Compact Down-Conversion Mixer Design Employing a Wide and Deep Stop-Band DGS-LPF

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***Abstract*—This paper investigates a compact 24-GHz hybrid down-conversion mixer. The proposed mixer is based on a wide and deep stop-band low pass filter, four Schottky diodes, two hybrid couplers and an open stub. The unwanted harmonics are rejected by means of a filter based on three uniforms dumbbell-shaped defected ground structure and a compensated microstrip line. A good conversion loss of 2.19dB, 1-dB compression point of 3-dBm and an LO-to-RF isolation better than 35dB are obtained. The validity of the mixer configuration and the design procedure are confirmed by a comparison between simulation results and measurements data reported in literature.**

***Index Terms*—open stub, coupler, Defected Ground Structure (DGS), Low Pass Filter (LPF)**

I. Introduction

In modern microwave and wireless communication systems, Mixers are among main parts of Radio Frequency (RF) front-end receiver which are focused on compact and high performances. Mixers design at 24GHz frequency for the Industrial, Scientific and Medical (ISM) band has become an appropriate choice for wireless communication solutions [1]. Additionally, the Federal Communication Commission (FCC) allocated a broadband between 22-29GHz for the Ultra-Wide Band (UWB) automotive Short Range Radars (SRR) [2], making the 24GHz range attractive for both ISM band and vehicle radar applications.

Mixers based on Schottky diodes have received considerable attention from the researchers in the area of RF/Microwave because of their simplicity and efficiency in the application of mixing signals [3]-[10]. A non-linearity of diode is used to generate an output spectrum which is consisted of sum and difference frequencies of two input signals. Passives and actives mixers have been presented in many literatures [3]-[10]. However, a small number of 24GHz hybrid mixers designs are developed and presented.

In this paper, a novel structure of a hybrid doubly balanced down-conversion mixer along with no DC power supply intended for a K-band front-end receiver system is presented The proposed mixer consists of four MA4E2502 Silicon Schottky Diodes (SSD) [11], two 180° rat-race hybrid couplers, an open stub which has an optimized length of 5.37mm connected to one port of the coupler and a wide and deep stop-band microstrip Low Pass Filter (LPF) using three uniforms dumbbell-shaped Defected Ground Structure (DGS) and a Compensated Microstrip Line (CML) [12]. All prototypes are simulated on RO4350B Rogers material substrate with thickness of 0.25mm and conductor layers of 35μm. The relative permittivity of the substrate is taken as 3.63 for all designs. Moreover, the RF power of -30dBm at 24.125GHz and LO power of 3dBm (and afterward 10dBm) at 24GHz are injected at the two inputs of the proposed mixer. The design aims are as follows: Conversion loss less than 15dB and Isolation much better than 25dB.

II. Down-Conversion Mixer Design

Generally, a double balanced diode mixer makes use of four diodes in a ring or star configurations as shown in Fig. 1(a) and Fig. 1(b) respectively [13]-[15]. All mixer ports are isolated from each other. Their advantages over a single balanced topology are as [13]-[15]:

- Good isolation between ports;
- Superior suppression of spurious products (all even order products of the LO and/or the RF are suppressed);
- Good linearity.

And their disadvantages are that they require:

- A higher level LO drive;
- Two transformers (Baluns).

In practical circuits, the star configurations are rarely used [14] so a common and conventional doubly balanced diode is ring mixer as shown in Fig. 1(a). It is based on four diodes, two transformers and a filter at IF port.

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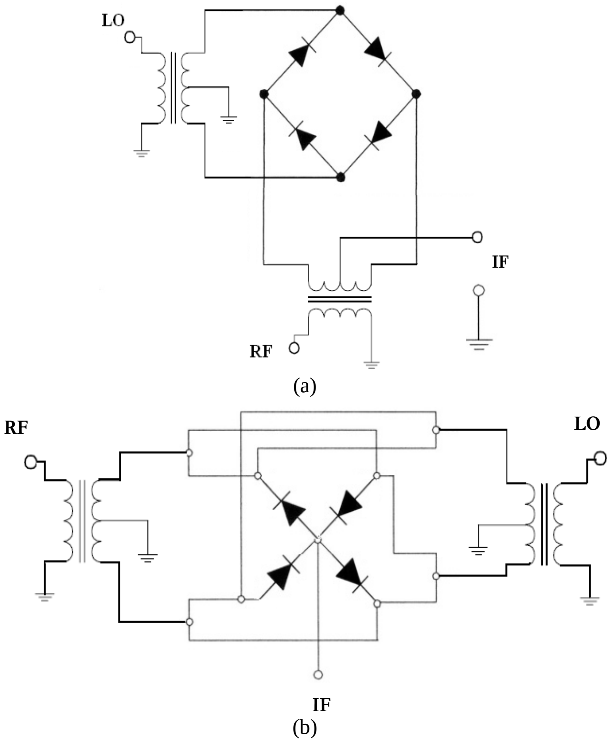

Figure 1. Block diagram of double-balanced diode mixers (a) ring topology and, (b) star topology.

For a microwave ring mixer, the transformers are replaced by baluns such as rat-race couplers or parallel coupled strip.

The rat-race coupler, shown in Fig. 2, is used for dividing the input signals into two equal components which are either in phase or 180° out of phase. The design at RF frequency, i.e., f_{RF}=24.125GHz is performed on the same substrate. The impedances Z_0=50Ω and $Z_1 = \sqrt{2}Z_0 = 70.71\Omega$, and the dimensions of the coupler after tuning by simulation are as follows:

$$W_0 = 0.52\text{mm},\ W_1 = 0.27\text{mm},\ \ell_1 = \lambda g/4 = 1.71\text{mm},$$

$$\ell_2 = 3\lambda g/4 = 5.13\text{mm}$$

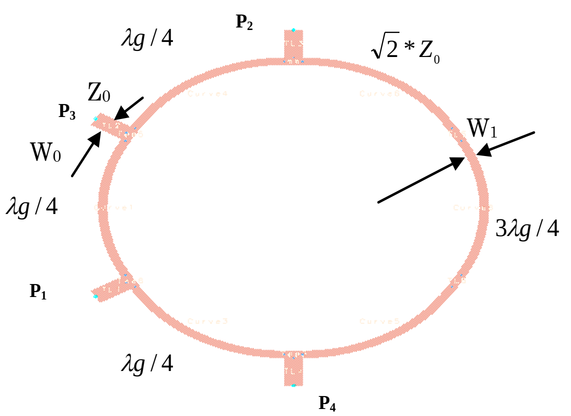

Figure 2. Layout and basic parameters of Ring-rat coupler with 04 ports.

The simulated results are shown in Fig. 3.

From Fig. 3, all ports are matched and good isolation is achieved between ports 2 and 1 and so it is between ports 3 and 4. Moreover, it is confirmed that the phase shifts defined as ph3 and ph4 are respectively equal to 180° and 0° as shown in Fig. 3(d).

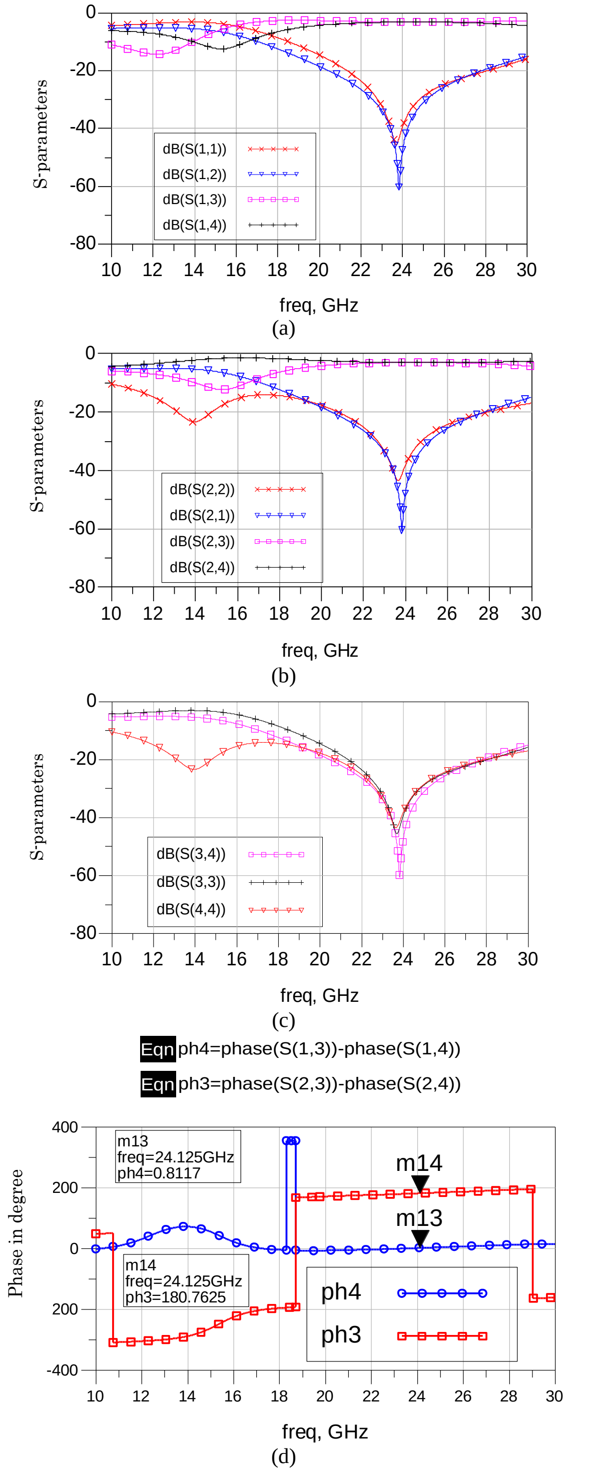

Figure 3. Simulated results of 04-port ring-rat coupler (a) S_{11}, S_{12}, S_{13} & S_{14} vs. frequency, (b) S_{22}, S_{21}, S_{23} & S_{24} vs. frequency, (c) S_{33}, S_{34} & S_{44} vs. frequency and (d) phase between ports.

In this work, mixer design based on rat-race couplers is adopted using a wide and deep stop-band DGS-LPF with a CML. Moreover, instead of connecting one port of the coupler to the ground as done in a conventional structure (Fig. 1), an open stub with a physical length has been used as shown in Fig. 4. This new idea allows us to control with awareness the performance of the mixer such as Conversion Loss (CL), 1-dB compression point and isolations. It has been shown that with conventional structure [14], the CL is quite acceptable and it is around 6 to 7dB for high LO power of 16dBm. With the proposed MIXER configuration, the CL can be very low with LO power of 10dBm, very small RF power of -30dBm and without DC power supply. The DGS patterns in Fig. 4 are indicated by dashed line.

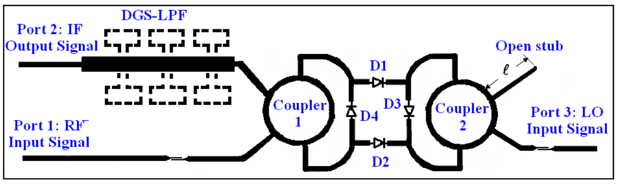

Figure 4. The proposed mixer topology.

A particular utilization of the Schottky diode is based on its performance such as a very good non-linear, low cost element and requires no DC power supply. It is a particular diode type with very low forward-voltage drop. The MA4E2502 SSD has been selected for its extremely low parasitic capacitance and inductance, surface mountable in microwave circuits and lower susceptibility to Electrostatic Discharge Damage (ESD) [11]. The spice model given in [11] has been implemented in the Advanced Design System (ADS) circuit simulator.

The diodes are considered as a switches controlled by the LO; the frequency mixing process can be expressed as [13]:

$$v_{IF}(t) = s(t).v_{RF}(t) \quad (1)$$

where $v_{IF}(t)$ and $v_{RF}(t)$ are respectively the voltage waveform at IF and RF port. $s(t)$ is a symmetrical square-wave switching function.

The expression (1) shows that the signal at the IF port is in fact the RF signal multiplied by an LO square wave of peak magnitude ±1, i.e., if a voltage waveform is applied to the RF port at a frequency of 24.125GHz and a square wave (switching waveform) is applied to the LO port at a frequency of 24GHz, the multiplication of the two signals will produce a waveform at the difference frequency, IF, of 125MHz.

Usually, microwave mixers are more complicated and require very precise design as well as very good performance. In order to achieve good performance such as low CL and high LO-to-RF isolation as possible, the dimensions of the different blocks of the proposed mixer structure are optimized using ADS software. The open stub shown in Fig. 4 has an optimized length of 5.37mm and permits achieving double-balancing of signals.

In the following section, IF output spectrum, relations between RF signal and IF output levels and, between RF signal and CL, are investigated and the obtained results are compared to the measurements data reported in the literature.

III. Results and Discussion

The simulations results of the proposed mixer are presented in this section. In order to illustrate the different output powers at IF output port of the mixer, two steps are considered as follows:

A. *Before Adding the DGS-LPF Along with a CML*

Fig. 5 shows the simulation results of the output powers in spectral domain at the IF output port when the DGS-LPF is not added. The RF power of -30dBm at 24.125GHz and LO power of 3dBm at 24GHz are injected at the two inputs of the mixer.

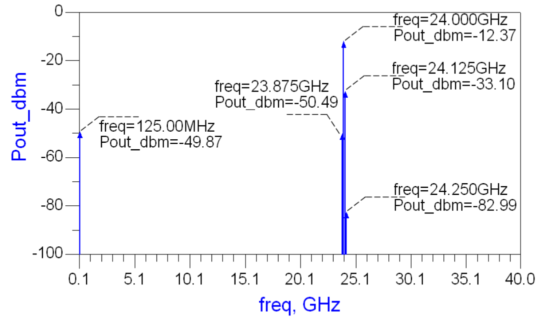

Figure 5. IF output spectrum before adding a DGS-LPF along with a CML.

From Fig. 5, it can be seen that the undesired harmonics are not rejected especially at LO frequency when the filter was not introduced.

B. *After Adding the DGS-LPF Along with a CML*

Fig. 6 shows the simulation results of the output powers in spectral domain at the IF output port while the DGS-LPF along with a CML is added. The same powers as stated in previous sub-section are injected at the two inputs of the mixer. In order to achieve a low CL and a high LO-to-RF isolation, RF power is keeping of -30dBm and LO power is increased to 10dBm are injected at the two inputs of the mixer.

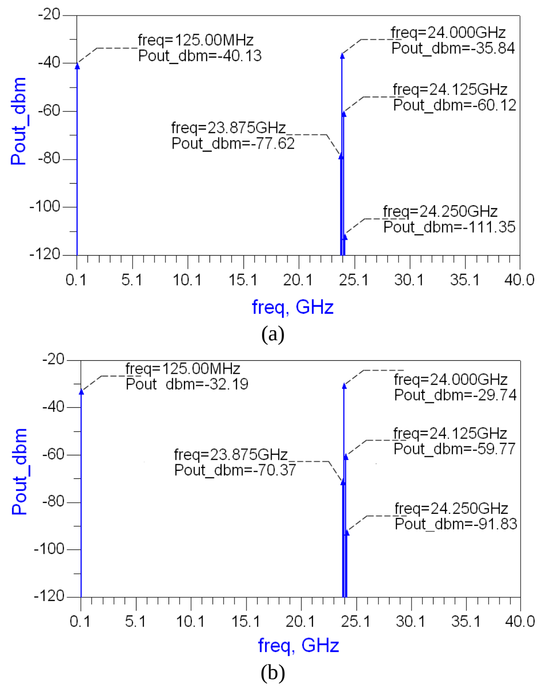

Figure 6. IF output spectrum after adding a DGS-LPF along with a CML. (a) P_RF=-30dBm & P_LO=3dBm and (b) P_RF=-30dBm & P_LO=10dBm

From Fig. 6(a) and Fig. 6(b), it can be seen that the undesired harmonics are well rejected when the filter was added at the IF output of the proposed mixer.

Fig. 7 and Fig. 8 show respectively the simulated results of both 1-dB compression point and conversion loss.

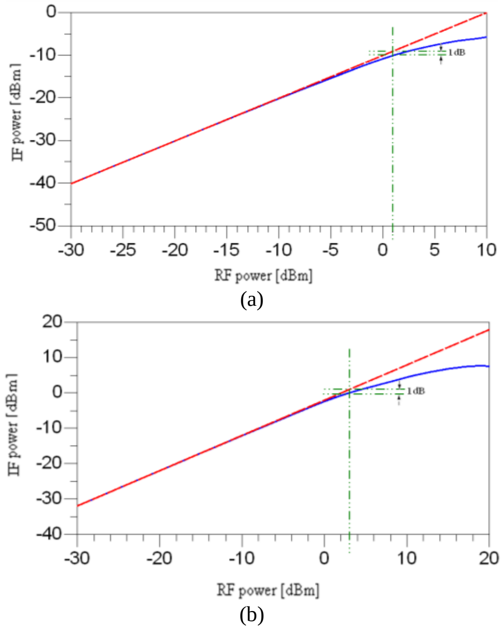

Figure 7. 1-dB compression point (a) P_RF=-30dBm & P_LO=3dBm and, (b) P_RF=-30dBm & P_LO=10dBm.

From Fig. 7(a) and Fig. 7(b), it is observed that the 1-dB compression point is equal to 1dBm and 3dBm, respectively.

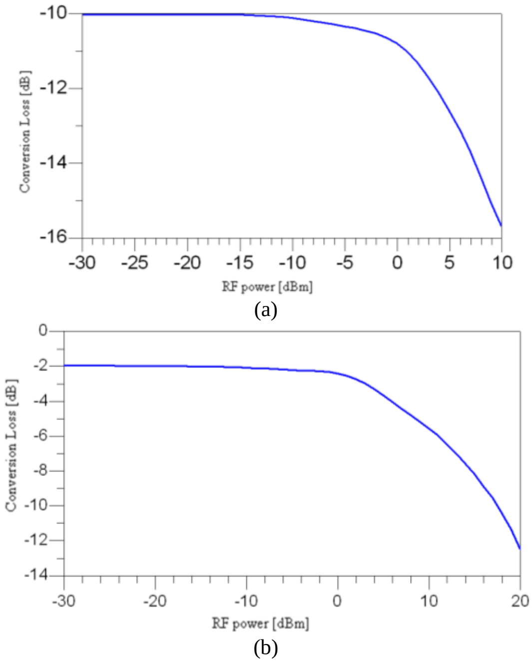

Figure 8. Conversion loss (a) P_LO=3dBm and (b) P_LO=10dBm.

From Fig. 8(a)-Fig. 8(b), the maximum conversion loss of a mixer is around 10.13dB for LO power of 3dBm and 2.19dB for LO power of 10dBm. Furthermore, it can be observed that it is constant below -15dBm for LO power of 3dBm and 0dBm for LO power of 10dBm. Afterward, the CL decreases due to the non linearity of the mixer.

The simulated results shown in Fig. 7 and Fig. 8 are reported in Table I together with those reported in the literature. Table I compares the simulations results of the proposed mixer with the measurements data reported in the literature. It shows a good agreement with the measured parameters in [10]. By optimizing the different blocks of the proposed mixer structure, it was possible to obtain a good performance. Moreover, it has been seen that the level 3dBm of the LO signal power is good enough for an attainment of CL of 10.13dB. Accordingly, low level of LO signal is a benefit for the mixer and knowledge of the optimal one is very important.

TABLE I. COMPARISON TO THE REPORTED DESIGN

Characteristic	Ref. [10]	Ref. [14]	This work	
f_{RF} [GHz]	–	22-26	24.125	
f_{LO} [GHz]	24.15	–	24	
f_{IF} [MHz]	0.18	–	125	
P_RF [dBm]	-30	–	-30	
P_LO [dBm]	3	16	3	10
V_{DC} [V]/I_{DC} [mA]	without bias	without bias	without bias	
CL [dB]	15	06 to 07	10.1	02.1
1-dB [dBm]	–	–	1	3
Isolation [dB]	–	–	>35	

IV. CONCLUSION

In this paper, a 24GHz compact hybrid double balanced down-conversion mixer for RF front-end receivers has been investigated. In order to reject the undesired harmonics, DGS-LPF with compensated microstrip line has been used at the IF output of the proposed mixer. Instead of connecting one port of the coupler to the ground as done in a conventional structure, an open stub with an optimized length of 5.37mm has been used. This original design allows us to manage with awareness the performance of the mixer. The proposed mixer has shown a minimum CL about 2.19dB and a 1-dB compression point around 1dBm. The simulation results show excellent agreement with the experimental ones reported elsewhere.

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