Tunable substrate integrated waveguide resonators

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***Abstract*—This paper presents a novel approach for providing SIW tunable resonators by means of placing an additional metalized via-hole on the waveguide cavity. The via-hole contains an open-loop slot on the top metallic wall. The dimensions, position and orientation of the open-loop slot defines the tuning range. Fabrication of some designs reveal good agreement between simulation and measurements. Additionally a preliminary prototype which sets the open-loop slot orientation manually is also presented, achieving the expected continuous tuning range of at least 8%.**

***Index Terms*—SIW, open-loop slot, tuning, resonator**

I. INTRODUCTION

The development of substrate-integrated waveguide (SIW) technology has opened new perspectives for circuits and systems in the microwave and millimeter-wave frequency range. Based on a synthesized waveguide in a planar dielectric substrate with two rows of metallic vias [1][2], SIW structures exhibit a number of advantages, including easy fabrication, compact size, low loss, and easy integration with active devices [3][4]. Among the wide class of SIW components proposed in the literature, SIW filters have received particular attention, due to the possibility of achieving higher quality-factor and better selectivity, compared to classical planar filters in microstrip and coplanar-waveguide technology.

A considerable amount of research has been conducted on the tuning of SIW. Filters implemented in waveguide technology are tuned by introducing screws. Although the design of SIW and waveguide filters is quite similar, this mechanical and easy tuning method is not adequate for SIW technology, due to their physical structure. In addition, mechanical tolerances are typically higher in SIW technology and also the tolerances in the dielectric permittivity of substrates introduce additional perturbation in the electromagnetic response. For this reason, tuning of SIW filters is crucial to compensate manufacturing and material tolerances. Moreover, this tuning could be applied not only to compensate tolerances but also to change the band in case the tuning range is wide enough.

Electrical tunable resonators have been proposed in [5] where a SIW cavity resonator is combined with a surface mounted varactor with a measured continuous tuning range of 1.2%. In [6] the authors propose the inclusion of PIN diodes to obtain discrete electrical tuning. Discrete mechanical tuning is proposed in [7] by opening or shortcircuiting a capacitive circular slot, with a tuning range of 5%, or by using MEMS [8]. A more complex system is proposed in [9] by introducing a cylinder of plasma in the resonator, with only simulated results. In this paper we propose a new mechanical system with a continuous tuning range, where measured resonators with tuning ranges up to 8% are presented.

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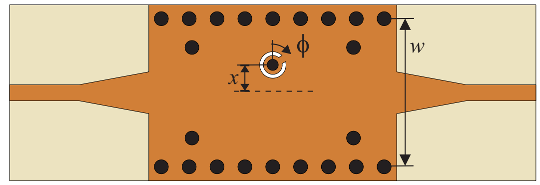

Fig. 1. SIW cavity with tuning element.

II. TUNABLE SIW: CONCEPT AND FABRICATION

The proposed structure is shown in Fig. 1. It consists of a conventional SIW resonator with an additional via hole inside of the cavity. The via hole is rounded by a circular slot connected to the top layer through a metallic contact placed at the angle ϕ. The via hole is located in the middle along the cavity and slightly displaced from the center by x. The existence of this via hole deviates the electromagnetic field distribution from the one in a uniform SIW resonator (see Fig. 2) and this variation gives rise to a change on the resonant frequency. The position of the via hole x and its orientation ϕ defines the path of the current and field distribution. In absence of contact with only the slot, the magnetic wall provides an electric field distribution similar to that for an empty cavity (see Fig. 2a), whereas with only the via hole in absence of slot, the electric field is compressed and the resonant frequency is highly increased (see Fig. 2c). The introduction of the metallic contact with angle ϕ provides field distributions and resonant frequencies between the both previously described states. For $\phi = 0°$ the contact is far from the maximum of the electric field and this case is more similar to the cavity with only the slot (see Fig. 2b). On the other hand, for $\phi = 180°$ the contact is close to the maximum of the electric field and the field distribution similar to the cavity without slot (see Fig. 2d).

The resonator in Fig. 1 has been simulated with a substrate ARLON 25N with $\epsilon_r = 3.38$, $\tan\delta = 0.0025$ and height $h = 0.512$ mm. The separation between both arrays of via holes is $w = 10.63$ mm, wich essentially sets the resonant frequency. The diameter of the via holes and separation between them is set to 1 mm and 2 mm, respectively, and 0.8 mm for the diameter of the tuning element. The slot has internal diameter of 1.4 mm and external 1.9 mm. The dimensions of the cavity

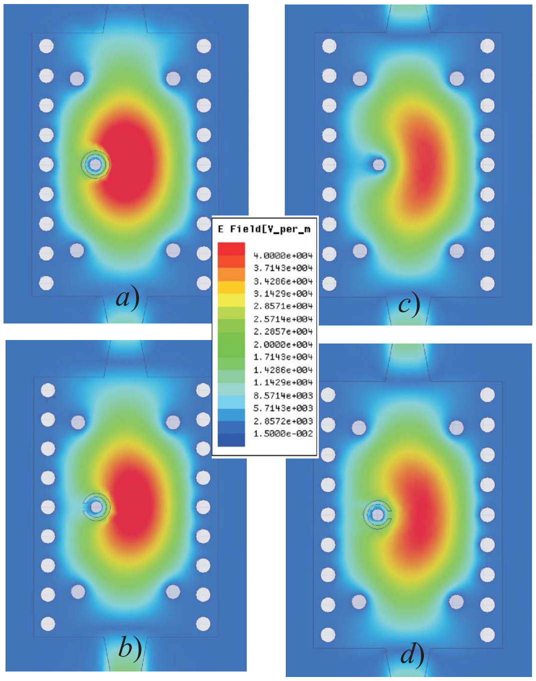

Fig. 2. Electric field at the resonant frequency for the cavity with full slot *a*), with contact for $\phi = 0$ *b*), without slot *c*), and with contact for $\phi = 180$ *d*).

TABLE I
TUNING RANGE FOR DIFFERENT X POSITIONS

	Frequency (GHz)		
x (mm)	$\phi = 180°$	$\phi = 0°$	% tuning
1	11.60	11.15	3.96
2	11.25	10.67	5.29
3	10.80	10.27	5.03
3.5	10.58	10.12	4.44

TABLE II
TUNING RANGE FOR DIFFERENT WIDTHS OF THE FLANGE

	Frequency (GHz)		
w_f (mm)	$\phi = 180°$	$\phi = 0°$	% tuning
0.2	10.59	11.10	4.0
0.5	10.67	11.27	5.3
1.0	10.81	11.47	6.0

TABLE III
TUNING RANGE AND UNLOADED QUALITY FACTOR FOR DIFFERENT SIZES OF THE TUNING ELEMENT

r_v (mm)	r_{s1} (mm)	r_{s2} (mm)	w (mm)	% tuning	Q_u
0.4	0.7	0.95	1.0	6.0	225
1.0	1.3	1.55	1.5	14.5	200
1.5	1.8	2.05	3.0	22.2	165

perform approximately a 10 GHz resonator. Several position x and orientation ϕ of the via hole have been considered. The results in Table I summarize the effect of x and ϕ on the resonant frequency. This table confirms that the minimum deviation from the original resonant frequency (cavity without the via-hole) occurs when $\phi = 0°$, whereas the maximum deviation corresponds to an open loop slot orientation of $\phi = 180°$. The value of x has influence in the resonant frequency and the tuning range. For values of $x = 2$ mm and $x = 3$ mm we obtain a tuning range higher than 5%. These results also reveal the tuning range decreases when the tuning element is very close to the center of the cavity ($x = 0$), where there is a minimum of the magnetic field, or when it is placed very close to the side via holes ($x = w/2$). Another important parameters for the tuning range are the radius of the via hole (r_v), the slot (internal r_{s1} and external r_{s2} radius) and the width of the flange w_f. Table II shows the variation of the tuning range with de width of the flange for $x = 2$, where de maximum tuning range is obtained when $w_f \approx 2r_{s1}$. When the longest tuning range is required, screws with higher diameter in the cavity and wider flanges can increase the tuning range up to 22% such as we can see in Table III, at the cost of a lower unloaded Q.

Fig. 3 (solid lines) outlines the simulated frequency responses (Ansoft HFSS) for the conventional SIW resonator and for the resonator with $x = 2$ and $w_f = 0.5$. Three values of ϕ have been considered, $\phi = 0°$, for lowest achievable resonant frequency, $\phi = 180°$ for the highest achievable resonant frequency and $\phi = 90°$ for an intermediate value. As indicate in Table I, the tuning range is larger than 5%. The simulated unloaded Q factor in these examples is 225, compared with the $Q_0 = 263$ for the empty cavity. These structures for $\phi = 0°$

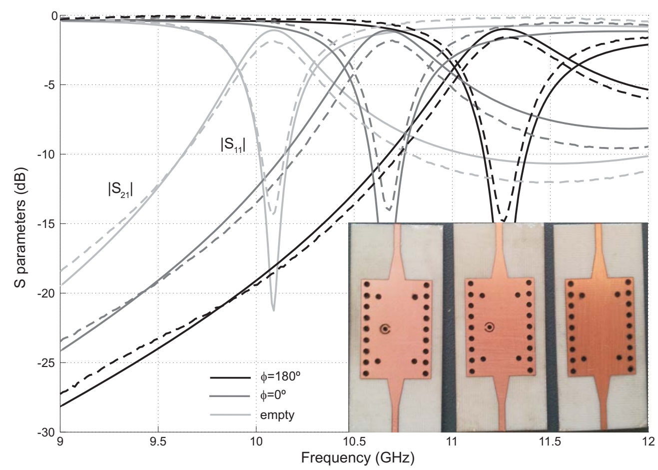

Fig. 3. Measured (solid) and simulated (dashed) scattering parameters for a cavity with a tuning element placed at $x = 2$mm, and picture of the fabricated resonators (inset).

and $\phi = 180°$ had then been fabricated and measured. Their frequency responses and the fabricated prototypes are shown in Fig. 3 (dashed lines). The measurements confirm the 5% tuning range and the Q factors of the resonators. Comparison with and empty cavity is also shown in Fig. 3. The measured unloaded Q factor for the empty cavity is 127, compared with the $Q_0 = 123$ for the cavity with the tuning element. Measured unloaded Q is higher due to real losses and probably measurement issues, but as we can observe, Q_0 is quite similar for both resonators, with and without the tuning element.

Some variations to the proposed structure could be introduced in order to modify the tuning range. When the main objective is to preserve the Q with small tuning range to

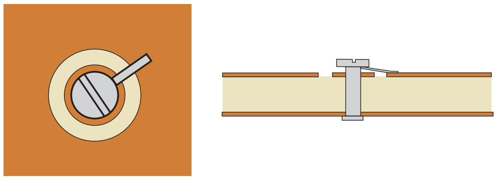

Fig. 4. Outlined of the proposed tuning mechanism. Left: top view. Right: side view.

compensate small fabrication tolerances, the tuning element can be placed close to the side walls with only half circular slot starting with $\phi = 90°$. In this case we obtain a tuning range about 2% and a quality factor of 237, very close to the Q factor of the empty cavity ($Q_0 = 263$).

III. Tuning screws for SIW resonators

This section uses the tuning concept detailed in previous section to propose a SIW resonator with a tuning screw. The scheme of this approach is outlined in Fig. 4. In this approach the tuning screw will act as a via hole and will be used as well for setting the orientation of the open loop slot by means of controlling a flange position and therefore to tune the resonant frequency.

As a proof of concept a preliminary basic prototype with a real screw has been fabricated. A picture of the prototype is shown in the inset of Fig. 5. In this case we employ a common screw of diameter 2 mm and a piece of copper wire as a flange of $w_f \approx 1$ mm. In this case the operating frequency has been reduced to 7 GHz in order to accommodate a screw of such size inside the resonator. We used the same substrate than for the prototypes of Fig. 3 (ARLON 25N with $\epsilon_r = 3.38$, $\tan\delta = 0.0025$ and height $h = 0.508$ mm). Separation between the arrays of via holes is $w = 15.63$ mm. The via hole of the tuning element has been specified to 2 mm in order to use the screw mentioned above. The position of the tuning via hole has been fixed at $x = 4$ mm, where a maximum tuning range could be achieved. Fig. 5 shows the measured results with the copper wire in three different positions, corresponding to an approximate orientation of $\phi = 0°$, $\phi = 90°$, and $\phi = 180°$, respectively, and the simulated and measured response of the resonator without the copper wire. The resonant frequency increases when the orientation angle increases, showing consistency with the statements of previous section. These results exhibit a tuning range of 8%, where the resonant frequency goes from 6.85 GHz to 7.42 GHz, with a measured quality factor of $Q_0 = 94$. In order to reduce overall losses due to the low conductivity of the screw the via hole has been plated and the copper wire has been place to short-circuit the slot, thus avoiding current flow through the screw.

IV. Conclusion

The proposed tuning screws allow for an easy tuning of SIW filters in a similar way that the method employed in waveguide filters. Taking into account that the tolerances in the dielectric constant and fabrication process may produce lack of accuracy in the measured response, the inclusion of these tuning screws

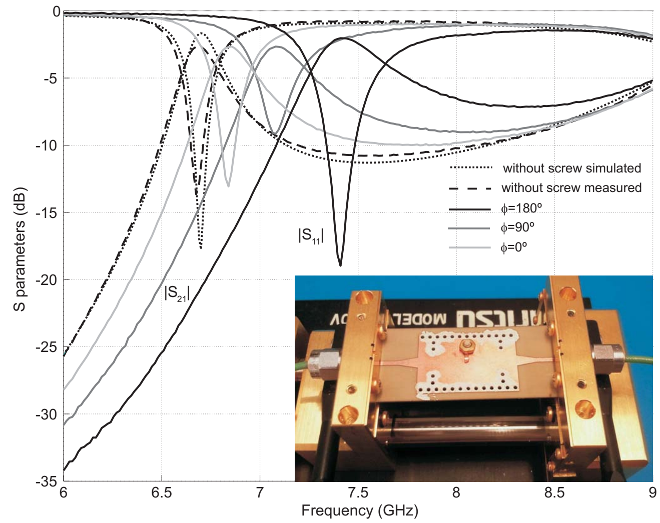

Fig. 5. Measured results of the prototype. The inset shows the picture of the fabricated prototype.

allows to obtain an improved performance of the filters, with low cost while almost the same performance is preserved. In this way, we avoid the repetition in the fabrication of filters to comply with the desired response or the necessity of very accurate and expensive fabrication technologies. Variation of the proposed topology it is possible to reduce the effects of the tuning element on the filter performance or to increase the range of tunability up to a 22%. In case of a SIW filter, tuning elements could also be included in the coupling apertures.

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