ORION — Microwave Water Vapor Radiometer Subsystem Design

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Electrical path delay caused by atmospheric water vapor may be a limiting error source for geodetic measurements made with very long baseline interferometry. Direct measurement of atmospheric water vapor is necessary to obtain path delay correction required by the ORION project. A dual-channel water vapor radiometer is described which operates at frequencies near the 22-GHz water vapor line and is capable of collecting data that will permit calculation of path delay with 2-cm accuracy.

I. Introduction

The ORION Microwave Water Vapor Radiometer (WVR) will collect radiometric data to permit subsequent calculation of the line-of-sight path delay to radio waves caused by tropospheric water vapor. The data shall be of quality such that the calculation of path delay can be made with an error of less than ±2 cm, a criterion of the overall system requirement.

II. Background

Microwave interferometric systems operating over long baselines on the earth's surface are sensitive to path delay errors induced by tropospheric water vapor. The total delay can vary from 3 to 150 cm for surface ambient temperatures of 0 to 50°C (for a surface temperature below −10°C, tropospheric water vapor will be negligible). Overall system errors from this source can be reduced to between 10 and 15 cm by using estimation techniques based on historical measurements of water vapor or models based on the measurement of surface meteorology. Reduction of path delay error below the 10-15 cm range requires measurements of tropospheric water vapor along the line-of-sight of the interferometer receiving antenna.

III. History

The Jet Propulsion Laboratory has been active in the design and fabrication of passive microwave radiometers for remote sensing of water vapor and atmospheric temperature for many years. During the early 1970's, radiometers were developed and successfully launched on the Nimbus E, Nimbus F, and Tiros series of weather satellites. Extensive work was also done in developing data reduction algorithms. In 1974, a JPL team used the prototype scanning multifrequency radiometer (SCAMS) from Nimbus F to demonstrate that water vapor in the atmosphere can be measured with ground-based remote sensing. Data from this test were compared with other data (Ref. 1) and the results indicated the radiometer yielded data that could enable calculation of the water-vapor-induced delay with an accuracy of ±2 cm.

A similar prototype water vapor radiometer (WVR) was integrated with a microprocessor to perform data collection functions and communication with a host computer. This prototype WVR was used as a support instrument on the long baseline program (Astronomical Radio Interferometric Earth Surveying, ARIES) project that was being conducted by JPL.

Another JPL team used the algorithms developed earlier for spacecraft instruments to generate software necessary to operate the WVR microprocessor. The WVR also had stand-alone capability via an RS232 serial data interface. The software generates all control and data taking functions on request from the host computer or RS232-compatible data terminal.

Results from the ARIES prototype were evaluated and a decision was then made to fabricate four WVR's for use on the Very Long Base Interferometer (VLBI) project. Several improvements were made, including better thermal control, use of a very low side-lobe corrugated horn antenna, and improved calibration load stability. The improved WVR's were built and the design was documented with formal drawings. An improved version of the software was also developed and integrated with the Mark III Data System. An additional unit was built to the formal drawings for ARIES II and served as a check of the documentation; all discrepancies have been corrected.

IV. WVR Subsystem Functional Description

A. General Description

The ORION Water Vapor Radiometer will be a modified version of the ARIES WVR, designed for the mobile operations environment. These descriptions and requirements are for the WVR. The functions and interface of the WVR are shown in Fig. 1. The WVR will be installed in the reflector of the ORION antenna and the pointing will be aligned within ±1 degree. Microwave radiation will be measured at two frequencies. One of the frequencies will be on the lower frequency skirt of the water vapor emission line at approximately 21 GHz. The other frequency will be off the emission line at approximately 31 GHz. The 31-GHz channel is twice (X2) as sensitive to liquid water as the 21-GHz, but it is only five tenths (X0.5) as sensitive as the 21-GHz to water vapor. This will permit calculation of both liquid water and water vapor by using combined data from both channels. Each frequency will have its own horn antenna and receiver system, and will operate simultaneously. The rationale for the frequency selection is discussed extensively in Ref. 2. A block diagram of the WVR is shown in Fig. 2.

B. WVR Assemblies

There are three assemblies to the WVR: (1) Radiometer Electronics Assembly, (2) Power Supply Assembly, and (3) Data and Control Assembly. Each is in a separate package for ease of installation and repair as well as thermal design considerations.

1. Radiometer Electronics Assembly. The Radiometer Electronics Assembly consists of an antenna, Dicke-switched superheterodyne receiver and associated circuitry for each channel. Incoming microwave radiation is collected by two low side-lobe corrugated horn antennas. The output of each antenna is fed to a port of a 5-port latching ferrite switch. The radiometer is switched between the antenna port and a reference load (Dicke-switching scheme) at a frequency of 1 kHz. The signal from the output port of the ferrite switch is mixed with a local oscillator (tuned to the center frequency of each channel and passed through an IF filter and amplifier). The signal is then detected by the first detector and the resulting video signal is amplified. The video signal is synchronously detected using the same 1-kHz reference previously used to drive the ferrite switch. The detected signal is integrated (low-pass filtered) and amplified to provide an analog output voltage proportional to the difference in signals at the switch ports. Internal calibration of the WVR is done by switching from the antenna port to each of two ports having microwave termination loads held at fixed temperatures, one at 310 K and the other at 373 K. Internal calibration is performed each time a data set is taken. This calibration will be supplemented by doing "tipping curve" calibrations, which require movement of the entire antenna subsystem for each tipping curve calibration sequence. Tipping curve sequences are planned at two-hour intervals. The sequence will be controlled by the host computer. The use of tipping curves to remove instrument error is discussed in Ref. 2. Temperature of the loads as well as other critical components will be measured using platinum temperature sensors. The Radiometer Electronics Assembly also contains the ferrite switch drivers, and heater controllers.

The Radiometer Electronics Assembly is housed in a thermally insulated enclosure that provides protection from the elements and thermal stability. Heaters are provided to stabilize the internal temperature of the enclosure and electronics. Electrical power to the Radiometer Electronics Assembly is controlled remotely from the control and data assembly.

2. Power Supply Assembly. The Power Supply Assembly provides all necessary voltage to operate the WVR electronics assembly from 117 V rms ±10%, 60-Hz, 1ϕ commercial power. Independent power supplies are used for each channel and separate ground returns are used for maximum dc isolation between channels.

Housing of the power supplies in a separate enclosure permitted better thermal stability in the Radiometer Electronics Assembly and allowed more freedom in mounting the subsystem. The power supply assembly is equipped with temperature-controlled heaters to assure reliable operation in low-temperature environments.

3. **Control and Data Assembly.** The Control and Data Assembly consists of a microprocessor system and associated circuitry, including analog I/O circuits, multiplexer, 12-bit A to D converter, memory, and an RS232 serial digital interface circuit. A local control panel is also included for checkout, testing, and troubleshooting of the subsystem. Internal power supplies provide all voltages necessary to operate the Control and Data Assembly from 117 V rms ±10%, 60-Hz, 1ϕ commercial power. During normal operation, all WVR functions will be controlled by external commands from the host computer.

The Control and Data Assembly will accept, digitize, and collect both analog data and monitor signals from the Radiometer Electronics Assembly. It will then format, buffer, and transmit the data on command to the host computer. There are provisions for only limited processing and memory in the Control and Data Assembly due to the limitations of the microprocessor. Conversion of antenna temperatures to path delay will be performed by the host computer.

V. ORION WVR Design

The previously described WVR was the ORION baseline design which was basically an add-on system with stand-alone capability. The ORION WVR is to be an integral part of the total ORION system, and necessary design revisions were made. The previous WVR's were mounted on a separate positioner that was controlled by the microprocessor, but this was not necessary for ORION because the WVR is located with the main ORION antenna and positioned by it. The narrow beamwidth of the radiometer antennas allowed the placing of the WVR at the rear of the main antenna looking through a hole in the antenna reflector without interference from the subreflector. When the positioner was removed from the WVR, the microprocessor was deleted and its remaining data and control functions assigned to the Monitor and Control Subsystem.

Mechanical design of the WVR has been revised and design changes were made in several areas to improve structural strength of the WVR to the main antenna interface.

VI. Current Design Status

Preliminary thermal analysis had indicated that the Radiometer Electronics and Power Supply Assemblies would operate normally over the specified ambient temperature range for ORION. Subsequent temperature qualification testing revealed a problem with the Power Supply Assembly at low temperature. The problem was solved by redesigning the heat sink and heater layout. The units operated satisfactorily on retest. Humidity and barometric tests have not been performed, and are not planned. Vibration and shock tests have not been performed and are not planned. Preliminary examination of available reliability data for the WVR subsystem indicates compliance with overall mean time between failure requirement.

The formal drawings for the WVR have been redlined to show corrections except for the Data and Control Assembly. Release of the redline corrections is not currently planned due to lack of funds. The functional requirements design review (Level D) has been completed and the Functional Design Requirements (FDR) document prepared. A preliminary Detail Design Specification (DDS) has been completed. The detail design review (Level E), release of the FDR, and completion of the final DDS is dependent upon revision of the Data and Control Assembly design, which is not currently planned due to lack of funds. Preliminary test procedures have been completed except for the Data and Control Assembly. The installation, maintenance and operation manual are planned for FY 82.

VII. Conclusions

The WVR design will meet functional requirements of the ORION system to provide calculation of path delays with an accuracy of ±2 cm. Minor mechanical design changes and interface modification are required before finalization of design. Project management has indicated that drawings currently completed in "redline" form are sufficiently developed to assure completion as scheduled.

References

1. Winn, F. B., et al., "Atmospheric Water Vapor Calibrations: Radiometer Techniques," in *The Deep Space Network Progress Report 42-32*, pp. 38-49, Jet Propulsion Laboratory, Pasadena, Calif., April 15, 1976.

2. Claflin, E. S., et al., "Microwave Radiometric Measurements of Water Vapor Path Delay: Data Reduction Techniques," in *The Deep Space Network Progress Report 42-48*, pp. 22-30, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1978.

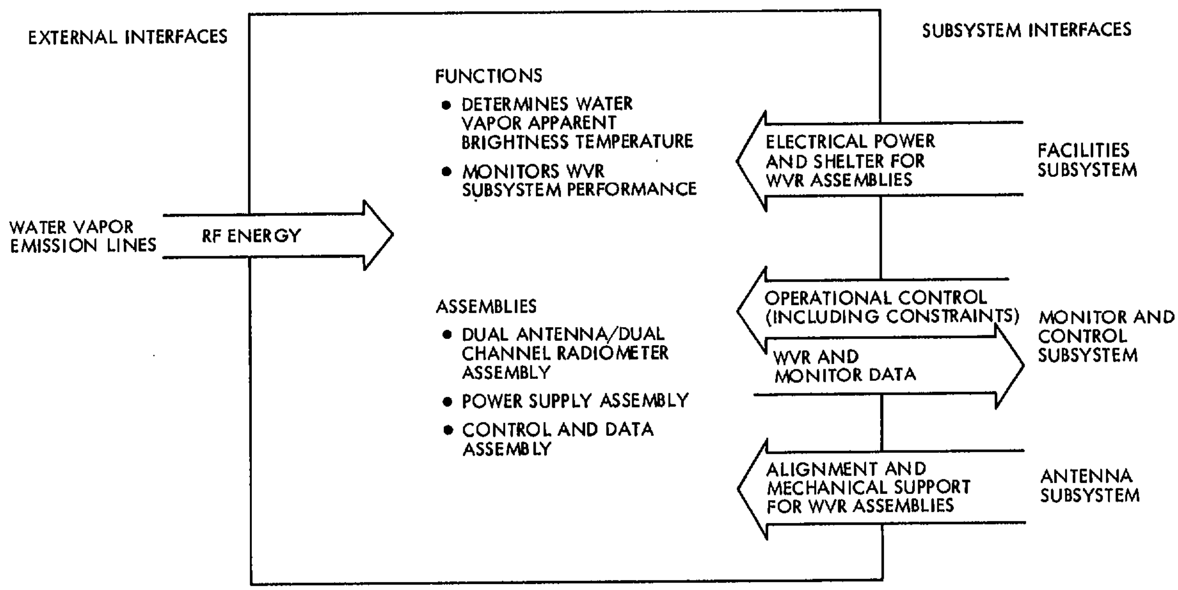

Fig. 1. ORION Water Vapor Radiometer Subsystem, function and interfaces

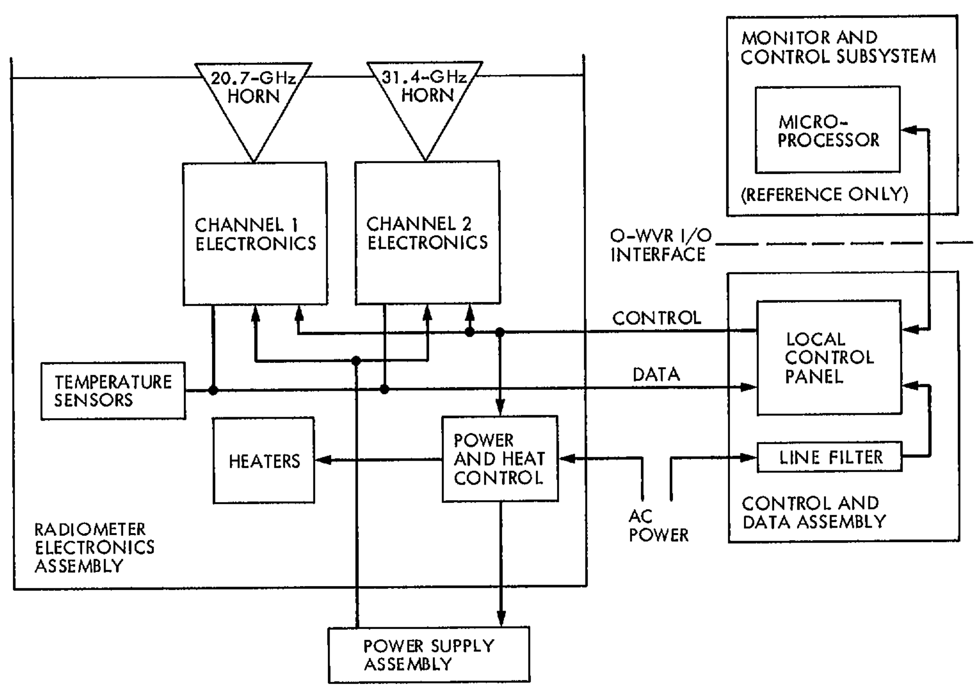

Fig. 2. ORION Water Vapor Radiometer, overall block diagram