TITLE: A Broadband Low Noise Heterodyne Receiver at 2.5 THz

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:
TITLE: International Conference on Terahertz Electronics [8th], Held in Darmstadt, Germany on 28-29 September 2000

To order the complete compilation report, use: ADA398789

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP011730 thru ADP011799
A Broadband Low Noise Heterodyne Receiver at 2.5 THz
K. Huber, H. Brand, L.-P. Schmidt

Abstract—A 2.5 THz low noise heterodyne receiver with an IF bandwidth of about 7 GHz operating at room temperature is presented. Its main component is an open structure Schottky diode mixer with a substrateless Schottky diode designed and fabricated at the IHFT Darmstadt. The weak IF-signals are amplified by a noise-matched IF-amplifier in a frequency range from 6 to 13 GHz, covering the emission lines of several important molecules involved in the stratospheric ozone chemistry. The local oscillator signal (provided by a CO₂-laser-pumped methanol FIR-laser) is fed to the mixer together with the received signals via a Fabry-Perot type diplexer, which allows for significantly reduced signal loss compared to commonly used Martin-Puplett diplexers especially at the band edges. System noise temperatures as low as 16000 K (DSB) have been achieved up to the moment.

I. INTRODUCTION

The 2.5 THz heterodyne receiver setup is depicted schematically in Fig. 1. It consists of a local oscillator subsystem, quasi-optical circuitry for calibration and diplexing and an open structure Schottky mixer combined with a noise matched IF-amplifier.

The local oscillator laser described previously [1] is capable of delivering a maximum output power of about 50 mW at 2522.8 GHz when powered by a 20 W CO₂-laser beam (λ ≈ 9 μm).

K. Huber, H. Brand and L.-P. Schmidt are with the Lehrstuhl für Hochfrequenztechnik, Universität Erlangen-Nürnberg, Cauerstr. 9, D-91058 Erlangen

The main objectives of the radiometer are broadband imaging radiometry as well as spectroscopy of molecules involved in the stratospheric ozone chemistry. Both areas of application mentioned above benefit from a large IF-bandwidth, by a shorter measurement time in the broadband case and by a larger amount of specific emissions detectable in the spectroscopy application (for example OH, H₂O and O₃).

Thus, special care has been taken on broadband noise match of the first amplifier as well as on broadband operation of the diplexer.

II. DIPLEXER

Fig. 2 shows a photograph of the Fabry-Perot diplexer. It consists of two total reflectors, one of them being a refocusing mirror, and two partial reflectors. As most of the dielectric materials commonly used as beamsplitters in millimeter wave systems are quite lossy at 2.5 THz, wire grids have been used as partially reflecting mirrors. The tungsten wires have a diameter of 10 μm and a grid spacing of 50 μm and were fabricated at the mechanical workshop of the "Lehrstuhl für Hochfrequenztechnik" (LHFT).

The free spectral range (FSR) of the diplexer has been chosen to be approximately 1.88 GHz, thus the receiver IF bandwidth limited by the mixer-amplifier chain is split
into four subbands with center frequencies of 6.6, 8.4, 10.3 and 12.2 GHz, covering the emission spectra of various molecules involved in the stratospheric ozone chemistry [2]. For continuous covering of the entire receiver band, as desirable in broadband radiometry applications, the FSR of the Fabry-Perot would have to be increased (i.e. the dimensions of the diplexer have to be decreased) or a Martin-Puplett type diplexer must be used.

The LO-path loss has been measured to be about 4 dB whereas the signal-path loss is only about 0.5 dB. These values are slightly worse than predicted by theory, which is assumed to be due to the preceding transformation of the LO-beam and the resulting beam distortions and due to non-ideal adjustment of the diplexer.

III. MIXER-AMPLIFIER COMBINATION

At frequencies in the Terahertz or far infrared (FIR) regime the junction capacitance of mixer diodes has to be kept well below 1 fF in order to provide a good conversion efficiency. This means anode diameters of 0.5 μm or even less have to be realized. As the bias current necessary for optimum conversion is not affected by the diode area, the current density inside the junction rises with decreasing anode diameters and reaches values of several thousand A/mm². Measurements of the noise contribution of small area Schottky diodes have proven that the available noise power of forward biased diodes exceeds the value predicted by the classical formula by far [3]. The so called excess noise is assumed to be mainly due to hot electrons and interfacial traps [4].

Fig. 3 shows the noise temperature of a 0.5 μm substrateless Schottky diode compared with the noise temperatures of an ideal Schottky diode without series resistance and with a series resistance of 30 Ω, respectively.

Based on the measurement results, a modified model for the Schottky diode according to Fig. 4 has been derived and implemented in a harmonic balance simulation of the mixer (with HP microwave design system). In the equivalent circuit $Z_S$ is the complex impedance of the diode substrate, $C_J$ is the bias dependent capacitance and $R_J$ the dynamic resistance of the junction. The noise sources $u_S$, $u_h$, $i_T$ and $i_N$ represent the thermal noise of the series resistance, the hot electron noise, the shot noise and the trap noise, respectively. The values of the unknown quantities $u_h$ and $i_T$ have been derived by least squares fits of various noise power measurements of substrateless diodes with anode diameters of 0.5μm and epi-layer doping concentrations of $3 \cdot 10^{17}$ cm⁻³.

It has been found, that the optimum diode bias current ranges between 150 μA and 300 μA depending on both the available LO power and the diode noise parameters.

The mixer diode, a substrateless Schottky diode fabricated by the IHFT in Darmstadt, has been soldered directly to the mixer block. The 4λ antenna is connected to the amplifier via a 90° bend and a 1.5 mm horizontal wire section (see Fig. 5).

The resulting IF path of this configuration is extremely short and thus eases a broadband noise match of diode and amplifier.

![Fig. 4. Modified equivalent circuit of the Schottky diode](image)

![Fig. 3. Measured noise temperatures of an 0.5 μm substrateless Schottky diode compared to the noise temperature of an ideal Schottky diode without and with a series resistance of 30 Ω, respectively](image)

![Fig. 5. SEM photographs of a contacted diode](image)
In Fig. 6, the equivalent circuit of the diode including the whisker antenna at IF frequencies is depicted. The element values are:

- diode and whisker series resistance $R_s = 30 \Omega$
- junction resistance at optimum operating point $r_j = 300 \Omega$
- whisker inductance $L_{w} = 1.5 \text{ nH}$

As the resulting IF-impedance of the whiskered diode is far from a value of 50 Ω, the noise contribution of commercially available 50 Ω amplifiers exceeds the value given in their datasheets when connected directly to the mixer. Instead of adding a passive IF-transformer between the mixer and a commercial 50 Ω amplifier, a noise-matched, two stage, uncooled HEMT-amplifier with FHX45X chips (Fujitsu) with an integrated bias supply for the mixer diode has been designed. Fig. 7 shows a photograph of the mixer-amplifier combination with the adjustable rooftop of the mixer’s corner cube antenna and the integrated bias supply circuit.

In Fig. 8 the simulated and measured effective noise temperatures of the amplifier are shown. As it is difficult to measure the noise figure of the amplifier connected to the mixer, the amplifier noise for a source impedance $r_s$ of 50 Ω has been simulated and compared to the measured values for this source impedance. The simulation of the actual noise temperatures of the amplifier connected to a source with $r_s = r_{IF}$ indicates values of about 100 K within a frequency range of 6 to 12.5 GHz.

IV. SYSTEM PERFORMANCE

In Fig. 9 the measurement setup for the determination of the DSB noise temperature of the system is displayed. The LO passes a variable attenuator and the Fabry-Perot diplexer and is then focused on the corner cube antenna of the mixer. The signal path is continuously switched between a hot and a cold load, the resulting IF-signal is then amplified, filtered and rectified by a diode detector. From the ratio between dc voltage $V_d$ and ac voltage $V$ and the corrected effective noise temperatures of the hot and cold load at 2.5 THz ($T'_h$, $T'_c$) the system noise temperature is calculated.

$$T_{sys} = (T'_h - T'_c) \cdot \frac{V_d}{2 \cdot V} - \frac{T'_h + T'_c}{2}$$  \hspace{1cm} (1)
ture mixer with a substrateless Schottky diode and a noise matched HEMT amplifier with an effective noise temperature as low as 100 K.

Diode improvement as well as optimization of the passive receiver components will certainly lead to a further decrease in system noise temperature.

ACKNOWLEDGMENTS

The authors would like to thank the technical staff of the LHFT for the fast and precise fabrication of mechanical components. The authors would also like to express their thanks to Dr. Chih-I Lin and the other members of the "Institut für Hochfrequenztechnik" of the Technical University of Darmstadt for supplying Terahertz Schottky diodes [5].

REFERENCES


V. CONCLUSIONS

A 2.5 THz heterodyne receiver with a large IF bandwidth and a system noise temperature of 16000 K (DSB) has been presented. Key to the low noise operation at room temperature is the combination of an open struc-