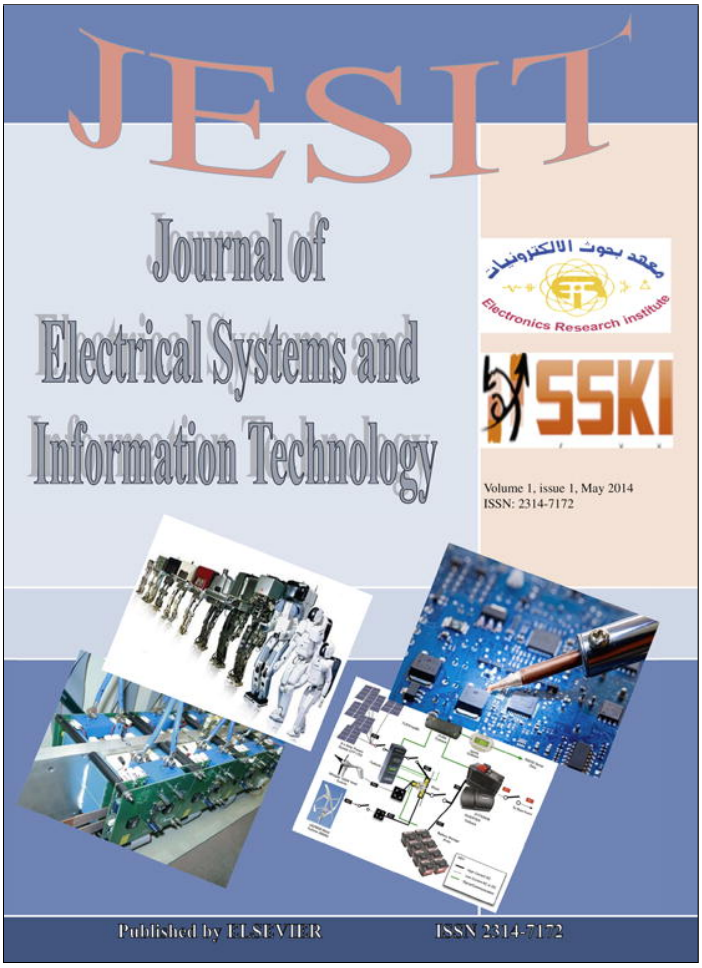
JESIT
Journal of
Electrical Systems and
Information Technology
Electronics Research institute
SSKI
Volume 1, issue 1, May 2014
ISSN: 2314-7172
Published by ELSEVIER
ISSN 2314-7172

Available online at www.sciencedirect.com

ScienceDirect

Journal of Electrical Systems and Information Technology 1 (2014) 36–44

www.elsevier.com/locate/jesit

A compact ultra wideband bandpass filter using arrow coupled lines with defected ground structure

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Available online 12 March 2014

Abstract

A new ultra wideband bandpass filter (UWB-BPF) using arrow coupled lines and U-slot defected ground structures (U-DGS) is proposed. The input and output feeding lines are connected to the coupled lines placed on the conductor side of the substrate while the U-slot DGS was etched from the ground side below. The effect of U-DGS slot dimensions on the operating bandpass of the filter was studied. The filter was simulated using both IE3D and HFSS simulators. The simulation results are in good agreement with the realized filter. The filter operating passband extended over the UWB frequency 3.0–9.5 GHz while the group delay variation in the passband is in the range of 0.5°.

Keywords: Compact; Ultra wideband; Bandpass filter; Defected ground Structure; Coupled lines; Arrows

1. Introduction

UWB technology with operating band (3.1–10.6 GHz) is an attractive technology for local area networks, positioning and tracking, and radar systems (Federal Communications Commission, 2002). It has the characteristics of low cost, low weight, high data transmission rate and very low power consumption. The UWB filters are important elements in many RF microwave applications where they are used to separate or combine different frequencies (Hong and Lancaster, 2001; Kuo and Shih, 2002). Radio frequency (RF) microwave filters can be designed as lumped element or distributed element circuits. The filters may be realized in various transmission line structures, such as waveguide, coaxial line, and microstrip. The recent advances of materials and fabrication technologies have stimulated the rapid development in filters. In the meantime, advances in computer-aided design (CAD) tools such as full-wave electromagnetic (EM) simulators have revolutionized filter design.

A planar bandpass filter based on a microstrip structure is widely used in a variety of RF microwave and millimeter wave systems to transmit energy in the passband and to attenuate energy in one or more stopbands. To achieve a

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Peer review under responsibility of Electronics Research Institute (ERI).

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http://dx.doi.org/10.1016/j.jesit.2014.03.001

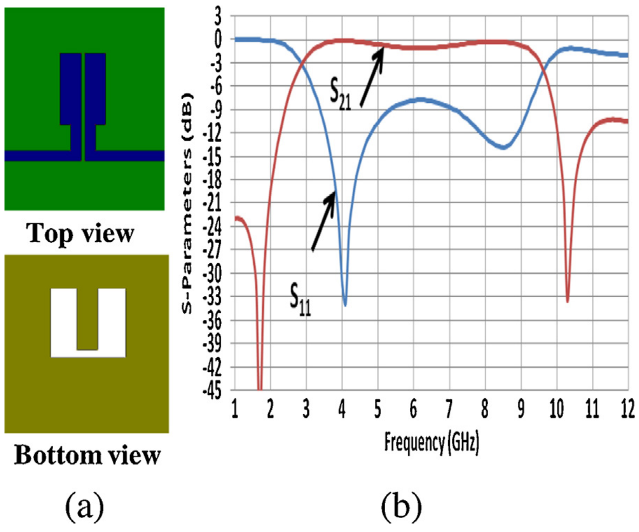

Fig. 1. (a) UWB-BPF with regular coupled lines and U-slot DGS. (b) Simulation results.

bandpass filter with a passband covering the UWB range, a fractional bandwidth of 110% is needed for the filter designs. In 2003, a bandpass filter with bandwidth that extended from 40% to 70% (Saito et al., 2003) was achieved and this filter was called broad bandpass filter. A bandpass filter covering the whole UWB frequency range was realized by fabricating conductor lines on a lossy composite substrate (Saito et al., 2003). In 2004, a ring resonator with a stub was proposed which shows a bandwidth of 86.6% (Ishida and Araki, 2004). In 2005, several articles were published to realize the UWB-BPF which were constructed from different structures such as microstrip multi-mode resonators (MMR) and a parallel coupled lines (Zhu et al., 2005), or hybrid coplanar waveguide (CPW) multi-mode resonators (MMR) on one side of the substrate materials and microstrip input and output on the other side (Wang and Zhu, 2005). Moreover, a broadside-coupled microstrip line on one side of the substrate and an open-end CPW on the other side (Li et al., 2005), or a combination of a highpass filter and a lowpass filter (Hsu et al., 2005). Recently, more articles, discussing the realization of UWB-BPF using different configurations, were reported (Tang et al., 2005; Sun and Zhu, 2006; Shaman and Hong, 2007; Chu and Tian, 2010; Tahanian et al., 2010; Hao and Hong, 2011; Abbosh et al., 2011).

In this paper, an UWB-BPF that consists of a two arrow shaped coupled microstrip lines on one side of the substrate and a modified U-shaped defected ground structure (DGS) on the other side is presented. The current design is of a compact size compared to other designs available in literature.

The proposed filter is simulated using both IE3D and HFSS simulators. The simulation results are in good agreement with the realized filter. The filter operating passband covers the frequency range 3.0–9.5 GHz while the group delay variation in the passband does not exceed 1.0°.

2. Design and simulation of the UWB-BPF

The design started with a conventional coupled microstrip lines on the top side and U-slot in the bottom side of the substrate material, Fig. 1a. Using IE3D (http://www.zeland.com/) simulator, the obtained results yielded a passband characteristic ($S_{11} < -8$ dB), Fig. 1b. The two rejection bands (lower and upper) showed good performance with lower cutoff frequency of 2.8 GHz and upper cutoff frequency of 9.6 GHz. By inclining the arms of the U-slot DGS outwardly, and changing the shape of the coupled lines into two arrows, instead of the regular shape, the upper cutoff frequency is extended to 11.8 GHz with a little shift in the lower cutoff frequency to be 3.0 GHz, Fig. 2. However, the passband performance suffers from low return loss ($S_{11} < -6$ dB). The defected ground U-slot has three degrees of freedom; each of which has different effect on the UWB-BPF performance and will be described in the following sections.

2.1. *Effect of U-slot width*

The effect of the U-slot width, (a) variation on the filter performance is shown in Fig. 3. The effect on the fractional bandwidth (FBW) and the frequency ranges ($S_{11} < -10$ dB) versus the slot width is given in Table 1. It is clear that,

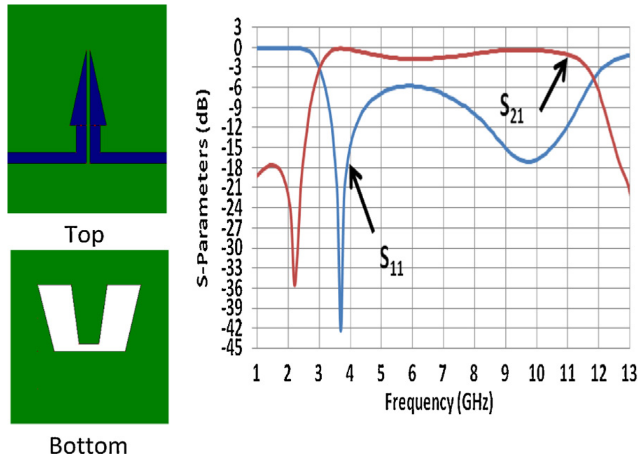

Fig. 2. UWB-BPF simulation for arrow coupled lines and reshaped U-slot DGS.

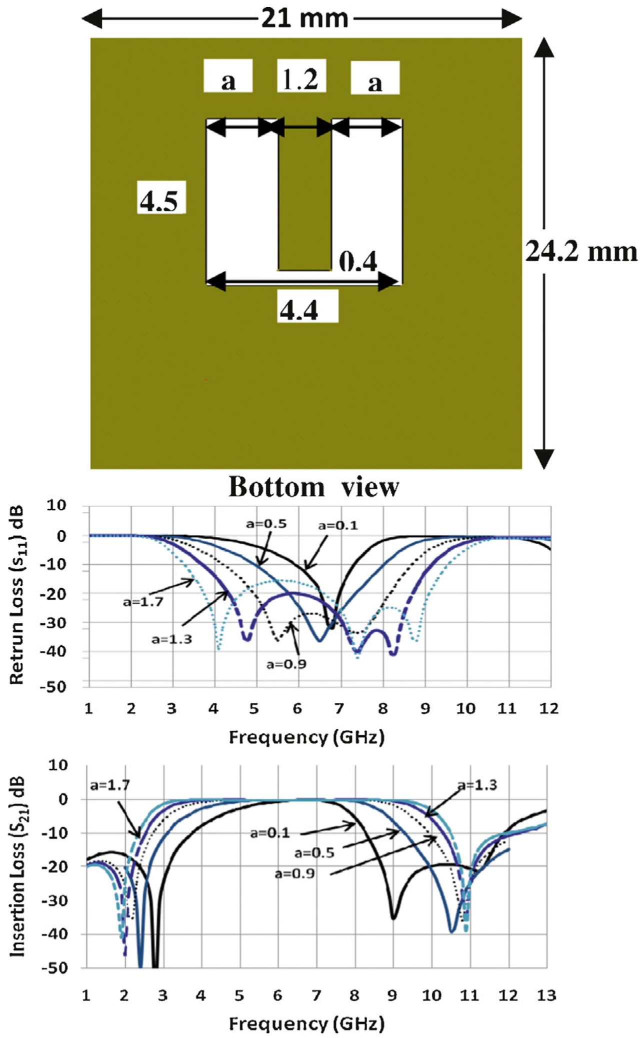

Fig. 3. The filter performance against different U-slot widths (*a*).

Table 1
The effect of the U-slot width (*a*).

a (mm)	B.W (GHz)	FBW	# of poles	1st zero (GHz)	2nd zero (GHz)
0.1	5.95–7.35	21.05	1	2.819	9.03
0.3	5.40–7.65	34.48	1	2.568	9.913
0.5	4.95–7.95	46.51	1	2.392	10.50
0.7	4.55–8.40	59.46	1	2.267	10.69
0.9	4.20–8.70	69.77	2	2.139	10.80
1.1	3.95–8.95	77.52	2	2.096	10.83
1.3	3.70–9.15	84.82	3	1.996	10.91
1.5	3.50–9.35	91.05	3	1.921	10.91
1.7	2.82–10.9	117.8	3	1.922	10.91
1.9	2.70–10.1	115.6	3	1.796	10.91

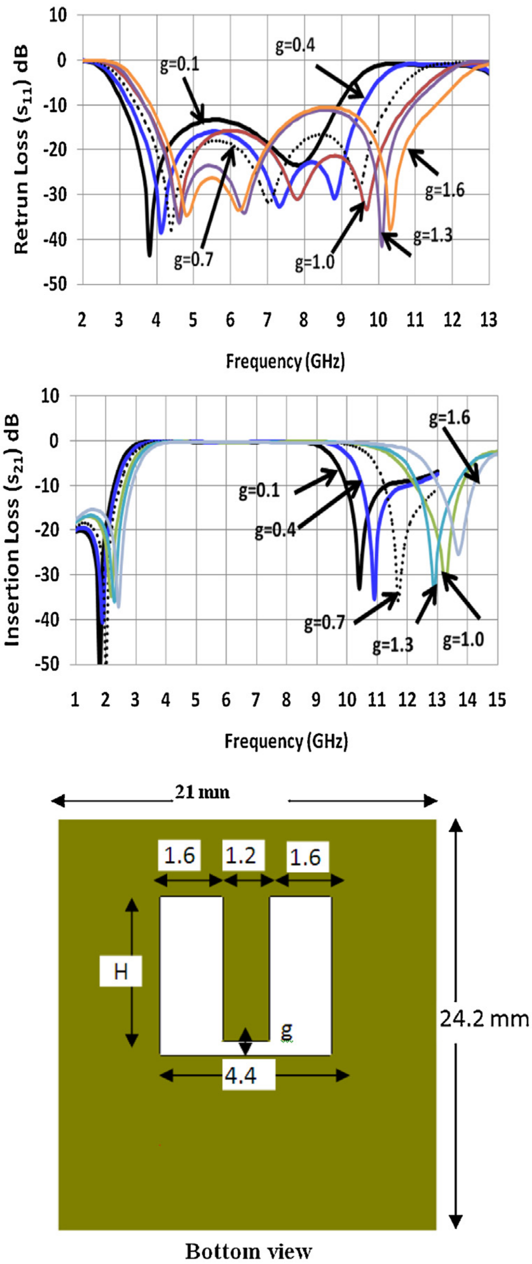

Fig. 4. The filter *S*-parameters against frequencies for different U-slot gap (*g*).

Table 2
The variations against the U-slot gap (*g*).

g (mm)	B.W (GHz)	FBW	# of poles	1st zero (GHz)	2nd zero (GHz)
0.1	3.1–8.9	97.35	2	1.82	10.39
0.3	3.2–9.5	98.58	3	1.839	10.80
0.5	3.4–9.8	98.09	3	1.903	11.10
0.7	3.5–10.3	99.27	3	1.99	11.72
0.9	3.5–10.8	101.0	3	2.096	12.57
1.1	3.7–10.7	97.22	3	2.167	12.91
1.3	3.8–11.1	98.26	3	2.299	13.58
1.5	3.9–11.7	99.68	3	2.37	14.45
1.7	3.9–11.8	98.99	3	2.499	14.58

Table 3
The variations against the U-slot height (*h*).

h (mm)	B.W (GHz)	FBW	# of poles	1st zero (GHz)	2nd zero (GHz)
2.5	4.6–7.3	45.37	1	2.14	11.50
2.9	4.3–7.6	56.54	2	2.12	11.18
3.3	3.9–8.0	67.78	2	2.02	10.95
3.7	3.8–10.2	92.47	3	1.97	10.78
4.1	3.9–9.8	86.13	3	1.89	10.58
4.5	3.2–9.2	96.36	3	1.79	10.40
4.9	3.0–8.6	96.55	2	1.69	10.15
5.1	2.9–8.7	97.51	2	1.77	10.18
5.3	2.8–8.2	97.15	2	1.67	10.01

as the U-slot width increases the FBW increases as well as the number of poles of the filter passband. The zeros in the stopband move toward the edges as the slot width increases.

2.2. *Effect of the U-slot gap*

The effect of the gap, *g* parameter of the U-slot on the filter performance is shown in Fig. 4. The FBW is nearly constant, but as the gap value increases the higher edge frequency of the passband moves to higher values, while the lower edge frequency is nearly constant, as well as the number of poles nearly constant (3 poles). As the U-slot gap increases, the zeros in the stopband shifted to higher values, so the *g* variations move the passband from lower to higher frequencies. The fractional bandwidth (FBW) and the frequency ranges ($S_{11} < -10$ dB) against the slot gap (*g*) variations are given in Table 2.

2.3. *Effect of the U-slot height*

The effect of U-slot height (*h*), on the filter performance is shown in Fig. 5. Table 3 shows the FBW variation for ($S_{11} < -10$ dB) versus U-slot height (*h*). For small heights ($h = 2.5$ mm), the passband bandwidth is small and the return loss is lower than (−10 dB) and the filter has one pole in the passband. As the U-slot height increases, the number of poles in the passband increases also, and the return loss in the passband exceeds (−10 dB).

3. The UWB-BPF simulations

After the modifications in the size of the U-defected ground structure slot (U-DGS); the coupled lines coupling length and separations; the feeder to the coupled lines, the performance of the bandpass filter altered to cover the UWB frequency range. The final design of the proposed filter is shown in Fig. 6, for each of the top and the bottom sides. The simulation results using each of IE3D software package (http://www.zeland.com/), and the HFSS software package (http://www.ansoft.com/products/hf/hfss/) are shown in Fig. 7. The IE3D simulator showed an operating passband

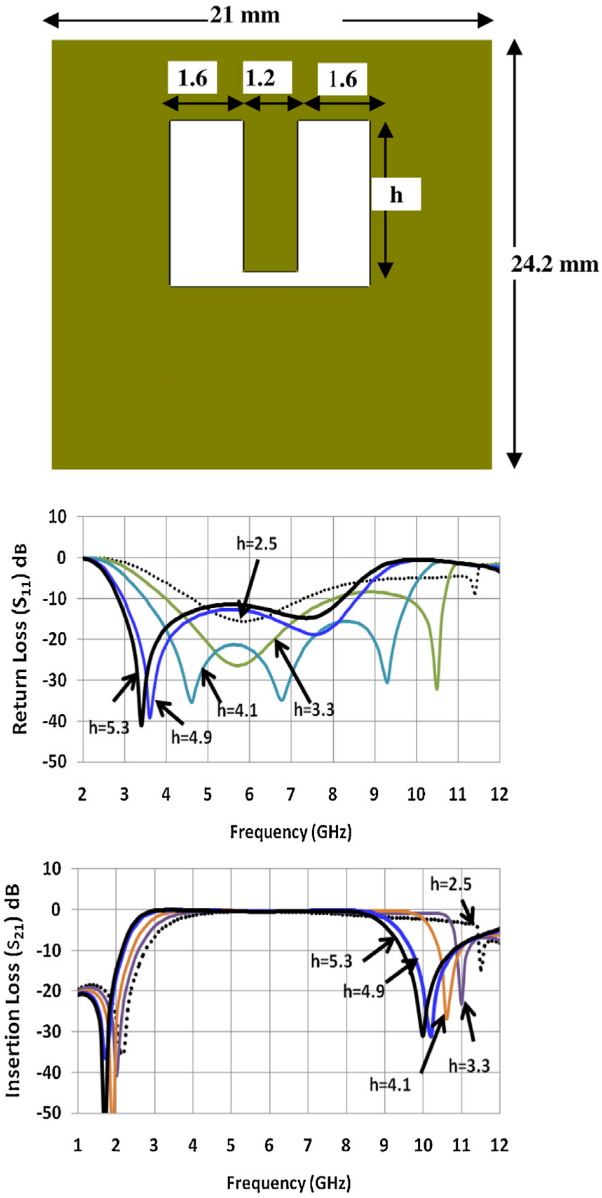

Fig. 5. The filter performance against different U-slot height (*h*).

(where $S_{11} < -10$ dB) that extend from (3.34–10.0 GHz), while the HFSS simulators showed an operating passband that extend from (3.5–9.1 GHz). Both of the simulators showed good rejection bands at the lower and upper frequency edges.

4. Group delay of the UWB-BPF

Group delay is defined as the rate of change of transmission phase angle with respect to frequency. The proposed UWB-BPF group delay was obtained from the IE3D simulator as shown in Fig. 8. It is clear that the variations in the group delay are around (1°) for the frequency band (3.5–9.5 GHz).

5. Fabrication and measurements

The designed UWB-BPF was fabricated using photolithographic technique at the microstrip laboratory of the Electronics Research Institute (ERI). The substrate used to realize the designed filter is RT/Duriod ($\varepsilon_r = 10.2$, $h = 0.635$ mm),

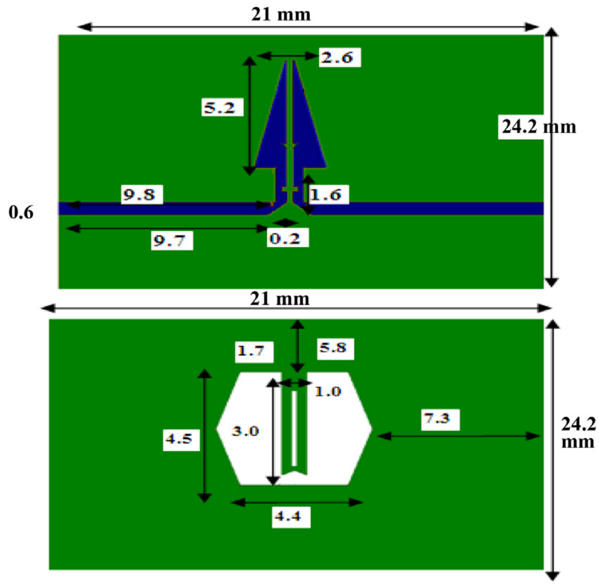

Fig. 6. The UWB-BPF dimension for upper and lower side.

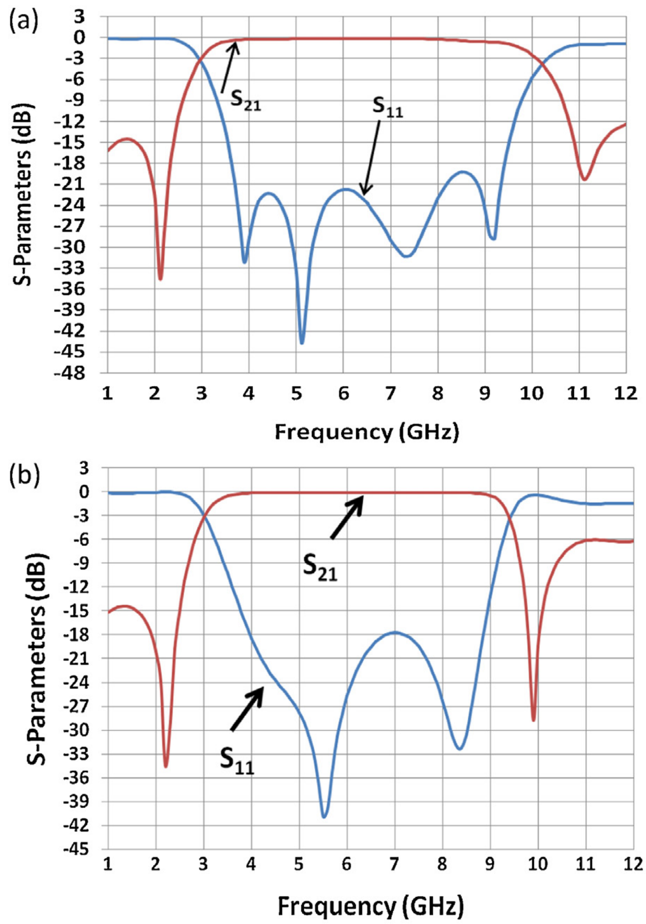

Fig. 7. The *S*-parameter simulation results for the proposed UWB-BPF. (a) IE3D simulation. (b) HFSS simulation.

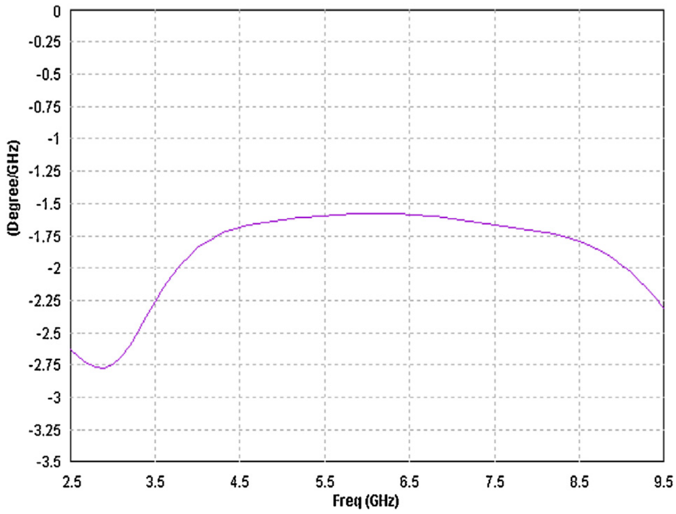

Fig. 8. The simulated group delay of the proposed bandpass filter.

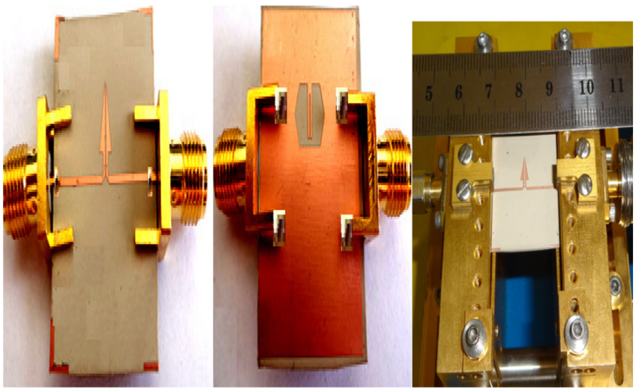

Fig. 9. The photos of the realized UWB-BPF.

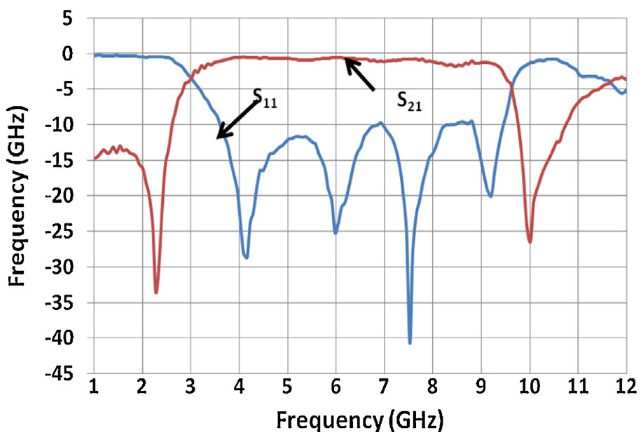

Fig. 10. The measured *S*-parameters for the realized UWB-BPF.

and their photos are shown in Fig. 9. The performance of the realized UWB-BPF was measured using VNA Agilent ES 8719, and are shown in Figs. 10 and 11.

From Fig. 10 it is clear that the filter operating passband extended over the UWB frequency 3.0–9.5 GHz. While, Fig. 11 demonstrates that the group delay variation in the passband does not exceed 0.5°.

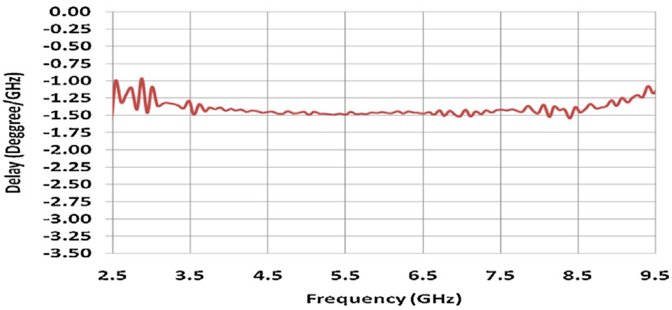

Fig. 11. The measured group delay for the realized UWB-BPF.

6. Conclusion

A compact Ultra-wide bandpass filter (UWB-BPF) is proposed using coupled lines incorporating arrow shape and U-slot defected ground structures (DGS). The input and output feeding lines are connected to the coupled lines on one side of the substrate while the U-slot DGS is etched in the other side of the substrate below the coupled lines. Parametric analysis of different variables of the design was carried out to obtain the optimized dimensions. The filter was simulated with two different simulators IE3D and HFSS and the simulation results are in a good agreement with each other. Finally, the designed filter was realized using photolithographic technique and the measured results are in good agreement with the simulated ones.

The measured operating passband covered the UWB frequency band (3.0–9.5 GHz), while the group delay variation in the passband was in the range of 0.5°.

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