ANN based Design of Planar Filters Using Square Open Loop DGS Resonators

Marin Nedelchev[1], Zlatica Marinkovic[2], Alexander Kolev[1]

Abstract – **This paper presents a novel design 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. This is even more complex when it is necessary to calculate the filter dimension for the given coupling coefficient. A novel method based on artificial neural networks (ANNs) is proposed in this paper. An ANN is used to develop the filter inverse model aimed to calculate the spacing between the resonators for predetermined coupling coefficients. There is a very good agreement between the simulations of the filter designed by the proposed method and the measurements.**

Keywords – **defected ground structure, planar filter, coupling coeffieicent, artificial neural network, inverse model**

I. Introduction

Microstrip filters are key components in microwave system design and their synthesis is a matter of persistent development and research. They must meet the stringent requirements for low passband loss and high steepness of the response in the stopband. Generally, planar filters are attractive to the designers because of their ease of manufacturing, adjustment and variety of topologies that offer realization of highly customized frequency responses. One of the most adopted microstrip resonators are the halfwave 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 wide bandwidths, that require small gaps between the resonators. The synthesis of microstrip filters can be improved by intentionally 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 calculationg the filter dimensions for the given value of the coupling coefficients. However, the accuracy of these formulas is not satisfactory 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 and the filter is manufactured. 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 Section II the considered model of DGS resonator and coupling structure is given. The ANN based design approach is described in Section III. Section IV contains the numerical results and discussion and the final conclusions are given in Section V.

II. 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 1.5mm, relative dielectric constant $\varepsilon_r = 4.4$ and loss tangent $tg\delta = 0.02$ and centre frequency $f_0 = 2.4\,\text{GHz}$. 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.

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 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.

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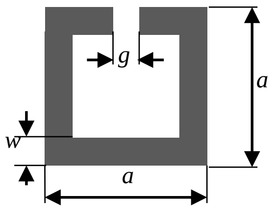


Fig.1. DGS resonator etched in the ground plane

For the further simulations and design procedures, the width of line is equal to the 50Ω microstrip line for FR-4 substrate. For simulations the Ansys Electronics Desktop 2016.2 planar 3D simulator is used. 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.

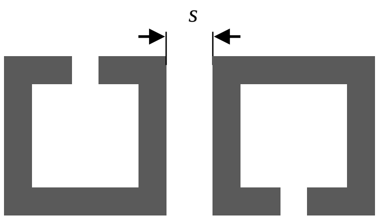


Fig.2. Coupling topology of DGS resonators etched in the ground plane

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 in Ansys Electronics Desktop and following the methods described in [1]. The obtained values are used for training and test of the ANN.

III. ANN Application in Microwave Filters Design and Inverse Modelling

As mentioned in the introductory section a curve fitting technique can be used to extract the relationship between the coupling coefficient and the filter dimensions, i.e. in the particular case the space between the resonators. However, using the extracted dependence results in the dimensions that require additional tuning in order to achieve the desired filter characteristics. In this paper ANNs are proposed to be used to model the dependence of the space between the resonators and the coupling coefficient. For this purpose a multilayered ANN with one hidden layer is proposed, Fig. 3. The ANN has three layers of neurons: input layer (IL), hidden layer (HL) and output layer (OL). In the input layer there is one neuron, having a buffer role, with unitary transfer function. This neuron corresponds to the input parameter, in this case the coupling coefficient. The hidden layer consists of several neurons having a sigmoid transfer function. The number of hidden neurons in not a priori known. In the output layer there is one neuron with the linear transfer functions. In the considered model there is only one neuron and it corresponds to the space between the resonators. Each connection between a neuron and the neurons from the next layer is weighted. The input of the neuron transfer functions is a sum of weighted neuron inputs with added a bias. The ANN learn the dependence between input-output data samples by adjusting the ANN parameters, which are the connection weights and the transfer function biases. This procedure is known as the ANN training and there are several different training algorithms, among them the Levenberg-Marquardt algorithm [5] which is used in the work presented in this paper. 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 parameters used for the ANN training but also for any other input value from the considered range of values. That means that the space between the resonators for the given coupling coefficient is determined by finding the network response without a need for additional full-wave simulations. It is important to note that the mathematical expressions which describe ANNs are easy to be further implemented in the working environment and therefore easy to be further used.

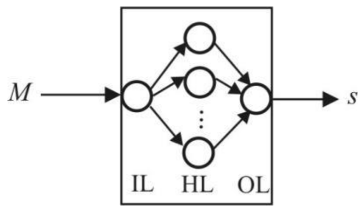


Fig.2. ANN inverse model of the filter coupling

IV. Numerical Results

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

- Centre frequency: $f_0 = 2400$ MHz
- Bandwidth: $\Delta f_0 = 270$ MHz
- Return Loss: $RL = -15$ 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 to the fractional bandwidth (FBW) and the external coupling factors are calculated as:

$$M_{12} = M_{23} = k_{12}.FBW = k_{23}.FBW \ ,$$
$$Q_e = \frac{k_{S1}}{FBW} = \frac{k_{3L}}{FBW} \qquad (2),$$

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.

The physical dimensions of the resonator tuned to the center frequency are found to be $a = 14.5\,\text{mm}$, $g = 1\,\text{mm}$, $w = 2.71\,\text{mm}$.

Following the simulations of the coupling topology, the coupling coefficient was extracted. Using curve fitting technique the dependence of the coupling coefficient to the space between the resonators is:

$$s_{mix} = 20.63e^{-25.11M_{mix}} \qquad (1)$$

As can be seen from Fig. 3 this dependence (dashed line) does not fit well the reference values. Therefore, as the next step the ANN inverse filter model was developed. Namely, as the number of hidden neurons is not a priori known, several ANNs with one input neuron, one output neuron and a different number of hidden neurons were trained. Comparing the accuracy of the trained ANNs, the ANN having one hidden layer with five neurons was chosen as the final ANN model. The spacing between resonators obtained by the chosen model is plotted in Fig. 4 with the step of 0.001. It is obvious that much better fitting was achieved. 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.

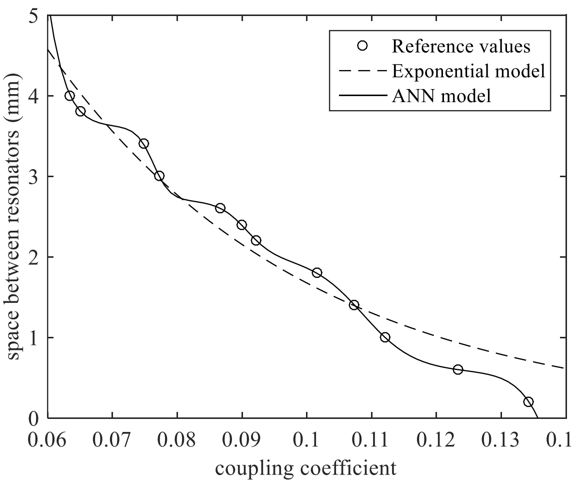
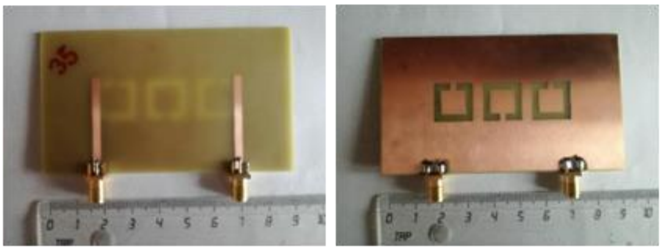


Fig. 3. Spacing between the resonators vs. coupling coefficient

Further, for the calculated coupling coefficient of 0.099 (which is not used neither for exponential fitting nor for the ANN training), the spacing between the resonators was calculated.

The computed distance between the resonators with the ANN is $s_{ANN} = 1.8948\,\text{mm}$ and from the curve fitting is $s_{curvefitting} = 1.7834\,\text{mm}$.

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) of the synthesized is shown in Fig. 4.



(a) (b)

Fig. 4. 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. 5. As it is seen, there is a very good agreement between the simulated and measured results.

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

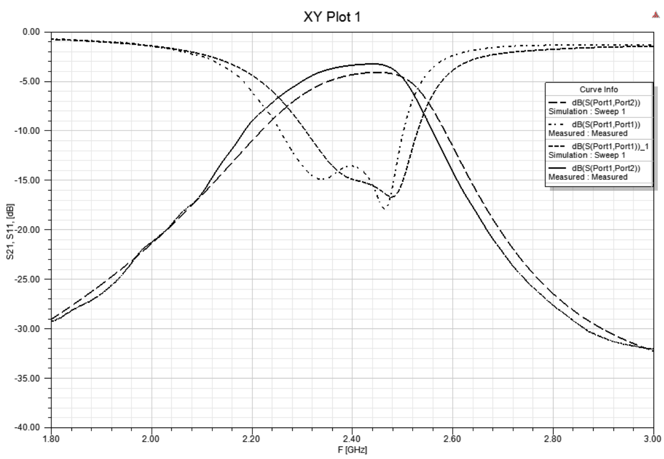


Fig. 5. Measured and simulated response of the third order DGS square open loop resonator filter

Table I 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.

The minimum measured return loss in the passband is -13.6 dB and the simulated value is -14dB. It is seen from Fig.4 that there is very good agreement between the simulated and measured results. Therefore the proposed method for design of planar DGS resonator filters can be used in the engineering practice.

V. 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 spacing between the resonators for predetermined coupling coefficients of the filter. The numerical results showed, 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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