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A Compact SIW Mixer for Millimeter-Wave Applications

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ABSTRACT

The present paper highlights an innovative broadband millimeter-wave single balanced diode mixer which is designed using a newly designed 90 substrate integrated waveguide (SIW) coupler and two cavities (SIW) filter. The mixer covers RF/LO operating frequency range which fluctuates between 10 to 12 GHz and IF port covers 2GHz. The proposed mixer exhibits a fairly low conversion loss of less than 10 dB and high port to-port isolations over the frequency band of interest as the simulated results make clear. Furthermore, the two cavities SIW filter is embedded to achieve a better image frequency suppression of about 28dB.

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1. INTRODUCTION

A high performance mixer module is required in the design of modern microwave telecommunication system. In normal single balanced mixer **[1]** the microstrip branch line hybrid is usually used as coupler section. However the fabrication will be more complex due to the dimension of such hybrid which could be very small [2]-[13]. So as an alternative, there is an extensive investigation for the design of low-cost, high performance microwave and millimeter wave (MMW) passive components, including directional couplers using the Substrate integrated waveguide (SIW). For instance, in [14] we used SIW single-aperture coupler to design a high performance mixer. We achieve a better conversion loss at price of larger size of a SIW coupler than other devices in the mixer circuit [15] [16].

In this paper, we propose the concept of substrate integrated circuits (SICs) [17] in order to offer an attractive solution for low cost, compact, efficient and hybrid integration of different kinds of conventional planar and non-planar structures within the same substrate at microwave and millimeter wave frequencies.
In addition to low conversion loss, this type of mixer can provide other attractive characteristics including good image frequency rejection.

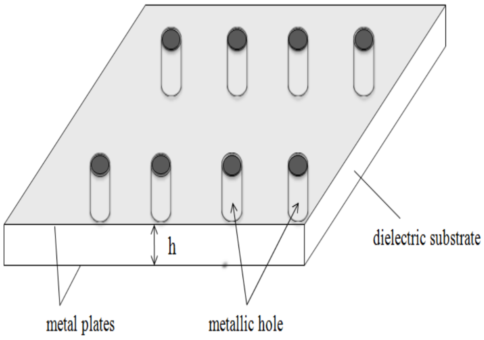
In this present paper, we will first of all describe the SIW filter, then discuss the design of the mixer, and finally present the results along with its electrical performances.

2. SIW FILTER DESIGN

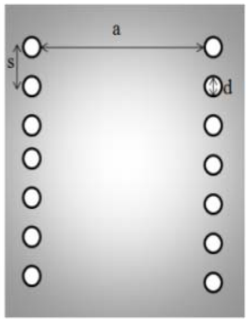
This section focuses on the principle of the substrate integrated waveguide technology and at the same time the design of the SIW filter.

2.1. SIW Design

The SIW consists of two linear metallic connected via dielectric substrate with a height of h. The electromagnetic fields within the SIW are confined by these metallic via arrays [3]. The width of SIW is a, the diameter of the metallic vias is d while the space between the adjacent vias is s. The geometric parameters are primarily determined by the relationship between the conventional rectangular waveguide and the SIW. The following is a description of this relationship [18]-[20].



(a)



(b)

Figure 1. Topology of SIW structure (a) Solid view. (b) Top view.

$$a = a_{eq} - \frac{d^2}{0.95\ S} \quad (1)$$

Noting that a_{eq} is the width of the correspondent rectangular waveguide.

2.2. Filter Design

In order to get a rough shape the SIW filter is first of all designed by using basic theory of coupled-resonator filters [7] [21], after that the precise structure is determined with full wave simulation. The rejection performance at the image frequency may slightly degraded, however the suppression remains satisfied. In SIW cavities the radiation loss is avoided so that it has intrinsic quality factor than microstrip resonators [8] [9]. It is well known that the SIW filters have lower insertion loss and higher selectivity than microstrip filters or coplanar waveguide (CPW). So, in the design of the SHM, SIW filter is adopted to suppress the image frequency. Figure 1 shows the filter photograph as well as its simulated results.

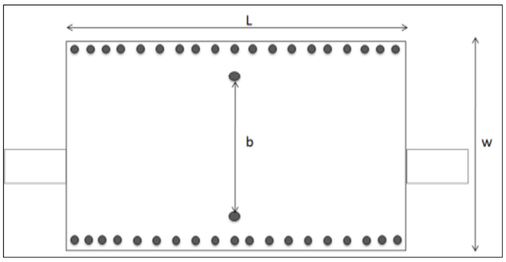


Figure 1. The model for this bandpass SIW filter

Table 1. Optimized Parameters of the Filter

Parameter	Optimized value (mm)
L	35.5
W	16
b	8

Figure 2 focuses on the simulation results with CST software and High Frequency Structure Simulator (HFSS). Three dimensional analyses are presented in order to optimize the proposed filter specification.The optimized parameters are shown in Table 1. The dielectric substrate used are Taconic TL-6 along with ε_r=2.65 as well as a dielectric thickness of h 1 mm and dielectric loss tangent of 0.0019.

The pass band of this filter is 1.34 GHZ at the central frequency of 12 GHz. The insertion loss in the passband is less than -1dB whereas the return loss is less than -30dB. All statistics are suitable to the filter design. While designing the SIW filter through using a tight structure not only the total spaces are saved but also a good performance is achieved, better than using other technology [22].

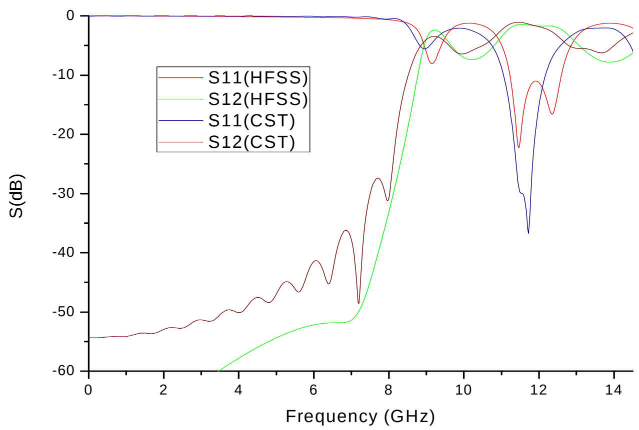


Figure 2. S-parameters of the proposed SIW filter

3. THE SINGLE BALANCED MIXER

Extra circuitry is required to route and separate input and output signals from the diodes in mixers. In addition, this extra circuitry in single diode consists of a mixture of passive coupling, power division, and filtering. However, as the multiplexing circuitry is frequency specific, it is difficult to make wideband single diode mixers with independent RF, LO, and IF bands. Moreover, mixer efficiency will be reduced as the circuitry engenders extra losses.

So to solve this problem, researchers found out that low loss wideband single-balanced mixers with independent input and output frequency bands could be created using the SIW 90° coupler which consists of a two input, two output and four port circuit that provides mutual isolation between input ports and equal power division at the output ports. It is noticeable that the hybrid junction for mixers is applicable while isolating the input LO and RF sources from one another, thus, it provides frequency band independence and equal power division to the load.

There is an essential limitation on the sensitivity of a microwave receiver using a diode mixer which occurs because there is only a part of the available RF signal power in the frequency conversion process which is converted into power at the intermediate frequency. In addition to some RF signal which is also converted to the usually unwanted image frequency and other harmonics.

It is preferred in many applications to eliminate or distinguish the image response from that of the desired signal response. Moreover, the signal and image frequency bandwidths cannot overlap when the IF frequency is high enough and the RF bandwidth is adequately narrow. Also, we can eliminate the image response through utilizing an appropriate input filtering. Besides, for narrow band systems this type of design is so appropriate where a high level of image rejection is achieved. However, filtering cannot be used for the desired image rejection with broadband applications especially with octave bandwidth mixers.

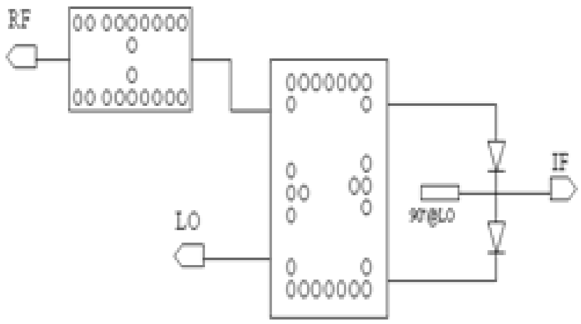


Figure 3. Configuration of the proposed SIW mixer

4. SIMULATED RESULTS

4.1. SIW Mixer

A single balanced mixer with two diodes connected back-to-back as well as an SIW coupler which is formed on the same dielectric substrate is presented in Figure 3. The SIW coupler is better than the classical couplers because it performs as the input and power delivery component. In addition, the insertion loss and interference on other circuits is minimized because of the radiation loss which exists only at the transitions between the SIW coupler and microstrip, thus, thanks to SIW structure. Moreover, through a careful design of the coupler and transitions, the performance of the mixer is enhanced and the 90° SIW coupler shows a considerably wide band performance at a desired frequency.

Not forgetting also the SIW filters which have lower insertion loss and higher selectivity better than microstrip or coplanar waveguide (CPW) filters and which have a significant role in suppressing the image frequency of the mixer [8]. A quarter-wavelength open-circuited stub at the LO frequency is adopted to prevent LO leakage.

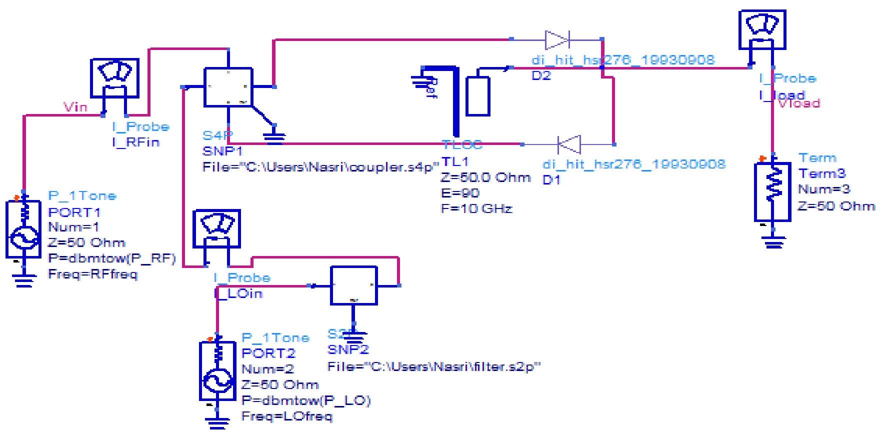


Figure 4. The structure of circuit for mixer diode

Figure 4 presents the structure of circuit for the single balanced mixer diode in ADS simulator .Through using “S4P” and 'S2P' data item of ADS, broad-band field analysis results of SIW coupler and filter from CST are included in the harmonic balance simulation. The two Schottky diodes which are used as the anti-parallel diodes pair are selected from the libraries of ADS.

We develop a single balanced mixer with 90° coupler and two-cavity SIW filter. Designing a mixer with a filter has its advantage as mixers are more sensitive to load than amplifiers.

Figure 5-7 presents the simulated results. It is noticeable that the balanced mixers characterize with good port-to-port isolation, and show approving LO and RF suppression. The primarily design issue in passive mixer is how to reduce the conversion loss and suppress the image frequency. Where the RF frequency is 12GHz, and the LO frequency is 10GHz, as well as the LO power is 9dBm and the RF power is -40dBm, the simulated conversion losses are under 8.8dB.

Concerning the image frequency, it is suppressed over 28dB relative to useful signal. Furthermore, the input RF 1dB compress point is 12dBm when exited by 9dBm LO power without filter and 14dBm with filter respectively.

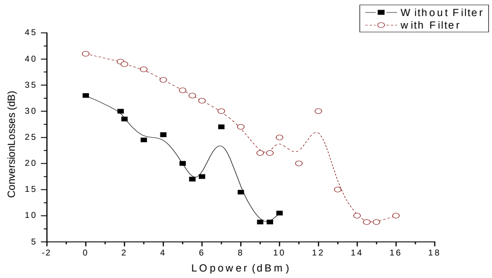


Figure 5. Conversion loss versus LO power

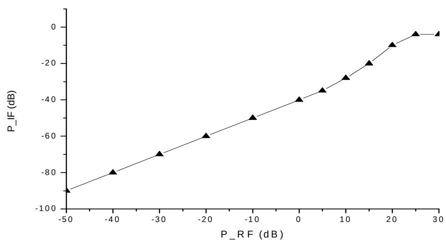


Figure 6. P1_dB gain compression

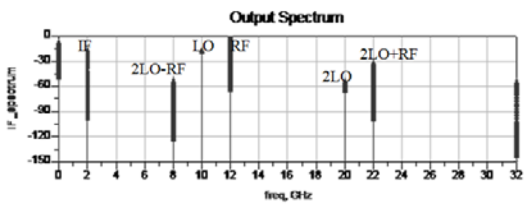


Figure 7. Mixing spectrum of the proposed mixer

4.2. A Comparison between the Proposed Mixer to other Published SIW Mixer

The characteristics of the SIW mixer as compared with other SIW mixers can be summarized as follows:

Table 1. Performance of the proposed mixer as compared to other published SIW mixer

	This work	Chen 2006 [2]	Tang 2005 [7]	Zhang 2012 [3]
Conversion loss (dB)	8.8	6.8	6.9	10
RF frequency (GHz)	12	10	11.5	24
Local oscillator power (dBm)	14	8	20	13
Image frequency suppression (dB)	28	--	38.2	--

Table1 presents a performance comparison of the proposed mixer with the various published SIW mixer. Compared with the SIW mixer in [2] and [3] the performance of the proposed mixer structure shows a considerable suppression of the image frequency. Also, compared with [7], our proposed mixer is characterized with low local oscillator power and simple structure.

5. CONCLUSION

In this present paper, a compact design of millimeter wave mixer module using a single balanced mixer with SIW coupler and SIW filter is proposed. The performances and the advantages of the proposed mixer module are validated by the simulated results. In order to design a high performance microwave and millimeter wave integrated circuits, we suggest that this kind of mixer is the best choice.

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