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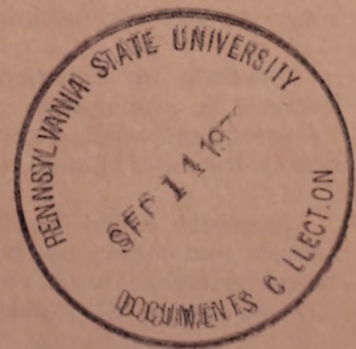
U.S. DEPARTMENT OF COMMERCE
Environmental Science Services Administration
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The Basis and Application of a Simulation Model for an Oceanographic Data Transmission System Using HF Radio

DALE N. HATFIELD

JEAN E. ADAMS

BOULDER, COLO.
JUNE 1970



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FOREWORD

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1. The first part of the report is a general
 introduction to the subject of the study.
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 3. The third part is a description of the
 results of the study.
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 5. The fifth part is a conclusion of the
 study.
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THE BASIS AND APPLICATION OF A SIMULATION MODEL FOR AN OCEANOGRAPHIC DATA TRANSMISSION SYSTEM USING HF RADIO

Dale N. Hatfield and Jean E. Adams

This report describes a digital computer program for simulating ocean data transmission systems that use high frequency radio. It is intended for use in the design and operation of the Integrated Global Ocean Station System (IGOSS) and the National Data Buoy Systems. Requirements for these two systems are reviewed, and important factors affecting overall transmission system performance are identified. The program predicts performance as a function of these parameters for use in cost/effectiveness studies. A baseline system is described, and sample results from the program are given for it.

Key words: Digital computer simulation, HF telemetry system, Integrated Global Ocean Station System, National Data Buoy Systems, oceanographic data transmission, performance predictions.

1. INTRODUCTION

This report describes a digital computer based simulation model for a high frequency (HF) data transmission system. Section 1.1 gives background information on the development of the Integrated Global Ocean Station System and the National Data Buoy Systems, which the data transmission system will serve. A brief summary of the characteristics and the methods used for predicting the performance of HF communication systems is given in section 1.2.

1.1 Background

After World War II, it was recognized that a large amount of marine environmental data were needed for predictions of weather, fish movements, etc. At the same time, automated data handling systems were being perfected, which enabled processing of large amounts of

data, thus providing a means for processing the data from a large scale ocean data system.

An interrelationship between the upper ocean and the lower atmosphere has been long recognized. Consequently, the atmosphere and the ocean should be considered as interacting parts of a single unified global fluid system. A comprehensive understanding of the interplay is essential in describing and predicting the states of the ocean-atmosphere environment. The need to understand and predict this environment necessitates the timely collection and dissemination of these data on a greatly expanded global basis. Considering that about 70 percent of the earth's surface is covered by oceans, and that these have traditionally been a sparse data zone, one sees the importance of a global ocean data system.

Such a system will contribute not only to the enhancement and safety of men and material, but will also be of great economic value to the fishing industry, ocean floor exploitation, and improved overall weather forecasting. It must be international in scope because a purely national development would probably be inadequate as well as inefficient. Recognition of this led to the development of the Integrated Global Ocean Station System (IGOSS) concept by the Intergovernmental Oceanographic Committee (IOC) that calls for just such international cooperation in gathering and exchanging of marine meteorological and oceanographic data.

At the national level, a similar concept of cooperation among Federal agencies, academic groups, and private research establishments evolved. The U.S. Coast Guard was given the responsibility for developing the national oceanographic data collection system. The National Data Buoy Development Project at U.S. Coast Guard Headquarters is the center for this development.

In 1962, the IOC recommended that a joint World Meteorological Organization (WMO) and IOC working group be established to explore in detail the gathering of data from platforms on the oceans.

The WMO, of course, has long been engaged in efforts to unify the national meteorological services on a global basis, notably through planning the World Weather Watch system. From joint WMO/IOC efforts, the World Administrative Radio Conference (held in Geneva in 1967) allocated six 3.5 kHz bands in the HF radio spectrum for ocean data transmission. The United States supported these proposals, and the Institute for Telecommunication Sciences (ITS) prepared a detailed analysis (Haydon, 1967) demonstrating the feasibility of HF radio transmission for a global system.

In 1968, ITS was given the responsibility to make further studies of the data transmission system using the six allocated frequency bands. The objectives were:

- (1) to review and make recommendations of system parameters, e. g. , modulation techniques, data rate, antennas, and required transmitting power.
- (2) to develop a plan for the coordinated use of the allocated spectrum.

These objectives were to be considered from an international and national standpoint.

Since the National Data Buoy System is an autonomous subset of the international system, the questions posed at the national level are paralleled by questions at the international level. The ultimate size of the system and the complexity and variability of HF propagation led to developing a digital computer model of the communication system. This report describes a preliminary version of this model, which should be useful not only for designing the communication system, but also for developing and evaluating national/international coordination procedures.

1.2 Characteristics and Prediction of High Frequency Circuit Performance

The oceanographic data transmission system can be considered as a large number of individual radio circuits that must be coordinated (a circuit is defined as the path from one platform to one shore station). The performance of the total system is obviously dependent on the performance of these individual circuits. These circuits will make use of the six frequency bands that were allocated by the ITU. These frequency bands are:

4,162.5 - 4,166.0 kHz
6,244.5 - 6,248.0
8,328.0 - 8,331.5
12,479.5 - 12,483.0
16,636.5 - 16,640.0
22,160.5 - 22,164.0

The performance (say in terms of error rate for a digital transmission system) on one of these circuits on one of the allocated bands is a highly variable factor. Fortunately this performance is predictable, in

a probabilistic sense, over a period of a month. That is, the percentage of days of the month that a required performance level will be met or exceeded at a specified hour can be calculated. This percentage of days is frequently referred to as the circuit reliability for that hour during the month, and it can be thought of as being the product of two probabilities:

- (1) the probability that the ionosphere will support (reflect) the signal at that hour, and
- (2) if it is reflected, the probability that it will be strong enough to give the desired performance.

Both probabilities depend upon the intensity and distribution of ionization of the ionosphere along the path.

The first factor, the probability of support, is essentially independent of circuit design parameters (e. g. , transmitter power level). It depends basically on the operating frequency, the angle of incidence on the reflecting layer, and the intensity of ionization. The higher the frequency and/or the steeper the angle of incidence, the more intense the ionization must be to reflect the signal. Thus for a given path geometry, i. e. , angle of incidence, the probability of support decreases with increasing frequency. For example, there may be only a 10% chance of a 22 MHz signal being supported, but a 95% chance for a 4 MHz signal. Also because of the steeper angles of incidence associated with shorter paths, the probability of support tends to decrease with decreasing path length. The ionization of the ionosphere is produced by solar radiation and the intensity of ionization depends on local time of day along the path, season, and general level of solar activity. The intensity, and hence probability of support, increases during daylight hours and during years of high solar activity. As a result, higher frequencies are more useful during these periods.

The second factor, the probability of adequate signal strength, depends upon (1) the ionization in the lower regions of the ionosphere along the path, (2) the geometry of the path, (3) equipment parameters and performance quality desired, (4) operating frequency, and (5) the radio noise and interference environment at the receiver site. HF signals are absorbed in passing through the lower regions of the ionosphere on their way to or from the higher regions where reflection normally takes place. The amount of this absorption increases with distance travelled through the lower regions and with the intensity of ionization present in them. Thus the signal strength and the probability of an adequate

signal decreases on longer paths, during daylight hours, during the summertime, and during years of higher solar activity. The absorption is inversely proportional to frequency, that is, lowering the operating frequency increases the absorption. The probability of adequate signal strength then decreases with decreasing frequency, while the first factor, the probability of support, increases with decreasing frequency.

In general, the curve of reliability versus operating frequency for a given time and set of parameters tends to have a peak because of these opposing propagation related factors. The circuit performance on frequencies below this peak is degraded faster due to absorption than it is improved due to a higher probability of propagation. Conversely, for frequencies higher than this peak, the probability of support drops faster than the probability of adequate signal increases.

The adequacy of the signal at the receiver also depends on the radio noise level on the operating frequency. This noise may be man-made (such as ignition noise from automobiles), atmospheric (lightning discharges) galactic, or, in rare instances in these bands, noise in the receiver itself. As an example, high man-made radio noise levels at urban receiving areas would require greater signal strengths than those at rural receiving areas for the same level of performance. Signal strengths increase with transmitter power and antenna gain. Thus higher radio noise levels tend to narrow the band of useful frequencies while higher transmitter powers and antenna gains tend to increase it by increasing the probability of an adequate signal.

A final consideration in factor two is the required signal-to-noise ratio (SNR) for the desired level of performance with the modem and coding used. In a digital data collection system, the major measure of performance is specified by the bit error rate. Higher allowable error rates require lower SNR, and expands the useful frequency band.

To summarize, the frequency at which the reliability is maximum and the value at that point of maximum reliability, as well as overall shape of the reliability versus frequency curve will change with geographic location, time of day, season, solar activity, equipment parameters, and required circuit performance. For best performance the operation of an individual circuit should be on a frequency at or near this point of maximum reliability.

Calculating HF circuit performance is a long, tedious process if manual methods are used. Recently computer programs have been developed

that can compute this reliability rapidly. The computer program originally developed at ITS is described in Lucas and Haydon (1966), and the latest improved version called HFMUFES, which has been adapted for this simulation program, is described in Barghausen et al. (1969). The program uses predictions of the sun's activity and basic ionospheric parameters that are obtained from long term collection of vertical incidence soundings, and atmospheric and man-made radio noise measurements. Both the ionospheric and noise data are supplied to the program in the form of numerical coefficients defining numerical map functions (Jones et al., 1966). From these functions the parameter of interest can be determined as a function of geographic coordinates and time. The computer program uses the predicted ionospheric parameters to predict propagation modes, probability of support, signal strengths, and other circuit factors. The atmospheric noise maps, and assumptions regarding the man-made noise environment, are used in the program to calculate the noise power at a given frequency, time, and receiver location. Then, from the predicted median signal power, the median noise power, the variances, and the required signal-to-noise ratio, the probability of an adequate signal is computed. The reliability is then computed.

2. IGOSS BASELINE TELEMETRY SYSTEM

This section describes the basic IGOSS communication system around which the simulation computer model was developed. This baseline system serves as a point of departure for the communication system analysis. The communication system is to efficiently transfer oceanographic and meteorological data collected by the ocean station to the shore where it can be processed and passed on to the users.

The IGOSS concept projects an ultimate system consisting of several types of ocean stations (platforms), including moored and unmoored buoys, instrumented merchant ships, and research vessels. For the baseline system, a group of several hundred buoys and a thousand ships might be considered. Platforms could be located in any ocean of the world, so no specific geographic distribution is inherent in the assumptions for the baseline system. The communication system performance will depend on the distribution of platforms. The importance of this point will be discussed later.

Data from the platforms are sent to shore stations that are appropriately equipped. The number and location of shore stations will affect the communication system performance and cost. For the initial system a group of 18 shore stations was selected such that any ocean area is

within 4,000 km of at least one shore station. The 4,000 km is about the maximum distance for a one hop propagation path. The ocean area within this 4,000 km radius will be referred to as the primary coverage area. Wherever possible, the shore station sites were chosen at existing World Weather Watch facilities. The distribution of these 18 stations is shown in figure 1. It must be emphasized that this is an initial assumption for a baseline system only, and the actual number and location of shore stations can be modified as required by the appropriate organization(s).

For the baseline system the data from the platforms would be transmitted to the shore stations at the synoptic hours of 0600, 1200, 1800, and 2400 GMT. These data transmissions can be initiated either by an interrogation transmission from a shore station, or by an onboard clock system. The transmission of a given platform would be in one of the six allocated frequency bands.

To illustrate the situation, a platform within the primary coverage area of three shore stations is shown in figure 2. The three shore stations can be considered as candidates to receive the data. Thus there are three circuits to consider, one to each of these stations. Furthermore, for each circuit there is a choice of the six frequency bands. Each station-frequency pair will generally have a different predicted reliability because the reflection areas, local times, and noise levels at the shore stations will be different. This results in a total of 18 possible station-frequency combinations. The object, of course, is to select the pair with the highest predicted reliability.

With 18 shore stations and 6 frequencies there are 108 such combinations on a worldwide basis. This means that a maximum of 108 transmissions could be accommodated at a given time. The actual number would be significantly less than this because many of the station-frequency combinations might be unreliable for a given platform; or a particular combination would be likely to interfere with another combination. With a possibility of having several hundred buoys and several thousand instrumented ships, it is necessary (and also technically desirable) to divide each of the six allocated 3.5 kHz-wide bands into several separate narrower bands (channels). As an example, if each band were to be divided into 13 such in-band channels, each 200 Hz wide*, (leaving 900 Hz for guard space) every station could then receive data from 13 platforms in the same

* The example of 200 Hz wide channels is purely arbitrary and should not be taken as a recommendation of channel bandwidth for the IGOSS.

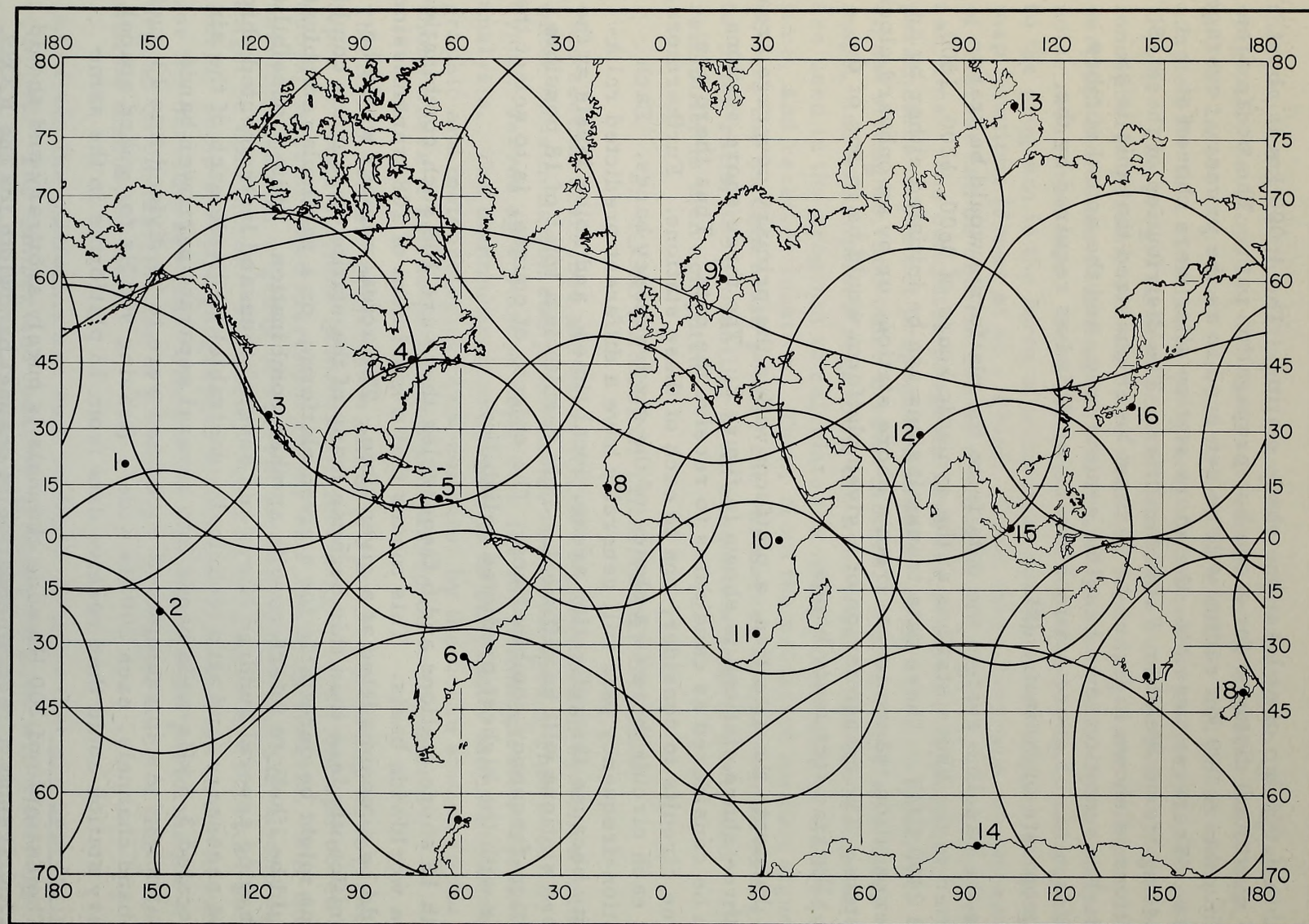


Figure 1. A possible distribution of shore stations

frequency band at the same time. This increases the number of combinations to 13 times 108 or, 1404. It is also possible to receive data at different times, but still with the allowable time limit following the synoptic hour. In other words, one buoy might be read out between 1800 and 1802 GMT, and another between 1802 and 1804 GMT, etc. These are called timeslots, and for the baseline system, it is assumed that there are six of them for each synoptic hour. The total is now 6 times 1404 or 8,424 station, frequency, in-band channel, and timeslot combinations available for gathering data. The object is to assign these combinations (resources) in such a way that the performance of the telemetry system is optimum. The overall telemetry system performance resulting from such assignments is discussed in section 3.

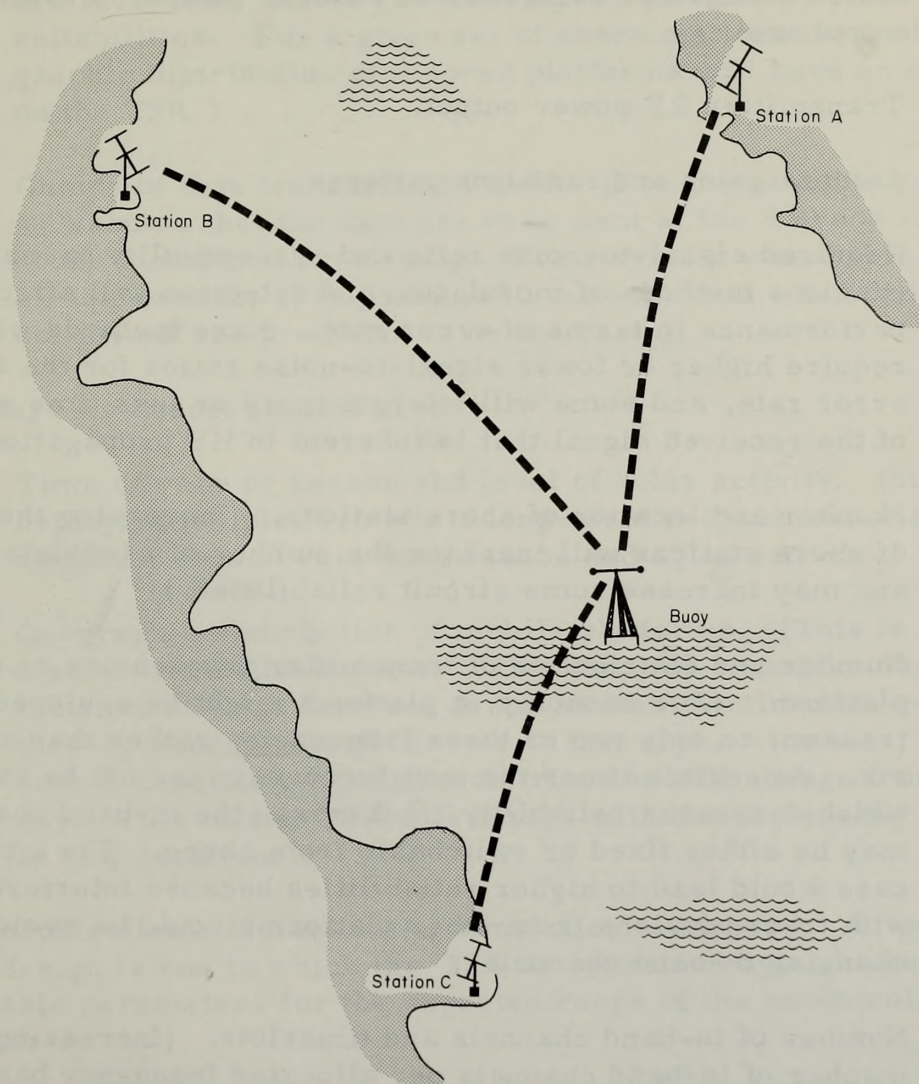


Figure 2. A sketch showing three possible candidate stations for communications to a single buoy.

3. TELEMETRY SYSTEM PERFORMANCE

The telemetry system reliability (TSR) at a given synoptic hour can be defined as the expected percentage of data messages from all platforms that is received at the shore stations with acceptable error rates. This reliability is the average of all the individual, predicted circuit reliabilities. For example, a given assignment of station-frequency-channel-timeslots (SFCT) might produce a TSR of 90 percent with individual circuit reliabilities ranging from 60 percent to 97 percent.

The telemetry system reliability and the distribution of reliabilities are functions of a number of parameters as discussed in section 1.2. Some of these can be changed or controlled and others cannot. Parameters we can control are:

- (1) Transmitter RF power output.
- (2) Antenna gains and radiation patterns.
- (3) Required signal-to-noise ratio and susceptibility to multipath. (Various methods of modulation and detection will affect the performance in terms of error rate. Some methods will require higher or lower signal-to-noise ratios for the same error rate, and some will tolerate more or less time spread of the received signal that is inherent in HF propagation).
- (4) Number and location of shore stations. (Increasing the number of shore stations will increase the number of candidate stations and may increase some circuit reliabilities.)
- (5) Number and distribution of transmitter frequencies on each platform. (For economy, a platform might be equipped to transmit on only two or three frequencies rather than all six. At certain times the best frequency may not be available, which decreases reliability. Likewise, the in-band channel may be either fixed or switchable from shore. The latter case would lead to higher reliabilities because interference with transmissions from other platforms could be avoided by changing in-band channels.)
- (6) Number of in-band channels and timeslots. (Increasing the number of in-band channels per allocated frequency band and increasing the number of timeslots permits greater flexibility

in assigning station-frequency combinations and thereby increases the circuit reliabilities.)

- (7) Assignment method. (If the system capacity is inadequate so that several platforms must compete for a good assignment, the method in which assignments are made will affect the telemetry system reliability. As an extreme example, platforms could be randomly assigned to SFCT combinations without regard to propagation predictions. This would be simple, but the resulting system reliability would be low.)
- (8) Geographic distribution of moored buoys. (Conceivably the moored buoys could be placed where propagation conditions are favorable, thereby increasing the associated circuit reliabilities. For a given set of shore stations then, the geographic distribution of moored platforms will have an effect on the TSR.)
- (9) Choice of data transmission time. (For the baseline system we assume that the data are to be sent at the 4 synoptic hours mentioned previously. For a system where this is not a requirement, it is possible to send the data when propagation conditions are predicted to be the best.)

Parameters we cannot control are:

- (1) Time of year or season and level of solar activity. (Since deploying the platforms is a long-term proposition, circuit reliabilities will vary with season and solar activity.)
- (2) Geographic distribution of mobile platforms. (This is actually a semi-controllable factor. One can, for example, choose to instrument ships involved in the North Atlantic trade routes and thereby concentrate platforms in that area. However, even in such a case the geographic distribution will change from day to day. This means TSR will change with the day-to-day changes in ship locations.)

These uncontrollable factors make simulation necessary. A "good" system design is one in which the TSR is optimized by a choice of the controllable parameters for the expected range of the uncontrollable parameters.

In the selection of the designed controlled variables, it is apparent that there are many trade-offs. The cost of a 3 dB increase in transmitter power can be compared with the cost of a 3 dB increase in antenna gain, or the cost of a more complex modem that would require 3 dB less SNR for the same error rate. From a systems standpoint, each would result in the same increase in TSR. This same increase in TSR might also be accomplished by an increase in the number of shore stations or by an increase in the number of channels or timeslots. The simulation program, which is described in the next section, investigates the TSR as a function of these parameters. In that way, the trade-offs can be evaluated in terms of cost/effectiveness.

4. PROGRAM DESCRIPTION

The computer based simulation model depends upon the HFMUFES computer program that was mentioned earlier for predicting HF communication performance. The program has been extensively modified, and most general purpose features have been eliminated. The basic propagation model has not been changed.

A block diagram of the simulation model is shown in figure 3. The main computer program is called SIMIGOSS (for SIMulation and IG OSS). It in turn has three main subroutines: (1) OPTIMAL, which makes the actual assignments, (2) PREDPRFM*, the basic circuit performance pre-performance prediction routine, and (3) SKEDULE, the statistical generation and assignment output subroutine.

In the computer simulation model, SIMIGOSS, predicting individual circuit reliability of each of the six frequencies and 4 synoptic hours now takes about 7 sec of computer time. Even at this rate, it is too expensive to re-run the simulation model program for each platform/shore station pair whenever controllable parameters are changed, or a different geographic distribution of platforms is assumed. Therefore, for this simulation model the ocean areas of the world have been divided into approximately 3,000 areas for which the performance of any circuit originating within each area can be considered a constant for a given shore station and set of input parameters.

* PREDPRFM utilizes a number of HFMUFES subroutines. For a brief description of these subroutines (as given by Barghausen et al.) see appendix A.

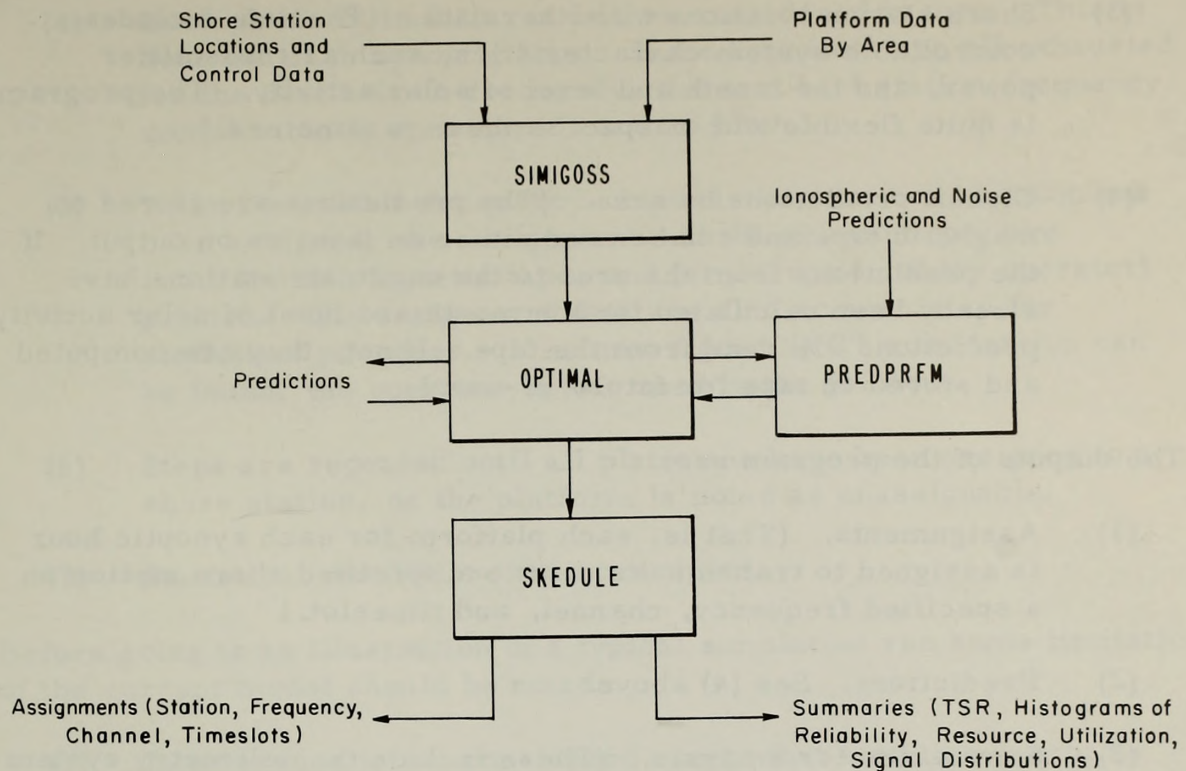


Figure 3. Block diagram of the simulation computer model.

Propagation predictions for these areas are then computed, and the results (such as path loss and probability of ionospheric support) are stored on magnetic tape. Changes in the geographic distribution of platforms, transmitter power, antenna gains, required SNR, or any other designer specified parameter (except shore station location) can then be evaluated in terms of TSR without re-running the propagation prediction portion of the program.

The inputs to SIMIGOSS follow:

- (1) Requirements by prediction area. (This includes the number of platforms in the area, frequencies and channels associated with each platform, and a list of the candidate shore stations. Limiting stations to the three closest rather than all 18 decreases computation time. Other criteria, besides the closest three, for assigning candidate stations can be incorporated easily.)
- (2) Ionospheric and noise parameters. (This is the basic data upon which propagation predictions for individual circuits are based.)

- (3) Shore station locations and other data. (The data includes controllable system characteristics, such as transmitter power, and the month and level of solar activity. The program is quite flexible with respect to these parameters.)
- (4) Circuit predictions by area. (The predictions are stored on magnetic tape and can be used either on input or on output. If the predictions from the area to the candidate stations have already been calculated for the month and level of solar activity, predictions are read from the tape. If not, they are computed and stored on tape for future re-use.)

The outputs of the program are:

- (1) Assignments. (That is, each platform for each synoptic hour is assigned to transmit its data to a specified shore station on a specified frequency, channel, and timeslot.)
- (2) Predictions. See (4) above.
- (3) Summaries for analysis. (These include the telemetry system reliability for each synoptic hour, histograms of circuit reliabilities, resource utilization, interference/conflict problems, and distributions of signal strength, antenna takeoff angles, and antenna bearings, that result from the assignments made. As currently implemented, the statistical summaries other than TSR are obtained from a separate program that will eventually be incorporated in the SKEDULE subroutine.)

The operation of the program is as follows:

- (1) The control information and prediction data are read in and stored.
- (2) In the current assignment technique, the data for the first (or next) area are read from tape and stored in the computer.
- (3) If predictions of reliability have not been previously obtained for the area, the PREDPRFM is called and circuit reliability predictions are computed for the circuit from this platform to the candidate stations for the six frequencies and the 4 synoptic hours. The best station-frequency that has an unassigned timeslot on the channel associated with the platform is then assigned.

- (4) Each platform in the area is then considered in turn. This is done for each synoptic hour. If the timeslots are all exhausted for the best station-frequency, the next best station-frequency combination is considered, and so forth.
- (5) When the station-frequency-channel-timeslot combination has been assigned, the assignment and the relevant data are recorded on magnetic tape, and (at the option of the operator) printed. The assignment data are also accumulated for statistical purposes. If no unassigned SFCT combination can be found, the operator is informed in the printout.
- (6) Steps are repeated until all platforms have been assigned to a shore station, or the platform is noted as unassignable.
- (7) Statistical results are then presented.

Before going to an illustration of a typical simulation run some limitations of the current model should be noted.

- (1) Interference is not considered except that a station cannot be assigned to receive more than one platform on the same frequency, channel, and timeslot. In effect this allows unlimited geographic sharing.
- (2) Multipath effects are not considered in the assignment. Multipath (the arrival of the signal via more than one path so that the signal is "smeared" in time) may seriously degrade the circuit performance on a given frequency.
- (3) Groundwave paths are not considered. When a platform is located very near a shore station, it may be possible to receive the data via groundwave, and the groundwave signal may interfere with the reception of the skywave signal.
- (4) A "sequential" assignment technique is used. With the assumption of 6 timeslots, 13 channels per frequency, and 18 shore stations, conflicts begin to occur in later assignments when a thousand or so platforms are considered. This means that the SFCT resources assigned early might be used more advantageously in the later assignments, thus implying that there may be another distribution of resources that would lead to a higher telemetry system reliability. This is a result of sequential assignment technique not always leading to an

optimal assignment. If the areas are processed sequentially but are sorted first in order of importance, this method may have merit. Otherwise, if the capacity of the system is taxed, a more sophisticated assignment technique may be needed, or the capacity must be increased by increasing the number of timeslots. The trade-off here is that for a given timeslot length, an increase in the number of timeslots will eventually exceed the allowable transmission period associated with each synoptic hour. Data received after this may be less useful for severe weather or ocean condition detection, or forecasting purposes. Also, the amount of time available outside the interrogation period would be reduced. The competition for favorable assignments will be even more severe when interference is considered fully.

- (5) Sporadic E modes are not considered.

5. SAMPLE RESULTS

This section of the report presents a sample of the outputs from the SIMIGOSS program. For this sample, computations were made using the simulation model with a worldwide distribution of 5,500 platforms. One platform was located in each of the 3,313 prediction areas, and the remaining 2,187 platforms were then distributed randomly over all areas. The total number of platforms and their geographic distribution is not realistic, but serves to exercise fully the SIMIGOSS program. Data on world ship traffic patterns is currently being analyzed to provide more realistic distributions for future runs. The other input data and assumptions for the sample computations with the simulation model were as follows:

- (1) June was chosen as representative of a Northern Hemisphere summer, or Southern Hemisphere winter.
- (2) The smoothed sunspot number (SSN) is assumed to be 110 for the month, which represents a high solar activity.
- (3) The platform transmitter is assumed to deliver 100 W of power to the platform antenna on all frequencies.
- (4) The platform antenna is assumed to be a discone, 11 m high, with a maximum power gain of 6 dB. The shore station antenna is assumed to be a vertical antenna with a 12 dB power gain.

- (5) The required SNR for a 10^{-3} error rate is assumed to be 38 dB for a FSK modulation system with diversity reception.
- (6) The man-made radio noise at shore stations is assumed to be typical of an urban environment.
- (7) The shore stations are those shown on the world map in figure 1.
- (8) Multipath, sporadic E, and groundwave propagation are not considered in the predictions.

A sample assignment of platforms to shore stations for one prediction area is shown in figure 4. The top line shows the area number (103), the geographic coordinates (6.36°S, 6.40°W), and the number of platforms in the area (2). The remainder of the page is divided for the 4 synoptic hours. At the 0600 GMT synoptic hour, platform number 168 has been assigned to station number 10 (Nairobi), on frequency band number 2 (6 MHz), on channel 3 and in timeslot number 1. Predicted reliability for this circuit is 98 percent and the predicted signal strength at the shore station is -73 dBW. The latitude and longitude of the shore station is 1.17°S and 36.50°E. The distance from the area to the station is 3,387 km.

The TSRs for each of the 4 synoptic hours are:

0600 GMT	80 percent
1200 GMT	78 percent
1800 GMT	78 percent
2400 GMT	73 percent

A histogram showing the percentage of the total assignments in reliability ranges of 10 percent is shown in figure 5. Figures showing TSR, and histograms of this type are useful outputs for system design. A histogram that shows the percentage of the assignments that were made to the best station-frequency pair, the second best, and so on (as a result of the limited number of channel/timeslots) is presented in figure 6. This figure is useful in studying the communication system capacity. A histogram showing station utilization is shown in figure 7. This information is operationally useful in showing the relative workload at each station. It is also useful in evaluating shore station locations during the design phase. Figure 8 is a histogram illustrating frequency utilization, and is useful in indicating the frequencies that will be most useful on the platforms.

```

AREA NO. 103 AREA LATITUDE = -6.36 AREA LONGITUDE = -6.40 No. OF PLATFORMS IN THE AREA = 2
*****
PLATFORM AREA STATION FREQ CHANNEL TIMESLOT RELIAB SIGNAL STATION STATION DIST
NO. NO. NO. NO. NO. PERCENT -DBW LATITUDE LONGITUDE KM
167 103 10 2 3 1 98 73.0 -1.17 36.50 3387
168 103 10 2 13 1 98 73.0 -1.17 36.50 3387
*****
PLATFORM AREA STATION FREQ CHANNEL TIMESLOT RELIAB SIGNAL STATION STATION DIST
NO. NO. NO. NO. NO. PERCENT -DBW LATITUDE LONGITUDE KM
167 103 11 6 9 1 94 88.0 -25.45 28.12 3135
168 103 11 6 10 2 94 88.0 -25.45 28.12 3135
*****
PLATFORM AREA STATION FREQ CHANNEL TIMESLOT RELIAB SIGNAL STATION STATION DIST
NO. NO. NO. NO. NO. PERCENT -DBW LATITUDE LONGITUDE KM
167 103 8 4 13 4 97 81.0 14.38 -17.27 3483
168 103 8 4 11 2 97 81.0 14.38 -17.27 3483
*****
PLATFORM AREA STATION FREQ CHANNEL TIMESLOT RELIAB SIGNAL STATION STATION DIST
NO. NO. NO. NO. NO. PERCENT -DBW LATITUDE LONGITUDE KM
167 103 8 3 12 1 97 76.0 14.38 -17.27 3483
168 103 8 3 8 2 97 76.0 14.38 -17.27 3483
*****

```

Figure 4. A sample output from the assignment routine.

Many other outputs from the program are possible, but the ones just illustrated are the most useful in the current stage of the system design. An example of another output, which has not yet been programmed, would be a summary of antenna take-off angles for each frequency, and azimuthal bearings to assigned platforms, so that the antenna requirements for each shore station can be determined. This would provide a basis for antenna design.

Normally several computations using different constraints on the simulation model would be made to test effects of changing one or more of the design parameters. For example, TSR can be plotted as a function of both buoy transmitter power and the number of timeslots (reflecting the system capacity) of the system. For examples of such runs, the reader is referred to the report by Adams et al. (1969).

The results given in this section should be considered examples only, since (1) they consider rather unrealistic numbers and distributions of platforms, (2) no attempt has been made at optimizing the system or assignment method, and (3) potential interference between operations on the same frequency at the same time is not considered.

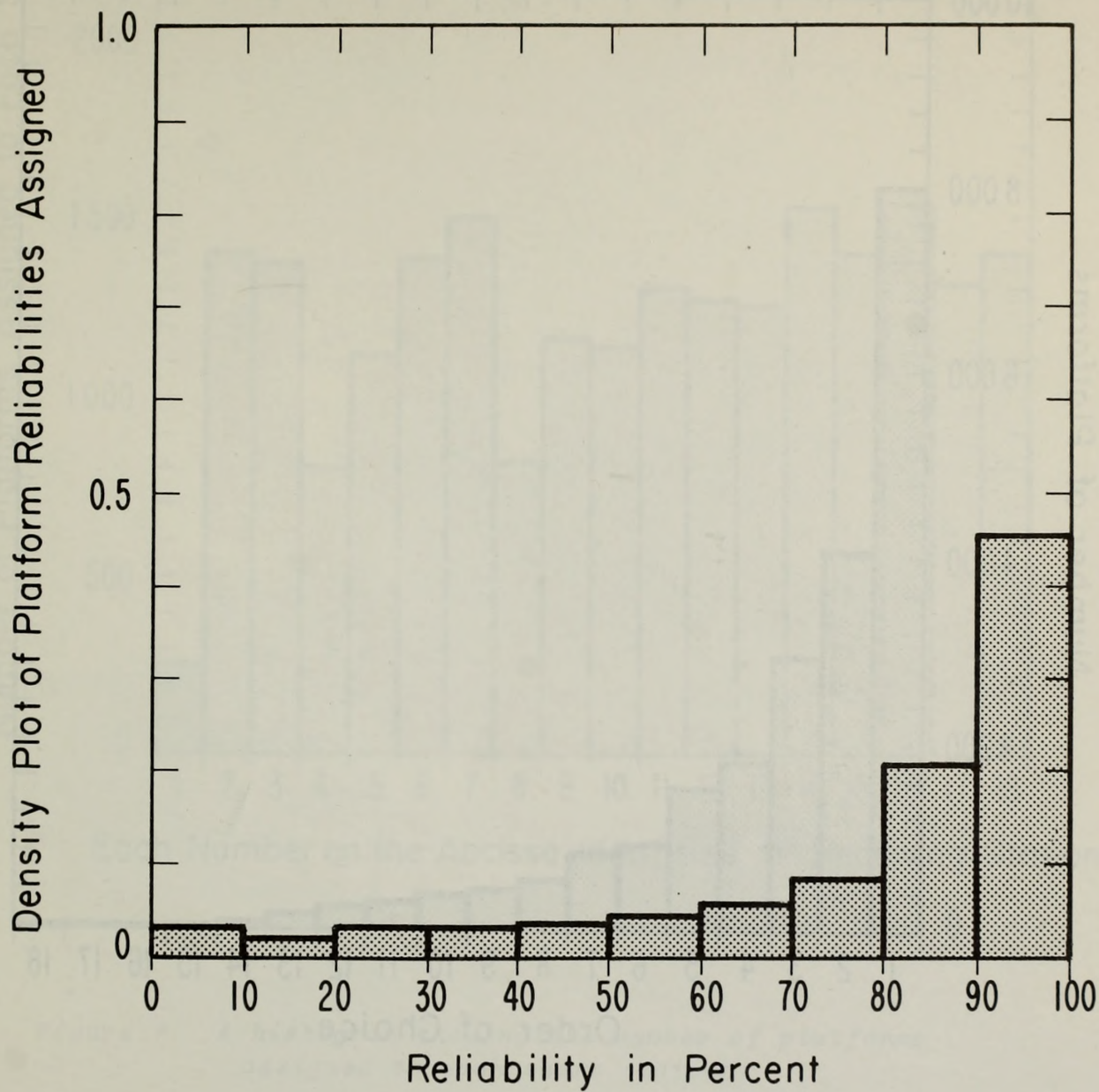


Figure 5. A histogram showing the distribution of shore-platform assignment circuit reliabilities.

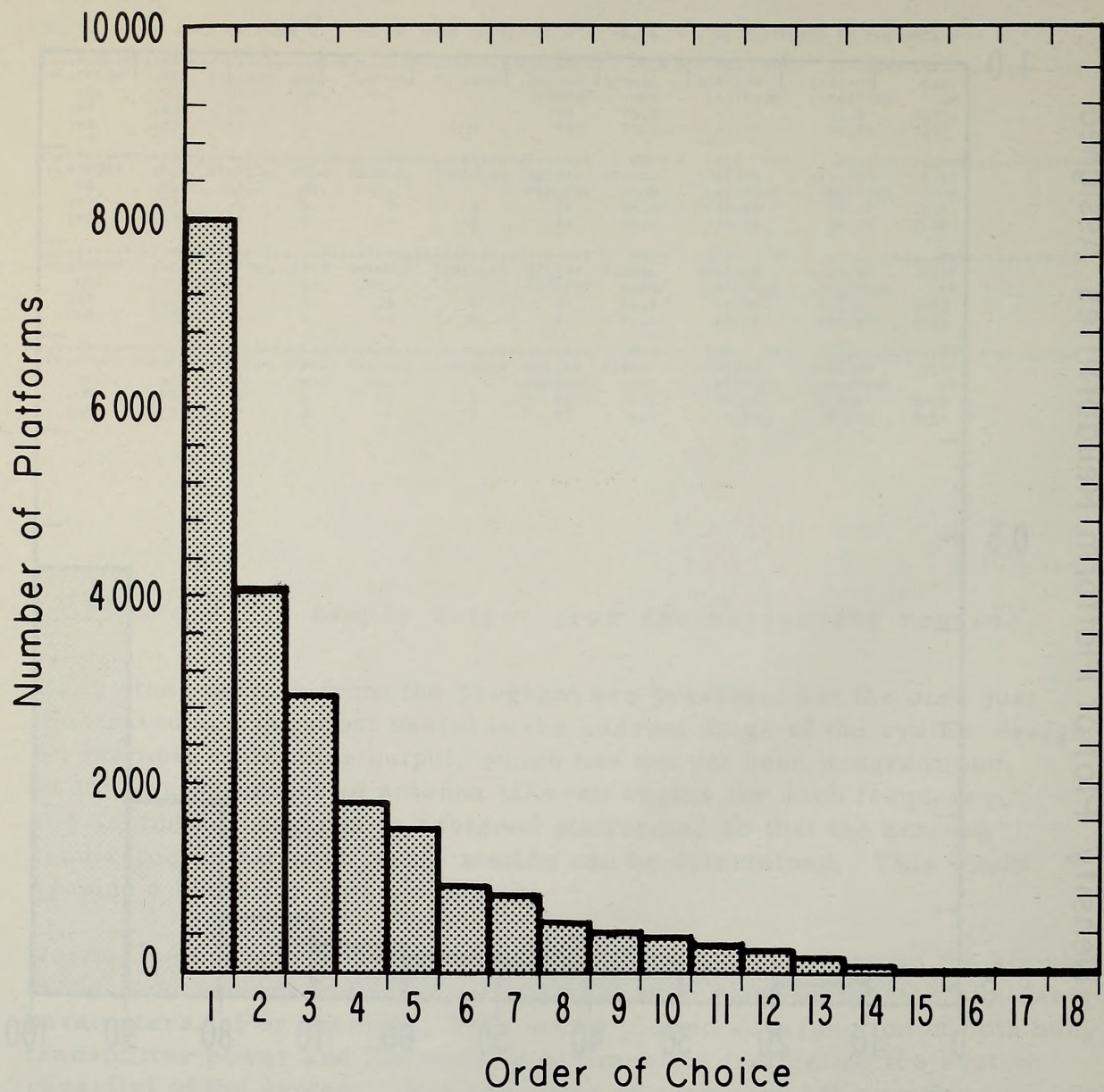


Figure 6. A histogram showing the number of platform-stations assignments made as a function of circuit reliability choice.

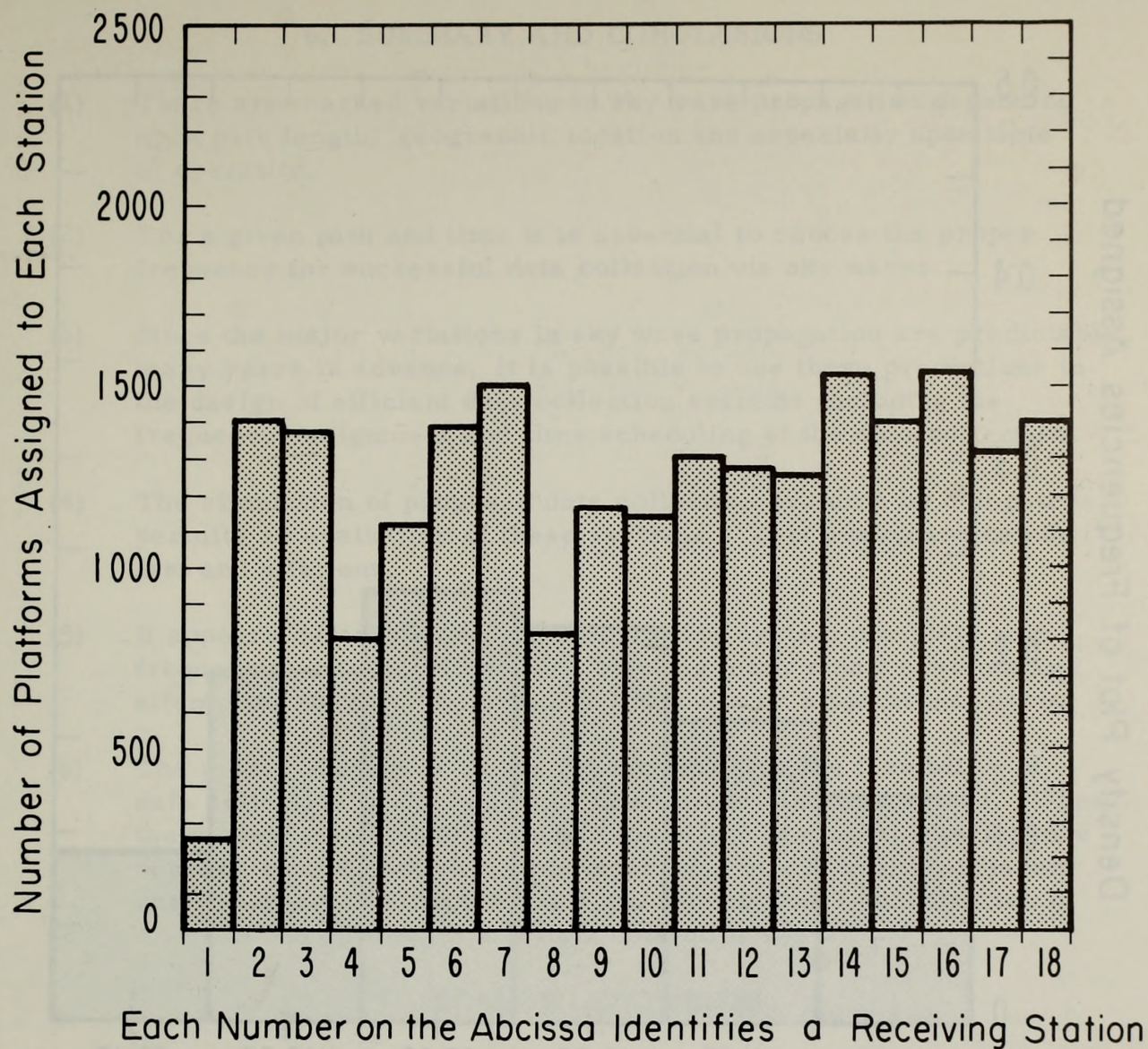


Figure 7. A histogram showing the number of platforms assigned to each shore station.

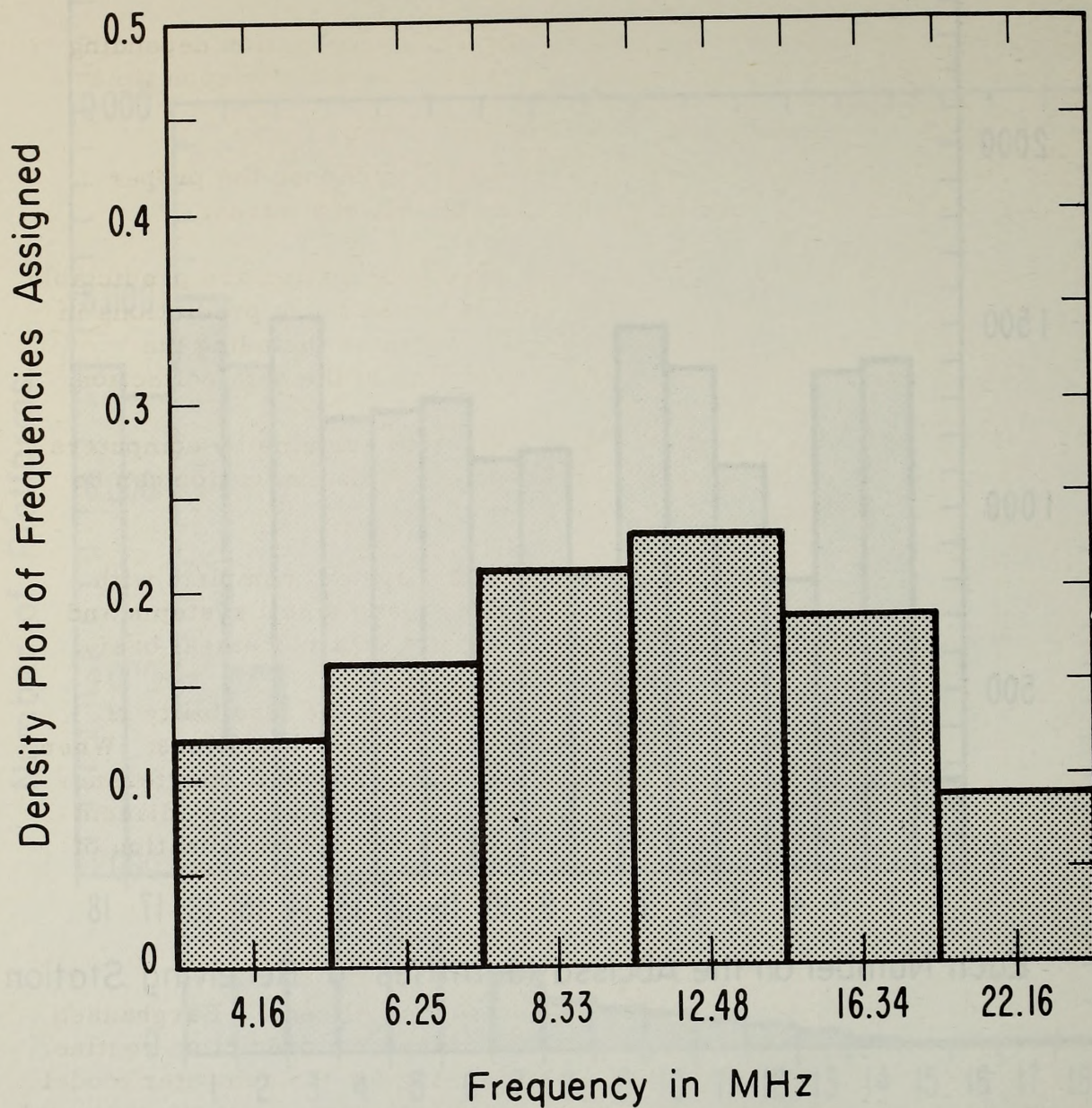


Figure 8. A histogram showing the distribution of station-platform assignments as a function of the allocated frequencies.

6. SUMMARY AND CONCLUSIONS

- (1) There are marked variations in sky wave propagation depending upon path length, geographic location and especially upon time of operation.
- (2) For a given path and time it is essential to choose the proper frequency for successful data collection via sky waves.
- (3) Since the major variations in sky wave propagation are predictable many years in advance, it is possible to use these predictions in the design of efficient data collection systems including the frequency assignment and time scheduling of the data collection.
- (4) The simulation of proposed data collection systems by computers permits an evaluation of these systems. This evaluation can be fast and efficient.
- (5) It appears desirable to plan a worldwide system complete with frequency planning rather than starting many small systems and attempting to integrate additional circuits on a piecemeal basis.
- (6) The model illustrated in the report indicates the feasibility of data collection in the presence of natural noise limitations. When the model is extended to include the effect of mutual interference between circuits which may be operating co-channel or adjacent channel it would form the basis for international coordination of a worldwide oceanographic data collection system.

7. ACKNOWLEDGMENTS

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8. REFERENCES

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¹ This document is in the public domain, but it is considered unpublished since it was not printed for wide public distribution.

APPENDIX A

Description of Subroutines Used by PREDPRFM

The subroutine PREDPRFM corresponds to the main program portion of HFMUFES. The subroutines and their descriptions, which are used by PREDPRFM, are given here. The descriptions are largely taken from Barghausen et al. (1969) where more detailed information is available.

- VERSY - evaluates coefficients for the world maps of ionospheric parameters that have been generated as a function of Universal Time (UT) and latitude (geographic or magnetic dip).
- MAGFIN - computes the magnetic field components of the earth at any height and geographic latitude and longitude.
- BEMUF - calculates, on the basis of parabolic layer theory, the maximum usable frequency, takeoff angle, and virtual height of reflection, or, for a specific frequency, only the last two parameters.
- LUFFY - calculates operational parameters for up to seven modes for each hour and frequency. Uses RELBIL to calculate SNR and reliabilities. (The original LUFFY in HFMUFES has been significantly modified to eliminate features not needed in the SIMIGOSS program.
- RELBIL - calculates atmospheric, galactic, and man-made noise and then determines controlling noise. Also calculates the SNR and reliability.
- NOISY - evaluates the world maps of noise and land areas that have been mapped by a Fourier series.
- GENFAM - calculates frequency dependence of the median 1 MHz atmospheric noise and its associated decile values and standard deviation of the median and upper and lower deciles of the atmospheric noise.

- CHISQ - evaluates the chi-square probability function.

- SYSSY - obtains from a table the values of median excess
 system loss, upper and lower standard deviations,
 and the error in predicting excess system loss and
 upper and lower standard deviations in the error.

- GAIN - calculates gain in decibels of the transmitter and
 receiver antennas. (In HFMUFES this is a very
 general subroutine. It has been completely changed
 for SIMIGOSS to compute gains as a function of
 frequency, takeoff angle, and bearing for only
 antennas contemplated for IGOSS.)