Development of a 105-130 GHz subharmonic mixer utilizing planar schottky diodes

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(Received September 19 2012)

Abstract: The paper presents the design, fabrication and measurement of a low-loss fixed tuned 105-130 *GHz* subharmonically pumped mixer, utilizing planar GaAs Schottky barrier diodes flip-chipped onto a suspended microstrip circuit. The substrate material is 0.127-*mm*-thick RT/duriod-5880 instead of expensive quartz. The measurement performance of the mixer exhibits a conversion loss below 10 *dB* over the range of 105-130 *GHz*, with a fixed local oscillator (LO) frequency of 59 *GHz* and its power of 5 *mW*.

Keywords: Terahertz, Schottky diodes, Sub-harmonic mixer

doi: 10.11906/TST.163-168.2012.12.15

1. Introduction

Terahertz (THz) waves lie in the frequency range from 100 *GHz* to l0 *THz*. Their corresponding wavelengths range from 30 *cm* to 30 μm. Sandwiched between the millimeter wave and light wave range, this field possesses some unique properties and hence has recently attracted increasing interest. Currently, one of the main application areas of THz solid state technology is space-borne earth observation. In these cases, THz mixers are commonly used as the first stage of receivers' front ends due to the lack of electronic amplifiers in such high frequencies [1-3].

The frequency band of 105-130 *GHz* includes 118 *GHz*, an oxygen vapor frequency line. For heterodyne receivers to detect the information of this frequency, there are three prevailing mixing technology candidates, specifically superconductor-insulator-superconductor (SIS) junctions, hot-electron bolometers and Schottky barrier diodes. Mixers based on SIS junctions have remarkably high sensitivity and are the best choice for radio astronomy at submillimeter wave and THz regime [4]. Hot-electron bolometer mixers also show excellent sensitivity similar to SIS mixers. Both require very low LO power [5]. However, both types of mixers need cooling to cryogenic temperatures, which complicates the construction and increases the mass of receivers. Mixers based on Schottky diodes have the advantage of operating well at either cryogenic or room temperatures, although not with the sensitivity of SIS or bolometric mixers. Due to this, heterodyne receivers incorporating Schottky diodes mixers are simpler to integrate into compact systems. They are also well suited for taking long term or repeated measurements since they operate at room temperature. In summary, Schottky diode receivers are a flexible and reliable device with moderate performance especially for space-borne application.

Subharmonic Schottky mixers utilizing an anti-parallel Schottky diode pair play a significant role in millimeterwave and THz heterodyne receivers. They have a number of attractive features from a system design point of view. First, RF and LO frequencies are well separated and can be isolated by simple filters within the waveguide cavity. Second, the LO requirements are easier to meet because the LO frequency is about half of that in the corresponding fundamentally pumped mixers, and because subharmonic mixers have substantial AM local oscillator noise suppression [6-8].

This paper presents the development of a low conversion loss fixed-tuned subharmonic mixer at 105-130 *GHz* utilizing an anti-parallel pair of planar Schottky diodes. The circuit is integrated on a RT/duriod-5880 substrate instead of expensive quartz, which simplifies the circuit's fabricating and assembling and thus has the potential of large scale production and real application.

2. Design procedure

A. Nonlinear elements

In essence, mixers act as a frequency converter in heterodyne receivers. Thus, mixers need nonlinear elements to operate. In this paper, GaAs Schottky diodes serve as this critical part. These diodes have very non-linear current voltage characteristics and generate some noise. In theory, in order to provide high sensitivity, low conversion loss and low noise, the mixing element must have certain special characteristics, such as frequency response, dynamic conductance range and noise characteristics. Over the past two decades, the fabrication technology of planar air-bridged Schottky diodes has made great progress. Air-bridged Schottky structures were demonstrated in the late 1980*s* as a reliable, high quality alternative to whisker contacted diodes for use at the higher frequencies [9]. This approach gives a mechanically stable structure with low parasitic capacitance [10]. The principle function of the air-bridge structure is to reduce the parasitic parameters, which is suitable for high frequency application. This technology makes it possible to realize high performance circuits in THz band.

B. Mixer architecture

The architecture of the mixer circuit is presented in Fig. 1. The design is based on an E-plane split-block waveguide architecture [11] with fixed RF and LO backshorts. This circuit consists of a grounded probe in the RF waveguide, an antiparallel diode pair in series with the transmission line, a low-pass filter to block the RF signal, a probe crossing the LO waveguide and a low-pass IF filter. The pair of planar diodes is flipped-chip mounted on a suspended 0.127-*mm*-thick RT/duriod-5880-based microstrip circuit. The circuit is precisely RF grounded at one end by contacting the RF waveguide wall, avoiding the use of bonding wires, which also provides the return ground for DC current from any imbalance between the diode pair without biasing the diode pair asymmetrically. At the other end, the microstrip circuit is silver-epoxy glued to a K-connector as the IF output port. Both RF and LO inputs are coupled to the suspended microstrip using reduced height waveguides and wide E-plane probes for broadband operation.

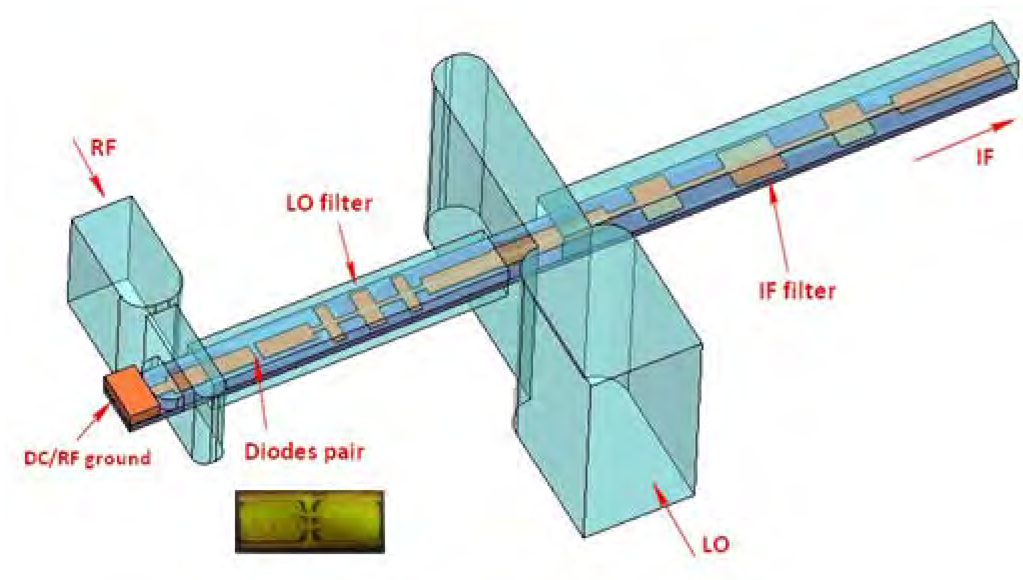

Fig. 1 The architecture of the mixer.

C. Circuit design

The anti-parallel pair of planar Schottky diodes was from Virginia Diodes Inc. (VDI) [12] featuring a low parasitic capacitance and series resistance. The non-linear behavior of the diodes was analyzed using the standard diode model provided in the Advanced Design System (ADS) [13] from Agilent. The passive parts of the mixer were analyzed using Ansoft's HFSS [14]. Then these results were exported to ADS bench to combine with the diodes model to calculate the performance of the real mixer.

According to the non-linear simulation, an optimum LO power of 4~5 mW for pumping the pair of diodes was achieved. In this LO pumping power condition, the optimum performance of the mixer was obtained by optimizing the matching network after taking HFSS S-parameter results account into ADS simulation bench. The matching circuits could be synthesized using the same method with the one defined in [15, 16] according to the Madjar's rule [17].

3. Mixer performance

The mixer is finally fabricated as shown in Fig. 2. To test its conversion loss performance, the LO signal was provided by a commercially available MMIC-based power amplifier module that could provide about 10 *mW* in 55-65 *GHz* band. The calibration of the LO power was performed using a power meter. The RF signal was generated by an F-band multiplier and its output power level was set at 0.1 *mW*, which acted as the input power of the mixer's RF port. The IF output signal was connected to the spectrum analyzer Agilent's 8563EC and the conversion loss could be calculated. The conversion loss measured with an LO frequency fixed at 59 *GHz* and its power of 5 *mW* is shown in Fig. 3, which is in good agreement with the simulation results.

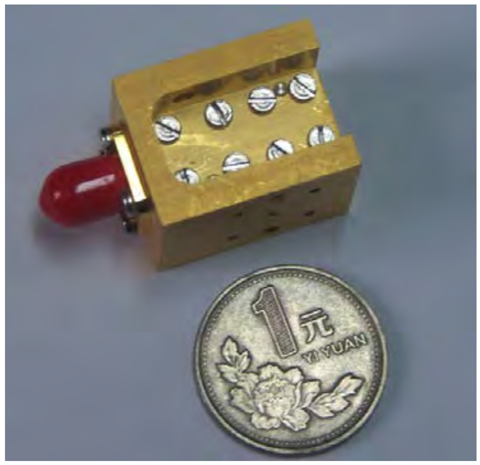

Fig. 2 The photograph of the fabricated mixer.

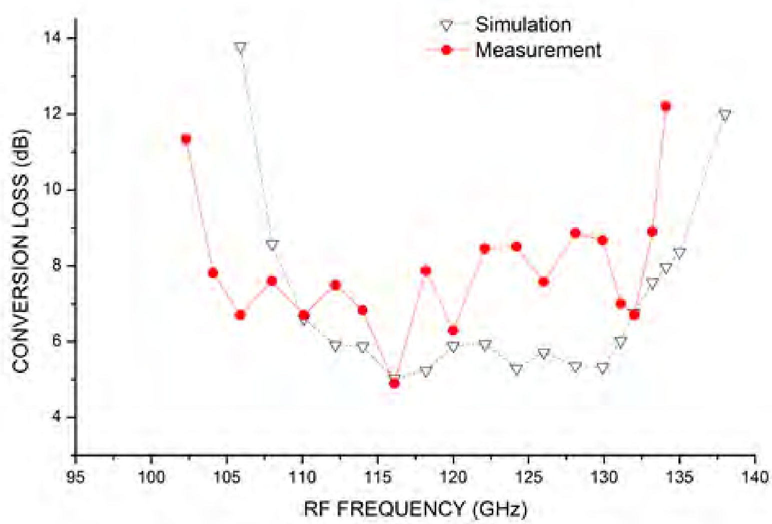

Fig. 3 The measured conversion loss.

4. Conclusion

The design of a subharmonic mixer using GaAs planar Schottky barrier diodes has been demonstrated in this paper. A very good measured conversion loss performance is achieved, which is in good agreement with the simulation results. Since planar GaAs Schottky diodes make it possible to design high performance mixers in higher frequency band in sub-millimeter wave and THz region, the design methodology demonstrated in this paper could be applied in future THz band mixer design. The mixer in this work also has the potential for large scale production and real application due to its using of low cost circuit substrate, which is easy for fabricating and assembling.

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