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136 MHz/400 MHz EARTH STATION ANTENNA-NOISE TEMPERATURE PREDICTION PROGRAM FOR RAE-B

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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136 MHz/400 MHz EARTH STATION ANTENNA-NOISE TEMPERATURE PREDICTION PROGRAM FOR RAE-B

Ralph E. Taylor
National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771 USA

Joseph J. Fee and M. Chin
Wolf Research and Development Corporation
6801 Kenilworth Avenue
Riverdale, Maryland 20840 USA

Prepared for:

National Aeronautics and Space Administration (NASA)
Goddard Space Flight Center
Greenbelt, Maryland 20771 USA

By:

Wolf Research and Development Corporation
6801 Kenilworth Avenue
Riverdale, Maryland 20840 USA

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September 1972

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

TABLE OF CONTENTS

SECTION 1.0

INTRODUCTION

In 1973, the Radio Astronomy Explorer-B (RAE-B) satellite will be placed in a 1100 km-altitude circular orbit around the Moon to make radio astronomy measurements.

The purpose of the simulation study described in this report is to determine the 136 MHz and 400 MHz noise temperature of the ground network antennas which will track the RAE-B satellite during data transmission periods. Since the noise temperature of the antenna effectively sets the Signal-to-Noise Ratio (SNR) of the received signal, a knowledge of SNR will be helpful in locating the optimum time windows for data transmission during low-noise periods.

Antenna-noise temperatures at 136 MHz and 400 MHz will be predicted for selected earth-based ground stations which will support RAE-B. Telemetry data acquisition will be at 400 MHz; tracking support at 136 MHz will be provided by the Goddard Range and Range Rate (RARR) stations.

The antenna-noise temperature predictions will include the effects of galactic-brightness temperature, the sun, and the brightest radio stars. Predictions will cover the ten-month period from March 1, 1973 to December 31, 1973. The RAE-B mission will be especially susceptible to SNR degradation during the two eclipses of the Sun occurring in this period.

The body of this report is divided into three parts:

- Development of Equations
- Computer Program Description
- Worst-Case Analysis Results

The worst-case analysis is a "first-look" approximation to determine preliminary estimates of antenna-noise temperature profiles. A more refined computer program is being written that predicts antenna-noise temperature more accurately by utilizing complete models of the antenna patterns and station location geometry. The refined model is based upon the Satellite Data Quality Program previously developed for GSFC/NASA under contract Number NAS 5-11736 PCN-523-W-70446.

SECTION 2.0
PROGRAM DESCRIPTION

2.1 DEVELOPMENT OF EQUATIONS

Four sources of antenna-noise temperature are considered in this study:

- Sky-Brightness Temperature
- Sun
- Radio Stars
- Antenna Back Lobe Noise Temperature
- Total Antenna-Noise Temperature

The formulation utilized within this program has been previously utilized in the Data Quality Prediction Program [1] developed by Wolf Research & Development Corp. for NASA/GSFC under contract NAS 5-11736 DCN 523-W-70446. The equations presented in the following are taken from References 1 and 2.

a) Sky-Brightness Temperature

Kraus [3] develops the following formulation for sky brightness temperature

$$T_{SKY} = \frac{\int_0^{\theta=90^\circ-\theta_o} \int_0^{\phi=2\pi} T(\theta,\phi)\, G(\theta,\phi) \sin\theta \partial\theta\partial\Phi}{\int_0^{\theta=90^\circ-\theta_o} \int_0^{\phi=2\pi} G(\theta,\phi) \sin\theta\partial\theta\partial\phi}$$

where

θ_0 = elevation angle between antenna's boresight axis and the horizon, degrees

$T(\theta,\phi)$ is the noise temperature distribution of the galaxy (excluding the sun and predominant radio stars) obtained from References 1 and 2.

$G(\theta,\phi)$ is the lossless antenna gain distribution.

θ and ϕ are the orientation angles defining the position of a radial surface element within the celestial hemisphere.

Figure 1 shows the physical relationship of the variables given in the above equations. The double integral is computed by rectangular integration assuming that the antenna boresight is directed at the center of the Moon's optical disk. The antenna patterns and brightness temperatures are accessed from magnetic tape storage in the computer program.

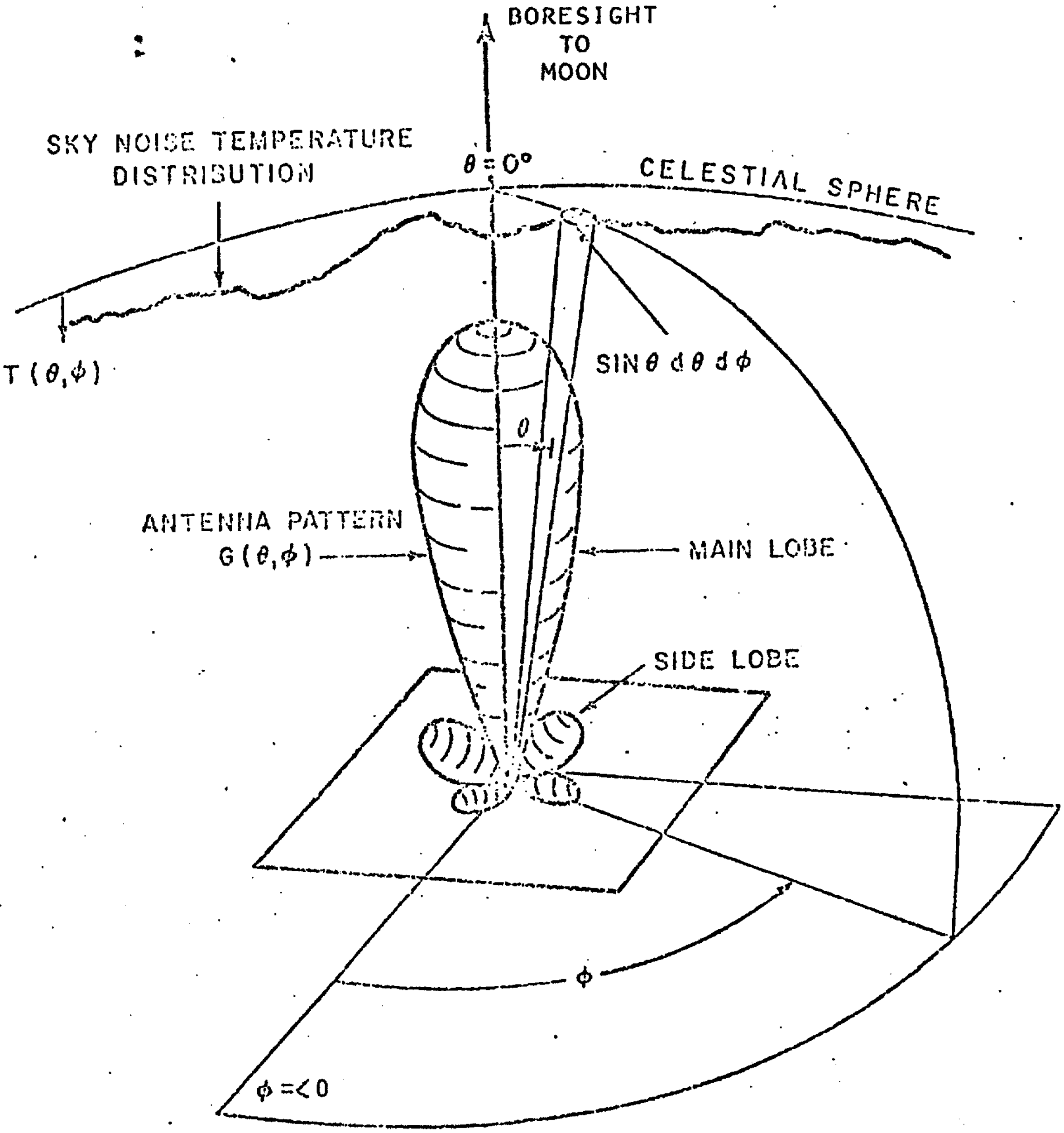


Figure 1. Relation of Antenna Pattern to Celestial Sphere.

This program required the use of an accurate radio-sky map which covers the celestial sphere completely, for both 136 MHz and 400 MHz. Since detailed sky-brightness temperature contours were not available at these frequencies, it became necessary to scale either existing radio maps in temperature, or to generate a composite map from various smaller maps. The 136 MHz and 400 MHz sky-brightness temperature maps, appearing in Appendix A-3, were prepared in this manner.

The 136 MHz radio map was scaled from data at 150 MHz, published in 1971 by Landecker and Wielebinski (Reference 4). The following relationship was used for scaling:

$$T_{136} = T_{150} \left(\frac{150}{136}\right)^{2.4} \text{ degs. K.}$$

Reference 5 was utilized for the conversion of galactic coordinates, employed by Landecker and Wielebinski, into the necessary equatorial coordinates required for this program.

The 400 MHz radio map, appearing in Appendix A-3, is a composite map formulated from the sectional maps published in 1962 by Pauliny-Toth and Shakeshaft (Reference 6), and in 1956 by Droge and Priester (Reference 7).

b) Sun

The contribution of the sun to the antenna-noise temperature is given by Berkowitz [8] as:

$$T_{SUN} = \left(\frac{\theta_s}{\theta_a}\right)^2 T_b, \text{ assuming } \theta_a >> \theta_s$$

where

θ_s = Angular radio diameter of sun's apparent temperature model, degrees; assume $\theta_s = 0.66°$ at 136 MHz and 400 MHz.

θ_a = Half-power beam width (HPBW) of symmetrical antenna main lobe.

T_b = 8×10^5 K for quiet sun ideal model at 136 MHz, and 6×10^5 K at 400 MHz.

c) Radio Stars

The following equation is used by Taylor [1,9] to compute antenna noise power rise due to a point-source radio star:

$$N_* = \sum_{n=1}^{M} \frac{1}{2} \frac{G_p \cdot G(\theta) \ \lambda^2}{4\pi} D_o \ \Delta f$$

for a single polarization,

where

M - is the number of radio stars

D_o - is the observed radio star noise flux density, $wm^{-2}Hz^{-1}$, constant over bandwidth Δf.

λ - wave length of transmission

G_p - peak antenna power gain, above isotropic

$G(\theta)$ - antenna gain attenuation at angle θ off-boresight i.e., $G(\theta)=1$ for $\theta = 0$.

Note that the antenna-noise temperature is

$$T_* = \frac{N_*}{k\Delta f} \quad \text{degs. K}$$

where

N_* = total noise power due to all radio stars within the antenna's radiation pattern

k = Boltzmann's constant, 1.38×10^{-23} J/K

Δf = noise bandwidth of receiver, Hz

d) Antenna Back Lobe Temperature

The black-body radiation of the Earth contributes to the overall antenna-noise temperature by means of the back lobe of the ground antenna.

Based on Blake's data (Reference 10), the effect of antenna back lobe temperature, T_{BACK}, is approximated by adding a constant to the equation for antenna-noise temperature as follows:

136 MHz $\quad T_{BACK} = 75°K$

400 MHz $\quad T_{BACK} = 35°K$

c) Total Antenna-Noise Temperature

The total antenna-noise temperature, T_{TOT}, is computed by summing each of the four contributions.

$$T_{TOT} = T_{SKY} + T_{SUN} + T_{*} + T_{BACK}$$

Antenna-noise temperature will be maximum at New Moon, once each month. A higher peak is reached once each year (December) when the Galactic Nucleus is eclipsed by the Sun, during New Moon (see Figure 2).

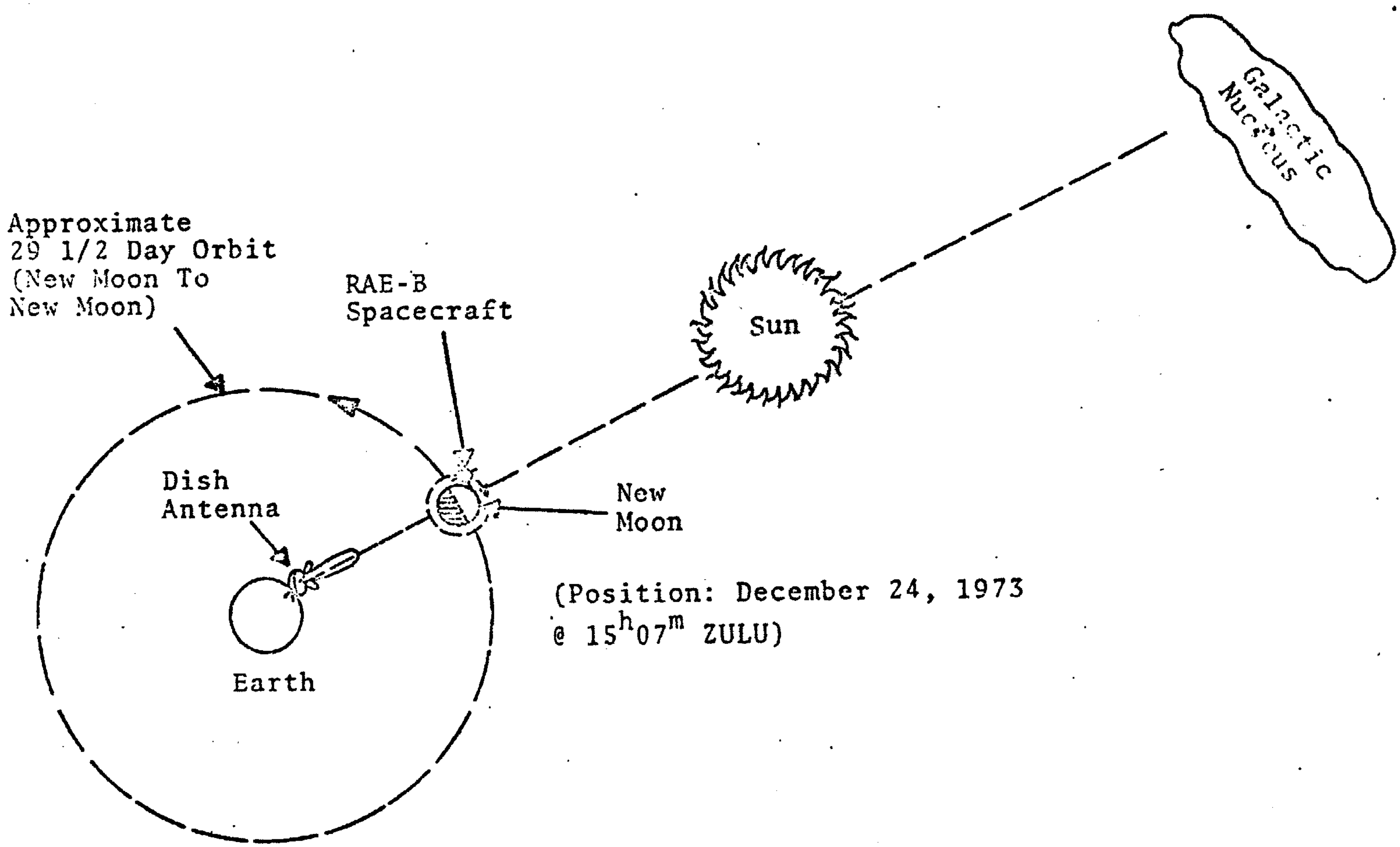


Figure 2. Celestial Source Spatial Arrangement in Month of December

2.2 PROGRAM LOGIC FLOW

The following logic steps determine the antenna-noise temperature for each ground antenna which will track the RAE-B:

- Each station is tested for a visible moon.
- Antenna-noise temperature is computed for each station having a visible moon.
- Antenna-noise temperature is recomputed at periodic time intervals from Moonrise to Moonset.

The equations and logic for each major portion of the program will now be described and followed by a Program flow chart.

2.2.1 Visibility Test (Block 1 to 4 In Section 2.2.5)

For each station, the zenith vector ($\bar{I}_T$) is computed as:

$$\bar{I}_T = \begin{bmatrix} \cos\phi \cos\lambda \\ \cos\phi \sin\lambda \\ \sin\phi \end{bmatrix}$$

where

ϕ is the geodetic latitude

λ is the geodetic longitude.

When the dot product of the moon's unit vector, $\bar{I}_M$, and $\bar{I}_T$ is negative the station is located below the horizon and the antenna-noise temperature is not calculated. $\bar{I}_M$ is computed as:

$$\bar{I}_M = \begin{bmatrix} \cos\phi_m \cos\lambda_m \\ \cos\phi_m \sin\lambda_m \\ \sin\phi_m \end{bmatrix}$$

where

ϕ_m is the declination of moon at the time antenna-noise temperature is computed

and

λ_m is the longitude of the moon.

When the dot product of $\bar{I}_T$ and $\bar{I}_M$ is not negative the station antenna-noise temperature is calculated. This visibility test is repeated for every station within the same time period.

2.2.2 Antenna-Noise Temperature Calculation (Block 5 to 16 In Section 2.2.5)

a. Contribution of Sun to Antenna-Noise Temperature (Block 5 to 10)

In order to determine if the sun's radio diameter falls within the antenna main lobe, the sun's position unit vector ($\bar{I}_S$) is computed in the earth-fixed coordinate system as

$$\bar{I}_S = \begin{bmatrix} \cos \phi_s \cos \lambda_s \\ \cos \phi_s \sin \lambda_s \\ \sin \phi_s \end{bmatrix}$$

where

ϕ_s is the declination of sun at a given time and

λ_s is the longitude of the sun.

If the dot product of the moon's unit vector, $\bar{I}_M$, and the sun's unit vector, $\bar{I}_S$, is less than the half power beam width of the antenna's main lobe, then the antenna-noise temperature due to the sun is calculated as shown in Section 2.1. Otherwise, the effect of the sun is assumed negligible.

b. Contribution of Radio Stars to Antenna-Noise Temperature (Block 11 to 14)

The position unit vector of each radio star is computed in the earth-fixed coordinate system as

$$\bar{I}_{STAR} = \begin{bmatrix} \cos\phi_{SR} \cos\lambda_{SR} \\ \cos\phi_{SR} \sin\lambda_{SR} \\ \sin\phi_{SR} \end{bmatrix}$$

where

ϕ_{SR} is the declination of radio star at a given time

λ_{SR} is the longitude of a given radio star.

When the arc cos of the dot product of the moon's unit vector, $\bar{I}_M$, and radio star's unit vector, $\bar{I}_{STAR}$, is less than one-half the beam width of antenna main lobe, the computation is performed as shown in Section 2.1. Otherwise, the effect of a radio star is considered negligible. For each radio star, a computation is performed. The antenna-noise temperature due to all radio stars is the sum of the temperature for each radio star.

c. Contribution of Sky Temperature To Antenna-Noise Temperature (Block 15)

Sky-noise temperatures are stored as discrete values at regular intervals. The total noise power is a function of the noise-temperature distribution of the sky, in convolution with the antenna gain distribution over the celestial sphere (shown in Section 2.1). The numerical integration required for T_{sky} is performed utilizing the sky map.

d. Contribution of Antenna Back Lobe to Antenna-Noise Temperature (Block 16)

Back lobe noise temperature is assumed constant at:

$T_{BACK} = 75°$ K (136 MHz) $T_{BACK} = 35°$ K (400 MHz)

e. Total Antenna-Noise Temperature (Block 16)

The tracking station's total antenna-noise temperature is the sum of contributions from the sun, radio stars, sky background temperature, and Antenna Back Lobe temperature.

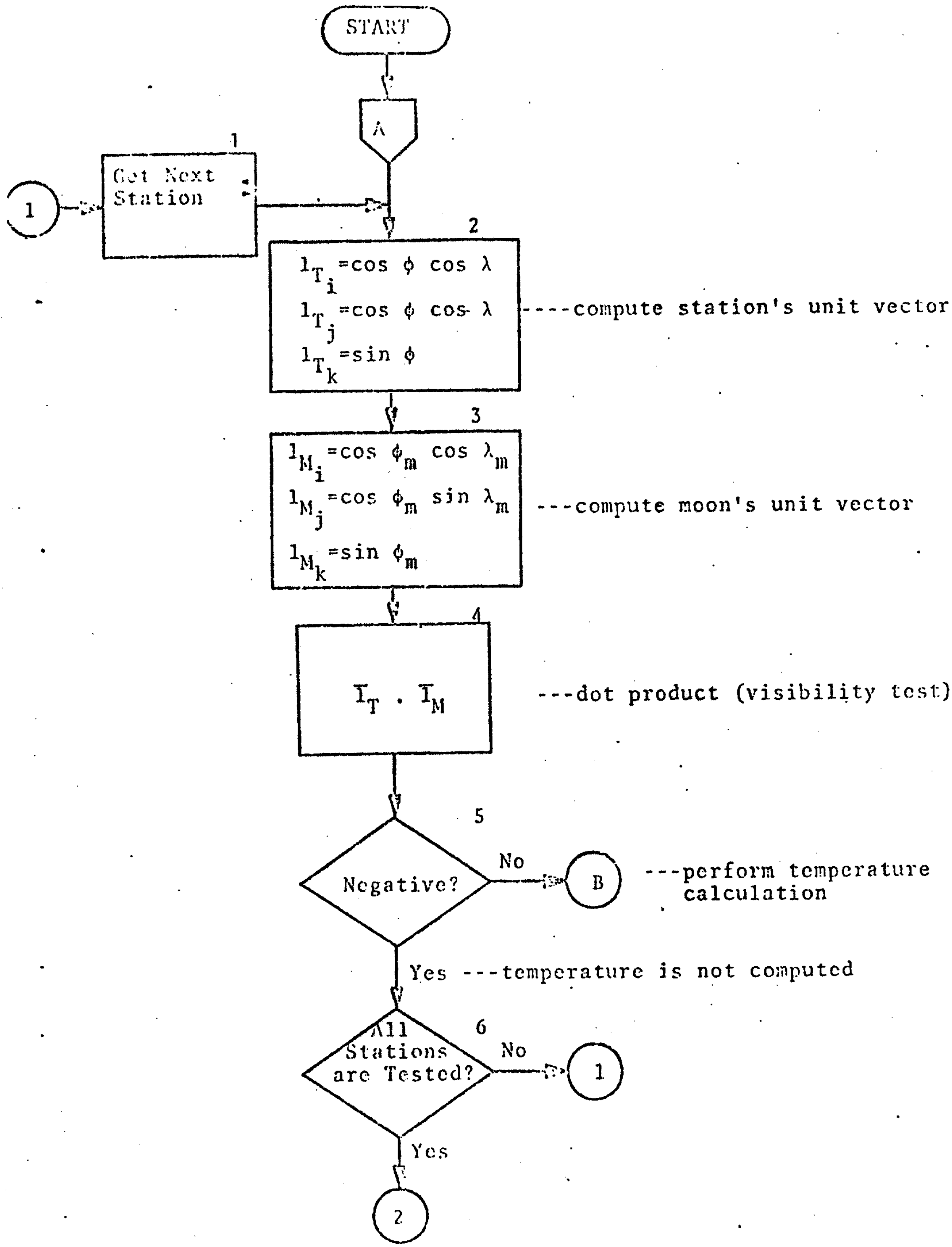
2.2.3 Terminal Test

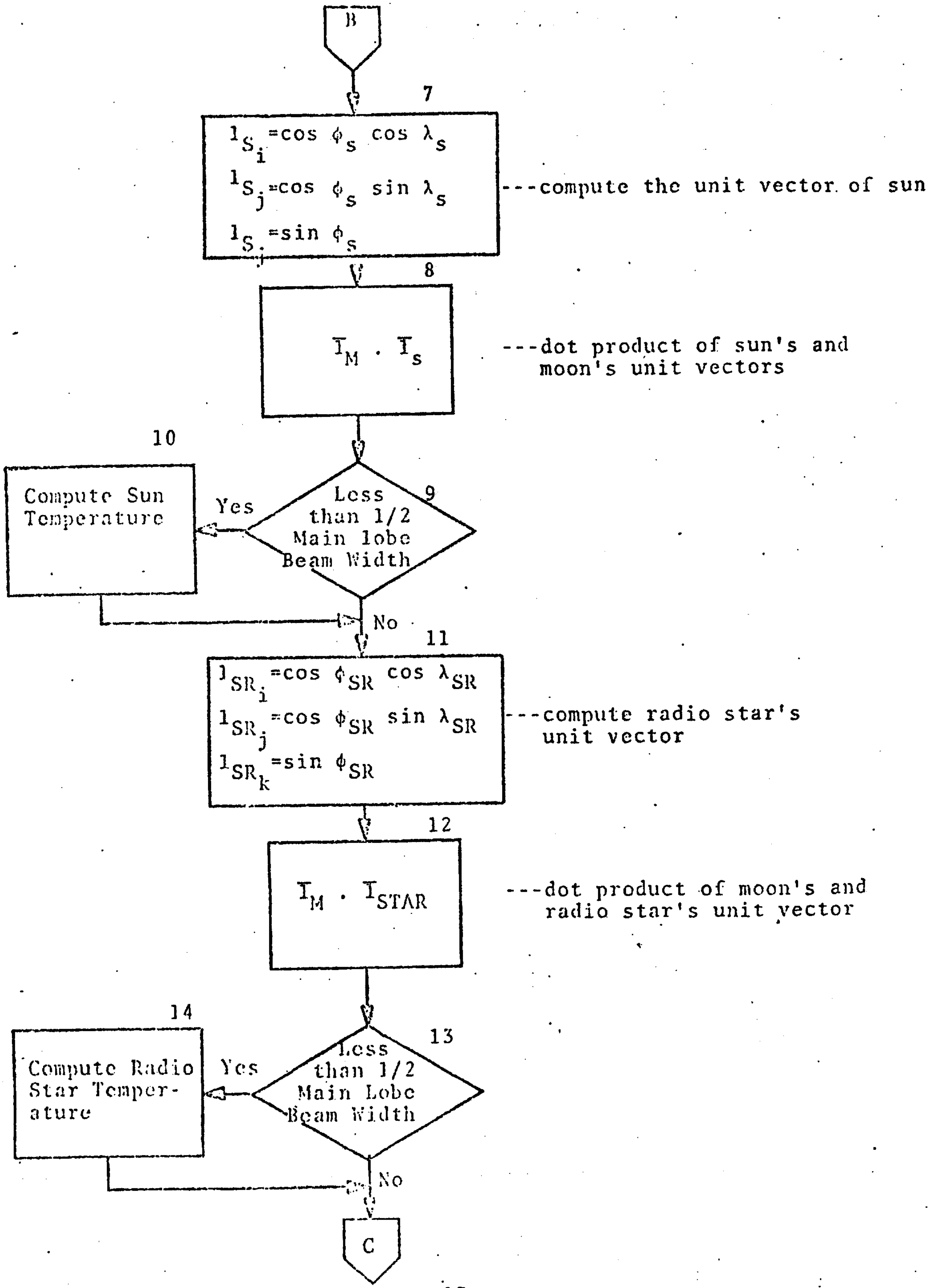
The above operations (Sections 2.2.1 and 2.2.2) are performed for each station antenna, for the same time interval. After all the stations have been tested for a visible moon, the total antenna-noise temperature is computed for the initial antenna-pointing angle; the computation is repeated at an incremental pointing angele, until Moonset.

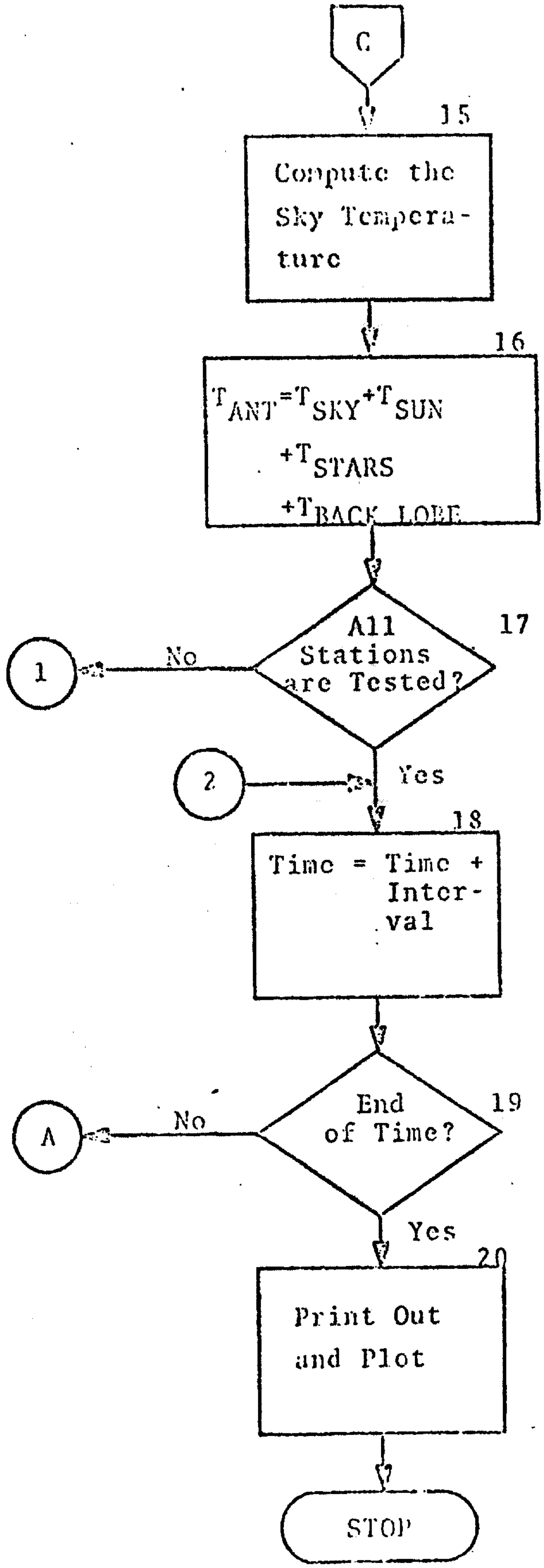
2.2.4 Output (Blocks 19 and 20, Section 2.2.5)

Plots of antenna-noise temperature versus time, for each station, are output using the WOLF Plot Package (Reference 11).

2.2.5 Program Flow Chart




B
7
$1_{S_i} = \cos \phi_s \cos \lambda_s$
$1_{S_j} = \cos \phi_s \sin \lambda_s$
$1_{S_k} = \sin \phi_s$
---compute the unit vector of sun
8
$\bar{1}_M \cdot \bar{1}_s$
---dot product of sun's and moon's unit vectors
10
Compute Sun Temperature
Yes
9
Less than 1/2 Main lobe Beam Width
No
11
$1_{SR_i} = \cos \phi_{SR} \cos \lambda_{SR}$
$1_{SR_j} = \cos \phi_{SR} \sin \lambda_{SR}$
$1_{SR_k} = \sin \phi_{SR}$
---compute radio star's unit vector
12
$\bar{1}_M \cdot \bar{1}_{STAR}$
---dot product of moon's and radio star's unit vector
14
Compute Radio Star Temperature
Yes
13
Less than 1/2 Main Lobe Beam Width
No
C


C
15
Compute the Sky Temperature
16
$T_{ANT} = T_{SKY} + T_{SUN} + T_{STARS} + T_{BACK\ LOBE}$
17
All Stations are Tested?
No
1
Yes
2
18
Time = Time + Interval
19
End of Time?
No
A
Yes
20
Print Out and Plot
STOP

SECTION 3.0

SIMPLIFIED COMPUTATION OF ANTENNA-NOISE TEMPERATURE

3.1 APPROXIMATIONS AND ASSUMPTIONS

The Simplified Computation program uses the logic and equations in Section 2 to predict the worst-case antenna-noise temperature for the ground station antennas. This program utilizes a number of approximations to obtain quick-look worst-case results. This program is based upon the following:

1. Time span for observation is for the last ten months in 1973 (March 1 to December 31). The time interval for computation is variable between 10 minutes to 60 minutes, the time span per run being variable.

2. Ephemeris tape (prepared by the Jet Propulsion Laboratory (JPL)) provides x,y,z coordinates (referenced to equinox) of Sun and Moon at any time. The station unit vector is computed from right ascension and declination, instead of geodetic latitude and longitude.

3. Antenna radiation pattern is approximated by an ideal, rectangular, gain distribution corresponding to the half power beamwidth of the main lobe. Effects of antenna side lobes are considered negligible with the exception that if the first side lobe impinges upon the Sun or the Galactic Nucleus, a uniformly-illuminated sidelobe of the appropriate gain is also employed in the calculation.

4. Center of the lunar disk is assumed aligned with the antenna's boresight axis.

5. Program ignores antenna back lobe temperature.

3.2 SIMPLIFIED COMPUTATION RESULTS

3.2.1 Worst Case Temperature Profiles for 1973

The maximum antenna-noise temperature is computed at 136 MHz and 400 MHz for each station on every day between March 1, 1973 and December 31, 1973. This date is shown in Figures 3 through 15 which show the envelopes of the peak daily temperatures. The measurement interval in each case is 60 minutes. Figures 3 through 8 plot the antenna-noise temperature at 136 MHz for the VHF Range and Range Rate antenna (RARR) for all tracking stations supporting this antenna configuration. Figures 9 through 11 give the temperature profiles for the 85-ft. (26-m) diameter antenna at 400 MHz, and Figures 10 through 13 show corresponding data for the 40-ft. (12-m) diameter antenna at 400 MHz.

The results show that a "cool sky" antenna-noise temperature for the 136 MHz antenna is approximately 500°K, while the corresponding value for the 400 MHz antennas is in the vicinity of 25°K.

Antenna-noise temperature "hot spots" occur roughly at $29\frac{1}{2}$ day intervals, corresponding to a New Moon (see Figure 3), when the Sun enters the antenna main lobe. The "Astronomical Phenomena For The Year 1973", issued by the Nautical Almanac Office, United States Naval Observatory, Washington, D.C., gives the Universal Time (UT) for a New Moon (covering March 1 to December 31, 1973) as:

New Moon Date	UT(hr.,min.)
March 5	00^h07^m
April 3	11^h45^m
May 2	20^h55^m
June 1	04^h34^m
June 30	11^h39^m
July 29	18^h59^m
August 28	03^h25^m
September 26	13^h54^m
October 26	03^h17^m
November 24	19^h55^m
December 24	15^h07^m

MAR 1, 1973 TO DEC 31, 1973. TRACKING STATION:
ALASKA, ANTENNA TYPE: VHF RARR, TRACKING INTERVAL: 60 MINUTES
FREQUENCY: 136 MHZ

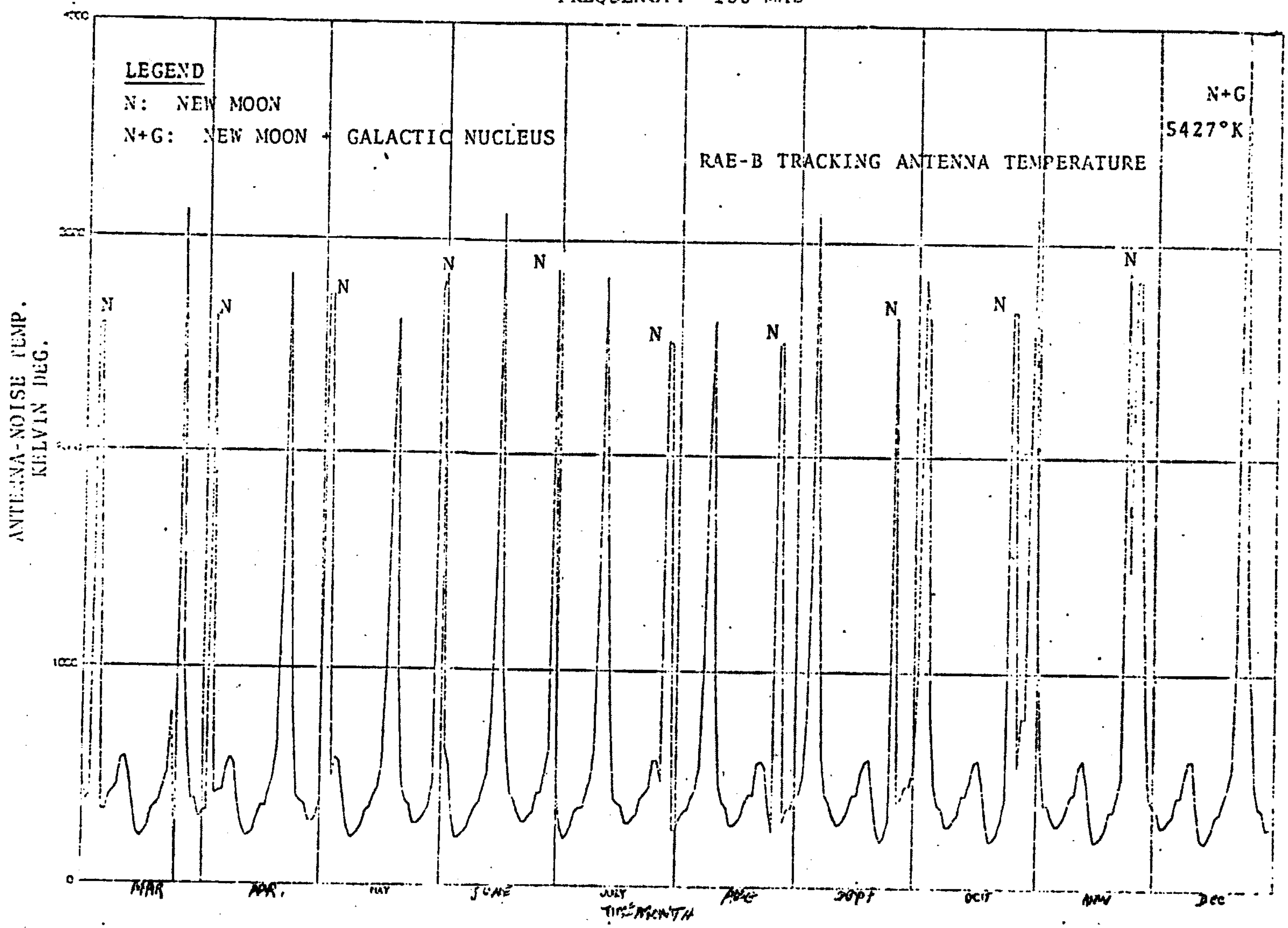


FIGURE 3

MAR 1, 1973 TO DEC 31, 1973. TRACKING STATION: CARVON, ANTENNA TYPE: VHF RARR. TRACKING INTERVAL: 60 MINUTES FREQUENCY: 136 MHZ

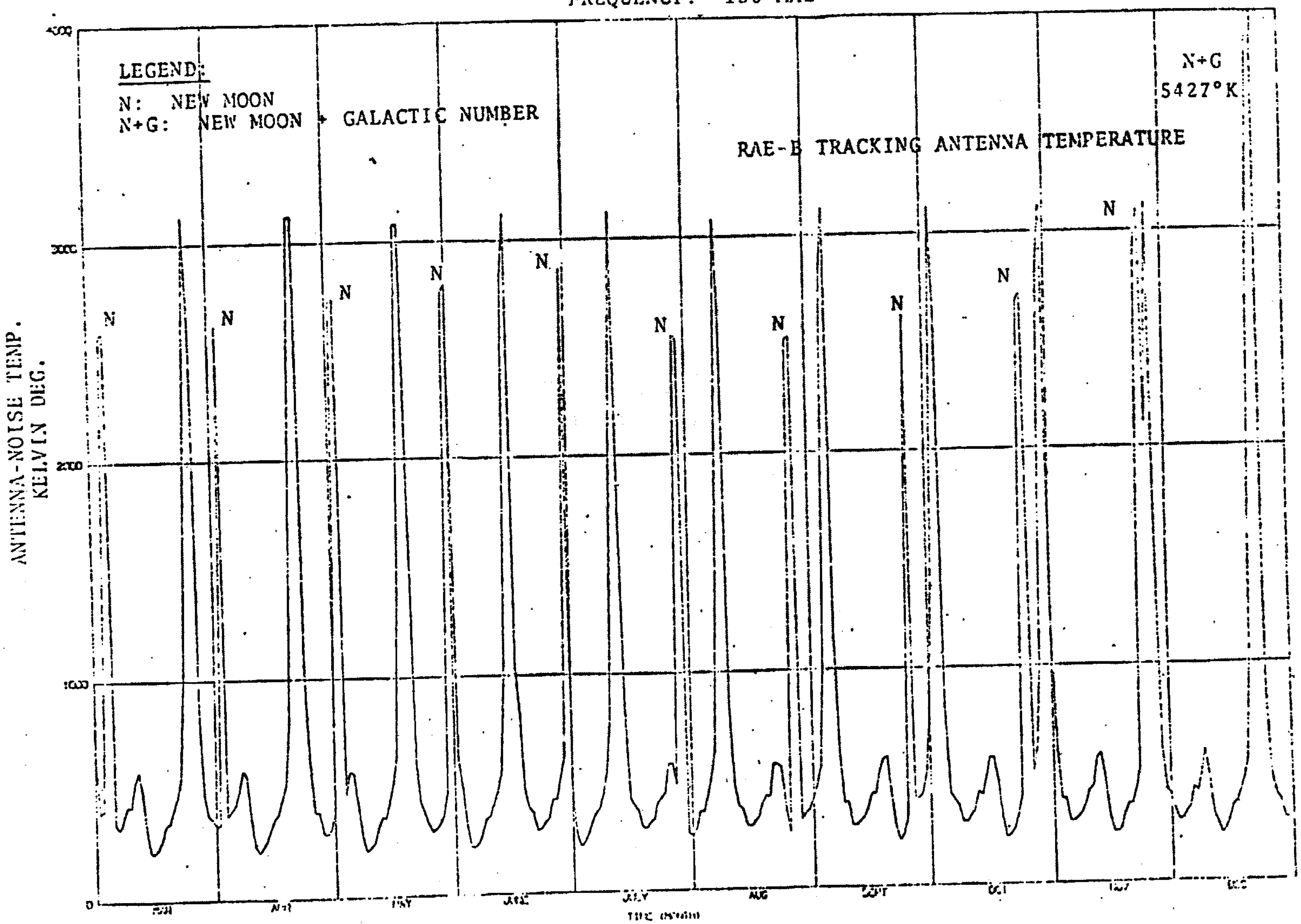


FIGURE 4

MAR 1, 1973 TO DEC 31, 1973. TRACKING STATION:
MADGAR, ANTENNA TYPE: VHF RARR. TRACKING INTERVAL: 60 MINUTES
FREQUENCY: 136 MHZ

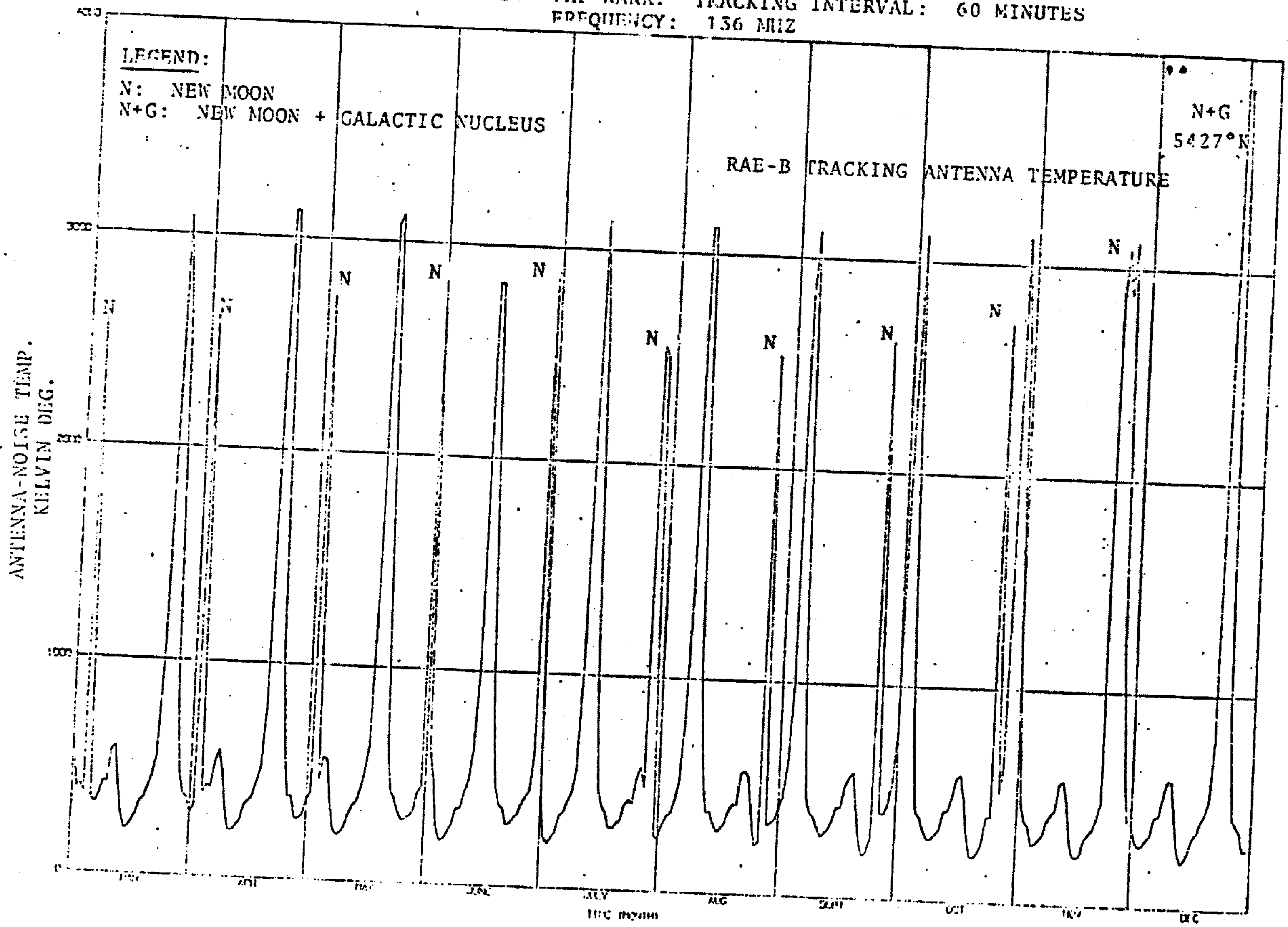
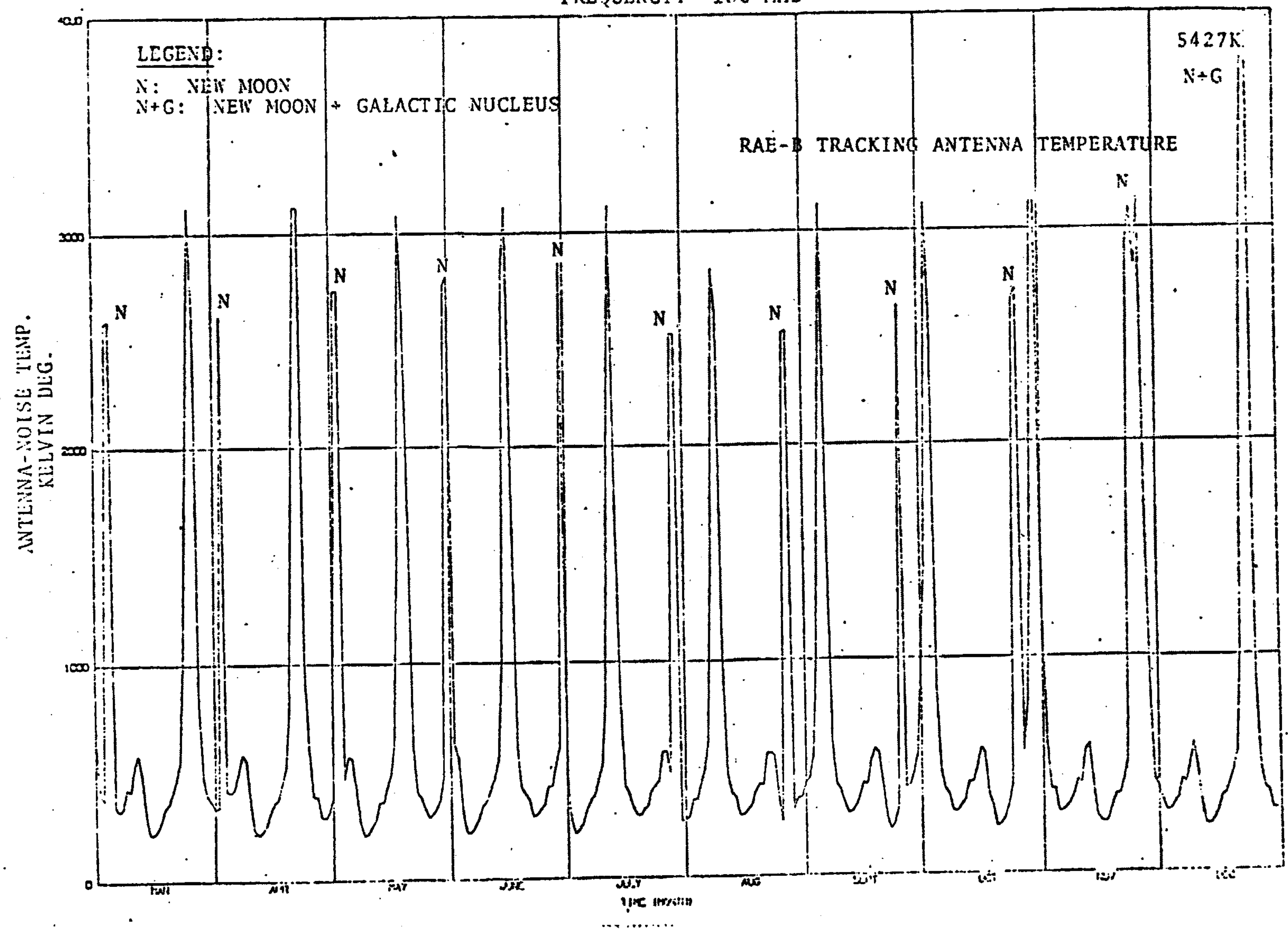


FIGURE 5

MAR 1, 1973 TO DEC 31, 1973. TRACKING STATION:
CRORAL, ANTENNA TYPE: VHF KARR. TRACKING INTERVAL: 60 MINUTES
FREQUENCY: 136 MHZ



MAR 1, 1973 TO DEC 31, 1973. TRACKING STATION:
ROSMAN, ANTENNA TYPE: VHF RARR. TRACKING INTERVAL: 60 MINUTES
FREQUENCY: 136 MHZ

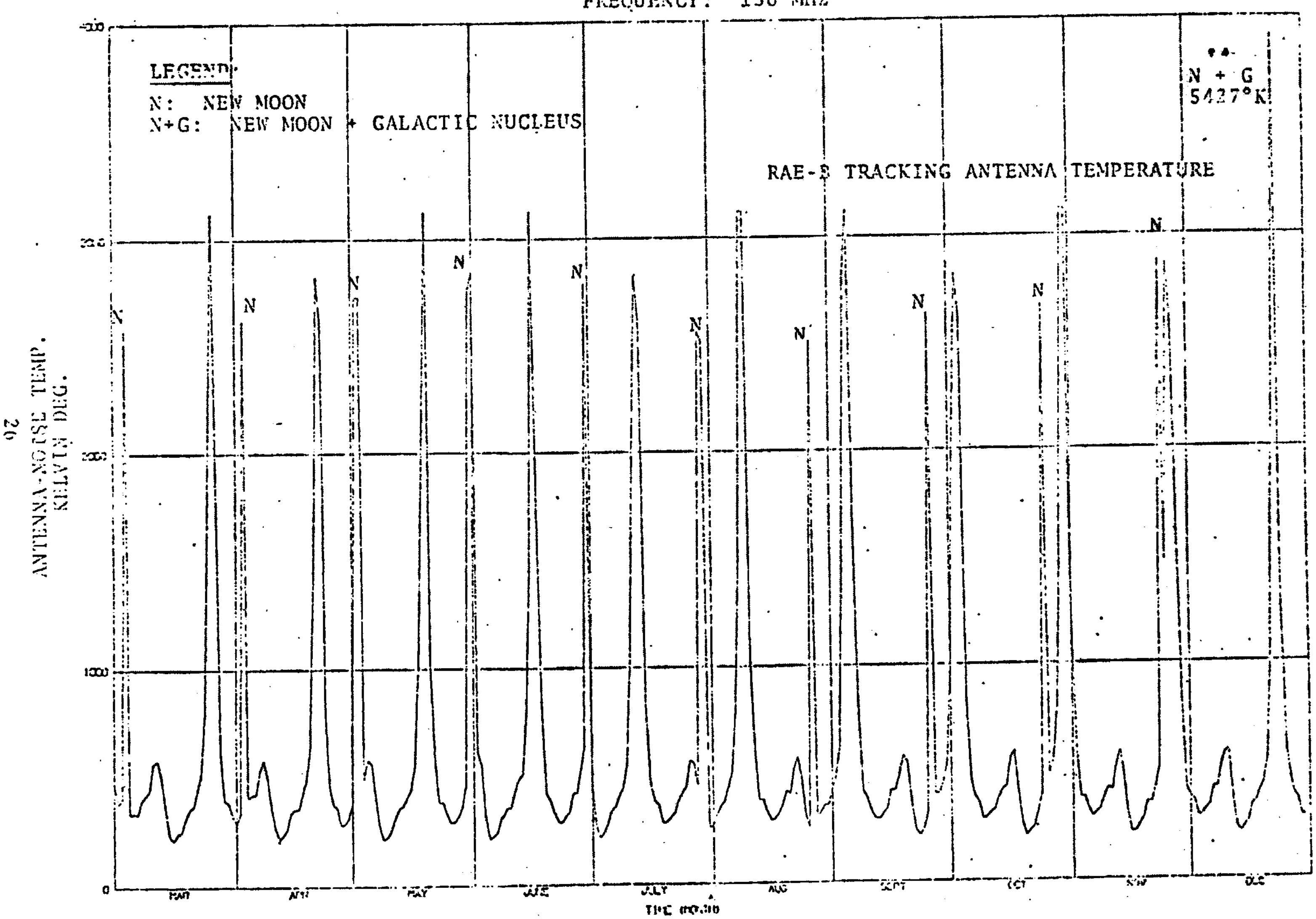
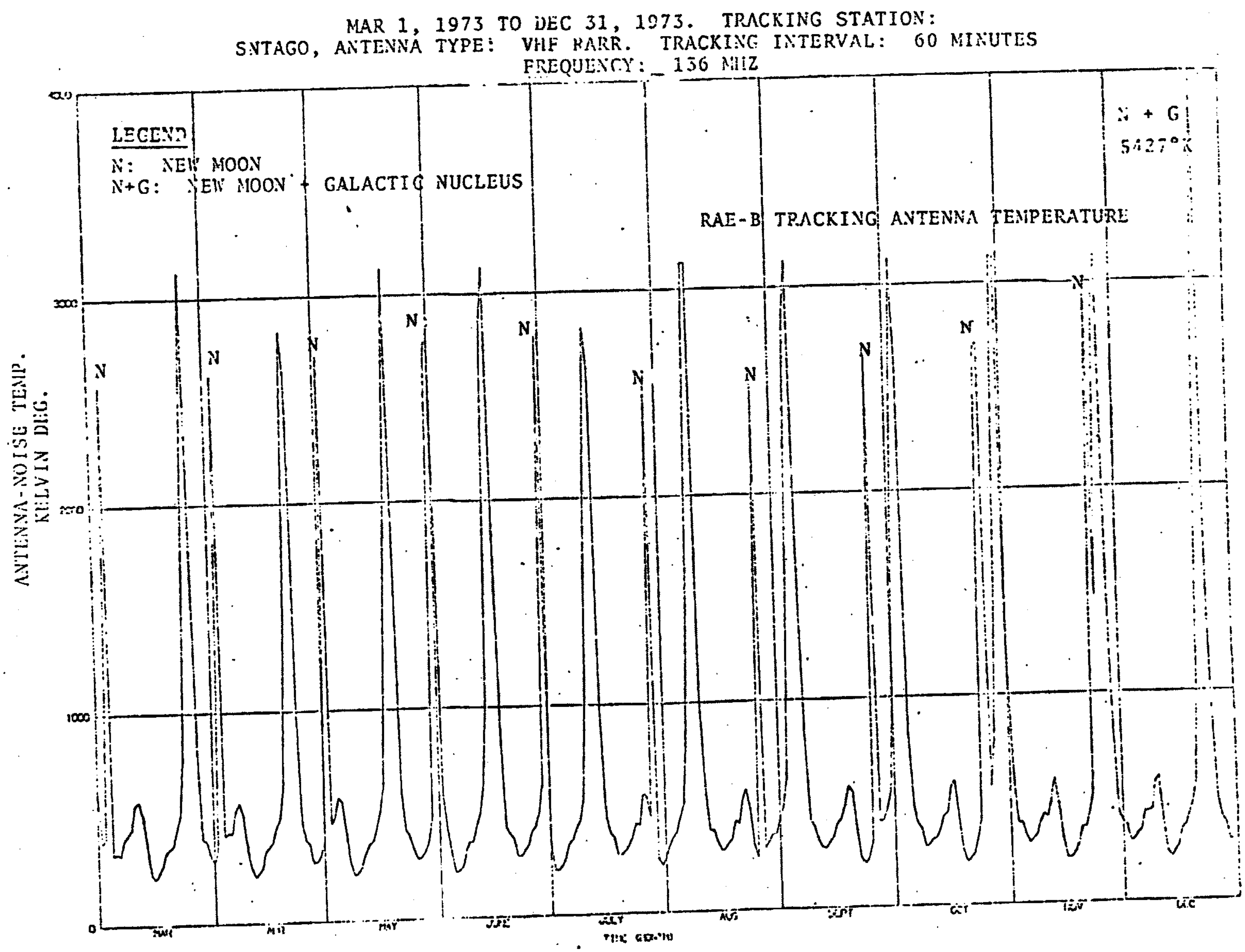
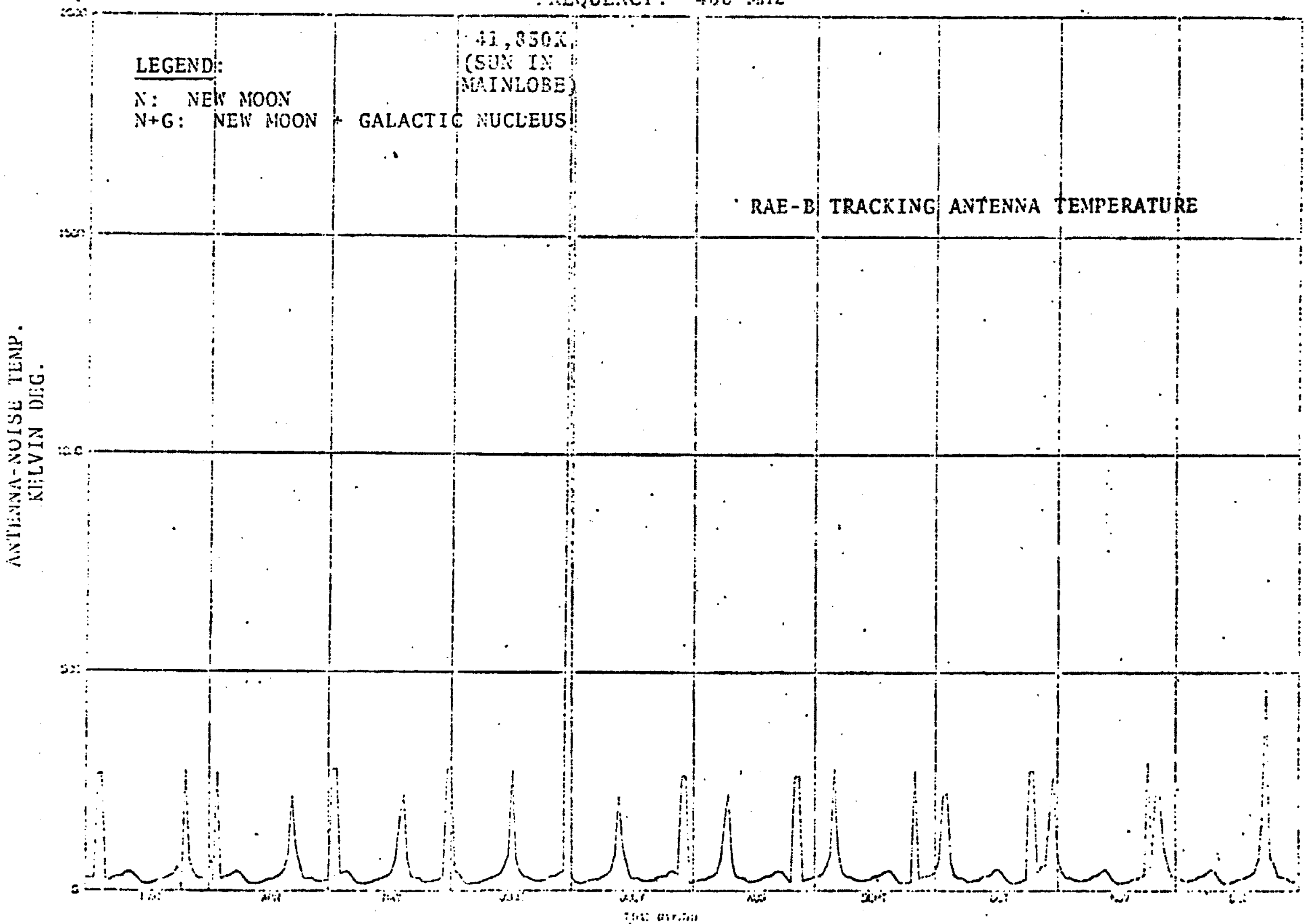


FIGURE 7



MAR 1, 1973 TO DEC 31, 1973. TRACKING STATION:
SNTAGO, ANTENNA TYPE: VHF RARR. TRACKING INTERVAL: 60 MINUTES
FREQUENCY: 136 MHZ
LEGEND
N: NEW MOON
N+G: NEW MOON + GALACTIC NUCLEUS
RAE-B TRACKING ANTENNA TEMPERATURE
N + G
5427°K
N
ANTENNA-NOISE TEMP.
KELVIN DEG.
4000
3000
2000
1000
0
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC

MAR 1, 1973 TO DEC 31, 1973. TRACKING STATION:
ALASKA, ANTENNA TYPE: 85FT. TRACKING INTERVAL: 60 MINUTES
FREQUENCY: 400 MHZ



MAR 1, 1973 TO DEC 31, 1973. TRACKING STATION:
ORORAL, ANTENNA TYPE: 85FT. TRACKING INTERVAL: 60 MINUTES
FREQUENCY: 400 MHZ

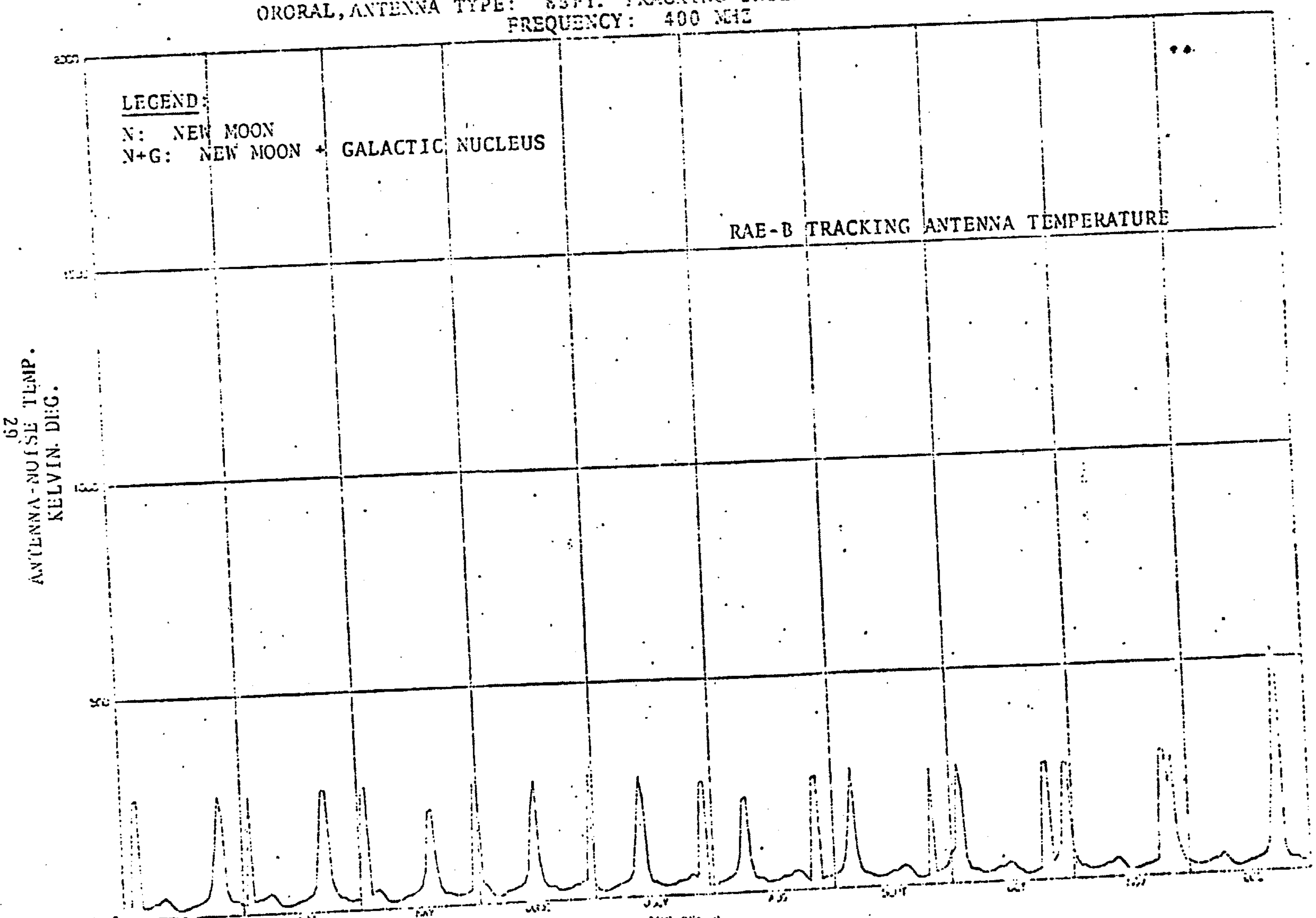
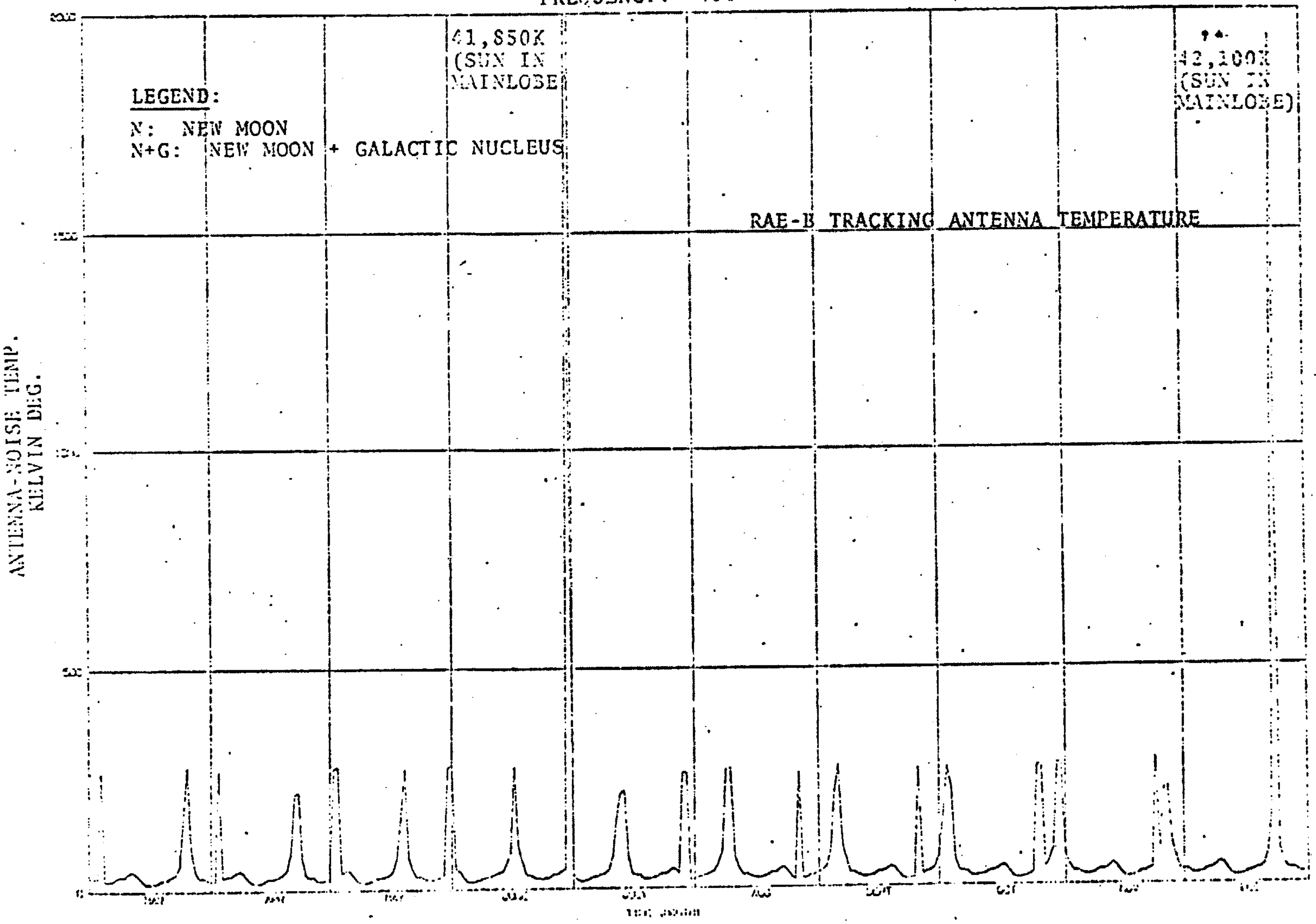
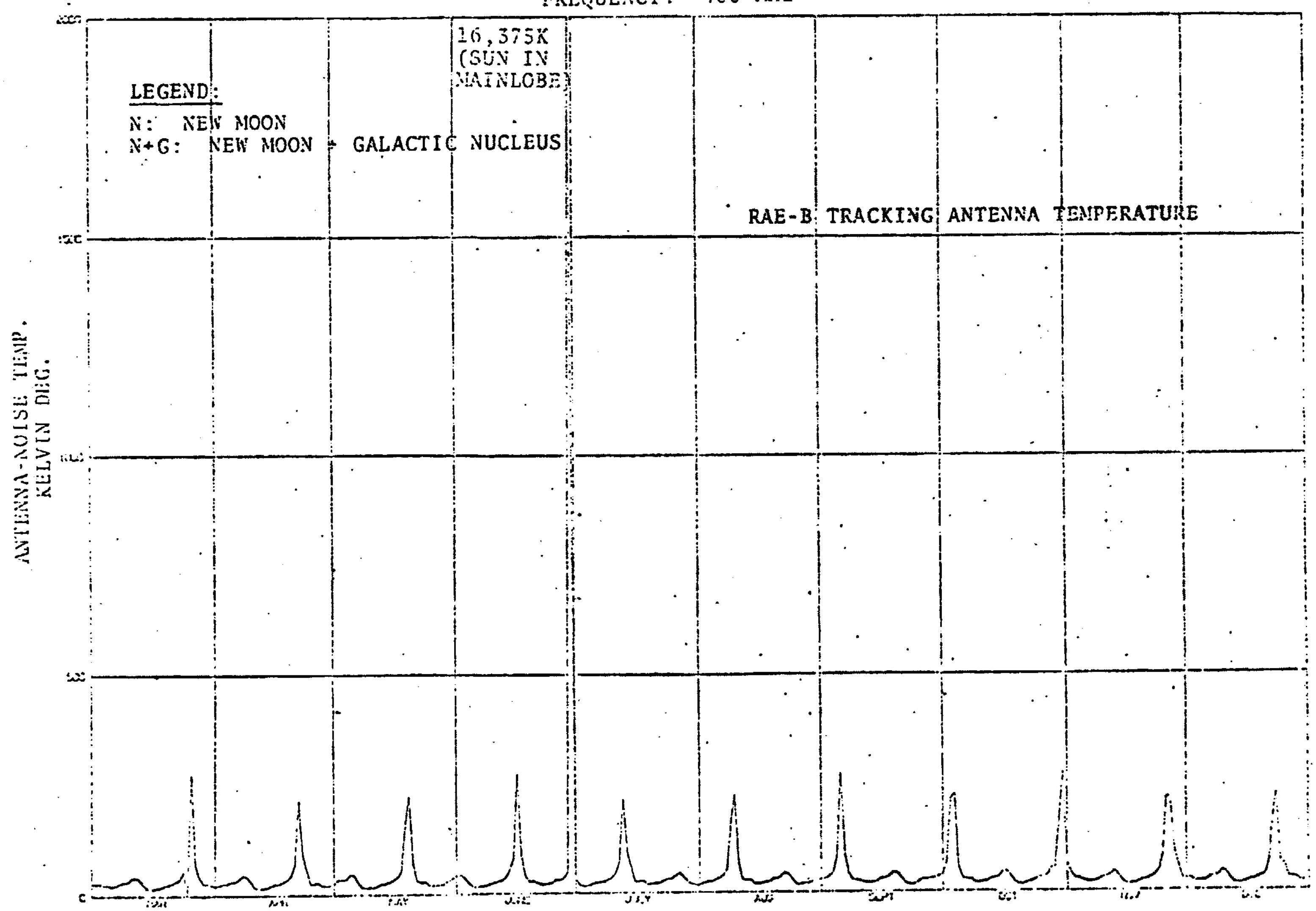


FIGURE 10

MAR 1, 1973 TO DEC 31, 1973. TRACKING STATION:
ROSMAN, ANTENNA TYPE: 85FT. TRACKING INTERVAL: 60 MINUTES
FREQUENCY: 400 MHZ



MAR 1, 1973 TO DEC 31, 1973. TRACKING STATION:
ALASKA, ANTENNA TYPE: 40FT. TRACKING INTERVAL: 60 MINUTES
FREQUENCY: 400 MHZ



MAR 1, 1973 TO DEC 31, 1973. TRACKING STATION
JOBURG, ANTENNA TYPE: 40FT. TRACKING INTERVAL: 60 MINUTES
FREQUENCY: 400 MHZ

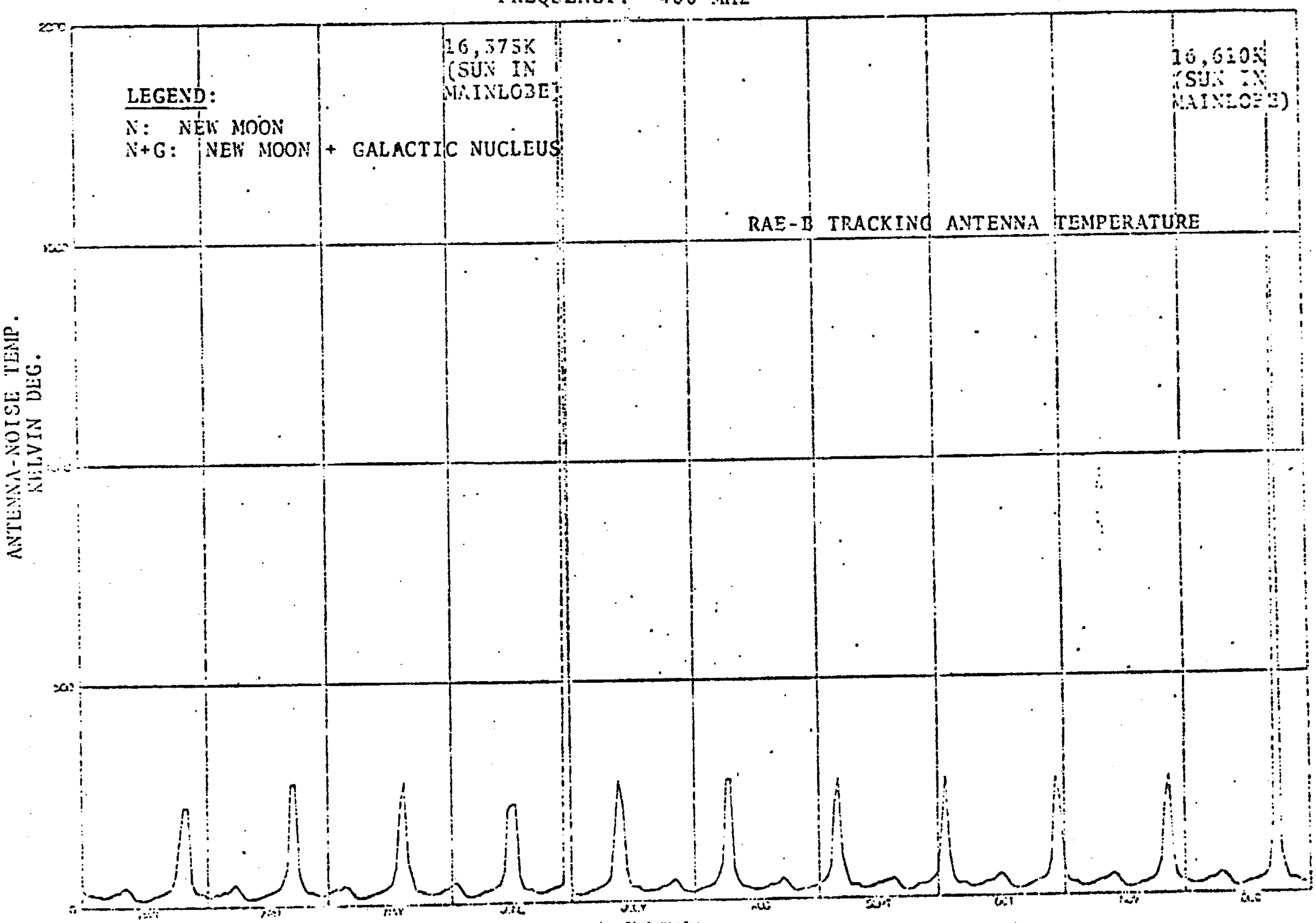
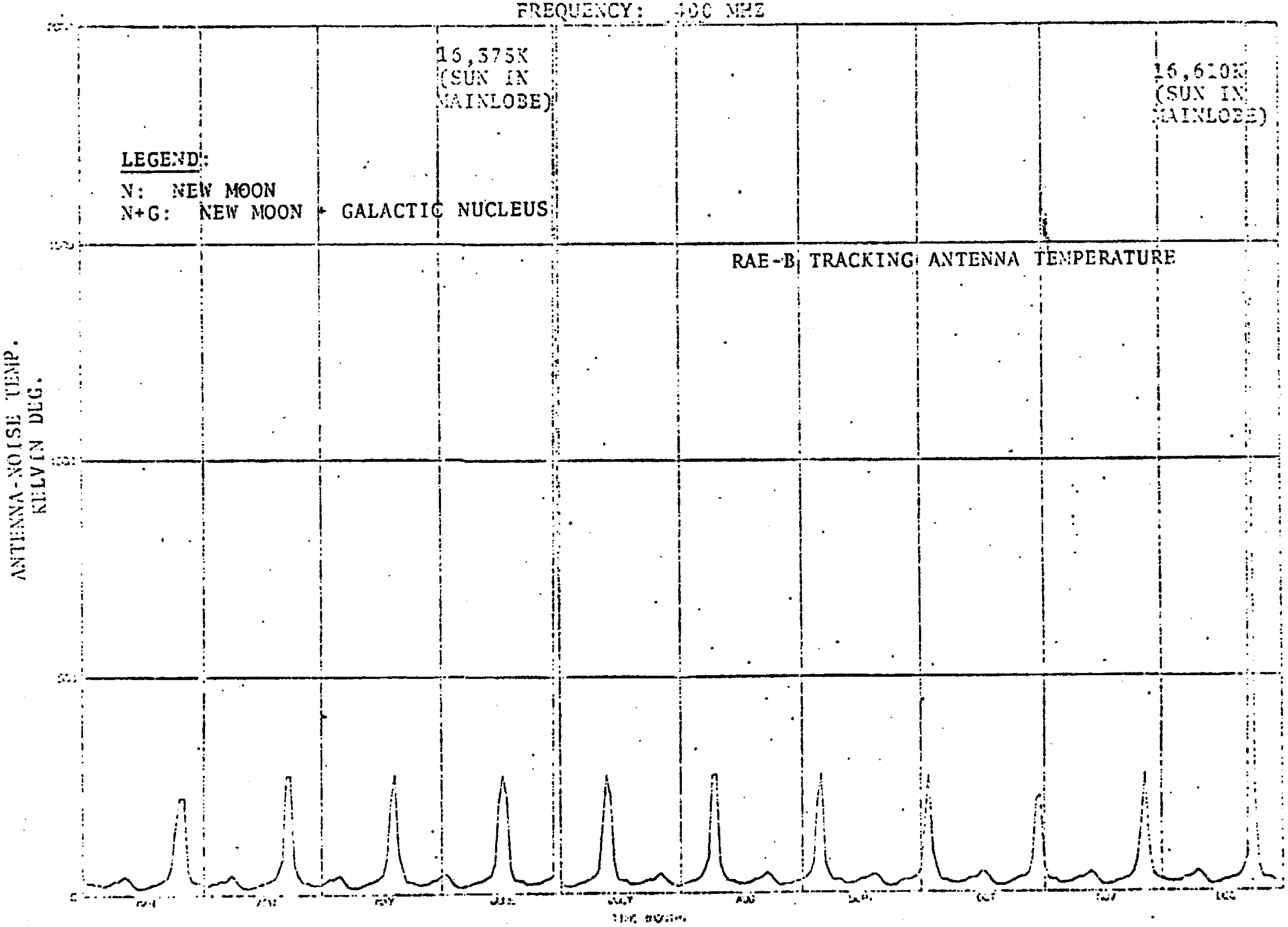
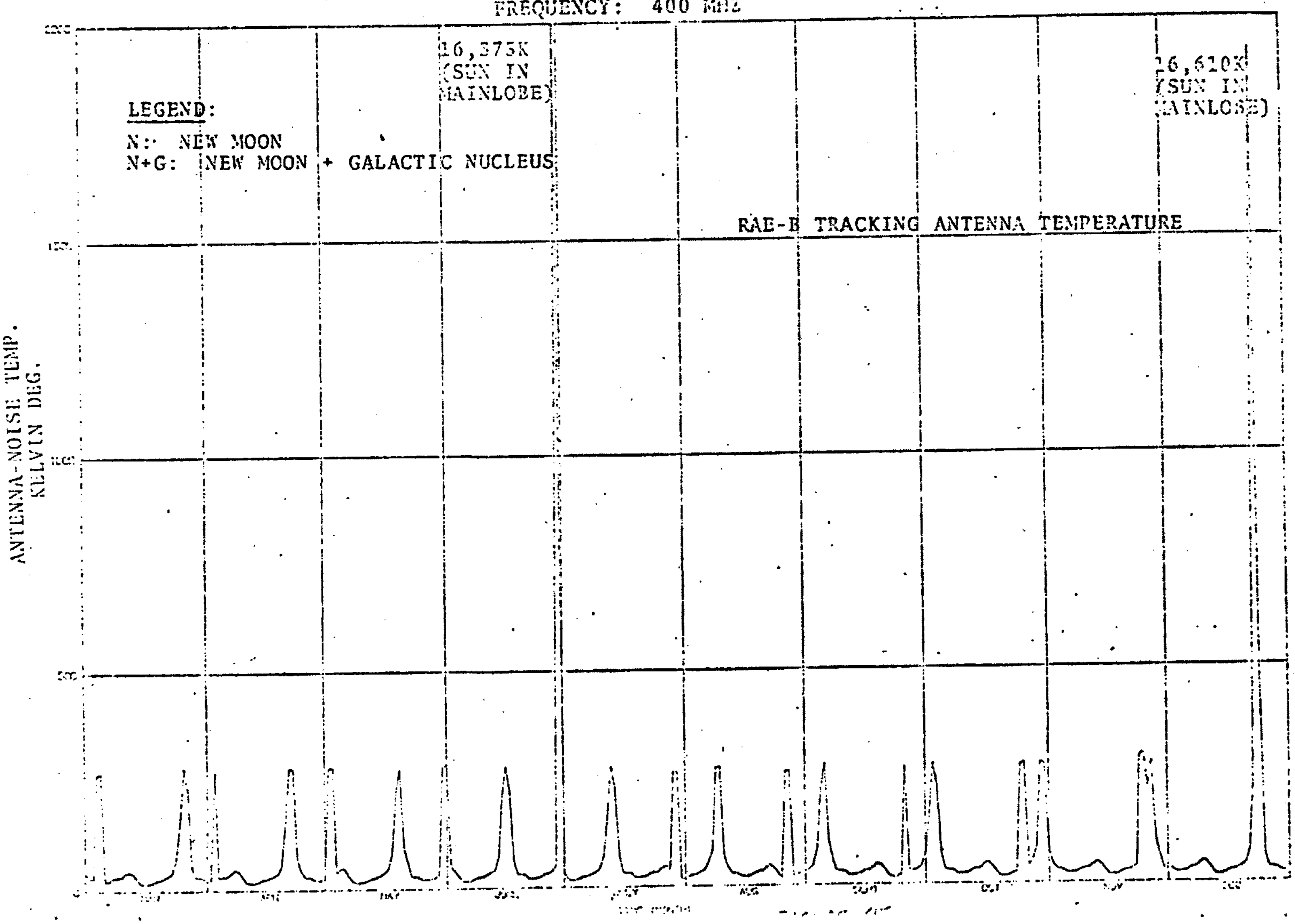


FIGURE 13

MAR 1, 1973 TO DEC 31, 1973. TRACKING STATION:
MADGAR, ANTENNA TYPE: 40FT. TRACKING INTERVAL: 60 MINUTES
FREQUENCY: 400 MHZ

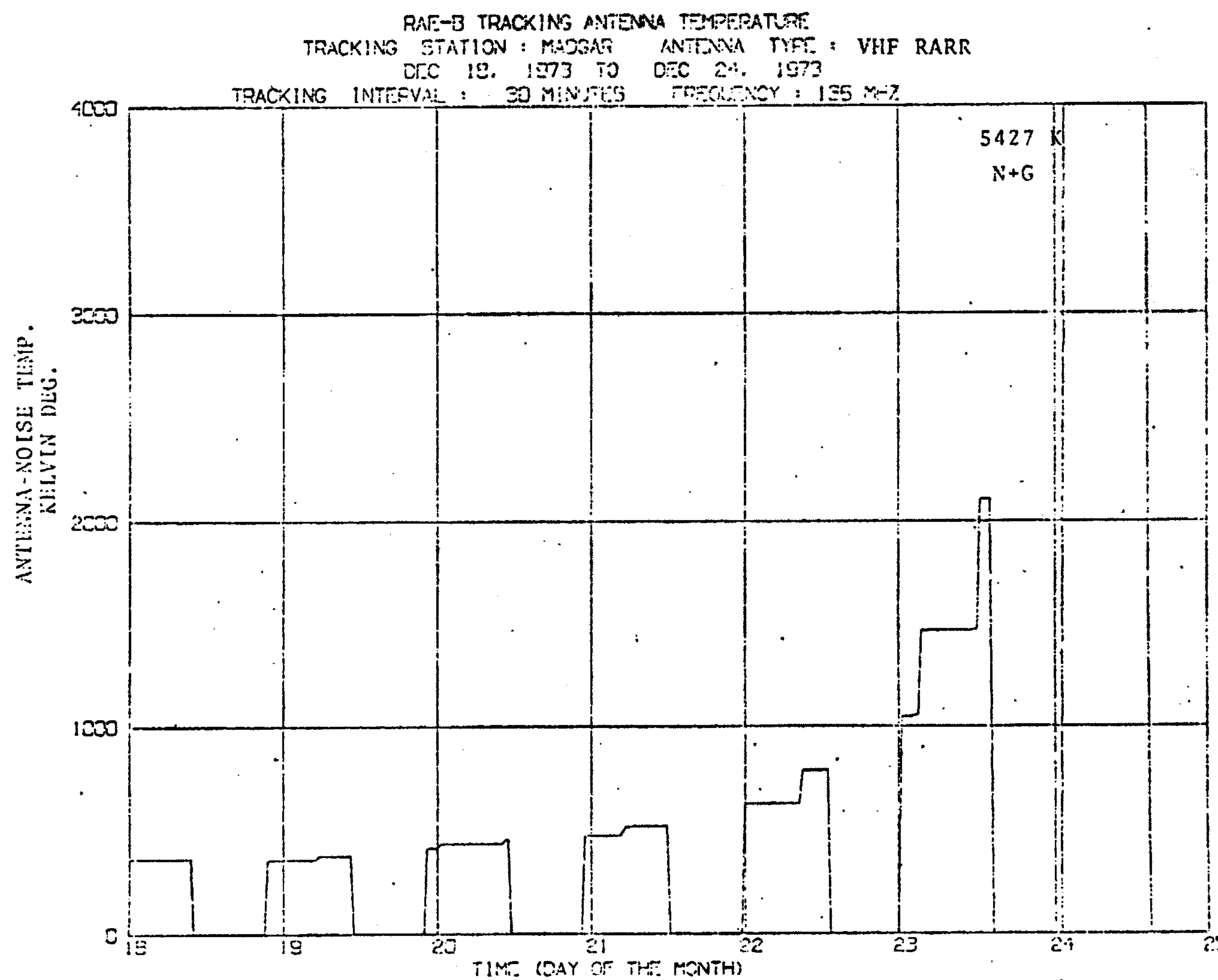


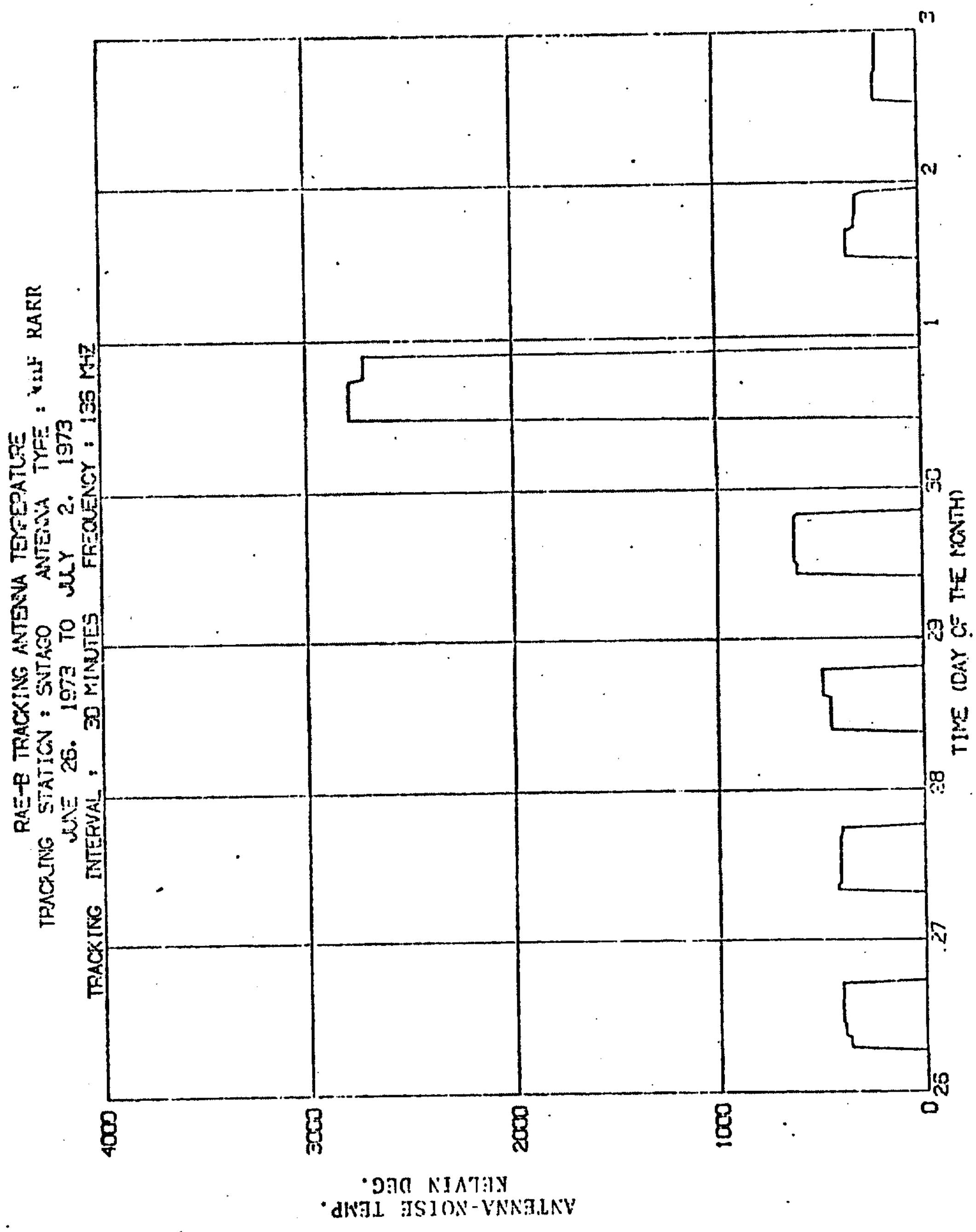
MAR 1, 1973 TO DEC 31, 1973. TRACKING STATION:
SNTAGO, ANTENNA TYPE: 40 FT. TRACKING INTERVAL: 60 MINUTES
FREQUENCY: 400 MHZ



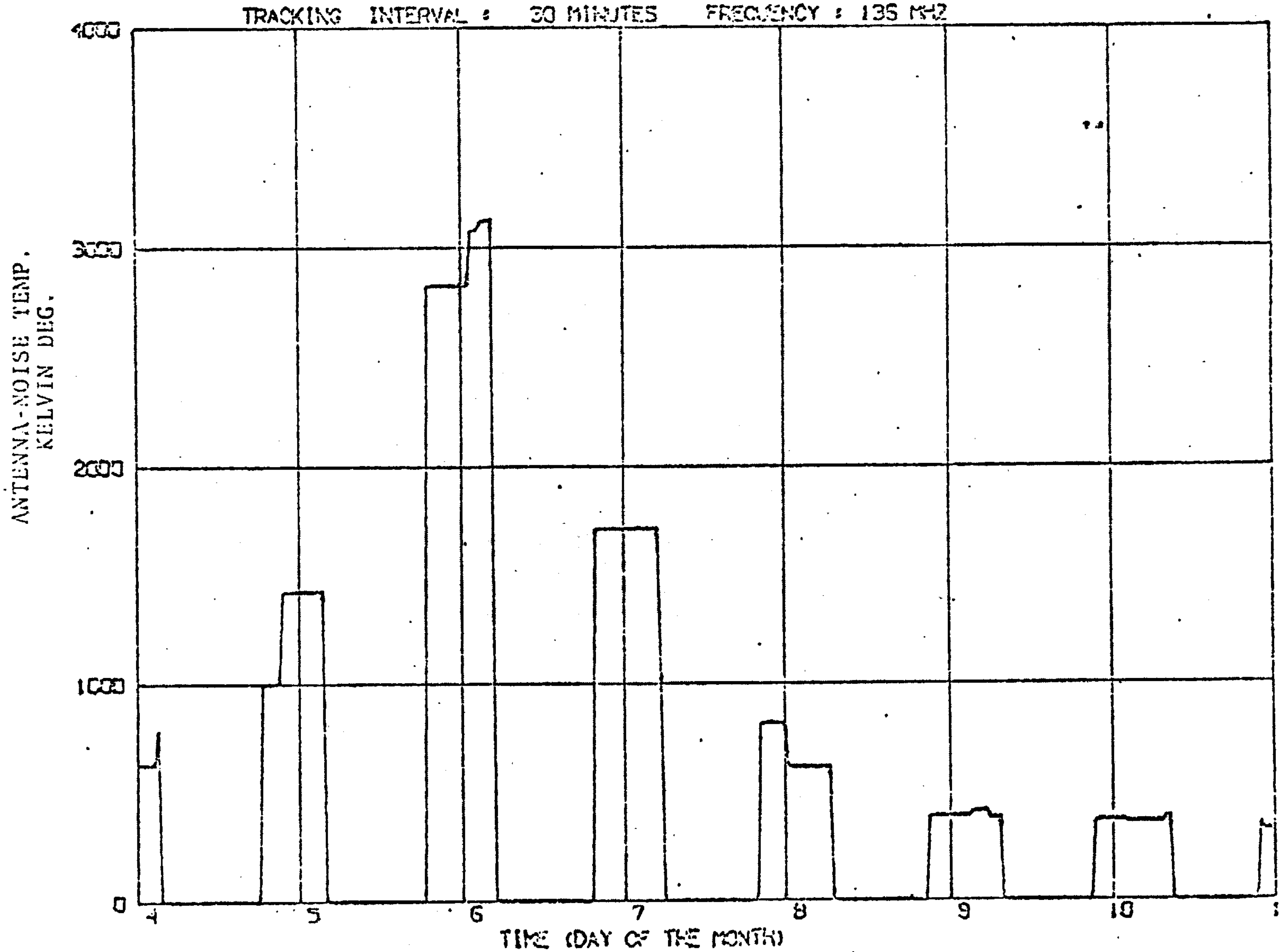
3.2.2 Fine-Grain Analysis of High Temperature Regions

Figures 16 thorugh 21 show fine-grain detail for typical high-temperature regions. The zero temperature portions of these curves represent periods when the moon is not visible. The peaks temperature recorded for each day is utilized as data for the cummulative temperature envelopes given in Figures 3 through 15.


RAE-B TRACKING ANTENNA TEMPERATURE
TRACKING STATION : MADGAR ANTENNA TYPE : VHF RARR
DEC 18, 1973 TO DEC 24, 1973
TRACKING INTERVAL : 30 MINUTES FREQUENCY : 136 MHZ
5427 K
N+G
ANTENNA-NOISE TEMP. KELVIN DEG.
4000
3000
2000
1000
0
18
19
20
21
22
23
24
25
TIME (DAY OF THE MONTH)
FIGURE 16


RAE-B TRACKING ANTENNA TEMPERATURE
TRACKING STATION : SNTAGO ANTENNA TYPE : VHF RARR
JUNE 26. 1973 TO JULY 2. 1973
TRACKING INTERVAL : 30 MINUTES FREQUENCY : 136 MHZ
ANTENNA-NOISE TEMP. KELVIN DEG.
0
1000
2000
3000
4000
TIME (DAY OF THE MONTH)
26
27
28
29
30
1
2
3

RAE-B TRACKING ANTENNA TEMPERATURE
TRACKING STATION : ROSMAN ANTENNA TYPE : VHF RARR
SEPT 4, 1973 TO SEPT 10, 1973
TRACKING INTERVAL : 30 MINUTES FREQUENCY : 135 MHZ



RAE-B TRACKING ANTENNA TEMPERATURE
TRACKING STATION : ROSMAN ANTENNA TYPE : 85FT
DEC 18. 1973 TO DEC 24. 1973
TRACKING INTERVAL : 30 MINUTES FREQUENCY : 400 MHZ

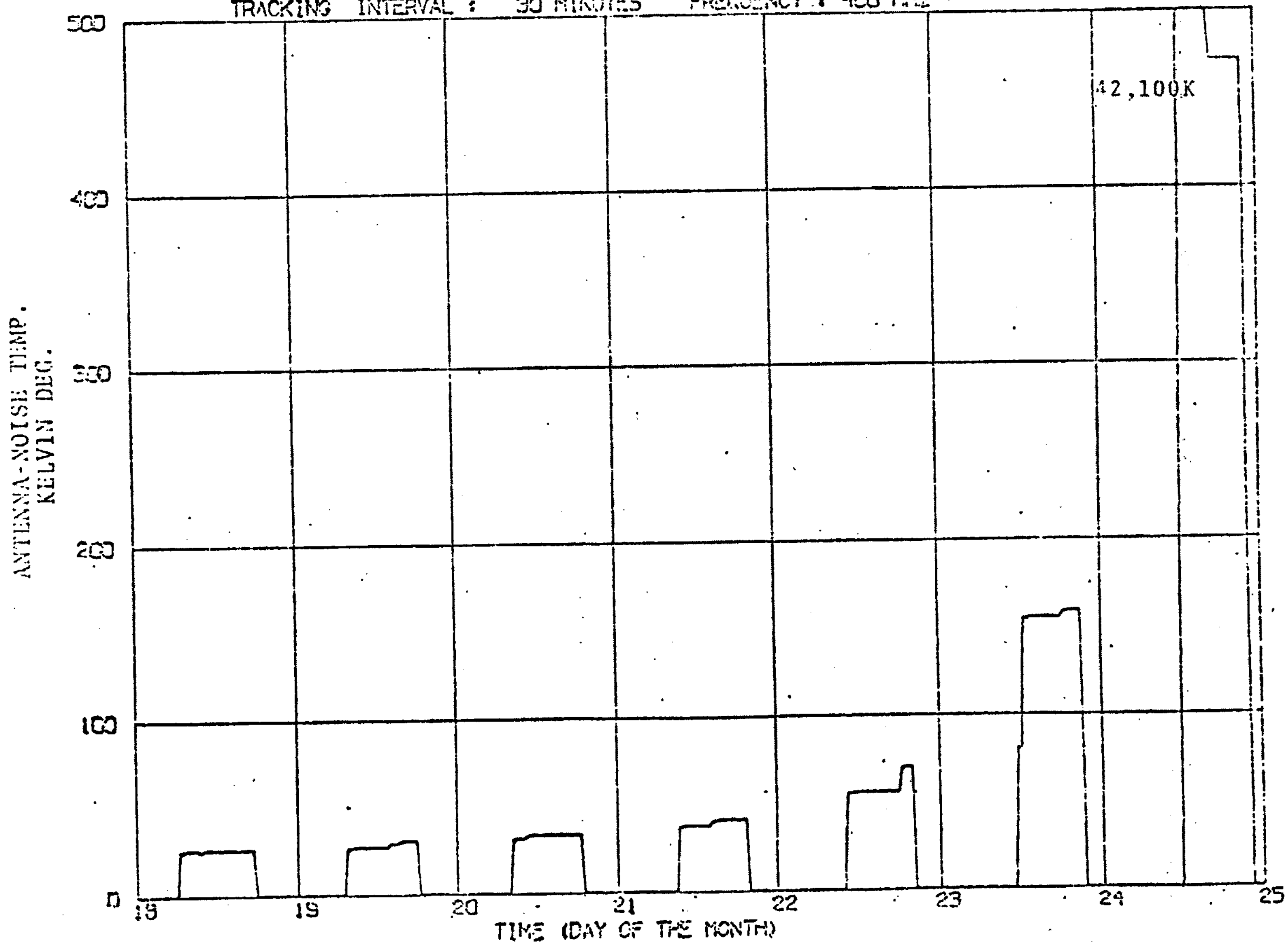
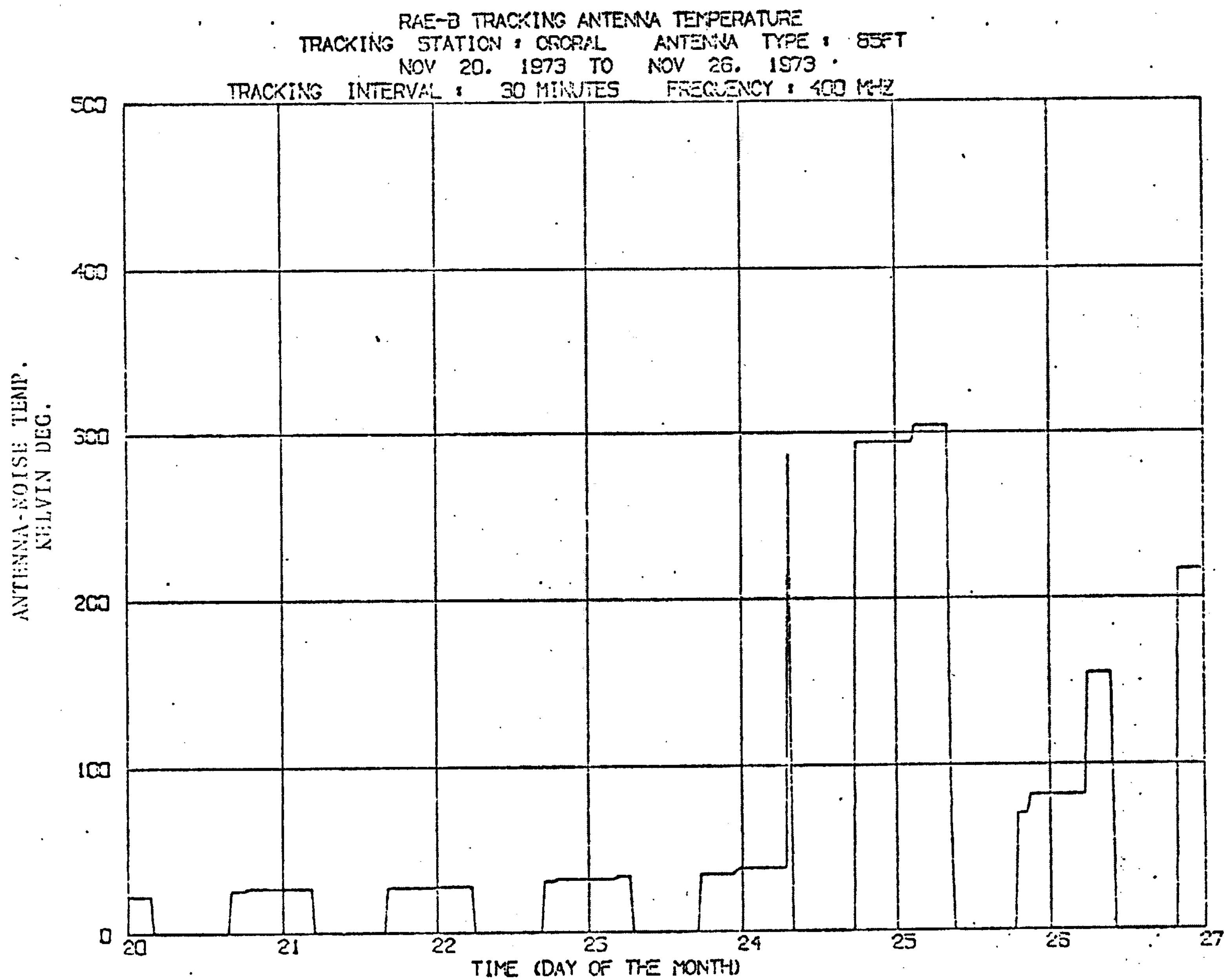


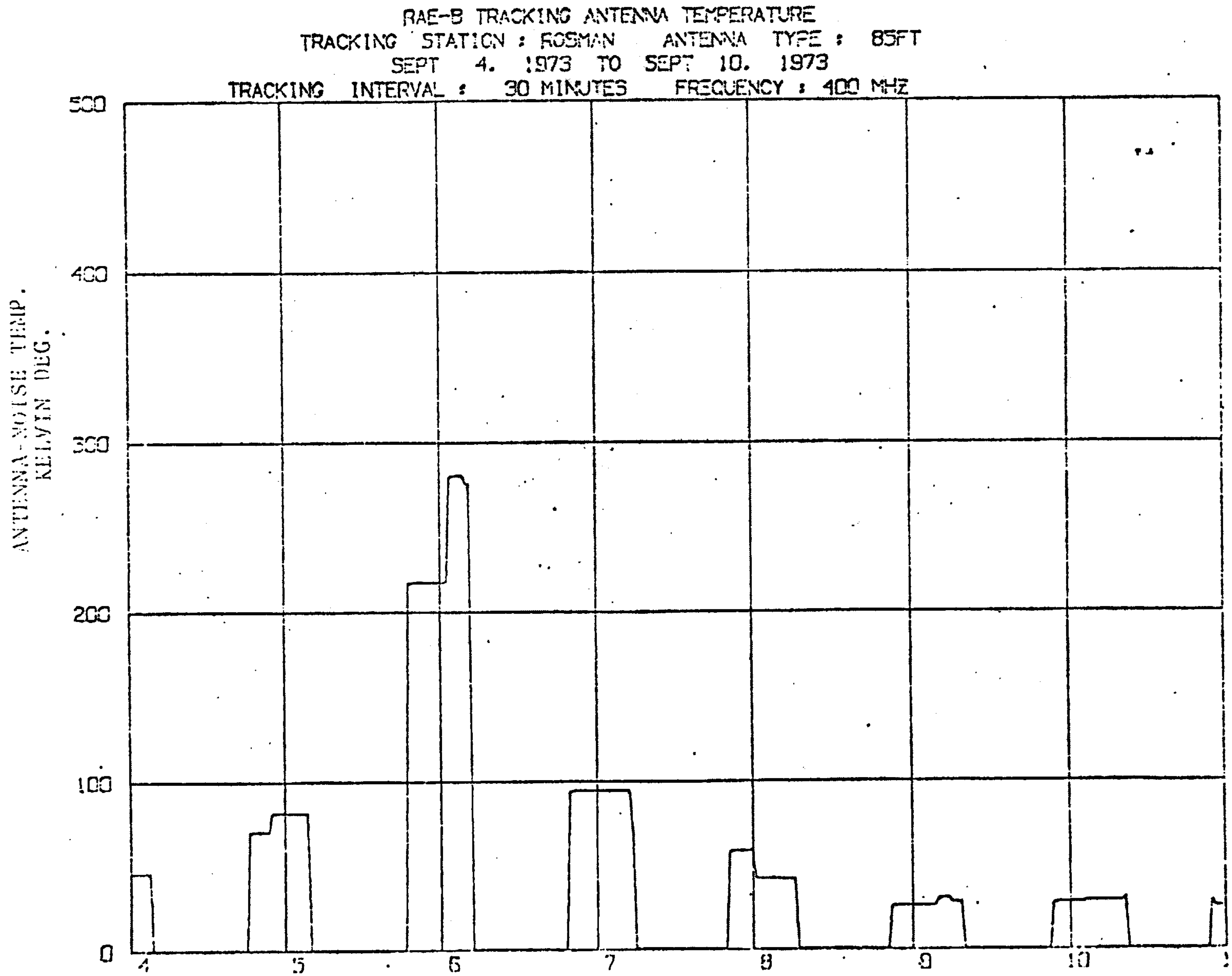
FIGURE 19



RAE-B TRACKING ANTENNA TEMPERATURE
TRACKING STATION : ORORAL ANTENNA TYPE : 85FT
NOV 20. 1973 TO NOV 26. 1973 .
TRACKING INTERVAL : 30 MINUTES FREQUENCY : 400 MHZ
ANTENNA-NOISE TEMP. KELVIN DEG.
0
100
200
300
400
500
20
21
22
23
24
25
26
27
TIME (DAY OF THE MONTH)

FIGURE 20

FIGURE 21


RAE-B TRACKING ANTENNA TEMPERATURE
TRACKING STATION : ROSMAN ANTENNA TYPE : 85FT
SEPT 4. 1973 TO SEPT 10. 1973
TRACKING INTERVAL : 30 MINUTES FREQUENCY : 400 MHZ
ANTENNA-NOISE TEMP.
KELVIN DEG.
500
400
300
200
100
0
4
5
6
7
8
9
10
11

SECTION 4.0
CONCLUDING REMARKS

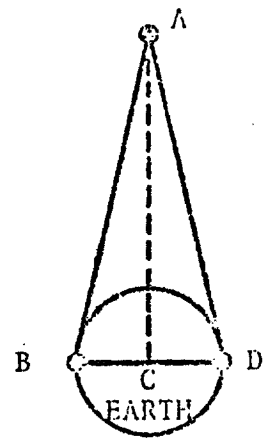
The results of the simplified simulation are expected to be accurate within twenty percent for the stations employing the VHF RARR or 40 foot dish antenna. However, the 85 foot dish results may not be at the same level of accuracy because the maximum error introduced by the geocentric simplification is almost the same magnitude as the half beam width of the 85 foot dish main lobe (1.25°). This simplification also causes a timing or phasing error in the temperature profile of between one to two hours for all stations.

These preliminary results will be verified and refined by the utilization of a more sophisticated program, now under development, which does not employ the approximations of the simplified program. The temperature profiles obtained from this program will be published in a subsequent report.

Appendices A and B have been inserted to further define the program.

4.1 ANGULAR ERROR INTRODUCED BY GEOCENTRIC APPROXIMATION

Consider the following geometry of the moon, earth's center and points of moon rise and moon set on the earth's surface



A - moon's position

B - moon rise

C - geocenter

D - moon set

Angle ACD = ACB = 90° since AC is the bisector of an isosceles triangle

Angle ABD = ADB = $90° - \tan^{-1} \frac{BC}{AC}$

BC = Average Earth's radius 6378.155 km

AC = Average distance from geocenter to selenocenter, 384000 km

$\tan^{-1} (\frac{BC}{AC})$ = 0.0166 = 0.95°

Therefore, the angular error introduced by the geocentric approximation is a maximum of 0.95°

SECTION 5.0
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APPENDIX A

PROGRAM INPUT DATA

FOR SIMPLIFIED PROGRAM

1. Time span for observation and interval of computation. For the last ten months in 1973 (from March 1, 1973 to December 31, 1973). The interval of computation is variable between 10 minutes to an hour. The span per run is variable.

2. Name and location of the tracking stations are given in Section A-1.

3. Antennas at 136 MHz and 400 MHz are specified in terms of:

   a. Main Lobe half power beam width

   b. Second lobe total beam width and gain factor.

   The tracking antenna patterns are displayed in Section A.2.

4. Sky Map. Both 136 MHz and 400 MHz brightness temperature maps are on tape which are accessed by the program. Contour plots of these data are given in Section A-3.

5. Jet Propulsion Laboratory emphemeris tape. This tape is accessed to obtain the positions of moon and sun.

6. Radio Star Locations. There are five radio stars at both 136 MHz and 400 MHz (in Section 5.3).

   The right ascension, declination and noise power for each radio star is shown in Section A-4.

A-1 RAE-B TRACKING STATIONS

136 MHz

STATION IDENT	ANTENNA TYPE
ALASKA	VHF RARR
CARVON	VHF RARR
MADGAR	VHF RARR
ORORAL	VHF RARR
ROSMAN	VHF RARR
SNTAGO	VHF RARR

400 MHz

STATION IDENT	ANTENNA TYPE	LATITUDE DEG-MIN-SEC	LONGITUDE DEG-MIN-SEC
ALASKA	85FT	64 58 36.57	212 29 5.79
ALASKA	40FT	64 58 36.57	212 29 5.79
JOBURG	40FT	-25 52 58.86	27 42 27.93
MADGAR	40FT	-19 0 27.11	47 18 0.47
ORORAL	85FT	-35 37 52.72	148 57 20.87
ROSMAN	85FT	35 12 0.71	277 7 41.23
SNTAGO	40FT	-33 8 58.11	289 19 51.28

A-2

TRACKING STATION ANTENNA PATTERNS

SKY NOISE CONSTANTS AND RECEIVER ANTENNA GAINS TABLE

SATAN TRACKING SYSTEM - 136 MHZ

ANTENNA HALF POWER BEAM WIDTH 12.30 DEGREES

RECEIVING ANTENNA GAINS AT 0.20 DEGREES INCREMENT

0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-1.	-1.	-1.	-1.	-1.	-1.	-1.
-1.	-1.	-1.	-2.	-2.	-2.	-2.	-2.	-2.	-3.	-3.	-3.	-3.	-4.	-4.	-4.	-4.	-5.	-5.	-5.
-5.	-6.	-8.	-6.	-7.	-7.	-7.	-8.	-9.	-9.	-9.	-9.	-9.	-10.	-10.	-11.	-11.	-11.	-12.	-12.
-13.	-13.	-14.	-14.	-15.	-15.	-16.	-16.	-17.	-17.	-18.	-18.	-19.	-19.	-20.	-20.	-21.	-21.	-21.	-20.
-20.	-19.	-19.	-18.	-18.	-17.	-17.	-16.	-16.	-16.	-16.	-15.	-15.	-15.	-15.	-14.	-15.	-15.	-15.	-15.
-16.	-15.	-15.	-15.	-15.	-15.	-15.	-15.	-15.	-15.	-15.	-16.	-16.	-16.	-16.	-16.	-15.	-16.	-17.	-17.
-17.	-17.	-17.	-17.	-18.	-18.	-18.	-18.	-18.	-18.	-18.	-18.	-18.	-18.	-18.	-18.	-18.	-18.	-18.	-18.
-18.	-18.	-18.	-18.	-17.	-17.	-17.	-15.	-15.	-15.	-15.	-15.	-15.	-15.	-15.	-15.	-15.	-15.	-15.	-15.
-15.	-18.	-15.	-15.	-16.	-15.	-15.	-15.	-16.	-16.	-16.	-16.	-16.	-16.	-16.	-16.	-16.	-16.	-17.	-17.
-17.	-17.	-17.	-17.	-17.	-17.	-18.	-18.	-18.	-18.	-18.	-18.	-19.	-18.	-19.	-19.	-19.	-19.	-19.	-19.
-19.	-19.	-19.	-19.	-19.	-19.	-20.	-20.	-21.	-21.	-22.	-22.	-23.	-23.	-24.	-24.	-24.	-25.	-25.	-26.
-26.	-27.	-27.	-28.	-28.	-29.	-29.	-30.	-30.	-30.	-31.	-31.	-32.	-32.	-33.	-33.	-34.	-34.	-35.	-35.
-36.	-36.	-38.	-37.	-37.	-38.	-38.	-39.	-39.	-40.	-40.	-39.	-38.	-37.	-36.	-35.	-34.	-33.	-32.	-32.
-31.	-30.	-30.	-29.	-29.	-28.	-27.	-27.	-27.	-26.	-26.	-25.	-25.	-23.	-25.	-24.	-24.	-24.	-24.	-24.
-23.	-23.	-23.	-23.	-23.	-23.	-23.	-23.	-23.	-23.	-23.	-23.	-23.	-23.	-23.	-23.	-23.	-23.	-23.	-23.
-23.	-23.	-23.	-24.	-24.	-24.	-24.	-24.	-24.	-24.	-24.	-24.	-24.	-25.	-25.	-25.	-25.	-25.	-25.	-25.
-25.	-25.	-25.	-26.	-26.	-26.	-26.	-26.	-26.	-26.	-26.	-26.	-26.	-26.	-26.	-26.	-26.	-26.	-26.	-26.
-26.	-26.	-26.	-26.	-25.	-26.	-26.	-26.	-26.	-26.	-26.	-26.	-25.	-26.	-26.	-25.	-25.	-25.	-25.	-25.
-25.	-25.	-25.	-25.	-25.	-25.	-25.	-25.	-24.	-24.	-24.	-24.	-24.	-24.	-24.	-24.	-24.	-24.	-24.	-24.
-24.	-24.	-23.	-23.	-23.	-23.	-23.	-23.	-23.	-24.	-24.	-24.	-24.	-24.	-24.	-24.	-24.	-24.	-25.	-25.
-25.	-25.	-25.	-26.	-25.	-25.	-27.	-27.	-28.	-28.	-29.	-29.	-30.	-30.	-31.	-31.	-32.	-33.	-34.	-34.
-35.	-38.	-37.	-40.	-40.	-40.	-40.	-40.	-40.	-40.	-40.	-40.	-40.	-40.	-40.	-40.	-40.	-40.	-40.	-40.
-40.	-40.	-40.	-40.	-40.	-40.	-40.	-40.	-40.	-40.	-40.									

SKY NOISE CONSTANTS AND RECEIVER ANTENNA GAINS TABLE

ESFT DISH TRACKING SYSTEM - 136 MHZ

ANTENNA HALF POWER BEAM WIDTH 6.70 DEGREES

RECEIVING ANTENNA GAINS AT 0.20 DEGREES INCREMENT

0.	-0.	-0.	-0.	-0.	-0.	-0.	-1.	-1.	-1.	-1.	-1.	-2.	-2.	-2.	-2.	-3.	-3.	-4.	-5.
-6.	-6.	-7.	-8.	-9.	-10.	-11.	-12.	-13.	-14.	-15.	-16.	-17.	-18.	-20.	-21.	-22.	-23.	-24.	-26.
-17.	-16.	-35.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-34.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-35.	-35.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-22.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.
-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.	-33.

SKY NOISE CONSTANTS AND RECEIVER ANTENNA GAINS TABLE

40FT DISH TRACKING SYSTEM - 136 MHZ

ANTENNA HALF POWER BEAM WIDTH 10.80 DEGREES

RECEIVING ANTENNA GAINS AT 0.20 DEGREES INCREMENT

-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-2.
-2.	-2.	-2.	-2.	-3.	-3.	-3.	-3.	-4.	-4.	-4.	-4.	-5.	-5.	-5.	-5.	-6.	-6.	-6.	-7.
-7.	-7.	-8.	-8.	-9.	-9.	-9.	-10.	-10.	-11.	-11.	-11.	-12.	-12.	-13.	-13.	-14.	-14.	-15.	-15.
-16.	-16.	-17.	-17.	-18.	-19.	-19.	-20.	-20.	-21.	-21.	-22.	-23.	-23.	-24.	-25.	-25.	-26.	-27.	-27.
-28.	-29.	-28.	-27.	-27.	-26.	-25.	-25.	-25.	-24.	-24.	-23.	-23.	-23.	-22.	-22.	-22.	-21.	-21.	-21.
-31.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
-20.	-21.	-21.	-21.	-21.	-22.	-22.	-22.	-23.	-23.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.									

SKY NOISE CONSTANTS AND RECEIVED ANTENNA GAINS TABLE

85FT DISH TRACKING SYSTEM - 400 MHZ

ANTENNA HALF POWER BEAM WIDTH 2.50 DEGREES

RECEIVING ANTENNA GAINS AT 0.20 DEGREES INCREMENT

-0.	-0.	-0.	-1.	-1.	-2.	-3.	-3.	-4.	-6.	-9.	-12.	-15.	-20.	-24.	-30.	-26.	-20.	-17.	-15.
-15.	-15.	-15.	-15.	-16.	-16.	-16.	-16.	-17.	-17.	-17.	-16.	-15.	-15.	-15.	-20.	-21.	-23.	-23.	-25.
-26.	-28.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.									

SKY NOISE CONSTANTS AND RECEIVER ANTENNA GAINS TABLE

40FT DISH TRACKING SYSTEM - 400 MHZ

ANTENNA HALF POWER BEAM WIDTH 4.00 DEGREES

RECEIVING ANTENNA GAINS AT 0.20 DEGREES INCREMENT

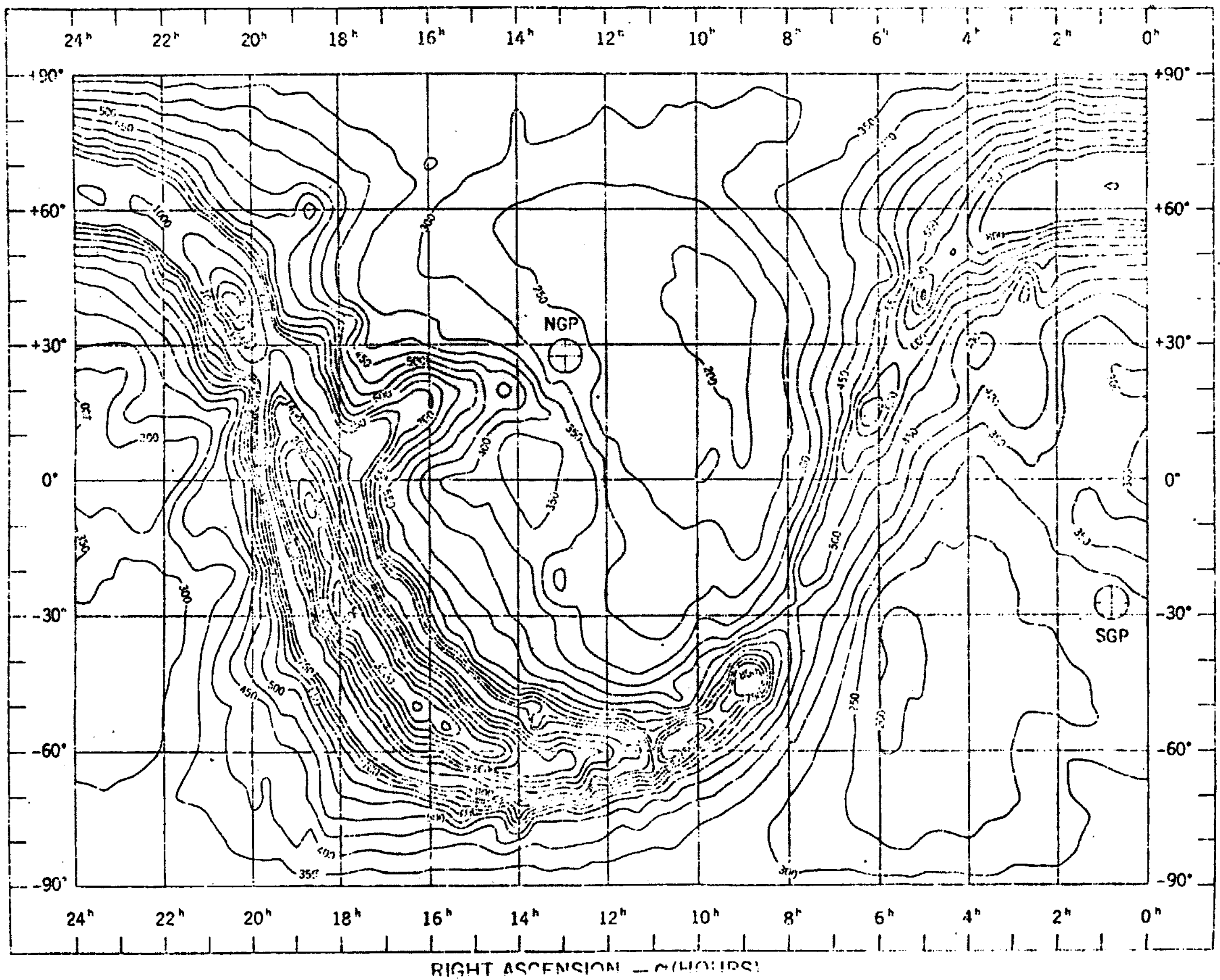
-0.	-0.	-0.	-1.	-1.	-1.	-2.	-2.	-2.	-3.	-3.	-3.	-4.	-4.	-5.	-5.	-5.	-6.	-6.	-7.
-7.	-8.	-8.	-9.	-10.	-10.	-11.	-11.	-12.	-13.	-13.	-14.	-15.	-15.	-16.	-17.	-18.	-19.	-19.	-20.
-21.	-21.	-22.	-23.	-24.	-25.	-25.	-26.	-26.	-27.	-27.	-28.	-29.	-29.	-29.	-29.	-29.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-29.	-29.	-29.	-29.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.
-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.	-30.									

A-3

SKY-BRIGHTNESS TEMPERATURE
CONTOUR MAPS

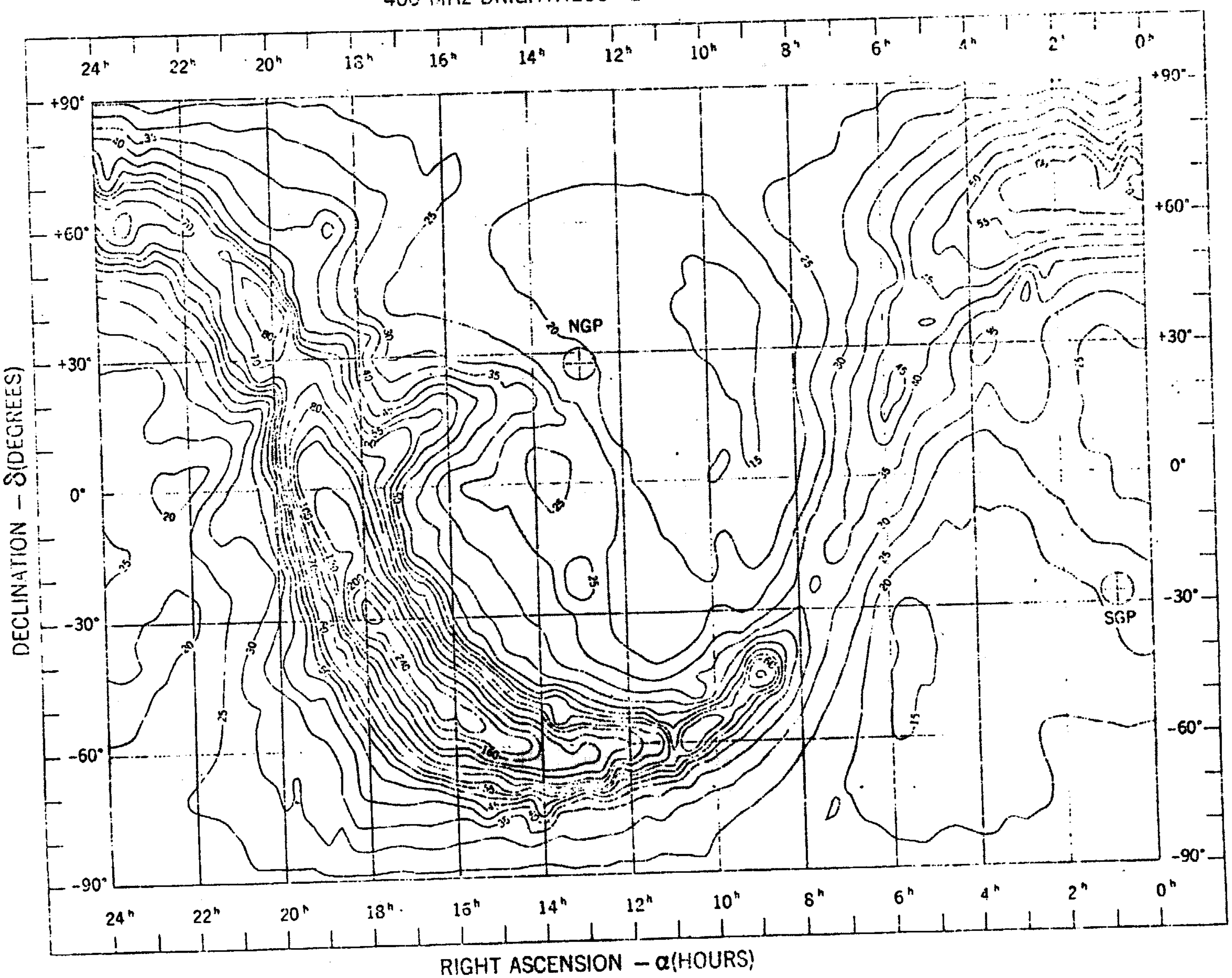
RADIO SKY MAP

136 MHz BRIGHTNESS TEMPERATURE (KELVIN)



RADIO SKY MAP

400 MHz BRIGHTNESS TEMPERATURE (KELVIN)



A-4 Primary Radio Star Noise Sources
at 136 MHZ and 400 MHZ

STAR NAME	RIGHT hrs.	ASCENSION min.	DECLINATION deg.	min.	136 MHZ FLUX DENSITY Watt m^{-2} Hz^{-1}	400 MHZ FLUX DENSITY Watt m^{-2} Hz^{-1}
CASSIOPEIA A	23	21	58	33	15×10^{-23}	5.7×10^{-23}
CYGNUS A	19	58	40	36	11×10^{-23}	4.5×10^{-23}
TAURUS A, Crab Nebula	5	32	21	58	1.8×10^{-23}	1.2×10^{-23}
CENTAURUS A	13	22	-42	46	1.5×10^{-23}	0.6×10^{-23}
VIRGO A	12	28	12	40	1.2×10^{-23}	0.5×10^{-23}

APPENDIX B

DETAILED COMPUTATIONAL PROCEDURES AND PROGRAM FLOW CHARTS

This section describes each processing step in the simplified program and is followed by an equation flow diagram which shows the computational flow and logic branches.

1. Find α (right ascension) and δ (declination) of moon and sun at inertial time from the JPL ephemeris tape, where the (x,y,z) of Sun and (x,y,z) of Moon (coordinator referenced to equinox) are given.

Then

$$\alpha = \tan^{-1} \frac{y}{x}$$

$$\delta = \tan^{-1} \frac{z}{\sqrt{x^2+y^2}}$$

and

module $(\alpha, 2\pi)$

2. Use x,y,z coordinate to compute the unit vector, then calculate the angle between Moon and Sun

a. Form earth-moon unit vector $\overline{1}_m$ and earth-sun unit vector $\overline{1}_s$

$$\text{moon-earth } \overline{1}_m = \begin{bmatrix} 1_{mi} \\ 1_{mj} \\ 1_{mk} \end{bmatrix}; \quad 1_{m_i} = \frac{X_m}{\sqrt{X_m^2+Y_m^2+Z_m^2}}, \quad 1_{m_j} = \frac{Y_m}{\sqrt{X_m^2+Y_m^2+Z_m^2}}, \quad 1_{m_k} = \frac{Z_m}{\sqrt{X_m^2+Y_m^2+Z_m^2}}$$

Note: Assumes antenna boresight is at moon's center.

$$\text{sun-earth } \overline{1}_s = \begin{bmatrix} 1_{si} \\ 1_{sj} \\ 1_{sk} \end{bmatrix}; \quad 1_{s_i} = \frac{X_s}{\sqrt{X_s^2+Y_s^2+Z_s^2}}, \quad 1_{s_j} = \frac{Y_s}{\sqrt{X_s^2+Y_s^2+Z_s^2}}, \quad 1_{s_k} = \frac{Z_s}{\sqrt{X_s^2+Y_s^2+Z_s^2}}$$

b. Calculate the angle between Moon and Sun. Use two unit vectors $\bar{I}_s$ and $\bar{I}_m$ compute cross product $\sin^{-1}(|\bar{I}_m| \times |\bar{I}_s|)$

5. Visibility Test

a. For each station, use the Greenwich Sidereal Time to get the position in the time of observation.

Let λ be the east longitude, Θ_g be the right ascension of Greenwich at the time

Julian Date JD = 2433283.423+365.2422(1973-1950) + Day of the year interested.

$$\text{Fraction of Julian Century} \quad T = \frac{JD-2415020.0}{36525}$$

$$\Theta_{go} = 99^\circ.6909833+36000^\circ.7689T+0^\circ.0003870ST^2$$

$$\Theta_g = \Theta_{go}^\circ + 0.250684477(\text{Min.})$$

$$\alpha \text{ (right ascension)} = \Theta_g + \lambda$$

$$\alpha = \text{AMOD}(\alpha,\ 6.283185)$$

$$\delta \text{ (declination)} = \text{latitude}$$

b. For each station, the unit vector is

$$\bar{1}_T = \begin{bmatrix} 1_{Ti} \\ 1_{Tj} \\ 1_{Tk} \end{bmatrix} \qquad \begin{aligned} 1_{Ti} &= \cos\alpha \cos\delta \\ 1_{Tj} &= \sin\alpha \cos\delta \\ 1_{Tk} &= \sin\delta \end{aligned}$$

Then calculates the Dot Product of two unit vector $\bar{1}_T$, $\bar{1}_m$. $\bar{1}_T \cdot \bar{1}_m$

If the result of dot product is negative, set temperature equal to zero and continue to test next station. Otherwise, select antenna corresponding to station and the temperature of the antenna for that time point is temperature of station.

4. Sun temperature (T_s) calculation

If $\sin^{-1}(|\bar{1}_m| x |\bar{1}_s|) \leq \frac{1}{2}$ main lobe beam width, perform computation.

$$T_s = T_b \left(\frac{\Theta_s}{\Theta_A}\right)^2$$

Θ_s = angular diameter of sun's apparent temperature model ($\sim$ • 66°).

Θ_A = full beamwidth of symmetrical antenna main lobe.

T_b = quiet sun ideal model.
$\approx 6 \times 10^5$ K° for 400 MHz.
8×10^5 K° for 136 MHz.

If any antenna first side lobe would contain sun

$$\gamma = 1/2\ \Theta_A\ (\text{PRIMARY}) + \Theta_A\ (\text{SECONDARY})$$

Θ_A (PRIMARY) = full beamwidth of main lobe.

Θ_A (SECONDARY) = full beamwidth of first side lobe.

Perform computation as before except substituting Θ_A (SECONDARY) $\rightarrow$ Θ_A (PRIMARY) and multiply by power gain.

so, the computation is

$$T_s = T_b \left(\frac{\theta_s}{\theta_A}\right)^2 \times 10^{\frac{\text{power gain}}{10}}$$

Power gain (DB): -15.5 -- in VHF RARR system, 136 MHz

(Average first side lobe gain)

-16.25-- in 85 FT antenna, 400MHz

-30.0 -- in 40 FT antenna, 400MHz

Otherwise, set T_s equals to zero.

5. For each Radio Star compute the position at prediction time and if the angle between the Moon and Radio Star is greater than antenna half beamwidth, set the temperature due to Radio Star (T_{STAR}) equal to zero, otherwise, compute the temperature .

a. Utilizing the right ascension and declination, compute the unit vector. Computation is the same as in 3.b.

b. Calculate the cross product of the two unit vectors; if $\sin^{-1}(|\bar{I}_m \times \bar{I}_{STAR}|) \leq \frac{1}{2}$ main lobe beam width, compute the temperature due to the Radio Star. Otherwise, set the temperature equal to zero, then test next Radio Star.

c. Computation of Radio Star temperature

$$T_{STAR} = \frac{1}{2} \times \frac{G_r \lambda^2 D_o}{4\pi K} \quad \text{(Kelvin degrees)}$$

G_r is the receiving antenna gain above isotropic. (DB)

λ is the wave length (meter).

D_o observed radio flux density (Watt $m^{-2}Hz^{-1}$)

K Boltzmann's constant. (1.38×10^{-23} J/K)

After test all five radio starts add each temperature to get the total temperature.

6. Compute Brightness Temperature

From reference 2, the following formulation is given:

$$T_A = \frac{\int_0^{\theta=90^\circ-\theta_o} \int_0^{\phi=2\pi} T(\theta,\phi)\, G(\theta,\phi) \sin\theta\, \partial\theta\, \partial\phi}{\int_0^{\theta=90^\circ-\theta_o} \int_0^{\phi=2\pi} G(\theta,\phi) \sin\theta\, \partial\theta\, \partial\phi}$$

Θ_o = elevation between boresight axis and the horizon (deg.)

$T(\Theta,\phi)$ is the noise temperature distribution of the galaxy (excluding the sun and predominant radio stars) obtained from input data.

$G(\Theta,\phi)$ is the lossless antenna gain distribution.

Θ and ϕ are the orientation angles defining the position of a radial surface element within the celestial hemisphere.

In this program, the numerical method used to solve this equation is as follows:

From Moon's right ascension (α) and declination (δ) and main lobe beam width (Θ_A), calculate:

$$\alpha \pm \frac{1}{2}\Theta_A \quad ; \quad \delta \pm \frac{1}{2}\Theta_A$$

Consider these four points as vertices of a rectangle and choose the temperature values which are in the rectangle. Then

T_{SKY} : = Average of each temperature values that were chosen

Exception: If galactic nucleus within main lobe and second lobe (Θ_B) of antenna, use the average temperature multiplied by its power gain. That means:

use

$$\alpha \pm (\frac{1}{2}\Theta_A + \Theta_B) \quad ; \quad \delta \pm (\frac{1}{2}\Theta_A + \Theta_B)$$

to make a rectangle, choose the temperature values which are in this rectangle, then

$$T_{SKY} = (\text{Average temperature}) \times 10^{\frac{\text{power gain}}{10}}$$

7. Add total temperature due to sun, radio stars and galaxy

$$T = T_s + T_{STAR} + T_{SKY}$$

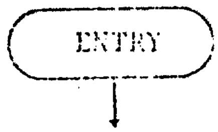
8. After testing all the stations, print the result and increase time (plus interval) and repeat from step 1

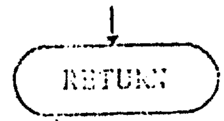
9. For each week, use WOLF Plot Package to plot the result.

FLOWCHART

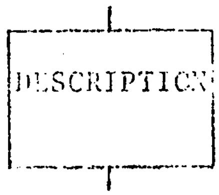
The symbols and their uses are as following:

1.

a) 

b) 

2.



Description of Operation being performed

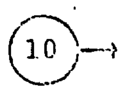
3.

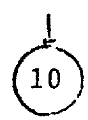
Subroutine or function call where:

NAME -- subroutine called

PURPOSE -- description of the purpose for the call.

4.

a) 

b) 

a) Statement number

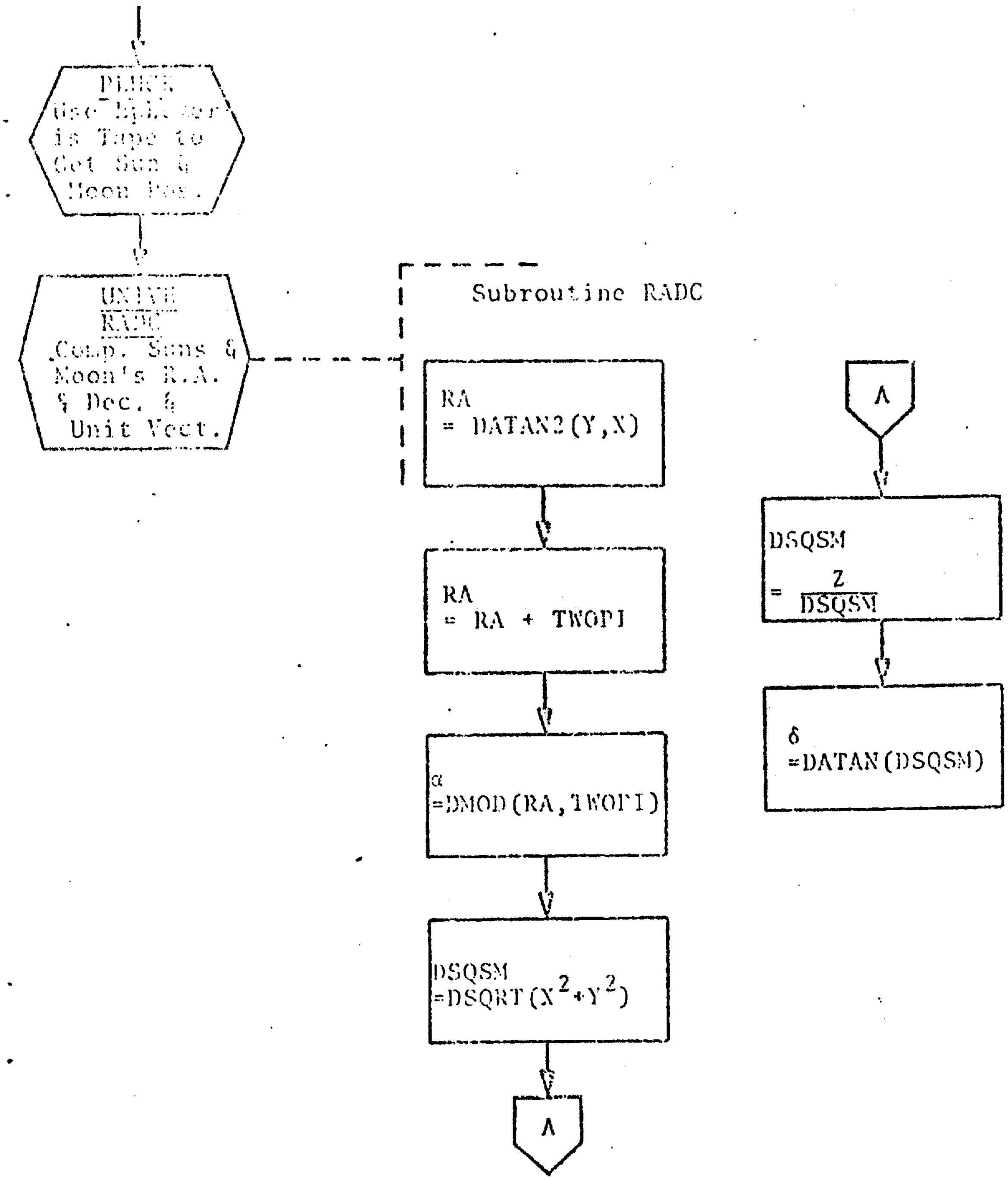
b) Transfer to statement number

5.

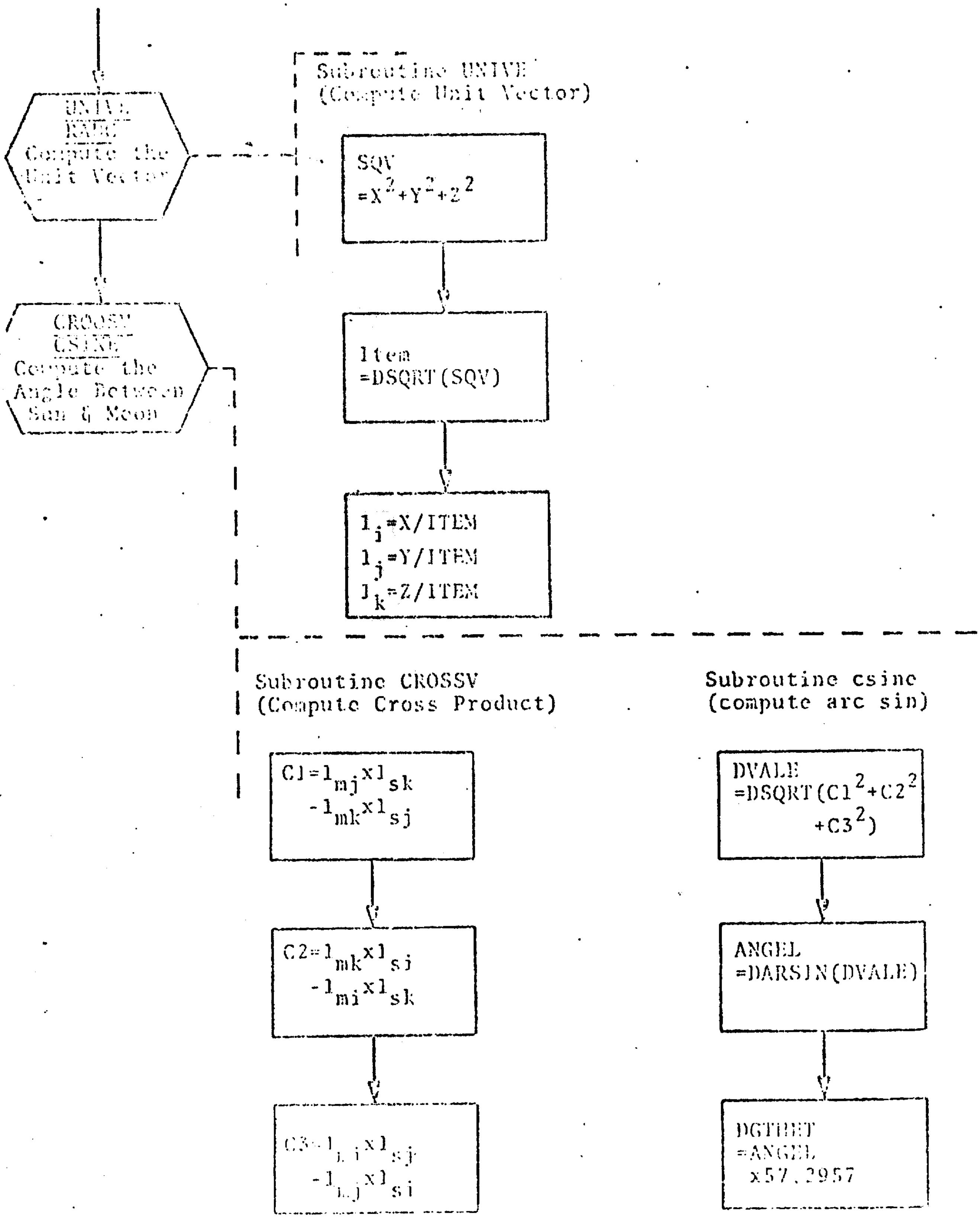
Off page connector

NOTE: Step Numbers correspond to preceding section numbers.

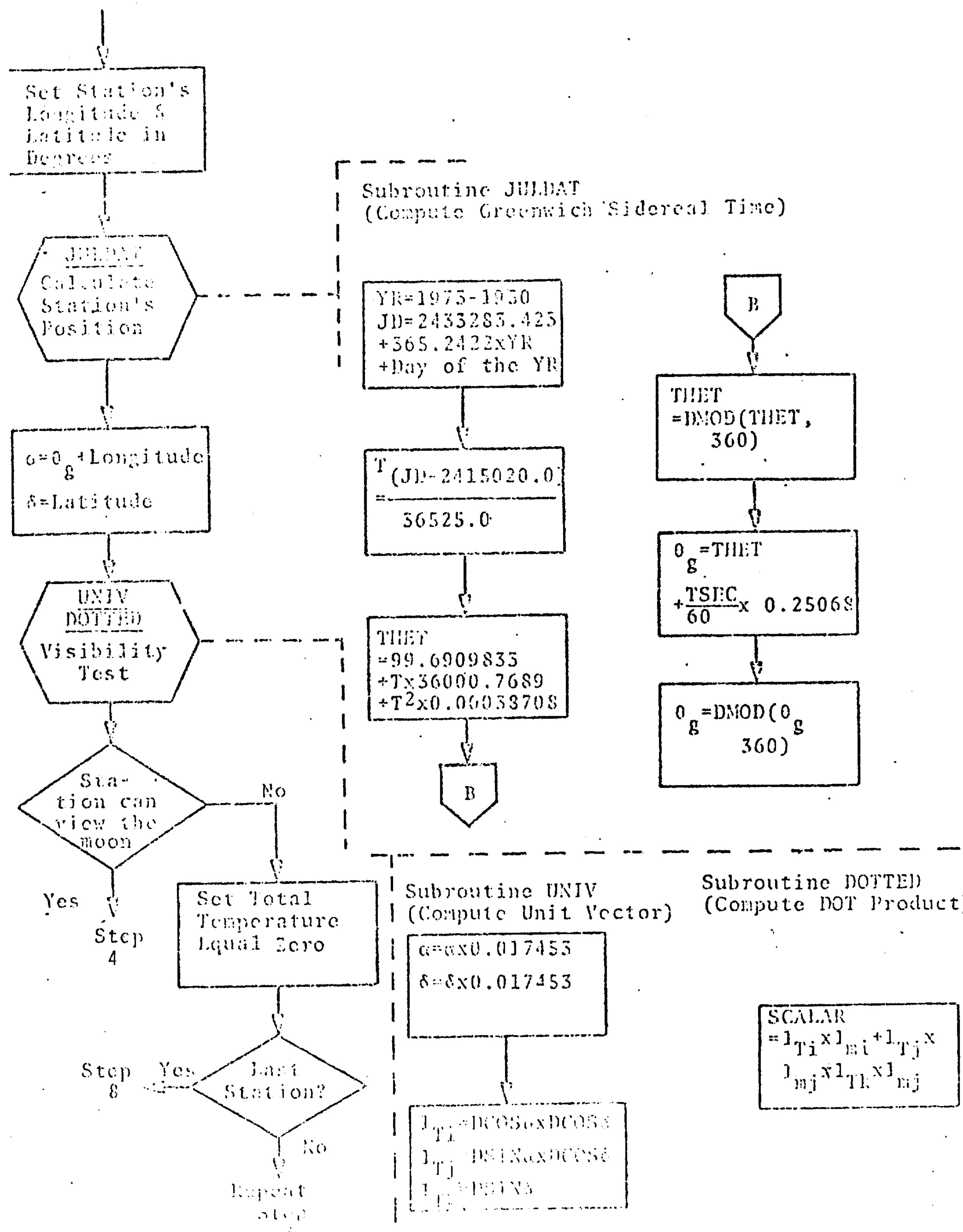
Step 1



Step 2

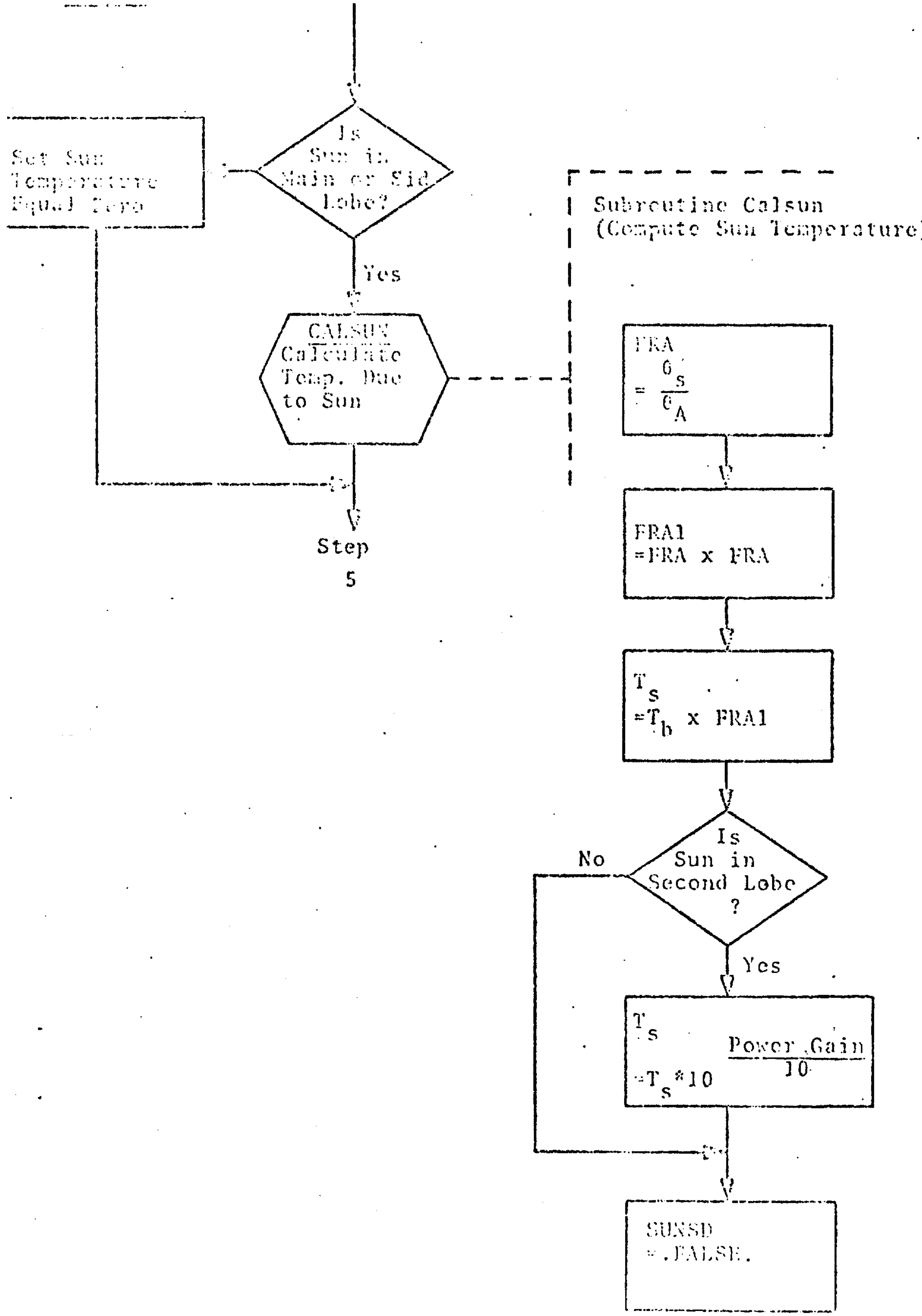

CROSSV
Compute the Angle Between Sun & Moon
Subroutine UNIVE
(Compute Unit Vector)
SQV =X^2+Y^2+Z^2
Item =DSQRT(SQV)
1i=X/ITEM
1j=Y/ITEM
1k=Z/ITEM
Subroutine CROSSV
(Compute Cross Product)
C1=1mjx1sk -1mkx1sj
C2=1mkx1si -1mix1sk
Subroutine csine
(compute arc sin)
DVALE =DSQRT(C1^2+C2^2 +C3^2)
ANGEL =DARSIN(DVALE)
DGTHET =ANGEL x57.2957

Step 3



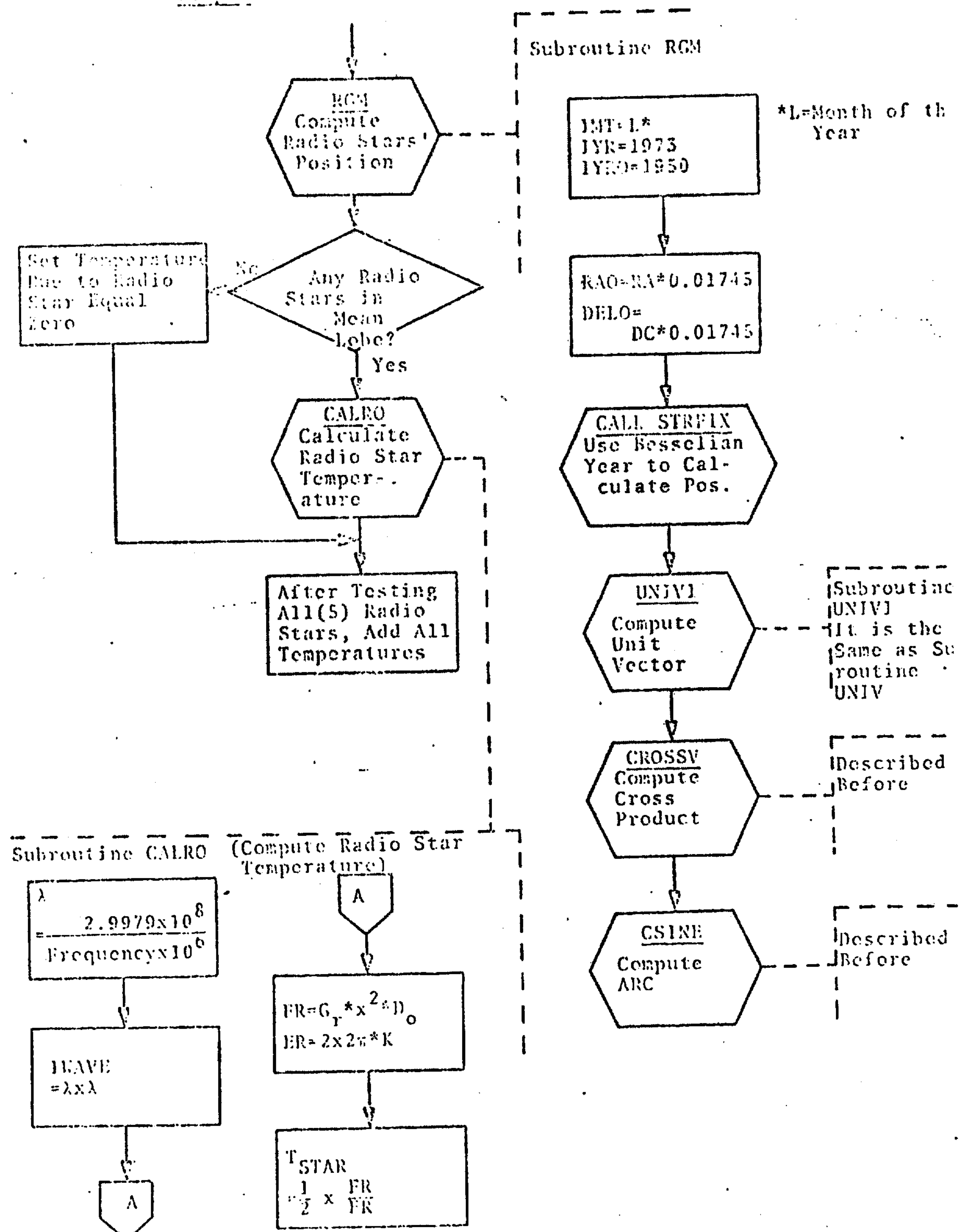
Set Station's Longitude & Latitude in Degrees
JULDAT Calculate Station's Position
Subroutine JULDAT (Compute Greenwich Sidereal Time)
YR=1975-1950 JD=2433283.425 +365.2422xYR +Day of the YR
T=(JD-2415020.0)/36525.0
THET =99.6909833 +Tx36000.7689 +T2x0.00038708
B
B
THET =DMOD(THET, 360)
0g=THET +TSEC/60 x 0.25068
0g=DMOD(0g 360)
ɑ=0g+Longitude
δ=Latitude
UNIV DOTTED Visibility Test
Station can view the moon
No
Yes
Step 4
Set Total Temperature Equal Zero
Last Station?
Yes
Step 8
No
Repeat step 3
Subroutine UNIV (Compute Unit Vector)
ɑ=ɑx0.017453
δ=δx0.017453
Subroutine DOTTED (Compute DOT Product)
SCALAR =1Tix1mi+1Tjx 1mjx1Tkx1mj

Step 4



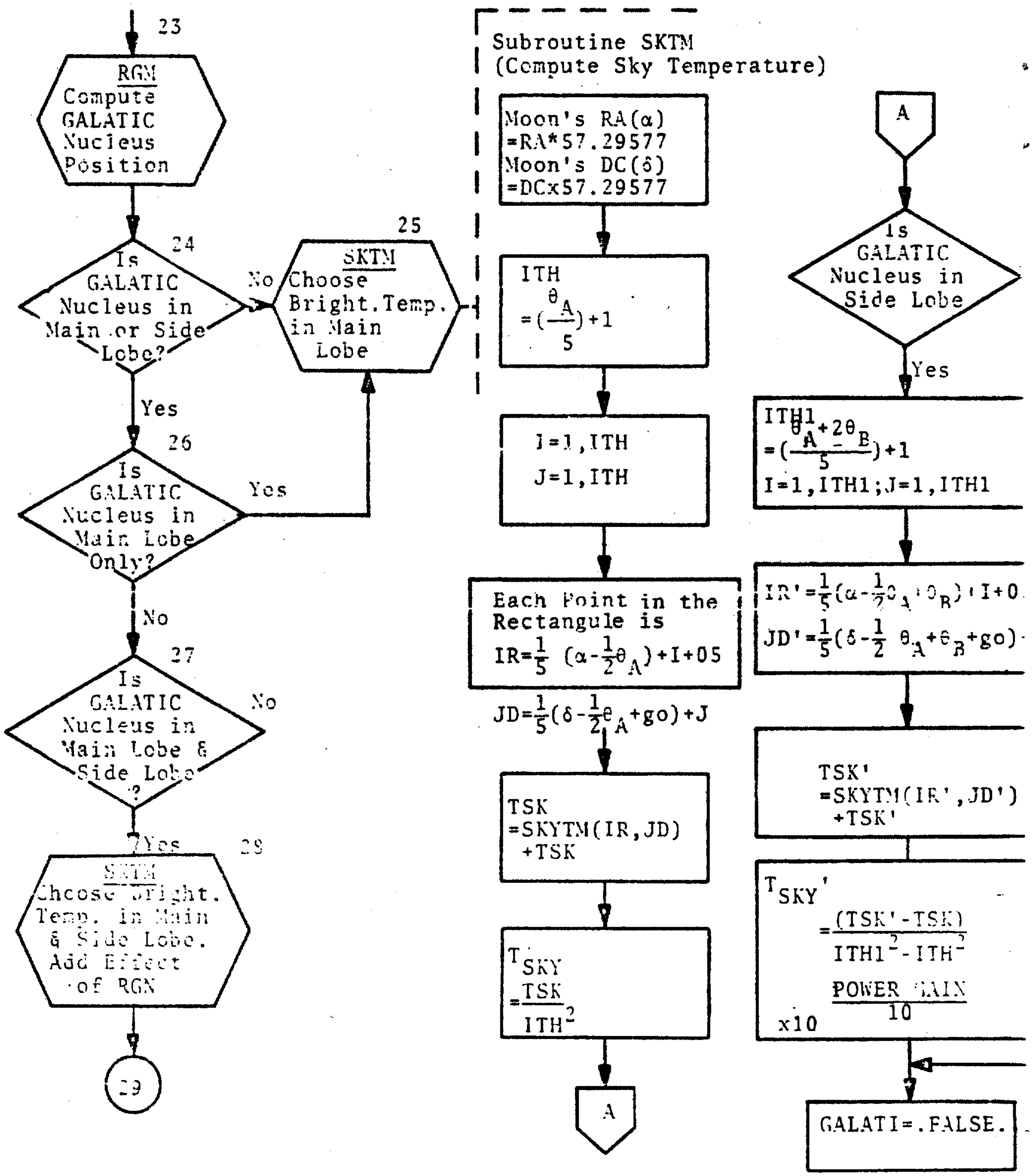
Set Sun Temperature Equal Zero
Is Sun in Main or Side Lobe?
Yes
CALSUN
Calculate Temp. Due to Sun
Step 5
Subroutine Calsun
(Compute Sun Temperature)
FRA = θs / θA
FRA1 =FRA x FRA
Ts =Th x FRA1
Is Sun in Second Lobe ?
No
Yes
Ts =Ts*10 Power Gain/10
SUNSD =.FALSE.

Step 5

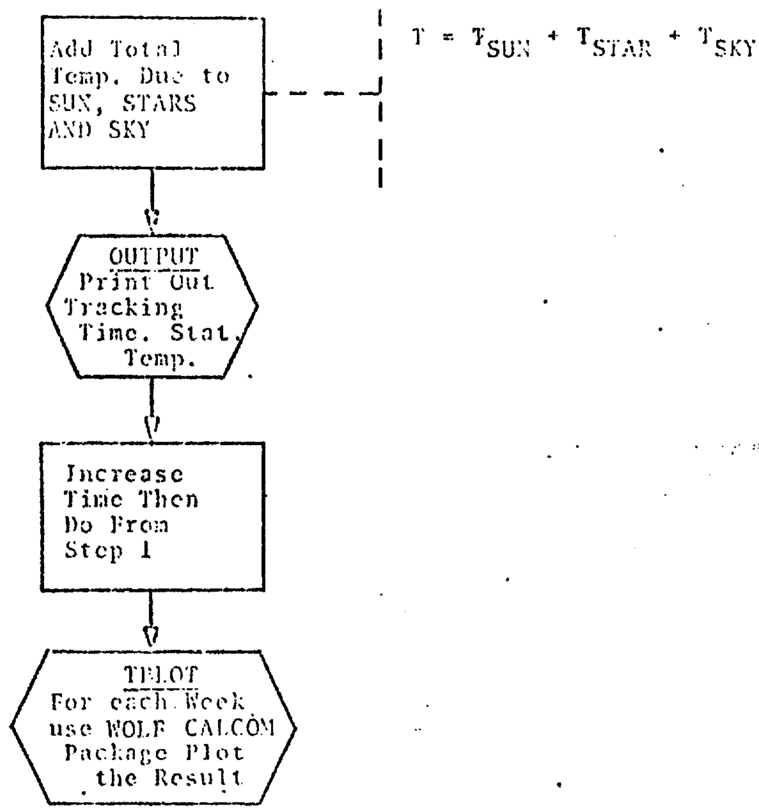


RGM
Compute
Radio Stars'
Position
Any Radio
Stars in
Mean
Lobe?
No
Yes
Set Temperature
Due to Radio
Star Equal
Zero
CALRO
Calculate
Radio Star
Temper-
ature
After Testing
All(5) Radio
Stars, Add All
Temperatures
Subroutine RGM
IMT=L*
IYR=1973
IYRO=1950
*L=Month of the
Year
RAO=RA*0.01745
DELO=
DC*0.01745
CALL STRFIX
Use Besselian
Year to Cal-
culate Pos.
UNIV1
Compute
Unit
Vector
Subroutine
UNIV1
It is the
Same as Sub
routine
UNIV
CROSSV
Compute
Cross
Product
Described
Before
CSINE
Compute
ARC
Described
Before
Subroutine CALRO (Compute Radio Star
Temperature)
λ
= 2.9979x10^8
Frequencyx10^6
IWAVE
=λxλ
A
A
FR=G_r*x^2*D_o
ER=2x2π*K
T_STAR
=1/2 x FR/ER

Step 6


23
RGM
Compute
GALATIC
Nucleus
Position
24
Is
GALATIC
Nucleus in
Main or Side
Lobe?
No
25
SKTM
Choose
Bright.Temp.
in Main
Lobe
Yes
26
Is
GALATIC
Nucleus in
Main Lobe
Only?
Yes
No
27
Is
GALATIC
Nucleus in
Main Lobe &
Side Lobe
?
No
Yes
28
SKTM
Choose Bright.
Temp. in Main
& Side Lobe.
Add Effect
of RGN
29
Subroutine SKTM
(Compute Sky Temperature)
Moon's RA(α)
=RA*57.29577
Moon's DC(δ)
=DCx57.29577
ITH
=(θA/5)+1
I=1,ITH
J=1,ITH
Each Point in the
Rectangule is
IR=1/5 (α-1/2θA)+I+05
JD=1/5(δ-1/2θA+go)+J
TSK
=SKYTM(IR,JD)
+TSK
TSKY
=TSK/ITH²
A
A
Is
GALATIC
Nucleus in
Side Lobe
Yes
ITH1
=((θA+2θB)/5)+1
I=1,ITH1;J=1,ITH1
IR'=1/5(α-1/2θA+θB)+I+0
JD'=1/5(δ-1/2 θA+θB+go)
TSK'
=SKYTM(IR',JD')
+TSK'
TSKY'
=(TSK'-TSK)/(ITH1²-ITH²)
x10 POWER GAIN/10
GALATI=.FALSE.

Step 7, 8 and 9



Add Total Temp. Due to SUN, STARS AND SKY
T = T_{SUN} + T_{STAR} + T_{SKY}
OUTPUT
Print Out Tracking Time. Stat. Temp.
Increase Time Then Do From Step 1
TELOT
For each Week use WOLF CALCOM Package Plot the Result