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Comparative Study of Three DGS Unit Shapes and Compact Microstrip Low-Pass and Band-Pass Filters Designs

M. Challal, F. Labu, M. Dehmas and A. Azrar

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. They are further used to low-pass and band-pass filters designs (LPF and BPF) and the obtained performances are examined. The LPF employing RH-DGS geometry presents the advantages of compact size, low-insertion loss and wide stopband compared to the other filters. It provides cutoff frequency of 2.5 GHz, largest rejection band width of 20 dB from 2.98 to 8.76 GHz, smallest transition region and smallest sharpness of the cutoff frequency. The BPF based on RH-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.

Keywords**—**Defected ground structure (DGS), triangular-head (TH) DGS, rectangular-head (RH) DGS, U-shape (US) DGS, low-pass filter (LPF) and band-pass filter (BPF).

I. Introduction

COMPACT size, low cost, and high performance are basic prerequisites for modern communication systems in general and RF/Microwave filters in particular. These filters can be designed using lumped and/or distributed elements for particular applications. 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 defected ground structures (DGS). These structures are used in design of microwave filters and offer undesired frequency bands rejection and size reduction of bulky microwave circuits [1].

Recently, an increasing interest is directed towards DGS for performance improvement of microstrip filters [2]-[6] and other variety of microstrip circuits [7]-[9]. However, to the best of our knowledge, no detailed study of such structures has been performed.

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In this paper, we present three DGS unit shapes which are triangular-head (TH), rectangular-head (RH) and U-shape (US) and their characteristics are compared. Further, these units are employed in low-pass and band-pass filters designs and the obtained performances are 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 layer of 35 μm and a relative permittivity of 3.63.

The following section of this paper describes the comparison of three DGS units. In Section III, LPFs based on the above DGS units are designed and their characteristics are investigated to determine which one offers the best filter specifications. In Section IV, BPFs based on the DGSs with a discontinuity in the 50 Ω (characteristic impedance) microstrip line are designed and analyzed. Finally, conclusions are drawn in Section V.

II. DGS units Comparison

The considered DGS units are illustrated in Fig. 1. They are located on the ground plane of a 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.

Fig. 2 shows the simulated parameters S_{21} and S_{11} versus frequency.

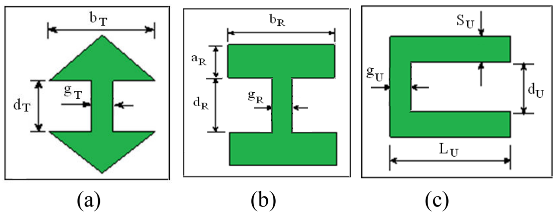

Fig. 1 Considered DGSs : (a) Triangular head, (b) Rectangular head and, (c) U-shape

The sharpness factor (SF) and the selectivity are expressed as follows [2]-[4]:

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

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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_H=6	d_U=2
-	b_H=6	S_U=2

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

where f_0, f_c, f_{20dB}, α_{20dB} and α_{3dB} denote respectively 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.

To evaluate the DGS units' performances, a comparative study of their properties obtained from Fig 2 and equations (1) and (2) is carried out. Moreover, the extracted circuit parameters are also calculated by inserting f_0 and f_c into equations in [1] to get values of C and L.

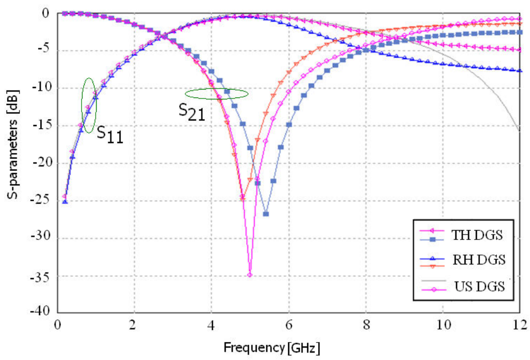

Fig. 2 Magnitude of the transfer function (S_{21}) and input reflection coefficient (S_{11}) of different types of DGS having the same cutoff frequency

The obtained results 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 f_0 of the RH-DGS unit is smaller than that of the other two DGS units, while the cutoff frequency f_c varies very slightly. Furthermore, the RH-DGS unit has a sharpness factor of 1.76, whereas for the other shapes the *SF* is much greater than 1.8. A higher value of *SF* shows wider transition region from the pass band to the stop band as confirmed by f_{20dB} –f_{3dB} in Table II. Accordingly, a LPF based on the RH-DGS can provide sharper f_c with narrower transition region.

TABLE II
COMPARISON OF THE CHARACTERISTICS OF DGS UNITS

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
C [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
ξ	7.13	8.84	8.56
f_{20dB} –f_{3dB} [GHz]	2.38	1.92	1.98

III. COMPACT MICROSTRIP LPF DESIGN USING DGS UNITS

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 [5] with a characteristic impedance of 25 Ω (i.e, w = 1.4 mm) is added to enhance the filter performances.

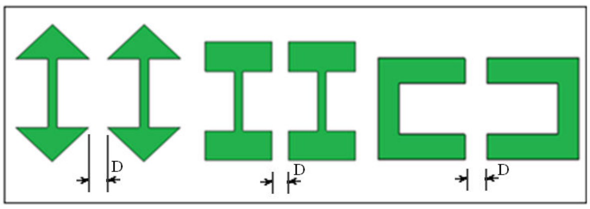

Fig. 3 Two DGS units placed at a distance (D) apart

Furthermore, for best LPF characteristics, two DGS units placed at different distance (D) apart are used and the obtained results are compared. Fig. 4, 5 and 6 show respectively the simulated parameters S_{21} and S_{11} of the TH-DGS LPF, RH-DGS LPF and US-DGS LPF with different D.

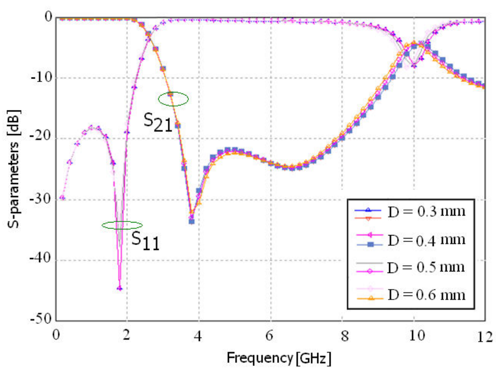

Fig. 4 Magnitudes of the transfer function (S_{21}) and input reflection coefficient (S_{11}) of the TH-DGS LPF for different D

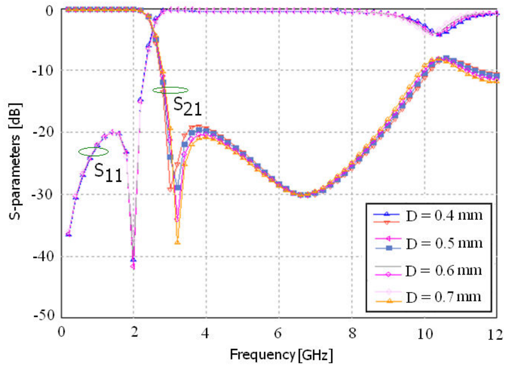

Fig. 5 Magnitudes of the transfer function (S_{21}) and input reflection coefficient (S_{11}) of the RH-DGS LPF for different D

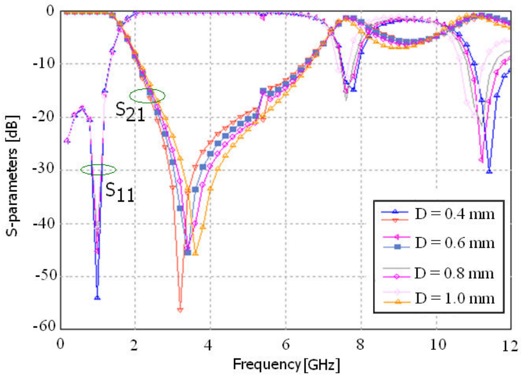

Fig. 6 Magnitudes of the transfer function (S_{21}) and input reflection coefficient (S_{11}) of the US-DGS LPF for different D

Tables III, IV and V summarize the performances of the considered LPF structures for different distances D.

It can be seen from Table III that a distance D of 0.4 mm provides a widest rejection band. Moreover, by increasing the number of a DGS unit, the designed TH-DGS LPF provides an attenuation pole frequency of 3.79 GHz with a magnitude of -33.62 dB while the insertion loss is as low as 0.1 dB in the pass-band. The obtained response is sharper and a 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 compared to the conventional filters based on high/low impedances [5] that show worse results in both insertion loss in the pass-band and, rejection of the undesirable harmonics in the stop band.

Table IV shows that the optimal distance between the two RH-DGS is D = 0.6 mm because of the widest rejection band.

The designed RH-DGS LPF (D = 0.6 mm) provides an attenuation pole frequency at 3.17 GHz with S_{21} of –32.39 dB while, the 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 the results shown in table V, the selected distance D between the US-DGS is 1 mm due to the widest rejection band (2.88 GHz) obtained as compared to other distance D. The US-DGS LPF cutoff frequency is 1.64 GHz, the filter presents an attenuation pole frequency of -51.29 dB achieved at 3.2 GHz with an insertion loss of 0.1 dB and a return loss below -18 dB. Besides this, an out-band rejection characteristic below -20 dB is achieved from 2.75 to 5.24GHz.

From Tables III to Table V, it can be observed that the LPF based on RH-DGS offers the widest rejection band of 5.87 GHz extending from 2.98 to 8.76, the smallest transition region of 0.48 and, the smallest cutoff sharpness. As conclusion, it is clear that an RH-DGS LPF exhibits the best characteristics compared to those based on TH-DGS and US-DGS.

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_0 [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 [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
$f_{20dB} - f_{3dB}$ [GHz]	0.42	0.43	0.48	0.49

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

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 [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

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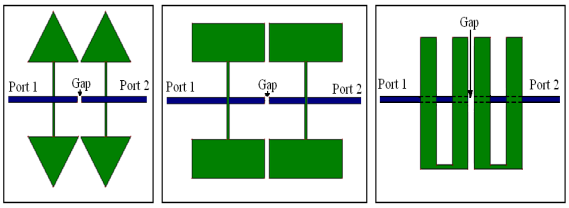
IV. Compact Microstrip BPF Design Using DGS Units

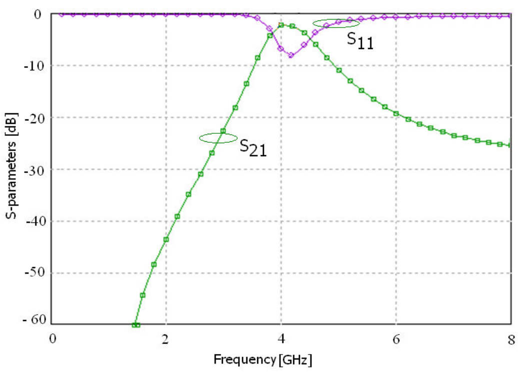
In order to design a compact microstrip BPF, a discontinuity is created on the microstrip feed at the substrate top layer by making a gap as compared to a continuous feed line of the LPF.

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

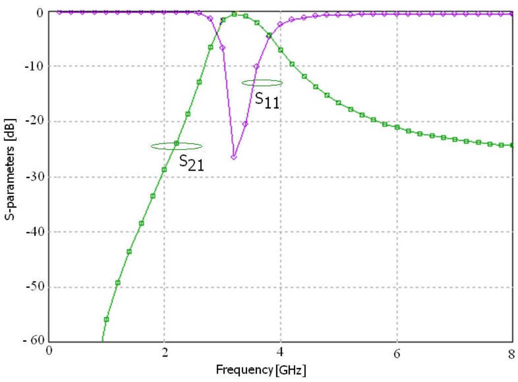


(a) (b) (c)

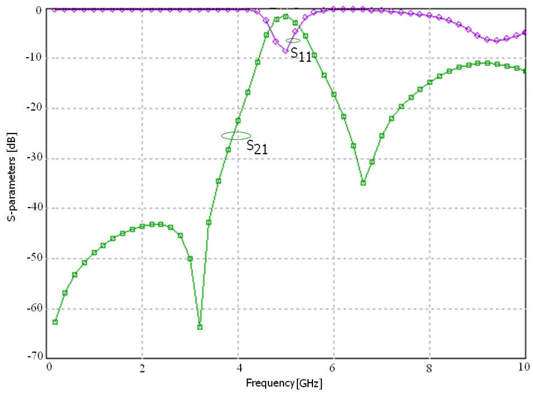
Fig. 7 BPFs geometries based on two DGS units with a gap on the microstrip line. (a) TH-DGS BPF, (b) RH-DGS BPF and, (c) US-DGS BPF



(a)



(b)



(c)

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

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

The obtained BPF characteristics are summarized in Table VI where it is seen that a BPF based on RH-DGS exhibits best characteristic compared to the other DGS BPFs types.

TABLE VI
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

V. 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 LPFs performances 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 a cutoff frequency at 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 BPF configurations based on the considered DGSs along with a gap created on the 50 Ω microstrip feed line have been designed and analyzed. Afterward, a comparative study of the designed BPFs performances 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 other two DGS BPFs.

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