Improved Circuit Model for DGS based Lowpass Filter

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Abstract — **We report a new and improved circuit model for the DGS slot based LPF which accounts for losses and mutual coupling between the slots. We also present a Hi-Lo LPF with DGS slots and investigate the impact of their position on improving the performance of the filter.**

Index Terms — **Lowpass filter, DGS slot, microstrip filter, Slot in ground plane.**

I. Introduction

Usually the microwave lowpass filter (LPF) is implemented either by all stunt stubs or by the series connected high-low (Hi-Lo) stepped-impedance microstrip line sections. Both types of LPF show spurious passbands. The lumped elements based LPF has no spurious passband. However, generally these are not available in the microwave range. The quasi-lumped element based on the electromagnetic-band-gap (EBG) ground plane and the defected ground plane structures (DGS) have been proposed to improve the stopband characteristics of a LPF [1]-[3]. The EGB based LPF are more difficult to design and characterize. Also they cause trouble to the design of other circuit elements on the same substrate. The design with DGS is on the other hand more compact.

A microstrip stub type 3-pole LPF with the DGS has been used to improve the stopband characteristics of a LPF [1]. Such a filter has also been realized with two DGS slots and compensated microstrip line width [4]. The slot in a ground plane, excited by the microstrip line works as an evanescent mode waveguide section [6]. Combined with the coupling capacitor between the microstrip and the slot, it produces a band-reject resonance. The DGS slot is modeled by a parallel LC resonant circuit. The 3-pole LPF configuration is shown in Fig.1 (a) [1]-[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. Therefore there is a need to improve the circuit model shown in Fig.1(a) to incorporate both these effects. The filter with two DGS slots and compensated microstrip line width is in fact a Hi-Lo LPF with DGS. The DGS slot provides the series inductance while the shunt capacitance is obtained by the patch capacitor. By controlling the separation between the two slots and off-setting the connecting line we can control the sharpness of the transition between the passband and the stopband. This work reports (I) an improved circuit model for the DGS slot and (II) design of Hi-Lo LPF with DGS slots with improved cut-off performance.

II. Equivalent Circuit Model of the DGS Slot

The presented equivalent circuit model for a 3-pole LPF is developed to account for the losses and mutual coupling between the DGS slots. We have adopted the 3-pole stub type LPF with DGS slot from reference [1]. Fig.1 (a) shows the original circuit model of the 3-pole LPF and Fig.1 (b) shows the proposed improved circuit model. The resistance R represents the loss of the slot due to radiation and surface waves. The interaction between the slots is accounted by the mutual inductance, $M = K_{12}\sqrt{(L_1 L_2)}$. In our case due to the symmetrical slots, $L_1=L_2=L_p$. Following the suggested method in [1] we can compute L and C_1 (C_p) of the series arm by the following expressions:

$$C_p = \frac{5 f_c}{\pi\left[f_0^2 - f_c^2 \right]} \qquad \text{pf} \qquad (1)$$

$$L_p = \frac{250}{C_p (\pi f_0)^2} \qquad \text{nH} \qquad (2)$$

Where, f_c, (in GHz) is the cut-off frequency of the band-reject response of the slot at 3 dB and f_0, (in GHz) is its pole frequency. These are obtained from the simulated response of the DGS circuit element using the 3D EM Simulator Microwave Studio [5]. Within the passband, i.e. for any frequency $f < f_0$, the parallel circuit behaves as an inductor and its equivalent inductance in nH is expressed as,

$$L_{eq} = \frac{L_p}{[1 - (\frac{f}{f_0})^2]} \qquad \text{nH} \qquad (3)$$

This expression is used to compute the series inductor of the prototype 3-pole LPF. We note that L_{eq} is frequency dependent which is inconvenient for the LPF design. However, the variation in L_{eq} is not very rapid for frequencies below f_c. On the other hand, we get rapid variation in L_{eq} between f_c and f_0 only. The resistance R and the mutual inductance M are optimized using the Microwave office package. Before doing so we have tested the accuracy of the EM simulation for the 3-pole stub type LPF with DGS slots for the dimensions given in reference [1].

Fig.2 shows very good agreement between the simulated and the experimental results of reference [1]. The model shown in Fig.1 (b) is constructed using the circuit simulator, Microwave Office [7]. Fig. 3(a) shows the effect of R on S_{12} of the filter. The Q-factor of the pole resonance decreases as the value of R decreases. Fig. 3(b) shows the influence of mutual coupling of the two slots on S_{12}. The coupling lowers the pole frequency obtained from the isolated slot. The mutual coupling has thus improved the circuit model in the transition region. However, the model response is not good in the stopband. In this simulation we have neglected the effect of losses, i.e. the resistance R. Finally Fig. 3(c) compares S_{12} obtained by the circuit model which includes the effect of both the losses and the mutual coupling with that obtained by the EM simulator. The excellent agreement of results confirms the accuracy of our improved circuit model.

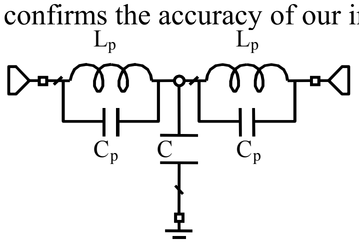


Fig.1(a) : Original circuit model [1] without coupling

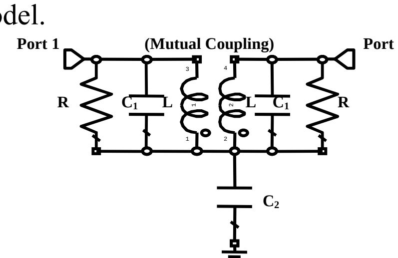
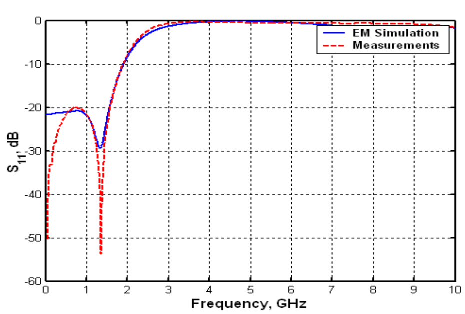
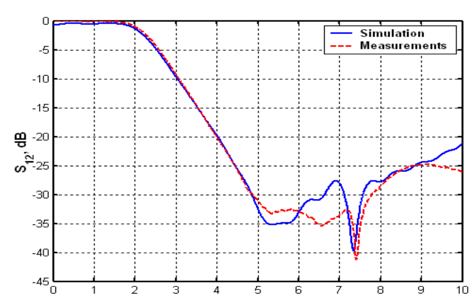


Fig. 1(b): Improved circuit model



(a) Refection loss-S_{11}



(b) Transmission loss-S_{12}

Fig.2 Comparison of measured and simulated performance of the 3-pole stub type LPF.

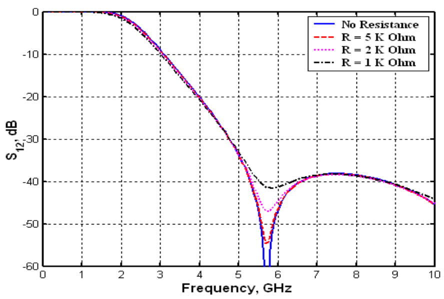


Fig 3(a) Effect of resistance R

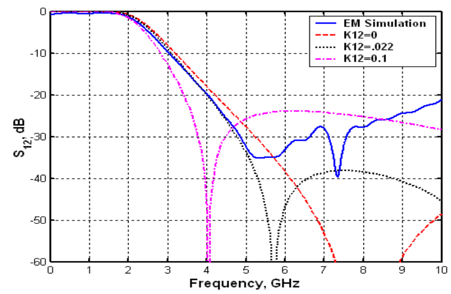


Fig 3(b) Effect of Mutual Coupling K12

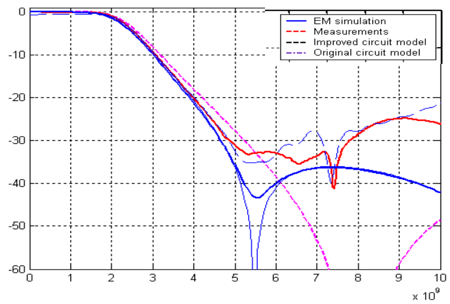


Fig 3(c) Comparitive results of S_{12} for R = 8 KΩ and K_{12} = 0.032

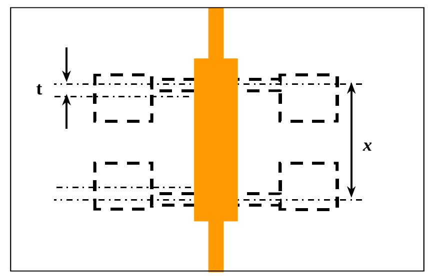


Fig. (4). Hi-Lo LPF with two squareheads DGS slots

III. Study on 3-pole Hi-Lo LPF with DGS Slots

Following Ahn et al. [1], we have designed a 3-pole Hi-Lo LPF with DGS slots. The structure is shown in Fig.4. The design procedure starts with the prototype LPF. The shunt capacitor is realized by a section of a microstrip line and the DGS slots represent the realization of the two inductors. The LPF is designed on a substrate with ε_r= 3.38, h= 0.0813 cm. The 50 Ω microstrip line has a width W=0.19 cm while the patch capacitor has a width

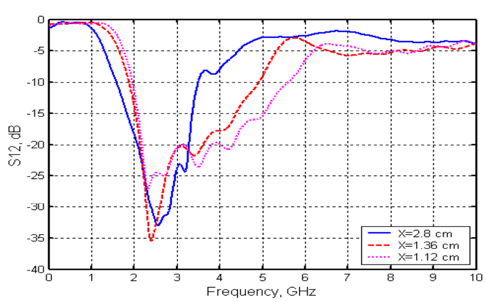


Fig.5: Effect of separation X of the DGS slots on S_{12}

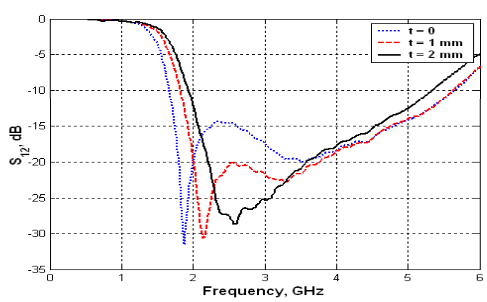


Fig.6: Effect of off-set of slot-head on S_{12}

W_c = 0.52 cm and a length L=1.53 cm. The separation X between the two DGS slots is optimized to achieve a better stopband response as shown in Fig.5. It is observed that the suppression bandwidth within the stopband becomes wider with decreasing the separation X. The cut-off frequency does not change much by this process. It is noted that there is a small increase in f_c with decreasing the separation X. The coupling between the slots can be controlled by shifting the heads centers by a distance t (off-set) from the slot centers as shown in Fig. 4. The effect of t on S_{12} is illustrated in Fig. 6. The area and other dimensions are kept the same in order to keep the values of the filter capacitances and inductances constant. By changing t, we achieve: 1) A shift of the filter pole and a decrease of the cut off frequency, 2) An improvement of the sharpness of the filter response, 3) A wider suppressed stop band and 4) A quasi-elliptic response. Thus a judicious choice of the separation X and the off-set distance t can improve the performance of the LPF with DGS.

Other geometries of the slot heads have been investigated. An arrow-head Hi-Lo LPF is shown in Fig. 7. Again, the effect of changing t (off-set) on S_{12} for this configuration is shown in Fig. 8. By changing t such that the two heads approach each other, the sharpness of the filter is improved and we get a wider stop band.

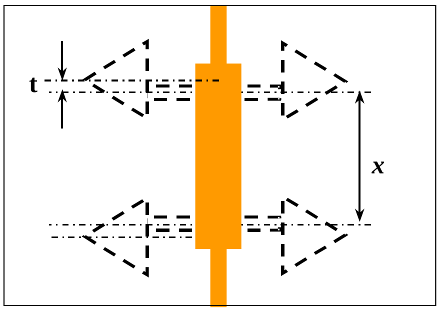


Fig. 7 Arrow head slot stepped impedance LPF

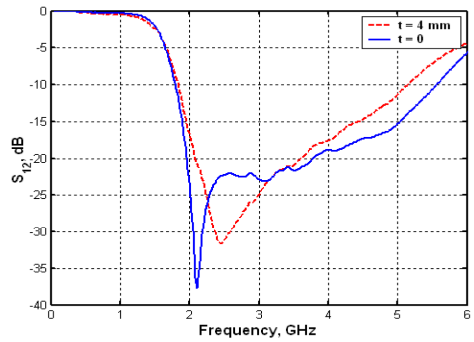


Fig.8 Coupling effect for arrow head slot stepped impedance LPF

VII. CONCLUSION

In this work we have presented an improved circuit model for the DGS slot, which accounts for the effect of losses and interaction between the slots on the 3-pole LPF performance. We have also demonstrated that the transition sharpness and the stopband response can be controlled by providing an off-set to the slot-heads with respect to their centers.

Acknowledgement

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