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# Design of frequency selective surface comprising of dipoles using artificial neural network

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**ABSTRACT**

This paper depicts the design of Frequency Selective Surface (FSS) comprising of dipoles using Artificial Neural Network (ANN). It has been observed that with the change of the dimensions and periodicity of FSS, the resonating frequency of the FSS changes. This change in resonating frequency has been studied and investigated using simulation software. The simulated data were used to train the proposed ANN models. The trained ANN models are found to predict the FSS characteristics precisely with negligible error. Compared to traditional EM simulation softwares (like ANSOFT Designer), the proposed technique using ANN models is found to significantly reduce the FSS design complexity and computational time. The FSS simulations were made using ANSOFT Designer v2 software and the neural network was designed using MATLAB software.



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## 1. INTRODUCTION

In microwave engineering, Frequency Selective Surfaces (FSSs) are planar periodic arrays of metal patches on a substrate or slots on a conducting sheet that function as a filter for free space radiation [1]. Many authors have made analysis on FSS through EM numerical methods, such as the Method of Moment [2]. But these numerical methods require high computational cost. So to avoid this, Artificial Neural Network (ANN) which are previously trained with results obtained by Method of Moment can be used for analysis of FSS [3-4]. Also, other algorithms like Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) can be blended with ANN for faster and accurate training of the ANN [5–16].

In this paper, patch type FSS consisting of dipoles (as shown in Figure 1) is used whose dimensions (i.e. patch length 'L', patch width 'W', x-periodicity 'Tx' and y-periodicity 'Ty') are varied and the corresponding resonating frequencies are noted. Then using these simulated results, some neural network models are designed and trained, which can be used for faster analysis and design of FSS comprising of dipoles.

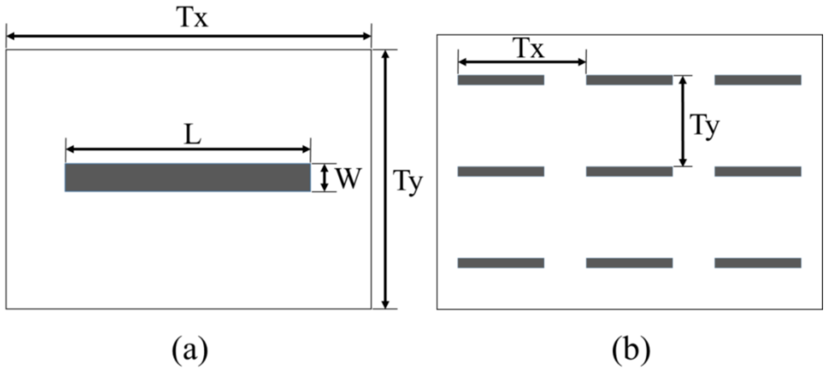



Figure 1. FSS comprising of dipoles: (a) geometry of unit cell, (b) geometry of array

## 2. BACKPROPAGATION TRAINING ALGORITHM

The Backpropagation is an algorithm for supervised training of ANN in which the error is propagated backward for update of weights of different layers of the neural network. A Multi-Layer Perceptron (MLP) is shown in Figure 2, having one input layer, one hidden layer and one output layer.

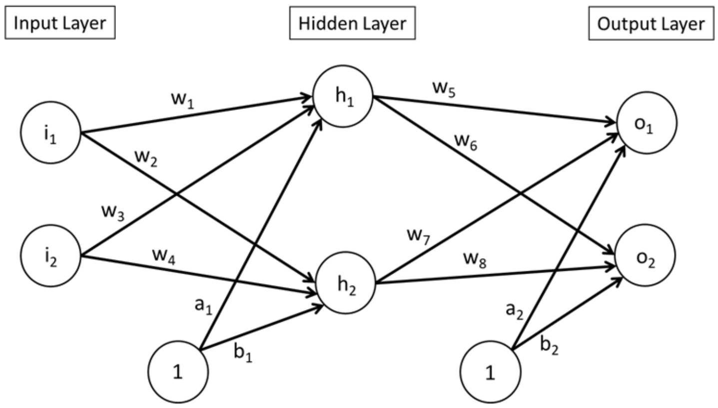



Figure 2. Example of an ANN model

The steps for Backpropagation Algorithm are as follows:

1. Weights and learning rate (α) are initialized
   Hidden Layer Weights: w1, w2, w3, w4
   Output Layer Weights: w5, w6, w7, w8
   Bias Weights: a1, a2, b1, b2
   Learning Rate (α): 0.0001
2. Steps 3 to 10 are performed when stopping condition is false.
3. Steps 4 to 9 are performed for each training pair.
4. Each input unit receives input signal (ii) and sends it to the hidden unit.
5. Each hidden unit sums its weighted input signals to calculate the net input (net $h_i$).
   net h1 = w1 i1 + w3 i2 + a1
   net h2 = w2 i1 + w4 i2 + b1
   Then an Activation function is applied to the net input to calculate the output of the hidden unit (hi). The output of the hidden layer is then sent to the output layer units.
   hi = f(net hi)
   Here Bipolar Sigmoid Activation Function is used: f(x) = 1 / (1 + e-x)
6. Similarly, for each output unit the net input (net $o_i$) is calculated and the activation function is applied to compute the output signals ($o_i$).

7. Each output unit receives a target pattern ($t_i$) corresponding to the input training pattern ($i_i$) and computes the error correction term($\delta_i$):
   $\delta_1 = (t_1 - o_1)\, f\,'(\text{net } o_1)$
   $\delta_2 = (t_2 - o_2)\, f\,'(\text{net } o_2)$
   Where, f '(x) is the derivative of f(x)
   These error correction terms are used to calculate the change in weights ($\Delta w_i$) and change in bias weights ($\Delta a_i$ and $\Delta b_i$).
   $\Delta w_5 = \alpha\delta_1 h_1$
   $\Delta a_2 = \alpha\delta_1$
   Similarly$\Delta w_6$, $\Delta w_7$, $\Delta w_8$ and $\Delta b_2$ are calculated
8. Similarly each hidden unit calculates its error correction term($\delta_{i\,j}$):
   $\delta_{56} = \delta_1 w_5 f\,'(\text{net } h_1) + \delta_2 w_6 f\,'(\text{net } h_1)$
   $\delta_{78} = \delta_1 w_7 f\,'(\text{net } h_2) + \delta_2 w_8 f\,'(\text{net } h_2)$
   These error correction terms are used to calculate the change in weights and bias weights.
   $\Delta w_1 = \alpha\delta_{56}\, i_1$
   $\Delta a_1 = \alpha\delta_{56}$
   Similarly$\Delta w_2$, $\Delta w_3$, $\Delta w_4$ and $\Delta b_1$ are calculated
9. Each output unit and each hidden unit updates its bias weights and weights.
   $w_i(\text{new})=w_i(\text{old}) + \Delta w_i$
   $a_i\,(\text{new})=a_i\,(\text{old}) + \Delta a_i$
   $b_i\,(\text{new})=b_i\,(\text{old}) + \Delta b_i$
10. The stopping condition is checked. The stopping condition may be certain number of epochs reached or when there is previously settled minimum error between actual output and target output.

## 3. RESEARCH METHOD

Here 5 MLPs are used. Each of them have 4 inputs and 1 output as shown in Figure 3, but the inputs and outputs are different as shown in Table 1.

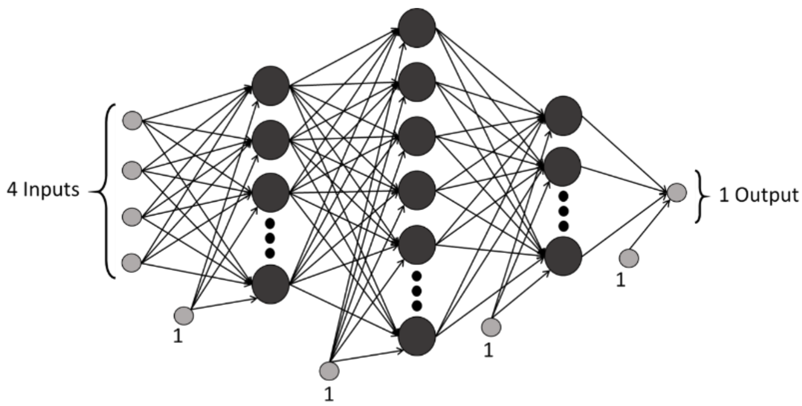



Figure 3. Common ANN model for all 5 networks

Table 1. Inputs and outputs of the 5 MLPs

| Neural Networks | Inputs | Output |
|---|---|---|
| Network 1 | In Network 1, the 4 inputs are the length, width, x-periodicity and y-periodicity of the proposed FSS | In Network 1. The output is the resonant frequency of the proposed FSS |
| Network 2 | In Network 2, the 4 inputs are the length, width, x-periodicity and resonant frequency of the proposed FSS | In Network 2. The output is the y-periodicity of the proposed FSS |
| Network 3 | In Network 3, the 4 inputs are the length, width, resonant frequency and y-periodicity of the proposed FSS | In Network 3. The output is the x-periodicity of the proposed FSS |
| Network 4 | In Network 4, the 4 inputs are the length, resonant frequency, x-periodicity and y-periodicity of the proposed FSS | In Network 4. The output is the width of the proposed FSS |
| Network 5 | In Network 5, the 4 inputs are the resonant frequency, width, x-periodicity and y-periodicity of the proposed FSS | In Network 5. The output is the length of the proposed FSS |

## 4. RESULTS AND ANALYSIS

Initially, the proposed ANN models are trained using the simulation results obtained from ANSOFT Designer v2 software. The training data set is provided in Table 2.

Table 2. Training data set for ANN models

| | Patch Length | Patch Width | x-periodicity | y-periodicity | Step Size |
|---|---|---|---|---|---|
| Data Set1 | 15 mm | 1.5 mm | 16.5 mm | 2.4 mm–15 mm | 0.9 mm |
| Data Set2 | 15 mm | 1.5 mm | 18 mm | 2.4 mm–15 mm | 0.9 mm |
| Data Set 3 | 15 mm | 1.5 mm | 19.5 mm | 1.5 mm–15 mm | 0.9 mm |
| Data Set4 | 15 mm | 1.5 mm | 21 mm | 2.4 mm–15 mm | 0.9 mm |
| Data Set5 | 15 mm | 1.5 mm | 22.5 mm | 1.95 mm–15 mm | 0.45 mm |
| Data Set6 | 15 mm | 1.5 mm | 15.5 mm–22.5 mm | 4.2 mm | 0.5 mm |
| Data Set7 | 15 mm | 1.5 mm | 15.5 mm–22.5 mm | 6.9 mm | 0.5 mm |
| Data Set8 | 15 mm | 1.5 mm | 15.5 mm–22.5 mm | 9.6 mm | 0.5 mm |
| Data Set9 | 15 mm | 1.5 mm | 15.5 mm–22.5 mm | 12.3 mm | 0.5 mm |
| Data Set10 | 15 mm | 1.5 mm | 15.5 mm–22.5 mm | 15 mm | 0.5 mm |
| Data Set11 | 9 mm | 1.2 mm–2 mm | 22.5 mm | 15 mm | 0.3 mm |
| Data Set12 | 12 mm | 0.5 mm–2 mm | 22.5 mm | 15 mm | 0.1 mm |
| Data Set13 | 15 mm | 0.1 mm–1.5 mm | 22.5 mm | 15 mm | 0.1 mm |
| Data Set14 | 6 mm–20 mm | 0.7 mm | 22.5 mm | 15 mm | 1 mm |
| Data Set15 | 6 mm–20 mm | 0.9 mm | 22.5 mm | 15 mm | 1 mm |
| Data Set16 | 6 mm–20 mm | 1.1 mm | 22.5 mm | 15 mm | 1 mm |
| Data Set17 | 7 mm–20 mm | 1.3 mm | 22.5 mm | 15 mm | 1 mm |
| Data Set18 | 7 mm–20 mm | 1.5 mm | 22.5 mm | 15 mm | 1 mm |

Next, the performance of the proposed ANN models in accurately predicting the FSS characteristics is validated using a test data. Here, an FSS comprising of dipoles having dimensionsL = 15 mm, W = 1.5 mm, Tx = 22 mm, Ty = 8 mm (as shown in Figure. 1) is used as a test data for the proposed ANN model validation. The dimensions considered here for testing the ANN models is not included in the data set used for training the MLPs. The FSS is simulated using ANSOFT Designer v2 software and its resonant frequency obtained is 8.15 GHz. Next, this data is used for checking the error of all the 5 MLPs, as shown in Table 3. Finally, the 1st MLP (having L, W, Tx and Ty as inputs and resonating frequency (RF) as output) is used to perform parametric study as given in Section 4.2.

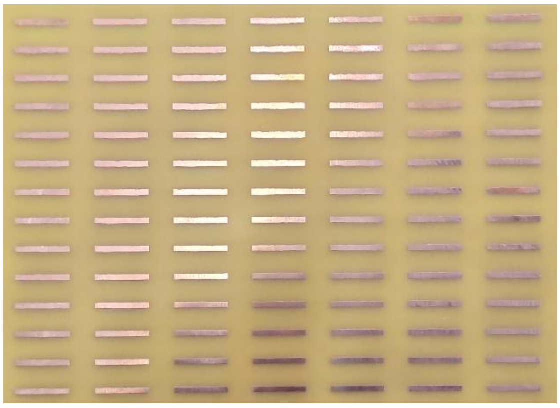
### 4.1. Single value check (interpolation) of the proposed ANN

The validation result of the 5 MLPs using the single test data is given in Table 3. MLP1 is found to predict the resonating frequency (RF) of the FSS for the given set of FSS design parameters with 0.076% error. MLP 2–5 predicts the FSS design parameter (y-periodicity, x-periodicity, Patch Width, and Patch Length, respectively) with 0.94%, 1.724%, 0.0298%, and 0.056% error, respectively for the given input set as shown in Table 3.

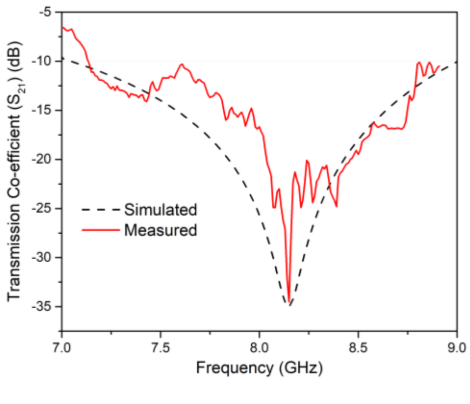
Table3. Result for single value check (interpolation)

| ANN Network | Input 1 | Input 2 | Input 3 | Input 4 | Simulated Output | ANN Output | % Error |
|---|---|---|---|---|---|---|---|
| MLP 1 | Patch Length 15 mm | Patch Width 1.5 mm | x-periodicity 22 mm | y-periodicity 8 mm | RF 8.15 GHz | RF 8.1562 GHz | 0.076 % |
| MLP 2 | Patch Length 15 mm | Patch Width 1.5 mm | x-periodicity 22 mm | RF 8.15 GHz | y-periodicity 8 mm | y-periodicity 8.0754 mm | 0.94 % |
| MLP 3 | Patch Length 15 mm | Patch Width 1.5 mm | y-periodicity 8 mm | RF 8.15 GHz | x-periodicity 22 mm | x-periodicity 21.6207 mm | 1.724 % |
| MLP 4 | Patch Length 15 mm | x-periodicity 22 mm | y-periodicity 8 mm | RF 8.15 GHz | Patch Width 1.5 mm | Patch Width 1.4996 mm | 0.0298 % |
| MLP 5 | Patch Width 1.5 mm | x-periodicity 22 mm | y-periodicity 8 mm | RF 8.15 GHz | Patch Length 15 mm | Patch Length 15.0084 mm | 0.056 % |

An FSS is fabricated using parameters corresponding to MLP1 given in Table 3. The fabricated prototype is shown in Figure 4(a). The transmission characteristic of the fabricated FSS is measured using R&S VNA (ZNB20) and Tx/Rx horn antennas. The simulated and measured transmission (S21) characteristic of the fabricated FSS is given in Figure 4(b). It is found that the resonant frequency of the proposed FSS is nearly same in both simulation and measurement.



(a)




(b)

Figure 4. (a) Fabricated prototype of the proposed FSS, (b) Simulated and measured transmission characteristics of the proposed FSS

### 4.2. Parametric study

In this section, extensive study has been conducted to test the performance of MLP 1. MLP 1 can only provide the resonating frequency (RF) as the output for the change in FSS design parameters- Patch Length, Patch Width, x-periodicity and y-periodicity. The values of FSS design parameters for this parametric study are tabulated in Table 4. Here, comparison is done between the simulated result obtained from Ansoft Designer and ANN.

Table 4. Data for parametric study

| | Constant Parameters | Variable Parameters |
|---|---|---|
| Parametric Study 1 | Patch Width = 1.5 mm, x-periodicity = 22.5 mm, y-periodicity = 15 mm | Patch Length = 7 mm to 20 mm with step 1 mm |
| Parametric Study 2 | Patch Length = 15 mm, x-periodicity = 22.5 mm, y-periodicity = 15 mm | Patch Width = 0.1 mm to 1.5 mm with step 0.1 mm |
| Parametric Study 3 | Patch Length = 15 mm, Patch Width = 1.5 mm, y-periodicity = 12.3 mm | x-periodicity = 15.5 mm to 22.5 mm with step 0.5 mm |
| Parametric Study 4 | Patch Length = 15 mm, Patch Width = 1.5 mm, x-periodicity = 22.5 mm | y-periodicity = 1.95 mm to 15 mm with step 0.45 mm |

Figure 5 shows the results of Parametric Study 1 where Patch Width, x-periodicity, y-periodicityare kept constant and Patch Length is varied. Figure 6 shows the results of Parametric Study 2 where Patch Length, x-periodicity, y-periodicity are kept constant and Patch Width is varied. In Figure 7 the results of Parametric Study 3 is given where Patch Length, Patch Width, y-periodicity are kept constant and x-periodicity is varied. Figure 8 shows the results of Parametric Study 4 where Patch Length, Patch Width, x-periodicity are kept constant and y-periodicity is varied.

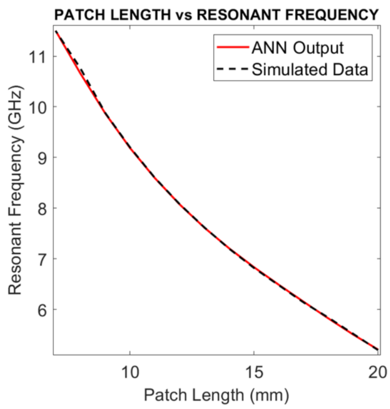


Figure 5. Results of parametric study 1: Variation of patch length from 7 mm to 20 mm with step 1 mm

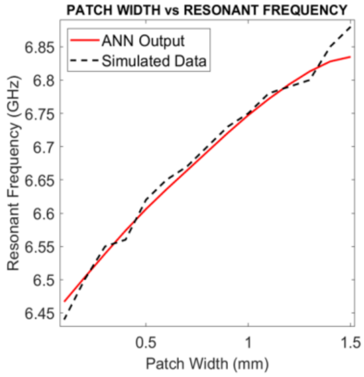



Figure 6. Results of parametric study 2: Variation of patch width from 0.1 mm to 1.5 mm with step 0.1 mm

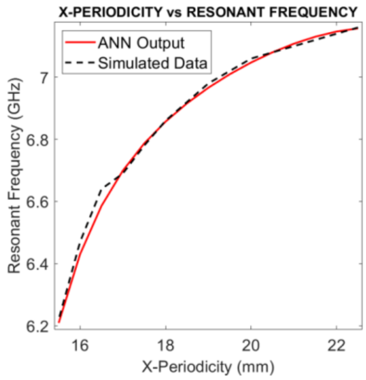



Figure 7. Results of parametric study 3: variation of X-periodicity from 15.5 mm to 22.5 mm with step 0.5 mm

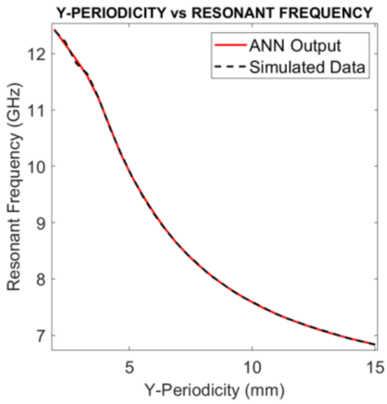



Figure 8. Results of parametric study 4: variation of Y-periodicity from 1.95 mm to 15 mm with step 0.45 mm

### 4.3. Performance comparison of the proposed technique using ANN with traditional EM simulation software (like Ansoft Designer)

In traditional EM simulation software, analysis on FSS is done using EM numerical methods, such as the Method of Moment (MOM). These numerical methods require high computational cost, so even with a system with high configuration, the simulation time remains very long. But if instead ANN is used, then it doesn't require any complex numerical methods, so naturally the computation time is reduced as compared to traditional EM simulation software. Here, firstly an FSS with patch-length = 15 mm, patch-width = 1.5 mm, x-periodicity = 22.5 mm and y-periodicity = 15 mm is taken. |S21| vs. Frequency plot is done from 2 GHz to 12 GHz with low step count and for this the time elapsed is 6 minutes. From this plot the approximate resonant frequency is located somewhere between 6 GHz and 7.5 GHz. Then again plot is done from 6 GHz to 7.5 GHz with high step count which took 2 minutes time and the resonant frequency obtained is 6.83 GHz. So, the total simulation time required is 8 minutes.

Then an FSS with patch-length = 8 mm, patch-width = 0.9 mm, x-periodicity = 22.5 mm and y-periodicity = 15 mm is taken. |S21| vs. Frequency plot is done from 2 GHz to 12 GHz with low step count and for this the time elapsed is 4 minutes. From this plot the approximate resonant frequency is located somewhere between 10 GHz and 11.5 GHz. Then again plot is done from 10 GHz to 11.5 GHz with high step count which took 2 minutes time and the resonant frequency obtained is 10.76 GHz. So, total simulation time required is 6 minutes. But in case of ANN, generation of |S21| vs. Frequency plot is not required, as it directly gives resonant frequency as output. In first case the resonant frequency obtained is 6.8348 GHz, and in the second case the resonant frequency obtained is 10.7404 GHz. Here in both the cases the ANN gave resonant frequency output in less than 1 sec time (i.e. in the first case 0.36036 sec and in the second case 0.27701 sec). The percentage reduction in computational time is 99.9249 % in the first case and 99.9230 % in the second case, as shown in Table 5.

Table 5. Performance comparison of the proposed technique using ANN with traditional EM simulation software

| Parameters | Simulation Time | ANN Output Time | % Reduction |
|---|---|---|---|
| patch-length = 15 mm<br>patch-width = 1.5 mm<br>x-periodicity = 22.5 mm<br>y-periodicity = 15 mm | 8 minutes | 0.36036 sec | 99.9249 % |
| patch-length = 8 mm<br>patch-width = 0.9 mm<br>x-periodicity = 22.5 mm<br>y-periodicity = 15 mm | 6 minutes | 0.27701 sec | 99.9230 % |

## 5. CONCLUSION

In this paper, an Artificial Neural Network model is trained using data obtained from ANSOFT Designer v2 software which uses Method of Moment for analysis of FSS. Hence, the ANN is properly trained and gives negligible error. Using this ANN, the results are obtained very quickly which saves time and also reduces the computational cost and complexity.

## REFERENCES

[1] Ben A. Munk, "Frequency Selective Surfaces – Theory and Design," *Wiley*, no. 1, pp. 1-5, 2000.

[2] Jianxun Su and Xiaowen Xu, "MOM analysis of the planar and curved FSS based on dipole elements," *International Conference on Microwave Technology and Computational Electromagnetics (ICMTCE 2009), Beijing, China*, pp. 127-130, 2009.

[3] P.L. da Silva and A.G. D'Assuncao, "Neuromodelling of Frequency Selective Surfaces and E-Shaped Microstrip Antennas," *The 2006 IEEE International Joint Conference on Neural Network Proceedings, Vancouver, BC, Canada*, pp. 2374-2377, 2006.

[4] P.H.F. Silva and A.L.P.S. Campos, "Fast and accurate modelling of frequency selective surfaces using a new modular neural network configuration of multilayer perceptrons," *IET Microwaves, Antennas & Propagation*, vol. 2, no. 5, pp. 503-511, 2008.

[5] P.H. da F. Silva, P. Lacouth, G. Fontgalland, A.L.P.S. Campos and A.G. D'Assuncao, "Design of frequency selective surfaces using a novel MoM-ANN-GA technique," *2007 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference, Brazil*, pp. 275-279, 2007.

[6] R.M.S. Cruz, P.H. da F. Silva and A.G. D'Assuncao, "Synthesis of crossed dipole frequency selective surfaces using genetic algorithms and artificial neural networks," *2009 International Joint Conference on Neural Networks, Atlanta, GA, USA*, pp. 627-633, 2009.

[7] P.H. da F. Silva, R.M.S. Cruz and A.G. D'Assunção, "Blending PSO and ANN for Optimal Design of FSS Filters With Koch Island Patch Elements," *IEEE Transactions on Magnetics*, vol. 46, no. 8, pp. 3010-3013, 2010.

[8] Anuradha, A. Patnaik, S.N Sinha and J.R. Mosig, "Design of customized fractal FSS," *Proceedings of the 2012 IEEE International Symposium on Antennas and Propagation, Chicago, IL, USA*, 2012.

[9] M.R. da Silva, C. de L. Nóbrega, P.H. da F. Silva and A.G. D'Assunção, "Optimal design of frequency selective surfaces with fractal motifs," *IET Microwaves, Antennas & Propagation*, vol. 8, no 9, pp. 627-631, 2014.

[10] W. C. Araujo, A. G. D’Assunção Junior, E. E. C. Oliveira and A. G. D’Assunção, “FSS designs using a population-based hybrid algorithm inspired on the echolocation of bats,” *2015 9th European Conference on Antennas and Propagation (EuCAP), Lisbon, Portugal*, 2015.
[11] M. C. Alcântara Neto, F. J. B. Barros, J. P. L. Araújo, H. S. Gomes, G. P. S. Cavalcante and A. G. D’Assunção, “A metaheuristic hybrid optimization technique for designing broadband FSS,” *2015 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC), Porto de Galinhas, Brazil*, 2015.
[12] M. Panda and P. P. Sarkar, “Prediction of Periodicity of FSS Structure Using Particle Swarm Optimization,” *I-manager’s Journal on Electronics Engineering*, vol. 7, no. 3, pp. 25-31, 2017.
[13] N. Liu, X. Sheng, C. Zhang, J. Fan and D. Guo, “Design of FSS radome using binary particle swarm algorithm combined with pixel-overlap technique,” *Journal of Electromagnetic Waves and Applications*, vol. 31, no. 5, pp. 522-531, 2017.
[14] M. Panda and P. P. Sarkar, “Hpnna Based Fss Designing: A Case Study,” *International Journal of Computer Sciences and Engineering*, vol. 6, no. 5, pp. 792-796, 2018.
[15] S. Agharezaei and M. Falamarzi, “Particle Swarm Optimization Algorithm for the Prepack Optimization Problem,” *Economic Computation and Economic Cybernetics Studies and Research*, vol. 53, no. 2, pp. 289-307, 2019.
[16] M. C. A. Neto, J. Araújo, R. J. S. Mota, F. J. B. Barros, F. H. C. S. Ferreira, G. P. dos S. Cavalcante and B. S. L. Castro, “Design and Synthesis of an Ultra Wide Band FSS for mm-Wave Application via General Regression Neural Network and Multiobjective Bat Algorithm,” *Journal of Microwaves, Optoelectronics and Electromagnetic Applications*, vol. 18, no. 4, pp. 530-544, 2019.

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