Comparative Study of Three Shapes of DGS Pattern and Design of Compact Microstrip Low-Pass and Band-Pass Filters

MOULOUD CHALLAL^[1, 2], FREDERICK LABU^[1], MOKRANE DEHMAS^[1] and ARAB AZRAR^[1]

^[1] Department of Electronic, Institute of Electrical Engineers and Electronics University of Boumerdes Avenue de l'indépendance ALGERIA mchallal@gmail.com

> ^[2] Electrical Engineering, ICTEAM, Université catholique de Louvain Louvain-la-Neuve, Belgium BELGIUM mouloud.challal@uclouvain.be

Abstract: - In this paper, three types of defected ground structure (DGS) units which are triangular-head (TH), rectangular-head (RH) and U-shape (US) are investigated and their characteristics are compared each other. Further, they are used in the design of low-pass filters (LPF) and band-pass filters (BPF) and the obtained performances are examined. The LPF employing RS-DGS geometry presents the advantages of compact size, low-insertion loss and wide stopband compared to the other filters. It provides a cutoff frequency at 2.5 GHz, a largest rejection band width of 20 dB from 2.98 to 8.76 GHz, a smallest transition region and a smallest sharpness response at the cutoff frequency. The BPF based on RS-DGS has the highest bandwidth (BW) of about 0.74 GHz and the lowest center frequency of 3.24 GHz whereas the other BPFs have BWs less than 0.7 GHz.

Key-Words: - Defected ground structure (DGS), low-pass filter (LPF) and band-pass filter (BPF).

1 Introduction

COMPACT size, low cost, and high performance are always a prerequisite in most of modern communication systems in general and in RF/Microwave filters in particular. These filters can be designed by lumped and/or distributed elements for a particular application. In the quest to better filter performances to match the above demands, there has been an introduction of electromagnetic band gap (EBG) also known as photonic band gap (PBG) and the defected ground structures (DGS). These structures are used in the design of microwave filters and offer a rejection of undesired frequency bands and a reduction in bulky microwave circuit sizes [1]-[6].

Recently, there has been an increasing interest in the using of DGS for performance improvement of microstrip filters [4]-[13] and other variety of microstrip circuits [14]-[20]. However, there is no a detailed study on the different structures.

In this paper, we present three types of DGS units which are triangular-head (TH), rectangular-head (RH) and U-shape (US) and their characteristics are compared each other. Further, these DGS units are employed in the design of low-pass filters (LPF) and (BPF) and the obtained band-pass filters each are performances of examined. The simulations are carried out using the full-wave EM IE3D simulator and all prototypes are designed on substrate material with thickness of 0.25 mm, conductor layers of 35 µm and a relative permittivity is taken of 3.63.

This paper is organized as follows. The following section describes the comparison of three DGS units. In Section 3, LPFs based on the above DGS units are designed and their characteristics are analyzed to determine which one offers the best filter specifications. In Section 4, BPFs based on the three DGSs with a discontinuity in the 50 Ω microstrip line are designed and analyzed. Finally, conclusions are drawn in Section 5.



Fig. 1 Considered DGSs (a) Triangular head, (b) Rectangular head and (c) U-shape

2 Comparison of Defected ground structure patterns

A variety of DGS shapes for filters applications has been presented in literature such as dumbbell shaped DGS [1]-[2], semicircle shaped DGS [4], E-shaped DFS [10], U and V shaped DGS [11] and so on. Three different DGS units are considered in this paper as shown in Fig. 1. They are placed on the ground plane of 50 Ω microstrip line of width 0.52 mm.

In order to compare their characteristics, the simulated S-parameters of the three DGS units are compared having the same cutoff frequency. Their dimensions are summarized in Table I.

 TABLE I

 DIMENSIONS OF THE THREE SHAPED DGS UNITS IN MM

Triangle-head (TH) DGS	Rectangular-head (RH) DGS	U-shape (US) DGS
$L_T = 8$	a _R =3	L _U =9
g _T =0.2	g _H =0.2	g _U =0.2
$d_T=4$	$d_{\rm H}=6$	$d_U=2$
_	b _H =6	$S_U=2$

The simulated S-parameters of S_{21} and S_{11} for the three DGS units are plotted as a function of frequency and are shown in Fig. 2.



Fig. 2 Magnitude of the transfer function (S_{21}) and input reflection coefficient (S_{11}) of different types of DGS having the same cutoff frequency

DGS configuration/characteristics	TH-DGS	RH-DGS	US-DGS
f_c [GHz]	2.70	2.72	2.69
f_0 [GHz]	5.40	4.80	4.99
<i>C</i> [pF]	0.19	0.27	0.24
L [nH]	4.42	7.94	4.19
S_{21max} [dB]	- 26.88	- 24.84	- 34.50
SF	2.00	1.76	1.85
BW_{20dB} [GHz]	0.61	0.43	0.60
ζ	7.13	8.84	8.56
f_{20dB} – f_{3dB} [GHz]	2.38	1.92	1.98

 TABLE II

 COMPARISON OF THE CHARACTERISTICS OF DGS UNITS

The Sharpness factor (SF) and the selectivity can be expressed as follows [5]-[7]:

$$SF = \frac{f_c}{f_0} \tag{1}$$

$$\xi = \frac{\alpha_{20dB} - \alpha_{3dB}}{f_{20dB} - f_c} \tag{2}$$

where f_0 , f_c , f_{20dB} , α_{20dB} and α_{3dB} are the attenuation pole frequency, the cutoff frequency, the 20-dB stopband frequency, the attenuation point at 20-dB and the attenuation point at 3-dB respectively.

To evaluate the performances of the three types of DGS, a comparison study of their properties obtained from Fig 2 and by equations (1) and (2) is carried out. Moreover, the extracted circuit parameters are also calculated by means of inserting of f_0 and f_c into equations in [1]-[3] yield values of C and L.

The achieved results for the three types of DGSs are summarized in Table II. The parameters under study are cutoff frequency, attenuation pole frequency, sharpness factor, selectivity, maximum attenuation (S_{21max}) and transition regions $(f_{20dB} - f_{3dB})$.

As seen in Table II, the attenuation pole frequency f0 of the RH-DGS unit is smaller than that of the other two DGS units, while the cutoff frequency fc varies very slightly. Furthermore, a RH-DGS unit has sharpness factor of 1.76, whereas for the other types of DGS the SF is more greater than 1.8.

A higher value of SF shows wider transition region from the passband to the stopband as confirmed by f20dB –f3dB in Table II. Accordingly, a LPF based on the RH-DGS can provide sharper fc with narrower transition region.

3 Compact microstrip LPF design using DGS pattern







To improve the rejection band shown in Fig. 2, more DGS units should be used so a LPF is achieved by cascading at least two DGS units on the ground plane as shown in Fig. 3. Besides, on the top plane of the substrate a compensated microstrip line [2] with 25 Ω impedance (i.e, w = 1.4 mm) is added to enhance the filter performances.

In order to get the best LPF performance, we placed two DGS units at different distance (D) apart and we compared the results obtained. Fig. 4, 5 and 6 show respectively the simulated S-parameters S_{21} and S_{11} of the TH-DGS LPF, RH-DGS LPF and US-DGS LPF for different D.



Fig. 4 Magnitude of the transfer function (S $_{21}$) and input reflection coefficient (S $_{11}$) of the TH-DGS LPF for different D



Fig. 5 Magnitude of the transfer function (S_{21}) and input reflection coefficient (S_{11}) of the RH-DGS LPF for different D



Fig. 6 Magnitude of the transfer function (S $_{21}$) and input reflection coefficient (S $_{11}$) of the US-DGS LPF for different D

TABLE III
SUMMARY OF THE TH-DGS LPF CHARACTERISTICS FOR DIFFERENT D

Characteristics/Distance 'D'	D = 0.3 mm	D = 0.4 mm	D = 0.5 mm	D = 0.6 mm
f_c [GHz]	2.62	2.62	2.61	2.62
$f_{ heta}$ [GHz]	3.80	3.79	3.795	3.795
$S_{21max}[dB]$	-33.00	-33.62	-32.88	-31.85
Return Loss [dB]	-18.44	-18.26	-18.32	-18.42
Insertion Loss [dB]	-0.10	-0.10	-0.10	-0.10
BW _{20dB} [GHz]	4.47	4.52	4.40	4.42
f_{20dB} – f_{3dB} [GHz]	0.88	0.84	0.867	0.79

TABLE IV

SUMMARY OF THE RH-DGS LPF CHARACTERISTICS FOR DIFFERENT D

Characteristics/Distance 'D'	D = 0.4 mm	D = 0.5 mm	D = 0.6 mm	D = 0.7 mm
f_c [GHz]	2.47	2.503	2.50	2.52
$f_0 [m GHz]$	3.02	3.19	3.17	3.18
S_{21max} [dB]	-28.86	-28.69	-32.39	-36.11
Return Loss [dB]	-20.01	-20.05	-20.06	-20.02
Insertion Loss [dB]	-0.10	-0.10	-0.10	-0.10
BW_{20dB} [GHz]	5.57	5.63	5.87	5.70
<i>f</i> _{20dB} – <i>f</i> _{3dB} [GHz]	0.42	0.43	0.48	0.49

Characteristics/Distance 'D'	D = 0.4 mm	D = 0.6 mm	D = 0.8 mm	D = 1.0 mm
f_c [GHz]	1.62	1.635	1.64	1.64
$f_0 [{ m GHz}]$	3.2	3.93	3.4	3.6
S _{21max} [dB]	-56.17	-45.25	-44.69	-51.29
Return Loss [dB]	-18.55	-18.45	-18.19	-18.37
Insertion Loss [dB]	-0.10	-0.10	-0.10	-0.10
BW _{20dB} [GHz]	2.20	2.45	2.52	2.88
f_{20dB} – f_{3dB} [GHz]	0.95	1.01	1.07	1.11

TABLE V SUMMARY OF THE US-DGS LPF CHARACTERISTICS FOR DIFFERENT D

Tables III, IV and V summarize the LPF performances for different value of D for the TH-DGS LPF, RH-DGS LPF and US-DGS LPF respectively.

From Table III, it can be seen that for a distance D of 0.4 mm, a widest rejection band has been obtained as compared to the other distance D. Moreover, by increasing the DGS units, the designed TH-DGS LPF provides an attenuation pole at 3.79 GHz with a magnitude of -33.62 dB while the insertion loss is as low as 0.1 dB in the passband. The obtained response is sharper and wide out-band rejection is achieved below -20 dB from 3.46 to 7.98 GHz due to the resonance characteristics of the TH-DGS and the compensated line. This shows excellent performances than the conventional filters based on high-low impedances [2] that show worse results in both insertion loss in the pass-band and rejection of the undesirable harmonics in the stop band.

From Table IV, the best distance between the two RH-DGS is D = 0.6 mm because of the widest rejection band (5.87 GHz) obtained as compared to other distance D.

The designed RH-DGS LPF (D of 0.6 mm) provides an attenuation pole of 3.17 GHz which is achieved at -32.39 dB while its insertion loss is as low as 0.1 dB. Additionally, the cutoff frequency response is at 2.50 GHz and the return loss keeps below -20 dB. The achieved out-band rejection characteristic below -20 dB is from 2.98 to 8.77 GHz due to the resonance characteristics of the RH-DGS and the compensated line. According to results obtained and depicted in Table V, the distance D between the US-DGS selected is 1 mm due to the widest rejection band (2.88 GHz) obtained as compared to other distance D. The cutoff frequency of the US-DGS LPF is 1.64 GHz, the filter has attenuation pole of -51.29 dB achieved at 3.2 GHz with an insertion loss of 0.1 dB and the return loss keeps below -18 dB. Besides, the outband rejection characteristic below -20 dB is from 2.75 to 5.24GHz.

From Table III to Table V, it is seen that a LPF based on RH-DGS offers the widest rejection band of 5.87 GHz from 2.98 to 8.76, the smallest transition region of 0.48 and the smallest sharpness of the cutoff. As conclusion, it is clearly that a RH-DGS LPF has the best filter characteristics compared to the other types of LPF based on TH-DGS and US-DGS.

4 Compact microstrip BPF design using DGS pattern

In order to design a compact microstrip BPF, a discontinuity is created on the microstrip feed at the top layer of the substrate by making a gap as compared to a continuous feed line of the LPF.

Fig. 7 (a-c) shows the BPFs geometries using two DGS units with a gap on the microstrip line. The two DGS units are placed at distance of 0.2 mm apart and the gap created in the microstrip line has a space of 0.4 mm. The obtained simulations results are shown in Fig. 8 (a-c) respectively.









Fig. 8 Magnitude of S_{21} and S_{11} of the three types of DGS BPF. (a) TH-DGS BPF, (b) RH-DGS BPF, and (c) US-DGS BPF

COMPARISON OF DGS BPF CHARACTERISTICS				
Characteristics/DGS BPFs	TH-DGS BPF	RH-DGS BPF	US-DGS BPF	
Center frequency [GHz]	4.07	3.24	4.98	
Return Loss [dB]	- 8.23	- 26.56	- 9.63	
Insertion Loss [dB]	- 2.10	- 0.5	- 1.60	
3-dB Bandwidth [GHz]	0.52	0.74	0.38	

 TABLE VI

 COMPARISON OF DGS BPF CHARACTERISTICS

From Fig. 8.a, it can be seen that the TH-DGS BPF has a center frequency around 4.07 GHz, a 3-dB bandwidth about 0.52 GHz, a return loss of - 8.23 dB and an insertion loss of - 2.10 dB where as in Fig. 8.b, the RH-DGS BPF has a center frequency around 3.24 GHz, a 3-dB bandwidth about 0.74 GHz, a return loss of -26.56 dB and an insertion loss of - 0.60 dB. Moreover, from Fig. 8.c, it can be observed that the US-DGS BPF has a centre frequency around 4.98 GHz, a 3-dB bandwidth about 0.38 GHz, a return loss of -9.63 dB and an insertion loss of - 1.8 dB.

The obtained characteristics of the three BPF are summarized in Table VI. From Table IV, it is seen that a BPF based on RH-DGS has the best characteristic compared to the other types of DGS BPFs.

5 Conclusion

A comparative study of characteristic performances of three types of DGSs having a same cutoff frequency is elaborated. Further, three LPFs based on the considered DGSs along with compensated microstrip line have been designed and analyzed. The performances of the LPFs were compared to determine the best filter specifications. It has been observed that an LPF using RH-DGS geometry along with compensated microstrip line presents compact size, low-insertion loss and wide stopband compared to the two other LPFs. It provides cutoff frequency of 2.5 GHz, largest rejection bandwidth of 20 dB from 2.98 to 8.76 GHz, smallest transition region and cut-off frequency sharpness. Furthermore, three types of BPF based on the considered DGSs along with a gap created on the microstrip feed line (50 Ω) have been designed and analyzed. Afterward, a comparative study on the performances of the designed BPFs has been performed. It has been noticed that a BPF using RH-DGS BPF shows the highest bandwidth of 0.74 GHz, the highest attenuation and the smallest center frequency compared to the two other DGS BPFs.

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