Design of a Novel CPW Filter using Asymmetric DGS

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***Abstract*— Two coplanar waveguide (CPW) low pass filter configurations based on rectangular dumbbell shaped Symmetric-DGS (SDGS) and Asymmetric-DGS (ADGS) have been designed and fabricated. For the designed filters, the equivalent RLC parameters have been extracted. Performance assessment of these filters has been carried out based on various parameters like, cut-off frequency, pass-band width, pass-band insertion loss, attenuation at resonant frequency, etc. The fabricated CPW-ADGS filter shows pass-band width of 0.9 GHz with attenuation at resonant frequency of -23 dB. IE3D simulation results and theoretical results show good agreement with measured results.**

Keywords*— *Asymmetric Defected Ground Structure , Coplanar Waveguide, Microwave filter.

I. Introduction

Filters play an important role in many microwave applications, such as wireless communications and radar systems. In this paper, two filters have been designed using the Coplanar Waveguide (CPW) proposed by C.P. Wen in 1969 [1]. Compared with microstrip structures, the CPW structures are more attractive because it requires only a single metal level and offers greater design flexibility as well as ease of fabrication. In 1987, Yablonovitch and Jhon proposed Photonic Band Gap (PBG) [2] structure (or the term Electromagnetic Band Gap Structure (EBG), usually preferred in the microwave community). PBG/EBG structures are large periodic arrays of defects to prevent the propagation of electromagnetic waves in a certain frequency band. In Defected Ground Structure (DGS) the periodicity is usually not implemented and the structures are based on a single defect (or a few defects) [3]. Apart from filters, DGS has prominent advantages in many other applications such as power dividers / couplers, amplifiers, and so on.

Filters can be implemented with shunt stubs or stepped-impedance lines in a microwave circuit, but these techniques require large circuit layout size and provide a narrow pass-band and spurious pass-bands in stop-band. The low-pass filter using DGS has a number of attractive features like, simple structure, wide and deeper stop-band than that of a conventional low-pass filter, low insertion loss, and easy circuit modeling.

The ref. [4] proposed EBG-CPW filter with double periodicity with T-shaped capacitive load located at periodic positions with strip width modulation. However, it required larger circuit board area and had a limitation in microwave circuit applications. Also, a few more complex EBG structures have been proposed in [5]. Dumbbell shaped DGS was explored first time by D. Ahn and applied to design a low-pass filter on microstrip lines [6]. In [7] CPW filters using square dumbbell DGS are proposed but it generates higher radiation losses.

In this paper, design, analysis and testing of two DGS filters have been carried out using CPW as a transmission line. One is CPW-SDGS (Symmetric DGS) filter, in which rectangular heads (upper and lower) of the dumbbell shaped DGS are symmetric in size. Second is CPW-ADGS (Asymmetric DGS) filter, in which rectangular heads (upper and lower) of the dumbbell shaped DGS are not symmetric in size. This work also explores the performance assessment of the above two types of CPW-DGS filters based on the following parameters: cut-off frequency at -3 dB, resonant frequency, attenuation at resonant frequency, fractional bandwidth at -10 dB, sharpness factor (at lower transition), pass-band width, pass-band insertion loss, RLC equivalent circuit components, quality factor, and percentage radiation losses. The proposed CPW-ADGS filter shows pass-band width of 0.9 GHz with attenuation at resonant frequency of -23 dB.

II. Design of CPW-DGS Filters

Figure 1 and Figure 2 show the layout of CPW-SDGS filter and CPW-ADGS filter respectively. The filter performance has been simulated using IE3D simulation tool. CPW of 50 Ω characteristic impedance has been designed at 2.5 GHz, with a length of 40.2 mm, strip width of w = 6 mm, and gap spacing of s = 0.5 mm. As shown in Figure 1, the rectangular head of the SDGS has dimensions, a = 6 mm, b = 3.92mm, t = 6 mm, g = 2 mm. As shown in Figure 2, the length of the upper rectangular head (‘m’) of the ADGS is designed by increasing 10% of that of SDGS, i.e. ‘m’ is 10 % more than ‘a’ which gives, m = 6.6 mm. And the length of the lower rectangular head (‘n’) of the ADGS is designed by decreasing 10% of that of SDGS, i.e. ‘n’ is 10 % less than ‘a’ which gives, n = 5.4 mm. The rest of the dimensions of ADGS are same as that of SDGS. The total circuit size is 40.2 mm X 36 mm. The substrate material is Arlon, with thickness of 1.6 mm, $\varepsilon_r = 4.5$, tan $\delta = 0.002$.

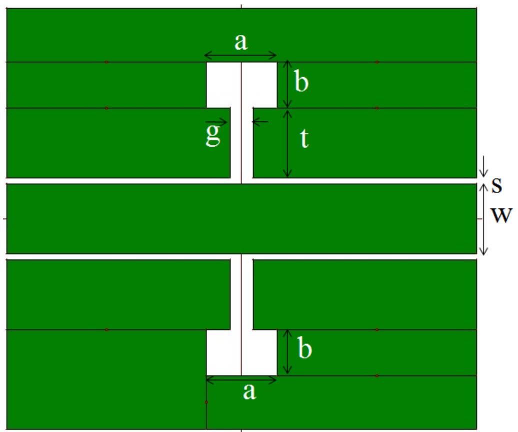

Fig.1 Layout of CPW-SDGS Filter

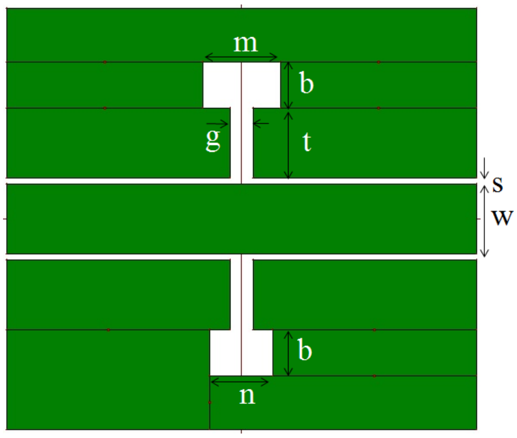

Fig.2 Layout of CPW-ADGS Filter

III. Analysis of CPW-DGS Filters

Figure 3 shows the RLC equivalent circuit model of a DGS unit [8]. It consists of the parallel RLC elements connected in series with the transmission line of electrical length ‘kd / 2’ on both sides. Here, ‘k’ is the propagation constant along the line without DGS and ‘d’ is the physical length of the transmission line used. RLC parameters are calculated based on (1), (2), (3) [9], where, resonant frequency is ‘f_0’, -3dB cut-off frequency is ‘f_c’, and characteristic impedance is ‘Z_0’which is 50 Ω.

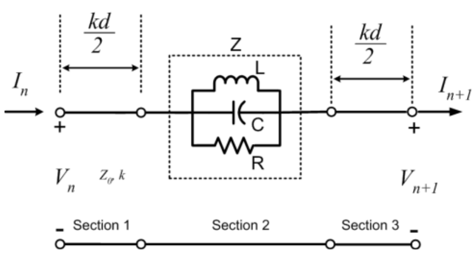

Fig.3 Equivalent RLC Circuit Model of DGS loaded transmission line [8]

$$R = 2Z_0\left(\frac{1}{|S21|} - 1\right) \quad (1)$$

$$C = \frac{\omega_c}{2Z_0}\cdot\frac{1}{\omega_0^2 - \omega_c^2} = \frac{f_c}{200\pi}\cdot\frac{1}{f_0^2 - f_c^2} \quad (2)$$

$$L = \frac{1}{\omega_0^2 C} = \frac{1}{4\pi f_0^2 C} \quad (3)$$

In the RLC circuit model, the lumped capacitance ‘C’ is the gap capacitance, the inductance ‘L’ is related with the extra magnetic flux passing through the apertures on the ground plane, and the radiation effect is explained by resistance ‘R’. The extracted RLC parameters based on EM simulation are shown in the Table 1 below.

TABLE I. Equivalent RLC Circuit Parameters

Filter Type	f_c (GHz)	f_0 (GHz)	Attenuation (α) at f_0 (dB)	R (KΩ)	L (nH)	C (pF)
CPW-SDGS	2.52	3.20	-18.1	0.70	2.37	1.04
CPW-ADGS	2.52	3.19	-24	1.48	2.39	1.03

The ABCD matrix of the unit DGS is given by (4) [10]

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos\frac{kd}{2} & jZ_0\sin\frac{kd}{2} \\ jY_0\sin\frac{kd}{2} & \cos\frac{kd}{2} \end{bmatrix}\begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}\begin{bmatrix} \cos\frac{kd}{2} & jZ_0\sin\frac{kd}{2} \\ jY_0\sin\frac{kd}{2} & \cos\frac{kd}{2} \end{bmatrix}$$

$$= \begin{bmatrix} \cos kd + \frac{jZ}{2Z_0}\sin kd & \frac{Z}{2}\cos kd + jZ_0\sin kd + \frac{Z}{2} \\ \frac{Z}{2Z_0^2}\cos kd + \frac{j}{Z_0}\sin kd - \frac{Z}{2Z_0^2} & \cos kd + \frac{jZ}{2Z_0}\sin kd \end{bmatrix} \quad (4)$$

where, $$Z = \frac{1}{1/R + 1/j\omega L + j\omega C} \quad (5)$$

After calculating ABCD parameters, now it is possible to transform it in terms of scattering parameters, given by (6) and (7) [11]. Since the filter is a reciprocal two port network, S_{ij} will be equal to S_{ji}, where i and j are the ports of the two port network.

$$S_{11} = \frac{A + B/Z_0 - CZ_0 - D}{A + B/Z_0 + CZ_0 + D} \quad (6)$$

$$S_{21} = \frac{2(AD - BC)}{A + B/Z_0 + CZ_0 + D} \quad (7)$$

IV. Results And Disscussion

Figure 4 and Figure 5 show the fabricated CPW-SDGS filter and CPW-ADGS filter (as per the dimensions given in section II) respectively. The measurements were carried out on Vector Network Analyzer. The simulated, theoretical and measured results are shown in Figure 6 and Figure 7, for CPW-SDGS filter and CPW-ADGS filter, respectively.

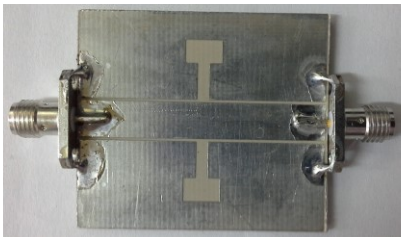

Fig.4 Photograph of fabricated CPW-SDGS Filter

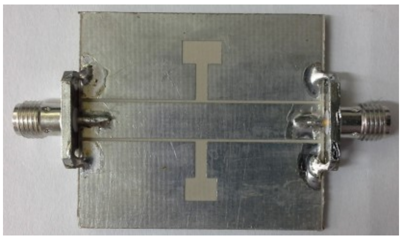

Fig.5 Photograph of fabricated CPW-ADGS Filter

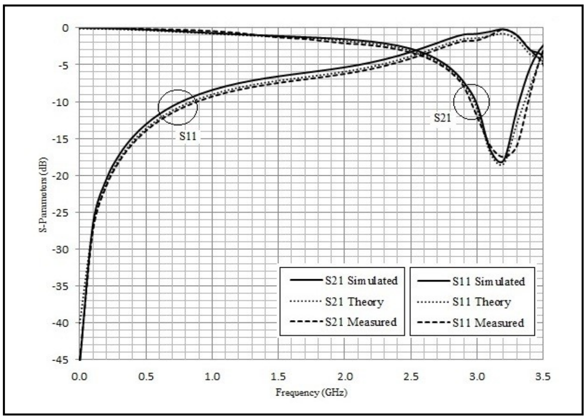

Fig.6 Resulting S-Parameters of CPW-SDGS Filter

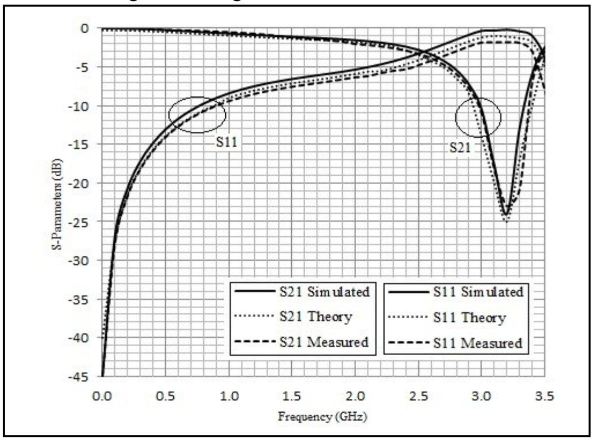

Fig.7 Resulting S-Parameters of CPW-ADGS Filter

The performance assessment has been done based on following parameters: Attenuation (α) at resonant frequency (f_0), Percentage Fractional Bandwidth (%FBW) at -10 dB, Pass-band width at impedance matching, Quality (Q) Factor, Percentage Radiation Loss (% η) of the DGS is given by (8) [12]. Here, Sharpness Factor (SF) at the lower transition is the ratio of differential value of attenuation variation to differential value of corresponding frequency variations, which in turns gives the gradient of the transition in (dB/GHz). The performance assessment of CPW-DGS filter reported in ref. [7] has been done based the S-parameters plot given in it.

Equation no. (8) shows, when R goes to infinity, the radiation losses due to DGS will be zero.

$$\eta = \frac{1}{\frac{R}{4Z_0} + \frac{Z_0}{R} + 1} \quad (8)$$

TABLE II. Performance Assessment

Reference	α at f_0 (dB)	% FBW	SF (dB/ GHz)	PBW (GHz)	Q Factor	% η
[7]	-14	11.67	5.78	0.76	5.14	31.9
This Work CPW-SDGS	-17.5	13.1	19.33	0.9	11.48	23.1
This Work CPW-ADGS	-23	12.18	25.64	0.9	23.18	13.1

As per the performance evaluation shown in Table 2, more attenuation (α) at the resonance frequency can be achieved if the square headed dumbbell DGS (as reported in ref. [7]), is replaced by rectangular headed dumbbell DGS. Maximum attenuation of -23 dB is provided by CPW-ADGS filter. Wide %FBW (at -10 dB) is offered by CPW-SDGS filter at good impedance matching. Highest sharpness factor (at lower transition) of 25.64 dB / GHz is given by CPW-ADGS filter than the other two cases. Proposed CPW-ADGS filter shows least radiation losses of 13.15 % compared to other two cases. Both the proposed filters gives more pass-band width (0.9 GHz) than that of the filter reported in ref. [7].

V. Conclusion

Two configurations of CPW-DGS filters have been designed, analyzed and fabricated. A novel CPW-ADGS filter has been proposed in this paper as an alternative to conventional low-pass filter with improved performance. This CPW-ADGS filter has been designed just by a slight variation (only 10%) in the lengths of the rectangular heads of CPW-SDGS filter. The performance of these two proposed filters has been compared and found better than the earlier reported work. The measured filter response on fabricated DGS filter shows good agreement with the simulated and theoretically calculated response.

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REFERENCES

[1] C. P. Wen, "Coplanar waveguide: a surface strip transmission line suitable for nonreciprocal gyro-magnetic device applications," IEEE Transaction on Microwave Theory and Techniques, vol. 17, no.12, pp. 1087-1090, December 1969.

[2] E. Yablonovitch, " Photonic band-gap structures," J. Opt. Soc.Amer. B, Opt. Phys., vol. 10. pp. 283-295, Feb.1993.

[3] K. C. Gupta, Microstrip lines and Slotlines, 3rd ed., Artech House Microwave Library, 2015.

[4] F. Martine, F.Falcone, J. Bonache, T. Lopetegi, M.A.G.Laso, and M. Sorolla, "Dual electromagnetic band-gap cpw structures for filter applications," IEEE Microwave Wireless Components Lett., vol 13,pp 393-395, September 2003.

[5] Yongzhuo Zoul, Xin Hu, Sailing He ,Zhili Lin , "Compact coplanar waveguide lowpass filter using a novel electromagnetic bandgap structure," Proc. International Symposium on Antennas Propagation & EM Theory,Guilin, Oct. 2006, pp 1-4.

[6] D. Ahn, Park, J.-S. Park, C.-S. Kim, J. Kim, Y. Qian, T. Itoh, " A design of the low-pass filter using the novel microstrip defected ground structure," IEEE Transaction on Microwave Theory and Techniques,vol.49, no. 1, pp. 86-93, Jan. 2001.

[7] Xiaoming Li, "Asymmetric Coplanar Waveguide Filter with Defected Ground Structure," Proc. General Assembly and Scientific Symposium (URSI GASS), Beijing, XXXIth URSI, August 2014.

[8] Insik Chang and Bomson Lee, "Design of Defected Ground Structures for Harmonic Control of Active Microstrip Antenna," Proc. Antenna and Propagation on Society International Symposium , June 2002, pp. 852 - 855.

[9] Shui-Yang Lin, Wei-Zhong Tian, Shu-Qi Zheng, Xiao-Wei Sun, "A Semicircle DGS With High Q Factor for Microstrip Line and Low-Pass Filter", Proc. of Asia-Pacific Microwave Conference, Dec. 2006, pp. 1197-1199.

[10] Robert E. Collin, Foundations for Microwave Engineering, 2nd ed., Mc Graw-Hill, N.Y.,1992.

[11] David M. Pozar, Microwave Engineering, 3rd ed.,Daryaganj, New Delhi, India: Wiley, 2010.

[12] Hyung-Mi Kim, and Bomson Lee, "Bandgap and slow/fast-wave characteristics of defected ground structures including left-handed features', IEEE Transaction on Microwave Theory And Techniques, vol. 54, no.7, pp.3113-3120, July 2006.