AN INTEGRATED, X-BAND, IMAGE AND SUM FREQUENCY ENHANCED MIXER WITH 1 GHz IF

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I. INTRODUCTION

The integrated X-band mixer described herein has been developed for an integrated phased array system requiring a 1 GHz intermediate frequency. This high IF allows several novel design approaches. A single ended mixer is feasible since LO noise suppression is not necessary at such a high IF. Also, image ($2f_{LO} - f_s$) and sum frequency ($f_{LO} + f_s$) enhancement techniques can be used to recover a portion of the energy normally lost in the mixing process; resulting in a conversion loss improvement of up to 1.5 dB in the enhanced mode as compared to the broadband mode of operation. To predict the "enhanced" mixer performance, Barber's[1] diode analysis has been modified to include a sum frequency port and also account for finite diode and filter losses.

II. MIXER DESIGN

The entire mixer, fabricated on a 0.4" x 0.7" x 0.25" thick sapphire substrate, is shown in Fig. 1. The six elements comprising the mixer—diplexer, three bypassing stubs (dc, IF, RF), image filter, and diode—were all designed for the following nominal center frequencies: $f_s = 9.5$ GHz, $f_{LO} = 8.5$ GHz, $f_I = 7.5$ GHz, $f_{IF} = 1.0$ GHz.

A single ring directional filter (diplexer) is used for LO injection and was measured to have a loss of 0.2 dB at the signal frequency and 2 dB at the LO frequency, the latter value being acceptable since LO power conservation is of secondary importance for this application.

The image filter consists of two $\lambda/2$ resonant lines coupled to the main line over a quarter wavelength. This filter exhibits an insertion loss to the signal less than 0.2 dB, a minimum return loss = 0.5 dB at the image center frequency, and a bandwidth of approximately 500 MHz over which the return loss < 2 dB (this value was determined theoretically to represent the point where conversion loss would degrade by 0.5 dB over its midband enhanced value). The use of this "double" image filter more than doubled the mixer bandwidth as compared to an earlier version employing a single $\lambda/2$ image filter.[2]

DC bypassing for the rectified diode current is provided by a shorted $\lambda/4$ stub while the IF bypassing network consists of a 70Ω stub whose length is one quarter wavelength at 9.5 GHz, terminated with a chip capacitor whose capacitance is chosen to resonate with the stub at 1.0 GHz.

Bypassing to prevent RF leakage out the IF port is accomplished using a combination of 4 stubs as shown in the right of Fig. 1. The two larger stubs are the usual $\lambda/4$ open circuited stubs used to bypass the signal, LO, and image frequencies. The other two smaller $\lambda/8$ open circuited stubs ($\lambda/4$ at 18 GHz) are used to bypass the sum frequency. These stubs were necessitated by the discovery that power was propagating out the IF port at the sum frequency leading to degraded conversion loss at the low end of the signal band (Fig. 2(a) solid curve). These stubs were added immediately adjacent to the diode to provide a short circuit to the sum frequency on the IF side of the diode. It was anticipated that terminating the sum frequency would provide additional conversion loss enhancement; this was subsequently verified as shown by the dashed curve in Fig. 2(a). A further significant improvement is the reduced LO drive required as evinced by the lower crystal current, I = 2 ma ($P_{LO} = 8.5$ mW) as compared to ~4 ma required with no sum frequency termination. If, in fact, the LO drive is restored to levels comparable to those required without sum frequency termination (I = 4-6 ma), the conversion loss at a single frequency can be reduced even lower with the best recorded value being 2.8 dB (2.4 dB referenced to the diode terminals). The results of additional experiments to determine the optimum terminations for both the sum frequency and the second harmonic of the LO frequency on the RF and IF sides of the diode will be reported.

In the course of the development, several different Schottky barrier diode types were evaluated including silicon chip diodes, silicon beam lead diodes, and GaAs chip diodes. The lowest conversion losses have been obtained with Westinghouse GaAs chip diodes. These diodes are fabricated on a 1 micron thick epitaxial layer and have a junction diameter of 5 microns, which is surrounded by a contact overlay 20 microns in diameter. These diodes typically have series resistances of 3-4Ω and slope parameters = 1.03.

To theoretically predict the performance of the mixer, Barber's[1] analysis of a mixer diode was expanded and modified to include the effects of (1) sum frequency as well as image terminations, (2) the diode series resistance, barrier capacitance, and bonding wire inductance, and (3) the finite return loss of image and sum frequency filters. Some results of this analysis are shown in Fig. 3, which illustrates the effects of various sum frequency terminations for the case where the image is short circuited.

III. EXPERIMENTAL RESULTS

The experimental results achieved with the mixer shown in Fig. 1 are illustrated in Figs. 2(b) and 4. All data is referred to the edges of the substrate; if referred to the diode terminals conversion losses would be approximately 0.4 dB lower.

(1) M. R. Barber, "Noise Figure and Conversion Loss of the Schottky Barrier Mixer Diode", IEEE Trans. on MTT, Vol. MTT-15, No. 11, pp. 629-635, November, 1967.

(2) J. B. Cahalan, J. E. Degenford, M. Cohn, "A Single Ended Integrated X-Band Image Enhanced Mixer with 1 GHz IF", 1970 GOMAC Conf. Digest, pp. 35-37, October, 1970.

Fig. 2(b) is a plot of conversion loss versus signal frequency for the case where f_{LO} is held constant at 8.5 GHz for 3 mixers, and clearly illustrates the benefits of the enhancement techniques employed. Because of the image filter, the mixer also rejects external signals in the image frequency band, exhibiting a conversion loss > 20 dB from 7.25-7.75 GHz.

Fig. 4 plots conversion loss versus LO power for the broadband case and for the enhanced case with and without the sum frequency bypass stubs. With sum frequency termination, it should be noted that the LO power required is less, and the ultimate **conversion loss** at high LO power levels is ~ 2.8 dB (2.4 dB referenced to the diode). Both Figs. 2(a) and 4 show a conversion loss improvement of 1-1.5 dB in the enhanced state as compared to the broadband state.

An additional benefit of image enhancement is improved RF match. For LO levels greater than 4 mW, the signal input VSWR is less than 1.3:1. The measured resistive component of the IF impedance is approximately 145Ω. A further benefit is large dynamic range. At an LO power level = 3.5 mW (measured at the LO port), the 1 dB compression point is not reached until the signal power has been increased to -1.5 dBm (.7 mW).

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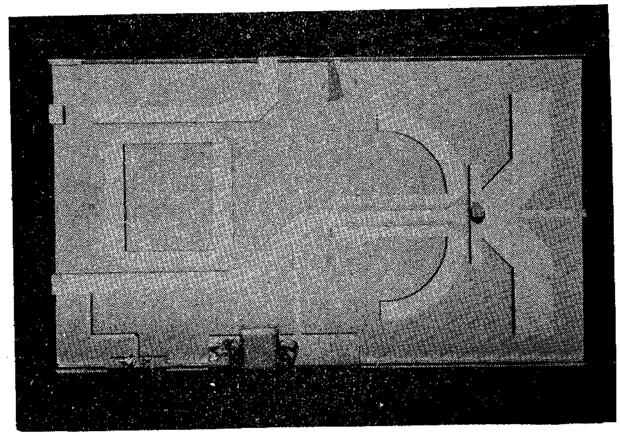

Fig. 1 Photograph of Mixer

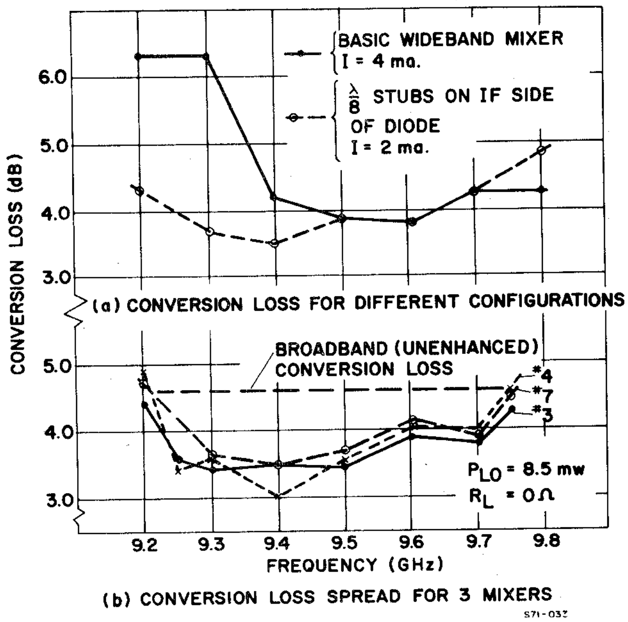

Fig. 2 Conversion Loss vs. Frequency

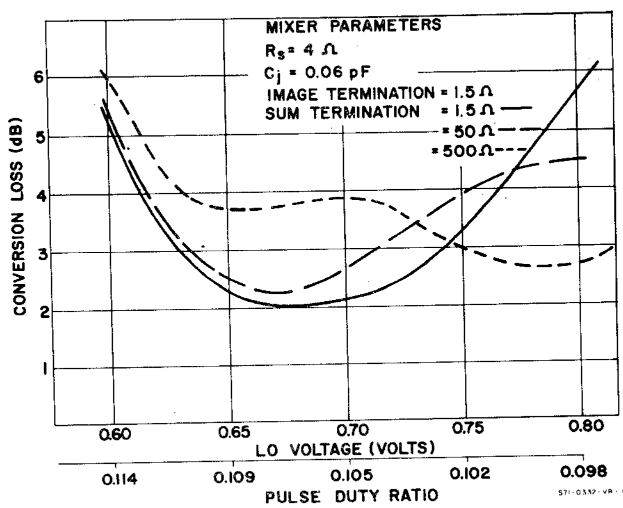

Fig. 3 Calculated Conversion Loss

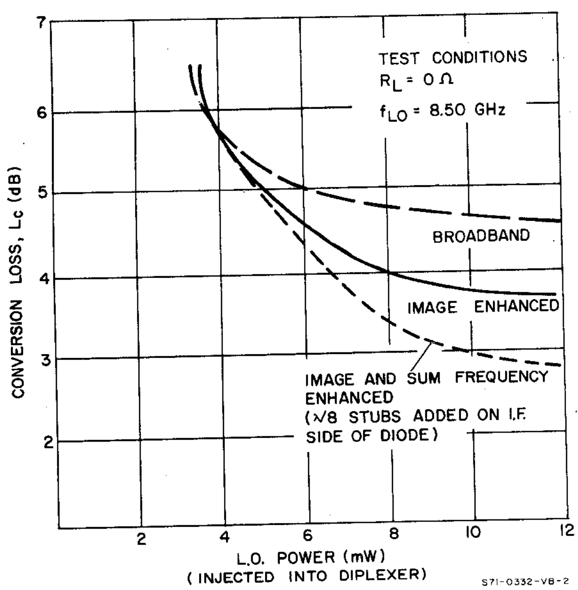

Fig. 4 Conversion Loss vs. LO Power