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SPURIOUS RESPONSE SUPPRESSION IN HAIRPIN FILTER USING DMS INTEGRATED IN FILTER STRUCTURE

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Abstract—In this paper, several Defected Microstrip Structure (DMS) are used to suppress the first and second spurious responses in microstrip hairpin filters. The DMSs are integrated in filter structure, and therefore this method keeps the filter size unchanged. The DMS interconnection disturbs the current distribution only across the strip, thereby giving a modified microstrip line with certain stop band. The undesired spurious harmonics are suppressed through multiple transmission zeros which are added at these frequencies by designed DMSs. Experimental results verify that 25 dB suppression for the first harmonic and 40 dB suppression for the second harmonic, respectively, without affecting the main passband response. There is a good agreement between the simulated and measured results.

1. 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 [1]. Parallel coupled microstrip filters are widely used in microwave circuits due to their insensitivity to fabrication tolerances, wide realizable bandwidth, and simple synthesis procedures [2, 3]. However, despite the aforementioned advantages, there are some disadvantages with

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these filters. The first one is their length. Because of several half wavelength ($\lambda/2$) resonators, the filter is too long considering the frequency and the order of the filter. Well known hairpin structures as a modification of parallel coupled line filters provides a possible way to decrease the length efficiently [4]. Another important disadvantage is that, they suffer from the appearance of the spurious passband especially at twice of the center frequency ($2f_0$). This undesirable spurious passband is caused by the different phase velocities (and, consequently, different electrical lengths) of the even and odd modes related to the inhomogeneous dielectric medium surrounding the conductors.

To circumvent this problem, two effective approaches have been explored by equalizing the phase velocities and differentiating the travelling routes of even and odd mode. A ground-plane aperture [5], meandered lines [6], complementary split-ring resonators [7], and grooved substrate [8] have been designed to equalize the modal phase velocities. Strip-width modulation technique is developed to make up wiggly-line, corrugated, grooved or even fractal shape bandpass filters which extend the actual odd mode travelling path toward its even mode counterpart [9–12]. These continuous and periodic perturbations with various forms are simple and effective approach which can be used to reallocate the transmission zero so that the first spurious passband is suppressed, while the desired passband response is maintained almost unchanged.

In this paper, a new method based on Defected Microstrip Structure (DMS) is presented to suppress the spurious harmonics in microstrip hairpin filters. 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 $3f_0$ will add a transmission zero at these frequencies. Here, we merge DMSs in hairpin structure with no increase in used area while these are excellent for the first and second harmonics suppression simultaneously with rejection levels up to 35 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. In Section 2, we describe the main idea of DMS strategy. Analysis of the proposed DMS resonator is investigated in Section 3. Section 4 presents the simulated and measured results of hairpin filter.

2. MAIN IDEA

In a DMS, there is no etching in the ground plane such as Defected Ground Structure (DGS). DMS is made by etching a uniform or nonuniform slit on the signal strip. The DMS increases the electric length and the associated inductance of the microstrip structure. This causes the stopband filter characteristics of the circuits to be improved while keeping the size of the filter small. So this effect can be used not only to make filters but to reduce effectively the dimensions of devices. The DMS disturbs the current distribution across the strip, thereby making a modified microstrip line with certain stopband and slow-wave characteristics. Its most important application is to reject certain harmonics at the output port. The CDMS is a cascade of DMS cells. CDMS has wider stopband characteristic and sharper transition from passband to stopband, with respect to the DMS. In comparison with DGS, if DMS is used as a filter, the harmful radiation can be decreased with lower etched area of defect. DMS interconnection provides good cut off frequency characteristics due to the more effective inductance with respect to DGS [13].

One common disadvantage for DGS structures having a periodic pattern etched in the ground plane is that the whole structure must be suspended far from other ground conductors for the periodic ground plane to be effective.

3. ANALYSIS OF THE DMS RESONATOR

Figure 1 depicts configuration of DMS resonator. Bandgap characteristics are modelled by LC resonator. The radiation effect and

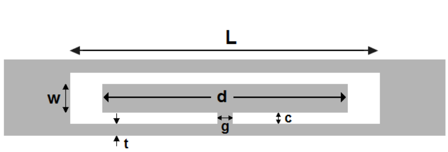

Figure 1. Configuration of unit cell DMS resonator.

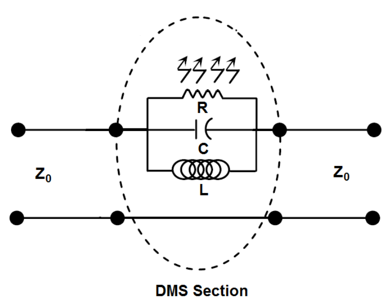

Figure 2. DMS model parameters with radiation and temperature losses.

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 3 dB bandwidth of S_{21} at f_r.

For the dimensions (L = 12 mm, d = 11.6 mm, g = 0.2 mm, t = 0.27 mm, c = 0.2 mm, w = 0.6 mm) the circuit model parameters are 2.345 kΩ, 0.48265 nH and 1.9711 pF. The DMS circuit model has been simulated using Agilent ADS. Fig. 3 shows the circuit model response which is in good agreement with full-wave simulated result.

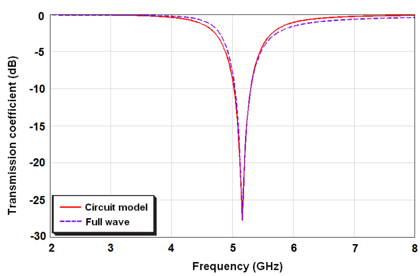

Figure 3. Comparison of the circuit model response and full-wave simulated result.

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.

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.

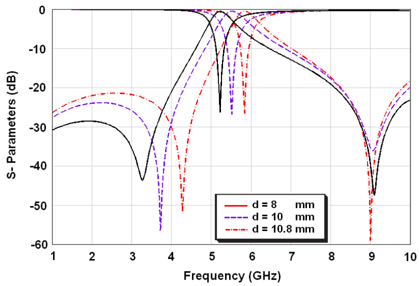

Figure 4. Full-wave simulated results for different length d. ($L = 12\,\text{mm}$, $g = 0.2\,\text{mm}$, $t = 0.27\,\text{mm}$, $c = 0.2\,\text{mm}$, $w = 0.6\,\text{mm}$).

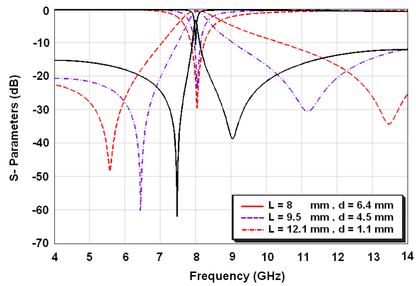

Figure 5. Full-wave simulated results for different lengths of d and L. ($g = 0.2\,\text{mm}$, $t = 0.27\,\text{mm}$, $c = 0.2\,\text{mm}$, $w = 0.6\,\text{mm}$).

The first transmission pole occurs in frequencies lower than resonant frequency. Location of the pole is adjusted using parameters d, w and t. Fig. 4 shows resonant frequency of the resonator for different lengths d on the $50\,\Omega$ 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 L. In other words, in frequencies where $L = \lambda/2$ one transmission pole appears in response. So, we can control the second pole by changing the length L. As it was, before the designing high Q resonator, it is necessary that the poles to be close to each other. By Increasing L 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 L and d we can bring the two transmission poles closer to each other while the transmission zero remains constant. Fig. 5 depicts S-parameters for different lengths d and L of this resonator etched on the $50\,\Omega$ microstrip line. Resonators which are merged in this filter structure must be having low Q or high bandwidth so difference between L and d should be equal to c.

4. HARMONICS SUPPRESSION OF HAIRPIN FILTER

Because of different phase velocities for even and odd modes of propagation in coupled section, the filter response exhibits a spurious passband at $2f_0$. This spurious response degrades the rejection properties of the system. It is predominantly caused by the nonsynchronous feature of even and odd mode of propagation in the inhomogeneous dielectric medium surrounding the conductors. The different field configuration in the vicinity of the air-dielectric interface leads to difference in even and odd mode phase velocities.

The proposed hairpin structure uses the rejection properties of DMSs etched in appropriate locations 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.

First, we design a conventional five order hairpin filter at center frequency of 2.1 GHz with 600 MHz passband on Rogers RO4003 substrate ($\varepsilon_r = 3.38$, $h = 0.7874$ mm). For spurious band suppression at $2f_0$ and $3f_0$, ten DMS resonator are designed and merged in coupled section. The DMSs designed to resonate around $2f_0$ and $3f_0$ will add a transmission zero at these frequencies to suppress the spurious bands while having almost no effect on the main pass band.

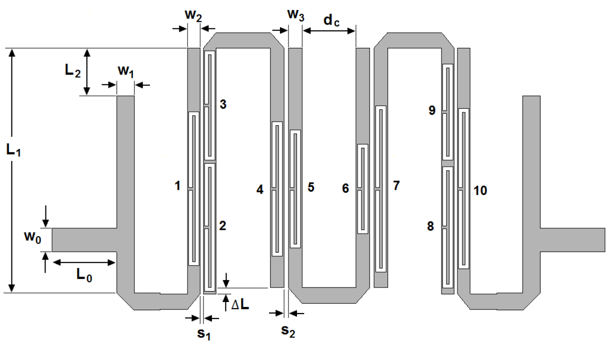

Figure 6. The proposed filter structure ($L_0 = 5.1$ mm, $L_1 = 19.1785$ mm, $L_2 =$ mm, $\Delta L = 0.4763$ mm, $w_0 = 1.84$ mm, $w_1 = 1.35$ mm, $w_2 = 0.98$ mm, $w_3 = 1.075$ mm, $s_1 = 0.26$ mm, $s_2 = 0.321$ mm, $d_c = 4.2$ mm).

The filter schematic integrated with the DMSs is shown in Fig. 6, and a comparison between the EM simulation results of filter with and without DMSs is shown in Fig. 7. As it is seen, the DMSs work as band-reject elements with almost no effect on filter performance and therefore could be designed independently. From the simulation, it exhibits that the proposed filter has successfully improved the spurious harmonics at $2f_0$ and $3f_0$ so as to achieve broader rejection bandwidth than the conventional case. Thus, the proposed structure offers these spurious response suppressions close to 40 dB in the entire rejection

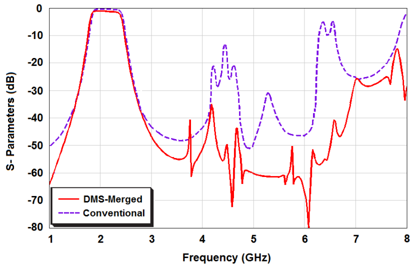

Figure 7. Comparison between the simulated responses of hairpin filter with and without DMSs.

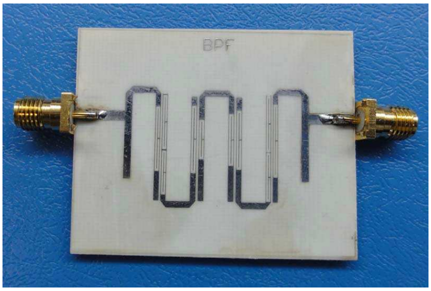

Figure 8. Image of fabricated proposed filter.

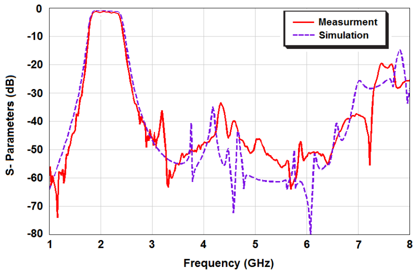

Figure 9. Comparison between measured and full-wave simulated frequency responses of proposed and conventional structure.

Table 1. Resonant frequency and dimensions d and L of DMS resonators which are merged in filter structure in Fig. 6.

	1	2	3	4	5	6	7	8	9	10
L (mm)	11.5	9.72	7.72	12	7	9.2	10.5	10.1	8.6	13
d (mm)	10.9	9.12	7.12	11.4	6.4	8.6	9.9	9.5	9	12.4
f_r (GHz)	6.14	9.06	7.22	5.84	9.7	7.5	6.54	8.18	6.84	5.3

band. In all the DMSs $w = 0.15$ mm, $g = 0.2$ mm, $t = 0.15$ mm and $c = 0.3$ mm. Resonant frequency for each of this resonators which is related to d and L and dimensions of this parameters are listed in Table 1.

The image of fabricated proposed filter is shown in Fig. 8. The comparison between measured and full-wave simulated results is shown in Fig. 9. There is a good agreement between simulated and measured results. The transmission coefficients are suppressed approximately to

25 dB and 40 dB at the first and second harmonics with respect to the original filter, respectively. This means that the first and second harmonics are reduced simultaneously by using the DMSs.

5. CONCLUSION

This paper introduced a simple compact DMS and effective application's to suppress the first and second spurious responses of the conventional hairpin filter simultaneously. In Comparison with DGS, DMS circuit has lower radiated from ground plane. This structure can be integrated more easily with other microwave circuits. The design method will add a transmission zero at even ($2f_0$) and odd ($3f_0$) spurious passbands so as suppress the spurious bands while no effect on the center frequency response. In experimental results, 25 dB suppression for the second harmonic and 40 dB suppression for the third harmonic are achieved.

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