MEASUREMENTS OF THE SINGLE SIDEBAND SUPPRESSION FOR A 650 GHZ HETERODYNE RECEIVER

$554-33$

160568

$P-7$

S. Crewell & H. Nett

N93-27780

Institute of Remote Sensing
University of Bremen, FB 1
P.O. Box 330440
D-2800 Bremen 33, FRG

ABSTRACT

A large number of atmospheric trace gases, involved in the process of stratospheric ozone depletion, show emission features in the submillimeter wavelength range ($\lambda = 0.1$-1mm). High-resolution heterodyne techniques are a particularly useful tool in this spectral region as vertical distribution of these species can be deduced. Here the receiver has to be operated in the single sideband (ssb) mode preferably to avoid any interferences between the contributions in both receiver sidebands. In the 625-655 GHz heterodyne receiver developed at the University of Bremen a Martin-Puplett interferometer is used as a ssb-filter. A laboratory set-up has been built up to measure the performance of this interferometer.

INTRODUCTION

Since the detection of stratospheric ozone depletion research activities have been focused on the study of upper atmospheric chemistry. In the catalytic reactions destroying the ozone the chlorine monoxide molecule is a key substance. Its influence in the chlorine and the nitrogen cycle leading to the "Antarctic ozone hole" is described in [1]. ClO and also many other chemically important molecules, for example HCl, N_2O, OClO, BrO.. , have emission lines in the submillimeter region [2].

To detect the weak thermal emission of these molecules low-noise heterodyne receivers can be used. They provide the possibility to observe the line shape of the molecules with a high spectral resolution allowing to derive the vertical VMR (volume-mixing-ratio) profiles from the pressure broadening of the line.

Due to the strong water vapor absorption in the troposphere submillimeter measurements of atmospheric trace gases have to be performed from high flying aircraft.

A 625-655 GHz heterodyne receiver for airborne operation, **SUMAS** (Submillimeter Atmospheric Sounder), has been developed at the University of Bremen in order to measure $ClO, HCl, O_3, N_2O....$ which all have transitions in this narrow frequency range.

Atmospheric measurements have been performed successfully on the research aircraft Falcon. The receiver has been further improved in a second project, SMS, with international participation funded by the ESA/ESTEC (*). The goal of this project was to develop spaceborne techniques for a submillimeter limb sounder and built up a demonstration model for airborne operation.

For atmospheric measurements it is desirable to operate the receiver in a ssb mode because emission lines, quite numerous in this frequency range, in the image band may interfere with the lines in the signal band. Due to the high ratio of radio frequency (r.f.) to intermediate frequency (i.f.) an external ssb-filter is preferable. In both radiometers a quasi-optical Martin-Puplett interferometer is used and the performance of this has to be verified over the bandwidth of interest.

In the following chapter the ssb transmission measurements for the HCl-frequency using the SUMAS radiometer will be discussed as an example .

Receiver Design

The SUMAS radiometer as illustrated in *Fig. 1* consists of a quasi-optical section (r.f.) and a two-stage i.f. secton. In the r.f. part all elements are realized with a quasi-optical design.
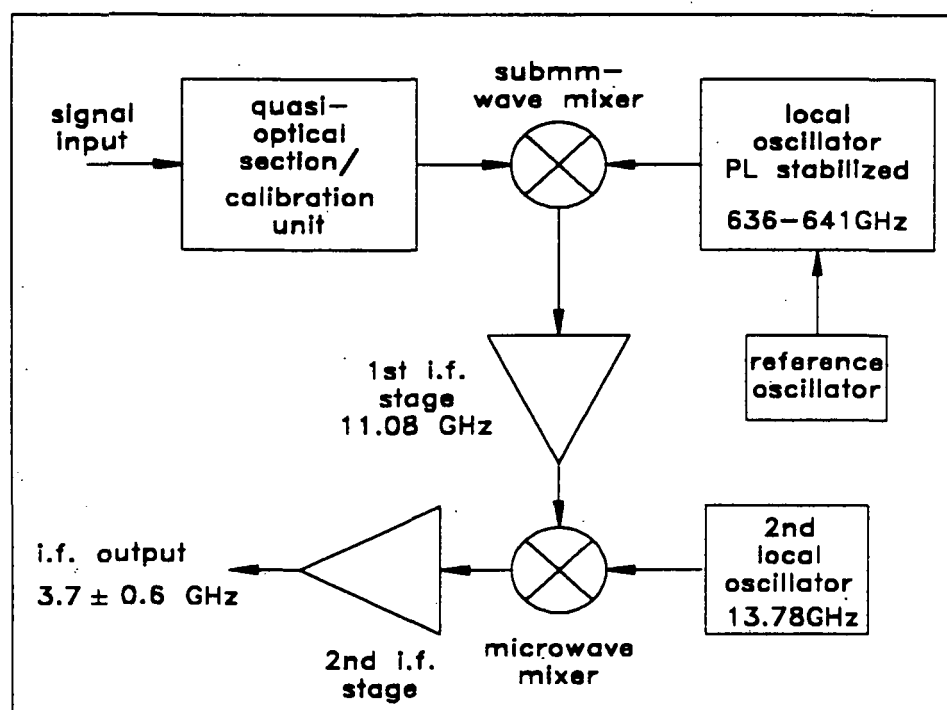

Fig. 1 : Block diagramm of the SUMAS radiometer

Total power calibration is performed; a phase wobbler is used to avoid standing waves; two cascaded Martin-Puplett interferometer serve for ssb-filtering and for diplexing of the local oscillator (L.O.) and signal radiation, respectively. The L.O. is tunable between 636-641 GHz and is phase-locked to a highly stable reference. The quasi-optical Schottky diode mixer operating at room temperature has a 3 λ whisker forming an approximately gaussian beam. In the 1st i.f. section at 11.08 GHz a low-noise HEMT cooled by liquid nitrogen acts as a preamplifier. After additional amplifing the signal is down converted by a microwave mixer to the second i.f. stage centered at 3.7 GHz. Here a post-amplifier and filter are used to provide an i.f. output with a power level of 0-5 dbm and a bandwidth of 1.2 GHz. A detailed description of the radiometer can be found in [3] and [4].

Single Sideband Filter

For a quasi-optical ssb-filter two main principles, dual-beam and multi-beam interferometer, exist. The Mach-Zehnder, an amplitude dividing interferometer, and the Martin-Puplett interferometer, a polarisation rotating device, are examples for a two-beam interferometer while the Fabry-Perot is the most common multi-beam interferometer (for additional informations see [5]). The Martin-Puplett interferometer was found well suited to meet our frequency requirements since it is easy to tune and to adjust. It consists basically of two rooftop mirrors and a 45° grid. In our radiometer design an aditionally first grid (90°) serves to define the vertical polarisation for our interferometer input and later to direct the unwanted sideband to an absorbing load. An incoming vertical polarized signal is splitted by the 45° grid in two beams with orthogonal polarisations, 45° and 135° respectively. Then the beams are reflected at the rooftop mirrors in a way that the polarisation rotates by 90°. Now the beam initially reflected by the 45° grid will be transmitted and the other beam vice versa. The superposition of both beams is given by their phase difference and therefore the power transmission is a function of the beams pathlength difference Δ an the wavelength λ :

$$P_{V->V} = 0.5 \, (1 + \cos(2\pi\Delta/\lambda)) \tag{1}$$

In order to measure HCl (f_{HCL}=625.912 GHz) the L.O. is adjusted to 636.992 GHz and the upper sideband frequency (f_{usb}=648.072 GHz) should be suppressed. If the interferometer should act as a ssb-filter P in (1) is required to be a maximum for the signal wavelength (Δ=$m\lambda_{HCL}$) and a minimum for the unwanted sideband (Δ=λ_{usb} (2n+1)/2). The pathlength difference can easy be tuned by a micrometer screw that translates one rooftop mirror while the other is fixed. Although the relative accuracy of the micrometer is good (Δx=2μm) an absolute calibration has to be performed for each wavelength. For this a signal corresponding to the frequency of interest is generated with the help of the experimental set-up described in the next chapter and coupled to the radiometer input. The
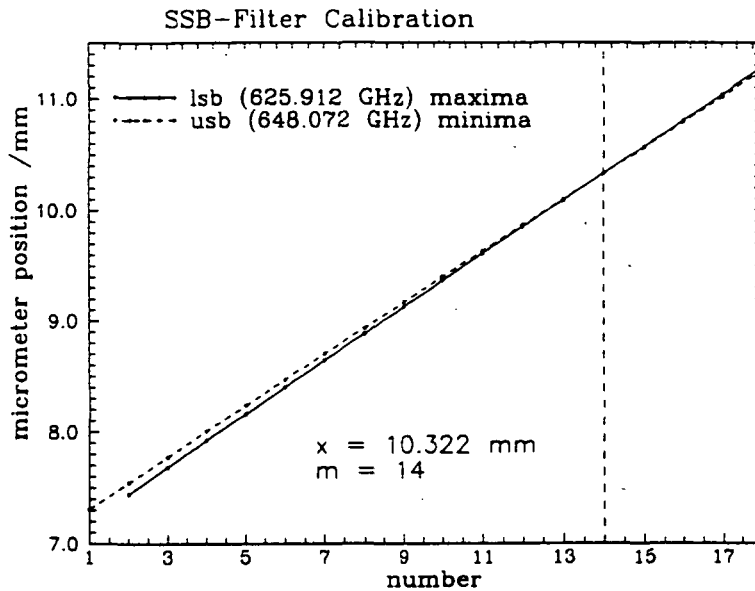
SSB−Filter Calibration

lsb (625.912 GHz) maxima
usb (648.072 GHz) minima

x = 10.322 mm
m = 14

micrometer position /mm

number

Fig. 2: Calibration curves for the ssb-filter

r.f. signal is detected by the radiometers submillimeter mixer and can be observed at the i.f. output with a spectrum analyzer or a powermeter. With this set-up the micrometer position for maximum and minimum transmission can be determined for each sideband. The results (*Fig.2*) show two straight lines, one for the maxima of f_{HCl} and the other for the minima of f_{usb}. Now the intersection of both curves give m=14 and Δ=6.706 mm, the micrometer position for the ssb mode. The theoretical transmission curves given by (1) with this micrometer settings yield a suppression of higher then 20 dB over the whole radiometer bandwidth for the upper sideband and negligible losses for the atmospheric signal (see *Fig.3*).
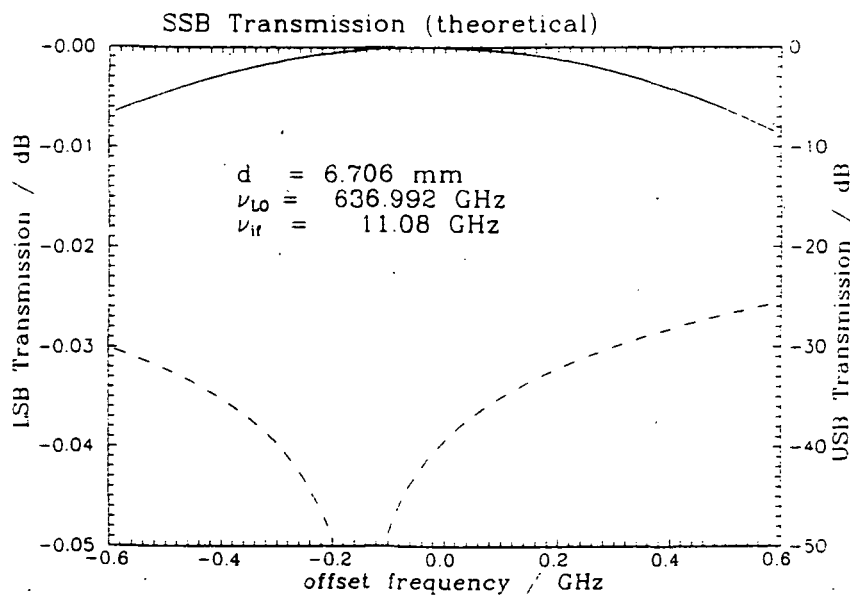
SSB Transmission (theoretical)

d = 6.706 mm
ν_{LO} = 636.992 GHz
ν_{if} = 11.08 GHz

LSB Transmission / dB

USB Transmission / dB

offset frequency / GHz

Fig. 3: Theoretical power transmission of the Martin-Puplett interferometer
solid curve : lower sideband (HCl) ; dashed curve : upper sideband

Experimental Setup

The experimental set-up (*Fig. 4*) used to measure the ssb-filter characteristic consists of three parts : a source generating the coherent submillimeter signal, the whole radiometer
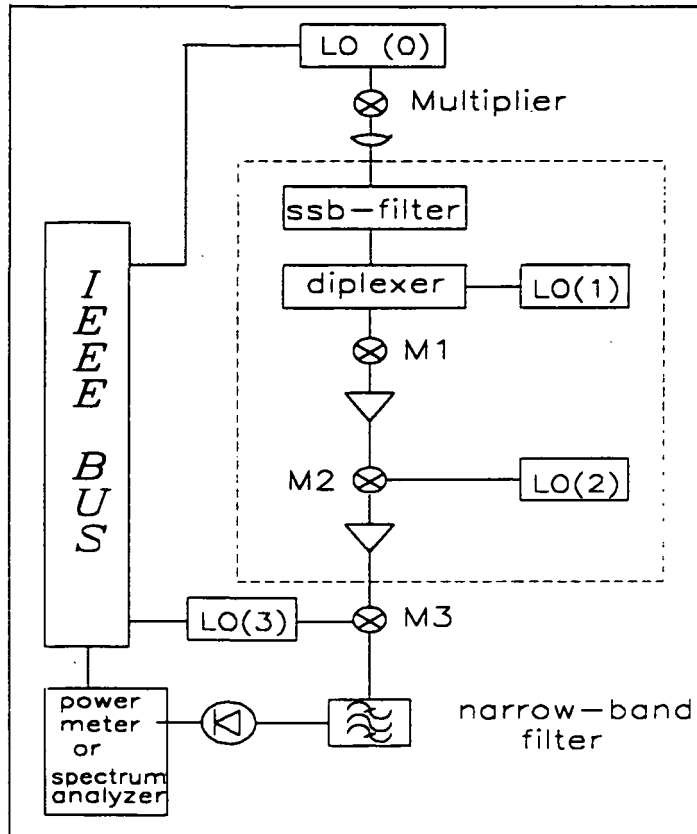

Fig.4 : Experimental set-up for measurements of the ssb-characteristics; dashed lines indicate the radiometer

with the integrated ssb-filter and a microwave output stage where the signal is analysed. A microwave synthesizer(HP 82620) operating in the range 11..13 GHz is used as a local oscillator LO(0). This signal is then multiplied by a quasi-optical schottky diode mixer mounted on a linear translation stage .This allows to move the block orthogonal to the axis of the radiometers antenna main lobe with a resolution of 0.5 μm in x and z direction. Additionally the multiplier signal can be matched to the receiver by a focusing (f=90mm) Teflon lens and it is possible to optimize the lens distance by a further linear translator. A coupling efficiency of more than 75 % can be attained theoretically by this set-up between both beams. In the quasi-optical part of the receiver the beam propagates through the ssb-filter and through the LO(1) diplexer and mixed down by the submillimeter mixer M1 of the radiometer. The signal is converted down to the second i.f. inside the radiometer by a microwave mixer M2 to the receiver output. In the analysing microwave stage a constant i.f. signal of 150 MHz is generated by a further microwave mixer that is driven by another tuneable microwave synthesizer LO(3). After narrowband-filtering the signal can be detected by a spectrum analyzer or a powermeter.

For a defined setting of the ssb-filter the incoupled signal can be tuned to any frequency in the lower or upper sideband including the whole bandwidth via the LO(0) . An experiment computer with a IEEE-bus system controlling the LO(0) provides a simultaneous tuning of the LO(3) that drives the Mixer 3 . The generated signal i.f. signal at 150 MHz is now monitored on a spectrum analyzer and recorded also via IEEE.

Measurement Results

If the generated signal corresponds to the HCl frequency largest power is obtained using the 49th harmonic of the LO(0) signal. Then a dynamic range of about 23 dB can be achieved for the measurements of the single sideband characteristics. The relative transmission curves for both sidebands with a given setting of the ssb-filter are obtained by normalyzing the measurement curves to the data measured for a pathlength difference $\Delta = 0$. In addition, the output signal without the generated submillimeter radiation was recorded at the beginning and the end of the measurements in order to eliminate baseline and drift effects of the radiometer. The results shown in *Fig.5*, here with a resolution of 50 MHz, indicate that the lower sideband is not affected by the setting of the ssb-filter corresponding to the theoretical calculations (*Fig.3*) while the upper sideband is suppressed more than 20 dB over the whole bandwidth. This measurement gives a minimum value for the suppression of the unwanted sideband because it is limited by the strength of the generated signal. An improvement of this is expected by a further optimization of the multipliers antenna properties. In order to reduce the noise in the curves (*Fig.5*) a new measurement procedure with a sampling of data points will be applied during future measurements.

To improve the dynamic range a measurement has been performed using the high-resolution chirp Transform Spectrometer (CTS) on loan from the Max-Planck Institute for Aeronomy
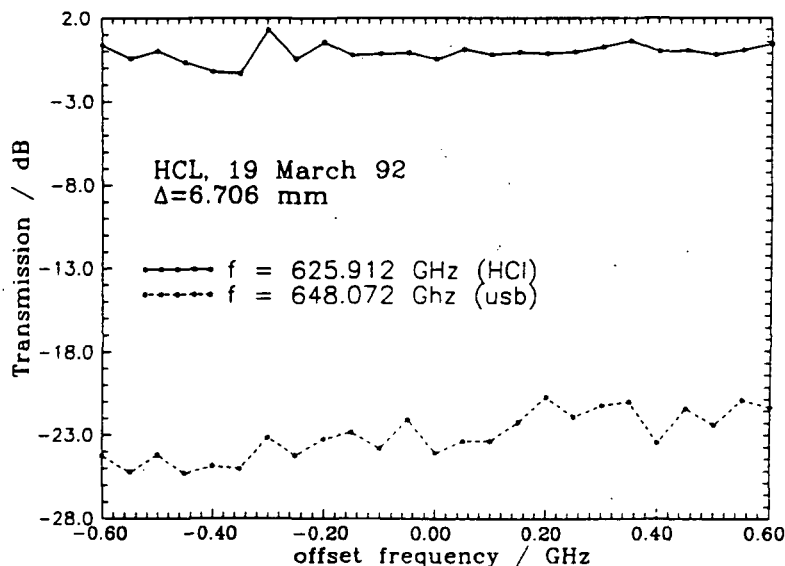

Fig.5: Measured power transmission of the Martin-Puplett interferometer
solid curve : lower sideband (HCl) ; dashed curve : upper sideband

to analyze the i.f. output. The receiver, here the SMS, was operated in a radimetric mode using the quasi-optical calibration unit (*Fig. 1*) and adjusted in order to measure ClO. A submillimeter signal corresponding at the center frequency of the image sideband was generated and observed with a CTS resolution of 400 KHz resulting in a side suppression of about 32 dB. This measurement required an integration of 40 s.

Conclusions

For the performance of atmospheric measurements it is desirable to operate the receiver in a ssb mode. The characteristics of a Martin-Puplett interferometer used as a ssb-filter in a 625-655 GHz heterodyne receiver has been measured by a laboratory setup. When the ssb-filter is adjusted to measure at the HCl frequency, for example, a suppression of more than 20 dB was obtained over a bandwidth of 1.2 GHz. Up to now the measurement is limited by the strength of the generated submillimeter signal which is expected to be improved by optimizing the antenna. A measurement using a narrow band filter shows that the performance of the Martin-Puplett interferometer at the center frequency gives a suppression of about 32 dB.

References

[1] J.C.Farman, B.G.Gardiner, J.D.Shanklin, "Large Losses of Total Ozone in Antarctica reveal seasonal ClO_x /NO_x interaction", *Nature*, Vol. 315, 16 May 1985

[2] J.W.Waters, "Microwave Limb-Sounder of Earth`s Upper Atmosphere", *Atm. Res.*, Vol. 23, pp 391-410, 1989

[3] H.Nett, S.Crewell, K.Künzi, "Heterodyne detection of strastosperic trace gases at sub-mm frequencies", *IGARSS 91,Digest*, Helsinki 91

[4] H.Nett, S.Crewell, K.Künzi, "A 625-650 GHz Heterodyne Receiver for Airborne Operation", *16th Int. conf. on Infrared and Millimeter Waves Symposium,*Digest, Vol. 1576, pp 460-461, 1991

[5] P.F.Goldsmith, *Infrared and Millimeter Waves. Vol.6.Ed.Button.K.S..Academic Press.* New York, pp 277-342, 1982