A Broadband, Planar, Doubly Balanced Monolithic Ka-Band Diode Mixer†

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ABSTRACT

This paper describes a planar monolithic diode mixer achieving 5-10 dB conversion loss and very low distortion and spurious responses over a 26- to 40-GHz RF and LO bandwidth and dc-10 GHz IF. The diodes are the gate-to-channel junctions of 0.2 × 80 μm InGaAs HEMTs, and the baluns are Marchand-like coplanar structures.

INTRODUCTION

One of the more frustrating problems in microwave mixer design is the realization of planar, doubly balanced mixers. Most types of doubly balanced mixers require some type of nonplanar structure; thus, they are not amenable to monolithic integration. Many of these, especially those using ring-diode designs [1] - [4], have considerable inductance in series with their IF ports; as a result, they do not have wide IF bandwidths.

We have developed a mixer that solves many of these problems. Its star structure has inherently wider IF bandwidth than ring structures, and its planar baluns have much better performance than other coplanar structures. These unique baluns are the key to the mixer's exceptional performance.

DESIGN AND MEASUREMENTS

Star-Mixer Structure

Virtually all doubly balanced diode mixers use diodes in either a star or ring configuration [3]. These are used alone or as building blocks for more complex mixers. One of the most common realizations, shown in Figure 1, is a ring mixer using parallel-line baluns at the RF and LO ports. (Many mixers that may not appear to have this structure, e.g., [3], do, in fact, use such baluns). This mixer requires a fairly complex IF decoupling circuit; this circuit usually has limited bandwidth, and often introduces troublesome resonances into the IF passband. A conventional star mixer is shown in Figure 2. The advantages of the star mixer, compared to the ring mixer, are its lower inductance in series with the IF port, resulting in broader IF bandwidth, and a symmetrical balun structure that enhances the mixer's balance.

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Mixer Baluns

Most coupled-line baluns used in balanced diode mixers have poor performance unless the coupled lines have high even-mode impedance and closely matched even- and odd-mode phase velocities. This usually requires that the mixer be realized on a suspended, low-dielectric-constant substrate, impractical for a monolithic circuit. If these requirements are not met, the result is poor balance and port-to-port isolation.

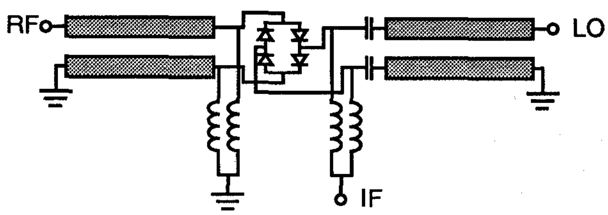

Figure 1. Ring-diode mixer. The parallel-line baluns at the RF and LO ports each consist of a pair of coupled transmission lines. For satisfactory operation, the even-mode characteristic impedance of these lines must be nearly ten times the odd-mode impedance

Marchand baluns are far more tolerant of low even-mode impedances than parallel-line baluns. Because of this tolerance, it is possible to realize successful star-mixer baluns as planar structures; we do this by locating the lower strips in Figure 2 on the upper surface of the substrate, on either side of the existing strip. The resulting balun is shown, connected as a single-output balun, in Figure 3. Such baluns have a significant advantage over the conventional, nonplanar baluns shown in Figure 2: when realized on high-dielectric-constant substrates such as alumina or GaAs, their even-and odd-mode phase velocities are much more closely matched. Furthermore, the coupling between the outer strips is much lower than in the conventional star mixer; this results in better LO-to-RF isolation.

In order to achieve adequate even-mode impedance on the high-ε_r GaAs substrate, it was necessary to use a thick substrate, 635 μm instead of the usual ~100 μm. The

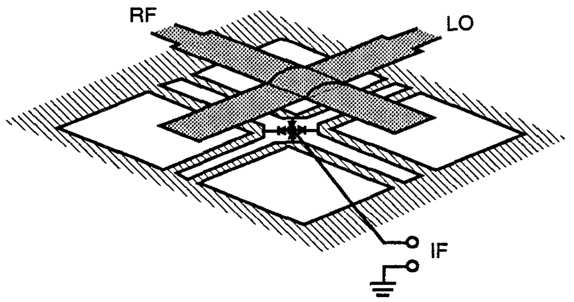

Figure 2. Conventional star mixer, realized as a hybrid. The shaded areas are metallizations on the top side of the substrate; the cross-hatched areas are on the bottom (ground-plane) side. This structure must be realized as a suspended-substrate component.

resulting even- and odd-mode impedances and effective dielectric constants, with the balun connected as shown in Figure 3, were as follows:

$$Z_{0e} = 112\ \Omega \qquad \varepsilon_{\text{eff},e} = 7.543$$

$$Z_{0o} = 31\ \Omega \qquad \varepsilon_{\text{eff},o} = 6.950$$

These were calculated by means of commercial coupled-line software [5].

Diodes

The gate-to-channel junction of a 0.2 × 80 μm InGaAs HEMT is used as a diode; compatibility with other devices on the same wafer dictated the choice of this structure. The diode has 0.03 pF zero-voltage junction capacitance and 21 ohms series resistance, resulting in a cutoff frequency of 253 GHz. this is an unusually low cutoff frequency for a diode used in a 40-GHz mixer; we believe that a better diode would provide lower intermodulation and spurious-response levels, lower LO-power requirements, and lower conversion loss. We are currently experimenting with other types of diodes that have much greater cutoff frequencies.

Mixer Structure

Figure 4 shows a microphotograph of the mixer. The structure is that of a classical star mixer using Marchand-like baluns. However, unlike the conventional star mixer, the baluns of Figure 3 are used. The odd-mode impedances of these baluns were chosen to match the 50-Ω RF and LO

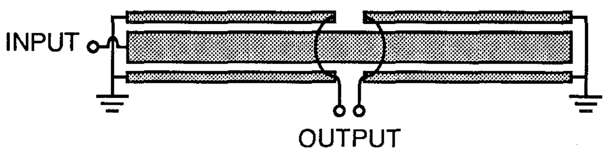

Figure 3. Planar star-mixer balun connected to form a coupled-line Marchand balun.

sources to the real parts of the diodes' input impedances. The baluns' lengths were slightly shorter than one-quarter wavelength, so their inductive output impedances compensated the diodes' capacitive reactance. All three ports–RF, LO, and IF–are coplanar-waveguide interfaces.

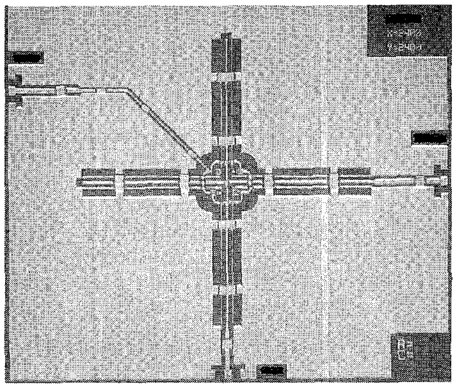

Figure 4. Top view of the mixer chip. The IF output is at the top left; the RF and LO ports are interchangeable.

A disadvantage of this structure is that the diodes are not connected at a common point, but instead are connected to a narrow strip that encircles the center of the structure. This reduces, to some degree, the symmetry of the circuit and its inductance limits the IF bandwidth. However, in a monolithic realization of this mixer, the ring is very small and its effects are minimal.

PERFORMANCE

Figure 5 shows the conversion loss and output third-order intercept point of the mixer at a fixed RF frequency of 28 GHz. This indicates that the IF bandwidth is at least 10 GHz. Figure 6 shows the conversion loss and (2,-2) spurious-response level a fixed IF frequency of 1 GHz; the RF and LO bandwidths cover 28 to 40 GHz. LO-to-RF and RF-to-IF isolations are shown in Figure 7.

CONCLUSIONS

We have described a Ka-band monolithic diode mixer having broad bandwidth and, in virtually all respects, high performance. It achieves this performance by employing a star structure and unique, Marchand-like baluns. The use of better diodes might improve performance even further.

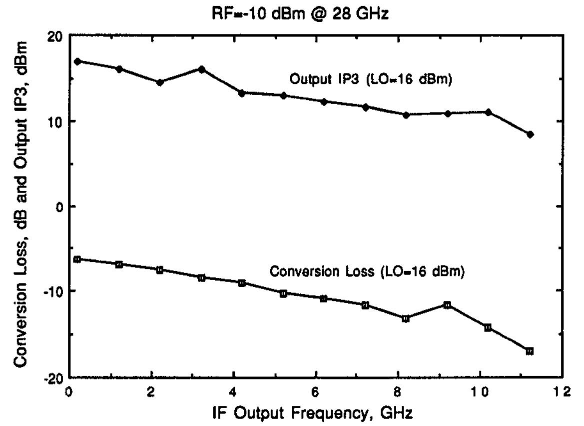

Figure 5. Conversion loss and third-order output intercept point, as a function of IF frequency.

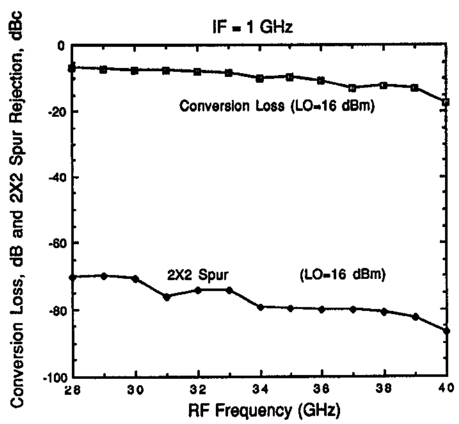

Figure 6. Conversion loss and (2,-2) spurious-response output level; P_{RF} = -10 dBm.

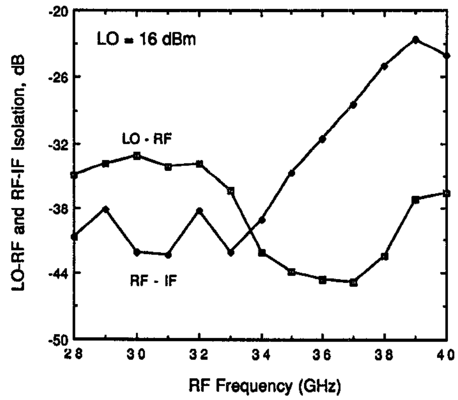

Figure 7. LO-to-RF and RF-to-IF isolations.

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