94 GHz Subharmonically Pumped MMIC Mixer

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Abstract

A 94 GHz subharmonically pumped anti-parallel diode pair MMIC mixer with a short circuit sum frequency termination is described. Advantages of the mixer configuration include: 1) reduced conversion loss, 2) elimination of the need for an area consuming hybrid junction while retaining the separation of LO, RF and IF ports, 3) inherent LO noise sideband suppression, and 4) very small size and cost.

Introduction

Described herein is a subharmonically pumped [1] anti-parallel diode pair 94 GHz MMIC mixer. The mixer employs a short circuit sum frequency termination which provides two important benefits: 1) Conversion loss is improved by ~1.5 dB compared to the matched termination case, and 2) RF and IF impedance levels are dramatically improved; i.e., brought closer to 50 ohms, making matching much easier.

Predicted conversion loss is ~8 dB using the high quality (f_{co} = 1.2 THz) Schottky barrier diodes described in the next section. In addition LO generation is considerably simplified since the LO is at ~46 GHz instead of 92 GHz.

The mixer's small area, 2.85 mm², and low required LO frequency make it ideal where space, power, and cost are critical. Note further that the mixer: 1) has separate LO, RF, and IF ports, 2) needs no area consuming hybrid junction, and 3) by virtue of its anti-parallel diode configuration has inherent suppression of LO noise sidebands [1].

Schottky Barrier Diode Design and Fabrication

The mixer nonlinear component is an interconnection of four GaAs Schottky-barrier diodes: two series connected anti-parallel pairs as shown in Figure 1. Each diode is a parallel combination of four 10μ x 0.5μ fingers for a total area of $20\mu^2$. The layout considerations are described in [2]. Fabrication featured an ideal VPE-grown active layer (2000Å $5\times10^{16} cm^{-3}$ film on 5000Å $10^{18} cm^{-3}$ buried n^+ on < $10^{13} cm^{-3}$ buffer), a proton damage implant for isolation to preserve planar processing, AuGeNiAu ohmics, direct write lithography for TiPtAu anode definition, simple lift-off patterning for T-lines, and RIE vias. Using a wafer-level diode evaluation technique (performed at 10 GHz but correlated to 94 GHz) described elsewhere [2, 3], a 97% yield was achieved on one wafer with cross-wafer averages at zero-bias of f_{co}=1220 GHz (σ=44 GHz), C_{jo} =13.2 fF (σ=0.75 fF), and R_s=10Ω (σ=0.66Ω) for a $10\mu^2$ test pattern.

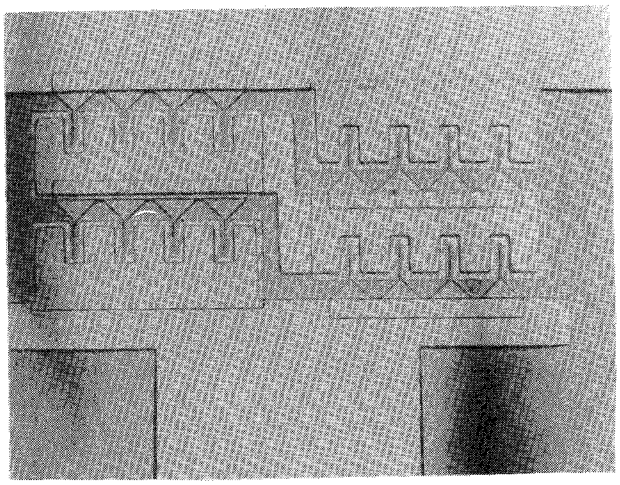

Figure 1. Anti-Parallel Schottky Barrier SB Diode Configuration.

Mixer Design

The basic performance goals for the mixer are shown below:

RF input frequency (f_R)	94 GHz ± 0.3 GHz
LO frequency (f_L)	$(f_R - f_I)/2$
IF frequency (f_I)	~2.5 GHz
P_L	+13 dBm
L_C	7 dB
1 dB compression	≥ +6 dBm input

Figure 2 is a photograph of the mixer chip. Chip size is ~1900 x 1500 x 100μm thick. The Schottky barrier diodes are connected in an anti-parallel configuration to suppress even order mixing products [1]. Two diodes in

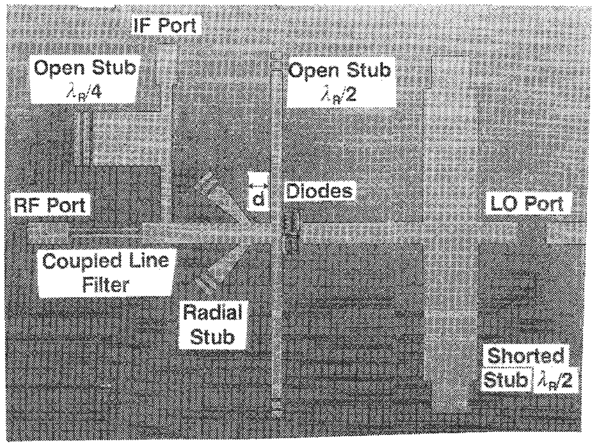

Figure 2. Millimeter Wave Mixer Circuit.

series are used in each arm to: 1) increase the 1 dB compression point to the required +6 dBm, and 2) maintain convenient RF and IF impedance levels. Open and short circuited stubs are used as the basic filtering elements. On the RF input side, a ($\lambda_R/2$) open circuited stub allows signal and IF to pass but stops the 45.7 GHz LO. Similarly on the LO side the ($\lambda_R/2$) short circuited stubs allow the LO to pass but stop RF and IF. IF extraction is through a short ($\lambda_R/4$) transmission line as shown which is terminated by a ($\lambda_R/4$) open stub to prevent RF from leaking out the IF port. Similarly the IF is prevented from going out the RF port by a coupled line filter which acts as an open circuit at the IF. The final set of radial stubs shown in the figure provides a sum frequency termination which improves performance and simplifies the RF and LO matching required as discussed below.

The mixer designs were evaluated with the software package LIBRA™. The large-signal-LO/small-signal-RF method of analysis was used to calculate the conversion loss, input impedances at the RF and IF ports, and the power absorbed in the port terminations at the various frequencies. The input impedance at the LO port, and the LO-RF and LO-IF port isolations were calculated using the harmonic balance routine.

The LIBRA analysis of the circuit design indicated that the conversion loss of the mixer could be improved by recovering the power in the sum frequency component of the mixing. Since $2f_L + f_R$ is nearly equal to $2f_R$, the sum frequency signal is blocked by the ($\lambda_R/2$) shorted stubs and passed by the ($\lambda_R/2$) open stubs. Therefore, a pair of radial stubs were added to the input side of the circuit to terminate the sum-frequency. The location of the radial stubs with respect to the diodes (distance d in Figure 2) was found to have a strong influence on the RF and IF port impedances as shown in Table 1.

Table 1. Calculated Mixer Parameters for Diodes with f_{co} = 800 GHz

d (microns)	RF Impedance (ohms)	IF Impedance (ohms)	Conv. Loss (dB)
50	24.3+j 11.5	34.7-j 9.8	8.2
75	50.0-j 0.6	40.0-j 12.5	7.7
100	42.4-j 35.9	43.0-j 18.4	8.6

P_{LO} = 13 dBm

Further improvements are expected if the image frequency ($4f_L - f_R$) is reactively terminated, which would be practical for a higher IF [4].

In laying out the mixer a matrix of nine designs was included on the mask to allow for 1) three variations of shorted stub length and 2) three variations in the location of the radial stubs. These parameters were expected to potentially have the greatest impact on mixer performance.

Experimental Results

Initial "as fabricated" untuned results on the first wafer, as shown in Figure 3, are very encouraging. Figure 3 plots predicted and measured conversion loss vs. P_L at 94 GHz for the nominal design. Minimum conversion loss is ~10 dB for an LO power of 12 dBm, compared to a predicted value of ~8 dB at an LO power of +13 dBm. Conversion loss results for the remaining eight designs are shown in Table 2.

Table 2.

		Shorted Stub Length (microns)		
		495	520	545
Radial Stub Location (microns)	25	12	10	11
	50	10	10	11
	75	17	11	11.5

Additional tuning is afforded by the small pads at the end of the open stubs as shown on Figure 2. Optimization of these stub lengths is underway and results will be presented at the symposium. The changes will be incorporated in the circuit mask for the next design iteration.

A 1 dB bandwidth of ~2 GHz was also measured which is more than adequate for this application.

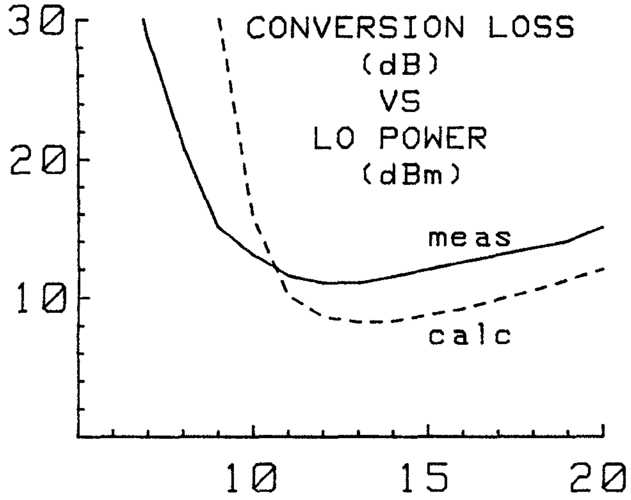

Figure 3. Conversion Loss vs. P_{LO}

References

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