For 1840 reference

NBS REPORT

7619

PREDICTING THE PERFORMANCE OF BAND 7 COMMUNICATION SYSTEMS USING ELECTRONIC COMPUTERS

by

Donald L. Lucas and George W. Haydon

NBS

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

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

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.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT		NBS REPORT
8530-20-85504	October 15, 1962	7619

PREDICTING THE PERFORMANCE OF BAND 7 COMMUNICATION SYSTEMS USING ELECTRONIC COMPUTERS

by

Donald L. Lucas and George W. Haydon

Prepared for

U. S. Navy - Bureau of Ships

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

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

PREDICTING THE PERFORMANCE OF BAND 7 COMMUNICATION SYSTEMS USING ELECTRONIC COMPUTERS

Donald L. Lucas and George W. Haydon

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 (foF2).

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

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

The following ionospheric characteristics are derived in the prediction process:

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

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

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

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

The following geophysical data are utilized:

(1) E-region gyro frequency.

(2) F-region gyro frequency.

(3) Geomagnetic latitudes.

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

(5) World-wide distribution of atmospheric noise including seasonal, diurnal and frequency variations.

(6) Cosmic noise including frequency dependence.

(7) Man-made noise in the receiving area including frequency dependence.

The following circuit data are needed:

(1) Transmitter location.

(2) Receiver location.

(3) Transmitter power.

(4) Transmitting antenna (physical dimensions and orientation).

(5) Receiving antenna (physical dimensions and orientation).

(6) Type of traffic (modulation, type of intelligence, speed of transmission, required quality).

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

(1) The Maximum Usable Frequency (MUF).

(2) The Optimum Traffic Frequency (FOT).

(3) System loss (ratio of power received to power transmitted).

(4) Field strength at the receiver.

(5) Monthly median of hourly median available signal-to-noise ratio.

(6) Circuit reliability (per cent of days the hourly median signal-to-noise ratio can be expected to equal or exceed a given value).

(7) The Lowest Useful Frequency (LUF), the frequency below which the circuit reliability is expected to be less than 90%.

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

(1) The short great circle distance.

(2) Bearing of the transmitter at the receiver.

(3) Bearing of the receiver at the transmitter.

(4) Propagation path having the lowest system loss, e.g., 2 hops via F layer = 2F.

(5) Vertical reception angle associated with the best propagation path.

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

(1) The transmitter power.

(2) The transmitter antenna gain.

(3) Loss due to spreading of the radio energy as it propagates to greater distance.

(4) Losses in the ionosphere due to absorption.

(5) Losses at each ground reflection.

(6) The gain of the receiving antenna.

The required signal depends upon:

(1) The atmospheric noise at the receiver location.

(2) The man-made noise at the receiver location.

(3) Cosmic noise.

(4) The required signal-to-noise ratio depending upon type and quality of service desired.

The most basic calculation in the estimation of available signal power is the system loss calculation. The ionospheric, geophysical and circuit characteristics are combined to estimate a quasi-minimum system loss (the minimum loss expected on any day of the month at the hour for which the calculations are made). The distribution of losses above the quasi-minimum have been empirically determined and are a function of geographic location and time of day. These statistical distributions are used to account for the numerous other factors which contribute to variations between predicted signal levels and those observed on a given day. These factors include polarization mismatch between the signal and the antenna, focusing by the ionosphere, defocusing by the earth, variations between theoretical and actual antenna performance and day to day variations in ionospheric layer heights, ionospheric absorption and critical frequencies.

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

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

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

II. PROGRAM DESCRIPTION

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

The computer method described is designed for any (32K IBM-7090 class) computer with the necessary compiler and tape units. The Fortran II computer language assures flexibility and ease of modification as better knowledge of the various parameters becomes available. The program provides the communicator with a completely general method for predicting the performance of any sky-wave high frequency radio system. The system performance calculations may be performed for any month of the year, and any degree of solar activity for any hour of the day. Numerical mapping is included for those parameters not evaluated directly by the closed mathematical expressions (Section IX).

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

1. MUF-FOT

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

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

2. System Loss

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

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

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

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

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

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

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

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

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

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

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

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

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

c. Vertical ship antennas for constant length elements or for multiples of any wave lengths not less than .02 λ. 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:

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

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

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

MUFLUF -- (2550 decimal locations)

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

LUFFY -- (3857 decimal locations)

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

POLY -- (107 decimal locations)

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

Example:

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

$$+ \left(A_{1,0} x^{0} + A_{1,1} x^{1} + \ldots + A_{1,n} x^{n}\right) Z^{1}$$

$$+ \ldots$$

$$+ \left(A_{m,0} x^{0} + A_{m,1} x^{1} + \ldots + A_{m,n} x^{n}\right) Z^{m}$$

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

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

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

when called for by the loss and gain routines.

NOISY -- (215 decimal locations)

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

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

CURVY -- (1462 decimal locations)

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

VREFCO -- (230 decimal locations)

This routine calculates the ground reflection coefficient ($K_{V.}$) for vertically polarized waves.

NOTE:

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

IV. DESCRIPTION OF DATA TAPES

1. "Long-term" Data Tape.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

A (M, N, 7) man-made noise level in residential area

A (M, N, 8) man-made noise level in rural area

A (M, N, 9) man-made noise level in remote unpopulous area

A (M, N, 10) daytime distribution of circuit reliability in temperate regions [Haydon, 1962]

A (M, N, 11) nighttime distribution of circuit reliability in temperate regions

A (M, N, 12) distribution of circuit reliability in polar region

A (M, N, 13) distribution of short circuit reliability in auroral region

A (M, N, 14) distribution of long circuit reliability in auroral region

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

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

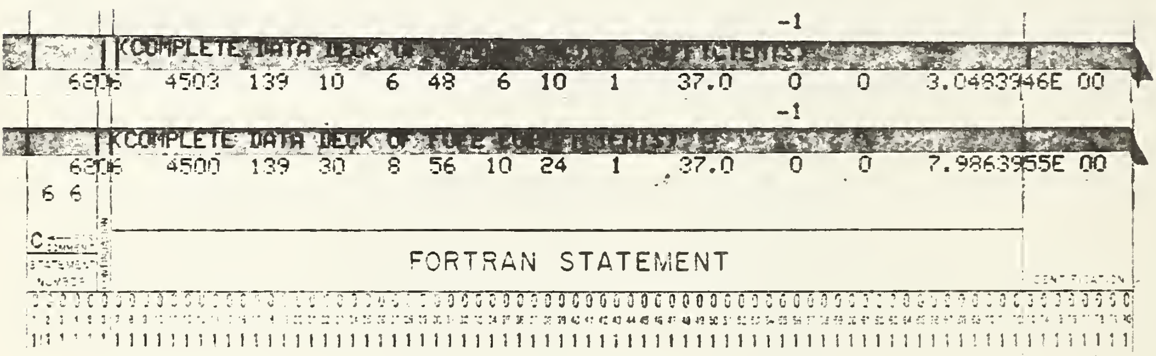
The array "ABP" contains the convergence factors for the Fourier generation of the "P" matrix [Lucas and Harper, 1962].

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

2. "Short-term" Data Tape.

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

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



(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(2I2)
      READ INPUT TAPE 5,101,MONTH1,MONTH2
      REWIND 2
      REWIND 3
      MONTH3=MONTH2+1
      LOCK = MONTH1-1
      IF(LOCK) 4,55,4
    4 DO 3 II=1,LOCK
      READ TAPE 2,IL,JL,KL,LK,JAL,Q,A,P1,ABP
    3 WRITETAPE 3,IL,JL,KL,LK,JAL,Q,A,P1,ABP
   55 DO 100 II=MONTH1,MONTH2
      READ TAPE 2, IL,JL,KL,LK,JAL,Q,A,P1,ABP
      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
```

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

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

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

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

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

V. PROGRAM OPTIONS

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

1. MUF and FOT (Figure 1)

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

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

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

3. FOT and LUF (Figures 3 and 4)

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

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

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

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

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

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

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

7. MUF, FOT AND RELIABILITY (Figure 8)

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

8. FOT GRAPHS (Figure 9)

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

9. FOT AND LUF GRAPHS (Figure 10)

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

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

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

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

VI. COMPUTER INPUTS

1. Circuit Card Format

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

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

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

NOTES:

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

2. Method Card Format

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

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

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

3. Assembling the Data Decks

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

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

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

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

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

(See Figures 14 and 15)

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

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

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

(See Figure 16)

4. Purpose of Cards in Data Deck

(a) Method Card:

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

(b) Frequency Complement Card:

The frequency card allows the communicator a choice of 10 frequencies for which calculations will be made, e.g., 3.1240, 4.7856 ...... 30.0000. If fewer than 10 frequencies are wanted merely put the desired ones sequentially on card from the beginning, then punch unused fields with 990000. If method #3 is to be run, it is suggested that a frequency card identical to Figure 12 be used.

(c) Circuit Cards (Figure 13):

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

(d) Nines Card (Figure 12):

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

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

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

(f) Minus One Card (Figure 12):

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

(g) Blank Card (Figure 12):

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

1	JAN	SSN= 25.	BR 32.007
TRANSMITTER	RECEIVER	BEARINGS	N.MILES
40.75N - 73.93W	32.33N - 64.70W	135.8 321.3	672.5

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

2	JAN	SSN= 25.	GC 2.016
TRANSMITTER	RECEIVER	BEARINGS	N.MILES
51.50N - 0.01W	27.92N - 15.67W	212.5 22.2	1581.3

GMT	MUF	FOT	GMT	MUF	FOT	GMT	MUF	FOT	GMT	MUF	FOT
1	10.3	8.8	7	8.1	6.9	13	22.7	19.3	19	13.5	11.5
2	10.8	9.2	8	12.9	11.0	14	21.7	18.5	20	11.8	10.1
3	10.6	9.0	9	19.6	16.6	15	21.5	18.2	21	10.8	9.2
4	9.9	8.4	10	22.8	19.3	16	21.0	17.8	22	9.8	8.3
5	9.3	7.9	11	23.6	20.0	17	19.5	16.6	23	9.7	8.3
6	8.1	6.9	12	23.7	20.2	18	16.6	14.2	24	10.1	8.6

3	JAN	SSN= 25.	LD 16.024
TRANSMITTER	RECEIVER	BEARINGS	N.MILES
12.10N - 8.50E	51.50N - 0.01W	351.8 167.0	2400.4

GMT	MUF	FOT	GMT	MUF	FOT	GMT	MUF	FOT	GMT	MUF	FOT
1	13.4	11.4	7	15.9	13.6	13	25.8	21.9	19	14.8	12.6
2	13.0	11.1	8	23.5	19.9	14	25.3	21.5	20	13.9	11.8
3	11.8	10.1	9	26.6	22.6	15	24.4	20.7	21	13.1	11.1
4	10.7	9.1	10	27.3	23.2	16	23.0	19.5	22	13.0	11.0
5	9.2	7.8	11	27.4	23.3	17	20.2	17.1	23	13.0	11.0
6	9.8	8.4	12	26.6	22.6	18	16.7	14.2	24	13.0	11.1

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

2 JAN SSN= 25. GC 2.016

TRANSMITTER: 51.50N - 0.01W | RECEIVER: 27.92N - 15.67W | BEARINGS: 212.5 22.2 | N.MILES: 1581.3

RHOMBIC 23H 96L 67DEG NOISE= 3 RHOMBIC 20H 114L 70DEG

PWR= 30.00KW OPERATING FREQUENCIES REQ.S/N= 45DB

GMT	MUF	FOT	3	5	7	9	11	13	15	20	25	30	FOT	
1	10.3	8.8												
			3F	2F	1F	1F	00	00	00	00	00	00	1F	MODE
			28	18	5	5	0	0	0	0	0	0	5	ANGLE
2	10.8	9.2	90	99	99	99	0	0	0	0	0	0	99	RELIABILITY
3	10.6	9.0												
			3F	2F	1F	00	00	00	00	00	00	00	1F	MODE
			28	18	4	0	0	0	0	0	0	0	4	ANGLE
4	9.9	8.4	90	99	99	0	0	0	0	0	0	0	99	RELIABILITY
5	9.3	7.9												
			3F	2F	00	00	00	00	00	00	00	00	1F	MODE
			26	16	0	0	0	0	0	0	0	0	4	ANGLE
6	8.1	6.9	89	99	0	0	0	0	0	0	0	0	99	RELIABILITY
7	8.1	6.9												
			3F	3F	2F	1F	00	00	00	00	00	00	1F	MODE
			25	25	16	3	0	0	0	0	0	0	3	ANGLE
8	12.9	11.0	0	98	99	99	0	0	0	0	0	0	99	RELIABILITY
9	19.6	16.6												
			2E	3F	2F	2F	2F	2F	1F	00	00	00	1F	MODE
			5	25	15	15	15	15	3	0	0	0	3	ANGLE
10	22.8	19.3	0	5	99	99	99	99	99	0	0	0	99	RELIABILITY
11	23.6	20.0												
			2E	2E	3F	2F	2F	2F	1F	1F	00	00	1F	MODE
			5	5	24	15	15	15	3	3	0	0	3	ANGLE
12	23.7	20.2	0	0	81	99	99	99	99	99	0	0	99	RELIABILITY
13	22.7	19.3												
			2E	2E	3F	2F	2F	2F	1F	00	00	00	1F	MODE
			5	5	24	15	15	15	3	0	0	0	3	ANGLE
14	21.7	18.5	0	0	89	99	99	99	99	0	0	0	99	RELIABILITY
15	21.5	18.2												
			2E	3F	2F	2F	2F	1F	1F	00	00	00	1F	MODE
			5	23	14	14	14	2	2	0	0	0	2	ANGLE
16	21.0	17.8	0	23	99	99	99	99	99	0	0	0	99	RELIABILITY
17	19.5	16.6												
			3F	3F	2F	2F	1F	1F	00	00	00	00	1F	MODE
			23	23	14	14	2	2	0	0	0	0	2	ANGLE
18	16.6	14.2	44	99	99	99	99	99	0	0	0	0	99	RELIABILITY
19	13.5	11.5												
			3F	3F	2F	1F	00	00	00	00	00	00	1F	MODE
			23	23	14	2	0	0	0	0	0	0	2	ANGLE
20	11.8	10.1	83	99	99	99	0	0	0	0	0	0	99	RELIABILITY
21	10.8	9.2												
			3F	2F	1F	00	00	00	00	00	00	00	1F	MODE
			25	16	3	0	0	0	0	0	0	0	3	ANGLE
22	9.8	8.3	87	99	98	0	0	0	0	0	0	0	99	RELIABILITY
23	9.7	8.3												
			3F	3F	1F	00	00	00	00	00	00	00	1F	MODE
			27	27	4	0	0	0	0	0	0	0	4	ANGLE
24	10.1	8.6	89	99	99	0	0	0	0	0	0	0	99	RELIABILITY

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

```
        2             JAN              SSN=  25.          GC  2.016
    TRANSMITTER               RECEIVER             BEARINGS        N.MILES
   51.50N -    0.01W      27.92N -  15.67W     212.5  22.2          1581.3
  RHOMBIC   23H  96L   67DEG      NOISE=  0      RHOMBIC   20H 114L   70DEG
                              OPERATING FREQUENCIES
```

GMT	MUF	FOT	3	5	7	9	11	13	15	20	25	30	FOT	
1	10.3	8.8												
			3F	2F	1F	1F	00	00	00	00	00	00	1F	MODE
			28	18	5	5	0	0	0	0	0	0	5	ANGLE
2	10.8	9.2	133	120	129	120	0	0	0	0	0	0	120	LOSS..DB
3	10.6	9.0												
			3F	2F	1F	00	00	00	00	00	00	00	1F	MODE
			28	18	4	0	0	0	0	0	0	0	4	ANGLE
4	9.9	8.4	133	121	131	0	0	0	0	0	0	0	124	LOSS..DB
5	9.3	7.9												
			3F	2F	00	00	00	00	00	00	00	00	1F	MODE
			26	16	0	0	0	0	0	0	0	0	4	ANGLE
6	8.1	6.9	134	122	0	0	0	0	0	0	0	0	134	LOSS..DB
7	8.1	6.9												
			3F	3F	2F	1F	00	00	00	00	00	00	1F	MODE
			25	25	16	3	0	0	0	0	0	0	3	ANGLE
8	12.9	11.0	169	137	121	131	0	0	0	0	0	0	123	LOSS..DB
9	19.6	16.6												
			2E	3F	2F	2F	2F	2F	1F	00	00	00	1F	MODE
			5	25	15	15	15	15	3	0	0	0	3	ANGLE
10	22.8	19.3	291	166	137	122	114	111	116	0	0	0	110	LOSS..DB
11	23.6	20.0												
			2E	2E	3F	2F	2F	2F	1F	1F	00	00	1F	MODE
			5	5	24	15	15	15	3	3	0	0	3	ANGLE
12	23.7	20.2	346	235	151	128	118	114	119	111	0	0	111	LOSS..DB
13	22.7	19.3												
			2E	2E	3F	2F	2F	2F	1F	00	00	00	1F	MODE
			5	5	24	15	15	15	3	0	0	0	3	ANGLE
14	21.7	18.5	332	229	149	127	118	113	120	0	0	0	114	LOSS..DB
15	21.5	18.2												
			2E	3F	2F	2F	2F	1F	1F	00	00	00	1F	MODE
			5	23	14	14	14	2	2	0	0	0	2	ANGLE
16	21.0	17.8	256	159	134	120	112	125	119	0	0	0	115	LOSS..DB
17	19.5	16.6												
			3F	3F	2F	2F	1F	1F	00	00	00	00	1F	MODE
			23	23	14	14	2	2	0	0	0	0	2	ANGLE
18	16.6	14.2	149	128	117	109	127	121	0	0	0	0	119	LOSS..DB
19	13.5	11.5												
			3F	3F	2F	1F	00	00	00	00	00	00	1F	MODE
			23	23	14	2	0	0	0	0	0	0	2	ANGLE
20	11.8	10.1	137	122	114	131	0	0	0	0	0	0	127	LOSS..DB
21	10.8	9.2												
			3F	2F	1F	00	00	00	00	00	00	00	1F	MODE
			25	16	3	0	0	0	0	0	0	0	3	ANGLE
22	9.8	8.3	135	123	136	0	0	0	0	0	0	0	129	LOSS..DB
23	9.7	8.3												
			3F	3F	1F	00	00	00	00	00	00	00	1F	MODE
			27	27	4	0	0	0	0	0	0	0	4	ANGLE
24	10.1	8.6	134	121	132	0	0	0	0	0	0	0	124	LOSS..DB

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

2 JAN SSN= 25. GC 2.016

TRANSMITTER RECEIVER BEARINGS N.MILES

51.50N - 0.01W 27.92N - 15.67W 212.5 22.2 1581.3

RHOMBIC 23H 96L 67DEG NOISE= 0 ANT= 0DB

PWR= 30.00KW OPERATING FREQUENCIES FIELD STRENGTH

GMT	MUF	FOT	3	5	7	9	11	13	15	20	25	30	FOT	
1	10.3	8.8												
			2F	2F	1F	1F	00	00	00	00	00	00	1F	MODE
			18	18	5	5	0	0	0	0	0	0	5	ANGLE
2	10.8	9.2	30	40	40	47	0	0	0	0	0	0	47	DBU
3	10.6	9.0												
			2F	2F	1F	00	00	00	00	00	00	00	1F	MODE
			18	18	4	0	0	0	0	0	0	0	4	ANGLE
4	9.9	8.4	29	40	40	0	0	0	0	0	0	0	44	DBU
5	9.3	7.9												
			2E	2F	00	00	00	00	00	00	00	00	1F	MODE
			5	16	0	0	0	0	0	0	0	0	4	ANGLE
6	8.1	6.9	29	39	0	0	0	0	0	0	0	0	38	DBU
7	8.1	6.9												
			3F	2F	2F	1F	00	00	00	00	00	00	1F	MODE
			25	16	16	3	0	0	0	0	0	0	3	ANGLE
8	12.9	11.0	-5	24	37	39	0	0	0	0	0	0	44	DBU
9	19.6	16.6												
			2E	3F	2F	2F	2F	2F	1F	00	00	00	1F	MODE
			5	25	15	15	15	15	3	0	0	0	3	ANGLE
10	22.8	19.3	-119	-8	21	35	41	45	47	0	0	0	52	DBU
11	23.6	20.0												
			2E	2E	3F	2F	2F	2F	1F	1F	00	00	1F	MODE
			5	5	24	15	15	15	3	3	0	0	3	ANGLE
12	23.7	20.2	-174	-61	4	29	37	42	45	51	0	0	52	DBU
13	22.7	19.3												
			2E	2E	3F	2F	2F	2F	1F	00	00	00	1F	MODE
			5	5	24	15	15	15	3	0	0	0	3	ANGLE
14	21.7	18.5	-160	-55	6	30	38	43	45	0	0	0	50	DBU
15	21.5	18.2												
			2E	3F	2F	2F	2F	1F	1F	00	00	00	1F	MODE
			5	23	14	14	14	2	2	0	0	0	2	ANGLE
16	21.0	17.8	-84	-0	25	38	43	43	47	0	0	0	50	DBU
17	19.5	16.6												
			2F	2F	2F	2F	1F	1F	00	00	00	00	1F	MODE
			14	14	14	14	2	2	0	0	0	0	2	ANGLE
18	16.6	14.2	16	33	42	49	43	47	0	0	0	0	48	DBU
19	13.5	11.5												
			2E	2F	2F	1F	00	00	00	00	00	00	1F	MODE
			5	14	14	2	0	0	0	0	0	0	2	ANGLE
20	11.8	10.1	29	38	45	41	0	0	0	0	0	0	44	DBU
21	10.8	9.2												
			2E	2F	1F	00	00	00	00	00	00	00	1F	MODE
			5	16	3	0	0	0	0	0	0	0	3	ANGLE
22	9.8	8.3	29	39	37	0	0	0	0	0	0	0	42	DBU
23	9.7	8.3												
			2F	2F	1F	00	00	00	00	00	00	00	1F	MODE
			17	17	4	0	0	0	0	0	0	0	4	ANGLE
24	10.1	8.6	29	40	39	0	0	0	0	0	0	0	44	DBU

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

2 JAN SSN= 25. GC 2.016

TRANSMITTER	RECEIVER	BEARINGS		N.MILES
51.50N - 0.01W	27.92N - 15.67W	212.5	22.2	1581.3

RHOMBIC 23H 96L 67DEG NOISE= 3 RHOMBIC 20H 114L 70DEG

PWR= 30.00KW OPERATING FREQUENCIES REQ.S/N= 45DB

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

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

1 JAN SSN= 25. BR 32.007

TRANSMITTER RECEIVER BEARINGS N.MILES

40.75N - 73.93W 32.33N - 64.70W 135.8 321.3 672.5

RHOMBIC 32H 118L 63DEG NOISE= 3 ANT= 3DB

PWR= 20.00KW RELIABILITIES REQ.S/N= 45DB

GMT	MUF	FOT	3	5	7	9	11	13	15	20	25	30	FOT	MCS
2	5.2	4.4	99	0	0	0	0	0	0	0	0	0	99	
4	5.4	4.6	99	0	0	0	0	0	0	0	0	0	99	
6	5.7	4.9	99	0	0	0	0	0	0	0	0	0	99	
8	5.5	4.7	99	0	0	0	0	0	0	0	0	0	99	
10	4.9	4.2	99	0	0	0	0	0	0	0	0	0	99	
12	7.4	6.9	99	99	0	0	0	0	0	0	0	0	99	
14	11.4	10.6	0	99	99	99	0	0	0	0	0	0	99	
16	11.8	11.8	0	97	99	99	99	0	0	0	0	0	99	
18	11.5	11.5	0	98	99	99	99	0	0	0	0	0	99	
20	11.7	9.9	32	99	99	99	0	0	0	0	0	0	99	
22	9.7	8.2	99	99	99	0	0	0	0	0	0	0	99	
24	6.5	5.5	99	99	0	0	0	0	0	0	0	0	99	

2 JAN SSN= 25. GC 2.016

TRANSMITTER RECEIVER BEARINGS N.MILES

51.50N - 0.01W 27.92N - 15.67W 212.5 22.2 1581.3

RHOMBIC 23H 96L 67DEG NOISE= 3 RHOMBIC 20H 114L 70DEG

PWR= 30.00KW RELIABILITIES REQ.S/N= 45DB

GMT	MUF	FOT	3	5	7	9	11	13	15	20	25	30	FOT	MCS
2	10.8	9.2	90	99	99	99	0	0	0	0	0	0	99	
4	9.9	8.4	90	99	99	0	0	0	0	0	0	0	99	
6	8.1	6.9	89	99	0	0	0	0	0	0	0	0	99	
8	12.9	11.0	0	98	99	99	0	0	0	0	0	0	99	
10	22.8	19.3	0	5	99	99	99	99	99	0	0	0	99	
12	23.7	20.2	0	0	81	99	99	99	99	99	0	0	99	
14	21.7	18.5	0	0	89	99	99	99	99	0	0	0	99	
16	21.0	17.8	0	23	99	99	99	99	99	0	0	0	99	
18	16.6	14.2	44	99	99	99	99	99	0	0	0	0	99	
20	11.8	10.1	83	99	99	99	0	0	0	0	0	0	99	
22	9.8	8.3	87	99	98	0	0	0	0	0	0	0	99	
24	10.1	8.6	89	99	99	0	0	0	0	0	0	0	99	

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

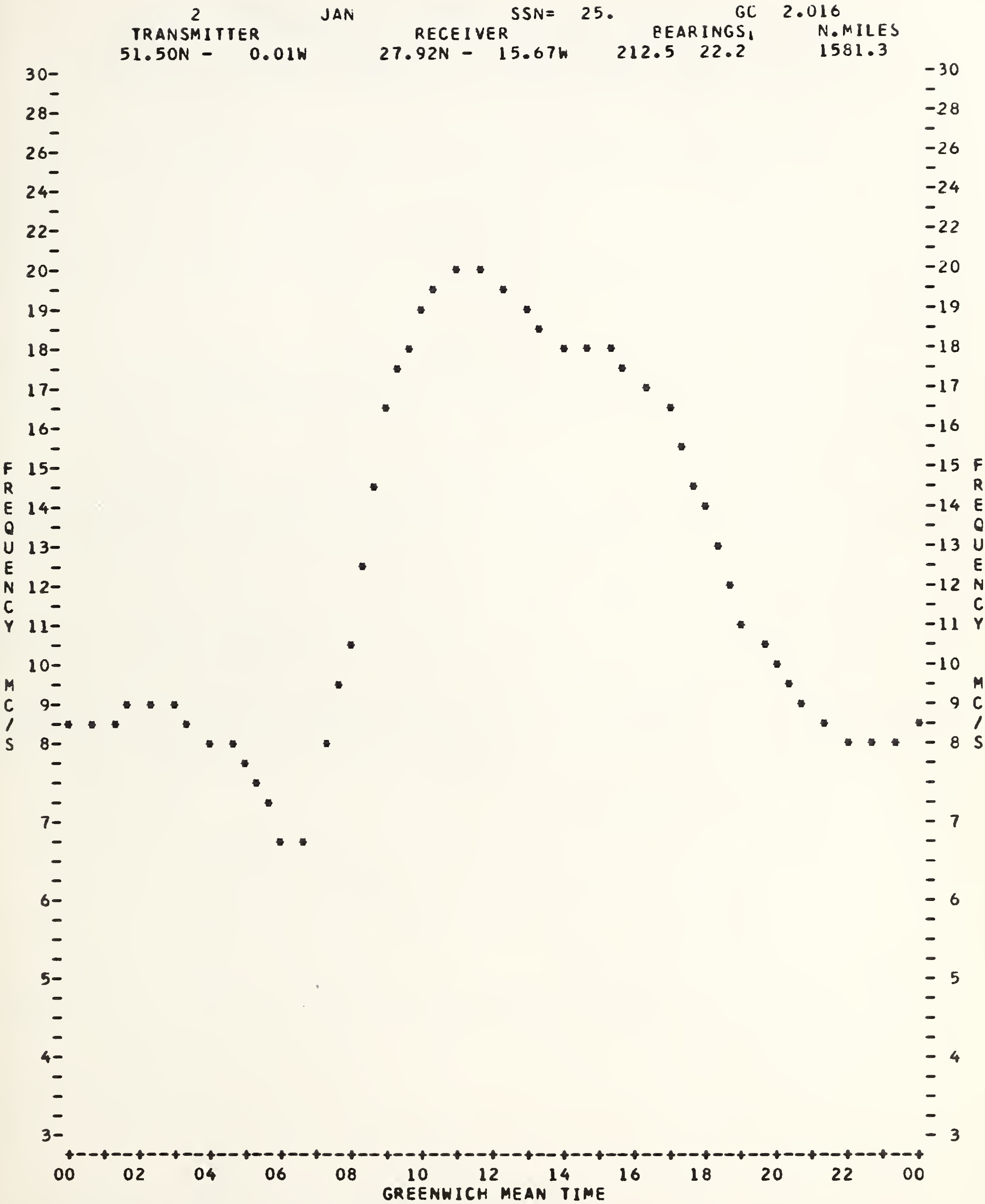


Figure 9. Graphical Representation of Circuit FOT

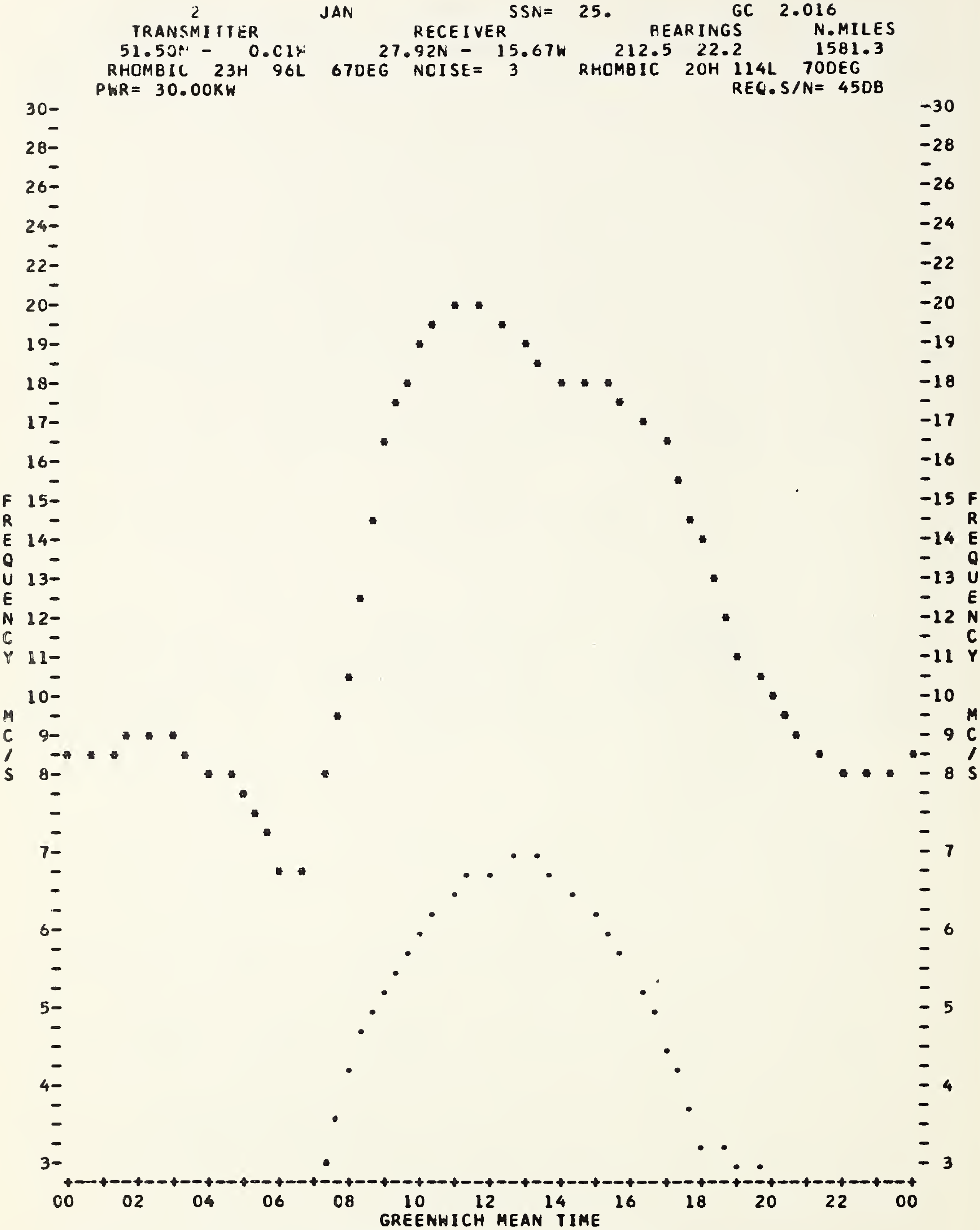


Figure 10. Graphical Representation of Circuit LUF and FOT

DATA FOR HIGH FREQUENCY COMMUNICATION PREDICTIONS

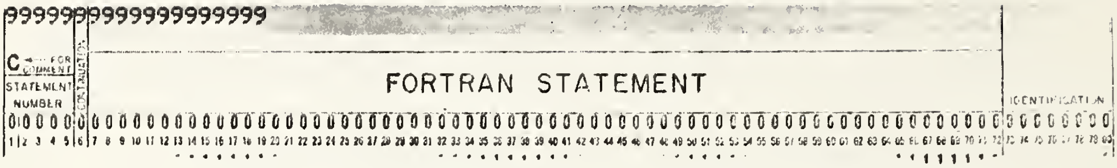
________________ To ________________ ________________

Transmitter Location | Receiver Location | Customer Circuit Number

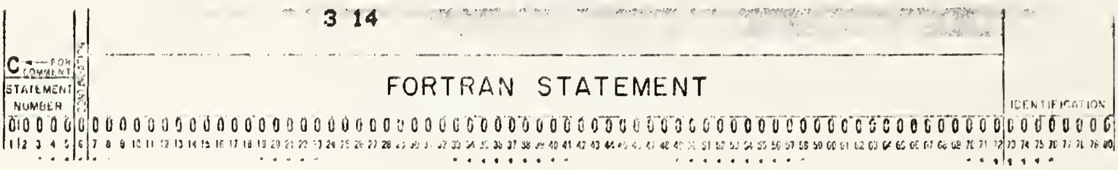
1. Transmitter Latitude (Degrees in Decimal Form) North = +; South = -	Degrees
2. Transmitter Longitude (Degrees in Decimal Form) West = +; East = -	Degrees
3. Receiver Latitude (Degrees in Decimal Form)	Degrees
4. Receiver Longitude (Degrees in Decimal Form)	Degrees
5. Power Delivered to Transmitting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

Figure 11

Nines Card



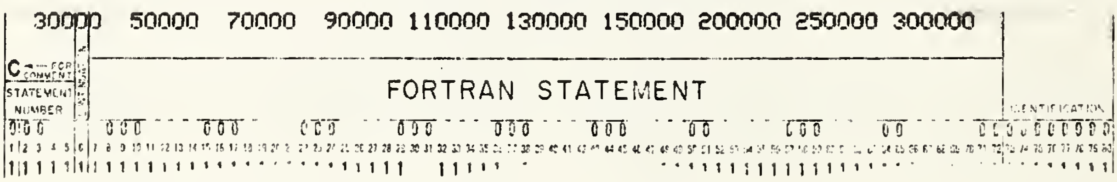
Month and Sunspot Card



Month = 3; Sunspot Number 14

Minus One Card

Frequency Complement Card

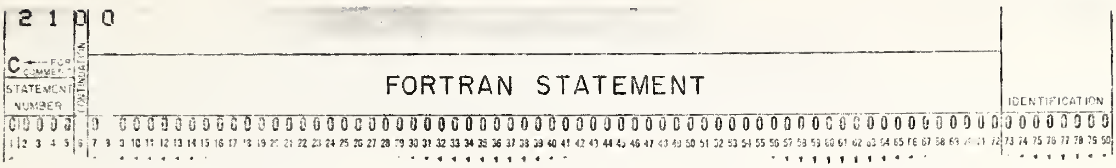


Frequencies = 3.0000, 5.0000 . . . . 30.0000

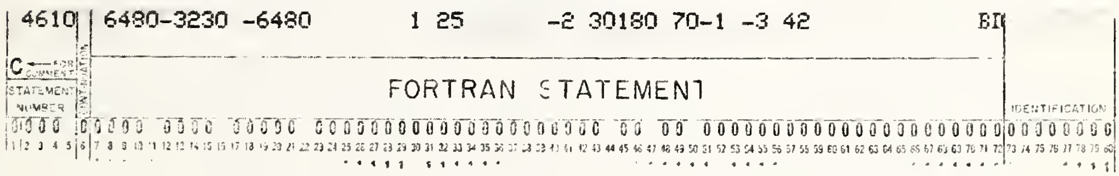
Note: This frequency card should contain only frequencies of the high frequency band (3-30 Mc/ s) unless fewer than ten frequencies are desired. In this case, enter 990000 in the unused fields at end of complement.

Figure 12

Example Method Card



Example Circuit Card



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

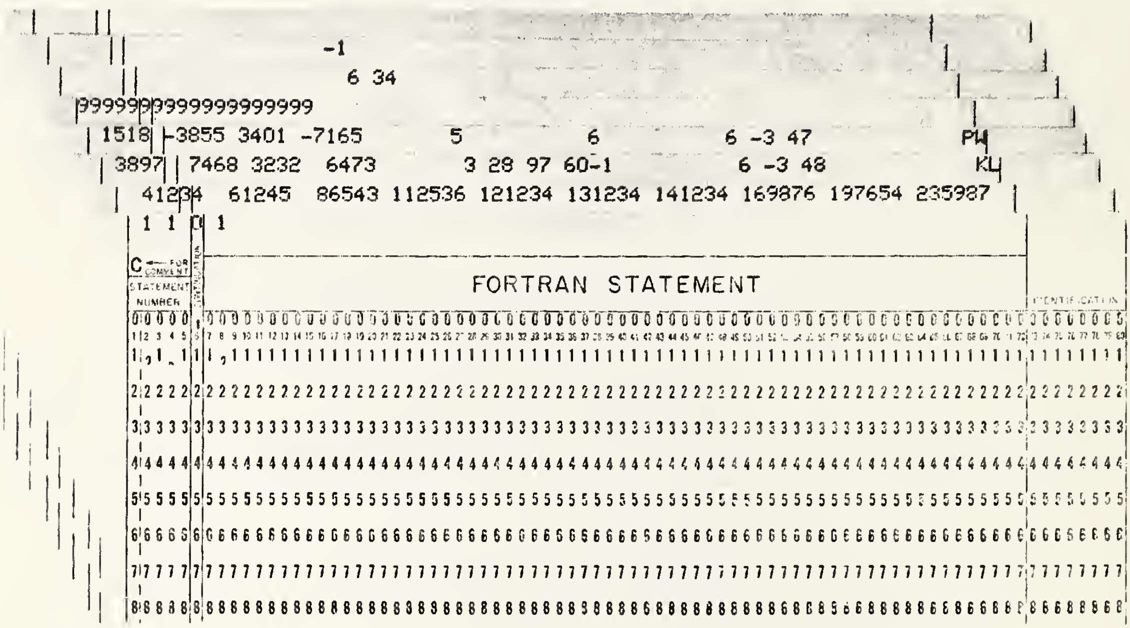


Figure 14

EXAMPLE DATA DECK FOR RUN UNDER TWO METHODS FROM CARD

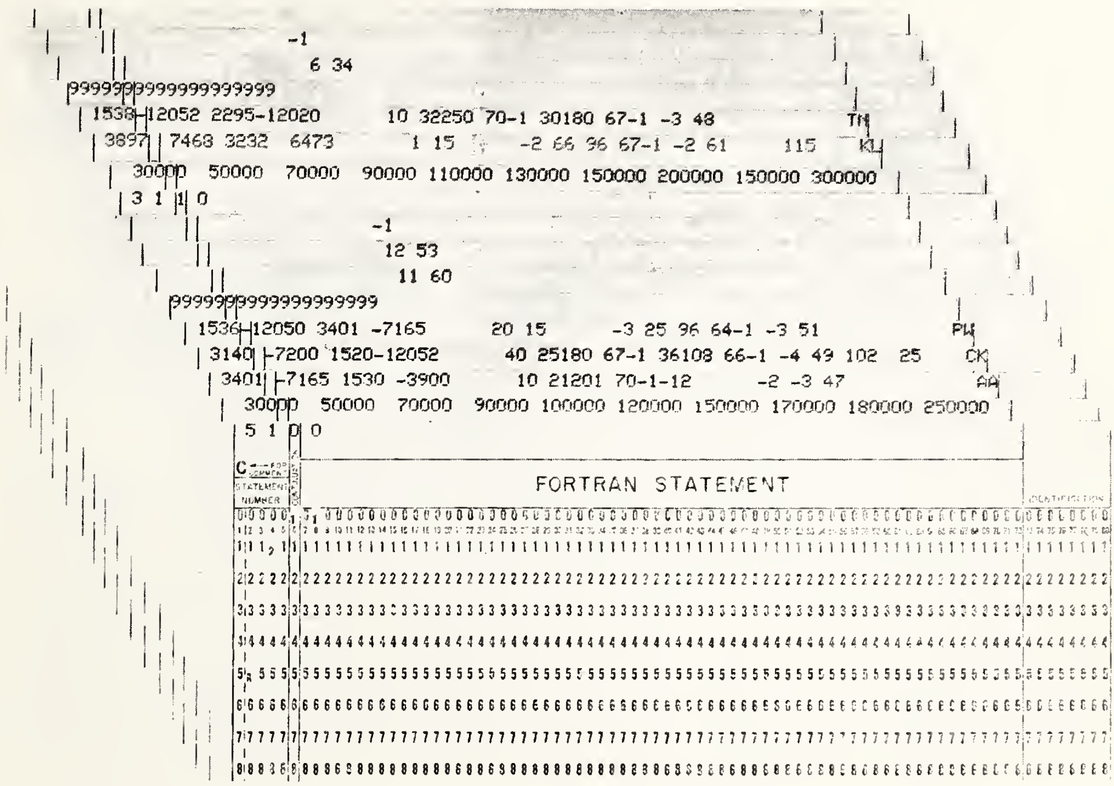


Figure 15

EXAMPLE DATA DECK FOR ONE METHOD
USING CIRCUITS FROM MAGNETIC TAPE

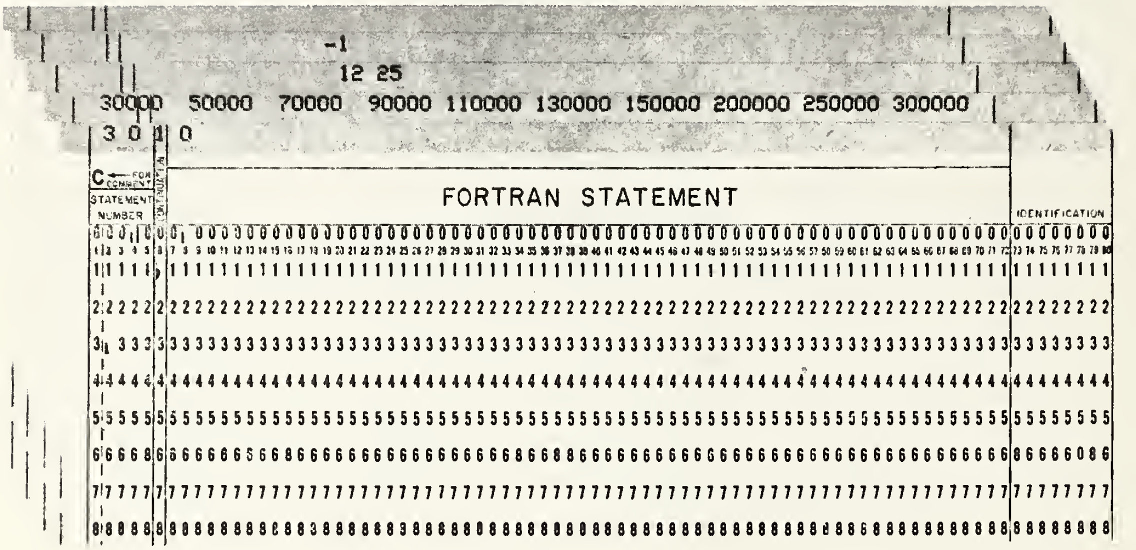


Figure 16

EXAMPLE HF PREDICTION DECK TO EXECUTE UNDER IBM-7090 FORTRAN MONITOR

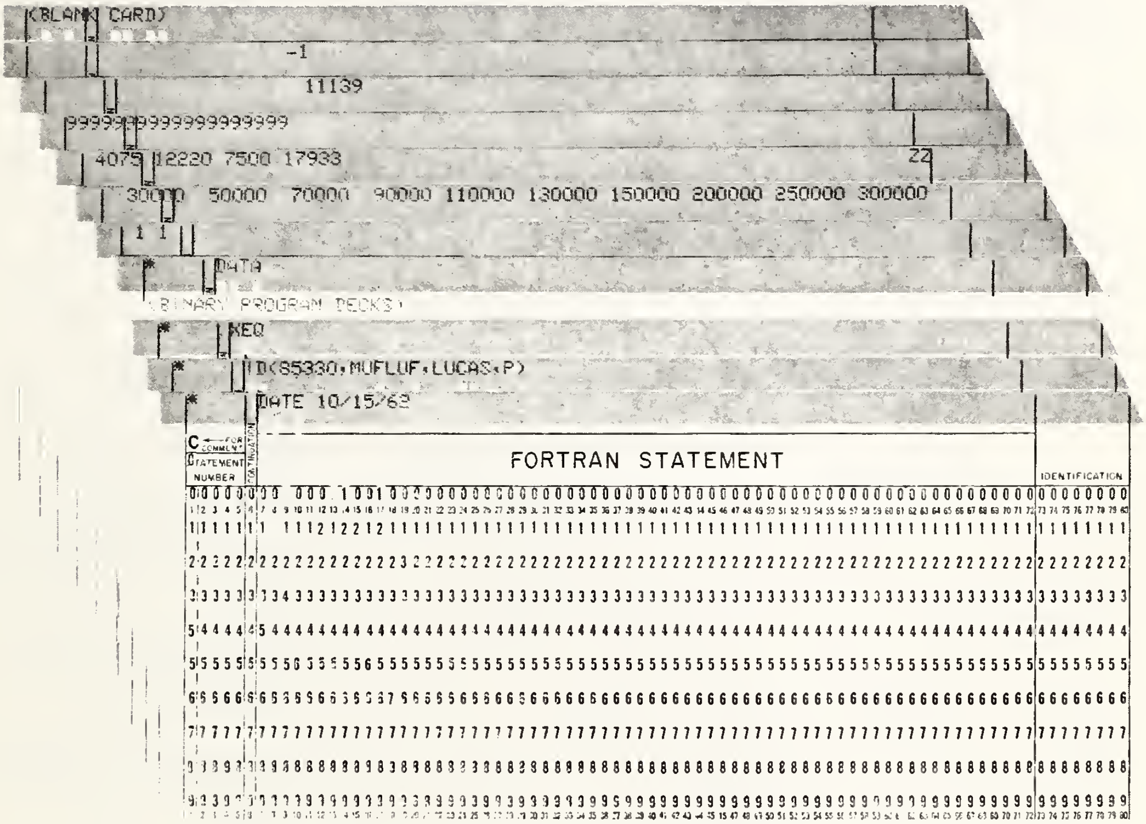


Figure 17

VII. PROGRAM OUTPUT

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

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

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

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

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

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

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

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

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

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

H - height in meters

L - leg length in meters

Deg = tilt angle in degrees

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

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

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

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

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

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

14. Greenwich mean time. Sample: GMT

15. Maximum Usable Frequency. Sample: MUF

16. Optimum Traffic Frequency. Sample: FOT

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

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

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

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

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

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

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

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

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

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

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

```
C  MUFLUF....H-F PREDICTIONS BY D.L.LUCAS AND G.W.HAYDON ......CRPL.....
C     FORMATS  AND  STORAGE  ASSIGNMENTS
    6 FORMAT(10F7.4)
    1 FORMAT(2(F5.2,F6.2),I2,5F3.0,I2,3F3.0,I2,I3,F3.0,2F4.0,4X,A2)
    3 FORMAT(10X,I5,10X,A6,         10X,4HSSN=F5.0,10X,A2,F7.3/9X,   11HTR
     2ANSMITTER,13X,8HRECEIVER,12X,8HBEARINGS,6X,7HN.MILES/7X  ,F6.2,A1,
     32H - ,F7.2,A1,5X,F6.2,A1,2H - ,F7.2,A1,3X,2F6.1,4X,F8.1)
    4 FORMAT (F10.0)
    5 FORMAT(4I2)
  676 FORMAT(12A6)
    7 FORMAT(1X/6X,
     43HGMT,2X,3HMUF,3X,3HFOT,3(5X,3HGMT,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)
      DIMENSION  AMON(12),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)
     2,ELD(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),JL(4),KL(4),LK(4),JAL(4) ,CKC(24)
     1,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)
     5,IG(24)
      DIMENSION UF(24),FOT(24),P(29,16,6),ABP(2,6)
      DIMENSION AHA(2),ARA(2),AVA(2)
      DIMENSION X1XX(12)
      DIMENSION 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,EEK,GLT,GLG,AAA,ALA,ASA,
     3AFC,ANC,AWC,AEC,ASC,AZZ,MAN,RSN,KW,PWR,IANT,IANR,Y2,X2,MOUSE,SSN,
     4NOCIR,K4,  AX,XLONG,AL,YLAT,XLAT,YLONG,YL,BTRY,GCDKM,GCDNM,K1,K2,K
     53,K5,GCD,IRSN,MON,ID,MOUSE,AY,METHOD,AHA,BMONS,MAP
      COMMON FREL
      COMMON XNH,XNL,XND,RNH,RNL,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
```

```
C       CONSTANTS TO BE USED FREQUENTLY
        AK=1.745329E-2
        BK=5.729577E1
        CK=1.11136E2
        DK=.0062137
        PI2=1.57079
        EK=.539956
        EEK=.6214
        GLT=78.*AK
        GLG=70.*AK
B       AMON(1)=412145606060
B       AMON(2)=262522606060
B       AMON(3)=442151606060
B       AMON(4)=214751606060
B       AMON(5)=442170606060
B       AMON(6)=416445606060
B       AMON(7)=416443606060
B       AMON(8)=216427606060
B       AMON(9)=622547606060
B       AMON(10)=462363606060
B       AMON(11)=454665606060
B       AMON(12)=242523606060
B       AAA=606060606060
B       AFC=266060606060
B       AHA(1)=606060603040
B       AHA(2)=243147464325
B       AVA(1)=606060606525
B       AVA(2)=516331232143
B       ARA(1)=606060606051
B       ARA(2)=304644223123
B       AZZ=006060606060
B       ANC=456060606060
B       AWC=666060606060
B       AEC=256060606060
B       ASC=626060606060
B       FNINE=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.
C     READ CIRCUIT DATA AND SEARCH DATA TAPE
      WRITE OUTPUT TAPE 6,909
  464 READ INPUT TAPE 5,5,
     1        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 5,676,X1XX
      WRITE OUTPUT TAPE 3,676,X1XX
      IF(FNINE-X1XX(1)) 7770,7771,7770
 7771 REWIND 3
   85 READ INPUT TAPE 5,1,
     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
      IANR=IRANT
      MAN=MANN
      RSN=RRSN
      IRSN=RSN
      PWR=TWR
      XNH=XNHO
      XNL=XNLO
      XND=XNDO
      RNH=RNHO
      RNL=RNLO
      RND=RNDO
      HA=HAO
      IF(MONS) 464,11,82
   82 LOCK= MONS-MONTH-1
      SSN=SUNS
      MONTH=MONS
      MOUSE=MONS
      KZ=1
      READ INPUT TAPE3,1,X1X,Y1Y,X2X,Y2Y,MONS,SUNS,TWR,XNHO,XNLO,XNDO,
     1ITANT,RNHO,RNLO,RNDO,IRANT,MANN,RRSN,XETA,WETA,HAO
      GO TO 10
   11 GO TO (15,77),KZ
   15 NOCIR=0
      WRITE OUTPUT TAPE 6,909
   62 JIG=0
      MIT=1
      KZ=2
      IF(LOCK) 77,731,33
   33 DO730  IU=1,LOCK
  730 READ TAPE 2
  731 READ TAPE 2,IL,JL,KL,LK,JAL,Q,A,P,ABP
   77 READ INPUT TAPE3,1,X1X,Y1Y,X2X,Y2Y,MONS,SUNS,TWR,XNHO,XNLO,XNDO,
     1ITANT,RNHO,RNLO,RNDO,IRANT,MANN,RRSN,XETA,WETA,HAO
      IF(91.-X1X) 78,78,16
   78 REWIND 3
      READ INPUT TAPE 5,1,
     1         X1X,Y1Y,X2X,Y2Y,MONS,SUNS,TWR,XNHO,XNLO,XNDO,ITANT,RNHO,RN
     1LO,RNDO,IRANT,MANN,RRSN,XETA,WETA,HAO
      IF(MONS)  83,16,83
```

```
   83 IF(MONS-MONTH)  84,16,16
   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=.5*(PI2-XX2+PI2-XX1+GCD)
      CIND=SINF(U)*SINF(U-PI2+XX2)
      IF(CIND) 57,778,57
   57 XTR=114.5816*ATANF(SQRTF(ABSF(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
   41 K1=1
      K2=1
      K3=1
      K4=1
      K5=1
C     CONTROL POINT LOCAL TIME , GEOGRAPHIC LATITUDE AND LONGITUDE
   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)
     1*SINF(PI2-XX2)*COSF(BTRY*AK)
```

```
      CENLAT=(PI2-ACOSF(CENLAT))*BK
      CENLG=     ((COSF(PP)-COSF(PI2-XX2)*COSF(PI2-CENLAT*AK))/(SINF(PI2
     1-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)*
     1COSF(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.+.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)
C     E-LAYER DISTANCE FACTOR
      ARC=DK*GCDKM
      IF(16.-ARC) 88,87,87
   87 ELFC=((((((-4.368460907E-9*ARC+1.334494261E-7)*ARC-5.976618436E-6)
```

```
     1*ARC+2.624808315E-4)*ARC-5.038476266E-3)*ARC+3.761385053E-2)*ARC-1
     2.133200756E-2)*ARC+.2085
      GO TO 100
   88 ELFC=1.02
C     E-2000 CONTROL POINT MUF
  100 EMC=(((-10.66484998*ABIC+39.26151056)*ABIC-52.41191754)*ABIC+37.67
     1726072)*ABIC+3.345996232
      EMF(II,IT)=EMC
 2112 EMUFY(II,IT)=EMC*ELFC
C     GENERATE CONTROL POINT FOF2 AND M-3000 FACTORS
      DO 1112 II=K2,K3
  504 CENLG=CLONG(II)
      CENLAT=CLAT(II)
      IF(CENLG) 412,414,414
  414 CLG=360.-CENLG
      GO TO 413
  412 CLG=ABSF(CENLG)
  413 BOY=SINF(CLG*AK)
      COG=SINF(2.*CLG*AK)
      DOG=COSF(2.*CLG*AK)
      GOB=COSF(CENLAT*AK)
      BOG=SINF(CENLAT*AK)
      HOG=COSF(CLG*AK)
      DO 500 IO=1,4
  415 I=IL(IO)
      J=JL(IO)
      K=KL(IO)
      L=LK(IO)
      JA=JAL(IO)
      DO 408 KA=1,K
      KP=KA-1
  408 G(KA)=BOG**KP
      LA=0
      LO=L-1
      KK=K+1
      DO 409 KA=KK,LO,2
      G(KA)=BOG**LA*GOB*HOG
      G(KA+1)=BOG**LA*GOB*BOY
  409 LA=LA+1
      LB=0
```

```
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,I
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,I
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 CLCK(II,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(1)
    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.
    GY(II)=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.-ARC) 157,157,158
  157 FLFC=1.
      GO TO 159
  158 FLFC=((((((-6.712654756E-9*ARC+4.49151441E-7)*ARC-9.985831104E-6)*
     1ARC+6.865259817E-5)*ARC+9.202437332E-5)*ARC+2.264634341E-3)*ARC+4.
     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))
      GML(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)=EMUFY(IR,IT)
 1009 FOTFY=.85*FMUFY(II,IT)
      IF((EMUFY(IR,IT)-FOTFY)) 1010,1011,1011
 1010 FOTY(II)=FOTFY
      GO TO 1000
 1011 FOTY(II)=EMUFY(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,
     1YLAT,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),
     1F2S(5,24),F2H(5,24),GML(5,24),GMH(5,24),MF(3),ME(2),ELL(10),FLL(10
     2),ELD(10),EDEL(10),FLD(10),FDEL(10),F24(5),GMA(5),FLF(10),FSKY(10)
     3,ESKY(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 Q(20,60,4),IL(4),JL(4),KL(4),LK(4),JAL(4) ,CKC(24)
     1,G(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)
     5,IG(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)
      DIMENSIONNXLOS(11),NANGLE(11)
      DIMENSION TOP(4)
      DIMENSION IFR(10)
      DIMENSION 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,EEK,GLT,GLG,AAA,ALA,ASA,
     3AFC,ANC,AWC,AEC,ASC,AZZ,MAN,RSN,KW,PWR,IANT,IANR,Y2,X2,MOUSE,SSN,
     4NOCIR,K4,  AX,XLONG,AL,YLAT,XLAT,YLONG,YL,BTRY,GCDKM,GCDNM,K1,K2,K
     53,K5,GCD,IRSN,MON,ID,MOUSE,AY,METHOD,AHA,BMONS,MAP
      COMMON FREL
      COMMON XNH,XNL,XND,RNH,RNL,RND,HA,JIG,HAR,XTR,XETA,WETA,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,4HPWR=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,4HSSN=F5.0,10X,A2,F7.3/9X,   11HTR
     2ANSMITTER,13X,8HRECEIVER,12X,8HBEARINGS,6X,7HN.MILES/7X  ,F6.2,A1,
     32H - ,F7.2,A1,5X,F6.2,A1,2H - ,F7.2,A1,3X,2F6.1,4X,F8.1)
    4 FORMAT(6X,4HANT=I3,2HDB,13X,6HNOISE=I3,7X,2A6,1X,I3,1HH,1X,I3,1HL,
     11X,I3,3HDEG)
```

```
    9 FORMAT(4X,I3,2F6.1/20X,11(I3,A1),6H  MODE/20X,11I4,7H  ANGLE/4X,
     2I3,2F6.1,1X,11I4,13H  RELIABILITY)
   12 FORMAT(1X,A2,F7.3,I5,2F10.2)
   13 FORMAT(6X,4HANT=I3,2HDB,20X,6HNOISE=I3,20X,4HANT=I3,2HDB)
   14 FORMAT(6X,4HPWR=F6.2,2HKW,11X,21HOPERATING FREQUENCIES,10X,8HREQ.S
     1/N=I3,2HDB/5X,14HGMT  MUF   FOT,1X,10I4,4H FOT)
   29 FORMAT(4X,I3,2F6.1/20X,11(I3,A1),6H  MODE/20X,11I4,7H  ANGLE/4X,
     2I3,2F6.1,1X,11I4,9H  S/N..DB)
   34 FORMAT(6X,4HPWR=F6.2,2HKW,16X,13HRELIABILITIES,13X,8HREQ.S/N=I3,2H
     1DB/9X,14HGMT  MUF   FOT,1X,10I4,9H FOT  MCS)
    7 FORMAT                                                        (6X,
     43HGMT,2X,3HLUF,3X,3HFOT,3(5X,3HGMT,2X,3HLUF,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)
    8 FORMAT(31X,21HOPERATING FREQUENCIES/5X,14HGMT  MUF   FOT,1X,10I4,
     14H FOT)
   19 FORMAT(4X,I3,2F6.1/20X,11(I3,A1),6H  MODE/20X,11I4,7H  ANGLE/4X,
     2I3,2F6.1,1X,11I4,10H  LOSS..DB)
   59 FORMAT(4X,I3,2F6.1/20X,11(I3,A1),6H  MODE/20X,11I4,7H  ANGLE/4X,
     2I3,2F6.1,1X,11I4,5H  DBU)
   24 FORMAT(6X,4HPWR=F6.2,2HKW,42X,8HREQ.S/N=I3,2HDB)
   70 FORMAT(6X,3HGMT,2X,3HLUF,3X,3HFOT,3( 5X,3HGMT,2X,3HLUF,3X,3HFOT)/1
     1H04(4X,I3,6X,F6.1)/1H04(4X,I3,2F6.1)/1H04(4X,I3,6X,F6.1)/1H04(4X,I
     23,2F6.1)/1H04(4X,I3,6X,F6.1)/1H04(4X,I3,2F6.1)/1H A1)
   94 FORMAT(8X,I3,2F6.1,1X,11I4)
  907 FORMAT(1H0/1H0/1H0)
  908 FORMAT(1H )
  909 FORMAT(1H1)
      FREL(11)=500.
      FREL(12)=500.
      DO 6461 IA=1,10
 6461 IFR(IA)=FREL(IA)
C     BEARINGS OF RHOMBICS
      IF(XETA)  1320,1320,1321
 1321 XETA=ABSF(XETA-XTR)
      IF(XETA-180.) 1320,1320,211
  211 XETA=360.-XETA
 1320 IF(WETA) 1323,1323,1324
 1324 WETA=ABSF(WETA-BTRY)
      IF(WETA-180.) 1323,1323,210
```

```
 210 WETA=360.-WETA
1323 XQ=.001
     RQ=.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
     RO=6376.6
     KIP=1
     IF(MAP) 5612,5612,5613
5612 WRITE OUTPUT TAPE 6,3,
    1        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
  251 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, CLCK(II,IT) /10.-1.2,CLAT(II)/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)
```

```
      PI=IM
      FLD(IM)=GCDKM/PI
      FDEL(IM)=ATANF((COSF(GCD/(2.*PI))-RO/(RO+FL   ))/SINF(GCD/(2.*PI)))
     1*BK
      IF(FDEL(IM)) 932,931,931
  932 DO 1933 II=1,3
 1933 MF(II)=MF(II)+1
      GO TO 1934
  931 CONTINUE
      GO TO(933,934),K2
C     PENETRATION FREQUENCIES --E-REGION
  934 DZ=EMF(4,IT)
      DY=EMF(5,IT)
      IF(DZ-DY) 940,940,941
  940 ZR=DZ
      I2=2
      ZS=DY
      GO TO 939
  941 ZR=DY
      I2=3
      ZS=DZ
      GO TO 939
  933 ZR=EMF(1,IT)
      ZS=ZR
  939 DO 1663 II=1,10
      ELL(II)=0.
 1663 FLL(II)=0.
      DO 827 II=1,2
      IM=ME(II)
      ERCR(IM)=0.
      EXMT(IM)=0.
C     MODE ELIMINATION E AND F2 REGIONS
      ARZ=ELD(IM)*DK
      IF(16.-ARZ) 2900,2900,2901
 2900 ELFK=1.02
      GO TO 2902
 2901 ELFK=((((((-4.368460907E-9*ARZ+1.334494261E-7)*ARZ-5.976618436E-6)
     1*ARZ+2.624808315E-4)*ARZ-5.038476266E-3)*ARZ+3.761385053E-2)*ARZ-1
     2.133200756E-2)*ARZ+.2085
 2902 Y=ZR*ELFK+.05
```

```
      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 ELFK=1.02
      GO TO 2905
 2904 ELFK=((((((-4.368460907E-9*ARZ+1.334494261E-7)*ARZ-5.976618436E-6)
     1*ARZ+2.624808315E-4)*ARZ-5.038476266E-3)*ARZ+3.761385053E-2)*ARZ-1
     2.133200756E-2)*ARZ+.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))
      IF(S1-S2) 947,947,948
  947 R=S2
      GO TO 949
  948 R=S1
  949 DO 945 IK=1,3
      IM=MF(IK)
      IF(FLL(IM)) 508,508,945
  508 ARK=FLD(IM)*DK
      FLF(IM)=((((((-6.712654756E-9*ARK+4.49151441E-7)*ARK-9.985831104E-
     16)*ARK+6.865259817E-5)*ARK+9.202437332E-5)*ARK+2.264634341E-3)*ARK
     2+4.699243101E-3)*ARK
      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
      ESKY(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*ABI(IT)/(COSF(ASINF(RO*SINF(PI2+FDEL(IM)*AK)/(RO
     1+100.)))*(FREQ+1.12*GYR)**1.98)
      RS=IM
C     ANGLE AT IONOSPHERE
      PHE=RO*SINF(PI2+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.*LOG10F(FR)+20.*LOG10F(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,EDEL(IM),XETA,FREQ,XQ,XP,XND,XNL,XNH,EXMT(IM))
```

```
  182 CONTINUE
C       POWER GAIN OF TRANSMITTING ANTENNA
      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=XABSF(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)
C       RESPONSE OF RECEIVING ANTENNA
  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,FRCR(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,IANT,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,JND,MA,IANR
      GO TO 388
  232 WRITE OUTPUT TAPE 6,4,IANT,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=ABSF(GLAT(II))
      IF(RM-60.*AK) 331,331,332
  331 ID=1
      IF(ABIY(1,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(II)
  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)) 965,965,966
  965 FL1=FLL(LG)
      MDF=LG
      GO TO 967
  966 FL1=FLL(LH)
      MDF=LH
  967 IF(FL1-FLL(LJ)) 968,968,969
  968 FLOS=FL1
      GO TO 970
  969 FLOS=FLL(LJ)
      MDF=LJ
  970 IF(ELOS-FLOS) 971,971,972
  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+1.334494261E-7)*ARZ-5.976618436E-6)
     1*ARZ+2.624808315E-4)*ARZ-5.038476266E-3)*ARZ+3.761385053E-2)*ARZ-1
     2.133200756E-2)*ARZ+.2085
 3902 Y=ZS*ELFK
 4332 IF(Y-FREQ) 3903,3905,3905
 3903 NOS(NF)=1000.
      GO TO 612
 3905 Y=ZR*ELFK
      IF(Y-FREQ) 650,650,651
  651 NOS(NF)=1000.
      GO TO 612
  650 ARK=(GCDKM*DK-ARZ)/FHOP
      FLFK   =((((((-6.712654756E-9*ARK+4.49151441E-7)*ARK-9.985831104E-
     16)*ARK+6.865259817E-5)*ARK+9.202437332E-5)*ARK+2.264634341E-3)*ARK
     2+4.699243101E-3)*ARK
      REF=(FREQ-GMA(I2))/(F24(I2)-GMA(I2))
      IF(FLFK-REF) 652,653,653
  652 NOS(NF)=1000.
      GO TO 612
C     SKY WAVE ABSORPTION
  653 EFSKY=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.*LOG10F(FR)+20.*LOG10F(FREQ)
      GO TO (3180,3180,3180,3181),KAP
 3181 EFXMT=IANT
      GO TO 3182
C     POWER GAIN OF TRANSMITTING ANTENNA
 3180 CALL GAIN(KAP,EFDEL,XETA,FREQ,XQ,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)) 623,622,622
  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)=AZZ
      NANGLE(NF)=0
      MODE(NF)=0
      GO TO 8740
 6911 KAJ=1
      GO TO (6912,6912,6912,9779,6912,6912),METHOD
 6912 POR=10.*LOG10F(PWR*1000.)
      IF(JUG)3869,3869,8712
C     1MC/S ATMOSPHERIC NOISE DETERMINATION
 3869 CC=ÇKC(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(JK,X2,CEG,ATNY)
     ATNQ=(ATNO+(ATNY-ATNO)*(CC-TM)/4.)
     LOB=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
8716 LOB=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= (((((((.1095032130E-10*FREQ+.2442852795E-8)*FREQ-.15854096
     108E-5)*FREQ+.1513740543E-3)*FREQ-.6306642189E-2)*FREQ+.1390178355E
     2+0)*FREQ-.1701088795E+1)*FREQ+.1121130396E+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=ID+10
      GO TO (888,8733,8733,8733),ID
  888 IF(ABIY(1,IT)) 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),KAT
 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) 9777,9777,9778
C     FIELD STRENGTH
 9778 ALOSS=-NXLOS(NF)
      NXLOS(NF)=ALOSS+107.2+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 6,94,
    1          IG(IT),UF(IT),FOT(IT),NXLOS
     NIG=NIG+1
     GO TO (3214,3214,21),NIG
  21 WRITE OUTPUT TAPE 6,908
     NIG=0
     GO TO 3214
 250 GO TO (2250,2666),LZP
2250 WRITE OUTPUT TAPE 6,14,PWR,IRSN,IFR
2666 GO TO (2667,2667,2667,2667,2667,2668),METHOD
2668 WRITE OUTPUT TAPE 6,29,
    1          IG(IT-1),UF(IT-1),FOT(IT-1),(MODE(I),ABC(I),I=1,11),NANGLE
    2,IG(IT),UF(IT),FOT(IT),NXLOS
     GO TO 3214
2667 WRITE OUTPUT TAPE 6,9,
    1          IG(IT-1),UF(IT-1),FOT(IT-1),(MODE(I),ABC(I),I=1,11),NANGLE
    2,IG(IT),UF(IT),FOT(IT),NXLOS
     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 6,8,IFR
3215 IF(IHR) 69,69,77
  69 WRITE OUTPUT TAPE 6,19,
    1          IG(IT-1),UF(IT-1),FOT(IT-1),(MODE(I),ABC(I),I=1,11),NANGLE
    2,IG(IT),UF(IT),FOT(IT),NXLOS
     GO TO 3214
  77 WRITE OUTPUT TAPE 6,59,
    1          IG(IT-1),UF(IT-1),FOT(IT-1),(MODE(I),ABC(I),I=1,11),NANGLE
    2,IG(IT),UF(IT),FOT(IT),NXLOS
```

```
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),
     1F2S(5,24),F2H(5,24),GML(5,24),GMH(5,24),MF(3),ME(2),ELL(10),FLL(10
     2),ELD(10),EDEL(10),FLD(10),FDEL(10),F24(5),GMA(5),FLF(10),FSKY(10)
     3,ESKY(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 Q(20,60,4),IL(4),JL(4),KL(4),LK(4),JAL(4) ,CKC(24)
     1,G(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)
     5,IG(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)
      DIMENSIONNXLOS(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,EEK,GLT,GLG,AAA,ALA,ASA,
     3AFC,ANC,AWC,AEC,ASC,AZZ,MAN,RSN,KW,PWR,IANT,IANR,Y2,X2,MOUSE,SSN,
     4NOCIR,K4,  AX,XLONG,AL,YLAT,XLAT,YLONG,YL,BTRY,GCDKM,GCDNM,K1,K2,K
     53,K5,GCD,IRSN,MON,ID,MOUSE,AY,METHOD,AHA,BMONS,MAP
      COMMON FREL
      COMMON XNH,XNL,XND,RNH,RNL,RND,HA,JIG,HAR,XTR,XETA,WETA,IHR,MIT
      COMMON KAP,KUP,MA,TANT,INH,INL,IND,RANT,JNH,JNL,JND
   73 FORMAT(10X,4HANT=I3,2HDB,20X,6HNOISE=I3,20X,4HANT=I3,2HDB)
   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=I3,2HDB)
   74 FORMAT(10X,4HANT=I3,2HDB,13X,6HNOISE=I3,7X,2A6,1X,I3,1HH,1X,I3,1HL
     1,1X,I3,3HDEG)
   24 FORMAT(10X,4HPWR=F6.2,2HKW,42X,8HREQ.S/N=I3,2HDB)
    3 FORMAT(14X,I5,10X,A6,       10X,4HSSN=F5.0,10X,A2,F7.3/13X,  11HTR
     2ANSMITTER,13X,8HRECEIVER,12X,8HBEARINGS,6X,7HN.MILES/11X, F6.2,A1,
     32H - ,F7.2,A1,5X,F6.2,A1,2H - ,F7.2,A1,3X,2F6.1,4X,F8.1)
```

```
     2ANSMITTER,13X,8HRECEIVER,12X,8HBEARINGS,6X,7HN.MILES/11X, F6.2,A1,
     32H - ,F7.2,A1,5X,F6.2,A1,2H - ,F7.2,A1,3X,2F6.1,4X,F8.1)
   15 FORMAT(7X,73A1/6X,74H00     02      04      06      08      10      12      14
     1    16      18      20      22      00/34X,19HGREENWICH MEAN TIME)
    2 FORMAT(2X,A1,1X,A2,A1,73A1,A1,A2,1X,A1)
   25 FORMAT(1H1)
    1 FORMAT(1H )
      WRITE OUTPUT TAPE 6,3,
     1          NOCIR,BMONS,SSN,HA,HAR,XLAT,AX,XLONG,AL,YLAT,AY,YLONG,YL,
     2XTR,BTRY,GCDNM
      IF(METHOD-3) 4044,4045,4045
 4045 GO TO (330,330,330,1331),KAP
 1331 GO TO (232,232,232,233),KUP
  233 WRITE OUTPUT TAPE 6,73,IANT,MA,IANR
      GO TO 388
  330 GO TO (335,335,335,336),KUP
  335 WRITE OUTPUT TAPE 6,91,
     1          TANT,INH,INL,IND,MA,RANT,JNH,JNL,JND
      GO TO 388
  336 WRITE OUTPUT TAPE 6,72,
     1          TANT,INH,INL,IND,MA,IANR
      GO TO 388
  232 WRITE OUTPUT TAPE 6,74,
     1          IANT,MA,RANT,JNH,JNL,JND
  388 LIP=2
      WRITE OUTPUT TAPE 6,24,PWR,IRSN
 4044 J=0
      DO 303 I=1,24
      X=COT(I-1)
      IF(I-1)  202,203,202
  203 X=COT(24)
      ROT(1)=X
  202 XX=COT(I)
      DO 303 II=1,3
      J=J+1
      CEG=II
  303 ROT(J+1)=X+(XX-X)*CEG/3.
      IF(METHOD-3) 6402,6405,6402
 6405 J=0
      DO 808 I=1,24
```

```
      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(1)=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=1,73,3
B  20 XOB(I)=206060606060
      DO 30 I=1,55
B     BOB(I)=606060606060
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)=011260606060
B     COB(27)=010160606060
B     COB(29)=010260606060
B     COB(31)=010360606060
B     COB(33)=010460606060
B     COB(35)=010560606060
B     COB(37)=010660606060
B     COB(39)=010760606060
B     COB(41)=011060606060
```

```
B       COB(43)=011160606060
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-20.) 4,4,63
   63   WOB=1.
        GO TO 5
    4   IF(ZOB-8.) 4062,4062,4063
 4063   WOB=.5
        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)-ZOB) 66,38,38
   38 SOB=ZOB+WOB
      IF(WOT(IT)-SOB) 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*.01745329252
      RELTA=DELTA*.01745329252
      GO TO (6,7,6),KOP
    6 T=COSF(RELTA)
      RETA=BETA*.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(AL
     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*U
     12)*SINF(FAC*U2)*(CH*CH+1.-2.*CH*COSF(PSIH-(12.56637062*H)/WAVE*Q))
     2)/(U1*U1*U2*U2)*(COSF(RETA)-SINF(RHI)*T)*(COSF(RETA)-SINF(RHI)*T)
      ROK=3.
      GO TO 4
    3 RAIN=(.5562474*COSF(1.570796*T)*COSF(1.570796*T)*(CH*CH+1.-2.*CH*C
     1OSF(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=INTF(ABSF(H)/10.)
   IF(EN) 50,51,50
51 H1=ABSF(H)
   GO TO 52
50 H1=EN/(ABSF(H) -10.*EN)
52 A=H1*6.283185
   X=H1
25 D=2.*A
   ROK=+5.
   Z=2.*D
   W=CI(Z,W1)
   W2=CI(D,W3)
   RA=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=4.342944819*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+
     1U*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=.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.
      IF(ABSF(TERM2/C)-10.E-10)65,65,63
   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
```

```
67 D=D+TERM2
   T=T+1.
   IF(ABSF(TERM2/D)-10.E-10)70,70,68
68 TERM1=TERM2
   GO TO 66
69 SD=2.*T+1.
   THETA=X-SD
   PI=.5-(1.-2.*THETA)/(4.*SD)+(1.-4.*THETA-2.*THETA*THETA)/(8.*SD*SD
  1)+(3.+18.*THETA+8.*THETA*THETA)/(16.*SD*SD*SD)
   D=D+TERM2*PI
70 CX=COSF(X)
   SX=SINF(X)
   CI=(C*SX-D*CX)/X
   SI=1.570796327-(C*CX+D*SX)/X
80 RETURN
   END
```

```
      SUBROUTINE LOSS(RELTA,ER,FREQ,SIGMA,Y)
      GROUND REFLECTION LOSS
      DELTA=RELTA*.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(AL
     1PHA*.5))
   50 CV=SQRTF(RHO*RHO+U*U*S-2.*RHO*U*R*COSF(ALPHA+2.*ASINF(X/V)))/(RHO+
     1U*R+2.*RHO12*V*Q*COSF(ALPHA*.5+ASINF(X/V)))
      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
   55 SX=SS
   56 ZZ(J)=R+P(J,16,KJ)
      Q=.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
   57 SX=SS
      ATNO=R+ALF+BET*Q
      RETURN
      END
```

IX. MATHEMATICAL EXPRESSIONS

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

$$\cos(gcd) = \sin(x1) \cdot \sin(x2) + \cos(x1) \cdot \cos(x2) \cdot \cos(y2 - y1)$$

gcd = great circle distance - degrees

x1 = transmitter latitude - degrees

y1 = transmitter longitude - degrees

x2 = receiver latitude - degrees

y2 = receiver longitude - degrees

2. Bearing from receiver to transmitter, degrees east of north. ($0 \leq btry \leq 360°$).

$$btry = 114.5816 \cdot \tan^{-1} \sqrt{\left| \sin(u-90+x2) \cdot \sin(u-gcd) \right| / cind}$$

$$u = (180. - x1 - x2 + gcd)/2$$

$$cind = \sin(u) \cdot \sin(u - 90 + x1)$$

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

$$x'1 = \cos(pp) \cdot \cos(90 - x2) + \sin(pp) \cdot \sin(90 - x2) \cdot \cos(btry)$$

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

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

4. Geographic longitude of control points along great circle route. ($y = y2 - y'$)

$$y' = \arccos \left[\cos(pp) - \cos(90 - x2) \cdot \cos(90 - x3) / \sin(90 - x2) \cdot \sin(90 - x3) \right]$$

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.

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

   ψ = sun's zenith angle - degrees

   z = control point latitude - degrees

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

   GMT - Greenwich mean time - hours

8. Ionospheric absorption index "I"

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

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

9. E-layer distance factor.

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

x = great circle distance - hundreds of statute miles

10. E-2000 MUF.

$$emc = 3.345996232 + 37.67736072 \cdot I - 52.41191754 \cdot I^2 + 39.26151056 \cdot I^3 - 10.66484988 \cdot I^4$$

I = absorption index

11. E-layer MUF.

emufy = (emc) · (elfc)

emc = E-2000 MUF

12. F-layer distance factor.

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

x = great circle distance - hundreds of statute miles

13. F2-layer Fourier generation of foF2 and M-3000 factors. Fourier time variation function, used to obtain foF2 or M-3000 factor:

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

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

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

x = geographic latitude of control point - degrees ($-90° \leq x \leq 90°$)

y = geographic longitude of control point - degrees ($0° \leq x \leq 360°$ - East of North)

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

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 $\Gamma(x,y,t)$ (Time variation)

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

For a detailed explanation of the generation of $\Gamma(x,y,t)$ refer to [Jones and Gallet, 1961]. The above formulas and constants have been altered from the originals in the reference to make the generation permissible on a larger variety of computers.

Table 1. Geographical Function in Latitude

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

Table 2. Geographical Functions in Latitude and Longitude.

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

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

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

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

y = gyro frequency of F2 layer - Mc/s

x = longitude of control point - degrees

z = latitude of control point = degrees

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

15. F2-4000 MUF.

F2-4000 MUF = (foF2) x (M-4000 factor)

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

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

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

M-4000 factor = (1. 1) · M-3000 factor

17. Interpolation for intermediate values of solar activity. $(10 \leq \text{SSN} \leq 180)$

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

$\text{F - MUF}_{(\ell)}$ = F-MUF for SSN 10

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

18. Angle at the ionosphere (ϕ).

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

ϕ' = angle of incidence - degrees

p = radius of earth - km

A' = great circle distance - degrees

H_ℓ = layer height - km

19. Ionospheric absorption

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

ϕ = angle of incidence for 100 km - degrees

f = operating frequency

I = absorption index

f_g = gyro frequency - Mc/s

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

$$L_{bf} = 10 \log_{10} (p_r/p_a) = 10 \log_{10} (4 \pi d/\lambda)^2$$

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

p_r = power available at receiving antenna

p_a = power delivered to transmitting antenna

d = ray path distance - miles

λ = wave length

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

21. Relationship between ϕ' and Δ.

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

ϕ' = angle of incidence at ionosphere

p = radius of earth

H_ℓ = 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,

$$x = \frac{\sigma}{\omega \epsilon_\nu} \simeq 18 \times 10^3 \sigma / f,$$

σ = conductivity of earth (mhos/meter),

ω = angular frequency,

f = frequency in megacycles,

Δ = angle of elevation in degrees, and

i = $\sqrt{-1}$.

ϵ_r = dielectric constant of free space

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

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

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

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

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

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

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

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

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

Δ = angle of departure in degrees,

β = angle of azimuth in degrees,

ℓ = rhombic leg lenth in meters,

h = antenna height in meters,

ϕ = tilt angle in degrees.

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

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

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

$$\psi_H = \tan^{-1}\left[\frac{2p^{\frac{1}{2}} \,.\, \sin\Delta \,.\, \sin\frac{\alpha}{2}}{p - \sin^2\Delta}\right]$$

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

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

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

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

ϵ_r = relative dielectric constant of the ground

σ = conductivity of the ground in mhos per meter

f = operating frequency in megacycles per second

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

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

24. Power gain of half-wave horizontal dipole.

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

$$\left. \cdot \left(\psi_H - \frac{4\pi H}{\lambda} \cdot \sin \Delta\right) \right\}$$

K_H = amplitude of horizontal reflection coefficient

ψ_H = phase amplitude of horizontal reflection coefficient

H = height of antenna - meters

λ = 299.7925/frequency in megacycles

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

Δ = angle of elevation

Note: 72 ohms assumed impedance of antenna

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

25. Power gain of vertical antennas

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

$$\left. - 2 \cdot K_V \cos (\psi_V - 2A \cdot \sin \Delta \right\}$$

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

$$+ \left\{ 1 + \cos (2A) \right\} \times \left\{ C + \ln (2A) - C_i (2A) \right\}$$

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

C = . 5772156649

H = height of antenna - meters

Si = sine integral

Ci = cosine integral

$A = 2 \pi H/\lambda$

26. Efficiency factor for short vertical antennas.

$$EFF = 25.64620146 - 364.8173803\, x + 2179.890548\, x^2 - 6091.333295\, x^3 + 6416.702573\, x^4$$

x = wave length of antenna

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

27. Ground reflection loss.

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

28. Relationship of field strength to transmission loss. (Decibels above isotropic)

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

f_{mc} = frequency - Mc/ s

L_b = transmission loss - decibels

X. GENERALIZED BLOCK DIAGRAM OF HF SYSTEM PERFORMANCE ROUTINE

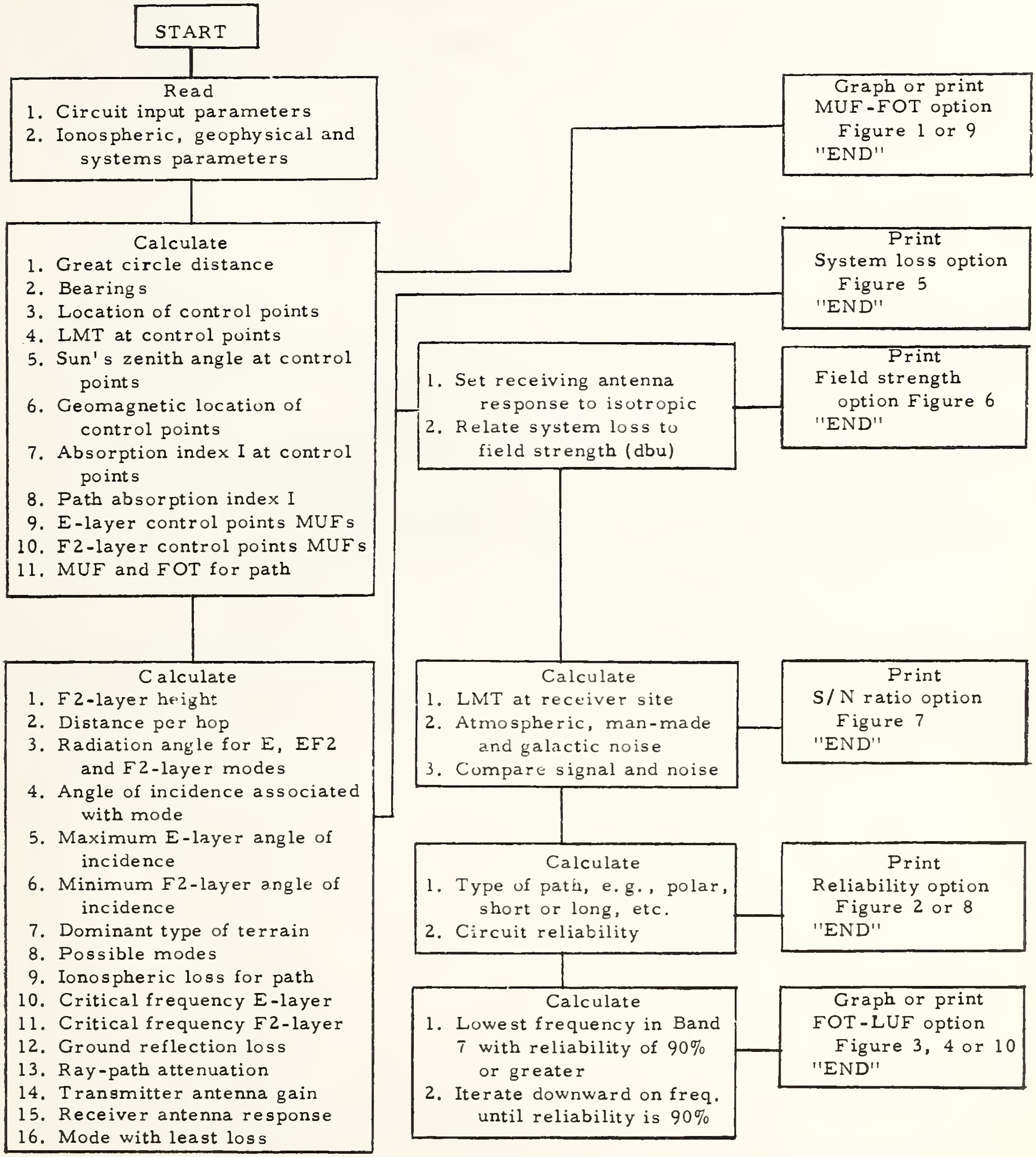


Figure 18

XI. CONCLUSIONS

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

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

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

XII. ACKNOWLEDGEMENT

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

XIII. REFERENCES

Chrisman, Mary E., and Charles D. Stearns, Computation and plotting of rhombic antenna gains using electronic digital computers, NBS Report 7235 (March 13, 1962).

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

Duncan, David B., and John F. Kenney, On the solution of the normal equation and related topics, Edwards Bros., Inc., Ann Arbor, Michigan (1946).

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

Jones, W. B., and R. M. Gallet, Numerical mapping in geophysics II. Methods for applying numerical maps of the ionosphere, NBS Report 6755 (March 8, 1961).

Laitinen, Paul O., Linear communication antennas, U. S. Army Signal Radio Propagation Agency, Technical Report No. 7 (May 1949).

Laitinen, Paul O., and George W. Haydon, Analysis and prediction of sky-wave field intensities in the high frequency band, Technical Report No. 9, U. S. Army Signal Radio Propagation Agency (March 1950).

Lucas, Donald L., and George W. Haydon, MUF-FOT predictions by electronic computers, NBS Report 6789 (August 13, 1961).

Lucas, Donald L., and John D. Harper, Jr., A numerical representation of atmospheric radio noise in band 7 (to be published) (1962).

McCracken, Daniel D., A guide to Fortran programming (Wiley and Sons, New York, N. Y., April 1962).

NBS Circular No. 462, Ionospheric radio propagation (June 25, 1948).

NBS CRPL Series D, Basic radio propagation.

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

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

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

THE NATIONAL BUREAU OF STANDARDS

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

WASHINGTON, D. C.

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

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Volume.

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

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

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

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

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

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

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

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

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

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

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

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

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

Office of Weights and Measures.

BOULDER, COLO.

CRYOGENIC ENGINEERING LABORATORY

Cryogenic Processes. Cryogenic Properties of Solids. Cryogenic Technical Services. Properties of Cryogenic Fluids.

CENTRAL RADIO PROPAGATION LABORATORY

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

Troposphere and Space Telecommunications. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Spectrum Utilization Research. Radio-Meteorology. Lower Atmosphere Physics.

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

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

RADIO STANDARDS LABORATORY

Radio Standards Physics. Frequency and Time Disseminations. Radio and Microwave Materials. Atomic Frequency and Time-Interval Standards. Radio Plasma. Microwave Physics.

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

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

DEPARTMENT OF COMMERCE ★ NATIONAL BUREAU OF STANDARDS ★