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DESIGN OF COMPACT STOP-BAND EXTENDED MICROSTRIP LOW-PASS FILTERS BY EMPLOYING MUTUAL-COUPLED SQUARE-SHAPED DEFECTED GROUND STRUCTURES

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Received 7 September 2007

ABSTRACT: *A new technique to reduce the size, improve the rejection in the stop-band of a low-pass filter using modified defected ground structure (DGS) is proposed. An equivalent circuit model is used to study the DGS characteristics. The parameters are extracted by using a simple circuit analysis method. Several comparisons between the EM-simulations and the circuit simulations of the new structure are demonstrated to show the validity of the proposed equivalent circuit model. We demonstrated that the filter can provide a sharp transition domain and a wide rejection in stop-band. To further verify the new technique, a filter employing the new deformed DGS is fabricated and measured. The agreement between the simulation and the measured results confirms the effectiveness of the proposed concept.* © 2008 Wiley Periodicals, Inc. Microwave Opt Technol Lett 50: 1107–1111, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.23273

Key words: *deformed-microstrip resonator; low-pass filter; defected ground structure; reject-band; sharp transition response*

1. INTRODUCTION

WAVE propagation in periodic structures has been studied in the area of applied physics for a long time [1]. Recently, periodic structures such as photonic band-gap and defected ground structure (DGS) for planar transmission lines have drawn a wide interest in applications for microwave, microstrip filter, antennas, and millimeter-wave circuits design. DGS is realized by etching off a defected pattern from the ground plane [2, 3]. An etched defect disturbs the shield current distribution in the ground plane. This disturbance can change characteristics of a transmission line such as line capacitance and inductance, which give rise to increasing the effective capacitance and inductance of a transmission line, respectively. Thus, an LC equivalent circuit can represent the proposed DGS loop circuit. The ring-loop resonator composed of a long arm square defected area in the backside metallic ground plane, and its extremity are not attached with each other. To extract the equivalent-circuit parameters for the DGS section, a simple relationship is used.

In this letter, a new method is used to obtain a compact LPF with extended stop-band, using a new deformed DGS-unit. The equivalent circuit of the proposed DGS unit section is derived by using the field analysis method. The new DGS consist of two square areas, which are connected with U-gap, so that, in using cascaded method, a new mixed coupling will appear, thus an improvement in the filter characteristics. Finally, the filter has been fabricated and measured. The measured results show excellent agreement with the field simulation results.

2. BASIC CELL OF THE PROPOSED COMPACT LPF

Figure 1 shows the conventional and the new deformed DGS section etched on the ground plane under the 50 Ω microstrip line [3]. The unit DGS pattern looks like a dumb-bell and is composed

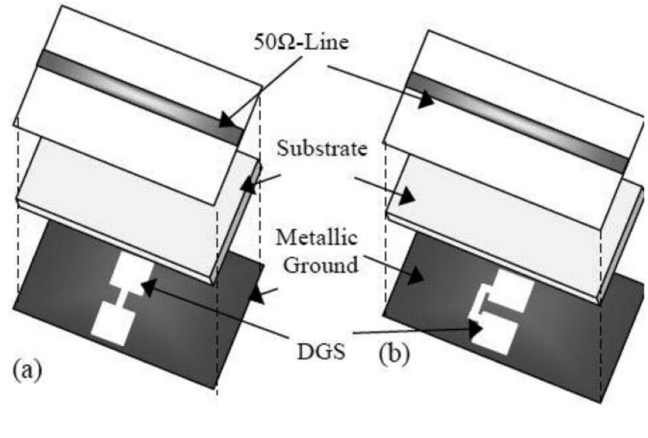

Figure 1 3-D view of the DGs. (a) Conventional Slot. (b) Proposed Slot

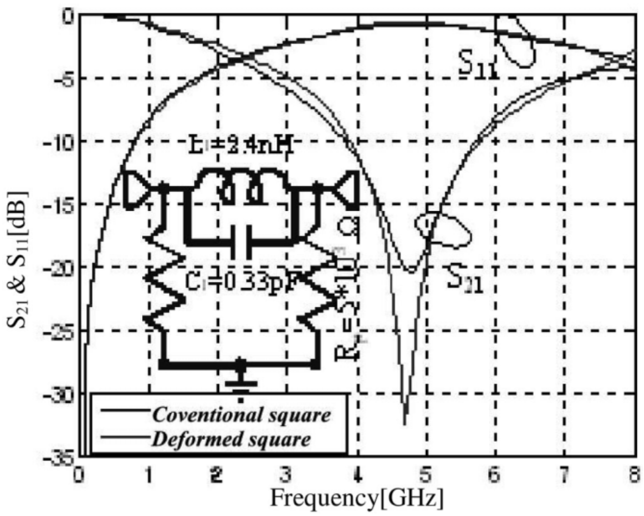

Figure 2 Simulated S-parameters of both DGS cells

of two 5 × 5 mm^2 square and a connecting slot with a gap of 0.7 mm. The length of the connecting slot is the same as the width of the microstrip line on the upper plane. We analyzed and measured the microstrip line with DGS shown in Figure 1 using a GaAs substrate with 3.38 of dielectric constant and a thickness of 0.813 mm. The EM-simulation result of both structures show that the investigated deformed DGS can improve the sharpness of the transmission domain opposite to the conventional DGS-slot as Figure 2 shows. Existence of the cutoff frequency means that employing the DGS shape increases the effective permittivity so that the effective inductance of a microstrip line is also increased. The cutoff frequency mainly depends on the etched square area in ground plane. These attenuation poles can be explained by parallel capacitance with the series inductance, which produces a resonant frequency. The parallel capacitance is mainly dependent on the gap distance. Thus, the equivalent circuit of the proposed DGS can be represented by a LC resonator circuit. The circuit parameters for the derived equivalent circuit can be extracted from the simulation result [3] as Figure 3 shows. The parallel capacitance value for the given DGS unit dimension can be extracted from the attenuation pole location, which exists at the resonance frequency of the parallel LC circuit and prototype low-pass filter characteristics by using the following equations:

$$X_{LC}\big|_{\omega=\omega_c} = X_L\big|_{\Omega=1} \tag{1}$$

$$C_p = \frac{5f_c}{\pi(f_0^2 - f_c^2)}pF \quad \text{and} \quad L_p = \frac{250}{C_p(\pi f_0)}nH \tag{2}$$

3. THE IMPROVED DGS

The microstrip line with the dumb-bell shape DGS are shown in Figure 4. The DGS consists of two bigger a × a square defects, which are connected with a g × w gap. The microstrip line with

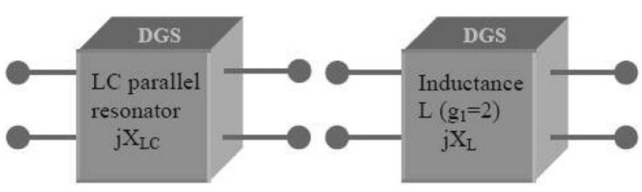

Figure 3 The box of the equivalent circuit model of DGS cell

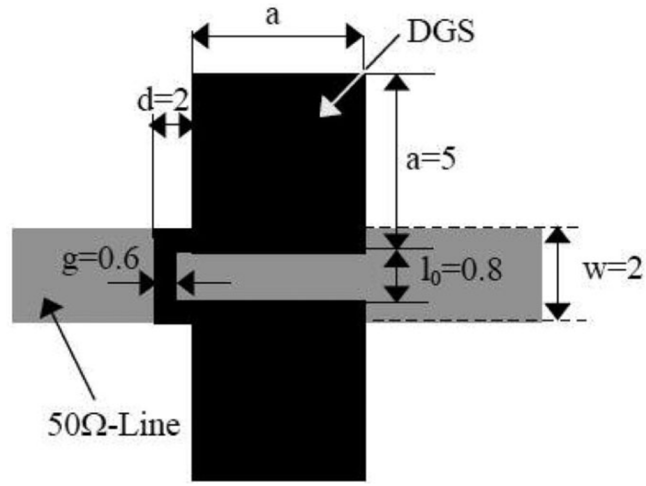

Figure 4 3-D view of the deformed U-gap-DGS resonator

width w, computed for a characteristic impedance $Z_0 = 50\ \Omega$, is on the top. In the simulation, we used a GaAs substrate with a relative dielectric constant of $\varepsilon_r = 3.38$ and a thickness of $h = 0.813$ mm. The simulation results are shown in Figure 2, which shows the characteristic of one-pole low-pass filter. Using the plot, we could get the attenuation pole frequency f_0 at 4.8 GHz and the 3-dB cutoff frequency f_c of the unit-Slot at 2.8 GHz. The only difference between the two DGS is that the suggested DGS consists of a U-gap instead of I-gap connecting both slotheads of the DGS. With this idea, we can increase the magnetic and electric coupling when cascading the slots, thus we can improve on the filter response.

4. COMPARISON BETWEEN THE CONVENTIONAL AND THE PROPOSED DGS-LPF

Two DGS-filters Figure 5 were simulated on a GaAs substrate with a relative dielectric constant of $\varepsilon_r = 3.38$ and a thickness of $h = 0.813$ mm using an electromagnetic (EM) simulator, Microwave Office. Simulation results are shown in Figure 6. We can see that the attenuation pole frequency f_0 is at 3 GHz and the 3-dB cutoff frequency f_c of the filter is at 1.8 GHz. Both filters have the same cutoff frequency $f_c = 1.8$ GHz and nearly the same resonance frequency $f_0 = 3$ GHz. However, as shown in Figure 6, the suggested LPF which employs the deformed DGSs has lower loss in the pass-band and better rejection in the stop-band as compared with the conventional LPF. This improvement is due to the gap's deformation. When placing the two deformed U-DGS next to each other, a mixed coupling between the two neighboring slots is

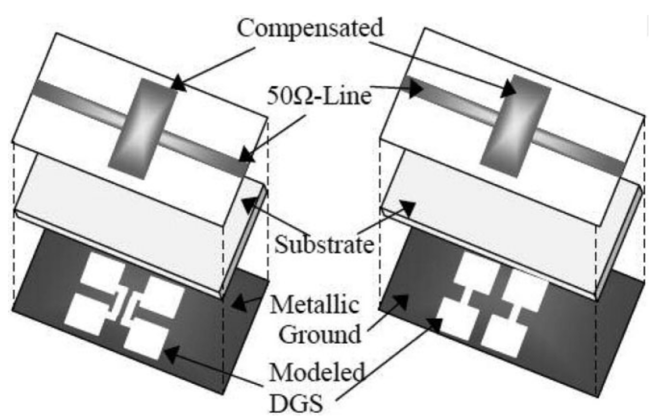

Figure 5 3-D views of the proposed deformed LPF

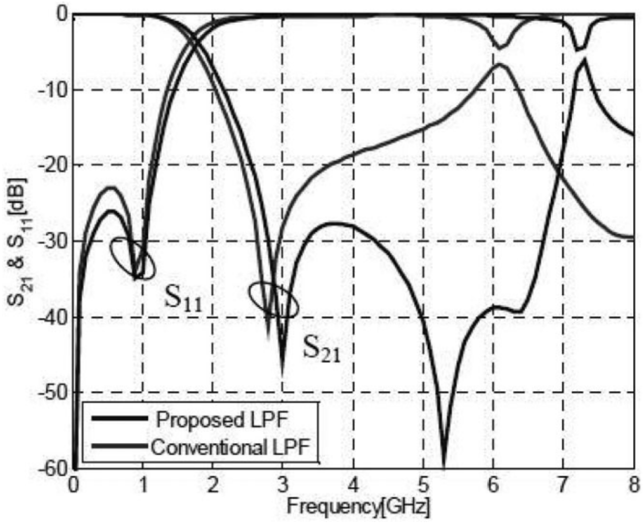

Figure 6 Comparison between S-parameters of the both LPFs

developed, producing a low loss pass-band from DC to cutoff frequency and at the same time a wide reject-band in the stop-band. The new gap's geometry involves an additional electric and magnetic coupling, which are due to the gaps and slotheads, respectively.

5. INFUENCE OF MAGNETIC COUPLING ON *S*-PARAMETER RESPONSE

Figure 7 shows an equivalent circuit of the DGS LPF. This circuit consists of two identical DGS parallel resonators, separated by one capacitance corresponding to the capacitor of the compensated microstrip. Figure 8 shows the EM-simulation and the circuit simulation of the proposed low-pass filter. We can see that the equivalent-circuit simulation result shows excellent agreement with field calculations. The classical 3-pole LPF configuration is shown in Ref. [2, 3]. This circuit model does not account for the effect of losses, which results in an unrealistic attenuation at the pole frequency. Likewise it does not include the effect of interaction between the two DGS slots [4]. Therefore there is a need to improve the circuit model. So we adjusted the equivalent circuit as shown in Figure 7.

6. FILTER DESIGN AND MEASUREMENT

To demonstrate the effectiveness of this mutual coupling a three pole low-pass filter using deformed U-gap DGS cells, is designed

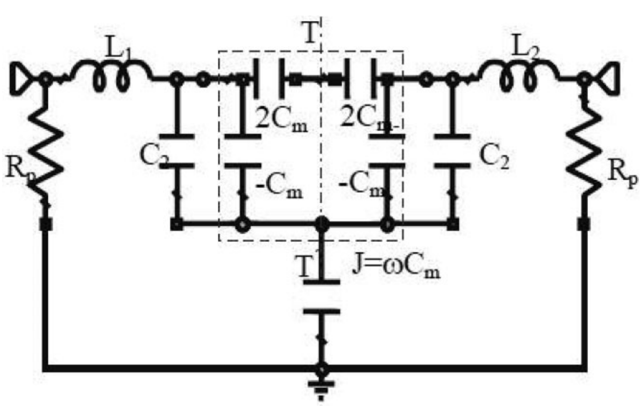

Figure 7 The alternative form of the equivalent circuit with an impedance inverter K = OL_m to represent the coupling

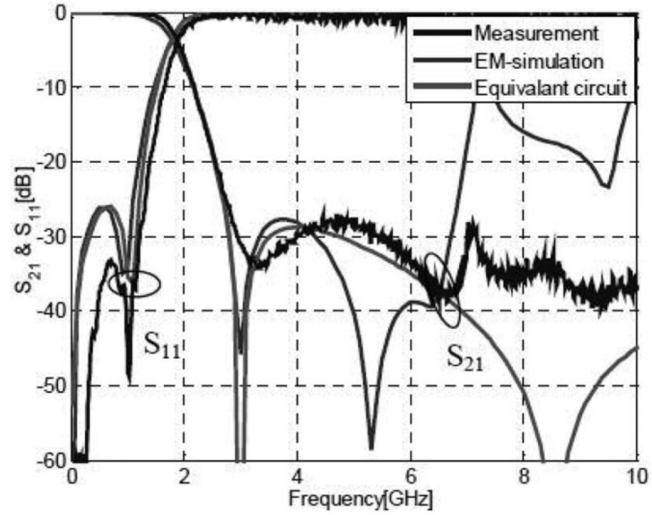

Figure 8 Measured and simulated S-parameters for the proposed deformed DGS-LPF

and compared with the conventional LPF as shown in Figures 6 and 9. Both DGS filters are designed for the same cutoff frequency at 2.8 GHz and they have the same attenuation pole f_0 = 3 GHz. The low-pass filters are simulated and measured with the same conditions as DGS-Element. All the dimensions are in mm.

It is observed that the proposed LPF has a sharper cutoff and a wider stop-band response compared with the conventional LPF. Figure 17 shows photographs of the fabricated DGS low-pass filter. The total area is 2 × 1.5 cm^2, the size is much reduced compared with a conventional LPF.

7. DESIGN OF AN IMPROVED ULTRA-WIDE-STOP-BAND LPF USING FRACTAL DGS

The filter has a size of 2 × 1.5 cm^2. Microstrip lines and metallic ground plane were prepared using copper material ($\sigma = 5.88e^7$ S/m). Photos of top and bottom views of filter are shown in Figure 9. Measurements were done in open box using vector network analyzer Hewlett-Packard 8722D Network Analyzer. Simulated *S*-parameters show good agreement with measurement results. As shown in Figure 10, the LPF has a cutoff frequency f_c = 1.8 GHz. All simulations are carried out using a Microwave Office. The filter has a sharp transition domain with a sharp roll off factor of 30 dB/GHz. Comparing the two proposed filters, the fractal filter has a wider reject-band under 20 dB from 2.8 GHz to 10 GHz, making it possible to obtain an ultra wide reject-band through a simple modification in slot-head, which has caused the slow wave and mutual coupling effects. Photograph and all dimensions of the proposed fractal LPF are shown in Figures 11, 12, and 4.

8. DESIGN OF A CONTROLLED REJECT-BAND OF L PF USING CASCADED DGS

With classic filters it is well-known that the resonance and cutoff frequencies of a filter shift nearly linear to the number of the used resonators. The question is how can we improve the reject-band of Fractal LPF while, at the same time, keeping the cutoff frequency constant? We know that the DGS slot causes a slow wave effect and unloaded capacitors, which implies an improvement in the stop-band. Their influence on stop-band is more dominant than in DC cutoff frequency domain. The idea was to insert a new DGS with equal design and small dimensions as the old slots in middle filter structure. The modification of the dimensions of the new DGS simplifies the control of the cutoff frequency position without

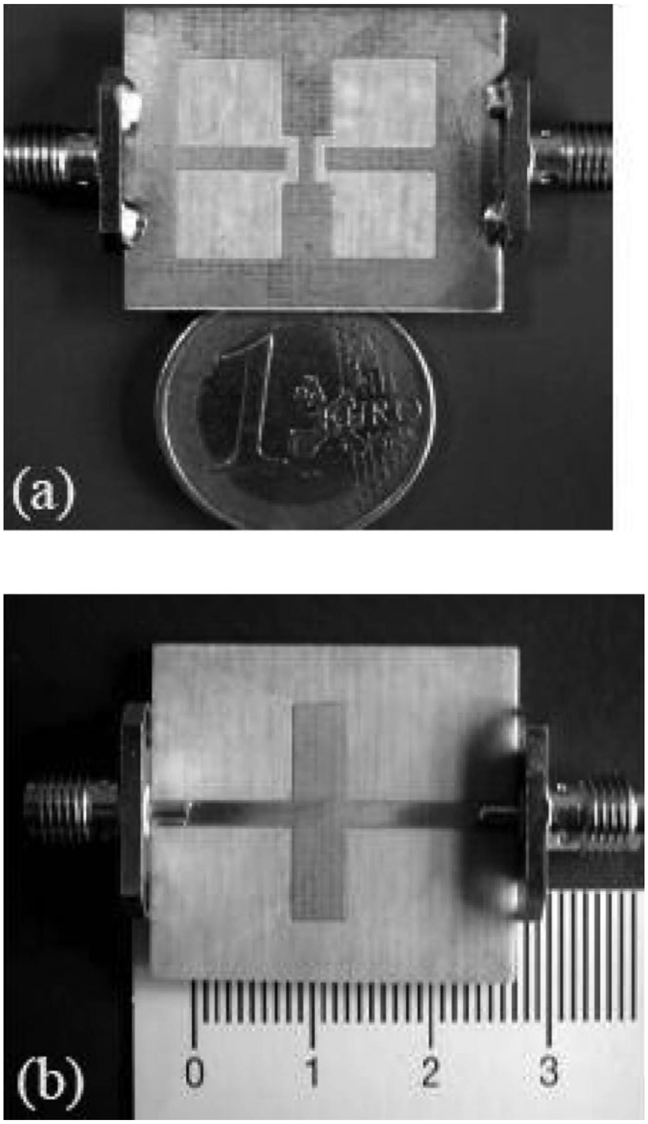

Figure 9 The photograph of the fabricated LPF (a) Bottom View (b) Top view

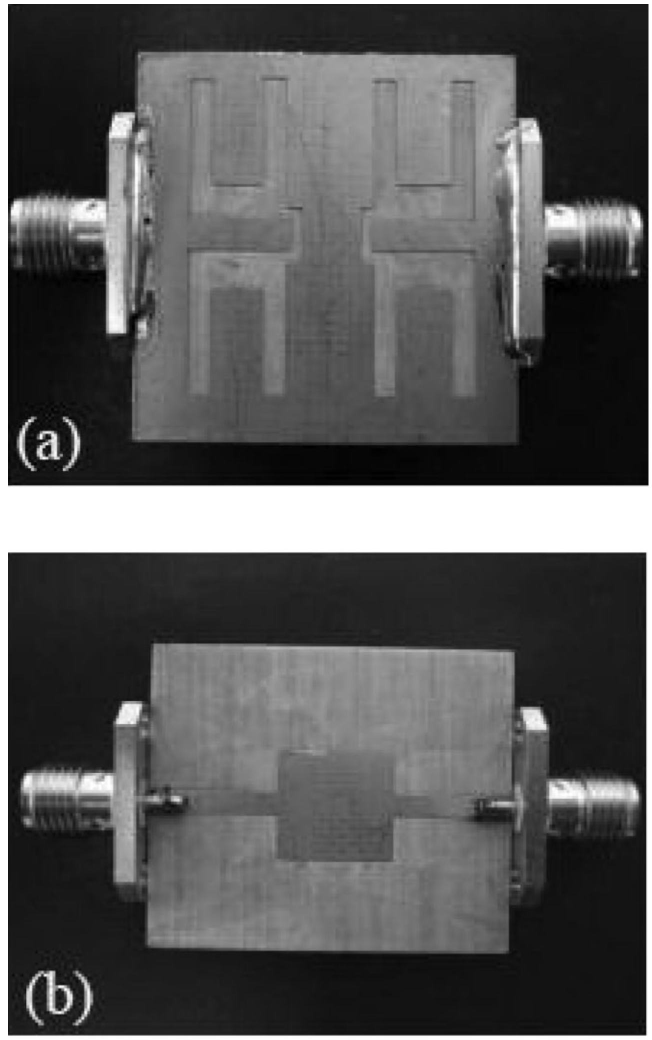

Figure 11 The photograph of the fabricated LPF (a) Bottom View (b) Top view

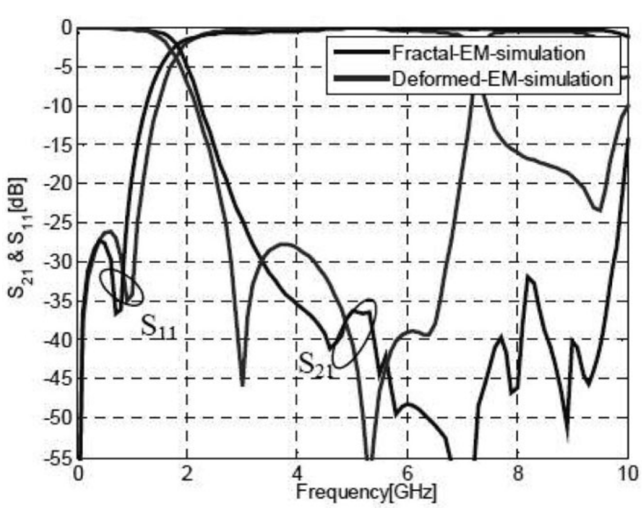

Figure 10 Simulated S-parameters for the deformed U-gap and fractal-DGS_LFPs

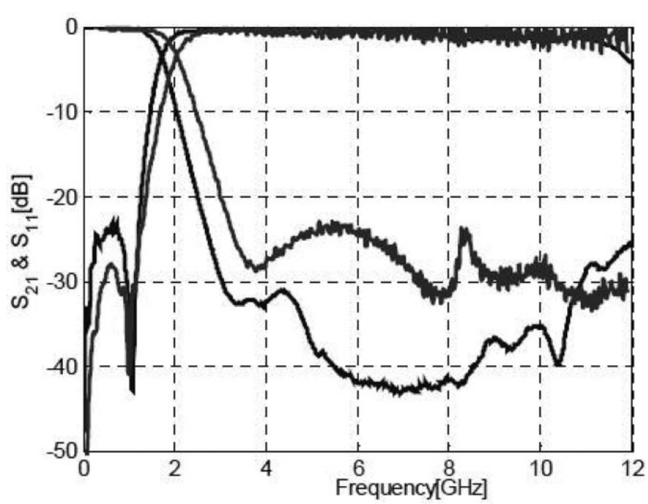

Figure 12 Comparison between the measured results of deformed and fractal DGS-LPFs. Deformed (——) Fractal (——)

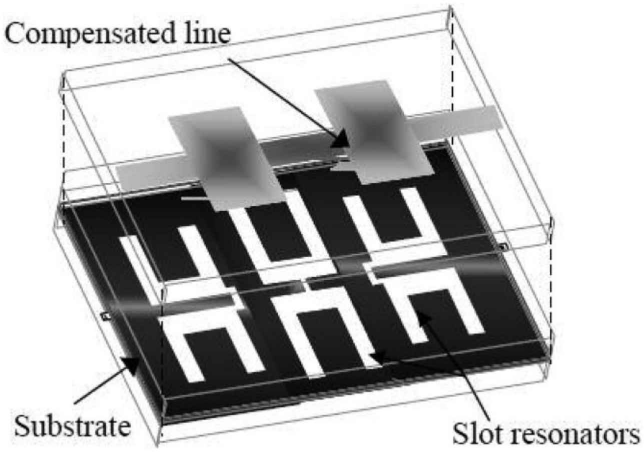

Figure 13 3-D view of the proposed multi-slots LPF

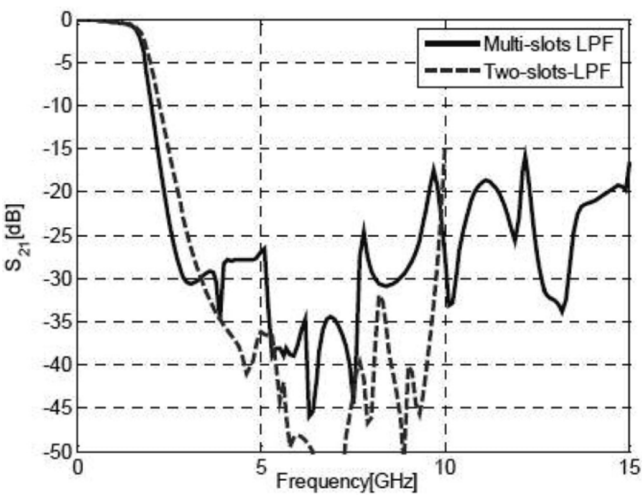

Figure 14 Comparison between the simulated results of multi-slots LPF and two DGS-LPF. Multi-slots (——). Two slots LPF (- - -)

significant influence on the stop-band. Figure 13 shows the proposed low-pass filter with symmetric structure, which is composed of a microstrip transmission line and two low impedance open stubs as capacitances in top layer and of three cascaded DGS resonators in metallic ground plane. The substrate has a thickness $h = 0.813$ mm and a dielectric constant $\varepsilon_r = 3.38$ for simulation. The line width w was chosen to be 1.9 mm in order to make the characteristic impedance equal to 50 Ω. The magnitude characteristics of microstrip multi-slots LPF were simulated by Microwave office and are shown in Figure 14. The both f_0 and f_c are 3 GHz and 1.8 GHz, respectively.

9. CONCLUSION

In the present work, a novel compact microstrip low-pass filter using a coupled DGS and a compensated microstrip line is proposed. The new DGS consists of two squareheads connected with a deformed U-gap. The equivalent circuit parameters of the DGS are extracted by using parametric relationship. It has been found that the proposed filter could have a compact size, high rejection, sharp transition domain, and wide stop-band. The measurement results have shown good agreement with the theoretical results. Finally, this newly proposed compact and high-performance low-pass filter is expected to be used in various microwave system applications.

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NOVEL SUBSTRATE INTEGRATED FOLDED WAVEGUIDE FILTER

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Received 8 September 2007

ABSTRACT: *In this study, a novel substrate integrated folded-waveguide resonator filter is presented and an aperture coupling between adjacent resonators is introduced, which is characterized using full-wave EM simulations and verified experimentally. A demonstrator of two-pole substrate integrated folded-waveguide resonator filter of this type has been designed, fabricated, and tested. As an example, a two-pole BPF centered at 4.675 GHz with a fractional bandwidth of 7.4% is designed, fabricated, and measured. Simulations and experimental results are presented to validate the design and to show the advantages of this type of filter. The simulated and measured results show an excellent agreement.* © 2008 Wiley Periodicals, Inc. Microwave Opt Technol Lett 50: 1111–1114, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.23272

Key words: *component; substrate integrated folded waveguide; SIFW; folded; microwave filter; resonator*

1. INTRODUCTION

Rectangular waveguides (RWG) are a common method of low loss propagation of electromagnetic (EM) waves. The research into compact and efficient waveguides has been considerable in last many decades allowing a large number of devices to come into use in the mm-wave spectrum. The most fundamental of these, the RWG, is today present in a wide range of applications from wireless local area networks to airborne radar and intelligent transportation systems. Unfortunately, RWGs, and many other commonly used devices, are by nature three dimensional, and can be difficult to integrate with planar circuitry. Moreover, at the lower part of mm-wave region, RWGs have large dimensions and a considerable weight. To overcome these problems several novel techniques relying on existing circuit fabrication have been proposed for the fabrication of waveguides. These have included low temperature co-fired ceramics (LTCC) [1], microwave laminates [2, 3], and photoimageable thick-films [4]. However, their 3-D nature can cause difficulties in manufacturing accuracy and planar circuitry integration. There is an increasing need for microwave systems, which use smaller sizes devices and enhanced performance. Both resonator filter topology and dielectric substrate are