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Electronically switchable lowpass/bandpass Filter with Controlled Bandwidth using Pin Diode-Loaded stubs

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Abstract— Electronically switchable and reconfigurable microwave devices such as filters are in great demand for wireless communication systems. The switchable Lowpass/Bandpass filter (LPF/BPF) can be used to control the spectrum of proposed signals and support multiple information channels. The PIN diodes are used to achieve exchange between the lowpass filter and bandpass filter with tunable bandwidth. The lowpass filter concept is demonstrated by ninth-order Chebyshev-type using stepped impedance resonators. as the number of diodes used increase as the roll off at the two 3dB frequency for bandpass is modified, with a little decrease in the bandwidth due to the shift of lower 3dB frequency to higher value, while the upper 3-dB frequency is nearly remain constant around 11 GHz. The switchable LPF/BPF is designed, fabricated and measured. Experimental results are in good agreement with the simulated results for each of the lowpass and bandpass filters response.

Index Terms— Lowpass filter, Bandpass filter, RF PIN diode, stepped impedance resonators (SIRs), switchable.

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1 Introduction

THE electronically switchable and reconfigurable microwave devices that using PIN-diodes are essential components in the front-end circuits, cognitive radios, and wireless communication systems. Articles [1]-[8] describe the integrating of diodes with bandpass filters to reduce the circuit size and achieve the switch mechanism with favourable selectivity. In [1], the diode loaded resonators were used to design single-band wide stopband switchable filters. The switchable multi-Mode bandpass filters given in [2-3] were successfully realized in monolithic microwave integrated circuit (MMIC) technology. In [4], the switchable parallel coupled line bandpass filter used diodes loaded to turn on/off the passband and produce the transmission zeros to improving the stopband responses. For switching between different multiband applications, a compact dual-band bandpass filter was proposed in [5]-[6]. The authors in [7]-[8] designed two independent filters to switch between them to achieves the reconfigurable on-state frequency responses. At [9], a switchable filter between two different order Chebyshev responses was described. Based on the theory of Chebyshev response, the selectivity and stopband rejection level in the proposed switching circuit can be easily predicted before designing each filter. The ultra-wideband (UWB) technology with operating band (3.1–10.6 GHz) is an attractive technology for local area networks (LAN), positioning and tracking for antennas, phase shifter and radar systems [10]. Ultra-wideband applications attract increasing attention, both in industry and academia, due to increasing levels of sophistication and demand for advanced communication systems. It has the characteristics of low cost, low weight, high data transmission rate and very low power consumption. 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.

In this work, a new class of microwave planar filters with switchable between lowpass and bandpass filter is given. The switchable lowpass/bandpass filter was achieved using Chebyshev type and short circuit stubs loaded by PIN diodes. The bandwidth of the bandpass filter response can be controlled with the number of PIN diodes loaded on short circuit stubs. The filter was design on RT/Duroid 5880 (ε_r=2.2, h=0.7874 mm, tan δ=0.0009) and simulated using readymade CST software package. The measurement of the realized filter are in good agreement with the simulated results.

2 Theory and Circuit Design

The design of lowpass filter involves two main steps: one is to select an appropriate lowpass prototype (g values), second the transformation of g values to lumped L–C elements for the desired cutoff frequency and the desired source impedances. The prototype g-values for the lowpass prototype with Chebyshev filter can calculated as follows [9]:

$$g_0 = 1.0 \qquad (1)$$

$$g_i = \frac{1}{g_{i-1}} \frac{4\sin\left((2i-1)\pi/2n\right).\sin\left((2i-3)\pi/2n\right)}{\gamma^2 + \sin^2\left((i-1)\pi/n\right)}, \quad i=1,2,3.. \qquad (2)$$

$$g_{i+1} = \begin{cases} 1.0 & for \quad n \quad odd \\ \coth^2(\beta/4) & for \quad n \quad even \end{cases} \qquad (3)$$

$$\beta = \ln\left[Coth(L_{AR}/17.37)\right] \qquad (4)$$

$$\gamma = \sinh(\beta/2n) \qquad (5)$$

Where n is the number of g-values which can be defined as

$$n \ge \frac{\cosh^{-1}\sqrt{(10^{0.1L_{AS}}-1)/(10^{0.1L_{AR}}-1)}}{\cosh^{-1}\Omega_S} \qquad (6)$$

$$\Omega_S = \omega_S / \omega_C \qquad (7)$$

Where, f_c is the cutoff frequency, f_S is the frequency at stopped attenuation, L_{AS} is the stopped attenuation in (dB) and L_{AR} is the ripple value in (dB). As a design example, choose the cut-off frequency as 11.2 GHz and the attenuation at F_s=14.5 GHz

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is L_{AS}=30 dB, while the ripple is L_{AR}=0.05 dB. Using the above equations, the number of filter elements will be nine (n=9) and the g values for the prototype will be as given in Tab. 1. Make a transformation for the g value to the lowpass lumped L-C elements based on the following equations [9]:

$$L_i = (g_i Z_o / \omega_C) \quad (8.a)$$

$$C_i = (g_i / \omega_C Z_o) \quad (8.b)$$

So the corresponding lumped inductances and capacitances (L-C) values will be as shown in Tab. 1. With representing the inductance as high impedance transmission line (Z_H=130Ω, W_1=0.36 mm), the corresponding lengths will based on the following equation:

$$l_i = (\lambda_H l 2\pi) \sin^{-1}(\omega_c L_i / Z_H) \quad (9)$$

With representing the capacitor with low impedance transmission line (Z_L=25Ω, W_2=6.121 mm), the corresponding lengths will based on the following equation:

$$l_i = (\lambda_L / 2\pi) \sin^{-1}(\omega_c C_i Z_L) \quad (10)$$

For the design on RT/Duroid 5880 Teflon substrate (ε_r=2.2, h=0.7874 mm and tan δ=0.0009), the corresponding lengths for each of inductance and capacitance are calculated using Eqs. (9-10). Due to microstrip tolerance and limited ratio of (Z_H/ Z_L) that can be achieved with using microstrip technology, the values of L and C are optimized to achieve the required performance as shown in Tab.1. The layout of the stepped impedance lowpass filter is shown in Fig.1. By ADS and CST, the simulation results for the designed lowpass filter gives (-0.245 dB), (<-17.dB) as insertion land return loss respectively, in the passband region. The filter achieve good stopband with cutoff frequency of 11.2 GHz and 10.36 dB/GHz rolloff of, Fig.2.

TABLE 1: THE G-VALUES AND CORESSPONDING L-C VALUES

g- values	Regular L-C values	Optimized L-C values	Length (mm)
g1=1.0499	L1=0.746 nH	L1=0.4397nH	*l*1=0.836
g2=1.4611	C2=0.4152pF	C2=0.2447pF	*l*2=1.461
g3=2.0065	L3=1.4257nH	L3=0.8403 nH	*l*3=1.798
g4=1.6698	C4=0.4745pF	C4=0.2797 pF	*l*4=1.763
g5=2.0858	L5=1.482 nH	L5=0.8735 nH	*l*5=1.904
g6=1.6696	C6=0.4745pF	C6=0.2797 pF	*l*4=1.763
g7=2.0065	L7=1.4257nH	L7=0.8403nH	*l*3=1.798
g8=1.4611	C8=0.4155 pF	C8=0.2447 PF	*l*2=1.462
g9=1.0499	L9=0.746 nH	L9=0.4397 nH	*l*1=0.836

3 DESIGN OF PROPOSED SWITCHABLE FILTER

In this section, the implementation and operation of the switchable LPF/BPF using PIN diodes and short circuited stubs will be described, Fig.3. The PIN diode used in the design is HPND 4005[11], where its equivalent circuit is shown in Fig.4 (a), where L_s = 0.7 nH, R_{on} =4.7 Ω and C_{off} =0.017 pF which are the parasitic series inductor, forward biased resistor and reverse biased capacitor, respectively. The diode characteristics is stable up to 12 GHz which is suitable for the ultra wideband range. When the diode terminals is connected with metal wire leads for biasing, the response may be changed, so we use the bias Tee for biasing the diodes without needs to metal terminals. Figure 4 (b) shows the Bias Tee electrical scheme [12].

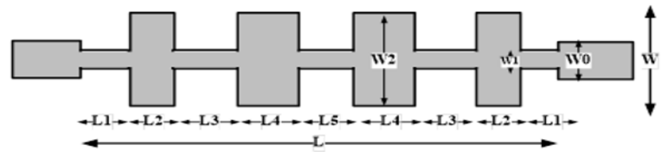

Figure 1: Chebyshev stepped impedance lowpass filter layout

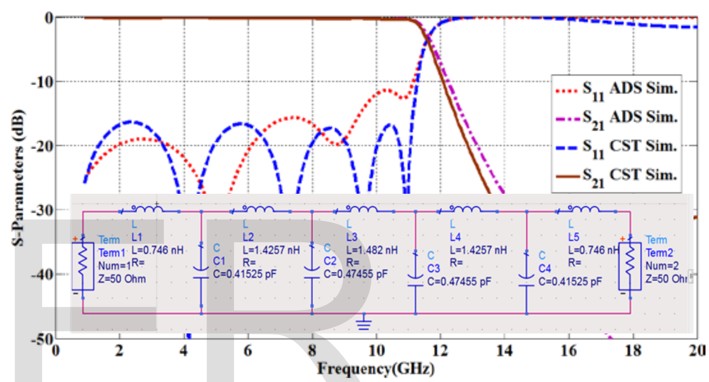

Figure 2: The simulated S-parameters and the ADS results of the LPF

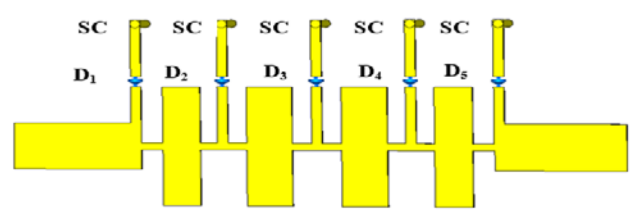

Figure3: the LPF/BPF performance using RF-PIN diodes

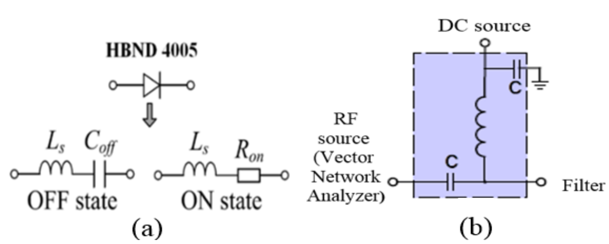

Figure 4: (a) Equivalent circuit of RF PIN diode HPND 4005
(b) Electrical scheme of bias Tee.

As an example, when using diode-3 only while other diodes are off it response is a lowpass filter for its OFF state with passband up to the cutoff frequency at 11.14 GHz with (S_{11}<-13.8dB) overall the passband, Fig.5 (a). When the diode-3 is in

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ON state, the response is bandpass filter extend from 1.4 GHs up to 11.14 GHz with (S_{11}<-11.5dB) over all the range, Fig.5 (b). This design suffers from low rolloff factor at the 1st 3-dB frequency for the bandpass filter response. The different situations for using two, three, and all diodes and their response for ON and OFF states are shown in Fig.5, and tabulated in Table 2. From the results, as the number of diodes used increase as the roll off at the two 3dB frequency for bandpass is modified, with a little decrease in the band width due to the shift of 1st 3dB frequency to higher value.

4 Measurement of Three Diodes Case

As an example to validate the above discussion, the case when using three pin diodes was measured. The simulated and the measured results when the three pin diodes (D2, D3, D4) are in the OFF state are shown in Fig. 6 (a), where the measured filter response is lowpass filter with 11 GHZ cutoff frequency. The return loss in the pass band is approximately less than -14dB overall the range. When these diodes are ON state, the realized filter give BPF response from 3.8 GHz to 11.75 GHz, with return loos (S_{11}<-10dB) overall the operating band. There are four poles in the measured passband which are at 5.4, 7.46, 8.96 and 10.5GHz, respectively. The realized BPF response exhibits ultra-wide stopband with at least 15 dB rejection from 11.2 GHz up to 20 GHz. The deviation between the simulated and measured results may be attributed to the resistances of the PIN diodes, the losses due to the short circuit stubs and mismatch between filter ends and connectors and also due to the tolerance in fabrications. The group delay of this UWB filter is shown in Fig. 7(a), where it is constant with little variation less than 2ns in the operating bandwidth. Figure 7(b) shown the photo of the fabricated filter three PIN diodes with bias Tee.

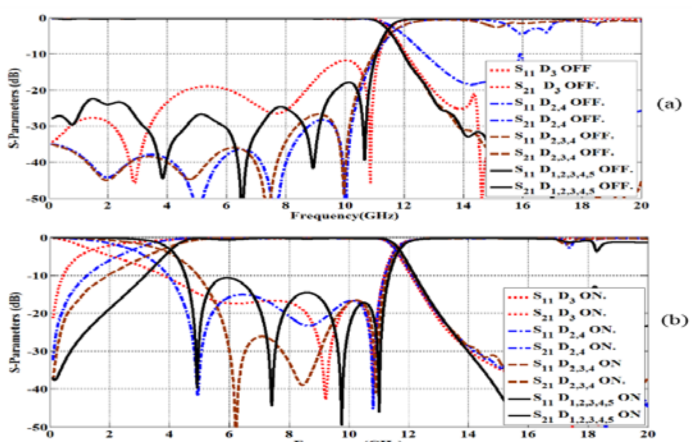

Figure 5: the lowpass/bandpass filter response for diodes OFF/On states

5 Comparison with Other Literatures

The results of the realized filter in this article was compared with other previous literatures [2]-[6], where Table 3 illustrated such comparsiosn. The presented filter can select multi-function lowpass-bandpass responses for receiving multiband signals. The overall size of the realized filter is 13.7 mm x 7.96 mm (0.41 λ_g x0.24 λ_g) with size reduction to the other published literatures [2]-[6].

TABLE 2: Diodes situations for different On/Off states

Diodes used	Diodes state	Response	lower F_{3dB} (GHz)	Upper F_{3dB} (GHz)
D_3 only Other off	Off	LPF	----	11.2
	On	BPF	1.4	11.55
D_2,D_4 only Other off	Off	LPF	----	11.78
	On	BPF	2.75	11.78
D_2,D_3,D_4 only Other off	Off	LPF	----	11.6
	On	BPF	3.65	11.6
All diodes	Off	LPF	----	11.45
	On	BPF	4.15	11.45

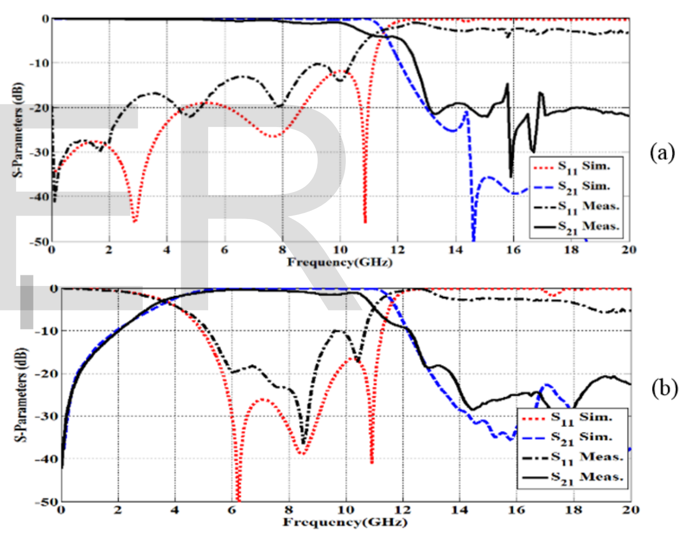

Figure 6: Simulated and measured S-parameters when the three diode are (a) OFF (b) ON

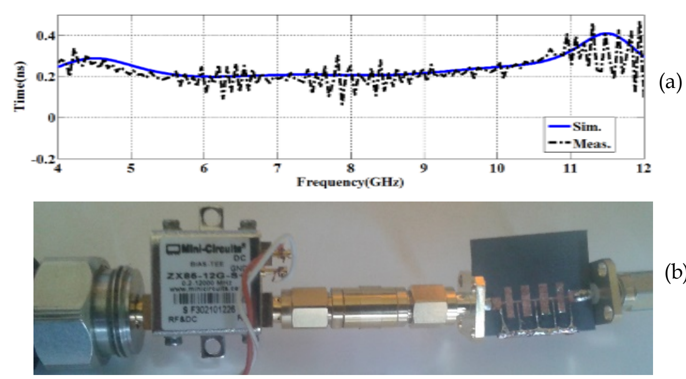

Figure7: (a) Group delay of the bandpass filter (b) Photo of the fabricated filter with bias Tee connected to VNA

6 Conclusion

The PIN diodes are used to achieve exchange between the lowpass filter and bandpass filter with tunable bandwidth. As the number of the pin diodes used increase as the roll-off for the lower and upper 3dB frequency is improved with decrease in the bandwidth due to the shift of the lower frequency to higher value. As an example the case when using three pin diodes was realized and measured. The experimental results are in good agreement with the simulated results for each of the lowpass and bandpass filters.

Table3: Comparison between the realized filter and other published literature [2]-[6].

Ref.	response	F_o GHZ	Size mm^2	Size by $(\lambda_g)^2$	Size/ other	ε_r/h (mm)
[2]	BPF BSF	2-4	22.5x24	0.76 x0.8	51.2%	2.2/0.5
[4]	LPF BPF	2-3.5	30.2x28	1.6 x0.95	87%	3.15/1.5
[5]	BPF BSF	3.2	26 x15	0.52 x0.27	64.2%	10.2/63
[6]	BSF BPF	2.8	32 x25	1.35 x1.03	86%	3.2/0.76
Our work	LPF BPF	6.85	13.7 x8	0.42 x0.25	-----	2.2/0.78

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