Single Balanced Mixer Using Substrate Integrated Waveguide (SIW) 90° Coupler

Abdelkhalek Nasri, Hassen Zairi, and Ali Gharsallah

Abstract—**The present paper focuses on an innovative broadband millimeter- wave single balanced diode mixer which is designed through using a newly designed substrate integrated waveguide (SIW) 90° coupler. The low cost single-balanced mixer has its own advantages of low cost, low profile, and high performance. In addition, it has a less conversion loss of 6.6 dB, a wide-band response from 9.5 to 12.5 GHz and better than -20dB port-to-port isolations.**

Index Terms—**Substrate integrated waveguide (SIW), single-balanced mixer, coupler, conversion loss.**

I. Introduction

It is well known that the design of modern microwave telecommunication system requires high performance and low-cost mixers. Many passive components such as filters and couplers are incorporated in the design of mixers [1], [2]. In order to minimize the insertion loss and the interference of mixers a good coupler performance is required. However, we cannot forget the low performance of the classical 90 ° couplers. That's why, the substrate integrated waveguide (SIW) technology has emerged recently as a substitute for the design of modern microwave and millimeter wave communication systems, thanks to its attractive advantages of low-cost, high quality factor, low insertion loss and high performance [2]-[7].

The electric field distribution in an SIW fills the volume inside the interconnected waveguide and the surface currents propagate on the larger total cross-sectional area of the waveguide walls, thus, it results lower conductor losses. [8]. SIW is considered as a 3-dimensional (3-D) structure for signal transmission, and it seems challenging when it integrates with planar circuits, lines, and connecting pads. In order to address this concern, a host of mode and impedance matching transitions from SIW to microstrip stripline coplanar waveguide (CPW), and conductor backed coplanar waveguide (CBCPW) have been developed recently. We implement all these transitions, like the SIW using the same fabrication process as the rest of system's layout [8], [9].

The millimeter-wave mixers have been subject to intensive studies by researchers particularly in the aspects of port-to-port isolation. It is commonly known that single balanced type mixers have their own advantages of low-profile, low insertion loss, higher power-handling capabilities and easy integration in SIW circuits [10]-[12]. Moreover, the single balanced mixers made up with a nonlinear devices interrelated by single or multiple hybrids, or transformers.

In This present paper, we will first of all describe the 90° coupler which is mainly characterized by low conduction loss, then discuss the design of the mixer, and finally present the results and the electrical performances of mixers**.**

II. Design of The SIW Coupler

At the mm-wave the traditional planar hybrid couplers experience an extremely high conduction loss [13]. In addition to their quarter-wave length segments which are shorter than the widths. So obviously, physical implementation and strong mutual coupling difficulties could happen due to this issue.

That's why many passive compact and low cost components have developed rapidly [14]-[17]. For decades, there have been intensive studies of couplers which have been widely used as key components in many systems.

SIW couplers can be used in both microwave and millimeter-wave systems, as well as in modular and in integrated form. However, the present coupler has a simpler design as compared to the narrow wall waveguide coupler.

The configuration of the SIW 90° coupler is shown in Fig. 1 with its geometry parameters. The spacing '*a*' which stands between the two rows of metallic vias is for the frequency band of the waveguide. The via diameter '*D*' is considered as equal or smaller than a tenth of the wavelength of the maximum operation frequency, while spacing '*s*' is chosen to be equal or smaller than twice the diameter of the metallic via. The geometric parameters are primarily determined by the relationship between the conventional rectangular waveguide and the SIW [1].

A concave area is formed with length 'l2' in the middle and depth '*h*' while the length of SIW in each port is '13'. The length between the port and the concave area is '*1*1' ,'*l*1', '*l*2', '*w*2', and '*h*' can be changed to control the coupling.

The width '*t*2' and '*w*1' and length '*t*l' of the microstrip taper is adopted to fit the microstrip and SIW in wideband to obtain 50Ω characteristic impedance [4].

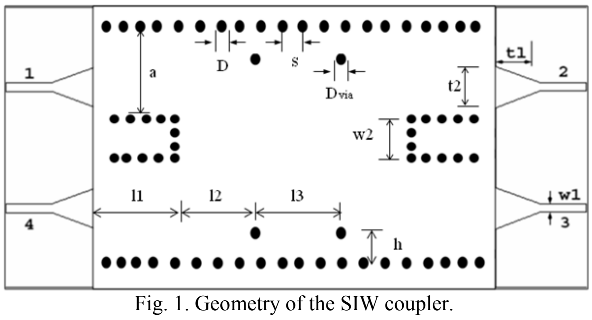

Fig. 1. Geometry of the SIW coupler.

The parameters of the SIW 90° coupler in Table I are

Manuscript received July 17, 2014; revised September 16, 2014.
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DOI: 10.7763/IJET.2016.V8.859

obtained after gradual optimization with HFSS (high-frequency structure simulator). It is obvious that the thickness of the dielectric substrate is 0.5 mm, ε_r=2.2 and the dielectric loss tangent is 0.009.

In order to achieve a wide-band performance, the parameters are finely tuned using three-dimensional (3-D) electromagnetic (EM) simulation software and high-frequency structure simulator (HFSS).

TABLE I: DIMENSION OF THE STRUCTURE

a	*s*	*D*	*t*1	*t*2	Dvia
12.25mm	0.7mm	0.4mm	20.5mm	7.2mm	0.8
*w*1	*w*2	*l*1	*l*2	*l*3	*h*
1.3mm	3.7mm	4.1mm	10.4mm	10.4mm	2.8mm

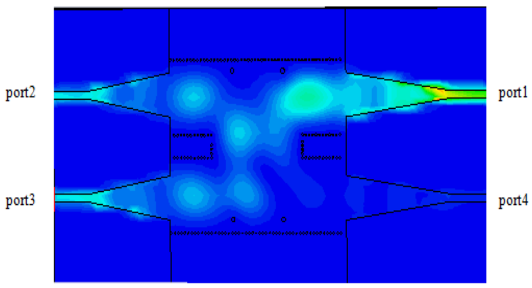

Fig. 2. Electric field distribution of TE10 mode for SIW coupler at *f*=12 GHz.

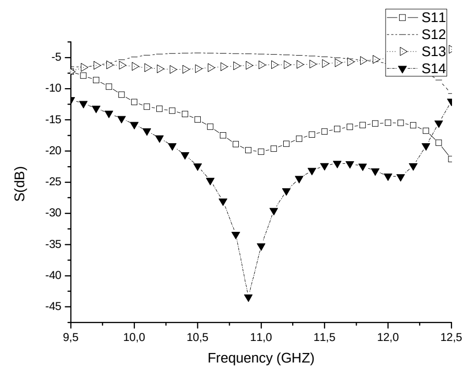

Fig. 3. Simulated S-parameters of SIW coupler.

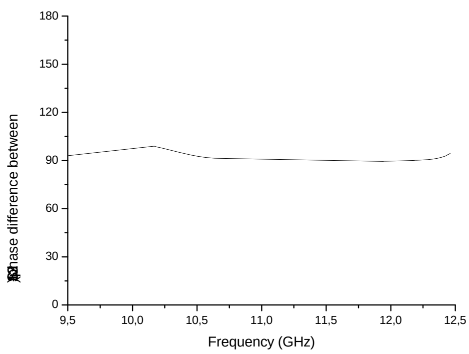

Fig. 4. Simulated phase difference.

The electric field distribution of the *TE*10 mode, the reflection coefficients *S*11, the transmission coefficients *S*12, the coupling coefficient *S*13 as well as the isolation coefficient *S*14 are presented in Fig. 2-Fig. 3, respectively. It is noticeable that the 90° coupler characterizes with good port-to-port isolation. Also, it presents the simulated phase difference between two output ports. It is obvious that -3 dB to -6 dB are the outputs at ports 2 and 3. The phase difference is distributed in the range of 89° to 94° in the frequency band of 9.5 to 12.5 GHz in Fig. 4.

So, it is clear that these simulation results demonstrate the good performance of this integrated structure.

III. DESIGN OF THE SINGLE-BALANCED MIXER

In order to get very high frequencies this low-cost and distributed microwave diode mixer, which is very similar to the above mixer, is a good choice when used with Schottky diodes.

Schottky diodes mixer are used in a large number of circuits. The development of these circuits is for enhancing the system performance and optimizing a specific design characteristic. Through combining two Schottky mixer circuits in a balanced configuration where the two diodes are driven in opposite phase, improvement upon the single ended mixer can be obtained.

This extra circuitry in single diode made up of a mixture of passive coupling, power division, and filtering. However, it is hard to make wideband single diode mixer with independent RF, LO, and IF bands while the multiplexing circuitry is frequency specific. In addition, such circuitry engenders extra losses which lead to mixer efficiency reduction [18]-[21].

So, as a solution to these problem researchers found out that wideband single balanced mixers with low loss and independent input and output frequency bands could be created using the SIW 90° coupler. This latter includes two inputs, two output, and four port circuit that provides mutual isolation between input ports and equal power division at the output ports [22], [23]. It makes clear that the hybrid junction for mixers is applicable as follows: the input LO and RF sources will be isolated from one another, which provide frequency band independence and equal power division to the load.

Fig. 5 presents a single balanced mixer with two diodes connected back-to-back, in addition to an SIW coupler formed on the same dielectric substrate. The SIW coupler performs as the input and power delivery component better than the classical couplers. Thanks to SIW structure, the insertion loss and interference on other circuits is minimized due to the radiation loss which exists only at the transitions between the SIW coupler and microstrip. In addition, the performance of the mixer is enhanced by designing carefully the coupler and transitions, in which the 90° SIW coupler shows a considerably wide band performance at a desired frequency.

The production of the difference frequency when two frequencies are combined or mixed in the diode is considered as the primarily application of the Schottky diode. Besides, this combination or mixing action is due to the non-linear relationship between current and voltage.

The mixing output signal at the output port made up with a signal whose designed frequency is the difference between RF frequency and LO frequency and this desired signal named intermediate frequency (IF) along with other unwanted signal products.

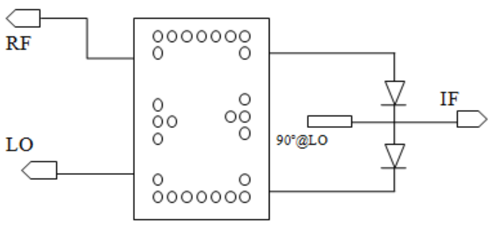

Fig. 5. Configuration of the proposed SIW mixer.

IV. Simulated Results

This part focuses on the simulation results of the single balanced mixer. Analysis results of SIW coupler from HFSS are included in the harmonic balance simulation through using "S4P" data item of ADS (Advanced Design System).

The major design issue in passive mixer is to reduce the conversion loss .Through the simulation results we can prove the good performance of this integrated structure. Fig. 6 and Fig. 7 shows the simulated results. Where the RF frequency is 12GHz, the LO frequency is 10GHz, the LO power sweep from -10 to 10dBm, the RF power is -30dBm, and the simulated conversion losses are under 6.6dB with LO power 8 dBm. The input power causes a drop of 1dB in the linear gain due to device saturation. Fig. 7 shows the 1dB compression point which is 12 dB of RF input power.

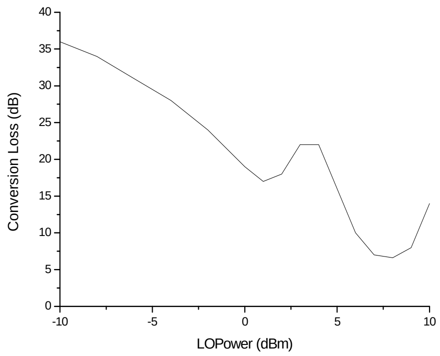

Fig. 6. Conversion loss versus LO power.

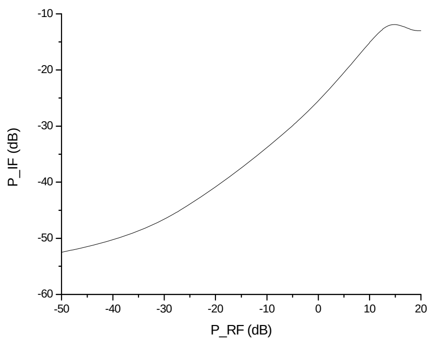

Fig. 7. P1_dB gain compression.

V. Conclusion

In this paper, we suggested a low cost single balanced microwave mixer design using a 90° SIW Coupler. The simulated results show a low conversion loss and a high performance. Our proposed mixer can guarantee a good port-to-port isolation.

So, it is noticeable that the suggested mixer has a good advantages that help design a high performance microwave and millimeter wave integrated circuits. Noting that, an antenna can be integrated directly with our design in order to structure a very compact receiver front-end of millimeter-wave communication system.

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