X-BAND INTEGRATED CIRCUIT MIXER WITH REACTIVELY TERMINATED IMAGE*

by
Kenneth M. Johnson
Texas Instruments Incorporated
P. O. Box 5012
Dallas, Texas 75227

The development of the Schottky barrier diode along with microwave integrated circuit techniques makes possible miniature high performance microwave detectors. This paper describes a low noise microwave integrated circuit mixer using Schottky barrier diodes and reactively terminated image with a 500 MHz thin film IF preamplifier. The entire mixer-IF preamplifier occupies an area of only 0.38 square inches and has a noise figure of 6.7 dB.

The basic theory of mixer operation has been known for a number of years[1,2,3], including various conditions of image termination. More recently the theory has been extended to include the Schottky barrier diode. With previous point contact diodes the improvement in noise figure to be gained by reactively terminating the image was quite small. This is not true with the Schottky barrier diode which has a series resistance an order of magnitude smaller than the point contact.

In analyzing the mixer, what is usually done is to assume the diode is pumped by a constant voltage local oscillator signal and then to compute the conductance coefficients of the Fourier series which results. This procedure however, requires that all the harmonics of the local oscillator be terminated in a short circuit. This is not a good assumption for a number of reasons. First, the presence of diode series resistance, line loss and filter loss result in an imperfect lossy termination. This is particularly true in microstrip where line losses are large. Second, in a balanced mixer this is not a valid assumption since each diode sees a local oscillator signal which has been shaped by the other diode. The microstrip mixer described here had a 90° hybrid to separate signal and local oscillator signals. (The reversing switch model described by Rafuse[4] therefore does not apply since his balanced mixer model requires a 180° hybrid.) Third, usually, little or no effort is made to terminate the harmonics nor often can be made without introducing more loss than is gained by using the proper termination.

In addition, most previous analyses neglect series resistance and do not consider the termination of other out of band frequency components especially the sum frequency ($\omega_{LO} + \omega_S$).[4] These factors however, are quite important in determining the type of image termination to use - whether short circuit or open circuit [5] Calculations on the effect of these factors reveal that

* The work reported in this paper was supported by the Air Force under Contract No. AF33(615)-67-C-1639.

the open circuited image is more strongly affected by series resistance, out of band and harmonic terminations than the short circuited image. Probably for this reason, the single ended and balanced mixers tested, with short circuited images were at least 1dB better than mixers with open circuited images. However, this does not mean to imply that the open circuited image is necessarily worse than the short circuited image but only that in practical X-band mixers it is more difficult to achieve low noise figure with open circuited than with short circuited image.

The series resistance is the predominant loss element which in addition to altering the conversion loss coefficients, degrades the conversion loss by direct RF and IF signal loss. For the X-band integrated circuit mixer this loss was 0.75 dB. Other circuit losses, filter, hybrid and mismatch, totaled about 1.5 dB. With a 1.85 dB conversion loss for the short circuited image this gave a total mixer conversion loss of 4.1 dB.

The filter developed for this mixer, shown in Figure 1, consists of a half wavelength line coupled to the main line over a quarter wavelength. The use of this type of filter for a mixer was reported by Tatsuguchi.[6] This filter provided 18 dB loss at the image and only 0.5 dB loss at the signal frequency.

Two mixers were developed, one with the image open circuited, the other with the image short circuited (Figure 2.) The short circuited image rejection mixer was 2 dB better than open circuited for reasons previously mentioned. Figure 3 shows a plot of the measured noise figure versus LO frequency for this mixer. Here a minimum noise figure of 6.3 dB is measured with a 2.2 dB low noise IF converter following the mixer. Figure 4 shows plot of the measured conversion loss versus frequency for the mixer at both the signal and image frequencies for a 500 MHz IF. Here the effect of the filter is seen. It shows that there is a 16 dB difference between the signal and image conversion.

To complete the integrated circuit mixer-IF preamplifier circuit, a thin film three stage IF preamplifier with a coupling network was connected to the mixer. The IF amplifier by itself had a 2.2 dB noise figure for optimum source resistance. A transforming network consisting of a series capacitor and shunt inductor were used to match the mixer IF output to the IF preamplifier. The total noise figure resulting was 6.7 dB indicating a 0.4 dB loss in the coupling network. Figure 5 shows the complete microwave integrated circuit mixer. In comparison with an integrated circuit mixer in which the image is not terminated, the noise figure is about 0.9 dB less considering filter losses. Comparing with a conventional waveguide mixer with a 2.2 dB IF noise figure, the noise figure is about the same.

REFERENCES

1. H. C. Torrey and A. C. Whitmer, *Crystal Rectifiers,* Vol. 15, Rad. Lab. series pp. 111-178, McGraw-Hill Book Co. Inc.; 1948

2. E. W. Herold, R. R. Bush and W. R. Ferris, "Conversion Loss of Diode Mixers Having Image - Frequency Impedance", *Proc IRE,* Vol. 33, pp. 603-609; Sept, 1945.

3. P. D. Strum, "Some Aspects of Mixer Crystal Performance", *Proc. IRE,* Vol. 41, pp. 875-889; July, 1953.

4. R. P. Rafuse "Low Noise and Dynamic Range in Symmetric Mixer Circuits" *Proc First Biennial Cornell Conference Engineering Applications of Electronic Phenomena,* pp. 147-151, August 1967.

5. M. R. Barber, "Noise Figure and Conversion Loss of the Schottky Barrier Mixer Diode," *IEEE Transaction on Microwave Theory and Techniques,* Vol. MTT-15, pp. 629-635, November 1967.

6. I. Tatsuguchi, "Integrated 4 GHz Balanced Mixer Assembly" *International Solid State Circuits Conference*, pp. 60-61; February 1967.

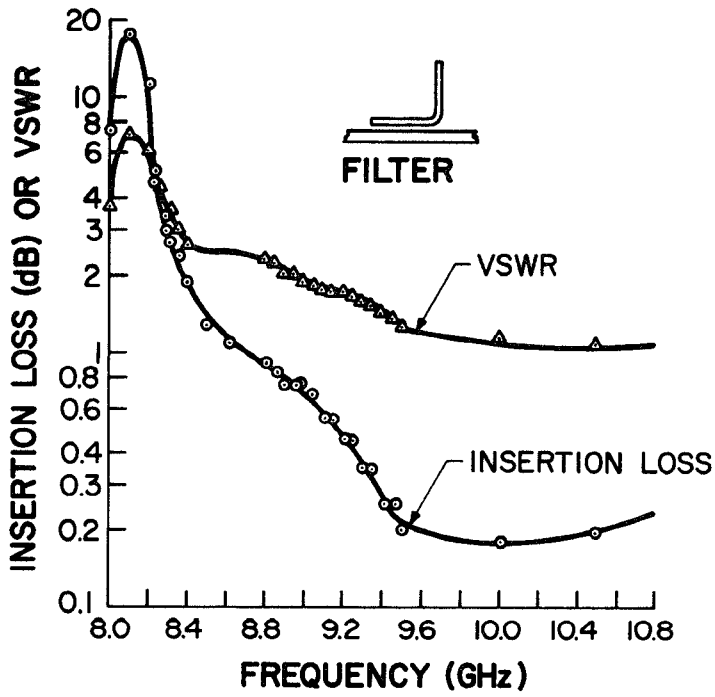

Figure 1. Filter for Image Terminated Mixer

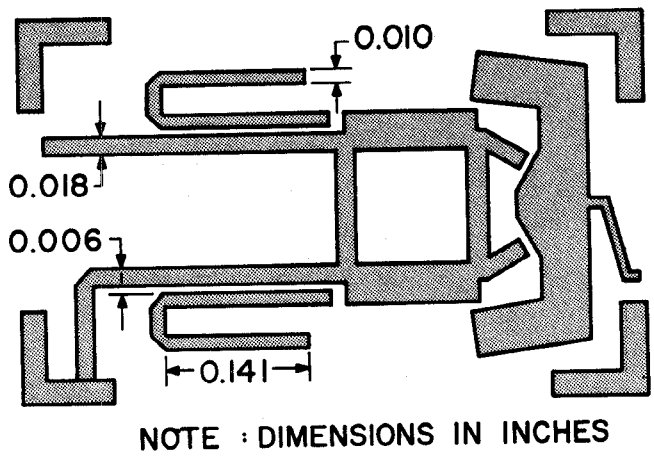

Figure 2. Mixer With Filters For Short Circuiting The Image

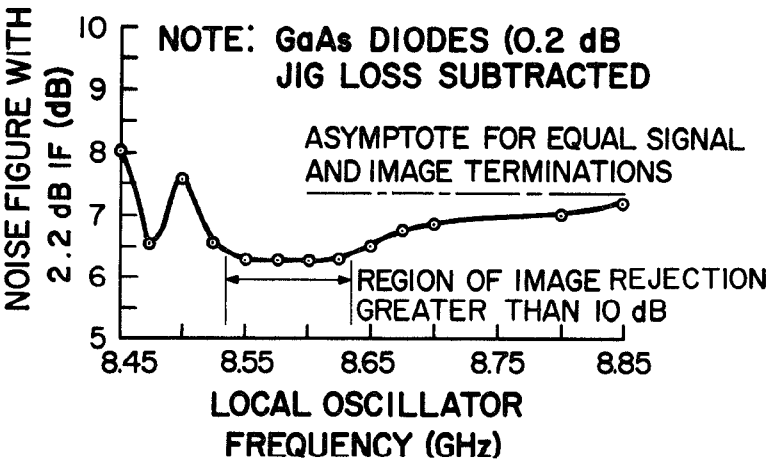

Figure 3. Measured Noise Figure Vs LO Frequency For Image Terminated Mixer.

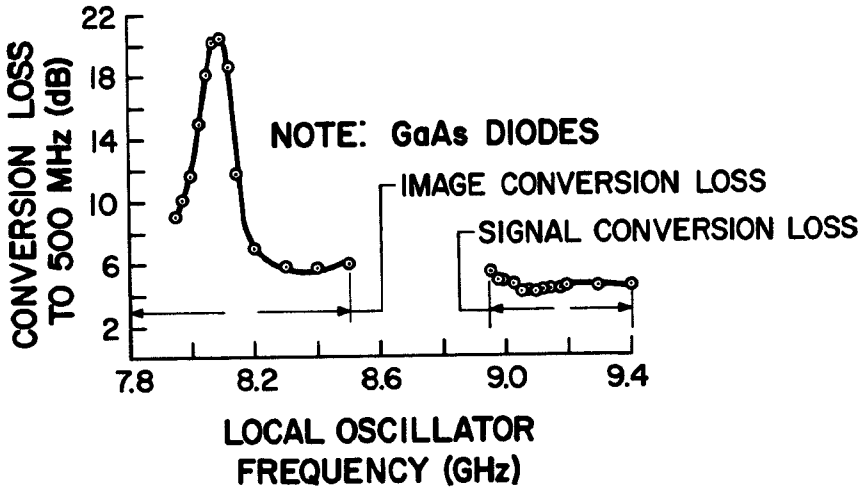

Figure 4. Conversion Loss To 500 MHz IF For Image Terminated Mixer.

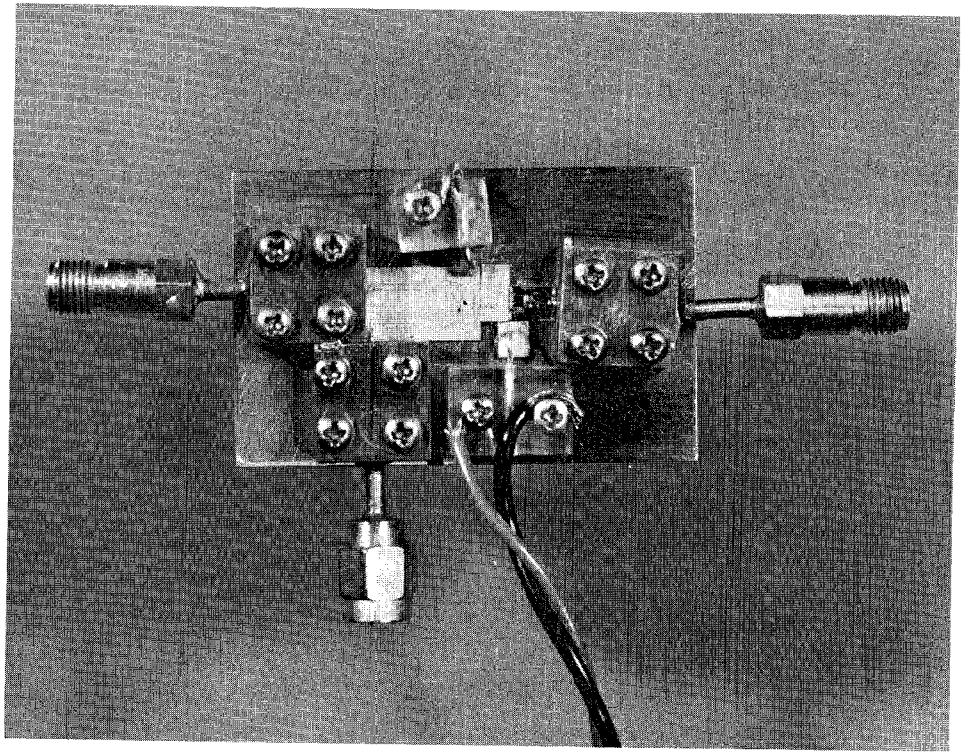

Figure 5. Complete Image Terminated Mixer IF Breadboard Assembly.