Design and Modeling of Uniplanar Double-Balanced Mixer

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***Abstract*—A novel uniplanar double-balanced mixer (UDBM) including coplanar waveguide (CPW)-to-coplanar stripline (CPS) baluns as well as CPS high-pass and low-pass filters is designed and implemented. This mixer is simulated by an equivalent-circuit model, and its measured and simulated results are compared. The proposed mixer has conversion loss ranging from 6 to 10 dB and LO-to-IF and LO-to-RF isolations greater than 30 and 20 dB, respectively, and also provides broader LO and IF bandwidths of 10–35 GHz and 0.1–5 GHz, respectively.**

***Index Terms*—Mixer, uniplanar components.**

I. Introduction

DOUBLE-BALANCED diode mixers have widespread applications in modern microwave systems. Their wide dynamic range and relatively low noise have made them attractive in the circuit design.

Most of the double-balanced mixers are nonplanar and not suitable for the planar monolithic microwave integrated circuit (MMIC) process. Major challenging problems of implementing a uniplanar mixer are the designs of uniplanar baluns and diplexer circuits in the local oscillator (LO), radio frequency (RF), and intermediate frequency (IF) ports. So far, only very few research works on uniplanar double-balanced mixers (UDBM) have been reported [1]–[4]. Most of these mixers were realized using the conventional baluns or transitions among coplanar waveguide (CPW), slotline, and coplanar stripline (CPS), which are either double Y-junction type or Marchand type [1]–[3]. But they require larger chip sizes for implementation at lower frequency and suffer from limited bandwidth due to the electrical length limitation associated with the open- and short-circuit stubs of baluns. Besides, the discontinuities in baluns increase the circuit power losses, which results in larger conversion loss in mixers. Another UDBM design was accomplished by including broad-band CPW-to-CPS baluns at RF and LO ports, but it still used the conventional four-wire IF balun for signal extraction which consists of four wires or strips of quarter-wavelength long at the center of RF and LO frequency ranges [2]–[4]. The need of long wires or strips restricts the IF bandwidth; it may also introduce imbalance which degrades the mixer's port-to-port isolations and increases difficulty in the MMIC process. Moreover, the LO and IF diplexer circuits were implemented by the chip capacitors and inductors [1], [3], [4], whose values are commercially restricted, adding the undesired feature of inflexible circuit design. In the conventional receiver architecture, the IF signal is amplified by an IF amplifier after the mixer. The LO leakage into the IF circuit may create problems in the IF amplifier, such as saturation and spurious responses [5]. To solve these problems, the use of an IF filter in the UDBM is necessary.

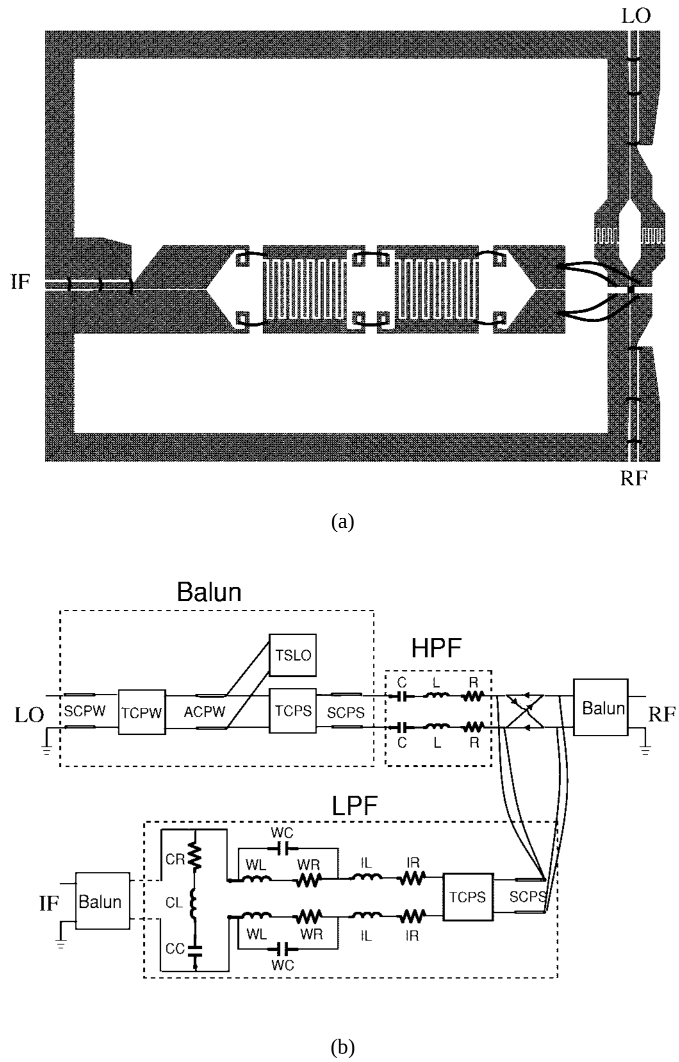

Fig. 1. Uniplanar double-balanced mixer: (a) physical configuration and (b) equivalent-circuit model.

In this letter, a novel UDBM structure to get rid of the aforementioned problems is proposed by incorporating CPW-to-CPS baluns as well as CPS high-pass and low-pass filters (Fig. 1) in the mixer design. To improve the bandwidth

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and conversion loss characteristics, the uniplanar baluns are adopted in the RF, LO, and IF ports. The CPS high-pass filter is included in the LO port to serve IF and dc blocking and the five-section CPS low-pass filter is also connected to the IF port in order to suppress those undesired harmonics from LO and RF ports. This proposed mixer configuration is suitable for MIC and MMIC fabrications because the chip capacitors, inductors, and long wires used in the conventional filter implementation [1], [3], [4] are replaced by the planar capacitors and inductors. In contrast to the microstrip components, the commercial computer-aided-design models for CPW and CPS components are still relatively limited, hence the simulated results of mixers using these components were not reported in [1], [3], and [4]. In this study, we propose an efficient equivalent-circuit model for the mixer by which the optimum filter designs for mixer responses can easily be achieved.

II. Mixer Design and Modeling

The UDBM [Fig. 1(a)] which consists of a diode quad, three CPW-to-CPS baluns, a CPS high-pass filter, and a CPS low-pass filter is implemented on a 635-μm-thick alumina substrate in a chip size of 7.62 $\times$ 10.92 mm^2. The Metelics MSS-30 diode quad with 0.07-pF zero-voltage junction capacitance and 15-Ω series resistance is mounted directly to the end of the CPS at the RF side, but is connected to the CPS high-pass filter with a cutoff frequency of 15 GHz at the LO side. The use of broad-band and low-loss baluns expands the operation frequency range and minimizes the conversion loss of mixer [6]. The CPS high-pass filter formed by the interdigital capacitors improves the LO matching and also blocks the dc bias and IF signal. Instead of using the conventional four-wire balun at the IF port, the five-section CPS low-pass filter with a cutoff frequency of 5 GHz is included for IF extraction and ground return [7]. This low-pass filter minimizes the leakages from the LO and RF ports to the IF port and improves the matching to the IF port, thus it may prevent the generation of unwanted mixing products and achieve small conversion loss through the mixer. For the characteristics and dimensions of associated baluns and filters, one may refer to the works in [6] and [7].

For theoretical modeling, the proposed UDBM structure [Fig. 1(a)] is decomposed into four parts, i.e., the CPW-to-CPS baluns, the CPS high-pass filter (HPF), the CPS low-pass filter (LPF), and the diode quad. The cascade of uniform and tapered transmission line sections yields the equivalent circuits for the baluns [6]. The filters are characterized by the equivalent-circuit models which consist of resistances, inductances, and capacitances as presented in [7]. Especially for the LPF, suitable uniform and tapered transmission line sections (SCPS and TCPS) should also be included in the equivalent circuit. The diode quad is simulated by the nonlinear p-n junction diode model (DIODEM) in *HP EEsof* circuit network library. By combining the equivalent circuits for these four parts, one may establish the equivalent-circuit model for the mixer as shown in Fig. 1(b) in which only parts of the equivalent circuits are explicitly presented. Specifically, the equivalent circuits for the baluns in RF and IF ports as well as half of the part for LPF are not shown in Fig. 1(b).

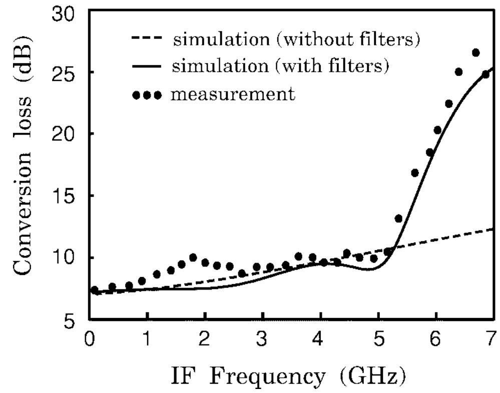

Fig. 2. Measured and simulated conversion losses as function of IF frequency (RF frequency = 30 GHz, RF power = −10 dBm, and LO power = 13 dBm).

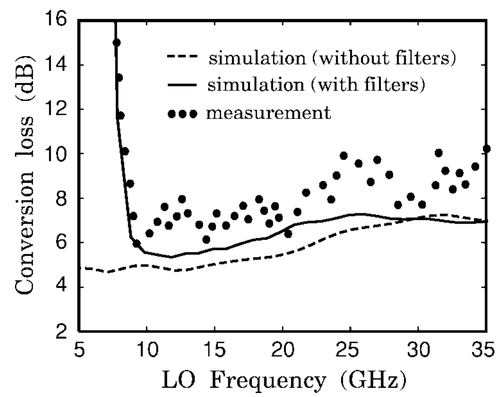

Fig. 3. Measured and simulated conversion losses as function of LO frequency (IF frequency = 0.1 GHz, RF and LO powers are the same as Fig. 2).

III. Results

The performance of the UDBM is simulated by the above equivalent-circuit model. The *HP EEsof* harmonic balance simulator is also used to compute the conversion loss of the mixer. Good agreement between measured and simulated results is observed in Figs. 2 and 3 and supports the usefulness of the proposed equivalent-circuit model. The measured and simulated conversion losses versus IF frequency are shown in Fig. 2 which indicates that the IF bandwidth is mainly determined by the CPS low-pass filter which has a cutoff frequency of 5 GHz. This IF bandwidth is broader than that of using the conventional four-wire balun at IF port [2], [3]. Also included in Fig. 2 is our model's result for the structure without CPS high-pass and low-pass filters. The structure without CPS filters shows no-cutoff property over 5 GHz which will result in larger LO leakages into the IF port.

Fig. 3 shows the measured and simulated conversion losses for the UDBM structure with CPS high-pass and low-pass filters as well as the simulated ones for the mixer structure without CPS filters. The simulated result of the UDBM structure without CPS filters has a no-cutoff property below 10 GHz when compared to the one with CPS filters. The larger

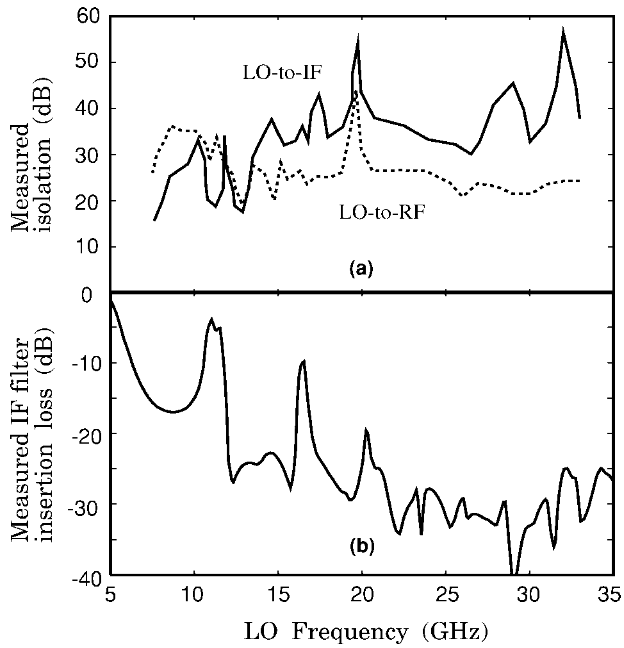

Fig. 4. (a) Measured LO-to-RF and LO-to-IF isolations, and (b) measured insertion loss of IF filter as function of LO frequency.

conversion loss below 10 GHz results mainly from the cutoff property of the CPS high-pass filter, which reduces the LO power and degrades the out-of-phase nature of LO balun at this frequency range. When the operation frequency is above 10 GHz, the LO power through CPS high-pass filter is large enough to activate the diode quad. That is why the mixer using CPS high-pass filter with a cutoff frequency of 15 GHz in LO port still has a low conversion loss from 10 to 15 GHz. By controlling the cutoff behaviors of CPS high-pass and low-pass filters, the operation frequencies of IF and LO ports in Figs. 2 and 3 can be suitably adjusted.

Fig. 4(a) and (b) depicts the measured LO-to-RF and LO-to-IF isolations as well as the measured insertion loss of IF filter for comparison. The measured LO-to-RF and LO-to-IF isolations are larger than 20 and 30 dB, respectively. But the latter decreases rapidly near the first spurious response in the IF filter insertion loss curve [Fig. 4(b)] at 11 GHz. These results reveal that the LO-to-IF isolation is closely related to the response of the IF filter.

IV. Conclusion

A novel UDBM with lower conversion loss, higher LO-to-IF isolation, and broader bandwidth has been realized by incorporating CPW-to-CPS baluns as well as CPS high-pass and low-pass filters in the mixer design. An efficient equivalent-circuit model of the mixer has been established and validated by comparison with the measurement. Being implemented with uniplanar components, the proposed structure is suitable for MIC and MMIC fabrications. The filters of other types, such as bandpass and bandstop, can easily be incorporated into any port of the mixer to satisfy different system requirements.

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