A WATER VAPOUR AND TEMPERATURE ATMOSPHERIC VERTICAL SOUNDER BETWEEN 110 AND 190 GHz : OBSERVING CAMPAIGNS IN PROSPECT.

Abba* P., Beaudin G., Deschamps A., Encrenaz P., Gheudin M.,
Jégou J.R., Prigent C., Ruffié G., Thomas** G.

Département de Radioastronomie Millimétrique - DEMIRM
Observatoire de Meudon 92190 MEUDON, FRANCE

ABSTRACT

Today meteorologists are interested in the ability to obtain atmospheric data even under predominantly cloudy conditions. This points to the use of a microwave instrument on a geostationary satellite. The french National Space Agency (CNES) is supporting a development of a 10 channels millimeter-wave vertical sounder in the 110 - 190 GHz range. Sounding five channels around the 118 GHz O_2 line gives a temperature profile of the atmosphere up to 25 km. For the water vapour retrieval from 2-3 km to 8-10 km, three channels analyse the H_2O line at 183 GHz. Two "window channels" (110 and 150 GHz) correct the 118 and 183 GHz measurements from the surface contamination. The receiver is described, with special emphasis on the quasi-optical filtering techniques and superheterodyne reception.

The purpose of flying this receiver is twofold:

- transfering the millimeter-wave technology from University laboratory to the industry (Meudon Observatory to Matra) and therefore testing the space technological reliability.
- flying on an airborne and validating the atmospheric parameters retrieving schemes at these frequencies for future satellite missions.

1 - INTRODUCTION

Since the operational success of the Microwave Sounding Unit (MSU - on board the american meteorological satellites TIROS-NOAA), the microwave technology advances have now made possible the use of higher frequencies in space, soon providing the meteorological community with

---

* Now in Alcatel-Espace, Toulouse, France.

** CNES - Centre National d'Etudes Spatiales, Toulouse, France.

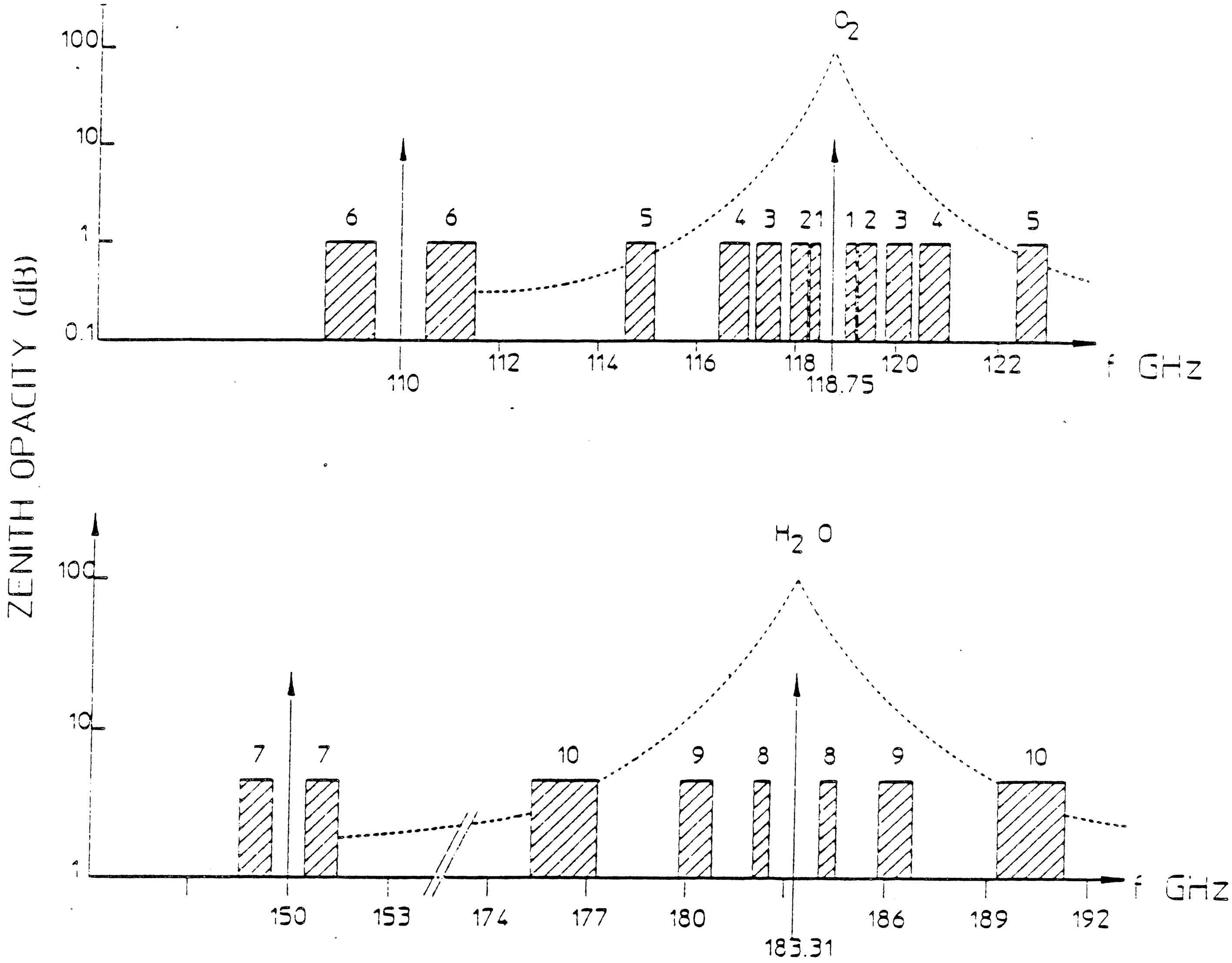
an "all weather" sounding capability of the temperature and water vapour profiles in the atmosphere (Figure 1).

Missons	Frequencies			Orbite	Resolution
	Temperature sounding	Humidity sounding	Window channel		
AMSU-A AMSU-B (NOAA) AMSUB-E (EUMETSAT)	11 channels between 52 and 58 GHz	3 channels around 183 GHz	23.8 , 31.4 50.3 , 89.0 157 GHz	polar	from 15 to 50 km nadir
METEOSAT 2de generation	5 channels around 118 GHz	3 channels around 183 GHz	110 - 150 GHz	geostationnary	from 50 to 100 km nadir
SSMT SSMT/2 (DMSP)	6 channels between 53 and 60 GHz	3 channels around 183 GHz	90 - 150 GHz	polar	from 40 to 180 km nadir

Figure 1 : future meteorological radiometric missions aboard satellites.

To prepare these future meteorological radiometric missions aboard satellites, a 10 channels radiometer between 110 and 190 GHz has been developed under the responsability of the french Centre National d'Etudes Spatiales (CNES) and with Matra Espace technical support.

The breadboard characteristics are derived from the European Space Agency (ESA) Meteosat 2nd Generation millimeter-wave project specifications [1]. Sounding five DSB (Double Side Band) channels around the 118 GHz O_2 line give a temperature profile of the atmosphere up to 25 km. For the water vapour retrieval from 2-3 km to 8-10 km, three DSB channels analyse the H_2O line at 183 GHz. Two "window channels " (110 and 150 GHz) correct the 118 and 183 GHz measurements from the surface contamination. Double orthogonal polarization measurements are available to analyse the polarized surface contribution.



Channel	Centre Frequency (GHz)	Bandwidth (MHz).	Sensitivity (K)
1	118.75 +/- 0.33	200	0.4
2	118.75 +/- 0.65	350	0.25
3	118.75 +/- 1.30	500	0.25
4	118.75 +/- 2.00	600	0.25
5	118.75 +/- 3.90	600	0.25
6	110	1000	0.25
7	150	1000	0.25
8	183.31 +/- 1.000	500	0.5
9	183.31 +/- 3.000	1000	0.5
10	183.31 +/- 7.000	2000	0.5

Figure 2: channel presentation with required sensitivity.

2 - RECEIVER DESIGN

Above 100 GHz, quasi-optical free-space propagation of the signal is adopted, waveguides being to lossy [2]. For a convenient separation of the 110 and 118 GHz channels, we propose a double input beam system. The half-power beamwidths are 4.5 degrees, compatible with sounding from a plane without additive antenna.

The two initial beams are then divided into four (O_2, H_2O and two "window channels") using quasi-optical filtering. Next each band is driven to a low-noise mixer for superheterodyne reception.

Each band is finally analysed. By demultiplexing the mixer outputs, the 118 and 183 GHz bands are separated into different channels.

To calibrate this total power receiver, the incoming beam is commuted to a hot load (300 K) and cold load (77 K), by rotation of a flat mirror.

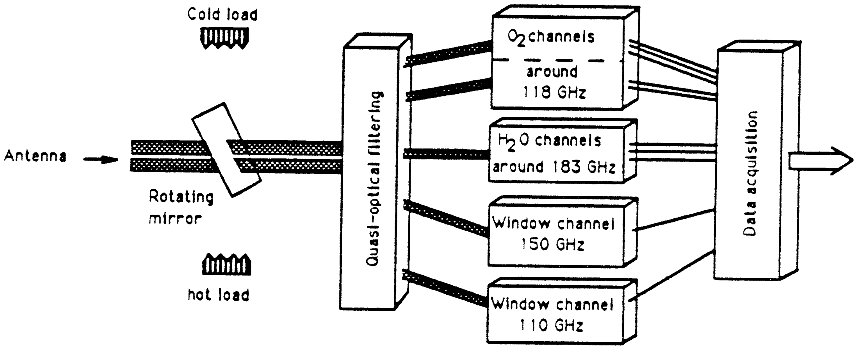


Figure 3: receiver general block-diagram.

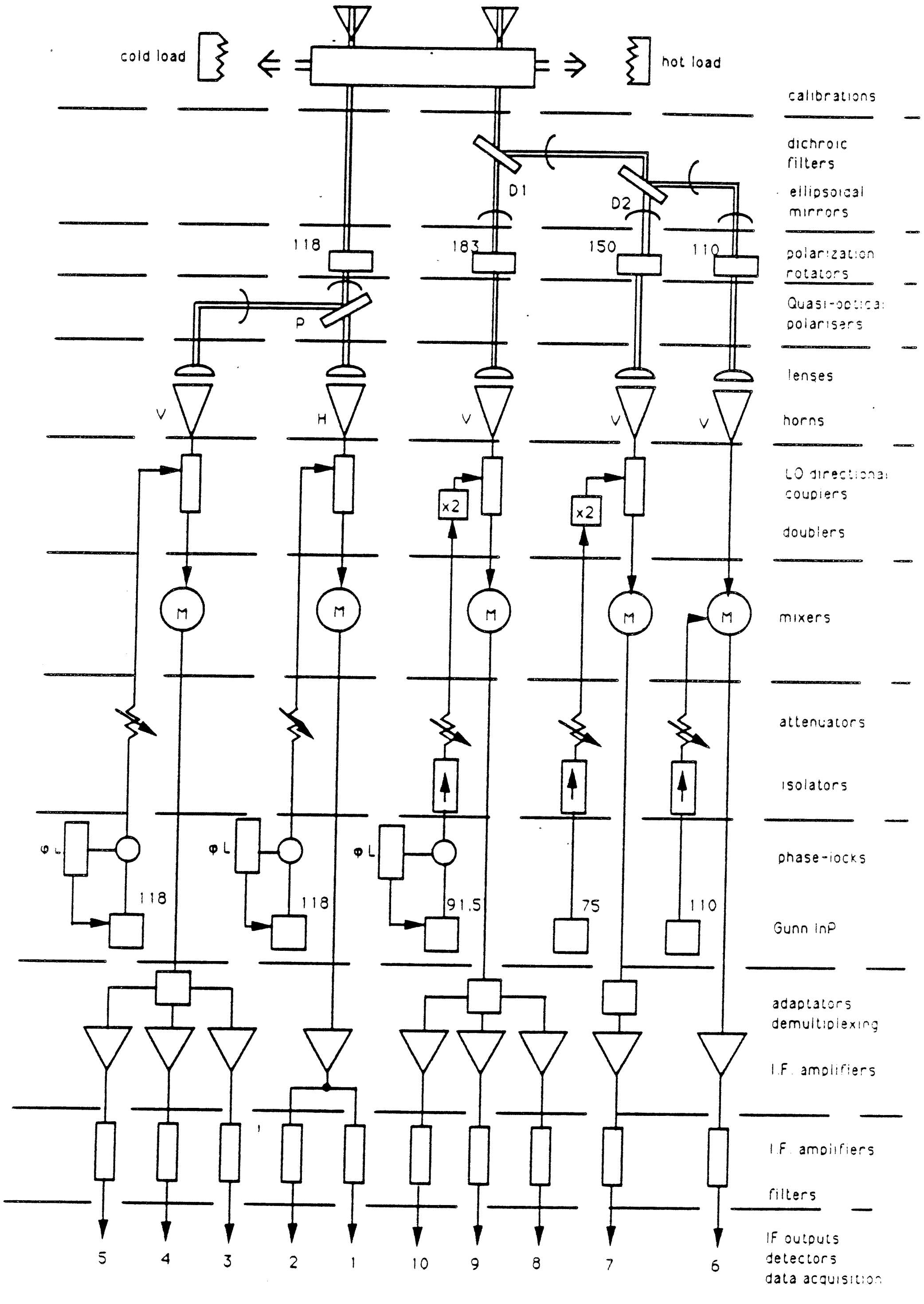


Figure 4 : breadboard schematic configuration.

Following is a complete breadboard description including quasi-optical and millimeter-wave techniques.

3 - QUASI-OPTICAL FILTERING AND INJECTION

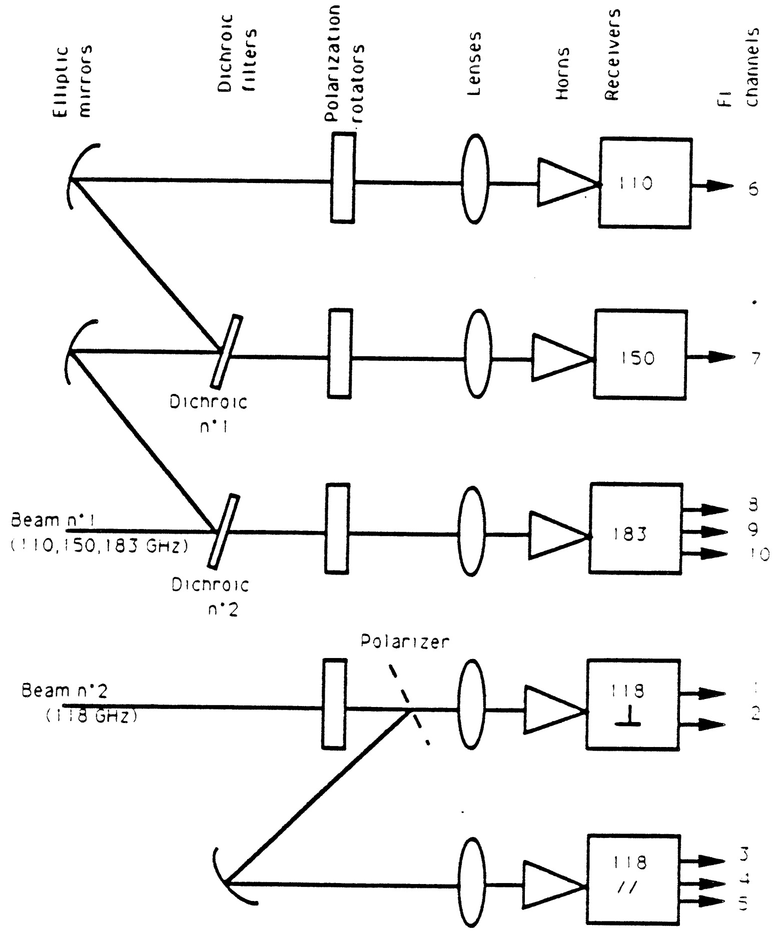


Figure 5 : quasi-optical synoptic.

The double input beam system is composed as follows: one part of the beam is analyzed at 118 GHz, the other part being dedicated to the other channels. The 110, 150 and 183 GHz are separated by two dichroic filters. For each beam, a polarization rotator enables alternative measurements of two orthogonal polarizations of the signal. To achieve proper separation of five IF channels around 118 GHz, the beam is splitted in two by a quasi-optical **polarizer**. Then corrugated lenses focus the beams down to the horns.

The dichroic filters consist of aluminium plates regularly drilled. An electromagnetic description was proposed considering the incident and reflected scattering field as a plane wave superposition with a 15° incident beam angle. Each hole behaves like a circular waveguide propagating the TE_{11} mode. The hole location and diameter and the plate thickness are determined in order to minimize the transmission losses: the 110 and 150 GHz are separated with 0.5 dB losses at 110 GHz and 15 dB rejection at 150 GHz [3].

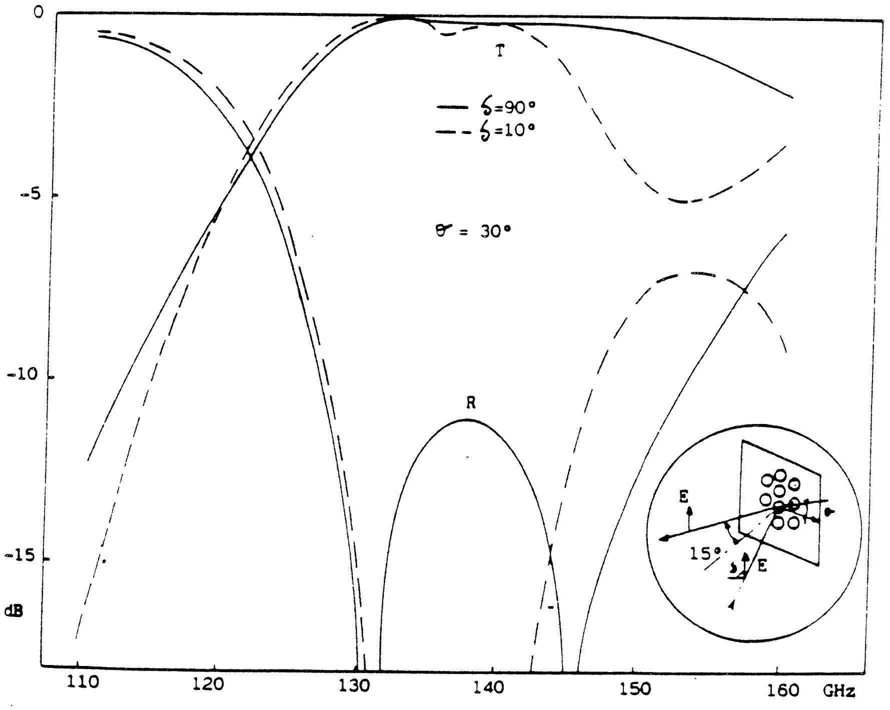


Figure 6 : transmission and reflection dichroic filter response.

The polarization rotators: oxygen and water vapour atmospheric emission is not polarized. On the contrary, ground or cloud reflected radiation is polarized which affects the window channels 6 - 7 and the edges (5 - 10). Polarization orientation depends on the reflecting surface roughness and on the incidence angle. For this reason the receiver includes a dual linear polarization capability (V and H) obtained with polarization rotators in front of each fixed horn-mixer assembly. They are simply composed of a grid of parallel brass wires (i.e. a polarizer) and of a metallic plate, placed a quarter of a wavelength behind the grid. When the wires are vertically oriented, the vertical component of the incident wave is reflected and detected; when the wires are π/4 oriented, the horizontal component of the wave is rotated to the vertical direction by the device and therefore detected by the fixed receiver. The plate-to-grid distance is adjusted with a high precision. The device is mounted on a rotating motor with two fixed positions [4].

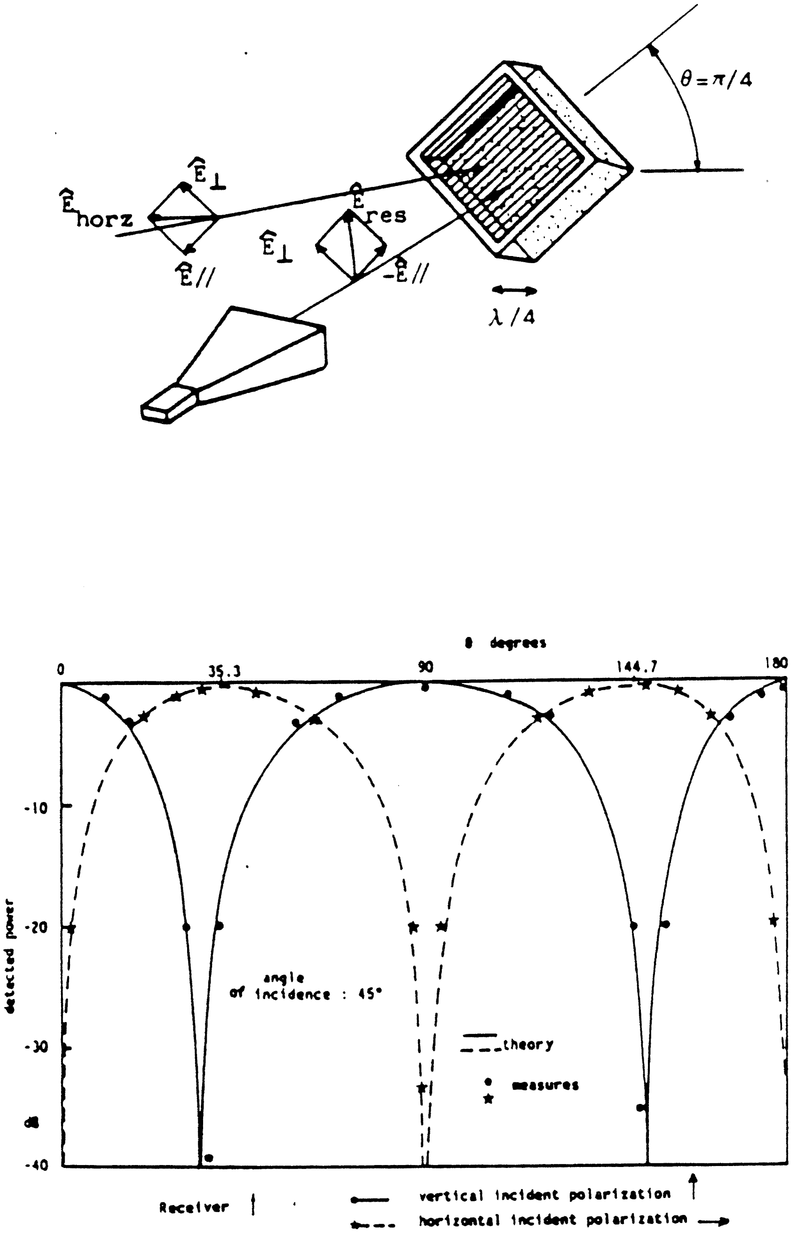


Figure 7 : polarization rotator design and performances.

The lenses: in each channel, a biconvex corrugated lens focuses the gaussian beam down to the horn phase center. The lens diameter is chosen at least four times the waist size to minimize diffraction losses. Corrugated teflon is used for its low reflection and transmission losses.

The horns: for a good operation of the quasi-optical devices, the propagating beams have to be highly gaussian and symetric. Corrugated horns are preferred to Potter's horns for their higher bandwidth (9% bandwidth is required around 183 GHz) [2], [5].

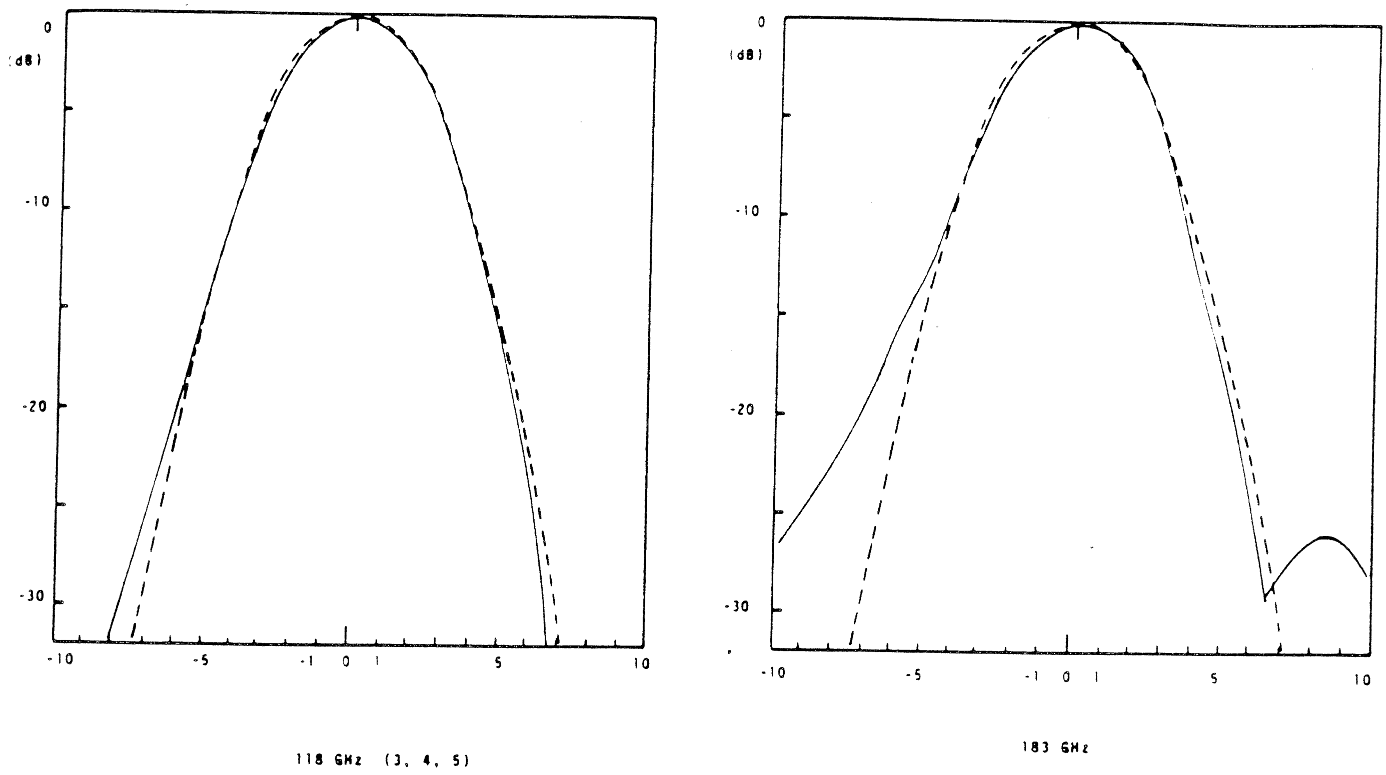


Figure 8: beam pattern of a 118 and 183 GHz channel.

4 - SUPERHETERODYNE LOW NOISE TECHNIQUE

The reception technique is that used in a radiotelescope superheterodyne receiver [6] working in the millimeter-wave field of the spectrum: each signal collected by a horn is delivered to a low-noise mixer for IF (Intermediate Frequency) conversion and then amplified for detection.

The local oscillators and multipliers: the local oscillators (LO) were developed in Bordeaux Observatory. InP Gunn diodes were preferred to GaAs Gunn diodes for working in fundamental mode beyond 100 GHz. They provide less power than Impatt diodes but their noise performances are much better. Thus, at 150 GHz and 183 GHz, frequency doublers are required.

The LO sources capabilities are: 70 mW at 75 GHz, 35 mW at 91.5 GHz, 10 mW at 110 GHz and 8 mW at 118 GHz.

The multiplier efficiencies are respectively 20 % and 8 % for the 75-150 GHz and 91.5-183 GHz doublers.

For stability sake local oscillators are phase-locked at 118 and 91.5 GHz.

The mixers [7], [8]: we have a good experience in low-noise single-ended mixers and we selected them, using honey-comb GaAs Schottky diodes provided by the University of Virginia - USA. The DSB measured performances in figure 9 are given at 1 GHz IF with 500 MHz bandwidth. Directional couplers are used for LO signals injection. Even at 183 GHz, such a solution is possible thanks to the high power available from the InP Gunn oscillator and despite the inherent waveguide-coupler losses.

F_{LO} (GHz)	118	150	183
T_M (K)	500	600	750
L_M (dB)	4.5	6.2	6.2
P_{LO}* (μW)	400	250	150

* P_{LO} designates the LO access mixer input power. The LO sources are combined with a 10 dB directional coupler.

Figure 9 : whisker-contacted diode mixer performances (DSB).

Because of the output mismatch, the performances of a single-ended mixer can significantly decrease when working on a IF very wide bandwidth. However, in the case of a meteorological instrument, the noise temperature performances are not as drastic as in a radiotelescope. It can be interesting to consider an other mixer technology than whisker-contacted diodes. Increasing progress in semiconductor components make the beam lead or planar Schottky diodes an attractive solution: their structure enables an easy and reliable balanced mounting compared with whisker-contacted diode, reducing the IF impedance and thus making the matching easier. A two beam lead diode balanced mixer was studied, thanks to a complete nonlinear and linear analysis based on the harmonic balance method [7], [8]. A computer program was developed for conversion loss prediction [9]. Our approach includes the beam lead diode electric scheme and the balanced configuration with respect to the external circuit depending on the harmonics and sideband frequencies parity. Each access of the mixer was investigated in order to provide an accurate embedding impedance network describing the linear external circuit. This yields to discuss the electomagnetic description of millimeter-wave circuits. The DSB measured performances are given in figure 10:

F_{LO} (GHz)	P_{LO}^* (mW)	IF (GHz)	L_M (dB)	T_M (K)
90	6	0.2 - 2**	3	300
110	6	0.2 - 2**	6	900
118	10	1 - 2	7.5	1050

* The crossbar configuration enables a direct LO signal injection.

** The test set-up includes three low noise amplifiers (NF = 1.3 dB) to cover the IF bandwidth.

Figure 10 : beam lead diode balanced mixer performances (DSB).

At the present time, the substitution of the single-ended whisker-contacted diode mixer can not be considered at 118 GHz. Some investigations should be lead with planar diodes (University of Virginia - USA).

At 110 GHz, the performances are comparable with those measured on the Alpha beam lead diode balanced mixer firstly selected for channel 6 (L_M = 6.2 dB, T_M = 1000 K).

Our mixer is already working on the Portos radiometer 90 GHz channel (CNES - Matra), and could be used on the AMSUB-E radiometer 89 GHz channel (ESA - Matra).

A subharmonical whisker-contacted diode balanced mixer is being studied at 183 GHz in collaboration with Matra Espace and MS2I. Such a solution will avoid the use of a doubler combined with a single-ended mixer. In addition to that, the balanced configuration will make the IF matching easier: this is a critical point for the channels 8, 9 and 10.

The IF demultiplexing and amplification: at each mixer output, demultiplexing and matching circuits for IF channels are realized in microstrip technology.

Cascaded low-noise IF amplifiers (around 1 dB noise figure and 30 dB gain) deliver a -20 dBm power level necessary for the tunnel diode detectors. Predetection bandwidths are determined by an accurate filtering of each channel.

A digitalizer is used to convert the detector output voltage into a frequency. Data are recorded by a specific 16 bits-counter board slotted in a AT Personal Computer. A 18 bits precision is obtained thanks to software data processing.

5 - PERFORMANCES

The quasi-optical losses are detailed in figure 11. For each channel, the receiver noise-temperature was measured many times, using a hot-cold load method. At each step an additional quasi-optical element was included, forming then a different receiver. The losses are deducted from two "successive receiver" measurements, considering the quasi-optical element to be characterized as an ideal attenuator at room temperature. The radiometer perfomances are gathered in figure 12.

Channel	FLO (GHz)	Lens	Polarizer	elliptical mirror	Polarization rotator	Dichroic 183/150	filter 150/110	Total quasi optical loss
1	118.75	0.25	T 0.35	0.1	0.1	-		0.8
2	118.75	0.25	T 0.35	0.1	0.1	-		0.80
3	118.75	0.23	R 0.2	0.1	0.12	-		0.65
4	118.75	0.2	R 0.1	0.1	0.13	-		0.53
5	118.75	0.26	R 0.1	0.1	0.12	-		0.58
6	110	0.25	-	0.12	0.1	R 0.1	R 0.18	0.75
7	150	0.38	-	0.1	0.24	R 0.11	T 0.55	1.38
8	183.31	0.25	-	0.1	0.38	T 0.54		1.27
9	183.31	0.33	-	0.15	0.38	T 0.54		1.4
10	183.31	-	-	-	-			

Figure 11 : quasi-optical losses (dB).

Channel	F (GHz)	IF (GHz)	T_R^* (K)	T_R^{**} (K)	ΔT^{***} (K)	ΔT (K) esa
1	118.75	0.23 - 0.43	1710	2180	0.47	0.4
2	118.75	0.475 - 0.825	1430	1800	0.3	0.25
3	118.75	1.05 - 1.55	2875	3390	0.46	0.25
4	118.75	1.7 - 2.3	1350	1580	0.2	0.25
5	118.75	3.6 - 4.2	2750	3250	0.4	0.25
6	110	0.05 - 1	1350	1670	0.16	0.25
7	150	1 - 2	2900	4250	0.4	0.25
8	183.31	0.75 - 1.25	2350	3090	0.42	0.5
9	183.31	2.5 - 3.5	3500	4760	0.46	0.5
10	183.31	6 - 8	—	—	—	0.5

* receiver temperature (excluding quasi-optical losses).

** total receiver temperature (including quasi-optical losses).

*** integration time is 110 ms.

Figure 12 : radiometer performances.

6 - OBSERVATION CAMPAIGNS

Related to the technological radiometric developments in our laboratory, we have been working on a direct radiative transfer model adapted to frequencies up to 200 GHz [10]. In order to validate this model and to prepare the retrieving schemes of the atmospheric parameters from satellite observations, we propose confrontation with radiometric observations.

Ground-based preparatory observations.

The meteorological station in Trappes (France) provides in situ measurements of atmospheric pressure, temperature and humidity, up to 35 km, every 12 hours. From observations in the less opaque radiometer channels, we will analyse the gazeous atmospheric continuum, still very controversal above 100 GHz.

Airborne campaigns.

The group is already involved in a joint English-French flying campaign for the analysis of 89 and 157 GHz atmospheric window-channels: the Microwave Airborne Radiometer and Scanning System (MARSS) has been developed by the BMO (British Meteorological Office) and the LMD (Laboratoire de Météorologie Dynamique).

The purpose of flying the 110-118-150-183 GHz receiver on a plane would be twofold:

- testing the space technology reliability.
- studying the radiative transfer in the atmosphere and the surface properties at frequencies corresponding to future satellite missions. At these millimeter wavelengths, the observations are sparse. Efforts have to be made to validate the retrieving schemes of the atmospheric parameters from spaceborne sounding at these frequencies.

7 - CONCLUSION

The sounder is at the moment under test. The first improvements will concern the IF mixer output matching which is at the present time a critical point, especially for channels 3, 5, 7 and 10. On one hand the microstrip demultiplexer combined with single-ended whisker-contacted diode mixer, and on the other hand the beam lead diode balanced mixer and the subharmonical balanced mixer will be thorougly studied in order to determine the best choice.

The double input beam system was adopted because of the difficulty to separate accurately the 110 and 118 GHz signals. A single input beam configuration could be selected by switching the "window channel" 6 (110 GHz) down to 100 GHz.

The breadboard should be used for ground-based observations in the middle of 1991. The first airborne campaign is planned for the year after. In order to better approach satellite conditions, we also envisage a stratospheric balloon or airplane fly.

Acknowledgment : this work was made with the technical support of F. Gadéa, S. Lebourg, J. Morin, G. Rérat (Meudon Observatory), M. Chauvet, J. Lacroix, G. Montignac (Bordeaux Observatory) and the collaboration of C. Letrou (INT-Evry), S. Toutain (ENSTBr-Brest), M. Chaubet (CNES-Toulouse), Matra Espace (Toulouse-Vélizy), MS2I (Montigny).

REFERENCES

[1] A. Chedin, D. Pick, R. Rizzi, "Second Generation Meteosat", Ravenna Workshop on the Operational Instruments, Summary Report, 3-5 nov. 1986.

[2] P. F. Goldsmith, "Quasi-optical techniques at millimeter and submillimeter wavelengths", in Infrared and Millimeter Waves, vol. 6: Systems and Components, K.J. Button (ed.), Academic Press, New York, pp. 277-343, 1982.

[3] C. Letrou, "Conception de diplexeurs dichroîques dans le domaine millimétrique", 6es Journées Nationales Microondes, pp. 64-65, Montpellier, France, juin 1989.

[4] C. Prigent, P. Abba, M. Gheudin, "A quasi-optical polarization rotator", International Journal of Infrared and Millimeter Waves, vol. 9, n° 5, pp. 477-490, may 1988.

[5] P. D. Potter, "A new horn antenna with suppressed sidelobes and equal beamwidths", Microwave J., vol. 6, pp. 71-78, 1963.

[6] J. D. Kraus, "Radio Astronomy", 2nd edition, Cygnus-Quasar Books, Powell, Ohio, 1986.

[7] D. N. Held, A. R. Kerr, "Conversion loss and noise of microwave and millimeter-wave mixers: Part 1-Theory, Part 2-Experiment", IEEE Trans. Microwave Theory Tech., vol. MTT-26, pp. 49-61, feb. 1978.

[8] P. H. Siegel, A. R. Kerr, W. Hwang, "Topics in the optimization of millimeter-wave mixers", NASA Technical Paper 2287, 1984.

[9] J. R. Jégou, J. M. Goutoule, G. Beaudin, G. Ruffié, S. Toutain, "Harmonic balance method for conversion loss prediction of a millimeter-wave crossbar balanced mixer", 20th European microwave conference, proceedings Vol. 1, pp. 157-161, Budapest , dec. 1990.

[10] C. Prigent, P. Abba, N. A. Scott, S. Stringer, "A synthetic atmospheric millimeter-wave propagation model for future meteorological radiometric missions", in IGARSS'88 (1988 International Geoscience And Remote Sensing Symposium), Remote sensing : moving towards the 21st century, 12-16 September 1988, Edinburgh, UK, vol. II, esa SP-284, IEEE 88CH2497-6, pp. 953-956, aug.. 1988.