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PPM/NAR 8.4-GHz Noise Temperature Statistics for DSN 64-Meter Antennas, 1982–1984

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From August 1982 through November 1984, X-band downlink (8.4-GHz) system noise temperature measurements were made on the DSN 64-m antennas during tracking periods. Statistics of these noise temperature values are needed by the DSN and by spacecraft mission planners to assess antenna, receiving, and telemetry system needs, present performance, and future performance. These measurements were made using the DSN Mark III precision power monitor noise-adding radiometers located at each station. It is found that for DSS 43 and DSS 63, at the 90% cumulative distribution level, equivalent zenith noise temperature values fall between those presented in the earlier (1977) and present (1983) versions of DSN/Flight Project design documents. Noise temperatures measured for DSS 14 (Goldstone) are higher than those given in existing design documents and this disagreement will be investigated as a diagnostic of possible PPM or receiving system performance problems.

I. Introduction

The precision power monitors (PPMs) installed on the three DSN 64-m antennas use a noise-adding radiometer (NAR) to monitor the system noise temperature, and a signal level estimator (SLE) to monitor the spacecraft signal level. Descriptions of these instruments will be published in the *TDA Progress Report* in the future. A description and analysis of NAR operation are given in Refs. 1 and 2. Over the two-year period from August 1982 through November 1984, over 240,000 system noise temperature measurements were made using the NARs during spacecraft tracking periods. While noise temperature variations are primarily due to weather effects, these variations may also be indicative of problems in the microwave/receiver systems. Thus, the PPM can serve as a useful real-time diagnostic indicator of station performance.

During Mark IV implementation, the three 64-m DSN stations were not operational for the full period of August 1982 through November 1984. The valid data periods for the stations are as follows:

DSS 14: September 1982–June 1983
DSS 43: August 1982–September 1984
DSS 63: August 1982–November 1984

Because of the shorter data collection period, DSS 14 statistics may not be directly comparable to those of DSS 43 and

DSS 63. In particular, the months of July and August (which are missing) are characterized by high absolute humidity and thunderstorm activity.

Typically, an NAR determines system operating noise temperature (T_{OP}) by pulsing a noise diode on and off and injecting this square-wave noise into the main signal channel of the receiving system. In the DSN application described above, a typical noise diode modulation rate is 10 Hz and the injected noise is typically ~1 K. Two fundamental equations govern NAR operation. They are, for T_{OP}:

$$T_{OP} = T_N/(Y - 1) \tag{1}$$

where

T_{OP} = system operating noise temperature, K (defined at system input reference plane)

T_N = noise diode injected noise temperature, K (defined at system input reference plane)

$Y = (V_2 + \alpha V_2^2)/(V_1 + \alpha V_1^2)$, ratio

V_2 = detector output voltage, noise diode on, V

V_1 = detector output voltage, noise diode off, V

α = detector nonlinearity constant, V^{-1} (= 0 in an ideal detector)

and for noise temperature resolution:

$$\Delta T_{OP} = 2T_{OP}(1 + T_{OP}/T_N)/\sqrt{\tau B} \tag{2}$$

where

τ = measurement time, s

B = predetection bandwidth, Hz

For DSN operational use, the value of this injected signal level (T_N) is kept low to avoid contamination of the very low system noise temperature (~20–25 K). On the other hand, for high resolution (small ΔT_{OP}), a large value of T_N is required.

In operation, the PPM performs the following steps to determine T_{OP}:

(1) The PPM switches the waveguide system to an ambient load (~300 K) and calibrates a large (~50 K) noise diode according to

$$T_N = T_{OP,\text{amb}}(Y - 1) \tag{3}$$

and

$$T_{OP,\text{amb}} = T_P + T_E \tag{4}$$

where

$T_E = T_M + T_F$ (equivalent noise temperature of the receiver, K)

T_M = maser noise temperature, K

T_F = followup receiver noise temperature, K

T_P = physical temperature of ambient termination, K.

(2) The PPM switches the waveguide out the horn and uses the calibrated 50 K noise diode to determine T_{OP} on the cold sky according to Eq. (1).

(3) Knowing the sky T_{OP}, the PPM chooses a smaller operational noise diode to give a T_{OP} resolution (ΔT_{OP}) of 0.1 dB (2.33%) of the value determined in Step (2).

Thus, for example, if cold sky T_{OP} is determined to be 40 K, the required ΔT_{OP} is 0.93 K, and the T_N chosen for operational use will have a value somewhat greater than 0.35 K for an integration time of 10 seconds and a bandwidth of 10^7 Hz. In this case, a 0.5 K noise diode would be chosen. This amount of injected noise will not seriously degrade receiving system performance.

Clearly, an inaccurate calibration of the large noise diode when looking at the ambient load will result in errors in determining T_{OP}. A possible source of calibration error is due to receiver nonlinearities (saturation) at large T_{OP} (>300 K). In this case, the measured Y factor will be smaller than it should be, and the value of T_N determined from Eq. (3) will thus be too low. This will ultimately result in a lower than actual determination of T_{OP} according to Eq. (1).

II. Data Reduction

Tapes of PPM data were generated monthly for each 64-m station. Only the X-band data were analyzed, as S-band weather effects are minimal and contribute insignificantly to increased system noise temperature. The data contained numerous PPM diagnostics and antenna tracking parameters, including date, time, spacecraft identification, maser assembly number, receiver assembly number, system noise temperature, standard deviation of T_{OP}, and antenna pointing (local hour-angle and declination). For each data point, antenna azimuth and elevation values were calculated based on the station's latitude and the local hour-angle and declination of the spacecraft. Each data point (typically one every 40 seconds) was examined for validity according to the following criteria:

(1) T_{OP} between 10 K and 300 K.

(2) Nonzero local hour-angle and declination.

(3) A changing (nonstuck) hour-angle.

(4) Elevation greater than 3 deg.

(5) Spacecraft declination in the range of +60 deg to -60 deg.

(6) Standard deviation of T_{OP} between 0 and 2 K.

Short of invoking overly sophisticated logic or hand-picking the data points, it was felt that the six criteria above would sort out the vast majority of bad data points. Of the 282,547 total points recorded, 37,715 (or 13.35%) were discarded as failing one or more of the above criteria. Table 1 shows the percentage of points taken on each spacecraft and the percentage of points taken in each 10-deg elevation-angle interval.

Initial inspection of the histogram of noise temperature values showed a small cluster of points between 10 and 14 K for DSS 14, and an "abnormal looking" distribution between 17 and 20 K for DSS 63. In each of these cases, the data points were discarded. They amounted to 1.5% and 3% of the totals, respectively. No adjustment of this sort was made for the DSS 43 data points.

An attempt was made to create a zenith noise temperature model from the elevation-angle (nonzenith) points in the raw data. A 1/sin(elevation) model was used. The method was as follows:

(1) The lowest T_{OP} value in each station's valid data was assumed to be the best weather and highest elevation angle point of the test period.

(2) From the value above, a zenith ground noise contribution (3 K) and zenith clear sky atmosphere contribution were subtracted. The remainder is the constant antenna noise contribution due to the horn, waveguide, maser, and cosmic background contribution (considered to be constant over a wide range of conditions).

(3) An equivalent zenith system noise temperature ($T_{OP,90}$) is calculated according to the equation

$$T_{OP,90} = T_{OP,\theta} (\sin \theta) - \Delta T_{ground} - (T_{const} + T_{ground,\theta}) (\sin \theta - 1) \qquad (5)$$

where

$T_{OP,\theta}$ = T_{OP} at elevation angle θ (raw data)

ΔT_{ground} = decrease in ground contribution when moving to zenith

= $T_{ground,\theta} - 3.0$

T_{const} = constant antenna contribution determined in Step (2)

$T_{ground,\theta}$ = $3.0 + 5.0\ [(90 - \theta)/90]$

This technique attempts to create a uniform condition (zenith-looking) by which the three 64-m antennas can be compared.

III. Results

Figure 1 shows the probability density function (histogram) of the X-band system noise temperature for the three 64-m stations. The integral of the PDF, over all noise temperatures, is by definition 1.0. In the data set presented here, all data points below 20 K have been removed as described above.

Note that DSS 43 shows a narrower range of system noise temperatures than do the other two stations. This does not necessarily indicate that "better weather" existed at DSS 43. Because of the preponderance of Voyager-related points (and Jupiter, Saturn, and Uranus have had significant southerly declinations for the past several years), DSS 43 would have tracked generally at higher elevation angles than the other two sites. This high elevation bias would result in lower atmospheric noise temperature values, even during clear sky conditions.

Figure 2 shows the cumulative distribution (CD) of system noise temperature (the integral of the histograms in Fig. 1) at the three 64-m sites. These CDs are for all valid data and represent a mix of elevation angles, spacecraft, and tracking periods. If one were to blindly infer weather statistics from these curves, it would appear that DSS 63 has the best weather, and DSS 14 the worst. At the 90% "confidence level" (CD = 0.90), the system noise temperatures are 44.5 K (DSS 14), 41.4 K (DSS 43), and 38.5 K (DSS 63). It must be reiterated that the three stations do not have similar distributions of elevation angle (see Table 1), and that data were not collected for a long enough time period to generate truly long-term statistics.

Figure 3 shows the equivalent zenith CDs for the distributions in Fig. 2. The method of generating these points is described in Section II. The equivalent zenith points for Fig. 3 were generated one by one; the distributions in Fig. 2 were not modified as a whole to create the zenith distributions. Also shown in Fig. 3 are system noise temperature CDs given in both the present (1983) and earlier (1977, "old 810-5") versions of DSN/Flight Project interface design documents[1]. The 810-5 curves are presented for comparison only; it is premature to attempt a replacement of the 810-5 models with the relatively short-term PPM measurements. The statistics of the older interface design documents are still being used in the Voyager telemetry prediction and performance (TPAP) computer program. It has been noted that the TPAP program, using the "old 810-5" model, generally predicts worse telemetry performance than is actually observed. Indeed, at the 90% confidence level (a commonly used performance reference point), the T_{OP} values at both DSS 43 and DSS 63 were predicted (old 810-5) to be higher than those measured by the PPM and higher than those predicted in the present version of the DSN/Flight Project design documents. At DSS 14, however, the measured PPM values appear to be substantially higher than both design-document models. If this is indeed an erroneous result, one possible explanation is that the short data gathering period (10 months) has somehow biased the data with worse than average weather conditions. Also, the method of creating the equivalent zenith model may be at fault, but then the zenith statistics at all stations would be wrong in the same way, not just those at Goldstone. Other possible sources of DSS 14 errors are receiver system linearity, unstable noise diode outputs, defective PPM operation, or systematic, incorrect operational calibration of the PPM. Further data collection and analysis using the Mark IV PPMs will help to resolve this question.

[1]*Deep Space Network/Flight Project Interface Design Handbook*, TDA document 810-5, Rev. D, TCI-40, Rev. B, pp. 1–31 (internal document), Jet Propulsion Laboratory, Pasadena, Calif., 1977 and 1983.

IV. Conclusions

Several years of system noise temperature data were collected using the noise-adding radiometers in the PPMs at the three DSN 64-m stations. At the 90% confidence level, it is seen that the equivalent zenith T_{OP} measurements made by the PPM fall between the earlier (1977) DSN/Flight Project Interface Design Document model (used for Voyager) and the more "optimistic" model developed in 1983. The zenith results presented for Goldstone (DSS 14) show substantially higher T_{OP} values than either the 1977 or 1983 models. The cause of this is presently unknown, but may be related to the short period of data recording. Qualitative observations of weather at the three 64-m sites indicate that Goldstone has the most benign weather conditions and should experience the lowest noise temperature increases. The resulting statistics, then, are puzzling, and may indicate problems with the PPM itself, the receiving system, or with certain operational procedures. These problems will be fully investigated in order to guarantee reliable and accurate data output from these instruments in the future.

References

1. Batelaan, P. D., Goldstein, R. M., and Stelzried, C. T., "A Noise Adding Radiometer for Use in the DSN," *Space Programs Summary 37–65, Vol. II*, Jet Propulsion Laboratory, Pasadena, Calif., pp. 66–69.
2. Stelzried, C., "Noise Adding Radiometer Performance Analysis," *TDA Progress Report 42–59*, Jet Propulsion Laboratory, Pasadena, Calif., October 15, 1980, pp. 98–106.

Table 1. Fractional occurrence of spacecraft tracks and antenna elevation angle

Parameter	DSS 14	DSS 43	DSS 63	All Stations
Spacecraft				
12 (Pioneer 12)	0.0881	0.1307	0.0390	0.0773
23 (Pioneer 10)	0.0036	0.0034	0.0031	0.0033
24 (Pioneer 11)	0.0026	0.0001	0.0000	0.0005
26 (Viking Lander 1)	0.0001	0.0000	0.0000	0.00004
31 (Voyager 1)	0.4040	0.3163	0.4952	0.4213
32 (Voyager 2)	0.5015	0.5492	0.4627	0.4973
90 (Helios 1)	0.0001	0.0003	0.0000	0.0001
Elevation Angle, deg				
0 - 10	0.0336	0.0158	0.0392	0.0308
10 - 20	0.1467	0.1084	0.1940	0.1580
20 - 30	0.2098	0.1361	0.3023	0.2322
30 - 40	0.3249	0.1700	0.1866	0.2082
40 - 50	0.1011	0.2221	0.1012	0.1391
50 - 60	0.1124	0.1163	0.1667	0.1403
60 - 70	0.0705	0.1445	0.0096	0.0638
70 - 80	0.0009	0.0867	0.0005	0.0276
80 - 90	0.0000	0.0000	0.0000	0.0000
Point Count				
Total	49568	98433	134546	282547
Good	47516 (95.86%)	76820 (78.04%)	120496 (89.56%)	244832 (86.65%)
Bad	2052 (4.14%)	21613 (21.96%)	14050 (10.44%)	37715 (13.35%)

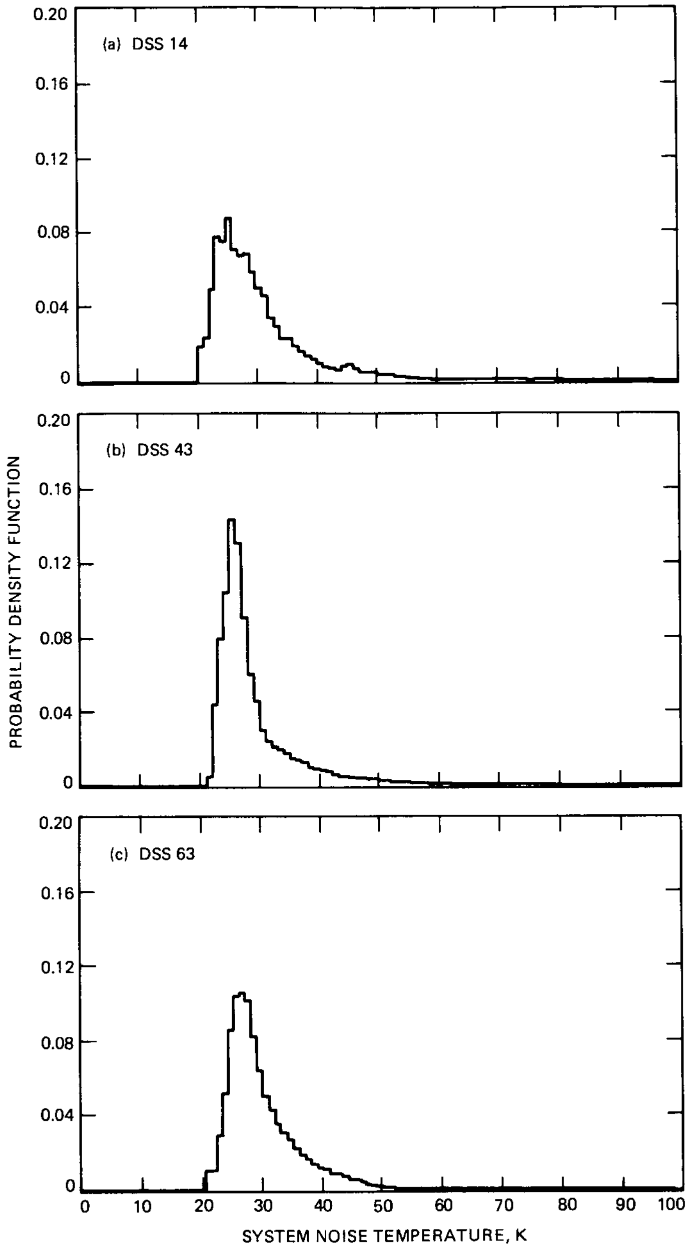

Fig. 1. X-band system noise temperature, probability density function (histogram)

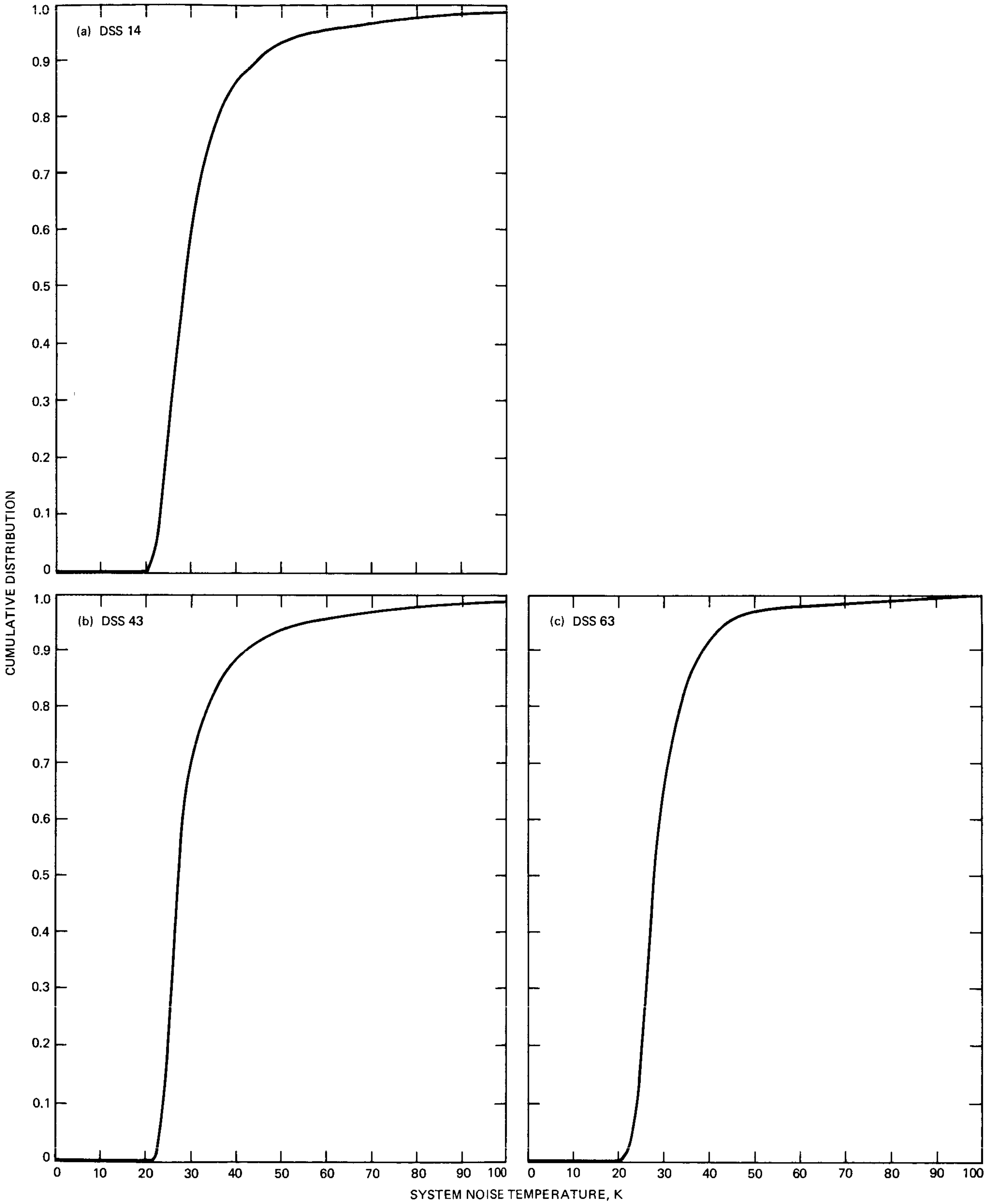

Fig. 2. X-band system noise temperature, cumulative distribution, all elevation angles

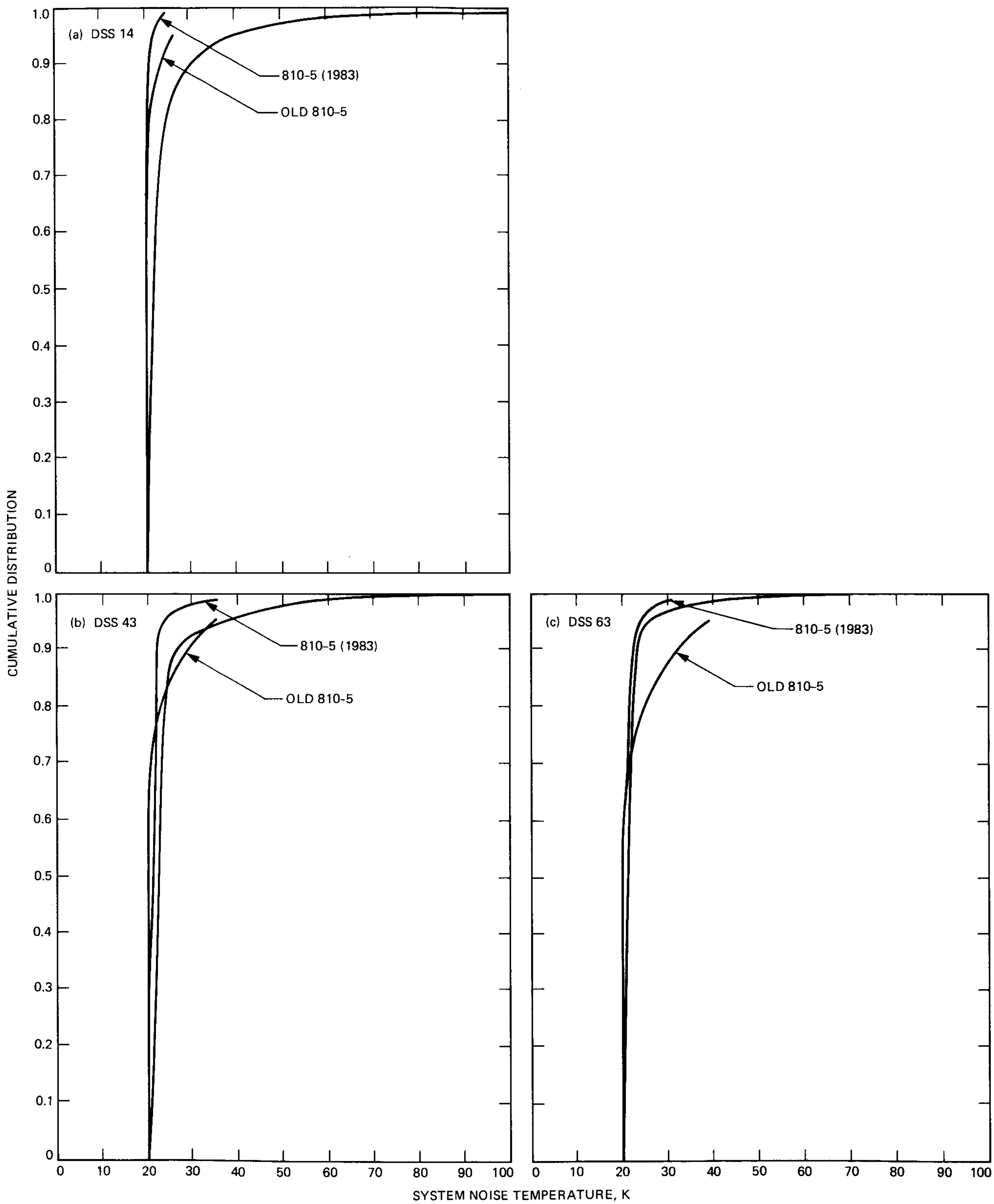

Fig. 3. Equivalent zenith X-band system noise temperature, cumulative distribution, with 810-5 models for comparison