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NOISE TEMPERATURE MEASUREMENT OF 40-FOOT AND 85-FOOT STADAN REFLECTOR ANTENNAS

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Charles E. H. Edward and Paul A. Lantz

February 1965

Goddard Space Flight Center
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ABSTRACT

A portable solid-state Dicke radiometer for use at 1.7 and 4.0 Gc is described. One application of this device to the measurement of the noise temperature of 40- and 85-foot reflector antennas is discussed. It is shown that measured values of temperatures fall within theoretical bounds.

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INTRODUCTION

This document reports the results of a program undertaken to measure the equivalent noise temperature of several STADAN parabolic reflector antennas. The program included the development of a portable "Dicke" radiometer, the study of techniques employed in radiometric measurement, and the measurement of the Rosman I 85-foot diameter antenna at 1700 Mc and the Mojave project 40-foot diameter antenna at 4000 Mc.

Table 1 summarizes the corrected measured zenith antenna noise temperatures and lists several system parameters based upon these values. The table shows that improvement in the present antenna noise temperature could greatly increase the operation range, or signal-to-noise ratio. The measured values should be considered to be representative of the particular antenna sites and at the time of measurement, because antenna noise temperature varies with antenna pointing direction, sun activity, weather, etc. Blake[1] has computed typical minimum and maximum antenna temperatures due to cosmic variation. Nomographs developed by Blake show that the temperature of the Rosman antenna can be expected to vary from 98°K to 180°K at 1700 Mc while the Mojave antenna temperature can be expected to vary from 77°K to 165°K, at 4000 Mc.

BRIEF DESCRIPTION OF THE RADIOMETER

The Advanced Development Division developed a solid-state portable "Dicke" radiometer, under contract NAS5-3291 with the Philco Corporation, for measurement of STADAN antenna noise temperatures. The resultant radiometer (Philco Model WDL-1D-183) includes a remote-control and readout unit, a replaceable radio-frequency head which allows selection of the test frequency (1700 or 4000 Mc), and a battery pack for portable operation. Figure 1 shows the radiometer block diagram. Figures 2 and 3 are pictures of the unit.

[1]Blake, L. V., Antenna and Receiving System Noise-Temperature Calculation, NRL Report 5668, 50 pp., September 19, 1961.

Table 1
Antenna Performance Based on Measured Temperature, Zenith Elevation

ANTENNA	PRESENT ANTENNAS			PROJECTED IMPROVEMENT (Based on $T_a = 20°K$)	
	Measured Noise Temperature at Zenith (T_a)	Corresponding Noise Sensitivity at Zenith	Corresponding Maximum Range ($P_t = 1$ watt) ($G_r = 50$ db) ($G_t = 0$ db)	Sensitivity Limit	Maximum Range ($P_t = 1$ watt) ($G_r = 50$ db) ($G_t = 0$ db)
40-foot Mojave antenna (4000 Mc)	80°K	-112 dbm	23,750 KM	-118 dbm	46,500 KM
85-foot Rosman I antenna (1700 Mc)	116°K	-110 dbm	44,400 KM	-118 dbm	109,500 KM

The radiometer is a conventional superhetrodyne receiver preceded by an RF switch which alternately selects the input signal and a reference noise source (a coaxial load in an oven). This RF switch is a four-port ferrite circulator driven at 80 cycles per second. A calibrating source is provided by immersing another coaxial load in a dry ice bath. This noise source is used in calibrating the instrument prior to making a measurement. The two signals are fed directly to a balanced crystal mixer without prior RF amplification. A balanced crystal mixer is used to minimize noise from the local oscillator source. The local oscillator frequency is driven from a crystal-controlled oscillator via a harmonic generator chain (not shown in Figure 1). Signals are next fed to the transistorized IF amplifier operating at 30 Mc with a nominal bandwidth of 6 Mc. After amplification, the square-law detector converts the noise difference between the two signals to a voltage difference. The audio amplifier then amplifies the signal to a suitable level for the correlation detector to determine the noise difference between the two inputs. Input and reference signals are separated by the synchronizing switch driver which synchronizes the correlation detector with the circulator and provides the driving signal to the circulator driver, which in turn actuates the circulator. The correlation circuitry integrates the received information over the duration of selected time constants (0 - 30 seconds). Difference in noise temperature between the reference and unknown input is displayed directly in degrees Kelvin on the antenna temperature readout meter.

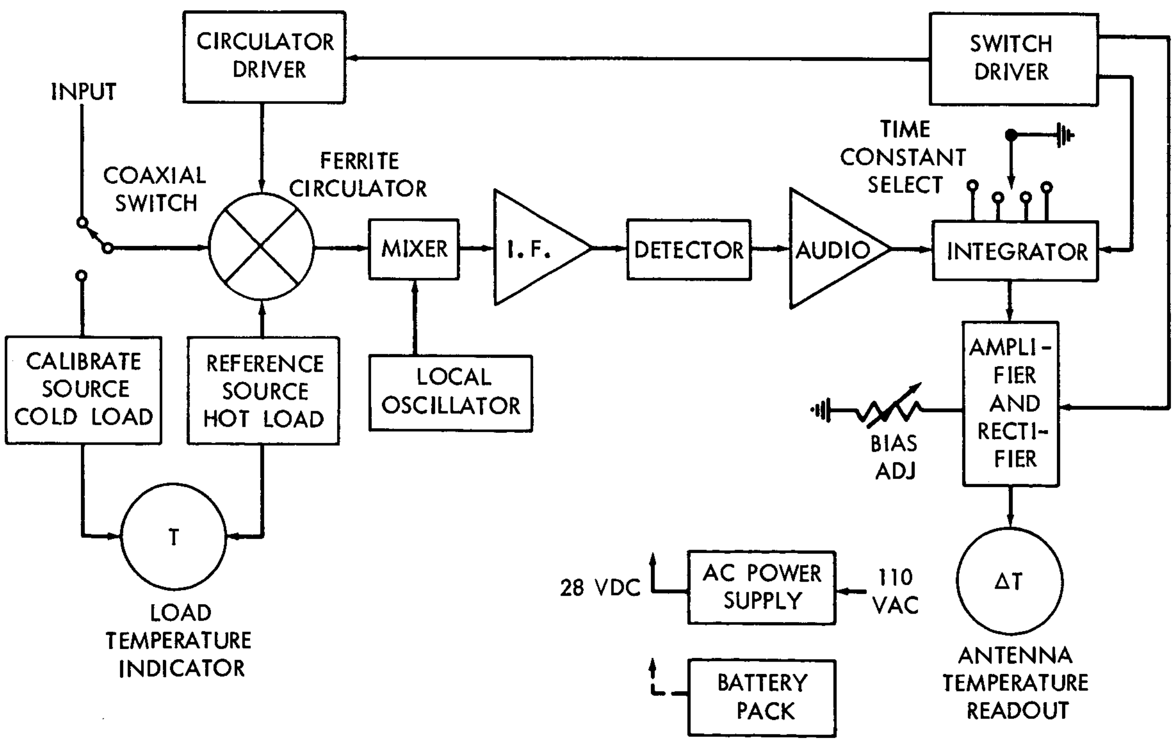


Figure 1—Radiometer Block Diagram

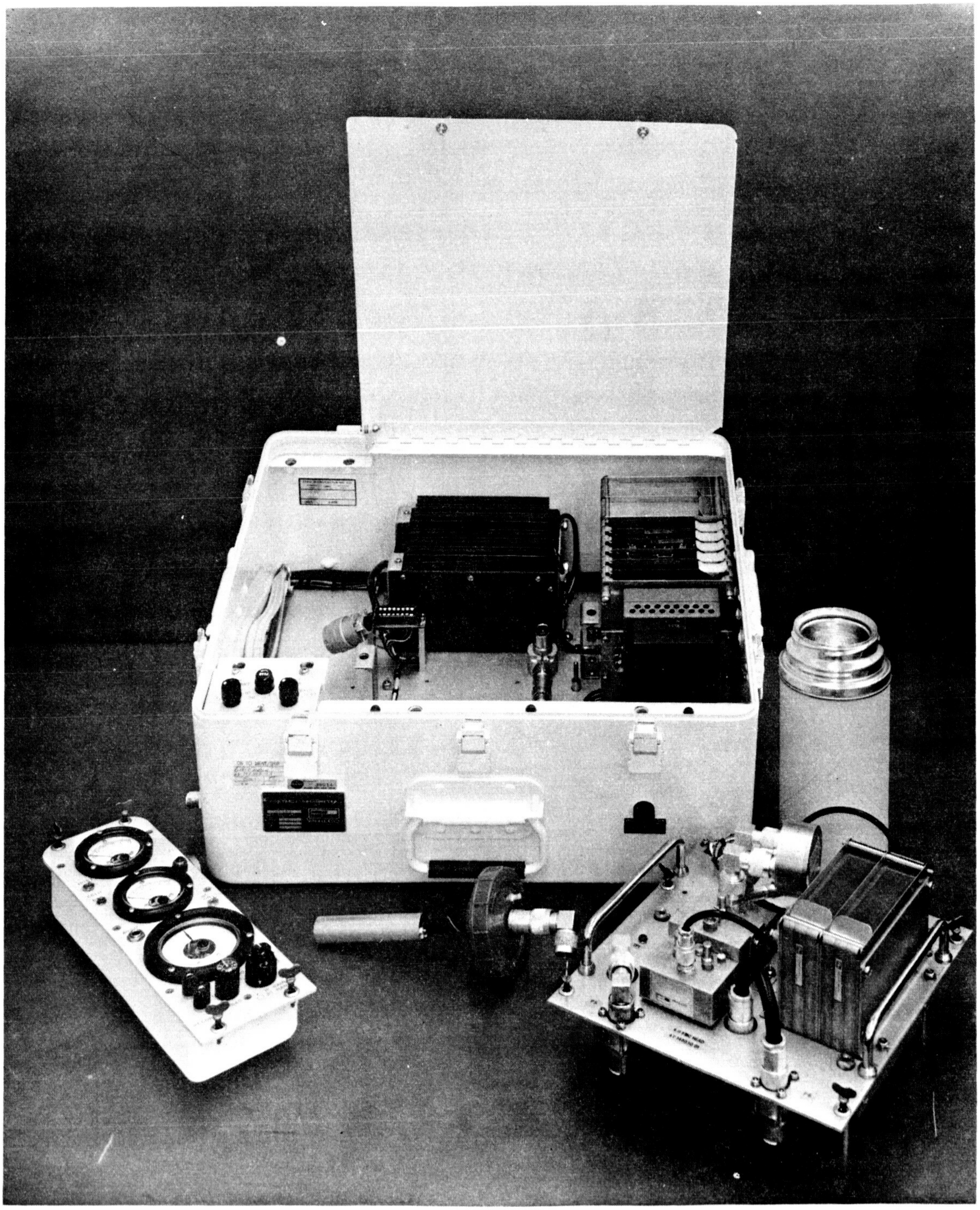


Figure 2–Radiometer (Unpackaged)

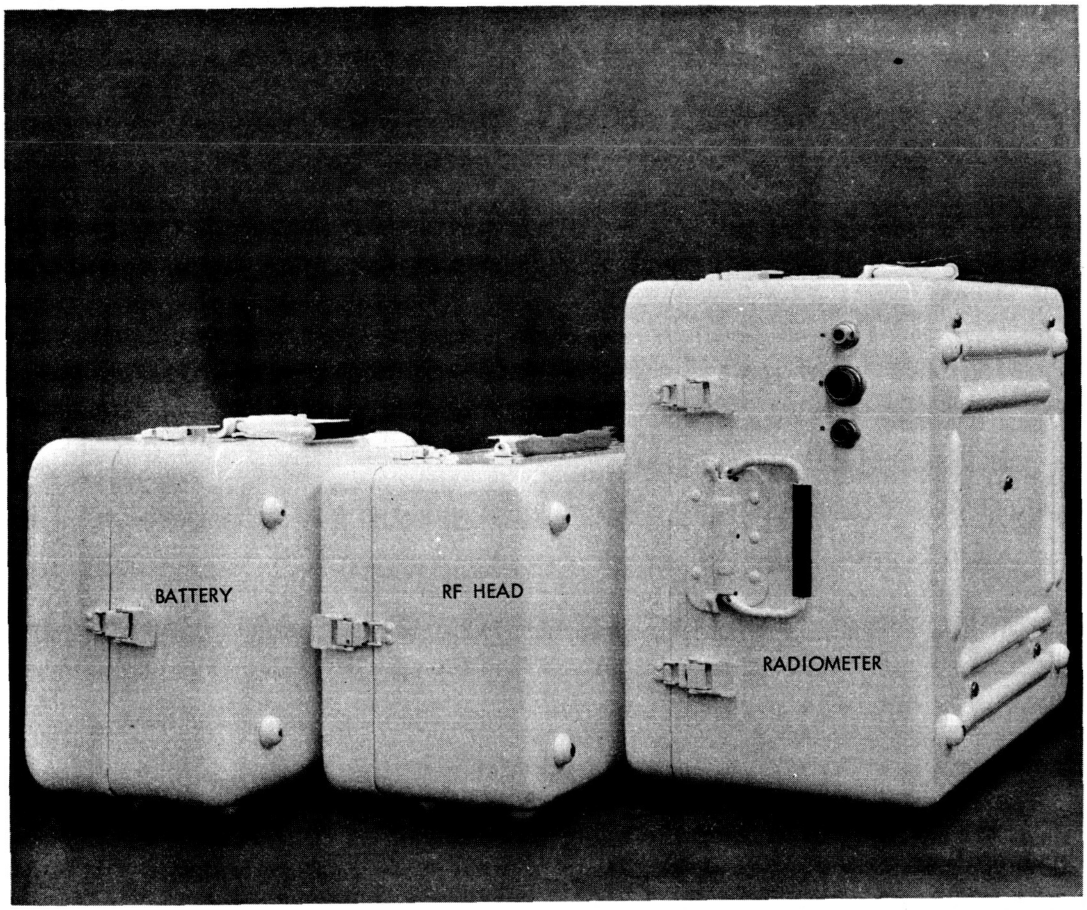


Figure 3–Radiometer (Packaged)

The radiometer electrical characteristics are:

1.	Frequency	Double sidebands centered at 1675 and 1735 Mc, and 4050 and 4110 Mc
2.	Sensitivity	2°K at 10-second integration time
3.	Maximum differential input signal	500°K
4.	Bandwidth	6 Mc
5.	Integration times	0.1, 0.3, 1.0, 3.0, 10, and 30 seconds

MEASUREMENT PROCEDURE

The procedure employed in these measurements is to connect the radiometer to the feed element to be measured by a short piece of calibrated cable. Data are recorded on the ground by using interconnecting instrumentation cable between the feed and the portable readout box. A permanent record of the noise-temperature difference and the reference oven temperature is recorded on dual-channel recording paper. The radiometer is calibrated by injecting noise voltage from a termination buried in subliming dry ice through a mechanical input selector. The intermediate frequency amplifier gain is adjusted to provide a direct reading of the temperature difference between the dry ice load and a reference termination maintained at 60°C. After calibration, the input is switched to the feed element and the noise temperature observed is recorded. Recalibration and repeated readings ensure minimum instrumentation and procedural error. The results to date indicate a probable error of ± 5°K, using an integration time of 1 second. After the data has been recorded, the antenna effective noise temperature is calculated and corrections are made for transmission line losses. The values presented in the tables are the antenna noise temperatures referred to the antenna input terminals.

NOISE TEMPERATURE OF MOJAVE ANTENNA

The Mojave project 40-foot diameter parabolic antenna (X-Y mount) equivalent noise temperature was measured during the week of January 6, 1964. This antenna is located in the Mojave Desert near the Goldstone Deep Space Instrumentation Facility. The weather was clear and temperatures ranged from 40°F to 70°F during the tests.

Figure 4 shows a block diagram of the antenna feed with radio frequency losses. The radiometer was connected in the system by breaking the waveguide in the sum line at point "D" and inserting a waveguide to coaxial transition and a length of transmission line.

The measurement procedure employed was to point the antenna to zenith, to calibrate the system with a built-in calibration load immersed in a dry ice bath, and to record the zenith temperature for several minutes. The antenna was then positioned in 10-degree elevation and azimuth steps to obtain the site survey shown in Figures 5, 6, and 7. The data shown in these figures are the uncorrected readings at the radiometer.

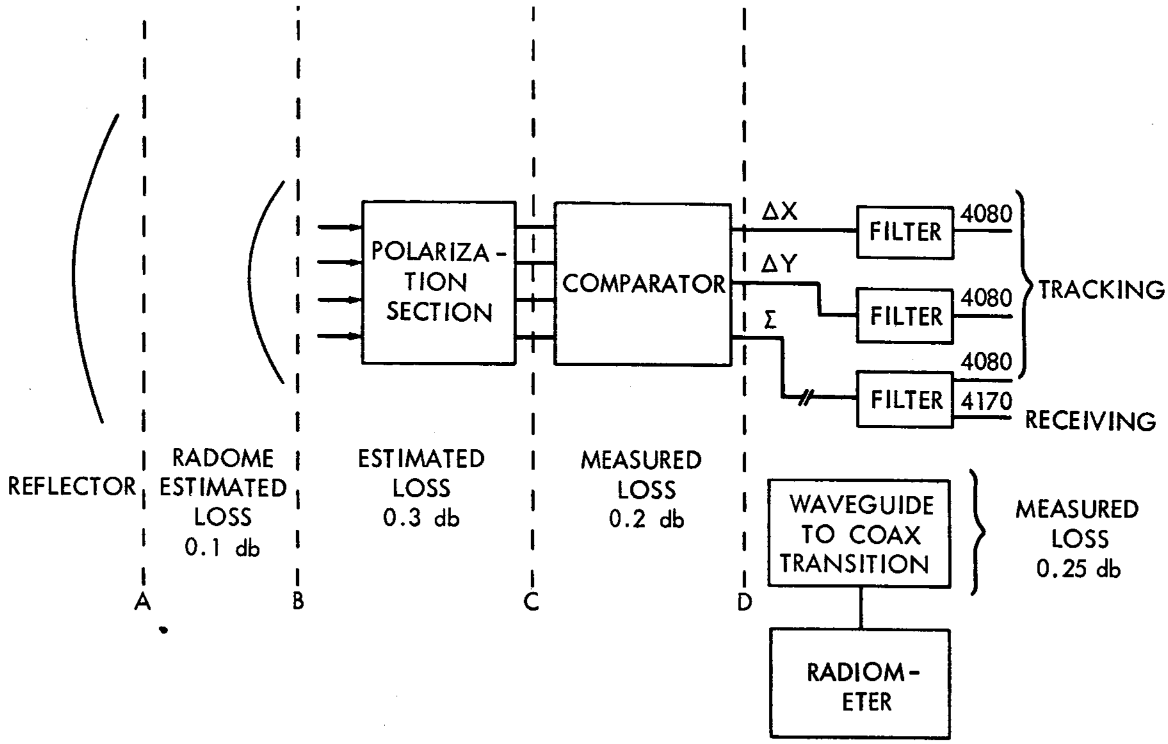


Figure 4—Mojave Antenna Feed Block Diagram

Table 2 presents the corrected, weighted average values referred to the feed input. These measurements have a probable error of ± 5°K. Table 2 shows that two values are given for antenna temperature at 80-degrees elevation during the day test. This is because of the pronounced asymmetry shown in the temperature plots (Figures 5, 6, and 7) which is especially pronounced at 80 degrees elevation. Temperature asymmetry is known to be a result of high-edge illumination and resultant spillover on one edge of the reflector. Edge illumination is 16 db down on one edge of the reflector and 19 db down on the other edge. The corrections applied and the methods for correction for radio frequency losses are discussed in Appendix 1.

Table 2
Weighted Average Temperature at Feed Input 40-Foot Mojave Antenna

Elevation Angle (degrees)	0 Zenith	10	20	30	40	50	60	70	80	90 Horizon
Day Test (°K)	80	66	87	92	82	59	62	62	23/99	201
Night Test (°K)	74	75		62		66		87		

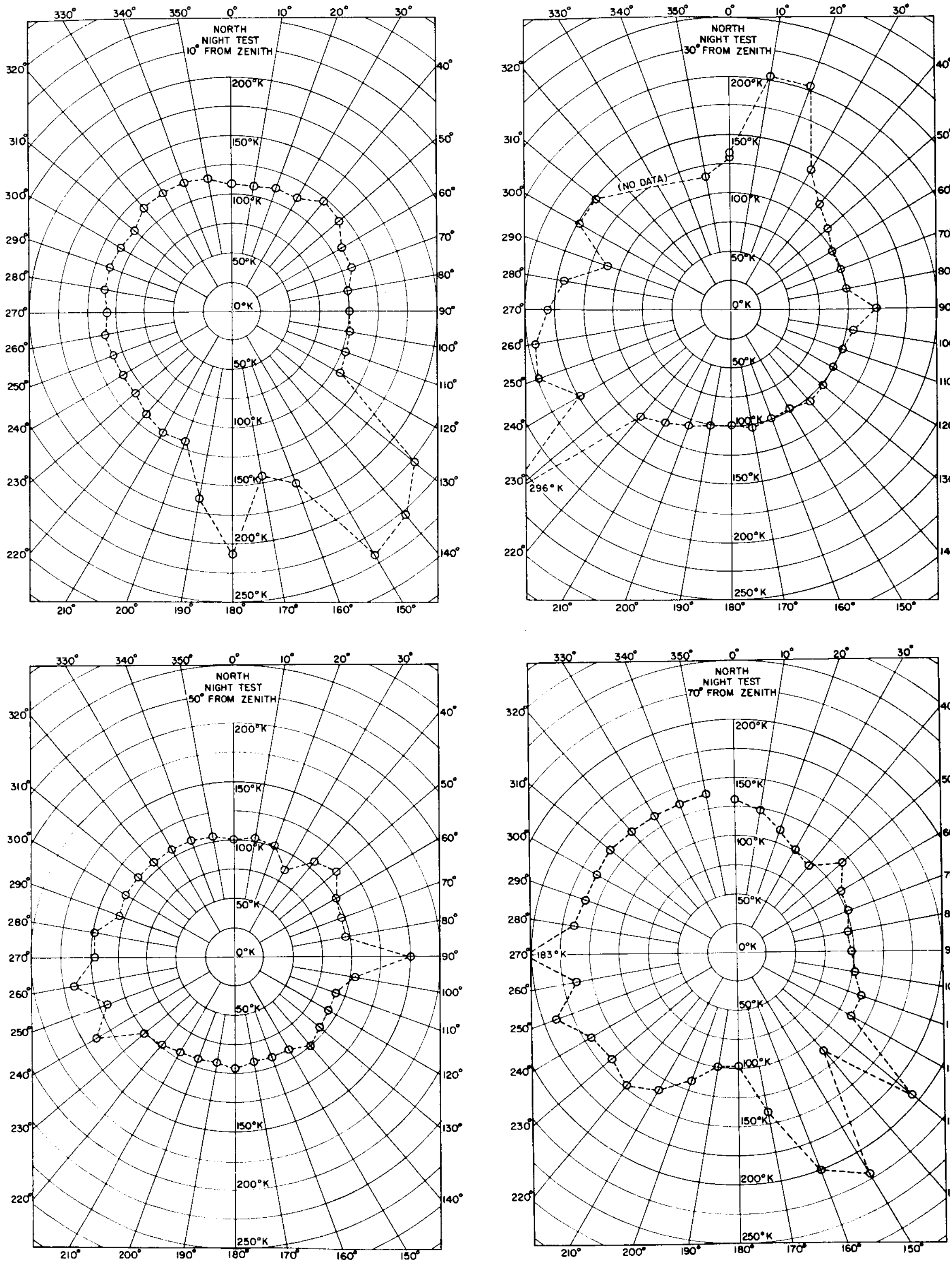


Figure 5—Mojave Antenna Noise Temperature Site Survey (Night Test)

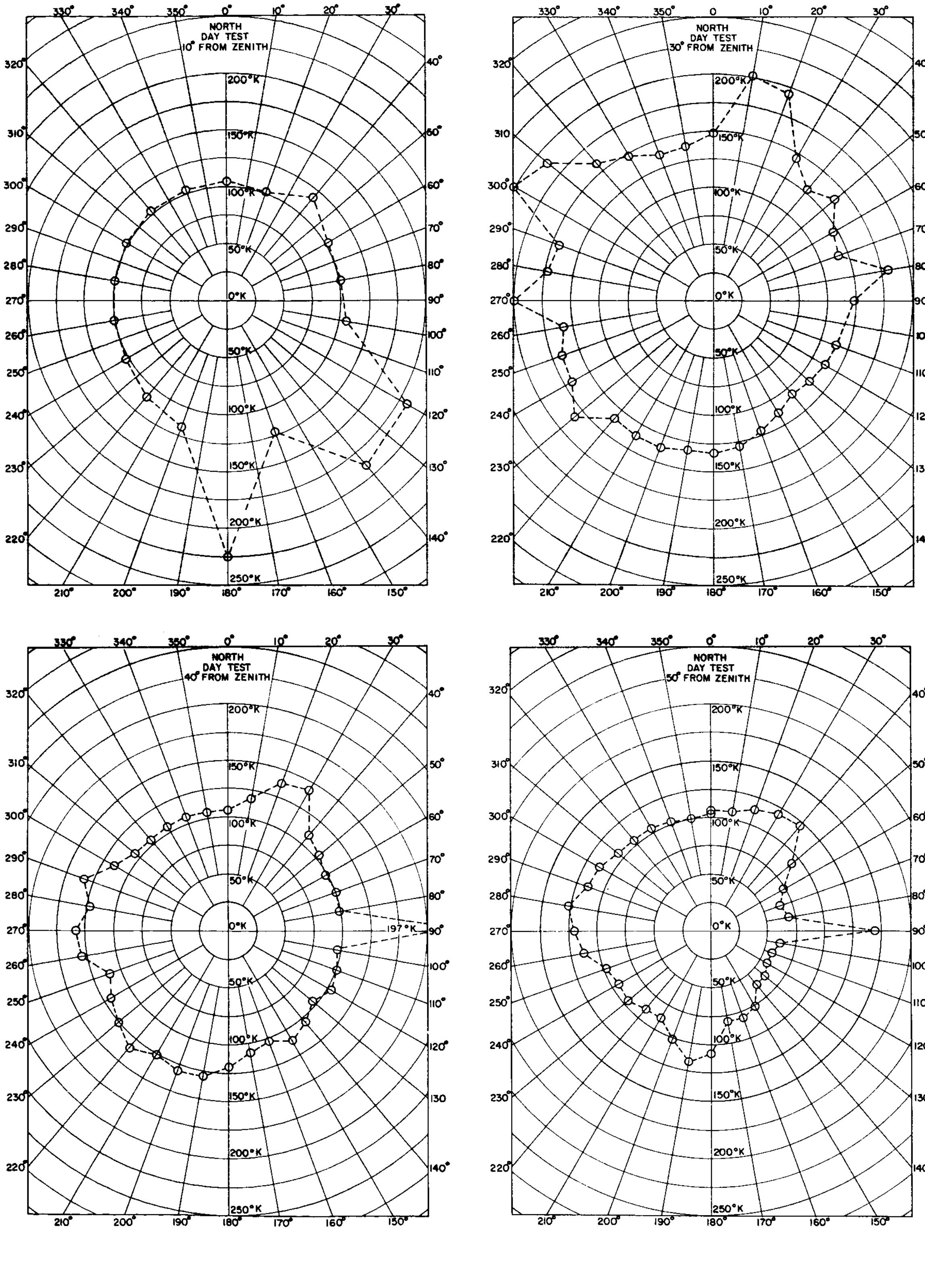


Figure 6–Mojave Antenna Noise Temperature Site Survey (Day Test to 50°)

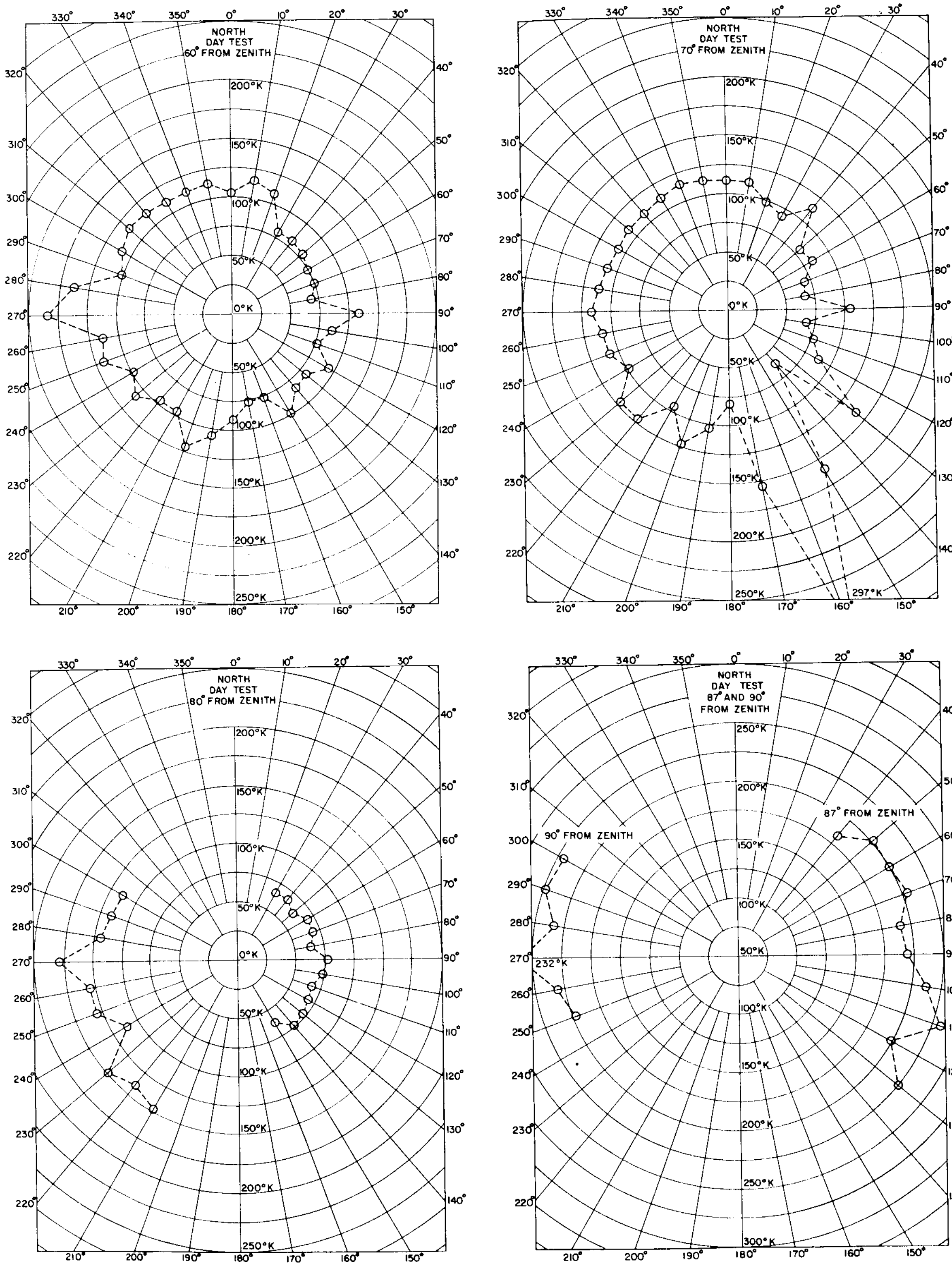
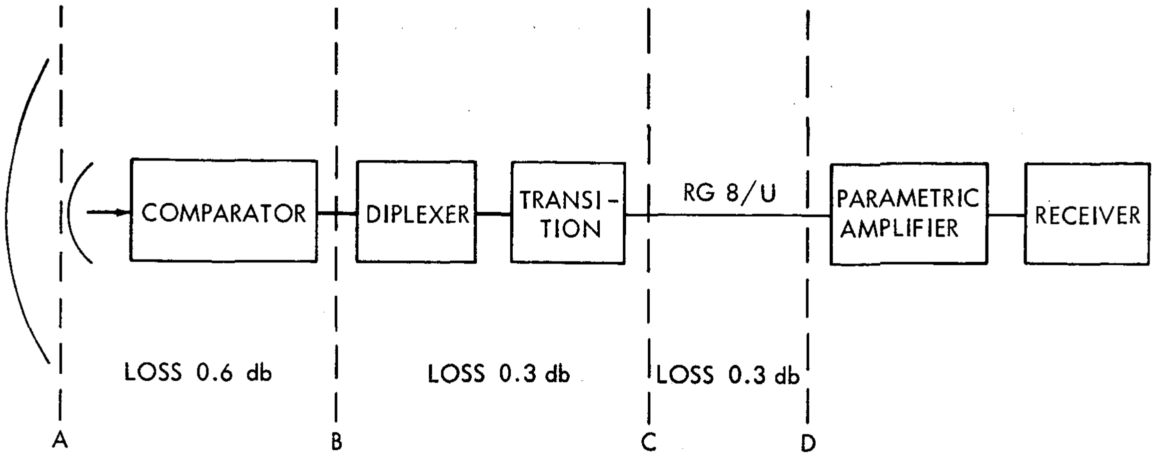


Figure 7—Mojave Antenna Noise Temperature Site Survey (Day Test to 90°)

Noise figure readings for the Mojave receiver were taken by L. W. Nicholson, GSFC, by inserting a calibrated noise source looking toward the receiver at points "B", "C", and "D" (Figure 8). The results of these measurements verified the losses shown and established a receiver noise temperature, T_e, of 370°K. System sensitivity based on these readings is -102 dbm. NOTE: The parametric amplifier was not cooled for these tests.



$$T_{system} = \frac{T_a}{L_r} + T_r + T_e$$

(SEE APPENDIX FOR SYMBOLS AND EXPLANATION)

$$= \frac{80°K}{1.318} + 290°K \left(1 - \frac{1}{1.318}\right) + 370°K$$

$= 501°K$ referred to point "D"

$= 660°K$ referred to point "A"

Figure 8—Measurement of Mojave Receiver Noise Figure

ROSMAN I ANTENNA NOISE TEMPERATURE

The antenna noise temperature of the Rosman I 85-foot diameter antenna (X-Y mount) was measured during the week of August 24, 1965. This antenna is located in mountainous forest terrain in western North Carolina about 30 miles from Ashville. The weather was mostly clear with temperatures between 70°F and 90°F.

Figure 9 shows the antenna feed structure block diagram with computed losses as before. The radiometer was connected to the sum 1 output as shown to prevent breaking the sealed feed package. Antenna noise temperature was measured by pointing the antenna to zenith, calibrating the system, and recording the temperature by repetitive measurements over a period of several minutes. Readings were taken randomly selected displacements of the X and the Y axis.

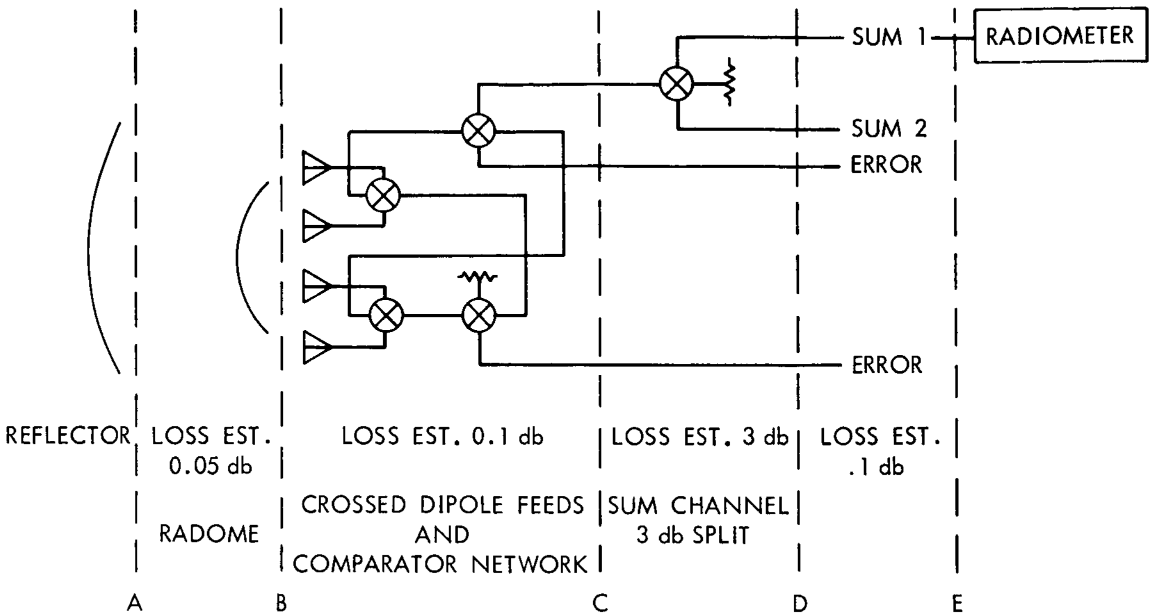


Figure 9–Analysis of Feed Losses

Table 3 shows the corrected, weighted average values referred to the feed input. These measurements have a probable error of ±5°K. Correction for radio-frequency losses is discussed in the Appendix. The site survey of this antenna location is not presented because the 3-db loss introduced in the hybrid network allowed insufficient resolution for meaningful data.

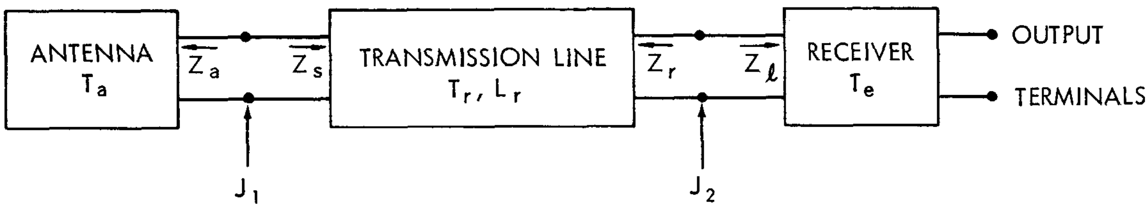
Table 3
Weighted Average Temperature at Feed Input 85-Foot Rosman Antenna

Elevation Angle (degrees)	0 Zenith	10	20	30	40	50	60	70	80	90 Horizon
Corrected Measured Value (°K)	116	123	124	123	125	127	131	137	145	223

APPENDIX A

NOISE TEMPERATURE CORRECTION FOR TRANSMISSION LINE LOSS

The antenna noise temperature as measured includes contributions due to the feed element transmission line and processing circuits. A general receiving system is diagrammed below.



The antenna is characterized by an effective noise temperature, T_a, and an internal impedance Z_a. The transmission line is characterized by an input impedance Z_s, and output impedance Z_r, a power loss factor L_r, a thermometric temperature T_t, and an effective noise temperature T_r. The receiver is characterized by an input impedance Z_ℓ and an effective noise temperature T_e which is related to its noise factor $\overline{F}$. The power loss factor of the transmission line, L_r, acts to reduce the amount of antenna noise power reaching the receiver input terminals; hence, the contribution of the antenna temperature to the system noise temperature is T_a/L_r. The transmission line will generate thermal noise, T_r, in its ohmic elements which also contributes to the system noise temperature. The various noise temperatures are given by the equations:

$$T_{system} = \frac{T_{antenna}}{L_r} + T_r + T_e \qquad (1)$$

$$T_r = \left(1 - \frac{1}{L_r}\right) T_e \qquad (2)$$

$$T_e = (\overline{F} - 1)\,To \quad \text{where } To = 290°K \qquad (3)$$

The system noise temperature given above refers to terminals J_2. Solving for T_a, we obtain:

$$T_a = L_r T_{system} - (L_r - 1) T_e - L_r T_e \tag{4}$$

which is the antenna temperature referred to terminals J_1.

The radiometer was used to measure the system temperature, T_{system}, at terminal J_2. These measured values of antenna noise temperature presented in the tables have been corrected for the transmission line losses according to the procedure above. These values represent the antenna equivalent noise temperature at the output of the antenna terminals J_1. The treatment employs the concepts of available power, available gain, and available loss which make the explicit discussion of impedances unnecessary. A more detailed discussion of these equations is given in Blake[2].

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[2]Blake, op. cit.