Novel Tunable Bandstop Resonators in SIW Technology and Their Application to a Dual-Bandstop Filter with One Tunable Stopband

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***Abstract*— Two novel tunable bandstop resonators in substrate integrated waveguide (SIW) technology are presented: a ridged SIW resonator and an open-ended coplanar waveguide (CPW) resonator that is etched into the SIW's top metallization. The ridged SIW resonator shows a tuning range of 200 MHz at 5.54 GHz. The CPW resonator has a tuning range of 600 MHz at 3.8 GHz. The two bandstop resonators are combined to design a dual-band bandstop filter with one tunable stopband. Measured results confirm that the tunable bandstop circuits presented in this letter can be effectively used in reconfigurable SIW systems.**

***Index Terms*— Coplanar waveguide (CPW) resonator, dual-bandstop filter, ridged SIW resonator, substrate integrated waveguide (SIW), tunable filter.**

I. INTRODUCTION

GREAT effort has been recently put into the implementation of fully reconfigurable and multi-purpose RF and microwave systems in order to develop universal high-frequency transceiver modules. Post-fabrication tuning is necessary in many cases to fine-tune the operating frequency of microwave devices to the desired specifications. Unlike multi-band/wideband microwave structures, tunable devices have better isolation and can be designed to be immune to cross talk from neighboring channels and to tune-out interference. Moreover, serving several frequency bands should not decrease quality factors and selectivity of devices.

The majority of published papers on tunable filters focus on microstrip technology. Depending on operating frequency, microstrip filters have low quality (Q) factors which degrade even more by integrating tuning elements. Theses filters cannot be used in stringent applications such as satellites or base stations. Recent works on silicon micro-machined and tunable substrate integrated waveguide (SIW) filters [1]–[4] have better Q, but their quality factor is not comparable with those of high-Q 3D coaxial, waveguide and dielectric resonator tunable filters [5].Tunable SIW band*pass* microwave filters are investigated in several papers, and a recent review of all these techniques is presented in [6]. However, only a handful of band*stop* SIW filters are reported in the literature, and all of them use evanescent-mode SIW cavities loaded with metallic posts at their centers, such as those reported in [7]–[10].

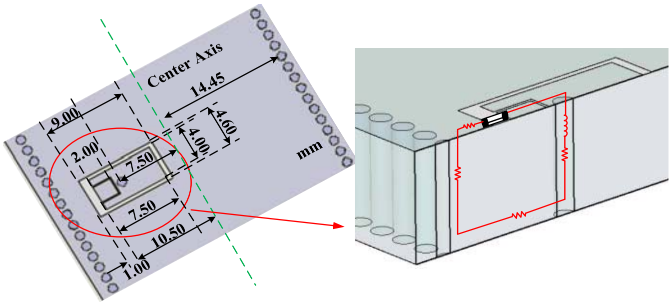

Fig. 1. Tunable ridged SIW resonator.

In this letter, we introduce two different and novel tunable band*stop* resonators, namely ridged SIW and open-ended CPW, using varactor diodes. A dual-band bandstop filter with one tunable stopband is presented by employing these two resonators. The filters are fabricated and measured to verify the design approaches.

II. TUNABLE RIDGED SIW RESONATOR

A. Resonator Design

As presented in [11], a partial-height off-centered post inside a waveguide represents a bandstop resonator whose resonant frequency is determined by the length of the post. This resonator can be modified properly to create a tunable bandstop resonator by employing a varactor diode. In the modified structure, shown in Fig. 1, the length of the off-centered metallic post is equal to the SIW height. The post connects the bottom metallization of the SIW to a patch which is isolated from the SIW's top metallization. The metallic post represents an inductor connected in parallel to a capacitor created by the spacing between the SIW's top metallization and the isolated patch. A tunable bandstop resonator is achievable if this capacitor is replaced by a varactor diode as illustrated in Fig. 1. Losses include conductor, dielectric and radiation losses. Simulated results of the bandstop resonator shown in Fig. 1 (without varactor diode) are presented in Fig. 2. The substrate height is 1.524 mm, and RT/Duroid 6002 with dielectric constant of 2.94 and loss tangent of 0.0012 is used as substrate material. The via diameters are 1 mm. The cutoff frequency of the SIW and the spacing between the two patches are 3.12 GHz and 0.25 mm, respectively. The total capacitance of the equivalent circuit is the sum of the capacitance of the varactor diode and the capacitance of the gap across it.

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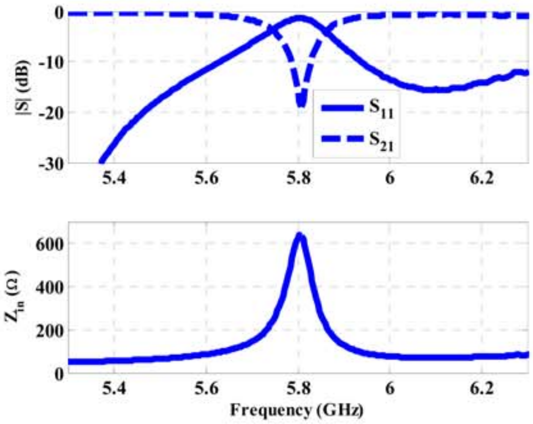


Fig. 2. Scattering parameters and input impedance of the bandstop ridged SIW resonator of Fig. 1.

The input impedance of the resonator, extracted from simulated scattering parameters and outlined in Fig. 2, has a maximum at resonant frequency which indicates that the resonator represents a parallel RLC circuit whose input impedance at resonance is purely real and equal to $|Z_{in}| = R$. The total resistance of the designed resonator is calculated as $R = 634.9\Omega$.

The loaded quality factor of the resonator is obtained as

$$Q_L = f_0/\Delta f_{3dB} \tag{1}$$

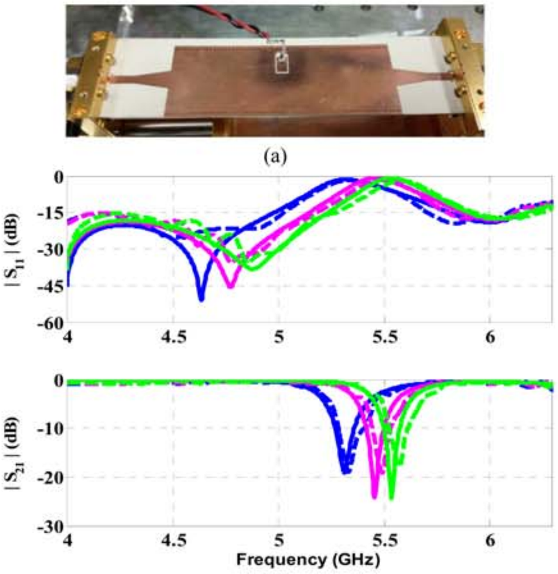
where f_0 and Δf_{3dB} are center frequency and 3 dB bandwidth of the resonator. The unloaded quality factor of the resonator, Q_U, is obtained from Q_L by

$$Q_U = Q_L/\left(1 - 10^{\frac{-IL}{20}}\right) \tag{2}$$

where IL is the attenuation at resonant frequency. The Q_U for this resonator is calculated as 55. To make a tunable bandstop resonator, a varactor diode is connected between the metallization of the resonator and the isolated patch. For biasing purpose, a small patch is isolated from the larger patch on the top (Fig. 1). A 150 Ω resistor is used as RF blocking element. Varactor diode SMV1232 is employed for tuning.

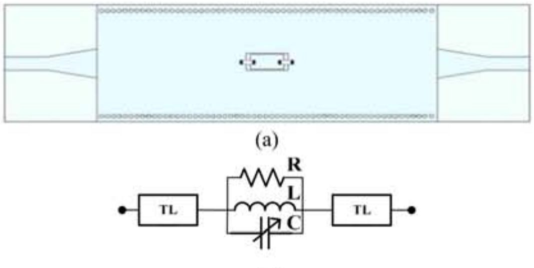
B. Simulated and Measured Results

The designed resonator is prototyped and measured. Fig. 3a shows the fabricated resonator with the biasing circuit and the varactor diode. The simulated and measured results are compared in Fig. 3b. The simulated results show a tuning range of 5.32-5.54 GHz which is in good agreement with that obtained from measurements. An upward frequency shift is observed in the measured transmission zeros that is attributed to manufacturing tolerances. The measured stopband attenuation and return loss are better than 17.89 dB and 2.02 dB, respectively, over the entire tuning range.



(b)

Fig. 3. a) Prototyped tunable ridged SIW bandstop resonator; b) comparison between simulated (solid lines) and measured (dashed lines) results.



(b)

Fig. 4. a) SIW transmission line loaded with tunable CPW resonator; b) equivalent circuit of the open-ended CPW resonator.

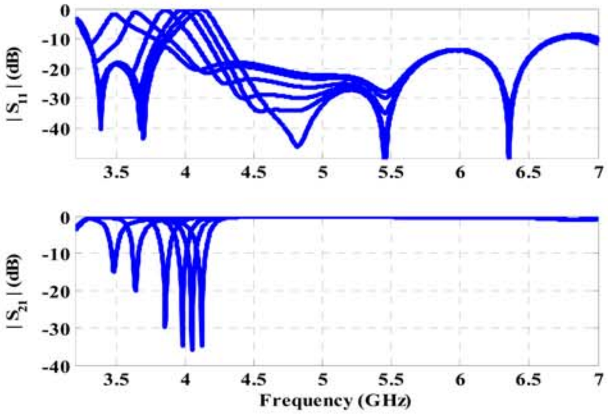


Fig. 5. Frequency response of the tunable CPW resonator of Fig. 4a.

III. TUNABLE OPEN-ENDED GROUNDED CPW RESONATOR ETCHED INTO AN SIW

One of the interesting aspects of CPW components is that surface mounted elements can be easily integrated due to their coplanar grounds. Therefore, CPW resonators are good candidates for tunable filter designs. Several types of CPW resonators are analyzed in [12], including an open-ended CPW resonator. For the first time, we use a half-wavelength open-ended CPW resonator on a SIW as shown in Fig. 4a with its equivalent circuit in Fig. 4b. The CPW resonator is loaded by two SMV1232 varactor diodes at both ends. The frequency responses of the resonator, for different applied reverse voltages over both varactor diodes, are presented in Fig. 5. The unloaded quality factor of the resonator varies between 24 and 35 over the tunable frequency range. The resonator has a tuning range of 3.5-4.1 GHz. Stopband return

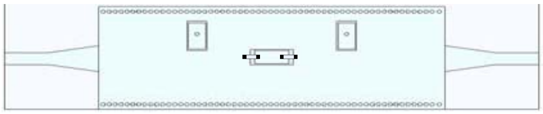


Fig. 6. Dual-band bandstop filter created by combining two ridged SIW resonators and one open-ended CPW resonator.

Fig. 7. Prototyped dual-band bandstop filter with one tunable stopband.

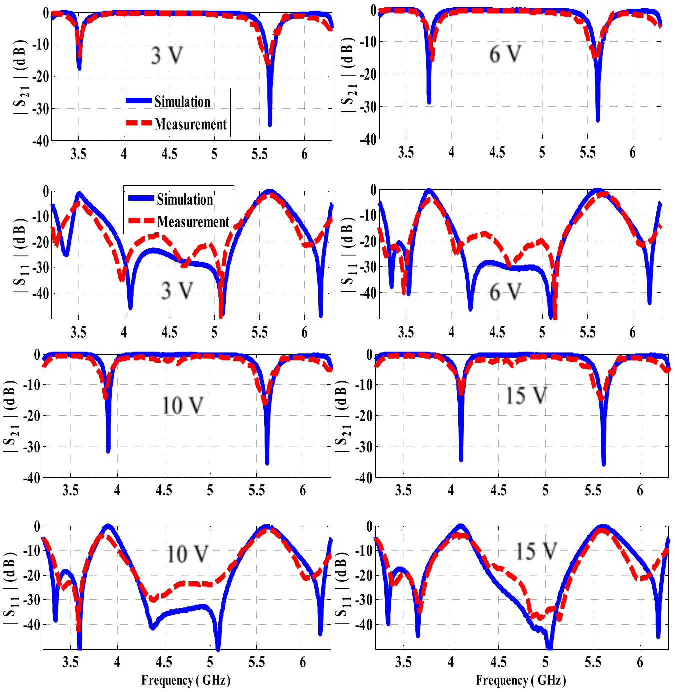


Fig. 8. Comparison between measured and simulated scattering parameters of the dual-band bandstop filter with one tunable stopband.

loss and attenuation are obtained better than 2 dB and 15 dB, respectively, for different applied reverse biasing voltages.

IV. DUAL-BAND BANDSTOP FILTER WITH ONE TUNABLE STOPBAND: DESIGN AND MEASUREMENT

To create a hybrid dual-band bandstop filter, we use a conventional method of cascading two ridged SIW bandstop resonators, designed in Section II, with a varactor-diode-loaded open-ended CPW resonator, designed in Section III, as outlined in Fig. 6. The two ridged resonators are $3\lambda_g/4$ apart at the center frequency of 5.6 GHz, and the tunable CPW resonator, located between the two ridged resonators, provides a tunable stopband with tuning range of 3.5-4.1 GHz. The designed filter is fabricated and measured.

Fig. 7 shows the fabricated component with biasing circuit. An inductor of 20 μH is used as DC feed. As shown in Fig. 8, good agreement is observed between simulated and measured results. The measured stopband attenuation varies between 13.22 dB and 13.68 dB over the tunable range. The measured stopband return loss is better than 4.9 dB for different reverse biasing voltages. The attenuation and return losses in the second stopband are measured better than 14 dB and 1.89 dB, respectively. Note that the second stopband center frequency at 5.6 GHz does not change by varying the reverse biasing voltage of the varactor diodes.

TABLE I
TUNING RANGE COMPARISON

	Ridged SIW	CPW	Ref. [7]	Ref. [8]	Ref. [9]	Ref. [10]
Tuning range	4.1%	15%	12%	18%	18%	47%

Table I compares the tuning ranges of the resonators in this letter with those of the evanescent-mode resonator filters reported in [7]–[10].

V. CONCLUSION

Two novel tunable bandstop resonators are presented. The first resonator is a tunable ridged SIW bandstop resonator and the second one is a tunable open-ended CPW resonator etched into the SIW's top metallization. By combining these two resonators, a dual-band bandstop filter is introduced with one tunable stopband. The simulated and measured results demonstrate that the tunable bandstop circuits presented in this letter have good attenuations in the stopbands and can be effectively used in reconfigurable SIW systems. The number of CPW resonators can be increased by adding more resonators in an in-line configuration at odd multiples of a quarter wavelength.

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