Distributed Diode Single-Balanced Mixer Using Defected and Protruded Structures for Doppler Radar Applications

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Abstract **─** In this paper, a single-balanced diode mixer using defected and protruded structures for wireless application is presented. The operating frequency is selected for WLAN applications. The RF frequency is 2.412-2.484 GHz and the Local Oscillator (LO) is 2.132-2.204 GHz for 269 MHz Intermediate Frequency (IF) output signal. A Branch-Line Coupler is designed for the single-balanced of mixer. Four protruded T-shaped strip are used to obtain good convention gain and suppress unwanted harmonics. Also by using Defected Ground Structure (DGS) with folded T-shaped arms in the filter, a harmonic rejection property is generated. The measured performances of fabricated circuit conventionalize to the simulated results and LO to RF isolation is lower than -20 dB, LO to IF isolation is lower than -28 dB and Radio Frequency (RF) to IF is lower than -37 dB.

Index Terms **─** Defected Ground Structure (DGS), folded T-shaped arms, protruded T-shaped strip, single-balanced diode mixer.

I. INTRODUCTION

As a part of signal recovery circuit, a down-conversion mixer circuit is a necessary part. The conventional design technique for a balanced-diode mixer will be combined with the low-pass response of DGS to overcome the leakage RF and LO as well as other unwanted harmonics. A three-port down-conversion mixer convert signal of High Frequency (RF) from low-noise amplifier and LO stable signal from local oscillator .The mixing output signal at the output port consists of the signal whose designed frequency is a difference frequency between RF and LO, which is desired signal so called Intermediate Frequency (IF) and other unwanted signal products. For affordable technology, a hybrid mixing circuit can be designed by using diode or transistor [1]. The diode mixing circuit is simple and can be used up to millimeter wave. There are many publications of balanced-diode mixer, focusing is a LO leakage elimination by using either radial stub or conventional low-pass filter [2]-[5]. The use of band-rejection like stub limits the operating range of LO while the conventional Low-Pass Filter (LPF) offers very good RF and LO suppression, but not the higher harmonics.

In this paper, we propose a novel single balanced diode mixer with harmonic rejection property. By using four protruded T-shaped strip in the ordinary branch-line coupler, an excellent isolation -33 dB at 2.4 GHz can be achieved. Also by using DGS with folded T-shaped arms in the filter, a harmonic rejection property is generated. The proposed mixer circuit was designed by using a simulator to design ADS, in part of DGS design by HFSS and export S-parameter for using in ADS simulator for design mixer circuit. The measurement of power spectrum of mixer was performed using spectrum analyzer.

II. SINGLE-BALANCED DIODE MIXER CONFIGURATION

In this paper, we simulated and manufactured single-balanced diode mixer using defected ground structure and protruded T-shaped strips for wireless applications by using 2 simulators, Advance Design System (ADS) [6] and High Frequency Structures Simulators (HFSS) [7]. The presented miniature packaged mixer with the integrated band-reject filter is shown in Fig. 1, which is printed on Rogers

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RT/Duroid 5880 substrate with 0.635 mm in thickness and with a relative dielectric constant of 2.2. In this structure we used Silicon Schottky diodes HSMS-2862. Mixer design for wireless LAN range with 2.412-2.484 GHz for RF, 269 MHz for IF output. The proposed design simplification of single-balanced diode mixer using DGS and the design are separated in 4 parts, design of branch-line coupler with protruded strip, design of matching circuit, design of defected ground structure, and circuit integration.

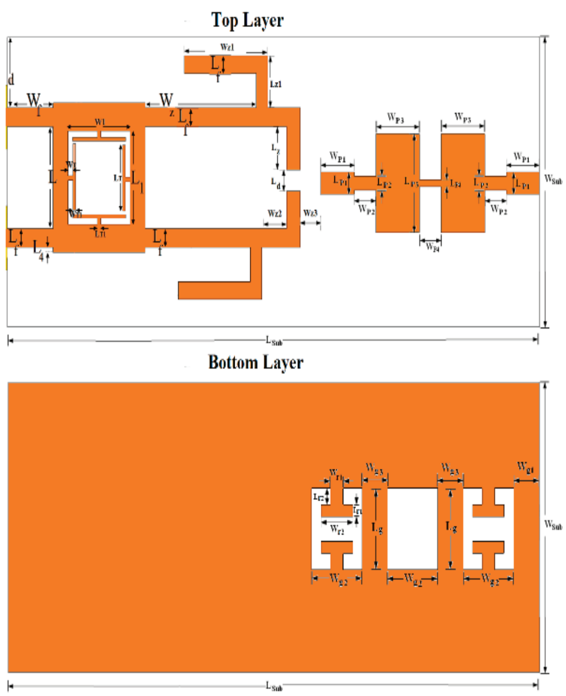

Fig. 1. Schematic of proposed single-balanced diode mixer using defected and protruded structures.

Quadrature hybrid mixers are used in microwave systems though their inherently poor LO-to-RF isolation, poor spurious-response rejection, and the fact that a poor RF-source VSWR at the LO frequency can unbalance themixer, they are distinctly inferior to 180-deg mixers. However, the practical advantages that the microstrip-line impedances used to realize a branch-line hybrid are easy to achieve, and the branch line is slightly smaller than ring hybrid at the same frequency. Also, the RF and LO ports of the branch-line hybrid mixer are on the same side of the hybrid, which is often an advantage in creating a compact circuit. The filter is used to reduce the out of band harmonics generated by the rectifying Schottkey diode. The width of the 50-Ω microstrip line is fixed at 0.9 mm. The matching circuit to the left and right of the device controls the degree of reflection. On the other side of the substrate, a conducting ground plane is placed. In addition, to satisfy the isolation requirement, the microstrip strips are fixed to a suitable electrical length [8].

The final values of presented single-balanced diode mixer design parameters are specified in Table 1.

Table 1: The final dimensions of the designed single-balanced diode mixer

Param.	mm.	Param.	mm.	Param.	mm.
W_f	10	L_f	1	W_1	12
L	18	W_l	14	L_l	16
W_T	1	L_T	12	W_{T1}	1
L_{T1}	1	L_4	1	d	5
L_z	8	L_d	2	Wz1	12
Wz2	2	Wz	15	Wz3	1
Lz1	4	W_{sub}	30	L_{sub}	71
W_{P1}	4	L_{P1}	6	W_{P2}	3
L_{P2}	2	W_{P3}	6	L_{P3}	14
W_{P4}	3	L_{P4}	1	L_g	10
W_{g1}	6	W_{g2}	8	W_{g3}	4
W_T	2	L_T	2	W_{T1}	6
L_g	10	W_{g1}	6	W_{g2}	8
W_{g3}	4	W_{r1}	2	L_{r1}	2
W_{r2}	6	L_{r2}	2		

III. MIXER COMPONENTS DESIGN

A. Design of branch-line coupler

Microwave branch-line coupler is one of the fundamental building blocks for balanced mixers. The schematic of the proposed branch-line coupler is shown in Fig. 2. This presented microstrip coupler was designed on a Rogers RT/Duroid 5880 substrate with 0.635 mm in thickness and with a relative dielectric constant of 2.2. The lines between the ports show the phase shift between them. This component has a 90 degree phase delay between ports 2 and 4 and between ports 1 and 3.

Ports 1 and 2 and ports 3 and 4 are mutually isolated pairs. The presented structure consists of a branch-line with four protruded T-shaped strips and a ground plane. As shown in Fig. 3, the proposed coupler can obtain excellent isolation 33 dB at 2.4 GHz [9]-[10].

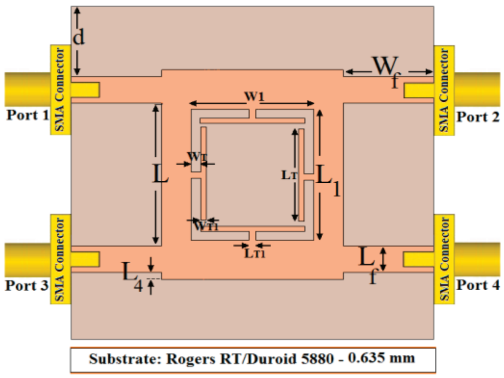

Fig. 2. Schematic of proposed branch-line coupler with four protruded T-shaped strips.

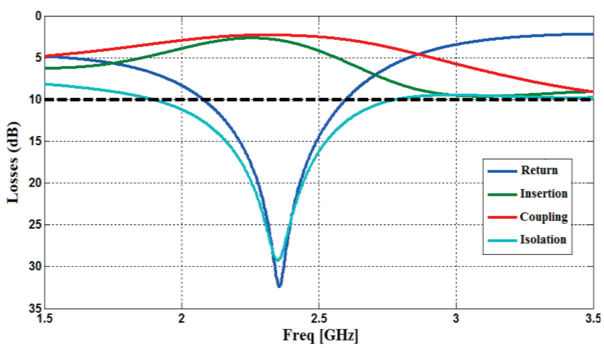

Fig. 3. Simulated losses for the proposed coupler.

B. Design of matching circuit

The matching circuits are designed to get minimum reflection coefficient at the diodes input. The analytical design of the input matching circuits is performed using the developed computer program [12]. The impedance transforming properties of transmission lines [13] can be used in the matching networks. A microstrip line can be used as a series transmission line, together with a short or open circuited shunt stub can transform a 50 Ω resister into any values impedance. We designed a series transmission line with open stub, and the series transmission line with short stub is chosen. Matching schematic for single-balanced diode mixer is shown in Fig. 1. Length of open circuit series stub (50 Ω) = 12.4569 mm, and width of open circuit series stub = 0.9 mm, length of balanced shunt stub (50 Ω) = 6.318 mm, width of balanced shunt stub = 0.9 mm.

C. Microstrip low-pass filters by using DGS structre with folded T-shaped arms

In this paper, two novel low-pass filters using Defected Ground Structure (DGS) slot with a pair of folded T-shaped arms are presented. The resonant frequency of the slot can be easily controlled by changing the folded T-shaped dimensions, without changing the area taken by the structure. Using this slot, two quasi-elliptic low-pass filters were designed, fabricated and tested. The experimental results show good agreement with simulation results and demonstrate that excellent stop-band performance could be obtained through the proposed low-pass filter. The filter has a cut-off frequency of about 2.4 GHz.

Defected Ground Structure (DGS) evolved from Photonic Band Gap (PBG) is realized by etching defected pattern and slot in the ground plane. The etched defect in ground plane disturbs the shield current distribution in the ground plane. This disturbance can increase the effective capacitance and inductance of a transmission line respectively. Thus, an LC equivalent circuit can represent the proposed unit DGS circuit [14]. The proposed DGS slot is shown in Fig. 2. The slot is etched in the ground metallization under the microstrip line. This slot has a major advantage in providing tighter capacitive coupling to the line in comparison to known microstrip DGS structures. Moreover, the resonant frequency of the structure can be controlled by changing the distance between the folded T-shaped arms. The resonant frequency of the slot can also be modified by changing the overall slot size this slot, however, shifts the cut-off frequency of the filter down. To shift the cut-off frequency back, it is necessary to reduce the inductance of the narrow stripline that is located over the slot. This can easily be done by increasing the width of the strip [14].

The microstrip low-pass filter, Fig. 4, was designed on both substrate sides by opening apertures in the ground metallization under the high-impedance transmission line. Replacing some of the apertures by the proposed folded T-shaped arms structure introduces transmission zeroes. The number of transmission zeroes is equal to the number of apertures with folded T-shaped arms.

Figure 5 shows the top and bottom layouts of the designed filter with central aperture replaced by the proposed folded T-shaped arms structure. Figure 6 shows the measured and simulated return and insertion loss of the filter. As shown in Fig. 6, a transmission zero, which improves behavior of the filter stop band, is observed at 6.42 GHz.

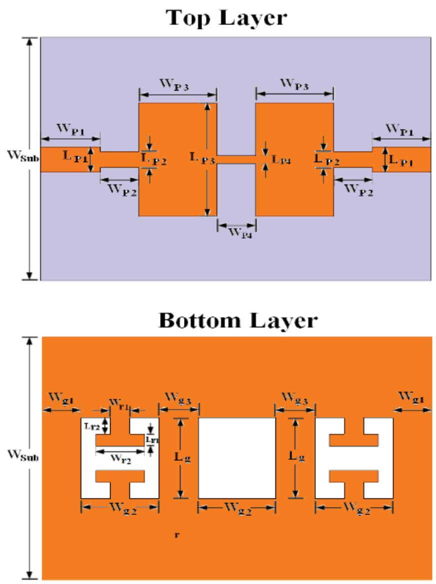

Fig. 4. Top and bottom layouts of a fifth-order low-pass filter with two DGS slots with folded T-shaped arms.

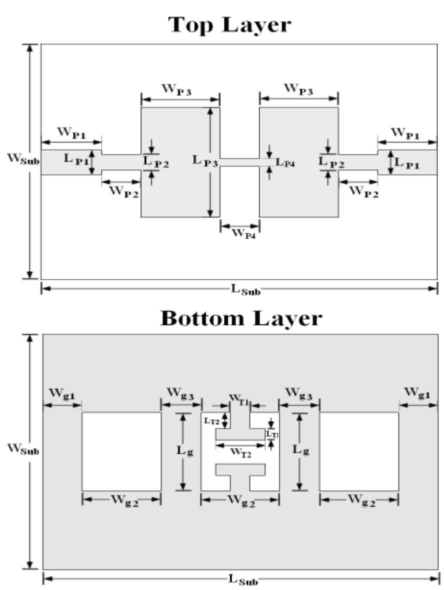

Fig. 5. Top and bottom layouts of a fifth-order low-pass filter with one DGS slot with folded T-shaped arms.

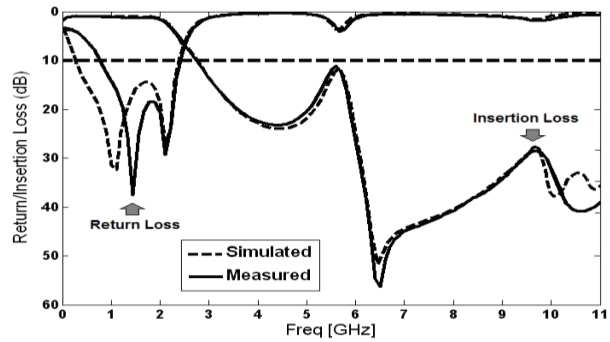

Fig. 6. Return and insertion loss of a fifth-order low-pass filter with one transmission zero.

In order to improve the stop-band behavior of filter responses, two rectangular slots with T-shaped arms inserted in the positions of the two apertures, as shown in Fig. 4. Another important parameter of this structure is the exterior length of the T-shaped open stubs L_{r1}. Figure 7 shows the insertion loss for different values of L_{r1}. It is found that by inserting the four T shaped strip of suitable dimensions at the ground plane, additional transmission zero at 10 GHz is created and hence much wider insertion loss bandwidth with multi transmission zeros can be produced, especially at the higher band.

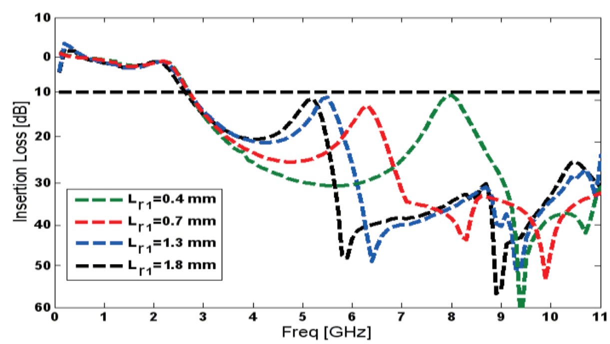

Fig. 7. Simulated insertion loss characteristics for various values of L_{r1}.

The proposed filter with optimal design, as shown in Fig. 8, was built and tested in the Antenna Measurement Laboratory at Iran Telecommunication Research Center (ITRC). Figure 6 shows the simulated and measured insertion and return loss of the filter. As shown in Fig. 9, two transmission zeros are introduced to the filter response at about 5.28 and 8.72 GHz. Consequently, a wide stop-band was achieved.

Additionally, the proposed DGS low-pass filter also has characteristics of wider and deeper stop-band than those of conventional low-pass filters [15]. In order to confirm the accurate measurement characteristics for the designed structure, it is recommended that the manufacturing and measurement processes need to be performed carefully. Moreover, SMA soldering accuracy and substrate quality need to be taken into consideration.

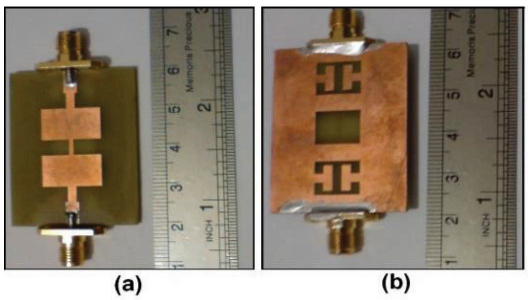

Fig. 8. Top (above) and bottom (below) layouts of fabricated low-pass filter.

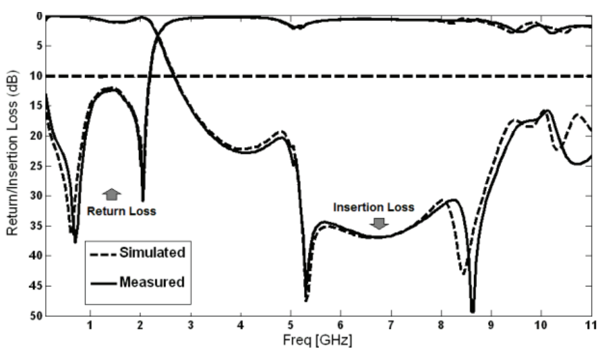

Fig. 9. Return and insertion loss of a fifth-order low-pass filter with two transmission zeroes.

IV. SINGLE-BALANCED DIODE MIXER MEASURMENTS

The proposed single-balanced diode mixer design, as shown in Fig. 10, was built and tested. For finding power spectrum in ADS simulator, we must edit equation for finding power at output port shown below:

$$P_{Out}(dBm) = 10\log(0.5 \times real(V_{load} \times conj(L_{load} \times i))) + 30\,, \quad (1)$$

P_{out}(dBm) is a power output at IF port in unit dBm, V_{load} is a voltage at output load at IF port, and I_{load} is a current at output load.

When we apply three design parts for single balanced diode mixer using DGS shown in Fig. 1, the power spectrum of mixer generate input RF at 2.448 GHz with power -10 dBm and input LO at 2.168 GHz with power 0 dBm.

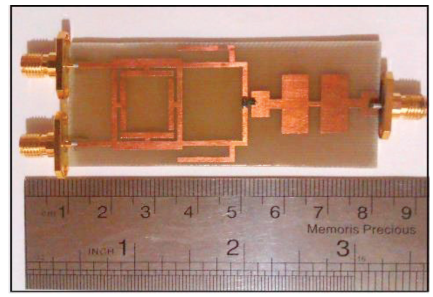

Fig. 10. Photograph of the realized single-balanced diode mixer.

For measured output power spectrum, the first sweep generator set at RF signal of 2.448 GHz with power -10 dBm and connected to RF port of mixer, then feed on LO signal of 2.168 GHz with power 0 dBm and connected to LO port of mixer. Output port is connected to the spectrum analyzer. The IF spectrum is shown in Fig. 11.

The port to port isolation parameters define how much signal leakage occurs between pairs of ports. LO to RF, LO to IF and RF to IF are shown in Fig. 12. LO to RF isolation is lower than -28 dB, LO to IF isolation is lower than -20 dB and RF to IF is lower than -37 dB.

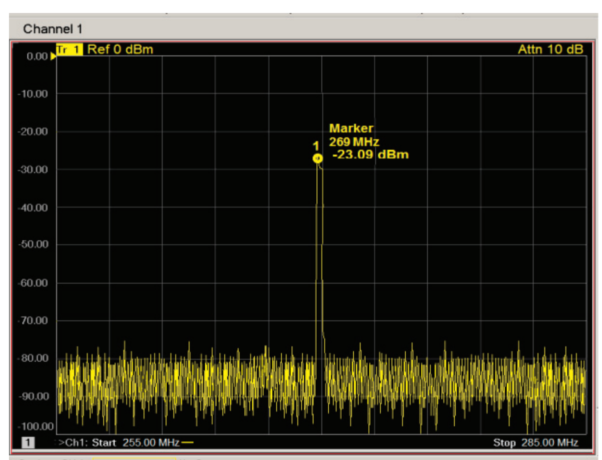

Fig. 11. Measurement of IF power spectrum of the proposed mixer.

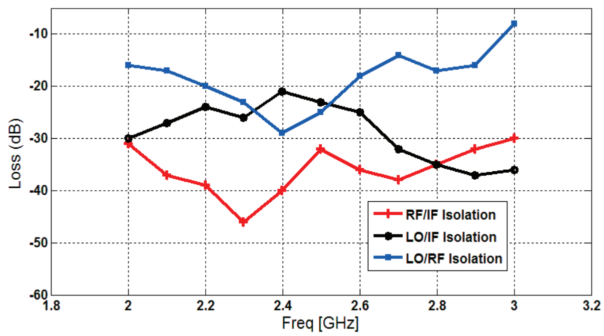

Fig. 12. Port to port isolation (LO to RF, LO to IF and RF to IF).

V. CONCLUSION

As presented above, a novel design of a down-conversion single-balanced diode mixer using defected structures for WLAN applications has been designed. By using four C-shaped slots in top and bottom arms in the branch-line coupler, an excellent isolation -33 dB at 2.4 GHz can be achieved. Also in this paper, two compact quasi-elliptic low-pass filters by using novel DGS slot with folded T-shaped arms are designed and fabricated. A mixer circuit was designed by using a simulator to design ADS, in part of DGS design by HFSS and export S-parameter for using in ADS simulator for design mixer circuit. The measurement of power spectrum of mixer was performed using spectrum analyzer. The mixer design based on the defected structures concept has been shown to provide an efficient and successful method for designing high isolation and compact systems.

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