Proceedings of The 24th International Conference of Microelectronics
ICM 2012, December 17-20, 2012, Algiers, Algeria.

A Novel Ultra-Wide Stopband Microstrip Low-Pass Filter for Rejecting High Order Harmonics and Spurious Response

Applications in Wideband Microstrip Circuits and Systems

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Abstract— **In this paper, an ultra-wide stopband microstrip low-pass filter (LPF) to reject higher harmonics and spurious response for wideband microwave applications is proposed. It is based on quasi-triangular (QT) defected ground structure (DGS) resonators and open stubs. An equivalent circuit model is also presented. The introduced LPF has small size, a low insertion loss and a return loss less than -20 dB. In addition, a round -20 dB suppression level ranging from 4 GHz to more than 20 GHz is achieved. The simulated results obtained by circuit model and full-wave EM show good agreement with the measured ones.**

Keywords-Quasi-Triangular (QT); Defected ground structure (DGS); Ultra-wide stopband; Low-pass filter (LPF).

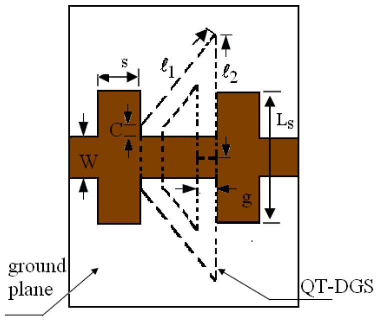
I. INTRODUCTION

A microstrip low-pass filter (LPF) is one of the fundamental components in RF/Microwave wireless communication systems. Low cost, low insertion loss, ultra-wide stopband and compact size are necessary to meet modern RF/Microwave communication systems requirements. Due to these features and, convenient integration with other microwave circuits, planar resonators have progressively been taken into consideration to be employed in microwave filter design. One of the techniques that can be applied in microstrip LPF is using a defected ground structure (DGS) technique instead of cascading several resonator cells. Many types of LPF for performance improvement have been introduced [1-5]. However, their performances such as stopband bandwidth, insertion loss and filter area do not completely achieve the communication systems requirements.

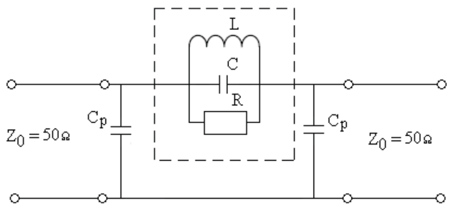
In this paper, we propose a novel ultra-wide stopband LPF using only two quasi-triangular (QT) DGS along with open stubs for rejecting higher harmonics and spurious response in wideband microstrip circuits and systems applications. Its equivalent circuit model is also analyzed and discussed. This type of structure avoids employment of cascaded LPF units and allows achievement of an ultra-wide stopband with very good insertion and return losses in the LPF passband. The simulation results achieved by circuit model and full-wave EM show a good agreement to the measurement ones.

II. DGS-LPF DESIGN CONCEPT AND CIRCUIT MODELING

Figure 1 shows the proposed DGS-LPF with its equivalent circuit model. It is composed of a QT defected areas etched in the ground plane below a 50 Ω microstrip line and H shape open stubs [5]. The filter is designed on a RO4350B Rogers material with a permittivity of the dielectric (εr) of 3.63 and a thickness (h) of 0.254 mm. The conductor strip of the microstrip line (50 Ω) on the top plane has a calculated width w of 0.52 mm.



(a)



(b)

Figure 1. The proposed of DGS-LPF (a) Geometry, and (b) Equivalent circuit model

The physical parameters of this DGS-LPF structure, ℓ_1 = 8.14 mm, ℓ_2 = 5.5 mm, c = 0.24 mm, g = 1, L_S = 6 mm and W_S = 1.3 mm, are considered.

The proposed DGS-LPF can be modelled as one resonator along with two shunt capacitors Cp which correspond to the open stubs as shown in Figure 1.b. The circuit elements are extracted using the following expressions [5]:

$$C = \frac{\omega_0}{2Z_0(\omega_0^2 - \omega_c^2)} \tag{1}$$

$$L = \frac{1}{\omega_0^2 C} \tag{2}$$

$$R = \frac{2Z_0}{\sqrt{\frac{1}{|S_{11}(\omega_0)|^2} - (2Z_0(\omega_0 C - \frac{1}{\omega_0 L}))^2 - 1}} \tag{3}$$

where $\omega_0 (= 2\pi f_0)$ and $\omega_c (= 2\pi f_c)$ are respectively the angular resonant and 3-dB cutoff frequencies of the DGS pattern.

According to the basic theories of transmission lines, an open stub is modeled as an equivalent capacitor. The equivalent capacitance with the characteristic impedance (Z_s) and length (ℓ_s) can be obtained from [6] as:

$$C_p = \frac{1}{\omega Z_s} \tan\left(\frac{2\pi \ell_s}{\lambda_g}\right) \tag{4}$$

where λ_g represents the guided wavelength.

For the assumed circuit model, the parameters L, C, R and C_p are respectively 4.70 nH, 3.89 pF, 3.50 kΩ and 1.09 pF. The structure is investigated using the full-wave EM IE3D simulator. Circuit model and EM simulations results are illustrated in Figure 2 which shows the characteristics of an LPF with 3-dB cutoff frequency (fc) is equal to 3.1 GHz. It can be observed from Figure 2 that the insertion loss is equal to 0.10 dB and the return loss is better than 26 dB in the whole passband. Furthermore, a large suppression band at attenuation level of -20 dB within 06-20 GHz is achieved in the stopband.

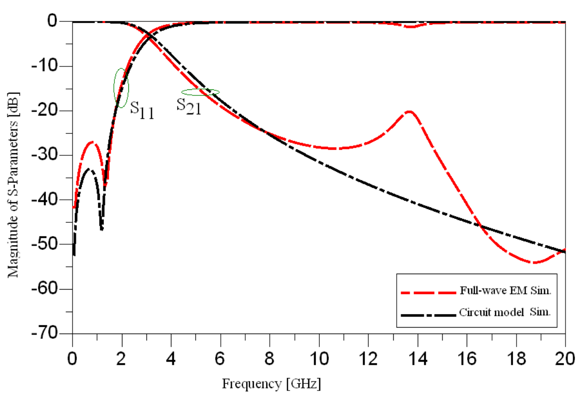
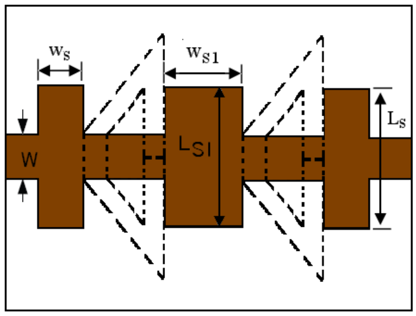


Figure 2. Circuit model and EM-Simulations of the proposed DGS-LPF

III. ULTRA-WIDE STOPBAND LPF DESIGN, CIRCUIT MODELING, IMPLEMENTATION AND MEASUREMENT

The proposed compact ultra-wide stopband LPF is shown in Figure 3. It is composed of two identical QT-DGS units and H- open stubs. This structure avoids employment of LPF units and allows significant enhancement of the characteristics shown in Figure 2 of the considered structure in the previous section.



(a)

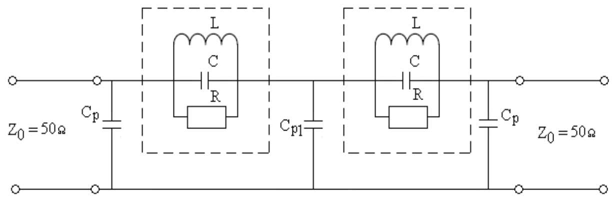


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Figure 3. Proposed ultra-wide stopband DGS-LPF (a) Geometry, and (b) Circuit model

The circuit model and full-wave EM simulations results are shown in Figure 4.

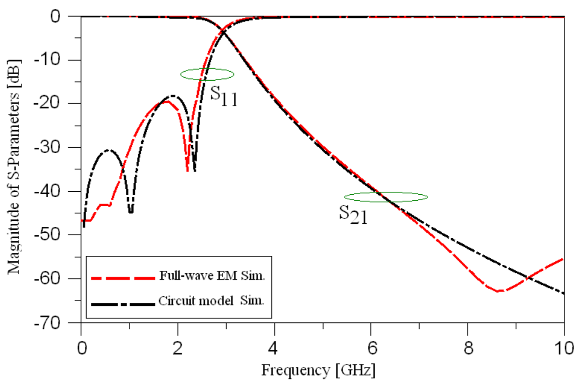

Figure 4. Circuit model and EM-Simulations of the proposed ultra-wide stopband DGS-LPF

From Figure 4, it is clear that the proposed LPF behaves well in both passband and stopband. It is observed from Figure 4 that the LPF has an insertion loss about 0.10 dB and a return loss better than 20 dB in the whole passband. Besides, reasonably good agreement between circuit model and full-wave EM simulations can be seen except some difference appears at more than 7 GHz for insertion loss and at less than 1.5 GHz for return loss. It could be resulted from the simplicity of the lumped circuit model that the distributed effects are not included in this model. This result shows that the circuit model provides quite good performances and confirms its validity.

The proposed LPF with two DGSs in the metallic ground plane and H-open stubs on the top layer with size of 25 x 11 mm^2 is fabricated as shown in Figure 4.

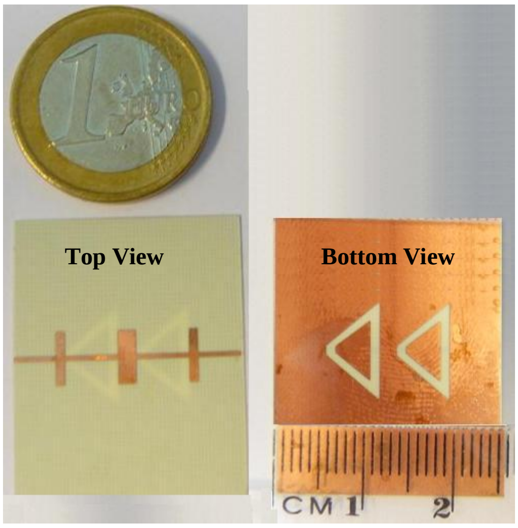

Figure 5. Photography of the proposed ultra-wide stopband DGS-LPF

Figure 6 shows the measured and the simulated results. It is observed from Figure 6 that the measured results agree with the simulated ones. From the measured results, it is seen that the fabricated LPF has an insertion loss lower than 0.1 dB in the filter pass-band and stopband suppression at a level lower than -20 dB from 4 GHz to more than 20 GHz. The small deviations between the simulated and measured results may most probably be caused by the usual connectors and manufacturing errors.

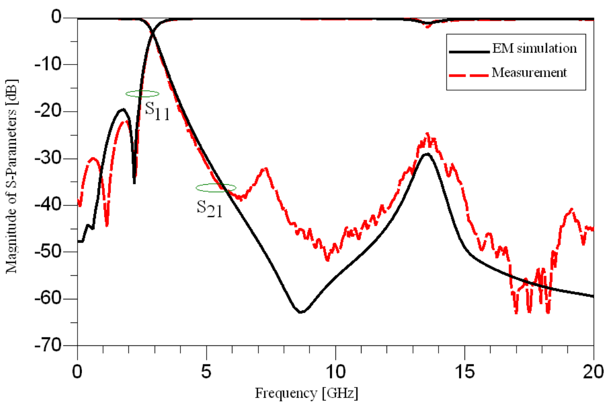

Figure 6. Measured and Simulated S-parameters of the proposed ultra-wide stopband DGS-LPF

The performance of the proposed filter is summarized in Table I with other reported filters for comparison. It can be observed from Table I that the proposed filter provides good performances in stopband rejection and passband insertion loss and smaller in size than those reported in literature.

TABLE I. COMPARISON OF THE PROPOSED DGS-LPF WITH OTHER RELATED LPF

	Substrate dielectric constant/ height (mm)	**Size (mm^2) x X y**	**fc (GHz)**	**Stopband (dB) with -20 dB rejection**	**Passband insertion loss (dB)**	**Passband return loss (dB)**
Ref. [2]	4.4/0.8	21 x 20	03.5	4.3 - 15.8	< 2	-
Ref. [3]	3.38/1.524	71 x 13	02.4	3.26 - 10	< 2.26	> 5
Ref. [4]	4.4/0.8	27 x 23	03.7	3.75 - 20	< 1	-
This work	3.63 / 0.254	25 x 11	3.1	4 - >20	0.1	> 20

IV. CONCLUSION

In this paper, a novel ultra-wide stopband microstrip low-pass filter (LPF) based on defected ground structure (DGS) technique has been introduced and investigated. The proposed LPF provides a low insertion loss of 0.1 dB, a return loss much lower than -20 dB, suppression levels approximately -20 dB from 4 GHz to more than 20 GHz and has small size. It has been shown that the simulations results achieved by circuit model and full-wave EM were in excellent agreement with the measurement ones. The proposed compact and high performance LPF can be broadly used to reject higher harmonics and spurious response for wideband microstrip circuits and systems applications.

ACKNOWLEDGMENT

The authors are grateful to D. Spote and P. Simon technical staff at the Electromagnetics Microwave Communication Laboratory, ICTEAM, UCLouvain.

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