUSION

The neural model presented in this work gives almost accurate results for the design of circular microstrip antenna with U-slot. Resonant frequency obtained with present techniques is closer to the experimental results generated by the simulating a large no. of a circular microstrip antenna with U-slot using CST software. It is proved that as the width of the U-shaped slot(introduced in antenna) increases, the resonant frequency of antenna decreases. Table 4 shows a comparison of MSE of the three networks. The paper concludes that results obtained using present ANN techniques are quite satisfactory and Cascaded forward back propagation (CFBP) Network gives the best approximation among all the three networks with least MSE which signifies more accurate results.

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