Environment Canada Imaging Cover Page

Report N.: *TEC-784*

SKP Box Number: 672672428

ATMOSPHERIC ENVIRONMENT SERVICE
DEPARTMENT OF THE ENVIRONMENT – CANADA

Technical Memoranda

CALCULATIONS TO TRACK WEATHER SATELLITES USING A SMALL COMPUTER

by

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U.D.C. 551.507.362.2

TEC. 784
5 MARCH 1973

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ABSTRACT

The sun-synchronous-type satellite orbit is described. Equations are developed that yield antenna look angles for tracking such satellites moving in circular orbits. A computer program is developed to allow the solution of these equations in a mini-computer to permit automated reception of weather satellite pictures and automatic control of the reception system.

CALCULS POUR LA POURSUITE DES SATELLITES MÉTÉOROLOGIQUES À L'AIDE D'UN PETIT ORDINATEUR

par

P.M. Brewster

RÉSUMÉ

La description d'une orbite de satellite de type héliostationnaire est suivie d'équations donnant les angles de réception d'antennes pour la poursuite de ces satellites se déplaçant sur des orbites circulaires. Un programme machine est mis au point pour permettre de résoudre ces équations à l'aide d'un petit ordinateur en vue d'obtenir une réception exploitable par machine des images transmises par le satellite météorologique et de pouvoir commander automatiquement le système de réception.

CALCULATIONS TO TRACK WEATHER SATELLITES USING A SMALL COMPUTER

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P.M. Brewster

(Manuscript received March 2, 1973)

1. Introduction

To track Automatic Picture Transmission (APT) satellites, the receiving antenna must be directed to within about three degrees of the real-time position of the satellite. For an orbital altitude of about 800 nautical miles, the antenna look angles must be updated at least every 10 seconds.

Four principal operations are required in the reception of satellite pictures:

(1) Store the live picture information on magnetic tape.
(2) Send the correct voltages to the antenna servo motors at the correct time throughout the pass.
(3) Calculate the parameters for the next orbit.
(4) Standby until the next orbit begins.

These operations can all be performed by a small computer system.

2. Description of Satellite Orbits

The satellite-earth-sun system may be considered at many levels of approximation. We will use the simplest approximations that will solve the problem within the allowed limits of error.

As a first approximation, we neglect the anisotropy of the mass distribution of the earth. In this case, the orbit is an ellipse, lying in a plane that does not change in orientation as the earth orbits the sun, Figure 1. Several constants may be used to describe this orbit:

- the nodal period, T, is the time for one orbit, i. e., time from one ascending node (northbound equator crossing) to the next ascending node,

- the inclination, i, is the angle between the plane of the equator and the plane of the satellite orbit, measured counter-clockwise from the equator as illustrated in Figure 2,

- the perigee distance, R_p, is the minimum radius of the orbit,

- the apogee distance, R_A, is the furthest distance of the satellite from the centre of the earth,

- the eccentricity of the orbit is given by

$$e = \sqrt{R_A^{\,2} - R_p^{\,2}} / R_A$$

The equatorial bulge of the earth has two effects upon the orbital motion of a satellite in that it causes:

(1) a precession of the plane of the orbit in space (called precession of the right ascension of the ascending node), and

(2) movement of the perigee position around the plane of the orbit.

The precession rate as given by theory is

$$\Omega = \lambda T^{-7/3} (1 + e^2)^2 \cos i \qquad (1)$$

and the perigee rate is

$$\omega = \lambda T^{-7/3} (1 + e^2)^2 (2 - \frac{5}{2} \sin^2 i) \qquad (2)$$

The empirical value of λ (reference 1) is:

$$\lambda = 3.11 \times 10^5 \text{ degree per day minutes } ^{7/3} \qquad (3)$$

We will assume the satellite is in a circular orbit but it will be necessary however to include the precession rate Ω in the calculations.

3. Development of the Equations for the Antenna Look Angles for Sun Synchronous Orbits

The azimuth and elevation angles of the antenna are determined by the location of the sub-satellite point (SSP) on the earth's surface, latitude and longitude of the receiving station, and the altitude of the satellite.

First we will develop equations for the longitude λ (t) and latitude φ (t) of the SSP as functions of t, the time after the ascending node.

Consider a spherical non-rotating earth. Figure 3 shows the arc described by the SSP above the equator crossing. For a circular orbit, the sub point moves with constant velocity along this arc, and the arc length is given by

$$\tau = \frac{2\pi t}{T} \tag{4}$$

where T is the period of the orbit and t the time elapsed after the ascending note (TAAN).

Figure 3 also shows the spherical triangle bounded by the great circle arcs τ, $\varphi(t)$ and λ' where λ' is the longitude of the SSP minus the longitude of the ascending node for a non-rotating earth.

$$\lambda' = \lambda_{n.r.}(t) - \lambda AN$$

Using the laws of spherical geometry, we solve for the co-ordinates of the sub-satellite point:

$$\sin \varphi(t) = \sin(\pi - i) \sin \tau$$

or $$\varphi(t) = \arcsin(\sin i \sin \tau)$$

and $$\tan \lambda' = \cos(\pi - i) \tan \tau \tag{5}$$

or $$\lambda' = -\arctan(\cos i \tan \tau)$$

Rotation of the earth does not change the value of the latitude of the sub-point. However, the value of the longitude increases westerly at a rate of $360/D_{sidereal}$ degrees west per minute, where $D_{sidereal}$ (which is approximately 23 hours 56 minutes 4 seconds) is the time it takes the Earth to make one rotation relative to stars fixed in space. Therefore, in time t after the ascending node at λAN, the Earth has rotated

$$2\pi t/D_{sidereal} \text{ radians.}$$

We must also include the effect of the precession of the orbital plane on the longitude of the SSP. In time t, the SSP longitude precesses $\dot{\Omega}$ t degrees. The precession rate $\dot{\Omega}$ can be obtained via Eq. 1. Finally the longitude of the sub-satellite point is

$$\lambda(t) = \lambda AN + \lambda' + \frac{2\pi}{D_{sidereal}} t + \dot{\Omega} t$$

This will be written:

$$\lambda(t) = \lambda AN - \arctan\left(\cos i \tan \frac{2\pi t}{T}\right) + \frac{\Delta\lambda}{T} t \qquad (6)$$

where the amount that the longitude advances per orbit is

$$\Delta \lambda = \left(\frac{360}{D_{sidereal}} + \dot{\Omega}\right) T \quad \text{degrees West}$$

Meteorological APT satellites are usually placed in sun-synchronous orbits, giving relatively equal illumination of the earth during each pass. Referring to Figure 1, it is clear that if the precession of the satellite orbit amounts to 360 degrees in one year, then the orbital plane will maintain the same average angle to the earth-sun line. In other words, the sun-synchronous precession rate is

$$\dot{\Omega}\,ss = 360^{o}/\text{year} = 0.9856\ ^{o}/\text{solar day} = 0.0006844\ ^{o}/\text{minute} \qquad (7)$$

To an observer on the sun, the earth appears to make one complete rotation in one solar day (1440 minutes). The relation between a sidereal day and a solar day is shown in Figure 4. From this point of view, the plane of a sun-synchronous orbit must advance at the same rate as the rotation of the earth as viewed from the sun, namely 360^{o} in one solar day. Thus, the advance of the ascending node per orbit may be written:

$$\Delta\lambda = \left(\frac{2\pi}{D_{sidereal}} + \dot{\Omega}\,ss\right) T = 2\pi T / D_{solar} \qquad (8)$$

for sun-synchronous orbits.

To find the antenna look angles, we need the great circle arc length, γ, from the SSP to the receiving station.

Consider the shperical triangle of Figure 5 with vertices the SSP $(\varphi(t), \lambda(t))$ the receiving station (φ_s, λ_s) and the north pole. Using the law of cosines for an oblique spherical triangle, the great circle arc length γ, is determined to be:

$$\cos\gamma = \sin\varphi s \sin\varphi(t) + \cos\varphi s \cos\varphi(t) \cos(\lambda_S - \lambda(t))$$

The azimuth angle, α, is given in the above triangle, using the law of sines,

$$\sin\lambda(t) = \cos\varphi(t) \sin\left|\lambda s - \lambda(t)\right| / \sin\gamma(t) \qquad (9)$$

To find the elevation angle, ϵ , we solve the plane triangle shown in Figure 6 with vertices the centre of the earth, the receiving station and the satellite. Let R be the radius of the earth, and A the altitude of the satellite. Then the distance from the station to the satellite is:

$$L = \sqrt{R^2 + (R + A)^2 - 2R(R + A)\cos\gamma} \qquad (10)$$

and the elevation angle given by

$$\sin(\pi/2 + \epsilon)/(R + A) = (\sin\gamma)/L$$

is

$$\epsilon(t) = \arcsin\left[(R+A)\sin\gamma(t)/L(t)\right] - \pi/2 \qquad (11)$$

4. Computer Calculations for ESSA-8

The equations of the previous section were used to calculate the azimuth and elevation angles for tracking ESSA-8. Three Fortran programs were used:

(a) ORBIT - finds the satellite sub-point coordinates at two minute intervals for comparison with the sub-point coordinates in the daily TBUS-1 predict messages.

(b) ANTNA -- finds the antenna look angles at one minute intervals for a given equator crossing.

(c) APR - is a Fortran routine for the Automatic Picture Reception from one satellite.

Accurate values of the orbit parameters for ESSA-8 were found from the daily APT predict messages. The average over 2,020 orbits, from January 21 to June 30 of the period and longitudinal increment was:

$$T = 114.703 \text{ minutes} = 1 \text{ hour } 54 \text{ minutes } 42.17 \text{ seconds}$$

$$\Delta\lambda = 28.675 \text{ degrees West per orbit}$$

This agrees with the value for a sun-synchronous orbit, Eq. 8

$$\Delta\lambda_{ss} = \frac{360T}{D_{solar}} = 28.6757 \ ^\circ/\text{orbit}$$

The inclination angle is the supplement of the maximum latitude reached by the sub-satellite point:

$$i = 180 - \varphi(t = {}^{T}/4) = 101.6 \text{ degrees.}$$

Other constants are:

altitude	$A \sim$	1450 K.M.
perigee	$R_p \sim$	768 nautical miles
apogee	$R_A \sim$	800 nautical miles
eccentricity squared	$e^2 \sim$	0.08

The perigee rate may be estimated from Eq. 2

$$\dot{\omega} = 3.11 \times 10^5\, T^{-7/3} (1 + e^2)^2 (2 - {}^5/2 \sin^2 i)$$

$$= 2.27 \text{ degrees/day}$$

i.e. the perigee moves 180° in about 80 days.

The perigee position can be found from the predict messages transmitted over teletype circuits from NOAA. The altitudes of ESSA-8 at 42 minutes after the ascending node, when the SSP latitude is approximately the same as the station latitude, are listed in Table 1. The perigee point was approximately overhead from March 15 to April 13, and apogee from June 10 to June 30. These intervals, about 80 days apart, are in good agreement with the calculated perigee rate.

To examine the effects of the slight ellipticity of ESSA-8 on the sub-point track, a perigee overhead orbit (March 15) and an apogee overhead orbit (June 17) were compared with the calculated values. The results are summarized in Table 2. It can be seen that the calculated sub-point positions fall between the sub-points given for the perigee and apogee orbits. As expected, the calculated values apply to an average circular orbit between the extremes of perigee overhead and apogee overhead. The differences are sufficiently small to permit the use of the circular orbit approximation for operational purposes.

The program called ANTNA includes the routine used in the program ORBIT but, in addition, it calculates the azimuth and elevation angles for the antenna. The variables used in the computer calculations are listed in Table 3 with a summary of the equations.

The azimuth value calculated by the program, Eq. 9, is an angle between 0 and 90 degrees. To find the azimuth on a 360 degree range, the quadrant of the SSP relative to the station must be determined. The east-west boundary is simply the meridian of longitude of the receiving station. The north-south boundary is the great circle through the station tangent to the east-west parallel. For example, this great circle through Downsview passes near Los Angeles and New York. To determine if a SSP is north or south of this plane, we will calculate the perpendicular coordinate from the SSP to the plane. First, consider the Cartesian co-ordinates with origin the centre of the earth and axes:

X: from 0 to the equator at the station longitude
Y: from 0 to the equator 90° East of the station
Z: the axis of the north pole.

Then the coordinates of the SSP, from Figure 7, are:

$$X = R \cos \varphi(t) \cos(\lambda_s - \lambda(t))$$
$$Y = R \cos \varphi(t) \sin(\lambda_s - \lambda(t))$$
$$Z = R \sin \varphi(t)$$

Now, consider a rotation of the coordinate system about the Y-axis by an angle φ_s, such that the new x-axis, X', intersects the station position. The X' - Y plane is the plane of the great circle running east-west through the station. The coordinate Z' in the rotated co-ordinate system is the distance above this plane. As shown in Figure 7,

$$Z' = \cos \varphi_s Z - \sin \varphi_s X$$

For the sub-satellite point:

$$Z' = R\left[\cos \varphi_s \sin \varphi(t) - \sin \varphi_s \cos \varphi(t) \cos(\lambda_s - \lambda(t))\right]$$

If Z' is positive the azimuth is in the range 270° to 360° or 0° to 90°. If Z' is negative, the azimuth falls in the range 90° to 270°.

The results of program ANTNA were approximately the same as the previously calculated azimuth and elevation angles.

The Automatic Picture Reception program, APR is given in Appendix 1. Included in APR are dummy command statements that indicate when a mini-computer would be used to control the receiving equipment. These commands are:

1. ORIENT ANTENNA (Azimuth voltage, elevation voltage)
2. WAIT UNTIL (Day, hour, minute, second)
3. CONNECT/ISOLATE (Automatic Picture Reproduction Unit)
4. RECORD/STOP (Tape recorder)

Additional commands would be required for more advanced control of the reception. These would be (a) to recognize picture start tone (3 seconds of 300 Hz in received signal), (b) to type picture time, latitude and longitude and (c) to halt the tape recorder during the 144 seconds of unmodulated signal between pictures.

To allow the antenna to follow any satellite pass, the horizontal swing of the aximuth motion is 270° right or left of a centre position before contacting a limit switch, i.e. 0 - 540° (see Figure 8). For any satellite, there is a limited range of ascending node longitudes for which the sub-point crosses the meridian of the station to the south of that station. For these equator crossings, the azimuth range of 0 - 180 - 270 degrees is used. All other satellite passes can be tracked using the range 180 - 360 - 540 degrees. The azimuth range is determined in the computer program by a series of three conditions asking:

(a) if the sub-point is north of the great circle tangent to the station latitude,
(b) if the sub-point is east of the station,
(c) if the ascending node is in the southbound meridian crossing range.

These are used to put the azimuth value in the correct range. The corresponding azimuth command voltage can then be found from the equation of the calibration curve.

There are ten constants in the APR program that refer to a specific satellute. For ESSA-8 these are:

(a) ALT = 1450 Km
(b) PERIOD = 114.703 min or 1:54:42.17
(c) ZINC = 101.6° (inclination)

Range of the ascending nodes acquirable by the station

(d) earliest AN 145° E
(e) latest AN 45° E

Range of times after equator crossing TAAN

(f) before pass 29 minutes
(g) completion of pass 55 minutes

Ascending node limits for southbound meridian crossing

(h) from 114° E
(i) to 99.9437° E (directly overhead pass)

And the longitude increment per orbit

$$\text{(j)} \quad \Delta\lambda = 28.675^{\circ}\ \text{W}$$

These constants would have to be changed if the program is used to track another satellite. The equations are unchanged for satellites that orbit from south to north in daylight if the ascending node longitude, ANLNG, value is replaced by 180 - ANLNG. APR can be adapted for tracking more than one satellite if the appropriate ten characteristics are read into the memory before the pass calculations commence.

An example of the FORTRAN APR printout is shown in Table 4.

APPROVED,

J.R.H. Noble,
Assistant Deputy Minister,
Atmospheric Environment Service.

5. Reference

Meteorological Satellite Report No. 14: "A Technique for Precise Analysis of Satellite Data; Volume 1 - Photogrammetry" by Tetsuya Fujita, Published by U.S. Department of Commerce Weather Bureau, January 1963. Especially pages 4 - 8.

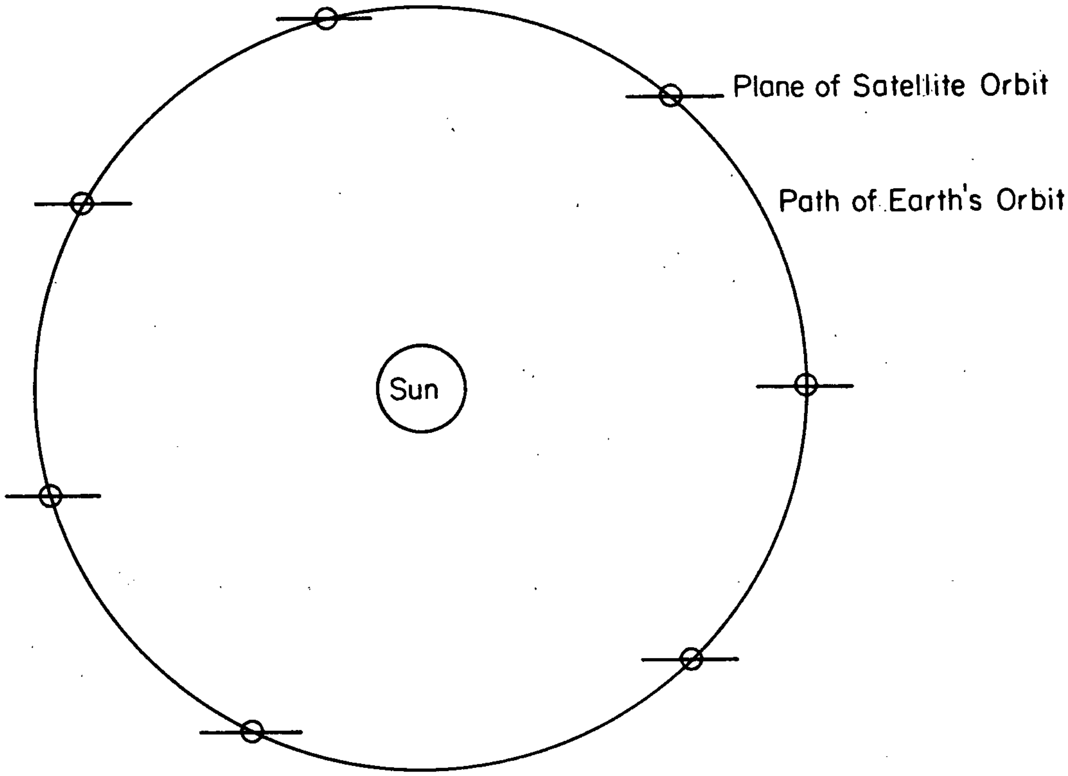

Figure 1

Simplified sketch of the earth's orbit about the sun, showing the fixed plane of a satellite orbit if the oblateness of the earth is neglected.

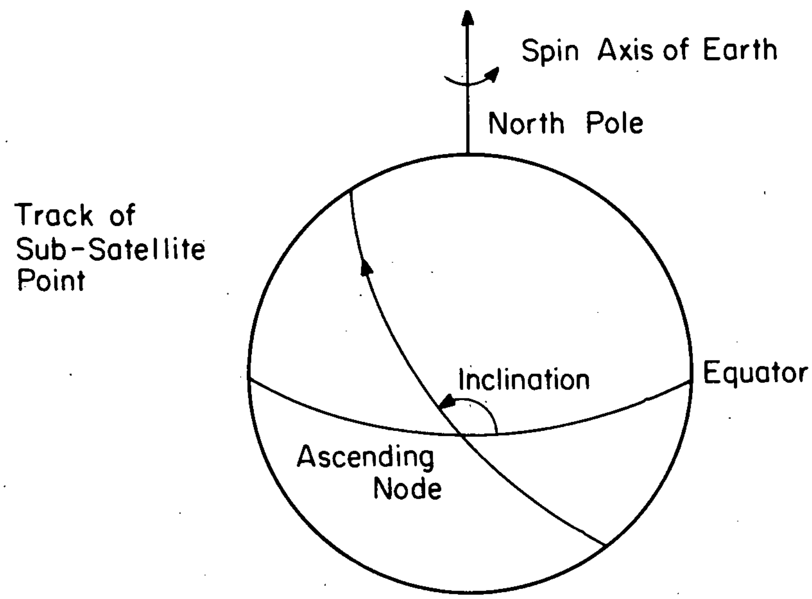

Figure 2

Definition of the inclination angle of a satellite orbit.

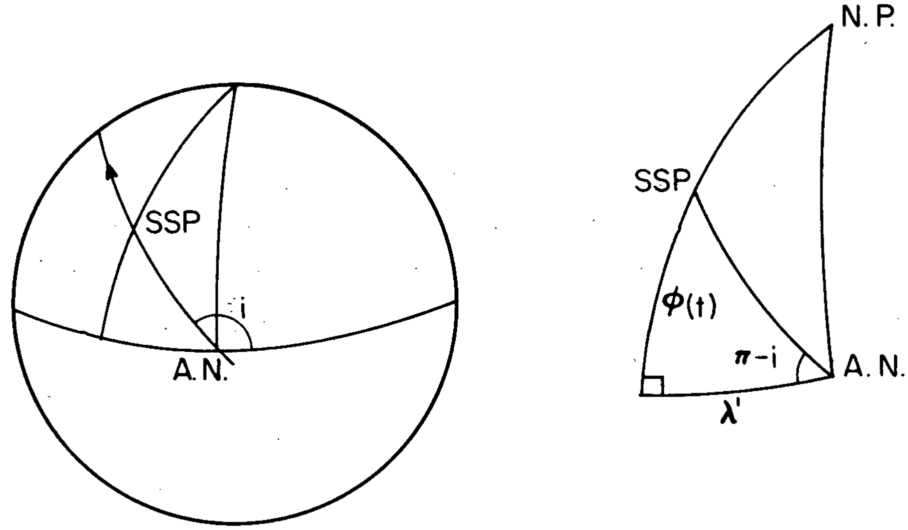

Figure 3

The right spherical triangle defining the great circle arc length of the sub-satellite point, SSP, above the ascending node.

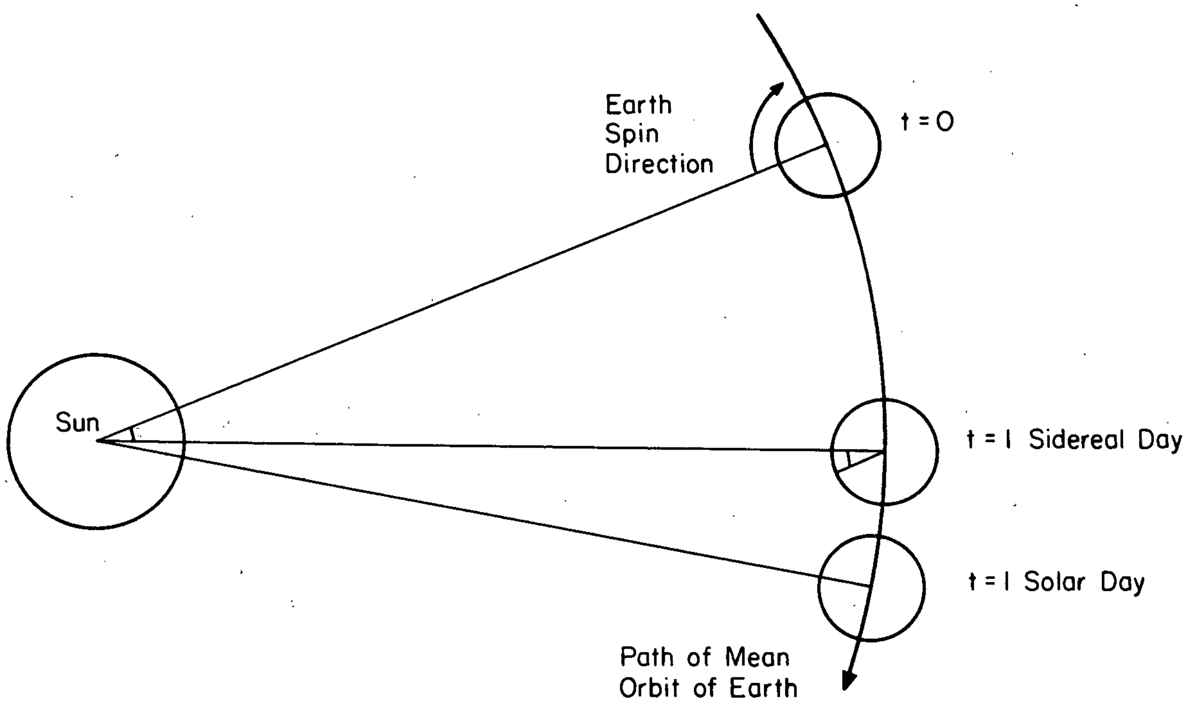

Figure 4

Relationship between the sidereal day and the solar day.

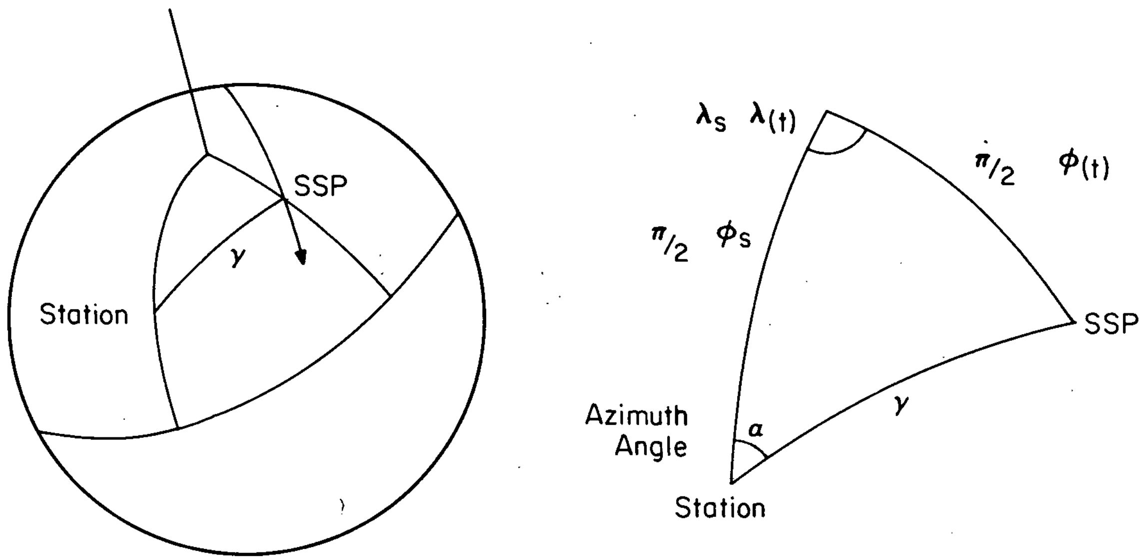

Figure 5

Showing great circle arc γ from sub-satellite point to station and the azimuth angle γ .

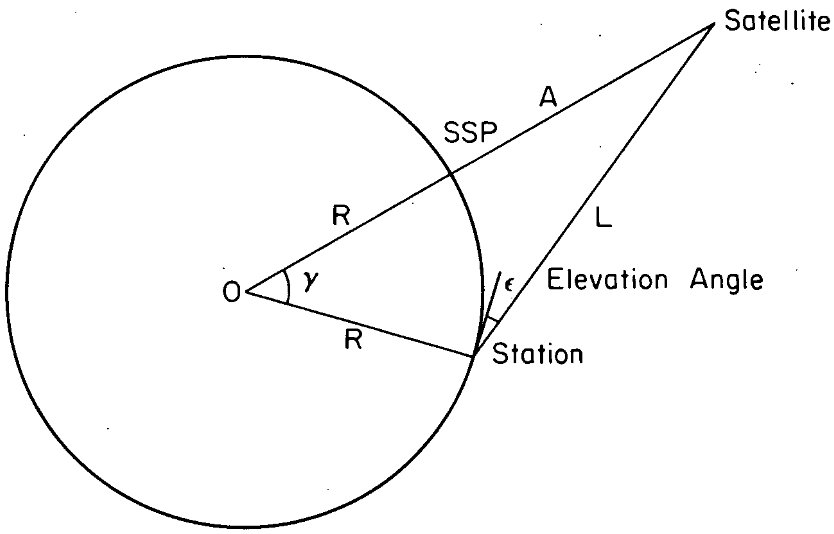

Figure 6

Sketch showing elevation angle ε .

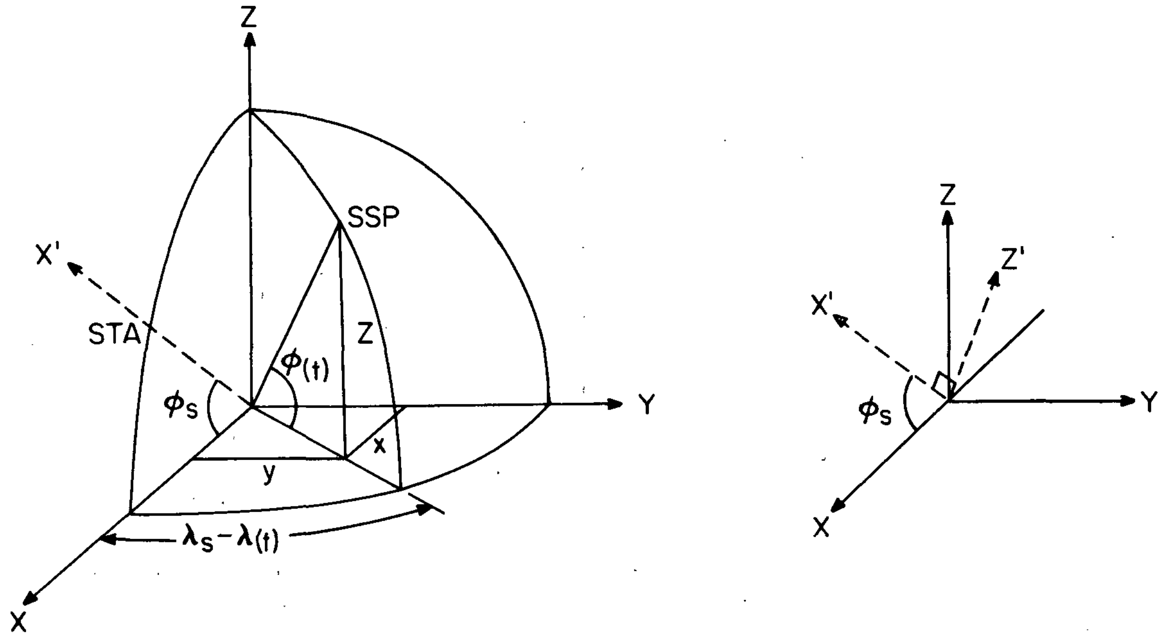

Figure 7

Octant of the earth in Cartesian co-ordinate system X, Y, Z and sketch of the rotated co-ordinate system X', Y', Z'.

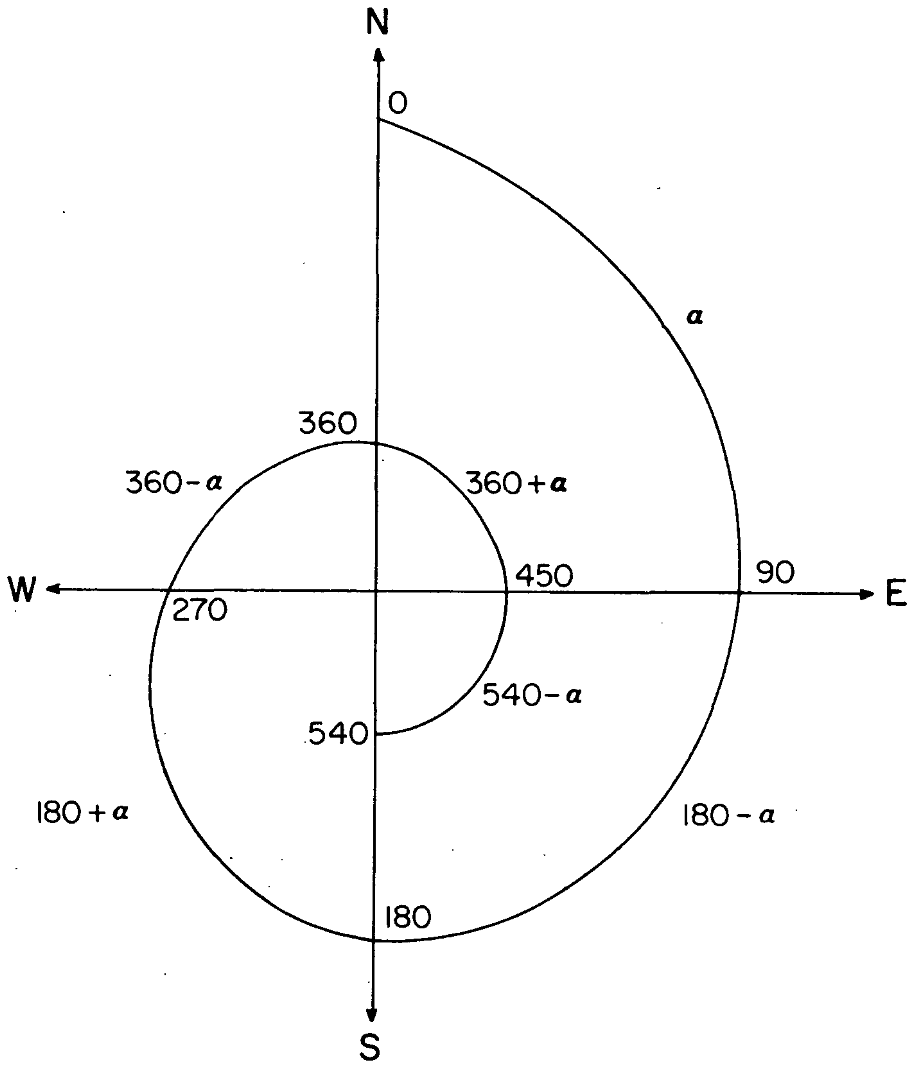

Figure 8

The six azimuth quadrants in the horizontal sweep of the antenna, showing the mathematical expression for the azimuth angle if the calculated angle α, is in the range 0 to 90 degrees.

TABLE I

Altitude of ESSA-8 42 minutes after ascending node at latitude 46.8°N. Data for five months taken from daily APT predict messages (TBUS-1)

TAAN = 42 Minutes ESSA-8

ALTITUDE	DATE 1972			NUMBER OF DAYS	REMARK
1420 KM	MAR 15	-	APR 13	29	PERIGEE
1430	APR 14	-	APR 26	13	
1440	APR 27	-	MAY 8	12	
1450	MAY 9	-	MAY 21	12	
1460	MAY 22	-	JUNE 9	19	
1470	JUNE 10	-	JUNE 30	21	APOGEE
1460	JULY 1	-	JULY 19	19	
1450	JULY 20	-	AUG 1	13	
1440	AUG 2	-	AUG 12	11	
1430	AUG 13	-	AUG 26	14	

TABLE 2 A

ORBIT Calculations for ESSA-8 PERIOD=114.70 Min. INCLINATION 101.6°

TAAN Minutes	Latitude of Sub Satellite Point °N			Calculated - Predicted Deviation °	
	From TBUS-1 Message		Calculated Orbit	Orbit -Mar 15	Orbit -June 17
	March 15	June 17			
30	77.6	77.6	77.7	.1	.1
36	64.2	64.4	64.4	.2	.0
42	46.6	47.0	46.9	.3	-.1
48	28.2	28.9	28.7	.5	-.2
54	09.6	10.5	10.3	.7	-.2
60	-8.9	-7.8	-8.2	.7	-.4
66	-27.4	-26.2	-26.6	.8	-.4
72	-45.6	-44.4	-44.8	.8	-.4
78	-63.1	-62.0	-62.4	.7	-.4
84	-77.0		-76.8	.2	
Remarks:	Perigee Overhead	Apogee Overhead		(Positive)	(Negative)

TABLE 2B

Comparison of Calculated SSP latitude and longitude with those predicted on March 15 and June 17, 1972.

TAAN Minutes	Longitude of Sub Satellite Point °W				Deviation °	
	A.N.Long=114.82°E		A.N.Long=117.97°E		Orbit - -March 15	Orbit - -June 17
	March 15	Orbit	June 17	Orbit		
30	2.7	2.6	00.2	0.6	-.1	+.4
36	48.8	48.8	45.5	45.7	.0	+.2
42	63.0	63.0	59.7	59.9	.0	+.2
48	70.8	70.7	67.4	67.6	-.1	+.2
54	76.6	76.5	73.3	73.4	-.1	+.1
60	82.0	81.9	78.6	78.7	-.1	+.1
66	87.8	87.6	84.3	84.4	-.2	+.1
72	95.3	94.9	91.7	91.8	-.4	+.1
78	108.7	107.8	104.4	104.7	-.9	+.3
84	150.0	147.2			-2.8	
	Perigee Overhead		Apogee Overhead		(Negative)	(Positive)

TABLE 3

Constants, Variable Names and Equations used in the Computer Programs for ESSA-8

R = RAD = 6367.8	mean radius of the earth, kilometers
D = SOLDAY = 1440	length of a solar day, minutes
$_s$ = STALAT = 43.78	latitude of receiving station, Downsview, °N
$_s$ = STALNG = 79.47	longitude of receiving station, °W
A = ALT = 1450	average altitude of ESSA-8 KM
T = PERIOD = 114.703	period of orbit of ESSA-8, minutes
i = ZINC = 101.6	inclination of orbit of ESSA-8 degrees
AN = ANLNG	variable longitude of the ascending node
	change in the longitude of ascending node per orbit
t = TAAN	time after ascending node, seconds
= ARCAAN = $\frac{2\ t}{T}$	arc along track after ascending node, radians

= SSPLAT = arcsin (sin i sin) latitude of SSP °N

$_s$ - = DLONG = $_s$ (°W) + AN (°E) - - $\frac{}{2}$ + arctan(cos i tan)

= SSPLNG = $_s$ - DLONG x 180/ longitude of SSP °W

= GCA = arccos (sin $_s$ sin ( ) + cos cos ( ) cos ($_s$ - ( ))
great circle arc length from station to sub-point

L ( ) = DIST = $\sqrt{R^2 + (R+A)^2 - 2R(R+A) \cos (\ )}$
distance from station to satellite, KM

( ) = AZIM = arcsin $\left(\frac{\cos (\ ) \sin\ _s - (\ )}{\sin (\ )}\right)$
antenna azimuth angle, (0 - 90°)

( ) = ELEV = arccos $\left(\frac{R+A}{L(\ )} \sin (\ )\right)$
antenna elevation angle.

ESSA 8 ORBIT No. 16734 DATE 8. 9. 1972
EQUATOR CROSSING 100.20 'E
EQUATOR CROSSING TIME 15. 14. 44. Z
ACQUISITION TIME 15. 47. 44. Z

TIME	AAN	AZIM	ELEV	AZVOLT	ELVOLT	MINUTE
33.:	0.	17.3	3.5	11.1	-7.9	0.00
35.:	0.	17.9	11.3	11.0	-7.3	2.00
37.:	0.	18.5	21.3	11.0	-6.5	4.00
39.:	0.	19.1	35.6	11.0	-5.5	6.00
41.:	0.	20.3	57.5	11.0	-3.8	8.00
43.:	0.	65.5	88.7	9.3	-1.5	10.00
45.:	0.	197.8	58.9	4.4	-3.7	12.00
47.:	0.	199.0	36.5	4.3	-5.4	14.00
49.:	0.	199.5	21.9	4.3	-6.5	16.00
51.:	0.	199.9	11.7	4.3	-7.3	18.00
53.:	0.	200.2	3.9	4.3	-7.9	20.00

ESSA 8 ORBIT No. 16735 DATE 8. 9. 1972
EQUATOR CROSSING 71.52 'E
EQUATOR CROSSING TIME 17. 9. 26. Z
ACQUISITION TIME 17. 40. 26. Z

TIME	AAN	AZIM	ELEV	AZVOLT	ELVOLT	MINUTE
31.:	0.	368.7	1.8	-1.9	-8.0	0.00
33.:	0.	361.6	7.7	-1.7	-7.6	2.00
35.:	0.	351.7	14.0	-1.3	-7.1	4.00
37.:	0.	337.6	19.9	-0.8	-6.7	6.00
39.:	0.	319.1	23.7	-0.1	-6.4	8.00
41.:	0.	298.5	23.5	0.7	-6.4	10.00
43.:	0.	280.2	19.5	1.3	-6.7	12.00
45.:	0.	266.5	13.5	1.8	-7.1	14.00
47.:	0.	256.7	7.3	2.2	-7.6	16.00
49.:	0.	249.6	1.4	2.5	-8.0	18.00

ESSA 8 ORBIT No. 16745 DATE 8. 10. 1972
EQUATOR CROSSING 144.78 'E
EQUATOR CROSSING TIME 12. 16. 28. Z
ACQUISITION TIME 12. 55. 28. Z

TIME	AAN	AZIM	ELEV	AZVOLT	ELVOLT	MINUTE
39.:	0.	411.1	0.7	-3.5	-8.1	0.00

```
C       AUTOMATIC PICTURE RECEPTION   APRIL
C       IF LUCKY
        SUBROUTINE NTIME(D,H,W,S)
C
C       RECTIFY TIME INTO DAY HOUR MINUTE SECOND
C
31      IF (S-60)  33, 32, 32
32      W=W+1
        S=S-60
        GO TO 31
33      IF  (W-60)  35, 34, 34
34      H=H+1
        W=W-60
        GO TO 33
35      IF  (H-24)  37, 36, 36
36      D=D+1
        H=H-24
        GO TO 35
37      RETURN
        END
C
2       FORMAT ('1ESSA 8 ORBIT No.', I6,' DATE'2F4.0,'  1972'/
        1' EQUATOR CROSSING ', F7.2,' ''E'/
        2' EQUATOR CROSSING TIME ', 3F4.0,'  Z')
3       FORMAT (6X'ACQUISITION TIME ', 3F4.0,'  Z'/)
7       FORMAT ('  TIME AAN AZIM ELEV AZVOLT ELVOLT MINUTE')
8       FORMAT (2H  , F3.0, 1H:, F3.0, 4F8.1, F8.2)
C
C       FUNCTIONS USED IN PROGRAM ARE :  **2, SQRT, ABS,
C       SIN, COS, ASIN, ACOS, ATAN.
C
C       PARAMETERS USED IN THE PROGRAM
C
        PI=3.14159
        PHI=PI/180.0
C
        RAD=6367.8
        SOLDAY=1440.0
        STALAT=43.78*PHI
        STALNG=79.47
C
        ALT=1450.0
        PERIOD=114.70
        ZINC=101.6
        XINC=ZINC*PHI
C
        INDEX=-1
        IN=120
        FIN=FLOAT (IN)
C
C       APT OPERATOR ENTERS THE EQUATOR CROSSING DATA
C       FROM THE TBUS1 PREDICT FORM AND CALIBRATES REAL TIME CLOCK
C
        XMONTH=08.
        NORBIT=16734
        XDAY=09.
        XHOUR=15.
        XMIN=14.
        XSEC=44.
```

```
      ANLNG=100.20
      EDAY=XDAY
C
C     IS EQUATOR CROSSING IN THE RANGE RECEIVED BY STATION
C
40    IF (ANLNG-145.00) 42, 42, 120
42    IF (ANLNG-45.00) 120, 43, 43
43    TYPE 2, NORBIT, XMONTH, XDAY, ANLNG, XHOUR, XMIN, XSEC
      IF (XDAY-EDAY-2) 89, 130, 130
C
C     SELECT TIME AND CALCULATE LOCATION OF SATELLITE SUB POINT
C
89    CONTINUE
      DO 90 ITAAN=1740,3300, IN
      TAAN=FLOAT(ITAAN)
      ARCAAN=PI*TAAN/PERIOD/30.
      SSPLAT=ASIN(SIN(XINC)*SIN(ARCAAN) )
      TAN=SIN(ARCAAN)/COS(ARCAAN)
      TSPLAT=SSPLAT/PHI
      DLONG=(STALNG+ANLNG)*PHI-PERIOD*ARCAAN/SOLDAY
     1+ATAN(TAN*COS(XINC) ) -PI
      SSPLNG = STALNG - DLONG/PHI
C
C     CALCULATE GREAT CIRCLE ARC LENGTH
C     FROM SUB POINT TO STATION
C
      GCA = ACOS(SIN(SSPLAT)*SIN(STALAT)
     1+COS(SSPLAT)*COS(STALAT)*COS(DLONG) )
C
C     IS GCA WITHIN RANGE OF STATION ?
C
      IF (COS(GCA)-RAD/(RAD+ALT) 45, 46, 46
45    IF (INDEX) 90, 90, 100
C     CALCULATE ANTENNA LOOK ANGLES
C
46    DIST=SQRT (RAD**2+(RAD+ALT)**2 -2. *RAD*(RAD+ALT)*COS(GCA) )
      ELEV=ACOS(SIN(GCA)*(RAD+ALT)/DIST)/PHI
      AZIM=ABS(ASIN(COS(SSPLAT)*SIN(DLONG)/SIN(GCA)))/PHI
C
C     DETERMINE AZIMUTH QUADRANT
C
      SOUTH=SIN(STALAT)*COS(SSPLAT)*COS(DLONG)
      IF (COS(STALAT)*SIN(SSPLAT)-SOUTH) 51, 52, 52
51    AZIM=180.0-AZIM
52    IF (DLONG) 53, 55, 55
53    AZIM=360.0-AZIM
      GO TO 59
C
C     DETERMINE IF MERIDIAN CROSSING IS SOUTHBOUND
C
55    IF (ANLNG-114.00) 56, 56, 57
56    IF (ANLNG-99.9437) 57, 57, 59
57    AZIM=AZIM+360.00
C
C     CALCULATE ANTENNA COMMAND VOLTAGES
C
59    AZVOLT=11.7-0.037*AZIM
      ELVOLT=0.075*ELEV-8.15
C
```

```
      IF (INDEX) 61, 66, 66
C
C     PREPARE FOR NEXT PASS
C     FIND ACQUISITION TIME
C
61    ASEC=XSEC+TAAN
      AMIN=XMIN
      AHOUR=XHOUR
      CALL NTIME (XDAY, AHOUR, AMIN, ASEC)
      TYPE 3, AHOUR, AMIN, ASEC
C
C     WAIT UNTIL ACQUISITION TIME -20 MIN
C     ORIENT ANTENNA
C     WAIT UNTIL ACQUISITION TIME
C     START TAPE RECORDER
C     AND CONNECT MUIRHEAD  K300
C
      TYPE 7
C     CURRENT TIME AFTER ASCENDING NODE
      CSEC=TAAN-FIN
      CMIN=0.
C
C     SATELLITE PASS IS IN PROGRESS
66    INDEX=INDEX+1
      CSEC=CSEC+FIN
      CALL NTIME (0., 0., CMIN, CSEC)
C     TIME INTO PASS : TIP
      TIP=FLOAT(INDEX)*FIN/60.
      TYPE 8, CMIN, CSEC, AZIM, ELEV, AZVOLT, ELVOLT, TIP
C     WAIT UNTIL TIME CMIN:CSEC
C     ORIENT ANTENNA (AZVOLT, ELVOLT)
90    CONTINUE
C
100   INDEX = -1
C     PASS ENDED
C     STOP TAPE RECORDER
C     WAIT 4 MINUTES TO PROCESS FINAL PICTURE
C     ISOLATE MUIRHEAD
C     STOW ANTENNA
C     ELEV=0.0
C     AZIM=315.0
C
C     SELECT NEXT ORBIT
C
120   NORBIT=NORBIT+1
      ANLNG=ANLNG-28.675
C
C     IS LONGITUDE OF ASCENDING NODE IN THE RANGE 0-360' EAST
      IF (ANLNG) 121, 121, 122
121   ANLNG=ANLNG+360.00
122   XHOUR=XHOUR+1
      XMIN=XMIN+54
      XSEC=XSEC+42.17
      CALL NTIME (XDAY, XHOUR, XMIN, XSEC)
124   GO TO 40
130   CONTINUE
      STOP
      END
```

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