DEVELOPMENT OF A 183 GHz SUBHARMONIC MIXER

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Abstract

Experimental results are presented for a 183.3 GHz subharmonic mixer operating in a broad IF (0.75 GHz-10.0 GHz) radiometer system. The results are compared to a low frequency (6.8 GHz) mixer model. Results from a similarly designed fourth harmonic low frequency model are also presented.

Introduction

Antiparallel diodes, when used as a subharmonically pumped mixing network, have several advantages over single diode mixers particularly for millimeter wave applications.[1,2,3] Pumping at half the frequency allows the use of lower cost or solid state local oscillators at millimeter wave frequencies while having similar mixer conversion loss characteristics to single ended mixers. Local oscillator AM noise cancellation occurs due to the nature of the antiparallel diode circuit.[4] Also, a dc bias is not required for mixer operation.

The use of Schottky barrier diodes placed in the signal waveguide and a specially designed suspended substrate circuit have extended this concept for use at 183 GHz. Preliminary results based on measurements made with a Dicke radiometer using this device are given in this paper.

Description

The mixer diagram shown in Figure 1 shows the functions of the stripline circuit and diode placement. This mixer was modeled at 6.8 GHz for circuit optimization and directly scaled using electromagnetic scaling techniques to 183 GHz. Great care was taken to model the actual mixer by choosing diodes with scaled cut-off frequencies. The size of the diodes was also scaled by using brass blocks in the waveguide. The IF filter consists of a low pass filter designed to reject the LO and pass the IF frequencies. The LO filter is another low pass filter designed to pass the LO but block the RF energy from leaking into the LO waveguide. The stripline circuit provides a broadband RF match to the diode pair, allows LO injection and provides an IF output port. The quartz substrate is 0.003″ thick with a Cr-Au vacuum deposited center conductor. The circuit is etched by common photolithographic methods. The signal waveguide has a linear taper to half-height WR-5 waveguide to improve the RF match.

The mixer has two orthogonal waveguides, WR-10 for the LO, and half-height WR-5 for the signal. These two waveguides are connected by a channel that supports the suspended substrate filter. One diode and one whisker are mounted on one end of the filter, the LO transition from waveguide to stripline is in the middle of the filter and the IF connection is made to the other end of the filter. Across the WR-5 waveguide from the end of the filter where a diode and whisker are mounted, two pins are inserted on which the other whisker and diode are mounted. When the two diodes are contacted, the antiparallel diode pair is formed inside the WR-5 waveguide. The diodes are 0.005″ x 0.01″ GaAs diode chips which contain arrays of 2μm Schottky barrier diodes.

The body itself is divided into three parts. One part holds both pins, one holds the IF filter, and the last contains the linear taper from full to half-height WR-5 waveguide.

Assembly

First a pre-shaped whisker is mounted on the end of the LO filter using normal solder. The whisker is then etched to 0.007″ in a 10% solution of NaOH at 2 Vac. The diode chip is then epoxied to the thin edge of the filter and a fillet of 90°C solder is added for the electrical connection. The filter is then mounted in the filter channel in the block using Loctite 404. The SMA connector is then attached and a piece of gold ribbon is soldered between the connector and the filter. When the diode chip is mounted on the diode pin, a glass cover slip is used to press it into a thin layer of low temperature, 90°C, solder. The preshaped whisker is mounted on the pin using normal solder and etched to the same length as the whisker on the filter. All soldering is done using Supersafe #30 flux.

The filter block is then bolted to the pin block and both of the pins are pressed into the block. A micrometer is used to position both pins to 0.005″ from their final positions. The waveguide transition block is now bolted to the other two and one diode at a time is contacted while being monitored on a curve tracer.

Performance

The design and testing was performed primarily to develop a 183 GHz mixer with a 20 GHz RF bandwidth to be used on a radiometer with three IF channels spanning a 0.75 GHz to 10.0 GHz IF. This radiometer and its system requirements have been set by the study of the water vapor absorption line at 183 GHz. This broad IF prohibits the use of standard IF matching techniques.

The mixer shown prior to assembly in Figure 2 was tested in a radiometer system. The signal was modulated by a Dicke chopper alternately viewing liquid nitrogen or room temperature distributed loads and a reference load. This modulated signal is then mixed down to between 0.75 GHz and 10.0 GHz by the subharmonically pumped mixer with a 91.65 GHz LO. The IF signal was amplified and then detected using square law detectors and a lock-in amplifier.

An RC time constant of 1.25 seconds was used to get the scale factor for determining the minimum detectable temperature by alternately viewing the room temperature and liquid nitrogen loads and reading the output of a DVM. This time constant corresponds to an integration time (τ) of 2.5 seconds for a simple RC integrator.[5] The RMS fluctuations were measured by graphic analysis of the radiometer output recorded on a chart recorder. The measurements were used to get the minimum detectable temperature (ΔT_{min}) for the system using

$$\Delta T_{min} = \left[(T_{RT} - T_C) / (V_{RT} - V_C)\right] \times V_{RMS}.$$

where

T_{RT} = Room Temperature (°K)

T_C = Temperature seen by antenna when viewing the cold load (°K)

V_{RT} = Voltage output of radiometer when viewing room temperature load

V_C = Voltage output of radiometer when viewing cold load

V_{RMS} = Measured standard deviation of radiometer output.

The system noise temperatures, frequencies, double sideband mixer noise figures (F_M) and bandwidths are summarized in Table 1. These numbers were achieved using no specialized matching networks and represent actual results obtained with a 183.3 GHz double sideband radiometer system.

Summary

These results show the feasibility of using subharmonic mixers with Schottky barrier diodes for system applications in the millimeter wave region. This design is adequate for frequencies up to 360 GHz by using the same scaling techniques.

A fourth harmonic mixer for use at 183.3 GHz is also being developed. Results from the model mixers (shown in Figure 3) show that with carefully designed stripline circuits comparable performance to the second subharmonic mixer may be obtained. Results from the 183 GHz version of this mixer should be available soon.

Acknowledgments

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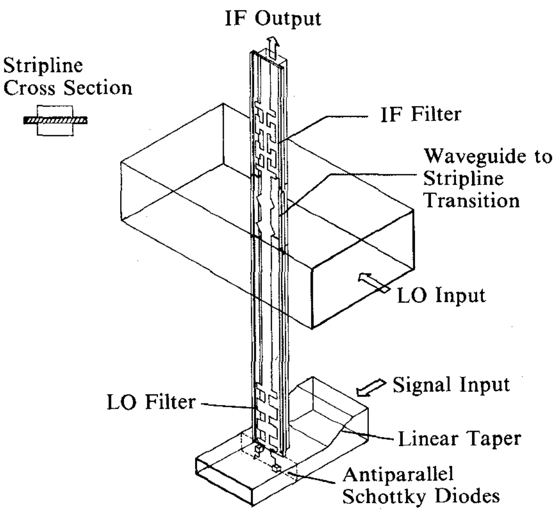

Figure 1. Functional Schematic of Subharmonic Mixer.

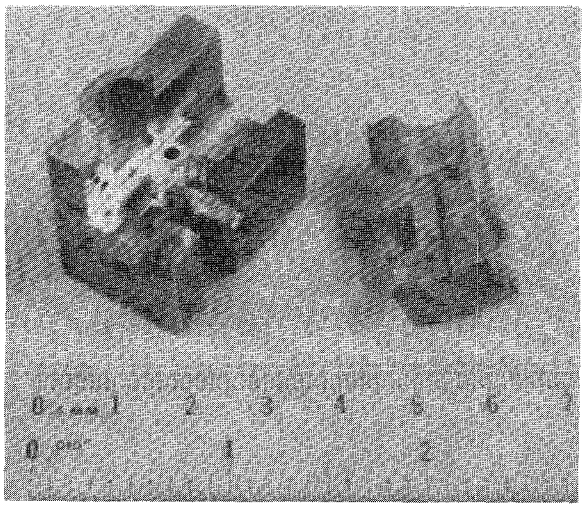

Figure 2. Photograph of Partially Disassembled 183 GHz Subharmonic Mixer.

TABLE I

NOISE FIGURE SUMMARY

IF CHANNEL (f_o)	ΔT_{min}	IF Bandwidth (B)	IF Noise Figure (F_{IF})	T_{SYS}	F_M
1.0 GHz	0.22°K	0.5 GHz	4.0 dB	3536°K	4.9 dB
5.0 GHz	0.25°K	1.0 GHz	5.0 dB	5680°K	5.9 dB
8.75 GHz	0.25°K	2.5 GHz	5.0 dB	8984°K	7.9 dB

where:

$$\Delta T_{min} = \frac{2.2\, T_{SYS}}{\sqrt{B\tau}}$$

$$T_{SYS} = T_A + (\alpha - 1)290 + \alpha(F_m - 1)290 + \alpha L_C(F_{IF} - 1)290$$

$$T_A = 290°K,\ \alpha = \text{RF losses} = 2.0\text{ dB},\ \tau = 2.5\text{ sec.}$$

and assuming,[6] $LC = F_M$ (Noise Ratio≈1)

$$F_M = \frac{T_{SYS}}{\alpha 290\, F_{IF}}$$

$f_{LO} = 91.65$ GHz $f_{SIG} = 183.3 \pm 10$ GHz

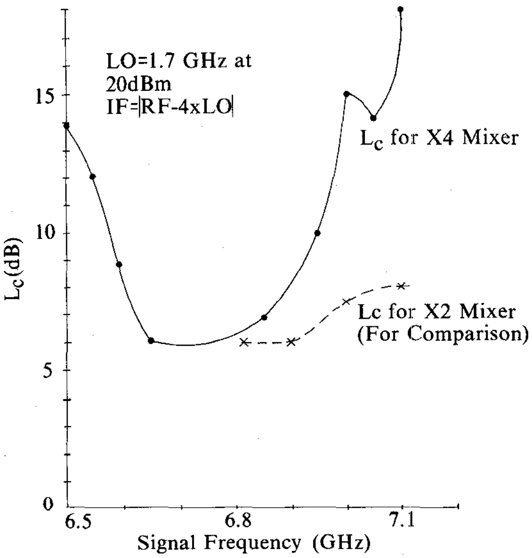

Figure 3. Measured Conversion Loss (L_C) versus Signal Frequency of Fourth Harmonic Mixer Model (Scaled 26.9:1)