Preliminary Design of an Ultra-Stable Microwave Radiometer for Radioscience Experiments

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Radio science experiments like the NASA Cassini-GWE (Gravitational-Wave Experiment) or the planned Bepi Colombo-MORE (Mercury Orbiter Radio-science Experiment) require the accurate calibration of the contribution of the Earth's troposphere to the ranging signal measured by the ground station. The assessment of the tropospheric wet and dry delay must be performed over long integration times (between 10^3 and 10^4 s) along the link between the ground station and the spacecraft. Ground based microwave radiometry is a well-established technique for the measurement of the tropopsheric wet delay (that represents the most variable contribution to the total delay) and multi-frequency microwave radiometers are now commonly used for meteorology and for setting the atmospheric reference level for communication satellite signal level. Nevertheless the characteristics of radio-science experiments results in 'extreme' requirements for a microwave radiometer in terms of instrument stability and antenna pattern. Furthermore current ESA and NASA ground stations for science missions are located in places like Cebreros (Spain) or Goldstone (California), characterised by relevant diurnal and seasonal fluctuation of environmental parameters (like air temperature and humidity).

In this paper a preliminary design for an ultra-stable Ka band radiometer designed to fulfil these requirements is presented. This activity has been performed in the framework of the ESA ARTES 5 contract 'Development of ground equipment for atmospheric propagation conditions assessment from 10 up 90 GHz' fully supported by the DLR (Germany).

The system is fully steerable in azimuth and elevation. The antenna design comprises a corrugated K-band feed horn illuminating a 1.5 m off-axis parabola mirror with a half power beam width of 0.7° @ 25 GHz, sidelobe level < 40 dB and minimum spill over loss. With these optical parameters it is possible to determine atmospheric propagation parameters even when the system is pointing close to the sun (>1.5°). Shall the spacecraft be visible at a smaller angular distance from the sun (like for the Bepi-Colombo mission) the tropospheric propagation parameters along the path could be retrieved by scanning of the atmosphere in the surroundings of the link. If this scan is performed in a time shorter than the atmospheric correlation interval it could be possible to retrieve the wet delay along the link to the spacecraft.

The high radiometric stability needed for radio science experiments is achieved by a fast magnetically switchable (10 kHz) pair of Y-junction isolators used as Dicke switches. The isolators have been optimized for the 22-32 GHz band and for minimum insertion loss of 0.35 dB each. In Dicke mode the isolator operation is reversed by changing the magnetic field polarity of the device, so that the receiver is 'looking' into the isolator termination. One isolator has an isolation of -25 dB so that two subsequent devices are used to achieve a near perfect isolation from the scene brightness temperature during the Dicke switch ON phase. Another switchable isolator is used to turn on/off a precision noise source that is coupled to the receiver input through a directional coupler of high directivity. The noise source allows to implement a balanced Dicke switch radiometer or to determine gain and system noise temperature fluctuations independently when combined with the Dicke switch operation.

Due to this fully automatic radiometer calibration system the instrument can observe without interruptions by external calibration procedures. As with other Dicke switching radiometers the system is continuously calibrated when looking to the scene. The overall system sensitivity in this operating mode is < 800 K for an uncooled instrument. A high initial radiometer stability is achieved by a thermal stabilization of the receiver front end including feed horn of better than 30 mK.

A one channel V-band test receiver that uses the described techniques, has been built and tested. An RMS noise level of 0.01 K could be achieved after integration periods of > 2000 seconds. For K-band this result is expected for integration periods < 1000 seconds. An Allan variance analysis was performed which demonstrated that the calibration procedure allows for integration times of even up to 10000 seconds with further RMS noise level reduction.