Fully Differential Single-Sideband Diode Ring Mixer using Optimum CPS Design Techniques

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Introduction

At microwave and mm-wave frequencies, single-sideband (SSB) and image-rejection mixers are traditionally implemented with double-balanced mixers combined with single-ended couplers and power dividers [1]. An elegant solution is presented in this paper that overcomes the need for many baluns at the interface between the individual mixers and the couplers or power dividers. The proposed SSB mixer topology is fully-differential and uses just one coplanar strip (CPS) branch-line coupler and one CPS Wilkinson combiner. In addition to its simple topology, the design presented in this paper makes use of optimum CPS design techniques to combat the deleterious effects of unwanted common-mode propagation [2].

Circuit Design

A simplified schematic of the proposed mixer is shown in Figure 1. It comprises of four main sub-circuits: (i) & (ii) differential CPS branch-line coupler and Wilkinson divider, (iii) double-balanced diode ring mixers (DBM1 & DBM2), and (iv) CPW-to-CPS Marchand baluns. The baluns are only used, however, in order to permit testing with standard test equipment. The first design consideration is choosing the balanced system characteristic impedance. This will be largely dictated by the minimum width/gap limits for a given fabrication process. For rapid prototyping at minimal cost, we employ FR4 substrate (1.6mm thickness and dielectric constant of 4.55) with single-layer copper metallization. Considering this, a balanced characteristic impedance of 150Ω was deemed suitable for the proposed mixer.

Having chosen the balanced system characteristic impedance, CPW-to-CPS type Marchand baluns [3] were synthesized using Agilent ADS Linecalc tool and the method described in [4]. The transmission lines forming the balanced power dividers were synthesized [5] by translating them directly from their single-ended counterparts. Indeed this gives a good first-cut differential-mode design on paper, but consideration must also be placed on the undesirable common-modes [2]. Table 1 summarizes the dimension for the Marchand baluns and necessary balanced transmission lines used in the design.

The unit mixers are based on a commercial quad Schottky diode ring (SMS3926) which is housed in an SOT-143 package. The crossover pin configuration was chosen because it interfaces neatly with the balanced CPS components. A manufacturer-provided SPICE model of the diodes [6], including package parasitics, was used for the circuit design. The diodes were unbiased but since the IF port is dc coupled, bias can be applied which will be useful in applications where limited LO power is of concern [7]. In addition, this allows for offset tuning which will be described later. The L-C network provides for the IF blocking and extraction in each DBM. Harmonic balance simulations were performed to optimize the conversion loss of the overall SSB mixer to below 10dB. Agilent ADS schematic-based models of passive components and transmission lines were used in the circuit design. For
simplicity, the balanced transmission lines were assumed to be perfectly symmetrical, as well as the diodes being identically matched. As such, no deliberate design steps were taken to minimize the overall sideband and LO suppression level of the SSB mixer, other than following good practice such as using layout symmetry wherever possible.

In CPS, the level of unwanted propagation of common-mode signals depends on the odd- to even-mode impedance ratio and line length [2]. Whilst there is no ground plane beneath the coplanar strips, common-mode resonances are still possible due to displacement current flow [8] to nearby ground pads or metal objects. Therefore, the balanced line extension from the Marchand balun is a quarter-wavelength CPS transmission line which will have its highest common-mode rejection at the centre operating frequency of 2GHz. This also places the CPS circuits sufficiently far away from the CPW ground plane.

Figure 1 shows the fabricated SSB mixer prototype which measures 140mm×75mm. Size 0402 surface-mount components were used to minimize discontinuity effects with the balanced transmission lines. The RF chokes (RFC) were formed by narrow (high impedance) copper tracks to the IF connections, IF1 and IF0, at the top and bottom of the circuit board. The prototype was completed using 25μm diameter gold bondwires to strap the CPW ground planes, and to form the CPS tee-junctions [9].

The IF hybrid was kept external to give maximum flexibility to the design. Finally, an additional CPW-to-CPS Marchand balun was included at the isolated port of the balanced branch-line coupler. This allows either an upper sideband (USB) or lower sideband (LSB) output to be easily configured as desired.

**Measured Results**

The prototype SSB mixer was tested around 2GHz using +5dBm of LO power and an external IF quadrature splitter (ZMSCQ-2-90). An IF frequency of 70MHz and input power of -10dBm was used. The RF output was measured on an Agilent E4404B spectrum analyzer. Figure 2(a) shows the conversion loss of the SSB mixer versus input LO power, and the frequency response of the SSB mixer with swept LO frequency is shown in Figure 2(b). This shows greater than 15dBc of opposite sideband suppression was achieved from 1.6GHz to 2.4GHz. In this frequency range, the LO leakage is around 20dB. The measured port matching are shown in Figure 3. The LO port return loss is better than 10dB up to 2.4GHz. The RF port return loss was measured under LO pumping conditions and is better than 7dB between 1.6GHz to 2.4GHz. Good agreement with simulations was obtained.

When integrated as part of a complete differential transceiver system, adaptive tuning methods can be applied to improve the overall LO and unwanted sideband suppression performance [10]. To demonstrate this capability, we manually tuned the SSB mixer using two synchronized arbitrary waveform generators (33250A) whose outputs could be independently adjusted in amplitude, relative phase, and dc offset. Using this IF predistortion tuning method, the mixer achieved greater than 40dB of LO and unwanted sideband suppression as shown in Figure 4.

To measure the mixer linearity, a two-tone test was applied (IF1=70MHz, IF2=75MHz) using a power combiner with two signal generators. The input IF powers were then swept and the lower sideband and IM3 tones were measured. With an LO at 2.3GHz, the input third-order intercept point (IIP3) was extrapolated to be around +10dBm.
Conclusions

An optimized fully-differential SSB mixer topology has been successfully demonstrated using CPS transmission lines. Compared to conventional microwave SSB mixers, our proposed mixer has several advantages which include zero dc power consumption, true uniplanarity, reduced number of baluns, and capability for frequency up- and down-conversion. In addition, the diode quad mixing elements can be easily substituted with quad ring resistive FETs or active double-balanced mixers with the potential benefit of achieving higher linearity or conversion gain, respectively. The proposed SSB mixer topology is therefore versatile and highly amenable to monolithic implementation, especially for millimeter-wave applications because the design is passive and truly uniplanar.

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References


Table 1. Dimensions (in mm) of the distributed elements

<table>
<thead>
<tr>
<th>Transmission line Element</th>
<th>Line Width</th>
<th>Line Spacing</th>
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<tbody>
<tr>
<td>106Ω CPS</td>
<td>0.84</td>
<td>0.25</td>
</tr>
<tr>
<td>150Ω CPS</td>
<td>0.28</td>
<td>0.30</td>
</tr>
<tr>
<td>212Ω CPS</td>
<td>0.26</td>
<td>0.90</td>
</tr>
<tr>
<td>50Ω CPW to 150Ω CPS Marchand balun</td>
<td>2.50</td>
<td>0.15 (strip to strip) 0.30 (strip to ground)</td>
</tr>
</tbody>
</table>
Figure 1. Schematic and photograph of the proposed differential SSB mixer. (L=6.2nH, C=2.2pF, and R=150Ω). CPW-to-CPS Marchand baluns used for measurement with single-ended test equipment.

Figure 2 (a) Conversion loss versus LO power (LO at 2.3GHz), and (b) Measured frequency response of the SSB mixer. (Conditions: IF freq = 70MHz, IF power = -10dBm, and LO power = +5dBm).

Figure 3 (a) Small-signal return loss at the LO port, and (b) Return loss at the RF port under LO pumped condition (LO power = +5dBm).

Figure 4. Measured output spectrum after tuning.