# A 4th Harmonic Schottky Diode Mixer - Facilitated Access to THz Frequencies

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***Abstract*—This paper will present first measurement results of a 4th harmonic Schottky diode mixer operating at 600 GHz. The mixer design compromises a rectangular waveguide based splitblock with an integrated quartz based mixer circuit. A low parasitic planar antiparallel Schottky diode pair is used to downconvert a 600 GHz signal by mixing with the 4th harmonic of the local oscillator. The local oscillator for the presented mixer consists of a 150 GHz PLL-locked frequency doubled Gunn oscillator providing a frequency and phase stabilized LO source for accurate measurements of the magnitude and phase of the RF signal. Simulations predict conversion losses well below 20 dB. Current evaluations of the mixer performance are proving the suitability for short range applications like material characterization and testing as well as for life sciences and medical applications.**

***Index Terms*—4th harmonic, mixer, 600 GHz, THz, GaAs Schottky diode**

## I. Introduction

Accurate measurements in the THz frequency range call for high performance receivers like sensitive diode detectors or low noise mixers. Especially if a signal's magnitude and phase are of interest downconverting devices like SIS or Schottky diode mixers are required. The Schottky technology exhibits relatively low demands on the system setup as no cryogenic cooling is needed and is therefore preferred for non-radiometric applications. With the availability of low parasitic planar Schottky diodes the challenges for those receivers are up to the local oscillator (LO) source. Especially if phase measurements have to be performed the demands on frequency and phase stability of the LO source limit the number of suitable oscillator concepts. Solid state sources are the devices of choice for those applications but in general the output power of these source is limited and costly. The idea of using harmonic mixers with a LO frequency at a fraction of the signal frequency reduces the requirements on the LO source with the order of the chosen harmonic but comes along with a degraded performance in terms of higher conversion losses and noise figures. This aspect leads to the fact that mainly 2nd harmonic mixers have been demonstrated for the THz frequency range in the last decade.

This work is intended to evaluate the performance of a 4th harmonic mixer for 600 GHz. Downconversion of the THz signal with the fourth harmonic of a local oscillator operating at 150 GHz is a promising effort as solid state based sources at this frequency are available at moderate costs compared to local oscillators for fundamental or second harmonic mixer approaches. The influence of the degraded performance for higher harmonic mixing can be reduced by using very low parasitic planar GaAs Schottky diodes.

## II. Mixer Circuit Design

The mixer design includes a high performance antiparallel diode pair fabricated by ACST [1]. The circuit of the mixer is a quartz substrate based microstrip environment designed for a robust and compact assembly in split-block technology. The splitblock is micromechanically milled in brass and gold plated after fabrication. Rectangular waveguides are included for feeding the RF- and LO-signals. The IF output is in coaxial configuration with a standard SMA connector. Fig. 1 depicts the split-block with the planar mixer circuit in a very compact and versatile design.

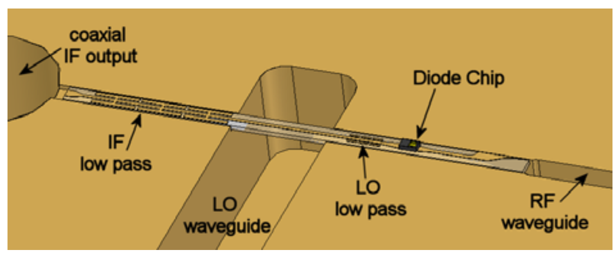


Fig. 1. 4th Harmonic Mixer Design - Splitblock Bottom Part

For coupling the input 600 GHz signal onto the planar circuit a tunerless antipodal finline transition is used. The LO coupling element is a narrow suspended ground microstrip line in the center of the 4 mm long quartz substrate acting like a coaxial probe in the WR-06 LO waveguide. Hammerhead low pass filters are used to separate the involved frequencies. The IF signal output is realized by a 1 mm semi-rigid coaxial cable (not shown in Fig. 1) with the center conductor bond wired to the microstrip. For improved grounding the outer conductor of the semi-rigid cable is bond wired twice to the split-block. The design and performance simulations presented in [2] state a conversion losses of around 14 dB for a LO power of 13 dBm at 150 GHz.

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## III. I-V Measurements

After the assembly of the mixer circuit substrate in the splitblock I-V measurements are performed to ensure a proper mounting and to evaluate the equivalent circuit parameters of the mounted diode.

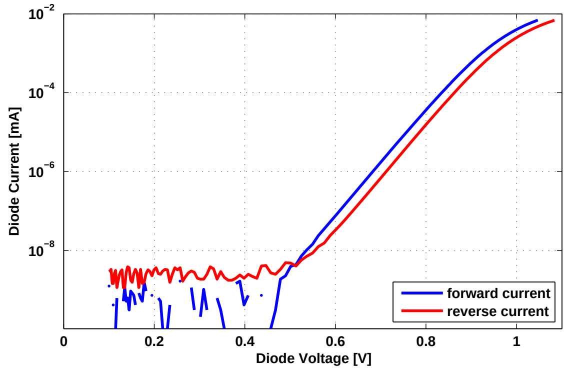


Fig. 2. I-V Measurement of the Mounted Diode

The plot (Fig. 2) shows the diode currents versus the applied diode voltage for both polarities. The obvious asymmetries between the two polarities in the plot are due to a small damage of diode chip which occurred in the dicing process of the quartz substrate. With the I-V measurement data the equivalent circuit parameters of the mixer can be derived by curve fitting the data to a theoretical diode curve (Tab. I).

TABLE I
Derived Equivalent Circuit Parameters of the Mixer

| **Polarity** | **Series Resistance** [$R_S$ Ω] | **Saturation Current** $I_S$ **[fA]** | **Ideality Factor** |
|---|---|---|---|
| forward | 10.6 | 1.20 | 1.29 |
| reverse | 12.1 | 0.40 | 1.27 |

The asymmetries in the I-V curves result in the occurrence of odd mixing products which would not occur for perfect symmetrical anti-parallel diodes.

## IV. RF Measurements

To determine the conversion loss of the mixer a preliminary test setup with a solid state based 600 GHz signal source and a 150 GHz local oscillator is used. By the time of writing local oscillator power could only be provided by a 150 GHz BWO tube with a maximum output power level of 3.5 dBm. The signal source is a doubled 75 GHz Gunn oscillator which drives a diode multiplier. The 150 GHz harmonics at the multiplier output are high pass filtered ($f_c$ = 525 GHz) resulting in a 600 GHz signal with a power level of 174 $\mu$W (-7.6 dBm) and further higher harmonics. This preliminary test setup is not suitable for phase measurements at 600 GHz due to the nature of the LO source. Furthermore the maximum output power is about 10 dB too low for the optimum mixer operation.
Using a spectrum analyzer to measure the IF signal power level at 870 MHz ($P_{IF} = -35$ dBm) a single sideband conversion loss of about 27 dB can be observed (Fig. 3).

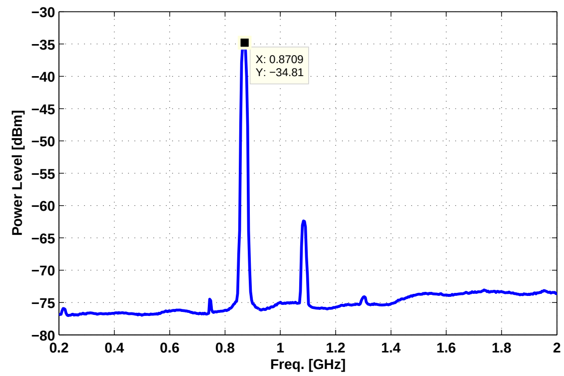


Fig. 3. Measured IF Spectrum of the Mixer

The second peak in the IF spectrum at 1.1 GHz is quite interesting. To determine the nature of this peak the 600 GHz signal frequency is varied by shifting the 150 GHz input frequency of the diode multiplier by 200 MHz. As expected the IF signal peak at 870 MHz is shifted by 800 MHz but the second peak in the IF spectrum now occurs at 2.1 GHz. This effect leads to the assumption that due to the asymmetry in the I-V curves the peak is an odd mixing product of the 5$^{\text{th}}$ harmonic of the LO and the 5$^{\text{th}}$ harmonic of the diode multiplier. Based on this assumption a mixer operation at 750 GHz can be derived.

## V. Conclusion

The first measurements of the 4$^{\text{th}}$ harmonic mixer already show a reasonable conversion loss of $L_{SSB}$ = 27 dB even though the available LO power is about a factor of 10 too low for optimum operation. Using a solid state based local oscillator with sufficient output power a considerable lower conversion loss can be expected. For further detailed characterization of the mixer combined conversion loss and noise figure measurements according to [3] will be performed. The promising results qualify the mixer for the intended use a versatile THz receiver with low system setup complexity at moderate costs.

## VI. Acknowledgments


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## References


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