A COMPUTER PROGRAM
FOR MAPPING SATELLITE-BORNE NARROW-BEAM
ANTENNA FOOTPRINTS
ON EARTH

Thomas W. Stagl
Jai P. Singh
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I. INTRODUCTION

A computer program has been developed that computes the locus of intersection of a quadric cone and a sphere. The outputs of the program are a list of the longitude and latitude coordinates of the locus of intersection and a plot of the locus. It was written primarily to define the area of the earth covered by a narrow-beam antenna carried on a synchronous satellite in circular, near equatorial orbits.

The program is basically an implementation of a report by S. L. Zolnay [1] with some modifications added. The main modifications are the incorporation of an elliptical cross section antenna beam and computation of the beam vertex angles and corresponding locus of intersection for any signal level between 0.1 and 10 db down from the beam center. Any number of signals up to 10 may be input for each data set. The output will be plotted on the same graph.

The program was written for use with a Cal Comp 570/563 off-line plotting system and uses the standard Cal Comp subroutines supplied with the system. The plot is drawn using linear longitude and latitude scales and non-linear scales such as Mercator scales cannot be used.

It should be noted that this program assumes the earth to be spherical rather than oblate as it actually is. However, by assuming a spherical earth, one introduces maximum error distances of about 11.5 nautical miles. For many purposes, this error can be ignored.
II. MATHEMATICAL ANALYSIS

Figure 1 shows the intersection geometry. The satellite is located at point SAT in a circular, near-equatorial orbit which is a distance DIST from center of the earth. Point P is the point of intersection of satellite antenna boresight (or beam center) and the earth. AL is the arc from the point on earth directly below the satellite (the subsatellite point) to P and is given by:

\[
AL = \cos^{-1} [\cos(LONCTR) \cos(LACTR + DElt)]
\]  

(1)

Where LATCTR is latitude of P, LONCTR is the longitude of P relative to the subsatellite point, and DElt is the instantaneous declination angle formed by a vector from satellite to the center of the earth and the equatorial plane. At \(DIST = \frac{22,300}{30,000}\) statute miles (geostationary equatorial orbit when DElt = 0), the maximum arc, AL, permissible for the point to be seen by the satellite is 81.3°. When AL is computed to be larger than 81.3°, the point is over the horizon seen by the satellite and any attempt at finding the locus of intersection would produce meaningless results. Therefore, the computation stops at this point.

The next step is to calculate the vector, RS, extending from the satellite to point P. A right-handed coordinate system is constructed with the origin at SAT, the positive Y axis extending through the earth center and the Z axis in the plane defined by SAT and the north and south poles. The vector RS is given in terms of coordinates along these axes:

\[
RS = RE \cos(LATCTR) \sin(LONCTR) \mathbf{i} + \\
\left[ \frac{DIST \cos(DElt) - RE \cos(LATCTR) \cos(LONCTR)}{DIST \sin(DElt) + RE \sin(LATCTR)} \right] \mathbf{j} + \\
\left[ \frac{DIST \sin(DElt) + RE \sin(LATCTR)}{DIST \sin(DElt) + RE \sin(LATCTR)} \right] \mathbf{k}
\]

(2)

Where RE is radius of earth, and \(\mathbf{i}\), \(\mathbf{j}\) and \(\mathbf{k}\) are unit vectors in the positive x, y, and z directions, respectively.

Pitch and roll angles are then defined as in Figure 2. These are given by:
FIGURE 2
GRAPHIC DESCRIPTION OF PITCH AND ROLL ANGLES
A new coordinate system is defined by rotating the old system about its z-axis by an angle equal to PITCH, and then about the resultant x-axis by an angle equal to ROLL.

A vector \( \mathbf{U} \) is then defined as lying in a plane perpendicular to vector \( \mathbf{RS} \). The origin of vector \( \mathbf{U} \) is at the point of intersection of \( \mathbf{RS} \) and that plane, see Figure 3.

The equation defining \( \mathbf{U} \) is:

\[
\mathbf{U} = [\cos(\text{BETA}) \mathbf{i'} + \sin(\text{BETA}) \mathbf{k'}] [A^{-2}\cos^2(\text{BETA}) + B^{-2}\sin^2(\text{BETA})]^{-\frac{1}{2}}
\]

where \( \mathbf{i'} \) and \( \mathbf{k'} \) are unit vectors in the new coordinate system. This equation is a parametric equation of an ellipse with \( \text{BETA} \) as the parameter and \( A \) and \( B \) corresponding to the semi-major and semi-minor axes, respectively.

A ray on the surface of the beam can now be generated by a vectorial addition of \( \mathbf{RS} \) and \( \mathbf{U} \). By incrementing \( \text{BETA} \) from 0° to 360° the entire outer surface of the beam can be generated.

Let a vector \( \mathbf{Mn} \) be a surface generator vector. The equation defining \( \mathbf{Mn} \) in the new coordinate system is:

\[
\mathbf{Mn} = [|\mathbf{RS}| \cos(\text{ROLL}) \sin(\text{PITCH}) + |\mathbf{U}| \cos(\text{BETA}) \cos(\text{PITCH}) - |\mathbf{U}| \sin(\text{BETA}) \sin(\text{ROLL}) \sin(\text{PITCH})] \mathbf{i'} + [|\mathbf{RS}| \cos(\text{ROLL}) \cos(\text{PITCH}) + |\mathbf{U}| \cos(\text{BETA}) \sin(\text{PITCH}) - |\mathbf{U}| \sin(\text{BETA}) \sin(\text{ROLL}) \cos(\text{PITCH})] \mathbf{j'} + [|\mathbf{RS}| \sin(\text{ROLL}) + |\mathbf{U}| \sin(\text{BETA}) \cos(\text{ROLL})] \mathbf{k'}
\]
Figure 3: Graphical Description of Beam Cross Section
In the old coordinate system:

\[
\begin{align*}
\overline{Mn} &= [Mn_i,] \hat{i} + [Mn_j, \cos(\text{DELT}) + Mn_k, \sin(\text{DELT})] \hat{j} \\
&\quad + [-Mn_i, \sin(\text{DELT}) + Mn_k, \cos(\text{DELT})] \hat{k} 
\end{align*}
\] (7)

Pitch and roll angles are defined for each \( Mn \) as follows:

\[
PITCH\ N = \sin^{-1} \frac{Mn_i,}{\sqrt{Mn_i^2 + Mn_j^2}}
\] (8)

\[
ROLL\ N = \tan^{-1} \frac{Mn_k,}{\sqrt{Mn_i^2 + Mn_j^2}}
\] (9)

The earth radius vector to the point of intersection of \( Mn \) is:

\[
\overline{RE} = [Mn \cos(ROLLN) \sin(PITCHN)] \hat{i} \\
&\quad + [\text{DIST} \cos(\text{DELT}) - Mn \cos(ROLLN) \cos(PITCHN)] \hat{j} \\
&\quad + [Mn \sin(ROLLN) - \text{DIST} \sin(\text{DELT})] \hat{k}
\] (10)

Where \( Mn \) in the length of \( Mn \) and \( \hat{i}, \hat{j}, \) and \( \hat{k} \) are unit vectors in an earth centered coordinate system whose positive z axis extends through the north pole and positive x axis intersects the 0° meridian.

The latitude and relative longitude coordinates of the point of intersection of \( Mn \) are found by:

\[
\text{LAT} = \tan^{-1} \frac{RE_k}{\sqrt{RE_i^2 + RE_j^2}}
\] (11)

\[
\text{LON} = \sin^{-1} \frac{RE_i}{\sqrt{RE_i^2 + RE_j^2}}
\] (12)
The actual longitude is found by adding the above longitude to the longitude of the subsatellite point.

The relative beamwidth for any signal level is found using a beamwidth conversion chart. The particular chart used in this program is taken from Microwave Engineers Handbook[2], (see Figure 4). The actual conversion in the program is done by using linear interpolation between the appropriate two consecutive points from the following set:

\[(.1, .18) (.2, .26) (.5, .4) (1., .56) (1.5, .7) (3., 1.) (5., 1.27) (10., 1.7)\]

These points were chosen such that the graph segment between any two consecutive points is approximately linear.

The above discussion assumes that the entire antenna beam intersects the earth. The case when the boresight location is near enough to the horizon that a portion of the beam passes the earth is considered next.

Define an angle, \(\theta_n\) formed by the vector \(\mathbf{M}_n\) and the vector from the satellite to earth center. The angle at which \(\mathbf{M}_n\) is tangent to the earth is given, from the law of sines, as:

\[
\theta_{\text{max}} = \sin^{-1} \frac{\mathbf{R}_{E}}{\text{DIST}}
\]  

(13)

When the angle \(\theta_n\) is larger than \(\theta_{\text{max}}\) the earth radius vector \(\mathbf{R}_E\) must be computed to the point of tangency, i.e. the horizon seen by the satellite. The vector \(\mathbf{R}_E\) is then defined by:

\[
\mathbf{R}_E = \mathbf{R}_E \left[ \cos(\theta_{\text{max}}) \sin(\text{TAUN}) \right] I
\]  
\[ - \mathbf{R}_E \left[ \cos(\text{DELT}) \sin(\theta_{\text{max}}) + \sin(\text{DELT}) \cos(\theta_{\text{max}}) \cos(\text{TAUN}) \right] J
\]  
\[ - \mathbf{R}_E \left[ \sin(\text{DELT}) \cos(\theta_{\text{max}}) - \cos(\text{DELT}) \cos(\theta_{\text{max}}) \cos(\text{TAUN}) \right] K
\]  

(14)

When \(\text{TAUN}\) is the tilt angle defined by:

\[
\text{TAUN} = \cos^{-1} \left( \frac{\mathbf{M}_{n_k}}{\sqrt{\mathbf{M}_{n_i}^2 + \mathbf{M}_{n_k}^2}} \right)
\]  

(15)
For a tapered circular aperture with 25 dB sidelobes, and for a 25 dB Taylor line source, the graph converts values of 3 dB beamwidth to other levels, for example, 10 dB beamwidth.

The pattern is

\[ p(u) = |A_2(u)|^2 \text{ where } u = \pi D_0/2\lambda \]
and \( RE \) is the radius of the earth. The latitude and relative longitude coordinate are found as in equations (11) and (12).

III. USAGE

The inputs to the program are:

- LONSS - longitude of point on earth directly below satellite (°E)
- LONCT - longitude of boresight intersection (°E)
- LATCT - latitude of boresight intersection (°N)
- INCR - increments of angular parameter \( \beta \), i.e. number of points plotted = \( 360°/\text{INCR} \)
- DELT - instantaneous declination of satellite - earth center vector from plane of equator (°below equatorial plane)
- THETA - orientation angle of elliptical beam about beam center (measured positive counter-clockwise)
- BW1 - beam vertex angle in plane defined by beam vertex and major axis of beam cross section at point 3 dB below beam center
- BW2 - beam vertex angle in plane defined by beam vertex and minor axis of beam cross section at point 3 dB below beam center
- L - number of signal levels to be plotted
- DB(I) - signal levels to be plotted (measured in dB below beam center)

It should be noted that all inputs except \( L \) and \( \text{DB}(I) \) are in degrees rather than radians. Longitude inputs can be expressed as degrees east of 0° or negative degrees west of 0°. The output will agree with the input.

Each input data set will consist of three cards. The format for the data is:

Card #1

<table>
<thead>
<tr>
<th>column</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 9</td>
</tr>
<tr>
<td>10 - 18</td>
</tr>
<tr>
<td>19 - 27</td>
</tr>
<tr>
<td>28 - 36</td>
</tr>
<tr>
<td>37 - 45</td>
</tr>
</tbody>
</table>
Card #2

1 - 9 THETA
10 - 18 BW1
19 - 27 BW2
28 - 29 L

Card #3

1 - 7
8 - 14 DB(I)
15 - 21

Every input, with the exception of L, must contain a decimal point. The input L must not contain a decimal point and must be right justified in columns 28-29, i.e. single digit input must be in column 29. The inputs DB(I) must be input in increasing order with the signal level closest to beam center listed first and the level farthest from beam center listed last.

The output of the program consists of two parts, the printout and the plot. The printout contains, for each set of input data, a list of the following parameters:

- SUB SAT LONG - longitude of point directly below satellite
- BOR SGHT LONG - longitude of boresight intersection
- BOR SGHT LAT - latitude of boresight intersection
- DECLINATION - instantaneous declination of satellite-earth center vector from equatorial plane
- MIN BMWDTH - beamwidth along minor axis of beam cross section at -3 db (half-power) level
- MAX BMWDTH - beamwidth along major axis of beam cross section at -3 db (half-power) level
- ORIENTATION - orientation angle of beam about beam center
- ELEVATION - angle formed by vector RS and a plane tangent to earth at boresight intersection

The remainder of the printout gives the maximum and minimum beamwidth and a listing of the coordinates of the locus of intersection for each signal level.
Each set of input data is given a data set number. This number appears on the printout and the plot for each data set. This facilitates matching of plots with printout when more than one data set is run.

A modification of this program has recently been developed to plot the coverage of a multi-beam satellite. This new program computes the locus of intersection of a number of sets of input data as does the original. However, the modification plots all of the intersection loci on one set of axes so that uncovered areas and overlapped areas are immediately obvious.

The major changes to the original program are:

1. The plotter tape is opened and the axes are drawn before the main calculation begins.
2. The axes are scaled once at the beginning of the program rather than being scaled for each data set.
3. The computed coordinates are checked to see that they do not extend beyond the limits of the axes.
4. The plot origin is not reset for each data set.

IV. TYPICAL EXAMPLES

Figures 5-9 present the area coverage plots for input values shown in Table 1. For each case, 3, 5 and 10 dB level contours are plotted. The inputs represent a wide variety of cases—satellites positioned in circular, equatorial and geosynchronous orbits; satellites positioned in slightly inclined stationary orbits; and area coverage at small inclination angles.

Figure 10 shows the coverage provided by a 4-beam satellite positioned at 120°W longitude. All plots use the same set of axes. The input values for various beams are given in Table 2. All four beams are designed to provide complete coverage to the United States—beam 1 covers Hawaii, beam 2 covers Alaska, and beams 3 and 4 provide coverage to the other 48 states.
<table>
<thead>
<tr>
<th>Input</th>
<th>Case I (Figure 5)</th>
<th>Case II (Figure 6)</th>
<th>Case III (Figure 7)</th>
<th>Case IV (Figure 8)</th>
<th>Case V (Figure 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsatellite Longitude</td>
<td>-115.00</td>
<td>-115.00</td>
<td>-115.00</td>
<td>-115.00</td>
<td>-115.00</td>
</tr>
<tr>
<td>Boresight Longitude</td>
<td>-157.00</td>
<td>-157.00</td>
<td>-74.00</td>
<td>-74.00</td>
<td>-74.00</td>
</tr>
<tr>
<td>Boresight Latitude</td>
<td>21.30</td>
<td>21.30</td>
<td>40.75</td>
<td>40.75</td>
<td>40.75</td>
</tr>
<tr>
<td>Declination (in degrees)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Minor-axis Beamwidth (in degrees)</td>
<td>1.50</td>
<td>0.75</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Major-axis Beamwidth (in degrees)</td>
<td>1.50</td>
<td>1.50</td>
<td>1.00</td>
<td>1.00</td>
<td>0.50</td>
</tr>
<tr>
<td>Orientation (in degrees)</td>
<td>0.00</td>
<td>-25.00</td>
<td>0.00</td>
<td>0.00</td>
<td>40.00</td>
</tr>
</tbody>
</table>
DATA SET NO. 1

Figure 5
DATA SET NO. 2

Figure 6
DATA SET NO. 3

Figure 7
DATA SET NO. 4

Figure 8
DATA SET NO. 5

Figure 9
Table 2. Input Values for 4-Beam Coverage Plot Shown in Figure 10

<table>
<thead>
<tr>
<th>Input</th>
<th>Hawaii</th>
<th>Alaska</th>
<th>Beam I for western and mountain states</th>
<th>Beam II for eastern and central states</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsatellite Longitude</td>
<td>-120.00</td>
<td>-120.00</td>
<td>-120.00</td>
<td>-120.00</td>
</tr>
<tr>
<td>Boresight Longitude</td>
<td>-158.00</td>
<td>-145.00</td>
<td>-112.00</td>
<td>-88.00</td>
</tr>
<tr>
<td>Boresight Latitude</td>
<td>21.00</td>
<td>63.00</td>
<td>37.00</td>
<td>36.00</td>
</tr>
<tr>
<td>Satellite Declination</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>(in degrees)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minor-axis Beamwidth</td>
<td>1.50</td>
<td>1.50</td>
<td>3.30</td>
<td>3.30</td>
</tr>
<tr>
<td>(in degrees)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major-axis Beamwidth</td>
<td>2.00</td>
<td>2.30</td>
<td>3.40</td>
<td>3.70</td>
</tr>
<tr>
<td>(in degrees)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orientation (in degrees)</td>
<td>135.00</td>
<td>110.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Figure 10. Four Beam Coverage of U.S. (see Table 2)
V. REFERENCES


IMPLICIT REAL*8, INTEGER*4
REAL*8 DSIN, DCOS, DSQRT, DAR, COSG, OAIR
INTEGER*4 NSIPS, ICT, NPLT, B1, FS100, NPL, NDB, LDB
INTEGER*4 J, ll, K
INTEGER*4 FMT(4)/'1', 'F7.3', '1'
INTEGER*4 DIGIT(10)/'1', '2', '3', '4', '5', '6', '7', '8', '9', '10'!
REAL*8 LON(722), LAT(722), N1, XCT, YCT
REAL*8 PI/3.141592653569793, DO/3.96D3, JUI/2.626041
DATA PI/3.

DO1=O

DO11 READ(5,500, END=1000) DLOS, DLONCT, DLATCT, DINCR, DDELT

1 READ(5,501) THETA1, BW1A, BW2A, L

500 FORMAT(5F9.3)

501 FORMAT(3F9.3, 12).

FMT(2)=DIGIT(1)

READ(5,FMT(1), I=1, L)

N=N+1

WRITE(6,600)* DLOS, DLONCT, DLATCT, DDEL, BW1A, BW2A, L

600 FORMAT(6X,'BSS=RE*OSINILATCTRI*DSINILOCTRI'

1 4X,'BSS', 'SGHT', 'LONG', '=+', 'F9.3', '4X,' 'BSS', 'SGHT', 'LAT', '=+', 'F9.3' /

2 4X,'DECLINATION', '=+', 'F9.3', '4X,' MIN, 'BWDDH', '*, '5X', '=+', 'F9.3' /

3 4X,'FAX', 'BWDTH', '*, '5X', '=+', 'F9.3' /

4X,'ORIENTATION', '=+', 'F9.3' )

C CONVERT FROM DEGREES TO RADIANS

INCR=DINCR+CONVR

LONCT=DLONCT-DLNNSS1*CONVR

LATCT=DLATCT*CONVR

DELT=DEL+CONVR

BW1=BA1*CONVR/2.0

BW2=BA2*CONVR/2.0

THE=THET+CONVR

C CHECK FOR BSSIGHT LOCATION IN RANGE OF SATELLITE

AL=DARCOS(OCOS*LENGTH)*DCOS(LATCT+DELT)

1 IFIAL.L.E.CHK1 GO TO 21

20 WRITE(6,600)

400 FORMAT(6X,'BSSIGHT LOCATION IS NOT IN RANGE OF SATELLITE.' )

GU TO 1

C COMPUTE VECTOR FROM SATELLITE TO BSSIGHT LOCATION

RSX=RE*DCOS(LATCT)*DSIN(LONCTR)

RSY=DI*DCOS(DELT)-RE*DCOS(LATCT)*DCOS(LONCTR)

RSZ=DI*DSIN(DELT)+RE*DSIN(LATCT)

KSM=DSQRT(RSX**2-55.5**2+K5**2)
GAM = DSIN(RM*DSIN(AL)/RSM)

WRITE(6, 300) EL

300 FORMAT(4X, 'ELEVATION', 6X, 1X, F9.3)

DENOM = DSGRT(RSX**2+RSY**2)
PITCH = 0.05774715929899981998268993514
ROLL = DATAN(RSZ/DEKOP)

CP = DCOS(PITCH)

CR = DCOS(ROLL)

SP = USIN(PITCH)

SR = USIN(ROLL)

IF (INPLT.GT.0.0) GO TO 15

C FIRST PLOT, OPEN PLOTTAPE AND SET ORIGIN

CALL PLOTS(1, BUF, 1000)

CALL PLOT(1, 0, 1.0, 23)

GO TO 12

C NOT FIRST PLOT, SET ORIGIN

15 CALL PLOT(1.0, 0, 1.0, -3)

DC JL K = 1

RDL = 16

LDD = L - K + 1

C INTERPOLATE FOR RELATIVE BEAMWIDTH

DO 8 J = 1, 8

IF (IDR1(LDD) - OBS(J)) > 0.8

7 RW = RW+WS(J)

GO TO 9

8 CONTINUE

6 J = J - 1

IF (IDR1(LDD) - OBS(J)1*(RW+WS(J1))/OBS(J) - OBS(J1)) > 0.8

1 *RW+WS(J1)

9 A = RMS*DATAN(RW*RW)

G = RMS*DATAN(RB*RB)

ALPH = A+RA*K BW

ALPH = B+2A*K RW

NSTEP = (360.0/DINCR)+1

BWPATH = DELTA*RBW

DO 10 ICT = 1, NSTEPL

BETAN = (ICT - 1) * INCR

ANG = BETAN + THEIA

UM = 1.0*USCR1*(DCOS(BETAN)/A)**2*(DSIN(BETAN)/B)**2

C COMPUTE N-TH M VECTOR FROM SATELLITE TO LOCUS ON EARTH

MNPX = RMS*CR*SP+UP*DCOS(ANG)*CP-U*CSIN(ANG)*SR+SP

MNPY = RMS*CR*CP+UP*DCOS(ANG)*SP-U*DSIN(ANG)*SR+SP

MNZ = RMS*SR+UM*USIN(ANG)*CR

MNX = MNPX

MNZ = MNPY*DCOS(DELTA)+MNZ*DSIN(DELTA)

MNZ = MNPY*USIN(DELTA)+MNZ*DCOS(DELTA)
### FORTRAN IV Level 19

#### Date: 7/20/53 13/37/49  Page: 0003

<table>
<thead>
<tr>
<th>Line</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0086</td>
<td><code>BN=DARCOS(MNY/DSCRTI(MAX**2*MNY**2+MNZ**2))</code></td>
<td>Computes angle BN from the Earth to the locus.</td>
</tr>
<tr>
<td>0087</td>
<td><code>IF(BN.GT.PI)GOTO_TEC_30</code></td>
<td>Conditional block for angle BN.</td>
</tr>
<tr>
<td>0088</td>
<td><code>CN=PI-DARCOS(DSIN(INBNT)*DIST/RE)</code></td>
<td>Computes angle CN from the Earth to the locus.</td>
</tr>
<tr>
<td>0089</td>
<td><code>UP=PI-(BN-CN)</code></td>
<td>Conditional block for angle CN.</td>
</tr>
<tr>
<td>0090</td>
<td><code>MNL=DSQRT(RE**2+DIST**2-2.*RE*DIST*cos(INBNT))</code></td>
<td>Computes MNL from the Earth to the locus.</td>
</tr>
<tr>
<td>0091</td>
<td><code>DENOM=DSQRT(MNPX**2+MNY**2+MNZ**2)</code></td>
<td>Computes denomer of the vector.</td>
</tr>
<tr>
<td>0092</td>
<td><code>PITCHN=DARCOS(DSIN(MNPX)/DENOM)</code></td>
<td>Computes angle PITCHN from the Earth to the locus.</td>
</tr>
<tr>
<td>0093</td>
<td><code>HOLLN=DATAN(MNPX/DENOM)</code></td>
<td>Computes angle HOLLN from the Earth to the locus.</td>
</tr>
<tr>
<td>0094</td>
<td><code>C_COMPUTE N-TH VECTOR FROM CENTER OF EARTH TO LOCUS</code></td>
<td>Computes vector from the Earth to the locus.</td>
</tr>
<tr>
<td>0095</td>
<td><code>REI=MNL*DARCOS(ROLLN)*DSIN(PITCHN)</code></td>
<td>Computes angle REI from the Earth to the locus.</td>
</tr>
<tr>
<td>0096</td>
<td><code>REJ=DSQRT(RE**2+DSIN(DELT)*HOLLN)**2+DSIN(DELT)**2)</code></td>
<td>Computes angle REJ from the Earth to the locus.</td>
</tr>
<tr>
<td>0097</td>
<td><code>REK=REI*DARCOS(DSIN(DELT))</code></td>
<td>Computes angle REK from the Earth to the locus.</td>
</tr>
<tr>
<td>0098</td>
<td><code>C_FROM CENTER OF EARTH TO HORIZON SEEN BY SATELLITE</code></td>
<td>Computes vector from the Earth to the horizon seen by the satellite.</td>
</tr>
<tr>
<td>0099</td>
<td><code>TAUN=DARCOS(MNX/DSCRT(MNX**2+MNZ**2))</code></td>
<td>Computes angle TAUN from the Earth to the locus.</td>
</tr>
<tr>
<td>0100</td>
<td><code>IF(MNX.LT.0.0)GOTO_TEC_40</code></td>
<td>Conditional block for angle TAUN.</td>
</tr>
<tr>
<td>0101</td>
<td><code>REJ=E+R*DARCOS(DSIN(DIST)*DIST/REI)</code></td>
<td>Computes angle REJ from the Earth to the locus.</td>
</tr>
<tr>
<td>0102</td>
<td><code>REK=DSQRT(RE**2+DSIN(DIST)*DIST**2)</code></td>
<td>Computes angle REK from the Earth to the locus.</td>
</tr>
<tr>
<td>0103</td>
<td><code>DEN=DSQRT(DIST**2+RE**2)</code></td>
<td>Computes denominator of the vector.</td>
</tr>
<tr>
<td>0104</td>
<td><code>LAT(ICT)=SNGL(DATAN(REI/DEN))</code></td>
<td>Computes latitude from the Earth to the locus.</td>
</tr>
<tr>
<td>0105</td>
<td><code>LON(ICT)=SNGL(DATAN(REI/DEN))</code></td>
<td>Computes longitude from the Earth to the locus.</td>
</tr>
<tr>
<td>0106</td>
<td><code>WRITE(6,100)100.0,ALPHA1,ALPHA2</code></td>
<td>Writes variables to the output file.</td>
</tr>
<tr>
<td>0107</td>
<td><code>100 FORMAT(1H,-3X,*AT*,F4.1,-1*) DB LEVEL:*4X,*MAX PMWDH= *,F5.2/*</code></td>
<td>Formatting the output file.</td>
</tr>
<tr>
<td>0108</td>
<td><code>4 4X,*MIN PMWDH= *,F5.2/*</code></td>
<td>Formatting the output file.</td>
</tr>
<tr>
<td>0109</td>
<td><code>2 5X,*LONITUDE*/,F6.3.(*DEGREES)*,6X,*.*(DEGREES)*</code></td>
<td>Formatting the output file.</td>
</tr>
<tr>
<td>0110</td>
<td><code>1 4X,*LATITUDE*/,F6.3.(*DEGREES)*,6X,*.*(DEGREES)*</code></td>
<td>Formatting the output file.</td>
</tr>
<tr>
<td>0111</td>
<td><code>IF(NDX.GT.11)GOTO_TEC_93</code></td>
<td>Conditional block for output file.</td>
</tr>
<tr>
<td>0112</td>
<td><code>C_IF FIRST DB LEVEL PLOT AXES AND TITLES</code></td>
<td>Computes vector from the Earth to the horizon seen by the satellite.</td>
</tr>
<tr>
<td>0113</td>
<td><code>CALL SCALE(LON,9.0,NP1)1</code></td>
<td>Computes vector from the Earth to the horizon seen by the satellite.</td>
</tr>
<tr>
<td>0114</td>
<td><code>NPI=NS16PS+1</code></td>
<td>Computes vector from the Earth to the horizon seen by the satellite.</td>
</tr>
<tr>
<td>0115</td>
<td><code>NP2=NS16PS+2</code></td>
<td>Computes vector from the Earth to the horizon seen by the satellite.</td>
</tr>
<tr>
<td>0116</td>
<td><code>IF(LON(NP2)-LON(NP1))=90,91,92</code></td>
<td>Computes vector from the Earth to the horizon seen by the satellite.</td>
</tr>
<tr>
<td>0117</td>
<td><code>LON(NP2)=LON(NP1)</code></td>
<td>Computes vector from the Earth to the horizon seen by the satellite.</td>
</tr>
<tr>
<td>0118</td>
<td><code>GOTO_TEC_91</code></td>
<td>Conditional block for output file.</td>
</tr>
<tr>
<td>0119</td>
<td><code>.92 LON(NP2)=LON(NP1)</code></td>
<td>Computes vector from the Earth to the horizon seen by the satellite.</td>
</tr>
<tr>
<td>0120</td>
<td><code>.91 CALL AXIS(0.0,3.0,*LONGITUDE (DEGREES)*,-19, 9.0,0.0,LON(NP1),</code></td>
<td>Computes vector from the Earth to the horizon seen by the satellite.</td>
</tr>
<tr>
<td>0121</td>
<td><code>1 LON(NP2))</code></td>
<td>Computes vector from the Earth to the horizon seen by the satellite.</td>
</tr>
<tr>
<td>0122</td>
<td><code>SCFCT=LON(NP2)</code></td>
<td>Computes vector from the Earth to the horizon seen by the satellite.</td>
</tr>
<tr>
<td>0123</td>
<td><code>FVLN=LON(NP1)</code></td>
<td>Computes vector from the Earth to the horizon seen by the satellite.</td>
</tr>
</tbody>
</table>
0124 FVLT=LAT(NP1)
0125 XCT=(SNGL(DLONCT)-LCN(NP1))/LCN(NP2)
0126 YCT=(SNGL(DLATCT)-LAT(NP1))/LAT(NP2)
0127 CALL SYMBOL(XCT,YCT,0.21,3,0,0,-1)
0128 CALL SYMBOL(1.0,8.0,0.21,*DATA SET NO.*,0.0,13)
0129 NI=FLOAT(N)
0130 CALL NUMBER(999.0,999.0,0.21,N1,0.0,-1)
0131 93 LCN(NP2)=SCFCT
0132 LAT(NP2)=SCFCT
0133 LON(NP1)=VFLN
0134 LAT(NP1)=FVLT
0135 C_PLOT COORDINATES OF LOCUS
0136 CALL LINE(LON,LAT,NSTEPS,1,0,0)
0137 31 CONTINUE
0138 CALL PLOT(14.0,-1.0,23)
0139 GO TO 1
0140 1000 IF(NPLT.LE.0) GO TO 1001
0141 C_CLOSE PLOTTAPE
0142 CALL PLOT(0.0,0.0,999)
0143 1001 WRITE(6,700),NPLT
0144 700 FORMAT(*NUMBER OF PLOTS PRODUCED =*,I3)
0145 STOP
0146 END