# A Ground-Based Multi-Frequency Millimetre-Wave Radiometer for Propagation Studies

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## Résumé
*On décrit un radiomètre multifréquence en ondes millimétriques exploité au sol pour l'observation de la troposphère et l'étude de la propagation. Cet instrument a été mis au point pour le compte de l'Agence par Officine Galileo (ex-SMA) avec le concours de RYMSA et de l'Université de Tor Vergata. Il peut effectuer des mesures précises qui permettent de déterminer les constituants de l'atmosphère (à l'état de vapeur et de liquide), les profils de température et les paramètres de propagation (affaiblissements et retards).*

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*Figure 1.*
*The multi-frequency radiometer.*


## Scientific background
The brightness temperature of the armosphere, as observed from the ground, is a function of its state and composition (e.g. water vapour, cloud, temperature). Using appropriate radio frequencies, it is possible to measure the integrated (along-path) water water vapour content, the integrated liquid watercontent and the mean atmospheric temperature. By increasing the complexity of the instrument and the processing algorithms, profiles of these variables can also be retrieved.

## Frequency selection
Due to the stringent accuracy requirements placed on the MFR, the following channels were selected: two channels around the water vapour absorption line (22.235, 23.87 GHz), one in the Ka band 'window region' (31.65 GHz), and several in the region of the 60 GHz oxygen complex (51.25, 52.85, 53.85, 54.85 GHz).

The choice of last four frequencies required careful study, partly influenced by the requirement to observe cloud conditions at medium-latitudes during the summer.

## Instrument parameters
An accurate estimate of the atmospheric components demands a radiometric sensitivity better than 0.5 K and a long term accuracy of 0.5 K. Further, very stringent requirements are placed on the antenna, which must have a relatively narrow beamwidth (2 ± 0.25°), high efficiency (90% at first null and 99% (goal) at 10° from boresight). In addition, the radiometer must operate continuously and autonomously in the open air under all weather conditions.

## Radiometer design
The instrument comprises two complete modules, for the K/Ka band channels and the other for the 50/60 GHz region (Figure 1). Both modules are housed in a thermally controlled enclosure mounted on a positioning subsystem which varies the pointing direction in elevation and azimuth. The temperature of the entire radiometer is rigorously controlled and the temperatures of critical points are monitored either for diagnostics or for small correction of the radiometric output data. The instrument is equipped with meteorological sensors for on-ground measurements of atmospheric pressure, temperature and humidity.

The calibration philosophy employs both the tipping curve method of measuring radiometer output versus elevation angle, and the switching of the receiver input between 'hot' and 'cold' reference loads placed in the receiving chain after the antenna. System control, data acquisition, data processing and storage are done by a remote control unit. The

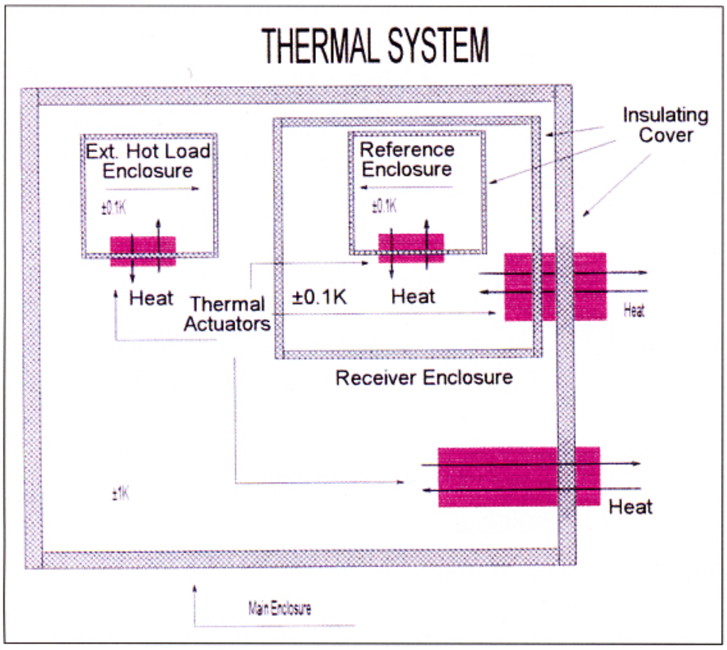


Figure 2.
*The thermal control system of the multi-frequency radiometer.*

system also includes the processing needed to derive atmospheric parameters from the raw radiometer data.

## Thermo-mechanical design

To meet the stringent thermal control requirements mentioned above, a three-stage (independent) control philosophy has been adopted. The antennas are located in a thermally insulated enclosure fitted with windows, transparent to radio frequencies, which is stabilised within ±1 °C. The receivers are contained in the same enclosure and are further insulated and stabilised within ±0.1°C. Additional high precision controllers (±0.1°C) are used to stabilise th ereference loads (Figure 2).

## Antenna design

The antenna subsystem consists of two offset reflector antennas, one for 20/30 GHz and one for 50/60 GHz, both having half-power beamwidths of 2°. Sidelobe levels are lower than -30 dB for both frequencies and beam efficiency is better than 96%. The feed spillover is reduced by a thermally controlled wall of absorbing material around the reflector. The two antennas are aligned to better than 0.2°. Figure 3 shows a block diagram of one enclosure with its antenna system.

## Receiver design

Receiver design is driven by stability requirements which are achieved using an automatic gain control loop, with two references kept at 280 K and 360 K. Since the temperatures of the reference loads are strictly controlled and continuously monitored, the residual overall receiver stability is equal to the total drift of the monitoring circuit which is less than 0.1 °C. Receiver sensitivity (integration time 1 s) ranges between 0.05 K (K band) and 0.2 K (Q band).

## Retrieval algorithm

The MFR uses a retrieval algorithm developed at Tor Vergata University [1]. This algorithm retrieves the profiles of the atmospheric variables, namely temperature, water vapour and cloud liquid. With this information, an atmospheric propagation model allows the propagation parameters to be evaluated. In the first place, the measured brightness temperature and the ground measurements are fed to a linear estimator which determines integrated vapour and liquid and mean temperature. In the second stage the temperature, vapour and cloud liquid profiles are also retrieved. The attenuation and path delays at the frequencies of interest are subsequently evaluated by means of Liebe's MPM propagation model.

## Conclusion

An advanced radiometer for ground-based research has been manufactured. It meets stringent design requirements in terms of frequency and gain stability, antenna performance and operational specifications. The radiometer design is also matched to the needs of parameter retrieval algorithms, developed in parallel, to ensure optimised performance. The first application of the instrument is already planned to conduct research on the lower atmosphere and clouds in particular.

## Reference

1. Del Frate F., et al., Use of natural orthogonal functions, PIERS'94.

Figure 3.
*Schematic of the antenna section of the multi-frequency radiometer.*