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Wide band (2.5 GHz) infrared heterodyne spectrometer

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1 Introduction

Infrared heterodyne spectrometers have been successfully used for astronomical and geophysical applications (Betz et al., 1976 ; Betz, 1981 ; Kostiuk, Mumma et al., 1976 ; Kostiuk, Hillman et Faris, 1981). The Reims GSMA laboratory has developed for several years high resolution heterodyne receivers for atmospheric ozone studies. The local oscillator was a CO₂ laser and the spectral range was about 1.5 GHz.

The development of a wider band heterodyne receiver has many advantages. First, it enables us to study lines which were out of range of the first apparatus. For the same reason, we use now either a ¹²C¹⁶O₂ or a ¹²C¹⁸O₂, laser as local oscillator. We also need this wide band spectrometer for recording ground-based atmospheric absorption spectra. For those spectra, the sun is used as a source and the absorption by the low altitude layers is very wide : because of the pressure broadening. In order to obtain the 100% transmission, we must record the whole line profile. A 2 GHz scan is, at least necessary to fulfill this condition.

2 Heterodyne spectrometer : description

In order to obtain a 2.5 GHz bandwidth, three main elements with this bandwidth must be associated :

- A fast photodiode which acts as an optical mixer
- Low noise, wide band amplifiers, in order to work at a sufficient level
- RF analysis and detection system.

A short description of these elements and of the data acquisitions System follows below.

2.1 Optical part

This part has been previously described, and so only a short description necessary for the understanding of this work will be given here (Thiébeaux et al., 1988 ; Courtois, Thiébeaux et Delahaigue, 1984). The beams of the local oscillator and of two thermal sources are focused onto a photodiode, which acts as an infrared mixer. The photodiode is one of the most important element of the spectrometer. The bandwidth of the apparatus is generally limited by the diode bandwidth. Therefore the choice of this element is particularly important. We use a reverse- biased, fast HgCdTe photodiode from S.A.T. (Société Anonyme de Télécommunications, France). This mixer is set in a down-looking special laboratory made Dewar. All connections are made by using as short as possible coaxial cables. It works at liquid nitrogen temperature_ The bandwidth is about 3 GHz for a bias between 1.3 and 2 Volts. Our set-up is a double beam heterodyne system. The two thermal beams are chopped at different frequencies. High precision mechanical choppers (EG&G model 197) are used. One of the beam is for reference and the other for measurement. Transmission is proportional to the ratio of the two signals. This technique suppresses low frequency drift of the spectrometer. For laboratory studies, an absorption cell is put on the second beam. For atmospheric studies, the measurement beam is obtained with a sun tracker (Delahaigue et al., 1988).

2.2 Radio frequency analysis

We first use two wide band and low noise preamplifiers which were specially studied for this experiment (Micronic - France). The first one has an incorporated bias tee. Their characteristics are :

- 70 dB total gain
- 2.5 dB noise

— 12.7 GHz bandwidth.

This amplification allows the analyzer to work at sufficient level. The analyzer is heterodyne type. It uses an RF mixer, a fixed filter and a local oscillator (see figure 1). The mixer works as following " for an input ν_{RF} frequency signal and a ν_{LO} frequency local oscillator signal, the output signal frequency is equal to $\nu_{IF} = \|\nu_{RF} - \nu_{LO}\|$. With a filter centered at f_{IF} , the analysis of the RF signal between 0 and f_{IF} is obtained by sweeping the local oscillator frequency from f_{IF} to $2 \times f_{IF}$. The resolution of the RF analyzer is then equal to the bandwidth B of the filter. The RF local oscillator is a Marconi 2042 synthesizer. It works between 10 kHz and 5.4GHz. Frequency and output level accuracies are widely sufficient for our experiment. The maximum frequency 5.4 GHz value leads to the choice of a 2.7 GHz filter. This synthesizer is completely controlled by a micro-computer via IEEE port. Several RF mixers were tested in order to obtain the best results. It was difficult to find a mixer which had sufficient bandwidth on the three ports (IF, RF, LO). We finally decided to use the Anzac MDC 154 (IF 0.1 - 3000 MHz, RF, LO 0.3- 5 GHz). The upper limit of the mixer on the LO port is slightly to low. The last part of the analyzer is composed of a selective amplifier centered at 2.7 GHz (Micronic) and a four sections cavity filter (Trilithic 2.7 GHz, 10 MHz). The detection of the RF signal is done by a RF diode Texscan CD51 operated in the square-law mode. This type of analyzer has several advantages. The apparatus function is well known and given by the filter response. The resolution is equal to the width of this response. With a 10 MHz filter, the resolution is at least 5 times lower than the Doppler line width of the studied molecules.

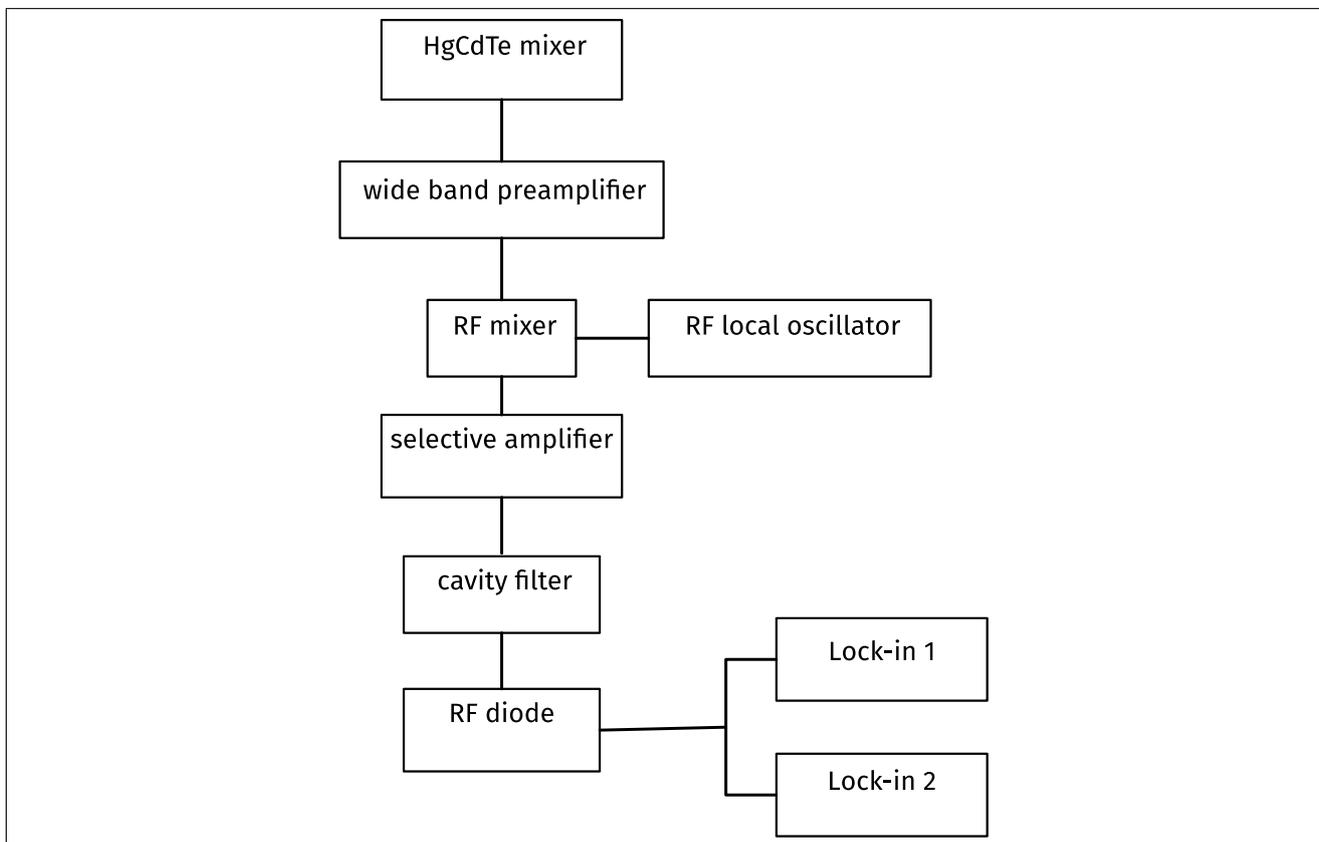


Figure 1 : Scheme of the RF analyzer

2.3 Data acquisition

The RF diode gives a signal proportional to the incident power on the of photodetector. We use two lock-in amplifiers (model EGG 5301) to discriminate the reference and measurement signals. Each one is adjusted on the modulation frequency of one of the thermal beams. The lock-in amplifiers are used with a time constant τ equal to 100 ms and a rolloff rate of 12 dB/Oct. The DC output signals between 0 and 10 volts are then digitized. In order to have high dynamic and high resolution, we use for each channel a voltage to frequency converter (0 - 10 Volts, 10 MHz) and a counter. The numerical integration is controlled by an accurate 4MHz quartz oscillator. The integration time is generally about 1 to 10 seconds. Pressure and temperature in the gas cell are simultaneously recorded. The laboratory developed software controls data acquisition and the local oscillator frequency. Parameters such as frequency step of the LO, number of steps, integration time are fixed with the computer. We can either record single spectra or accumulate them. The system speed is only limited

by file response time of the synthesizer which is IEEE controlled. The results of the measurements are directly visualized on the screen of the computer.

3 Results

3.1 Test of the photomixer

Many methods for measuring the bandwidth of a photodetector are available. The best known is the measure of the noise spectrum of the detector when it is illuminated by a laser. Another consists in recording the beat signal of a local oscillator beam and a frequency-shifted beam. The shifted beam is often obtained by using an acousto-optic modulator (Vérié et Sirieix, 1972). As tunable diode lasers emitting in the 10 μm region are available in our laboratory, we decided to use the TDL's beam as the frequency-shifted beam. In this case, the radiation of the CO_2 laser and of the TDL are superimposed on the HgCdTe photodiode.

The frequency of the signal is then equal to the difference between the CO_2 laser line frequency and the TDL frequency. For a fixed value of the injection current of the diode, the spectral width of this signal can be measured and is about 50 MHz. This value is negligible in comparison with the total bandwidth of the detector. The beat signal is recorded for different values of the diode frequency. This measurement gives a good description of the photomixer response. The two following conditions are required : the diode emission must be monomode and there must be no mode hop on an interval greater than the double of the bandwidth around the frequency of the CO_2 laser line. The diodes we use are PbSnSe diodes : working between 20 and 40 K. They are set in a closed-cycle helium cooler. The cooler and the current driver are from Mütek (Germany). The diode is operated in a multilongitudinal mode. A grating monochromator selects one mode. The frequency of the diode is swept around the CO_2 laser line frequency by tuning the injection current. The fringes of a spherical Fabry-Perot are simultaneously recorded so we could have a relative scale frequency versus injection current. The confocal etalon is a 25 cm one with an invar structure. It takes place in a vacuum cell and its sharpness is about 40 when illuminated by a well stabilized CO_2 laser. The free spectral range is 0.01 cm^{-1} . Measurements have been done near the 9P20 line of $^{12}\text{CO}_2$ laser (1046.85 cm^{-1}). Figure 2 shows an example of measurement. It has been obtained with the infrared mixer and the preamplifiers. The frequency scale is in megahertz and the signal scale is linear. The total width of the signal is approximately of 0.185 cm^{-1} . This value corresponds to a bandwidth of 2.7 MHz. The receiver's bandwidth is therefore limited by the amplifiers bandwidth. The peak is obtained when the diode frequency is close to the laser line frequency. It seems to be due to a peak response of the preamplifiers for low frequency ($< 50 \text{ MHz}$).

3.2 First spectra

In order to check this new apparatus, we decided to record an absorption line shifted from more than 2 GHz from the local oscillator. The Ammonia molecule seems to be a good choice for these tests. The research of coincidences between NH_3 and the CO_2 laser lines in the Hitran Database (Rothman et al., 1992) leads to only a few possibilities. We chose to record the NH_3 R(5,1) line near 9 μm (see Table 1). The line's center is shifted from - 2343 MHz from the 9P10 CO_2 laser line. As we need at least 200 MHz on both sides to record the whole line profile, this line is at the limit of the 2.5 GHz heterodyne receiver. We present in figure 3 one of the recorded spectra. It has been recorded with approximately 2 torrs of NH_3 and a path length of 1.60 meter. The characteristics are :

- 200 points
- 3 MHz steps
- 10 s for each point (total time : 35 min.).

The most important element we can see on this spectrum is that the line position is slightly different from the expected value. The line center is found at $- 2100 \text{ MHz} \pm 5 \text{ MHz}$ from the 9P10 CO_2 laser line. (Table 2). This value is coherent with previous measurements (Sasada et al., 1986).

4 Conclusion

A double beam heterodyne spectrometer with 2.5 GHz bandwidth was built in Reims. The receiver's bandwidth was measured by heterodyning radiation from a CO_2 laser with the radiation from a tunable diode laser. The

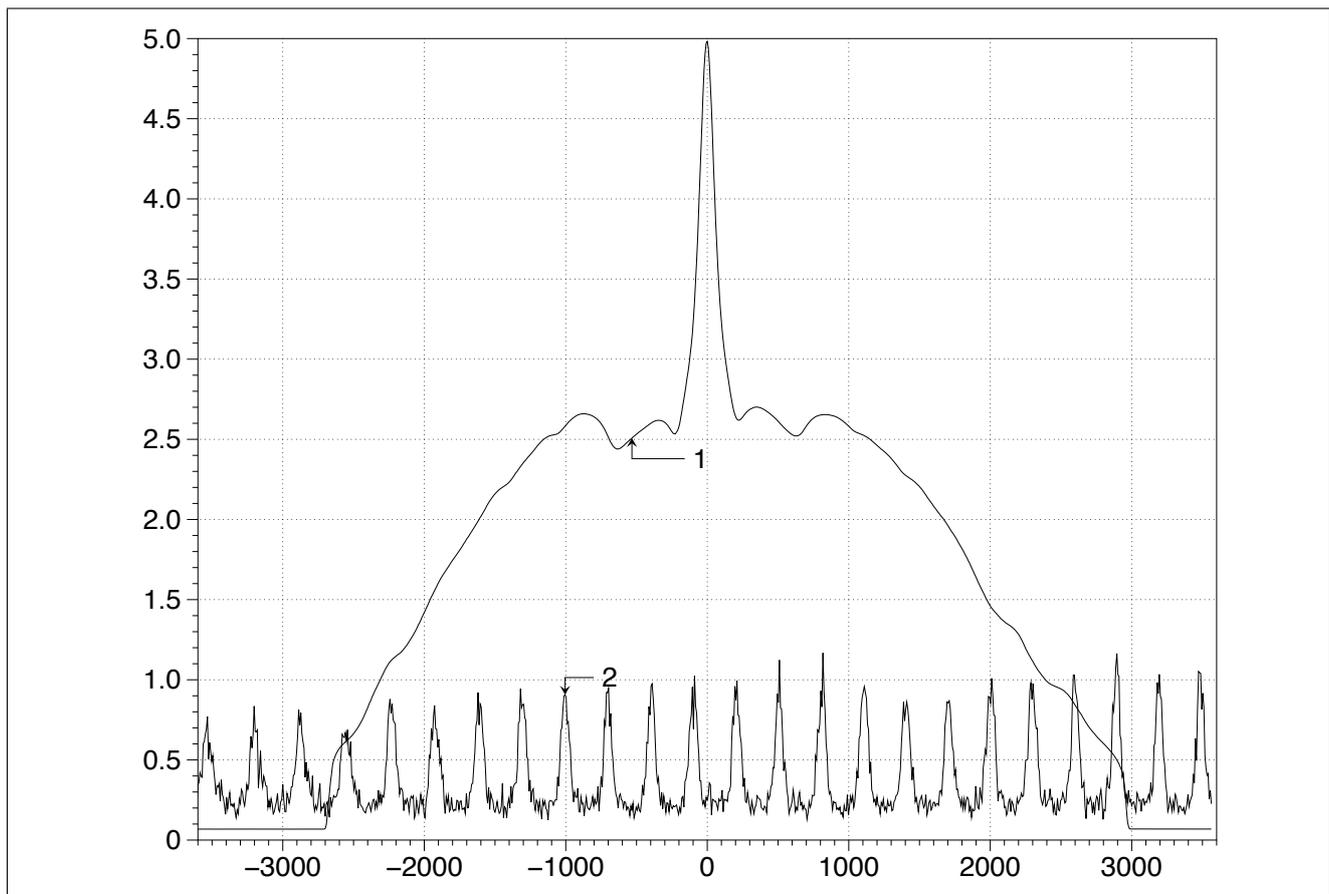
Figure 2 : 1 beat signal of the CO₂ laser and a TDL - 2 confocal etalon fringes

Table 1 – Position and intensity of the R(5,1) line of Ammonia (Hitran database 1992)

frequency (cm ⁻¹)	intensity (cm ⁻¹ /(molec · cm ⁻²))
1055.5470	9.33×10^{-22}

Table 2 – Position of the R (5 1) line of NH₃

Source	wave number (cm ⁻¹)	shift with the 9P10 line of CO ₂ (MHz)
(Rothman et al., 1992)	1055.5470	-2343
(Sasada et al., 1986)	1055.5540	-2130
This work	1055.5550	-2100

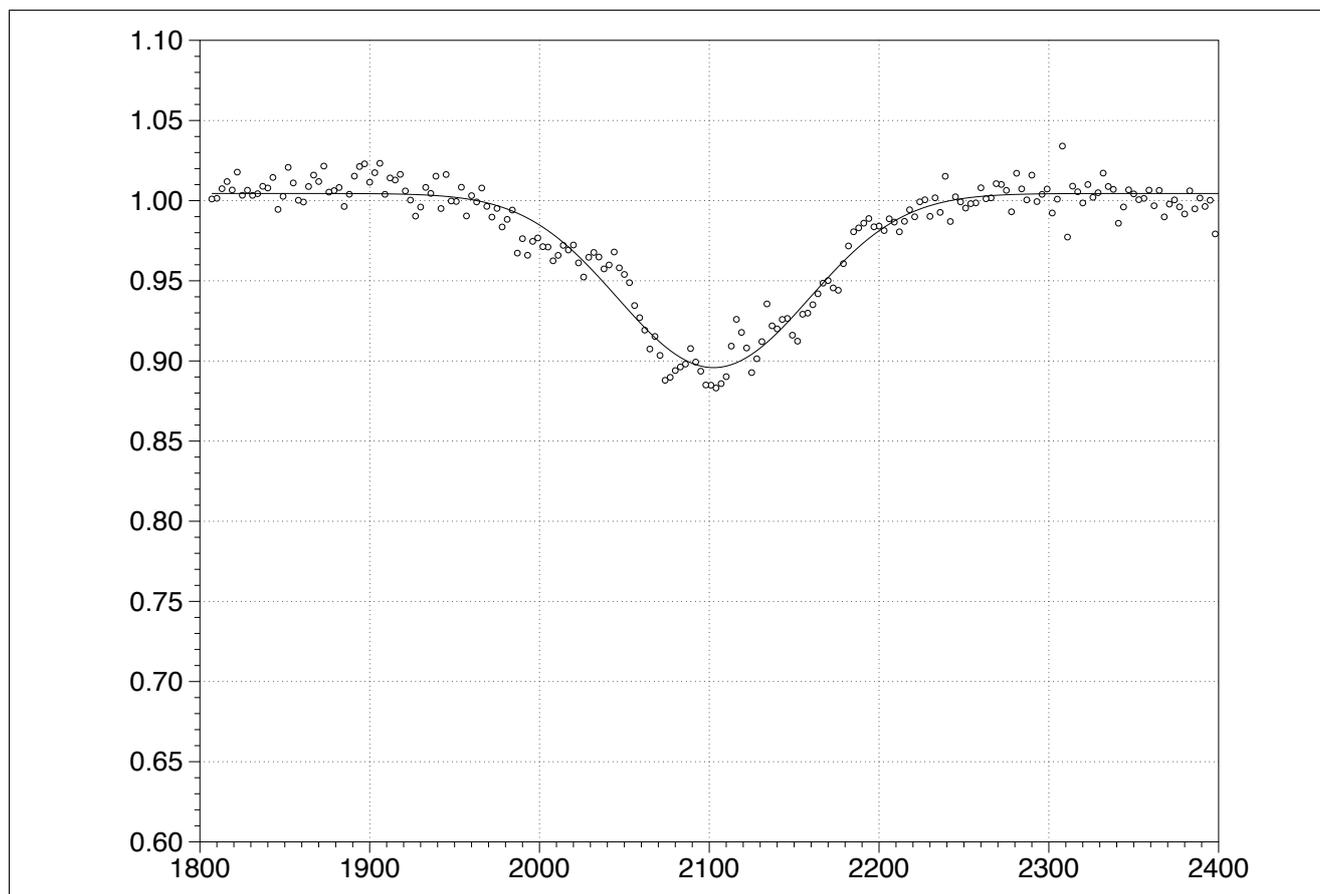


Figure 3 : Heterodyne spectrum of the R(5,1) Ammonia line

spectrometer was used for laboratory studies. Ammonia absorption spectra were recorded. Line positions in agreement with other works were measured. This apparatus will soon be used for atmospheric ozone studies in association with an isotopic $^{12}\text{C}^{18}\text{O}_2$ laser to avoid atmospheric CO_2 absorption.

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