A Multioctave Bandwidth Rat-Race Singly Balanced Mixer

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***Abstract*—In this letter, we describe a broad-band 7.5–46 GHz rat-race ring singly balanced mixer. The rat-race ring consists of an ideal crossover phase inverter and is designed to have a Chebyshev response of order two. The mixer diodes are virtually grounded via a quarter-wavelength low-impedance FCPW (finite ground plane CPW) open circuit stubs. The mixer shows more than 5 times RF bandwidth and dc to 5 GHz IF bandwidth. The circuit is realized using FCPW on 25 mil Al_2O_3 substrate.**

***Index Terms*—Multioctave mixer, uniplanar rat-race ring.**

I. Introduction

THE rat-race ring mixer is a commonly used component in microwave systems. The conventional rat-race ring coupler is realized by microstrip line with three sections of $lambda/4$ 70.7 Ω lines and one section of $3\lambda/4$ 70.7 Ω line. The $3\lambda//4$ line section that is $\lambda/2$ longer than others is performed as a phase inverter. The conventional rat-race ring mixer, however, is limited to a bandwidth of about 40%. The main constraint that limits the bandwidth of the conventional rat-race mixer is rat-race ring coupler itself. Many efforts have been made to increase the bandwidth of the rat-race ring coupler [1]–[6]. In this letter, we propose a rat-race ring mixer showing much broader bandwidth than that of conventional one. The measured bandwidth of proposed mixer is more than six times. The circuit configuration and the photograph of the proposed rat-race ring mixer realized by FCPW are shown in Fig. 1, where y is the normalized ring admittance and θ is the half-electrical length of the ring arm. In Fig. 1, there is a crossover in the middle of one of the rat-race ring arm. Electrically, this crossover is an ideal phase inverter. Therefore, the infinity isolation should hold for all frequencies. Unlike the conventional rat-race ring coupler with 70.7-Ω ring impedance, the ring impedance of the proposed rat-race ring coupler is designed to be 55 Ω. The conventional rat-race ring with 70.7-Ω ring impedance shows a Butterworth-type response. However, the proposed rat-race ring shows a Chebyshev-type response of order two with 12-dB return loss.

II. Circuit Design

Instead of half-wavelength phase inverter in conventional rat-race ring, the proposed rat-race ring has an ideal phase inverter, as shown in Fig. 1(a). Using the even- and odd-mode analysis, the insertion loss function of the rat-race ring coupler can be synthesized as the form [7] of (1), shown at the bottom of the next page, where $= \cos 2\theta, x_c = \cos 2\theta_c$ and h is the parameter to control the ripple level. The electrical length is defined to be quarter wavelength (i.e., $\theta = 45°$) at the center frequency. The Chebyshev response of order 2 [i.e. $n = 2$ in (1)] is fit to the ring. The design equations are

$$h = \left(y - \frac{1}{2y}\right) \Big/ \sqrt{2} \tag{2a}$$

$$x_c^2 = \frac{\sqrt{2}yh + h^2}{(y/\sqrt{2} + h)\cdot}. \tag{2b}$$

The relationship between h and the return loss bump value (at

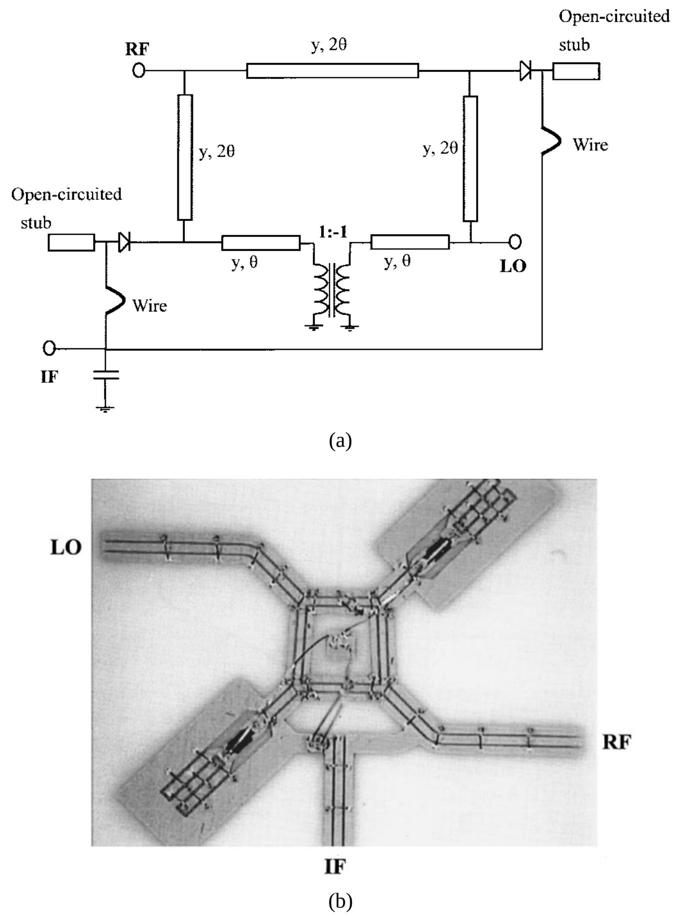

Fig. 1. (a) Circuit configuration and (b) photograph of the rat-race ring singly balanced mixer. The rat-race ring coupler uses a crossover as an ideal phase inverter.

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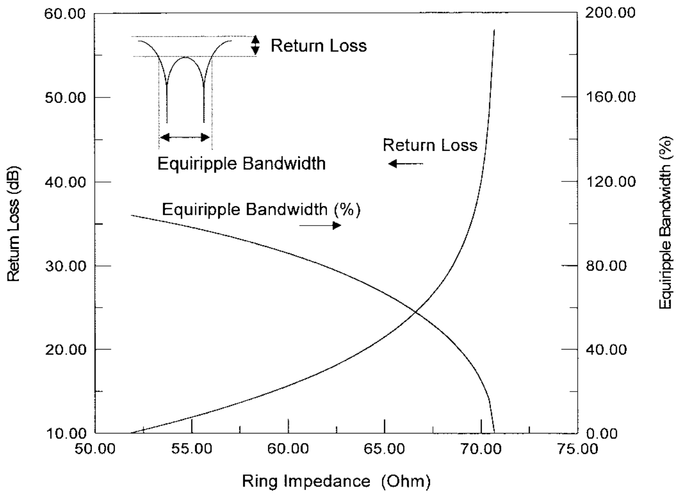


Fig. 2. Return loss bump value and equiripple bandwidth versus ring impedance for the rat-race ring coupler.

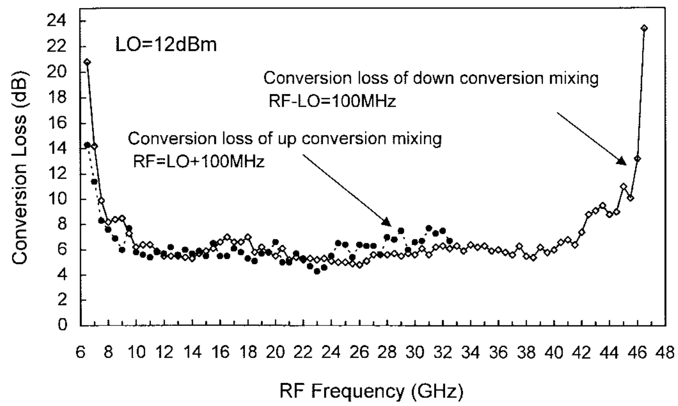
the center frequency) is

$$RL = 10\log(1 + 1/h^2) \quad \text{(dB)}. \tag{3}$$

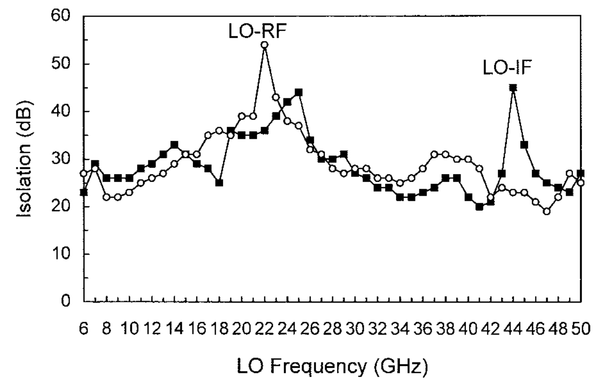
Fig. 2 shows the return loss bump (at center frequency) value and the equiripple bandwidth as a function of the ring impedance. The coupler shows a Butterworth response when the return loss bump disappears (infinity return loss bump value). According to the design curve of Fig. 2, we choose 12-dB return loss bump corresponding to 55-Ω ring impedance, which is acceptable for mixer application and preferable for circuit fabrication. The coupler is designed with 32-GHz center frequency. A prototype circuit is fabricated with FCPW on Al_2O_3 substrate and measured. The measured results are very close to theoretical prediction. Because of the crossover, the signal line of the coupler is dc grounded. We must use radio frequency (RF) virtue ground to terminate two mixer diodes and the IF signals are picked up from these RF virtue grounds. The RF virtue ground is formed by a low-impedance FCPW open-circuit stub. Here, we use two 50-Ω FCPW lines in parallel to form a 25-Ω open-circuit stub. The bandwidth of this low-impedance stub is broad enough to cover the operating frequency of the mixer. The IF signals are picked up via a low-pass filter of order two and cutoff frequency of 5 GHz. The mixer diodes used in the mixer are M/A40416 GaAs Schottky beam-lead diodes. The mixer is fabricated on a 25-mil-thick Al_2O_3 substrate. The whole mixer is .25 in by .2 in, as shown in Fig. 1(b).

III. Measured Results

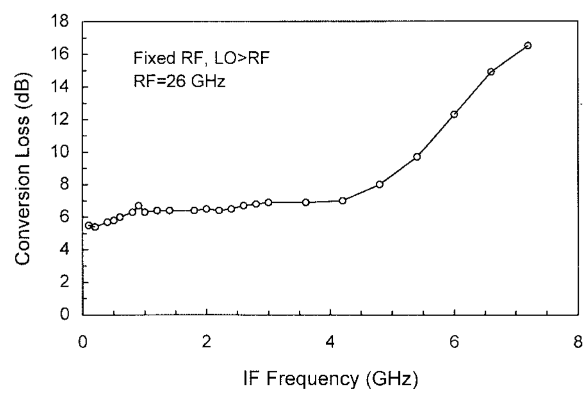
Before measuring the mixer, a Chebyshev rat-race ring with 12-dB return loss and center frequency of 32 GHz was fabricated and measured. The measured performances are summarized as follows. The Chebyshev bandwidth (return loss better than the bump value i.e. 12 dB in our case) is from 16 to 47 GHz. The amplitude imbalance is better than ± 1 dB and the phase difference error is better than $\pm 8^\circ$ from .1 to 47 GHz. The isolation is better than 15 dB from .1 to 50 GHz. Because of the excellent phase and amplitude balance,



(a)



(b)



(c)

Fig. 3. Measured performance of the rat-race ring mixer. (a) Down- and up-conversion loss versus RF frequency. (b) LO to RF and LO to IF isolation versus LO frequency. (c) Down-conversion loss versus IF frequency for fixed RF frequency.

$$P_l = 1 + h^2\left\{\frac{(1+\sqrt{(1-x_c^2)}T_n(x/x_c) - (1-\sqrt{1-x_c^2})T_{n-2}(x/x_c)}{2\sqrt{1-x^2}}\right\}^2 \tag{1}$$

the mixer using this rat-race ring may be worked with much broader bandwidth than that of Chebyshev bandwidth. The measured performances of the mixer are shown in Fig. 3. Fig. 3(a) shows that the conversion loss of down-conversion is better than 10 dB from 7.5 to 46 GHz with a fixed 100-MHz IF frequency and the conversion loss of the up-conversion is better than 8 dB from 7.5 to 33 GHz. Higher than 33 GHz is not measured because of the limitation of our measuring equipment. Fig. 3(b) shows that both the LO to RF and LO to IF isolation are better than 20 dB from 6 to 50 GHz. The IF bandwidth shown in Fig. 3(c) is from dc to 5 GHz with a fixed 26-GHz RF frequency. The LO power used for up and down conversion are 12 dBm.

IV. Conclusion

The multioctave rat-race ring mixer has been designed and fabricated. The measured performances of conversion loss, isolation, and LO power requirement are as good as conventional rat-race ring mixers, but the bandwidth is much broader. The mixer was fabricated with an uniplanar structure and on a most commonly used MIC substrate.

Acknowledgment

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