A NEW "PHASED-TYPE" IMAGE ENHANCED MIXER

L. E. Dickens and D. W. Maki
Westinghouse D&ESC, Systems Development Division
Box 1521, MS 3717, Baltimore, Maryland 21203

Abstract

GaAs Schottky Barrier diodes with a zero bias cutoff frequency of 800 GHz have been used in an integrated circuit balanced mixer operating with a signal frequency centered at 12 GHz and an IF of 70 MHz. L_c at center-band was 2.2 dB. For an LO tunable bandwidth of over .65 GHz, the conversion loss was under 3.0 dB. No image filter is used in this mixer. The conversion loss across the image band was greater than 25 dB.

Introduction

This paper reports generally on a microwave mixer for operation at X-band, and more specifically on an integrated mixer circuit having very low conversion loss. Microwave diode mixers have been used for many years to obtain conversion of a signal at microwave frequencies to one at a much lower frequency. Such mixers have been the subject of much study and development. However, there is a continuing need for improvements which can result in better electrical performance, higher reliability, improved reproducibility, and lower production costs.

Briefly, the present paper describes an improved integrated circuit mixer. The mixer includes an integrated circuit dielectric substrate on which is defined a pair of balanced mixers of the coplanar line-slot line type. The pair of balanced mixers are so configured that one of the pair is the mirror image of the other. The RF inputs to each are then directly connected together and the LO inputs and IF outputs are coupled by 90 degree (quadrature) hybrid 3 dB couplers. This arrangement causes the image signals appearing at the RF input line and generated by each of the balanced mixers to be out of phase with each other, resulting in maximum image current or equivalently the short-circuited image condition, but now without the use of an image filter.

Theory of Image Enhancement

Well known are the fundamental techniques for the enhancement of mixer operation by the proper control of the impedances at each of the mixer terminals and at each of the frequencies of importance. The frequencies of importance are the modulation products which exist according to the heterodyne principle by which the mixer operates. The received signal (RF), together with a higher level signal from a local oscillator (LO), are applied to a nonlinear element. If the RF signal is sufficiently small, then the resulting frequencies can be given as $f_n = nf_p + f_o$; $n = -\infty, \ldots, +\infty$; where $f_o = |f_s - f_p|$ is the output (IF) frequency, f_s and f_p being the RF and LO frequencies, respectively. Note also that for the present application, $-f_{-1}$ corresponds to the signal frequency, and f_{+1} to the conventionally designated image frequency. For most mixer applications $f_o \ll f_p$, thus this notation has the advantage of that $|f_n| \simeq f_{+n} \simeq nf_p$; $n = 1, \ldots + \infty$; and the magnitude of the frequency is readily identifiable by its subscript. Further, for a particular group about nf_p, the plus (+) subscript always refers to the upper sideband and the negative (-) subscript always refers to the lower sideband. The three frequencies at the n^{th} level are sometime referred to as the n^{th} order idler frequencies.

The loss in converting an RF signal to an IF signal depends not only on properly matching the RF and IF impedances, but also upon properly terminating the sum and image frequencies as well as various other idler frequencies.[1] Equally as important as proper signal termination is the attainment of the proper form of mixer modulation by the LO.

It has been shown that, in a mixer without limiting parasitics, the lowest theoretically attainable conversion loss is obtained with a symmetrical rectangular LO drive waveform and dual terminations at the even and odd idler frequencies (that is, open circuits for the even and short circuits for the odd idlers or vice versa). These are the G- and H-type mixers.

In practical cases, mixer diodes are not purely resistive. The diode parasitics play an important role in the determination of the type of mixer to be used and the type of analysis that applies. The diode junction capacitance and series resistance represent the known diode parasitics. In the literature are found many authors who have dealt with this problem in Y-mixers. These authors assumed that the junction capacitance short circuits across the variable resistance all the higher order out-of-band frequencies. Thus, only the signal, IF, and image frequency voltages were considered. This assumption reduced the Y-mixer equations to a complex 3 x 3 Y-matrix which could be easily handled.

Barber[2] has presented such an analysis of microwave Y-type mixers. An extension[3,4] of Barber's analysis has allowed the calculation of the conversion loss of the three frequency Y-type mixer as a function of the pulse duty ratio and as limited by the operating frequency to cutoff frequency ratio (f/f_{co}). As noted by Saleh, this type of analysis can be extended to treat all mixer circuits by considering more than three frequencies. If one takes all the out-of-band frequencies above the m-order idlers to be short-circuited across the variable resistance, the mixer can be treated as a Y-mixer with 2 m + 1 frequencies. Such a (2m+1) frequency Y-mixer can be provided with the appropriate external idlers according to the type of mixer being analyzed. The idler termination would include the junction capacitance and series resistance as well as any external termination.

In an earlier paragraph it was pointed out that for the mixer without limiting parasitics, the minimum conversion loss was attained with a symmetrical square wave modulation of the resistance. This is an equivalent pulse duty ratio of 0.5. Figure 1 shows the computed minimum conversion loss for the Y-mixers (curve A) and the H- and G-mixers (curve B). Note that the mixers of curve A require a variable pulse duty ratio (up to 0.5) while the mixers of curve B need only the fixed pulse duty ratio of 0.5.

In a practical circuit we are limited by the parasitics of the diode and the fact that in a broadband circuit the open-/short-circuited idler requirements of the G-type and H-type mixers cannot be readily attained. Thus we apply the extended analysis, as suggested previously, to a mixer with more than three frequencies so that a reasonable number of idlers can be controlled. Such control is then expected to yield a conversion loss between the two curves shown in Figure 1, and for an equivalent pulse duty ratio of less than 0.5 but greater than the ≤ 0.1 as required by the Y-type mixer for low conversion loss; the low value of pulse duty ratio of < 0.1 being very difficult to realize in actual practice. The impedance which will be generated across any reasonable frequency band to the idlers, in general, will not be the theoretically desirable open/short circuits but will usually be restricted to a range of large mismatch in the form of a dominately reactive termination. The magnitude of the reactance will be large or small relative to the signal (and IF) impedances when approximating an open-or short-circuited idler.

The control of the idlers is important in obtaining the low conversion loss, but the dominant frequency to be controlled is the image. If the image cannot be well shorted or opened across the full band, then control of the other idlers will do no good. Whatever scheme is used (there are an infinite number of possibilities), they all begin with means to either open-or short-circuit the image. Traditionally, image enhanced mixers have been single-ended (unbalanced) mixers[5,6] as opposed to balanced mixers, and have suffered the limitation of narrow band operation imposed by the use of a narrow band filter for image termination control. Single-ended mixers do not affect even and odd idler separations and so are usually constrained to Y-type mixer operation. Balanced mixers do affect idler separation as the odd idlers appear at the input and all the even idlers appear at the output. This more easily allows the imposition of the constraints of the G- and H-type mixers.

Mixer Configuration

The idler control features of the balanced mixer are desirable and so the balanced mixer was selected for the present design. Because of the desired large bandwidth and low IF, image control cannot be obtained by any form of bandwidth limiting filter. Therefore, two separate balanced mixers are used, the RF inputs of which are directly connected together and the LO inputs and IF outputs of which are coupled by 90-degree (quadrature) hybrids. See Figure 2. This configuration causes the image signals appearing at the RF input line and generated by each of the balanced mixers to be out of phase with each other, resulting in maximum image current or equivalently the short-circuited image condition. This short-circuit condition is not bandwidth limited because the electrical length between the diodes of the two balanced mixers is essentially zero.

The complete circuit is a truly integrated circuit comprising: microstrip transmission lines, coplanar strip transmission lines, slot transmission lines, a coplanar line-slot line hybrid junction for balanced semiconductor diode modulation, a broadband transition from slot line to microstrip line, and a broadband microstrip to coplanar line transition. See Figure 3 and 4.

Figure 3 is a sketch showing the layout of the two balanced mixers and the LO hybrid (Lange type) for LO injection. The IF hybrid is not shown. Figure 4 shows the details of the coplanar line-slot line-microstrip coupler circuits as well as the four diode mounting details.

The mixer configuration is designed to short-circuit the image, open-circuit the second idlers, and short-circuit all higher idlers. The parameters of the circuit, when adjusted for maximum bandwidth, will closely approximate these constraints. The circuit consists of a 180-degree hybrid ("T" junction) at the signal input port which feeds two balanced mixers. Local oscillator (LO) power supplied to the balanced mixers has a constant phase difference of 90 degrees at the output ports of the LO quadrature hybrid (Lange coupler). IF outputs from the mixers are combined in an IF quadrature hybrid. Due to their difference in phase, the image and signal components at IF due to image and signal components received at RF are summed in separate (and isolated) arms of the IF hybrid.

A photograph of the mixer is shown in Figure 5. The circuit is made up of a single substrate on which is mounted the RF circuitry. The IF hybrid is a 4-port quadrature hybrid of lumped element design and mounted in a low profile flatpack package.

Results

The following characteristics indicate the advancement of the state-of-the-art performance obtained. The measured curve of conversion loss versus frequency is shown in Figure 6. Two curves are shown. The one is for the complete mixer including all connector losses IF hybrid losses and track losses. The lower curve is a constant 0.4 dB less than the first and represents the conversion process without the 0.4 dB loss of the IF hybrid. Ultimately this mixer will be connected (without IF hybrid) to a pair of balanced, low-noise IF amplifiers. The IF will then be combined by the hybrid and after preamplification. Thus the lower curve is used for L_c in determining the ultimate noise figure of the overall mixer. At 70 MHz, a 1.0 dB noise figure preamp is to be used; thus, an overall noise figure of ≤ 3.0 dB is anticipated for this combination over a bandwidth of 250 MHz. The instantaneous bandwidth is 40 MHz and is limited by the IF hybrid used. The band shown in Figure 6 is the tunable bandwidth. This does not mean circuit tuning. Only the frequency of the LO is tuned across the band to realize the results in Figure 6.

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References

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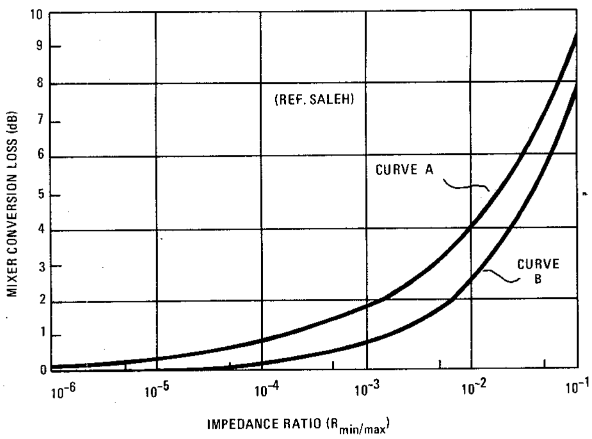

Figure 1 - Computed Minimum Conversion Loss for: Curve A Z-Mixer or Y-Mixer; Curve B, H-Mixer or G-Mixer.

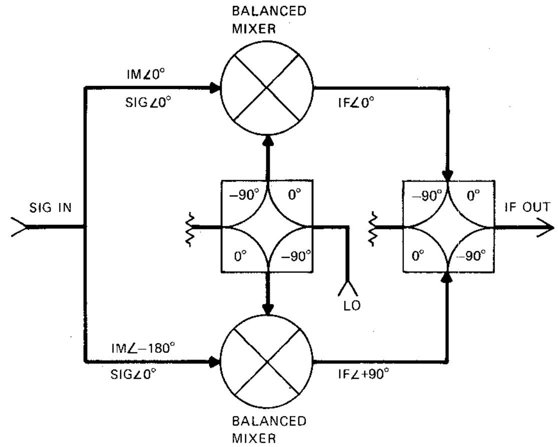

Figure 2 - Image Phasing Type of Single Sideband Mixer.

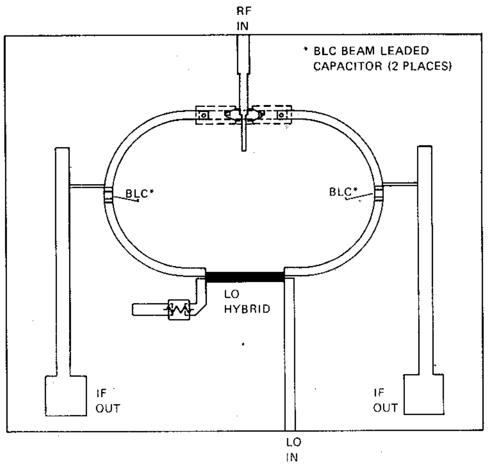

Figure 3 - Complete MIC Mixer Circuit.

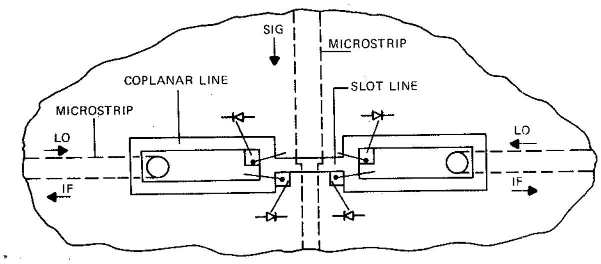

Figure 4 - Blow-up Mixer Plan View.

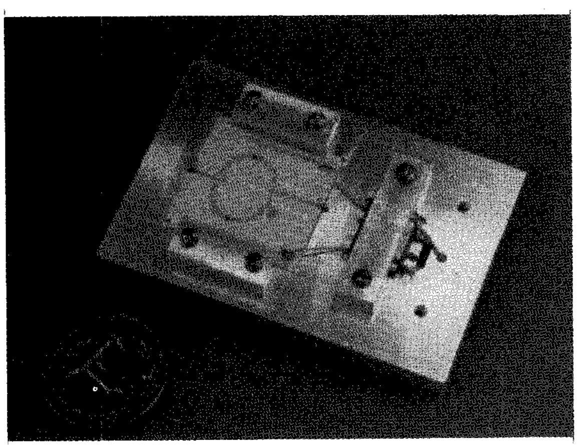

Figure 5 - Photograph Complete Mixer.

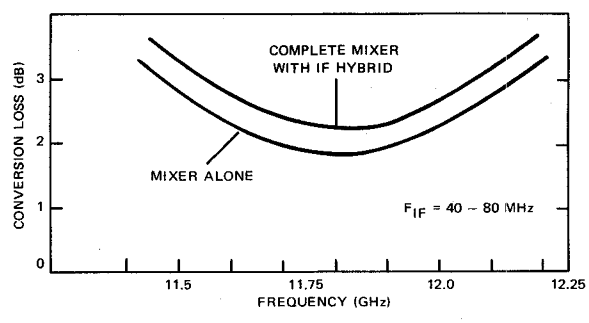

Figure 6 - Curve of Measured Conversion Loss versus Frequency.