Harmonics blocking in hairpin filter using Defected Microstrip Structure

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Abstract: In this paper, it is demonstrated that the first and second spurious passbands suppression in microstrip hairpin filters can be achieved by simply patterning appropriate geometries of several Defected Microstrip Structure (DMS) in parallel coupled sections. By properly tuning DMS resonator dimensions, multiple transmission zeros can be generated in the vicinity of spurious harmonics and a wide stopband can be obtained. Experimental results verify that 25 dB and 40 dB suppression for the first and the second harmonics, respectively, without affecting the main passband response.

Keywords: hairpin filter, Defected Microstrip Structure (DMS), harmonics blocking

Classification: Microwave and millimeter wave devices, circuits, and systems

References

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. Parallel coupled microstrip filters are widely used in microwave circuits due to their insensitivity to fabrication tolerances, wide realizable bandwidth, and simple synthesis procedures [1]. However, despite the aforementioned advantages, there are some disadvantages with 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. 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 [2], meandered lines [3], complementary split-ring resonators [4], and grooved substrate [5] 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 [6, 7, 8, 9]. 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 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 [10, 11]. In [12], the stopband characteristic of a DMS is studied and probes the relationships between the etched slot dimensions and the characteristics of the stopband.

In this paper, a new design of a compact hairpin filter using Defected Microstrip Structure (DMS) by etching Open Square Ring (OSR) to suppress the spurious harmonics is proposed 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 $3f_0$ will add multiple transmission zeros 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.

2 DMS design and scrutinization

The basic topology of Complementary Open Square Ring-DMS (COSR-DMS) COSR is depicted in Fig. 1 (a), which is located in the center of the microstrip line. The line width is chosen in a way to exhibit a 50 Ω transmission line.

Defected Microstrip Structure (DMS) increases the electric length and the associated inductance of the microstrip line. So, improvement in filter characteristics of the circuits can be achieved and size of the filter circuits can be reduced.

Considering the amplitude simulation result for DMS resonator in Fig. 1 (b) one transmission zero and two poles is observed. Fig. 1 (b) shows resonant frequency of the resonator for different lengths $d$ on the 50 Ω microstrip line. As can be seen second transmission pole for different length $d$ remains constant. In addition appearance of second transmission pole is due to the length $L$. So, we can control the second pole by changing the length $L$.

If we can move the poles closer together without any change at the zero point, resonator bandwidth decreases and according to $Q = f_r/BW$, reduction of bandwidth will result in increase of $Q$. 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 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. 1 (c) depicts S-parameters for different lengths \(d\) and \(L\). 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 \(c\).

### 3 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 \(2f_0\). 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 passband 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.
Fig. 2. (a) The proposed filter structure \((L_0 = 5.1\, \text{mm}, L_1 = 19.1785\, \text{mm}, L_2 = 3.73\, \text{mm}, \Delta L = 0.4763\, \text{mm}, w_0 = 1.84\, \text{mm}, w_1 = 1.35\, \text{mm}, w_2 = 0.98\, \text{mm}, w_3 = 1.075\, \text{mm}, s_1 = 0.26\, \text{mm}, s_2 = 0.321\, \text{mm}, d_c = 4.2\, \text{mm})\). (b) Photograph of fabricated proposed filter.

to suppress the spurious bands while having almost no effect on the main pass band.

The filter schematic integrated with the DMSs is shown in Fig. 2 (a), and a comparison between the EM simulation results of filter with and without DMSs is shown in Fig. 3 (a). 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 band. In all the DMSs \(w = 0.15\, \text{mm}, g = 0.2\, \text{mm}, t = 0.15\, \text{mm}\) and \(c = 0.3\, \text{mm}\). Resonant frequency for each of these resonators which is related to \(d\) and \(L\) and dimensions of these parameters are listed in Fig. 2 (a). From this geometry, we have tuned COSRs dimensions in
order to obtain multiple closed notches and hence achieve spurious passbands rejection.

The image of fabricated proposed filter is shown in Fig. 2(b). The comparison between measured and full-wave simulated results is shown in Fig. 3(b). There is a good agreement between simulated and measured results. The transmission coefficient is suppressed 25 dB and 40 dB at the first and second harmonics with respect to the original filter. This means that the first and second harmonics are reduced simultaneously by using the DMSs.

4 Conclusion

It has been demonstrated that the frequency response of microstrip hairpin filters 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 spurious passbands of the filter can be rejected, with no effect on the allowed band. 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.
This structure can be integrated more easily with other microwave circuits. A prototype device fabricated exhibits spurious suppression levels 25 dB for the first and 45 dB for the second harmonic.