ANN Modelling of Planar Filters Using Square Open Loop DGS Resonators

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Abstract. This paper presents a novel modelling method for planar defected ground structure (DGS) square open loop resonator filters. The increased complexity of the coupling mechanism between the resonators and the impossibility to analytically calculate the coupling coefficients created the need of accurate modelling of the coupled resonators. Design process requires to calculate the filter dimension for the given coupling coefficient. A novel method based on artificial neural networks (ANNs) is proposed in this paper. ANNs are used to develop the filter forward and inverse models aimed to calculate the spacing between the resonators for predetermined coupling coefficients from the approximation. An example filter is designed, simulated and measured. A very good agreement between the measurements and the filter requirements is observed.

Keywords: Defected ground structure · Planar filter · Coupling coefficient · Artificial neural network · Inverse model

1 Introduction

Microstrip filters are important components in microwave systems and their synthesis is a matter of persistent development and research. They must meet the stringent requirements for low passband loss and high rejection in the stopband, while suppress the harmonics spurious passbands. Planar filters are attractive to implement, because of their ease of manufacturing, adjustment and variety of topologies that offer realization of cascaded or cross-coupled filters with quasi-elliptic response. One of the most adopted microstrip resonators are the half-wave resonators and their derivatives - hairpin resonator, square open loop resonator, miniaturized hairpin resonator [1–3]. Increasing the order of the filter in order to achieve better suppression in stopband leads to increase of the sizes of the entire filter. Consequently, the main purpose is to reduce the size of the filter in order to implement it in modern compact systems in the low microwave band. The benefit of the square open loop filter is the compact topology, but it suffers from realization of wide bandwidths, that require smaller gaps between the resonators. The synthesis of microstrip filters can be improved by intentionally

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implementing slots in the ground plane of the microstrip line. These slots are known as defected ground structures (DGS) and can be used as resonators combined to the microstrip line. The advantage is that no manufacturing constraints exist as the DGS and the microstrip line can overlap. The DGS resonators are investigated in [4] as the coupling coefficient is investigated and curve fitting formulas are derived. Also, it is possible to derive the formulas for the inverse relationship, i.e. for calculating the filter dimensions for the given value of the coupling coefficients. However, the accuracy of these formulas can be improved and additional tuning in a simulator is necessary. Having in mind good fitting abilities of the artificial neural networks (ANNs), which has qualified them as a good modeling tool in the field of RF and microwaves [5–15], this paper presents an alternative approach for design of planar filters using coupling coefficients derivation based on the ANNs. An example filter with DGS square open loop resonators is synthesized using the ANN for calculation of the coupling coefficients and the external coupling factor. The filter response is simulated in Ansys Electronics Desktop and the filter is manufactured and its response is measured. The measured and simulated results coincide in order to prove the validity of the proposed approach.

The structure of the paper is as follows. After this introductory section, in Sect. 2 the considered model of DGS resonator and coupling structure is given. The ANN based design approach is described in Sect. 3. Section 4 contains the numerical results and discussion and the final conclusions are given in Sect. 5.

2 Model of DGS Resonator and Coupling Structure

In this paper, all the simulations and design procedures are performed for dielectric substrate FR-4 with height h = 1.5 mm, relative dielectric constant $\varepsilon_r = 4.4$ and loss tangent $tg\delta = 0.02$ and center frequency $f_0 = 2.4$ GHz. The square open loop resonator considered in this paper is etched in the ground plane of the microstrip line and appears to be dual to the standard microstrip square open loop resonator described in [4]. It is shown in Fig. 1, where a denotes the side of the square, w is the width of the slot and g is the gap between the arms.

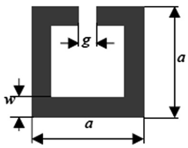


Fig. 1. DGS resonator etched in the ground plane

The resonator consists of a slot line nearly half wavelength long. The etched resonator is symmetrical around the axis and the open end is in the middle of the main transmission line. The magnetic field is stronger at the both ends of the line and the electric filed is at its maximum near the middle of the resonator.

For the further simulations and design procedures, the width of line is equal to the 50Ω microstrip line for specified FR-4 substrate. The resonance frequency can be found using the topology shown in Fig. 1 with a feeding line on the top side of the substrate. Once, the resonance frequency is found by the simulation, the filter design process continues with realization of the coupling coefficients with proper coupling topologies.

The most common coupling topology used is shown in Fig. 2. It consists of two closely positioned resonators with their sides.

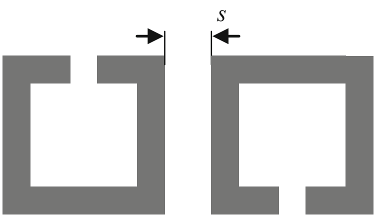


Fig. 2. Coupling topology of DGS resonators etched in the ground plane

The nature of the coupling is mixed as neither the electric, nor the magnetic field is dominating over. The sign of the coupling coefficient is positive and this topology can be used in cascade topologies of microstrip filters. The resonance frequency and the coupling coefficients are extracted from the performed simulations and following the methods described in [1]. The obtained values are used for training and test of the ANN.

3 ANN Application in Microwave Filters Design

The proposed approach is based on two ANNs, one for forward model modeling the coupling coefficient dependence on the spacing between resonator, Fig. 3(a), and the other for modeling the inverse dependence, i.e., the dependence of the spacing between resonators on the coupling coefficient, Fig. 3(b).

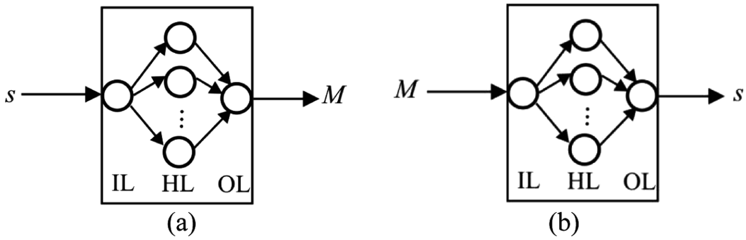


Fig. 3. ANN model of the filter coupling: (a) forward model and (b) inverse model

Multilayered ANNs with one hidden layer are used. The ANNs have one neuron in the input layer (IL) corresponding to the input parameter and one neuron in the output layer (OL) corresponding to the modeled parameter. Between the input and output layer, there is a hidden layer (HL), consisting of neurons having a sigmoid transfer function. The number of hidden neurons is determined during the model development. The input layer has a buffer role, and therefore the input neuron has the unitary transfer function. The neuron for the input layer has a linear transfer function. Connection between neurons from adjacent layer are weighted. The connection weights and biases of transfer functions are the ANN parameters which are optimized in order to train the ANN to learn the dependence between the input and output parameters, which is represented by a dataset of the input-output parameter combinations. There are several different training algorithms, such as the Levenberg-Marquardt algorithm [5] which is used here. The input-output pairs used for the ANN training are obtained in a full-wave simulator.

The trained ANN gives accurate response not only for the input values used for the ANN training but also for any other input value from the considered range of values. It should be noted that the range of the validity of this model, regarding to the input range, is determined by the range of the values of the training input data.

Once ANNs has been properly trained, the modeled parameters can be calculated accurately in a very short time by finding the response of the corresponding ANN, avoiding need for simulations or optimizations and tuning in full wave-simulator.

4 Numerical Results

The described modeling approach was applied to the resonators having the physical dimensions a = 14.5 mm, g = 1 mm, w = 2.71 mm, which is tuned to the center frequency of $f_0 = 2400\,\text{MHz}$. For several different values of the spacing between the resonators the coupling coefficient was calculated. Further, the ANNs for the forward and inverse model were developed. In both cases the ANNs with different number of hidden neurons were trained and the ones giving the best modeling results were taken as the final models. For the both cases the ANNs having five hidden neurons gave the best accuracy.

To illustrate the modeling accuracy, in Fig. 4 the coupling coefficient was plotted against the spacing between the resonators. The reference values are shown as symbols, and the values simulated by using the developed forward neural model is shown as a solid line. It should be noted that the shown simulated values were plotted with the step of 0.1 mm, which is significantly smaller than the step of training data sampling. It is obvious that a very good accuracy was achieved. Therefore, for an arbitrary value of the spacing between resonators the coupling coefficient can be determined within a moment making the design process more efficient.

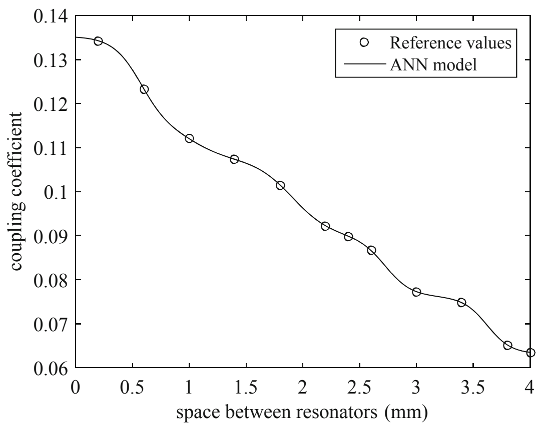


Fig. 4. Filter coupling coefficient versus the space between resonators

As far as the inverse model is considered, the spacing between resonators obtained by the chosen ANN is plotted in Fig. 4 with the step of 0.001 and compared with the reference data used for the model development. As for the forward model, a very good modeling accuracy was achieved. It is much better than the previous models based on the exponential approximation of the modeled dependence [16] (Fig. 5).

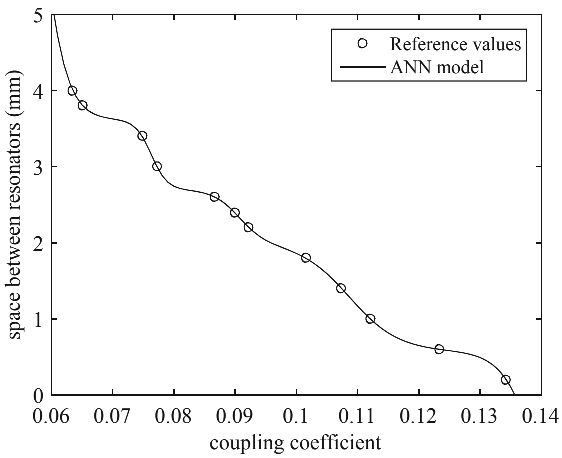


Fig. 5. Spacing between the resonators vs. coupling coefficient

Further the inverse model is used to synthesize a third order filter.

In order to prove the proposed approach, a third order filter is synthesized. The filter specifications are:

- Center frequency: $f_0 = 2400\,\text{MHz}$
- Bandwidth: $\Delta f_0 = 270\,\text{MHz}$
- Return Loss: $RL = -15\,\text{dB}$

The design process of DGS square open loop resonator filter is carried out using the method described in [1, 4]. It starts with calculation of the coupling matrix $[k]$ for low pass canonical filter topology for Chebyshev approximation. Then all the coupling coefficients are renormalized with the fractional bandwidth (FBW) and the external coupling factors are calculated as:

$$\begin{aligned} M_{12} &= M_{23} = k_{12}.FBW = k_{23}.FBW, \\ Q_e &= \frac{k_{S1}}{FBW} = \frac{k_{3L}}{FBW} \end{aligned} \qquad (1)$$

where k_{ij} are the coupling coefficients from the approximation and Q_e is the external quality factor.

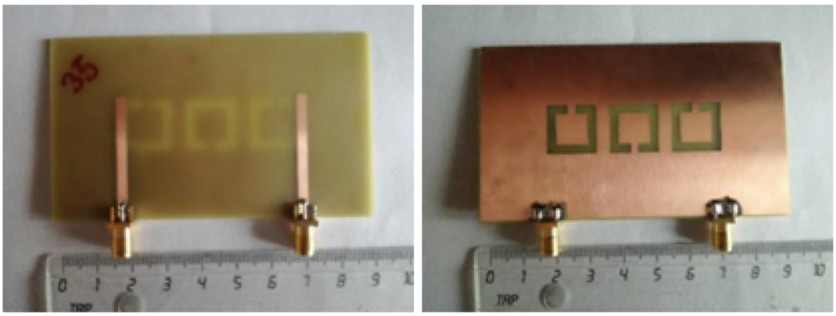
The calculated values of the coupling coefficients from the Chebyshev approximation are $M_{12} = M_{23} = 0.099$ and the external quality factor is $Q_e = 8.4027$. For the realization of the computed coupling coefficients the topology of mixed coupling was used.

Following the simulations of the coupling topology, the coupling coefficient was extracted.

Further, for the calculated coupling coefficient of 0.099 (which is for the ANN training), the spacing between the resonators was calculated.

The computed distance between the resonators with the ANN is $s_{ANN} = 1.8948\,\text{mm}$.

The designed filter was simulated in Ansys Electronics Desktop with the dimensions computed using the ANN and the all the distances were kept as they are calculated. No further optimizations were performed in order to correctly prove the accuracy and the applicability of the proposed approach for filter design. The synthesized filter was fabricated and the layout (top and bottom side) is shown in Fig. 6.



(a) (b)

Fig. 6. Manufactured and measured slot resonator filter (a) top layer, (b) bottom layer

The measured and simulated results are presented on a common plot on Fig. 7. As it is seen, there is a very good agreement between the simulated and measured results.

Table 1 summarizes the main parameters of the design requirements, the simulation and measured results. f_{low} and f_{high} denote the low and high cut-off frequency in the filter response.

Table 1. Simulation and measurement parameter comparison

	f_0 [MHz]	f_{low} [MHz]	f_{high} [MHz]	BW [MHz]
Design	2400	2265	2535	270
Simulation	2438	2272	2552	280
Measurement	2402	2228	2525	297

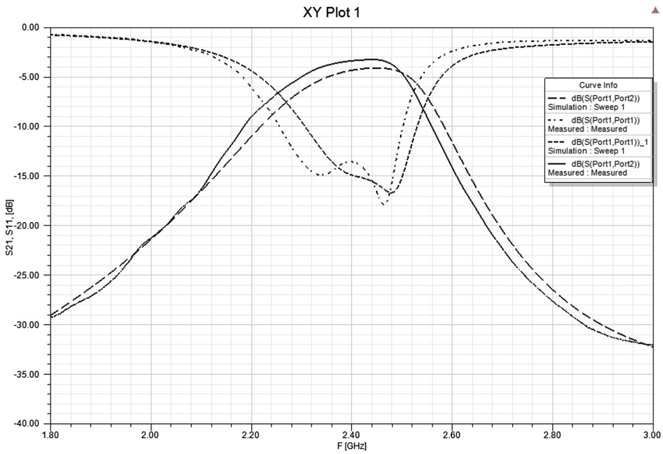


Fig. 7. Measured and simulated narrowband response of the third order DGS square open loop resonator filter

The minimum measured return loss in the passband is −13.6 dB and the simulated value is −14 dB. The minimum passband loss is −4 dB due to the high dielectric losses in the substrate FR-4. It is seen from Fig. 7 that there is very good agreement between the simulated and measured results.

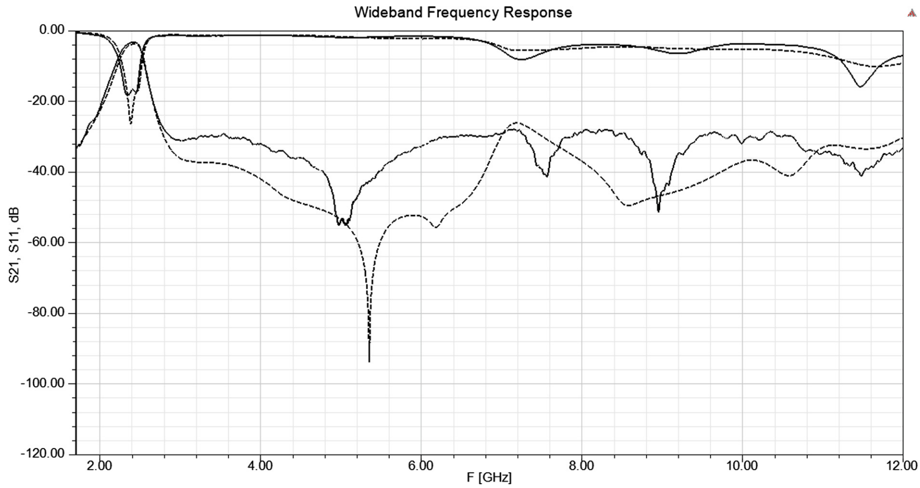


Fig. 8. Measured and simulated wideband response of the third order DGS square open loop resonator filter

Figure 8 show the measured simulated and wideband frequency response of the designed filter. The out-of-passband suppression up to $5f_0$ is more than −25 dB with no well pronounced spurious passband. This makes such filters convenient for use where harmonics' suppression is necessary.

Therefore the proposed method for design of planar DGS resonator filters can be used in the engineering practice.

5 Conclusion

A design method for planar DGS square open loop resonator filters is presented in this paper. The method is based on developing the ANN aimed to calculate the coupling coefficient for the given spacing between resonators (forward model) as well as the spacing between the resonators for predetermined coupling coefficients of the filter (inverse model). The numerical results showed, that very good modeling accuracy was achieved. Furthermore, that this method enables calculating of the spacing between the resonators which will results in the filter characteristics according to the design requirements, which was not the case when simple curve fitting exponential formulas are used, when it was necessary to perform additional tuning of the spacing value. The filter with the dimensions calculated by the proposed approach was fabricated and the filer was measured. The simulation and measurement results show very good agreement and prove the applicability of the proposed method for the filter dimensions calculation.

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References

1. Hong, J., Lancaster, M.J.: Microstrip Filters for RF/Microwave Applications. Wiley, Hoboken (2001)
2. Carg, M.K.: A review of defected ground structures (DGS) in microwave design. Int. J. Innov. Res. Electr. Electron. Instrum. Control Eng. **2**(3), 1285–1290 (2004)
3. Parui, S.K., Das, S.: A new defected ground structure for different microstrip circuit applications. Radioengineering **16**(1), 16 (2007)
4. Vagner, K.: A novel bandpass filter using a combination of open-loop defected ground structure and half-wavelength microstrip resonators. Radioengineering **19**(3), 392–396 (2010)
5. Zhang, Q.J., Gupta, K.C.: Neural Networks for RF and Microwave Design. Artech House, Boston (2000)
6. Christodoulou, C., Gerogiopoulos, M.: Applications of Neural Networks in Electromagnetics. Artech House, Inc., Norwood (2000)
7. Rayas-Sanchez, J.E.: EM-based optimization of microwave circuits using artificial neural networks: the state-of-the-art. IEEE Trans. Microw. Theory Tech. **52**(1), 420–435 (2004)
8. Kabir, H., Zhang, L., Yu, M., Aaen, P., Wood, J., Zhang, Q.J.: Smart modelling of microwave devices. IEEE Microw. Mag. **11**, 105–108 (2010)
9. Michalski, J.: Artificial neural networks approach in microwave filter tuning. Prog. Electromagn. Res. **13**, 173–188 (2010)
10. Marinković, Z., Marković, V., Caddemi, A.: Artificial neural networks in small-signal and noise modelling of microwave transistors. In: Kwon, S.J. (ed.) Chapter 6 in Artificial Neural Networks, pp. 219–236. Nova Science Publishers Inc. (2011)
11. Agatonović, M., Stanković, Z., Doncov, N., Sit, L., Milovanović, B., Zwick, T.: Application of artificial neural networks for efficient high-resolution 2D DOA estimation. Radioengineering **21**(4), 1178–1185 (2012)
12. Agatonović, M., Marinković, Z., Marković, V.: Application of ANNs in evaluation of microwave pyramidal absorber performance. Appl. Comput. Electromagn. Soc. J. **27**(4), 326–333 (2012)
13. Marinković, Z., et al.: Neural approach for temperature-dependent modeling of GaN HEMTs. Int. J. Numer. Model. Electron. Netw. Devices Fields **28**(4), 359–370 (2015)
14. Marinković, Z., Kim, T., Marković, V., Milijić, M., Pronić-Rančić, O., Vietzorreck, L.: Artificial Neural network based design of RF MEMS capacitive shunt switches. Appl. Comput. Electromagn. Soc. J. **31**(7), 756–764 (2016)
15. Đorđević, V., Marinković, Z., Marković, V., Pronić-Rančić, O.: Extraction of microwave FET noise wave temperatures by using a novel neural approach. Int. J. Comput. Math. Electr. Electr. Eng. COMPEL **35**(1), 339–349 (2016)
16. Nedelchev, M., Marinkovic, Zl., Kolev, Al.: ANN based design of planar filters using square open loop DGS resonators. In: ICEST 2018, Nis, Serbia, pp. 89–93 (2018)