A Broadband Planar Monolithic Ring Mixer

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ABSTRACT

This paper reports the development of a mixer having RF and LO bands of 3 to 11 GHz and an overlapping IF of 1 to 11 GHz. This was achieved through the use of novel planar spiral RF and LO baluns and a new type of four-wire IF balun. We believe that this is the broadest-bandwidth planar monolithic mixer having an overlapped IF reported to date.

INTRODUCTION

A major challenge in monolithic circuit technology is the design of balanced planar components, especially mixers, frequency multipliers, and other circuits that are traditionally realized as nonplanar hybrids. The latter often use coupled-line baluns on suspended substrates. Such baluns minimize the capacitance between the balun's conductors and the ground plane; this capacitance, if too great, allows the propagation of even modes, which degrade port isolation, VSWR, and conversion efficiency. Because monolithic circuits use thin, high-dielectric-constant (ε_r) substrates, keeping even-mode capacitance adequately low is very difficult, and many of the types of baluns used in hybrid circuits are not practical in planar monolithic form. Moreover, in suspended-substrate hybrid circuits, it is possible to create a transition from the coaxial feed that excites primarily an odd mode in the balun, and minimizes the excitation of an even mode. This is not possible in monolithic circuits, where we must depend on a high even-mode impedance (i.e., low even-mode capacitance) to minimize the unwanted even mode.

Since minimizing the even-mode capacitance in monolithic circuits is largely futile, our approach has been to develop planar balun structures that tolerate it sufficiently to achieve good performance. One useful structure is the Marchand balun [1]. This balun is relatively insensitive to a low even-mode impedance, and we have developed successful broadband mixers and frequency multipliers using it [2].

In the work reported here, we achieve a high even-mode impedance in the coupled-line balun not by minimizing capacitance, but by maximizing even-mode inductance. Additionally, to allow for an IF band that overlaps the RF and LO, we use a new type of four-wire IF balun. The resulting mixer achieves a broad, flat passband, good conversion efficiency, and high port-to-port isolation.

THE MIXER

In this work we attempted to achieve very wide RF, LO, and overlapping IF bands, consistent with good port isolation, acceptably low conversion loss, and even-order intermodulation and spurious-response rejection. The circuit that best met these goals was a doubly balanced diode-ring mixer having a four-wire IF balun. The basic circuit for such a mixer is shown in Figure 1.

SPIRAL RF AND LO BALUNS

The RF and LO baluns are realizations of the coupled-line balun commonly used in diode-ring mixers. In the design of such mixers, the pair of strips is often treated as a floating, parallel-wire transmission line. However, this model ignores the capacitance between the strips and ground surface, which has a strong effect on the balun's performance. To include the effect of this capacitance, we model the balun as a set of coupled transmission lines. The strip-to-ground capacitance contributes primarily (but not exclusively)

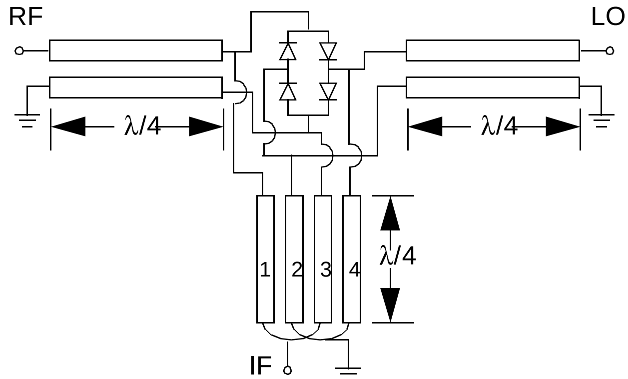

Figure 1. Doubly balanced ring mixer using coupled-line RF and LO baluns, and a four-wire IF balun.

to the even-mode impedance. In planar monolithic circuits, excitation of even modes on these lines is prevented only by a high even-mode characteristic impedance; ideally, this impedance should be infinite.

Ideally, the coupled strips should also have equal even- and odd-mode phase velocities. (This is one reason for the use of low-ε_r substrates in suspended-substrate mixers; high-ε_r substrates have much lower odd-mode than even-mode phase velocity.) If a high ε_r must be used, planar circuits have more closely matched phase velocities than suspended-substrate circuits.

The baluns, shown in Figure 2, are wrapped in a spiral to increase their even-mode impedance. The spiral has minimal effect on the odd-mode impedance. The principal is the same as in “transmission-line transformers” used in RF circuits, which consist of a twisted pair of wires wound on a magnetic core: the winding increases the even-mode inductance, but has minimal effect on the odd-mode [3], [4].

The spiral balun is very difficult to analyze by means of an electromagnetic simulator. We have therefore developed an empirical method for the design. This is successful because of the broad bandwidth and low sensitivity of this balun to its dimensions and other design parameters.

The baluns are designed largely as described in [5] (p. 256). The balun is one-quarter wavelength long (in terms of odd-mode phase velocity) and its odd-mode characteristic impedance is

$$Z_{0o} = 0.5\sqrt{Z_s Z_L} \quad (1)$$

where Z_S and Z_d are the source impedance and the real part of the RF or LO impedance at the diode junction, respectively. The dimensions of

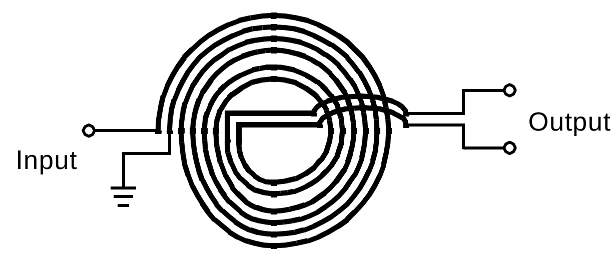

Figure 2. The spiral balun.

the spiral are those of a single-strip spiral inductor whose characteristics have been measured carefully; the main concern is to avoid the spurious resonances that are often observed in planar spirals at high frequencies.

To extend the low-frequency bandwidth one can either increase the length of the balun or cascade two smaller baluns. Increasing the length of a single balun reduces the frequency at which resonances occur, thus reducing the upper band edge of the balun. Using a pair of smaller baluns in series usually provides increased low-end bandwidth while avoiding restriction of the upper-end bandwidth. Since the LO range extended to low frequencies, we chose to use two spirals for the LO balun.

IF BALUN

A four-wire balun allows the IF band to overlap the RF and LO [6]. In hybrid mixers such baluns usually consist of four wires twisted together or four conductors printed on a suspended substrate.

In planar mixers such baluns are difficult to realize. Ideally, a four-wire balun’s capacitance matrix must have equal C_{ij}, $i \neq j$, and equal C_{ii}. This set of conditions is not difficult to achieve in the classical four-wire circuit described in [6], but it is very difficult to achieve in a planar circuit.

Several different configurations were examined by means of specialized coupled-line software [7]. The arrangement that came closest to meeting the ideal conditions is shown in Figure 3. This consists of five conductors, in which one of the outer conductors has been split and the resulting two strips are located on the opposite sides of the balun.

Unlike many diode-ring mixers, no blocking capacitors are used to decouple the IF at low frequencies from the RF and LO ports. Such capacitors invariably introduce low-frequency resonances into the mixer's IF circuit. Since the IF and RF/LO bands overlap, the baluns should reject the IF adequately, and no such blocking is necessary.

DIODES

The diodes are GaAs Schottky-barrier devices realized in HBT technology. They consist of a metallization deposited on the collector mesa of the HBT. To minimize series resistance, the anode region of the diode—the top of the collector mesa—is recessed, minimizing the thickness of the undepleted epitaxial material.

The zero-voltage junction capacitance of each diode is 0.025 pF and the series resistance is 8 ohms. These parameters are determined from broadband microwave measurements; they are not dc parameters. The diodes are similar to those described in [2].

PERFORMANCE

The mixer's performance is shown in Figure 4 through Figure 7. Figure 4 shows the conversion loss of the mixer with the IF fixed at 2.2 GHz. The conversion loss averages 9 dB; this is about 2 dB higher than expected, and probably results from loss in the long, narrow conductors of the IF balun. The roll-off at the low end of the band, near 3 GHz, is clearly caused by the IF balun; for this reason there is little difference in the low-frequency roll-off of the RF and LO ports, even though the LO balun's bandwidth extends lower in frequency. The low-frequency response could be extended by lengthening the IF balun, but greater IF loss would result.

Figure 3. The spiral balun.

Figure 5 shows the LO and RF port return loss. The RF return loss is measured with the LO fixed at 6 GHz. Figure 6 shows the IF return loss. The usable IF band is from below 1 GHz to approximately 13 GHz.

Figure 7 shows the LO-to-RF and LO-to-IF isolations. Because isolation can be related directly to the even-mode performance of the RF and LO baluns, this is perhaps the most meaningful indication that the baluns are doing their jobs. The LO-to-RF isolation is better than 40 dB from 3 to 13 GHz, and the LO-to-IF isolation is 23-33 dB over the same frequency range.

CONCLUSIONS

This paper has described a high-performance, broadband mixer having usable RF, LO, and IF bandwidths of approximately two octaves. This has been achieved through the use of planar spiral baluns and a four-wire IF balun.

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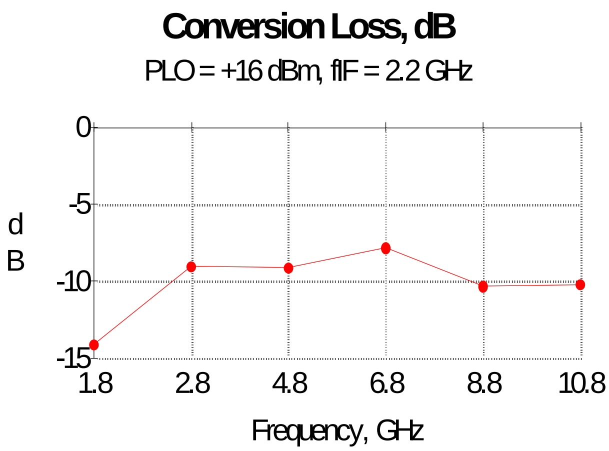

Figure 4. Conversion loss of the mixer at a fixed IF of 2.2 GHz.

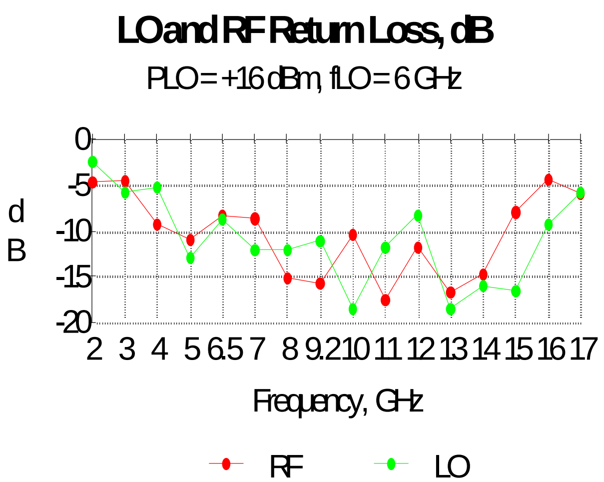

Figure 5. LO- and RF-port return loss. The RF port return loss was measured with a fixed IF of 6 GHz.

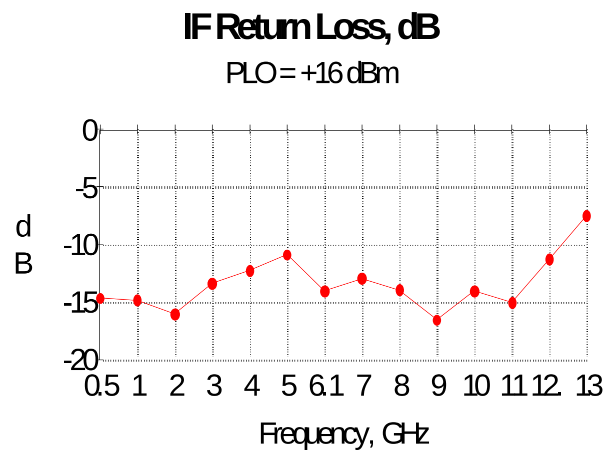

Figure 6. IF return loss.

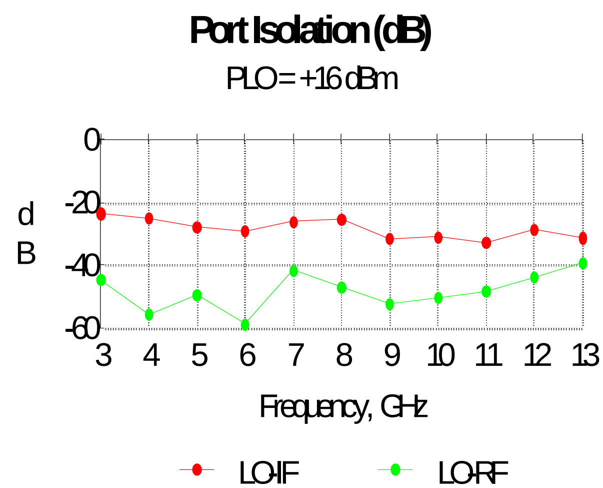

Figure 7. LO-to-RF and LO-to IF isolation of the mixer.

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