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VOL VII

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- [ ] This submittal applies to AN/BRN-7 (Submarine Ω) only.
- [ ] This submittal applies to AN/SRN-( ) (Hydrofoil Ω) only.
- [X] This submittal applies to both AN/BRN-7 and AN/SRN-( ).

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NORT 73-48

AN/BRN-7 COMPUTER PROGRAM SPECIFICATION

Volume VII

PROPAGATION PREDICTION SUBPROGRAM DESIGN

October 12, 1973

Approved by

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Volume VII
of the
AN/BRN-7 OMEGA COMPUTER
PROGRAM SPECIFICATION

Volume	
I	Performance Specification
II	Design Specification
III	Synchronization Subprogram Design
IV	OMEGA Processing Subprogram Design
V	Tracking Filter Subprogram Design
VI	Kalman Filter Subprogram Design
VII	Propagation Prediction Subprogram Design
VIII	Navigation Subprogram Design
IX	Executive Subprogram Design
X	Control-Indicator Subprogram Design
XI	Built-in Test Subprogram Design
XII	Common Subroutines Subprogram Design
XIII	Appendix

CONTENTS

SECTION 1

SCOPE

1.1 IDENTIFICATION

Volume I, Submarine OMEGA Computer Program Performance Specification, defines the functional requirements for the Submarine OMEGA Computer Program which is used by the AN/ARN-99 OMEGA Navigation Set. The Navigation set and the OMEGA program together comprise the Submarine OMEGA Navigation System. The tape which defines the computer program is entitled AN/BRN-7 Navigation Program.

Volume II, Submarine OMEGA Computer Program Design Specification, allocates the functional requirements of Volume I to the computer routine and subprogram level.

This volume describes the subprogram designated as Propagation Prediction, which has the abbreviation PP in the program listing (Volume XIII).

1.2 PROPAGATION PREDICTION SUBPROGRAM TASKS

1.2.1 Overview

In order to successfully determine the current submarine position from the phase information received, it is necessary to know the phase velocity of the incoming wave along the path, and the path length. To obtain a more accurate estimate of submarine position, we will investigate a number of effects (magnetic, day/night (diurnal), ground conductivity, and variations in radius of the earth) that cause position to deviate from that calculated using constant velocity over an assumed perfect sphere.

Operation of the OMEGA Navigation System is based on the measurement of the phase of several transmitters operating in the 10-14 kHz electromagnetic spectrum. It has been established that the eight proposed OMEGA transmitters will cover the earth with signal levels adequate to permit that phase measurement. Furthermore, it is generally accepted that signals in this spectrum propagate through a waveguide made up of two concentric spheres, one sphere is the earth; the other is the ionosphere.

Under ideal conditions a simple phase measurement would suffice to precisely locate a receiving station. However, the walls of the waveguide are not perfect and are affected by several parameters, specifically the effect of the sun on the ionosphere; earth's magnetic field; ground conductivity, and others. These imperfections in the waveguide walls cause changes in the propagation of the electromagnetic signal, the phase velocity, which reduce the accuracy of the phase measurement.

The phase velocity of such waves in a perfect waveguide with this geometry has been found to depend on the width of the waveguide (the height of the ionosphere) and on the electrical conductivity of the surfaces. The electric conductivity of the earth's surface is important, as well as that of ionosphere. In the case of the ionosphere, the problem is complicated theoretically because a continuous wall does not exist; rather, the electron density and collision frequency vary with height in some manner which can be approximated as exponential. The effect of the earth's magnetic field on the phase velocity must also be considered. This has been analyzed theoretically and the assymetry between propagation from east to west and from west to east has been observed.

These factors, along with one to account for the oblateness of the earth, are incorporated into a computer program designed to provide incremental real-time corrections along the propagation path.

1.2.2 Tasks

There are four tasks of the Propagation Prediction Subprogram. They are reflected in Figure 1.

a) Initialization: Calculation of those environmental parameters which are independent of frequency and need only be calculated once. Included are:

- The central path angle between station and OMEGA receiver,
- The first magnetic parameter,
- The seasonal Index, and
- The sun vector.

b) Integration Over the Transmission Path: In order to evaluate the effect of the ionosphere on the transmitted signal, it is necessary to superpose the known signal path on the model of the world contained in the subprogram. The following subtasks are frequency or path dependent:

- Calculation of the diurnal constants,
- Auroral compensation,
- Earth conductivity Index,
- Diurnal function and average,
- Correction factors for propagation modes, and
- Integration.

c) Generation of Output Data: As a result of the incremental integration the subprogram generates:

- Averaging constant; correction for incremental integration,
- Base station control angle; used for phase,

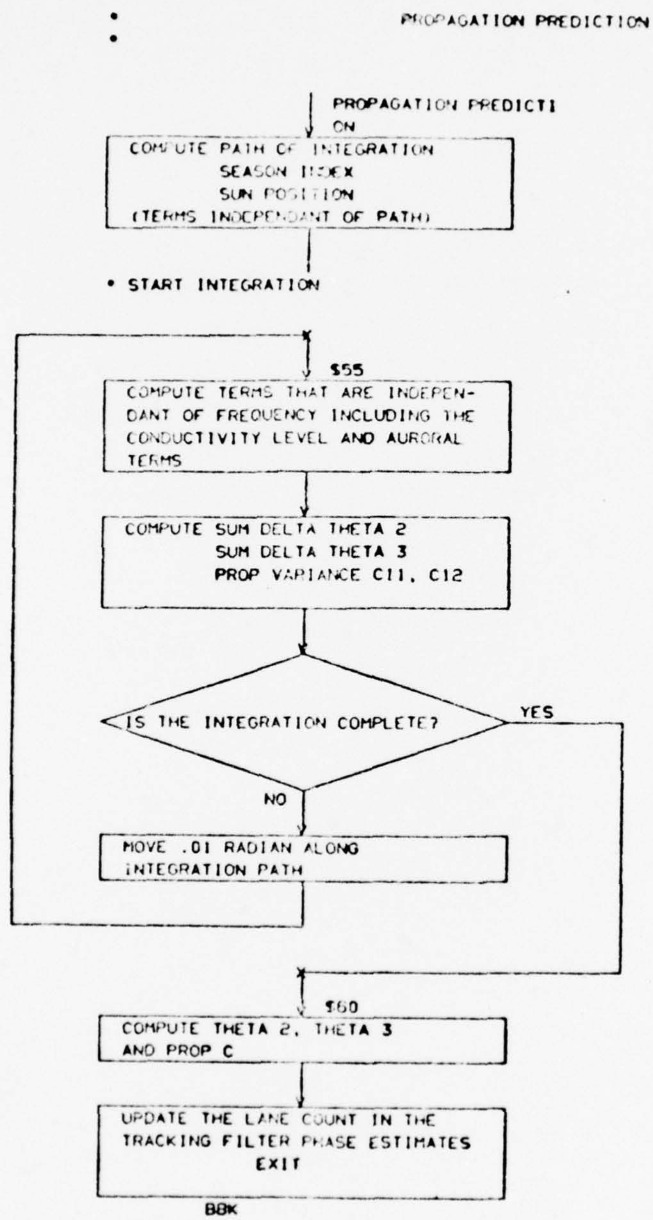

PROPAGATION PREDICTION
PROPAGATION PREDICTI ON
COMPUTE PATH OF INTEGRATION
SEASON INDEX
SUN POSITION
(TERMS INDEPENDANT OF PATH)
START INTEGRATION
S55
COMPUTE TERMS THAT ARE INDEPENDANT OF FREQUENCY INCLUDING THE CONDUCTIVITY LEVEL AND AURORAL TERMS
COMPUTE SUM DELTA THETA 2
SUM DELTA THETA 3
PROP VARIANCE C11, C12
IS THE INTEGRATION COMPLETE?
YES
NO
MOVE .01 RADIAN ALONG INTEGRATION PATH
S60
COMPUTE THETA 2, THETA 3 AND PROP C
UPDATE THE LANE COUNT IN THE TRACKING FILTER PHASE ESTIMATES
EXIT
BBK

FIGURE 1

- Propagation Correction, θ_3.
- Predicted Variance σ^2_{PPi}
- Spherocdal Correction, θ_2.

d) Tracking Filter Update: Includes:

- Predicted Tracking Filter measurement.
- Lane count corrections.

SECTION 2

APPLICABLE DOCUMENTS

a) Submarine OMEGA Computer Program Performance Specification (Volume I of the Submarine OMEGA Computer Program Specification)

Applicable Sections:

3.1 Introduction
3.2 Functional Description
  3.2.5 Detailed System Operations
3.3 Detailed Functional Requirements
  3.3.10 Tracking Filters
  3.3.11 Combinational Kalman Filter
  3.3.12 Propagation Prediction

b) Submarine OMEGA Computer Program Design Specification (Volume II of the Submarine OMEGA Computer Program Specification).

c) NORT 68-66, NAP70 User's Manual, July 1968.

d) NORT 68-115A, Detailed Description of NDC-1070, Computer Instructions, Revision A, February 1970.

e) NORT 69-87A, NDC-1070 Flow Chart Program, User's Manual.

SECTION 3

REQUIREMENTS

In order to understand the sub-program description contained in the following pages, it is necessary that the reader will have become familiar with the associated functional requirements found in Volume I, Performance Specification, and with the sub-program allocation found in Volume II, Design Specification.

3.1 DETAILED DESCRIPTION

3.1.1 Reference Labels to Flow Diagrams

The code used to reference the particular block in the flow diagrams, Section 3.2, is as follows: The first number is that page number found in the upper right corner of the diagrams. This will be followed by a slash sign (/) to separate the page number from the block designator. The designator will either be a mnemonic label (e.g., TEST SYNC), a local label indicated by a dollar sign ($), or an integer. The two types of labels reference the particular information block, on the given page, to which the label is attached. The integer number, n, means that the referenced block is the n^{th} block from the top of the page; p8/3 would refer to page 8 and the third information block down.

Finally, the label p1/$ 2 + 3 refers to page 1, and the 3^{rd} information block after the label $ 2. p2/7, 8, 9 refers to page 2 and the 7^{th}, 8^{th}, and 9^{th} blocks.

3.1.2 Description of Flow Diagrams

3.1.2.1 Initialization

a) Central Path Angle; p1/PROPAGATION PREDICTION, 2, 3, 4:

After setup of the registers the subroutine THETA 1 is called to calculate the earth central angle between the submarine and the station selected by the argument.

$$\theta_1 = \text{ATAN}\left(\frac{|\vec{S} \times \vec{R}_1|}{\vec{S} \cdot \vec{R}_1}\right)$$

where $\vec{R}_1$ = geocentric unit vector directed to the submarine estimated position

$\vec{S}$ = the geocentric unit vector directed to the station

and $0 < \theta_1 < \pi$

b) First Magnetic Parameter; A_2, p1/5:

Obtain the unit vector, $\vec{AX}$, normal to the path of transmission from the station to the submarine receiver

$$-\vec{AX} = \frac{\vec{S} \times \vec{R}_1}{|\vec{S} \times \vec{R}_1|}$$

p1/6:

P_1, P_2, P_3 are components of the integration position $\vec{P}$, oriented in the geocentric axis. This vector is initialized to the transmitter position coordinates, then moved along the propagation path in increments of $d\theta$ radians as the integration progresses.

$d\theta = 0.01$ radian

$$P_1 = S_1$$

$$P_2 = S_2$$

$$P_3 = S_3$$

p2/1:

A_2 is "The first magnetic parameter" and NP is a constant geocentric unit vector directed toward the magnetic north pole, and is given by:

$$\vec{NP} = (0.9664,\ 0.0044864,\ -0.25705)$$

Calculate: $A_2 = -(\vec{AX} \cdot \vec{NP})$

c) Seasonal Index IS; p2/2 through p3/6:

The seasonal index IS will be used in estimating the diurnal effect later. Theoretically the seasonal year can be segmented into 24 2.16-week periods. However, the currently used diurnal table requires only five entries.

TABLE 1 SEASONAL INDEX

IS	CALENDAR SPAN
0	JAN 1 - JAN 15
3	JAN 16 - JAN 31
6	FEB 1 - JUN 30
9	JUL 1 - DEC 15
12	DEC 15 - DEC 31

d) Sun Vector; S(I), p4/$ 2:

Computation of the sun vector S(I) = S(1), S(2), S(3). These form a geocentric unit vector representing solar information required to compute the diurnal function; i.e., a unit vector originating at the earth's center, pointing at the sun.

1) To start, D_m, the number of days since Jan 0.0, of 1968 is calculated, to be used in determining the sun position, and from that the daylight portion of the propagation path.

   This can be accomplished by determining the number of days in prior years, looking up in Table 2 the number of days in the months preceding the current one, and adding these to the number of days already past in the current month, plus the fractional part of the current day.

TABLE 2 DAY OF THIS YEAR

Current Month	M (Jan = 1, Dec = 12)	Dm (Days in prior months, since Jan 1)
Jan 31	1	0
Feb 28	2	31
Mar 31	3	59
Apr 30	4	90
May 31	5	120
Jun 30	6	151
Jul 31	7	181
Aug 31	8	212
Sep 30	9	243
Oct 31	10	273
Nov 30	11	304
Dec 31	12	334

D = Number of days since Jan 0.0, 1968

D = 365 (year - 68) + Dm + (Number of days in current month) + LEAP

(year - 68): (Last two digits); Dm: (From table above)

$$+ \frac{(3600)\ (hrs) + (60)\ (min) + secs}{86400}$$ (fraction of present day)

where LEAP = number of Feb 29 days between Jan 1, 1968 and present.

2) E, the fractional part of D + 0.5

$$E = (D + 0.5), \text{ modulo } 1$$

3) L_s, the longitude of the sun

$$L_s = K_1 D + K_2$$

where $K_1 = 0.0172027914$

$K_2 = 4.8649521$

K_2 represents L_s on Jan 1, 1968 and is subject to update to current year.

4) M_s, the orbital angle of the earth relative to the perihelion (point in earth's orbit at which earth is closest the sun).

$M_s = K_3 D + K_4$

where $K_3 = 0.0172019699$
$K_4 = 6.21950155$

K_4 represents M_s on Jan 1, 1968 and is subject to update to current year.

5) First complement of sun vector

$S(1) = K_5 \sin L_s$

where $K_5 = 0.39784368$ and is the tilt of sun's orbit.

6) L, sun's apparent longitude

$L = -2\pi E - K_6 \sin M_s - K_7 \sin (2L_s)$

where K_6 and K_7 are ellipticity corrections
$K_6 = 0.0334440$
$K_7 = 0.04127339$

7) Second complement of sun vector

$S(2) = (1-S(1)^2)^{\frac{1}{2}} \cos L$

8) Third complement of sun vector

$S(3) = (1-S(1)^2)^{\frac{1}{2}} \sin L$

3.1.2.2 Path Integration

p4/$ 55 through p13/1 constitutes the main iteration algorithm where the Propagation Prediction terms will be obtained by integration in incremental steps of 0.01 radian.

a) Diurnal Constant Vector, FM; p4/$ 55 through p5/$ 15:

Calculate the solar zenith angle, Z, from which the diurnal functions will be obtained by the table following.

$COSZ = \vec{P} \cdot \vec{S}(I)$

Calculate the diurnal constant using the frequency, JF, and the season index IS.

TABLE 3 DIURNAL CONSTANTS

K (JF, IS)

JF = frequency index
IS = season index

IS \ JF	10.2	11.3	13.6
0	0.271	0.241	0.212
3	0.300	0.268	0.237
6	0.340	0.304	0.269
9	0.210	0.186	0.162
12	0.241	0.214	0.187

NOTE: For IS = 6 and IS = 9, K is at present constant. It is possible that this would not be so in a more sophisticated version of the mode.

TABLE 4 DIURNAL FUNCTION

IF \ THEN	F (JF)	FM_1	FM_2	FM_3
$\cos Z < a$	1	1	0	0
$a \le \cos Z \le b$	$\frac{\cos(Z-b) + K(JF,IS)(a-\cos Z)}{a-b}$	$\frac{\cos Z-b}{a-b}$	$\frac{a-\cos Z}{a-b}$	0
$b < \cos Z$	$\frac{K(JF,IS)(1-\cos Z)}{1-b}$	0	$\frac{1-\cos Z}{1-b}$	$\frac{\cos Z-b}{1-b}$

where a = -0.15

b = -0.04

k = (JF,IS) from Table 3.

and JF is the frequency index, 1, 2, and 3, corresponding to 10.2, 13.6 and 11-1/3.

IS is the season index determined in the description of p2/2.

FM_1, FM_2, FM_3 are three "scatter diurnal" functions that apply to all three frequencies.

F (JF) is the diurnal function, and is calculated for each frequency.

On the first pass through the diurnal calculations (above) for a given station, a value $F(JF)_o$ is set equal to F(JF) for use in subsequent computations.

p5/$ 20:

b) Auroral Compensation; p5/$ 20 through p7/$7 1+1"

The following algorithm will provide compensation for auroral effects when integrating over a path vector near the pole. For values of constants refer to Table 5.

The first calculation is the magnetic latitude AA6.

$$A5 = |\vec{P} \cdot \vec{NP}| = \sin \phi$$

where $\vec{NP}$ is a constant vector to north mag pole

$$AA6 = |ASIN\ (A5)|$$

p5/$ 20+1 through p6/7:

The auroral constants are determined by the following iteration.

If	$AA_6 < AU(1)$	I = 1
	$AU(1) < AA_6 < AU(2)$	I = 2
	$AU(2) < AA_6 < AU(3)$	I = 3
	$AU(3) < AA_6 < AU(4)$	I = 4
	$AU(4) < AA_6$	I = 1

$$AAUR = a\ (I) * AA_6 * AA_6 + b\ (I) * AA_6 + c\ (I)$$

$$BAUR = Da\ (I) * AA_6 * AA_6 + Db\ (I) * AA_6 + Dc\ (I)$$

TABLE 5 AURORAL CONSTANTS

		1	2	3	4
	AU	1.02974	1.13446	1.16064	1.41371
All x 10^{-6}	a	0	310.04	- 1805.55	60.30
	b	0	- 641.39	+ 4179.73	-171.32
	c	0	+ 331.71	- 2414.90	+121.65
	Da	0	+ 930.13	- 5197.77	- 93.80
	Db	0	-1905.09	+11840.17	+206.28
	Dc	0	+ 975.47	- 6731.36	-104.13

p7/$ 71:

Finish calculation of auroral constants.

$$B1 = -A2/\sqrt{1 - (A5)^2} = \sin\theta$$

$$B2 = 1 - 2\,(B1)^2 = \cos 2\theta$$

$$B4 = \frac{\pi}{2} - AA_6 = \frac{\pi}{2} - |\phi|$$

$$AA_5 = (B4)^3 = \left(\frac{\pi}{2} - |\phi|\right)^3$$

$$AA_2 = AA_5 * B_1 = \left(\frac{\pi}{2} - |\phi|\right)^3 \sin\theta$$

$$AA_3 = AA_5 * B_2 = \left(\frac{\pi}{2} - |\phi|\right)^3 \cos 2\theta$$

$$AA_4 = B4 * B2 - \left(\frac{\pi}{2} - |\phi|\right) \cos 2\theta$$

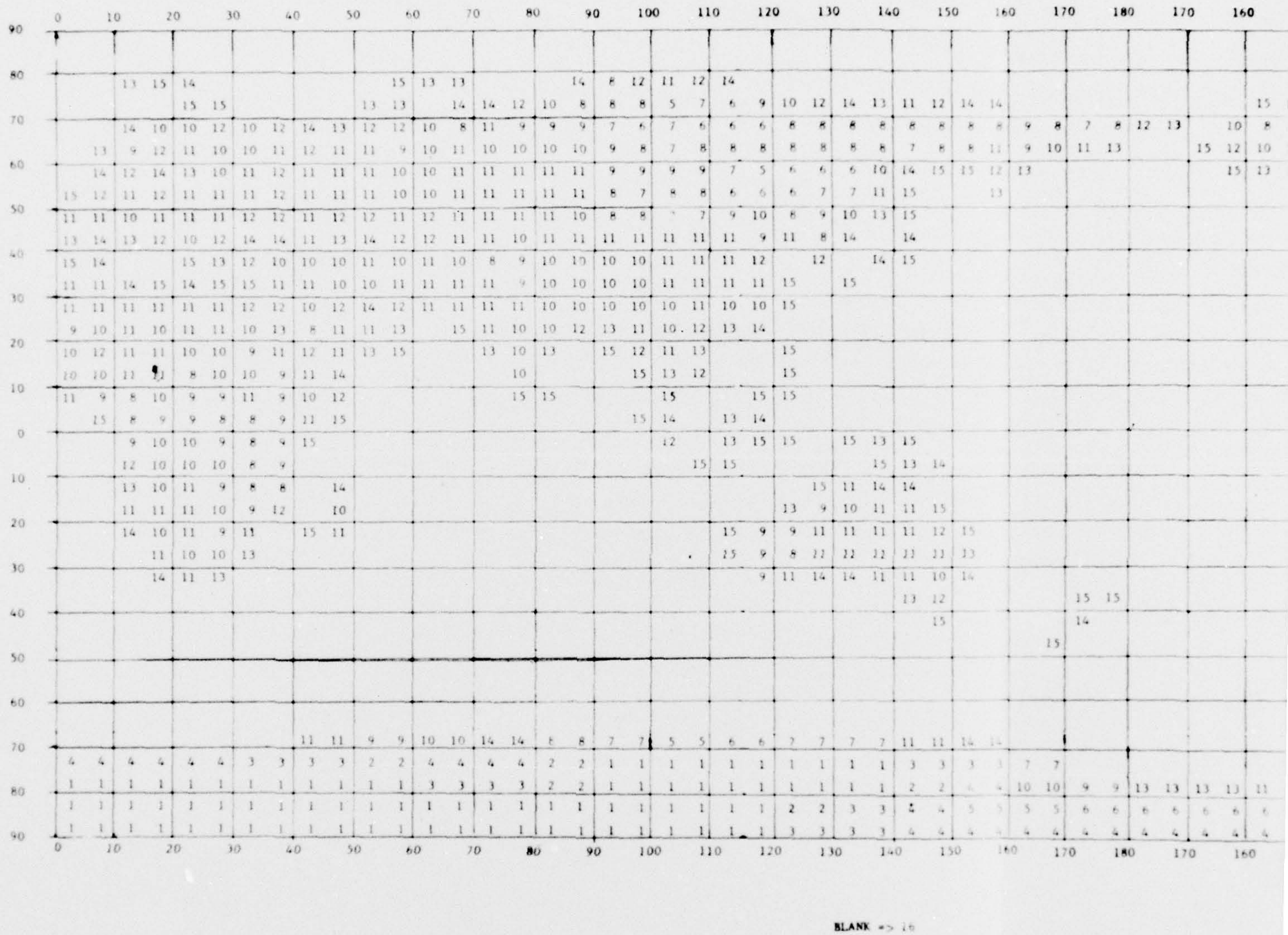
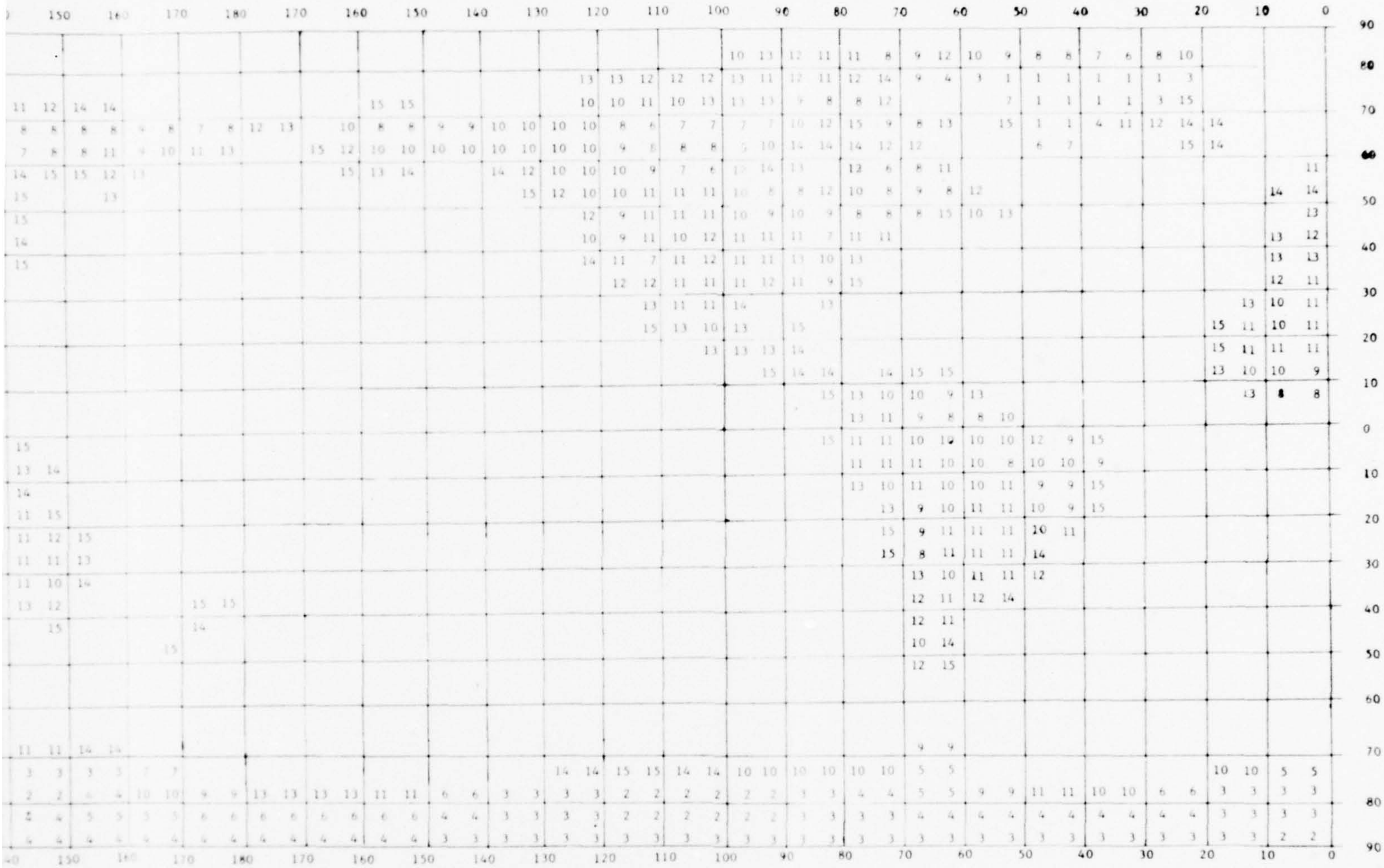


FIGURE 2 CONDUCTIVITY MAP



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c) The Conductivity Index, IC; p8/1 through p10/$ 36+1:

This algorithm takes the position vector $\vec{P}$ and searches the conductivity map to find the conductivity index IC of the region of the earth's surface corresponding to $\vec{P}$.

The conductivity map (Figure 2) has the following form:

For latitude north of 55°S, the earth is broken up into boxes each 5° by 5°.

For latitudes south of 55°S, the earth is broken up into boxes 5° in latitude and 10° in longitude.

There are 16 conductivity levels ranging from 16 (sea water) to 1 (permafrost).

The conductivity of each box is the average conductivity of the earth's surface within the box, weighted according to the areas of each conductivity. The Westinghouse Conductivity Map was used.

The three pages which describe the conductivity search are straightforward and do not require elaboration.

d) Diurnal Function, F; p11/3, 4:

From Table 4 under description for p4/$55 the value for K(JF,IS) is obtained. Then

$$F = FM_1 + K\ (JF,IS)\ FM_2$$

where JF is used as index to distinguish it from the diurnal function.

If this is first time through, then go to $41; otherwise continue.

e) Correction Factors, C_{11}, C_{21}; p11/5:

C_{11} is the correction factor for reconverted first mode of propagation.

$C_{11}(JF) = C_{11}(JF) + K_{11}(JF)\ (F(JF) - F(JF)_o)$

C_{21} is the correction factor for higher propagation modes.

$C_{21}(JF) = C_{21}(JF)\ \alpha_o(JF)\ F(JF) + K_{21}(JF)\ (F(JF) - F(JF)_o)$

Here set $F(JF) = F(JF)_o$

where K_{21} and K_{11} are constants, defined for each frequency, and represent the excitation of 2nd mode and reexcitation of 1st mode, α_o is the relative nighttime attenuation of 2nd mode and is a function of frequency.

$\alpha_o(1) = 0.91$	$K_{11}(1) = 6.7$	$K_{21}(1) = 25.0$
$\alpha_o(2) = 0.925$	$K_{11}(2) = 6.7$	$K_{21}(2) = 25.0$
$\alpha_o(3) = 0.94$	$K_{11}(3) = 6.7$	$K_{21}(3) = 25.0$

e) Diurnal Function Average, GG; p11/$ 42:

GG(JF) = GG(JF) + F(JF)

f) Integration; p12/1,2:

$$Q = \sum_{I=2}^{6} CAY(JF,I)AA_I + CAY1\ (JF,IC)$$

$$A(JF) = Q\ C_4\ C_5 + AAUR^*$$

$$Q = \sum_{I=2}^{6} DCAY(JF,I)\ AA_I + DCAY1\ (JF,IC)$$

$$B(JF) = Q\ C_4\ C_5 + BAUR^*$$

$$\Delta\theta_2 = C_1\ C_4\ C_5\ RAT(JF)P_1^2$$

$$SUM\ \Delta\theta_2 = SUM\Delta\theta_2 + \Delta\theta_2$$

$$\Delta\theta_3 = (A(JF) + F(JF)\ B(JF))\ RAT(JF)$$

$$SUM\ \Delta\theta_3 = SUM\Delta\theta_3 + \Delta\theta_3$$

where CAY, CAY1, DCAY, DCAY1 can be found in tables 6 and 7.

C_1 is the ellipsoidal correction constant
$= -0.336 \times 10^{-4}$

C_4 is the chart conversion factor
$= 0.9974$

C_5 is the nominal 10.2 wavelengths/radian
$= 217.021$.

*Note that in the flow diagrams the terms AAUR, BAUR were erroneously excluded.

RAT(I) is the frequency conversion number

RAT(1) = 1.0

RAT(2) = 10/9

RAT(3) = 4/3

p12/3:

If more frequencies to process, then increment JF and return to p11/$ 50 where more frequency-dependent terms will be generated.

If JF = 3, then continue.

TABLE 6 CAY and DCAY VALUES

CAY (JF, I)

	10.2	11.3	13.6
1	323.0	291.0	242.0
2	Same	-0.4	Same
3	as	0.0	as
4	11.3	-0.65	11.3
5		0.0	
6		1.32	

DCAY (JF, I)

1	207.0	185.0	155.0
2	2.8	2.36	1.82
3	-1.5	-1.44	-1.43
4	0.65	0.65	0.65
5	4.70	4.22	3.38
6	-1.32	-1.32	-1.32

Multiply all by 10^{-6}

TABLE 7 CAY1 and DCAY1 VALUES

CAY1 (JF, IC)

IC \ JF	10.2	11.3	13.6
1	-27.0	-32.0	-40.0
2	-20.0	-27.0	-35.0
3	9.0	- 8.0	-23.0
4	33.0	36.3	27.5
5	24.6	32.7	44.0
6	16.3	25.3	38.5
7	7.9	19.1	33.2
8	3.2	14.8	30.0
9	- 0.2	12.0	27.6
10	- 3.0	9.2	25.6
11	- 5.1	7.5	23.8
12	- 6.4	6.2	22.9
13	- 7.2	5.2	22.2
14	- 8.0	4.5	21.5
15	- 8.8	3.8	21.0
16	- 9.0	3.9	20.8

Multiply all by 10^{-6}

DCAY1 (JF, IC)

IC \ JF	10.2	11.3	13.6
1	0.0	30.0	60.0
2	3.8	28.2	55.0
3	8.3	21.2	38.5
4	5.5	5.5	12.0
5	22.3	19.4	15.2
6	26.3	23.3	19.2
7	30.2	27.0	23.3

TABLE 7 (continued)

IC \ JF	10.2	11.3	13.6
8	32.8	29.5	25.2
9	33.8	30.0	25.2
10	34.2	30.2	25.2
11	33.6	30.0	25.2
12	33.2	29.4	24.4
13	32.9	28.9	23.7
14	32.6	28.8	23.7
15	32.1	28.5	23.7
16	31.8	27.6	23.7

Multiply all by 10^{-6}

g) Integration Complete Test; *p12/4 through p13/1*:

The integration counter sums the number of $d\theta$ increments used where $d\theta$ = 0.01 radian.

$\overrightarrow{TEST} = \overrightarrow{P} - \overrightarrow{S}$

If $|\overrightarrow{Test}| > (d\theta)^2$

then Increment $\overrightarrow{P}$

$\overrightarrow{P} = (\overrightarrow{AX} \times \overrightarrow{P}) \cdot \text{Sin}(d\theta) + \overrightarrow{P} \cdot \cos(d\theta)$

Return to Paragraph p4/$ 55.

If $|\overrightarrow{Test}| \leq (d\theta)^2$

Then continue.

3.1.2.3 Generation of Output Data

a) Averaging Constant, AVG; p13/$ 60+1:

Corrects for incremental integration

AVG = $\theta 1/n \Delta\theta$

where n is number of increments used and $\Delta\theta = 0.01$ radian.

b) Base Station Central Angle:

Call subroutine THETA1 to compute θ_1(base)

c) Summation Average; p14/1:

ASUM θ_2 = AVG (SUM$\Delta\theta_2$)

ASUM θ_3 = AVG (SUM$\Delta\theta_3$)

(frequency dependence implied)

d) Propagation Correction; θ_3:

$$\theta_3(JF) = \theta_3(JF) + CAY\ (JF, 1) + \frac{\Delta\theta GG(JF)\ DCAY\ (JF, 1)}{\theta_1(JF)}$$

e) Predicted Variance; σ^2_{ppi}; p14/3:

Combine the effects of second mode and reconverted first to compute an estimate of the variance on the predicted phase.

$$\sigma^2_{ppi} = (C_{21} + C_{11} + .04)^2$$

f) Spheroidal Correction; θ_2, p14/4:

$$\theta_2(JF) = ASUM\theta_2$$

3.1.2.4 Tracking Filter Update

a) Predicted Tracking Filter Measurement, θ_p(JF):

p14/6,7

θ_{Ci}(JF) for station i is obtained by subroutine THETAC. It is the predicted phase for station i.

p15/2

θ_{Ck}(JF) for base-station k is similarly calculated.

p15/3:

$\theta_p(JF) = \theta_{ci}(JF) - \theta_{ck}(JF)$

p15/$ 45 + 1:

The integer lane count is adjusted in the tracking filter for station ik on frequency JF.

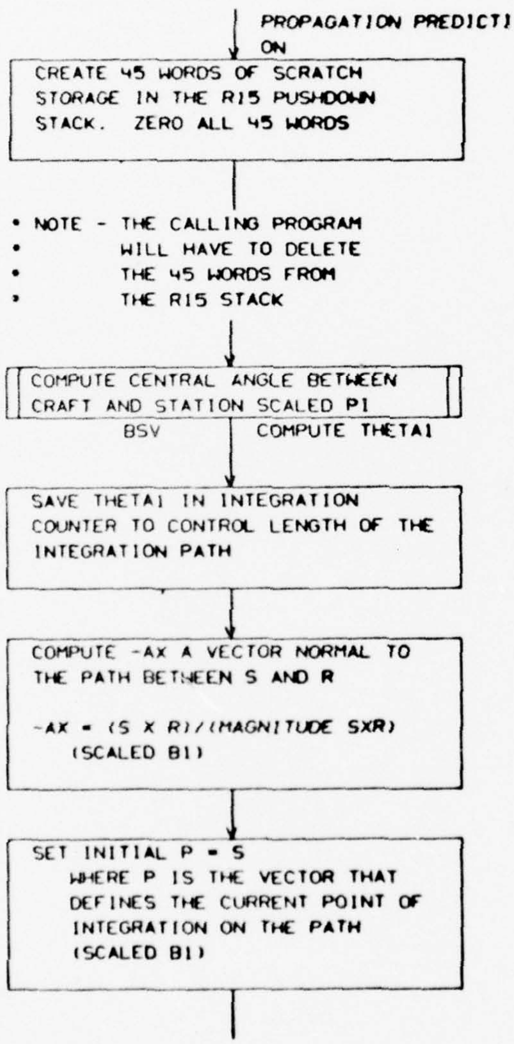
p15/$ 45 + 2:

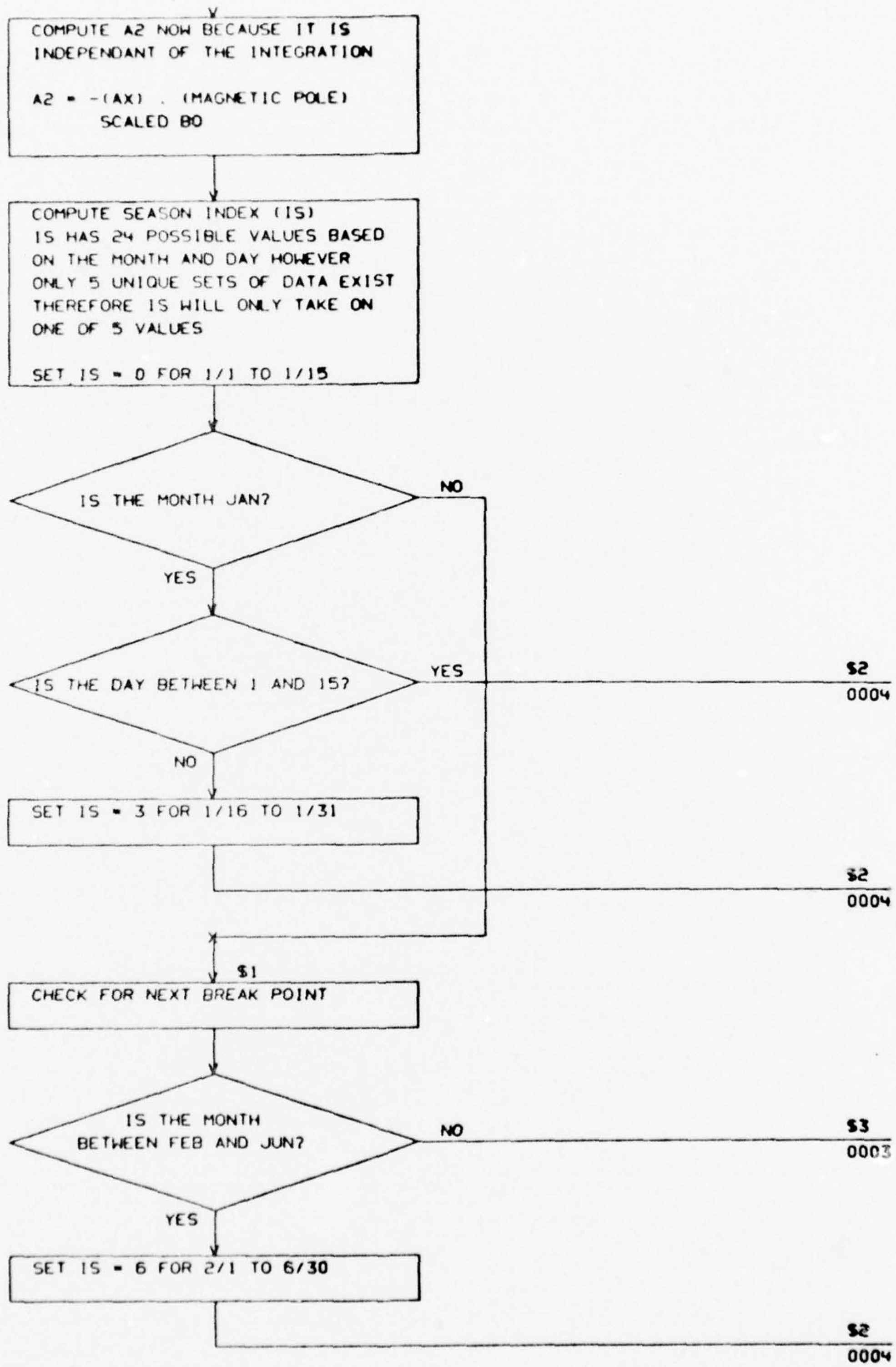
If more frequencies to process, increment JF and return to p13/$ 61, otherwise exit.

3.2 FLOW DIAGRAMS

The Propagation Prediction Subprogram flow diagrams are presented on the following pages.

```
*                        PROPAGATION PREDICTION
*
* THIS PROGRAM WILL COMPUTE THE PREDICTED SPHEROIDAL ANE PROPAGATION
* CORRECTIONS TO THE NOMINAL PREDICTED PHASE MEASUREMENTS FROM A GIVEN
* STATION.  IT ALSO COMPUTES AN ASSOCIATED VARIANCE.  THE THREE PARA-
* METERS ARE COMPUTED FOR ALL 3 FREQUENCIES AND SAVED IN MEMORY FOR EACH
* STATION.  THE TOTAL LANE COUNT FROM THE CORRECTED PREDICTED PHASE
* REPLACES ANY LANE COUNTS CONTAINED IN THE MEASURED PHASE IN THE
* TRACKING FILTER.  THE STATION NUMBER IS THE ONLY ARGUMENT.
*
```




COMPUTE A2 NOW BECAUSE IT IS INDEPENDANT OF THE INTEGRATION
A2 = -(AX) . (MAGNETIC POLE)
SCALED B0
COMPUTE SEASON INDEX (IS)
IS HAS 24 POSSIBLE VALUES BASED ON THE MONTH AND DAY HOWEVER ONLY 5 UNIQUE SETS OF DATA EXIST THEREFORE IS WILL ONLY TAKE ON ONE OF 5 VALUES
SET IS = 0 FOR 1/1 TO 1/15
IS THE MONTH JAN?
NO
YES
IS THE DAY BETWEEN 1 AND 15?
YES
$2
0004
NO
SET IS = 3 FOR 1/16 TO 1/31
$2
0004
$1
CHECK FOR NEXT BREAK POINT
IS THE MONTH BETWEEN FEB AND JUN?
NO
$3
0003
YES
SET IS = 6 FOR 2/1 TO 6/30
$2
0004

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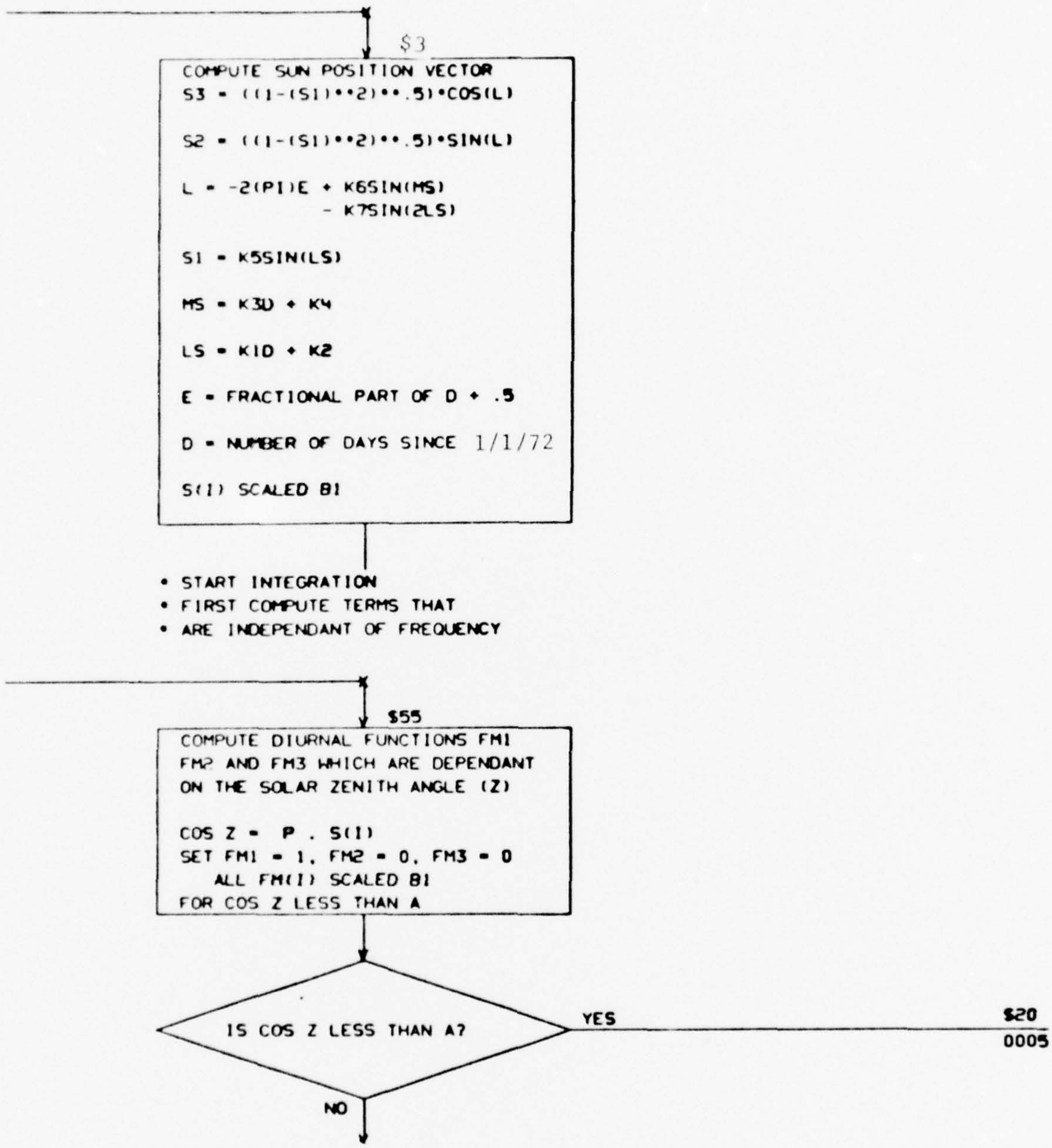
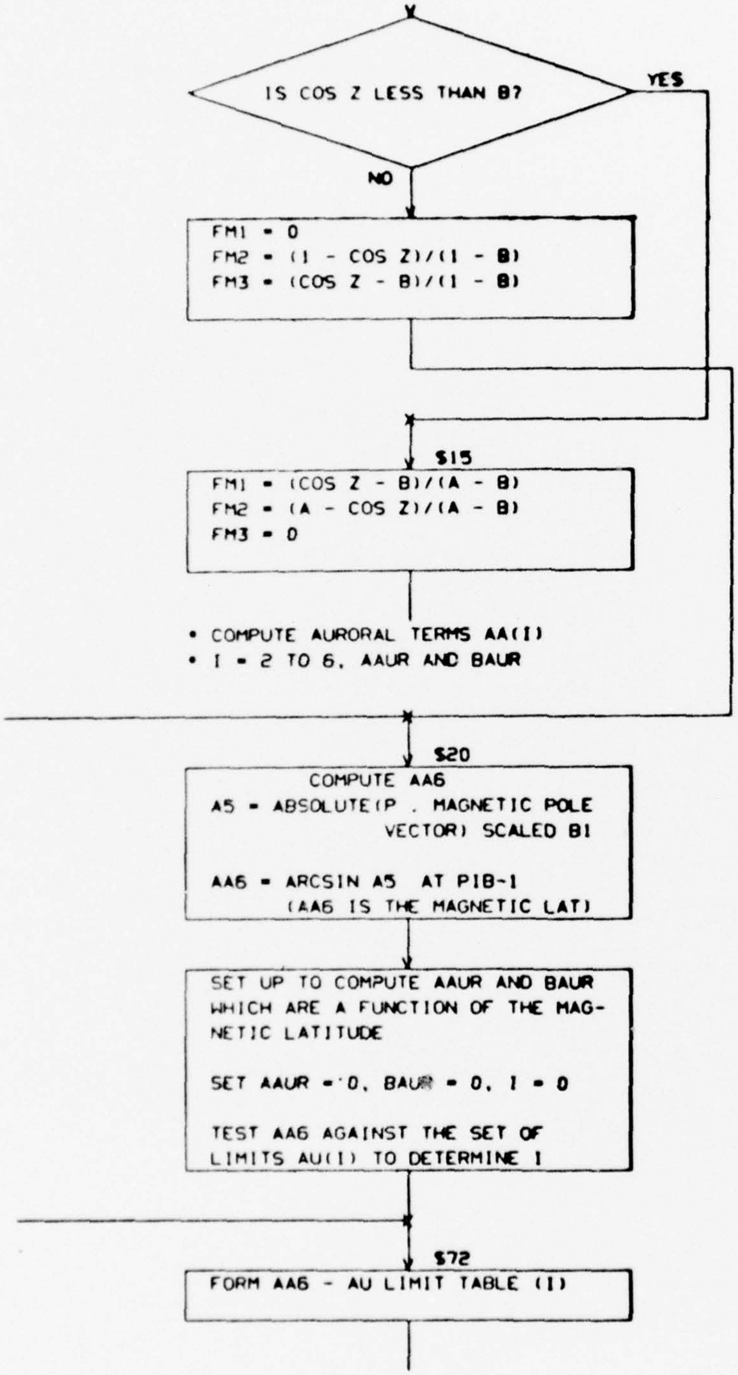
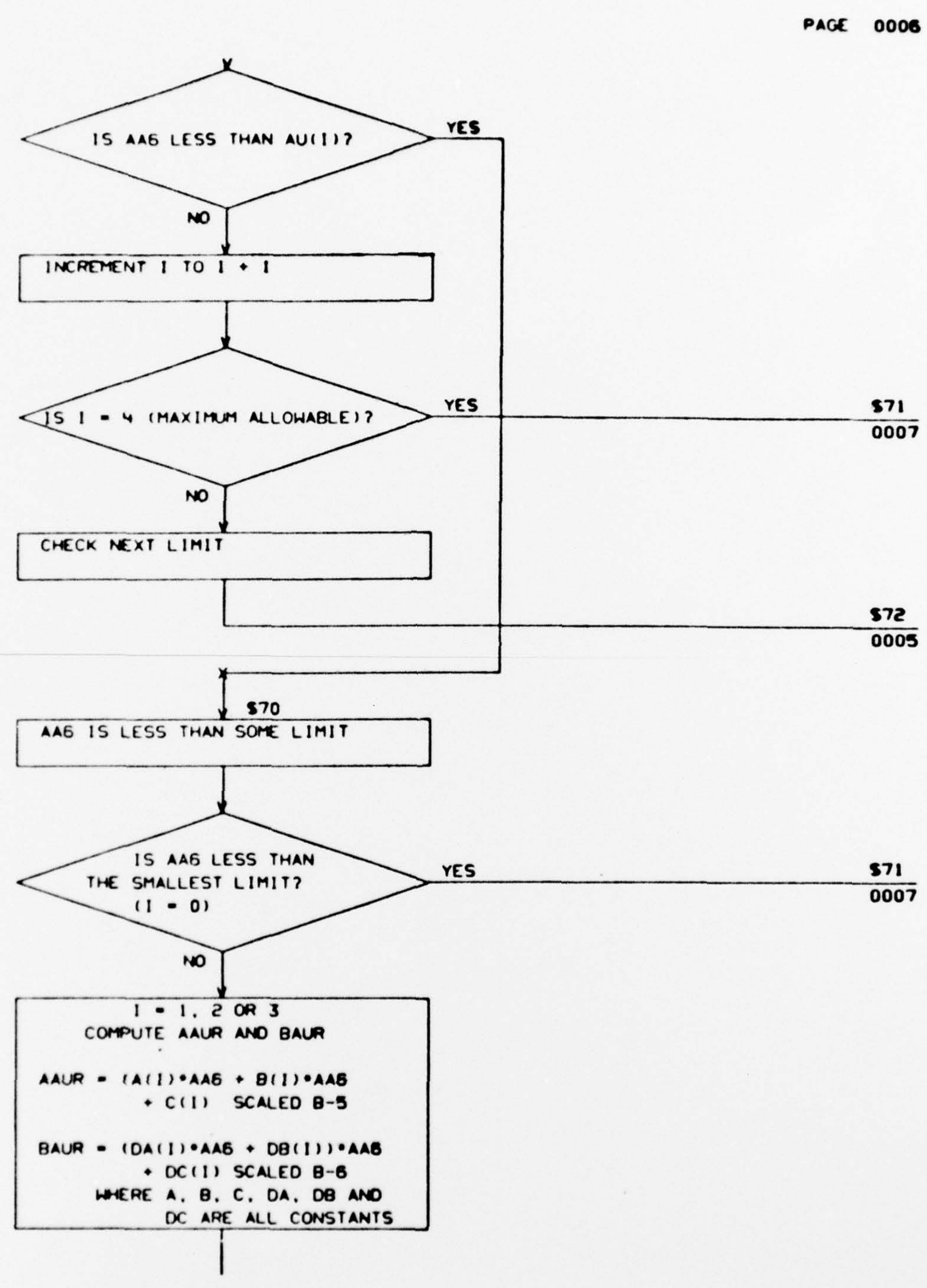
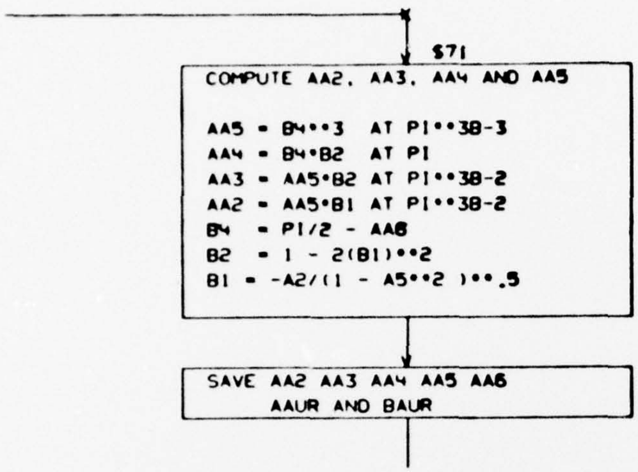

$3
COMPUTE SUN POSITION VECTOR
S3 = ((1-(S1)**2)**.5)*COS(L)
S2 = ((1-(S1)**2)**.5)*SIN(L)
L = -2(PI)E + K6SIN(MS)
- K7SIN(2LS)
S1 = K5SIN(LS)
MS = K3D + K4
LS = K1D + K2
E = FRACTIONAL PART OF D + .5
D = NUMBER OF DAYS SINCE 1/1/72
S(I) SCALED B1
• START INTEGRATION
• FIRST COMPUTE TERMS THAT
• ARE INDEPENDANT OF FREQUENCY
$55
COMPUTE DIURNAL FUNCTIONS FM1
FM2 AND FM3 WHICH ARE DEPENDANT
ON THE SOLAR ZENITH ANGLE (Z)
COS Z = P . S(I)
SET FM1 = 1, FM2 = 0, FM3 = 0
ALL FM(I) SCALED B1
FOR COS Z LESS THAN A
IS COS Z LESS THAN A?
YES
$20
0005
NO


IS COS Z LESS THAN B?
YES
NO
FM1 = 0
FM2 = (1 - COS Z)/(1 - B)
FM3 = (COS Z - B)/(1 - B)
$15
FM1 = (COS Z - B)/(A - B)
FM2 = (A - COS Z)/(A - B)
FM3 = 0
• COMPUTE AURORAL TERMS AA(I)
• I = 2 TO 6, AAUR AND BAUR
$20
COMPUTE AA6
A5 = ABSOLUTE(P . MAGNETIC POLE VECTOR) SCALED B1
AA6 = ARCSIN A5 AT PIB-1
(AA6 IS THE MAGNETIC LAT)
SET UP TO COMPUTE AAUR AND BAUR WHICH ARE A FUNCTION OF THE MAGNETIC LATITUDE
SET AAUR = 0, BAUR = 0, I = 0
TEST AA6 AGAINST THE SET OF LIMITS AU(I) TO DETERMINE I
$72
FORM AA6 - AU LIMIT TABLE (I)


PAGE 0006
IS AA6 LESS THAN AU(I)?
YES
NO
INCREMENT I TO I + 1
IS I = 4 (MAXIMUM ALLOWABLE)?
YES
$71
0007
NO
CHECK NEXT LIMIT
$72
0005
$70
AA6 IS LESS THAN SOME LIMIT
IS AA6 LESS THAN
THE SMALLEST LIMIT?
(I = 0)
YES
$71
0007
NO
I = 1, 2 OR 3
COMPUTE AAUR AND BAUR
AAUR = (A(I)*AA6 + B(I)*AA6
+ C(I) SCALED B-5
BAUR = (DA(I)*AA6 + DB(I))*AA6
+ DC(I) SCALED B-6
WHERE A, B, C, DA, DB AND
DC ARE ALL CONSTANTS



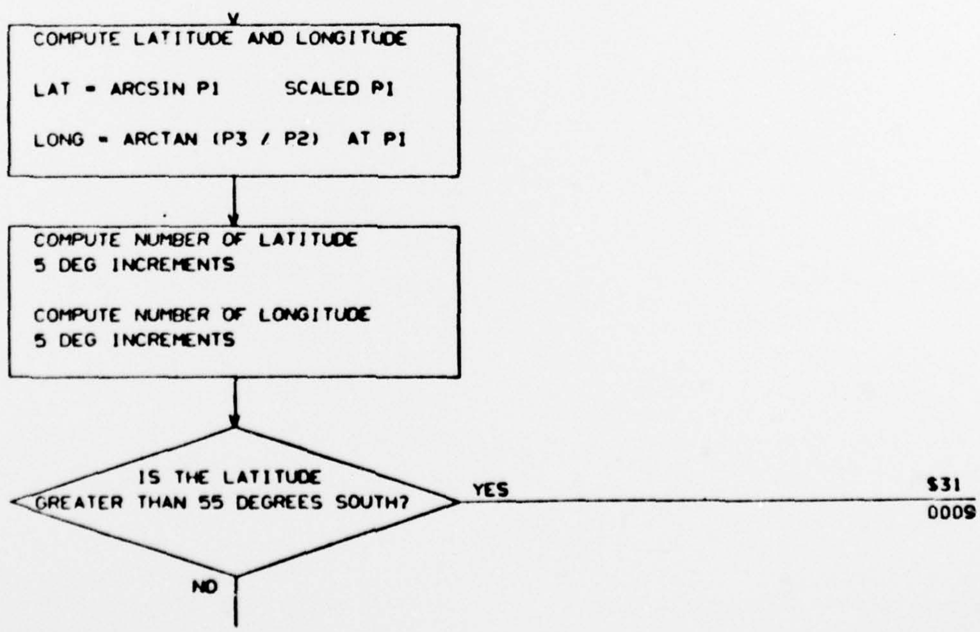
$71
COMPUTE AA2, AA3, AA4 AND AA5
AA5 = B4**3 AT P1**38-3
AA4 = B4*B2 AT P1
AA3 = AA5*B2 AT P1**38-2
AA2 = AA5*B1 AT P1**38-2
B4 = P1/2 - AA6
B2 = 1 - 2(B1)**2
B1 = -A2/(1 - A5**2)**.5
SAVE AA2 AA3 AA4 AA5 AA6
AAUR AND BAUR

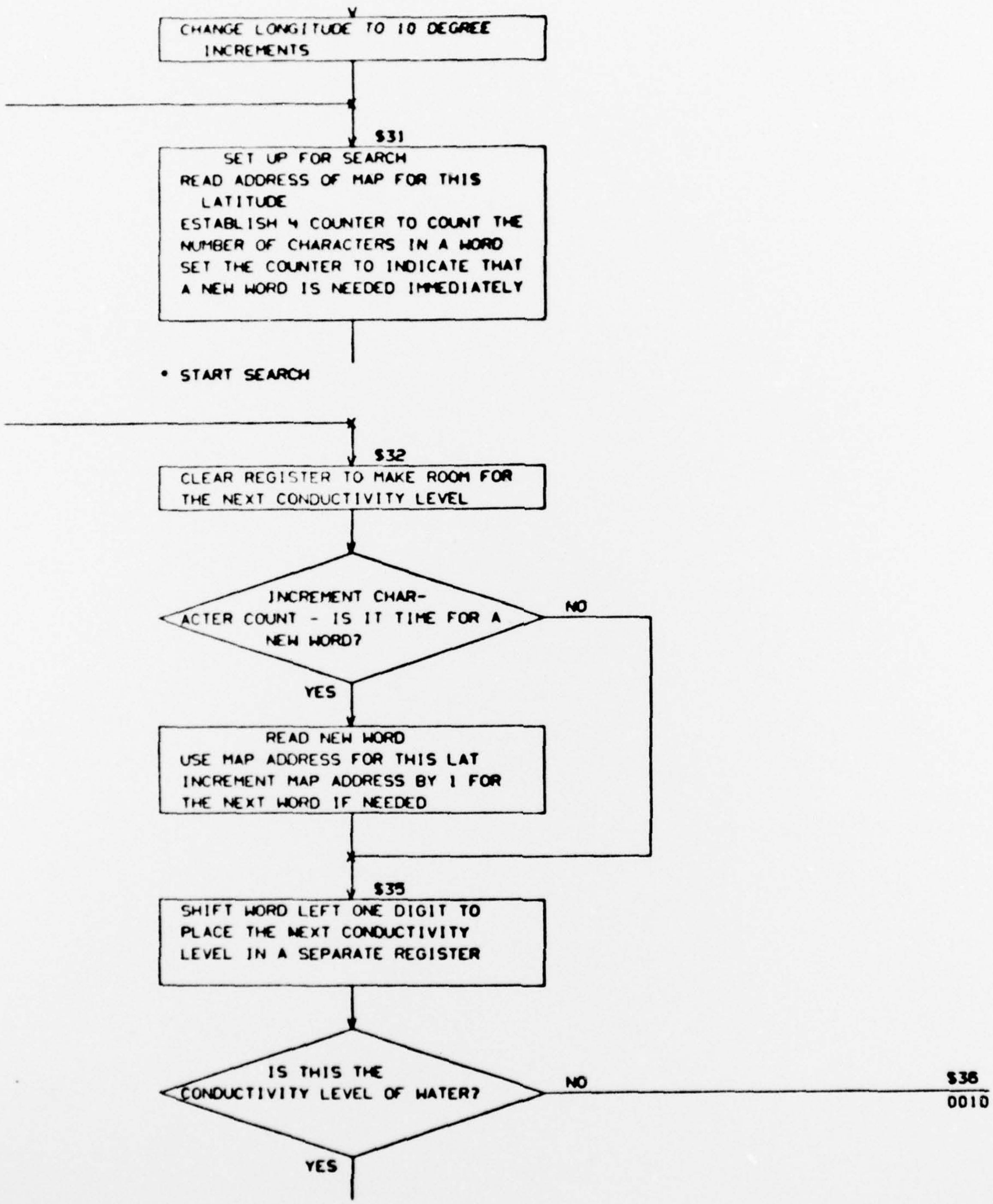
DETERMINE CONDUCTIVITY LEVEL

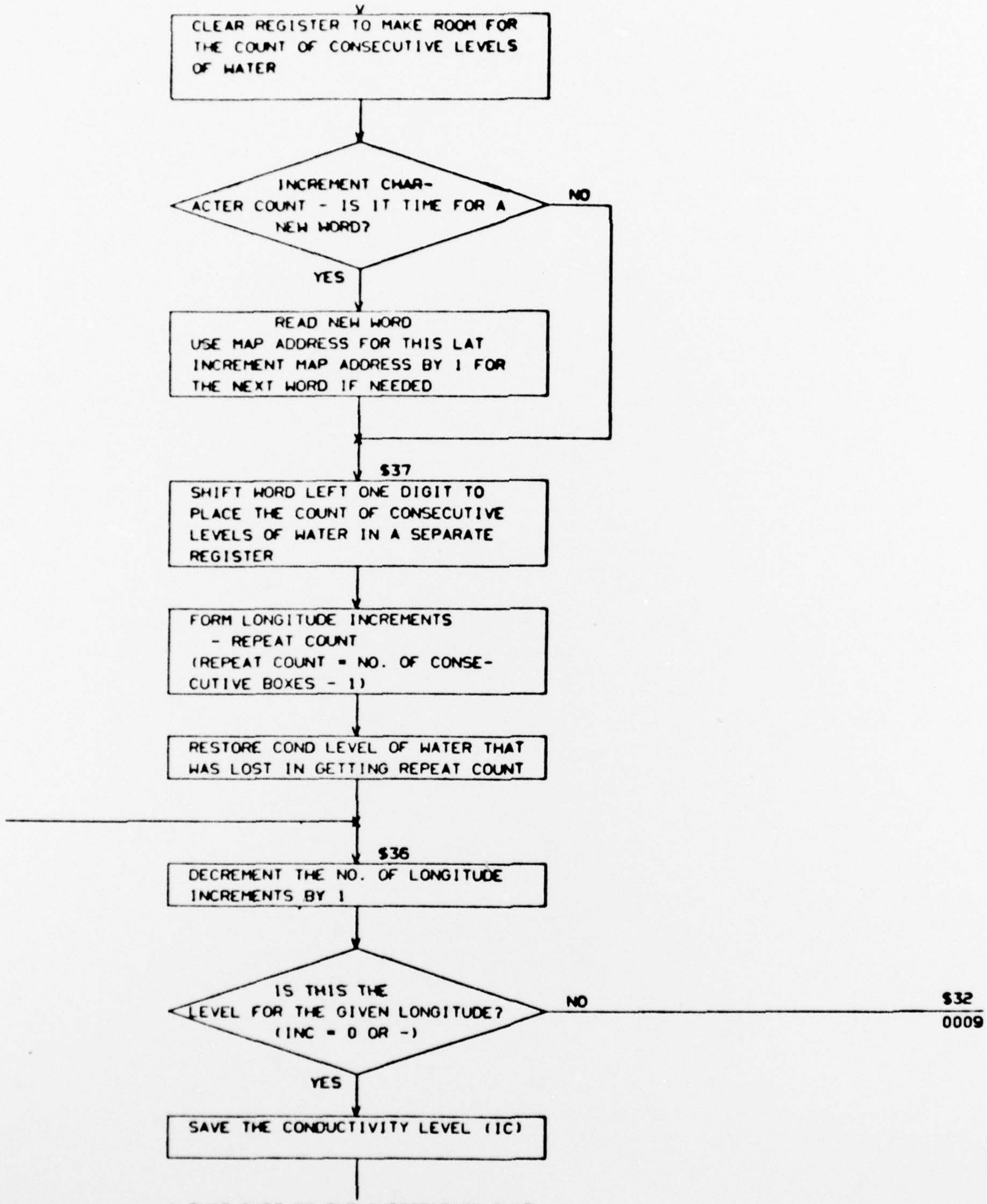
THE FOLLOWING SECTION OF THE PROPAGATION PREDICTION PROGRAM USES THE CONDUCTIVITY MAP TO DETERMINE THE CONDUCTIVITY LEVEL AT THE PRESENT POINT ON THE PATH OF INTEGRATION DEFINED BY THE VECTOR P. FOR PROGRAMMING EFFICIENCY THE EARTH HAS BEEN DIVIDED INTO BOXES EVERY FIVE DEGREES OF LATITUDE AND LONGITUDE EXCEPT THAT BELOW SOUTH 55 LATITUDE THE LONGITUDE SIDES ARE 10 DEGREES IN LENGTH. THE MAP HAS BEEN DIVIDED INTO 36 PARTS (1 FOR EACH INCREMENT OF LATITUDE) AND A TABLE OF ADDRESSES POINTS TO THE PART OF THE MAP THAT IS TO BE USED FOR A GIVEN LATITUDE. THE PROPER ENTRY IS DETERMINED BY COMPUTING THE NUMBER OF 5 DEG LATITUDE INCREMENTS ABOVE THE SOUTH POLE. THE FIRST ENTRY IS FOR 90S TO 85S AND THE LAST ENTRY IS FOR 85N TO 90N. FOR A GIVEN LATITUDE THE 4 BIT CONDUCTIVITY LEVELS FOR THE LONGITUDE INCREMENTS ARE STORED IN CONSECUTIVE HEXADECIMAL CHARACTERS STARTING AT 20 DEG EAST LONGITUDE AND CONTINUING ALL THE WAY AROUND THE EARTH FOR INCREASING EAST LONGITUDE. THE CORRECT CONDUCTIVITY LEVEL IS THEN OBTAINED BY COMPUTING THE NUMBER OF LONGITUDE INCREMENTS AND COUNTING THROUGH THE TABLE UNTIL THE CORRECT ITEM IS REACHED.

EACH 16 BIT COMPUTER WORD CONTAINS THE CONDUCTIVITY LEVEL FOR FOUR INCREMENTS OF LONGITUDE. THE MOST SIGNIFICANT 4 BITS OF THE FIRST WORD OF THE MAP FOR A GIVEN LATITUDE CONTAIN THE LEVEL BETWEEN 20 AND 25 DEG EAST LONG. THE LEAST SIGNIFICANT 4 BITS ARE FOR LONG E35 TO E40. THE MAP THEN CONTINUES IN THE NEXT HIGHER MEMORY LOCATION FOR THE NEXT LONGITUDE INCREMENT. THE CONDUCTIVITY LEVEL IS A NUMBER BETWEEN 0 AND 15 THAT IS USED TO INDEX A TABLE.

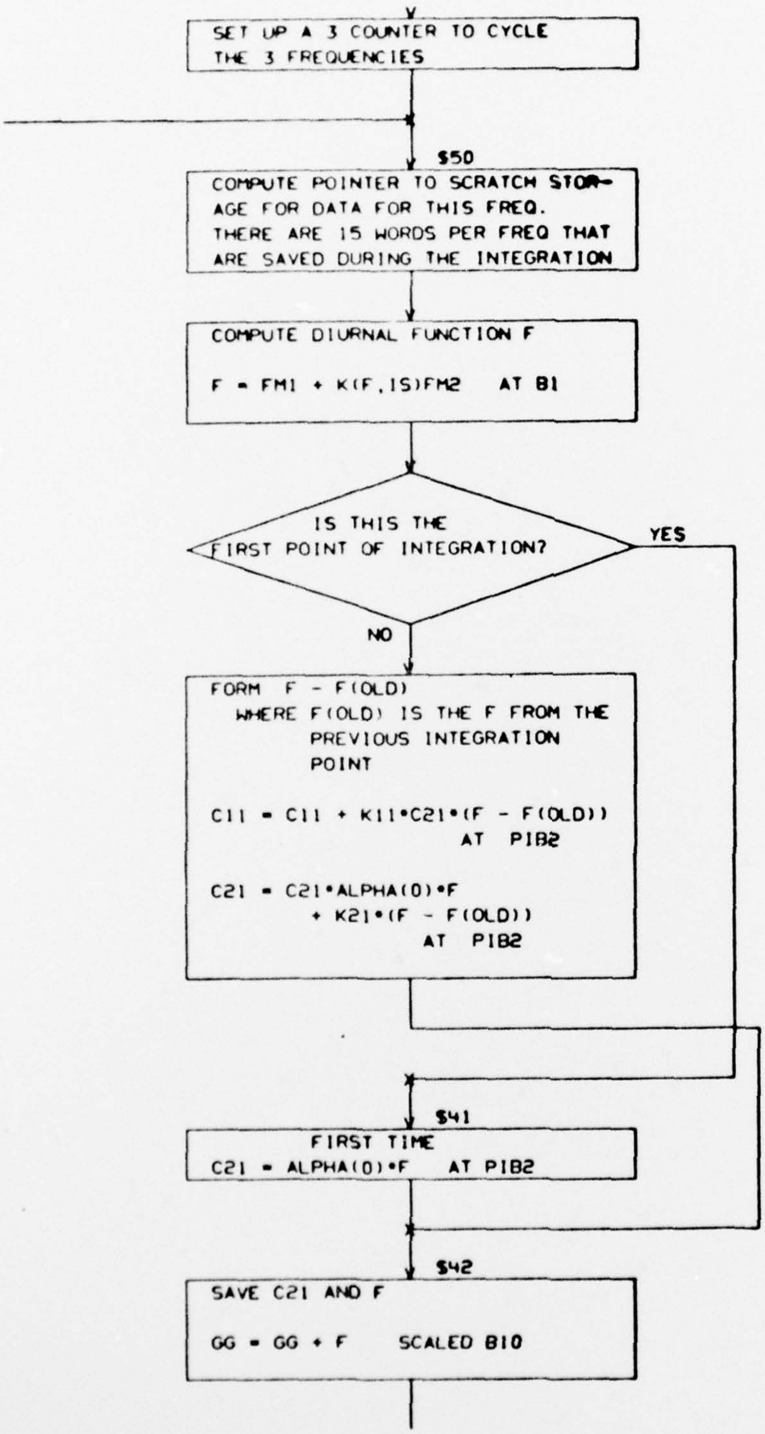
BECAUSE MOST OF THE EARTH IS WATER AND THEREFORE HAS THE SAME CONDUCTIVITY LEVEL A COMPACTING TECHNIQUE IS USED THAT REDUCES THE SIZE OF THE TABLE BY APPROXIMATELY HALF. WHENEVER THE LEVEL FOR WATER (15) IS ENCOUNTERED FOR A LONGITUDE THE NEXT HEXADECIMAL CHARACTER IS A COUNT OF THE NUMBER OF CONSECUTIVE BOXES OF WATER FOR THAT LONGITUDE UP TO A MAXIMUM OF 15.

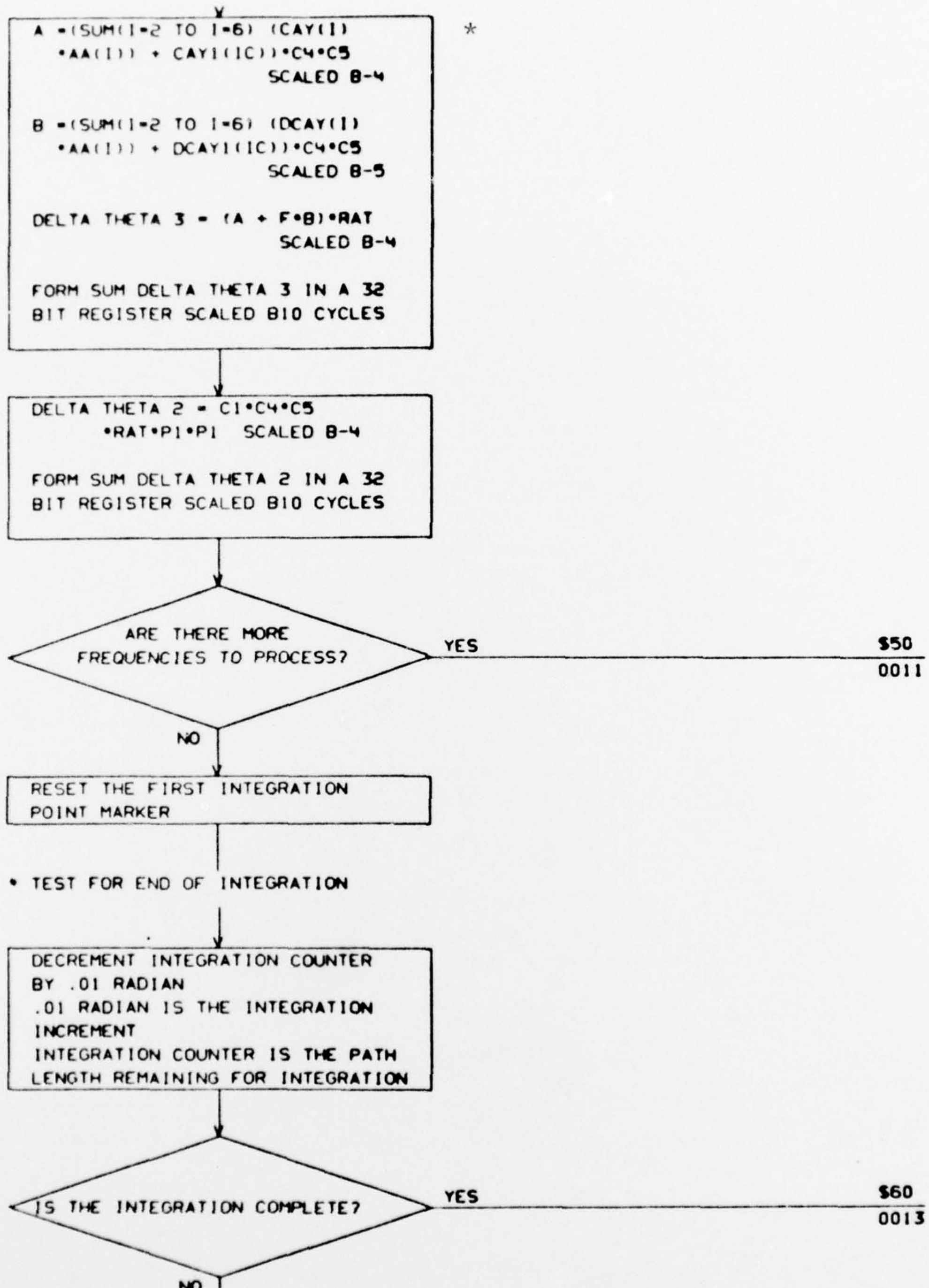



CHANGE LONGITUDE TO 10 DEGREE INCREMENTS
$31
SET UP FOR SEARCH
READ ADDRESS OF MAP FOR THIS LATITUDE
ESTABLISH 4 COUNTER TO COUNT THE NUMBER OF CHARACTERS IN A WORD
SET THE COUNTER TO INDICATE THAT A NEW WORD IS NEEDED IMMEDIATELY
• START SEARCH
$32
CLEAR REGISTER TO MAKE ROOM FOR THE NEXT CONDUCTIVITY LEVEL
INCREMENT CHARACTER COUNT - IS IT TIME FOR A NEW WORD?
NO
YES
READ NEW WORD
USE MAP ADDRESS FOR THIS LAT
INCREMENT MAP ADDRESS BY 1 FOR THE NEXT WORD IF NEEDED
$35
SHIFT WORD LEFT ONE DIGIT TO PLACE THE NEXT CONDUCTIVITY LEVEL IN A SEPARATE REGISTER
IS THIS THE CONDUCTIVITY LEVEL OF WATER?
NO
$36
0010
YES

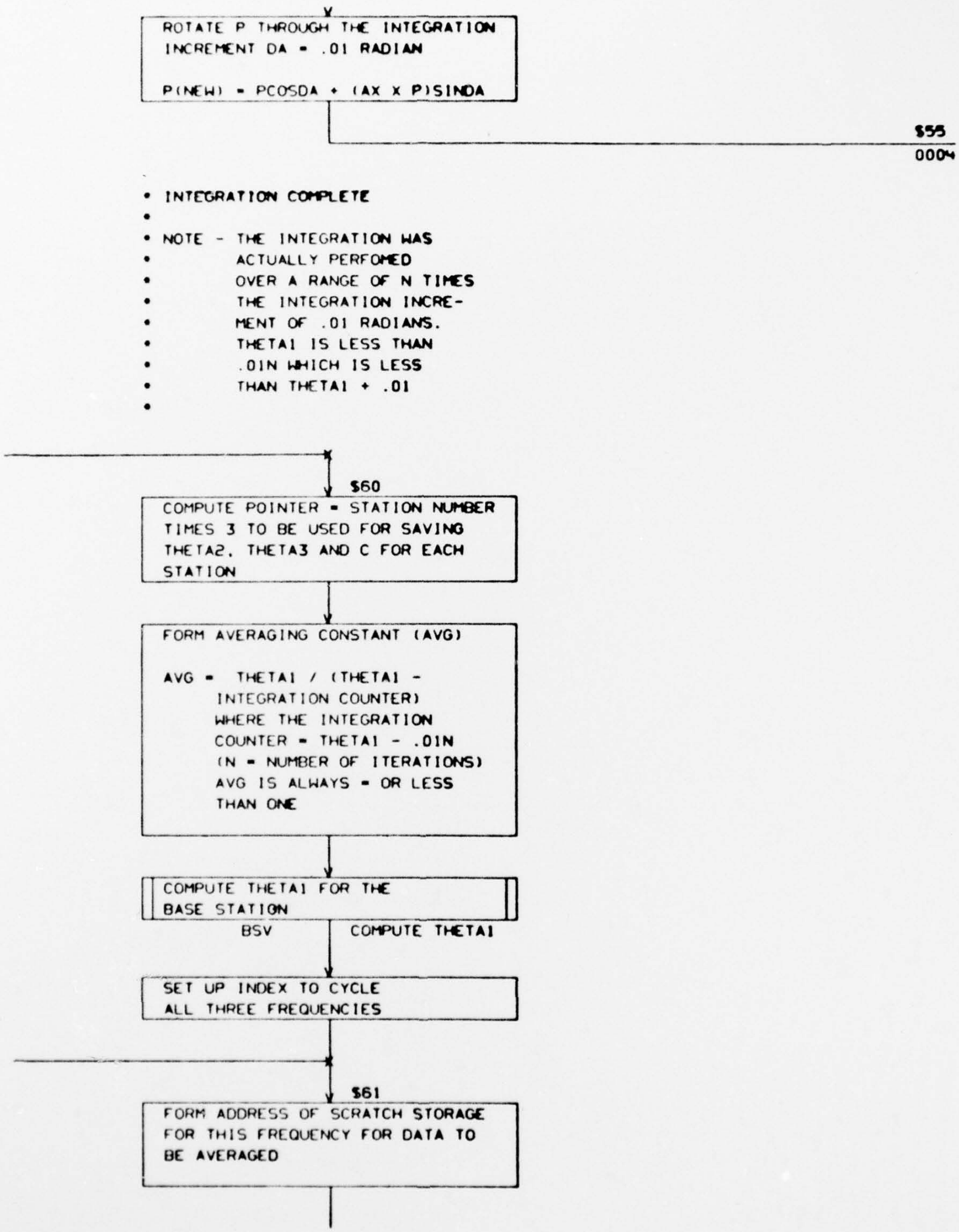


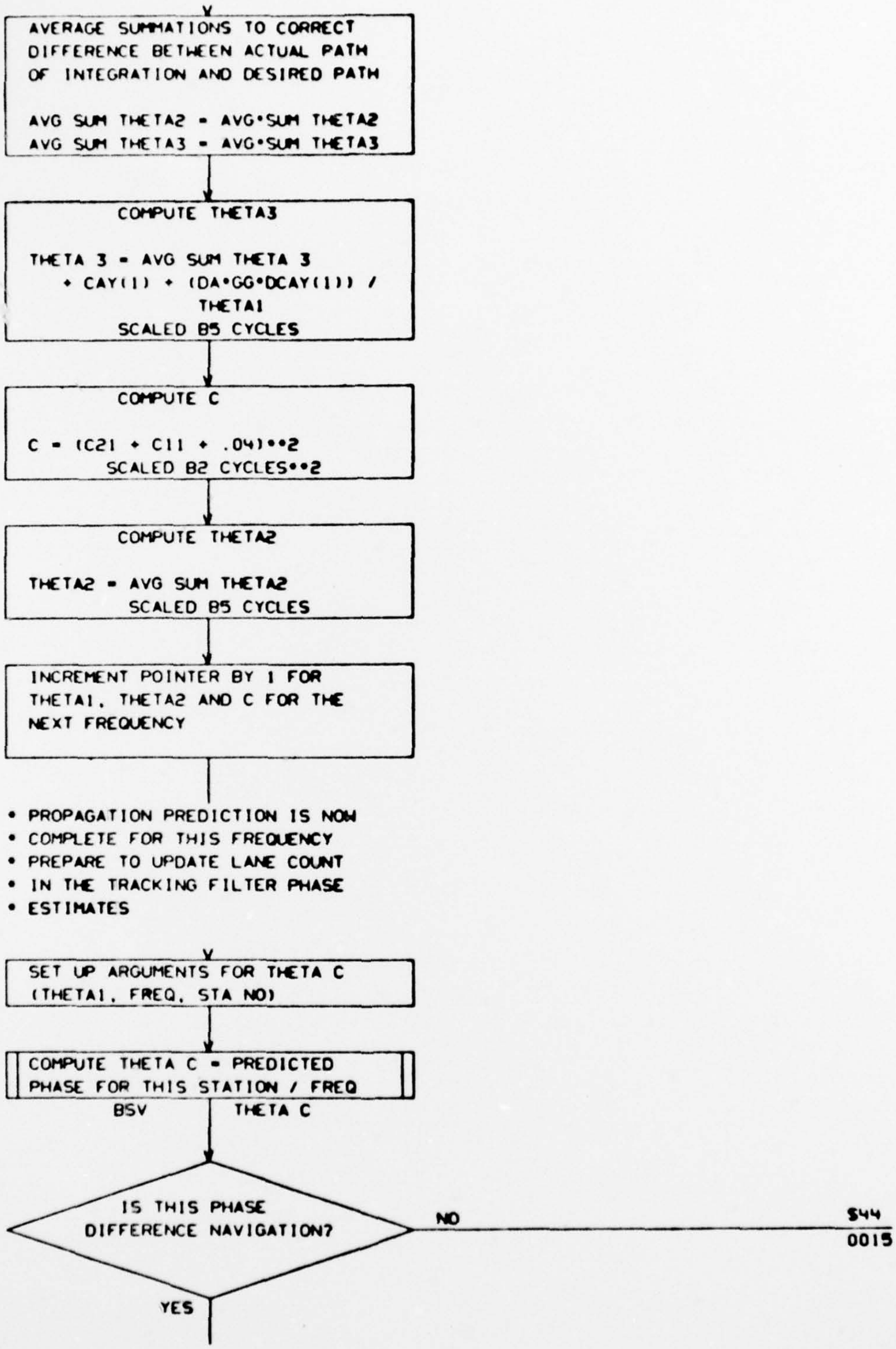
* THAT PART OF THE INTEGRATION THAT
* IS INDEPENDANT OF FREQUENCY IS
* COMPLETE. NOW START TERMS THAT
* ARE A FUNCTION OF FREQUENCY.

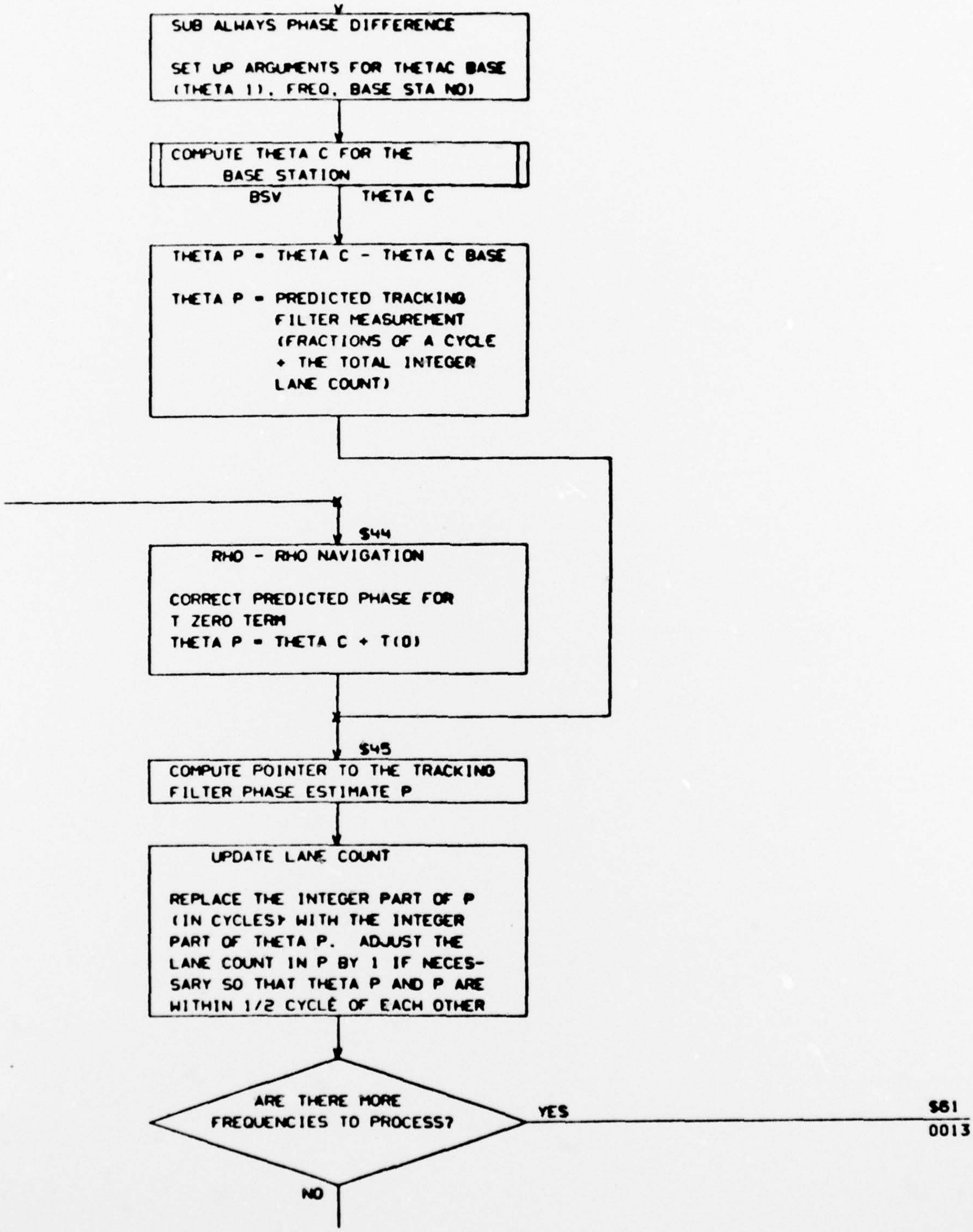

SET UP A 3 COUNTER TO CYCLE THE 3 FREQUENCIES
$50
COMPUTE POINTER TO SCRATCH STORAGE FOR DATA FOR THIS FREQ. THERE ARE 15 WORDS PER FREQ THAT ARE SAVED DURING THE INTEGRATION
COMPUTE DIURNAL FUNCTION F
F = FM1 + K(F,IS)FM2 AT B1
IS THIS THE FIRST POINT OF INTEGRATION?
YES
NO
FORM F - F(OLD)
WHERE F(OLD) IS THE F FROM THE PREVIOUS INTEGRATION POINT
C11 = C11 + K11•C21•(F - F(OLD)) AT PIB2
C21 = C21•ALPHA(0)•F + K21•(F - F(OLD)) AT PIB2
$41
FIRST TIME
C21 = ALPHA(0)•F AT PIB2
$42
SAVE C21 AND F
GG = GG + F SCALED B10



*See under p12/1.


ROTATE P THROUGH THE INTEGRATION
INCREMENT DA = .01 RADIAN
P(NEW) = PCOSDA + (AX X P)SINDA
$55
0004
* INTEGRATION COMPLETE
*
* NOTE - THE INTEGRATION HAS
* ACTUALLY PERFOMED
* OVER A RANGE OF N TIMES
* THE INTEGRATION INCRE-
* MENT OF .01 RADIANS.
* THETA1 IS LESS THAN
* .01N WHICH IS LESS
* THAN THETA1 + .01
*
$60
COMPUTE POINTER = STATION NUMBER
TIMES 3 TO BE USED FOR SAVING
THETA2, THETA3 AND C FOR EACH
STATION
FORM AVERAGING CONSTANT (AVG)
AVG = THETA1 / (THETA1 -
INTEGRATION COUNTER)
WHERE THE INTEGRATION
COUNTER = THETA1 - .01N
(N = NUMBER OF ITERATIONS)
AVG IS ALWAYS = OR LESS
THAN ONE
COMPUTE THETA1 FOR THE
BASE STATION
BSV
COMPUTE THETA1
SET UP INDEX TO CYCLE
ALL THREE FREQUENCIES
$61
FORM ADDRESS OF SCRATCH STORAGE
FOR THIS FREQUENCY FOR DATA TO
BE AVERAGED


AVERAGE SUMMATIONS TO CORRECT
DIFFERENCE BETWEEN ACTUAL PATH
OF INTEGRATION AND DESIRED PATH
AVG SUM THETA2 = AVG*SUM THETA2
AVG SUM THETA3 = AVG*SUM THETA3
COMPUTE THETA3
THETA 3 = AVG SUM THETA 3
+ CAY(1) + (DA*GG*DCAY(1)) /
THETA1
SCALED B5 CYCLES
COMPUTE C
C = (C21 + C11 + .04)**2
SCALED B2 CYCLES**2
COMPUTE THETA2
THETA2 = AVG SUM THETA2
SCALED B5 CYCLES
INCREMENT POINTER BY 1 FOR
THETA1, THETA2 AND C FOR THE
NEXT FREQUENCY
* PROPAGATION PREDICTION IS NOW
* COMPLETE FOR THIS FREQUENCY
* PREPARE TO UPDATE LANE COUNT
* IN THE TRACKING FILTER PHASE
* ESTIMATES
SET UP ARGUMENTS FOR THETA C
(THETA1, FREQ, STA NO)
COMPUTE THETA C = PREDICTED
PHASE FOR THIS STATION / FREQ
BSV
THETA C
IS THIS PHASE
DIFFERENCE NAVIGATION?
NO
S44
0015
YES


SUB ALWAYS PHASE DIFFERENCE
SET UP ARGUMENTS FOR THETAC BASE (THETA 1), FREQ, BASE STA NO)
COMPUTE THETA C FOR THE BASE STATION
BSV
THETA C
THETA P = THETA C - THETA C BASE
THETA P = PREDICTED TRACKING FILTER MEASUREMENT (FRACTIONS OF A CYCLE + THE TOTAL INTEGER LANE COUNT)
$44
RHO - RHO NAVIGATION
CORRECT PREDICTED PHASE FOR T ZERO TERM
THETA P = THETA C + T(0)
$45
COMPUTE POINTER TO THE TRACKING FILTER PHASE ESTIMATE P
UPDATE LANE COUNT
REPLACE THE INTEGER PART OF P (IN CYCLES) WITH THE INTEGER PART OF THETA P. ADJUST THE LANE COUNT IN P BY 1 IF NECESSARY SO THAT THETA P AND P ARE WITHIN 1/2 CYCLE OF EACH OTHER
ARE THERE MORE FREQUENCIES TO PROCESS?
YES
$61
0013
NO

EXIT

THE ARGUMENT IS UNDISTURBED
45 WORDS HAVE BEEN ADDED TO THE
R15 PUSH DOWNSTACK

BBK

3.3 COMPUTER SUBPROGRAM ENVIRONMENT

3.3.1 Propagation Prediction Tables

a) Magnetic Pole: This table contains the three-element vector that defines the position of the North Magnetic Pole. It is defined in detail in the listing. The official name of this table is NORTH MAGNETIC POLE VECTOR.

b) Auroral Compensation Limits: This table is used to test the Magnetic Latitude for selection of the appropriate auroral constants. The first entry is the lowest limit (AU(1)), the second entry is AU(2)-AU(1), the third entry is AU(3)-AU(2) and the last entry is AU(4)-AU(3). See the listing for more detail. The official name of this table is AUR LIMITS.

c) Conductivity Table: This table defines the conductivity level for any point on the earth. It is defined in detail in the flow charts and in the listing. The official name of this table is COND TABLE.

d) Diurnal Constants: This table contains the diurnal constants for the calculation of the diurnal function F. For convenience, the five different entries in the original table for the 24 values of the season index have been renumbered 0 to 4. This table is defined in detail in the listing. The official name of this table is DIURMAL CONSTANT TABLE.

e) Second Mode Excitation Factor: This table is used in the computation of PROP C. It is defined in detail in the listing. The official name of this table is K21.

f) Second Mode Relative Night Attenuation Factor: This table is used in the computation of PROP C. It is defined in detail in the listing. The official name of this table is ALPHA 0.

g) Model Constants: This table contains five entries for CAY(2) to CAY(6) used in the computation of A. Each entry has been modified by C4 and C5. It is defined in detail in the listing. The official name of this table is CAY TABLE.

h) Model Constants: This table contains five entries for each frequency for DCAY(2) to DCAY(6). Each entry has been modified by C4 and C5. It is defined in detail in the listing. The official name of this table is DCAY TABLE.

i) Conductivity Constants: This table contains 16 entries for each frequency for CAY1(1) to CAY1(16). Each entry has been modified by C4 and C5. It is defined in detail in the listing. The official name of this table is CAY1 TABLE.

j) Conductivity Constants: This table contains 16 entries for each frequency for DCAY1(1) to DCAY1(16). Each entry has been modified by C4 and C5. It is defined in detail in the listing. The official name of this table is DCAY1 TABLE.

k) Frequency Conversion Factor: This table contains the factors that convert 10.2 data into 13.6 or 11.3. It is defined in detail in the listing. This official name of this table is RAT.

l) Ellipsoidal Correction: This table contains C1 modified by C4, C5 and the frequency conversion factors. It is defined in detail in the listing. The official name of this table is C1 TABLE.

m) Model Constants: This table contains CAY(1) modified by C4, C5 and the frequency conversion factor. It is defined in detail in the listing. The official name of this table is CAY ONE.

n) Model Constants: This table contains DCAY(1) modified by C4, C5 and the frequency conversion factor. It is defined in detail in the listing. The official name of the table is DCAY ONE.

o) Auroral Constants: This table contains the three sets of auroral constants modified by C4 and C5. It is defined in detail in the listing. The official name of this table is AUR DATA.

p) Station Locations: This table contains the locations of all existing OMEGA transmitting stations. Each location is specified in a three-element grocentric position vector. The first entry is for station A. The table is defined in detail in the listing. The official name of this table is STATION VECTOR TABLE.

3.3.2 Propagation Prediction Temporary Storage

All temporary storage used by the Propagation Prediction Program is in the R15 pushdown stack except for seven words associated with the Auroral corrections called AUR SAVE which are placed in the Kalman program storage for new state vectors during measurement update.

3.3.3 Required System Library Subroutines

SUBROUTINE	FLOW DIAGRAM REFERENCE	SUBPROGRAM DESIGN DOCUMENT (by Volume Number)
ASIN	p5/$ 20	
CROSS	p1/3	All Subroutines found in
	p1/5	Volume XII
DOT	p1/3	
SIN-Cos	p4/1	
SQRT	p1/5 p7/$ 71	
	p4/1	
THETA1	p1/3	
THETAC	p14/6	
	p15/2	