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DESIGN OF RECONFIGURABLE MINIATURIZED UWB-BPF WITH TUNED NOTCHED BAND

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Abstract—A new miniaturized ultra-wideband bandpass filter with embedded reconfigurable multiband frequency notch function was designed and implemented by embedding all the passive components into a printed circuit board with a high dielectric constant. The proposed filter consists of compact 2U-shaped DGS resonators shunt connected to parallel coupled lines to achieved frequency notch. To tune the notched band, suitable capacitor elements within the inner/outer U-DGS and RF PIN diode within the outer U-DGS are integrated. A curve fitting formula is derived to show the effect of the capacitor value on the center frequency of the notched band, which is decreased by 56.7%. These capacitors improved the quality factor and have the effect of reducing the filter size by 72% as compared to other filters. The RF PIN diode in the outer U-DGS acts as a switch to exhibit a band notch covering the bandwidth of the WLAN for IEEE 802.11 a/h at 5.5 GHz and RFID ISO 18000 series pars 5 in microwave (MW) which is set at 5.8 GHz, 6.1 GHz and 6.8 GHz, and the other bands. RF PIN diodes control the notched band and raises it from 5.25 GHz to 6.85 GHz (27%) or remove the band notched according to its positions. In order to validate the feasibility of the proposed structure, UWB BPF with center frequency of 6.85 GHz is designed, fabricated, and measured. The filter has passband from 3.2 GHz to 10.7 GHz and notched band designed to generate stop band from 5.25 to 6.85 GHz, and the two transmission zeros are observable at 2 GHz and 12.5 GHz, respectively by measurement. This paper shows the

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miniaturized filter with size 6.7 mm $\times$ 6.5 mm occupying a circuit area of about $0.41\lambda_g$ by $0.39\lambda_g$. The measured results for the proposed filter are in good agreement with simulations and verify the excellent performance of the designed filter and the validity of the proposed approach.

1. INTRODUCTION

Since the Federal Communications Committee (FCC) authorized the unlicensed use of the ultra-wideband (UWB: 3.1–10.6 GHz) frequency spectrum for indoor and hand-held wireless communications in early 2002 [1], a tremendous interest has been attracted to explore various UWB bandpass filters (BPFs) with a 110% fractional frequency bandwith (FBW). Recently, a variety of UWB filters have been introduced via different methods and structures, e.g., nonperiodical shunt-stub loading [2, 3], composite lowpass-highpass topology [4, 5], cascaded broadside-coupling [6], and multiple-mode resonator (MMR) [7–9]. One general problem of UWB systems is a possible interference with relatively strong narrowband signals within the allocated UWB spectrum like those from wireless local-area network (WLAN) applications. Therefore, a narrow notched band or multi notched bands in the UWB passband is (are) necessary in order to avoid interference that may occur with the existing systems [10–12]. In [13], a single stopband was obtained in the passband of UWB filter by asymmetric parallel-coupled lines. Also, a UWB suspended stripline filter which has a single stopband by incorporating a resonant slot into one of its elements is introduced in [14]. In order to generate compact microstrip double/single notch-band in the UWB passband, slots are integrated in the mid of the conductors of a broadside-coupled UWB filter [15] and multi rejection bands in the passband of UWB filter [16]. Today, reconfigurable filters may replace a bank of filters used to produce more than one response. Devices used to provide tunable or reconfigurable properties to filter topologies are PIN diodes [17], UWB filters integrated with tunable notch filters using MEMS switches [18] and Tunable notch characteristics by varactor [19]. These elements usually account for a significant amount of the cost when reconfigurable components are fabricated.

In this paper, we propose a new technique for tuned notched bands implementation in UWB BPFs. Thus, the filter with multi notched bands in the UWB passband will avoid interference that may occur with the existing radio systems. The notched bands are introduced by integrating 2U-DGS with lumped capacitors and RF PIN diodes on the bottom side of coupled line BPF. The outline of the paper is as following, in Section 2, structure and design considerations of 2U-DGS of UWB BPF with notch band with electromagnetic (EM) simulated and equivalent circuit results are presented. Section 3 gives reconfigurable filter with capacitors in inner U-DGS. Reconfigurable filter with capacitors in outer U-DGS demonstrated with experimental measurement is described in Section 4. Reconfigurable filter with PIN diode in outer U-DGS is discussed in Section 5. Results and discussions are described in Section 6. Finally, a conclusion is given in Section 7.

2. STRUCTURE AND DESIGN CONSIDERATIONS OF UWB BPF WITH NOTCHED BAND

The configuration of U-DGS UWB filter was initially exhibited in [10]. The filter mainly has two quarter-wavelength parallel coupled lines on the top surface of the substrate and a U-DGS coupled to the two parallel lines. The proposed filter is achieved by etching another inner U-DGS in the ground plane as shown in Fig. 1. The filter is implemented on RT/Duroid 3010 with a dielectric constant of $\varepsilon_r = 10.2$, a thickness h of 0.635 mm and a loss tangent of 0.0025. The characteristic impedance Z_{ce} sand Z_{co} of the parallel-coupled lines with quarter-wavelength at 6.85 GHz are selected to be 45.8 Ω and 28.2 Ω, respectively. All filters are constructed and tested by the 3-D EM simulator MICROWAVE STODI$^{\text{TM}}$(CST 2011) [20] based on time domain finite element integral and used for characterizing the frequency response. Dimensions of the proposed UWB BPF with 2U-DGS are for the coupled line $W_0 = 0.57$ mm, $S = 1$ mm, $L = 5$ mm, and gap distance g is 0.25 mm. The lattice dimensions for the proposed 2U-DGS are $L_1 = 6.1$ mm, $W_1 = 0.6$ mm, $S_1 = 1.2$ mm, $D_1 = 6.7$ mm,

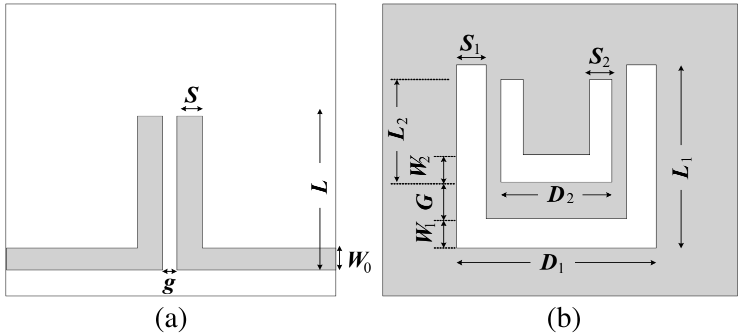


Figure 1. (a) Top view of the structure. (b) 2U-shaped DGS structure on the ground plane.

$S_2 = 1\,\mathrm{mm}$, $L_2 = 2.5\,\mathrm{mm}$, $D_2 = 3.8\,\mathrm{mm}$ and $W_2 = 0.5\,\mathrm{mm}$ as shown in Fig. 1.

The aim of this section is to integrate a notch band in the previously presented compact UWB filter, keeping all its advantages with respect to low loss and sharp rejection. The parameters of this notch are completely controlled by inner U-DGS. The center frequency location is determined based on the defect length given by $2L_2 + D_2$, while the bandwidth of the notch is determined by the defect width (S_2). The proposed notched technology requires no additional circuit and exhibits design flexibility. Moreover, the equivalent circuit model of such a structure can be easily established. In this section, we will present a design of an UWB filter with a notch band from 5.25 to 5.75 GHz, representing the WLAN application. When adding the inner DGS, it results in a rejection notched band at center frequency of 5.5 GHz. Moreover, changing the physical dimensions of the inner U-DGS can easily control the effective inductance L, and shift notch band, which can be designed for some move notch frequency applications.

Figure 2 shows the equivalent circuit of the proposed UWB

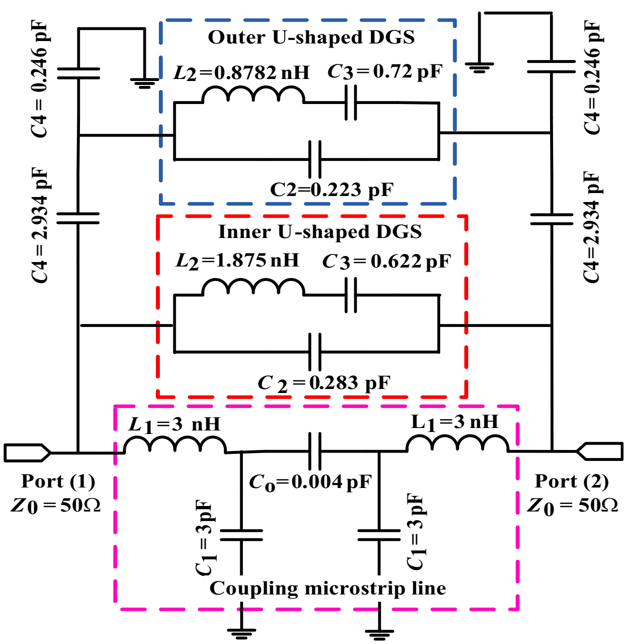


Figure 2. Equivalent circuit of the proposed UWB bandpass filter with notch band implementation by using 2U-DGS by ADS simulator [21].

bandpass filter with notch band implementation using 2U-DGS by Agilent ADS simulator [21]. The inner DGS results in a rejection band, Fig. 3 shows the diagram of simulated current distribution at 5.5 GHz for the bottom view. Excellent agreement is obtained and the filter exhibited an excellent UWB bandpass performance with a FBW of about 107% at a midband frequency of 6.78 GHz. The simulated results show the notched bands in the passband with 27 dB, and rejection FBW of about 3.6%, at a center frequency of 5.5 GHz, Fig. 4. The measured attenuation at the center of the notched band is more than 22 dB. At the midband frequency, low insertion loss less than 1 dB was obtained. The measured group delay of the fabricated UWB BPF with notch band implementation at 5.5 GHz is shown in Fig. 4(b). Within

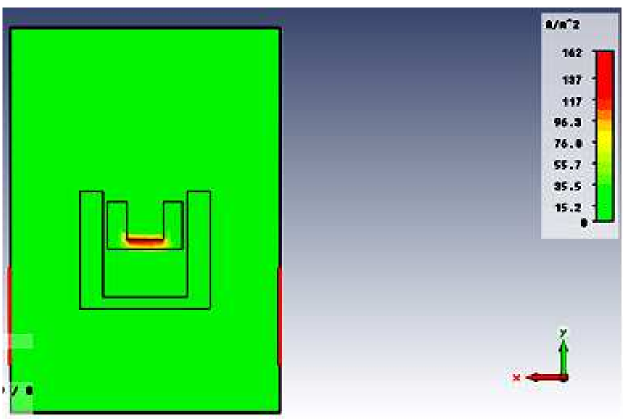


Figure 3. Simulated current distribution at 5.5 GHz for the bottom view.

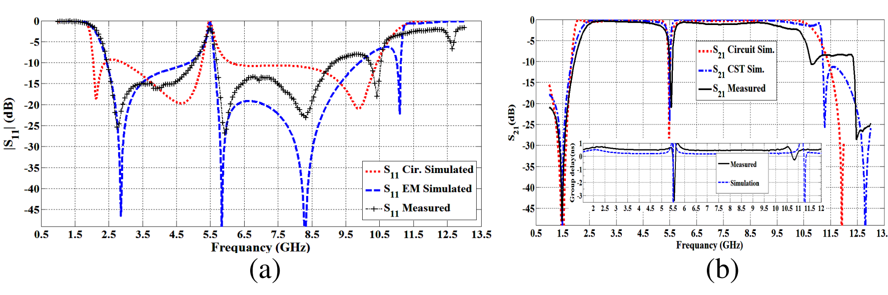
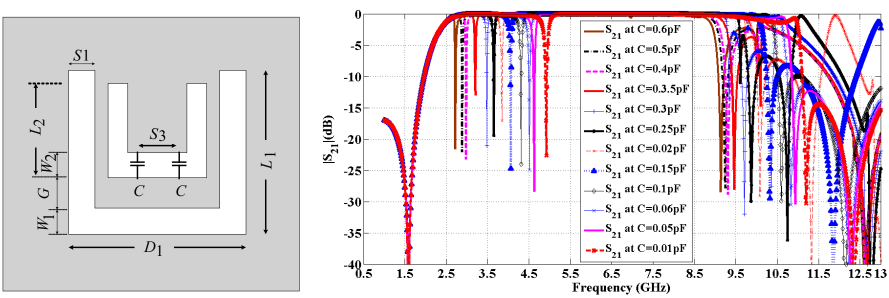


Figure 4. CST EM-simulated, equivalent-circuit modeled and measured S-parameters of the proposed 2U-UWB BPF. (a) S_{11}, and (b) S_{21}.

the UWB lower and higher passband, the group delay is below 0.2 ns with the total size of the filter 6.7 m × 6.5 mm.

3. RECONFIGURABLE FILTER WITH CAPACITORS IN INNER U-DGS

In particular, the RF circuitry and antennas must be designed to be able to operate at multiple frequency bands and dual-frequency operation is achieved by loading a slot antenna with two lumped variable capacitors (varactors) placed in proper locations along the slot [22]. A reconfigurable ultra-wideband (UWB) bandpass filter (BPF) with switchable notch is presented. The UWB BPF is embedded with two identical switchable notch DGS structures, in which lumped capacitors are used for electronic switching. According to current distribution in Fig. 3, we can put lumped capacitors on the effective region on inner U-DGS as shown in Fig. 5(a). Then the center frequency of notched band is reduced by inserting a lumped capacitor in the region of the active slot and the resonant frequency of the slot is found to be proportional to the value of the capacitors (C), Fig. 5(b). Curve fitting was carried out and a formula was derived to get relative between the center frequency of the notch and the value of the inserted capacitors.



(a) (b)

Figure 5. (a) Bottom view showing the 2U-shaped DGS with lumped capacitors. (b) Effect of lumped capacitor values on filter notch frequency response.

The advantage of the capacitors is that the magnetic and electric fields are concentrated near the lumped capacitors and coupling coefficients can be realized easily [23]. It should be noted be noted adding capacitors in the inner U-shaped slot reduces the passband bandwidth due to increasing the overall quality factor Q of the filter which cause a reduce in bandwidth. The resonant frequencies have the values of 4.7 GHz, 4.61 GHz, 4.32 GHz, 2.77 GHz and 2.37 GHz, or drop by 12.7%, 16%, 21.7%, 48.5%, and 56.7%, respectively, when inserting lumped capacitors of values 0.01 pF, 0.05 pF, 0.1 pF, 0.5 and 0.5 pF. This means that the resonant frequency drops by 56.7% by increasing the lumped capacitor that varies from 0.01 to 0.6 pF, with the same compact size, so inserting lumped capacitor leads to changing the notched frequency as shown in curve fitting in Fig. 6 and the following formula with maximum error 3% in the capacitor range $0.01\,\text{pF} \leq C \leq 0.6\,\text{pF}$.

$$F_{notched}(C)=339.2C^5-518.6C^4+261.6C^3-42.98C^2-4.555C+4.916$$

where $F_{notched}$ (GHz) is the center of the notched frequency and C (pF) the value of capacitors.

To demonstrate this filter experimentally, we added the tune capacitors in the equivalent circuit model in Fig. 2. Capacitance value of 1.092 pF was added to the equivalent circuit of inner U-DGS to control the notched frequency. Fig. 7 demonstrates measured, CST simulated, and circuit simulation S-parameters of the proposed filter, where good agreement is obtained. The capacitor 388-6153-6-ND was used which has typical 0.1 pF as depicted from curve fitting in Fig. 6 with center of notched band of 4.32 GHz which rejected the telemetry frequency band from UWB. It should be noted that adding these capacitors improved the filter matching and the mismatch which appeared in the region 8–10 GHz disappeared.

The notched band is located at 4.32 GHz with insertion loss of −23.7 dB and notched FBW of 4.6% (4.21–4.41 GHz). In addition, the implemented filter exhibits a flat group-delay response below 0.46 ns

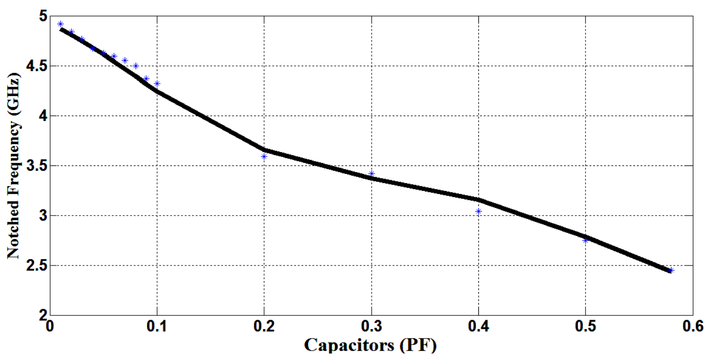
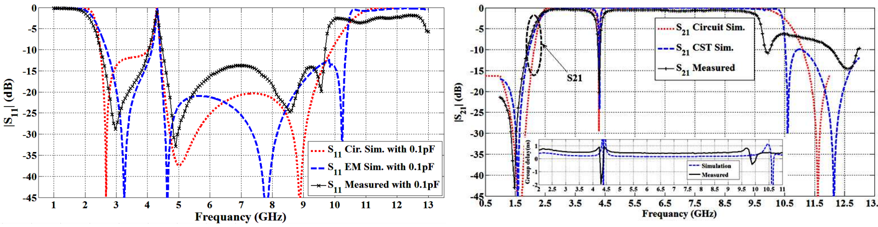


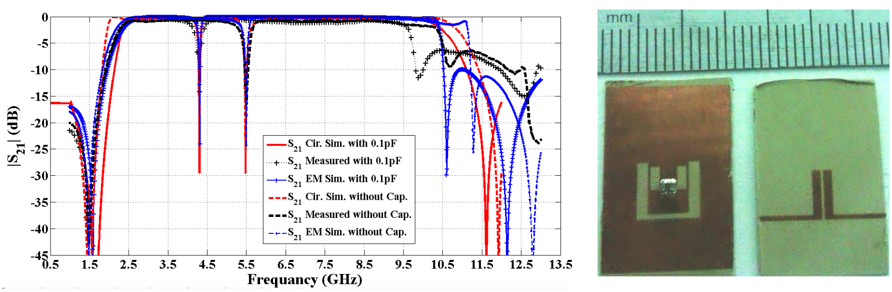
Figure 6. Fitting curve for the effect of lumped capacitor values on filter notch frequency response.



(a) (b)

Figure 7. Simulated, equivalent-circuit modelled and measured S-parameters of notched band in UWB BPF with capacitor 0.1 pF in inner U shaped DGS. (a) S_{11}, and (b) S_{21}.

with variation less than 0.21 ns over the whole passband. It is also worth mentioning that the capacitor improves the rejection at the band notch. Based on the parametric analysis, optimization was carried out on the capacitor value, position and slot length constrained to the desired frequency band notch of frequency 4.32 GHz, the distance between the two capacitors is ($S_3 = 1$ mm) in Fig. 5(a). A comparison between the simulation and measurement of S-parameters of the filter with and without lumped capacitor is shown in Fig. 8. The notch band is shifted from 5.5 GHz to 4.32 GHz when switched capacitors OFF, and ON respectively, without changing the bandwidth of the notch band filter. A photo of the fabricated filter with two lumped capacitor of 0.1 pF is shown in Fig. 8.



(a) (b)

Figure 8. Simulated, equivalent-circuit model and measured S_{21} of notched band in UWB BPF with/without capacitors of 0.1 pF in inner U-DGS. (b) Photograph of fabricated filter.

4. RECONFIGURABLE FILTER WITH CAPACITORS IN OUTER U-DGS

The reconfigurable UWB filter can work as a UWB BPF with/without notch band by switching the capacitors ON and OFF. Lumped capacitors C_1 and C_2 are then added to outer U-shaped DGS to increase the capacitance of DGS resonators which determines the required UWB BPF as in Fig. 9(a). To achieve the response of the previous notched filter based on the effect of a capacitance, a capacitor (712-12220-6-ND) of 22 pF is selected.

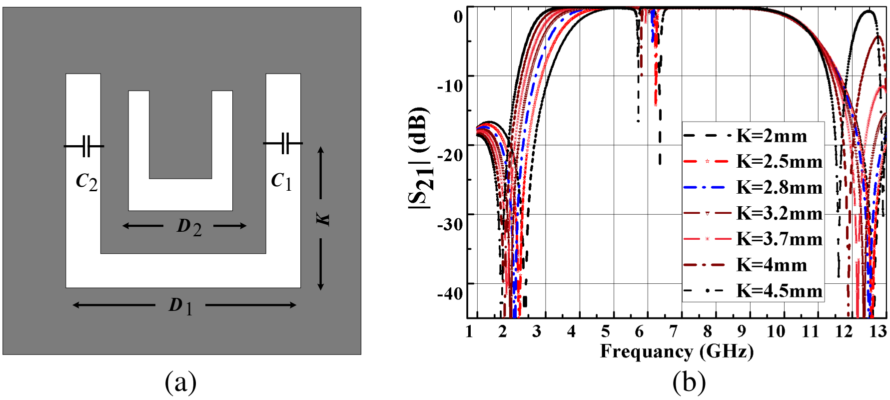


Figure 9. (a) Bottom view of 2U-DGS BPF. (b) Effect of distance (K) of lumped capacitor value of 22 pF on filter notch frequency response.

A reconfigurable ultra-wideband (UWB) bandpass filter (BPF) with switchable notch for UWB system is presented. The UWB BPF is embedded with two identical switchable capacitors ($C_1 = C_2$). According to equivalent circuit, the notch frequency response of the filter is changed as shown in Fig. 9. The center frequency of notched band is increased by changing the position "K" of the inserted lumped capacitor according to the magnetic and electric fields which are concentrated near the lumped capacitors and coupling coefficients can be realized easily [14]. The lumped capacitor basically controls the resonant frequency. To shift the notch band from 5.5 GHz to 6.4 GHz without changing the bandwidth of the notch band filter, "K" varies from 2 mm to 4.5 mm, the center of notched band frequencies have the values of 5.7 GHz, 5.8 GHz, 5.9 GHz, 6.1 GHz, 6.32 GHz, and 6.4 GHz or rise by 3.6%, 5.4%, 7.2%, 10.9%, 14.9%, and 17%, respectively, with reference notched at 5.5 GHz when inserting a lumped capacitor at distance "k" with values 4.5 mm, 4 mm, 3.7 mm, 2.8 mm, 2.5 mm, 2 mm, respectively.

This means that the resonant frequency rises by 17% by decreasing the distance "K" of lumped capacitor from 4.5 mm to 2 mm as shown in Figs. 9(a) and (b) with the same compact size. The position of the capacitor affects the resonance frequency. It decreases as the capacitor go away from the side of the slot. This could be attributed to the electric field distribution inside the slot. It is known that for the fundamental mode of the slot resonator, the electric field is maximum at the position of the capacitors. Therefore, the effect of the capacitor is maximum there. While moving the capacitor away from the middle of the slot, its effect begins to decrease till it vanishes at the side end where the electric field tends to zero at $K = 3.2$ mm. For the equivalent

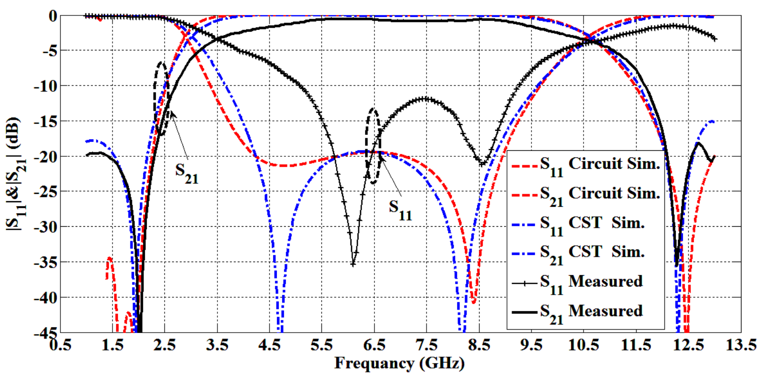


Figure 10. EM-simulated, equivalent-circuit model and measured S-parameters of UWB BPF with capacitor 22 pF in outer U-shaped DGS.

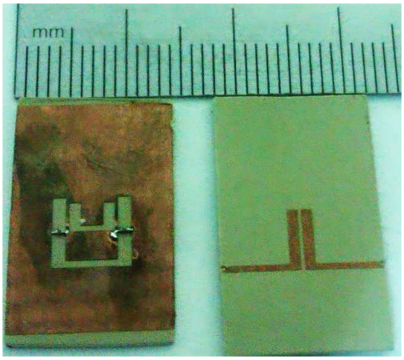


Figure 11. A photo for the fabricated 2U-shaped DGS filter with two lumped capacitors 22 pF each loaded in outer U-DGS.

circuit model in Fig. 2(a) capacitance value of 1.82 pF added to the equivalent circuit of outer U-DGS is used to remove this notched band. As illustrated in Fig. 10 close agreement between the measured results and full-wave simulations is observed. A photo of the fabricated filter is shown in Fig. 11 with two lumped capacitors each of 22 pF.

5. RECONFIGURABLE FILTER WITH RF PIN DIODE IN OUTER U-DGS

In this section, RF PIN diodes are used as the switching elements in outer U-DGS. The equivalent circuit used in the simulation software is presented in Fig. 12. RF PIN diodes have the advantages of low-cost, low-losses and are easily modeled by lumped elements. However, the RF PIN diode requires extra biasing circuits and also it has high power consumption. HPND 4005 PIN diode is used which has low series resistance, low capacitance, occupies less space and high frequency coverage (up to 12 GHz) as compared to other PIN diodes According to the HPND-4005 PIN diode datasheet [24], the resistor element in forward bias is equivalent to 4.7 Ω (R_S) while the main capacitor element is 0.017 pF (C_T) in the reverse bias state. This model gives a very good approximation for the real commercial PIN diode HPND-4005 manufactured by HP. The selection of this diode type is based on its characteristics of high frequency coverage as stated in datasheet. However, the diode material is brittle, it bears low power and its size is too small for basic soldering capabilities, the HPND-4005 PIN diode soldering consumes much effort. The resistor (R_P) is 10 kΩ representing the net dissipative resistance of the diode in the reverse bias state. RLC equivalent circuit is used to model the PIN diodes in the simulation.

As a first step a metal strip of area $0.9 * 0.3\,\text{mm}^2$ was used to represent the ideal switch parameters. The opened (OFF) state and

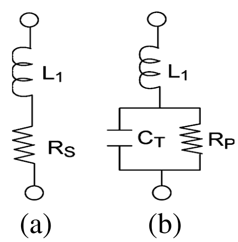
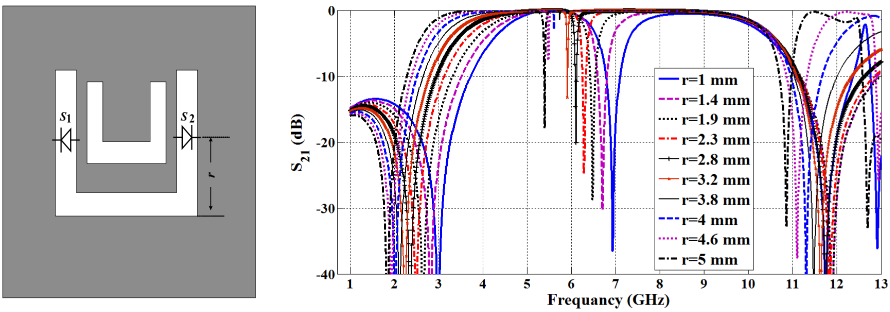


Figure 12. Equivalent circuit for PIN diode. (a) Forward bias. (b) Reverse bias.

closed (ON) state of the switch were represented by the absence or presence of this metal strip. Fig. 13(a) shows the bottom view of the 2U-DGS BPF, while Fig. 13(b) shows the effect of diode [25]. Changing and optimization of length (r) is a design issue in Fig. 13. The role of the switches here is to reconfigure the filter between the ON/OFF states. A state where the filter exhibit a band notch covering from 5.3 GHz to 6.98 GHz or removing the notched frequency band and the response returned flat in position of $r = 3.8$ mm in Fig. 13(b). In Fig. 13(b) the center of notched band is increased by changing the position "r" of the RF PIN diode.



(a) (b)

Figure 13. (a) Bottom view of 2U-DGS BPF with PIN diodes. (b) Effect of distance (r) of PIN diode position on filter notch frequency response.

The next step is to insert real switch with its biasing circuit. It requires 1.2 V to operate in forward bias state, while above 10 V to operate in reverse bias state at 10 GHz. The reconfigurabilty is achieved when the RF PIN diodes and coupled lines of microstrip filter are integrated to control the notched band of the filter response. This reconfigurable mechanism can avoid the interference of noise source coming from different frequency bands of traditional multi-band systems.

The role of the switches here is to reconfigure the filter between the ON/OFF states. A state where the filter exhibit a band notch covering the bandwidth of the WLAN for IEEE 802.11 a/h at 5.5 GHz and RFID ISO 18000 series part 5 in microwave (MW) which set 5.8 GHz, 6.1 GHz and 6.8 GHz, and the other bands. These characteristics are represented in notch center frequency, its bandwidth and how shallow the notch is controlled (S_{21} is large as much as possible). To shift the notch band from 5.5 GHz to 6.89 GHz without changing the dimensions of the filter, the position of PIN diode "r" varies from 5.5 mm to 1 mm, by the distance "r" with values 5 mm, 4.6 mm, 4 mm, 3.2 mm, 2.8 mm, 2.3 mm, 1.9 mm, 1.4 mm, and, 1 mm, then the center of notched band frequencies have the values of 5.3 GHz, 5.47 GHz, 5.57 GHz, 5.9 GHz, 6.2 GHz, 6.3 GHz, 6.58 GHz and 6.98 GHz, respectively, or maximum rise by 22%. Advantage of the PIN diodes configurations is that the magnetic and electric fields are concentrated near the PIN diode.

Figure 14 shows the equivalent circuit of the proposed UWB BPF with reconfigurable notch band implementation by using RF PIN diode 4005 in outer U-DGS by ADS simulator [21]. Fig. 15 shows the simulated and measured frequency responses of S-parameters and the group delays. It is shown that the measured insertion loss is less than

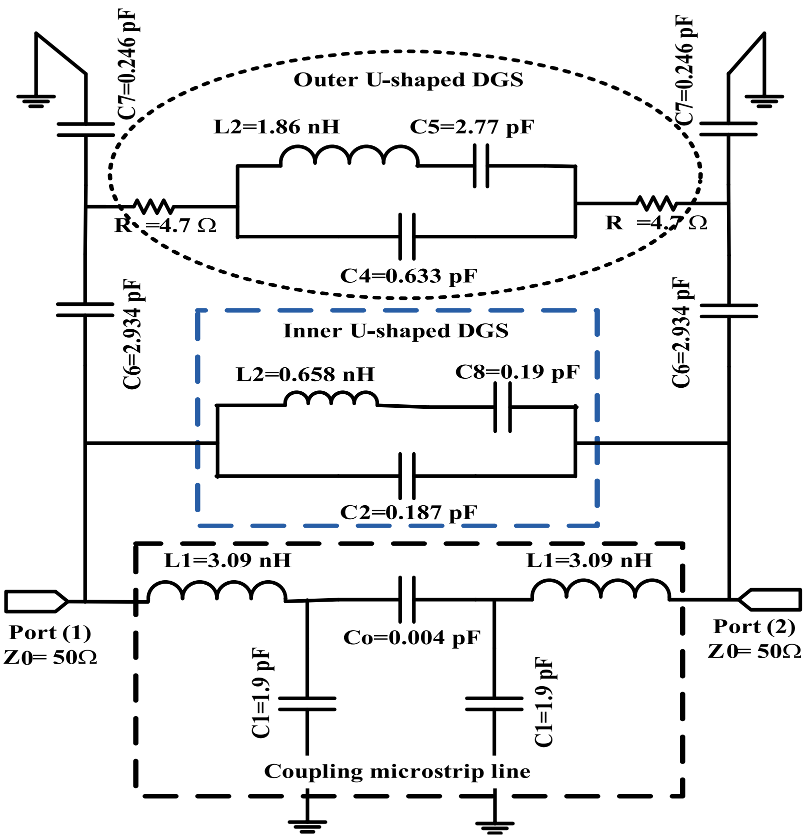


Figure 14. Equivalent circuit of the proposed UWB BPF with reconfigurable notch band implementation by using RF PIN diode in outer U-DGS by ADS simulator [21].

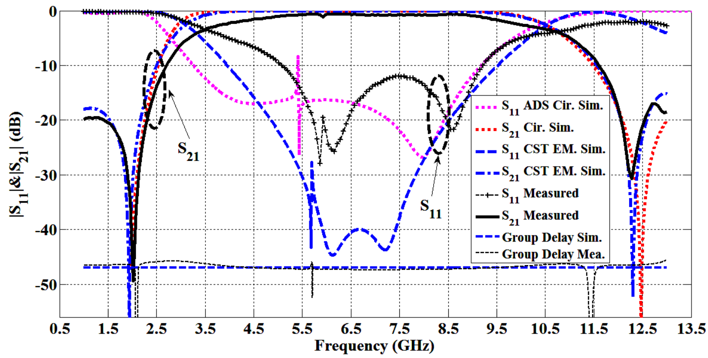


Figure 15. EM-simulated, equivalent-circuit modelled and measured S-parameters of UWB BPF with PIN diode in outer U-DGS.

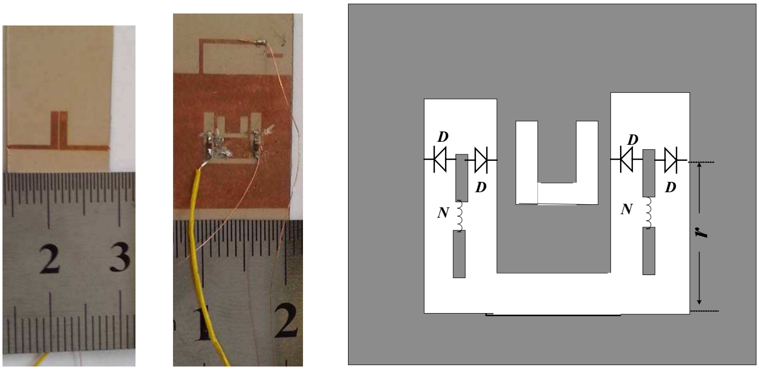


Figure 16. (a) Photograph of the final circuit top view, (b) bottom view, and (c) the filter with pads for switches soldering.

1 dB from 4.4 to 9.5 GHz and lowers than 1.8 dB over the frequency range of 3.9 to 10 GHz, which includes the loss of two SMA connectors in substrate test fixtures and loss of four PIN diode as shown in Fig. 13 in the measurement, the 3 dB UWB passband is from 3.4 to 10.9 GHz, or 112% bandwidth centered at 6.85 GHz. Meanwhile, the measured group delay is nearly flat in the passband.

The bias lines are designed for providing the DC voltage. Fig. 16 depicts the fabricated filter, when +1.2 volts DC is applied to each PIN diode, it becomes a forward bias (ON state) while when no voltages is applied, the PIN diode becomes in OFF states. For soldering the

PIN diodes, we make pads at the switch terminals with dimensions $0.15 * 0.2$ mm as shown in Fig. 16(c). From the datasheet, the channel bandwidth of the HPND-4005 PIN diode is 0.32 mm, hence the space between the pads is 0.32 mm. Electrically conductive epoxy materials were used for soldering the switches.

6. RESULTS AND DISCUSSION

The designed filters were fabricated on a high frequency printed circuit board RT/Duroid 3010 with a dielectric constant of $\varepsilon_r = 10.2$, a thickness h of 0.635 mm and a loss tangent of 0.0025. After optimization, the dimensions of the proposed UWB bandpass filter with notch band are listed in Table 1.

Table 1. List of the dimensions of the proposed UWB bandpass filter with notch band.

Item	L	S	g	W_o	L_1	S_1	W_1	D_1	L_2	S_2	W_2	D_2	G	S_3
Dim. (mm)	5	1	0.25	0.58	6.1	1.2	0.6	6.7	1.5	1	0.5	3.8	2.5	1

The simulation and measurement of 3-dB bandwidth extends from 2.5 GHz to 10.86 GHz, representing a FBW of 106% at the center frequency of 6.85 GHz and the size of this filter is 6.7 mm × 6.5 mm, respectively. From the measurement, there are three-pole responses and the filter possesses a good selectivity at passband stopband edges. The group delay shown in Figs. 4(b), 7(b) and 15 are measured curves using the Agilent 7819ES vector network analyzer with range 50 MHz to 13.5GH and facility is inherent in it the UWB filter with notch at 5.5 GHz corresponding to the simulated results show center notch band frequency in the passband with 27 dB with FBW of about 3.6%, at a center frequency of about 5.5 GHz. The measured attenuation at the center of the notched band is more than 20 dB. By using lumped capacitor in inner U-DGS the notched band is controlled and a curve fitting formula is derived to show the effect of the capacitor value on the center frequency of the notched band, which is decreased by 56.7%.

A notched band of WLAN at 5.5 GHz and RF telemetry at 4.3 GHz with capacitors value of 0.1 pF was obtained. By loading 22 pF lumped capacitors in the outer U-DGS BPF, the notched frequency rises by 17% when changing the distance K from 4.5 mm to 2 mm. This capacitor improves the quality factor and has the effect of reducing the filter size by 72% as compared to other filters in Table 2. HPND 4005 PIN diode is used which has low series resistance, low capacitance, low-cost, low-losses, easily modeled by lumped elements, occupies less space

Table 2. Comparison among various UWB BPFs.

Parameters / Reference	[7] 2008	[8] 2009	[23] 2009	[19] 2009
Permittivity	10.7	2.2	10.2	10.2
Thickness (mm)	1.27	0.507	0.635	0.635
Loss tangent	0.0023	0.0027	0.0023	0.0023
Passband (GHz)	2.7–10.7	3.1–8.7	3.1–10.6	3.1–10.4
Notch band	5.47	5.5	5.5	5.6
Etched size (mm * mm)	36×16	25×25	25.4×6.4	11×8
Relative size	12.456	13.5	3.608	2.81
Size reduction (%)	81.8%	82.8%	72.2%	49%
Parameters / Reference	**[11] 2011**	**[15] 2012**	**[26] 2010**	**This work**
Permittivity	2.2	2.2	4.4	10.2
Thickness (mm)	1	0.787	0.7	0.635
Loss tangent	0.002	0.002	0.0245	0.0023
Passband (GHz)	2.8–10.8	3.87–11.527	3.1–10.6	2.5–10.86
Notch band	5.3	5.75	5.5	5.5
Etched size (mm * mm)	35×20	21×12	26×55	6.7×6.5
Relative size	15.1	5.4	16	1
Size reduction (%)	93.5%	71.4%	87.4%	—

and high frequency coverage (up to 12 GHz) as compared to other PIN diodes. The RF PIN diode switches in the outer U-DGS either control the notched band from 5.25 GHz to 6.85 GHz which means raising the band notch center by 27% or removing the notched band according to its positions. By using two switches RF PIN diodes at certain position in outer U-DGS, the notched band was removed over all the operating band. The measured insertion loss is less than 1 dB from 4.4 to 9.5 GHz and lowers than 1.8 dB over the frequency range of 3.9 to 10.7 GHz. Finally, measured results demonstrated good agreement with the circuit and EM-simulated results. The slight difference in the simulated frequency responses compared to the measured ones are due to the fabrication tolerance, difficulty in alignment between the top and bottom sides because the filter size is very small and mismatch between the feed lines and substrate test fixture connectors. In addition to some numerical errors cause by the simulations when meshing is done. The performance of the proposed filter along with the parameters of other UWB BPFs with only one notch band in the previous publication are compared in Table 1. The results show that the presented UWB BPF with notch band structure has the advantage of miniaturization.

7. CONCLUSION

In this paper, the design and implementation of a new miniaturized UWB BPF with tuned notch bands was proposed. A compactness of up to 72% compared to the other filters using U-DGS slot without lumpedcapacitor was obtained. The frequency reduction of the resonator had been achieved due to the increase in the effective capacitance of the resonator. Reconfigurabilty of this filter was achieved by variable values of capacitors. Curve fitting to select the notched frequency was carried out and the frequency reduction of the resonator has been achieved owing to the increase in the effective capacitance of the resonators. The resonant frequency drops by 57.77% by increasing the lumpedcapacitor from 0.01 to 0.6 pF. An UWB BPF with switchable notched band of WLAN at 5.5 GHz to RF altimeters of 4.32 GHz with 0.1 pF loaded in the inner U-DGS was implemented. While changing the position of 22 pF capacitor in outer U-DGS the resonantfrequency rises by 17% and gets UWB at $K = 3.2$ mm. the filter returns to UWB by using 22 pF loaded in the outer U-DGS. Another reconfigurable filter design was done by RF PIN diode to control the notched frequency from 5.25 GHz to 6.89 GHz which means rising the band notch center by 27% or removing the band notched according to its positions in the same size to obtain UWB BPF from 3.4 to 10.9 GHz, or 112% bandwidth centered at 6.85 GHz and the two transmission zeros are observable at 2 GHz and 12.5 GHz, respectively. Also, the RF PIN diode in the outer U-DGS acts as switch between applications of UWB BPF with notched band of the WLAN for IEEE 802.11 a/h at 5.5 GHz and RFID ISO 18000 series part5 in microwave (MW) which sets 5.8 GHz, 6.1 GHz and 6.8 GHz, and the other bands. This paper shows miniaturized filter with size 6.7 mm $\times$ 6.5 mm occupying a circuit area of about $0.41\lambda_g$ by $0.39\lambda_g$. Validity of the proposed filters and their equivalent circuits are achieved by demonstrating the bandpass filters design examples. Finally, measured results demonstrated good agreement with the circuit and EM-simulated results.

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