Harmonic Suppression of Parallel Coupled-Line Bandpass Filters using Defected Microstrip Structure

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Abstract **─** This paper presents a novel miniaturized parallel coupled-line bandpass filter by etching some slot resonators on the strip for suppressing the first spurious response. These slots perform a serious *LC* resonance property in certain frequency and suppress the spurious signals. By properly tuning these slot dimensions, multiple closed notches can be generated in the vicinity of spurious harmonic and a wide stopband can be obtained. Slot on the strip that is called Defected Microstrip Structure (DMS). The DMS interconnection disturbs the current distribution only across the strip, thereby giving a modified microstrip line with certain stop band and slow-wave characteristics. The simulation and measurement of a 4.7 GHz prototype bandpass filter are presented. The measured results show a satisfactory rejection level more than 30 dB at first spurious passband without affecting the passband response. Good agreement between the experimental and full-wave simulated results has been achieved.

Index Terms **─** Defected Microstrip Structure (DMS), harmonic suppression, parallel coupled-line filter.

I. INTRODUCTION

High-performance microwave filters are essential circuits in many microwave systems where they serve to pass the wanted signals and suppress unwanted ones in the frequency domain. Microstrip parallel coupled-line bandpass filters are widely used in microwave circuits due to their low sensitivity to fabrication tolerances, wide realizable bandwidth, and simple synthesis procedure. However, despite the aforementioned advantages, an undesirable disadvantage is the existence of the first spurious passband at twice the passband frequency. This spurious response degrades the rejection properties of the system. The undesired spurious passband is related to the inhomogeneous dielectric medium surrounding the conductors, which causes the odd-mode wave to propagate faster than the even mode wave in the coupled microstrip lines [1-4]. The even and odd mode phase velocities are different for coupled microstrip lines due to their different field configuration in the vicinity of the air–dielectric interface. There are two basic methods in equalizing the modal transmission phase: providing different lengths for the even and odd mode waves, or equalizing the modal phase velocities. In [5], an over-coupled resonator was constituted to extend the odd-mode phase length, thus compensating the phase velocity difference between two modes. The structure in [6] uses capacitors to extend the travelling route of the odd-mode. The strip-width modulation technique tries to modify or perturb the widths of the conventional lines in various forms, such as wiggly [7], grooved [8], or even fractal [9] shapes. The above periodic structures can be used to create Bragg reflections so that the first spurious passband is rejected, while the desired passband response is maintained almost unchanged. Split Ring Resonator (SSR) structure was proposed to achieve a large imaginary component in effective permeability due to its unique resonance nature [10]. In recent years, Complementary Split Ring Resonator (CSRR) is presented and investigated on the basis of Defected Ground Structure (DGS) [11]. It has been demonstrated that CSRRs etched in the ground plane or in the conductor strip of planar transmission media (microstrip or CPW) provide a negative effective permittivity to the structure, and signal propagation is precluded (stopband behaviour) in the vicinity of their resonant frequency [12]. In DMS, there is no etching in ground plane. DMS is made by etching some uniform or non uniform slits or patterns over the transmission line. DMS was originally proposed in [13, 14]. In [15], the stopband characteristic of a DMS is studied and probes the relationships between the etched slot dimensions and the characteristics of the stopband.

For housing the DGS, it should be suspended for correctness of its performance. However, in DMS, the circuit needs not be elevated from the housing. The size of slot in DGS is much greater than to the size of slot in DMS for getting the same frequency response. So, this defect causes radiation problem. The radiation from the defects of interconnection is a harmful phenomenon for measurements or integration of components. Compared to DGS, if DMS is used as a filter, the harmful radiation

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can be decreased with lower etched area of defect. Dissimilar DGS, the DMS has less radiated EMI ground noise. In addition, ground plane defect will significantly increase the crosstalk between parallel interconnections that cross over them [16].

In this paper, a new design of a parallel coupled bandpass filter using Defected Microstrip Structure (DMS) by etching Open Square Ring (OSR) is proposed to suppress the first spurious harmonic and its resonant properties are scrutinized. Low insertion loss in the passband, high rejection level and integrated structure should be mentioned as advantages for this resonator. By employing the DMS structure, the unwanted harmonics can be suppressed with appropriately selected slot length tuned to block some specific harmonic band and great rejection can be obtained. These resonators designed to resonate around $2f_0$ and will add a transmission zero at undesired frequency. Here, we merge DMS resonators in filter structure with no increase in used area while was excellent for the first harmonic suppression with rejection levels up to 30 dB. This enhanced performance of the proposed bandpass filter has been verified by full-wave analysis and experimental results; and a good agreement between these results is obtained. Analysis of the proposed DMS resonator is scrutinized in Section II. Section III presents the simulated and measured results of proposed filter.

II. DESIGN AND ANALYSIS OF THE RESONATOR

The basic topology of Complementary Open Square Ring-DMS (COSR-DMS) is depicted in Fig. 1, which is located in the center of the microstrip line. As shown in Fig. 1, the microstrip line width is chosen in a way to exhibit a 50 Ω transmission line. The substrate Rogers RO4350 with the thickness of 1.52 mm and dielectric constant of 3.66 is used in the simulation. The EM simulations are performed using Ansoft HFSS v.12 (an electromagnetic simulator). The amplitude simulation result is shown in Fig. 3, which illustrates the characteristic of a bandstop filter.

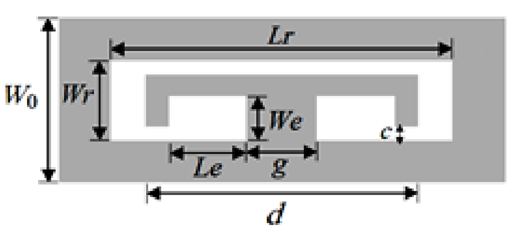

Fig. 1. Configuration of Complementary Open Square Ring-DMS (COSR-DMS).

As shown in Fig. 2, the frequency characteristics of the proposed DMS can be modeled by a single parallel *RLC* resonator circuit which blocks the signal as an open at the resonant frequency. The radiation effect and transmission loss are considered by including the resistor, *R*. A simple lumped element model is shown in Fig. 2. From the illustrated full-wave simulation results, the circuit model parameters can be extracted as follows:

$$R = 2Z_0\left(1/\left|S_{21}\right| - 1\right)\Big|_{f=f_r}, \tag{1}$$

$$C = \frac{\sqrt{0.5\left(R+2Z_0\right)^2 - 4Z_0^2}}{2.83\pi Z_0 RB}, \tag{2}$$

$$L = \frac{1}{\left(2\pi f_r\right)^2 C}, \tag{3}$$

where Z_0 is the characteristic impedance of the transmission line, f_r is the resonant frequency, S_{21} is the transmission coefficient, and *B* is the 3dB bandwidth of S_{21} at f_r.

For the dimensions (Lr = 9 mm, Wr = 2 mm, We = 1.2 mm, Le = 1 mm, d = 7.1 mm, g = 1 mm, c = 0.2 mm, W_0 = 3.55 mm) the circuit model parameters are 1.33 kΩ, 0.3085 nH and 3.62pF.

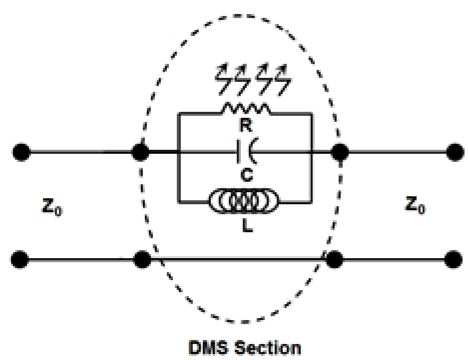

Fig. 2. The related equivalent circuit of unit cell DMS and its losses.

Figure 3 compares the S-parameters calculated by electromagnetic (EM) simulation for COSR-DMS in Fig. 1 and those calculated by using the equivalent circuit in Fig. 2. Circuit simulation is performed by employing Advanced Design System (ADS). For S_{21} simulation, the results are in good agreement over a wide frequency range.

The resonant frequency of COSR depends only on its total physical length for a constant value of space gap (*g*). The resonant frequency is independent of the physical width (*c*) of the COSR. The physical width determines bandwidth of frequency response.

Considering the frequency response of DMS resonator in Fig. 4 one transmission zero and two poles is observed. If we can move the poles closer together without any change at the location of zero (resonant frequency), afterwards resonator bandwidth decreases and according to the equation $Q=f_r/BW$, reduction of bandwidth will result in increase of *Q*.

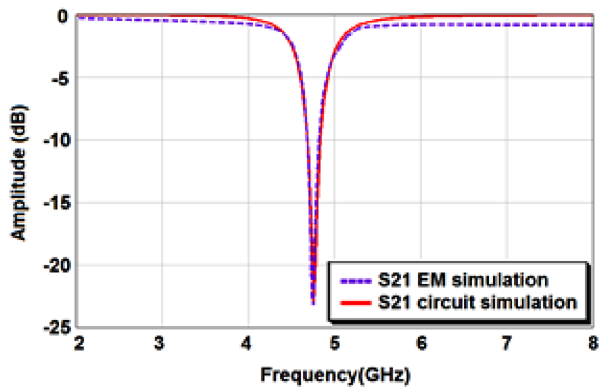

Fig. 3. Comparison between EM and circuit simulations for proposed COSR-DMS.

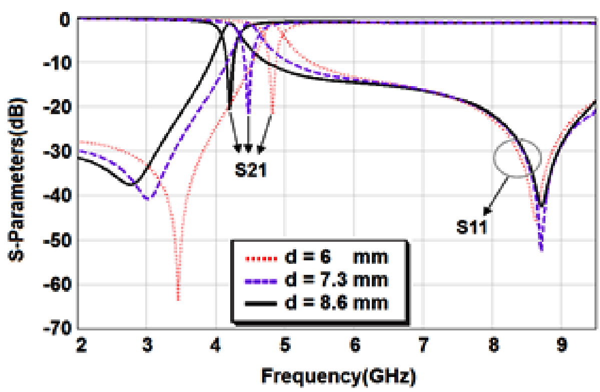

Fig. 4. Simulated scattering parameters for different length *d* (*Lr* = 12 mm, *We* = 1.3 mm, *Wr* = 2mm, *Le* = 1 mm, *g* = 0.2 mm, *c* = 0.3 mm).

To eliminate unwanted harmonics near the desired signal and also to improve oscillator phase noise, high quality factor resonator is required. By utilizing the introduced resonant structure and small physical changes we can adjust *Q*.

The first transmission pole occurs in frequencies lower than resonant frequency. Location of the pole is adjusted using *d*. Figure 4 shows resonant frequency of the resonator for different lengths *d* on the 50 Ω microstrip line. As can be seen second transmission pole remains constant.

In addition, appearance of second transmission pole which is observed in Fig. 4 is due to the length *Lr*. In other words, in frequencies where $Lr = \lambda/2$ one transmission pole appears in response. So we can control the second pole by changing the length *Lr*. As it was, before the designing high *Q* resonator, it is necessary that the poles be close to each other. By Increasing *Lr* not only the frequency of second pole decreases, but the first pole and the resonant frequency also will decrease. Decreasing *d* causes the first pole and resonant frequency increase while the second pole frequency does not change. Thus, with tuning *Lr* and *d* we can bring the two transmission poles closer to each other while the transmission zero remains constant. Figure 5 depicts *S*-parameters for different lengths *d* and *Lr* of this resonator etched on the 50 Ω microstrip line. Resonators which are merged in this filter structure must be having low *Q* or high bandwidth so difference between *Lr* and *d* should be equal to *c*.

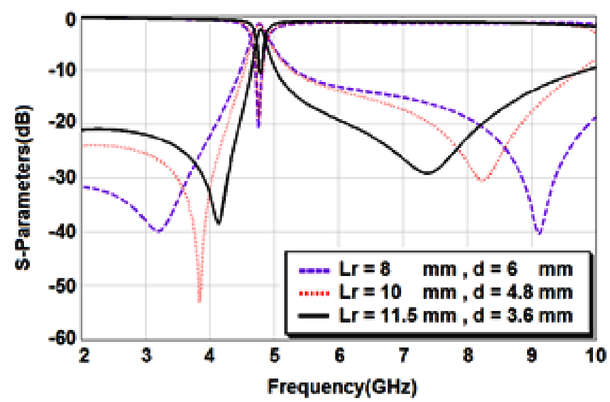

Fig. 5. Simulated scattering parameters for different length *Lr* and *d* (*We* = 1.3 mm, *Wr* = 2mm, *Le* = 1 mm, *g* = 0.2 mm, *c* = 0.3 mm).

III. FILTER IMPLEMENTATION

The DMS structure increases the electric length and the associated inductance of the microstrip. So, improvement in filter characteristics of the circuits can be achieved and size of the filter circuits can be reduced. DMS presents good cut off frequency characteristics due to the more effective inductance with respect to DGS.

In order to demonstrate the effectiveness of this DMS pattern to harmonic suppression, the novel filter is compared with a conventional parallel coupled-line filter with center frequency f_0 = 4.7 GHz with 600 MHz bandwidth on Rogers RO4350 substrate which has a relative permittivity ε_r = 3.66 and thickness *h* = 1.52 mm.

The conventional parallel coupled-line filter exhibiting a five-order filter response comprises of three open transmission line resonators which are designed to have a length of approximately half of the wavelength, $\lambda_g/2$, at the center frequency of The conventional parallel coupled-line filter exhibiting a five-order filter response comprises of three open transmission line resonators which are designed to have a length of approximately half of the wavelength, $\lambda_g/2$, at the center frequency of the conventional parallel coupled-line filter. Figure 6 shows the design parameters of the conventional parallel coupled-line filter. *Wi*, *Si*, and *Li* are width, separation between coupled sections, and length of the *i*th section, respectively.

Simulated S-parameters of the conventional parallel coupled-line filter are shown in Fig. 7. The response curve shows that the spurious harmonic of the parallel coupled-line filter is around $2f_0$. This is major disadvantage of the conventional parallel coupled-line filter.

The configuration of the proposed parallel coupled-line filter with the four COSR-DMS sections is illustrated in Fig. 8.

Etched defects on the top metal conductor of microstrip line provide higher effective permittivity and characteristic impedance than those of the conventional microstrip line due to increase of the effective inductance of transmission lines.

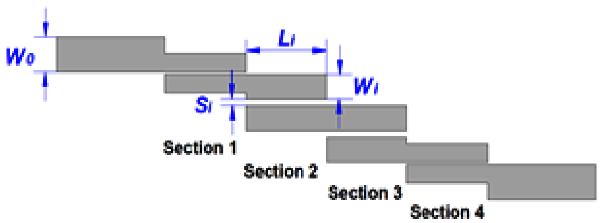

Fig. 6. Schematic of a five-order conventional parallel coupled-line filter ($W_1 = W_4 = 1.85$ mm, $W_2 = W_3 = 2.49$ mm, $S_1 = S_4 = 0.23$ mm, $S_2 = S_3 = 0.68$ mm, $L_1 = L_4 = 9.1$ mm, $L_2 = L_3 = 8.9$ mm).

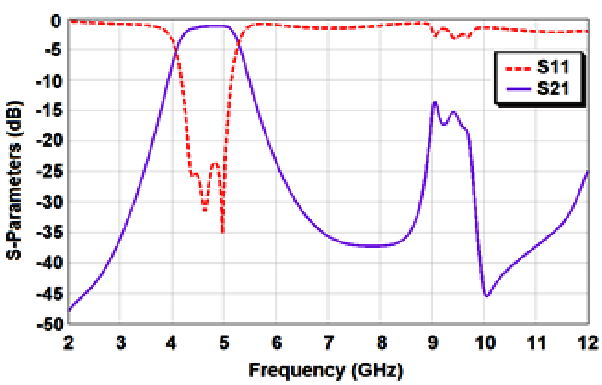

Fig. 7. Simulated S-parameters of the conventional parallel coupled-line filter.

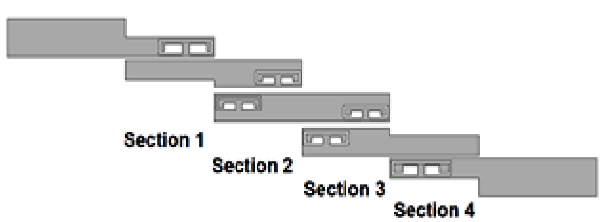

Fig. 8. Proposed parallel coupled-line filter.

The relevant design parameters of each resonator are optimized as follows: $Lr_1 = 5.5$ mm, $Lr_2 = Lr_3 = 4.53$ *mm*, $Lr_4 = 6$ mm, $Le_1 = 1.8$ mm, $Le_2 = Le_3 = 1.2$ mm, $Le_4 = 1.5$ mm, $We_1 = We_4 = 0.9$ mm, $We_2 = 0.65$ mm, $We_3 = 0.675$ mm, $Wr_1 = Wr_4 = 1.3$ mm, $Wr_2 = Wr_3 = 1.2$ mm. The input and output port strip width are $W_0 = 3.55$ mm, corresponding to 50 Ω. The etched physical width (*c*) and space gap (*g*) is chosen to be 0.2 mm and 0.7 mm for all DMSs. From this geometry, we have tuned COSRs dimensions in order to obtain multiple closed notches and hence achieve spurious passbands rejection.

DMS resonators perform a serious *LC* resonance property in certain frequency. The proposed structure uses the rejection properties of DMSs merged in filter structure to reject specific frequencies while having the least effect on the filter pass band response. Thus, it is more reasonable to use multiple DMSs to make a wide reject band without meaningful effect on main response. This technique eliminates the first harmonic response and makes better sharpness level of transition from passband to stopband region.

Comparison of transmission characteristics between conventional and proposed parallel coupled-line filter described in Fig. 8 is given in Fig. 9. As it is seen, the DMSs work as band-reject elements with almost no effect on filter performance and therefore could be designed independently. The simulation, exhibits that the proposed filter has successfully improved the spurious harmonics at $2f_0$. The center frequency and bandwidth of the fundamental passband is kept as in the original filter and no significant deviation is observed. Figure 10 displays the image of the fabricated proposed filter.

The first spurious passband is suppressed by more than 30 dB at twice the centre frequency and 50 dB suppression at 6.5 GHz. Figure 11 provides a comparison measured and full-wave simulated results. Good agreement between simulations and experimental data has been obtained.

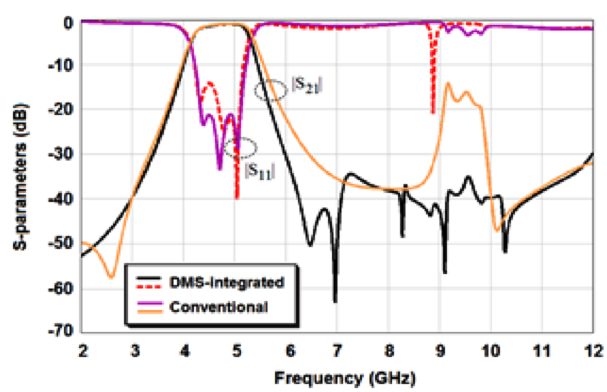

Fig. 9. Comparison between the simulated S_{21} of the proposed and conventional parallel coupled-line filter.

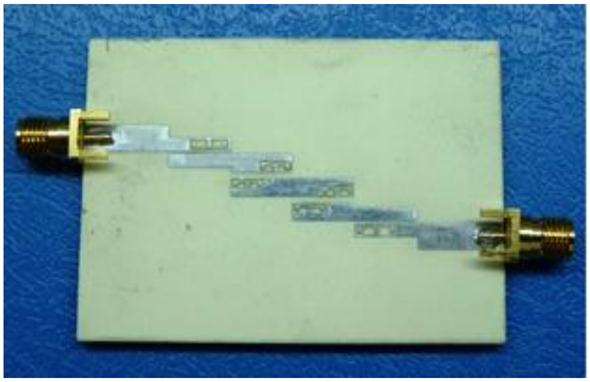

Fig. 10. Fabricated parallel coupled-line filter with COSR-DMS.

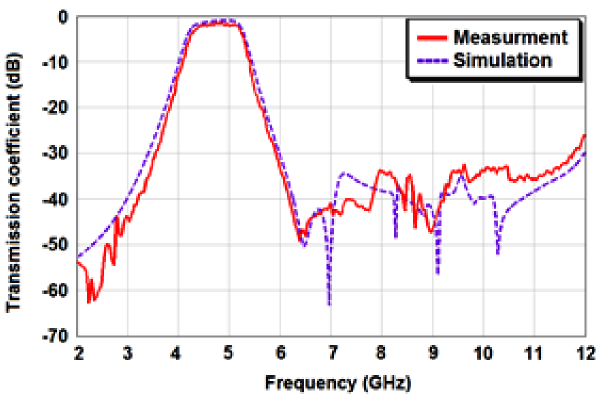

Fig. 11. Measured S_{21} of the fabricated proposed parallel coupled-line filter.

IV. CONCLUSION

In this paper, the compact parallel coupled-line filter having harmonic suppression has been presented. It has been demonstrated that the frequency response of proposed filter can be improved by merely etching COSR-DMS in parallel coupled sections. By properly tuning the dimensions of COSRs, it has been experimentally found that the first spurious band of the filter can be rejected, with no effect on the allowed band. By the simulation and experimental results of 4.7 GHz with a 600 MHz bandwidth a satisfactory rejection level more than 30 dB at first spurious harmonic in the stopband can be achieved, without affecting the original passband. We would like to highlight the fact that the topology of the proposed structure only differs from that of the conventional design on the presence of COSRs, and these are etched in the signal strip. The filter structure has great advantages as: achievable bandwidth, minimization of radiation from the defects and broad stopband. The proposed technique may have wide applications in miniaturization and harmonic rejection of various microwave circuits

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