

UNCLASSIFIED

AD 295 083

*Reproduced
by the*

**ARMED SERVICES TECHNICAL INFORMATION AGENCY
ARLINGTON HALL STATION
ARLINGTON 12, VIRGINIA**



UNCLASSIFIED

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.



CATALOGUED BY ASTIA
AS AD No. 29508

295 083

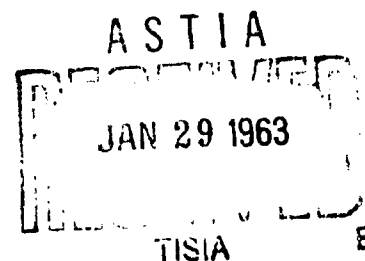
NBS REPORT

7619

PREDICTING THE PERFORMANCE OF BAND 7
COMMUNICATION SYSTEMS
USING ELECTRONIC COMPUTERS

by

Donald L. Lucas and George W. Haydon



NO OTS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
BOULDER LABORATORIES
Boulder, Colorado

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. Research projects are also performed for other government agencies when the work relates to and supplements the basic program of the Bureau or when the Bureau's unique competence is required. The scope of activities is suggested by the listing of divisions and sections on the inside of the back cover.

Publications

The results of the Bureau's research are published either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three periodicals available from the Government Printing Office: The Journal of Research, published in four separate sections, presents complete scientific and technical papers; the Technical News Bulletin presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of non-periodical publications: Monographs, Applied Mathematics Series, Handbooks, Miscellaneous Publications, and Technical Notes.

A complete listing of the Bureau's publications can be found in National Bureau of Standards Circular 460, Publications of the National Bureau of Standards, 1901 to June 1947 (\$1.25), and the Supplement to National Bureau of Standards Circular 460, July 1947 to June 1957 (\$1.50), and Miscellaneous Publication 240, July 1957 to June 1960 (Includes Titles of Papers Published in Outside Journals 1950 to 1959) (\$2.25); available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT

8530-20-85504

October 15, 1962

NBS REPORT

7619

PREDICTING THE PERFORMANCE OF BAND 7 COMMUNICATION SYSTEMS USING ELECTRONIC COMPUTERS

by

Donald L. Lucas and George W. Haydon

Prepared for

U. S. Navy - Bureau of Ships

Delivery Order 1700R-692-61, dated April 12, 1961



**U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
BOULDER LABORATORIES
Boulder, Colorado**

IMPORTANT NOTICE

NATIONAL BUREAU OF STANDARDS REPORTS are usually preliminary or progress accounting documents intended for use within the Government. Before material in the reports is formally published it is subjected to additional evaluation and review. For this reason, the publication, reprinting, reproduction, or open-literature listing of this Report, either in whole or in part, is not authorized unless permission is obtained in writing from the Office of the Director, National Bureau of Standards, Washington 25, D. C. Such permission is not needed, however, by the Government agency for which the Report has been specifically prepared if that agency wishes to reproduce additional copies for its own use.

CONTENTS

	<u>Page</u>
List of Figures - - - - -	i
List of Tables - - - - -	ii
I. Introduction - - - - -	1
II. Program Description - - - - -	5
1. MUF-FOT - - - - -	6
2. System Loss - - - - -	7
3. Field Strength Option - - - - -	9
4. Radio Noise - - - - -	9
5. Available Signal-to-Noise - - - - -	9
6. Required Signal-to-Noise - - - - -	10
7. Reliability - - - - -	10
8. Lowest Useful Frequency - - - - -	10
III. Program Use - - - - -	10
IV. Description of Data Tapes - - - - -	13
1. "Long-term" Data Tapes - - - - -	13
2. "Short-term" Data Tapes - - - - -	15
(a) Description - - - - -	15
(b) Program - - - - -	17
V. Program Options - - - - -	19
1. MUF and FOT - - - - -	19
2. MUF, FOT, Mode, Arrival Angle, and Reliability	19
3. FOT and LUF - - - - -	19
4. MUF, FOT, Mode, Arrival Angle, and System Loss - - - - -	19
5. MUF, FOT, Mode, Arrival Angle, and Field Strength - - - - -	20

	<u>Page</u>
6. MUF, FOT, Mode, Arrival Angle, and Signal-to-Noise - - - - -	20
7. MUF, FOT, and Reliability - - - - -	20
8. FOT Graphs - - - - -	20
9. FOT and LUF Graphs - - - - -	20
VI. Computer Inputs - - - - -	21
1. Circuit Card Format - - - - -	21
2. Method Card Format - - - - -	23
3. Assembling the Data Decks - - - - -	24
4. Purpose of Cards in Data Deck - - - - -	25
(a) Method Card - - - - -	25
(b) Frequency Complement Card - - - - -	25
(c) Circuit Cards - - - - -	26
(d) Nines Card - - - - -	26
(e) Month and Sunspot Number Card - - - - -	26
(f) Minus One Card - - - - -	26
(g) Blank Card - - - - -	26
VII. Program Output - - - - -	44
VIII. Complete Fortran Listing of Computer Program for Predicting HF System Performance - - - - -	47
IX. Mathematical Expressions - - - - -	90
1. Great Circle Distance - - - - -	90
2. Bearing from Receiver to Transmitter - - - - -	90
3. Geographic Latitude of Control Points Along Great Circle Route - - - - -	90
4. Geographic Longitude of Control Points Along Great Circle Route - - - - -	90

	<u>Page</u>
5. Geomagnetic Latitude of Control Points Along Great Circle Route - - - - -	91
6. Local Mean Time at Receiver - - - - -	91
7. Sun's Zenith Angle at Control Points - - - - -	91
8. Ionospheric Absorption Index "I" - - - - -	91
9. E-Layer Distance Factor - - - - -	92
10. E-2000 MUF - - - - -	92
11. E-Layer MUF - - - - -	92
12. F-Layer Distance Factor - - - - -	92
13. F2-Layer Fourier Generation of foF2 and M-3000 Factor - - - - -	92
14. F2-Layer Gyro Frequency - - - - -	96
15. F2-4000 MUF - - - - -	96
16. F-MUF for Low and High Solar Activity - - - - -	96
17. Interpolation for Intermediate Values of Solar Activity - - - - -	96
18. Angle at the Ionosphere - - - - -	97
19. Ionospheric Absorption (single reflection) - - - - -	97
20. Basic Transmission Loss for Isotropic Antenna in Free Space - - - - -	97
21. Relationship Between ϕ and Δ - - - - -	98
22. Ground Reflection Factors for Vertical and Horizontal Polarization - - - - -	98
23. Rhombic Antenna Power Gain Relative to Isotropic in Free Space - - - - -	99
24. Power Gain of Half-Wave Horizontal Dipole - - - -	101
25. Power Gain of Vertical Antennas - - - - -	101

	<u>Page</u>
26. Efficiency Factor for Short Vertical Antennas - - - -	102
27. Ground Reflection Loss - - - - -	102
28. Relationship of Field Strength to Transmission Loss - - - - -	102
X. Generalized Block Diagram of HF Systems Performance	
Routine - - - - -	103
XI. Conclusions - - - - -	104
XII. Acknowledgement - - - - -	105
XIII. References - - - - -	106

LIST OF FIGURES

	<u>Page</u>
1. Computer Print-Out of Circuit MUF and FOT - - - - -	27
2. Computer Print-Out of Circuit MUF, FOT and Circuit Reliability - - - - -	28
3. Computer Print-Out of Circuit LUF and FOT - - - - -	29
4. Alternative Computer Print-Out of Circuit LUF and FOT - - - - -	30
5. Computer Print-Out of Circuit MUF, FOT and System Loss - - - - -	31
6. Computer Print-Out of Circuit MUF, FOT and Received Field Strength - - - - -	32
7. Computer Print-Out of Circuit MUF, FOT and Available Signal-to-Noise - - - - -	33
8. Alternative Computer Print-Out of Circuit MUF, FOT and Circuit Reliability - - - - -	34
9. Graphical Representation of Circuit FOT - - - - -	35
10. Graphical Representation of Circuit LUF and FOT - - - -	36
11. Data for High Frequency Communication Predictions - - -	37
12. Auxiliary Data Cards - - - - -	38
13. Example Method Card and Circuit Card - - - - -	39
14. Example Data Deck for Run Under One Method Only from Cards - - - - -	40
15. Example Data Deck for Run Under Two Methods from Cards - - - - -	41
16. Example Data Deck for One Method Using Circuits from Magnetic Tape - - - - -	42

	<u>Page</u>
17. Example HF Prediction Deck to Execute Under IBM-7090 Fortran Monitor - - - - -	43
18. Generalized Block Diagram of HF Systems Performance Routine - - - - -	103

LIST OF TABLES

1. Geographical Function in Latitude - - - - -	94
2. Geographical Functions in Latitude and Longitude - - - -	95

PREDICTING THE PERFORMANCE OF BAND 7 COMMUNICATION SYSTEMS USING ELECTRONIC COMPUTERS

by

Donald L. Lucas and George W. Haydon

ABSTRACT

Radio system parameters are combined with geophysical and ionospheric characteristics to predict the performance of high frequency sky-wave communication circuits through the use of electronic computers. A program is presented to compute Maximum Usable Frequencies, Optimum Traffic Frequencies, Lowest Useful Frequencies, probable mode of propagation, angle of arrival, circuit reliability, system loss, available signal-to-noise and field strength. Numerical representation is used for all parameters not expressed in closed mathematical form.

I. INTRODUCTION

Long distance high frequency radio systems are subject to marked variations in performance, most of which are directly related to changes in the ionosphere. Changes in the ionosphere result in variations in the maximum frequency which will be returned back to earth, in the strength of the radio waves due to increased absorption, in optimum vertical angles of wave arrival and departure, and in the background noise level as atmospheric radio noise is propagated from great distances. Effective operation of long distance high frequency radio systems increases in proportion to the ability to predict variations in circuit performance and thereby optimize frequency selection, antenna

choice and other circuit parameters to capitalize on anticipated ionospheric conditions. It is the purpose of this report to present a current computer routine which has been developed to combine the more predictable ionospheric characteristics with circuit parameters to calculate the expected performance of high frequency sky-wave radio systems. Basic ionospheric characteristics which are considered predictable enough to be useful are:

- (1) The monthly median of the ordinary ray vertical incident critical frequencies of the F2 layer (f_oF_2).

- (2) The monthly median of the factors relating the vertical incident critical frequency to Maximum Usable Frequency on a 3000 km path (M-3000 factor).

- (3) The monthly median minimum virtual height of the F2 layer.

The following ionospheric characteristics are derived in the prediction process:

- (1) The E-layer critical frequency as a function of solar activity and angle of the sun.

- (2) Ionospheric absorption as a function of operating frequency, gyro frequency, solar activity, angle of the sun, and vertical angle of departure.

- (3) Factors relating the E-layer critical frequencies at different departure angles.

- (4) Factors relating F-layer critical frequencies at different departure angles.

The following geophysical data are utilized:

- (1) E-region gyro frequency.

- (2) F-region gyro frequency.

- (3) Geomagnetic latitudes.

- (4) World-wide distribution of land and sea.

- (5) World-wide distribution of atmospheric noise including seasonal, diurnal and frequency variations.
- (6) Cosmic noise including frequency dependence.
- (7) Man-made noise in the receiving area including frequency dependence.

The following circuit data are needed:

- (1) Transmitter location.
- (2) Receiver location.
- (3) Transmitter power.
- (4) Transmitting antenna (physical dimensions and orientation).
- (5) Receiving antenna (physical dimensions and orientation).
- (6) Type of traffic (modulation, type of intelligence, speed of transmission, required quality).

The above data are combined to determine the following performance characteristics of the circuit:

- (1) The Maximum Usable Frequency (MUF).
- (2) The Optimum Traffic Frequency (FOT).
- (3) System loss (ratio of power received to power transmitted).
- (4) Field strength at the receiver.
- (5) Monthly median of hourly median available signal-to-noise ratio.
- (6) Circuit reliability (per cent of days the hourly median signal-to-noise ratio can be expected to equal or exceed a given value).
- (7) The Lowest Useful Frequency (LUF), the frequency below which the circuit reliability is expected to be less than 90%.

In addition to the above circuit performance characteristics, the following other circuit characteristics are determined:

- (1) The short great circle distance.
- (2) Bearing of the transmitter at the receiver.

- (3) Bearing of the receiver at the transmitter.
- (4) Propagation path having the lowest system loss, e.g., 2 hops via F layer = $2F$.
- (5) Vertical reception angle associated with the best propagation path.

The solution of the problem is divided into two parts: (1) an estimation of the available signal, and (2) an estimation of the required signal. The available signal depends upon:

- (1) The transmitter power.
- (2) The transmitter antenna gain.
- (3) Loss due to spreading of the radio energy as it propagates to greater distance.
- (4) Losses in the ionosphere due to absorption.
- (5) Losses at each ground reflection.
- (6) The gain of the receiving antenna.

The required signal depends upon:

- (1) The atmospheric noise at the receiver location.
- (2) The man-made noise at the receiver location.
- (3) Cosmic noise.
- (4) The required signal-to-noise ratio depending upon type and quality of service desired.

The most basic calculation in the estimation of available signal power is the system loss calculation. The ionospheric, geophysical and circuit characteristics are combined to estimate a quasi-minimum system loss (the minimum loss expected on any day of the month at the hour for which the calculations are made). The distribution of losses above the quasi-minimum have been empirically determined and are a function of geographic location and time of day. These statistical distributions are used to account for the numerous other factors which

contribute to variations between predicted signal levels and those observed on a given day. These factors include polarization mismatch between the signal and the antenna, focusing by the ionosphere, defocusing by the earth, variations between theoretical and actual antenna performance and day to day variations in ionospheric layer heights, ionospheric absorption and critical frequencies.

Basic F2-layer data for long term predictions are numerical maps of the F2 region as determined from world-wide observations using 1954 as typical of a low solar activity period and 1958 as typical of a high solar activity period. In addition to 1954 and 1958, F2 data from other periods of high and low solar activity have been incorporated in the March, June, September and December predictions, since these seasonal extremes are often used in long term planning.

Numerical maps of the F2 layer for monthly predictions will be a part of the "Ionospheric Predictions" CRPL Series D issued by the Central Radio Propagation Laboratory starting with the January 1963 issue.

Sporadic E and F1-layer predictions are considered in this report, only insofar as propagation by these modes enter into the empirically determined signal distributions.

II. PROGRAM DESCRIPTION

The computer routine is based on established manual methods and assumes a working knowledge of these methods [Laitinen, 1949], [Haydon, 1962], [NBS Circular No. 462], along with a familiarity of Fortran II computer language [McCracken, 1962].

The computer method described is designed for any (32K IBM-7090 class) computer with the necessary compiler and tape units. The Fortran II computer language assures flexibility and ease of modification

as better knowledge of the various parameters becomes available. The program provides the communicator with a completely general method for predicting the performance of any sky-wave high frequency radio system. The system performance calculations may be performed for any month of the year, and any degree of solar activity for any hour of the day. Numerical mapping is included for those parameters not evaluated directly by the closed mathematical expressions (Section IX).

The program is designed to be used with either a "long-term" prediction data tape which utilizes coefficients foF2 and M-3000 factors representing periods for high and low solar extremes, or a "short-term" data tape which utilizes monthly coefficients issued by CRPL approximately three months in advance.

1. MUF-FOT

The Maximum Usable Frequency and Optimum Traffic Frequency are based on F2-region numerical mapping of ionospheric characteristics recently developed by CRPL [Jones and Gallet, 1961], and a semi-empirical relationship between the sun's zenith angle and solar activity for the regular E region [Haydon, 1962]. Conventional prediction methods [NBS Circular No. 462] using control points along the great circle 2000 kilometers from each terminal for the F2 layer, and control points 1000 kilometers from each terminal for the regular E layer are used for paths greater than 4000 kilometers. The midpoint of the path is considered as the control point for both E and F layer on paths less than 4000 km.

Since the basic data for the predictions are monthly median values, predictions for specific days within the month are not available.

2. System Loss

1. System loss computations are based on ray-path theory with path limitations based on ray-path geometry between a spherical earth and a concentric ionosphere. Limitations fall into two categories, arrival angle and penetration frequency, and the probable paths for a given circuit at a given hour and frequency are chosen on the basis of these limitations.

F2-region propagation is considered unlikely in these computations if the angle at the F2 region is too sharp for F2-layer support or if the penetration frequency of the E region rises to a value which will support the operating frequency. In this last case, E region transmission is geometrically possible. Multiple hop transmission for a given circuit is possible solely by the E region or the F2 region, but the computer routine also includes the case where some hops of a given path are supported by the E region and other hops supported by the F2 region.

Three F2-region paths, two E-region paths, and one E-F2-region path are inspected for a given circuit at a given hour for a given frequency. The path that is geometrically possible with the least theoretical loss is assumed to be the most useful mode with a loss typical for the circuit. The total field is not included in this routine.

2. Layer heights used for the F2 region are minimum vertical heights averaged for a given month. E-layer height is assumed to be 110 km. The average height of the absorbing region is assumed to be 100 km.

3. Ionospheric layer heights at the reflection points are averaged in calculation of the vertical radiation angle (Δ) and the angle of incidence at the ionosphere (ϕ'). Unequal take-off angles in multi-hop cases are not included.

4. Absorption in the lower regions is represented by a semi-empirical relationship involving the angle of incidence at the ionosphere, the gyro frequency in the absorbing region, the zenith angle of the sun, solar activity, and the operating frequency.

5. Estimation of the ground reflection losses is evaluated for either land or sea reflections. Shore line and mixed paths are not included and random polarization of the downcoming waves is assumed.

6. Convergence and divergence of the ionospheric waves are included in the routine only in the empirical determined system loss distributions.

7. Theoretical vertical and horizontal reflection coefficients are evaluated for the ground losses and the antenna patterns.

8. Receiving antenna response (gain) is assumed to be equal to the antenna gain of an identical antenna used as a transmitting antenna. All gains are relative to an isotropic in free space.

The complete computer routine contains a subroutine for three general types of antennas.

a. Terminated rhombics at any height above the terrain, any leg length and tilt angle. Poor earth ($\sigma = .001$ mhos/meter; $\epsilon = 4$) is assumed as the terrain, but any ground conductivity and dielectric constant could be used. Off-azimuth radiation may be computed for the rhombics.

b. Horizontal half-wave dipoles for any height above finite earth.

c. Vertical ship antennas for constant length elements or for multiples of any wave lengths not less than $.02 \lambda$. Practical efficiencies of grounded verticals less than one-quarter wave length are computed and included in the antenna gain.

9. Signal distribution is assumed to vary with geomagnetic latitude and length of the circuit and quasi-minimum losses are adjusted to median losses in terms of these empirical distributions [Haydon, 1962].

10. Off-great-circle transmissions are not included in these calculations.

3. Field Strength Option

The field strength option is computed similar to the system loss, then mathematically related to the system loss (Section IX).

4. Radio Noise

The CCIR world-wide maps of atmospheric noise are used as representative of the distribution of noise [CCIR Report No. 65].

Man-made noise estimates are based upon the type of receiving area [Haydon, 1962]. Measured values of man-made noise are also acceptable.

Galactic noise at the receiver site [CCIR Report No. 65] is estimated by a least squares polynomial in frequency. The highest of the three noise types is assumed to predominate and the total noise field is not estimated. All noise values are expressed in db relative to 1 watt for a one-cycle bandwidth. The 1 Mc/s atmospheric noise above KTB is adjusted to a 1 c/s band relative to one watt by least squares polynomial representation of the seasonal maps [Lucas and Harper, 1962].

5. Available Signal-To-Noise

The monthly median of the hourly median available signal is compared with the average noise in a four-hour time block at the receiver site. This gives an estimate of the monthly median of hourly median total signal power relative to noise in a one-cycle band.

6. Required Signal-To-Noise

The required signal-to-noise depends upon the service required, e.g., error rate in teletype, intelligibility of voice, etc. A basic signal-to-noise requirement based upon a steady static signal and random noise adjusted for signal fading degradation, diversity improvement, etc., determines the required signal-to-noise.

7. Reliability

Reliability is estimated at discrete frequency bands by calculating the ratio of the available monthly median signal-to-noise of Paragraph 5 to the required hourly median signal-to-noise of Paragraph 6. Using the above parameter and the operating frequency, theoretical reliability is obtained for a given circuit of a given length and geomagnetic latitude by use of statistical two-dimensional maps.

8. Lowest Useful Frequency

The Lowest Useful Frequency is calculated by stepping through the HF band until a reliability of 90% or more is obtained, then stepping down in small increments of frequency until a frequency is found that has (within the tolerance of the frequency increment) 90% reliability. This frequency is the classical 90% LUF.

III. PROGRAM USE

The IBM-7090 Fortran II listing is shown in Section VIII. The cards corresponding to these listings with the associated control cards necessary for the specific monitor being used are all that is necessary to compile the program. A pictorial view of a sample deck ready to run under the IBM-7090 monitor is shown in Figure 17. System sub-routines used in the program are as follows:

<u>Subroutine</u>	<u>Call</u>	<u>Argument</u>
1. Sine	SINF (x)	(radians)
2. Arc sine	ASINF (x)	($-1 \leq x \leq 1$)
3. Cosine	COSF (x)	(radians)
4. Arc cosine	ACOSF (x)	($-1 \leq x \leq 1$)
5. Absolute value	ABSF (x)	(floating)
6. Absolute value	XABSF (x)	(fixed)
7. Arc tangent	ATANF (x)	($-\infty \leq x \leq \infty$)
8. Square root	SQRTF (x)	($0 \leq x \leq \infty$)
9. Transfer of sign	SIGNF (x, y)	(arg 1, arg 2)
10. Logarithm (Base 10)	LOG10F (x)	($0 < x \leq \infty$)
11. Natural logarithm	LOGF (x)	($0 < x \leq \infty$)
12. Integer function	INTF (x)	($-\infty \leq x \leq \infty$)

The entire program including common variables and system subroutines occupies approximately 24000 decimal locations.

Routines included in the program with a brief description of their function are:

MUFLUF -- (2550 decimal locations)

This is the main program. It calculates the Maximum Usable Frequencies, Optimum Traffic Frequencies, and other parameters needed not only in the calculation of these critical frequencies but also in one or more subroutines.

LUFFY -- (3857 decimal locations)

This subroutine is larger and more complex than MUFLUF, but is a subprogram because the option is asked for in MUFLUF. This routine calculates the systems performance of a given circuit, i. e., system loss, reliability, signal-to-noise and field strength. The subprograms that follow are used by LUFFY to perform a specific task needed in the system performance calculations.

POLY -- (107 decimal locations)

This subroutine is called upon to evaluate all parameters that are represented by Nth degree polynomials of the power series in X.

Example:

$$\begin{aligned} Y = & \left(A_{0,0} x^0 + A_{0,1} x^1 + \dots + A_{0,n} x^n \right) Z^0 \\ & + \left(A_{1,0} x^0 + A_{1,1} x^1 + \dots + A_{1,n} x^n \right) Z^1 \\ & + \dots \\ & + \left(A_{m,0} x^0 + A_{m,1} x^1 + \dots + A_{m,n} x^n \right) Z^m \end{aligned}$$

LOSS -- (214 decimal locations)

This subroutine evaluates the ground reflection losses as a function of the reflection angle and operating frequency over finite earth. Random polarization is assumed in the calculations as the vertical and horizontal reflection coefficients are assumed to contribute equally in the polarization effects of the loss.

This routine is unique in that complex arithmetic is absent in the calculations of these reflection losses [Phillips, 1961].

GAIN -- (684 decimal locations)

This routine calculates theoretical power gains of horizontal rhombics in three dimensions, horizontal dipoles, and practical grounded vertical radiators, all over finite earth. Practical lower limits of gain have been set as -10 db relative to an isotropic in free space.

CI -- (411 decimal locations)

This function subroutine evaluates the sine and cosine integral

$$Si(x) = \int_0^x \frac{\sin v}{v} dv$$

$$Ci(x) = \int_0^x \frac{\cos v}{v} dv$$

when called for by the loss and gain routines.

NOISY -- (215 decimal locations)

This routine calculates the world-wide distribution of atmospheric noise and major land bodies which are represented by Fourier coefficients.

The evaluation is made at a given longitude and latitude of the receiving location or ground reflection point.

CURVY -- (1462 decimal locations)

This routine, although not pertinent to the solution of any problem encountered in system performances, produces a semi-line graph representation of the diurnal variation of either or both the Optimum Traffic Frequency and the Lowest Useful Frequency.

VREFCO -- (230 decimal locations)

This routine calculates the ground reflection coefficient (K_v) for vertically polarized waves.

NOTE:

The ground reflection coefficient (K_H) for horizontally polarized waves is calculated within subroutine GAIN.

IV. DESCRIPTION OF DATA TAPES

1. "Long-term" Data Tape.

The binary data tape for the storage of coefficients representing those variables not expressed in closed form has a packing density of

556 frames per inch. Twelve logical records - one for each month - are used. Each logical record is composed of physical records 256 words in length. Approximately 800 feet of tape are used.

Each logical record contains six one-dimensional arrays, three three-dimensional arrays, one two-dimensional array in the following order:

IL (4), JL (4), KL (4), LK (4), JAL (4), Q (20, 60, 4),

A (10, 7, 14), P (29, 16, 6), ABP (2, 6)

The variables IL, JL, KL, LK, and JAL are limits to which the Fourier generation of the foF2 and M-3000 factors are carried, e.g., IL (1) is associated with the two dimensional set of coefficients Q (M, N, 1).

The "Q" arrays [Lucas, 1961] contains the coefficients used in the generation of the foF2 and M-3000 factors in the following order for each month:

1. Q (M, N, 1) foF2 - low solar activity
2. Q (M, N, 2) foF2 - high solar activity
3. Q (M, N, 3) M-3000 - low solar activity
4. Q (M, N, 4) M-3000 - high solar activity

The "A" array contains the coefficients needed for other parameters not represented in closed form:

A (M, N, 1) gyro-frequency distribution [Lucas, 1961]

A (M, N, 2) H'f2 layer height charts [Haydon, 1962]

A (M, N, 3) blank to leave space for numerical representation of measured patterns of antennas

A (M, N, 4) nighttime frequency dependence of atmospheric noise [Lucas and Harper, 1962].

A (M, N, 5) daytime frequency dependence of atmospheric noise

A (M, N, 6) man-made noise level in industrial area [Haydon, 1962]

- A (M,N, 7) man-made noise level in residential area
- A (M,N, 8) man-made noise level in rural area
- A (M,N, 9) man-made noise level in remote unpopulous area
- A (M,N, 10) daytime distribution of circuit reliability in
temperate regions [Haydon, 1962]
- A (M,N, 11) nighttime distribution of circuit reliability in
temperate regions
- A (M,N, 12) distribution of circuit reliability in polar region
- A (M,N, 13) distribution of short circuit reliability in
auroral region
- A (M,N, 14) distribution of long circuit reliability in
auroral region

The "P" array of each logical record contains five maps of the world-wide distribution of atmospheric noise [Lucas and Harper, 1962] for the month being considered. The major land bodies of the world are also represented in this array.

- P (M,N, 1) 2000-0400 LMT
- P (M,N, 2) 1600-2000 LMT
- P (M,N, 3) 1200-1600 LMT
- P (M,N, 4) 0800-1200 LMT
- P (M,N, 5) 0400-0800 LMT
- P (M,N, 6) major land bodies of the world

The array "ABP" contains the convergence factors for the Fourier generation of the "P" matrix [Lucas and Harper, 1962].

The elements of the matrices that are not sensitive to month are identical for all logical records.

2. "Short-term" Data Tape.

(a) Description of "Short-term" Data Tape

The "short-term" data tape is identical to the "long-term" data tape with the exception of the foF2 and the M-3000 coefficients. On the "short-term" tape each particular month's coefficients are stored in positions used by the coefficients representing high and low solar activity extremes on the "long term" tape. The solar activity index associated with the "short-term" coefficients must be used when predictions are made using these coefficients. The routine which follows is designed to generate and update a "short-term" data tape as the coefficients become available. It is designed to use the "long-term" or "short-term" tape (Logical #2 and Logical tape #3) which will become the new "short-term" data tape. Precede the data deck with one card which contains the first and last months for which the "short-term" tape is to be updated. A minus 1 card punched in columns 55-56 must follow each individual foF2 or M-3000 coefficient deck. A sample deck for one month's data is:

												-1
UNP												
6206	4503	139	10	6	48	6	10	1	37.0	0	0	3.0483946E 00
												-1
COMPLETE												
6206	4500	139	30	8	56	10	24	1	37.0	0	0	7.9863955E 00
6 6												
C	FORTRAN STATEMENT											

(b) Program to Use CRPL Series D Predicted Coefficients
to Generate and Update "Short-term" Tape.

```
C    ALWAYS USE MOST RECENT TAPE FOR UPDATING SHORT-TERM TAPE
      DIMENSION Q(20,60,4),IL(4),JL(4),KL(4),LK(4),JAL(4),A(10,7,14),P1(
129,16,6),ABP(2,6)
1  FORMAT (19X,2I4,4X,2I4,12X,2I5,E17.7)
2  FORMAT (51X,2I5,E17.7)
101 FORMAT(2I2)
      READ INPUT TAPE 5,101,MONTH1,MONTH2
      REWIND 2
      REWIND 3
      MONTH3=MONTH2+1
      LOCK = MONTH1-1
      IF(LOCK) 4,55,4
4  DO 3 II=1,LOCK
      READ TAPE 2,IL,JL,KL,LK,JAL,Q,A,P1,ABP
3  WRITETAPE 3,IL,JL,KL,LK,JAL,Q,A,P1,ABP
55 DO 100 II=MONTH1,MONTH2
      READ TAPE 2, IL,JL,KL,LK,JAL,Q,A,P1,ABP
      IO=1
5  READ INPUT TAPE 5,1,I,J,K,L,M,N,P
      IL(IO)=I+1
      JL(IO)=J+1
      KL(IO)=K+1
      LK(IO)=L+1
      JAL(IO)=2*J+1
20 M=M+1
      N=N+1
      Q(M,N,IO)=P
      READ INPUT TAPE 5,2,M,N,P
      IF(M) 40,20,20
```

```
40 IO=IO+2
   IF(4-IO) 6,5,5
6 DO 7 IO=2,4,2
   IL(IO)=IL(IO-1)
   JL(IO)=JL(IO-1)
   KL(IO)=KL(IO-1)
   LK(IO)=LK(IO-1)
   JAL(IO)=JAL(IO-1)
   DO 7 M=1,20
   DO 7 N=1,60
7 Q(M,N,IO)=Q(M,N,IO-1)
100 WRITETAPE 3, IL,JL,KL,LK,JAL,Q,A,P1,ABP
   IF(MONTH3-12) 301,301,401
301 DO 201 K=MONTH3,12
   READ TAPE 2,IL,JL,KL,LK,JAL,Q,A,P1,ABP
201 WRITETAPE 3,IL,JL,KL,LK,JAL,Q,A,P1,ABP
401 REWIND 2
   REWIND 3
   CALL EXIT
   END
```

Minor changes in the Fortran program found above would allow the updating of the "long-term" tape as better coefficients become available.

Extreme caution should be exercised when changes are being made to the data tape. Fortran statements identical to the read statements in the main program "MUFLUF" should be used to re-write the tape.

Inspection and checking of coefficients contained on the tape may be accomplished by merely dumping the tape off-line. It is suggested, however, that for easier inspection it be read by the "read tape" statements contained in "MUFLUF".

Data tapes for the IBM-7090 containing all the logical records may be obtained from the Radio Systems Division, National Bureau of Standards, Boulder, Colorado.

V. PROGRAM OPTIONS

Options included in the program aid in the solution of a wide range of systems problems. Options designed to be printed on standard 9 by 11 paper are:

1. MUF and FOT (Figure 1)

The Maximum Usable Frequency (MUF) and Optimum Traffic Frequency (FOT) are printed three circuit months per page.

2. MUF, FOT, MODE, ARRIVAL ANGLE, AND RELIABILITY (Figure 2)

The Maximum Usable Frequency, Optimum Traffic Frequency, theoretical angle of arrival, probable mode of propagation and circuit reliability are printed one circuit month per page. MUF-FOT's are calculated for each hour of GMT. Mode, angle and reliability are calculated only for even hours of GMT.

3. FOT and LUF (Figures 3 and 4)

The Optimum Traffic Frequency and the Lowest Useful High Frequency are printed three circuit months per page. The Optimum Traffic Frequency is always given each hour of GMT while the communicator has a choice of each hour or every even hour of GMT for the Lowest Useful High Frequency.

4. MUF, FOT, MODE, ARRIVAL ANGLE AND SYSTEM LOSS (Figure 5)

The Maximum Usable Frequency, Optimum Traffic Frequency, theoretical angle of arrival, probable mode of propagation and monthly median of hourly median system loss are printed one circuit month per

page. MUF and FOT's are calculated for all hours of GMT while mode, angle, and system loss are calculated for even hours of GMT.

5. MUF, FOT, MODE, ARRIVAL ANGLE AND FIELD STRENGTH
(Figure 6)

The Maximum Usable Frequency and Optimum Traffic Frequency, theoretical angle of arrival, probable mode of propagation and monthly median of the hourly median field strength are printed one circuit month per page. MUF and FOT's are calculated for all hours of GMT while mode, angle, and field strength are calculated for even hours of GMT.

6. MUF, FOT, MODE, ARRIVAL ANGLE AND SIGNAL-TO-NOISE (Figure 7)

The Maximum Usable Frequency, Optimum Traffic Frequency, probable mode of propagation, theoretical angle of arrival and monthly median of the hourly signal-to-noise at the receiving antenna terminals are printed one circuit month per page. MUF and FOT's are calculated for all hours of GMT while mode, angle, and signal-to-noise are calculated for even hours of GMT.

7. MUF, FOT AND RELIABILITY (Figure 8)

The Maximum Usable Frequency, Optimum Traffic Frequency and circuit reliability are calculated every even hour of GMT and printed two circuit months per page.

8. FOT GRAPHS (Figure 9)

The Optimum Traffic Frequencies are plotted frequencies vs. GMT time on a nonlinear frequency scale by the on-line printer.

9. FOT AND LUF GRAPHS (Figure 10)

The Optimum Traffic Frequencies and Lowest Useful High Frequencies are plotted frequencies vs. GMT time on a nonlinear frequency scale by the on-line printer.

The above options may utilize one of two input data tapes. Long-term predictions are available from a data tape with numerical coefficients for the months representing both high and low solar activity.

These extremes are used to predict MUF associated with the intermediate sunspot number.

Short-term predictions are available from a data tape with numerical coefficients for approximately three months in advance. No interpolation is made when using this data tape.

VI. COMPUTER INPUTS

1. Circuit Card Format

A data sheet should be prepared for each circuit before punching the card. The number in the left hand column below refers to information on the data sheet (Figure 11). The fields should be punched as follows (Figure 13) with numbers right justified.

<u>Data Sheet</u>	<u>Card Columns</u>
1.	1-5
2.	6-11
3.	12-16
4.	17-22
5.	28-30
6.	31-33
7.	34-36
8.	37-39
9. (See Note #1)	40-41
10. (See Note #2)	40-41
11.	42-44
12.	45-47
13.	48-50

14.	(See Note #1)	51-52
15.	(See Note #2)	51-52
16.	(See Note #4)	53-55
17.	(See Note #3)	53-55
18.		56-58
19.	Does not apply	
20.	(See Note #5)	59-62
21.	(See Note #5)	63-66
22.		71-72

NOTES:

1. (a) If rhombic is circled, enter -1
(b) If $\lambda/2$ dipole is circled, enter -3
(c) If vertical is circled, enter -2
(d) If vertical in multiples of wave length
is given, enter in height cols. -14 for
 $\lambda/4$; -12 for $\lambda/2$; -1 for λ , etc.
2. If this number is given instead of the
information which appears in Note 1 (d)
above, enter this number.
3. (a) If check in Industrial, enter -1
(b) If check in Residential, enter -2
(c) If check in Rural, enter -3
(d) If check in Remote Unpopulous, enter -4
4. If number is given, enter this number in
lieu of #17 from data sheet.
5. Bearing in degrees east of north.

2. Method Card Format

The following is a list of methods available. The numbers on the right call the various methods when placed in the columns shown.

Calculations to be Performed	Card Columns				Sample Print-Out
	2	4	6	8	
MUF-FOT listing from circuits on cards	1	1	0	0	Figure 1
MUF-FOT listing from circuits on tape	1	0	0	0	
FOT curve from circuits on cards	1	1	0	1	Figure 9
FOT curve from circuits on tape	1	0	0	1	
Reliability-mode-angle from circuits on cards	2	1	0	0	Figure 2
Reliability-mode-angle from circuits on tape	2	0	0	0	
FOT-LUF listing every hour from circuits on cards	3	1	0	0	Figure 3
FOT-LUF listing every hour from circuits on tape	3	0	0	0	
FOT listing every hour, LUF every 2 hours from circuits on cards	3	1	1	0	Figure 4
FOT listing every hour, LUF every 2 hours from circuits on tape	3	0	1	0	
FOT-LUF curves from circuits on cards	3	1	0	1	Figure 10
FOT-LUF curves from circuits on tape	3	0	0	1	
System loss from circuits on cards	4	1	0	0	Figure 5
System loss from circuits on tape	4	0	0	0	
Field strength (dbu) from circuits on cards	4	1	1	0	Figure 6
Field strength (dbu) from circuits on tape	4	0	1	0	
Reliability-FOT every 2 hours from circuits on cards	5	1	0	0	Figure 8
Reliability-FOT every 2 hours from circuits on tape	5	0	0	0	

Available S/N from circuits on cards 6 1 0 0 Figure 7
Available S/N from circuits on tape

3. Assembling the Data Decks

Only one data tape is needed with these routines (Tape #2). A utility tape #3 is also needed which will contain the circuits from a given run. If a large number of circuits are to be run repeatably, it is wise to save the tape and run from it in lieu of circuit cards.

To assemble a data deck, first make the method and frequency complement cards for the desired HF predictions. If the circuits are to be read from cards, the circuit cards must follow the frequency card. Following the last circuit card, insert a "nines card" (the number 9 punched in columns 1 through 19), to indicate the end of the circuit cards. The next cards will indicate the months and solar activity levels for which the calculations are to be made.

The months January through December are indicated by numbers 1 through 12 placed on the card in columns 23 and 24. On the same card, in columns 25, 26 and 27, punch the appropriate sunspot number. If it is desired to terminate the calculations of these circuits under the called method, a card with -1 punched in columns 23 and 24 should follow the "month and sunspot number" card. However, if another method is to be run for the same circuits, follow the -1 card by method and frequency cards that allow the circuits to be read from tape (see method card format). The circuits will be read from tape #3 just prepared. Following the new frequency and method cards, place the desired month and sunspot number cards. Notice the nine's card has been omitted. A -1 card inserted after the month and sunspot number card will terminate the method and a blank card following the -1 card will terminate the job.

The data deck (to be run from cards) is composed of the following cards in the order they appear.

1. Method card
2. Frequency complement card
3. Group of circuit cards
4. Nines card
5. Group of month and sunspot cards
6. -1 card

(See Figures 14 and 15)

Any number of different methods with different circuits may be set up sequentially in the above order. When it is desired to terminate the job, place a blank card after the -1 card.

A data deck to be run from tape is composed of only:

1. Method card
2. Frequency complement card
3. Group of month and sunspot cards
4. -1 card

(See Figure 16)

4. Purpose of Cards in Data Deck

(a) Method Card:

The method card shown in Figure 13 allows the communicator a choice of computations shown in the example print-outs (Figures 1 through 10) with the option of having data for the circuits on either cards or magnetic tape.

(b) Frequency Complement Card:

The frequency card allows the communicator a choice of 10 frequencies for which calculations will be made, e.g., 3.1240, 4.7856 30.0000. If fewer than 10 frequencies are wanted merely put

the desired ones sequentially on card from the beginning, then punch unused fields with 990000. If method #3 is to be run, it is suggested that a frequency card identical to Figure 12 be used.

(c) Circuit Cards (Figure 13):

The circuit cards are designed to contain all necessary circuit parameters to be run under any choice of the computations shown in Figures 1 through 10.

(d) Nines Card (Figure 12):

The nines card is a circuit card which is not computed. The machine senses this card and is told the entire list of circuits has been calculated for the given month.

(e) Month and Sunspot Number Card (Figure 12):

The month card contains the month of the year and its associated sunspot number for the desired circuit calculations.

(f) Minus One Card (Figure 12):

The minus one card instructs the machine that all computations are complete for a given method.

(g) Blank Card (Figure 12):

A blank card following a "minus one card" instructs the machine that all computations for a given run are complete.

1 TRANSMITTER 40.75N - 73.93W			JAN	RECEIVER 32.33N - 64.70W			SSN= 25.	BEARINGS 135.8 321.3			BR 32.007 N.MILES 672.5
GHT	MUF	FOT	GHT	MUF	FOT	GHT	MUF	FOT	GHT	MUF	FOT
1	5.7	4.9	7	5.7	4.9	13	10.3	9.2	19	11.6	10.8
2	5.2	4.4	8	5.5	4.7	14	11.4	10.6	20	11.7	9.9
3	5.2	4.5	9	5.4	4.6	15	11.6	11.4	21	11.2	9.5
4	5.4	4.6	10	4.9	4.2	16	11.8	11.8	22	9.7	8.2
5	5.4	4.6	11	5.1	4.3	17	11.8	11.8	23	7.7	6.6
6	5.7	4.9	12	7.4	6.9	18	11.5	11.5	24	6.5	5.5
2 TRANSMITTER 51.50N - 0.01W			JAN	RECEIVER 27.92N - 15.67W			SSN= 25.	BEARINGS 212.5 22.2			GC 2.016 N.MILES 1581.3
GHT	MUF	FOT	GHT	MUF	FOT	GHT	MUF	FOT	GHT	MUF	FOT
1	10.3	8.8	7	8.1	6.9	13	22.7	19.3	19	13.5	11.5
2	10.8	9.2	8	12.9	11.0	14	21.7	18.5	20	11.8	10.1
3	10.6	9.0	9	19.6	16.6	15	21.5	18.2	21	10.8	9.2
4	9.9	8.4	10	22.8	19.3	16	21.0	17.8	22	9.8	8.3
5	9.3	7.9	11	23.6	20.0	17	19.5	16.6	23	9.7	8.3
6	8.1	6.9	12	23.7	20.2	18	16.6	14.2	24	10.1	8.6
3 TRANSMITTER 12.10N - 8.50E			JAN	RECEIVER 51.50N - 0.01W			SSN= 25.	BEARINGS 351.8 167.0			LD 16.024 N.MILES 2400.4
GHT	MUF	FOT	GHT	MUF	FOT	GHT	MUF	FOT	GHT	MUF	FOT
1	13.4	11.4	7	15.9	13.6	13	25.8	21.9	19	14.8	12.6
2	13.0	11.1	8	23.5	19.9	14	25.3	21.5	20	13.9	11.8
3	11.8	10.1	9	26.6	22.6	15	24.4	20.7	21	13.1	11.1
4	10.7	9.1	10	27.3	23.2	16	23.0	19.5	22	13.0	11.0
5	9.2	7.8	11	27.4	23.3	17	20.2	17.1	23	13.0	11.0
6	9.8	8.4	12	26.6	22.6	18	16.7	14.2	24	13.0	11.1

Figure 1. Computer Print-Out of Circuit MUF and FOT

2 TRANSMITTER			JAN			SSN= 25.			GC 2.016			N.MILES		
51.50N - 0.01W			27.92N - 15.67W			212.5 22.2			1581.3					
RHOMBIC 23H 96L			67DEG			NOISE= 3			RHOMBIC 20H 114L 70DEG					
PWR= 30.00KW			OPERATING FREQUENCIES			REQ.S/N= 45DB								
GMT	MUF	FOT	3	5	7	9	11	13	15	20	25	30	FOT	
1	10.3	8.8	3F	2F	1F	1F	00	00	00	00	00	00	1F	MODE
			28	18	5	5	0	0	0	0	0	0	5	ANGLE
2	10.8	9.2	90	99	99	99	0	0	0	0	0	0	99	RELIABILITY
3	10.6	9.0	3F	2F	1F	00	00	00	00	00	00	00	1F	MODE
			28	18	4	0	0	0	0	0	0	0	4	ANGLE
4	9.9	8.4	90	99	99	0	0	0	0	0	0	0	99	RELIABILITY
5	9.3	7.9	3F	2F	00	00	00	00	00	00	00	00	1F	MODE
			26	16	0	0	0	0	0	0	0	0	4	ANGLE
6	8.1	6.9	89	99	0	0	0	0	0	0	0	0	99	RELIABILITY
7	8.1	6.9	3F	3F	2F	1F	00	00	00	00	00	00	1F	MODE
			25	25	16	3	0	0	0	0	0	0	3	ANGLE
8	12.9	11.0	0	98	99	99	0	0	0	0	0	0	99	RELIABILITY
9	19.6	16.6	2E	3F	2F	2F	2F	2F	1F	00	00	00	1F	MODE
			5	25	15	15	15	15	3	0	0	0	3	ANGLE
10	22.8	19.3	0	5	99	99	99	99	99	0	0	0	99	RELIABILITY
11	23.6	20.0	2E	2E	3F	2F	2F	2F	1F	1F	00	00	1F	MODE
			5	5	24	15	15	15	3	3	0	0	3	ANGLE
12	23.7	20.2	0	0	81	99	99	99	99	99	0	0	99	RELIABILITY
13	22.7	19.3	2E	2E	3F	2F	2F	2F	1F	00	00	00	1F	MODE
			5	5	24	15	15	15	3	0	0	0	3	ANGLE
14	21.7	18.5	0	0	89	99	99	99	99	0	0	0	99	RELIABILITY
15	21.5	18.2	2E	3F	2F	2F	2F	1F	1F	00	00	00	1F	MODE
			5	23	14	14	14	2	2	0	0	0	2	ANGLE
16	21.0	17.8	0	23	99	99	99	99	99	0	0	0	99	RELIABILITY
17	19.5	16.6	3F	3F	2F	2F	1F	1F	00	00	00	00	1F	MODE
			23	23	14	14	2	2	0	0	0	0	2	ANGLE
18	16.6	14.2	44	99	99	99	99	99	0	0	0	0	99	RELIABILITY
19	13.5	11.5	3F	3F	2F	1F	00	00	00	00	00	00	1F	MODE
			23	23	14	2	0	0	0	0	0	0	2	ANGLE
20	11.8	10.1	83	99	99	99	0	0	0	0	0	0	99	RELIABILITY
21	10.8	9.2	3F	2F	1F	00	00	00	00	00	00	00	1F	MODE
			25	16	3	0	0	0	0	0	0	0	3	ANGLE
22	9.8	8.3	87	99	98	0	0	0	0	0	0	0	99	RELIABILITY
23	9.7	8.3	3F	3F	1F	00	00	00	00	00	00	00	1F	MODE
			27	27	4	0	0	0	0	0	0	0	4	ANGLE
24	10.1	8.6	89	99	99	0	0	0	0	0	0	0	99	RELIABILITY

Figure 2. Computer Print-Out of Circuit MUF, FOT and Circuit Reliability

1			JAN			SSN= 25.			BR 32.007		
TRANSMITTER			RECEIVER			BEARINGS			N.MILES		
40.75N - 73.93W			32.33N - 64.70W			135.8 321.3			672.5		
RHOMBIC 32H 118L			63DEG			NOISE= 3			ANT= 30B		
PWR= 20.00KW									REQ.S/N= 45DB		
GMT	LUF	FOT	GMT	LUF	FOT	GMT	LUF	FOT	GMT	LUF	FOT
1	-3.0	4.9	7	-3.0	4.9	13	-3.0	9.2	19	3.5	10.8
2	-3.0	4.4	8	-3.0	4.7	14	3.5	10.6	20	3.2	9.9
3	-3.0	4.5	9	-3.0	4.6	15	4.1	11.4	21	-3.0	9.5
4	-3.0	4.6	10	-3.0	4.2	16	4.4	11.8	22	-3.0	8.2
5	-3.0	4.6	11	-3.0	4.3	17	4.4	11.8	23	-3.0	6.6
6	-3.0	4.9	12	-3.0	6.9	18	4.1	11.5	24	-3.0	5.5

2			JAN			SSN= 25.			GC 2.016		
TRANSMITTER			RECEIVER			BEARINGS			N.MILES		
51.50N - 0.01W			27.92N - 15.67W			212.5 22.2			1581.3		
RHOMBIC 23H 96L			67DEG			NOISE= 3			RHOMBIC 20H 114L 70DEG		
PWR= 30.00KW									REQ.S/N= 45DB		
GMT	LUF	FOT	GMT	LUF	FOT	GMT	LUF	FOT	GMT	LUF	FOT
1	-3.0	8.8	7	-3.0	6.9	13	7.2	19.3	19	3.2	11.5
2	-3.0	9.2	8	4.4	11.0	14	6.9	18.5	20	3.2	10.1
3	-3.0	9.0	9	5.5	16.6	15	6.4	18.2	21	-3.0	9.2
4	-3.0	8.4	10	6.1	19.3	16	5.8	17.8	22	-3.0	8.3
5	-3.0	7.9	11	6.7	20.0	17	4.7	16.6	23	-3.0	8.3
6	-3.0	6.9	12	6.9	20.2	18	3.5	14.2	24	-3.0	8.6

3			JAN			SSN= 25.			LD 16.024		
TRANSMITTER			RECEIVER			BEARINGS			N.MILES		
12.10N - 8.50E			51.50N - 0.01W			351.8 167.0			2400.4		
RHOMBIC 20H 114L			70DEG			NOISE= 3			RHOMBIC 20H 114L 70DEG		
PWR= 10.00KW									REQ.S/N= 43DB		
GMT	LUF	FOT	GMT	LUF	FOT	GMT	LUF	FOT	GMT	LUF	FOT
1	4.1	11.4	7	6.4	13.6	13	9.2	21.9	19	4.4	12.6
2	4.1	11.1	8	7.5	19.9	14	8.7	21.5	20	4.4	11.8
3	4.4	10.1	9	8.4	22.6	15	8.1	20.7	21	4.4	11.1
4	4.4	9.1	10	8.9	23.2	16	6.7	19.5	22	4.4	11.0
5	4.4	7.8	11	9.5	23.3	17	5.5	17.1	23	4.4	11.0
6	4.7	8.4	12	9.5	22.6	18	4.4	14.2	24	4.4	11.1

Figure 3. Computer Print-Out of Circuit LUF and FOT

1
TRANSMITTER
40.75N - 73.93W
RHOMBIC 32H 118L
PWR= 20.00KW
63DEG
JAN
RECEIVER
32.33N - 64.70W
NOISE= 3
SSN= 25.
BEARINGS
135.8 321.3
BR 32.007
N.MILES
672.5
ANT= 3DB
REQ.S/N= 45DB

GMT	LUF	FOT	GMT	LUF	FOT	GMT	LUF	FOT	GMT	LUF	FOT
1		4.9	7		4.9	13		9.2	19		10.8
2	-3.0	4.4	8	-3.0	4.7	14	3.5	10.6	20	3.2	9.9
3		4.5	9		4.6	15		11.4	21		9.5
4	-3.0	4.6	10	-3.0	4.2	16	4.4	11.8	22	-3.0	8.2
5		4.6	11		4.3	17		11.8	23		6.6
6	-3.0	4.9	12	-3.0	6.9	18	4.1	11.5	24	-3.0	5.5

2
TRANSMITTER
51.50N - 0.01W
RHOMBIC 23H 96L
PWR= 30.00KW
67DEG
JAN
RECEIVER
27.92N - 15.67W
NOISE= 3
SSN= 25.
BEARINGS
212.5 22.2
GC 2.016
N.MILES
1581.3
RHOMBIC 20H 114L 70DEG
REQ.S/N= 45DB

GMT	LUF	FOT	GMT	LUF	FOT	GMT	LUF	FOT	GMT	LUF	FOT
1		8.8	7		6.9	13		19.3	19		11.5
2	-3.0	9.2	8	4.4	11.0	14	6.9	18.5	20	3.2	10.1
3		9.0	9		16.6	15		18.2	21		9.2
4	-3.0	8.4	10	6.1	19.3	16	5.8	17.8	22	-3.0	8.3
5		7.9	11		20.0	17		16.6	23		8.3
6	-3.0	6.9	12	6.9	20.2	18	3.5	14.2	24	-3.0	8.6

3
TRANSMITTER
12.10N - 8.50E
RHOMBIC 20H 114L
PWR= 10.00KW
70DEG
JAN
RECEIVER
51.50N - 0.01W
NOISE= 3
SSN= 25.
BEARINGS
351.8 167.0
LD 16.024
N.MILES
2400.4
RHOMBIC 20H 114L 70DEG
REQ.S/N= 43DB

GMT	LUF	FOT	GMT	LUF	FOT	GMT	LUF	FOT	GMT	LUF	FOT
1		11.4	7		13.6	13		21.9	19		12.6
2	4.1	11.1	8	7.5	19.9	14	8.7	21.5	20	4.4	11.8
3		10.1	9		22.6	15		20.7	21		11.1
4	4.4	9.1	10	8.9	23.2	16	6.7	19.5	22	4.4	11.0
5		7.8	11		23.3	17		17.1	23		11.0
6	4.7	8.4	12	9.5	22.6	18	4.4	14.2	24	4.4	11.1

Figure 4. Alternative Computer Print-Out of Circuit LUF and FOT

2 TRANSMITTER			JAN		RECEIVER		SSN= 25.		GC 2.016		N.MILES		
51.50N - 0.01W			27.92N - 15.67W		212.5 22.2		1581.3						
RHOMBIC 23H 96L			67DEG		NOISE= 0		RHOMBIC 20H 114L		70DEG				
OPERATING FREQUENCIES													
GMT	MUF	FOT	3	5	7	9	11	13	15	20	25	30	FOT
1	10.3	8.8											
			3F	2F	1F	1F	00	00	00	00	00	00	1F
			28	18	5	5	0	0	0	0	0	0	5
2	10.8	9.2	133	120	129	120	0	0	0	0	0	0	120
3	10.6	9.0											
			3F	2F	1F	00	00	00	00	00	00	00	1F
			28	18	4	0	0	0	0	0	0	0	4
4	9.9	8.4	133	121	131	0	0	0	0	0	0	0	124
5	9.3	7.9											
			3F	2F	00	00	00	00	00	00	00	00	1F
			26	16	0	0	0	0	0	0	0	0	4
6	8.1	6.9	134	122	0	0	0	0	0	0	0	0	134
7	8.1	6.9											
			3F	3F	2F	1F	00	00	00	00	00	00	1F
			25	25	16	3	0	0	0	0	0	0	3
8	12.9	11.0	169	137	121	131	0	0	0	0	0	0	123
9	19.6	16.6											
			2E	3F	2F	2F	2F	2F	1F	00	00	00	1F
			5	25	15	15	15	15	3	0	0	0	3
10	22.8	19.3	291	166	137	122	114	111	116	0	0	0	110
11	23.6	20.0											
			2E	2E	3F	2F	2F	2F	1F	1F	00	00	1F
			5	5	24	15	15	15	3	3	0	0	3
12	23.7	20.2	346	235	151	128	118	114	119	111	0	0	111
13	22.7	19.3											
			2E	2E	3F	2F	2F	2F	1F	00	00	00	1F
			5	5	24	15	15	15	3	0	0	0	3
14	21.7	18.5	332	229	149	127	118	113	120	0	0	0	114
15	21.5	18.2											
			2E	3F	2F	2F	2F	1F	1F	00	00	00	1F
			5	23	14	14	14	2	2	0	0	0	2
16	21.0	17.8	256	159	134	120	112	125	119	0	0	0	115
17	19.5	16.6											
			3F	3F	2F	2F	1F	1F	00	00	00	00	1F
			23	23	14	14	2	2	0	0	0	0	2
18	16.6	14.2	149	128	117	109	127	121	0	0	0	0	119
19	13.5	11.5											
			3F	3F	2F	1F	00	00	00	00	00	00	1F
			23	23	14	2	0	0	0	0	0	0	2
20	11.8	10.1	137	122	114	131	0	0	0	0	0	0	127
21	10.8	9.2											
			3F	2F	1F	00	00	00	00	00	00	00	1F
			25	16	3	0	0	0	0	0	0	0	3
22	9.8	8.3	135	123	136	0	0	0	0	0	0	0	129
23	9.7	8.3											
			3F	3F	1F	00	00	00	00	00	00	00	1F
			27	27	4	0	0	0	0	0	0	0	4
24	10.1	8.6	134	121	132	0	0	0	0	0	0	0	124

Figure 5. Computer Print-Out of Circuit MUF, FOT and System Loss

2 TRANSMITTER			JAN			SSN= 25.			GC 2.016			N.MILES		
51.50N - 0.01W			27.92N - 15.67W			212.5 22.2			1581.3			ANT= ODB		
RHOMBIC 23H 96L			67DEG			NOISE= 0			FIELD STRENGTH					
PWR= 30.00KW			OPERATING FREQUENCIES											
GMT	MUF	FOT	3	5	7	9	11	13	15	20	25	30	FOT	
1	10.3	8.8												
			2F	2F	1F	1F	00	00	00	00	00	00	1F	MODE
			18	18	5	5	0	0	0	0	0	0	5	ANGLE
2	10.8	9.2	30	40	40	47	0	0	0	0	0	0	47	DBU
3	10.6	9.0												
			2F	2F	1F	00	00	00	00	00	00	00	1F	MODE
			18	18	4	0	0	0	0	0	0	0	4	ANGLE
4	9.9	8.4	29	40	40	0	0	0	0	0	0	0	44	DBU
5	9.3	7.9												
			2E	2F	00	00	00	00	00	00	00	00	1F	MODE
			5	16	0	0	0	0	0	0	0	0	4	ANGLE
6	8.1	6.9	29	39	0	0	0	0	0	0	0	0	38	DBU
7	8.1	6.9												
			3F	2F	2F	1F	00	00	00	00	00	00	1F	MODE
			25	16	16	3	0	0	0	0	0	0	3	ANGLE
8	12.9	11.0	-5	24	37	39	0	0	0	0	0	0	44	DBU
9	19.6	16.6												
			2E	3F	2F	2F	2F	2F	1F	00	00	00	1F	MODE
			5	25	15	15	15	15	3	0	0	0	3	ANGLE
10	22.8	19.3	-119	-8	21	35	41	45	47	0	0	0	52	DBU
11	23.6	20.0												
			2E	2E	3F	2F	2F	2F	1F	1F	00	00	1F	MODE
			5	5	24	15	15	15	3	3	0	0	3	ANGLE
12	23.7	20.2	-174	-61	4	29	37	42	45	51	0	0	52	DBU
13	22.7	19.3												
			2E	2E	3F	2F	2F	2F	1F	00	00	00	1F	MODE
			5	5	24	15	15	15	3	0	0	0	3	ANGLE
14	21.7	18.5	-160	-55	6	30	38	43	45	0	0	0	50	DBU
15	21.5	18.2												
			2E	3F	2F	2F	2F	1F	1F	00	00	00	1F	MODE
			5	23	14	14	14	2	2	0	0	0	2	ANGLE
16	21.0	17.8	-84	-0	25	38	43	43	47	0	0	0	50	DBU
17	19.5	16.6												
			2F	2F	2F	2F	1F	1F	00	00	00	00	1F	MODE
			14	14	14	14	2	2	0	0	0	0	2	ANGLE
18	16.6	14.2	16	33	42	49	43	47	0	0	0	0	48	DBU
19	13.5	11.5												
			2E	2F	2F	1F	00	00	00	00	00	00	1F	MODE
			5	14	14	2	0	0	0	0	0	0	2	ANGLE
20	11.8	10.1	29	38	45	41	0	0	0	0	0	0	44	DBU
21	10.8	9.2												
			2E	2F	1F	00	00	00	00	00	00	00	1F	MODE
			5	16	3	0	0	0	0	0	0	0	3	ANGLE
22	9.8	8.3	29	39	37	0	0	0	0	0	0	0	42	DBU
23	9.7	8.3												
			2F	2F	1F	00	00	00	00	00	00	00	1F	MODE
			17	17	4	0	0	0	0	0	0	0	4	ANGLE
24	10.1	8.6	29	40	39	0	0	0	0	0	0	0	44	DBU

Figure 6. Computer Print-Out of Circuit MUF, FOT and Received Field Strength

2 TRANSMITTER			JAN			SSN= 25.			GC 2.016			N.MILES		
51.50N - 0.01W			27.92N - 15.67W			212.5 22.2			1581.3					
RHOMBIC 23H 96L			67DEG			NOISE= 3			RHOMBIC 20H 114L 70DEG					
PWR= 30.00KW			OPERATING FREQUENCIES			REQ. S/N= 45DB								
GMT	MUF	FOT	3	5	7	9	11	13	15	20	25	30	FOT	
1	10.3	8.8												
			3F	2F	1F	1F	00	00	00	00	00	00	1F	MODE
			28	18	5	5	0	0	0	0	0	0	5	ANGLE
2	10.8	9.2	59	77	72	84	0	0	0	0	0	0	84	S/N..DB
3	10.6	9.0												
			3F	2F	1F	00	00	00	00	00	00	00	1F	MODE
			28	18	4	0	0	0	0	0	0	0	4	ANGLE
4	9.9	8.4	59	76	70	0	0	0	0	0	0	0	80	S/N..DB
5	9.3	7.9												
			3F	2F	00	00	00	00	00	00	00	00	1F	MODE
			26	16	0	0	0	0	0	0	0	0	4	ANGLE
6	8.1	6.9	58	75	0	0	0	0	0	0	0	0	67	S/N..DB
7	8.1	6.9												
			3F	3F	2F	1F	00	00	00	00	00	00	1F	MODE
			25	25	16	3	0	0	0	0	0	0	3	ANGLE
8	12.9	11.0	23	60	80	73	0	0	0	0	0	0	83	S/N..DB
9	19.6	16.6												
			2E	3F	2F	2F	2F	2F	1F	00	00	00	1F	MODE
			5	25	15	15	15	15	3	0	0	0	3	ANGLE
10	22.8	19.3	-98	31	64	82	92	97	93	0	0	0	102	S/N..DB
11	23.6	20.0												
			2E	2E	3F	2F	2F	2F	1F	1F	00	00	1F	MODE
			5	5	24	15	15	15	3	3	0	0	3	ANGLE
12	23.7	20.2	-153	-37	50	76	88	94	90	102	0	0	102	S/N..DB
13	22.7	19.3												
			2E	2E	3F	2F	2F	2F	1F	00	00	00	1F	MODE
			5	5	24	15	15	15	3	0	0	0	3	ANGLE
14	21.7	18.5	-139	-31	52	77	88	95	89	0	0	0	98	S/N..DB
15	21.5	18.2												
			2E	3F	2F	2F	2F	1F	1F	00	00	00	1F	MODE
			5	23	14	14	14	2	2	0	0	0	2	ANGLE
16	21.0	17.8	-63	38	67	84	94	83	90	0	0	0	96	S/N..DB
17	19.5	16.6												
			3F	3F	2F	2F	1F	1F	00	00	00	00	1F	MODE
			23	23	14	14	2	2	0	0	0	0	2	ANGLE
18	16.6	14.2	43	69	84	95	79	87	0	0	0	0	90	S/N..DB
19	13.5	11.5												
			3F	3F	2F	1F	00	00	00	00	00	00	1F	MODE
			23	23	14	2	0	0	0	0	0	0	2	ANGLE
20	11.8	10.1	55	75	87	73	0	0	0	0	0	0	78	S/N..DB
21	10.8	9.2												
			3F	2F	1F	00	00	00	00	00	00	00	1F	MODE
			25	16	3	0	0	0	0	0	0	0	3	ANGLE
22	9.8	8.3	57	74	65	0	0	0	0	0	0	0	74	S/N..DB
23	9.7	8.3												
			3F	3F	1F	00	00	00	00	00	00	00	1F	MODE
			27	27	4	0	0	0	0	0	0	0	4	ANGLE
24	10.1	8.6	58	76	69	0	0	0	0	0	0	0	80	S/N..DB

Figure 7. Computer Print-Out of Circuit MUF, FOT and Available Signal-to-Noise

1			JAN		SSN= 25.					BR 32.007			
TRANSMITTER					RECEIVER					BEARINGS			
40.75N - 73.93W					32.33N - 64.70W					135.8 321.3			
RHOMBIC 32H 118L			63DEG		NOISE= 3					ANT= 3DB			
PWR= 20.00KW					RELIABILITIES					REQ.S/N= 45DB			
GMT	MUF	FOT	3	5	7	9	11	13	15	20	25	30	FOT
2	5.2	4.4	99	0	0	0	0	0	0	0	0	0	99
4	5.4	4.6	99	0	0	0	0	0	0	0	0	0	99
6	5.7	4.9	99	0	0	0	0	0	0	0	0	0	99
8	5.5	4.7	99	0	0	0	0	0	0	0	0	0	99
10	4.9	4.2	99	0	0	0	0	0	0	0	0	0	99
12	7.4	6.9	99	99	0	0	0	0	0	0	0	0	99
14	11.4	10.6	0	99	99	99	0	0	0	0	0	0	99
16	11.8	11.8	0	97	99	99	99	0	0	0	0	0	99
18	11.5	11.5	0	98	99	99	99	0	0	0	0	0	99
20	11.7	9.9	32	99	99	99	0	0	0	0	0	0	99
22	9.7	8.2	99	99	99	0	0	0	0	0	0	0	99
24	6.5	5.5	99	99	0	0	0	0	0	0	0	0	99

2			JAN		SSN= 25.					GC 2.016			
TRANSMITTER					RECEIVER					BEARINGS			
51.50N - 0.01W					27.92N - 15.67W					212.5 22.2			
RHOMBIC 23H 96L			67DEG		NOISE= 3					RHOMBIC 20H 114L 70DEG			
PWR= 30.00KW					RELIABILITIES					REQ.S/N= 45DB			
GMT	MUF	FOT	3	5	7	9	11	13	15	20	25	30	FOT
2	10.8	9.2	90	99	99	99	0	0	0	0	0	0	99
4	9.9	8.4	90	99	99	0	0	0	0	0	0	0	99
6	8.1	6.9	89	99	0	0	0	0	0	0	0	0	99
8	12.9	11.0	0	98	99	99	0	0	0	0	0	0	99
10	22.8	19.3	0	5	99	99	99	99	99	0	0	0	99
12	23.7	20.2	0	0	81	99	99	99	99	99	0	0	99
14	21.7	18.5	0	0	89	99	99	99	99	0	0	0	99
16	21.0	17.8	0	23	99	99	99	99	99	0	0	0	99
18	16.6	14.2	44	99	99	99	99	99	0	0	0	0	99
20	11.8	10.1	83	99	99	99	0	0	0	0	0	0	99
22	9.8	8.3	87	99	98	0	0	0	0	0	0	0	99
24	10.1	8.6	89	99	99	0	0	0	0	0	0	0	99

Figure 8. Alternative Computer Print-Out of Circuit MUF, FOT and Circuit Reliability

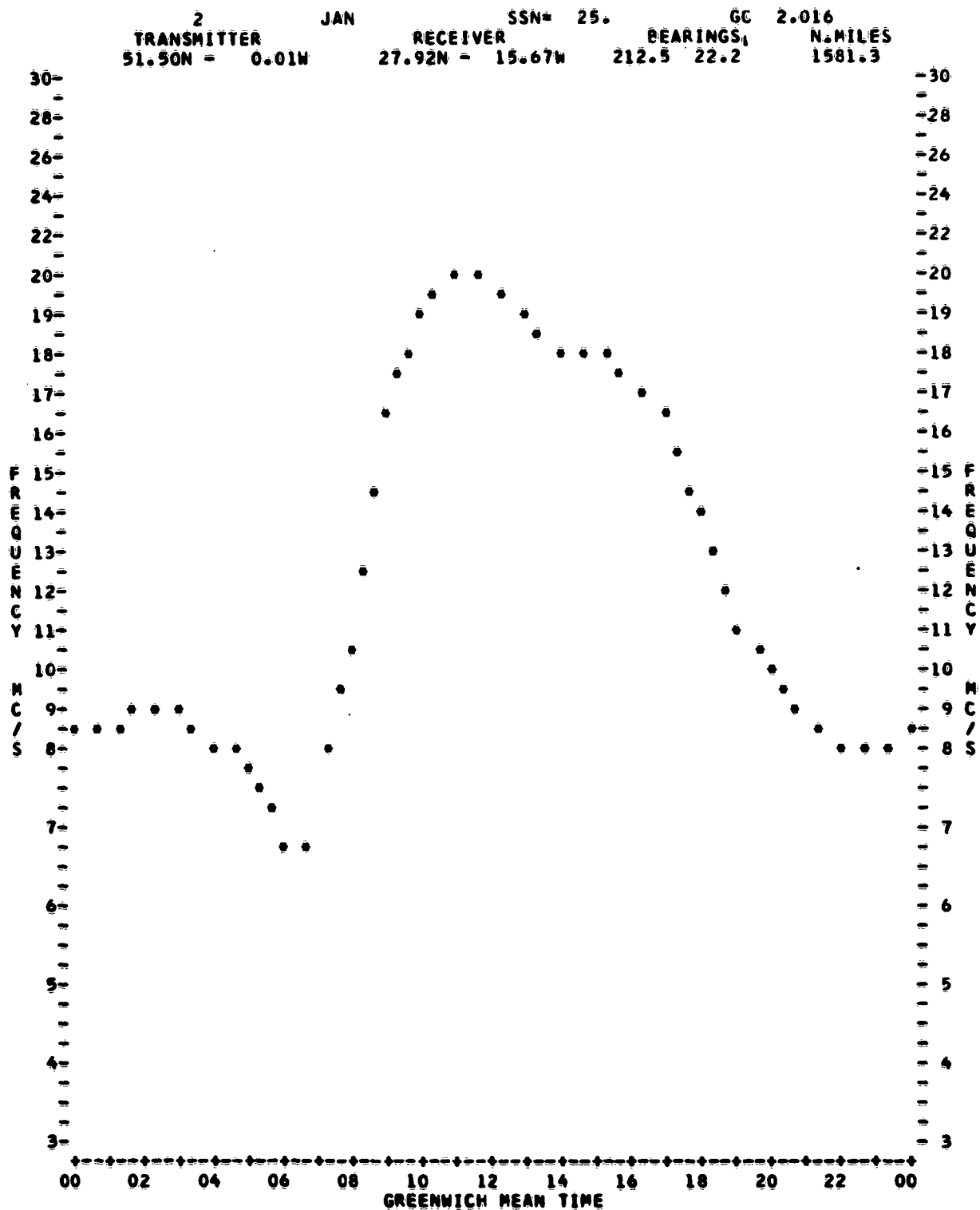


Figure 9. Graphical Representation of Circuit FOT

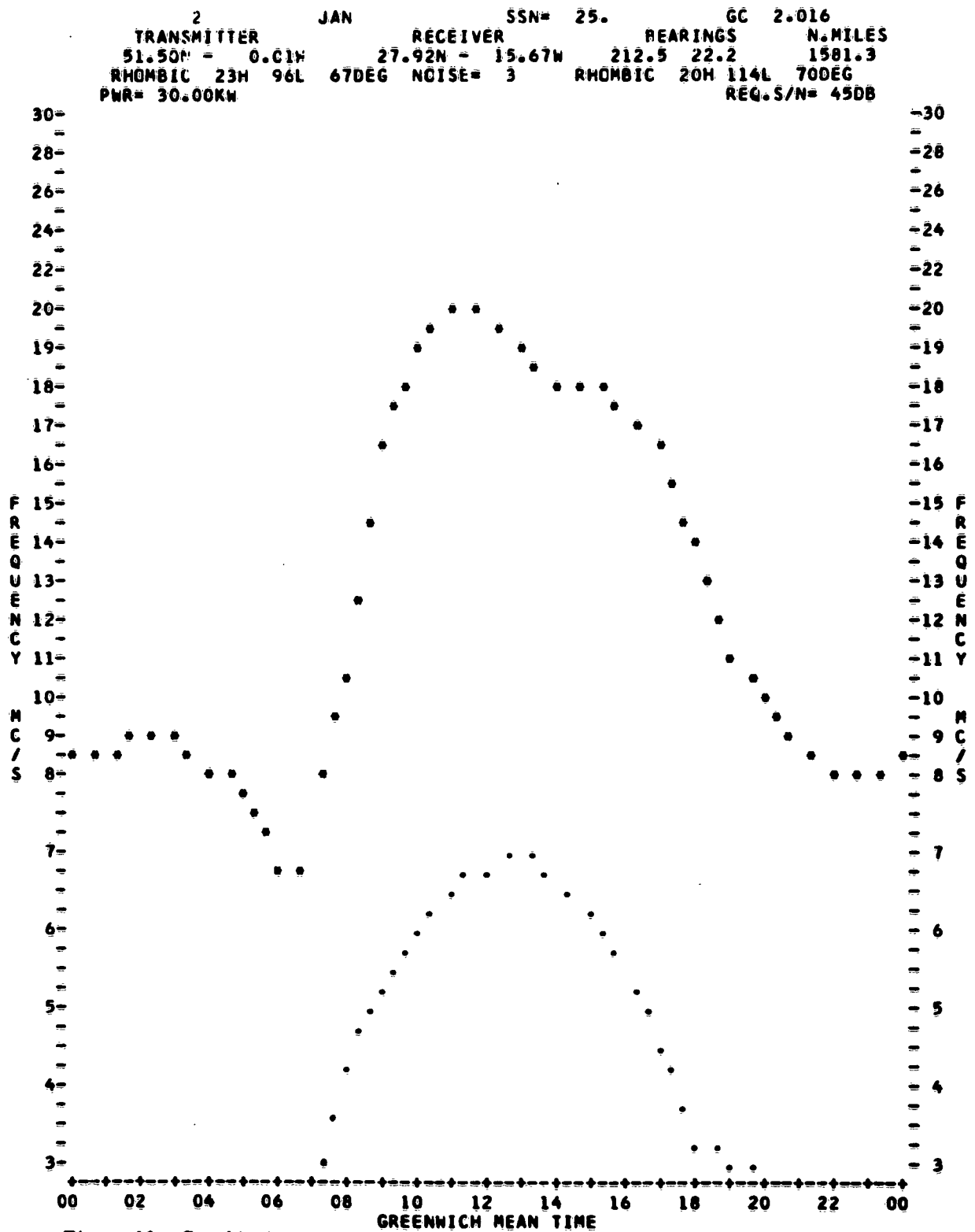


Figure 10. Graphical Representation of Circuit LUF and FOT

DATA FOR HIGH FREQUENCY COMMUNICATION PREDICTIONS

To		
Transmitter Location	Receiver Location	Customer Circuit Number
1. Transmitter Latitude (Degrees in Decimal Form) North = +; South = -		Degrees
2. Transmitter Longitude (Degrees in Decimal Form) West = +; East = -		Degrees
3. Receiver Latitude (Degrees in Decimal Form)		Degrees
4. Receiver Longitude (Degrees in Decimal Form)		Degrees
5. Power Delivered to Transmitting Antenna		KW
6. Transmitting Antenna - Height		Meters
7. - Leg Length		Meters
8. - Tilt Angle		Degrees
9. - Type; Rhombic, $\lambda/2$ Dipole, or Vertical		
10. Transmitting Antenna Gain if Type Other Than Item #9		DB
11. Receiving Antenna - Height		Meters
12. - Leg Length		Meters
13. - Tilt Angle		Degrees
14. - Type; Rhombic, $\lambda/2$ Dipole, or Vertical		
15. Receiving Antenna Gain if Type Other Than Item #14		DB
16. Man-Made Noise at Receiver Input		
Frequency _____ Bandwidth _____ DB < 1 Watt _____		
17. Type of Receiving Area if #16 is Unknown		
Industrial Residential Rural Remote Unpopulous		
18. Required Hourly Median Signal-to-Noise in 1 c/s Bandwidth		DB
19. Detailed Description of Service if #18 is Unknown		
Type of Service, e.g., Radiotelephone	_____	
Modulation, e.g., SSB	_____	
Bandwidth	_____	
Number of Channels	_____	
Words Per Minute Per Channel	_____	
Maximum Teletype Error Rate	_____	
Minimum Radiotelephone Intelligibility	_____	
Diversity Employed	_____	
Any Other Description of Service	_____	
20. Enter Bearing of Transmitting Rhombic Antenna if Off-Great-Circle Path		
21. Enter Bearing of Receiving Rhombic Antenna if Off-Great-Circle Path		
22. Two Letter Code for Receiver Location		

Figure 11

Month and Sunspot Card

Month = 3; Sunspot Number 14

Frequency Complement Card

Frequencies = 3.0000, 5.0000 30.0000

Note: This frequency card should contain only frequencies of the high frequency band (3-30 Mc/s) unless fewer than ten frequencies are desired. In this case, enter 990000 in the unused fields at end of complement.

Figure 12

EXAMPLE DATA DECK FOR RUN UNDER TWO METHODS FROM CARD

[illegible]

Figure 15

EXAMPLE DATA DECK FOR ONE METHOD USING CIRCUITS FROM MAGNETIC TAPE

FORTRAN STATEMENT

Figure 17

VII. PROGRAM OUTPUT

The output is shown in Figures 1 through 10. The output is designed for 9 by 11 standard computer paper.

A description of variables appearing in the print-outs reading left to right:

1. Sequential circuit number appearing in the extreme upper left is generated within the machine and is designed to be useful for ready reference to a master list. Sample: 118

2. Month of year for which predictions are calculated.
Sample: MARCH

3. Sunspot number used in predictions. Sample: SSN = 10.

4. Customer identification number which is generated from a two-letter code for receiver location, bearing (receiver to transmitter), and great circle distance of path. Sample: KD 12.012

5. Transmitter geographic coordinates in hundredths of degrees. Sample: 13.45N - 144.80E

6. Receiver geographic coordinates in hundredths of degrees.
Sample: 26.72N - 127.80E

7. Great circle bearing of transmitter to receiver and bearing of receiver to transmitter. Sample: 312.4 - 126.5

8. Type of antenna used at transmitting terminal. Sample:
Rhombic 12H 39L 58 Deg.

H - height in meters

L - leg length in meters

Deg = tilt angle in degrees

9. Level of man-made noise at receiver site. Sample:
NOISE = 3

10. Type of antenna used at receiving terminal. Sample:
VERTICAL - 14H 0L ODEG.

The -14H indicates the grounded vertical is $1/4 (\lambda)$. The same analogy would apply for -12H ($\lambda/2$), -1H (λ), etc. A print-out without the minus indicates the vertical height in meters (e.g., 13H indicates the grounded vertical is 13 meters high).

11. Great circle distance of path in nautical miles. Sample: N. Miles 1243.2

12. The effective power delivered to the transmitting antenna. Sample: PWR = 20.00 kw

13. The required signal-to-noise in a one-cycle band (db > 1 watt) at receiving antenna terminals. Sample: REQ. S/N = 45 db

14. Greenwich mean time. Sample: GMT

15. Maximum Usable Frequency. Sample: MUF

16. Optimum Traffic Frequency. Sample: FOT

17. Truncated numbers representing the frequency complement card (Figure 14). Sample 4, 6, 8 23

18. Probable mode associated with least loss. Sample: 3F, 4E and 4X. 4X indicates propagation by E and F_2 region using four hops.

19. The theoretical angle of arrival associated with the most probable mode of propagation. Sample: 20

20. Reliability defined as the per cent of days with the month the available signal-to-noise will be adequate. Sample: Reliability

21. Signal-to-noise defined as the available monthly median. Sample: S/N db

22. System loss defined as the ratio of the power delivered to the transmitting antenna relative to that available at the receiving antenna terminals. Transmission loss may be obtained by using isotropic antennas. Sample: Loss . . . db

23. The Lowest Useful High Frequency defined as the lowest frequency that will give 90% reliability at a given hour. Sample: LUF

24. A zero appearing in the LUF column denotes a LUF greater than the FOT.

25. A -3 in the LUF column denotes a LUF below 3 Mc/s.

26. A calculation in any method showing all zeros denotes a frequency for which the calculation was not completed due to mode limitations or the primary calculation for the desired mode exceeded the absolute value 999.

VIII. COMPLETE FORTRAN LISTING OF COMPUTER PROGRAM FOR PREDICTING HF SYSTEM PERFORMANCE

```

C MUFLUF....H-F PREDICTIONS BY D.L.LUCAS AND G.W.HAYDON .....CRPL.....
C FORMATS AND STORAGE ASSIGNMENTS
6 FORMAT(10F7.4) 0001
1 FORMAT(2(F5.2,F6.2),I2,5F3.0,I2,3F3.0,I2,I3,F3.0,2F4.0,4X,A2) 0002
3 FORMAT(10X,I5,10X,A6, 10X,4HSSN=F5.0,10X,A2,F7.3/9X, 11HTR 0003
2ANSMITTER,13X,8HRECEIVER,12X,8HBEARINGS,6X,7HN,MILES/7X ,F6.2,A1, 0004
32H - ,F7.2,A1,5X,F6.2,A1,2H - ,F7.2,A1,3X,2F6.1,4X,F8.1) 0005
4 FORMAT (F10.0) 0006
5 FORMAT(4I2) 0007
676 FORMAT(12A6) 0008
7 FORMAT(1X/6X, 0009
43HGMT,2X,3HMUF,3X,3HFOT,3(5X,3HGMT,2X,3HMUF,3X,3HFOT)/ 1H04(4X,I3, 0010
52F6.1)/1H04(4X,I3,2F6.1)/1H04(4X,I3,2F6.1)/1H04(4X,I3,2F6.1)/1H04( 0011
64X,I3,2F6.1)/1H04(4X,I3,2F6.1)/1H A1) 0012
DIMENSION AMON(12), GLAT(5),ABI(24),ABIY(5,24),CLCK(24),GY(5), 0013
1F2S(5,24),F2H(5,24),GML(5,24),GMH(5,24),MF(3),ME(2) 0014
2,ELD(10),FLD(10),F24(5),GMA(5),ADJ(4),ABC(12) 0015
DIMENSION RD(5),SUN(12),A(10,7,14),RASSN(12),EMF(5,24) 0016
DIMENSION Q(20,60,4),IL(4),JL(4),KL(4),LK(4),JAL(4) ,CKC(24) 0017
1,G(60),AB(60),S(20,24),C(20,24),GAMMA(5,24),BA(50) 0018
DIMENSION CLAT(5),CLONG(5),EMUFY(5,24),FMUFY(5,24), UFY(5),FOTY(5) 0019
5,IG(24) 0020
DIMENSION UF(24),FOT(24),P(29,16,6),ABP(2,6) 0021
DIMENSION AHA(2),ARA(2),AVA(2) 0022
DIMENSION X1XX(12) 0023
DIMENSION FREL(12) 0024
COMMON ABP,P 0025
COMMON A,Q,G,AB,S,C,GAMMA,BA,EMUFY,FMUFY,IG,UF,FOT,SUN,AVA,ARA,GLA 0026
1T,ABI,ABIY,CLCK,GY,F2S,F2H,GML,GMH,MF,ME,ELD,FLD,F24,GMA,ADJ,ABC, 0027
2EMF,CKC,CLAT,CLONG,AK,BK,CK,DK,PI2,EK,EEK,GLT,GLG,AAA,ALA,ASA, 0028
3AFC,ANC,AWC,AEC,ASC,AZZ,MAN,RSN,KW,PWR,IANT,IANR,Y2,X2,MOUSE,SSN, 0029
4NOCIR,K4, AX,XLONG,AL,YLAT,XLAT,YLONG,YL,BTRY,GCDKM,GCDNM,K1,K2,K 0030
53,K5,GCD,IRSN,MON,ID,MOUSE,AY,METHOD,AHA,BMONS,MAP 0031
COMMON FREL 0032
COMMON XNH,XNL,XND,RNH,RNL,RND,HA,JIG,HAR,XTR,XETA,WETA,IHR,MIT 0033
REWIND 2 0034
REWIND 3 0035
909 FORMAT(1H1) 0036
DO 101 I=1,24 0037
101 IG(I)=I 0038

```

C CONSTANTS TO BE USED FREQUENTLY

	AK=1.745929E-2	0039
	BK=5.729577E1	0040
	CK=1.11136E2	0041
	DK=.0062137	0042
	PI2=1.57079	0043
	EK=.539956	0044
	EEK=.6214	0045
	GLT=78.*AK	0046
	GLG=70.*AK	0047
B	AMON(1)=412145606060	0048
B	AMON(2)=262522606060	0049
B	AMON(3)=442151606060	0050
B	AMON(4)=214751606060	0051
B	AMON(5)=442170606060	0052
B	AMON(6)=416445606060	0053
B	AMON(7)=416443606060	0054
B	AMON(8)=216427606060	0055
B	AMON(9)=622547606060	0056
B	AMON(10)=462363606060	0057
B	AMON(11)=454665606060	0058
B	AMON(12)=242523606060	0059
B	AAA=606060606060	0060
B	AFC=266060606060	0061
B	AHA(1)=606060603040	0062
B	AHA(2)=243147464325	0063
B	AVA(1)=606060606525	0064
B	AVA(2)=516331232143	0065
B	ARA(1)=606060606051	0066
B	ARA(2)=304644223123	0067
B	AZZ=006060606060	0068
B	ANC=456060606060	0069
B	AWC=666060606060	0070
B	AEC=256060606060	0071
B	ASC=626060606060	0072
B	FNINE=111111111111	0073
	SUN(1)=-21.	0074
	SUN(2)=-13.	0075
	SUN(3)=-03.	0076
	SUN(4)=09.	0077

SUN(5)=18.	0078
SUN(6)=23.	0079
SUN(7)=21.	0080
SUN(8)=14.	0081
SUN(9)=04.	0082
SUN(10)=-08.	0083
SUN(11)=-14.	0084
SUN(12)=-23.	0085
ADJ(1)=9.	0086
ADJ(2)=17.	0087
ADJ(3)=20.	0088
ADJ(4)=28.	0089
C READ CIRCUIT DATA AND SEARCH DATA TAPE	
WRITE OUTPUT TAPE 6,909	0090
464 READ INPUT TAPE 5,5.	0091
1 METHOD,METH,IHR,MAP	0092
READ INPUT TAPE 5,6,(FREL(I),I=1,10)	0093
MIT=1	0094
IF (METHOD) 463,12,463	0095
12 REWIND 2	0096
WRITE OUTPUT TAPE 6,909	0097
REWIND 3	0098
CALL EXIT	0099
463 L1=2	0100
GO TO (30,30,30,30,31,30),METHOD	0101
30 L1=1	0102
31 NOCIR= 0	0103
MONTH=0	0104
IF(METH) 7770,7771,7770	0105
7770 READ INPUT TAPE 5,676,X1XX	0106
WRITE OUTPUT TAPE 3,676,X1XX	0107
IF(FNINE-X1XX(1)) 7770,7771,7770	0108
7771 REWIND 3	0109
85 READ INPUT TAPE 5,1.	0110
1 X1X,Y1Y,X2X,Y2Y,MONS,SUNS,TWR,XNHO,XNLO,XNDO,ITANT,RNHO,RN	0111
1LO,RNDO,IRANT,MANN,RRSN,XETA,WETA,HAO	0112
10 X1=X1X	0113
Y1=Y1Y	0114
X2=X2X	0115
Y2=Y2Y	0116

IANT=ITANT	0117
IANR=IRANT	0118
MAN=MANN	0119
RSN=RRSN	0120
IRSN=RSN	0121
PWR=TWR	0122
XNH=XNHO	0123
XNL=XNLO	0124
XND=XNDO	0125
RNH=RNHO	0126
RNL=RNLO	0127
RND=RNDO	0128
HA=HAO	0129
IF(MONS) 464,11,82	0130
82 LOCK= MONS-MONTH-1	0131
SSN=SUNS	0132
MONTH=MONS	0133
MOUSE=MONS	0134
KZ=1	0135
READ INPUT TAPE3,1,X1X,Y1Y,X2X,Y2Y,MONS,SUNS,TWR,XNHO,XNLO,XNDO,	0136
1ITANT,RNHO,RNLO,RNDO,IRANT,MANN,RRSN,XETA,WETA,HAO	0137
GO TO 10	0138
11 GO TO (15,77),KZ	0139
15 NOCIR=0	0140
WRITE OUTPUT TAPE 6,909	0141
62 JIG=0	0142
MIT=1	0143
KZ=2	0144
IF(LOCK) 77,731,33	0145
33 DO730 IU=1,LOCK	0146
730 READ TAPE 2	0147
731 READ TAPE 2,IL,JL,KL,LK,JAL,Q,A,P,ABP	0148
77 READ INPUT TAPE3,1,X1X,Y1Y,X2X,Y2Y,MONS,SUNS,TWR,XNHO,XNLO,XNDO,	0149
1ITANT,RNHO,RNLO,RNDO,IRANT,MANN,RRSN,XETA,WETA,HAO	0150
IF(91.-X1X) 78,78,16	0151
78 REWIND 3	0152
READ INPUT TAPE 5,1,	0153
1 X1X,Y1Y,X2X,Y2Y,MONS,SUNS,TWR,XNHO,XNLO,XNDO,ITANT,RNHO,RN	0154
1LO,RNDO,IRANT,MANN,RRSN,XETA,WETA,HAO	0155
IF(MONS) 83,16,83	0156

83 IF(MONS-MONTH) 84,16,16	0157
84 REWIND 2	0158
MONTH=0	0159
16 SSP=SUN(MOUSE)*AK	0160
BMONS=AMON(MOUSE)	0161
NOCIR=NOCIR+1	0162
JIP=1	0163
JEP=1	0164
C GREAT CIRCLE DISTANCE AND DISTANCE TO CONTROL POINTS	
XX1=X1*AK	0165
XX2=X2*AK	0166
YY1=Y1*AK	0167
YY2=Y2*AK	0168
GCD=SINF(XX1)*SINF(XX2)+COSF(XX1)*COSF(XX2)*COSF(YY2-YY1)	0169
GCD=ACOSF(GCD)	0170
RD(1)=GCD/2.	0171
RD(2)=18.*AK	0172
RD(3)=GCD-18.*AK	0173
RD(4)=9.*AK	0174
RD(5)=GCD-9.*AK	0175
GCDKM=GCD*CK*BK	0176
GCDNM=GCDKM*EK	0177
C BEARINGSS-- FORWARD AND BACKWARD	
DF=YY2-YY1	0178
IF(ABSF(DF)-3.141592654) 26,22,22	0179
22 IF(DF) 24,25,25	0180
24 DF=6.283185308+DF	0181
GO TO 26	0182
25 DF=-6.283185308+DF	0183
26 U=.5*(PI2-XX1+PI2-XX2+GCD)	0184
CIND=SINF(U)*SINF(U-PI2+XX1)	0185
IF(CIND) 27,28,27	0186
27 BTRY=114.5816*ATANF(SQRTF(ABSF(SINF(U-PI2+XX2)*SINF(U-GCD))/CIND))	0187
IF(DF) 7029,21,39	0188
21 IF(XX1-XX2) 28,39,39	0189
28 BTRY=180.	0190
GO TO 39	0191
7029 BTRY=360.-BTRY	0192
39 RF=YY1-YY2	0193
IF(ABSF(RF)-3.141592654) 126,122,122	0194

122 IF(RF) 124,125,125	0195
124 RF=6.283185308+RF	0196
GO TO 126	0197
125 RF=-6.283185308+RF	0198
126 U=.5*(PI2-XX2+PI2-XX1+GCD)	0199
CIND=SINF(U)*SINF(U-PI2+XX2)	0200
IF(CIND) 57,778,57	0201
57 XTR=114.5816*ATANF(SQRTF(ABSF(SINF(U-PI2+XX1)*SINF(U-GCD))/CIND))	0202
IF(RF) 8029,51,79	0203
51 IF(XX2-XX1)778,79,79	0204
778 XTR=180.	0205
GO TO 79	0206
8029 XTR =360.-XTR	0207
79 IF(4000.-GCDKM) 40,41,41	0208
40 K1=1	0209
K2=2	0210
K3=3	0211
K4=4	0212
K5=5	0213
GO TO 43	0214
41 K1=1	0215
K2=1	0216
K3=1	0217
K4=1	0218
K5=1	0219
C CONTROL POINT LOCAL TIME , GEOGRAPHIC LATITUDE AND LONGITUDE	
43 DO 61 IT=L1,24,L1	0220
GMT = IT	0221
COLO=GMT-Y2/15.	0222
IF(24.-COLO) 94,95,95	0223
94 COLO=COLO-24.	0224
GO TO 96	0225
95 IF(COLO) 98,98,96	0226
98 COLO=COLO+24.	0227
96 CKC(IT)=COLO	0228
SSL=(15.*GMT-180.)	0229
DO 61 II=K1,K5	0230
PP=RD(II)	0231
CENLAT=COSE(PP)*COSE(PI2-XX2)+SINF(PP)	0232
1*SINF(PI2-XX2)*COSE(BTRY*AK)	0233

CENLAT=(PI2-ACOSF(CENLAT))*BK	0234
CENLG= ((COSF(PP)-COSF(PI2-XX2)*COSF(PI2-CENLAT*AK))/(SINF(PI2	0235
1-XX2)*SINF(PI2-CENLAT*AK)))	0236
IF(ABSF(CENLG)=1.) 3001,3001,3000	0237
3000 CENLG=1.	0238
3001 CENLG=ACOSF(CENLG)	0239
CENLG=(YY2-SIGNF(CENLG,DF))*BK	0240
IF(180.-ABSF(CENLG)) 71,69,69	0241
71 IF(CENLG) 73,72,72	0242
73 CENLG=360.+CENLG	0243
GO TO 69	0244
72 CENLG=CENLG-360.	0245
C GEOMAGNETIC LOCATION OF CONTROL POINTS	
69 GAT=ACOSF(SINF(GLT)*SINF(CENLAT*AK)+COSF(GLT)*COSF(CENLAT*AK)*	0246
1COSF(CENLG*AK-GLG))	0247
GLAT(II)=PI2-GAT	0248
CLAT(II)=CENLAT	0249
70 CLONG(II)=CENLG	0250
C SUNS ZENITH ANGLE	
Z=(SSL-CENLG)*AK	0251
56 CYCEN=SINF(CENLAT*AK)*SINF(SSP)+COSF(CENLAT*AK)*COSF(SSP)*COSF(Z)	0252
CYCEN=ACOSF(CYCEN)	0253
CYCEN=ABSF(CYCEN)	0254
C ABSORPTION INDEX 1 AT CONTROL POINTS	
32 IF(102.*AK-CYCEN) 58,58,59	0255
58 ABIY(II,IT)=0.	0256
GO TO 886	0257
59 ABIY(II,IT)=(1,+.0037*SSN)*COSF(.881*CYCEN)**1.3	0258
886 GO TO (165,166),K2	0259
165 ABI(IT)=ABIY(II,IT)	0260
GO TO 61	0261
166 ABI(IT)=(ABIY(1,IT)+ABIY(2,IT)+ABIY(3,IT))/3.	0262
61 CONTINUE	0263
DO 2112 II=K1,K5	0264
DO 2112 IT=L1,24,L1	0265
ABIC=ABIY(II,IT)	0266
C E-LAYER DISTANCE FACTOR	
ARC=DK*GCDKM	0267
IF(16.-ARC) 88,87,87	0268
87 ELFC=(((((-4.368460907E-9*ARC+1.334494261E-7)*ARC-5.976618436E-6)	0269

1*ARC+2.624808315E-4)*ARC-5.038476266E-3)*ARC+3.761385053E-2)*ARC-1	0270
2.133200756E-2)*ARC+.2085	0271
GO TO 100	0272
88 ELFC=1.02	0273
C E-2000 CONTROL POINT MUF	
100 EMC=(((-10.66484998*ABIC+39.26151056)*ABIC-52.41191754)*ABIC+37.67	0274
1726072)*ABIC+3.345996232	0275
EMF(II,IT)=EMC	0276
2112 EMUFY(II,IT)=EMC*ELFC	0277
C GENERATE CONTROL POINT FOF2 AND M-3000 FACTORS	
DO 1112 II=K2,K3	0278
504 CENLG=CLONG(II)	0279
CENLAT=CLAT(II)	0280
IF(CENLG) 412,414,414	0281
414 CLG=360.-CENLG	0282
GO TO 413	0283
412 CLG=ABSF(CENLG)	0284
413 BOY=SINF(CLG*AK)	0285
COG=SINF(2.*CLG*AK)	0286
DOG=COSF(2.*CLG*AK)	0287
GOB=COSF(CENLAT*AK)	0288
BOG=SINF(CENLAT*AK)	0289
HOG=COSF(CLG*AK)	0290
DO 500 IO=1,4	0291
415 I=IL(IO)	0292
J=JL(IO)	0293
K=KL(IO)	0294
L=LK(IO)	0295
JA=JAL(IO)	0296
DO 408 KA=1,K	0297
KP=KA-1	0298
408 G(KA)=BOG**KP	0299
LA=0	0300
LO=L-1	0301
KK=K+1	0302
DO 409 KA=KK,LO,2	0303
G(KA)=BOG**LA*GOB*HOG	0304
G(KA+1)=BOG**LA*GOB*BOY	0305
409 LA=LA+1	0306
LB=0	0307

LL=L+1	0308
IM=I-1	0309
DO 410 KA=LL,IM,2	0310
G(KA)=BOG**LB*GOB**2*DOG	0311
G(KA+1)=BOG**LB*GOB**2*COG	0312
410 LB=LB+1	0313
DO 411 JB=1,J	0314
AB(JB)=0.	0315
IS=2*JB-1	0316
DO 411 KA=1,I	0317
411 AB(JB)=AB(JB)+Q(IS,KA,IO)*G(KA)	0318
DO 407 JB=2,J	0319
BA(JB)=0.	0320
IS=2*JB-2	0321
DO 407 KA=1,I	0322
407 BA(JB)=BA(JB)+Q(IS,KA,IO)*G(KA)	0323
DO 500 IT=L1,24,L1	0324
503 GMT=IT	0325
CLOCK=GMT-CENLG/15.	0326
IF(24.-CLOCK) 64,65,65	0327
64 CLOCK=CLOCK-24.	0328
GO TO 66	0329
65 IF(CLOCK) 68,68,66	0330
68 CLOCK=CLOCK+24.	0331
66 CLCK(IT)=CLOCK	0332
TIME=(15.*CLOCK-180.)*AK	0333
DO 998 JB=2,J	0334
FB=JB-1	0335
S(JB,IT)=SINF(FB*TIME)	0336
998 C(JB,IT)=COSF(FB*TIME)	0337
GAMMA(IO,IT)=AB(1)	0338
DO 500 JB=2,J	0339
500 GAMMA(IO,IT)=GAMMA(IO,IT)+AB(JB)*C(JB,IT)+BA(JB)*S(JB,IT)	0340
C F2-REGION GYRO=FREQUENCY	
132 CALL POLY(1,7,7,CENLG/180.,CENLAT/90.,Y)	0341
GYRO=Y/2.	0342
GY(IT)=Y	0343
C F2-LAYER CONTROL POINT F2=4000 MUF	
DO 1112 IT=L1,24,L1	0344
F2LS=GAMMA(1,IT)*GAMMA(3,IT)*1.1	0345

F2S(11,IT)=F2LS	0346
F2HS=GAMMA(2,IT)*GAMMA(4,IT)*1.1	0347
F2H(11,IT)=F2HS	0348
C F2=LAYER DISTANCE FACTOR	
IF(24.-ARC) 157,157,158	0349
157 FLFC=1.	0350
GO TO 159	0351
158 FLFC=((((-6.712654756E-9*ARC+4.49151441E-7)*ARC-9.985831104E-6)*	0352
1ARC+6.865259817E-5)*ARC+9.202437332E-5)*ARC+2.264634341E-3)*ARC+4.	0353
2699243101E-3)*ARC	0354
159 GAMMA(1,IT)=GAMMA(1,IT)+GYRO	0355
GAMMA(2,IT)=GAMMA(2,IT)+GYRO	0356
FMLS=GAMMA(1,IT)+FLFC*(F2LS-GAMMA(1,IT))	0357
GML(11,IT)=GAMMA(1,IT)	0358
FMHS=GAMMA(2,IT)+FLFC*(F2HS-GAMMA(2,IT))	0359
GMH(11,IT)=GAMMA(2,IT)	0360
C F2=LAYER CONTROL POINT MUF	
FMUFY(11,IT)=(FMLS*(180.-SSN)+FMHS*(SSN-10.))/170.	0361
1112 CONTINUE	0362
C CIRCUIT MUF AND FOT	
DO 1012 IT=L1,24,L1	0363
GMT=IT	0364
DO 1000 II=K2,K3	0365
IF(K2-1) 602,603,602	0366
603 IR=1	0367
GO TO 604	0368
602 IR=II+2	0369
604 IF(EMUFY(IR,IT)-FMUFY(11,IT)) 1007,1007,1008	0370
1007 UFY(11)=FMUFY(11,IT)	0371
GO TO 1009	0372
1008 UFY(11)=EMUFY(IR,IT)	0373
1009 FOTFY=.85*FMUFY(11,IT)	0374
IF(EMUFY(IR,IT)-FOTFY) 1010,1011,1011	0375
1010 FOTY(11)=FOTFY	0376
GO TO 1000	0377
1011 FOTY(11)=EMUFY(IR,IT)	0378
1000 CONTINUE	0379
II=K2	0380
IF(1-II) 606,605,606	0381
605 UF(IT)=UFY(1)	0382

FOT(IT)=FOTY(1)	0383
GO TO 1012	0384
606 IF (UFY(2)=UFY(3)) 607,607,608	0385
607 UF(IT)=UFY(2)	0386
GO TO 609	0387
608 UF(IT)=UFY(3)	0388
609 IF (FOTY(2)=FOTY(3)) 610,610,611	0389
610 FOT(IT)=FOTY(2)	0390
GO TO 1012	0391
611 FOT(IT)=FOTY(3)	0392
1012 CONTINUE	0393
IRY=BTRY/10.	0394
TRY=IRY	0395
HAR=TRY+.00001*GCDNM	0396
XLAT=ABSF(X1)	0397
XLONG=ABSF(Y1)	0398
YLAT=ABSF(X2)	0399
YLONG=ABSF(Y2)	0400
AX=ANC	0401
IF(X1) 700,701,701	0402
700 AX=ASC	0403
701 AL=AWC	0404
IF(Y1) 702,703,703	0405
702 AL=AEC	0406
703 AY=ANC	0407
IF(X2) 704,705,705	0408
704 AY=ASC	0409
705 YL=AWC	0410
IF(Y2) 706,2221,2221	0411
706 YL=AEC	0412
2221 GO TO (2223,2224,2224,2224,2224,2224),METHOD	0413
2223 IF(MAP) 3223,3223,3224	0414
3224 CALL CURVY(FOT,UF)	0415
GO TO 10	0416
3223 WRITE OUTPUT TAPE 6,3,NOCIR,BMONS,SSN,HA,HAR,XLAT,AX,XLONG,AL,	0417
1YLAT,AY,YLONG,YL,XTR,BTRY,GCDNM	0418
WRITE OUTPUT TAPE 6,7,	0419
1 (IG(I),UF(I),FOT(I),IG(I+6),UF(I+6),FOT(I+6),IG(I+12),	0420
2 UF(I+12),FOT(I+12),IG(I+18),UF(I+18),FOT(I+18),I=1,6),AAA	0421
IF(3-MIT) 969,969,970	0422

969 WRITE OUTPUT TAPE 6,909	0423
MIT=1	0424
GO TO 10	0425
970 MIT=MIT+1	0426
GO TO 10	0427
2224 CALL LUFFY	0428
GO TO 10	0429
END	0430

	SUBROUTINE LUFFY	0001
C	FORMATS AND STORAGE ASSIGNMENTS	
	DIMENSION FDEK(10),EDEK(10)	0002
	DIMENSION AMON(12), GLAT(5),ABI(24),ABIY(5,24),CLCK(24),GY(5),	0003
	1F2S(5,24),F2H(5,24),GML(5,24),GMH(5,24),MF(3),ME(2),ELL(10),FLL(10	0004
	2),ELD(10),EDEL(10),FLD(10),FDEL(10),F24(5),GMA(5),FLF(10),FSKY(10)	0005
	3,ESKY(10),GE(10),GF(10),FSE(10),FSF(10),NOS(11),FXMT(10),EXMT(10),	0006
	4FRCR(10),ERCR(10),ADJ(4),ABC(12),MODE(12)	0007
	DIMENSION Q(20,60,4),IL(4),JL(4),KL(4),LK(4),JAL(4),CKC(24)	0008
	1,G(60),AB(60),S(20,24),C(20,24),GAMMA(5,24),BA(60)	0009
	DIMENSION RD(5),SUN(12),A(10,7,14),RASSN(12),EMF(5,24)	0010
	DIMENSION CLAT(5),CLONG(5),EMUFY(5,24),FMUFY(5,24),UFY(5),FOTY(5)	0011
	5,IG(24)	0012
	DIMENSION UF(24),FOT(24),FF(24),P(29,16,6),ABP(2,6)	0013
	DIMENSION AHA(2),ARA(2),AVA(2),RANT(2),TANT(2)	0014
	DIMENSIONNXLOS(11),NANGLE(11)	0015
	DIMENSION TOP(4)	0016
	DIMENSION IFR(10)	0017
	DIMENSION FREL(12)	0018
	COMMON ABP,P	0019
	COMMON A,Q,G,AB,S,C,GAMMA,BA,EMUFY,FMUFY,IG,UF,FOT,SUN,AVA,ARA,GLA	0020
	1T,ABI,ABIY,CLCK,GY,F2S,F2H,GML,GMH,MF,ME,ELD,FLD,F24,GMA,ADJ,ABC,	0021
	2EMF,CKC,CLAT,CLONG,AK,BK,CK,DK,PI2,EK,EEK,GLT,GLG,AAA,ALA,ASA,	0022
	3AFC,ANC,AWC,AEC,ASC,AZZ,MAN,RSN,KW,PWR,IANT,IANR,Y2,X2,MOUSE,SSN,	0023
	4NOCIR,K4, AX,XLONG,AL,YLAT,XLAT,YLONG,YL,BTRY,GCDKM,GCDNM,K1,K2,K	0024
	53,K5,GCD,IRSN,MON,ID,MOUSE,AY,METHOD,AHA,SMONS,MAP	0025
	COMMON FREL	0026
	COMMON XNH,XNL,XND,RNH,RNL,RND,HA,JIG,HAR,XTR,XETA,WETA,IHR,MIT	0027
	COMMON KAP,KUP,MA,TANT,INH,INL,IND,RANT,JNH,JNL,JND	0028
	2 FORMAT(2X,2A6,1X,I3,1HH,1X,I3,1HL,1X,I3,3HDEG,12X,6HNOISE=I3,12X,4	0029
	1HANT=I3,2HDB)	0030
	1 FORMAT(2X,2A6,1X,I3,1HH,1X,I3,1HL,1X,I3,3HDEG,4X,6HNOISE=I3,2A6,1X	0031
	1,I3,1HH,1X,I3,1HL,1X,I3,3HDEG)	0032
	80 FORMAT(6X,4HPWR=F6,2,2HKW,11X,21HOPERATING FREQUENCIES,9X,14HFIELD	0033
	1 STRENGTH/5X,14HGMT MUF FOT,1X,10I4,4H FOT)	0034
	3 FORMAT(10X,I5,10X,A6, 10X,4HSSN=F5,0,10X,A2,F7,3/9X, 11HTR	0035
	2ANSMITTER,13X,8HRECEIVER,12X,8HBEARINGS,6X,7HN,MILES/7X ,F6,2,A1,	0036
	32H - ,F7,2,A1,5X,F6,2,A1,2H - ,F7,2,A1,3X,2F6,1,4X,F8,1)	0037
	4 FORMAT(6X,4HANT=I3,2HDB,13X,6HNOISE=I3,7X,2A6,1X,I3,1HH,1X,I3,1HL,	0038
	11X,I3,3HDEG)	0039

9	FORMAT(4X,I3,2F6.1/20X,11(I3,A1),6H MODE/20X,11I4,7H ANGLE/4X,	0040
	2I3,2F6.1,1X,11I4,13H RELIABILITY)	0041
12	FORMAT(1X,A2,F7.3,I5,2F10.2)	0042
13	FORMAT(6X,4HANT=I3,2HDB,20X,6HNOISE=I3,20X,4HANT=I3,2HDB)	0043
14	FORMAT(6X,4HPWR=F6.2,2HKW,11X,21HOPERATING FREQUENCIES,10X,8HREQ.S	0044
	1/N=I3,2HDB/5X,14HGMT MUF FOT,1X,10I4,4H FOT)	0045
29	FORMAT(4X,I3,2F6.1/20X,11(I3,A1),6H MODE/20X,11I4,7H ANGLE/4X,	0046
	2I3,2F6.1,1X,11I4,9H S/N..DB)	0047
34	FORMAT(6X,4HPWR=F6.2,2HKW,16X,13HRELIABILITIES,13X,8HREQ.S/N=I3,2H	0048
	1DB/9X,14HGMT MUF FOT,1X,10I4,9H FOT MCS)	0049
7	FORMAT (6X,	0050
	43HGMT,2X,3HLUF,3X,3HFOT,3(5X,3HGMT,2X,3HLUF,3X,3HFOT)/1H04(4X,I3,	0051
	52F6.1)/1H04(4X,I3,2F6.1)/1H04(4X,I3,2F6.1)/1H04(4X,I3,2F6.1)/1H04(	0052
	64X,I3,2F6.1)/1H04(4X,I3,2F6.1)/1H A1)	0053
8	FORMAT(31X,21HOPERATING FREQUENCIES/5X,14HGMT MUF FOT,1X,10I4,	0054
	14H FOT)	0055
19	FORMAT(4X,I3,2F6.1/20X,11(I3,A1),6H MODE/20X,11I4,7H ANGLE/4X,	0056
	2I3,2F6.1,1X,11I4,10H LOSS..DB)	0057
59	FORMAT(4X,I3,2F6.1/20X,11(I3,A1),6H MODE/20X,11I4,7H ANGLE/4X,	0058
	2I3,2F6.1,1X,11I4,5H DBU)	0059
24	FORMAT(6X,4HPWR=F6.2,2HKW,42X,8HREQ.S/N=I3,2HDB)	0060
70	FORMAT(6X,3HGMT,2X,3HLUF,3X,3HFOT,3(5X,3HGMT,2X,3HLUF,3X,3HFOT)/1	0061
	1H04(4X,I3,6X,F6.1)/1H04(4X,I3,2F6.1)/1H04(4X,I3,6X,F6.1)/1H04(4X,I	0062
	23,2F6.1)/1H04(4X,I3,6X,F6.1)/1H04(4X,I3,2F6.1)/1H A1)	0063
94	FORMAT(8X,I3,2F6.1,1X,11I4)	0064
907	FORMAT(1H0/1H0/1H0)	0065
908	FORMAT(1H)	0066
909	FORMAT(1H1)	0067
	FREL(11)=500.	0068
	FREL(12)=500.	0069
	DO 6461 IA=1,10	0070
6461	IFR(IA)=FREL(IA)	0071
C	BEARINGS OF RHOMBS	
	IF(XETA) 1320,1320,1321	0072
1321	XETA=ABSF(XETA-XTR)	0073
	IF(XETA=180.) 1320,1320,211	0074
211	XETA=360.-XETA	0075
1320	IF(WETA) 1323,1323,1324	0076
1324	WETA=ABSF(WETA-BTRY)	0077
	IF(WETA=180.) 1323,1323,210	0078

210 WETA=360.-WETA	0079
1323 XQ=.001	0080
RQ=.001	0081
XP=4.	0082
RP=4.	0083
INH=XNH	0084
INL=XNL	0085
IND=XND	0086
JNH=RNH	0087
JNL=RNL	0088
JND=RND	0089
NIG=0	0090
JIG=JIG+1	0091
MA=XABSF(MAN)	0092
C CONSTANTS TO BE USED FREQUENTLY	
TOP(1)=20.	0093
TOP(2)=20.	0094
TOP(3)=25.	0095
TOP(4)=23.5	0096
RO=6376.6	0097
KIP=1	0098
IF(MAP) 5612,5612,5613	0099
5612 WRITE OUTPUT TAPE 6,3.	0100
1 NOCIR,BMONS,SSN,HA,HAR,XLAT,AX,XLONG,AL,YLAT,AY,YLONG,YL,	0101
2XTR,BTRY,GCDNM	0102
5613 FK=69.057	0103
LZP=1	0104
LIP=1	0105
MIP=2	0106
IF(IHR) 8400,8400,3219	0107
8400 GO TO (3219,3219,3220,3221,3219,3219),METHOD	0108
3220 MIP=1	0109
GO TO 3219	0110
3221 MA=0	0111
3219 DO 3214 IT=MIP,24,MIP	0112
FREL(11)=FOT(IT)	0113
JUG=0	0114
KAT=1	0115
DO 251 IJ=1,11	0116
NANGLE(IJ)=0	0117

MODE(IJ)=0	0118
251 ABC(IJ)=AZZ	0119
FREQ=FREL(1)	0120
DFREQ=3.	0121
NF=1	0122
C F2 REGION LAYER HEIGHTS	
FL=0.	0123
DO 926 II=K1,K3	0124
CALL POLY(2,7,7,CLCK(IT)/10.=1.2,CLAT(II)/90.,Y)	0125
926 FL=FL+Y	0126
RK=K3	0127
FL=FL/RK*100.	0128
GO TO (927,928),K2	0129
C MODE CHOOSING F2 AND E-LAYER	
928 ME(1)=GCDKM/2000.+0.9	0130
ME(2)=ME(1)+1	0131
MF(1)=GCDKM/4000.+0.8	0132
MF(2)=MF(1)+1	0133
MF(3)=MF(2)+1	0134
GO TO 929	0135
927 ME(1)=1	0136
ME(2)=2	0137
MF(1)=1	0138
MF(2)=2	0139
MF(3)=3	0140
C RADIATION ANGLE -- E-LAYER MODES	
929 DO 930 IK=1,2	0141
IM=ME(IK)	0142
PI=ME(IK)	0143
ELD(IM)=GCDKM/PI	0144
EDEL(IM)=ATANF((COSF(GCD/(2.*PI))=RO/(RO+110.))/SINF(GCD/(2.*PI)))	0145
1*BK	0146
IF(EDEL(IM)) 1032,930,930	0147
1032 DO 1033 II=1,2	0148
1033 ME(II)=ME(II)+1	0149
GO TO 929	0150
930 CONTINUE	0151
C RADIATION ANGLE-- F2-LAYER MODES	
1934 DO 931 IK=1,3	0152
IM=MF(IK)	0153

PI=IM	0154
FLD(IM)=GCDKM/PI	0155
FDEL(IM)=ATANF((COSF(GCD/(2.*PI))-RO/(RO+FL))/SINF(GCD/(2.*PI)))	0156
1*BK	0157
IF(FDEL(IM)) 932,931,931	0158
932 DO 1933 II=1,3	0159
1933 MF(II)=MF(II)+1	0160
GO TO 1934	0161
931 CONTINUE	0162
GO TO(933,934),K2	0163
C PENETRATION FREQUENCIES --E-REGION	
934 DZ=EMF(4,IT)	0164
DY=EMF(5,IT)	0165
IF(DZ-DY) 940,940,941	0166
940 ZR=DZ	0167
I2=2	0168
ZS=DY	0169
GO TO 939	0170
941 ZR=DY	0171
I2=3	0172
ZS=DZ	0173
GO TO 939	0174
933 ZR=EMF(1,IT)	0175
ZS=ZR	0176
939 DO 1663 II=1,10	0177
ELL(II)=0.	0178
1663 FLL(II)=0.	0179
DO 827 II=1,2	0180
IM=ME(II)	0181
ERCR(IM)=0.	0182
EXMT(IM)=0.	0183
C MODE ELIMINATION E AND F2 REGIONS	
ARZ=ELD(IM)*DK	0184
IF(16.-=ARZ) 2900,2900,2901	0185
2900 ELFK=1.02	0186
GO TO 2902	0187
2901 ELFK=((((-4.368460907E-9*ARZ+1.334494261E-7)*ARZ-5.976618436E-6)	0188
1*ARZ+2.624808315E-4)*ARZ-5.038476266E-3)*ARZ+3.761385053E-2)*ARZ-1	0189
2.133200756E-2)*ARZ+.2085	0190
2902 Y=ZR*ELFK+.05	0191

IF(Y=FREQ) 328,328,827	0192
328 ELL(IM)=1000.	0193
827 CONTINUE	0194
DO 227 II=1,3	0195
IM=MF(II)	0196
FRCR(IM)=0.	0197
FXMT(IM)=0.	0198
ARZ=RO*2.*(PI2=FDEL(IM)*AK-ASINF(RO*SINF(PI2+FDEL(IM)*AK)/(RO+110.	0199
1)))*DK	0200
IF(16.-ARZ) 2903,2903,2904	0201
2903 ELFK=1.02	0202
GO TO 2905	0203
2904 ELFK=((((-4.368460907E-9*ARZ+1.334494261E-7)*ARZ-5.976618436E-6)	0204
1*ARZ+2.624808315E-4)*ARZ-5.038476266E-3)*ARZ+3.761385053E-2)*ARZ-1	0205
2.133200756E-2)*ARZ+.2085	0206
2905 Y=ELFK*ZS+.05	0207
IF(Y=FREQ) 227,227,228	0208
228 FLL(IM)=1000.	0209
227 CONTINUE	0210
DO 946 II=K2,K3	0211
F24(II)=(F2S(II,IT)*(180.-SSN)+F2H(II,IT)*(SSN-10.))/170.	0212
946 GMA(II)=(GML(II,IT)*(180.-SSN)+GMH(II,IT)*(SSN-10.))/170.	0213
S1=(FREQ-GMA(K2))/(F24(K2)-GMA(K2))	0214
S2=(FREQ-GMA(K3))/(F24(K3)-GMA(K3))	0215
IF(S1-S2) 947,947,948	0216
947 R=S2	0217
GO TO 949	0218
948 R=S1	0219
949 DO 945 IK=1,3	0220
IM=MF(IK)	0221
IF(FLL(IM)) 508,508,945	0222
508 ARK=FLD(IM)*DK	0223
FLF(IM)((((-6.712654756E-9*ARK+4.49151441E-7)*ARK-9.985831104E-	0224
16)*ARK+6.865259817E-5)*ARK+9.202437332E-5)*ARK+2.264634341E-3)*ARK	0225
2+4.699243101E-3)*ARK	0226
IF(FLF(IM)-R) 950,945,945	0227
950 FLL(IM)=1000.	0228
945 CONTINUE	0229
GYR=(GY(K2)+GY(K3))/2.	0230
GO TO (1740,9119),KIP	0231

C	MAJOR LAND BODIES	
1740	WLD=0.	0232
	DO 826 II=K1,K3	0233
	IF (CLONG(II)) 1702,1702,1701	0234
1701	CZG=360.-CLONG(II)	0235
	GO TO 1703	0236
1702	CZG=ABSF(CLONG(II))	0237
1703	CALL NOISY(6,X2,CZG,Y)	0238
826	WLD=WLD+Y	0239
	WD=WLD/RK	0240
9119	IF(WD) 953,954,954	0241
953	ER=80.	0242
	SIGMA=5.	0243
	GO TO 955	0244
954	ER=4.	0245
	SIGMA=.001	0246
C	E-LAYER MODES	
C	GROUND LOSS REFLECTION FACTORS AND LOSS	
955	DO 726 II=1,2	0247
	IM=ME(II)	0248
	IF(ELL(IM))600,600,726	0249
600	RS=IM-1	0250
	CALL LOSS(EDEL(IM),ER,FREQ,SIGMA,Y)	0251
	GE(IM)=ABSF(Y*RS)	0252
	RI=IM	0253
C	SKYWAVE ABSORPTION	
	ESKY(IM)=615.5*RI*ABI(IT)/(COSF(ASINF(RO*SINF(PI2+EDEL(IM)*AK)/(RO	0254
	1+100.)))*(FREQ+1.12*GYR)**1.98)	0255
	RS=IM	0256
C	ANGLE AT IONOSPHERE	
	PHE=RO*SINF(PI2+EDEL(IM)*AK)/(RO+110.)	0257
C	FREE SPACE LOSS	
	ZOR= GCD/(2.*RS)	0258
	FR=(2.*RS*SINF(ZOR)*RO/PHE)*EEK	0259
	FSE(IM)=36.58+20.*LOG10F(FR)+20.*LOG10F(FREQ)	0260
726	CONTINUE	0261
C	F2-LAYER MODES	
C	GROUND LOSS REFLECTION FACTORS AND LOSS	
DO 626	II=1,3	0262
	IM=MF(II)	0263

IF(FLL(IM)) 601,601,626	0264
601 RS=IM-1	0265
CALL LOSS(FDEL(IM),ER,FREQ,SIGMA,Y)	0266
GF(IM)=ABSF(Y*RS)	0267
RI=IM	0268
C SKY WAVE ABSORPTION	
FSKY(IM)=615.5*RI*ABI(IT)/(COSF(ASINF(RO*SINF(PI2+FDEL(IM)*AK)/(RO	0269
1+100.)))*(FREQ+1.12*GYR)**1.98)	0270
RS=IM	0271
C ANGLE AT IONOSPHERE	
PHE=RO*SINF(PI2+FDEL(IM)*AK)/(RO+FL)	0272
C FREE SPACE LOSS	
ZOR= GCD/(2.*RS)	0273
FR=(2.*RS*SINF(ZOR)*RO/PHE)*EEK	0274
FSF(IM)=36.58+20.*LOG10F(FR)+20.*LOG10F(FREQ)	0275
626 CONTINUE	0276
C ANTENNA DETERMINATION	
KAP=XABSF(IANT)	0277
IF(IANT) 18 ,181,181	0278
181 KAP=4	0279
DO 82 II=1,2	0280
IM=ME(II)	0281
82 EXMT(IM)=IANT	0282
DO 62 II=1,3	0283
IM=MF(II)	0284
62 FXMT(IM)=IANT	0285
GO TO 1185	0286
18 GO TO (31,32,33),KAP	0287
31 TANT(1)=ARA(1)	0288
TANT(2)=ARA(2)	0289
GO TO 180	0290
32 TANT(1)=AVA(1)	0291
TANT(2)=AVA(2)	0292
GO TO 180	0293
33 TANT(1)=AHA(1)	0294
TANT(2)=AHA(2)	0295
180 DO 182 II=1,2	0296
IM=ME(II)	0297
IF(ELL(IM))603,603,182	0298
603 CALL GAIN(KAP,EDEL(IM),XETA,FREQ,XQ,XP,XND,XNL,XNH,EXMT(IM))	0299

182 CONTINUE	0300
C POWER GAIN OF TRANSMITTING ANTENNA	
DO 382 II=1,3	0301
IM=MF(II)	0302
IF(FLL(IM)) 605,605,382	0303
605 CALL GAIN(KAP,FDEL(IM),XETA,FREQ,XQ,XP,XND,XNL,XNH,FXMT(IM))	0304
382 CONTINUE	0305
1185 IF(METHOD=4) 185,184,185	0306
184 IF(IHR) 185,185,183	0307
183 IANR=0	0308
MA=0	0309
185 KUP=XABSF(IANR)	0310
IF(IANR) 187,281,281	0311
281 KUP=4	0312
DO 482 II=1,3	0313
IM=MF(II)	0314
482 FRCR(IM)=IANR	0315
DO 582 II=1,2	0316
IM=ME(II)	0317
582 ERRCR(IM)=IANR	0318
GO TO 1285	0319
187 GO TO (741,42,43),KUP	0320
741 RANT(1)=ARA(1)	0321
RANT(2)=ARA(2)	0322
GO TO 280	0323
42 RANT(1)=AVA(1)	0324
RANT(2)=AVA(2)	0325
GO TO 280	0326
43 RANT(1)=AHA(1)	0327
RANT(2)=AHA(2)	0328
C RESPONSE OF RECEIVING ANTENNA	
280 DO 282 II=1,3	0329
IM=MF(II)	0330
IF(FLL(IM)) 607,607,282	0331
607 CALL GAIN(KUP,FDEL(IM),WETA,FREQ,RQ,RP,RND,RNL,RNH,FRCR(IM))	0332
282 CONTINUE	0333
DO 782 II=1,2	0334
IM=ME(II)	0335
IF(ELL(IM)) 609,609,782	0336
609 CALL GAIN(KUP,EDEL(IM),WETA,FREQ,RQ,RP,RND,RNL,RNH,ERRCR(IM))	0337

782 CONTINUE	0338
1285 IF(MAP) 285,285,388	0339
285 GO TO (286,388),LIP	0340
286 GO TO (330,330,330,1331),KAP	0341
1331 GO TO (232,232,232,233),KUP	0342
233 WRITE OUTPUT TAPE 6,13,IANT,MA,IANR	0343
GO TO 388	0344
330 GO TO (335,335,335,336),KUP	0345
335 WRITE OUTPUT TAPE 6,1,	0346
1 TANT,INH,INL,IND,MA,RANT,JNH,JNL,JND	0347
GO TO 388	0348
336 WRITE OUTPUT TAPE 6,2,	0349
1 TANT,INH,INL,IND,MA,IANR	0350
GO TO 388	0351
232 WRITE OUTPUT TAPE 6,4,IANT,MA,RANT,JNH,JNL,JND	0352
388 LIP=2	0353
DO 333 II=K2,K3	0354
TIP=0.	0355
C DETERMINATION OF TYPE OF CIRCUIT(POLAR,TEMPERATE,ETC)	
RM=ABSF(GLAT(II))	0356
IF(RM-60.*AK) 331,331,332	0357
331 ID=1	0358
IF(ABIY(1,IT)) 9732,9732,333	0359
9732 TIP=5.	0360
GO TO 333	0361
332 IF(RM-70.*AK) 334,334, 35	0362
334 ID=3	0363
IF(K2-1) 333,333, 36	0364
36 ID=4	0365
GO TO 1725	0366
35 ID=2	0367
333 CONTINUE	0368
C TRANSMISSION LOSS E-LAYER MODES	
1725 DO 960 II=1,2	0369
IM=ME(II)	0370
960 ELL(IM)=ESKY(IM)+GE(IM)+FSE(IM)-EXMT(IM)-ERCR(IM)+ADJ(ID)+ELL(IM)	0371
LD=ME(1)	0372
LE=ME(2)	0373
IF(ELL(LD)-ELL(LE)) 961,961,962	0374
961 ELOS=ELL(LD)	0375

MDE=LD	0376
GO TO 963	0377
962 ELOS=EEL(LE)	0378
MDE=LE	0379
C TRANSMISSION LOSS F2-LAYER MODES	
963 DO 964 II=1,3	0380
IM=MF(II)	0381
964 FLL(IM)=FSKY(IM)+GF(IM)+FSF(IM)-FXMT(IM)-FRCR(IM)+ADJ(ID)+FLL(IM)	0382
LG=MF(1)	0383
LH=MF(2)	0384
LJ=MF(3)	0385
IF(FLL(LG)-FLL(LH)) 965,965,966	0386
965 FL1=FLL(LG)	0387
MDF=LG	0388
GO TO 967	0389
966 FL1=FLL(LH)	0390
MDF=LH	0391
967 IF(FL1-FLL(LJ)) 968,968,969	0392
968 FLOS=FL1	0393
GO TO 970	0394
969 FLOS=FLL(LJ)	0395
MDF=LJ	0396
970 IF(ELOS=FLOS) 971,971,972	0397
971 NXLOS(NF)=ELOS	0398
NANGLE(NF)=EDEL(MDE)+.5	0399
MODE(NF)=MDE	0400
ABC(NF)=AEC	0401
GO TO 911	0402
972 NXLOS(NF)=FLOS	0403
NANGLE(NF)=FDEL(MDF)+.5	0404
MODE(NF)=MDF	0405
ABC(NF)=AFC	0406
C MIXED MODES OF PROPAGATION	
911 FHOP=MF(1)-1	0407
IF(FHOP) 3903,3903,3898	0408
3898 XHOP=FHOP+1.	0409
C AVERAGE HEIGHT OF REFLECTING LAYERS	
EFHT=(110.+FHOP*FL)/(FHOP+1.)	0410
C RADIATION ANGLE	
EFDEL=ATANF((COSF(GCD/(2.*XHOP))-RO/(RO+EFHT))/SINF(GCD/(2.*XHOP)))	0411

1)*BK	0412
C ANGLE AT IONOSPHERE	
PHE=RO*SINF(PI2+EFDEL*AK)/(RO+110.)	0413
ARZ=79.138*(PI2-EFDEL*AK-ASINF(PHE))	0414
IF(EFDEL-1.) 3899,3900,3901	0415
3899 FHOP=FHOP+1.	0416
GO TO 3898	0417
C MODE ELIMINATION	
3900 ELFK=1.02	0418
GO TO 3902	0419
3901 ELFK=(((((1-4.368460907E-9*ARZ+1.334494261E-7)*ARZ-5.976618436E-6)	0420
1*ARZ+2.624808315E-4)*ARZ-5.038476266E-3)*ARZ+3.761385053E-2)*ARZ-1	0421
2.133200756E-2)*ARZ+.2085	0422
3902 Y=ZS*ELFK	0423
4332 IF(Y-FREQ) 3903,3905,3905	0424
3903 NOS(NF)=1000.	0425
GO TO 612	0426
3905 Y=ZR*ELFK	0427
IF(Y-FREQ) 650,650,651	0428
651 NOS(NF)=1000.	0429
GO TO 612	0430
650 ARK=(GCDKM*DK-ARZ)/FHOP	0431
FLFK =((((1-6.712654756E-9*ARK+4.49151441E-7)*ARK-9.985831104E-	0432
16)*ARK+6.865259817E-5)*ARK+9.202437332E-5)*ARK+2.264634341E-3)*ARK	0433
2+4.699243101E-3)*ARK	0434
REF=(FREQ-GMA(I2))/(F24(I2)-GMA(I2))	0435
IF(FLFK-REF) 652,653,653	0436
652 NOS(NF)=1000.	0437
GO TO 612	0438
C SKY WAVE ABSORPTION	
653 EFSKY=615.5*XHOP*ABIY(1,IT)/(COSF(ASINF(RO*SINF(PI2+EFDEL*AK)/(RO	0439
1+100.)))*(FREQ+1.12*GYR)**1.98)	0440
C GROUND REFLECTION LOSS	
3908 CALL LOSS(EFDEL,ER,FREQ,SIGMA,Y)	0441
3909 GEF=ABSF(Y*FHOP)	0442
C ANGLE AT IONOSPHERE	
SPHE=RO*SINF(PI2+EFDEL*AK)/(RO+EFHT)	0443
C FREE SPACE LOSS	
ZOR=GCD/(2.*(FHOP+1.))	0444
FR=(2.*(FHOP+1.)*SINF(ZOR)*RO/SPHE)*EEK	0445

EFSE=36.58+20.*LOG10F(FR)+20.*LOG10F(FREQ)	0446
GO TO (3180,3180,3180,3181),KAP	0447
3181 EFXMT=IANI	0448
GO TO 3182	0449
C POWER GAIN OF TRANSMITTING ANTENNA	
3180 CALL GAIN(KAP,EFDEL,XETA,FREQ,XQ,XP,XND,XNL,XNH,EFXMT)	0450
3182 GO TO (3183,3183,3183,3184),KUP	0451
3184 EFRCR=IANR	0452
GO TO 3190	0453
C RESPONSE OF RECEIVING ANTENNA	
3183 CALL GAIN(KUP,EFDEL,WETA,FREQ,RQ,RP,RND,RNL,RNH,EFRCR)	0454
C TRANSMISSION LOSS	
3190 NOS(NF)=EFSKY+GEF+EFSE-EFXMT-EFRCR+ADJ(ID)	0455
612 IF(NOS(NF)-NXLOS(NF)) 623,622,622	0456
623 NANGLE(NF)=EFDEL+.5	0457
MODE(NF)=FHOP+1.	0458
B ABC(NF)=676060606060	0459
NXLOS(NF)=NOS(NF)	0460
622 IF(NXLOS(NF)-990) 6911,624,624	0461
624 ABC(NF)=AZZ	0462
NANGLE(NF)=0	0463
MODE(NF)=0	0464
GO TO 8740	0465
6911 KAJ=1	0466
GO TO (6912,6912,6912,9779,6912,6912),METHOD	0467
6912 POR=10.*LOG10F(PWR*1000.)	0468
IF(JUG)3869,3869,8712	0469
C IMC/S ATMOSPHERIC NOISE DETERMINATION	
3869 CC=QKC(IT)	0470
C SEASON AND HOUR BLOCK FOR ATMOSPHERIC NOISE DETERMINATION	0471
LIB=4	0472
ICC=CC/2.	0473
IF(ICC) 8889,8889,8888	0474
8888 GO TO (8701,8701,8702,8702,8705,8705,8706,8706,8708,8708,8887,	0475
18887),ICC	0476
8887 CC=CC-24.	0477
8889 KJ=1	0478
TM=-2.	0479
JK=1	0480
GO TO 8703	0481

8701 KJ=1	0482
TM=2.	0483
JK=5	0484
GO TO 8703	0485
8702 KJ=5	0486
TM=6.	0487
JK=4	0488
KAJ=2	0489
GO TO 8703	0490
8705 KJ=4	0491
TM=10.	0492
JK=3	0493
LIB=5	0494
GO TO 8703	0495
8706 KJ=3	0496
TM=14.	0497
JK=2	0498
LIB=5	0499
GO TO 8703	0500
8708 KJ=2	0501
TM=18.	0502
JK=1	0000
KAJ=2	0503
8703 IF(Y2) 9702,9702,9701	0504
9701 CEG=360.-Y2	0505
GO TO 9703	0506
9702 CEG=ABSF(Y2)	0507
9703 CALL NOISY(KJ,X2 ,CEG,ATNO)	0508
CALL NOISY(JK,X2,CEG,ATNY)	0509
ATNQ=(ATNO+(ATNY-ATNO)*(CC-TM)/4.)	0510
LOB=0	0511
JUG=JUG+1	0512
GO TO(8712,8713),KAJ	0513
C FREQUENCY DEPENDENCE OF ATMOSPHERIC NOISE	
8713 MOT=MOUSE/3	0514
IF(MOT) 8714,8715,8714	0515
8715 MOT=4	0516
8714 IF(X2) 8716,8717,8717	0517
8716 LOB=1	0518
8717 IF(MOT-3) 8718,8719,8719	0519

8718 LIB=5-LOB	0520
GO TO 8712	0521
8719 LIB=4+LOB	0522
8712 IF(LIB=4) 2179,2179,2178	0523
2179 IF(ATNQ=20.) 2130,2178,2178	0524
2130 ATNQ=20.	0525
2178 CALL POLY(LIB,7,7,ATNQ/10.-5.,FREQ/10.-1.35,Y)	0526
ATNO=Y*10.+130.	0527
C GALACTIC NOISE	
IF(FREQ=GMA(2)) 8720,8720,8721	0528
8721 GNOS= ((((((1095032130E-10*FREQ+.2442852795E-8)*FREQ-.15854096	0529
108E-5)*FREQ+.1513740543E-3)*FREQ-.6306642189E-2)*FREQ+.1390178355E	0530
2+0)*FREQ-.1701088795E+1)*FREQ+.1121130396E+2)*FREQ-.3426395658E+2)	0531
3*FREQ+.2020285454E+3	0532
GO TO 9797	0533
8720 GNOS=1000.	0534
C MAN MADE NOISE	
9797 IF(MAN) 8722,8723,8723	0535
8722 KJ=XABSF(MAN)+5	0536
SOB=0.	0537
CALL POLY (KJ,1,10,SOB,FREQ,Y)	0538
XNOIS=Y	0539
GO TO 8724	0540
8723 XNOIS=MAN	0541
C DETERMINATION OF CONTROLLING NOISE	
8724 RCNSE=ATNO	0542
IF(ATNO=GNOS) 8725,8725,8726	0543
8726 RCNSE=GNOS	0544
8725 IF(RCNSE=XNOIS) 8729,8729,8728	0545
8728 RCNSE=XNOIS	0546
C AVAILABLE SIGNAL-TO-NOISE RATIO	
8729 XLOS=NXLOS(NF)	0547
ROT = XLOS-POR	0548
GOT=RCNSE-ROT	0549
GO TO(505,505,505,505,505,506),METHOD	0550
506 NXLOS(NF)=GOT	0551
GO TO 9777	0552
505 WANT=GOT-RSN	0553
C CIRCUIT RELIABILITY	
IF(ABSF(WANT)-(TOP(ID)+TIP))867,867,868	0554

868 REL=SIGNF(100.,WANT)	0555
GO TO 869	0556
867 KJ=ID+10	0557
GO TO (888,8733,8733,8733),ID	0558
888 IF(ABIY(1,IT)) 8733,8733,8732	0559
8732 KJ=KJ-1	0560
8733 CALL POLY(KJ,5,10,FREQ/10.-1.35,WANT/10.,Y)	0561
REL=Y*10.+50.	0562
869 IF(ID-1) 8734,8734,8735	0563
8735 XRL=90.	0564
GO TO 8736	0565
8734 XRL=99.	0566
8736 IF(REL-XRL) 8739,8739,8738	0567
8738 REL=XRL	0568
8739 IF(REL-1.) 8740,8740,8741	0569
8740 REL=0.	0570
8741 NXLOS(NF)=REL	0571
KIP=2	0572
IF(METHOD-3) 9777,3207,9777	0573
C ITERATION FOR LUF	
3207 IF(REL-90.) 3201,3202,3203	0574
3201 GO TO (3204,3202),KAT	0575
3202 FF(IT)=FREQ	0576
GO TO 3214	0577
3203 IF(FREQ-3.) 3208,3208,3209	0578
3208 FF(IT)=-3.	0579
GO TO 3214	0580
3209 FREQ=FREQ-.1*DFREQ	0581
IF(FREQ-3.)3208,4850,4850	0582
4850 KAT=2	0583
GO TO 939	0584
3204 ZJ=KJ	0585
GO TO 9777	0586
9779 IF(IHR) 9777,9777,9778	0587
C FIELD STRENGTH	
9778 ALOSS=-NXLOS(NF)	0588
NXLOS(NF)=ALOSS+107.2+8.6859*LOGF(FREQ)+4.343*LOGF(1000.*PWR)	0589
C FURTHER ITERATION FOR LUF	
9777 NF=NF+1	0590
IF(NF-11) 914,914,260	0591

914 FREQ=FREL(NF)	0592
IF(FREQ-FREL(11)) 917,917,916	0593
917 IF(FREQ-30.) 939,939,916	0594
916 NXLOS(NF)=0	0595
FF(IT)=0.	0596
GO TO 9777	0597
260 GO TO (250,250,3214,3212,7007,250),METHOD	0598
7007 GO TO (7009,7008),LZP	0599
7009 WRITE OUTPUT TAPE 6,34,PWR,IRSN,IFR	0600
7008 WRITE OUTPUT TAPE 6,94,	0601
1 IG(IT),UF(IT),FOT(IT),NXLOS	0602
NIG=NIG+1	0603
GO TO (3214,3214,21),NIG	0604
21 WRITE OUTPUT TAPE 6,908	0605
NIG=0	0606
GO TO 3214	0607
250 GO TO (2250,2666),LZP	0608
2250 WRITE OUTPUT TAPE 6,14,PWR,IRSN,IFR	0609
2666 GO TO (2667,2667,2667,2667,2667,2668),METHOD	0610
2668 WRITE OUTPUT TAPE 6,29,	0611
1 IG(IT-1),UF(IT-1),FOT(IT-1),(MODE(I),ABC(I),I=1,11),NANGLE	0612
2,IG(IT),UF(IT),FOT(IT),NXLOS	0613
GO TO 3214	0614
2667 WRITE OUTPUT TAPE 6,9,	0615
1 IG(IT-1),UF(IT-1),FOT(IT-1),(MODE(I),ABC(I),I=1,11),NANGLE	0616
2,IG(IT),UF(IT),FOT(IT),NXLOS	0617
GO TO 3214	0618
3212 GO TO (3213,3215),LZP	0619
3213 IF(IHR) 8002,8002,8003	0620
8003 WRITE OUTPUT TAPE 6,80,PWR,IFR	0621
GO TO 77	0622
8002 WRITE OUTPUT TAPE 6,8,IFR	0623
3215 IF(IHR) 69,69,77	0624
69 WRITE OUTPUT TAPE 6,19,	0625
1 IG(IT-1),UF(IT-1),FOT(IT-1),(MODE(I),ABC(I),I=1,11),NANGLE	0626
2,IG(IT),UF(IT),FOT(IT),NXLOS	0627
GO TO 3214	0628
77 WRITE OUTPUT TAPE 6,59,	0629
1 IG(IT-1),UF(IT-1),FOT(IT-1),(MODE(I),ABC(I),I=1,11),NANGLE	0630
2,IG(IT),UF(IT),FOT(IT),NXLOS	0631

3214 L2P=2	0632
GO TO (2270,51,290,51,41,51),METHOD	0633
41 GO TO (40,51),JIG	0634
40 WRITE OUTPUT TAPE 6,907	0635
GO TO 270	0636
51 WRITE OUTPUT TAPE 6,909	0637
JIG=0	0638
GO TO 270	0639
290 IF(MAP) 6228,6228,6229	0640
6229 CALL CURVY(FOT,FF)	0641
GO TO 270	0642
6228 WRITE OUTPUT TAPE 6,24,PWR,IRSN	0643
IF(IHR) 2291,2291,2290	0644
2291 WRITE OUTPUT TAPE 6,7.	0645
1 (IG(I),FF(I),FOT(I),IG(I+6),FF(I+6),FOT(I+6),IG(I+12),	0646
2 FF(I+12),FOT(I+12),IG(I+18),FF(I+18),FOT(I+18),I=1,6),AAA	0647
GO TO 2270	0648
2290 WRITE OUTPUT TAPE 6,70.	0649
1 (IG(I),FOT(I),IG(I+6),FOT(I+6),IG(I+12),FOT(I+12),IG(I+1	0650
28),FOT(I+18),IG(I+1),FF(I+1),FOT(I+1),IG(I+7),FF(I+7),FOT(I+7),IG	0651
3(I+13),FF(I+13),FOT(I+13),IG(I+19),FF(I+19),FOT(I+19),I=1,6,2),AAA	0652
2270 IF(3-MIT) 1969,1969,1970	0653
1969 WRITE OUTPUT TAPE 6,909	0654
MIT=1	0655
GO TO 270	0656
1970 MIT=MIT+1	0657
270 RETURN	0658
END	0659

```

SUBROUTINE CURVY(COT,BOT)                                0001
C  GENERATES LINE GRAPHS
DIMENSION COT(24),ROT(73),BOT(24),WOT(73)              0002
DIMENSION AOT(73),COB(55),BOB(55),XOB(73)              0003
DIMENSION FDEK(10),EDEK(10)                            0004
DIMENSION AMON(12), GLAT(5),ABI(24),ABIY(5,24),CLCK(24),GY(5), 0005
1F2S(5,24),F2H(5,24),GML(5,24),GMH(5,24),MF(3),ME(2),ELL(10),FLL(10 0006
2),ELD(10),EDEL(10),FLD(10),FDEL(10),F24(5),GMA(5),FLF(10),FSKY(10) 0007
3,ESKY(10),GE(10),GF(10),FSE(10),FSF(10),NOS(11),FXMT(10),EXMT(10), 0008
4FRCR(10),ERCR(10),ADJ(4),ABC(12),MODE(12)             0009
DIMENSION Q(20,60,4),IL(4),JL(4),KL(4),LK(4),JAL(4),CKC(24) 0010
1,G(60),AB(60),S(20,24),C(20,24),GAMMA(5,24),BA(60)   0011
DIMENSION RD(5),SUN(12),A(10,7,14),RASSN(12),EMF(5,24) 0012
DIMENSION CLAT(5),CLONG(5),EMUFY(5,24),FMUFY(5,24),UFY(5),FOTY(5) 0013
5,IG(24)                                                  0014
DIMENSION UF(24),FOT(24),FF(24),P(29,16,6),ABP(2,6)   0015
DIMENSION AHA(2),ARA(2),AVA(2),RANT(2),TANT(2)         0016
DIMENSIONNXLOS(11),NANGLE(11)                          0017
DIMENSION TOP(4),FREL(12)                               0018
COMMON ABP,P                                             0019
COMMON A,U,G,AB,S,C,GAMMA,BA,EMUFY,FMUFY,IG,UF,FUT,SUN,AVA,ARA,GLA 0020
1T,ABI,ABIY,CLCK,GY,F2S,F2H,GML,GMH,MF,ME,ELD,FLD,F24,GMA,ADJ,ABC, 0021
2EMF,CKC,CLAT,CLONG,AK,BK,CK,DK,PI2,EK,EEK,GLT,GLG,AAA,ALA,ASA, 0022
3AFC,ANC,AWC,AEC,ASC,AZZ,MAN,RSN,KW,PWR,IANT,IANK,Y2,X2,MOUSE,SSN, 0023
4NOCIR,K4, AX,XLONG,AL,YLAT,XLAT,YLONG,YL,BTRY,GCDKM,GCDNM,K1,K2,K 0024
53,K5,GCD,IRSN,MON,ID,MOUSE,AY,METHOD,AHA,BMONS,MAP 0025
COMMON FREL                                             0026
COMMON XNH,XNL,XND,RNH,RNL,RND,HA,JIG,HAR,XTR,XETA,WETA,IHR,MIT 0027
COMMON KAP,KUP,MA,TANT,INH,INL,IND,RANT,JNH,JNL,JND 0028
73 FORMAT(10X,4HANT=I3,2HDB,20X,6HNOISE=I3,20X,4HANT=I3,2HDB) 0029
91 FORMAT(6X,2A6,1X,I3,1HH,1X,I3,1HL,1X,I3,3HDEG,2X,6HNOISE=I3,2A6,1X 0030
1,I3,1HH,1X,I3,1HL,1X,I3,3HDEG) 0031
72 FORMAT(6X,2A6,1X,I3,1HH,1X,I3,1HL,1X,I3,3HDEG,12X,6HNOISE=I3,12X, 0032
14HANT=I3,2HDB) 0033
74 FORMAT(10X,4HANT=I3,2HDB,13X,6HNOISE=I3,7X,2A6,1X,I3,1HH,1X,I3,1HL 0034
1,1X,I3,3HDEG) 0035
24 FORMAT(10X,4HPWR=F6,2,2HKW,42X,8HREQ,S/N=I3,2HDB) 0036
3 FORMAT(14X,I5,10X,A6, 10X,4HSSN=F5,0,10X,A2,F7,3/13X, 11HTR 0037

```

```
2ANSMITTER,13X,8HRECEIVER,12X,8HBEARINGS,6X,7HN,MILES/11X, F6.2,A1, 0038
32H - ,F7.2,A1,5X,F6.2,A1,2H - ,F7.2,A1,3X,2F6.1,4X,F8.1) 0039
15 FORMAT(7X,73A1/6X,74H00 C2 04 06 08 10 12 14 0040
1 16 18 20 22 00/34X,19HGREENWICH MEAN TIME) 0041
2 FORMAT(2X,A1,1X,A2,A1,73A1,A1,A2,1X,A1) 0042
25 FORMAT(1H1) 0043
1 FORMAT(1H ) 0044
WRITE OUTPUT TAPE 6,3, 0045
1 NOCIR,BMONS,SSN,HA,HAR,XLAT,AX,XLONG,AL,YLAT,AY,YLONG,YL, 0046
2XTR,BTRY,GCDNM 0047
IF(METHOD-3) 4044,4045,4045 0048
4045 GO TO (330,330,330,1331),KAP 0049
1331 GO TO (232,232,232,233),KUP 0050
233 WRITE OUTPUT TAPE 6,73, IANT,MA, IANR 0051
GO TO 388 0052
330 GO TO (335,335,335,336),KUP 0053
335 WRITE OUTPUT TAPE 6,91, 0054
1 TANT,INH,INL,IND,MA,RANT,JNH,JNL,JND 0055
GO TO 388 0056
336 WRITE OUTPUT TAPE 6,72, 0057
1 TANT,INH,INL,IND,MA, IANR 0058
GO TO 388 0059
232 WRITE OUTPUT TAPE 6,74, 0060
1 IANT,MA,RANT,JNH,JNL,JND 0061
388 LIP=2 0062
WRITE OUTPUT TAPE 6,24,PWR,IRSN 0063
4044 J=0 0064
DO 303 I=1,24 0065
X=COT(I-1) 0066
IF(I-1) 202,203,202 0067
203 X=COT(24) 0068
ROT(1)=X 0069
202 XX=COT(I) 0070
DO 303 II=1,3 0071
J=J+1 0072
CEG=II 0073
303 ROT(J+1)=X+(XX-X)*CEG/3, 0074
IF(METHOD-3) 6402,6405,6402 0075
6405 J=0 0076
DO 808 I=1,24 0077
```

X=XX	0078
IF(I=1) 802,803,802	0079
803 X=BOT(24)	0080
IF(X) 51,53,54	0081
51 X=1.	0082
GO TO 54	0083
53 X=COT(24)	0084
54 WOT(1)=X	0085
802 XX=BOT(I)	0086
IF(XX) 55,57,58	0087
55 XX=1.	0088
GO TO 58	0089
57 XX=COT(I)	0090
58 DO 808 I1=1,3	0091
J=J+1	0092
CEG=I1	0093
808 WOT(J+1)=X+(XX-X)*CEG/3.	0094
6402 DO 608 I=2,72,1	0095
B 608 XOB(I)=406060606060	0096
DO 20 I=1,73,3	0097
B 20 XOB(I)=206060606060	0098
DO 30 I=1,55	0099
B BOB(I)=606060606060	0100
B 30 COB(I)=606060606060	0101
B COB(1)= 600360606060	0102
B COB(5)= 600460606060	0103
B COB(9)= 600560606060	0104
B COB(13)=600660606060	0105
B COB(17)=600760606060	0106
B COB(21)=601060606060	0107
B COB(23)=601160606060	0108
B COB(25)=011260606060	0109
B COB(27)=010160606060	0110
B COB(29)=010260606060	0111
B COB(31)=010360606060	0112
B COB(33)=010460606060	0113
B COB(35)=010560606060	0114
B COB(37)=010660606060	0115
B COB(39)=010760606060	0116
B COB(41)=011060606060	0117

B	COB(43)=011160606060	0118
B	COB(45)=021260606060	0119
B	COB(47)=020260606060	0120
B	COB(49)=020460606060	0121
B	COB(51)=020660606060	0122
B	COB(53)=021060606060	0123
B	COB(55)=031260606060	0124
B	BOB(29)=456060606060	0125
B	BOB(21)=622060606060	0126
B	BOB(22)=616060606060	0127
B	BOB(23)=236060606060	0128
B	BOB(24)=446060606060	0129
B	BOB(27)=706060606060	0130
B	BOB(28)=236060606060	0131
B	BOB(30)=256060606060	0132
B	BOB(31)=646060606060	0133
B	BOB(32)=506060606060	0134
B	BOB(33)=256060606060	0135
B	BOB(34)=516060606060	0136
B	BOB(35)=266060606060	0137
B	DOT=546060606060	0138
	ZOB=31.	0139
B	DOB=406060606060	0140
	DO 200 IK=1.55	0141
	IM=56-IK	0142
	DO 100 I=1.73	0143
B 100	AOT(I)=606060606060	0144
	IF(ZOB-20.) 4.4.63	0145
63	WOB=1.	0146
	GO TO 5	0147
4	IF(ZOB-8.) 4062.4062.4063	0148
4063	WOB=.5	0149
	GO TO 5	0150
4062	WOB=.25	0151
5	ZOB=ZOB+WOB	0152
	IT=1	0153
12	ISPOT=IT	0154
	IF(ROT(IT)=ZOB) 6.8.8	0155
8	SOB=ZOB+WOB	0156
	IF(ROT(IT)=SOB) 10.6.6	0157

10 AOT(ISPOT)=DOT	0158
IT=IT+2	0159
GO TO 16	0160
6 IT=IT+1	0161
16 IF(ISPOT-73) 12,13,13	0162
13 IF(METHOD-3) 200,6565,200	0163
6565 IT=1	0164
33 ISPOT=IT	0165
IF(WOT(IT)-ZOB) 66,38,38	0166
38 SOB=ZOB+WOB	0167
IF(WOT(IT)-SOB) 80,66,66	0168
80 IF(AOT(ISPOT)-DOT) 81,66,81	0169
B 81 AOT(ISPOT)=336060606060	0170
IT=IT+2	0171
GO TO 67	0172
66 IT=IT+1	0173
67 IF(ISPOT-73) 33,200,200	0174
200 WRITE OUTPUT TAPE 6,2,	0175
1 BOB(IM),COB(IM),DOB,AOT,DOB,COB(IM),BOB(IM)	0176
14 WRITE OUTPUT TAPE 6,15,XOB	0177
WRITE OUTPUT TAPE 6,25	0178
RETURN	0179
END	0180

SUBROUTINE GAIN(KOP,DELTA,BETA,FMC,SIGMA,ER,PHI,EL,H,RAIN)	0001
C POWER GAIN OF ANTENNAS	
9749 FORMAT (1F12.6)	0002
RHI=PHI*.01745329252	0003
RELT=DELTA*.01745329252	0004
GO TO (6,7,6),KOP	0005
6 T=COSF(RELT)	0006
RETA=BETA*.01745329252	0007
Q=SINF(RELT)	0008
R=Q*Q	0009
S=R*R	0010
X=18000.*SIGMA/FMC	0011
RHO=SQRTF((ER-T*T)*(ER-T*T)+X*X)	0012
RHO12=SQRTF(RHO)	0013
ALPHA=-ATANF(X/(ER-T*T))	0014
PSIH=ATANF(2.*RHO12*Q*SINF(ALPHA*.5)/(RHO-R))	0015
CH=SQRTF(RHO*RHO+S-2.*RHO*R*COSF(ALPHA))/(RHO+R+2.*RHO12*Q*COSF(ALPHA*.5))	0016
WAVE=299.7925/FMC	0018
FAC=(3.141592654*EL)/WAVE	0019
U1=1.-T*SINF(RHI+RETA)	0020
U2=1.-T*SINF(RHI-RETA)	0021
EFF=0.	0022
X=1.	0023
GO TO (2,2,3),KOP	0024
2 RAIN=(3.2*COSF(RHI)*COSF(RHI)*SINF(FAC*U1)*SINF(FAC*U1)*SINF(FAC*U12)*SINF(FAC*U2)*(CH*CH+1.-2.*CH*COSF(PSIH-(12.56637062*H)/WAVE*Q))2)/(U1*U1*U2*U2)*(COSF(RETA)-SINF(RHI)*T)*(COSF(RETA)-SINF(RHI)*T)	0025
ROK=3.	0026
GO TO 4	0027
3 RAIN=(.5562474*COSF(1.570796*T)*COSF(1.570796*T)*(CH*CH+1.-2.*CH*COSF(PSIH-(12.56637062*H)/WAVE*Q)))/S	0028
ROK=-4.77	0029
GO TO 4	0030
7 E=ER	0031
IF(H) 24,24,20	0032
20 WAVE=299.7925/FMC	0033
A=(6.283185*H)/WAVE	0034
X=H/WAVE	0035
GO TO 25	0036
	0037
	0038
	0039

24 EN=INTF(ABSF(H)/10.)	0040
IF(EN) 50,51,50	0041
51 H1=ABSF(H)	0042
GO TO 52	0043
50 H1=EN/(ABSF(H) -10.*EN)	0044
52 A=H1*6.283185	0045
X=H1	0046
25 D=2.*A	0047
ROK=+5.	0048
Z=2.*D	0049
W=C1(Z,W1)	0050
W2=C1(D,W3)	0051
RA=30.*(=.5*COSF(D)*(1.5772156649+LOGF(Z)-W	0052
12156649+LOGF(D)-W2	0053
)+SINF(D)*(1.5*W1-W3))	0054
26 S=SINF(RELTA)	0055
C=COSF(RELTA)	0056
HM=A/6.283185307	0057
ANUM=COSF(A*S)-COSF(A)	0058
28 CALL VREFCO(RELTA,E,FMC,SIGMA,CV,PSIV)	0059
FAC1=CV*CV+1.-2.*CV*COSF(PSIV-12.5663706*HM*S)	0060
FAC2=2.*COSF(6.2831853072*HM*S)	0061
29 RAIN=(120.*ANUM*ANUM)/(RA*C*C)	0062
RAIN=RAIN*FAC1	0063
4 IF(RAIN) 11,11,31	0064
31 RAIN=4.342944819*LOGF(RAIN)	0065
IF(X-.25) 69,70,70	0066
69 EFF=((16416.702573*X-6091.333295)*X+2179.890548)*X-364.8173803)*X+	0067
125.64620146	0068
GO TO 71	0069
70 EFF=0.	0070
71 RAIN=RAIN-EFF-ROK	0071
41 IF(RAIN+10.)11,11,10	0072
11 RAIN=-10.	0073
10 RETURN	0074
END	

```

SUBROUTINE VREFCO(DELTA,ER,FREQ,SIGMA,CV,PSIV)      0001
C  VERTICAL GROUND REFLECTION COEFFICIENT
PI=3.141592654      0002
X=18000.*SIGMA/FREQ      0003
U=(ER*ER+X*X)      0004
V=SQRTF(U)      0005
Q=SINF(DELTA)      0006
R=Q*Q      0007
S=R*R      0008
T=COSF(DELTA)      0009
RHO=SQRTF((ER-T*T)*(ER-T*T)+X*X)      0010
RHO12=SQRTF(RHO)      0011
ALPHA=-ATANF(X/(ER-T*T))      0012
A=2.*RHO12*Q*V*SINF(ALPHA*.5+ASINF(X/V))      0013
B=RHO-U*R      0014
IF(B) 10,20,30      0015
20 IF(A) 21,22,23      0016
21 PSIV=-.5*PI      0017
GO TO 50      0018
22 PSIV=0.      0019
GO TO 50      0020
23 PSIV=.5*PI      0021
GO TO 50      0022
10 PSIV=ATANF(A/B)+PI      0023
GO TO 50      0024
30 PSIV=ATANF(A/B)      0025
50 CV=SQRTF(RHO*RHO+U*U*S-2.*RHO*U*R*COSF(ALPHA+2.*ASINF(X/V)))/(RHO+      0026
1U*R+2.*RHO12*V*Q*COSF(ALPHA*.5+ASINF(X/V)))      0027
RETURN      0028
END      0029
```

	FUNCTION CI(X,SI)	0001
C	SINE AND COSINE INTEGRAL	
4	IF(X-10.)5,60,60	0002
5	SQ=X*X	0003
	CI=.5772156649+LOGF(X)	0004
	TERM=-1.*SQ/4.	0005
	G=4.	0006
10	CI=CI+TERM	0007
	TERM=-1.*TERM*SQ*(G-2.)/((G-1.)*G*G)	0008
	G=G+2.	0009
	IF(ABSF(TERM)-.00005) 20,20,10	0010
20	SI=0.	0011
	TERM=X	0012
	G=3.	0013
25	SI=SI+TERM	0014
	TERM=-1.*TERM*SQ*(G-2.)/((G-1.)*G*G)	0015
	G=G+2.	0016
	IF(ABSF(TERM)-.00005) 80,80,25	0017
60	TERM1=1.	0018
	T=1.	0019
	C=1.	0020
61	FAC=(4.*T*T-2.*T)/(X*X)	0021
	TERM2=-1.*FAC*TERM1	0022
	IF(ABSF(TERM2)-ABSF(TERM1))62,64,64	0023
62	C=C+TERM2	0024
	T=T+1.	0025
	IF(ABSF(TERM2/C)-10.E-10)65,65,63	0026
63	TERM1=TERM2	0027
	GO TO 61	0028
64	SC=2.*T	0029
	THETA=X-SC	0030
	PI=.5-(1.-2.*THETA)/(4.*SC)+(1.-4.*THETA-2.*THETA*THETA)/(8.*SC*SC	0031
	1)+(3.+18.*THETA+8.*THETA*THETA)/(16.*SC*SC*SC)	0032
	C=C+TERM2*PI	0033
65	TERM1=1./X	0034
	D=TERM1	0035
	T=1.	0036
66	FAC=(4.*T*T+2.*T)/(X*X)	0037
	TERM2=-1.*FAC*TERM1	0038
	IF(ABSF(TERM2)-ABSF(TERM1))67,69,69	0039

67 D=D+TERM2	0040
T=T+1.	0041
IF(ABSF(TERM2/D)-10.E-10)70,70,68	0042
68 TERM1=TERM2	0043
GO TO 66	0044
69 SD=2.*T+1.	0045
THETA=X-SD	0046
PI=.5-(1.-2.*THETA)/(4.*SD)+(1.-4.*THETA-2.*THETA*THETA)/(8.*SD*SD	0047
1)+(3.+18.*THETA+8.*THETA*THETA)/(16.*SD*SD*SD)	0048
D=D+TERM2*PI	0049
70 CX=COSF(X)	0050
SX=SINF(X)	0051
CI=(C*SX-D*CX)/X	0052
SI=1.570796327-(C*CX+D*SX)/X	0053
80 RETURN	0054
END	0055

SUBROUTINE LOSS(RELTA,ER,FREQ,SIGMA,Y)	0001
GROUND REFLECTION LOSS	
DELTA=RELTA*.01745329	0002
PI=3.141592654	0003
X=18000.*SIGMA/FREQ	0004
U=(ER*ER+X*X)	0005
V=SQRTF(U)	0006
Q=SINF(DELTA)	0007
R=Q*Q	0008
S=R*R	0009
T=COSF(DELTA)	0010
RHO=SQRTF((ER-T*T)*(ER-T*T)+X*X)	0011
RHO12=SQRTF(RHO)	0012
ALPHA=-ATANF(X/(ER-T*T))	0013
CH=SQRTF(RHO*RHO+S-2.*RHO*R*COSF(ALPHA))/(RHO+R+2.*RHO12*Q*COSF(ALPHA*.5))	0014
1PHA*.5))	0015
50 CV=SQRTF(RHO*RHO+U*U*S-2.*RHO*U*R*COSF(ALPHA+2.*ASINF(X/V)))/(RHO+1U*R+2.*RHO12*V*Q*COSF(ALPHA*.5+ASINF(X/V)))	0016
1U*R+2.*RHO12*V*Q*COSF(ALPHA*.5+ASINF(X/V)))	0017
Y=10.*LOG10F((CH*CH+CV*CV)/2.)	0018
RETURN	0019
END	0020

SUBROUTINE POLY(KJ,NN,MM,V,X,Y)	0001
POWER SERIES VARIABLES	
DIMENSION A(10,7,14)	0002
DIMENSION P(29,16,6),ABP(2,6)	0003
COMMON ABP,P	0004
COMMON A	0005
Y=0	0006
M=MM	0007
120 N=NN	0008
COEF=0	0009
127 COEF=COEF*V+A(M,N,KJ)	0010
N=N-1	0011
IF(N) 122,122,127	0012
122 Y=Y*X+COEF	0013
M=M-1	0014
IF(M) 126,126,120	0015
126 RETURN	0016
END	0017

SUBROUTINE NOISY(KJ,XP,CEG,ATNO)	0001
FOURIER VARIABLES AND ATMOSPHERIC RADIO NOISE	
DIMENSION P(29,16,6),ABP(2,6),ZZ(29)	0002
COMMON ABP,P	0003
ALF=ABP(1,KJ)	0004
BET=ABP(2,KJ)	0005
Q=0.00872664664626*CEG	0006
C1=COSF(Q)	0007
S1=SINF(Q)	0008
DO 56 J=1,29	0009
R=0.	0010
SX=S1	0011
CX=C1	0012
DO 55 K=1,15	0013
R=R+SX*P(J,K,KJ)	0014
SS=SX*C1+CX*S1	0015
CX=CX*C1-SX*S1	0016
55 SX=SS	0017
56 ZZ(J)=R+P(J,16,KJ)	0018
Q=.01745329252*(XP+90.)	0019
S1=SINF(Q)	0020
SX=S1	0021
C1=COSF(Q)	0022
CX=C1	0023
R=0.	0024
DO 57 K=1,29	0025
R=R+SX*ZZ(K)	0026
SS=SX*C1+CX*S1	0027
CX=CX*C1-SX*S1	0028
57 SX=SS	0029
ATNO=R+ALF+BET*Q	0030
RETURN	0031
END	0032

IX. MATHEMATICAL EXPRESSIONS

1. Great circle distance in kilometers, degrees and nautical miles

$$\cos(\text{gcd}) = \sin(x_1) \cdot \sin(x_2) + \cos(x_1) \cdot \cos(x_2) \cdot \cos(y_2 - y_1)$$

gcd = great circle distance - degrees

x1 = transmitter latitude - degrees

y1 = transmitter longitude - degrees

x2 = receiver latitude - degrees

y2 = receiver longitude - degrees

2. Bearing from receiver to transmitter, degrees east of north. ($0 \leq \text{btry} \leq 360^\circ$).

$$\text{btry} = 114.5816 \cdot \tan^{-1} \sqrt{\left| \sin(u - 90 + x_2) \cdot \sin(u - \text{gcd}) \right| / \text{cind}}$$

$$u = (180. - x_1 - x_2 + \text{gcd}) / 2$$

$$\text{cind} = \sin(u) \cdot \sin(u - 90 + x_1)$$

3. Geographic latitude of control points along great circle route.

$$x'1 = \cos(pp) \cdot \cos(90 - x_2) + \sin(pp) \cdot \sin(90 - x_2) \cdot \cos(\text{btry})$$

$$(\text{Control Lat}) = 90 - \arccos(x'1)$$

pp = great circle distance in degrees from transmitter terminal to control point

4. Geographic longitude of control points along great circle route. ($y = y_2 - y'$)

$$y' = \arccos \left[\frac{\cos (pp) - \cos (90 - x_2) \cdot \cos (90 - x_3)}{\sin (90 - x_2) \cdot \sin (90 - x_3)} \right]$$

x_3 = control point geographic latitude

5. Geomagnetic latitude of control points along great circle route. ($y = 90 - y'$)

$$y' = \arccos \left[\sin (x_4) \cdot \sin (x_3) + \cos (x_4) \cdot \cos (x_3) \cdot \cos (x_3 - x_4) \right]$$

x_4 = latitude of geomagnetic north pole

6. Local time at receiver terminal.

$$LMT = GMT - y_2/15$$

LMT = local mean time - hours

GMT - Greenwich mean time - hours

7. Sun's zenith angle at control points.

$$\cos (\psi) = \sin (z) \cdot \sin (ssp) + \cos (z) \cdot \cos (ssp) \cdot \cos [(15 \times GMT) - 180].$$

ψ = sun's zenith angle - degrees

z = control point latitude - degrees

ssp = latitude of subsolar point of sun for middle of month in question - degrees

GMT - Greenwich mean time - hours

8. Ionospheric absorption index "I"

$$I = (1 + .0037 SSN) (\cos .881 \psi)^{1.3}$$

SSN ψ predicted or observed 12 month moving average
Zurich sunspot number. ($0 \leq \text{SSN} \leq 200$)

9. E-layer distance factor.

$$\begin{aligned} \text{elfc} = & 2.085000000 \cdot 10^{-1} - 1.33200756 \cdot 10^{-2} \cdot x + \\ & 3.761385053 \cdot 10^{-2} x^2 - 5.038476266 \cdot 10^{-3} \cdot x^3 + \\ & 2.624808315 \cdot 10^{-4} x^4 - 5.976618436 \cdot 10^{-6} \cdot x^5 + \\ & 1.334494261 \cdot 10^{-7} x^6 - 4.368460907 \cdot 10^{-9} \cdot x^7 \end{aligned}$$

x = great circle distance - hundreds of statute miles

10. E-2000 MUF.

$$\begin{aligned} \text{emc} = & 3.345996232 + 37.67736072 \cdot I - 52.41191754 \cdot I^2 \\ & + 39.26151056 \cdot I^3 - 10.66484988 \cdot I^4 \end{aligned}$$

I = absorption index

11. E-layer MUF.

$$\text{emufy} = (\text{emc}) \cdot (\text{elfc})$$

emc = E-2000 MUF

12. F-layer distance factor.

$$\begin{aligned} \text{flfc} = & 4.699243101 \cdot 10^{-3} x + 2.264634341 \cdot 10^{-3} \cdot x^2 \\ & + 9.202437332 \cdot 10^{-5} \cdot x^3 + 6.865259817 \cdot 10^{-5} \cdot x^4 - \\ & 9.985831104 \cdot 10^{-6} \cdot x^5 + 4.49151441 \cdot 10^{-7} \cdot x^6 - \\ & 6.712654756 \cdot 10^{-9} \cdot x^7 \end{aligned}$$

x = great circle distance - hundreds of statute miles

13. F2-layer Fourier generation of foF2 and M-3000 factors.

Fourier time variation function, used to obtain foF2
or M-3000 factor:

$$\Gamma(x, y, t) = ab(x, y) + \sum_{jb=2}^j \left[ab_{jb}(x, y) \cos(jb - 1)t + ba_{jb}(x, y) \sin(jb - 1)t \right]$$

$$ab_{jb}(x, y) = \sum_{ka=1}^I Q_{is, ka, io} G_{ka}(xy) \quad \begin{matrix} is = 2jb - 1 \\ jb = 1, 2, 3, \dots, j \end{matrix}$$

$$ba_{jb}(x, y) = \sum_{ka=1}^I Q_{is, ka, io} G_{ka}(xy) \quad \begin{matrix} is = 2jb - 2 \\ jb = 2, 3, 4, \dots, j \end{matrix}$$

x = geographic latitude of control point - degrees

$(-90^\circ \leq x \leq 90^\circ)$

y = geographic longitude of control point - degrees

$(0^\circ \leq x \leq 360^\circ$ - East of North)

t = local time at receiver - (hour angle) $(180 \leq t \leq 180^\circ)$

I, j, k, L = constants describing number of harmonics in the Fourier functions

io = matrix for foF2 or M-3000 (high or low SSN)

$Q_{is, ka, io}$ = Fourier coefficients defining the function

$$\Gamma(x, y, t) \text{ (Time variation)}$$

Latitudinal and longitudinal variation functions are shown in Tables 1 and 2.

For a detailed explanation of the generation of $\Gamma(x, y, t)$

refer to [Jones and Gallet, 1961]. The above formulas and constants have been altered from the originals in the reference to make the generation permissible on a larger variety of computers.

Table 1. Geographical Function in Latitude

MAIN LATITUDINAL VARIATION	
ka	$G_{ka}(x, y)$
1	1
2	$\sin(x)$
3	$\sin^2(x)$
...	...
k	$\sin^{k-1}(x)$

Table 2. Geographical Functions in Latitude and Longitude.

MIXED LATITUDINAL AND LONGITUDINAL VARIATION - FIRST ORDER IN LONGITUDE	
ka	$G_{ka}(x, y)$
$k + 1$	$\cos(x) \cos(y)$
$k + 2$	$\cos(x) \sin(y)$
$k + 3$	$\sin(x) \cos(x) \cos(y)$
$k + 4$	$\sin(x) \cos(x) \sin(y)$
...	...
...	...
$L - 1$	$\sin^{L_a}(x) \cos(x) \cos(y)$
L	$\sin^{L_a}(x) \cos(x) \sin(y)$
	$L_a = \frac{L - k}{2} - 1$
MIXED LATITUDINAL AND LONGITUDINAL VARIATION - SECOND ORDER IN LONGITUDE	
$L + 1$	$\cos^2(x) \cos(2y)$
$L + 2$	$\cos^2(x) \sin(2y)$
$L + 3$	$\sin(x) \cos^2(x) \cos(2y)$
$L + 4$	$\sin(x) \cos^2(x) \sin(2y)$
...	...
...	...
$I - 1$	$\sin^{L_b}(x) \cos^2(x) \cos(2y)$
I	$\sin^{L_b}(x) \cos^2(x) \sin(2y)$
	$L_b = \frac{I - L}{2} - 1$

14. F2-layer gyro frequency may be adequately represented for MUF-FOT predictions by a set of least squares coefficients describing the orthogonal polynomial.

$$y = (a_{1,1} + a_{1,2} x + a_{1,3} x^2 \dots a_{1,7} x^6) z^0 + \dots$$

$$(a_{7,1} + a_{7,2} x + a_{7,3} z^2 \dots a_{7,7} x^6) z^6$$

y = gyro frequency of F2 layer - Mc/s

x = longitude of control point - degrees

z = latitude of control point = degrees

a = set of least squares coefficients describing the orthogonal polynomial (y)

15. F2-4000 MUF.

$$F2-4000 \text{ MUF} = (foF2) \times (M-4000 \text{ factor})$$

16. F-MUF for low and high solar activity.

$$F-MUF = ZDF + flfc \cdot \left[(F2-4000) - ZDF \right]$$

$$ZDF = foF2 + \frac{1}{2} \text{ F2-layer gyro frequency}$$

$$M-4000 \text{ factor} = (1.1) \cdot M-3000 \text{ factor}$$

17. Interpolation for intermediate values of solar activity.

$$(10 \leq SSN \leq 180)$$

$$F-MUF = \left[F-MUF_{(L)} \cdot (180 - SSN) + F-MUF_{(H)} \cdot (SSN - 10) \right] / 170$$

$$F-MUF_{(L)} = F-MUF \text{ for SSN } 10$$

$$F-MUF_{(H)} = F-MUF \text{ for SSN } 180$$

18. Angle at the ionosphere (ϕ).

$$\phi' = \sin^{-1} \left[\frac{p \left(\sin \left(90 + \tan^{-1} \left(\cos \frac{A'}{2} - p / (p + H_f) \right) \right) \right)}{p + H_f} \right]$$

ϕ' = angle of incidence - degrees

p = radius of earth - km

A' = great circle distance - degrees

H_f = layer height - km

19. Ionospheric absorption (single reflection)

$$A = \frac{615.5 N \sec \phi (I)}{(f + f_g)^{1.98}}$$

ϕ = angle of incidence for 100 km - degrees

f = operating frequency

I = absorption index

f_g = gyro frequency - Mc/s

20. Basic transmission loss for isotropic antennas in free space.

$$\begin{aligned} L_{bf} &= 10 \log_{10} (p_r / p_a) = 10 \log_{10} (4 \pi d / \lambda)^2 \\ &= 36.58 + 20 \log_{10} (d) + 20 \log_{10} (f_{Mc/s}) \end{aligned}$$

p_r = power available at receiving antenna

p_a = power delivered to transmitting antenna

d = ray path distance - miles

λ = wave length

$f_{Mc/s}$ = frequency - Mc/s

21. Relationship between ϕ' and Δ .

$$\sin \phi' = \frac{p}{p+H_f} \cos \Delta$$

ϕ' = angle of incidence at ionosphere

p = radius of earth

H_f = layer height

Δ = radiation angle of wave

22. Ground reflection factors for vertical and horizontal polarization.

$$K_H = \frac{\sin \Delta - \sqrt{(\epsilon_r - ix) - \cos^2 \Delta}}{\sin \Delta + \sqrt{(\epsilon_r - ix) - \cos^2 \Delta}}$$

$$K_V = \frac{(\epsilon_r - ix) \sin \Delta - \sqrt{(\epsilon_r - ix) - \cos^2 \Delta}}{(\epsilon_r - ix) \sin \Delta + \sqrt{(\epsilon_r - ix) - \cos^2 \Delta}}$$

ϵ_r = relative dielectric constant of earth,

$$x = \frac{\sigma}{\omega \epsilon_v} \approx 18 \times 10^3 \sigma / f,$$

σ = conductivity of earth (mhos/meter),

ω = angular frequency,

f = frequency in megacycles,

Δ = angle of elevation in degrees, and

$i = \sqrt{-1}$.

ϵ_r = dielectric constant of free space

23. Rhombic antenna power gain relative to isotropic in free space.

$$g(\Delta, \beta) = 3.2 \left(\frac{\pi l}{\lambda} \right) \left[\{D_V(\Delta, \beta)\}^2 + \{D_H(\Delta, \beta)\}^2 \right]$$

$$D_V(\Delta, \beta) = \cos \phi \cdot \frac{\sin u_1}{u_1} \cdot \frac{\sin u_2}{u_2} \cdot \sin \beta \cdot \sin \Delta$$

$$\cdot \left[|K_V|^2 + 1 - 2 |K_V| \cos (\psi_V - \frac{4\pi h}{\lambda} \cdot \sin \Delta) \right]^{\frac{1}{2}}$$

$$D_H(\Delta, \beta) = \cos \phi \cdot \frac{\sin u_1}{u_1} \cdot \frac{\sin u_2}{u_2} \cdot (\cos \beta - \sin \phi \cdot \cos \Delta)$$

$$\left[|K_H|^2 + 1 - 2 |K_H| \cos (\psi_H - \frac{4\pi h}{\lambda} \cdot \sin \Delta) \right]^{\frac{1}{2}}$$

$$u_1 = \frac{\pi l}{\lambda} \left[1 - \cos \Delta \cdot \sin (\phi + \beta) \right]$$

$$u_2 = \frac{\pi l}{\lambda} \left[1 - \cos \Delta \cdot \sin (\phi - \beta) \right]$$

$g(\Delta, \beta)$ = power gain relative to isotropic in free space

Δ = angle of departure in degrees,

β = angle of azimuth in degrees,

l = rhombic leg length in meters,

h = antenna height in meters,

ϕ = tilt angle in degrees.

$$\psi_V = \tan^{-1} \left[\frac{2p^{\frac{1}{2}} \cdot y^{\frac{1}{2}} \cdot \sin \Delta \cdot \sin \left(\tan^{-1} \frac{x}{\epsilon_r} + \frac{a}{2} \right)}{p - y \cdot \sin^2 \Delta} \right] + \pi$$

$$|K_H| = \frac{[p^2 + \sin^4 \Delta - 2p \cdot \sin^2 \Delta \cdot \cos a]^{\frac{1}{2}}}{[p + \sin^2 \Delta + 2p^{\frac{1}{2}} \cdot \sin \Delta \cdot \cos \frac{a}{2}]}$$

$$|K_V| = \frac{[p^2 + y^2 \cdot \sin^4 \Delta - 2p \cdot y \cdot \sin^2 \Delta \cdot \cos (a + 2 \sin^{-1} \frac{x}{y^{\frac{1}{2}}})]^{\frac{1}{2}}}{p + y \cdot \sin^2 \Delta + 2p^{\frac{1}{2}} y^{\frac{1}{2}} \cdot \sin \Delta \cdot \cos (\frac{a}{2} + \sin^{-1} \frac{x}{y^{\frac{1}{2}}})}$$

$$\psi_H = \tan^{-1} \left[\frac{2p^{\frac{1}{2}} \cdot \sin \Delta \cdot \sin \frac{a}{2}}{p - \sin^2 \Delta} \right]$$

$$y = \epsilon_r^2 + x^2$$

$$p = [(\epsilon_r - \cos^2 \Delta)^2 + x^2]^{\frac{1}{2}}$$

$$a = -\tan^{-1} \frac{x}{(\epsilon_r - \cos^2 \Delta)}$$

$$x = 18 \times 10^3 \sigma / f$$

ϵ_r = relative dielectric constant of the ground

σ = conductivity of the ground in mhos per meter

f = operating frequency in megacycles per second

$K_H = - |K_H| e^{i\psi_H}$ = horizontal reflection coefficient, and

$K_V = - |K_V| e^{i\psi_V}$ = vertical reflection coefficient.

24. Power gain of half-wave horizontal dipole.

$$E_{\Delta} = (.74582)^2 \left[\frac{\cos \left(\frac{\pi}{2} \cdot \cos \Delta \right)}{\sin^2 \Delta} \right]^2 \left\{ K_H^2 + 1 - 2 \cdot K_H \cdot \cos \left(\psi_H - \frac{4\pi H}{\lambda} \cdot \sin \Delta \right) \right\}$$

K_H = amplitude of horizontal reflection coefficient

ψ_H = phase amplitude of horizontal reflection coefficient

H = height of antenna - meters

λ = 299.7925/frequency in megacycles

$$\frac{H}{\lambda} = \frac{1}{2}$$

Δ = angle of elevation

Note: 72 ohms assumed impedance of antenna

$$\text{Gain}_{\text{decibels}} = 10 \cdot \log_{10} (E_{\Delta})$$

25. Power gain of vertical antennas

$$E_{\Delta} = \frac{120}{RA} \cdot \left[\frac{\cos(A) \sin \Delta - \cos(A)}{\cos(\Delta)} \right]^2 \cdot \left\{ K_V^2 + 1 - 2 \cdot K_V \cos(\psi_V - 2A \cdot \sin \Delta) \right\}$$

$$R_a = 30 \left[- \frac{\cos(2A)}{2} \cdot \left\{ C + \ln(4A) - C_i(4A) \right\} + \left\{ 1 + \cos(2A) \right\} \times \left\{ C + \ln(2A) - C_i(2A) \right\} \right]$$

$$+ \sin (2A) \times \left\{ \frac{S_i (4A)}{2} - S_i (2A) \right\} \Bigg]$$

$$C = .5772156649$$

H = height of antenna - meters

Si = sine integral

Ci = cosine integral

$$A = 2 \pi H/\lambda$$

26. Efficiency factor for short vertical antennas.

$$\begin{aligned} \text{EFF} = & 25.64620146 - 364.8173803 x \\ & + 2179.890548 x^2 - 6091.333295 x^3 \\ & + 6416.702573 x^4 \end{aligned}$$

x = wave length of antenna

$$(1/16 \leq x \leq 1/4)$$

27. Ground reflection loss.

$$G_l = 10 \log_{10} \left[\frac{K_H^2 + K_V^2}{2} \right]$$

28. Relationship of field strength to transmission loss.

(Decibels above isotropic)

$$E = 107.2 + 20 \log_{10} (f_{mc}) - L_b$$

f_{mc} = frequency - Mc/s

L_b = transmission loss - decibels

X. GENERALIZED BLOCK DIAGRAM OF HF SYSTEM PERFORMANCE ROUTINE

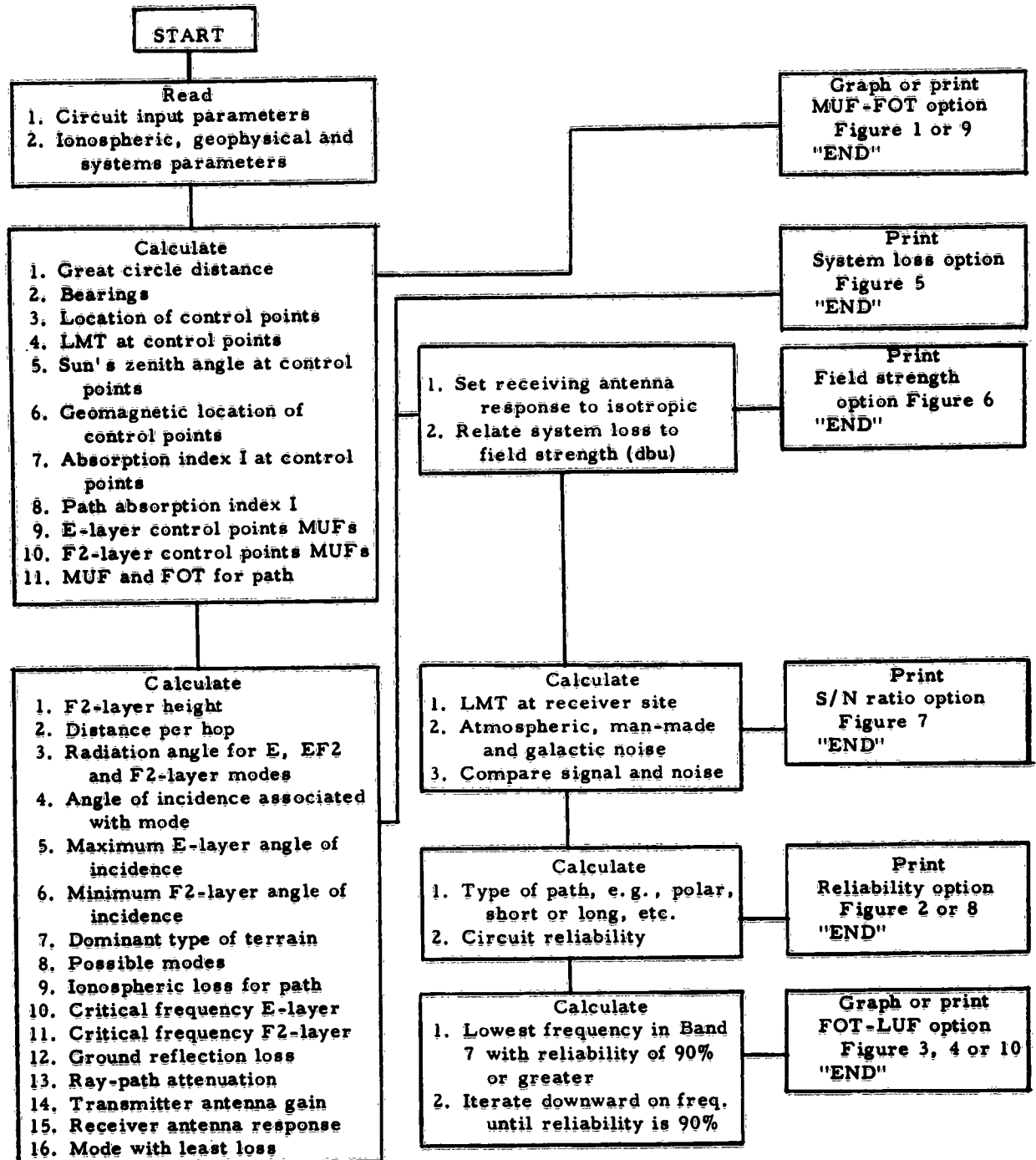


Figure 18

XI. CONCLUSIONS

The computer solution of HF systems problems based on established manual methods is efficient and practical.

The radio systems engineer may with this basic tool check predictions against operational data to update the prediction scheme and to test new prediction parameters with little effort.

The routine is based on average monthly values; therefore, it is most useful in systems problems such as allocation of frequencies and circuit design. Use of the relative values produced by the prediction scheme are no doubt more important to the communication engineer than are absolute values. The routine is most valuable for the experienced engineer with an adequate knowledge of the shortcomings, as well as the usefulness of such a prediction scheme.

XII. ACKNOWLEDGEMENT

The invaluable assistance in program development techniques by John D. Harper, Jr., of the National Bureau of Standards, is gratefully acknowledged.

XIII. REFERENCES

- Chrisman, Mary E., and Charles D. Stearns, Computation and plotting of rhombic antenna gains using electronic digital computers, NBS Report 7235 (March 13, 1962).
- CCIR Report No. 65, Atmospheric radio noise data (Los Angeles, 1959).
- Duncan, David B., and John F. Kenney, On the solution of the normal equation and related topics, Edwards Bros., Inc., Ann Arbor, Michigan (1946).
- Haydon, George W., Ionospheric predictions and disturbance forecasts, Lecture No. 47, NBS Radio Propagation Course (to be published) (1962).
- Jones, W. B., and R. M. Gallet, Numerical mapping in geophysics II. Methods for applying numerical maps of the ionosphere, NBS Report 6755 (March 8, 1961).
- Laitinen, Paul O., Linear communication antennas, U. S. Army Signal Radio Propagation Agency, Technical Report No. 7 (May 1949).
- Laitinen, Paul O., and George W. Haydon, Analysis and prediction of sky-wave field intensities in the high frequency band, Technical Report No. 9, U. S. Army Signal Radio Propagation Agency (March 1950).
- Lucas, Donald L., and George W. Haydon, MUF-FOT predictions by electronic computers, NBS Report 6789 (August 13, 1961).
- Lucas, Donald L., and John D. Harper, Jr., A numerical representation of atmospheric radio noise in band 7 (to be published) (1962).
- McCracken, Daniel D., A guide to Fortran programming (Wiley and Sons, New York, N. Y., April 1962).
- NBS Circular No. 462, Ionospheric radio propagation (June 25, 1948).
- NBS CRPL Series D, Basic radio propagation.

Ostrow, S. M. , and M. PoKempner, The difference in the relationship between ionospheric critical frequencies and sunspot number for different sunspot cycles, J. of Geo. Res. , 57, No. 4, pp. 473-480 (December 1952).

Phillips, Keith L. , Theory of radiation patterns and gains for horizontal rhombic antennas adapted to electronic computers, NBS Report 7200 (October 10, 1961).

U. S. Army Signal Radio Propagation Agency, Radiation from antennas in the 2 to 30 megacycle band, Technical Report No. 2 (May 1958).

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*
NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*



THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D. C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics. High Voltage.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research. Crystal Chemistry.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Polymers. Macromolecules: Synthesis and Structure. Polymer Chemistry. Polymer Physics. Polymer Characterization. Polymer Evaluation and Testing. Applied Polymer Standards and Research. Dental Research.

Metallurgy. Engineering Metallurgy. Microscopy and Diffraction. Metal Reactions. Metal Physics. Electrolysis and Metal Deposition.

Inorganic Solids. Engineering Ceramics. Glass. Solid State Chemistry. Crystal Growth. Physical Properties. Crystallography.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials. Metallic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Far Ultraviolet Physics. Solid State Physics. Electron Physics. Atomic Physics. Plasma Spectroscopy.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Elementary Processes. Mass Spectrometry. Photochemistry and Radiation Chemistry.

Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering Laboratory. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Cryogenic Technical Services.

CENTRAL RADIO PROPAGATION LABORATORY

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Frequency Utilization. Modulation Research. Antenna Research. Radiodetermination.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. High Latitude Ionosphere Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

RADIO STANDARDS LABORATORY

Radio Physics. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time-Interval Standards. Radio Plasma. Millimeter-Wave Research.

Circuit Standards. High Frequency Electrical Standards. High Frequency Calibration Services. High Frequency Impedance Standards. Microwave Calibration Services. Microwave Circuit Standards. Low Frequency Calibration Services.