PREDICTING THE PERFORMANCE OF BAND 7 COMMUNICATION SYSTEMS USING ELECTRONIC COMPUTERS

by

Donald L. Lucas and George W. Haydon
The National Bureau of Standards

Functions and Activities

The functions of the National Bureau of Standards 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, including assistance to industry, business and consumers in the development and acceptance of commercial standards and simplified trade practice recommendations. 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 Central Radio Propagation Laboratory Ionospheric Predictions provides data for determining the best frequencies to use for radio communications throughout the world. There are also seven series of nonperiodical publications: Monographs, Applied Mathematics Series, Handbooks, Miscellaneous Publications, Technical Notes, Commercial Standards, and Simplified Practice Recommendations.

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, D.C., 20402.
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
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Figures</td>
<td>i</td>
</tr>
<tr>
<td>List of Tables</td>
<td>ii</td>
</tr>
<tr>
<td>I. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>II. Program Description</td>
<td>5</td>
</tr>
<tr>
<td>1. MUF-FOT</td>
<td>6</td>
</tr>
<tr>
<td>2. System Loss</td>
<td>7</td>
</tr>
<tr>
<td>3. Field Strength Option</td>
<td>9</td>
</tr>
<tr>
<td>4. Radio Noise</td>
<td>9</td>
</tr>
<tr>
<td>5. Available Signal-to-Noise</td>
<td>9</td>
</tr>
<tr>
<td>6. Required Signal-to-Noise</td>
<td>10</td>
</tr>
<tr>
<td>7. Reliability</td>
<td>10</td>
</tr>
<tr>
<td>8. Lowest Useful Frequency</td>
<td>10</td>
</tr>
<tr>
<td>III. Program Use</td>
<td>10</td>
</tr>
<tr>
<td>IV. Description of Data Tapes</td>
<td>13</td>
</tr>
<tr>
<td>1. &quot;Long-term&quot; Data Tapes</td>
<td>13</td>
</tr>
<tr>
<td>2. &quot;Short-term&quot; Data Tapes</td>
<td>15</td>
</tr>
<tr>
<td>(a) Description</td>
<td>15</td>
</tr>
<tr>
<td>(b) Program</td>
<td>17</td>
</tr>
<tr>
<td>V. Program Options</td>
<td>19</td>
</tr>
<tr>
<td>1. MUF and FOT</td>
<td>19</td>
</tr>
<tr>
<td>2. MUF, FOT, Mode, Arrival Angle, and Reliability</td>
<td>19</td>
</tr>
<tr>
<td>3. FOT and LUF</td>
<td>19</td>
</tr>
<tr>
<td>4. MUF, FOT, Mode, Arrival Angle, and System Loss</td>
<td>19</td>
</tr>
<tr>
<td>5. MUF, FOT, Mode, Arrival Angle, and Field Strength</td>
<td>20</td>
</tr>
<tr>
<td>6.</td>
<td>MUF, FOT, Mode, Arrival Angle, and Signal-to-Noise</td>
</tr>
<tr>
<td>7.</td>
<td>MUF, FOT, and Reliability</td>
</tr>
<tr>
<td>8.</td>
<td>FOT Graphs</td>
</tr>
<tr>
<td>9.</td>
<td>FOT and LUF Graphs</td>
</tr>
<tr>
<td>VI.</td>
<td>Computer Inputs</td>
</tr>
<tr>
<td>1.</td>
<td>Circuit Card Format</td>
</tr>
<tr>
<td>2.</td>
<td>Method Card Format</td>
</tr>
<tr>
<td>3.</td>
<td>Assembling the Data Decks</td>
</tr>
<tr>
<td>4.</td>
<td>Purpose of Cards in Data Deck</td>
</tr>
<tr>
<td>(a)</td>
<td>Method Card</td>
</tr>
<tr>
<td>(b)</td>
<td>Frequency Complement Card</td>
</tr>
<tr>
<td>(c)</td>
<td>Circuit Cards</td>
</tr>
<tr>
<td>(d)</td>
<td>Nines Card</td>
</tr>
<tr>
<td>(e)</td>
<td>Month and Sunspot Number Card</td>
</tr>
<tr>
<td>(f)</td>
<td>Minus One Card</td>
</tr>
<tr>
<td>(g)</td>
<td>Blank Card</td>
</tr>
<tr>
<td>VII.</td>
<td>Program Output</td>
</tr>
<tr>
<td>VIII.</td>
<td>Complete Fortran Listing of Computer Program for Predicting HF System Performance</td>
</tr>
<tr>
<td>IX.</td>
<td>Mathematical Expressions</td>
</tr>
<tr>
<td>1.</td>
<td>Great Circle Distance</td>
</tr>
<tr>
<td>2.</td>
<td>Bearing from Receiver to Transmitter</td>
</tr>
<tr>
<td>3.</td>
<td>Geographic Latitude of Control Points Along Great Circle Route</td>
</tr>
<tr>
<td>4.</td>
<td>Geographic Longitude of Control Points Along Great Circle Route</td>
</tr>
</tbody>
</table>
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 $\phi$ and $\Delta$ 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
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>26. Efficiency Factor for Short Vertical Antennas</td>
<td>102</td>
</tr>
<tr>
<td>27. Ground Reflection Loss</td>
<td>102</td>
</tr>
<tr>
<td>28. Relationship of Field Strength to Transmission</td>
<td>102</td>
</tr>
<tr>
<td>X. Generalized Block Diagram of HF Systems Performance Routine</td>
<td>103</td>
</tr>
<tr>
<td>XI. Conclusions</td>
<td>104</td>
</tr>
<tr>
<td>XII. Acknowledgement</td>
<td>105</td>
</tr>
<tr>
<td>XIII. References</td>
<td>106</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>1.</td>
<td>Computer Print-Out of Circuit MUF and FOT</td>
</tr>
<tr>
<td>2.</td>
<td>Computer Print-Out of Circuit MUF, FOT and Circuit Reliability</td>
</tr>
<tr>
<td>3.</td>
<td>Computer Print-Out of Circuit LUF and FOT</td>
</tr>
<tr>
<td>4.</td>
<td>Alternative Computer Print-Out of Circuit LUF and FOT</td>
</tr>
<tr>
<td>5.</td>
<td>Computer Print-Out of Circuit MUF, FOT and System Loss</td>
</tr>
<tr>
<td>6.</td>
<td>Computer Print-Out of Circuit MUF, FOT and Received Field Strength</td>
</tr>
<tr>
<td>7.</td>
<td>Computer Print-Out of Circuit MUF, FOT and Available Signal-to-Noise</td>
</tr>
<tr>
<td>8.</td>
<td>Alternative Computer Print-Out of Circuit MUF, FOT and Circuit Reliability</td>
</tr>
<tr>
<td>9.</td>
<td>Graphical Representation of Circuit FOT</td>
</tr>
<tr>
<td>10.</td>
<td>Graphical Representation of Circuit LUF and FOT</td>
</tr>
<tr>
<td>11.</td>
<td>Data for High Frequency Communication Predictions</td>
</tr>
<tr>
<td>12.</td>
<td>Auxiliary Data Cards</td>
</tr>
<tr>
<td>13.</td>
<td>Example Method Card and Circuit Card</td>
</tr>
<tr>
<td>14.</td>
<td>Example Data Deck for Run Under One Method Only from Cards</td>
</tr>
<tr>
<td>15.</td>
<td>Example Data Deck for Run Under Two Methods from Cards</td>
</tr>
<tr>
<td>16.</td>
<td>Example Data Deck for One Method Using Circuits from Magnetic Tape</td>
</tr>
</tbody>
</table>
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
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 ($f_{0}F2$).
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.
(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 \((\sigma = 0.001 \text{ mhos/meter}; \epsilon = 4)\) 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 \(0.02 \lambda\). 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 subroutines used in the program are as follows:
<table>
<thead>
<tr>
<th>Subroutine</th>
<th>Call</th>
<th>Argument</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sine</td>
<td>SINF (x)</td>
<td>(radians)</td>
</tr>
<tr>
<td>2. Arc sine</td>
<td>ASINF (x)</td>
<td>(-1 ≤ x ≤ 1)</td>
</tr>
<tr>
<td>3. Cosine</td>
<td>COSF (x)</td>
<td>(radians)</td>
</tr>
<tr>
<td>4. Arc cosine</td>
<td>ACOSF (x)</td>
<td>(-1 ≤ x ≤ 1)</td>
</tr>
<tr>
<td>5. Absolute value</td>
<td>ABSF (x)</td>
<td>(floating)</td>
</tr>
<tr>
<td>6. Absolute value</td>
<td>XABSF (x)</td>
<td>(fixed)</td>
</tr>
<tr>
<td>7. Arc tangent</td>
<td>ATANF (x)</td>
<td>(-∞ ≤ x ≤ ∞)</td>
</tr>
<tr>
<td>8. Square root</td>
<td>SQRTF (x)</td>
<td>(0 ≤ x ≤ ∞)</td>
</tr>
<tr>
<td>9. Transfer of sign</td>
<td>SIGNF (x, y)</td>
<td>(arg 1, arg 2)</td>
</tr>
<tr>
<td>10. Logarithm (Base 10)</td>
<td>LOG10F (x)</td>
<td>(0 &lt; x ≤ ∞)</td>
</tr>
<tr>
<td>11. Natural logarithm</td>
<td>LOGF (x)</td>
<td>(0 &lt; x ≤ ∞)</td>
</tr>
<tr>
<td>12. Integer function</td>
<td>INTF (x)</td>
<td>(-∞ ≤ x ≤ ∞)</td>
</tr>
</tbody>
</table>

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:

\[ Y = \left( A_{0,0} x^0 + A_{0,1} x^1 + \ldots + A_{0,n} x^n \right) Z^0 \]
\[ + \left( A_{1,0} x^0 + A_{1,1} x^1 + \ldots + A_{1,n} x^n \right) Z^1 \]
\[ + \ldots \]
\[ + \left( A_{m,0} x^0 + A_{m,1} x^1 + \ldots + A_{m,n} x^n \right) Z^m \]

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
\[ \text{Si}(x) = \int_0^x \frac{\sin v}{v} \, dv \]

\[ \text{Ci}(x) = \int_0^x \frac{\cos v}{v} \, dv \]

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.

\[
\begin{align*}
P(M,N,1) & : 2000-0400 \text{ LMT} \\
P(M,N,2) & : 1600-2000 \text{ LMT} \\
P(M,N,3) & : 1200-1600 \text{ LMT} \\
P(M,N,4) & : 0800-1200 \text{ LMT} \\
P(M,N,5) & : 0400-0800 \text{ LMT} \\
P(M,N,6) & : \text{major land bodies of the world}
\end{align*}
\]

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:

```
63 6 4500 139 10 6 48 6 10 1 37.0 0 0 3.043346E 00
```

FORTRAN STATEMENT

```
(b) Program to Use CRPL "Ionospheric Predictions" 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), P 129,16,6), ABP(2,6)

1 FORMAT (19X,2I4,4X,2I4,12X,2I5,E17.7)
2 FORMAT (51X,2I5,E17.7)
101 FORMAT(212)

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
DO 600 KP=1,4800

600 Q(KP)=0.
   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
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
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.

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

<table>
<thead>
<tr>
<th>Calculations to be Performed</th>
<th>Card Columns</th>
<th>Sample Print-Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>MUF-FOT listing from circuits on cards</td>
<td>1 1 0 0</td>
<td>Figure 1</td>
</tr>
<tr>
<td>MUF-FOT listing from circuits on tape</td>
<td>1 0 0 0</td>
<td></td>
</tr>
<tr>
<td>FOT curve from circuits on cards</td>
<td>1 1 0 1</td>
<td>Figure 9</td>
</tr>
<tr>
<td>FOT curve from circuits on tape</td>
<td>1 0 0 1</td>
<td></td>
</tr>
<tr>
<td>Reliability-mode-angle from circuits on cards</td>
<td>2 1 0 0</td>
<td>Figure 2</td>
</tr>
<tr>
<td>Reliability-mode-angle from circuits on tape</td>
<td>2 0 0 0</td>
<td></td>
</tr>
<tr>
<td>FOT-LUF listing every hour from circuits on cards</td>
<td>3 1 0 0</td>
<td>Figure 3</td>
</tr>
<tr>
<td>FOT-LUF listing every hour from circuits on tape</td>
<td>3 0 0 0</td>
<td></td>
</tr>
<tr>
<td>FOT listing every hour, LUF every 2 hours from circuits on cards</td>
<td>3 1 1 0</td>
<td>Figure 4</td>
</tr>
<tr>
<td>FOT listing every hour, LUF every 2 hours from circuits on tape</td>
<td>3 0 1 0</td>
<td></td>
</tr>
<tr>
<td>FOT-LUF curves from circuits on cards</td>
<td>3 1 0 1</td>
<td>Figure 10</td>
</tr>
<tr>
<td>FOT-LUF curves from circuits on tape</td>
<td>3 0 0 1</td>
<td></td>
</tr>
<tr>
<td>System loss from circuits on cards</td>
<td>4 1 0 0</td>
<td>Figure 5</td>
</tr>
<tr>
<td>System loss from circuits on tape</td>
<td>4 0 0 0</td>
<td></td>
</tr>
<tr>
<td>Field strength (dbu) from circuits on cards</td>
<td>4 1 1 0</td>
<td>Figure 6</td>
</tr>
<tr>
<td>Field strength (dbu) from circuits on tape</td>
<td>4 0 1 0</td>
<td></td>
</tr>
<tr>
<td>Reliability-FOT every 2 hours from circuits on cards</td>
<td>5 1 0 0</td>
<td>Figure 8</td>
</tr>
<tr>
<td>Reliability-FOT every 2 hours from circuits on tape</td>
<td>5 0 0 0</td>
<td></td>
</tr>
</tbody>
</table>
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.
### Table 1: Computer Print-Out of Circuit MUF and FOT

<table>
<thead>
<tr>
<th>Transmitter</th>
<th>Receiver</th>
<th>Bearing</th>
<th>N.Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 40.75N - 73.93W</td>
<td>32.33N - 64.70W</td>
<td>321.3</td>
<td>672.5</td>
</tr>
<tr>
<td>2 51.50N - 0.01W</td>
<td>27.92N - 15.67W</td>
<td>212.5</td>
<td>1581.3</td>
</tr>
<tr>
<td>3 12.10N - 8.50E</td>
<td>51.50N - 0.01W</td>
<td>351.8</td>
<td>2400.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>MUF</th>
<th>FOT</th>
<th>Time</th>
<th>MUF</th>
<th>FOT</th>
<th>Time</th>
<th>MUF</th>
<th>FOT</th>
<th>Time</th>
<th>MUF</th>
<th>FOT</th>
<th>Time</th>
<th>MUF</th>
<th>FOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMT</td>
<td></td>
<td></td>
<td>GMT</td>
<td></td>
<td></td>
<td>GMT</td>
<td></td>
<td></td>
<td>GMT</td>
<td></td>
<td></td>
<td>GMT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5.7</td>
<td>4.9</td>
<td>7</td>
<td>5.7</td>
<td>4.9</td>
<td>13</td>
<td>10.3</td>
<td>9.2</td>
<td>19</td>
<td>11.6</td>
<td>10.8</td>
<td>1</td>
<td>10.3</td>
<td>8.8</td>
</tr>
<tr>
<td>2</td>
<td>5.2</td>
<td>4.4</td>
<td>8</td>
<td>5.5</td>
<td>4.7</td>
<td>14</td>
<td>11.4</td>
<td>10.6</td>
<td>20</td>
<td>11.7</td>
<td>9.9</td>
<td>2</td>
<td>10.8</td>
<td>9.2</td>
</tr>
<tr>
<td>3</td>
<td>5.2</td>
<td>4.5</td>
<td>9</td>
<td>5.4</td>
<td>4.6</td>
<td>15</td>
<td>11.6</td>
<td>11.4</td>
<td>21</td>
<td>11.2</td>
<td>9.5</td>
<td>3</td>
<td>11.8</td>
<td>9.3</td>
</tr>
<tr>
<td>4</td>
<td>5.4</td>
<td>4.6</td>
<td>10</td>
<td>4.9</td>
<td>4.2</td>
<td>16</td>
<td>11.8</td>
<td>11.8</td>
<td>22</td>
<td>9.7</td>
<td>8.2</td>
<td>4</td>
<td>10.6</td>
<td>8.3</td>
</tr>
<tr>
<td>5</td>
<td>5.4</td>
<td>4.6</td>
<td>11</td>
<td>5.1</td>
<td>4.3</td>
<td>17</td>
<td>11.8</td>
<td>11.8</td>
<td>23</td>
<td>7.7</td>
<td>6.6</td>
<td>5</td>
<td>9.2</td>
<td>6.9</td>
</tr>
<tr>
<td>6</td>
<td>5.7</td>
<td>4.9</td>
<td>12</td>
<td>7.4</td>
<td>6.9</td>
<td>18</td>
<td>11.5</td>
<td>11.5</td>
<td>24</td>
<td>6.5</td>
<td>5.5</td>
<td>6</td>
<td>9.2</td>
<td>6.9</td>
</tr>
</tbody>
</table>

**Figure 1.** Computer Print-Out of Circuit MUF and FOT
<table>
<thead>
<tr>
<th>GMT</th>
<th>MUF</th>
<th>FOT</th>
<th>TEMPERATURE</th>
<th>FREQUENCY</th>
<th>SNR</th>
<th>RELIABILITY</th>
<th>ANGLE</th>
<th>MODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.3</td>
<td>8.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>10.8</td>
<td>9.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10.6</td>
<td>9.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>9.9</td>
<td>8.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>9.3</td>
<td>7.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>8.1</td>
<td>6.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>8.1</td>
<td>6.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>12.9</td>
<td>11.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>19.6</td>
<td>16.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>22.8</td>
<td>19.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>23.6</td>
<td>20.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>23.7</td>
<td>20.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>22.7</td>
<td>19.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>21.7</td>
<td>18.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>21.5</td>
<td>18.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>21.0</td>
<td>17.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>19.5</td>
<td>16.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>16.6</td>
<td>14.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>13.5</td>
<td>11.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>11.8</td>
<td>10.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>10.8</td>
<td>9.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>9.8</td>
<td>8.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>9.7</td>
<td>8.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>10.1</td>
<td>8.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Computer Print-Out of Circuit MUF, FOT and Circuit Reliability
<table>
<thead>
<tr>
<th>JAN</th>
<th>SSN = 25</th>
<th>BR 32.007</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANSMITTER</td>
<td>RECEIVER</td>
<td>BEARINGS</td>
</tr>
<tr>
<td>40.75N - 73.93W</td>
<td>32.33N - 64.70W</td>
<td>135.8 321.3</td>
</tr>
<tr>
<td>RHOMBIC 32H 118L</td>
<td>NOISE</td>
<td>3</td>
</tr>
<tr>
<td>PWR= 20.00KW</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>JAN</th>
<th>SSN = 25</th>
<th>GC 2.016</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANSMITTER</td>
<td>RECEIVER</td>
<td>BEARINGS</td>
</tr>
<tr>
<td>51.50N - 0.01W</td>
<td>27.92N - 15.67W</td>
<td>212.5 22.2</td>
</tr>
<tr>
<td>RHOMBIC 23H 96L</td>
<td>NOISE</td>
<td>3</td>
</tr>
<tr>
<td>PWR= 30.00KW</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GMT</th>
<th>LUF FOT</th>
<th>GMT</th>
<th>LUF FOT</th>
<th>GMT</th>
<th>LUF FOT</th>
<th>GMT</th>
<th>LUF FOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-3.0  8.8</td>
<td>7</td>
<td>-3.0  6.9</td>
<td>13</td>
<td>7.2  19.3</td>
<td>19</td>
<td>3.2  11.5</td>
</tr>
<tr>
<td>2</td>
<td>-3.0  9.2</td>
<td>8</td>
<td>4.4  11.0</td>
<td>14</td>
<td>6.9  18.5</td>
<td>20</td>
<td>3.2  10.1</td>
</tr>
<tr>
<td>3</td>
<td>-3.0  9.0</td>
<td>9</td>
<td>5.5  16.6</td>
<td>15</td>
<td>6.4  18.2</td>
<td>21</td>
<td>-3.0  9.2</td>
</tr>
<tr>
<td>4</td>
<td>-3.0  8.4</td>
<td>10</td>
<td>6.1  19.3</td>
<td>16</td>
<td>5.8  17.8</td>
<td>22</td>
<td>-3.0  8.3</td>
</tr>
<tr>
<td>5</td>
<td>-3.0  7.9</td>
<td>11</td>
<td>6.7  20.0</td>
<td>17</td>
<td>4.7  16.6</td>
<td>23</td>
<td>-3.0  8.3</td>
</tr>
<tr>
<td>6</td>
<td>-3.0  6.9</td>
<td>12</td>
<td>6.9  20.2</td>
<td>18</td>
<td>3.5  14.2</td>
<td>24</td>
<td>-3.0  8.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>JAN</th>
<th>SSN = 25</th>
<th>LD 16.024</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANSMITTER</td>
<td>RECEIVER</td>
<td>BEARINGS</td>
</tr>
<tr>
<td>12.10N - 8.50E</td>
<td>51.50N - 0.01W</td>
<td>351.8 167.0</td>
</tr>
<tr>
<td>RHOMBIC 20H 114L</td>
<td>70DEG</td>
<td>3</td>
</tr>
<tr>
<td>PWR= 10.00KW</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GMT</th>
<th>LUF FOT</th>
<th>GMT</th>
<th>LUF FOT</th>
<th>GMT</th>
<th>LUF FOT</th>
<th>GMT</th>
<th>LUF FOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.1  11.4</td>
<td>7</td>
<td>6.4  13.6</td>
<td>13</td>
<td>9.2  21.9</td>
<td>19</td>
<td>4.4  12.6</td>
</tr>
<tr>
<td>2</td>
<td>4.1  11.1</td>
<td>8</td>
<td>7.5  19.9</td>
<td>14</td>
<td>8.7  21.5</td>
<td>20</td>
<td>4.4  11.8</td>
</tr>
<tr>
<td>3</td>
<td>4.4  10.1</td>
<td>9</td>
<td>8.4  22.6</td>
<td>15</td>
<td>8.1  20.7</td>
<td>21</td>
<td>4.4  11.1</td>
</tr>
<tr>
<td>4</td>
<td>4.4  9.1</td>
<td>10</td>
<td>8.9  23.2</td>
<td>16</td>
<td>6.7  19.5</td>
<td>22</td>
<td>4.4  11.0</td>
</tr>
<tr>
<td>5</td>
<td>4.4  7.8</td>
<td>11</td>
<td>9.5  23.3</td>
<td>17</td>
<td>5.5  17.1</td>
<td>23</td>
<td>4.4  11.0</td>
</tr>
<tr>
<td>6</td>
<td>4.7  8.4</td>
<td>12</td>
<td>9.5  22.6</td>
<td>18</td>
<td>4.4  14.2</td>
<td>24</td>
<td>4.4  11.1</td>
</tr>
</tbody>
</table>

Figure 3. Computer Print-Out of Circuit LUF and FOT
<table>
<thead>
<tr>
<th>Transmitter</th>
<th>Receiver</th>
<th>Bearings</th>
<th>N.Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>40.75N - 73.93W</td>
<td>32.33N - 64.70W</td>
<td>NOISE = 3</td>
<td>672.5</td>
</tr>
<tr>
<td>RHOMBIC 32H 118L</td>
<td>63DEG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWR = 20.00KW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GMT</td>
<td>LUF</td>
<td>FOT</td>
<td>GMT</td>
</tr>
<tr>
<td>1</td>
<td>4.9</td>
<td>7</td>
<td>4.9</td>
</tr>
<tr>
<td>2</td>
<td>-3.0</td>
<td>4.4</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>4.5</td>
<td>9</td>
<td>4.6</td>
</tr>
<tr>
<td>4</td>
<td>-3.0</td>
<td>4.6</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>4.6</td>
<td>11</td>
<td>4.3</td>
</tr>
<tr>
<td>6</td>
<td>-3.0</td>
<td>4.9</td>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transmitter</th>
<th>Receiver</th>
<th>Bearings</th>
<th>N.Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>51.50N - 0.01W</td>
<td>27.92N - 15.67W</td>
<td>NOISE = 3</td>
<td>1581.3</td>
</tr>
<tr>
<td>RHOMBIC 23H 96L</td>
<td>67DEG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWR = 30.00KW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GMT</td>
<td>LUF</td>
<td>FOT</td>
<td>GMT</td>
</tr>
<tr>
<td>1</td>
<td>8.8</td>
<td>7</td>
<td>6.9</td>
</tr>
<tr>
<td>2</td>
<td>-3.0</td>
<td>9.2</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>9.0</td>
<td>9</td>
<td>16.6</td>
</tr>
<tr>
<td>4</td>
<td>-3.0</td>
<td>8.4</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>7.9</td>
<td>11</td>
<td>20.0</td>
</tr>
<tr>
<td>6</td>
<td>-3.0</td>
<td>6.9</td>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transmitter</th>
<th>Receiver</th>
<th>Bearings</th>
<th>N.Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.10N - 8.50E</td>
<td>51.50N - 0.01W</td>
<td>NOISE = 3</td>
<td>2400.4</td>
</tr>
<tr>
<td>RHOMBIC 20H 114L</td>
<td>70DEG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWR = 10.00KW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GMT</td>
<td>LUF</td>
<td>FOT</td>
<td>GMT</td>
</tr>
<tr>
<td>1</td>
<td>11.4</td>
<td>7</td>
<td>13.6</td>
</tr>
<tr>
<td>2</td>
<td>4.1</td>
<td>11.1</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>10.1</td>
<td>9</td>
<td>22.6</td>
</tr>
<tr>
<td>4</td>
<td>4.4</td>
<td>9.1</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>7.8</td>
<td>11</td>
<td>23.3</td>
</tr>
<tr>
<td>6</td>
<td>4.7</td>
<td>8.4</td>
<td>12</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>GMT</th>
<th>MUF</th>
<th>FOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>01H</td>
<td>10.3</td>
<td>8.8</td>
</tr>
<tr>
<td>01H</td>
<td>10.8</td>
<td>9.2</td>
</tr>
<tr>
<td>01H</td>
<td>10.6</td>
<td>9.0</td>
</tr>
<tr>
<td>01H</td>
<td>9.9</td>
<td>8.4</td>
</tr>
<tr>
<td>01H</td>
<td>9.3</td>
<td>7.9</td>
</tr>
<tr>
<td>01H</td>
<td>8.1</td>
<td>6.9</td>
</tr>
<tr>
<td>01H</td>
<td>8.1</td>
<td>6.9</td>
</tr>
<tr>
<td>02H</td>
<td>12.9</td>
<td>11.0</td>
</tr>
<tr>
<td>02H</td>
<td>19.6</td>
<td>16.6</td>
</tr>
<tr>
<td>02H</td>
<td>22.8</td>
<td>19.3</td>
</tr>
<tr>
<td>02H</td>
<td>23.6</td>
<td>20.0</td>
</tr>
<tr>
<td>02H</td>
<td>23.7</td>
<td>20.2</td>
</tr>
<tr>
<td>02H</td>
<td>22.7</td>
<td>19.3</td>
</tr>
<tr>
<td>03H</td>
<td>21.7</td>
<td>18.5</td>
</tr>
<tr>
<td>03H</td>
<td>21.5</td>
<td>18.2</td>
</tr>
<tr>
<td>03H</td>
<td>21.0</td>
<td>17.8</td>
</tr>
<tr>
<td>03H</td>
<td>19.5</td>
<td>16.6</td>
</tr>
<tr>
<td>03H</td>
<td>16.6</td>
<td>14.2</td>
</tr>
<tr>
<td>03H</td>
<td>13.5</td>
<td>11.5</td>
</tr>
<tr>
<td>03H</td>
<td>11.8</td>
<td>10.1</td>
</tr>
<tr>
<td>03H</td>
<td>10.8</td>
<td>9.2</td>
</tr>
<tr>
<td>03H</td>
<td>9.8</td>
<td>8.3</td>
</tr>
<tr>
<td>03H</td>
<td>9.7</td>
<td>8.3</td>
</tr>
<tr>
<td>03H</td>
<td>10.1</td>
<td>8.6</td>
</tr>
</tbody>
</table>

Figure 5. Computer Print-Out of Circuit MUF, FOT and System Loss
Figure 6. Computer Print-Out of Circuit MUF, FOT and Received Field Strength
<table>
<thead>
<tr>
<th>GMT</th>
<th>MUF</th>
<th>FOT</th>
<th>JAN</th>
<th>SSN= 25</th>
<th>GC 2.016</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.3</td>
<td>8.8</td>
<td>2</td>
<td>10.8</td>
<td>9.2</td>
</tr>
<tr>
<td>2</td>
<td>10.6</td>
<td>9.0</td>
<td>3</td>
<td>9.9</td>
<td>8.4</td>
</tr>
<tr>
<td>4</td>
<td>9.3</td>
<td>7.9</td>
<td>5</td>
<td>8.1</td>
<td>6.9</td>
</tr>
<tr>
<td>6</td>
<td>8.1</td>
<td>6.9</td>
<td>7</td>
<td>12.9</td>
<td>11.0</td>
</tr>
<tr>
<td>8</td>
<td>19.6</td>
<td>16.6</td>
<td>9</td>
<td>22.7</td>
<td>19.3</td>
</tr>
<tr>
<td>10</td>
<td>23.6</td>
<td>20.0</td>
<td>11</td>
<td>23.7</td>
<td>20.2</td>
</tr>
<tr>
<td>12</td>
<td>22.7</td>
<td>19.3</td>
<td>13</td>
<td>21.7</td>
<td>18.5</td>
</tr>
<tr>
<td>14</td>
<td>21.5</td>
<td>18.2</td>
<td>15</td>
<td>21.0</td>
<td>17.8</td>
</tr>
<tr>
<td>17</td>
<td>19.5</td>
<td>16.6</td>
<td>18</td>
<td>16.6</td>
<td>14.2</td>
</tr>
<tr>
<td>19</td>
<td>13.5</td>
<td>11.5</td>
<td>20</td>
<td>11.8</td>
<td>10.1</td>
</tr>
<tr>
<td>21</td>
<td>10.8</td>
<td>9.2</td>
<td>22</td>
<td>9.8</td>
<td>8.3</td>
</tr>
<tr>
<td>23</td>
<td>9.7</td>
<td>8.3</td>
<td>24</td>
<td>10.1</td>
<td>8.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TRANSMITTER</th>
<th>RECEPTOR</th>
<th>BEARINGS</th>
<th>N.MILES</th>
</tr>
</thead>
<tbody>
<tr>
<td>51.50N - 0.01W</td>
<td>27.92N - 15.67W</td>
<td>212.5 22.2</td>
<td>1581.3</td>
</tr>
<tr>
<td>RHOMBIC 23H 96L</td>
<td>67DEG</td>
<td>3</td>
<td>RHOMBIC 20H 114L 70DEG</td>
</tr>
<tr>
<td>PWR= 30.00KW</td>
<td>OPERATING FREQUENCIES</td>
<td>REQ.S/N= 45DB</td>
<td></td>
</tr>
<tr>
<td>GMT MUF FOT</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| 1 | 10.3 | 8.8 |
| 2 | 10.6 | 9.0 |
| 4 | 9.3  | 7.9 |
| 6 | 8.1  | 6.9 |
| 8 | 12.9 | 11.0|
| 9 | 19.6 | 16.6|
| 10| 22.8 | 19.3|
| 11| 23.6 | 20.0|
| 12| 23.7 | 20.2|
| 13| 22.7 | 19.3|
| 14| 21.7 | 18.5|
| 15| 21.5 | 18.2|

**Figure 7.** Computer Print-Out of Circuit MUF, FOT and Available Signal-to-Noise
<table>
<thead>
<tr>
<th>JAN</th>
<th>SSN= 25</th>
<th>BR 32.007</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANSMITTER</td>
<td>RECEIVER</td>
<td>BEARINGS</td>
</tr>
<tr>
<td>40.75N - 73.93W</td>
<td>32.33N - 64.70W</td>
<td>135.8 321.3</td>
</tr>
<tr>
<td>RHOMBIC 32H 118L</td>
<td>63DEG</td>
<td>NOISE= 3</td>
</tr>
<tr>
<td>PMR= 20.00Km</td>
<td>RELIABILITIES</td>
<td>REQ. S/N= 45DB</td>
</tr>
<tr>
<td>GMT MUF FOT</td>
<td>3 5 7 9 11 13 15 20 25 30</td>
<td>FOT MCS</td>
</tr>
<tr>
<td>2 5.2 4.4</td>
<td>99 0 0 0 0 0 0 0 0 99</td>
<td></td>
</tr>
<tr>
<td>4 5.4 4.6</td>
<td>99 0 0 0 0 0 0 0 0 99</td>
<td></td>
</tr>
<tr>
<td>6 5.7 4.9</td>
<td>99 0 0 0 0 0 0 0 0 99</td>
<td></td>
</tr>
<tr>
<td>8 5.5 4.7</td>
<td>99 0 0 0 0 0 0 0 0 99</td>
<td></td>
</tr>
<tr>
<td>10 4.9 4.2</td>
<td>99 0 0 0 0 0 0 0 0 99</td>
<td></td>
</tr>
<tr>
<td>12 7.4 6.9</td>
<td>99 99 0 0 0 0 0 0 0 99</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>JAN</th>
<th>SSN= 25</th>
<th>GC 2.016</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANSMITTER</td>
<td>RECEIVER</td>
<td>BEARINGS</td>
</tr>
<tr>
<td>51.50N - 0.01W</td>
<td>27.92N - 15.67W</td>
<td>212.5 22.2</td>
</tr>
<tr>
<td>RHOMBIC 23H 96L</td>
<td>67DEG</td>
<td>NOISE= 3</td>
</tr>
<tr>
<td>PMR= 30.00Km</td>
<td>RELIABILITIES</td>
<td>REQ. S/N= 45DB</td>
</tr>
<tr>
<td>GMT MUF FOT</td>
<td>3 5 7 9 11 13 15 20 25 30</td>
<td>FOT MCS</td>
</tr>
<tr>
<td>2 10.8 9.2</td>
<td>90 99 99 99 0 0 0 0 0 99</td>
<td></td>
</tr>
<tr>
<td>4 9.9 8.4</td>
<td>90 99 99 0 0 0 0 0 0 99</td>
<td></td>
</tr>
<tr>
<td>6 8.1 6.9</td>
<td>89 99 0 0 0 0 0 0 0 99</td>
<td></td>
</tr>
<tr>
<td>8 12.9 11.0</td>
<td>0 98 99 99 0 0 0 0 0 99</td>
<td></td>
</tr>
<tr>
<td>10 22.8 19.3</td>
<td>0 5 99 99 99 99 99 0 0 0 99</td>
<td></td>
</tr>
<tr>
<td>12 23.7 20.2</td>
<td>0 0 81 99 99 99 99 99 0 0 99</td>
<td></td>
</tr>
<tr>
<td>14 21.7 18.5</td>
<td>0 0 89 99 99 99 99 99 0 0 99</td>
<td></td>
</tr>
<tr>
<td>16 21.0 17.8</td>
<td>0 0 23 99 99 99 99 99 0 0 99</td>
<td></td>
</tr>
<tr>
<td>18 16.6 14.2</td>
<td>44 99 99 99 99 99 99 0 0 99</td>
<td></td>
</tr>
<tr>
<td>20 11.8 10.1</td>
<td>83 95 99 99 99 0 0 0 0 99</td>
<td></td>
</tr>
<tr>
<td>22 9.8 8.3</td>
<td>87 99 98 0 0 0 0 0 0 99</td>
<td></td>
</tr>
<tr>
<td>24 10.1 8.6</td>
<td>89 99 99 0 0 0 0 0 0 99</td>
<td></td>
</tr>
</tbody>
</table>

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

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

Figure 11
Nines Card

Month and Sunspot Card

3 14

Month = 3; Sunspot Number 14

Minus One Card

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
Transmitter latitude = 46.10 North
Transmitter longitude = 64.80 West
Receiver latitude = 32.30 South
Receiver longitude = 64.80 East
Transmitter power = 1 kilowatt
Transmitter antenna height = 25 meters
Transmitter antenna leg length = 0
Transmitter antenna tilt angle = 0
Transmitter antenna type = -2 (vertical)
Receiver antenna height = 30 meters
Receiver antenna leg length = 180 meters
Receiver antenna tilt angle = 70 degrees
Receiver antenna type = -1 (rhombic)
Required S/N = 42 decibels
Bearing of transmitting rhombic = 0 (on great circle or not rhombic type)
Bearing of receiving rhombic = 0 (on great circle or not rhombic type)
Abbreviation for receiving location = BD
Figure 13
EXAMPLE DATA DECK FOR RUN UNDER ONE METHOD ONLY FROM CARDS

FORTRAN STATEMENT

Figure 14
EXAMPLE DATA DECK FOR RUN UNDER TWO METHODS FROM CARD

<table>
<thead>
<tr>
<th></th>
<th>6 34</th>
</tr>
</thead>
<tbody>
<tr>
<td>2295-12052</td>
<td>10 32250 70-1 30180 67-1 -3 48</td>
</tr>
<tr>
<td>7469 3232 6473</td>
<td>-1 15 -2.66 96 67-1 -2 61 115</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>30000 50000 70000 90000 110000 120000 150000 200000 150000 300000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1536</td>
<td>12050 3401 -7165</td>
</tr>
<tr>
<td>3140</td>
<td>1720 1520-12052</td>
</tr>
<tr>
<td>3401</td>
<td>-7165 1530 -3900</td>
</tr>
</tbody>
</table>

FORTRAN STATEMENT

Figure 15
EXAMPLE DATA DECK FOR ONE METHOD USING CIRCUITS FROM MAGNETIC TAPE
EXAMPLE HF PREDICTION DECK TO EXECUTE UNDER IBM-7090 FORTRAN MONITOR

![FORTRAN STATEMENT](image)

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


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.

\[
\begin{align*}
H & \text{ - height in meters} \\
L & \text{ - leg length in meters} \\
Deg & \text{ - tilt angle in degrees}
\end{align*}
\]

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

10. Type of antenna used at receiving terminal. Sample:
VERTICAL - 14H OL ODEG.
The \(-14H\) indicates the grounded vertical is \(1/4 \lambda\). The same analogy would apply for \(-12H (\lambda/2), -1H (\lambda)\), 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


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


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

MUFLUF• • ••*H—F PREDICTIONS BY D.L. LUCAS AND G.W. HAYDON ••••••CRPL••••

FORMATS AND STORAGE ASSIGNMENTS

6 FORMAT(10F7.4) 0001
1 FORMAT(2(F5.2,F6.2),I2,5F3.0,I2,I3,F3.0,2F4.0,4X,A2) 0002
3 FORMAT(10X*I5,10X*A6, 10X*I4,HSSN,F5.0,10X*A2,F7.3/9X, 11HTR
2ANTSMITTER,13X*8HRECEIVER,12X*8HBearings,6X*7HMILES/7X *F6.2,A1,
4 FORMAT (F10.0) 0004
5 FORMAT(4I2) 0005
676 FORMAT(12A6) 0006
7 FORMAT(1X/6X » 0007
43HGMT»2X»3HMUF,3X»3HFOT,3(5X»3HGM,T»2X»3HMUF,3X»3HFOT)/ 1H04(4X»I3,
52F6.1)/1H04(4X»I3,2F6.1)/1H04(4X»I3,2F6.1)/1H04(4X»I3,2F6.1)/1H04(
64X»I3,2F6.1)/1H04(4X»I3,2F6.1)/1H A1) 0008
DIMENSION AMONI12),GLAT(5),ABI(24),ABIY(5,24),CLCK(5,24),GY(5),
1F2S(5,24),F2H(5,24),GML(5,24),GMH(5,24),MF(3),ME(2)
2ELD(10),FLD(10),F24(5),GMA(5),ADJ(4),ABC(12)
DIMENSION RD(5),SUN(12),A(10,7,14),RASSN(12),EMF(5,24)
DIMENSION Q(20,60,4),IL(4),IL(4),KL(4),JAL(4),CKC(24)
1G(60),AB(60),S(20,24),C(20,24),GAMMA(5,24),BA(60)
DIMENSION CLAT(5),CL0NG(5),EMUFY(5,24),FMUFY(5,24),UFY(5),FOTY(5)
5IG(24)
DIMENSION UF(24),FOT(24),P(29,16,6),ABP(2,6)
DIMENSION AHA(2),ARA(2),AVA(2)
DIMENSION XIXX(12)
DIMENSION FREL(12)
COMMON ABP,P
COMMON A,\Q,GB,ABS,C,\GAMMA,BA,EMUFY,FMUFY,IG,UF,FOT,SUN,AVA,ARA,GLA
1T,\ABI,\AHO,CLCK,GY,F2S,F2H,GML,GMH,MF,ME,ELD,FLD,F24,GMA,ADJ,ABC,
2EMF,CKC,CLAT,CLONG,AK,BK,CK,DK,P12,EK,EEK,GLT,GLG,AAA,ALAS,ASA,
3AFC,\ANC,\AWC,\AEC,ASC,AZZ,\MAN,RSN,KW,\PW,R,\IANT,\IANR,Y2,X2,MOUSE,SSN,
4NOCR,K4, AX,XLONG,AL,YLAT,XLAT,YLONG,YL,BTRY,GCDK,MCDNM,K1,K2,K
53,K5,GCD,\IRS,\M0N,\ID,\MOUSE,\AAY,\METHOD,\AHA,\BM0NS,\MAP
COMMON FREL
COMMON XNH,XNL,XND,RNH,RLN,RND,HA,JIG,HAR,XTR,XETA,WETA,IHR,MIT
REWIND 2
REWIND 3
909 FORMAT(1H1)
DO 101 I=1,24
101 IG(I)=I
0026
0027
0028
0029
0030
0031
0032
0033
0034
0035
0036
0037
0038
CONSTANTS TO BE USED FREQUENTLY

AK = 1.745329E-2
BK = 5.729577E1
CK = 1.11136E2
DK = 0.0062137
PI2 = 1.57079
EK = 539956
EEK = 621.4
GLT = 78 * AK
GLG = 70 * AK

AMON(1) = 412145606060
AMON(2) = 262522606060
AMON(3) = 442151606060
AMON(4) = 214751606060
AMON(5) = 442170606060
AMON(6) = 416445606060
AMON(7) = 416443606060
AMON(8) = 216427606060
AMON(9) = 622547606060
AMON(10) = 462363606060
AMON(11) = 454665606060
AMON(12) = 242523606060
AAA = 606060606060
AFC = 266060606060
AHA(1) = 606060603040
AHA(2) = 243147464325
AVA(1) = 606060606525
AVA(2) = 516331232143
ARA(1) = 606060606051
ARA(2) = 30464423123
AZZ = 006060606060
ANC = 456060606060
AWC = 666060606060
AEC = 256060606060
ASC = 626060606060
FNIHE = 111111111111
SUN(1) = -21
SUN(2) = -13
SUN(3) = -03
SUN(4) = 09
SUN(5)=18
SUN(6)=23
SUN(7)=21
SUN(8)=14
SUN(9)=04
SUN(10)=-08
SUN(11)=-14
SUN(12)=-23
ADJ(1)=9
ADJ(2)=17
ADJ(3)=20
ADJ(4)=28

READ CIRCUIT DATA AND SEARCH DATA TAPE
WRITE OUTPUT TAPE 6,909

READ INPUT TAPE 5,5,
METHOD,METH,IHR,MAP
READ INPUT TAPE 5,6,(FREL(I),I=1,10)
MIT=1
IF (METHOD) 463,12,463
12 REWIND 2
WRITE OUTPUT TAPE 6,909
REWIND 3
CALL EXIT

463 L1=2
GO TO (30,30,30,30,31,30),METHOD
30 L1=1
31 NOCIR= 0
MONTH=0
IF(METH) 7770,7771,7770
7770 READ INPUT TAPE 5,6,76,X1XX
WRITE OUTPUT TAPE 3,6,76,X1XX
IF(FNINE-X1XX(1)) 7770,7771,7770
7771 REWIND 3
85 READ INPUT TAPE 5,1,
X1X,Y1Y,X2X,Y2Y,MONS,SUNS,TWR,XNHO,XNLO,XNDO,ITANT,RNHO,RN
1LO,RNDO,IRANT,MANN,RRSN,XETA,WETA,HAO
10 X1=X1X
Y1=Y1Y
X2=X2X
Y2=Y2Y
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,X1,X1,Y1,Y1,X2,X2,Y2,Y2,MONS,SUNS,TWR,XNHO,XNLO,XNDO,
IANT,RNHO,RNLO,RNDO,IRANT,MANN,RRSN,XETA,WETA,HAO 0136
GO TO 10 0137

11 GO TO (15,77),KZ 0138
15 NOCIR=0 0139
WRITE OUTPUT TAPE 6,909 0140

62 JIG=0 0141
MIT=1 0142
KZ=2 0143
IF(LOCK) 77,731,33 0144
33 D0730 IU=1,LOCK 0145
730 READ TAPE 2 0146
731 READ TAPE 2,IL,VL,KL,VL,IVAL,AP,ABP 0147
77 READ INPUT TAPE3,1,X1,X1,Y1,Y1,X2,X2,Y2,Y2,MONS,SUNS,TWR,XNHO,XNLO,XNDO,
IANT,RNHO,RNLO,RNDO,IRANT,MANN,RRSN,XETA,WETA,HAO 0148
IF(91,-X1,X) 78,78,16 0149
78 REWIND 3 0150
READ INPUT TAPE 5,1,
1 X1,X1,Y1,Y1,X2,X2,Y2,Y2,MONS,SUNS,TWR,XNHO,XNLO,XNDO,IANT,RNHO,RN
LO,RNDO,IRANT,MANN,RRSN,XETA,WETA,HAO 0151
IF(MONS) 83,16,83 0152
51
83 IF(MONS-MONTH) 84,16,15
84 REWIND 2
MONTH=0
16 SSP=SUN(MOUSE)*AK
BMONS=AMON(MOUSE)
NOCIR=NOCIR+1
JIP=1
JEP=1
C GREAT CIRCLE DISTANCE AND DISTANCE TO CONTROL POINTS
XX1=X1*AK
XX2=X2*AK
YY1=Y1*AK
YY2=Y2*AK
GCD=SINF(XX1)*SINF(XX2)+COSF(XX1)*COSF(XX2)*COSF(YY2-YY1)
GCD=ACOSF(GCD)
RD(1)=GCD/2.
RD(2)=18.*AK
RD(3)=GCD-18.*AK
RD(4)=9.*AK
RD(5)=GCD-9.*AK
GCDKM=GCD*CK*BK
GCDNM=GCDKM*EK
C BEARINGSS-- FORWARD AND BACKWARD
DF=YY2-YY1
IF(ABSF(DF)-3.141592654) 26,22,22
22 IF(DF) 24,25,25
24 DF=6.283185308+DF
GO TO 26
25 DF=-6.283185308+DF
26 U=5*(PI2-XX1+PI2-XX2+GCD)
CIND=SINF(U)*SINF(U-PI2+XX1)
IF(CIND) 27,28,27
27 BTRY=114.5816*ATANF(SQRTF(ABSF(SINF(U-PI2+XX2)*SINF(U-GCD))/CIND))
IF(DF) 7029,21,39
21 IF(XX1-XX2) 28,39,39
28 BTRY=180.
GO TO 39
7029 BTRY=360.-BTRY
39 RF=YY1-YY2
IF(ABSF(RF)-3.141592654) 126,122,122
122 IF(RF) 124,125,125
124 RF=6.283185308+RF
  GO TO 126
125 RF=-6.283185308+RF
126 U=0.5*(PI2-XX2+PI2-XX1+GCD)
   CIND=SINF(U)*SINF(U-PI2+XX2)
   IF(CIND) 57,77,8,778.57
57 XTR=114.5816*ATANF(SQRTF(ARSF*SINF(U-PI2+XX1)*SINF(U-GCD))/CIND)
   IF(RF) 8029,51,79
51 IF(XX2-XX1)778,79,79
778 XTR=180.
  GO TO 79
8029 XTR=360.-XTR
79 IF(4000.-GCDKM) 40,41,41
40 K1=1
   K2=2
   K3=3
   K4=4
   K5=5
   GO TO 43
43 DO 61 IT=L1,24,L1
   GMT = IT
   COLO=GMT-Y2/15.
   IF(24.-COLO) 94,95,95
94 COLO=COLO-24.
   GO TO 96
95 IF(COLO) 98,98,96
98 COLO=COLO+24.
96 CKC(IT)=COLO
   SSL=(15.*GMT-180.)
   DO 61 II=K1,K5
   PP=RD(II)
   CENLAT=COSF(PP)*COSF(PI2-XX2)+SINF(PP)
   I*SINF(PI2-XX2)*COSF(BTRY*AK)
CENLAT=(PI2-ACOSF(CENLAT))*BK

CENLG= ((COSF(PP)-COSF(PI2-XX2)*COSF(PI2-CENLAT*AK))/(SINF(PI2-XX2)*SINF(PI2-CENLAT*AK)));

IF(ABSF(CENLG)-1.)* 3001, 3001, 3000

3000 CENLG=1.

3001 CENLG=ACOSF(CENLG)

CENLG=(YY2-SIGNF(CENLG,DF))*BK

IF(180.-ABSF(CENLG)) 71, 69, 69

71 IF(CENLG) 73, 72, 72

73 CENLG=360.+CENLG

GO TO 69

72 CENLG=CENLG-360.

C GEOMAGNETIC LOCATION OF CONTROL POINTS

69 GAT=ACOSF(SINF(GLT)*SINF(CENLAT*AK)+COSF(GLT)*COSF(CENLAT*AK)*C0SF(CENLG*AK-GLG))

GLAT(II)=PI2-GAT

CLAT(II)=CENLAT

70 CLONG(II)=CENLG

C SUNS ZENITH ANGLE

Z=SSL-CENLG)*AK

56 CYCEN=SINF(CENLAT*AK)*SINF(SSP)+COSF(CENLAT*AK)*COSF(SSP)*COSF(Z)

CYCEN=ACOSF(CYCEN)

CYCEN=ABSF(CYCEN)

C ABSORPTION INDEX I AT CONTROL POINTS

32 IF(102.*AK-CYCEN) 58, 58, 59

58 ABIY(II,IT)=0.

GO TO 886

59 ABIY(II,IT)=(1.+-0.0037*SSN)*COSF(.881*CYCEN)**1.3

886 GO TO (165,166), K2

165 ABI(IT)=ABIY(II,IT)

GO TO 61

166 ABI(IT)=(ABIY(1,IT)+ABIY(2,IT)+ABIY(3,IT))/3.

61 CONTINUE

DO 2112 II=K1,K5

DO 2112 IT=L1,24, L1

ABIC=ABIY(II,IT)

2112 CONTINUE

C E-LAYER DISTANCE FACTOR

ARC=DK*GCDKM

IF(16.-ARC) 88, 87, 87

87 ELFC=(((((1-4.368460907E-9*ARC+1.334494261E-7)*ARC-5.976618436E-6))}

0234

0235

0236

0237

0238

0239

0240

0241

0242

0243

0244

0245

0246

0247

0248

0249

0250

0251

0252

0253

0254

0255

0256

0257

0258

0259

0260

0261

0262

0263

0264

0265

0266

0267

0268

0269
1*ARC+2*624808315E-4)*ARC-5.038476266E-3)*ARC+3.761385053E-2)*ARC-10270
2.133200756E-2)*ARC+.20850271
GO TO 1000272
88 ELFC=1.0273

E-2000 CONTROL POINT MUF
100 EMC=((<-10.66484998*ABIC+39.26151056)*ABIC-52.41191754)*ABIC+37.670274
1726072)*ABIC+3.3459962320275
EMF(II,IT)=EMC0276
EMUF(Y,IT)=EMC*ELFC0277

C GENERATE CONTROL POINT FOF2 AND M-3000 FACTORS
DO 1112 II=K2*K30278
504 CENLG=CLONG(II)0279
CENLAT=CLAT(II)0280
IF(CENLG) 412.414.414 0281
412 CLG=ABSFCENLG0282
GO TO 4130283
412 CLG=ABSFCENLG 0284
413 BOY=SINF(CLG*AR1K)0285
COG=SINF(2*CLG*AR1K)0286
DOG=COSF(2*CLG*AR1K)0287
GOB=COSF(AR1LAT*AR1K)0288
HOG=COSF(CLG*AR1K)0289
DO 500 IO=1,40290
415 I=IL(IO)0291
J=JL(IO)0292
K=KL(IO)0293
L=LK(IO)0294
JA=JAL(IO)0295
DO 408 KA=1,K0296
KP=KA-10297
408 G(KA)=BOG**KP0298
LA=00300
LO=L-10301
KK=K+10302
DO 409 KA=KK,LO,20303
G(KA)=BOG**LA*GOB*HOG0304
G(KA+1)=BOG**LA*GOB*BOY0305
409 LA=LA+10306
LB=00307
409 LA=LA+1
LB=0
LL=L+1
IM=I-1
DO 410 KA=LL*IM*2
G(KA)=BOG**LB*GOB**2*DOG
G(KA+1)=BOG**LB*GOB**2*COG
410 LB=LB+1
DO 411 JB=1*J
AB(JB)=0.
IS=2*JB-1
DO 411 KA=1*1
411 AB(JB)=AB(JB)+Q(IS,KA,IO)*G(KA)
DO 407 JB=2*J
BA(JB)=0.
IS=2*JB-2
DO 407 KA=1*1
407 BA(JB)=BA(JB)+Q(IS,KA,IO)*G(KA)
DO 500 IT=L1,24,L1
503 GMT=IT
CLOCK=GMT-CENLG/15.
IF(24.-CLOCK) 64,65,65
64 CLOCK=CLOCK-24.  
GO TO 66
65 IF(CLOCK) 68,68,66
68 CLOCK=CLOCK+24.
66 CLOCK(IT,IT)=CLOCK
TIME=(15.*CLOCK-180.)*AK
DO 998 JB=2*J
FB=JB-1
S(JB,IT)=SINF(FB*TIME)
998 C(JB,IT)=COSF(FB*TIME)
GAMMA(IO,IT)=AB(IO)
DO 500 JB=2*J
500 GAMMA(IO,IT)=GAMMA(IO,IT)+AB(JB)*C(JB,IT)+BA(JB)*S(JB,IT)
F2-REGION GYRO-FREQUENCY
132 CALL POLY(1,7,7,CENLG/180.,CENLAT/90.,Y)
GYRO=Y/2. 
GYI(IT)=Y
F2-LAYER CONTROL POINT F2-4000 MUF
F2S(II,IT) = F2LS
F2HS = GAMMA(2,IT) * GAMMA(4,IT) * 1.1
F2H(II,IT) = F2HS

C F2-LAYER DISTANCE FACTOR
IF(24.0-ARC) = 157, 157, 158

157 FLFC = 1.0
GO TO 159

158 FLFC = (((((-6.712654756E-9*ARC+4.49151441E-7)*ARC-9.985831104E-6)*
(1ARC+6.865259817E-5)*ARC+9.26634341E-3)*ARC+4.0352
2699243101E-3)*ARC

159 GAMMA(1,IT) = GAMMA(1,IT) + GYRO
GAMMA(2,IT) = GAMMA(2,IT) + GYRO
FMLS = GAMMA(1,IT) + FLFC*(F2LS-GAMMA(1,IT))
GM(II,IT) = GAMMA(1,IT)
FMHS = GAMMA(2,IT) + FLFC*(F2HS-GAMMA(2,IT))
GMH(II,IT) = GAMMA(2,IT)

C F2-LAYER CONTROL POINT MUF
FMUFY(II,IT) = (FMLS*(180.-SSN)+FMHS*(SSN-10.))/170.

1112 CONTINUE

C CIRCUIT MUF AND FOT
DO 1012 IT = L1, 24, L1
GMT = IT
DO 1000 II = K2, K3
IF(K2-1) = 602, 603, 602
603 IR = 1
GO TO 604
602 IR = II + 2
604 IF(EMUFY(IR,IT)-FMUFY(II,IT)) = 1007, 1007, 1008

1007 UFY(II) = FMUFY(II,IT)
GO TO 1009

1008 UFY(II) = EUMFY(IR,IT)

1009 FOTFY = 0.85*FMUFY(II,IT)
IF((EMUFY(IR,IT)-FOTFY)) = 1010, 1011, 1011

1010 FOTY(II) = FOTFY
GO TO 1000

1011 FOTY(II) = EUMFY(IR,IT)

1000 CONTINUE
II = K2
IF(1-II) = 606, 605, 606

605 UF(IT) = UFY(1)
FOT(IT) = FOTY(1)
GO TO 1012

606 IF (UFY(2) - UFY(3)) 607.607.608
607 UF(IT) = UFY(2)
GO TO 609

608 UF(IT) = UFY(3)

609 IF (FOTY(2) - FOTY(3)) 610.610.611

610 FOT(IT) = FOTY(2)
GO TO 1012

611 FOT(IT) = FOTY(3)

1012 CONTINUE

IRY = BTRY/10.
TRY = IRY
HAR = TRY + .00001 * GCDNM
XLAT = ABSF(X1)
XLONG = ABSF(Y1)
YLAT = ABSF(X2)
YLONG = ABSF(Y2)
AX = ANC

IF(X1) 700, 701, 701

700 AX = ASC
701 AL = AWC

IF(Y1) 702, 703, 703
702 AL = AEC
703 AY = ANC

IF(X2) 704, 705, 705
704 AY = ASC
705 YL = AWC

IF(Y2) 706, 2221, 2221

706 YL = AEC

2221 GO TO (2223, 2224, 2224, 2224, 2224, 2224) METHOD

2223 IF(MAP) 3223, 3223, 3224

3224 CALL CURVY(FOT, UF)
GO TO 10

3223 WRITE OUTPUT TAPE 6, 3, NOCIR, BMONS, SSN, HA, HAR, XLAT, AX, XLONG, AL,
YLAT, AY, YLONG, YL, XTR, BTRY, GCDNM

WRITE OUTPUT TAPE 6, 7,

1 (IG(I) * UF(I) * FOT(I) * IG(I+6) * UF(I+6) * FOT(I+6) * IG(I+12) *
2 UF(I+12) * FOT(I+12) * IG(I+18) * UF(I+18) * FOT(I+18) * I=1*6) * AAA
IF(3-MIT) 969, 969, 970
969 WRITE OUTPUT TAPE 6,909
  MIT=1
  GO TO 10
970 MIT=MIT+1
  GO TO 10
2224 CALL LUFFY
  GO TO 10
END
SUBROUTINE LUFFY

FORMATS AND STORAGE ASSIGNMENTS

DIMENSION FDEK(10), EDEK(10)

DIMENSION AMON(12), GLAT(5), ABI(24), ABIY(5, 24), CLCK(5, 24), GY(5),
F2S(5, 24), F2H(5, 24), GML(5, 24), GMH(5, 24), MF(3), ME(2), ELL(10), FLL(10),
ELD(10), EDEL(10), FDEL(10), F24(5), GMA(5), FLF(10), FSKY(10),
ESKY(10), GE(10), GF(10), FSE(10), FSF(10), NOS(11), FMXT(10), EXMT(10),
FRCR(10), ERCR(10), ADJ(4), ABC(12), MODF(12)

DIMENSION Q(20*60*4), IL(4), JL(4), KL(4), JAL(4), CKC(24)

DIMENSION G(60), AB(60), S(20, 24), C(20, 24), GAMMA(5, 24), BA(60)

DIMENSION CLAT(5), CLONG(5), EMUFY(5, 24), FMUFY(5, 24), UFY(5), FOTY(5)

DIMENSION UF(24), FOT(24), FF(24), P(29, 16, 6), ABP(2, 6)

DIMENSION AHA(2), ARA(2), AYA(2), RANT(2), TANT(2)

DIMENSIONNXLXS(11), NANGLE(11)

DIMENSION TOP(4)

DIMENSION FREL(12)

COMMON ABP, P

COMMON A, Q, G, AB, S, C, GAMMA, BA, EMUFY, FMUFY, IG, UF, FOT, SUN, AVA, ARA, GLA

COMMON AHI, ABIY, CLCK, GY, F2S, F2H, GML, GMH, MF, ME, ELD, FLD, F24, GMA, ADJ, ABC

COMMON EME, CKC, CLAT, CLONG, AK, BK, CK, DK, PI2, EK, EEM, GLT, GLG, AAA, ALN, ASA

COMMON 3FC, ANC, AWC, AEC, ASC, AZZ, MAN, RSN, KW, PWR, IANT, IANR, Y2, X2, MOUSE, SSN

COMMON K4, AX, XLONG, AL, YLAT, XLAT, YLONG, YPT, GCD, GCDNM, K1, K2, K

COMMON 53, K5, GCD, IRSN, MON, ID, MOUSE, AY, METHOD, AHA, BMOMS, MAP

COMMON FREL

COMMON XNH, XNL, XND, RNH, RNL, RND, HA, JIG, HAR, XTR, XETA, WTA, IHR, MIT

COMMON KAP, KUP, MA, TANT, INH, INL, IND, RANT, JNH, JNL, JND

2 FORMAT(2X, 2A6, 1X, I3, 1HH, 1X, I3, 1HL, 1X, I3, 3HDEG, 12X, 6HNOISE=I3, 12X, 4
1HANT=I3, 2HDB)

1 FORMAT(2X, 2A6, 1X, I3, 1HH, 1X, I3, 1HL, 1X, I3, 3HDEG, 4X, 6HNOISE=I3, 2A6, 1X
1, I3, 1HH, 1X, I3, 1HL, 1X, I3, 3HDEG)

80 FORMAT(6X, 4HFWR=F6.2, 2HKW, 11X, 21HOPERATING FREQUENCIES, 9X, 14HFIELD
1 STRENGTH/5X, 14HGMT MUF FOT, 1X, 10I4, 4H FOT)

3 FORMAT(10X, I5, 10X, A6, 10X, 6HSSN=F5.0, 10X, A2, F7.3/9X, 11HTR
2ANSWER, 13X, 8HRECEIVER, 12X, 8HBEARINGS, 6X, 7HN, MILES/7X, F6.2, A1,

4 FORMAT(6X, 4HANT=I3, 2HDB, 13X, 6HNOISE=I3, 7X, 2A6, 1X, I3, 1HH, 1X, I3, 1HL,
11X, I3, 3HDEG)
213,2F6.1,1X,11I4,13H RELIABILITY) 0041
12 FORMAT(1X,A2,F7.3,15,2F10,2) 0042
13 FORMAT(6X,*HANT=I3,2HDB/20X,6HNOISE=I3,20X,*HANT=I3,2HDB) 0043
14 FORMAT(6X,*HPOWER=F6.2,2HKW/11X,21OPERATING FREQUENCIES,10X,8HREQL/6X, 0044
1/N=I3,2HDB/5X,14HGMT MUF FOT,1X,10I4,4H FOT) 0045
213,2F6.1,1X,11I4,9H S/N=DB) 0047
34 FORMAT(6X,*HPOWER=F6.2,2HKW/16X,13HRELIABILITIES,13X,8HREQLS/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,13,2F6.1)/1H04(4X,13,2F6.1)/1H04(4X,13,2F6.1,1)/H04( 0052
64X,13,2F6.1)/1H04(4X,13,2F6.1)/1H04(4X,13,2F6.1)/1H A1) 0053
8 FORMAT(31X,21OPERATING FREQUENCIES/5X,14HGMT MUF FOT,1X,10I4, 0054
14H FOT) 0055
213,2F6.1,1X,11I4,10H LOSS=DB) 0057
213,2F6.1,1X,11I4,5H DBU) 0059
24 FORMAT(6X,*HPOWER=F6.2,2HKW/42X,8HREQLS/N=I3,2HDB) 0060
70 FORMAT(6X,3HGMT,2X,3HLUF,3X,3HFOT,3(5X,3HGMT,2X,3HLUF,3X,3HFOT))/1 0061
1H04(4X,13,6X,F6.1)/1H04(4X,13,2F6.1)/1H04(4X,13,6X,F6.1,1)/H04(4X,1 0062
23,2F6.1)/1H04(4X,13,6X,F6.1)/1H04(4X,13,2F6.1,1/H A1) 0063
94 FORMAT(8X,13,2F6.1,1X,1I4) 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 IFRIA=)FREL(IA) 0071
C BEARINGS OF RHOMBICS
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
1323 XQ=0.001
   RQ=0.001
   XP=4.*
   RP=4.*
   INH=XNH
   INL=XNL
   IND=XND
   JNH=RNH
   JNL=RNL
   JND=RND
   NIG=0
   JIG=JIG+1
   MA=XABSF(MAN)
C CONSTANTS TO BE USED FREQUENTLY
   TOP(1)=20.*
   TOP(2)=20.*
   TOP(3)=25.*
   TOP(4)=23.5
   R0=6376.6
   KIP=1
   IF(MAP) 5612,5612,5613
5612 WRITE OUTPUT TAPE 6,3,
      NOCIR,BMONS,SSN,HA,HAR,XLAT,AX,XLONG,AL,YLAT,AY,YLONG,YL,
      2XTR,BTRY,GCDNM
5613 FK=69.057
   LZP=1
   LIP=1
   MIP=2
   IF(IHR) 8400,8400,3219
8400 GO TO (3219,3219,3220,3221,3219,3219),METHOD
3220 MIP=1
      GO TO 3219
3221 MA=0
3219 DO 3214 IT=MIP,24,MIP
       FREL(11)=FOT(IT)
       JUG=0
       KAT=1
      DO 251 IJ=1,11
       NANGLE(IJ)=0
MODE(IJ) = 0

ABC(IJ) = AZZ
FREQ = FREL(1)
DFREQ = 3.
NF = 1

C F2 REGION LAYER HEIGHTS
FL = 0.
DO 926 II = K1, K3
CALL POLY(2, 7, 7, CLK(II, IT) /10, -1, 2, CLAT(I)/90, Y)
926 FL = FL + Y
RK = K3
FL = FL / RK * 100.
GO TO (927, 928), K2

C MODE CHOOSING F2 AND E-LAYER
928 ME(1) = GCDKM / 2000. + 9
ME(2) = ME(1) + 1
MF(1) = GCDKM / 4000. + 8
MF(2) = MF(1) + 1
MF(3) = MF(2) + 1
GO TO 929
927 ME(1) = 1
ME(2) = 2
MF(1) = 1
MF(2) = 2
MF(3) = 3

C RADIATION ANGLE — E-LAYER MODES
929 DO 930 IK = 1, 2
IM = ME(IK)
PI = ME(IK)
ELD(IM) = GCDKM / PI
EDEL(IM) = ATANF((COSF(GCD/(2*PI)) - RO/(RO + 110.))/SINF(GCD/(2*PI)))
1*BK
IF(EDEL(IM)) 1032, 930, 930
1032 DO 1033 II = 1, 2
1033 ME(II) = ME(II) + 1
GO TO 929
930 CONTINUE

C RADIATION ANGLE—F2-LAYER MODES
1934 DO 931 IK = 1, 3
IM = MF(IK)
\[ \begin{align*}
\text{PI} &= \text{IM} \\
\text{FLD} \text{(IM)} &= \frac{\text{GCDKM}}{\text{PI}} \\
\text{FDEL} \text{(IM)} &= \text{ATAN} \left( \frac{\cos \left( \frac{\text{GCD}}{2 \cdot \text{PI}} \right) - \text{RO}}{\text{RO} + \text{FLD}} \right) / \sin \left( \frac{\text{GCD}}{2 \cdot \text{PI}} \right) \\
1 \cdot \text{BK} &= \text{IF} \text{(FDEL(\text{IM}))} \\
&= 932, 931, 931 \\
\text{DO} 1933 \quad \text{II} &= 1, 3 \\
1933 \quad \text{MF} \text{(II)} &= \text{MF} \text{(II)} + 1 \\
&= \text{GO TO} 1934 \\
931 \quad \text{CONTINUE} \\
&= \text{GO TO} (933, 934), K2 \\
\text{C PENETRATION FREQUENCIES --E-REGION} \\
934 \quad \text{DZ} &= \text{EMF} \text{(4, IT)} \\
\text{DY} &= \text{EMF} \text{(5, IT)} \\
&= \text{IF} \text{(DZ-DY)} 940, 940, 941 \\
940 \quad \text{ZR} &= \text{DZ} \\
\quad IZ &= 2 \\
\quad ZS &= \text{DY} \\
&= \text{GO TO} 939 \\
941 \quad \text{ZR} &= \text{DY} \\
\quad IZ &= 3 \\
\quad ZS &= \text{DZ} \\
&= \text{GO TO} 939 \\
933 \quad \text{ZR} &= \text{EMF} \text{(1, IT)} \\
\quad ZS &= \text{ZR} \\
939 \quad \text{DO} 1663 \quad \text{II} &= 1, 10 \\
\quad \text{ELL} \text{(II)} &= 0 \\
1663 \quad \text{FLL} \text{(II)} &= 0 \\
\quad \text{DO} 827 \quad \text{II} &= 1, 2 \\
\quad \text{IM} &= \text{ME} \text{(II)} \\
\quad \text{ERCR(\text{IM})} &= 0 \\
\quad \text{EXMT(\text{IM})} &= 0 \\
\text{C MODE ELIMINATION E AND F2 REGIONS} \\
\quad \text{ARZ} &= \text{ELD(\text{IM})} \cdot \text{D} \\
\quad \text{IF} \text{(16, -ARZ)} &= 2900, 2900, 2901 \\
2900 \quad \text{ELFK} &= 1.02 \\
&= \text{GO TO} 2902 \\
2901 \quad \text{ELFK} &= 1 \cdot (1 \cdot \left( (1 \cdot \left( -4.368460907 \cdot 10^{-9} \cdot \text{ARZ} + 1.334494261 \cdot 10^{-7} \right) \cdot \text{ARZ} - 5.976618436 \cdot 10^{-6} \right) \cdot \text{ARZ} - 2.624808315 \cdot 10^{-4} ) \cdot \text{ARZ} - 5 \cdot 0.38476266 \cdot 10^{-3} ) \cdot \text{ARZ} + 3 \cdot 761385053 \cdot 10^{-2} ) \cdot \text{ARZ} - 1 \cdot 2.133200756 \cdot 10^{-2} ) \cdot \text{ARZ} + 0.2085 \\
2902 \quad \text{Y} &= \text{ZR} \cdot \text{ELFK} + 0.05 \\
\end{align*} \]
IF(Y-FREQ) 328,328,827
328 ELL(IM)=1000.
827 CONTINUE
   DO 227 II=1,3
   IM=MF(II)
   FRCR(IM)=0.
   FXMT(IM)=0.
   ARZ=RO*2.*(PI2-FDEL(IM)*AK-ASINF(RO*SINF(PI2+FDEL(IM)*AK)/(RO+110.*
1.)))*DK
IF(16.-ARZ) 2903,2903,2904
2903 EFK=1.02
   GO TO 2905
2904 EFK=((((-4.368460907E-9*ARZ+1.334494261E-7)*ARZ-5.976618436E-6)
1*ARZ+2.624808315E-4)*ARZ-5.6385053E-2)*ARZ+3.761385053E-2)*ARZ+7.2085
2905 Y=ELFK*ZS+.05
   IF(Y-FREQ) 227,227,228
228 FLL(IM)=1000.
227 CONTINUE
   DO 946 II=K2,K3
   F24(II)=(F2S(II+IT)*(180.-SSN)+F2H(II+IT)*(SSN-10.))/170.
946 GMA(II)=(GML(II+IT)*(180.-SSN)+GMH(II+IT)*(SSN-10.))/170.
   S1=(FREQ-GMA(K2))/(F24(K2)-GMA(K2))
   S2=(FREQ-GMA(K3))/(F24(K3)-GMA(K3))
947 R=S2
   GO TO 949
948 R=S1
949 DO 945 IK=1,3
   IM=MF(IK)
   IF(FLL(IM)) 508,508,945
945 CONTINUE
   DO 946 IK=K2,K3
   IM=MF(IK)
   IF(FLL(IM)) 508,508,945
508 ARK=FLD(IM)*DK
   IF(FLF(IM)-R) 950,945,945
950 FLL(IM)=1000.
945 CONTINUE
   GYR=(GY(K2)+GY(K3))/2.
   GO TO (1740,9119).KIP
C MAJOR LAND BODIES

1740 WLD=0.

DO 826 II=K1,K3
IF (CLONG(II)) 1702,1702,1701

1701 CZG=360.-CLONG(II)
GO TO 1703

1702 CZG=ABSF(CLONG(II))
1703 CALL NOISY(6,X2,CZG,Y)
826 WLD=WLD+Y
WD=WLD/RK

9119 IF(WD) 953,954,954
953 ER=80.
SIGMA=5.
GO TO 955

954 ER=4.
SIGMA=.001

C E-LAYER MODES
C GROUND LOSS REFLECTION FACTORS AND LOSS

955 DO 726 II=1,2
IM=ME(II)
IF(ELL(IM))600,600,726

600 RS=IM-1
CALL LOSS(EDEL(IM),ER,FREQ.SIGMA,Y)
GE(IM)=ABSF(Y*RS)
RI=IM

C SKYWAVE ABSORPTION
ESK Y ( IM)=615.5*RI*ABI ( IT ) / ( COSF ( ASINF ( RO*SINF(PI2+EDEL( IM)*AK) ) / ( RO
1+100.*)) )*(FREQ+1.12*GYR)**1.98
RS=IM

C ANGLE AT IONOSPHERE
PHE=RO*SINF(PI2+EDEL( IM)*AK)/(RO+110.)

C FREE SPACE LOSS
ZOR=GCD/(2.*RS)
FR=(2.*RS*SINF(ZOR)*RO/PHE)*EEK
FSE(IM)=36.58+20.*LOG10F(FR)+20.*LOG10F(FREQ)

726 CONTINUE

C F2-LAYER MODES
C GROUND LOSS REFLECTION FACTORS AND LOSS

DO 626 II=1,3
IM=MF(II)

IF(FLL(IM)) 601,601,626

601 RS=IM-1

CALL LOSS(FDEL(IM)*ER,FREQ,SIGMA,Y)

GF(IM)=ABSF(Y*RS)

RI = IM

C SKY WAVE ABSORPTION

FSKY(IM)=615.5*RI*ABSI(IT)/(COSF(ASINF(RO*SINF(P12+FDEL(IM)*AK)))/(RO

1+100.))*((FREQ+1.12*GYR)**1.98)

RS=IM

C ANGLE AT IONOSPHERE

PHE=RO*SINF(P12+FDEL(IM)*AK)/(RO+FL)

C FREE SPACE LOSS

ZOR= GCD/(2.*RS)

FR=(2.*RS*SINF(ZOR)*RO/PHE)*EEK

FSF(IM)=36.58+20.*LOG10(FR)+20.*LOG10(FREQ)

626 CONTINUE

C ANTENNA DETERMINATION

KAP=XABSF(IANT)

IF(IANT) 18 ,181,181

181 KAP=4

DO 82 II=1,2

IM=ME(II)

82 EXMT(IM)=IANT

DO 62 II=1,3

IM=MF(II)

62 FXMT(IM)=IANT

GO TO 1185

18 GO TO (31,32,33),KAP

31 TANT(1)=ARA(1)

TANT(2)=ARA(2)

GO TO 180

32 TANT(1)=AVA(1)

TANT(2)=AVA(2)

GO TO 180

33 TANT(1)=AHA(1)

TANT(2)=AHA(2)

180 DO 182 II=1,2

IM=ME(II)

IF(ELL(IM)) 603,603,182

603 CALL GAIN(KAP,FDEL(IM),XI,ETA,FREQ,XQ,XP,XN,XN,XNL,XNH,EXMT(IM))
POWER GAIN OF TRANSMITTING ANTENNA

C

DO 382 II=1,3
IM=MF(II)
IF(FLL(IM)) 605,605,382
605 CALL GAIN(KAP,FDEL(IM),XETA,FREQ,XQ,XP,XND,XNL,XNH,FXMT(IM))
382 CONTINUE

1185 IF(METHOD=4) 185,184,185
184 IF(IHR) 185,185,183
183 IANR=0
MA=0
185 KUP=ABS(IANR)
IF (IANR) 187,281,281

281 KUP=4
DO 482 II=1,3
IM=MF(II)
482 FRCR(IM)=IANR
DO 582 II=1,2
IM=ME(II)
582 ERCR(IM)=IANR
GO TO 1285

187 GO TO (741,42,43)*KUP

741 RANT(1)=ARA(1)
RANT(2)=ARA(2)
GO TO 280
42 RANT(1)=AVA(1)
RANT(2)=AVA(2)
GO TO 280
43 RANT(1)=AHA(1)
RANT(2)=AHA(2)

RESPONSE OF RECEIVING ANTENNA

C

280 DO 282 II=1,3
IM=MF(II)
IF(FLL(IM)) 607,607,282
607 CALL GAIN(KUP,FDEL(IM),WETA,FREQ,RQ,RP,RND,RNL,RNH,FRKR(IM))
282 CONTINUE

DO 782 II=1,2
IM=ME(II)
IF(ELL(IM)) 609,609,782
609 CALL GAIN(KUP,EDEL(IM),WETA,FREQ,RQ,RP,RND,RNL,RNH,ERCR(IM))
782 CONTINUE
1285 IF(MAP) 285,285,388
285 GO TO (286,388),LIP
286 GO TO (330,330,330,1331),KAP
1331 GO TO (232,232,232,233),KUP
233 WRITE OUTPUT TAPE 6,13,IAN,T,MA,IANR
   /GO TO 388
330 GO TO (335,335,335,336),KUP
335 WRITE OUTPUT TAPE 6,1,
   1 TANT,INH,INL,IND,MA,RANT,JNH,JNL,JND
   /GO TO 388
336 WRITE OUTPUT TAPE 6,2,
   1 TANT,INH,INL,IND,MA,IANR
   /GO TO 388
232 WRITE OUTPUT TAPE 6,4,IAN,MA,RANT,JNH,JNL,JND
388 LIP=2
   DO 333 II=K2,K3
   TIP=0.
   C DETERMINATION OF TYPE OF CIRCUIT (POLAR, TEMPERATE, ETC)
   RM=ABS(GLAT(I1))
   IF(RM-60.*AK) 331,331,332
331 ID=1
   IF(ABIY(I1,IT)) 9732,9732,333
   9732 TIP=5.
   /GO TO 333
332 IF(RM-70.*AK) 334,334, 35
334 ID=3
   IF(K2-1) 333,333, 36
36 ID=4
   /GO TO 1725
35 ID=2
333 CONTINUE
   C TRANSMISSION LOSS E-LAYER MODES
1725 DO 960 II=1,2
   IM=ME(I1)
960 ELL(IM)=ESKY(IM)+GE(IM)+FSE(IM)-EXMT(IM)-ERCR(IM)+ADJ(ID)+ELL(IM)
   LD=ME(1)
   LE=ME(2)
   IF(ELL(LD)-ELL(LE)) 961,961,962
961 ELOS=ELL(LD)
MDE=LD
GO TO 963

962 ELOS=ELL(LE)
MDE=LE

C TRANSMISSION LOSS F2-LAYER MODES

963 DO 964 II=1,3
IM=MF(II)

964 FLL(IM)=FSKY(IM)+GF(IM)+FSF(IM)-FXMT(IM)-FRCR(IM)+ADJ(ID)+FLL(IM)
LG=MF(1)
LH=MF(2)
LJ=MF(3)
IF(FLL(LG)-FLL(LH)) 965

965 FL1=FLL(LG)
MDF=LG
GO TO 967

966 FL1=FLL(LH)
MDF=LH

967 IF(FL1-FLL(LJ)) 968

968 FLOS=FL1
GO TO 970

969 FLOS=FLL(LJ)
MDF=LJ

970 IF(ELOS-FLOS) 971

971 NXLOS(NF)=ELOS
NANGLE(NF)=EDEL(MDE)+.5
MODE(NF)=MDE
ABC(NF)=AEC
GO TO 911

972 NXLOS(NF)=FLOS
NANGLE(NF)=FDEL(MDF)+.5
MODE(NF)=MDF
ABC(NF)=AFC

C MIXED MODES OF PROPAGATION

911 FHOP=MF(1)-1
IF(FHOP) 3903,3903,3898

3898 XHOP=FHOP+1*

C AVERAGE HEIGHT OF REFLECTING LAYERS

EFHT=(110+FHOP*FL)/(FHOP+1*)

C RADIATION ANGLE

EFDEL=ATANF{(COSF(GCD/(2*XHOP))-RO/(RO+EFHT))/SINF(GCD/(2*XHOP))}
1)*BK

C ANGLE AT IONOSPHERE
PHE=RO*SINF(PI2+EFDEL*AK)/(RO+110.)
ARZ=79.138*(PI2-EFDEL*AK-ASINF(PHE))
IF(EFDEL<1.) 3899,3900,3901

3899 FHOP=FHOP+1.
GO TO 3898

C MODE ELIMINATION
3900 ELFK=1.02
GO TO 3902

3901 ELFK=(((((-+4.368460907E-9*ARZ+1.33494261E-7)*ARZ-5.976618436E-6)
1*ARZ+2.*624808315E-4)*ARZ-5.038476266E-3)*ARZ+3.761385053E-2)*ARZ-2.133200756E-2)*ARZ+.2085

3902 Y=ZS*ELFK

4332 IF(Y-FREO) 3903,3905,3906

3903 NOS(NF)=1000.
GO TO 612

3905 Y=2R*ELFK
IF(Y-FREQ) 650,650,651

651 NOS(NF)=1000.
GO TO 612

650 ARK=(GCDKM*DK-ARZ)/FHOP

2+4.699243101E-3)*ARK
REF=(FREQ-GMA(I2))/(F24(I2 J-GMA(I2))
IF(FLFK-REF) 652,653,653

652 NOS(NF)=1000.
GO TO 612

C SKY WAVE ABSORPTION
653 EFISKY=615.5*XHOP*ABIY(1,IT)/(COSF(ASINF(RO*SINF(PI2+EFDEL*AK))/RO
1+100.))*((FREQ+1.12*GYR)**1.98)

C GROUND REFLECTION LOSS
3908 CALL LOSS(EFDEL,ER,FREQ,SIGMA,Y)
3909 GEF=ABSF(Y*FHOP)

C ANGLE AT IONOSPHERE
SPHE=RO*SINF(PI2+EFDEL*AK)/(RO+EFHT)

C FREE SPACE LOSS
ZOR=GCD/(2.*(FHOP+1.))
FR=(2.*(FHOP+1.)*SINF(ZOR)*RO/SPHE)*EEK
EFSF = 36.58 + 20 \cdot \log_{10}(FREQ) + 20 \cdot \log_{10}(FREQ)

GO TO (3180, 3180, 3180, 3181), KAP

3181 EFXMT = I ANT

GO TO 3182

C POWER GAIN OF TRANSMITTING ANTENNA

3180 CALL GAIN(KAP, EFDEL, XETA, FREQ, XP, XND, XNL, XNH, EFXMT)

3182 GO TO (3183, 3183, 3183, 3184), KUP

3184 EFRCR = IANR

GO TO 3190

C RESPONSE OF RECEIVING ANTENNA

3183 CALL GAIN(KUP, EFDEL, WETA, FREQ, RQ, RP, RND, RNL, RNH, EFRCR)

C TRANSMISSION LOSS

3190 NOS(NF) = EFSKY + GEF + EFSF - EFXMT - EFRCR + ADJ(ID)

612 IF(NOS(NF) - NXLOS(NF)) 623, 623, 623

623 NANGLE(NF) = EFDEL + 5

MODE(NF) = FHOP + 1

B ABC(NF) = 676060606060

NXLOS(NF) = NOS(NF)

622 IF(NXLOS(NF) - 990) 6911, 624, 624

624 ABC(NF) = A2Z

NANGLE(NF) = 0

MODE(NF) = 0

GO TO 8740

6911 KAJ = 1

GO TO (6912, 6912, 6912, 9779, 6912, 6912) METHOD

6912 POR = 10 \cdot \log_{10}(PWR \cdot 10^{Q})

IF(JUG) 3869, 3869, 8712

C 1MC/S ATMOSPHERIC NOISE DETERMINATION

3869 CC = CKC(IT)

C SEASON AND HOUR BLOCK FOR ATMOSPHERIC NOISE DETERMINATION

LIB = 4

ICC = CC / 2

IF(ICC) 8889, 8889, 8888

8888 GO TO (8701, 8701, 8702, 8702, 8705, 8705, 8706, 8706, 8708, 8708, 8887, 18887), ICC

8887 CC = CC - 24

8889 KJ = 1

TM = - 2

JK = 1

GO TO 8703
8701 KJ=1
TM=2
JK=5
GO TO 8703
8702 KJ=5
TM=6
JK=4
KAJ=2
GO TO 8703
8705 KJ=4
TM=10
JK=3
LIB=5
GO TO 8703
8706 KJ=3
TM=14
JK=2
LIB=5
GO TO 8703
8708 KJ=2
TM=18
JK=1
KAJ=2
8703 IF(Y2 > 9702.9702.9701)
9701 CEG=360.-Y2
GO TO 9703
9702 CEG=ABSF(Y2)
9703 CALL NOISY(KJ,X2,CEG,ATNO)
     CALL NOISY(KJ,X2,CEG,ATNY)
     ATNQ=(ATNO+(ATNY-ATNO)*(CC-TM)/4.)
     L06=0
     JUG=JUG+1
     GO TO(8712,8713),KAJ
C FREQUENCY DEPENDENCE OF ATMOSPHERIC NOISE
8713 MOT=MOUSE/3
     IF(MOT) 8714,8715,8714
8715 MOT=4
8714 IF(X2) 8716,8717,8717
8716LOB=1
8717 IF(MOT=3) 8718,8719,8719
8718 LIB=5-LOB
  GO TO 8712
8719 LIB=4+LOB
8712 IF(LIB=4) 2179,2179,2178
2179 IF(ATNQ=20+) 2130,2178,2178
2130 ATNQ=20.
2178 CALL POLY(LIB,7,7,ATNQ/10.-5.,FREQ/10.-1.35,Y)
  ATNO=Y*10.+130.*
C GALACTIC NOISE
  IF(FREQ-GMA(2)) 8720,8720,8721
8721 GNOS = (((((((1.095032130E-10*FREQ+.2442852795E-8)*FREQ-.15854096
  108E-5)*FREQ+.1513740543E-3)*FREQ-.6306642189E-2)*FREQ+.1390178355E
  2+0)*FREQ+.1701088795E+1)*FREQ+.1211130396E+2)*FREQ-.3426395658E+2)
  3*FREQ+.2020285454E+3
  GO TO 9797
8720 GNOS=1000.*
C MAN MADE NOISE
9797 IF(MAN) 8722,8723,8723
8722 KJ=XABSF(MAN)+5
  SOB=0.
  CALL POLY(KJ,1,10,SOB,FREQ,Y)
  XNOIS=Y
  GO TO 8724
8723 XNOIS=MAN
C DETERMINATION OF CONTROLLING NOISE
8724 RCNSE=ATNO
  IF(ATNO-GNOS) 8725,8725,8726
8726 RCNSE=GNOS
8725 IF(RCNSE-XNOIS) 8729,8729,8728
8728 RCNSE=XNOIS
C AVAILABLE SIGNAL-TO-NOISE RATIO
8729 XLOS=NXLOS(NF)
  ROT = XLOS-POR
  GOT=RCNSE-ROT
  GO TO(505,505,505,505,505,506)*METHOD
506 NXLOS(NF)=GOT
  GO TO 9777
505 WANT=GOT-RSN
C CIRCUIT RELIABILITY
  IF(ABSF(WANT)-(TOP(ID)+TIP))867,867,868
868 REL=SIGNF(100.*WANT)
   GO TO 869
867 KJ=1D+10
   GO TO (888,8733,8733,8733,1D)
888 IF(ABY(1,IT)) 8733,8733,8733,8732
8732 KJ=KJ-1
8733 CALL POLY(KJ,5,10,FREQ/10,-1.35,WANT/10.,Y)
   REL=Y*10.+50.
869 IF[ID-1] 8734,8734,8735
8735 XRL=90.
   GO TO 8736
8734 XRL=99.
8736 IF(REL-XRL) 8739,8739,8738
8738 REL=XRL
8739 IF(REL-1.) 8740,8740,8741
8740 REL=0.
8741 NXLOS(NF)=REL
   KIP=2
   IF(METHOD-3) 9777,3207,9777
C ITERATION FOR LUF
3207 IF(REL-90.) 3201,3202,3203
3201 GO TO (3204,3202,3202,3202,3201,3202)
3202 FF(IT)=FREQ
   GO TO 3214
3203 IF(FREQ-3.) 3208,3208,3209
3208 FF(IT)=-3.
   GO TO 3214
3209 FREQ=FREQ-1.*DFREQ
   IF(FREQ-3.) 3208,4850,4850
4850 KAT=2
   GO TO 939
3204 ZJ=KJ
   GO TO 9777
9779 IF(IHR) 9777,9777,9777
C FIELD STRENGTH
9778 ALOSS=-NXLOS(NF)
   NXLOS(NF)=ALOSS+107.*Z+8.6859*LOGF(FREQ)+4.343*LOGF(1000.*PWR)
C FURTHER ITERATION FOR LUF
9777 NF=NF+1
   IF(NF-11) 914,914,260
914 FREQ=FREL(NF)
    IF(FREQ=FREL(11)) 917,917,916
917 IF(FREQ-30.) 939,939,916
916 NXLOS(NF)=0
    FF(IT)=0.
    GO TO 9777
260 GO TO (250,250,3214,3212,7007,250).METHOD
7007 GO TO (7009,7008).LZP
7009 WRITE OUTPUT TAPE 6,.34,PWR,IRSN,IFR
7008 WRITE OUTPUT TAPE 6,.24,
    1      I(1),U(1),F(1),NXLOS
    N(1)=N(1)+1
    GO TO (3214,3214,21),N(1)
21 WRITE OUTPUT TAPE 6,.208
    N(1)=0
    GO TO 3214
250 GO TO (2250,2666).LZP
2250 WRITE OUTPUT TAPE 6,.14,PWR,IRSN,IFR
2666 GO TO (2667,2667,2667,2667,2667,2667,2667,2667,2667).METHOD
2668 WRITE OUTPUT TAPE 6,.29,
    1      I(1),U(1),F(1),NXLOS
    N(1)=N(1)+1
    GO TO (3214,3214,21),N(1)
2667 WRITE OUTPUT TAPE 6,.29,
    1      I(1),U(1),F(1),NXLOS
    N(1)=N(1)+1
    GO TO 3214
3212 GO TO (3213,3215).LZP
3213 IF(IHR) 8002,8002,8003
8003 WRITE OUTPUT TAPE 6,.80,PWR,IFR
    GO TO 77
8002 WRITE OUTPUT TAPE 6,.80,IFR
3215 IF(IHR) 69,.69,77
69 WRITE OUTPUT TAPE 6,.19,
    1      I(1),U(1),F(1),NXLOS
    N(1)=N(1)+1
    GO TO 3214
77 WRITE OUTPUT TAPE 6,.59,
    1      I(1),U(1),F(1),NXLOS
    N(1)=N(1)+1
    GO TO 3214
3214 Lzp = 2
  GO TO (2270, 51, 290, 51, 41, 51), METHOD
41 GO TO (40, 51), JIG
40 WRITE OUTPUT TAPE 6, 907
  GO TO 270
51 WRITE OUTPUT TAPE 6, 909
  JIG = 0
  GO TO 270
290 IF (MAP) 6228, 6228, 6229
6229 CALL CURVY (FOT, FF)
  GO TO 270
6228 WRITE OUTPUT TAPE 6, 24, PWR, IRSN
  IF (IHR) 2291, 2291, 2290
2291 WRITE OUTPUT TAPE 6, 7,
  1 (IG (I), FF (I), FOT (I), IG (I+6), FF (I+6), FOT (I+6), IG (I+12),
  2 FF (I+12), FOT (I+12), IG (I+18), FF (I+18), FOT (I+18), I=1, 6), AAA
  GO TO 2270
2290 WRITE OUTPUT TAPE 6, 70,
  1 (IG (I), FOT (I), IG (I+6), FOT (I+6), IG (I+12), FOT (I+12), IG (I+1
  28), FOT (I+18), IG (I+1), FF (I+1), FOT (I+1), IG (I+7), FF (I+7), FOT (I+7), IG
  3 (I+13), FF (I+13), FOT (I+13), IG (I+19), FF (I+19), FOT (I+19), I=1, 6, 2), AAA
2270 IF (3-MIT) 1969, 1969, 1970
1969 WRITE OUTPUT TAPE 6, 909
  MIT = 1
  GO TO 270
1970 MIT = MIT + 1
270 RETURN
END
SUBROUTINE CURVY(COT,BOT)
GENERATES LINE GRAPHS
DIMENSION COT(24), ROT(73), BOT(24), WOT(73)
DIMENSION AOT(73), COB(55), BOB(55), XOB(73)
DIMENSION FDEK(10), EDEK(10)
DIMENSION AMON(12), GLAT(5), ABI(24), ABIY(5, 24), CLCK(5, 24), GY(5),
F2S(5, 24), F2H(5, 24), GML(5, 24), GMH(5, 24), MF(3), ME(2), ELL(10), FLL(10),
2ELD(10), EDEL(10), FLD(10), FDEL(10), F24(5), GMA(5), FLF(10), FSKY(10),
3ESKY(10), GE(10), GF(10), FSE(10), FSF(10), NOS(11), FXMT(10), EXMT(10),
4FRCR(10), ERCR(10), ADJ(4), ABC(12), MODE(12)
DIMENSION O(20, 60, 4), IL(4), JL(4), KL(4), JAL(4), CKC(24)
1G(60), AB(60), S(20, 24), C(20, 24), GAMMA(5, 24), BA(60)
DIMENSION RD(5), SUN(12), A(10), 7, 14, RASSN(12), EMF(5, 24)
DIMENSION CLAT(5), CLONG(5), EMUFY(5, 24), FMUFY(5, 24), UFY(5), FOTY(5)
5IG(24)
DIMENSION UF(24), FOT(24), FF(24), P(29, 16, 6), ABP(2, 6)
DIMENSION AHA(2), ARA(2), AVA(2), RANT(2), TANT(2)
DIMENSIONN XLOS(11), NANGLE(11)
DIMENSION TOP(4), FREL(12)
COMMON ABP, P
COMMON A, Q, G, AB, S, C, GAMMA, BA, EMUFY, FMUFY, IG, UF, FOT, SUN, AVA, ARA, GLA
1T, ABI, ABIY, CLCK, GY, F2S, F2H, GML, GMH, MF, ME, ELD, FLD, F24, GMA, ADJ, ABC,
2EMF, CKC, CLAT, CLONG, AK, BK, CK, DK, PI2, EK, EEL, GLT, GLG, AAA, ALA, ASA,
3AFC, ANC, AWC, AEC, ASC, AAZ, MAN, RSN, K, PW, IANT, IANR, Y2, X2, MOUSE, SSN,
4NOCR, K4, AX, XLONG, AL, YLAT, XLAT, YLONG, YLBTRY, GCDKM, GCdN, K1, K2, K
53, K5, GCD, IRSN, M0N, ID, MOUSE, AK, METHOD, AHA, BMONS, MAP
COMMON FREL
COMMON XNH, XNL, XND, RH, RL, RNL, RND, HA, JG, HAR, XTR, XETA, WETA, IHR, MIT
COMMON KAP, KUP, MA, TANT, INH, IND, RANT, JNH, JNL, JN
73 FORMAT(10X, 4HANT=I3, 2HD, B, 20X, 6HNOISE=I3, 20X, 4HANT=I3, 2HD)
91 FORMAT(6X, 2A6, 1X, I3, 1HH, 1X, I3, 1HL, 1X, I3, 3HDEG, 2X, 6HNOISE=I3, 2A6, 1X,
1, I3, 1HH, 1X, I3, 1HL, 1X, I3, 3HDEG)
72 FORMAT(6X, 2A6, 1X, I3, 1HH, 1X, I3, 1HL, 1X, I3, 3HDEG, 12X, 6HNOISE=I3, 12X,
14HANT=I3, 2HD)
74 FORMAT(10X, 4HANT=I3, 2HD, 13X, 6HNOISE=I3, 7X, 2A6, 1X, I3, 1HH, 1X, I3, 1HL,
1, I3, 1HH, 1X, I3, 1HL, 1X, I3, 3HDEG)
24 FORMAT(10X, 4HPOWER=I6, 2H, 2HKW, 42X, 8HREQ, S/N=I3, 2HD)
3 FORMAT(14X, I5, 10X, A6, 10X, 4HSSN=F5, 0, 10X, A2, F7.3/13X, 11HTR
2ANSMSITTER, 13X, 8HRECEIVER, 12X, 8HBEARINGS, 6X, 7HN, MILES/11X, F6.2, A1,
2ANSMITTER.13X.8HRECEIVER . 12X »8HBEARINGS»6X,7HN.MILES/1IX, F6.2,A1, 0038
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(1H1 ) 0044
WRITE OUTPUT TAPE 6,3. 0045
1 NOCIR.BMONS.SSN.HA.HAR.XLAT.AX.XLONG.AL.YLAT.AY.YLONG.YL. 0046
2XTX.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,RANT,JNH,JNL,JND 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 1=1,24 0065
X=COT(1-1) 0066
IF(1-1) 202,203.202 0067
203 X=COT(24) 0068
ROT(1)=X 0069
202 XX=COT(1) 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

IF (I - 1) 802, 803, 802

803 X = BOT(24)
    IF (X) 51, 53, 54

51 X = 1
    GO TO 54

53 X = COT(24)

54 WOT(I) = X

802 XX = BOT(I)
    IF (XX) 55, 57, 58

55 XX = 1
    GO TO 58

57 XX = COT(I)

58 DO 808 II = 1, 3
    J = J + 1
    CEG = II

808 WOT(J + 1) = X + (XX - X) * CEG / 3

6402 DO 608 I = 2, 72, 1

B 608 XOB(I) = 406060606060
    DO 20 I = 1, 1, 73, 3
B 20 XOB(I) = 206060606060
    DO 30 I = 1, 1, 55
B 30 COB(I) = 606060606060
    B COB(1) = 600360606060
    B COB(5) = 600460606060
    B COB(9) = 600560606060
    B COB(13) = 600660606060
    B COB(17) = 600760606060
    B COB(21) = 601060606060
    B COB(23) = 601160606060
    B COB(25) = 601260606060
    B COB(27) = 601360606060
    B COB(29) = 601460606060
    B COB(31) = 601560606060
    B COB(33) = 601660606060
    B COB(35) = 601760606060
    B COB(37) = 601860606060
    B COB(39) = 601960606060
    B COB(41) = 602060606060
B COB(43)=01160606060
B COB(45)=021260606060
B COB(47)=020260606060
B COB(49)=020460606060
B COB(51)=020660606060
B COB(53)=021060606060
B COB(55)=031260606060
B BOB(29)=456060606060
B BOB(21)=622060606060
B BOB(22)=616060606060
B BOB(23)=236060606060
B BOB(24)=446060606060
B BOB(27)=706060606060
B BOB(28)=236060606060
B BOB(30)=256060606060
B BOB(31)=646060606060
B BOB(32)=506060606060
B BOB(33)=256060606060
B BOB(34)=516060606060
B BOB(35)=266060606060
B DOT=546060606060
ZOB=31
B DOB=406060606060
DO 200 IK=1,55
IM=56-IK
DO 100 I=1,73
B 100 AOT(I)=606060606060
IF(ZOB-2Q.) 4,4,63
63 WOB=1.4.4,63
GO TO 5
4 IF(ZOB-8.) 4062,4062,4063
4063 WOB=5.6
GO TO 5
4062 WOB=25
5 ZOB=ZOB-WOB
IT=1
12 ISPOT=IT
IF(ROT(IT)-ZOB) 6,8,8
8 SOB=ZOB+WOB
IF(ROT(IT)-SOB) 10,6,6
10 AOT(ISPOT)=DOT
   IT=IT+2
   GO TO 16
 6 IT=IT+1
16 IF(ISPOT-73) 12,13,13
13 IF(METHOD-3) 200,6565,200
6565 IT=1
 33 ISPOT=IT
   IF(WOT(IT)-ZO)= 66,38,38
 38 SOB=ZOB+WOB
   IF(WOT(IT)-SO)= 80,66,66
 80 IF(AOT(ISPOT)-DOT) 81,66,81
 B 81 AOT(ISPOT)=336060606060
   IT=IT+2
   GO TO 67
 66 IT=IT+1
 67 IF(ISPOT-73) 33,200,200
200 WRITE OUTPUT TAPE 6,2,
   1 BOB(IM),COB(IM),DOB,AOT,DOB,COB(IM),BOB(IM)
14 WRITE OUTPUT TAPE 6,15,XOB
   WRITE OUTPUT TAPE 6,25
   RETURN
   END
SUBROUTINE GAIN(KOP, DELTA, BETA, FMC, SIGMA, ER, PHI, EL, H, RAIN)  
C POWER GAIN OF ANTENNAS

9749 FORMAT (1F12.6)  
RHI = PHI * 0.01745329252  
RELTA = DELTA * 0.01745329252  
GO TO (6*7*6)*KOP  
6 T = COSF(RELTA)  
RETA = BETA * 0.01745329252  
Q = SINF(RELTA)  
R = Q * Q  
S = R * R  
X = 18000 * SIGMA / FMC  
RHO = SQRTF((ER - T * T) * (ER - T * T) + X * X)  
RHO12 = SQRTF(RHO)  
ALPHA = - ATANF(X / (ER - T * T))  
PSIH = ATANF(2 * RHO12 * Q * SINF(ALPHA * 5) / (RHO - R);  
CH = SQRTF(RHO * RHO + S - 2 * RHO * R * COSF(ALPHA)) / (RHO + R + 2 * RHO12 * Q * COSF(ALPHA))  
1PHA * 5))  
WAVE = 299.7925 / FMC  
FAC = (3.141592654 * EL) / WAVE  
U1 = 1. - T * SINF(RHI + RETA)  
U2 = 1. - T * SINF(RHI - RETA)  
EFF = 0.  
X = 1.  
GO TO (2*2*3)*KOP  
2 RAIN = (3.2 * COSF(RHI) * COSF(RHI) * SINF(FAC * U1) * SINF(FAC * U1) * SINF(FAC * U1) * SINF(FAC * U1)) / (U1 * U1 * U2 * U2) * (COSF(RELTA) - SINF(RHI) * T) * (COSF(RELTA) - SINF(RHI) * T)  
ROK = 3.  
GO TO 4  
3 RAIN = (5562474 * COSF(1.570796 * T) * COSF(1.570796 * T) * (CH * CH + 1. - 2. * CH * COSF(PSIH - (12.56637062 * H) / WAVE * Q)) / (CH * CH + 1. - 2. * CH * COSF(PSIH - (12.56637062 * H) / WAVE * Q)) / S  
ROK = -4.77  
GO TO 4  
7 E = ER  
IF(H) 24.24*20  
20 WAVE = 299.7925 / FMC  
A = (6.283185 * H) / WAVE  
X = H / WAVE  
GO TO 25
24  EN=INT(ABS(F(H)/10.))  
    IF(EN) 50, 51, 50  
51  H1=ABS(F(H))  
    GO TO 52  
50  H1=EN/(ABS(F(H) -10.*EN))  
    X=H1  
25  D=2.*A  
    ROK=+5.  
    Z=2.*D  
    W=CI(Z+W1)  
    W2=CI(D+W3)  
    R^=30.*(-.5*COSF(D)*(.5772156649+LOGF(Z)-W }+(1.*COSF(D))*(.577  
    12156649+LOGF(D)-W2 )+SINF(D)*(.5*W1-W3))  
26  S=SINF(RELTA)  
    C=COSF(RELTA)  
    HM=A/6.283185307  
    ANUM=COSF(A*S)-COSF(A)  
28  CALL VREFCO(RELTA,E,FMC,SIGMA,CV,PSIV)  
    FAC1=CV*CV+1.-2.*CV*COSF(PSIV-12.5663706*HM*S)  
    FAC2=2.*COSF(6.2831853072*HM*S)  
29  RAIN = (120.*ANUM*ANUM)/(RA*C*C)  
    RAIN=RAIN*FAC1  
4  IF(RAIN) 11, 11, 31  
31  RAIN=4.*34294819*logF(RAIN)  
    IF(X<25) 69, 70, 70  
69  EFF=(((6416.702573*X-6091.333295)*X+2179.890548)*X-364.8173803)*X+  
    125.64620146  
    GO TO 71  
70  EFF=0.  
71  RAIN=RAIN-EFF-ROK  
41  IF(RAIN+10.) 11, 11, 10  
11  RAIN=-10.  
10  RETURN  
END
SUBROUTINE VREFCO(DELTA, ER, FREQ, SIGMA, CV, PSIV)

C VERTICAL GROUND REFLECTION COEFFICIENT

PI=3.141592654

X=18000.*SIGMA/FREQ

U=(ER*ER+X*X)

V=SQRTF(U)

Q=SINF(DELTA)

R=Q*Q

S=R*R

T=COSF(DELTA)

RHO=SQRTF((ER-T*T)*(ER-T*T)+X*X)

RHO12=SQRTF(RHO)

ALPHA=-ATANF(X/(ER-T*T))

A=2.*RHO12*Q*V*SINF(ALPHA*.5+ASINF(X/V))

B=RHO-U*R

IF(B) 10,20,30

20 IF(A) 21,22,23

21 PSIV=-.5*PI

GO TO 50

22 PSIV=0.

GO TO 50

23 PSIV=.5*PI

GO TO 50

10 PSIV=ATANF(A/B)+PI

GO TO 50

30 PSIV=ATANF(A/B)

50 CV=SQRTF(RHO*RHO+U*U*S-2.*RHO*U*R*COSF(ALPHA+2.*ASINF(X/V)))/(RHO+1*U*R+2.*RHO12*V*Q*COSF(ALPHA+.5+ASINF(X/V))

RETURN

END
FUNCTION CI(X,*SI)
C SINE AND COSINE INTEGRAL
4 IF(X-10.5,60,60
5 SQ=X*X
CI=0.5772156649+LOGF(X)
TERM=-1.*SQ/4.
G=4.
10 CI=CI+TERM
TERM=-1.*TERM*SQ*(G-2.)/(G-1.)*G*G)
G=G+2.
IF(ABSF(TERM)-.00005) 20,20,10
20 SI=0.
TERM=X
G=3.
25 SI=SI+TERM
TERM=-1.*TERM*SQ*(G-2.)/(G-1.)*G*G)
G=G+2.
IF(ABSF(TERM)-.00005) 80,80,25
60 TERM1=1.
T=1.
C=1.
61 FAC=(4.*T*T-2.*T)/(X*X)
TERM2=-1.*FAC*TERM1
IF(ABSF(TERM2)-ABSF(TERM1)) 62,64,64
62 C=C+TERM2
T=T+1.
63 TERM1=TERM2
GO TO 61
64 SC=2.*T
THETA=X-SC
PI=.5-(1.2.*THETA)/(4.*SC)+(1.4.*THETA-2.*THETA*THETA)/(8.*SC*SC
1)+(3.18.*THETA+8.*THETA*THETA)/(16.*SC*SC*SC)
C=C+TERM2*PI
65 TERM1=1./X
D=TERM1
T=1.
66 FAC=(4.*T*T+2.*T)/(X*X)
TERM2=-1.*FAC*TERM1
IF(ABSF(TERM2)-ABSF(TERM1)) 67,69,69
D = D + TERM2  
T = T + 1.  
IF(ABS(TERM2/D) - 10. * E-10) 70  70  68
TERM1 = TERM2  
GO TO 66
SD = 2. * T + 1.  
THETA = X - SD
PI = 5 - (1.2 * THETA)/(4. * SD) + (1 - 4 * THETA - 2 * THETA * THETA)/(8. * SD * SD)
D = D + TERM2 * PI
CX = COSF(X)  
SX = SINF(X)  
CI = (C * SX - D * CX)/X
SI = 1.570796327 - (C * CX + D * SX)/X
RETURN
END
SUBROUTINE LOSS(REA, FREQ, SIGMA, Y)
GROUND REFLECTION LOSS
DELTA = RELTA * 0.01745329
PI = 3.141592654
X = 18000 * SIGMA / FREQ
U = (ER * ER + X * X)
V = SQRTF(U)
Q = SINF(DELTA)
R = Q * Q
S = R * R
T = COSF(DELTA)
RHO = SQRTF((ER - T * T) * (ER - T * T) + X * X)
RHO12 = SQRTF(RHO)
ALPHA = -ATANF(X / (ER - T * T))
CH = SQRTF(RHO * RHO + S - 2 * RHO * R * COSF(ALPHA)) / (RHO + R + 2 * RHO12 * Q * COSF(ALPHA + 0.5))
CV = SQRTF(RHO * RHO + U * U - 2 * RHO * U * R * COSF(ALPHA + 2 * ASINF(X / V))) / (RHO + 1 * U * R + 2 * RHO12 * V * Q * COSF(ALPHA + 0.5 + ASINF(X / V)))
Y = 10 * LOG10F((CH * CH + CV * CV) / 2.)
RETURN
END
SUBROUTINE POLY(KJ,NN,MM,V,X,Y)
POWER SERIES VARIABLES
DIMENSION A(10,7,14)
DIMENSION P(29,16,6),ABP(2,6)
COMMON ABP,P
COMMON A
Y=0
M=MM
120 N=NN
  COEF=0
127 COEF=COEF*V+A(M,N,KJ)
  N=N-1
  IF(N) 122,122,127
122 Y=Y*X+COEF
  M=M-1
  IF(M) 126,126,120
126 RETURN
END
SUBROUTINE NOISY(KJ, XP, CEG, ATNO)
FOURIER VARIABLES AND ATMOSPHERIC RADIO NOISE
DIMENSION P(29, 16*6), ABP(2*6), ZZ(29)
COMMON ABP, P
ALF=ABP(1, KJ)
BET=ABP(2, KJ)
Q=0.00872664664626*CEG
C1=COSF(Q)
S1=SINF(Q)
DO 56 J=1, 29
R=0.
SX=S1
CX=C1
DO 55 K=1, 15
R=R+SX*P(J, K, KJ)
SS=SX*C1+CX*S1
CX=CX*C1-SX*S1
SX=SS
ZZ(J)=R+P(J, 16, KJ)
Q=0.01745329252*(XP+90.)
S1=SINF(Q)
SX=S1
C1=COSF(Q)
CX=C1
R=0.
DO 57 K=1, 29
R=R+SX*ZZ(K)
SS=SX*C1+CX*S1
CX=CX*C1-SX*S1
SX=SS
ATNO=R+ALF+BET*Q
RETURN
END
IX. MATHEMATICAL EXPRESSIONS

1. Great circle distance in kilometers, degrees and nautical miles
   \[ \cos (gcd) = \sin (x1) \cdot \sin (x2) + \cos (x1) \cdot \cos (y2 - y1) \]
   \[ gcd = \text{great circle distance - degrees} \]
   \[ x1 = \text{transmitter latitude - degrees} \]
   \[ y1 = \text{transmitter longitude - degrees} \]
   \[ x2 = \text{receiver latitude - degrees} \]
   \[ y2 = \text{receiver longitude - degrees} \]

2. Bearing from receiver to transmitter, degrees east of north. \((0 \leq \text{btry} \leq 360^\circ)\).
   \[ \text{btry} = 114.5816 \cdot \tan^{-1} \sqrt{\frac{\sin (u - 90 + x2) \cdot \sin (u - gcd)}{\sin (u - 90 + x2) \cdot \sin (u - gcd)}} / \text{cind} \]
   \[ u = \frac{(180. - x1 - x2 + gcd)}{2} \]
   \[ \text{cind} = \sin (u) \cdot \sin (u - 90 + x1) \]

3. Geographic latitude of control points along great circle route.
   \[ x'1 = \cos (pp) \cdot \cos (90 - x2) + \sin (pp) \cdot \sin (90 - x2) \cdot \cos (\text{btry}) \]
   \[ (\text{Control Lat}) = 90 - \arccos (x'1) \]
   \[ pp = \text{great circle distance in degrees from transmitter terminal to control point} \]

4. Geographic longitude of control points along great circle route. \((y = y2 - y')\)
y' = \arccos \left[ \cos (pp) - \cos (90 - x2) \right.
\left. \cdot \cos (90 - x3) / \sin (90 - x2) \cdot \sin (90 - x3) \right] 

x3 = control point geographic latitude 

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

\[
y' = \arccos \left[ \sin (x4) \cdot \sin (x3) + \cos (x4) \cdot \cos (x3) \cdot \cos (x3 - x4) \right]
\]

x4 = latitude of geomagnetic north pole 

6. Local time at receiver terminal. 
LMT = GMT - \(y2/15\) 
LMT = local mean time - hours 
GMT = Greenwich mean time - hours 

7. Sun's zenith angle at control points. 
\[
\cos (\psi) = \sin (z) \cdot \sin (ssp) + \cos (z) \cdot \cos (ssp) \cdot \cos [(15 \times GMT) - 180].
\]
\(\psi = \) 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"
\[
I = (1 + 0.0037 \text{ SSN}) (\cos 0.881 \psi)^{1.3}
\]
SSN $\psi$ predicted or observed 12 month moving average Zurich sunspot number. ($0 \leq \text{SSN} \leq 200$)

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

$x = \text{great circle distance - hundreds of statute miles}$

10. E-2000 MUF.
$$\text{emc} = 3.345996232 + 37.67736072 \cdot I - 52.41191754 \cdot I^2$$
$$+ 39.26151056 \cdot I^3 - 10.66484988 \cdot I^4$$

$I = \text{absorption index}$

11. E-layer MUF.
$$\text{emufy} = (\text{emc}) \cdot (\text{elfc})$$
$$\text{emc} = \text{E-2000 MUF}$$

12. F-layer distance factor.
$$\text{flfc} = 4.699243101 \cdot 10^{-3} \cdot x + 2.264634341 \cdot 10^{-3} \cdot x^2$$
$$+ 9.202437332 \cdot 10^{-5} \cdot x^3 + 6.865259817 \cdot 10^{-5} \cdot x^4 -$$
$$9.985831104 \cdot 10^{-6} \cdot x^5 + 4.49151441 \cdot 10^{-7} \cdot x^6 -$$
$$6.712654756 \cdot 10^{-9} \cdot x^7$$

$x = \text{great circle distance - hundreds of statute miles}$

13. F2-layer Fourier generation of $\text{foF2}$ and M-3000 factors.
Fourier time variation function, used to obtain $\text{foF2}$
or M-3000 factor:
\[ (x, y, t) = ab(x, y) + \sum_{jb=2}^{j} \left[ ab_{jb}(x,y) \cos(jb - 1)t + \right. \\
\left. ba_{jb}(x,y) \sin(jb - 1)t \right] \]

\[ \begin{align*}
\text{ab}_{jb}(x,y) &= \sum_{ka=1}^{I} Q_{is,ka,io} G_{ka}(xy) \\
&\quad \text{is} = 2jb - 1 \\
&\quad \text{jb} = 1, 2, 3, \ldots, j \\
\text{ba}_{jb}(x,y) &= \sum_{ka=1}^{I} Q_{is,ka,io} G_{ka}(xy) \\
&\quad \text{is} = 2jb - 2 \\
&\quad \text{jb} = 2, 3, 4, \ldots, j 
\end{align*} \]

x = geographic latitude of control point - degrees
(-90° ≤ x ≤ 90°)
y = geographic longitude of control point - degrees
(0° ≤ x ≤ 360° - East of North)
t = local time at receiver - (hour angle) (180° ≤ t ≤ 180°)
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
\[ (x, y, t) \] (Time variation)

Latitudinal and longitudinal variation functions are shown in Tables 1 and 2.
For a detailed explanation of the generation of \[ (x, y, t) \] 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

<table>
<thead>
<tr>
<th>ka</th>
<th>( G_{ka}(x, y) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>( \sin(x) )</td>
</tr>
<tr>
<td>3</td>
<td>( \sin^2(x) )</td>
</tr>
<tr>
<td>( \ldots )</td>
<td>( \ldots )</td>
</tr>
<tr>
<td>k</td>
<td>( \sin^{k-1}(x) )</td>
</tr>
</tbody>
</table>
Table 2. Geographical Functions in Latitude and Longitude.

<table>
<thead>
<tr>
<th>MIXED LATITUINAL AND LONGITUDINAL VARIATION - FIRST ORDER IN LONGITUDE</th>
<th>G_{ka}(x, y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( k + 1 )</td>
<td>( \cos (x) \cos (y) )</td>
</tr>
<tr>
<td>( k + 2 )</td>
<td>( \cos (x) \sin (y) )</td>
</tr>
<tr>
<td>( k + 3 )</td>
<td>( \sin (x) \cos (x) \cos (y) )</td>
</tr>
<tr>
<td>( k + 4 )</td>
<td>( \sin (x) \cos (x) \sin (y) )</td>
</tr>
<tr>
<td>( \ldots )</td>
<td>( \ldots \ldots \ldots )</td>
</tr>
<tr>
<td>( \ldots )</td>
<td>( \ldots \ldots \ldots )</td>
</tr>
<tr>
<td>( L - 1 )</td>
<td>( \sin \left( \frac{L - k}{2} \right) \cos (x) \cos (y) )</td>
</tr>
<tr>
<td>( L )</td>
<td>( \sin \left( \frac{L - k}{2} \right) \cos (x) \sin (y) )</td>
</tr>
</tbody>
</table>

\( \frac{L - k}{2} = \frac{L}{2} - 1 \)

<table>
<thead>
<tr>
<th>MIXED LATITUINAL AND LONGITUDINAL VARIATION - SECOND ORDER IN LONGITUDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L + 1 )</td>
</tr>
<tr>
<td>( L + 2 )</td>
</tr>
<tr>
<td>( L + 3 )</td>
</tr>
<tr>
<td>( L + 4 )</td>
</tr>
<tr>
<td>( \ldots )</td>
</tr>
<tr>
<td>( \ldots )</td>
</tr>
<tr>
<td>( I - 1 )</td>
</tr>
<tr>
<td>( I )</td>
</tr>
</tbody>
</table>

\( \frac{I - L}{2} = \frac{I}{2} - 1 \)
14. F2-layer gyro frequency may be adequately represented for MUF-FOT predictions by a set of least squares coefficients describing the orthogonal polynomial.

\[ y = (a_{1,1} + a_{1,2} x + a_{1,3} x^2 + \ldots + a_{1,7} x^6) z^0 + \ldots \]

\[ (a_{7,1} + a_{7,2} x + a_{7,3} z^2 + \ldots + a_{7,7} x^6) z^6 \]

\[ y = \text{gyro frequency of F2 layer - Mc/s} \]
\[ x = \text{longitude of control point - degrees} \]
\[ z = \text{latitude of control point - degrees} \]
\[ a = \text{set of least squares coefficients describing the orthogonal polynomial (y)} \]

15. F2-4000 MUF.

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

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

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

\[ \text{ZDF} = \text{foF2} + \frac{1}{2} \text{F2-layer gyro frequency} \]
\[ \text{M-4000 factor} = (1.1) \cdot \text{M-3000 factor} \]

17. Interpolation for intermediate values of solar activity.

\(10 \leq \text{SSN} \leq 180\)

\[ F\text{-MUF} = \left[ F\text{-MUF}_{(\ell)} \cdot (180 - \text{SSN}) + F\text{-MUF}_{(H)}(\text{SSN-10}) \right] / 170 \]

\[ F\text{-MUF}_{(\ell)} \text{ = F-MUF for SSN 10} \]
\[ F\text{-MUF}_{(H)} \text{ = F-MUF for SSN 180} \]
18. Angle at the ionosphere (\(\phi\)).

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

\(\phi'\) = angle of incidence - degrees

\(p\) = radius of earth - km

\(A'\) = great circle distance - degrees

\(H_L\) = layer height - km

19. Ionospheric absorption

\[
A = \frac{615.5 \, N \, \text{sec} \, \phi \, (I)}{(f + \frac{f_g}{g})^{1.98}}
\]

\(\phi\) = 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.

\[
L_{bf} = 10 \log_{10} \left( \frac{p_r}{p_a} \right) = 10 \log_{10} \left( 4 \pi d/\lambda \right)^2
\]

\[
= 36.58 + 20 \log_{10} (d) + 20 \log_{10} (f_{\text{Mc/s}})
\]

\(p_r\) = power available at receiving antenna

\(p_a\) = power delivered to transmitting antenna

\(d\) = ray path distance - miles

\(\lambda\) = wave length

\(f_{\text{Mc/s}}\) = frequency - Mc/s
21. Relationship between φ' and Δ.

\[ \sin \phi' = \frac{p}{p+H_\ell} \cos \Delta \]

φ' = angle of incidence at ionosphere
p = radius of earth
H_\ell = 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,

\[ x = \frac{\sigma}{\omega \epsilon_v} \sim 18 \times 10^3 \ \Omega / f, \]

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.

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

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

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

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

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

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

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

\[ g(\Delta, \beta) = \text{power gain relative to isotropic in free space} \]
\[ \Delta = \text{angle of departure in degrees,} \]
\[ \beta = \text{angle of azimuth in degrees,} \]
\[ \ell = \text{rhombic leg length in meters,} \]
\[ h = \text{antenna height in meters,} \]
\[ \phi = \text{tilt angle in degrees.} \]
\[ \psi_V = \tan^{-1} \left[ \frac{2p^{\frac{1}{2}} \cdot y^{\frac{1}{2}} \cdot \sin \Delta \cdot \sin \left( \tan^{-1} \frac{x}{\epsilon_r} + \frac{a}{2} \right)}{p - y \cdot \sin^2 \Delta} \right] + \pi \]

\[ |K_H| = \left[ \frac{p^2 + \sin^4 \Delta - 2p \cdot \sin^2 \Delta \cdot \cos a}{p + \sin^2 \Delta + 2p^{\frac{3}{2}} \cdot \sin \Delta \cdot \cos \frac{a}{2}} \right]^{\frac{1}{2}} \]

\[ |K_V| = \left[ \frac{p^2 + y^2 \cdot \sin^4 \Delta - 2p \cdot y \cdot \sin^2 \Delta \cdot \cos \left( a + 2 \sin^{-1} \frac{x}{y^2} \right)}{p + y \cdot \sin^2 \Delta + 2p^{\frac{3}{2}} \cdot \sin \Delta \cdot \cos \left( \frac{a}{2} + \sin^{-1} \frac{x}{y^2} \right)} \right]^{\frac{1}{2}} \]

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

\[ y = \epsilon_r^2 + x^2 \]

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

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

\[ x = 18 \times 10^3 \text{ } \Omega/f \]

\( \epsilon_r = \text{relative dielectric constant of the ground} \)

\( \sigma = \text{conductivity of the ground in mhos per meter} \)

\( f = \text{operating frequency in megacycles per second} \)

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


\[
K_V = - |K_V| e^{i\psi_V} = \text{vertical reflection coefficient.}
\]

24. Power gain of half-wave horizontal dipole.

\[
E_\Delta = (0.74582)^2 \left[ \cos \left( \frac{\pi}{2} \cdot \cos \Delta \right) \right]^2 \left\{ K_H^2 + 1 - 2 \cdot K_H \cdot \cos \frac{2\pi h}{\lambda} \sin \Delta \right\}
\]

\[
K_H = \text{amplitude of horizontal reflection coefficient}
\]

\[
\psi_H = \text{phase amplitude of horizontal reflection coefficient}
\]

\[
H = \text{height of antenna - meters}
\]

\[
\lambda = 299.7925 / \text{frequency in megacycles}
\]

\[
H = \frac{1}{2}
\]

\[
\Delta = \text{angle of elevation}
\]

Note: 72 ohms assumed impedance of antenna

\[
\text{Gain}_{\text{decibels}} = 10 \times \log_{10} \left( E_\Delta \right)
\]

25. Power gain of vertical antennas

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

\[
- 2 \cdot K_V \cos (\psi_V - 2A \cdot \sin \Delta)
\]

\[
R_a = 30 \left\{ - \frac{\cos(2A)}{2} \cdot \left\{ C + \ln(4A) - C_1(4A) \right\} + \left\{ 1 + \cos(2A) \right\} \times \left\{ C + \ln(2A) - C_1(2A) \right\} \right\}
\]
\[ + \sin(2A) \times \left\{ \frac{S_i(4A) - S_i(2A)}{2} \right\} \]

\[ C = 0.5772156649 \]

\[ H = \text{height of antenna - meters} \]

\[ S_i = \text{sine integral} \]

\[ C_i = \text{cosine integral} \]

\[ A = 2 \pi \frac{H}{\lambda} \]


\[ \text{EFF} = 25.64620146 - 364.8173803 \times \]

\[ + 2179.890548 \times x^2 - 6091.333295 \times x^3 \]

\[ + 6416.702573 \times x^4 \]

\[ x = \text{wave length of antenna} \]

\[ (1/16 \leq x \leq 1/4) \]

27. Ground reflection loss.

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

28. Relationship of field strength to transmission loss.

(Decibels above isotropic)

\[ E = 107.2 + 20 \log_{10} \left( f_{mc} \right) - L_b \]

\[ f_{mc} = \text{frequency - Mc/s} \]

\[ L_b = \text{transmission loss - decibels} \]
X. GENERALIZED BLOCK DIAGRAM OF HF SYSTEM PERFORMANCE ROUTINE

START

Read
1. Circuit input parameters
2. Ionospheric, geophysical and systems parameters

Calculate
1. Great circle distance
2. Bearings
3. Location of control points
4. LMT at control points
5. Sun's zenith angle at control points
6. Geomagnetic location of control points
7. Absorption index I at control points
8. Path absorption index I
9. E-layer control points MUFs
10. F2-layer control points MUFs
11. MUF and FOT for path

Calculate
1. F2-layer height
2. Distance per hop
3. Radiation angle for E, EF2 and F2-layer modes
4. Angle of incidence associated with mode
5. Maximum E-layer angle of incidence
6. Minimum F2-layer angle of incidence
7. Dominant type of terrain
8. Possible modes
9. Ionospheric loss for path
10. Critical frequency E-layer
11. Critical frequency F2-layer
12. Ground reflection loss
13. Ray-path attenuation
14. Transmitter antenna gain
15. Receiver antenna response
16. Mode with least loss

Calculate
1. LMT at receiver site
2. Atmospheric, man-made and galactic noise
3. Compare signal and noise

Print
S/N ratio option Figure 7 "END"

Print
Reliability option Figure 2 or 8 "END"

Calculate
1. Lowest frequency in Band 7 with reliability of 90% or greater
2. Iterate downward on freq. until reliability is 90%

Print
FOT-LUF option Figure 3, 4 or 10 "END"

Graph or print
MUF-FOT option Figure 1 or 9 "END"

Print
System loss option Figure 5 "END"

Print
Field strength option Figure 6 "END"

1. Set receiving antenna response to isotropic
2. Relate system loss to field strength (dbu)

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


CCIR Report No. 65, Atmospheric radio noise data (Los Angeles, 1959).


Haydon, George W., Ionospheric predictions and disturbance forecasts, Lecture No. 47, NBS Radio Propagation Course (to be published) (1962).


NBS CRPL Series D, Basic radio propagation.


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.


Office of Weights and Measures.

BOULDER, COLO.

CRYOGENIC ENGINEERING LABORATORY


CENTRAL RADIO PROPAGATION LABORATORY


RADIO STANDARDS LABORATORY


Joint Institute for Laboratory Astrophysics - NBS Group (Univ. of Colo.).