Microstrip Switchable Bandstop Filter using PIN Diodes with Precise Frequency and Bandwidth Control

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***Abstract*— In this paper a switchable bandstop filter able to switch between two different central frequency states while precisely maintaining a fixed bandwidth is presented. The filter topology allows precise control over the design parameters frequency and bandwidth, achieved by choosing adequate resonator sections which are switched by PIN diodes to obtain two discreet states. The central frequency control was obtained by modifying resonator length. Bandwidth control was achieved by choosing a resonator width and controlling the normalized reactance slope parameter of a decoupling resonator by means of a switchable resonator extension. The filter was designed to have center frequencies of 2 and 1.5 GHz both having an 8% fractional bandwidth. The comparison between simulations and measurements showed a central frequency deviation of 4 MHz for the 2 GHz frequency response, and a deviation of 2 MHz for the 1.5 GHz frequency response. The fractional bandwidth deviation for the 2 GHz filter response was 0.67%, while at 1.5 GHz a 0.4% deviation was observed. The simulation and measured responses are in very good agreement.**

I. INTRODUCTION

Switchable filters can reduce the complexity of a system by allowing filter re-configurability instead of having switched filter banks; most designs found through literature focus on central frequency control, however for the different central frequency states, the bandwidth is not included as a design parameter. The filter described in this paper, is capable of having two central frequency states, where precise bandwidth control is used to fix filter central frequency states to an 8% fractional bandwidth. In [1],[2] tunable bandstop filters using varactor loaded resonators are presented. The filters are capable of tuning their center frequency; however the stopband bandwidths of the filters increase rapidly for different filter central frequency states. The microstrip bandstop filter discussed in [3] uses a tuning plate with a tri-layer thermal actuator to achieve re-configurability; the filter has frequency operation range from 6.09 to 5.75 GHz, without filter bandwidth control. In [4] a tunable bandstop filter was designed using electromagnetic band gap structures on CPW transmission lines, MEMS bridges were used as tuning elements, a variable central frequency from 17 to 22.5 GHz was obtained, the bandwidth progressively changes with filter center frequency. The bandstop filter in [5] uses RF MEMS switches, the filter is based on microstrip transmission lines with radial stubs, presenting a tuning rage form 8 to 15 GHz, however the bandwidth has arbitrary values at each center frequency. In [6] a bandstop filter based on quarter wavelength stubs is discussed, the filter is based on cantilever MEMS switches, central frequencies with different bandwidths were obtained from 39 to 58 GHz. In [7],[8] PIN diodes have been used to control filter central frequency, and varactors provide a continuously tuned bandwidth at a given filter central frequency. The filter has a frequency range from 0.5 to 2 GHz with bandwidths in the range of 30 to 42%. The microstrip filter presented in this paper consists of a main microstrip transmission line, and two switchable decoupling half-wavelength resonators. Center frequency is controlled by adjusting the length of the switchable resonators; on the other hand, a section of transmission line on the resonators allows the adjustment of the normalized reactance slope parameter of the resonator to the main transmission line [9], to control the fractional bandwidth at each center frequency. The objective of this filter was to produce central frequencies of 1.5 and 2 GHz, both having a same fractional bandwidth of 8%, this was achieved using the proposed switchable filter topology. It can be noted that design parameters can be used to produce different bandwidths and center frequencies using the topology discussed in this paper. This paper is divided in four sections, section II contains a discussion of the proposed filter topology, describing how the filter design parameters frequency and bandwidth were controlled. Section III contains a discussion of the simulated and measured filter responses and bias circuitry. Finally section IV gives an overall conclusion of this work.

II. SWITCHABLE BANDSTOP FILTER TOPOLOGY

The design of a narrow bandstop filter can be based on the normalized reactance slope parameter of individual resonators as discussed in [9]. Taking the filter terminating impedance

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equal to the characteristic impedance of the immittance inverters results in the following equation:

$$\frac{x_i}{Z_0} = \frac{g_0}{g_1 \Omega_C FBW} \quad (1)$$

Where the g values correspond to the lowpass Chebyshev prototype filter, Ω_C is the angular cutoff frequency, FBW is the fractional bandwidth for the filter, and x_i/Z_0 is the normalized reactance slope parameter of an individual resonator coupled to the main transmission line. The lowpass prototype g values used for the two resonator filter are summarized in table I for a 0.1 dB passband ripple.

TABLE I
LOW PASS ELEMENT VALUES FOR THE CHEBYSHEV PROTOTYPE FILTER

g_0	g_1	g_2	g_3
1.0	0.8431	0.6220	1.3554

The plot of eq. (1) is shown on Fig. 1 using the filter design parameters, where an appropriate value of x_i/Z_0 can be obtained to achieve the 8% fractional bandwidth. To obtain x_i/Z_0 using a simulator [10], a single resonator coupled to the main line must be simulated as discussed in [9], and then an appropriate value of x_i/Z_0 can be determined by finding the appropriate spacing between the resonator and the main line using the following expression:

$$\frac{x_i}{Z_0} = \frac{f_0}{2\Delta f_{3dB}} \quad (2)$$

Where f_o is the resonator center frequency and Δf_{3dB} is the 3dB bandwidth produced by the decoupling resonator.

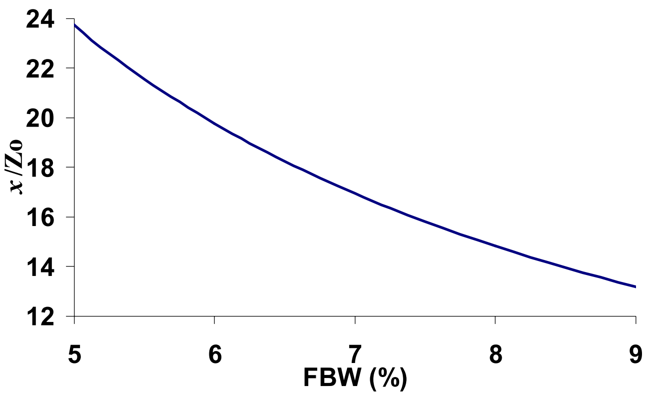

Fig. 1 Fractional bandwidth vs normalized reactance slope parameter of a single resonator coupled to the main line.

It is apparent from Fig. 1 that larger fractional bandwidths require smaller x_i/Z_0 values, which results on small distances between the main line and the resonators. Depending on photolithographic resolution, this dimension can become critical for a given case, e.g. for the filter discussed in this paper, a minimum achievable spacing between the main line and resonator with good resolution was defined as a 100 µm gap. From Fig. 2 we demonstrate that x_i/Z_0 can also be adjusted by varying resonator width, this parameter was used to fix x_i/Z_0 for the 8% fractional bandwidth, allowing the filter to be realizable using standard photolithographic techniques, while maintaining adequate unloaded quality factor values for the resonators.

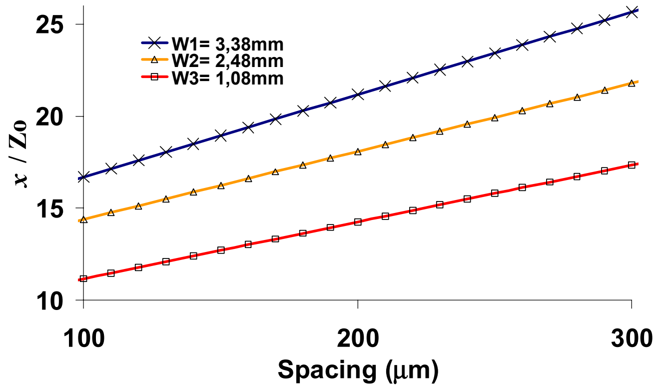

Fig. 2 Resonator spacing from the main transmission line vs normalized reactance slope parameter for different resonator widths

Fig. 3 shows the two pole switchable bandstop filter topology using four PIN diodes. In this filter topology all PIN diodes are reverse biased to produce a filter central frequency of 2 GHz, and all PIN diodes when forward biased produce the 1.5 GHz central frequency.

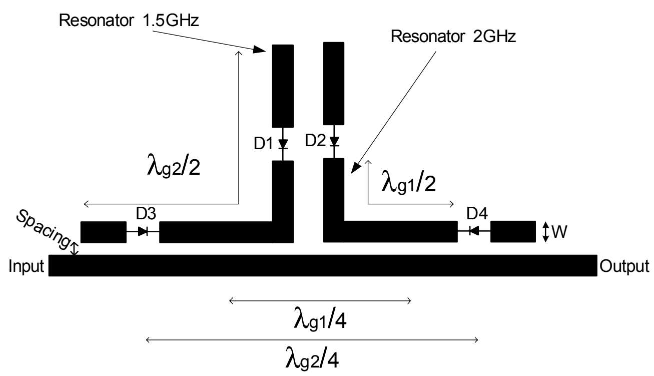

Fig. 3 Two-pole Switchable bandstop filter

The relation between the normalized reactance slope parameter and the spacing between the main transmission line and both resonators is shown in Fig. 4. The length of the switchable resonator extensions in Fig. 3 are chosen to produce two central frequency states with a fixed fractional bandwidth. By altering these resonator extensions, other values of bandwidth and central frequency can be obtained. It is evident from Fig. 4 that for the two filter states, the value of x_i/Z_0 at both frequencies is approximately the same, thus a fixed fractional bandwidth will be obtained for both filter central frequency states.

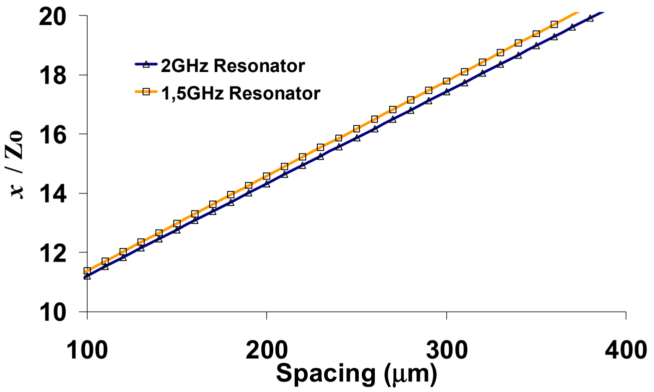

Fig. 4 Normalized reactance slope parameter vs resonator spacing from the main transmission line.

III. Simulated and Experimental Results

Using the technique describe above, a bandstop filter was designed with central frequencies of 1.5 and 2 GHz. The fractional bandwidth of the design is fixed to 8%. A photograph of the fabricated filter is shown in Fig. 5.

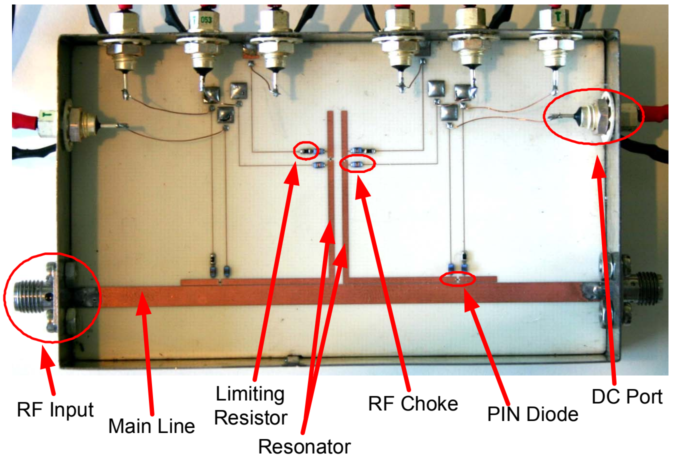

Fig. 5 Photograph of the switchable bandstop filter

A 1.524 mm thick Rogers substrate having a 30µm cooper metallization was used for the design. The substrate has a dielectric constant of 3.55, and a loss tangent of 0.0021. The diodes were HPND-4028 Avago Technologies beam lead PIN diodes. The layout including the DC bias lines was fabricated using standard photolithographic techniques. The Bias network consisted of a choke inductor to supply DC bias to the microwave circuit [11]. The inductor has a self-resonance at 1.7 GHz and provides isolation better than 20 dB at the frequencies of interest. Due to the high isolation of the choke inductor, the microwave is not influenced by the termination on port DC shown on Fig. 5. The current on each diode was limited to 10 mA by placing a 1 kΩ series resistance in the forward bias state, a voltage of -10 V was supplied in the reverse bias state. The lumped element models for the PIN diodes used in simulations, for both forward and reverse bias states are similar to the ones exposed in [12]. The forward "on" state of the diode was equivalent to a 3 Ω contact resistance of the anode and cathode, in series with a 6 pF junction and diffusion capacitance across the PIN diode's depletion region. The reverse "off" state of the PIN diode was modeled as a 45 fF capacitance of the intrinsic region. Full wave simulations of the filter topology were made including lumped element models for the PIN diodes. The filter was optimized using [10] to accomplish the two discrete central frequencies. The measurements were taken using a HP8510C network analyzer. Table II contains a comparison between simulated and measured results, where a good agreement in terms of central frequency and bandwidth was obtained.

TABLE II
Simulated and Measured Results

	f_1	FBW_1	f_2	FBW_2
Simulated	1.542GHz	8.5%	2.004GHz	8.08%
Measured	1.540GHz	8.1%	2.000GHz	8.75%

A comparison between the simulated and measured responses of the switchable bandstop filter in the "off" state (with the four diodes in reverse polarization), is shown in Figs. 6 and 7. Fig. 6 contains S_{21} where a central frequency deviation of 4 MHz between simulations and experiment was found.

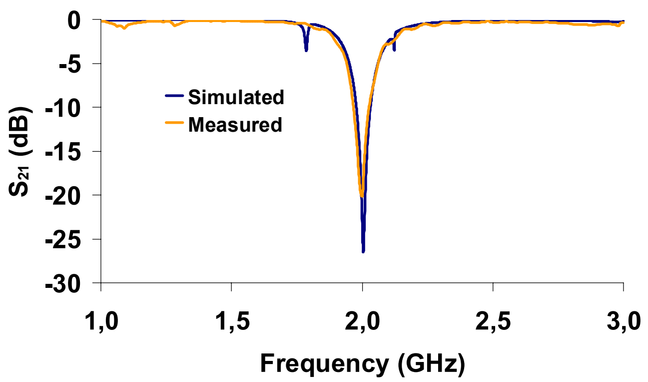

Fig. 6 Simulated and measured S_{21} (off state)

The difference between the simulated and measured fractional bandwidth was 0.67%. Fig. 7 contains S_{11} for the filter "off" state. Good agreement between the simulation and experiment was obtained. The measured and simulated results in the "on" state (with the four diodes in forward polarization) are shown in Figs. 8 and 9, Fig. 8 contains S_{21} where a central frequency deviation of 2 MHz between simulations and experiment was found. The difference between the simulated and measured fractional bandwidth was 0.4%. Fig 9 contains S_{11}, for the filter "on" state. Good agreement between the simulation and experiment was obtained.

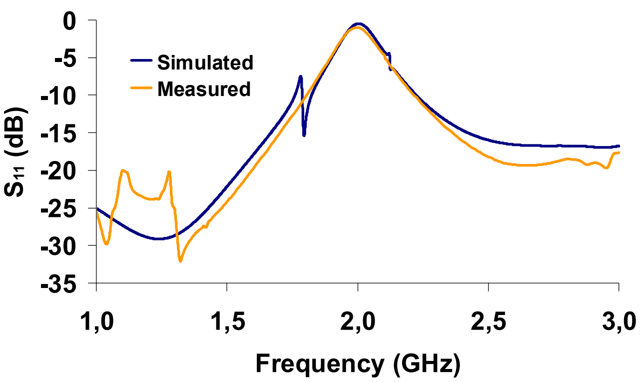

Fig. 7 Simulated and measured S_{11} (off state)

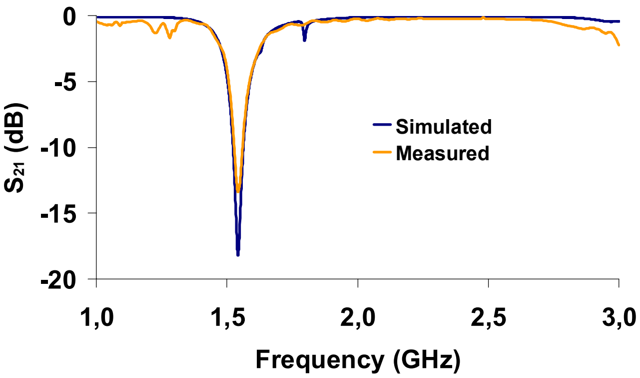

Fig. 8 Simulated and measured S_{21} (on state)

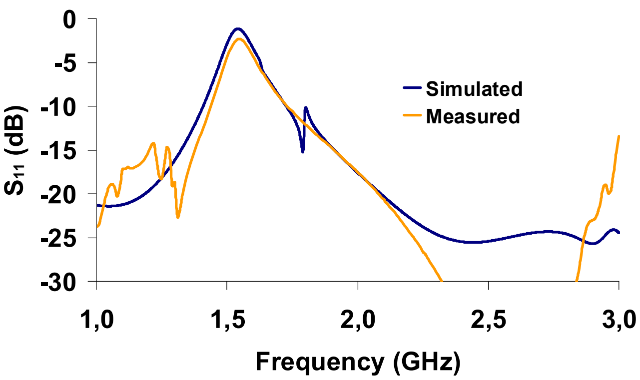

Fig. 9 Simulated and measured S_{11} (on state)

IV. Conclusions

A switchable bandstop filter with two discrete central frequencies having the same fractional bandwidth has been demonstrated. Bandwidth control for the filter has been obtained by controlling the normalized reactance slope parameter of the resonators by means of a switchable resonator extension and defining resonator width. A very good agreement between simulations and measurements has been obtained. The filter topology also presents the possibility of producing other frequencies and bandwidths which can be controlled independently by choosing adequate resonator dimensions.

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