AN 18-40 GHZ MONOLITHIC RING MIXER

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ABSTRACT

This paper describes a doubly balanced monolithic ring mixer using a unique planar balun consisting of a Marchand section followed by a coupled-line structure. The latter provides additional even-mode rejection and a convenient point for IF extraction. The mixer achieves low conversion loss and high isolation over an 18-40 GHz RF/LO bandwidth and a dc-10 GHz IF bandwidth.

INTRODUCTION

The development of broadband monolithic mixers has been hampered by the lack of high-performance, broadband balun designs suitable for monolithic applications. The fundamental limit to the performance of coupled-line baluns, the most common kind, appears to be the capacitance between the strips and the ground plane, or in other terms, the low even-mode impedance of the coupled lines. This allows even modes to be excited, which unbalance the mixer, degrade the port-to-port isolation, and degrade the passband flatness.

A number of techniques can be used to minimize these difficulties. Some of the most common, such as the use of a hybrid instead of a balun, are limited in bandwidth. Others, such as slotline structures [1], [2], have achieved very good bandwidth but are difficult to characterize for computer-aided design. Our solution is to use certain types of coupled-line baluns that tolerate low even-mode impedance. The Marchand balun [3], [4] is one such structure. Star mixers using simple Marchand baluns have achieved octave bandwidths with very good performance [5].

This paper describes a ring mixer using Marchand baluns for the LO and RF. The RF balun, however, includes an extra coupled-line section that improves the performance of the balun and provides an output port for the IF. The result is an 18-40 GHz RF/LO bandwidth and dc-10 GHz IF.

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DESCRIPTION

Figure 1 illustrates the basic structure of the mixer. This structure derives from a common circuit for hybrid mixers. In hybrid mixers the RF and LO baluns are usually simple, broadside-coupled lines on a suspended substrate, but such baluns are not adequate in monolithic circuits. Instead, we use Marchand baluns. An additional coupled-line section, which we shall call the *U section* in honor of its shape, is used in the RF. This section has several effects. First, it provides additional even-mode rejection. This improves the balance of the balun, and thus improves the port-to-port isolation and even-order spurious-response rejection of the mixer. Second, it provides an IF-output port. If the baluns are ideal, IF port is isolated from both the RF and LO, although in practical mixers, high RF-to-IF isolation is difficult to achieve, and often requires additional filtering. The Marchand LO balun provides a convenient ground return for the IF currents.

The coupled lines of the U section require a low even-mode impedance and a high odd-mode impedance. This is easy to achieve on a suspended-substrate hybrid mixer but very difficult in a planar monolithic circuit. To meet this requirement we use multiple coupled lines, in a

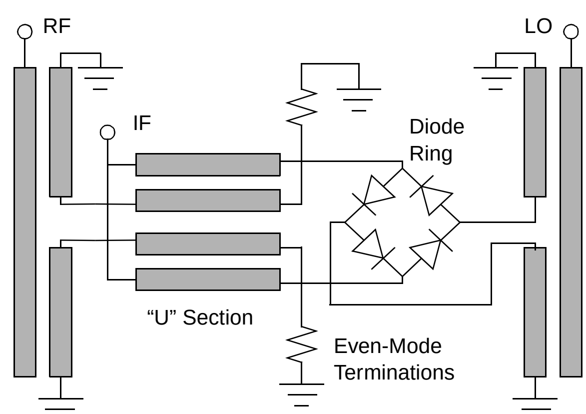

Figure 1 Basic configuration of the mixer.

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technique similar to a Lange coupler. Another deviation from the conventional, hybrid approach is the use of 50-ohm even-mode terminations. These provide a modest overall improvement in the performance of the balun and significantly improve the output return losses. This makes the balun useful as a power splitter.

Figure 2 shows the calculated return losses and input-to-output losses of the balun configured as a power divider; the output terminals are each treated as a 50-ohm terminated port. Predicted balance is better than 0.2 dB from 10 to 50 GHz. Figure 3 shows the measured quantities. The reason for the higher-than-expected input return loss at low frequencies is not clear; anomalous behavior above 40 GHz is undoubtedly caused by the bend in the coupled lines and parasitics associated with interconnections. Finally, Figure 4 shows the layout of the complete mixer.

MIXER DESIGN

The design of doubly balanced ring mixers is covered elsewhere [6]. The design of such mixers largely amounts to the design of the baluns. The baluns are

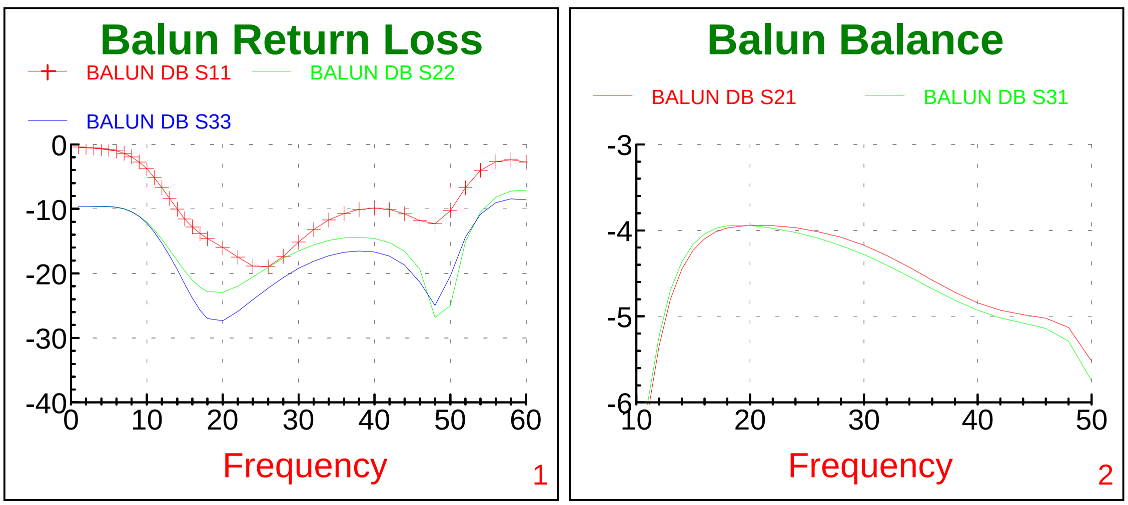

Figure 2 Calculated return loss and input-to-output loss of the balun. The excess loss that increases with frequency is caused by conductor losses. These may have been slightly overestimated.

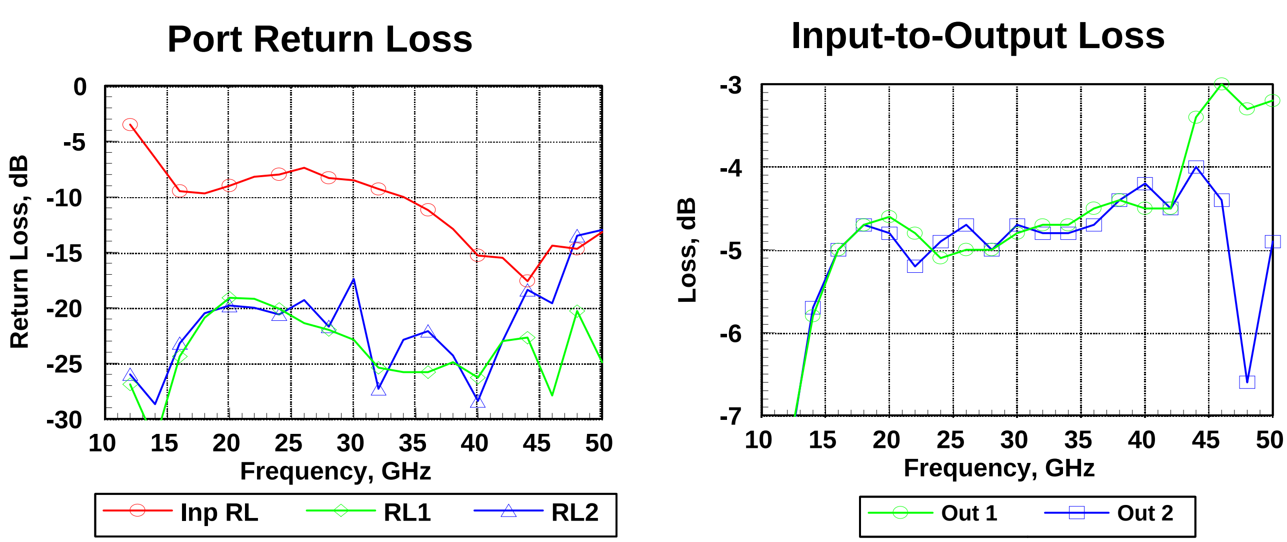

Figure 3 Measured return loss and input-output loss of the balun.

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designed according to the odd mode impedances or the coupled-line sections. The even-mode impedances are made as high as possible, primarily by making the lines narrow.

The design of the Marchand section is covered in [6]. In these mixers we use an asymmetrical structure in which the first section's odd-mode impedance is approximately 25 Ω, but the second section has a low impedance, approximately 11 Ω. This provides greater bandwidth than could be achieved in a symmetrical balun.

The U section's odd-mode impedance is

$$Z_{0o} = \sqrt{\frac{Z_s Z_L}{8}} \qquad (1)$$

where Z_s is the output impedance of the Marchand section, usually 50 Ω, and Z_L is the load impedance. Ideally the sections are one-quarter wavelength long, but in practice the balun is often made shorter than this to reduce its IF inductance and to improve the broadband IF VSWR.

LINPAR [7] is used to determine the modal characteristics of the multiple coupled-line sections. The LINPAR output is read directly into our in-house harmonic-balance simulator and an admittance matrix of the line section is generated. Since the admittance matrix is generated in the simulator, and not in the electromagnetic analysis, the length of the balun can be varied by the simulator to optimize the design.

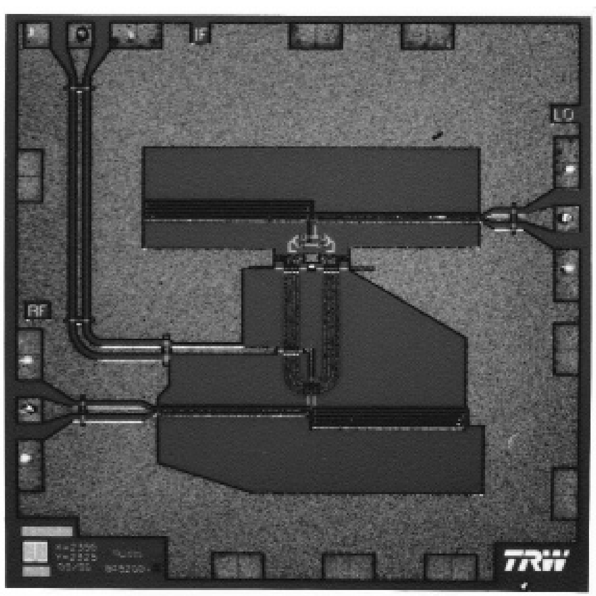

Figure 4 Photograph of the mixer.

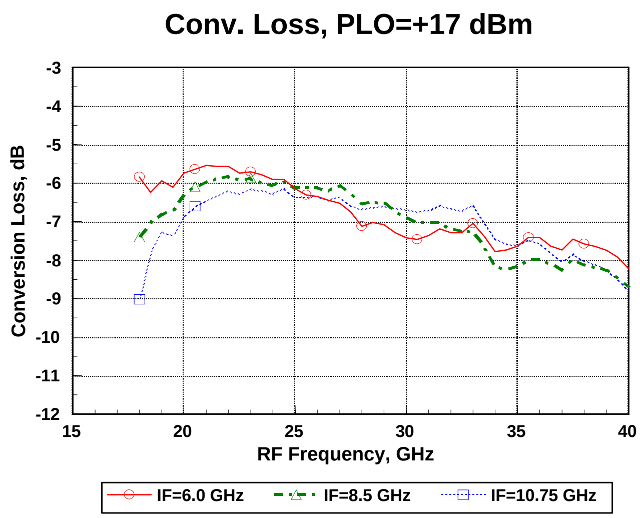

Figure 5 Conversion loss of the mixer at +17 dBm LO level, at three IF frequencies.

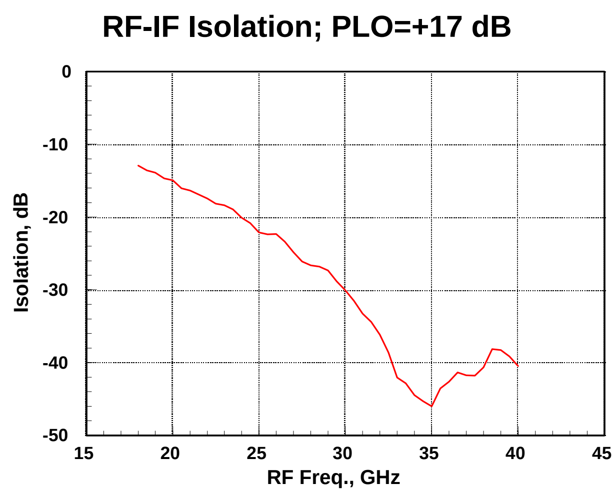

Figure 6 RF-to-IF isolation of the mixer at +17 dBm LO power.

MIXER PERFORMANCE

Figure 5 shows the conversion loss of the mixer. The losses in the baluns cause the conversion loss to increase with frequency. The RF-to-IF isolations are shown in Figure 6 and the LO-to-IF in Figure 7. Although the LO-IF isolation is very good, >24 dB, the RF-IF isolation is only 15 dB at the bottom of the band. This moderate isolation is observed in hybrid mixers as well. One purpose of the IF stub is to improve the RF-to-IF isolation at the top of the band.

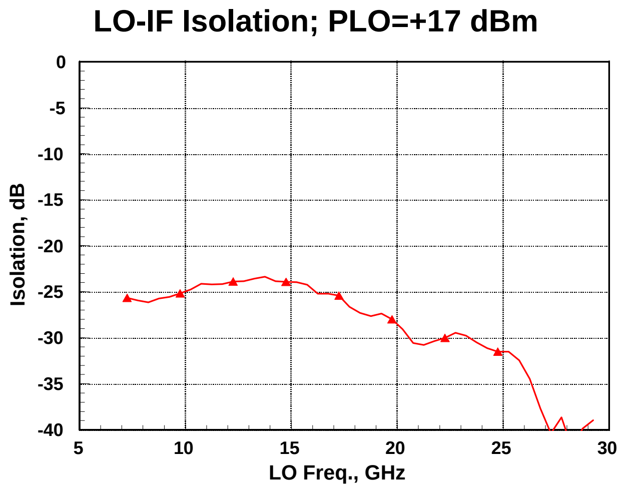

Figure 7 LO-to-IF isolation.

Figures 5-7 include the effects of an IF stub in a second-iteration design that improved IF VSWR and provided additional LO and RF rejection. This stub is not shown in Figure 4.

CONCLUSIONS

We have shown that coupled-line baluns can be used to realize broadband, high-performance mixers as planar monolithic integrated circuits. The baluns' even-mode problem is ameliorated through the use of Marchand baluns combined with the coupled-line "U" section. Such mixers exhibit good conversion loss and port isolation.

REFERENCES

[1] J. Eisenberg, J. Panelli, and W. Ou, "A New Planar Double-Double Balanced MMIC Mixer Structure," *IEEE 1991 Microwave and Millimeter-Wave Monolithic Circuits Symposium Digest*, p. 69.

[2] D. Cahana, "A New, Single-Plane Double-Balanced Mixer," *Applied Microwaves*, Aug./Sept. 1989, p. 78.

[3] N. Marchand, "Transmission-Line Conversion Transformers," *Electronics*, Vol. 17, no. 12, 1944, p. 142.

[4] J. Cloete, "Exact Design of the Marchand Balun," *Microwave J.*, vol. 23, no. 5, p. 99 (May, 1980).

[5] S. A. Maas and K. W. Chang, "A Broadband, Planar, Doubly Balanced Monolithic Ka-Band Diode Mixer," *IEEE 1993 Microwave and Millimeter-Wave Monolithic Circuits Symposium Digest*, p. 53.

[6] S. A. Maas, *Microwave Mixers*, Artech, Norwood, MA, 1993.

[7] A. Djordjevic et. al., *LINPAR for Windows*, Artech House, Norwood MA, 1996.