# Synthesis of Wideband Edge Coupled Microstrip Filters with Defected Ground Structures

Marin Nedelchev, Alexander Kolev, Ilia Iliev[1]

*Abstract* – **The paper presents design, simulation and measurement of an edge coupled microstrip filter with a dumbbell type defected ground structure (DGS). For the design purposes, the coupling coefficients of the coupled resonators with defected ground structure were investigated using full wave electromagnetic simulator. The design graphs for the coupling coefficient used for the filter synthesis are presented. Based on the simulation results a five pole filter with a Chebyshev response was simulated, manufactured and measured. There is a very good agreement between the simulation and the measured results.**

*Keywords* – **microstrip coupled, resonator, coupling coefficient, defected ground, dumbell**

## I. INTRODUCTION

The emerging communication systems, allow users to communicate at ever higher speeds, which result in stringent requirements on the increase of bandwidth in which the devices have to operate. Filters play an important role in many microwave applications. But the filter response requirements become more stringent to the insertion loss, wider bandwidth, and steeper response in the stopband. In most cases the microstrip filters are designed using Chebyshev approximation.

The main problem designing wideband and ultrawideband coupled resonator filters are the tight gaps between the resonators. Then the manufacturing tolerances have serious impact on the coupling coefficients and the filter's response. One of the possible solution of this problem is using interdigital or combline filters, but their common drawback that they require a short circuit in microstrip technology. Another possible solution is using etched topologies in the ground plane of the microstrip, known as defected ground structures in edge coupled halfwave filter. This filter is proposed by S. Cohn in his famous paper [11]. It is preferred by the designer because of its clear theoretical and practical design procedure, easy adjustment, descent performance in the stopband and relatively large size in the lower GHz band. The realizable relative bandwidth of the filter is between 5 and 35%.

DGS is realized by introduction of a topology etched in the ground plane of microstrip as shown on Fig.1 [9]. It disturbs the shielded current distribution depending on the shape and dimension of the defect. The disturbance at the shielded current distribution will influence the input impedance and the current flow of the microstrip lines. The positions and lengths of the dumbbell sections control the response and insertion loss of the designed device. DGS increases the effective values of dielectric constant of substrates $(\varepsilon_{eff})$ , thus, decreases the wavelength and the overall length of the design.

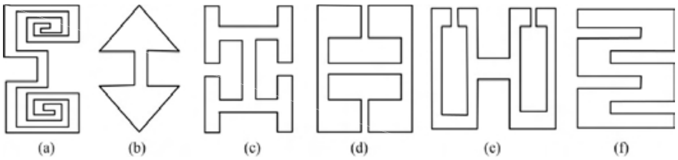

Fig.1 Types of DGS elements-(a) spiral head, (b) arrowhead-shot, (c) "H"-shape slot, (d) a square open-loop with a slot in middle section, (e) open-loop dumbbell and (f) interdigital DGS

Defected ground structures has many practical applications in microwave planar devices. They can be applied in the design of microstrip filters, microstrip antennas, power dividers, matching networks. The main effects connected to introduction of DGS are size reduction of the device [5], harmonic control [4], sharp rejection and wide stopband[2], better matching of the feed lines [6]. It is shown in [1] that the DGS can improve and control the radiation property of microstrip antenna and suppress the cross-polarized radiation from microstrip array [7].

Introduction of DGS in coupled resonator microstrip filters can increase the bandwidth and to cause multiband response. This is the reason to investigate in more details the possibilities of design of wideband microstrip filter using DGS.

The coupling enhancement scheme is based on the difference between the dielectric constants in even and odd modes of the coupled lines. The defected ground structure can control the effective dielectric constant. In even mode, the wave travels longer way and the signals slow down. In that case the phase velocity for even mode decreases. Therefore, the effective dielectric constant increases. In odd mode E-field pattern is asymmetric i.e., E-field is continuous even in presence of a DGS. So the signal path in odd mode is exactly the same as without a DGS. Hence waves do not experience any slow-wave effect and thus the dielectric constant for odd mode remains unchanged. Therefore, the overall effective dielectric constant increases with the inclusion of a DGS and thus, the coupling coefficient enhances [3,8].

This paper presents a synthesis procedure of wideband edge coupled halfwave microstrip resonators with a dumbbell type defected ground structure. The procedure follows the Chebyshev approximation and calculation the coupling

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coefficient between the resonators. A fullwave planar EM simulator is used in order to obtain the corresponding coupling coefficients. The synthesized filter is simulated, manufactured and its frequency responses are measured. There is a very good agreement between the simulated and measured results.

## II. HALFWAVE COUPLED RESONATOR WITH DUMBBELL TYPE DEFECTED GROUND STRUCTURE

All the simulations, design procedures in the paper are performed for dielectric substrate FR-4 with height 1.5mm, relative dielectric constant $\varepsilon_r = 4.4$ and loss tangent $tg\delta = 0.02$ .

The form of the dumbbell type defected ground structure and its dimensions is shown on Fig. 2. It consists of a main slot connected on both ends to rectangular dumbbell heads.

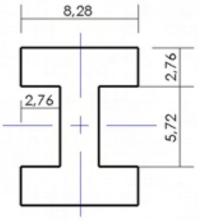

Fig.2. Form and size of the DGS (all sizes in mm)

The edge halfwave coupled resonators have width corresponding to the width of a line with a characteristics impedance of 50Ω. For the dielectric substrate FR-4, it is computed that the width of the line is $w = 2.76\,mm$ .

Fig.3 shows two coupled resonators with length l=32.82mm for center frequency $f_0 = 2.4\,GHz$ . The length is determined using a simulation in a full wave EM simulator.

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Fig.3 Two coupled resonators with length 32.82mm and width 2.76mm

Fig.4 shows two coupled resonators with length l=32.82mm for center frequency $f_0 = 2.4\,GHz$ with the DGS shown on Fig.2 in the ground plane.

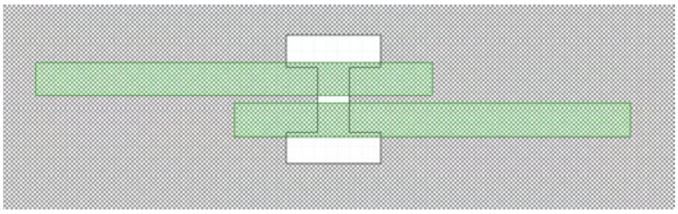


Fig.4 Two coupled resonators with length 32.82mm and width 2.76mm with DGS in the ground plane

The corresponding coupling coefficient for synchronously tuned resonators can be calculated easily by the resonance frequencies of even and odd mode [10], when the coupled resonators are overcoupled:

$$k = \frac{f_e^2 - f_0^2}{f_e^2 - f_0^2} \tag{1}$$

A full wave EM simulator based on the Method of the Moments (MoM) is used to identify the resonance frequencies in the response. Figure 5 shows the calculated coupling coefficient of the coupled resonators, when there is no DGS and when we place a dumbbell DGS with the form and dimensions shown in Fig.4.

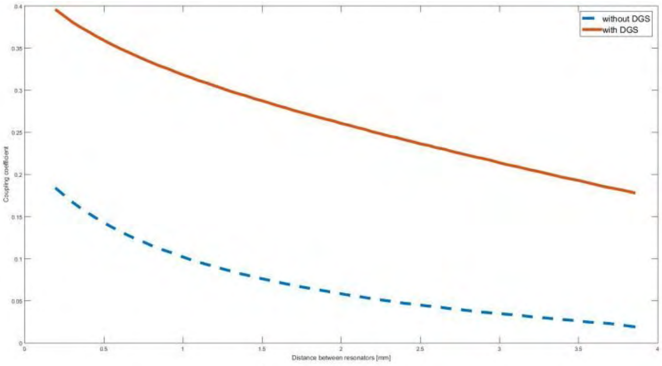


Fig.5 Coupling coefficient between halfwave resonators with (dashed line) and without DGS (solid line)

## III. DESIG OF A WIDEBAND EDGE COUPLED FILTER WITH DGS

The designed filter will have a frequency response based on the Chebishev approximation of the 5 order. Therefore the required coupling coefficients must be computed using [10]

$$k_{n,n+1} = \frac{FBW}{\sqrt{g_n \cdot g_{n+1}}} \tag{2}$$

Where FBW is the fractional bandwidth and $g_n$ $n = 0-5$ are the values of the element of the lowpass fiter prototype. There are various sources of precomputed values for the elements for different pass band ripple. The current design uses $L_r = 0.1\,dB$ and the values for the elements [10] are

$$g_0 = g_6 = 1$$

$$g_1 = g_5 = 1{,}1468$$

$$g_2 = g_4 = 1{,}3712$$

$$g_3 = 1{,}9750$$

The needed coupling coefficient are computed using (2) and are

$$k_{0.1} = k_{5.6} = 0.19563$$

$$k_{1.2} = k_{4.5} = 0.16707$$

$$k_{2.3} = k_{3.4} = 0.12731$$

Next step is to determine the needed separation between the edge coupled resonators. This is done using a full wave EM simulator and extracting the coupling coefficient when the resonators are overcoupled. After a parametric study of the DGS the extracted separation between the resonators are as follows

$$s_{0,1}=s_{5,6}=0.7\,mm$$

$$s_{2.3}=s_{4.5}=1.05\,mm$$

$$s_{3.4}=1.75\,mm$$

For comparison without the DGS etched in the ground the plane the distances between the resonators has to be

$$s_{0,1}=s_{5,6}=0.13\,mm$$

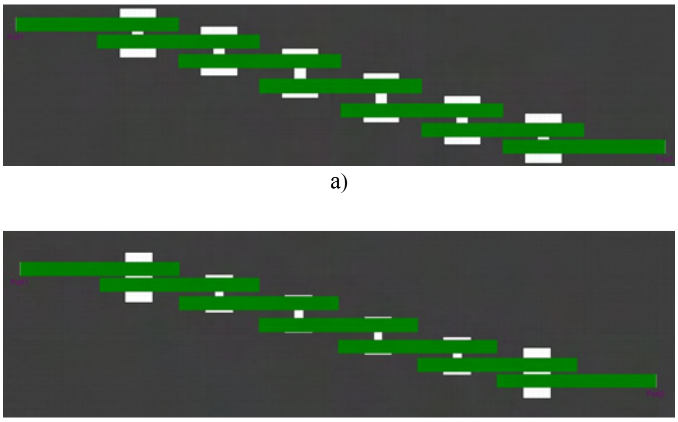
$$s_{2.3}=s_{4.5}=0.30\,mm$$

$$s_{3.4}=0.65\,mm$$

It is obvious how much the separation between the resonators can be increased then a DGS are inserted under the coupled lines of the filter.

Based on the previous calculation the resulted microstrip edge coupled coupled filter is shown on figure 5 a). Figure 5 b) depicts the filter after tuning with an EM simulator.

Figure 6 show the simulated return loss and insertion loss of the designed filter



a)

b)

Fig 5 Topology of the designed filter a) based upon calculation b) tuned using a electromagnetic simulator

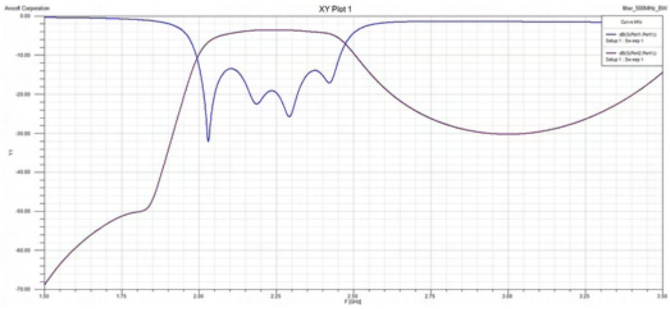
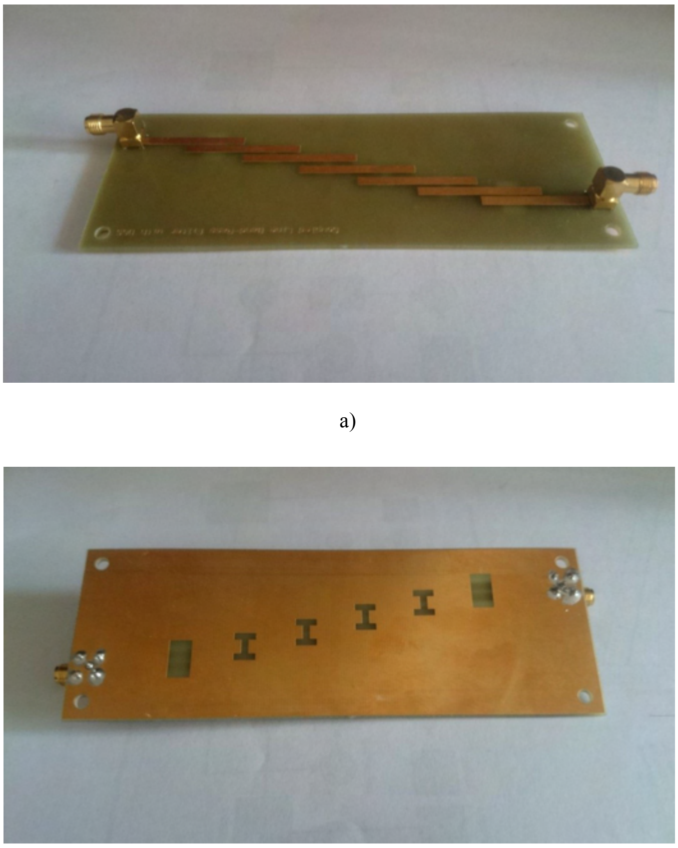


Fig.6 Simulated frequency response of the return loss and inserted loss.

After simulation the filter was fabricated. Figure 7 depicts a top and bottom view of the manufactured filter. Afterwards the return loss and the inserted loss of the manufactured filter ware measured. The measurements are shown on figure 8.



a)

b)

Fig. 7 Top a) and bottom b) side of the manufactured filter.

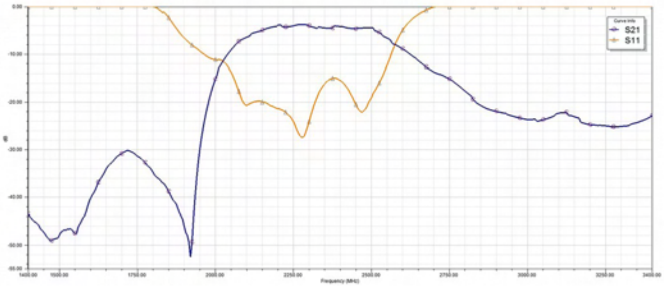


Fig.8 Measured return loss /S11/ and inserted loss /S21/

## IV. CONCLUSION

This paper presents the procedures for designing a wideband edge coupled filter using DGS. The filter was designed according to the Chebishev approximation. A full-wave electromagnetic simulator was used to extract the required distances with regards to the coupling coefficients and to model the frequency response of the designed filter. The modeled filter was produced and the measured results are in good agreement with the ones acquired from the EM simulator.

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