Development of a Water Vapor Radiometer to Correct for Tropospheric Range Delay in DSN Applications

P. D. Batelaan, T. Sato, S. D. Slobin, and H. Reilly
Communications Elements Research Section

The rationale for a Water Vapor Radiometer (WVR) as an aid in predicting tropospheric delay correction is presented. Included is a block diagram and a description of the present developmental WVR with the semiautomated operating sequence outlined. A brief summary of field tests at El Monte airport and Pt. Mugu is given.

I. Introduction

Continued improvements in spacecraft navigation and radio interferometry have resulted in lowering the uncertainties that are contributed by various error sources. As a result of this, the uncertainty caused by tropospheric delay has come under consideration. This delay can be conveniently separated into two components, dry and wet. The dry, nearly constant atmospheric component is well understood and because of its relationship to easily measured surface parameters, it can be readily accounted for. The wet, variable atmospheric component varies from a delay of nearly zero, for dry air, to about 30 cm for saturated air at zenith (Ref. 1). A means of remotely sensing the integrated value of the total water that causes this delay, in the line of sight, is microwave radiometry. This knowledge can then lead to an RF delay correction for the wet component for use in spacecraft navigation or various forms of interferometry.

This RF delay is primarily due to the dielectric effects of water vapor and is only slightly coupled to water droplets. However, the converse is true of the radiometric emission qualities; the radio noise is largely due to liquid water (when present in the form of rain and clouds), and only slightly to water vapor. This means that in a single measurement of total water radiometric emission for the purpose of sensing delay-causing vapor, the noise from the vapor is dominated by the noise from the liquid component. This problem has been overcome by using a two-frequency radiometer with one channel at 18 GHz and the other channel at 22.2 GHz. The 22.2-GHz channel is largely sensitive to water vapor because this is a resonant frequency of the water vapor, while the 18-GHz channel responds largely to liquid water as previously described. This allows separation of the contaminating liquid component signal from the desired vapor component signal in the data stream (Ref. 2).

II. Description

The Water Vapor Radiometer (WVR) presently under development for Earth-based/DSN applications benefited from the previous accomplishments of the Science Division radiometers for use on NIMBUS satellites (Refs. 3, 4). Because the present effort was started as an upward-looking, ground-based philosophy rather than a nadir-viewing, spacecraft-based one, some aspects of the design were changed. These changes and their rationale will be described in detail in a future article.

The frequencies selected allow use of a single corrugated right circular polarization (RCP) horn of about 8-deg beamwidth. As shown in the block diagram (Fig. 1), this horn is followed by a waveguide switch that allows receiver selection of the three receiver loads; horn, ambient calibration, or cold calibration. Next is a coupler to inject the noise for the Noise Adding Radiometer (NAR) (Ref. 5). A mixer, intermediate frequency (IF) amplifier, dual Gunn-diode local oscillators and a local oscillator (LO)-select switch complete the receiver. The receiver package, including the coupler onward, is enclosed in a temperature-controlled box. A special effort has been made to use commercially available components and assemblies wherever possible. Exceptions to this are the horn antenna, the cold calibration load, and the load-select waveguide switch. The horn was required to have small size combined with high beam efficiency. The load-select switch needed to be low loss, low voltage standing wave ratio (VSWR), very repeatable, and with three positions. The cold calibration load subassembly required a portable, reliable, refrigeration scheme combined with a high-quality waveguide load. The requirements for these could not be met by any known commercial items.

The operation of the radiometer is semiautomated. A JPL-developed microprocessor/controller selects local oscillator frequencies, loads, controls the NAR, and receives and outputs data to a teletype and paper tape punch.

The radiometer is presently mounted on a commercial, small antenna positioner with remote manual readout and control (Fig. 2). For field operations this assembly is placed atop a trailer with the several racks of support equipment, and space for personnel, inside (Figs. 3, 4).

Briefly, the WVR automatically sequences as follows:

(1) At 18 GHz, the relative RF noise and the physical temperature of the ambient calibration load are measured and recorded.

(2) At 18 GHz, the relative RF noise and the physical temperature of the cold calibration load are measured and recorded.

(3) At 18 GHz, the relative noise from the horn is measured and recorded.

(4–6) Repeat Steps 1–3 at 22.2 GHz.

Also recorded are azimuth, elevation, day, and time. The nonreal time data reduction corrects the relative RF noise mesurements of ambient load, cold load, and horn, for match and loss, scales the corrected RF noise values for hot load and cold load to their measured physical temperatures, and outputs absolute radiometric sky temperature.

III. Operations

To date the instrument has gone through one upgrade in its design as a result of its first field test at El Monte Airport in May 1975. It has also recently (March 1976) been field tested at the Naval Pacific Missile Test Center (PMTC) at Pt. Mugu. Both tests were accomplished in conjunction with the Mission Analysis and Space Sciences Divisions.

At El Monte, the WVR was operated for side-by-side comparisons with two Space Sciences Division instruments, the Scanning Microwave Inversion Layer Experiment (SMILE) and the Nimbus-E Microwave Spectrometer (NEMS) (Figs. 5, 6). In addition, Division 39 arranged for an aircraft (provided under contract with MRI, Inc.) instrumented with various water-sensing equipment to fly radial vectors at several elevation angles. While the aircraft instruments recorded the line-of-flight water data, the radiometers simultaneously recorded at the same azimuth and elevation vectors. In addition, data from the U.S. Weather Service radiosondes, launched twice daily at El Monte Airport, were made available. In all, four flight tests were conducted during the one month that the three radiometers remained at this location. Data for radiosonde comparison were taken twice daily, and various other operational techniques and tests were conducted.

The March 1976 tests at Pt. Mugu were also conducted side-by-side with SMILE. The MRI aircraft was again flown along various vectors, but with improved instrumentation aboard. Radiosonde data were made available from twice-daily flights made by Pt. Mugu personnel. These sondes (technically Rawinsondes) and their associated ground receivers and instrumentation, were of much better accuracy than the units at El Monte. The Navy also furnished an aircraft, fitted with a microwave refractometer (AN/AMH-3), which flew the same vectors as the MRI aircraft. The aircraft flight tests were conducted during four days over a two-week period. During the remainder of the two-week time, the WVR was used to conduct various other tests and develop operational techniques.

IV. Results

Reductions and analysis of the data taken at El Monte showed that several problem areas existed, some equipmental and some operational.

Equipment difficulties encountered were: poor LO stability on the 18-GHz channel, unstable match on the LO select switch, calibration load match uncertainties, and calibration load radiometric temperature uncertainties.

Operations at El Monte demonstrated the need to better understand the nature of how water is distributed in the air, and the best way to measure this phenomenon for use as a range correction. Based on this, the instrument was upgraded to correct the deficiencies mentioned above, and the tests at Pt. Mugu were conducted.

The Pt. Mugu data are presently being reduced and will be reported in the near future. Preliminary examination shows much improved stability over previous data.

References

1. Waters, J., "Atmospheric Effects on Radio Wave Phase and the Correction of Vapor-Caused Phase Fluctuations by Radiometric Measurements of Water Vapor Emission," VLA Scientific Memo No. 8. National Radio Astronomy Observatory, Charlottesville, Va., September 15, 1967.
2. Webster, W. J., "On the Determination of Atmospheric Path Length by Passive Microwave Radiometer," X-922-75-107. Goddard Space Flight Center, Greenbelt, Md., May 1975.
3. Staelin, D. H., et al., "The Nimbus-E Microwave Spectrometer," *The Nimbus-5 Users Guide*, Goddard Space Flight Center, November 1972.
4. Staelin, D. H., et al., "The Scanning Microwave Spectrometer Experiment," *The Nimbus-6 Users Guide*, Goddard Space Flight Center, February 1975.
5. Batelaan, P. D., et al., "A Noise-Adding Radiometer for Use in the DSN," *The Deep Space Network*, Space Programs Summary 37-65, Vol. II, Jet Propulsion Laboratory, Pasadena, Calif., September 1970.

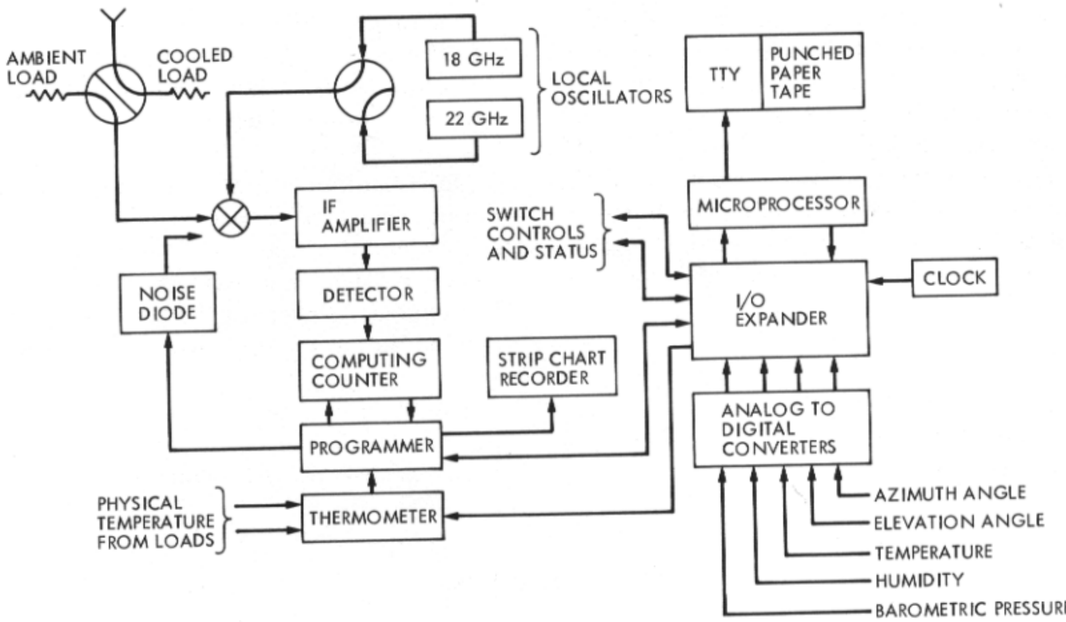

Fig. 1. Block diagram of developmental Water Vapor Radiometer

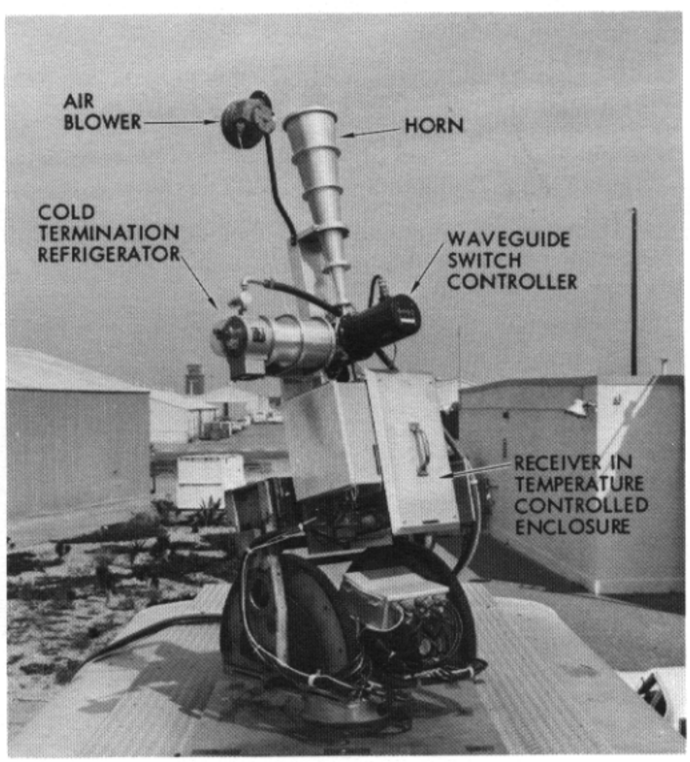

Fig. 2. The Water Vapor Radiometer. In the background is the Pt. Mugu Flight Control Tower

Fig. 3. The Water Vapor Radiometer mounted on its trailer for field testing

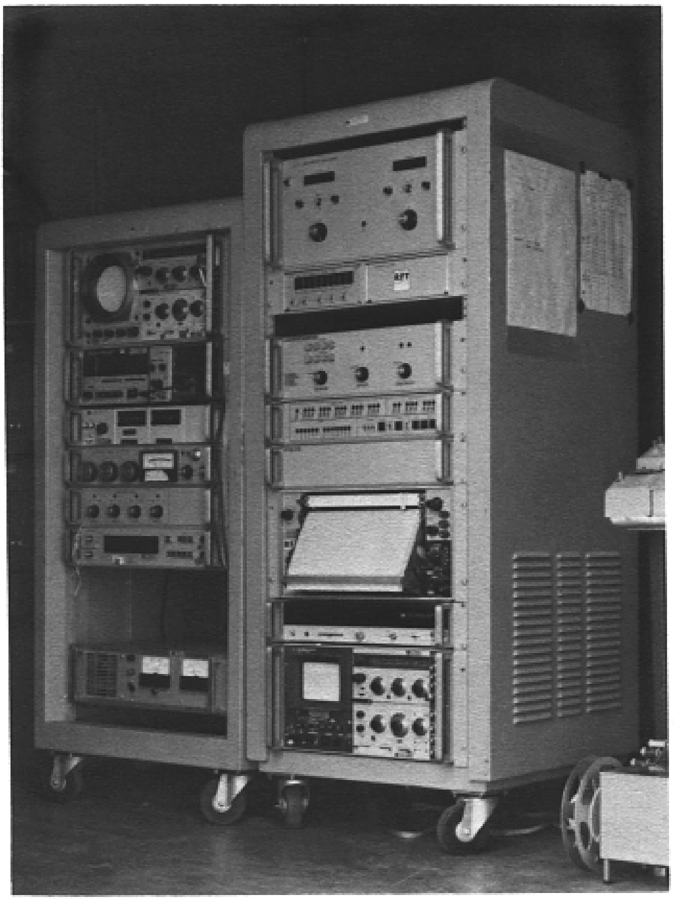

Fig. 4. Control monitor and recording equipment for the Water Vapor Radiometer located inside trailer

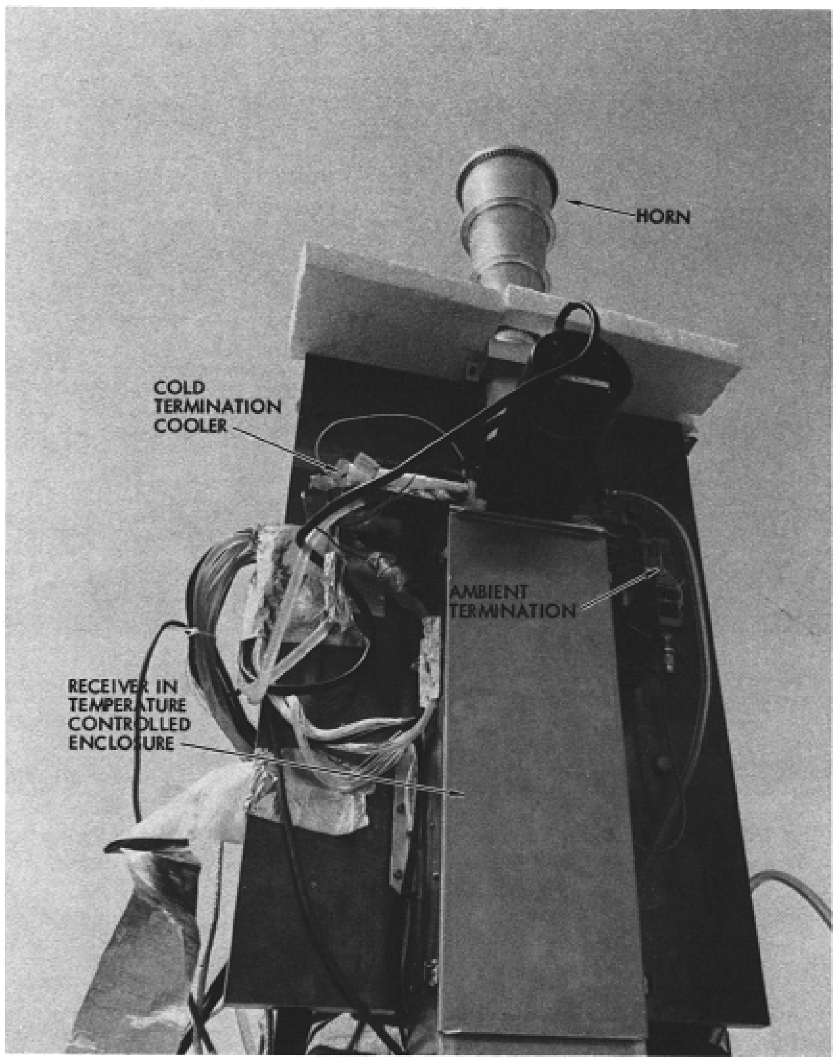

Fig. 5. The Water Vapor Radiometer configured for the May 1975 tests at El Monte Airport

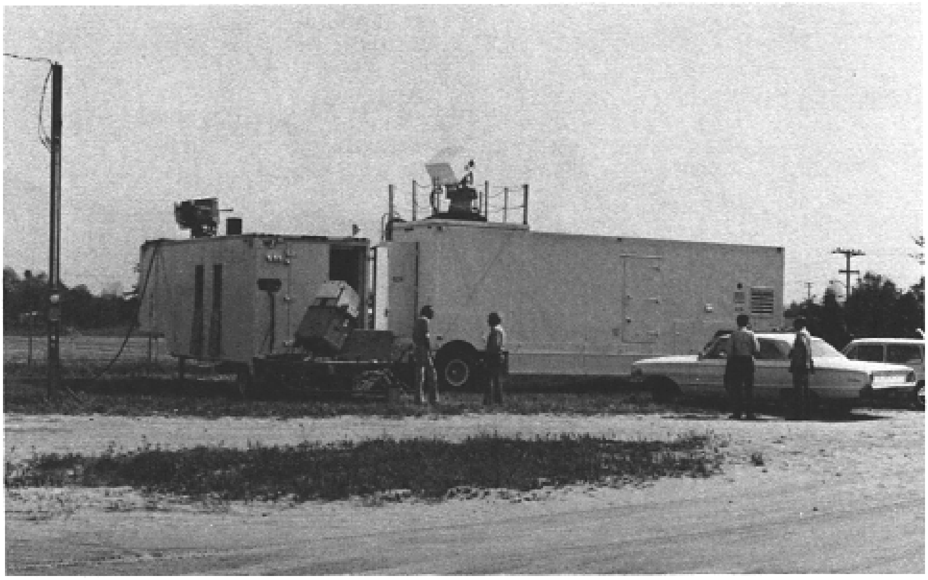

Fig. 6. The Telecommunications Division Water Vapor Radiometer and the Space Sciences Division SMILE and NEMS Radiometers (left to right) at El Monte Airport