RECOMMENDATION ITU-R S.733-1*

DETERMINATION OF THE *G/T* RATIO FOR EARTH STATIONS OPERATING IN THE FIXED-SATELLITE SERVICE

(Question ITU-R 42/4 (1990))**

(1992-1993)

The ITU Radiocommunication Assembly,

considering

a) that the primary figure of merit for earth stations operating in the fixed-satellite service is the ratio of the antenna power gain-to-system noise temperature (*G/T*);

b) that there are two commonly used methods for measuring earth station *G/T*, each of which has advantages for different situations and one method for its prediction,

recommends

1. that one method of measuring the ratio of antenna power gain-to-system noise temperature (*G/T*) is by the measurement of noise power emanating from a radio star, using the method explained in Annex 1;

2. that an alternative method for measuring this ratio is the measurement of a reference signal from a geostationary satellite, using the method explained in Annex 2;

3. that when neither of the methods explained are applicable, the ratio must be determined by a measurement of the antenna gain and an estimation of the system noise temperature;

4. that the following Notes should be regarded as part of this Recommendation.

Note 1 – The *G/T* of an earth station can be degraded by various naturally occurring processes. Increases in receiving noise temperature due to the atmosphere and precipitation, ground radiation and cosmic sources are treated in Appendix 1 to this Recommendation.

Note 2 – Information on determining the *G/T* of earth stations operating at frequencies greater than 10 GHz and the effects of various noise sources on the performance of earth stations operating in this frequency range is given in Annex 3 of this Recommendation.

Note 3 – The accuracy of the alternative method in § 2 depends on the measuring accuracy of the power flux-density of satellite emissions at the reference earth station, which is of the order of ±1 dB. Further information regarding *G/T* measurements of receiving systems is given in ex-CCIR Volume 1 (Monitoring of radio emissions from spacecraft at fixed monitoring stations) and IEC Publication 835 part 3.

ANNEX 1

Measurement of the *G/T* ratio with the aid of radio stars

1. Introduction

It is desirable to establish a practical method of measuring the *G/T* ratio with high accuracy, which will permit comparison of values measured at various stations. This Annex describes a method for the direct measurement of the *G/T* ratio using radio stars. It should be noted however, that the radio star method is not practical in certain cases (see § 5).

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* New version of CCIR Recommendation 733.

** Former CCIR Question 42/4.

2. Method of measurement

By measuring the ratio, *r*, of the noise powers at the receiver output, the *G/T* ratio can be determined using the formula:

$$\frac{G}{T} = \frac{8 \pi k (r - 1)}{\lambda^2 \Phi(f)} \qquad (1)$$

where:

k : Boltzmann's constant

λ : wavelength (m)

$\Phi(f)$: radiation flux-density of the radio star at frequency (f) at measurement (Wm^{-2} Hz^{-1})

r = $(P_n + P_{st}) / P_n$

P_n : noise power corresponding to the system noise temperature T

P_{st} : additional noise power when the antenna is in exact alignment with the radio star

G (antenna gain) and *T* (system noise temperature) are referred to the receiver input.

In equation (1), account is taken of the fact that the radiation of the star is generally randomly polarized and only a portion corresponding to the received polarization is received. The radiation flux-density $\Phi(f)$ is obtained by radio astronomical measurements.

This method has a basic advantage when compared with the calculation of *G/T* from *G* and *T* measured separately as only one relative measurement is necessary to determine the ratio, instead of two absolute measurements.

3. Suitable radio stars

The discrete radio sources Cassiopeia A, Cygnus A and Taurus A appear to be the most appropriate for measurements of *G/T* by earth stations. The flux-density of Cygnus A, however, may not be sufficient in every case.

The declination of all these radio stars is such that they may not be entirely suitable sources for earth stations situated in some southern latitudes.

Table 1 gives values of the flux-density of the radio stars indicated.

For the measurements at frequencies above 10 GHz, the use of the radio waves from planets, Venus for example, as well as above-mentioned radio stars could be advantageous. Flux-densities of the radio waves from planets increase with frequency and their solid angle is very small giving rise to negligible correction errors due to angular extension. The flux-density $\Phi(f)$ is expressed by:

$$\Phi(f) = \frac{4 \pi k \, Tb(f)}{\lambda^2} (1 - \cos \psi) \qquad (2)$$

where:

$Tb(f)$: brightness temperature of a planet (K)

ψ : semi-diameter.

The value of $\Phi(f)$ derived from equation (2), is substituted in equation (1) to obtain the value of *G/T* of an earth station. The value of ψ can be found elsewhere in American Ephemeris and Nautical Almanac (US Government Printing Office, Washington DC 20402). In the case of the planet Venus, the values $Tb(f)$ are thought to be about 580 K and 506 K at 15.5 and 31.6 GHz, respectively. Since the values of $Tb(f)$ are based on a limited amount of measured data at the frequencies mentioned, and have not yet been determined for other frequencies, further study is required to confirm and extend the results given here.

TABLE 1

Flux-densities from radio sources

Radio source	Cassiopeia A	Taurus A	Cygnus A
$\Phi(4)$ Flux-density at 4 GHz (Wm^{-2} Hz^{-1})	$1\,067 \times 10^{-26}$ (1)	679×10^{-26}	483×10^{-26}
$\Phi(f)$ Flux-density at f GHz	$\Phi(4)\left(\frac{f}{4}\right)^{-0.792}$ (1) (2)	$\Phi(4)\left(\frac{f}{4}\right)^{-0.287}$ (2)	$\Phi(4)\left(\frac{f}{4}\right)^{-1.198}$ (3)

(1) Value of January 1965 (see § 4.2).

(2) Where f is between 1 and 16 GHz. The formulae may be used provisionally up to 32 GHz.

(3) Where f is between 2 and 16 GHz.

4. Correction factors and assessment of errors

The corrected value of G/T is given by:

$$(G/T)_c = G/T + C_1 + C_2 + C_3 + C_4 \tag{3}$$

where:

C_1 : atmospheric absorption

C_2 : correction for angular extension of radio stars

C_3 : change of flux with time

C_4 : change of flux with frequency.

All factors to be given in decibels.

The value of atmospheric absorption C_1 can be estimated using § 2.2 of Recommendation ITU-R PN.676*.

4.1 Angular extension of radio stars

If the angular extension of the radio star in the sky is significant compared with the antenna beamwidth, a correction must be applied. This correction, C_2, is shown in Fig. 1.

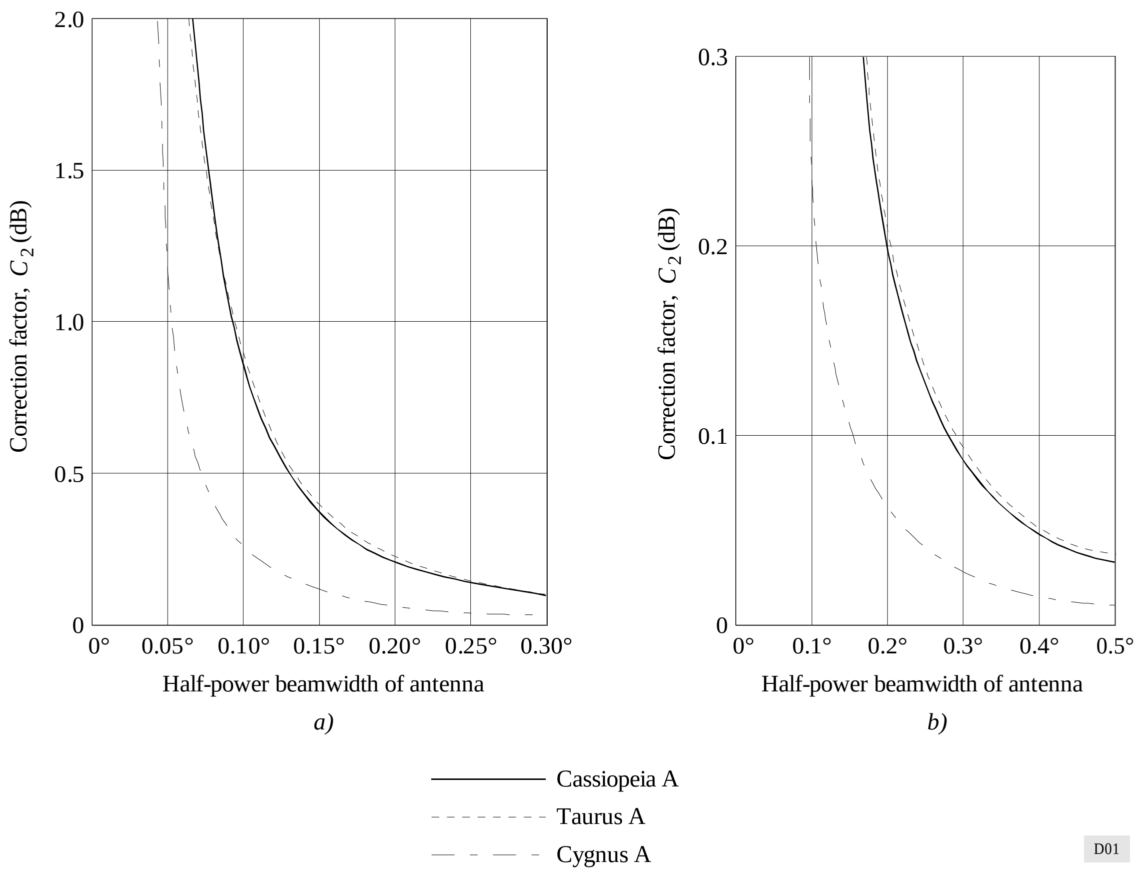
The curve for Cassiopeia A is calculated by numerical convolution of the observed brightness map with the antenna power pattern, approximated by a $(\sin x)/x$ function. The brightness distribution of Cassiopeia A can be well modelled by the annular distribution shape of which the inner diameter is 0.044° and the outer diameter is 0.071°, and the ratio of inner-to-outer brightness is 0.391. Using this model, the correction factor can also be calculated easily by combining two disc models for which the correction factor can be expressed by a conventional formula. The results using this model agree with a detailed calculation within an error of 0.06 dB.

The curves for Taurus A and Cygnus A have been obtained by the same method as that used for the curve for Cassiopeia A. The calculations were based on the high resolution brightness distribution maps observed at 5 GHz for Taurus A and observed at 5 GHz for Cygnus A.

* Former CCIR Recommendation 676.

FIGURE 1

Correction factor for the angular extent of radio stars



The measured brightness distribution for Cygnus A can be adequately described by a dual columnar shape with 0.02 min of arc in each column's diameter and 2.06 min of arc in angular distance.

If the annular model for Cassiopeia A and the dual columnar model for Cygnus A are adopted, a convenient approximation is available for the correction factor. These models may also be useful to measure the half-power beamwidth of antennas by observing the half intensity width of the drift curve. This also means that the correction factor for the angular extension of radio stars can be determined from the observed drift curve itself without the knowledge of the half-power beamwidth of the antenna.

4.2 Change of flux with time

Cassiopeia A is subject to a frequency dependent reduction of flux with time. The correction may be obtained from:

$$C_3 = (0.042 - 0.0126 \log f)\, n \qquad \text{dB} \qquad (4)$$

where:

n : number of years elapsed, with $n = 0$ in January 1965

f : frequency (GHz).

4.3 Change of flux with frequency

The variation of flux with frequency is also shown in Table 1.

4.4 Polarization effects

Taurus A is elliptically polarized and it is necessary to use the mean of two readings taken in two orthogonal directions. These precautions are not necessary for measurements using Cassiopeia A or Cygnus A.

4.5 Assessment of errors

The maximum relative error is given by:

$$\frac{\Delta\,(G/T)}{G/T} = \frac{\Delta\,\Phi(f)}{\Phi(f)} + \frac{\Delta r}{r} \times \frac{r}{(r\,-\,1)} \tag{5}$$

where errors in $\Phi(f)$ and r are considered.

The relative error which results from the measurement of the power ratio r is particularly marked when the star noise, P_{st}, is insufficient in relation to the system noise, P_n, because $r\,/\,(r - 1) \rightarrow \infty$ when $r = 1$. The measurement accuracy will be considerably reduced when r is less than 2 dB. This will occur at the following values of *G/T*:

Cassiopeia A	36 dB(K^{-1})
Taurus A	37 dB(K^{-1})
Cygnus A	39 dB(K^{-1})

If $r = 2.5$ (4 dB), for example, r must be measured to ±0.01 (0.05 dB) if the error term is not to exceed 0.02 (approximately 0.1 dB).

The error contribution due to:

$$\frac{\Delta\,\Phi(f)}{\Phi(f)}$$

is approximately 0.02. There is an additional uncertainty of ±0.01 in the corrections applied. Thus the total maximum error, for high elevation angles, is about 0.05 or approximately ±0.2 dB.

5. Limitations of the radio star method

The method described in this Annex has several disadvantages. These are:

– accuracy is not very good for smaller earth stations;

– the radio star method is not suitable for stations in the Southern Hemisphere where the stars are visible only at low elevation angles or not at all;

– tracking of the radio stars is required which may not be possible for stations with limited steerability.

APPENDIX 1

TO ANNEX 1

Contributions to the noise temperature of an earth-station receiving antenna

1. Introduction

The noise temperature of an earth-station antenna is one of the factors contributing to the system noise temperature of a receiving system, and it may include contributions associated with atmospheric constituents such as water vapour, clouds and precipitation, in addition to noise originating from extra-terrestrial sources such as solar and cosmic noise. The ground and other features of the antenna environment, man-made noise and unwanted signals, and thermal noise generated by the receiving system, which may be referred back to the antenna terminals, could also make a contribution to the noise temperature of the earth-station antenna. Numerous factors contributing to antenna noise, particularly those governed by meteorological conditions, are not stable and the resulting noise will therefore exhibit some form of statistical distribution with time. A knowledge of these factors and their predicted variation would be a valuable aid to earth-station designers, and there is therefore the need to gather information on the antenna noise characteristics of existing earth stations in a form which can best be interpreted for future use.

This Appendix presents results of antenna noise measurements made at 11.45 GHz, 11.75 GHz, 17.6 GHz, 18.4 GHz, 18.75 GHz and 31.65 GHz. From the results measured at 17.6 GHz and 11.75 GHz, cumulative distributions of temperatures have been derived together with the dependency of the clear-sky noise temperature on the elevation angle.

2. Measuring equipment

The antenna noise temperature measurements have been performed in the Netherlands using a series of radiometers equipped with a 10 m Cassegrain antenna fed by a corrugated horn. These measurements have also been performed in Japan using noise adding type and Dicke type radiometers equipped with 13 m and 10 m Cassegrain antennas, and an 11.5 m offset Cassegrain antenna.

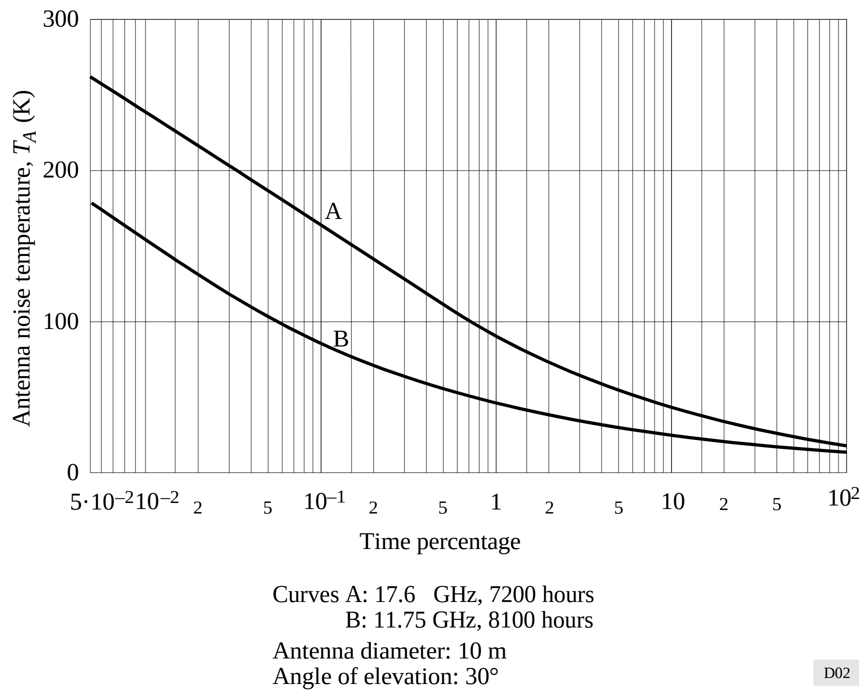
Noise measurements made in Germany were carried out on a 18.3 m diameter antenna using the *y*-factor method, under clear-sky conditions.

3. Results of measurements

Figure 2 shows the cumulative time distribution of the measured antenna noise temperature at 11.75 GHz and 17.6 GHz. The noise temperature shown in Fig. 2 is the value measured at the output flange of the feedhorn.

FIGURE 2

Measured antenna temperature as a function of the percentage of time each level was exceeded



The main contribution to the antenna noise temperature is caused by atmospheric attenuation. Other contributions are caused by cosmic effects and radiation from the ground.

The measurements presented in Fig. 2 have been performed at an angle of elevation of the antenna of 30°. The measurement period was between August 1975 and June 1977. The conditions during the measuring period can be considered as being typical for the local rain conditions.

Figure 3 shows the elevation dependence of the antenna noise temperature under clear sky conditions. The value of antenna noise temperature of Fig. 3 corresponds to those of Fig. 2 at the 50% time percentage. An analysis of the measurement results given in Fig. 3 showed that the antenna noise temperature consists of an elevation dependent part and a component which is roughly constant.

This constant part is formed by:

– cosmic background microwave radiation having a value of the order of 2.8 K;

– noise resulting from earth radiation. This contribution changes slightly with the angle of elevation of the antenna due to the side-lobe performance of the radiation diagram. A value of the order of 4 to 6 K is expected from this source;

– a noise contribution due to ohmic losses of the antenna system which is of the order of 0.04 dB. This component is expected to be 3 to 4 K.

The elevation dependent part of the antenna noise temperature is caused by losses due to water and oxygen in the atmosphere and in order to estimate this elevation dependent part the curves of measured points in Fig. 3 may be approximated by the following function which is accurate to 1% for elevation angles greater than 15°:

$$T_A = T_c + T_m \left(1 - \beta_0^{\text{cosec } \alpha}\right) \qquad \text{K} \tag{6}$$

where:

T_A : antenna noise temperature

T_c : constant part of the noise temperature

T_m : mean radiating temperature of the absorbing medium

β_0 : transmission coefficient of the atmosphere in the zenith direction

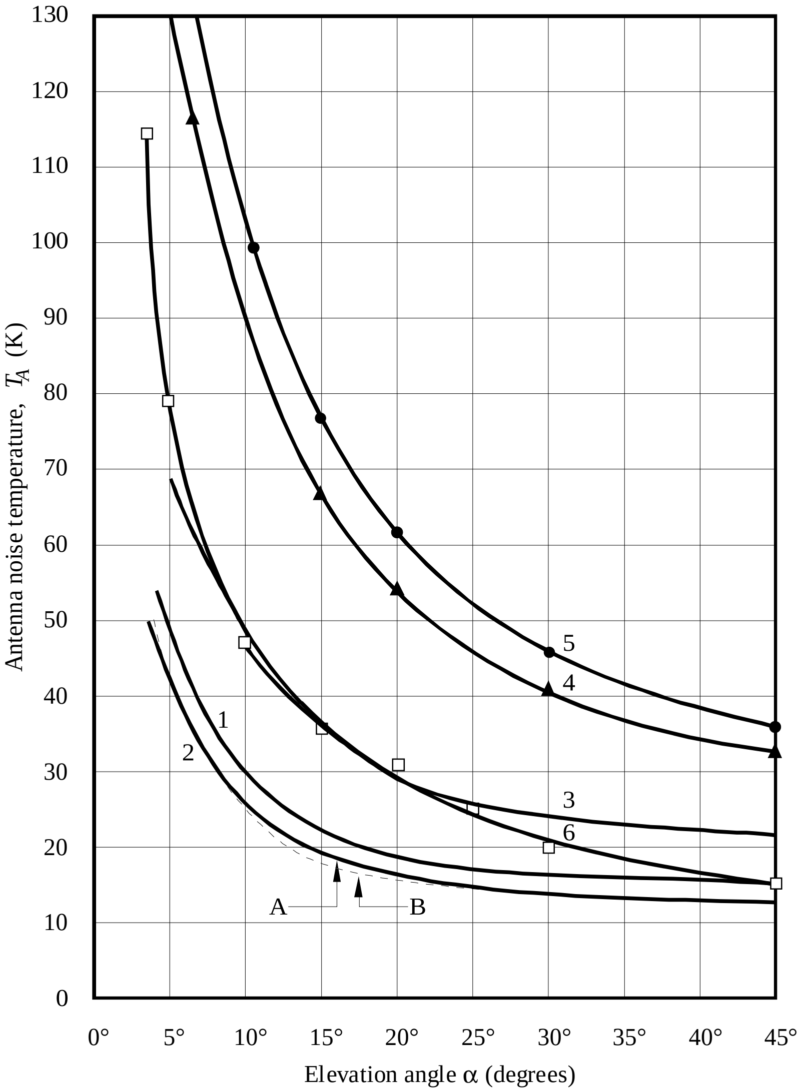
α : angle of elevation of the antenna.

In the range of angles of elevation between 5° and 90°, the constants of the function T_A are as given in Table 2.

Based on the constants given in Table 2 and for α = 90° in equation (6), the second term in this expression leads to the value of the zenith sky temperature caused by atmospheric attenuation. The zenith brightness temperature can be found by the addition of the zenith sky temperature and the cosmic microwave background radiation temperature. In this particular case, where atmospheric losses are very low, simple addition is allowed.

FIGURE 3

Antenna noise temperature (T_A) as a function of the angle of elevation (α) of the antenna under clear-sky conditions



Note 1 – Curves 1 to 6 are identified by reference to Table 2.

Note 2 – Measurement conditions were as follows:

Characteristics	Temperature (K)	Relative humidity (%)	Absolute humidity (g/m³)	Barometric pressure (mbar)
Curves 1 and 3	279	82	6	1 016
Curve 2 A: calculated B: measured	294	51	10	1 018
Curve 4 ▲: measured	296	50	10	1 006
Curve 5 ●: measured	290	49	7	1 013
Curve 6 □: measured	281.5	66	6	1 017

TABLE 2

Reference No. (see Fig. 3)	Frequency (GHz)	Antenna diameter (m)	T_c (K)	β_0	Measuring technique	Reference station
1	11.75	10	8.3	0.9858	Radiometer	10 m OTS Netherlands
2	11.45	18.3	7.3	0.988	*y*-factor	18.3 m OTS/IS-V Germany
3	17.6	10	8.3	0.9738	Radiometer	10 m OTS Netherlands
4	18.4	13	9.3	0.940	Radiometer	13 m CS Japan
5	31.65	10	11.5	0.934	Radiometer	10 m ECS Japan
6	18.75	11.5	4.5	0.970	Radiometer	11.5 m CS Japan

The zenith sky temperature can also be calculated using the humidity at the earth surface as input parameter. The result of such calculation and the value found by measurements are summarized in Table 3.

TABLE 3

Frequency (GHz)	Zenith sky temperature		Zenith brightness temperature measurements (K)
	Calculation (K)	Measurements (K)	
11.75	3.2	3.9	6.7
17.6	7.8	7.2	10.0
18.4	14.7	16.7	19.5
31.65	14.3	18.3	21.1

ANNEX 2

Measurement of the *G/T* ratio with a signal from a geostationary satellite

1. Introduction

The method described in this Annex utilizes a signal from a geostationary satellite instead of the emissions of a radio star. Due to this fact, several disadvantages of the method outlined in Annex 1 are overcome.

2. Method of measurement

In this method, a satellite signal is substituted for the signal emanating from the radio star. Instead of measuring the ratio of the radio star signal plus noise to the noise, the ratio of the total signal coming from the satellite plus noise to the noise power is measured. Since there is noise also emanating from the satellite, due to factors such as the noise figure of the spacecraft receiver, this additional noise must be taken into account. Further, a reference earth station with known *G/T* and known receive gain with respect to the satellite being used for the measurement, must be available to make a measurement of the satellite output power simultaneously with the measuring earth station.

By measuring the ratio *r*, of the satellite signal power plus noise power to the noise power, the ratio *G/T* can be determined using the formula:

$$G/T = [(k\,B\,L\,A) \;/\; E] \cdot [(r - 1) - (T_{sat} \;/\; T)]$$

where:

- k : Boltzmann's constant
- B : noise bandwidth of the earth-station receiver (Hz)
- L : free-space loss
- A : satellite antenna aspect correction factor
- E : satellite beam centre e.i.r.p. (W)
- T_{sat} : noise temperature of the earth station originating from the satellite (K)
- T : earth-station system noise temperature (K)
- $r =$ $(C + k\,T_{sat}\,B + k\,T\,B) \;/\; (k\,T\,B)$
  - C : satellite carrier power at the receiving earth station (W).

3. Limitations of the method

When using signals that originate from an uplinking earth station, as opposed to a spacecraft beacon signal, it is very difficult to measure T_{sat}. In order to overcome this difficulty, the ratio *r* should be made as large as possible. Neglecting the noise contribution due to the satellite, the equation for *G/T* becomes:

$$G/T = [k\,B\,L\,A \cdot (r - 1)] \;/\; E$$

The error introduced by this approximation is given by:

$$d = (r - 1) \;/\; [(r - 1) - (T \;/\; T_{sat})]$$

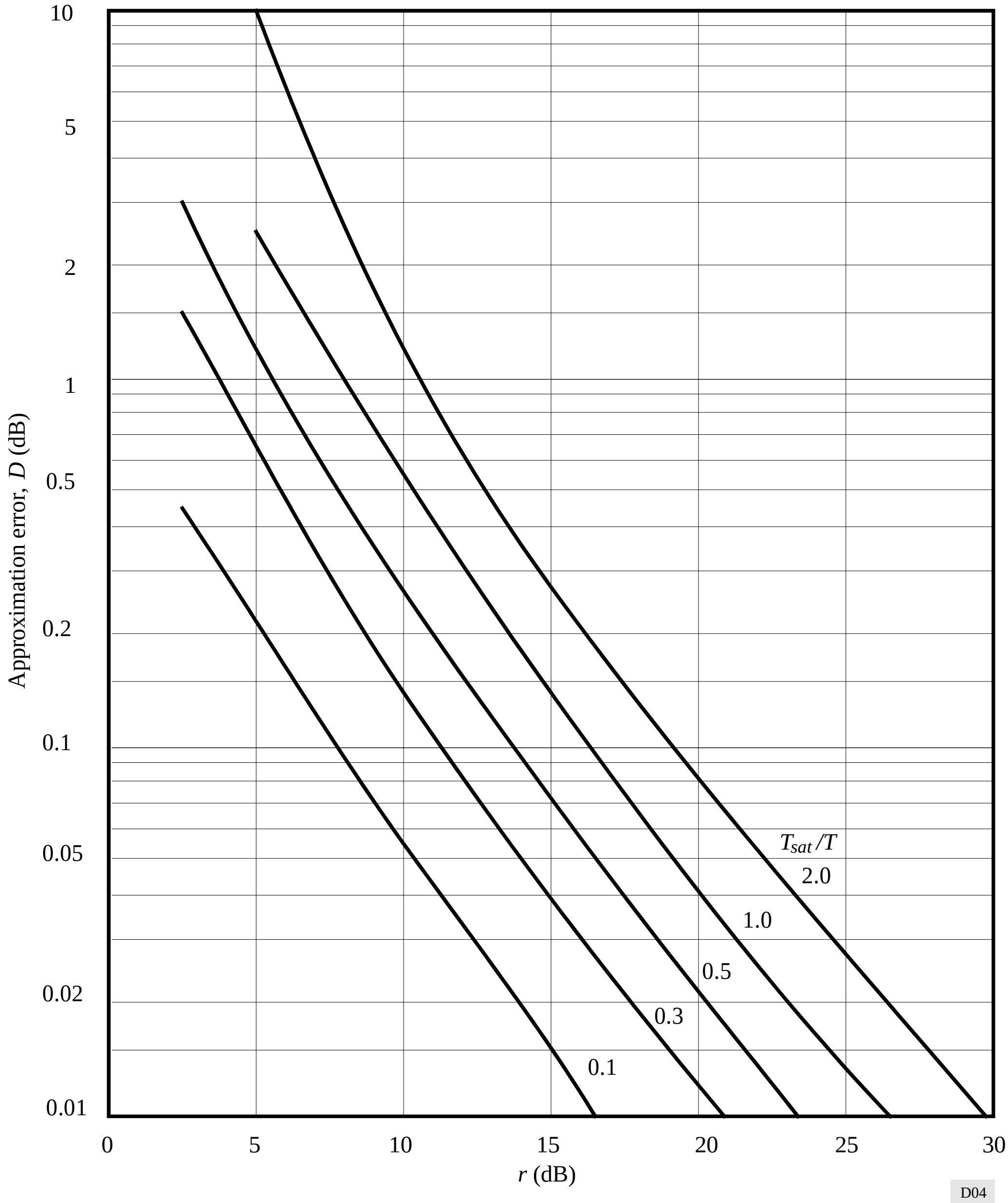
or in decibels:

$$D = 10 \log \Big[(r - 1) \;/\; [(r - 1) - (T \;/\; T_{sat})] \Big]$$

This error can be determined from Fig. 4, where the parameter is $T \;/\; T_{sat}$.

FIGURE 4

Approximation error *D* as a function of *r* with parameter T_{sat}/T



ANNEX 3

Method of determining earth-station antenna characteristics at frequencies above 10 GHz

1. Introduction

In communication-satellite systems operating at frequencies above 10 GHz, the specifications of the earth stations, in particular the figure of merit, must take account of *G/T* losses due to atmospheric effects and precipitation. These losses are generally specified for a percentage of time determined by the desired quality of the system.

The specification of the *G/T* must take account of losses:

– in the first place directly, since they lead to an increase in the required *G/T*;
– in the second place indirectly, since they entail an increase in the noise temperature, *T*.

The formulae given below are designed to standardize the methods used in determining the antenna characteristics from the standpoint of losses.

2. Specification of the figure of merit

The general formula used to specify the *G/T* of earth-station antennas at frequencies above 10 GHz is usually written as follows:

$$\frac{G}{T_i} - L_i \geq \left(K_i + 20 \log \frac{F}{F_0} \right) \qquad \text{dB(K}^{-1}\text{)} \qquad (7)$$

in the receiving band of the frequencies *F* for at least (100 – P_i)% of the time.

L_i, expressed in dB, is the additional loss on the downlink caused by the climatic conditions specific to the site of the earth station concerned referred to nominal clear-sky conditions.

T_i is the receive system noise temperature, including noise contribution due to L_i and referred to the input of the receiving low noise amplifier.

The following example may be cited:

The following dual specification is for 11-12/14 GHz band TDMA-TV earth stations belonging to the European network (EUTELSAT):

$$\frac{G}{T_1} - L_1 \geq \left(37 + 20 \log \frac{F}{11.2} \right) \qquad \text{dB(K}^{-1}\text{)} \qquad \text{under clear-sky conditions}$$

$$\frac{G}{T_2} - L_2 \geq \left(26.5 + 20 \log \frac{F}{11.2} \right) \qquad \text{dB(K}^{-1}\text{)} \qquad \text{for at least 99.99\% of the year.}$$

3. Calculation model

It is proposed to establish a relation $D = \mathrm{f}\,(L_i, K_i, T_R)$ which may be used to determine the circular aperture diameter *D* for the antenna of an earth station with G/T_i specified according to formula (7) and taking account of the receiving equipment noise temperature T_R.

Taking into account the expression for antenna gain *G*:

$$G = 10 \log \left[\eta \left(\frac{\pi D F}{c} \right)^2 \right]$$

formula (7) may be expressed as follows:

$$20 \log D \geq L_i + K_i + \log T_i - 10 \log \eta + 20 \log \frac{c}{\pi F_0} \qquad (8)$$

where:

- D : antenna diameter (m)
- c : speed of light: 3×10^8 m/s
- F_0 : frequency (GHz)
- η : antenna efficiency at receiving port at frequency F_0
- L_i : atmospheric attenuation factor (referred to clear-sky conditions) (dB)
- K_i : value specified for clear-sky figure of merit at frequency F_0 (dB(K^{-1}))
- T_i : noise temperature of the earth station, referred to the receiving port (K).

The earth-station noise temperature T_i, is fairly accurately represented by the formula:

$$T_i = \frac{L'_i - 1}{\alpha L'_i} (T_{atm} - T_c) + \frac{1}{\alpha} \left[T_c + T_s + (\alpha - 1) T_{phys} \right] + T_R \qquad \text{K} \tag{9}$$

where:

- T_c : antenna noise temperature due to clear sky
- T_s : antenna noise temperature due to ground
- T_{atm} : physical temperature of atmosphere and precipitations
- T_{phys} : physical temperature of the non-radiating elements of the antenna feed
- T_R : receiving equipment noise temperature
- $\alpha \geq 1$: resistive losses due to non-radiating elements of the antenna feed
- $L'_i \geq 1$: losses due to atmospheric effects and precipitation ratio

$L'_i = 10^{\frac{L_i}{10}}$, where L_i is expressed in dB.

Formula (9) may conveniently be expressed as follows:

$$T_i = T_A + (\Delta T_A) + T_R \tag{10}$$

where:

T_A : antenna noise temperature in clear-sky conditions ($L_i = 0$ dB)

$$T_A = \frac{T_c + T_s}{\alpha} + \frac{\alpha - 1}{\alpha} T_{phys} \tag{11}$$

(ΔT_A): additional antenna noise temperature caused by atmospheric and precipitation losses.

$$\Delta T_A = \frac{L'_i - 1}{\alpha L'_i} (T_{atm} - T_c) \tag{12}$$

Inserting relation (9) or relation (10) into relation (8), one can solve

$$D = \text{f}\,(L_i, K_i, T_R)$$

using additional data relating to the typical characteristics of earth-station antennas operating in the frequency band considered.

4. Sample calculation

In the following example the diameter D of an EUTELSAT 11-12/14 GHz band TDMA-TV station antenna meeting the dual specification of § 2 is calculated.

4.1 Assumptions

- the calculations are made at $F_0 = 11.2$ GHz for an elevation angle of about 30° above the horizon;
- the antenna performances at receiving port at the frequency F_0 are:

$\eta = 0.67$

$T_c = 15$ K
$T_s = 10$ K
(typical values of contribution to antenna noise temperature at an elevation angle of 30° at $F_0 = 11.2$ GHz)

$T_{atm} = 270$ K

$T_{phys} = 290$ K

$\alpha = 1.122$ (resistive losses $= 0.5$ dB);

- the specifications are:

$K_1 = 37$ dB

$K_2 = 26.5$ dB.

4.2 Calculation results

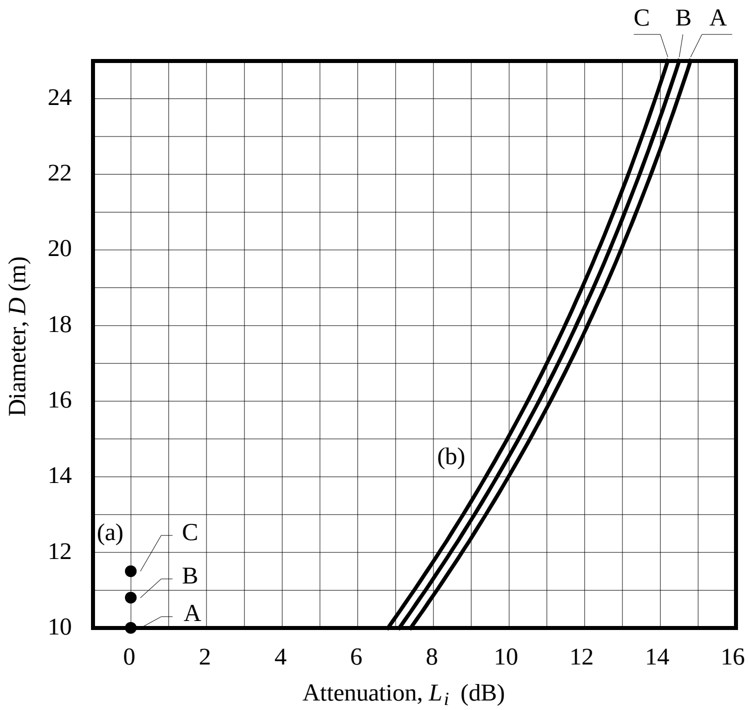
Figure 5 shows two series of curves:

$$D = f(L_i)$$

using as parameters the dual specification for the clear-sky figure of merit (K_i) (see § 2) and three receiving equipment noise temperature values T_R (130 K, 160 K and 190 K).

FIGURE 5

Variation of the antenna diameter *D* as a function of attenuation L_i



For two figures of merit at 11.2 GHz:

(a): G/T_1 = 37 dB(K^{-1})
(b): G/T_2 = 26.5 dB(K^{-1})

and for three receiving equipment noise temperature values T_R:

A: T_R = 130 K
B: T_R = 160 K
C: T_R = 190 K

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In the case of the example given above, if T_R = 160 K and if it is wished to install a station at a site where the propagation data are such that:

L_1 = 0 dB, under clear-sky conditions,

$L_2 \leq$ 8 dB for 99.99% of the year,

the following two values for the antenna diameter are obtained:

D_1 = 10.70 m

D_2 = 11.40 m

consequently $D \geq$ 11.40 m must be selected, so as to meet the dual specification requirements.