URSI AP-RASC 2019, New Delhi, India, 09 - 15 March 2019

Frequency Tunable SIW Cavity Resonator Integrated With Schottky Diode

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Abstract

A Frequency Tunable Substrate Integrated Waveguide (SIW) Cavity Resonator Integrated with Schottky Diode has been reported in this paper. Frequency tunability between 8.5 GHz to 11.9 GHz (X band) has been achieved by varying the biasing voltage of the Schottky diode. Further we have also presented a physical model describing the phenomenon by the help of an equivalent circuit. The design of the SIW is done by the HFSS based on finite Element Method (FEM) and the integration of Schottky diode in the structure is done by ADS based on Method of Moment (MoM). Frequency tunability by integrating schottky diode in the SIW structure has shown better improvement in voltage requirement, temperature range and conversion efficiency. The structure implementation is quite simple and thus will be appropriate in the application of low cost microwave and millimeter wave devices.

1. Introduction

Microwave Resonators are the key components in microwave and millimeter wave communication. A high Performance microwave resonator should have less insertion loss, high quality factor along with compact size. A Conventional waveguide can be used for this purpose but on the cost of bulky size and their incompatibility with the planar circuits.
Recently substrate integrated waveguide (SIW) technology has shown a better choice over conventional waveguide due to smaller size, high quality factor and low loss [1]. Additionally, SIW can be easily integrated with a planar structures. SIW structures are designed by the help of periodic arrangements of vias or slots embedded in the planar substrate which creates artificial guided channels. These channel behaves as artificial vertical walls of a conventional waveguide.
Since past decade researchers have proposed many resonators which are either based on conventional waveguide or Substrate integrated waveguide design [2]. Many of them are either single frequency resonators [3] or are incapable to integrate with the planar circuits.
S. Sirci et.al [4] has designed a tunable SIW resonator by integrating varactor diode, but the performance obtained is not up to the mark due to the limitation of capacitance variation in varactor diodes. Further, M. Armendariz et.al [5] has tried to design frequency tunable SIW resonator by the use of PIN diode, but the performance obtained is not good due to the self-limitation of PIN diode.
In this paper we have designed a tunable SIW structure in the X-band region. For tunability we have used Schottky diode which is better in frequency conversion, voltage requirement and temperature variations as compared with other microwave diodes. A comparative study between the performances of different microwave diodes is shown in Table 2. An equivalent circuit diagram of SIW structure integrated with schottky diode is further modelled in this paper.

2. SIW Design

The side view and the top view of the proposed SIW structure is shown in Figure 1(a) and Figure 1 (b) respectively. As evident from Figure 1(a), the structure is a three layered structure, where the top and bottom layers are metallic layer. The middle layer comprises of Arlon as dielectric substrates having a dielectric constant of 2.5 and height of 1.6 mm. SIW designed by the periodical arrangement of air holes perforated in the dielectric substrate from top to bottom metallic plates is shown in Figure 2 (a). This periodic arrangement of the air holes on the substrate act as a vertical walls of waveguide and confines the electromagnetic wave in axial direction [6]. The excitation of SIW has been done by microstrip feed line as shown in Figure 3. Width of microstrip feed for proper impedance matching has been calculated by the well-known equation taken from [7]. The microstrip width for Arlon ($\varepsilon_r = 2.5$) and height 1.6 mm is obtained as $w_m = 3.25$ mm.
Frequency tunability of the structure has been achieved by integrating a Schottky diode externally to the resonator as shown in Figure 4 (a). By varying the biasing voltage of the Schottky diode, we can vary the effective capacitance of the proposed structure which further varies the resonant frequency of the structure.

The simulation of the structure has been done in two part, the design of the SIW structure has been done in HFSS whereas the integration of Schottky diode to the SIW has been done in ADS simulation tool. The complete design of SIW integrated with Schottky diode is shown in Figure 4 (a).

In Figure 4(a) box X represents the SIW structure which is shown in Figure 2(a). The Schottky diode is integrated parallel to box X. (i.e. SIW structure). All the dimension as shown in Figure 1(b) has been calculated by the equations (1), (2) and (3) [8].

$$F_{R(TEmnq)} = \frac{c_0}{2\sqrt{\varepsilon_r}} \sqrt{\left(\frac{m}{W_{eff}}\right)^2 + \left(\frac{q}{L_{eff}}\right)^2} \quad (1)$$

$$L_{eff} = L - \frac{d^2}{0.95 * b} \quad (2)$$

$$W_{eff} = W - \frac{d^2}{0.95 * b} \quad (3)$$

Where F_R is the resonant frequency, c_o is the speed of light. The calculation of resonant frequency has been done for the dominant mode where the value of m, n and q are 1, 0 and 1 respectively. The value of different parameters shown in Figure 1(b) are d =1 mm, b =1.4 mm .The calculated value of different parameters shown in Figure 2 (a) are L=35 mm, $W/2$ = 15.225 mm and S = 0.2 mm. By the use of above equations values of $L_{eff} = 34.45$ mm and $W_{eff} = 29.68$ mm has been determined.

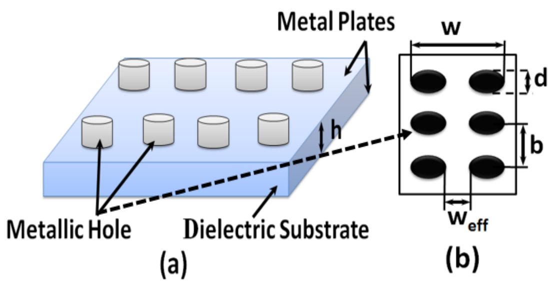

Figure 1. (a) Side view and (b) top view of SIW structure.

3. Results and Discussion

Figure 2 (b) shows the Reflection (S_{11}) and Transmission (S_{21}) coefficient curve when there is no diode applied to the SIW structure. We can see that the structure resonates at 10.73 GHz. Now when we apply a Schottky diode the resonance frequency changes as shown in figure 4 (b). By varying the biasing voltage of the diode the resonant frequency changes. This is nothing but the tuning of the frequency by biasing Schottky diode with different biasing voltage. The above mentioned physics can be well understood by Table 1.

Table **1** Resonant Frequency Variation by Changing Bias Voltage

Design	Frequency (GHz)	S_{11} (dB)	S_{21} (dB)	B.W. (GHz)
Without Diode	10.73	-29	0	0.02
With Diode (0 bias)	10.76	-30	0	0.03
With Diode (Applied bias)	10.75	-30	0	0.01

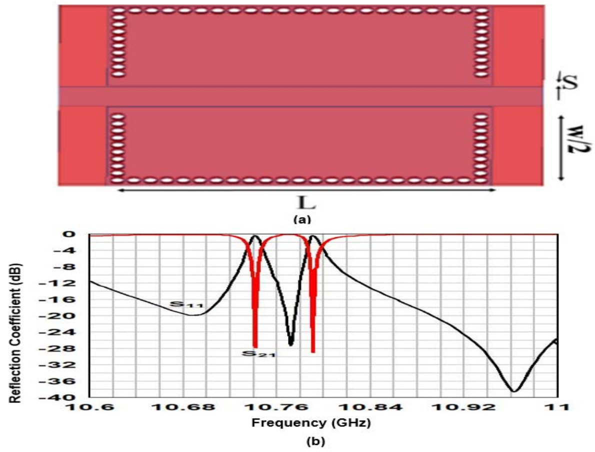

Figure 2. (a) Top view of SIW resonator and (b) simulated result without Schottky diode.

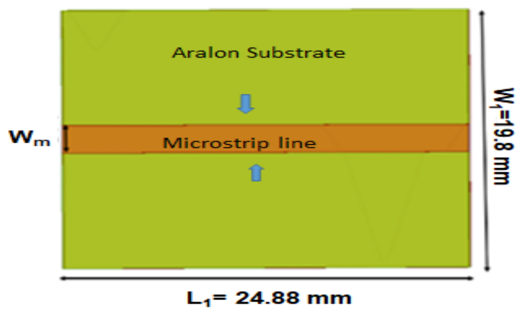

Figure 3. Design of Microstrip feed to excite the SIW structure.

An equivalent circuit model of the structures shown in Figure 4(a) is calculated and modelled in Figure 5 (a). For the desired operating resonant frequency the value of all the circuit parameters have been calculated theoretically and the obtained value of each parameters are R1 = 1Ω, R2 = 10KΩ, L1 = 10 nH, L2 = 1.04 nH, C1 = 0.01pF, R = 50KΩ, L= 0.3856 nH, C = 0.72pF, Z = 50 KΩ.

Variation of junction capacitance in the whole range of X band i.e. from 8 GHz to 12 GHz has been shown in figure 6. It is well evident from the figure that the junction capacitance varies from 0.085pF to 0.17pF for the frequency range between 8 GHz to 12 GHz.

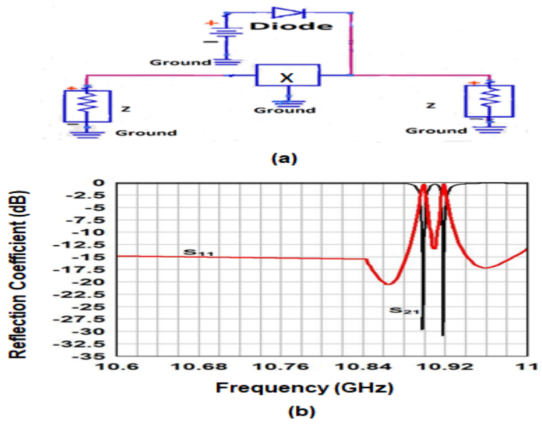

Figure 4. (a) SIW structure as box X with Schottky diode (b) Simulation results of SIW resonator with Schottky diode.

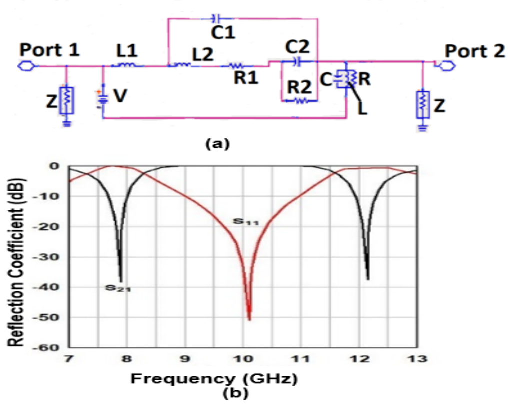

Figure 5. (a)Equivalent circuit model of Schottky diode integrated SIW resonator and (b) simulated results.

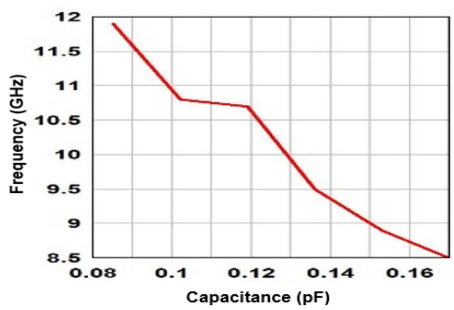

Figure 6. Variation of resonant frequency with junction capacitance.

The performance of Schottky diode which is being used in this structure is compared with other microwave diodes in Table 2. It is found that Schottky diode is better as compared to other diodes in all the three main parameters i.e. temperature range, voltage requirements and conversion efficiency.

Table **2**. Comparison of performance parameters of Schottky Diode with other Microwave Diodes

Parameter	Tunnel Diode	Varactor Diode	Schottky Diode	PIN Diode
Voltage Requirements	60-350 mV	>6 V	0.15-0.45V	6-12V
Temperature Range	-73□-150□	-55□-150□	-65□-150□	-65□-150□
Conversion Efficiency	25-50%	<10%	90.6%	35-55%

4. Conclusion

A frequency tunable SIW cavity resonator integrated with Schottky diode is proposed in this paper. An equivalent circuit model with all the circuit parameters has been done in this paper. A performance comparison table is done in the last which shows Schottky diode is better in voltage requirement, conversion efficiency and temperature range as compared to other microwave diodes like tunnel diode, PIN diode and Varactor diode. Due to the above mentioned advantages the design may find application as a resonator for planar structure in X band frequency regime.

5. References

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