A 110 GHz OZONE RADIOMETER WITH A CRYOGENICALLY COOLED PLANAR SCHOTTKY MIXER

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Abstract– **A total power radiometer is presented for monitoring of stratospheric ozone spectral line at 110 GHz. Special features, such as a cooled planar Schottky mixer as the front end and efficient reduction of standing waves in the quasi-optics, shall be discussed in detail. The noise temperature of the receiver is 500 K (SSB), and total bandwidth of the receiver is 1 GHz. A dual acousto-optical spectrometer is used for the signal detection.**

I Introduction

Ozone has many strong spectral lines in the millimeter-wave region, of which the line at 110.836 GHz has been selected to be monitored with the radiometer at Helsinki University of Technology. This spectral line is strong, which makes it rather easy to detect.The receiver technology at W-band is also well established. On the other hand, the spectral line lies on the side wing of a very strong oxygen absorption line at 118 GHz that causes both attenuation and a strong tropospheric baseline to the measurement. The main component in tropospheric attenuation, however, is atmospheric water, which dominates at low altitudes. Water absorption increases with frequency, making the spectral lines at high frequencies impossible to be measured at low altitude measurement sites.

The receiver is a total power radiometer using internal calibration sources. The drifts in the receiver, detected with Allan-variance measurements, restrict the measurement cycle to max. 6-7 seconds. During one cycle hot and cold calibration loads and the sky are measured equal times.

The calibration is made for each channel separately, which means that the noise temperatures of the loads have to be accurately known as a function of frequency. Therefore the suppression of the standing waves is of utmost importance in order to get valid results, as will be seen later. Fig. 1 shows the block diagram of the receiver.

II Receiver

Quasi-optics

The quasi-optical unit does SSB filtering as well as directs the beam to calibration loads and to the sky. The mirrors are offset ellipsoids, and a Mach-Zehnder interferometer is used as the SSB filter to filter out the unwanted lower sideband. A quarter-wave matched teflon lens focuses the beam to the feed horn. The measured losses along the path between the feed horn and the cold calibration source are less than 0.1 dB. The elevation angle of the main mirror is adjustable and can be set by the operator in the beginning of a measurement.

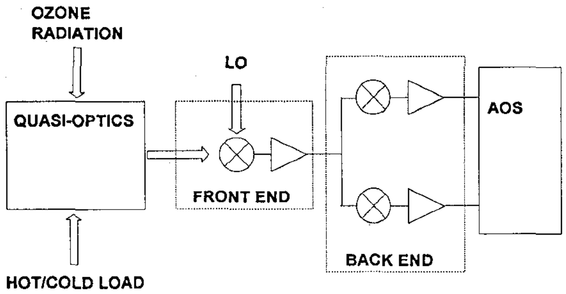

Fig. 1: Block diagram of the receiver.

Front end

The front end of the receiver consists of a dual mode horn antenna, a ring filter for LO power injection, a planar Schottky mixer and a LNA. All these components are cooled to 20 K with a closed cycle helium cooler. The measured cross-polarization level of the feed horn is -23 dB, which is sufficient for the application. The local oscillator is a phase-locked Gunn oscillator emitting +8 dBm at 107.636 GHz. One of the advantages of choosing the 110 GHz spectral line is that sufficiently high LO power is available from solid state devices without multipliers. The LNA is a 3-stage HEMT-amplifier, which has 10 K noise temperature at 3.0–4.2 GHz and at 20 K physical tamperature.

Schottky mixer

The mixer block, shown in Fig. 2, is based on WR-10 waveguide, and has total dimensions of 20 × 20 × 65 mm. The block is divided into two parts through the center of the wide waveguide wall. The input waveguide is tapered to $\frac{1}{4}$ height to match the diode pair. The diodes are mounted between the parts of the mixer block. The IF output of the diodes is matched to 50 Ω by properly chosen reactive elements, shown also in Fig. 2. The IF bandwidth of the mixer is 1 GHz, the center frequency being 3.6 GHz. A non-contacting backshort which consists of two pairs of high- and low-impedance sections isolated by thin (20 μm) mylar tape is used in this mixer. A contacting backshort was also tested and provides the same total performance of the mixer. The characteristics of the commercially available beam-lead planar diodes used in the mixer are given in Table 1.

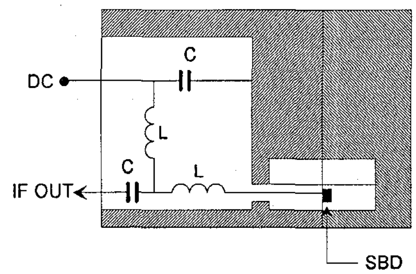

Fig. 2: Schottky mixer.

The best diodes for cooling were selected by measuring a number of points of the diodes' I-V-curves and calculating R_S, η, N_C and T for the cooled diode, as described in [1].

Table 1: Characteristics of the planar Schottky diodes.

f_c (THz)	R_S (Ω)	C_{tot} (fF)	C_j (fF)	η	N_C (cm^{-3})
2.8	6	20	7	1.12	8×10^{16}

Back end

The first IF is split and mixed into two channels for the acousto-optical spectrometer. The center frequencies of the channels are 2.0 GHz and 75 MHz.

The signal is detected by a dual acousto-optical spectrometer [2]. The broad-band unit measures 128 channels over the total 1 GHz bandwidth, while the narrow-band unit measures 1024 channels over a 50 MHz band around the center frequency.

Noise temperature

The noise temperature of the receiver was measured with Y-factor method using an absorber in ambient temperature and in liquid nitrogen. The characteristics of the receiver were calculated as described in [3].

The measured DSB noise temperature of the receiver is 230 K, and the SSB noise temperature is 530 K with a 60 K cryogenic image sideband termination. The conversion loss of the mixer is 7.2 dB.

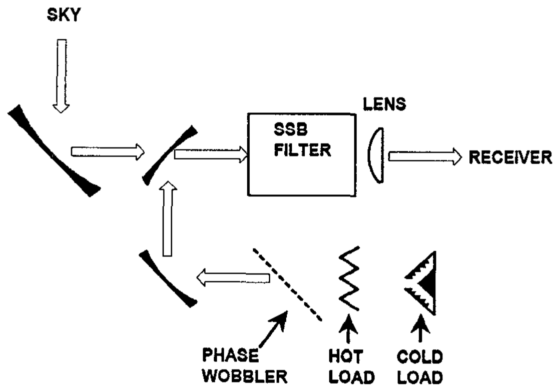

Fig. 3: Quasi-optical unit of the receiver.

III Calibration

The quasi-optical unit and the calibration sources are presented in Fig. 3. The radiometer uses internal hot and cold loads for calibration. The hot load is a room temperature Eccosorb WG-4 foam absorber. To detect the standing waves caused by the hot load a comparison measurement was made using the ozone radiometer with a randomly moving absorber as the hot calibration source and the radiometer's hot load as the measurement target. The random movement eliminates the standing wave caused by the calibration source at long integration times, and so the measured standing wave is due only to the radiometer's hot load. The ± 0.6 K standing wave is too high and has to be reduced with methods described later.

The cold calibration source is designed to efficiently block the incoming infrared radiation. If the blocking is not good, the surface of the absorber is heated and the noise temperature is different from the temperature of the cold plate. The cold load designed at HUT has been measured to have broad band noise temperature equal to its physical temperature within the measurement accuracy, which means that infrared radiation is blocked excellently. The reflection level of the cold load has been measured with HP 8510C network analyzer to be -27 dB. A rooftop metal structure painted with Eccosorb 269E absorber coating is used to cause multiple reflections to the incoming wave. The absorber is added in a thin layer on the metal, and so it has high reflection level. This causes the overall reflection level to become high enough to cause clearly observable standing wave in ozone measurement. A similar measurement as for the hot load was not made for the cold load because of lack of a reflectionless comparison load. According to network analyzer measurements at room temperature the cold load has 2 dB higher reflection level than the hot calibration load.

The standing waves seen in the results are caused by reflections between the calibration loads and the teflon lens. The standing waves can be efficiently reduced by adding a differential phase shift of 180° to the quasi-optical path for half of the measurement time. Adding a rotating dielectric plate to the gaussian beam causes the desired effect [4]. This is used in the HUT ozone radiometer. The material of the plate is teflon, which has negligible losses and rather low dielectric constant. The plate is in Brewster angle to avoid reflections, and it is moved into the beam every second measurement cycle. Rapid rotating of the plate was also tested, but excess reflections caused by the edges of the plate were detected. The plate is made with an accurate milling machine using a special kind of a vacuum mount plate. The accuracy of the thickness of the plate is ± 10 μm. The measurement of the hot load was repeated with the phase shifter. With the phase wobbler the hot calibration load is accurate within ± 0.1 K. The standing wave has reduced by 8 dB. A small standing wave is still observable, and it is due to the inaccuracy of the phase wobbler's angle.

The measurement error due to the standing waves of the calibration loads is 0.1 K for one channel, and it reduces to less than 0.05 K when the channels are averaged to obtain exponentially broadened channels for the inversion routine. The error caused by nonlinearity of the receiver is negligible. The resulting total error of 0.05 K allows measurements when the zenith tropospheric noise temperature is less than 170 K (usually heavily cloudy weather). The tropospheric attenuation determines the strength of the ozone

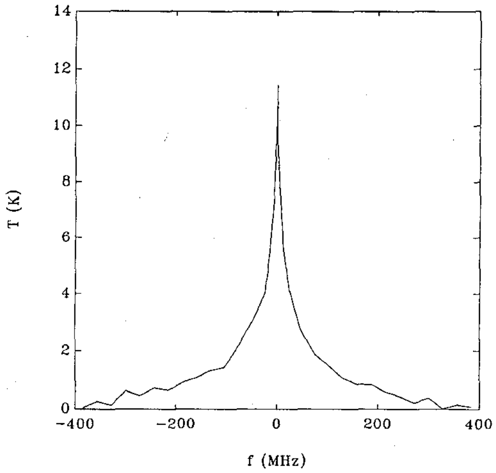

Fig. 4: Measured ozone spectral line.

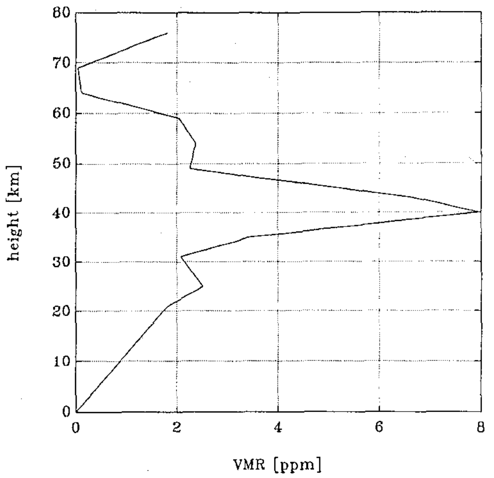

Fig. 5: Inverted vertical ozone profile.

spectral line at ground level and thus the maximum level of the systematic errors of the receiver.

IV Results

Fig. 4 shows a typical daytime measurement and a preliminary inverted vertical ozone profile is presented in Fig. 5. An integration time of 20 minutes was needed at clear and cold weather. A very fine spectral resolution is achieved around the peak of the ozone line.

V Conclusions

A radiometer has been built for continuous ground-based measurements of stratospheric ozone. Semi-operative ozone measurements with the receiver will be started at Helsinki Univ. of Technology March, 1993. With the achieved level of systematic errors, measurements can be made most days of year at the low-altitude measurement site.

References

[1] Bozhkov V. G., Kurkan K. I., Genneberg V. A., "Diodes for converters and integrated converters for 3-mm wavelength," *5 Celostatni Konference o Microluvne Technice.-MITECO 90. Sbornik Prepnasek-Dil 2* (Pardubice), pp. 89-97, 1990. (in Russian)

[2] Malkamäki L. J., "Actively stabilized acousto-optical spectrum analyzer," *Doctor Thesis, University of Helsinki*, Helsinki, 1990.

[3] Räisänen A. V., "Experimental studies on cooled millimeter wave mixers," *Acta Polytechnica Scandinavica*, Electrical Engineering Series, Nr. 46, 1980.

[4] Goldsmith P. F., Scoville N. Z., "Reduction of baseline ripple in millimeter radio spectra by quasi-optical phase modulation," *Astron. Astrophys.*, Vol. 82, pp. 337-339, 1980.