# SOME EXPERIENCE WITH PERFORMANCE EVALUATION TESTS FOR THE FOUR REFLECTOR CASSEGRAIN ANTENNA OF RIYADH 4 EARTH STATION, SAUDI ARABIA

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Abstract

G/T of the four reflector Cassegrain antenna of Riyadh 4 earth station is measured using the radio star Cassiopeia 4. The pointing parameters of the radio star are calculated and then used to estimate the azimuth and elevation angles of the earth station in direction of the radio star. The flux density and brightness temperature of Cassiopeia A at any frequency is calculated. Corrections for angular extension of radio star and atmospheric absorption are also calculated. G/T is then related to the above parameters and receiving system noise temperature. The test mainly consists of measuring the received noise power at output of LNR with and without the radio star in the antenna beam and thus G/T can be determined. The significance of the results is discussed and results were found to be in good agreement with INTELSAT technical specifications.

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## I. Introduction

A feed system employing a sub-reflector is a Cassegrain system. This technique is not new; having been invented in the 17th century by "William Cassegrain". In recent years, the double reflectors Cassegrain antenna has been employed in a wide variety of radar antennas, microwave antennas and satellite earth station antennas. The latest generation of earth stations concentrated on electronic equipment at the antenna base and the RF connection to the feedhorn is made by a four reflector-focused beam system [1]. This antenna system is capable of transmitting twin orthogonally-polarized signals towards a communication satellite while simultaneously receiving a similar pair of orthogonally polarized signals from satellite. This technique has reduced the axial dimension of the antenna and eliminated the need for long transmission lines since the feed is physically located at the vertex of the parabolic main reflector. In Riyadh 4 earth station, Saudi Arabia, a four focusing reflector and primary horn assemblies make up the beam waveguide assembly which transmits the signal across the motional axes of the antenna without loss. Riyadh 4 earth station is employing a corrugated conical horn with numerous fins inside the wall, this horn behaves as a launcher realizing a rotationally-symmetric pattern across the wide frequency band from 3.7 to 6.5 GHz [2].

The purpose of the present work is to report the results of the performace verification tests which have been carried out on the Cassegrain antenna fed by four reflector beam waveguide in Riyadh 4 earth station. This has a 32 meters Cassegrain antenna for major path-2 Atlantic ocean satellite operation. These tests include the gain to noise temperature (G/T) measurement using the radio star method, receiving system noise temperature using the Y factor method, antenna receive gain, antenna transmit gain and antenna side-lobe levels (both transmit and receive). This paper deals with G/T measurement using the radio star technique.

## II. G/T Measurement With the Aid of Radio Star

### A. General

It is not accurate to find the gain of a large aperture antenna by a measurement employing a collimation tower because a significant error might appear due to the terrain reflection [3]. The preferred method is by the radio star measurement and at an elevation angle close to that which would be employed during operation. For radio star measurements, Cassiopeia A, Tauras A and dygmas A are recommended sources as they have reasonably large flux densities and have been well studied in the field of radio astronomy [4]. Cassiopeia radio star is used in the present work.

### B. Performance objective

G/T will equal or exceed 40.7 + 20 log f/4 dB under clear sky conditions and at eleven angle of 5° over the local horizon where f is the frequency in GHz.

### C. Test procedures

Step 1: Calculate the pointing data of the radio star "Cassiopeia A" by using the right ascension $\Gamma$, the declination $\Delta$, the perturbation value for the right ascension $P_{\Gamma}$, the perturbation value for the declination $P_{\Delta}$, Greenwich sideral time $\theta$, the longitude I and the lattitude L of the place where the earth station is located. The hour angle of the radio star H at Greenwich mean time T on the Xth day of the Yth month of the year Z (the Xth day of the Yth month is the Wth day from 1st January) is given by [5],

$$H = \theta + L - \Gamma + 1.002738\ T \qquad (1)$$

where θ, L, Γ and T are in degrees.

The following data are used,

1. The longitude I and latitude L of Riyadh 4 earth station are 56° 31' E and 24° 25' N respectively.
2. $\Gamma$ = 23 Hrs. 21 min. 11.45 sec.
3. $P_{\Gamma}$ = 2.71 sec.
4. $\Delta$ = 58° 31.9'.
5. $P_{\Delta}$ = 0.33 min.
6. The sideral day is the period of one rotation of earth with respect to a fixed star. It comes to 23 Hrs. 56 min. 4.09 sec.

The data from 1 to 5 apply for January 1st, 1950 [6].

Then the azimuth angle AZ (in degrees) and elevation angle EL (in degrees) of the earth station in the direction of the radio star are given by [5,6],

$$AZ = \tan^{-1}\left(\frac{-\cos\Delta\ \sin H}{\cos I\ \sin\Delta - \sin I\ \cos\Delta\ \cos H}\right) \qquad (2)$$

and

$$EL = \sin^{-1}\left(\cos I\ \cos\Delta\ \cos H + \sin I\ \sin\Delta\right) \qquad (3)$$

The pointing parameters are converted into degrees as follows,

a) $\Gamma_{1979} = \Gamma_{1950} + P_{\Gamma} x (1979 - 1950 + \frac{W}{365})$

which is written in the form $\Gamma_{Hour}$, $\Gamma_{Min}$, $\Gamma_{Sec}$

Therefore $\Gamma_{Deg} = \Gamma_{Hour} x \frac{360}{24} + \Gamma_{Min} x \frac{360}{24x60} + \Gamma_{Sec} x \frac{360}{24x60x60}$

b) $\Delta_{1979} = \Delta_{1950} + P_{\Delta} x (1979 - 1950 + \frac{W}{365})$

which is written in the form $\Delta_{Hour}$, $\Delta_{Min}$, $\Delta_{Sec}$

Therefore $\Delta_{Deg} = \Delta_{Hour} x \frac{360}{24} + \Delta_{Min} x \frac{360}{24x60} + \Delta_{Sec} x \frac{360}{24x60x60}$

c) $\theta_{Deg} = \theta_{Hour} x \frac{360}{24} + \theta_{Min} x \frac{360}{24x60} + \theta_{Sec} x \frac{360}{24x60x60}$

d) $T_{Deg} = T_{Hour} x \frac{360}{24} + T_{Min} x \frac{360}{24x60} + T_{Sec} x \frac{360}{24x60x60}$

e) $I_{Deg} = I_{Deg} + I_{Min} x \frac{1}{60} x I_{Sec} + \frac{1}{60 x 60}$

f) $L_{Deg} = L_{Deg} + L_{Min} x \frac{1}{60} x L_{Sec} + \frac{1}{60 x 60}$

Step 2: Calculate the flux density $\phi$ from the radio star "Cassiopeia A" as follows:

The flux density of Cassiopeia A at 4 GHz, $\phi$ (4), in January 1965 is given by [7],

$$\phi(4)_{1965} = 1.061 x 10^{-23} \quad Wm^{-2} Hz^{-1}$$

and at any arbitrary frequency f (GHz),

$$\phi(f)_{1965} = \phi(4)_{1965} x (\frac{f}{4})^{-0.792}$$

$$= 1.061 \times 10^{-23} \times (\frac{f}{4})^{-0.792} \qquad (4)$$

Since Cassiopeia A is subject to a frequency reduction of flux with time, a correction factor Q(dB) has to be considered [7],

$$Q = (0.042 - 0.0126 \log f)\, n \qquad \text{dB} \qquad (5)$$

where f is the operating frequency in GHz and n is the number of years elapsed with n = 0 in 1st of January 1965. At any day W of the year Z, n is given by,

$$n = Z - 1965 + \frac{W}{365} \qquad (6)$$

Therefore, from Equations (4-6), the flux density $\phi(f)$ at frequency f on any day W of the year Z is given by,

$$\phi(f) = 10 \log \phi(4)_{1965} - 0.042 - 0.0126 \log f)$$

$$(Z - 1965 + \frac{W}{365}) \qquad (7)$$

Considering that the test has been conducted on December 20th, 1979 at f = 3.7, 4 and 4.2 GHz respectively, then the following flux densities can be readily obtained,

$$\phi(3.7)_{1979} = 1.00078 \times 10^{-23} \quad Wm^{-2}\ Hz^{-1}$$

$$\phi(4)_{1979} = 0.94236 \times 10^{-23} \quad Wm^{-2}\ Hz^{-1}$$

$$\phi(4.2)_{1979} = 0.90744 \times 10^{-23} \quad Wm^{-2}\ Hz^{-1}$$

Step 3: Calculate the correction for the angular extension of the radio star $C_s$ at frequencies 3.7, 4.0 and 4.2 GHz. $C_s$ has been calculated on the basis that the angular extension of the source in the sky is significant compared with the beamwidth of such antenna and its radiation is generally randomly polarized with an intensity varying over various parts of the star. $C_s$ is directly obtained from the curve given in Fig. (1) when the half-power beamwidth BW is known. This latter quantity is calculated from the following equation,

$$BW = 61 \frac{\lambda}{D} \text{ degrees} \tag{8}$$

where D is the main reflector diameter (D = 32 meters for Riyadh 4 earth station).

The following results can be readily obtained:

$BW_{3.7} = 0.15456°$, $BW_{4.0} = 0.14297°$, $BW_{4.2} = 0.13616°$,

$(C_s)_{3.7} = 0.44$ dB, $(C_s)_{4.0} = 0.52$ dB and $(C_s)_{4.2} = 0.55$ dB

It is noticed that in Fig. (1), Curve A has been calculated on an averaging assumption while Curve B has been calculated on the basis of latest measurements and is believed to be more accurate [7].

Step 4: Calculate the correction for atmospheric absorption from Fig. (2); the correction for angles of elevation above 5 degrees is given by [7],

$$C_a = \frac{X}{\sin EL} \text{ dB} \tag{9}$$

where X is the one-way absorption for a vertical path in dB (X = 0.036 at 4 GHz), X at other frequencies is obtained from Fig. (3).

Step 5: Calculate the brightness temperature of the radio star $T_s$ by using the following equation [5],

$$T_s = \eta \frac{\phi(f)\ R^2\ \pi}{2\ K} \qquad °K \qquad (10)$$

where the flux density of the radio star $\phi(f)$ is calculated from Step 2, R is the antenna radius in meters, K is Boltzmann's constant and $\eta$ is the aperture efficiency ($\eta$ = 0.7 for Riyadh 4 earth station antenna). $T_s$ for 3.7, 4.0 and 4 GHz can be readily calculated to be 204.13, 192.22 and 185.1 °K respectively.

Step 6: Calculate the suitable initial setting value $A_2$ of the flap attenuator $E_6$ (See Fig. (4)) by measuring the ratio of the noise power received when the antenna points exactly in the direction of the radio star and when the antenna is deviated by more than 2° from it. The initial setting value of the flap attenuator is selected as follows: point the antenna at the radio star and set the flap attenuator at the value obtained by [5],

$$A_2' = 10 \log \frac{T_s + 100}{T_s} \qquad dB \qquad (11)$$

where the value 100 is the receiving system noise temperature (the noise temperature at standard A earth stations is practically less than this value). Then the value of $A_2$ is approximated to $A_2$ as follows,

$$A_2 = (\text{Integer part of } A_2') + 1 \qquad dB \qquad (12)$$

Table (1) gives $A_2$ at 3.7, 4.0 and 4.2 GHz. $A_2$ should be kept constant during each test.

| Frequency (GHz) | $T_s$ (°K) | $A'_2$ (dB) | $A_2$ (dB) |
|---|---|---|---|
| 3.7 | 204.13 | 5.21 | 6 |
| 4.0 | 192.22 | 4.66 | 5 |
| 4.2 | 185.10 | 4.66 | 5 |

Table (1). $A_2$ at different frequencies.

Step 7: While pointing the antenna exactly to the radio star, record the maximum received noise level $P_n + P_{st}$ where $P_n$ is the noise power corresponding to the system noise temperature T and $P_{st}$ is the additional noise power when the antenna is in exact alignment with the radio star.

Step 8: Deviate the antenna from the radio star in azimuth direction by more than 2° and alter the attenuation $A_1$ of the RF variable attenuator $E_5$ (see Fig. (4)) in order to maintain the power level constant. The parameter r will be calculated from the difference between $A_2$ and $A_1$.

D. <u>Calculation of G/T</u>

The antenna gain is given by,

$$G = 4 \pi A_e / \lambda^2 \tag{13}$$

where $A_e$ is the effective antenna aperture area in meter$^2$. The relation between $\phi(f)$ and $T_s$ is expressed as follows [5],

$$A_e \, \phi(f) = 2 \, K \, T_s \qquad WHz^{-1} \tag{14}$$

Therefore, G is obtained by substituting $A_e$ from Equation (14) into Equation (13),

$$G = \frac{8 \, \pi \, K \, T_s}{\lambda^2 \, \phi(f)} \tag{15}$$

and G/T is thus given by,

$$G/T = \frac{8 \, \pi \, K \, T_s}{\lambda^2 \, \phi(f) \, T} \cdot C_a \, C_s \tag{16}$$

where corrections $C_a$ and $C_s$ have been included.

Defining r to be the numerical ratio of the received noise power when the antenna points exactly in the direction of the radio star and the received noise power when the antenna deviates in the azimuth direction, thus

$$r = \frac{P_{st} + P_n}{P_n} \tag{17}$$

and r in dB is given by,

$$r, \, dB = 10 \log \frac{P_{st} + P_n}{P_n} \tag{18}$$

$$\text{Therefore } \frac{P_{st}}{P_n} = \frac{T_s}{T} = 10^{\frac{r,dB}{10}} - 1 \tag{19}$$

and G/T can be readily written as follows,

$$\frac{G}{T}, \, dB/°K = S, \, dB/°K + 10 \log \left\{ 10^{r,dB/10} - 1 \right\}, \, dB + C_a, \, dB \tag{20}$$

where

$$S = \frac{8 \pi K C_s}{\lambda^2 \phi(f)} \qquad (21)$$

is the radio star factor and r, dB will be obtained from $A_2 - A_1$.

E. Test set-up block diagram and equipment

Fig. (4) shows the test set up block diagram, $E_1$: precision test receiver, $E_2$: mixer preamplifier, $E_3$: signal generator, $E_4$: Frequency meter, $E_5$: RF variable attenuator and $E_6$: Flap attenuator.

F. Test results

Tables (2-4) give G/T for LNR No. (1) at 3.7, 4 and 4.2 GHz while Tables (5-7) give G/T for LNR No. (2).

## III. Discussions and Conclusions

In the present technique, the parameter measured is the ratio r of the received noise power at the output of the low noise receiver (LNR) under test with and without the radio source in the antenna beam. The system noise temperature of a standard A earth station (which is in the range from 50°K to less than 100°K) is dependent on the elevation angle. The results show that angles ranging from 9.4° to 23° give a value of r in the order of 5 dB. The variation of G/T with elevation angle is more significant below 20° than above 20°. Thus in order to demonstrate satisfactorily that an earth station meets specifications, it is necessary to make measurements at several frequencies in the receiving band (3.7 - 4.2 GHz) over a range of elevation angles, preferably covering the operating elevation angle of the earth station ± 10°.

The present test has been conducted using the radio star Cassiopeia A, the advantages of which are,

i. Cassiopeia A flux density is large enough to be detected.

ii. At the latitude of Riyadh 4 earth station, Cassiopeia A goes down to the horizon, making it possible to measure G/T at low elevation angles. Data for radio stars prepared by INTELSAT for Riyadh 4 earth station are as follows,

| Time (GMT) | Source | Elevation angle |
|---|---|---|
| 0400 - 1300 | Cassiopeia A | 5° - 57° |
| 1210 - 1500 | Taurus A | 5° - 40° |
| 1500 - 1800 | Cygnus A | 18° - 5° |
| 1800 - 2200 | Cassiopeia A | 32° - 5° |
| 2300 - 0100 | Taurus A | 30° - 5° |
| 0150 - 0300 | Cygnus A | 5° - 15° |

The above data shows that Cassiopeia A is the best fit source for Riyadh 4 earth station and the suitable time to conduct the test is from 0400 - 1300 GMT.

iii. For Taurus A which is elliptically-polarized, it is necessary to use the mean of two readings taken in two orthogonal directions. This is not necessary when using Cassiopeia A or Cygnus A.

iv. The flux density of Cygnus A may not be reasonably sufficient to carry the test.

Two methods can be employed when measuring G/T with the aid of a radio star: i) a program track unit which accepts a paper tape input containing the position of the radio source as a function of time and provides output to the antenna to drive it along the path followed by the source, ii) the other method is a receiving unit with facilities to display and measure the power received by the antenna. The latter method is the one used in the present test. The LNR has been connected to the RF variable attenuator $E_5$ so that observations are made at the chosen carrier frequencies. The mixer preamplifier $E_2$ is driven by a signal generator $E_3$ as a local oscillator, thus enabling observations to be made at any required frequency by connecting it into the RF sector of the receiving system. The measurement of r is obtained by altering $E_5$ to maintain the output level of the noise power constant when the antenna is driven on and off the radio star. This technique has the advantage of minimizing errors resulting from the nonlinearity of the power meter. The use of the flap attenuator $E_6$ is to provide a constant reference value so that when altering $E_5$, any increase or decrease in the receive noise power is the accurate result obtained with and without the radio star.

It is concluded that the experimental results obtained in the present work are in agreement with the technical characteristics in the INTELSAT document ICSC-37-38 E W/1/69 which states that G/T should be $\geqslant$ 40.7 at 5° elevation angle.

## References

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[2] Antenna and Tracking System, Operation and Maintenance Handbook for Saudi Arabia New Earth Station, Vol. II, 2/6, Mitsubishi Elect. Corp., 1980.

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[4] CCIR: "Earth Station Antennas for Fixed Satellite Service", Question I-2/4, Study Program IC-1/4, XIV th Plenary Assembly, p. 319, Koyoto, 1978.

[5] "Direct Measurement of G/T by Measurement of the Radiation Patterns", Kokusai Denshin Menwa Co. (KDD), Tokyo, 1980.

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[7] CCIR: "Measurement of the Ratio G/T with the Aid of Radio Stars", Rep. 390-1, 2, 3-Annex II, XIIth Plenary Assembly, P. 177, New Delhi, 1970.

Table (2). Figure of Merit (G/T)

| Radio Star | : Cassiopeia - A | Weather | : Fine |
|---|---|---|---|
| Frequency | : 3.700 GHZ | LNR No. | : 1 |
| Star Factor "S" | : 37.659 dB/°K | | |

$G/T = S, dB/°K + 10 \log (10^{r,dB/10} - 1), dB + C_a, dB$

| Time GMT | AZ. "deg." | EL. "deg." | r "dB" | $10 \log(10^{r,\frac{dB}{10}} - 1)$ | $C_a$ "dB" | G/T "dB" |
|---|---|---|---|---|---|---|
| 10:30 | 28.68 | 9.41 | 4.91 | 3.2169 | 0.220 | 41.096 |
| 10:32 | 28.78 | 9.62 | 5.00 | 3.3491 | 0.215 | 41.228 |
| 11:04 | 30.89 | 13.30 | 5.15 | 3.5668 | 0.156 | 41.381 |
| 11:08 | 31.09 | 13.70 | 5.16 | 3.5812 | 0.152 | 41.392 |
| 11:38 | 32.58 | 17.30 | 5.29 | 3.7670 | 0.121 | 41.547 |
| 11:41 | 32.73 | 17.70 | 5.31 | 3.7953 | 0.117 | 41.571 |
| 11:43 | 32.80 | 17.90 | 5.32 | 3.8095 | 0.117 | 41.585 |
| 12:12 | 33.86 | 21.60 | 5.40 | 3.9223 | 0.098 | 41.679 |
| 12:16 | 33.94 | 22.10 | 5.42 | 3.9504 | 0.096 | 41.705 |
| 12:18 | 33.99 | 22.30 | 5.38 | 3.9842 | 0.095 | 41.648 |

Table (3). Figure of Merit (G/T)

| | | | |
|---|---|---|---|
| Radio Star | : Cassiopeia - A | Weather | : Fine |
| Frequency | : 4.000 GHZ | LNR No. | : 1 |
| Star Factor "S" | : 38.678 dB/°K | | |

$G/T = S, dB/°K + 10 \log (10^{r,dB/10} - 1), dB + C_a, dB$

| Time GMT | AZ. "deg." | EL. "deg." | r "dB" | $10 \log(10^{r,\frac{dB}{10}} - 1)$ | $C_a$ "dB" | G/T "dB" |
|---|---|---|---|---|---|---|
| 10:34 | 28.92 | 9.82 | 4.94 | 3.261 | 0.211 | 42.150 |
| 10:37 | 28.18 | 10.20 | 4.99 | 3.334 | 0.203 | 42.215 |
| 11:10 | 31.17 | 13.90 | 5.19 | 3.624 | 0.150 | 42.452 |
| 11:13 | 31.36 | 14.30 | 5.20 | 3.639 | 0.146 | 42.463 |
| 11:45 | 32.90 | 18.20 | 5.24 | 3.696 | 0.115 | 42.489 |
| 11:47 | 32.95 | 18.40 | 5.27 | 3.739 | 0.114 | 42.531 |
| 11:48 | 33.03 | 18.60 | 5.24 | 3.696 | 0.113 | 42.487 |
| 12:19 | 34.04 | 22.50 | 5.33 | 3.824 | 0.094 | 42.546 |
| 12:21 | 34.08 | 22.70 | 5.38 | 3.894 | 0.093 | 42.665 |
| 12:12 | 34.11 | 22.90 | 5.35 | 3.852 | 0.093 | 42.623 |

Table (4). Figure of Merit (G/T)

| | | | |
|---|---|---|---|
| Radio Star | : Cassiopeia - A | Weather | : Fine |
| Frequency | : 4.200 GHZ | LNR No. | : 1 |
| Star Factor "S" | : 39.296 dB/°K | | |

$G/T = S, dB/°K + 10 \log (10^{r,dB/10} - 1), dB + C_a, dB$

| Time GMT | AZ. "deg." | EL. "deg." | r "dB" | $10 \log(10^{r,\frac{dB}{10}} -1)$ | $C_a$ "dB" | G/T "dB" |
|---|---|---|---|---|---|---|
| 10:37 | 29.29 | 10.40 | 4.63 | 2.7970 | 0.199 | 42.292 |
| 10:43 | 29.53 | 10.80 | 4.63 | 2.7970 | 0.192 | 42.285 |
| 11:14 | 31.44 | 14.50 | 4.71 | 2.9180 | 0.144 | 42.358 |
| 11:16 | 31.54 | 14.70 | 4.79 | 3.0380 | 0.142 | 42.476 |
| 11:18 | 31.64 | 14.90 | 4.77 | 3.0080 | 0.140 | 42.444 |
| 11:51 | 33.15 | 19.00 | 4.92 | 3.2320 | 0.111 | 42.639 |
| 11:55 | 33.27 | 19.40 | 4.92 | 3.2320 | 0.108 | 42.636 |
| 12:24 | 34.16 | 23.10 | 4.97 | 3.3052 | 0.092 | 42.693 |
| 12:25 | 34.19 | 23.30 | 4.98 | 3.3198 | 0.091 | 42.707 |
| 12:27 | 34.22 | 23.50 | 4.98 | 3.3198 | 0.090 | 42.706 |

Table (5). Figure of Merit (G/T)

Radio Star : Cassiopeia - A Weather : Fine

Frequency : 3.700 GHZ LNR No. : 2

Star Factor "S" : 37.659 dB/°K

$G/T = S, dB/°K + 10 \log (10^{r, dB/10} - 1), dB + C_a, dB$

| Time GMT | AZ. "deg." | EL. "deg." | r "dB" | $10 \log(10^{r,\frac{dB}{10}} - 1)$ | $C_a$ "dB" | G/T "dB" |
|---|---|---|---|---|---|---|
| 10:45 | 29.71 | 11.11 | 4.51 | 2.612 | 0.187 | 40.458 |
| 10:49 | 29.93 | 11.50 | 4.57 | 2.705 | 0.181 | 40.545 |
| 11:20 | 31.76 | 15.20 | 4.63 | 2.797 | 0.137 | 40.593 |
| 11:22 | 31.85 | 15.40 | 4.63 | 2.797 | 0.136 | 40.592 |
| 11:24 | 31.93 | 15.60 | 4.65 | 2.827 | 0.134 | 40.620 |
| 11:58 | 33.39 | 19.80 | 4.76 | 2.993 | 0.106 | 40.758 |
| 12:01 | 33.49 | 20.20 | 4.75 | 2.9780 | 0.104 | 40.741 |
| 12:30 | 34.29 | 23.90 | 4.82 | 3.083 | 0.0889 | 40.830 |
| 12:32 | 34.32 | 24.10 | 4.82 | 3.083 | 0.0882 | 40.830 |
| 12:33 | 34.36 | 24.30 | 4.82 | 3.083 | 0.0875 | 40.830 |

Table (6). Figure of Merit (G/T)

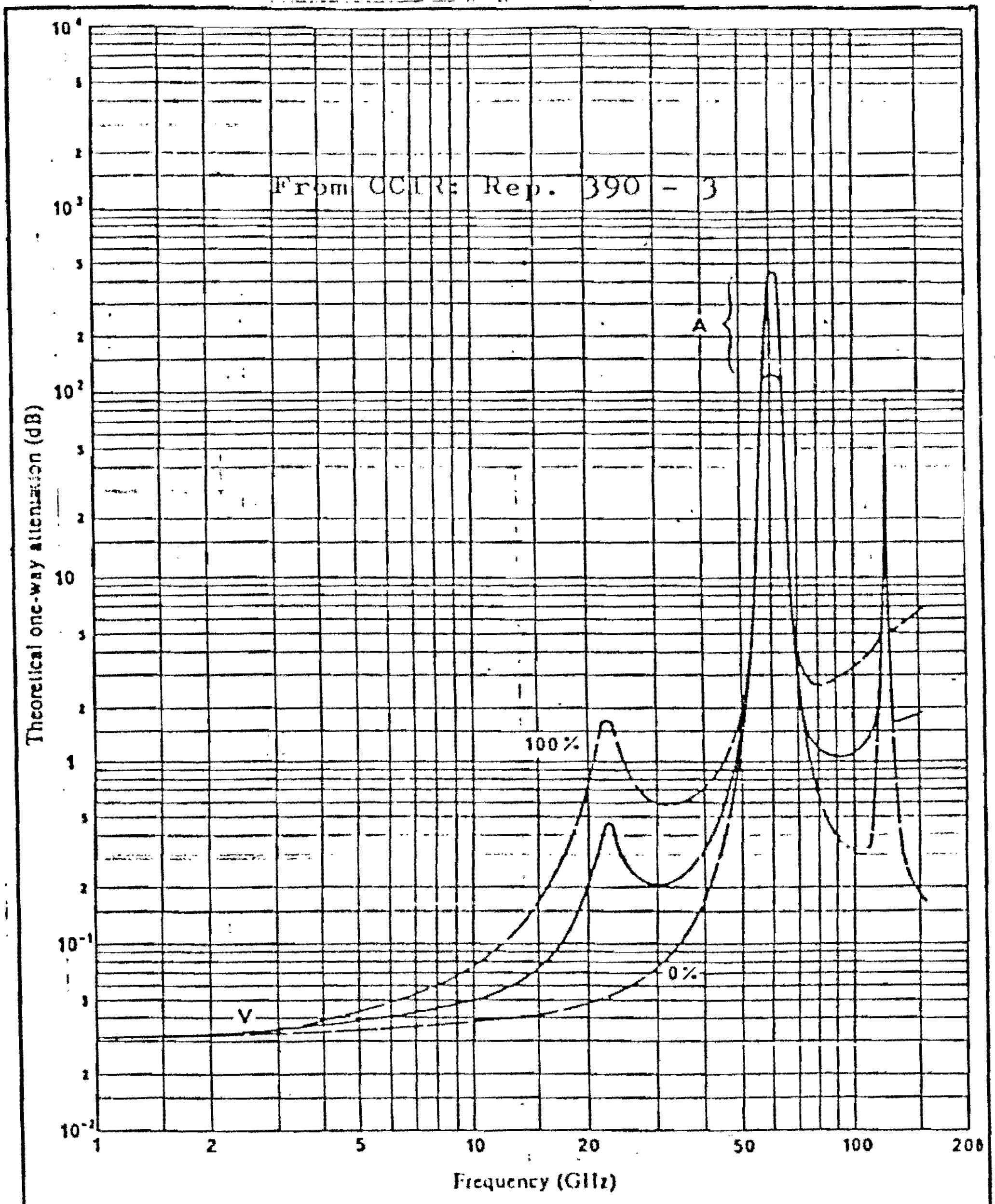
Radio Star : Cassiopeia - A    Weather : Fine

Frequency : 4.000 GHZ    LNR No. : 2

Star Factor "S" : 38.678 dB/°K

$G/T = S, dB/°K + 10 \log (10^{r, dB/10} - 1), dB + C_a, dB$

| Time GMT | AZ. "deg." | EL. "deg." | r "dB" | $10 \log(10^{r, \frac{dB}{10}} - 1)$ | $C_a$ "dB" | G/T "dB" |
|---|---|---|---|---|---|---|
| 10:53 | 30.20 | 12.00 | 4.64 | 2.812 | 0.173 | 41.663 |
| 10:55 | 30.33 | 12.20 | 4.67 | 2.858 | 0.170 | 41.706 |
| 10:57 | 30.43 | 12.40 | 4.64 | 2.812 | 0.168 | 41.658 |
| 11:25 | 32.01 | 15.80 | 4.73 | 2.948 | 0.132 | 41.758 |
| 11:27 | 32.10 | 16.00 | 4.80 | 3.053 | 0.131 | 41.862 |
| 11:29 | 32.17 | 16.20 | 4.77 | 3.008 | 0.129 | 41.815 |
| 12:03 | 33.54 | 20.40 | 4.87 | 3.158 | 0.103 | 41.939 |
| 12:04 | 33.61 | 20.60 | 4.90 | 3.202 | 0.102 | 41.982 |
| 12:35 | 34.38 | 24.50 | 4.92 | 3.232 | 0.087 | 41.997 |
| 12:38 | 34.43 | 24.90 | 4.93 | 3.245 | 0.086 | 42.009 |




*Theoretical one-way attenuation for vertical paths through the atmosphere (calculated using the United States' standard atmosphere for July at 45°N latitude). Solid curves are for a moderately humid atmosphere, dashed curves for vertical attenuation represent the limits for 0 and 100% relative humidity*

A: Limits of uncertainty V: Vertical

Fig. (3) Correction for atmospheric absorption at any frequency (1 - 200 GHZ).

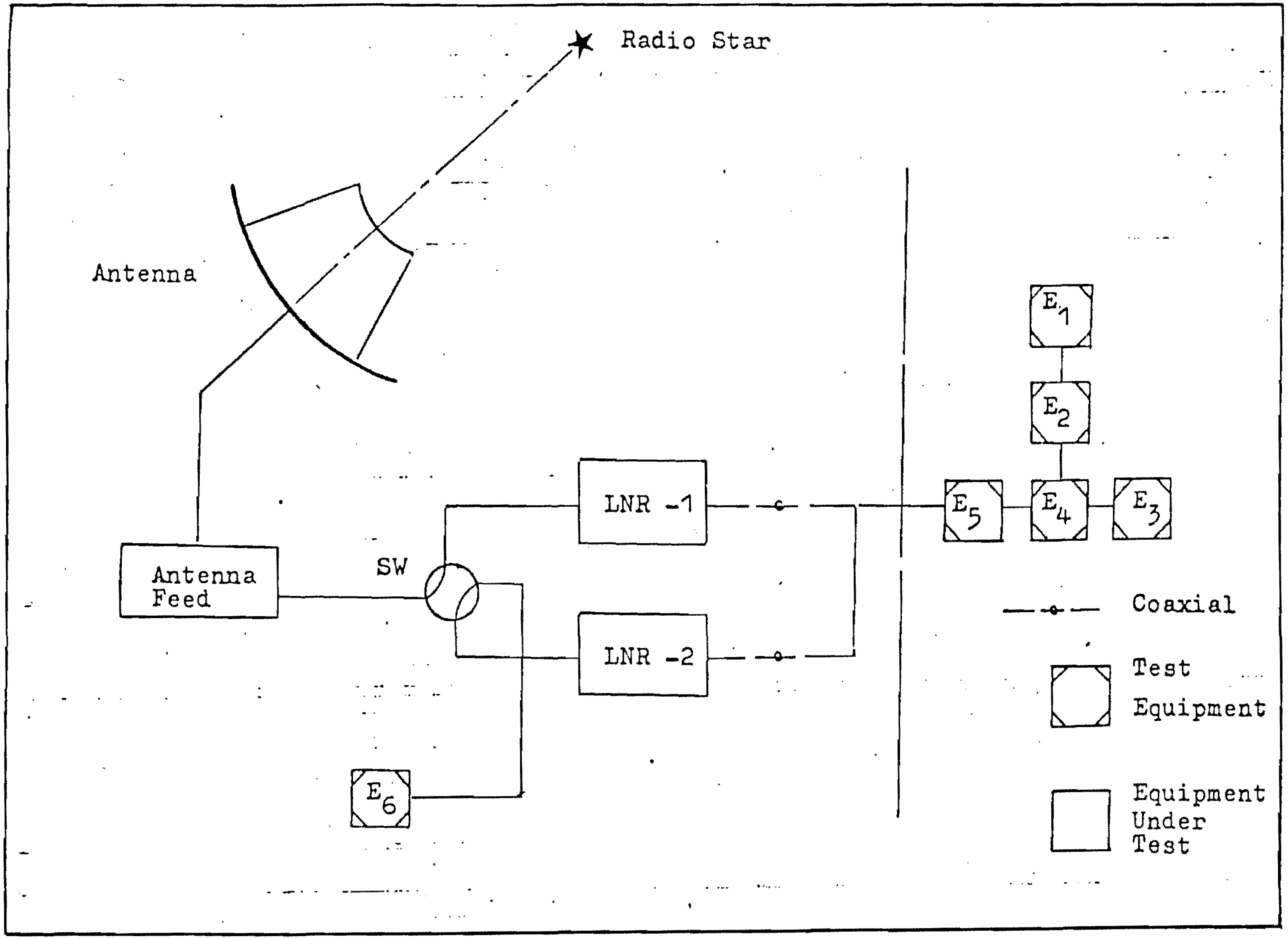



Fig. (4): Test set-up block diagram for G/T measurement