X-Band Narrow-Beam Radiometer for DSS 13

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A narrow-beam X-band (8.448 GHz) radiometer has been designed, constructed, and tested at JPL. This radiometer will be operated at the Goldstone Deep Space Station (DSS 13). Continuous calibration is obtained by switching the receiver sequentially among the hot termination, ambient termination and antenna positions. The measured antenna noise temperatures (10-second total integration time) have a standard deviation of about 0.4 K, which is in good agreement with theory. It is felt that radiometer performance is satisfactory for the purpose of making atmospheric noise temperature measurements.

I. Introduction

A narrow-beam X-band (8.448 GHz) radiometer has been designed, constructed, and tested at JPL. This radiometer will be installed and operated at the Goldstone Venus Deep Space Station (DSS 13) for the purpose of making atmospheric microwave noise temperature measurements. The radiometer input is automatically switched among a hot termination, ambient termination, and the antenna. This system will augment the wide-beam X-band measurements of atmospheric noise temperature also made at DSS 13 (Refs. 1 and 2). These measurements are used to generate statistics of noise temperature increase above baseline values for use in Deep Space Network communication-link design tables. This report describes the radiometer and gives an example of performance based on preliminary JPL test data.

II. Radiometer Description

The antenna used for the narrow-beam system is a 6-foot-diameter (1.8-meter) dish with a focal-point feed (Fig. 1). This antenna will have a beamwidth of 1.4 degrees; the existing wide-beam system has a beamwidth of 15 degrees. A metal shroud, lined with absorbing material, surrounds the aperture of the dish. This addition is purported to give both low sidelobes and to minimize any changes in system noise temperature due to scattering and spillover effects. Antennas of the type described here are used commercially in horizontal line-of-sight applications, and the shroud may or may not be an advantage in the DSS 13 application where the antenna nearly always points upward at an elevation angle of 30 degrees or more. Antenna pattern and noise temperature tests will be made both with and without the shroud installed on the antenna.

The radiometer electronics package is mounted on the back of the antenna structure (Fig. 2), which itself is mounted on an elevation over azimuth positioner. Figure 3 shows the block diagram of the radiometer. This radiometer is continuously calibrated by switching the receiver sequentially among the hot termination, ambient termination, and antenna positions. The receiver consists of an 8.448 GHz mixer and a 10-100

MHz IF amplifier with appropriate gain to interface with the square-law detector (Refs. 3-5).

III. Radiometer Calibration

The programmer (Fig. 3) controls the switching sequence and continuously calculates the antenna noise temperature. This calculation utilizes the output of the square-law detector and the appropriate termination physical temperatures. Antenna noise temperature is computed from

$$T_A = T_{AMB} - \left(\frac{T_{HOT} - T_{AMB}}{V_{HOT} - V_{AMB}}\right)(V_{AMB} - V_{ANT}) \quad (1)$$

where

T_{AMB} = radiometric noise temperature of ambient termination, K

T_{HOT} = radiometric noise temperature of hot termination, K

V_{HOT} = detector output when switched to the hot termination, V

V_{AMB} = detector output when switched to the ambient termination, V

V_{ANT} = detector output when switched to the antenna, V

The radiometer gain, $(T_{HOT} - T_{AMB})/(V_{HOT} - V_{AMB})$K/V, is continuously monitored to assess radiometer performance. The physical temperature of the hot termination is not generally its radiometric noise temperature. The radiometric noise temperature of the ambient termination is equal to its physical temperature if all lossy elements of the termination and associated waveguide are at the same physical temperature. The correction for the hot termination is found by means of tipping curve measurements. T_{HOT} in Eq. (1) is adjusted to correct the antenna temperatures as determined at various elevation angles.

IV. Radiometer Analysis

The resolution (1σ) of a radiometer measurement is obtained from Eq. (1)

$$\sigma_{T_A} = \sqrt{\left(\sigma_{T_{A,TP}}\right)^2 + \left(\frac{T_{AMB} - T_{ANT}}{T_{HOT} - T_{AMB}}\right)^2 \left(\sigma_{T_{HOT,TP}}\right)^2 + \left(\frac{T_{HOT} - T_{ANT}}{T_{HOT} - T_{AMB}}\right)^2 \left(\sigma_{T_{AMB,TP}}\right)^2} \quad (2)$$

where

$\sigma_{T_{A,TP}}$ = total power radiometer resolution when switched to the antenna, K

$= \dfrac{T_{op,A}}{\sqrt{B\tau}}$

$\sigma_{T_{HOT,TP}}$ = total power radiometer resolution when switched to the hot termination, K

$= \dfrac{T_{op,HOT}}{\sqrt{B\tau}}$

$\sigma_{T_{AMB,TP}}$ = total power radiometer resolution when switched to the ambient termination, K

$= \dfrac{T_{op,AMB}}{\sqrt{B\tau}}$

T_{ANT} = antenna noise temperature, K,

and

T_{op} = total system noise temperature on any signal source, K

B = IF bandwidth, Hz

τ = measurement integration time, sec

Substituting the above (and using T_{ANT} = 10 K, T_{AMB} = 310 K, T_{HOT} = 425 K, $\tau \cong 10$ sec, and B = 10 MHz) into Eq. (2) results in a theoretical antenna noise temperature measurement resolution (σ_{T_A}) of approximately 0.4 K.

V. Radiometer Performance

Atmospheric noise temperature tipping curves have been performed during radiometer tests at JPL. The data taken on September 21, 1981 are reported here. The sky was clear, the ground relative humidity was 55% and the ground temperature was 32°C. The tipping curves were performed by moving the antenna between zenith and 30° elevation.

The radiometer was switched to each termination position for approximately 10 secs. The calibration sequence takes ≅40 secs. These data are shown in Fig. 4.

The standard deviation of the antenna noise temperature measurements at zenith is approximately 0.4 K, which agrees closely with theory. The separately averaged temperatures ($\approx$20 min) at zenith agree with each other within 0.2 K, which is reasonable for this data since the atmosphere itself may have changed during the two-hour test period. It is felt that radiometer performance is satisfactory.

An analysis of Fig. 4 indicates several calibration problems which need to be solved. First, the zenith antenna temperature values average around 1.6 kelvins. This is clearly in error, since the cosmic background contribution is 2.7 kelvins and a generally accepted clear sky atmospheric contribution is about 2.5 to 2.8 kelvins, for a total of approximately 5.5 kelvins. Ground and waveguide contributions may add another 5 kelvins for a minimum total expected antenna temperature of about 10 kelvins. This error is clearly due to the use of the hot termination physical temperature instead of a calibrated radiometric noise temperature, and an unmodelled ground and waveguide contribution. A clue to ground contribution is seen from the approximately 3.3-kelvin differences between zenith and 30-degree noise temperatures. Since the atmospheric path length increases by one atmosphere (from 1 to 2 atmospheres) in the tipping curve method, a 2.5- to 2.8-kelvin noise temperature would be expected. The excess noise temperature is probably due to increasing ground contribution and will be modelled to obtain a total radiometer calibration. The corrections will be incorporated into Eq. (1).

Acknowledgment

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References

1. Reid, M. S., Parham, O. B., and Gardner, R. A., "An X-Band Radiometer for the Microwave Weather Project," *DSN Progress Report 42-29*, pp. 54-59, Jet Propulsion Laboratory, Pasadena, Calif.

2. Slobin, S. D., Stelzried, C. T., Andres, E. M., and Franco, M. M., "X-Band Atmospheric Noise Temperature Statistics at Goldstone, DSS 13, 1979 and 1980, and Clear Air Noise Temperature Models for Goldstone," *TDA Progress Report 42-64*, pp. 161-167, Jet Propulsion Laboratory, Pasadena, Calif., August 15, 1981.

3. Reid, M. S., Gardner, R. A., and Stelzried, C. T., "A New Broadband Square Law Detector," Technical Report 32-1526, Vol. XVI, pp. 78-86, Jet Propulsion Laboratory, Pasadena, Calif., August 15, 1973.

4. Reid, M. S., Gardner, R. A., and Stelzried, C. T., "Improvement in the Accuracy of the New Broadband Square Law Detector," Technical Report 32-1526, Vol. XVIII, pp. 94-98, Jet Propulsion Laboratory, Pasadena, Calif., December 15, 1973.

5. Gardner, R. A., Stelzried, C. T., and Reid, M. S., "Radiometric Applications of the New Broadband Square Law Detector," Technical Report 32-1526, Vol. XIX, pp. 89-92, Jet Propulsion Laboratory, Pasadena, Calif., February 15, 1974.

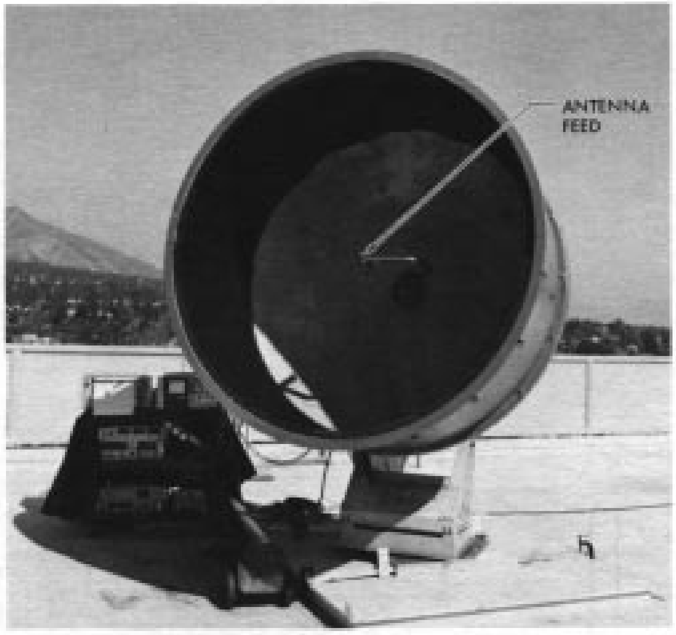

Fig. 1. Narrow-beam X-band radiometer (front view)

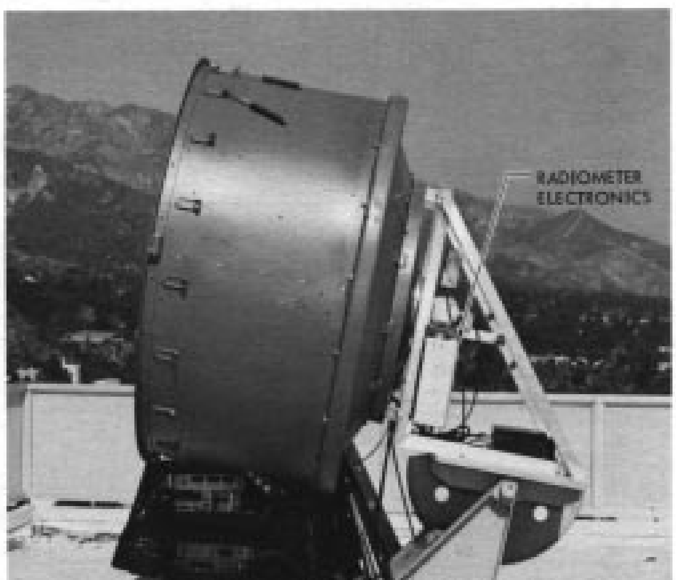

Fig. 2. Narrow-beam X-band radiometer (side view)

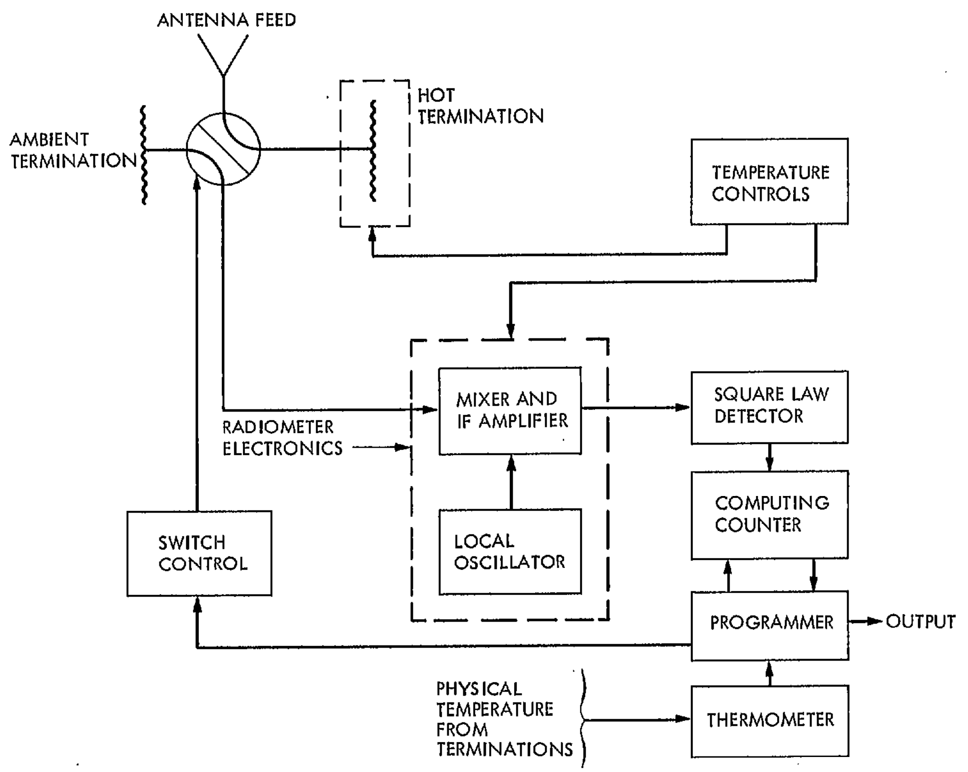

Fig. 3. Block diagram of the narrow-beam X-band radiometer

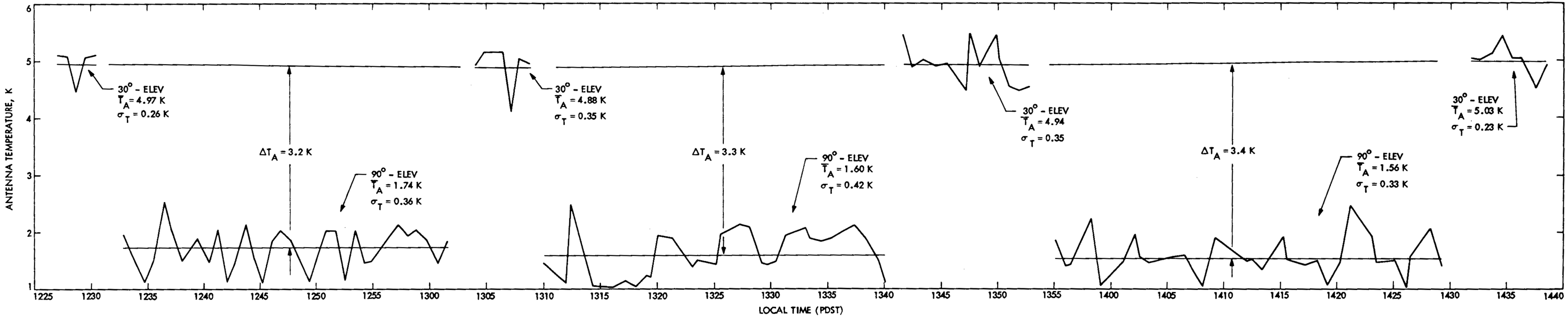

Fig. 4. Antenna noise temperature measurements performed at JPL, September 21, 1981 with the narrow-beam X-band radiometer