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Design and Synthesis of Two Tunable Bandpass Filters Based On Varactors and Defected Ground Structure

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***Abstract*—**This paper presents two types of microstrip bandpass filter (BPF) at microwave frequencies. The first one is a tunable BPF using planar patch resonators based on a varactor diode. The filter is formed by a triple mode circular patch resonator with two pairs of slots, in which the varactor diodes are connected. Indeed, this filter is initially centered at 2.4 GHz; the center frequency of the tunable patch filter could be tuned up to 1.8 GHz simultaneously with the bandwidth, reaching high tuning ranges. Lossless simulations were compared to those considering the substrate dielectric, conductor losses and the equivalent electrical circuit model of the tuning element in order to assess their effects. Within these variations, simulation results showed insertion loss better than 2 dB and return loss better than 10 dB over the passband. The second structure is a BPF for ultra-wideband (UWB) applications based on multiple-mode resonator (MMR) and rectangular-shaped defected ground structure (DGS). This filter, which is compact size of 25.2 x 3.8 mm^2, provides in the pass band an insertion loss of 0.57 dB and a return loss greater than 12 dB. The proposed filters presents good performances and the simulation results are in satisfactory agreement with the experimentation ones reported elsewhere.

***Keywords*—**Defected ground structure, varactor diode, microstrip bandpass filter, multiple-mode resonator.

I. Introduction

RECENTLY, ultra-wideband (UWB) radio technology has received much attention in academic and industrial fields since the release of the commercial use of UWB technology in 2002. With the rapid development of modern mobile and wireless communication systems, the need for filters is challenged by not only its compact size but also the high performance. To make the filter more compact, one of the effective ways is to modify the traditional resonator to generate additional modes, causing the resonator to have multiple resonant frequencies, thus one resonator in physical can be treated as multiple resonators in electrical [1]. Among them, dual-mode filter is the most common multiple-mode filter, which has been analyzed deeply and comprehensively in many literatures with various configurations [2], [3]. However, triple-mode or other multimode microstrip planar filters are rarely reported in literatures. For decades several topologies of tunable filters have been reported in literature using YIGs, varactors [4], [5] and more recently MEMS. The use of varactors and MEMS became interesting, especially for their integration with planar resonators which provides advantages for high performance such as miniaturization.

In this paper, firstly, the tunable bandpass patch filter uses a circular patch resonator modified by four slots. This topology studied in this paper has advantages such as low cost and miniaturized layout. The employ of four slots permits forming a triple-mode patch filter with reasonably large band. This filter can be tuned by means of either varactor diodes or capacitors connected across its slots. Secondly, a microstrip UWB-BPF using multiple-mode resonator (MMR) and rectangular-shaped DGS is investigated. Indeed, the former filter is designed in such a way that signal bandwidth (BW) is around 500 MHz or a fractional bandwidth (FBW) larger than 20 percent at all times of transmission. Designing an UWB-BPF is mostly based in improving filter performance and overcoming some narrowband shortcomings. Different techniques have been used to develop these types of UWB filters [6]. Lumped-element filter design is generally unpopular because of the difficulty of its use at microwave frequencies along with the limitations of lumped-element values [7]. The design of an UWB-BPF with compact size, low insertion loss and wide rejection-band is a challenging task. Introducing defected ground structure (DGS) technique, in planar circuit, is one of the key to achieve high performances in low and band pass filters [6]-[8]. A DGS is an etched periodic or non-periodic cascaded configuration defect in ground of a planar transmission line which disturbs the shield current distribution in the ground plane. This disturbance will change characteristics of the transmission line such as line capacitance and inductance [8], [9].

The simulated results are compared with the measured ones reported elsewhere. The proposed UWB-BPF presents good performance in terms of insertion loss, return loss, fractional bandwidth and compact size.

II. The Designed Structures

A. First Structure

The first layout of the filter that is based on four strips parallel to each slot is shown in Fig. 1. This layout is a triple-mode patch filter formed by coupling three resonant modes: two fundamental degenerate modes (TM^z1,1,0 and TM^z1,1,0) and the second mode (TM^z2,1,0). The four slots were

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employed to perturb these first three modes and to couple them. Each slot can trouble one mode or more, i.e., each slot raises the current path of a specific mode resulting in a reducing of its resonant frequency. The substrate used has ε_r = 10.2 and h=0.63 mm.

The central frequency of the filter is tuned by controlling the degenerate fundamental modes. The topology with uncoupled modes allows the control of each resonant mode frequency by varactor diodes connected across the slots of the patch resonator.

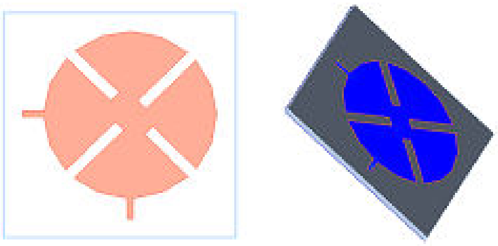

Fig. 1 The circular bandpass filter

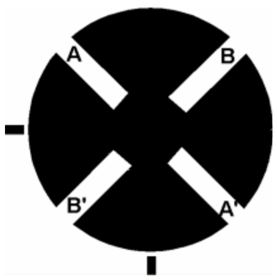

Fig. 2 Circular patch resonator with four slots A-A' and B-B'

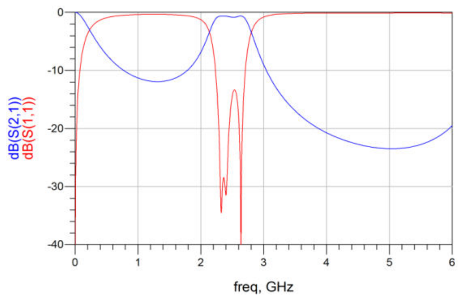

Fig. 3 Simulated frequency responses of the unloaded triple-mode circular patch filter

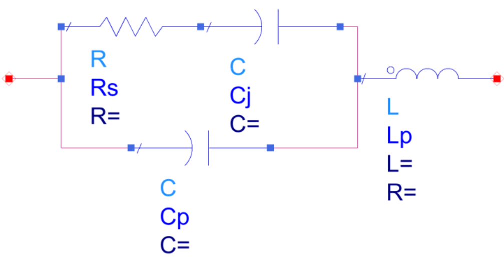

Fig. 4 Varactor's equivalent model

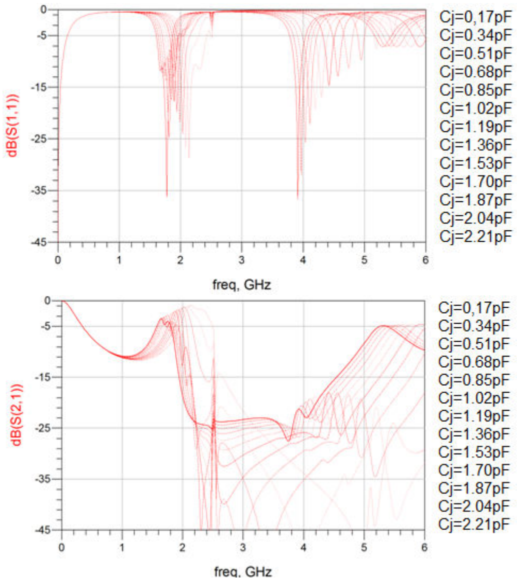

Fig. 5 Simulated frequency response for different Cj values from the model of Fig. 4

From Fig. 2, the primary slots dimensions were chosen in order to split the degenerate modes, lower their resonant frequency, and lower the second mode frequency so that the three resonant frequencies are around 2.4 GHz. The filter dimensions are: radius=8.1 mm, length of slots A-A'=5.8 mm, length of slots B-B'=6.5 mm and slots width=1.1 mm. The simulated frequency response of the triple-mode patch filter is shown in Fig. 3. Simulations were carried out on ADS software using the varactor's model shown in Fig. 4 where inductance L_p and the capacitance C_p represent the package and mounting parasitic.

The simulations indicate a better performance of the filter when C_j is within 0.17 to 2.25 pF. These values can be obtained by using a commercial available SMV2019 varactor from Skyworks Corp.

Fig. 5 shows that the patch filter can be continuously tuned from 1.8 GHz to 2.35 GHz which means 27% of tuning.

The influence of the varactor diodes in the filter was analyzed in terms of its unloaded quality factor Q_u, calculated from (1) and (2):

$$Q_u = Q_l/(10^{(S_{21}/20)} - 1) \tag{1}$$

$$Q_l = f_c/BW_{3dB} \tag{2}$$

where S_{21} is the insertion loss in dB at the central frequency f_c of the filter, Q_l is the loaded Q factor which is the ratio of f_c and the passband in MHz BW_{3dB}. The tunable patch filter presents at its higher f_c, 2.35 GHz, a Q_u equal to 40 and at its lower f_c, 1.8 GHz, a Q_u equals to 142, a high value compared to results reported in literature using this technology.

B. Second Structure

The proposed UWB-BPF structure is shown in Figs. 6 (a) and (b). The filter consists of interdigital feed lines and coupling gaps on the top and rectangular shaped etched in the ground plane. It is designed on a substrate with a relative dielectric constant of 4.4 and a thickness of 1.6 mm. The use of interdigital feed lines is able to enhance the coupling degree between the feed lines. This coupling can be adjusted to control the bandwidth. Therefore, the symmetrical inter digital feed lines can work together to keep the UWB-BPF in the desired range. Several techniques have been used for designing filters to cover the desired range of UWB System [6]-[11]. The input and output ports are designed for Z_0 of 50 Ω.

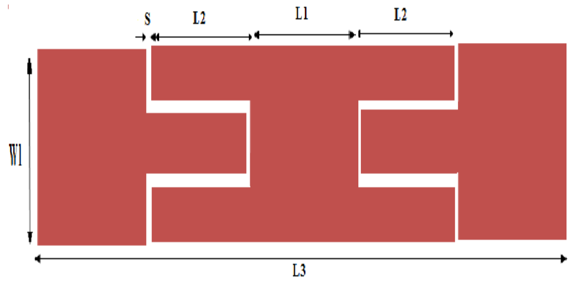

Fig. 6 (a) Top view of the proposed UWB-BPF structure

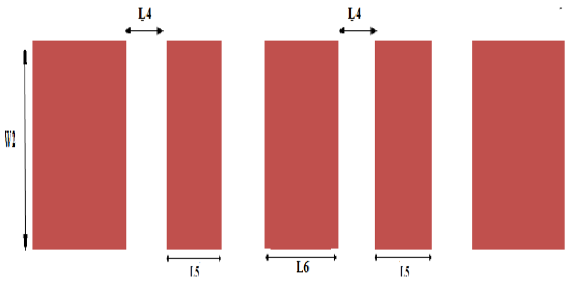

Fig. 6 (b) Bottom view of the proposed UWB-BPF structure

In order to investigate the effect of the dimensions on the filter performances, the proposed filter is simulated with different physical lengths L1, L2, L3, L4, L5, L6 and widths W1, W2, S. First, the length L2 is set successively to 3.05 mm, 4.05 mm, 5.05 mm, and 6.05 mm while the other dimensions are kept constant (W1=3.06 mm, W2=3.8 mm, S=0.05 mm, L1 =5 mm, L4=2.1 mm, L5=0.81mm, L6=5.2). The simulated S-parameters are plotted in Figs. 7 and 8. It is observed, from Fig. 7, that by decreasing the length L2, the bandwidth of the filter is affected significantly. When L_2 is equal to 5.05 mm, the filter exhibits an ultra-wide bandwidth from 3.3 to 11.4 GHz and an insertion loss less than 0.57 dB. Fig. 8 shows the simulated S-parameters when W1 is varied whereas the other dimensions are kept constant (W2=3.8 mm, S=0.05 mm, L1 =5 mm, L2=5.05, L3=25.2 mm, L4=2.1 mm, L5 = 0.81 mm, L6=5.2 mm). As the width W1 increases the bandwidth decreases. For W1= 3.06 mm, the filter exhibits an ultra-wide bandwidth from 3.3 to 11.4 GHz and insertion loss less than 0.57 dB. Now, the width Sis set consecutively to 0.05 mm, 0.1 mm, 0.2 mm, and 0.3 mm while the other parameters are kept constant (W1=3.06 mm, W2=3.8 mm, L1=5 mm, L2 =5.05 mm, L4=2.1, L5=0.81 mm, L6=5.2 mm).

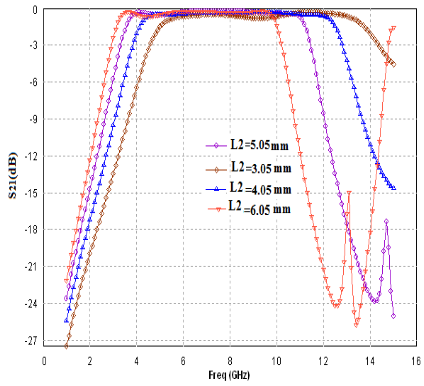

Fig. 7 Magnitude of S_{21} of the proposed UWB-BPF for different values of L2

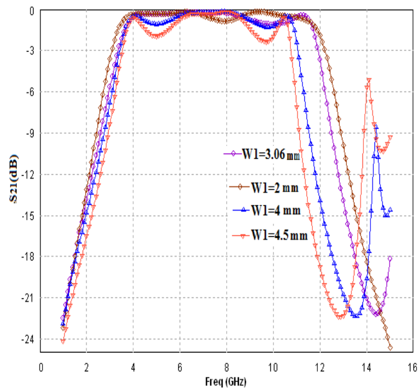

Fig. 8 Magnitude of S_{21} of the proposed UWB-BPF for different W1

The simulated S-parameters are plotted in Fig. 9. It can be seen from Fig. 9 that by increasing the width S, S = 0.05, 0.1, 0.2 the bandwidth of the filter increases. S= 0.3mm the bandwidth decreasing. When S is equal to 0.05 mm, the filter exhibits an ultra-wide bandwidth from 3.3 to 11.4 GHz and an insertion loss less than 0.57 dB. Roughly, all dimensions have a great effect on the characteristics of the proposed UWB-BPF. Detailed studies of the effect of the other parameters are lengthy and are not included in this paper.

After a thorough parametric study of the filter, the optimum design parameters of the proposed UWB-BPF are listed in Table I. The simulated frequency response of the proposed filter, shown in Fig. 10, shows an obvious UWB bandpass response with a wide passband range of 8.1 GHz, a low insertion loss of 0.57 dB and a return loss higher than 12 dB.

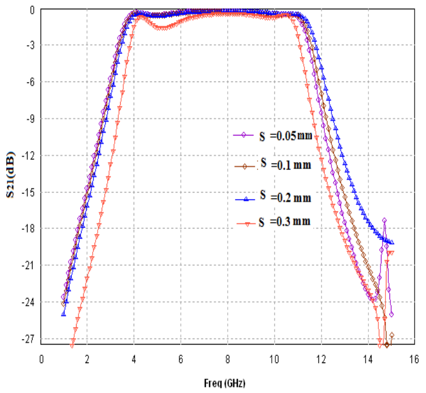

Fig. 9 Magnitude of S_{21} of the proposed UWB-BPF for different S

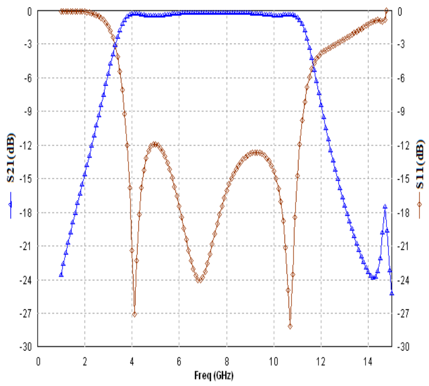

Fig. 10 Magnitude of S_{21} and S_{11} of the proposed UWB-BPF

TABLE I
PHYSICAL PARAMETERS OF AN UWB-BPF STRUCTURE

Parameters l	Dimensions [mm]
Parameters	Dimensions [mm]
W1	3.06
W2	3.8
S	0.05
L1	5
L2	5.05
L3	25.2
L4	2.1
L5	0.81
L6	5.2

Figs. 11 (a) and (b) show the current distributions in the top and bottom of the UWB-BPF at central frequency f_0 of 7.35 GHz. As can be seen, the current density is concentrated at the interdigital feed lines where the etched DGS units are placed. The performance of the proposed filter is summarized in Table II with other filters for comparison. It can be observed from Table II that the proposed filter provides good performances in stopband rejection, insertion loss, return loss and more compact size (25.2 x 3.8 mm^2) than those reported in the literature [8]–[10].

TABLE II
PERFORMANCE COMPARISON OF MICROSTRIP UWB-BPFS

Ref.	IL(dB)	RL(dB)	BW(Ghz)	Stopband (GHz) with -12 dB rejection	Size (mm^2)
[8]	1.5	10	6.39	2.5–10.5	15x30
[9]	0.53	14.8	6.59	3.3–10.8	25x14.7
[10]	0.8	13.18	7.56	2.2–11.5	22.95x19.25
This work	< 0.57	> 12	8.1	2.2–12.2	25.2 x 3.8

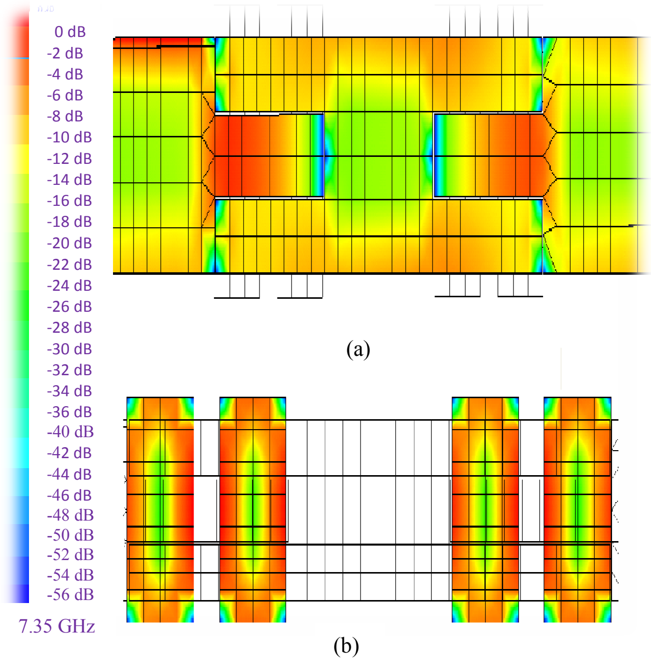

Fig. 11 (a) Current distributions at f_0=7.35 GHz in top view (b) Current distributions at f_0=7.35 GHz in bottom view

III. CONCLUSION

This paper presents a design and synthesis of two new structures ultra wideband (UWB) microstrip bandpass filter (BPF).The first one is a tunable patch filter formed by a triple mode circular patch resonator with two pairs of slots, in which varactor diodes were connected. The simulated results show that the central frequency of the patch filter can be tuned from 1.8 GHz to 2.35. In addition, an insertion loss lower than 2 dB and a return loss better than 10 dB were obtained. The second structure is an UWB-BPF using DGS technique. This proposed BPF has the advantages of low insertion loss of 0.57 dB, return loss higher than 12 dB, stopband with -12 dB rejection from 2.2 GHz to 11 GHz and compact size of 25.2 x 3.8 mm^2. This type of filter could be widely used for UWB microwave applications.

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