A Low-Noise 2.5 THz Heterodyne Receiver with Tunable Reflector Antenna for Atmospheric OH–Spectroscopy

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ABSTRACT

For atmospheric research reliable low–noise receivers are necessary. In this paper we present a novel low–noise heterodyne receiver for 2.5 THz. A Schottky diode, the mixer key element, is embedded in a planar structure for optimized coupling to a low–noise broadband amplifier. The corner cube antenna can be tuned for optimal coupling to the local oscillator.

INTRODUCTION

From the global climate change arises the demand for a better understanding of the atmospheric chemistry. One of the key molecules in the atmospheric chemistry is the hydroxyl radical OH. This molecule can be detected due to its thermal radiation by remote sensing techniques in the terahertz range. The DLR operates the only airborne 2.5 THz heterodyne receiver for atmospheric research [1]. This receiver uses a GaAs–Schottky diode in an open structure corner cube.

Hot electron bolometers [2] and SIS–junctions [3] have previously been reported as new mixing elements for terahertz heterodyne systems. These mixing elements require low local oscillator (LO) power of approximately a few μW, but the necessary cooling with liquid helium is a technological effort. Our Schottky diode receiver works at room temperature, but LO power of approximately 5 mW is needed.

Until now the antenna performance was often poor, because a precise adjustment of the antenna characteristics was not possible. Furthermore, a liquid nitrogen cooled amplifier was necessary in the IF chain. With this receiver we achieved a noise temperature of 16,000 K.

To overcome these drawbacks we developed a new receiver. In this new design a low–noise HEMT amplifier working at room temperature is integrated in the mixer. The amplifier is noise matched to the diode. Furthermore, a new antenna assembly was built, which allows tuning of the far–field pattern.

The principle setup of the heterodyne system is shown in Fig. 1. The thermal radiation of the OH molecules (f = 2514.3 GHz; λ = 118 mm) is coupled into the aircraft through a special window. A

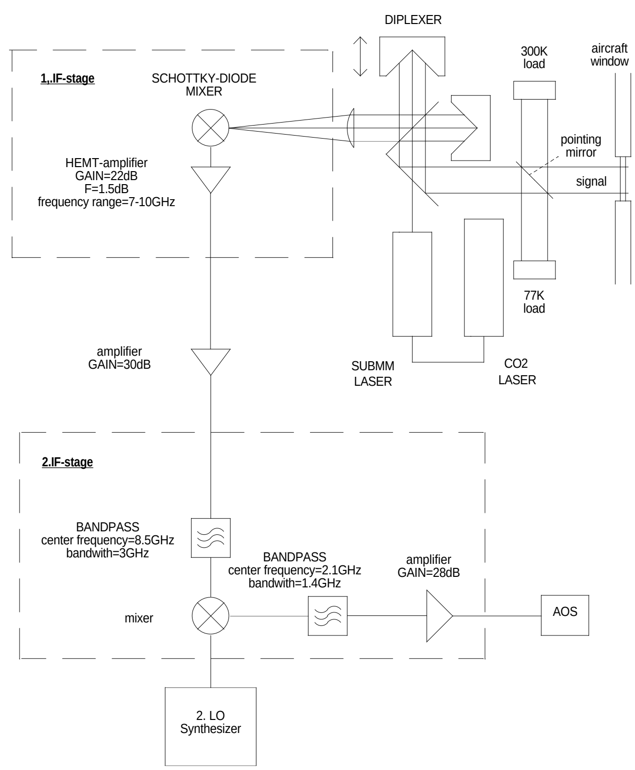

Figure 1: 2.5 THz heterodyne system.

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pointing mirror is used to calibrate on a hot and cold load. In a Martin–Puplett–interferometer, which is used in this application as a diplexer, the signal of the molecules is superposed by the LO. A CO_2–laser pumped FIR–ringlaser (*f* = 2522.8 GHz) is used as a LO with an output power of about 7 mW. An off–axis parabolic mirror focuses the superposed beams on the antenna of the mixer. The mixing element is a GaAs Schottky diode manufactured by the University of Virginia, Charlottesville. The diode is a honeycomb structure with an anode diameter of about 250 nm. The IF is 8.5 GHz with a bandwidth of 3 GHz. The second mixer matches the output frequency of the first stage to the acousto–optical spectrometer(AOS). The investigated bandwidth around the center frequency of the AOS is about 1.4 GHz.

OPEN STRUCTURE CORNER CUBE ANTENNA

The principal geometry is illustrated in Fig. 2. The diode is contacted with a thin AuNi wire (diameter 25 μm). This whisker forms a traveling wave antenna with a length *L* of about $4\,\lambda$. At the top of the antenna the wire is bent for a low reflection termination of the line. This bend forms one corner of an U–loop in the wire. This loop works as a spring that keeps the wire electrically contacted to the diode. The U–loop slides on one side of the reflector to ensure an electrical contact to ground. This contact is necessary for the IF performance. The reflector can be moved to tune the spacing *d* to the wire. For a $4\,\lambda$–antenna the optimal spacing is $1.2\,\lambda$ (d = 141 μm).

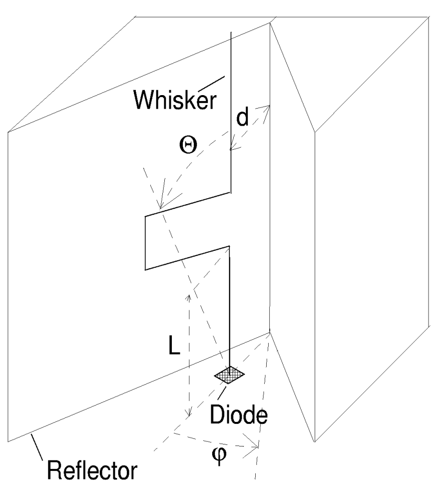

Figure 2: Corner cube antenna with whisker.

In order to characterize the shape of the main lobe the far field patterns have been measured and calculated (Fig. 3 and Fig. 4, respectively). Furthermore, the sensitivity of the antenna performance to the spacing *d* is shown in Fig 5. We observe a good agreement between measurement and calculation. The spacing of the reflector to the wire is very sensitive. In the classical corner cube antenna for submillimeter applications the whisker has to be clamped in a gap of the reflector [4] without the possibility to adjust this critical parameter *d*. Contacting and correct spacing of the wire was more or less a random process. The influence of *d* to the shape of the main lobe of the antenna is shown in Fig. 5. In this case the reflector is mismatched by about 30 μm. Now, no unique main lobe is observed.

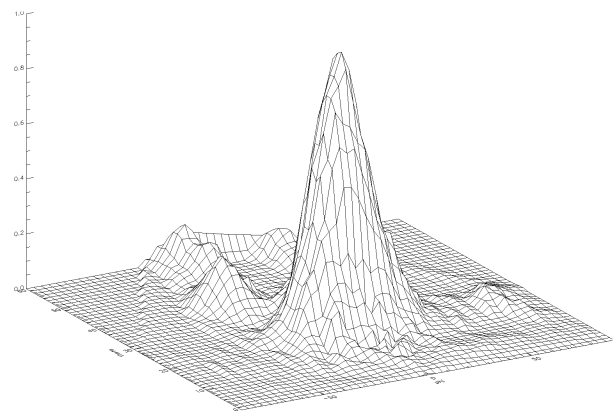

Figure 3: Measured far field (normalized power density vs. θ and φ) of the antenna for optimum *d.*

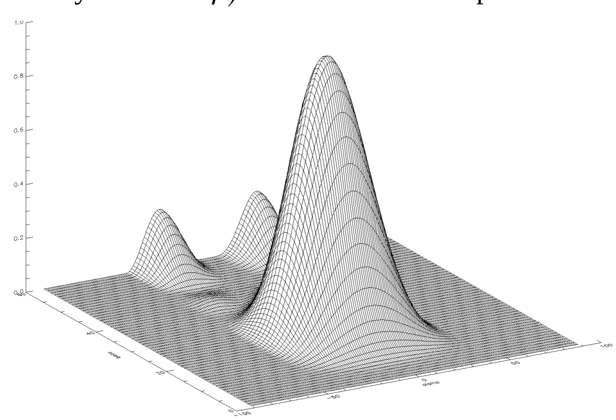

Figure 4: Calculated far field of the antenna for optimum *d.*

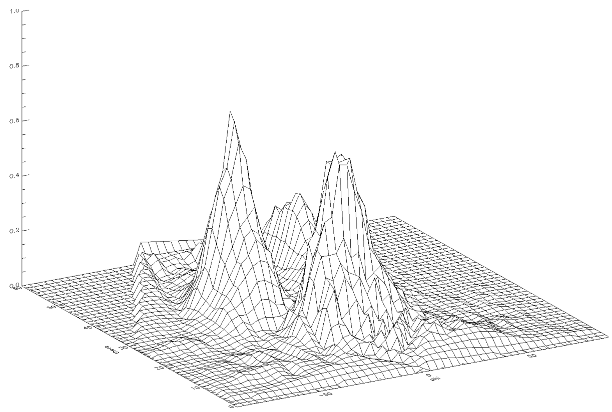

Figure 5: Measured far field of the antenna for a *d*–mismatch of 30 μm.

INTEGRATED HEMT AMPLIFIER

Until now a liquid nitrogen cooled IF amplifier was used. The former mixer was connected with this amplifier by a semi rigid cable. Due to the losses between the mixer and the amplifier the noise figure increased. In order to improve the noise performance of the new design a special amplifier in microstrip technique has been developed. The amplifier consists of two stages and includes the bias network for the diode. The first stage of the amplifier has been optimized for optimum noise figure and the second stage for maximum gain. The amplifier works at room temperature and is mounted at the back side of the diode carrier. The short electrical path between the diode and the amplifier allows a broadband noise matching [5,6,7]. This improvement decreased the system noise temperature by 25 %. The measured and calculated gain are shown in Fig. 6. The measured noise figure is about 1.5 dB within the IF band from 7 GHz to 10 GHz.

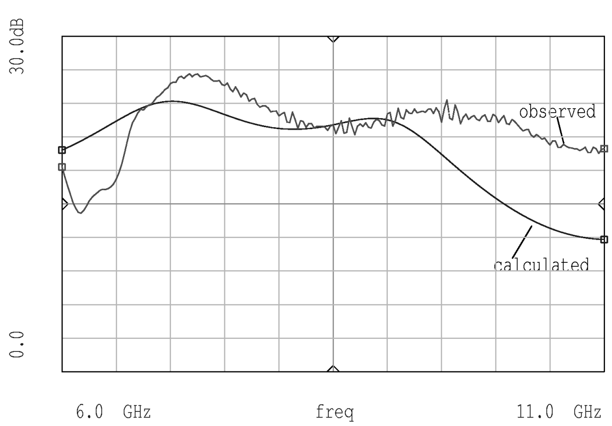

Figure 6: Gain of the integrated amplifier.

2.5 THZ RECEIVER

The spacing between the rooftop reflector and the whisker can be adjusted by a micrometer. Another micrometer on top of the corner cube controls the distance between whisker tip and anode of the Schottky diode. Below the antenna and mixer assembly the low–noise IF amplifier is mounted within a brass shielding box. The output signal of the amplifier is provided at a SMA connector.

The noise temperature of the receiver was measured using 77 K and 300 K black bodies at the input of the diplexer. We determined a noise temperature of 12,000 K in the laboratory with no correction for the humidity.

The new receiver design has been successfully tested under flight conditions during the Shuttle/MAHRSI campaign (**M**iddle **A**tmosphere **H**igh **R**esolution **S**pectrograph **I**nvestigation). An OH–spectrum measured at an altitude of 42,500 feet is given in Fig. 7. The characteristic OH–peaks can clearly be identified and quantitatively evaluated (integration period: 1 h).

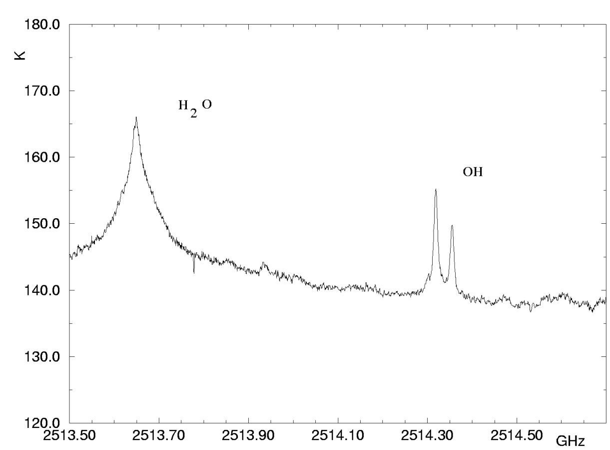

Figure 7: In-flight measurement of the FIR–spectrum at an altitude of 42,500 feet.

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CONCLUSION

A new 2.5 THz open structure corner cube design has been developed. The new amplifier needs no cooling with liquid nitrogen. The noise temperature of the receiver has been decreased to 12,000 K. The antenna can be tuned to optimize the coupling to the radiation source. The new design results in a compact device, consisting of antenna, mixer and low–noise broadband IF amplifier. The receiver has been successfully tested during the Shuttle/MAHRSI campaign.

REFERENCES

[1] R.U. Titz, M. Birk, D. Hausamann, R. Nitsche, F. Schreier, J. Urban, H. Küllmann, and H.P. Röser, „Observation of stratospheric OH at 2.5 THz with an airborne heterodyne system,“ *Infrared Physics*, vol. 36, pp. 883–891, 1995.

[2] W. McGrath, „Hot-electron bolometer mixers for submillimeter wavelengths: An overview of recent developments,“ *6th Int. Symposium on Space Terahertz Technology*, Mar. 1995.

[3] J. Mees, S. Crewell, H. Nett, G. de Lange, H. van de Stadt, J.J. Kuipers, and R.A. Panhuyzen, „ASUR – An airborne SIS receiver for atmospheric measurements of trace gases at 625 GHz to 760 GHz,“ *IEEE Trans. Microw. Theory Tech.*, vol. 43, pp. 2543–2548, 1995.

[4] H.P. Röser, „Heterodyne spectroscopy for submillimeter and far infrared wavelength from 100 μm to 500 μm, *Infrared Physics*, vol. 32, pp. 385–407, 1991.

[5] R.G. Nitsche, R.U. Titz, and E.M. Biebl, „Quasi–planar Schottky diode design,“ *7th Int. Symp. on Space Terahertz Techn.*, (Charlottesville, VA), pp. 488–493, Mar. 1996.

[6] R.G. Nitsche, R.U. Titz, and E.M. Biebl, „Open structure corner cube mixer with planar integrated diode and amplifier,“ *5th Int. Workshop on Terahertz Electronics*, (Erlangen, Germany), Paper 8–1, Sep. 1996.

[7] R.G. Nitsche, R.U. Titz, and E.M. Biebl}, „Open structure corner cube mixer with movable roof–top reflector, planar integrated diode, and low–noise amplifier,“ *6th Int. Workshop on Terahertz Electronics*, (Grenoble, France), Sep. 1997.