1984

Computer aided antenna design and frequency selection for HF communications.

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Monterey, California. Naval Postgraduate School

https://hdl.handle.net/10945/19203

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

COMPUTER AIDED ANTENNA DESIGN AND FREQUENCY SELECTION FOR HF COMMUNICATIONS

by

Warren P. Averill

June 1984

Thesis Advisor: H. M. Lee

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle) Computer Aided Antenna Design and Frequency Selection for HF Communications	5. TYPE OF REPORT & PERIOD COVERED Master's Thesis June 1984
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Warren P. Averill	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943	12. REPORT DATE June 1984
	13. NUMBER OF PAGES 173
14. MONITORING AGENCY NAME & ADDRESS(If different from Controlling Office)	15. SECURITY CLASS. (of this report) UNCLASSIFIED
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Antenna; Propagation; Noise; PROPHET; Numerical Electromagnetics Code; Tactical Communications

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Efficient and reliable high frequency skywave communication can be obtained only if wave propagation paths are carefully analyzed and if an antenna which transmits and receives signals along the desired paths can be selected and designed. A micro-computer based program was developed to accomplish this task.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Computer Aided Antenna Design and Frequency Selection for HF Communications

by

Warren P. Averill
Captain, United States Marine Corps
B.S.E.E., Oklahoma University, 1978

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
June 1984

ABSTRACT

Efficient and reliable high frequency skywave communication can be obtained only if wave propagation paths are carefully analyzed and if an antenna which transmits and receives signals along the desired paths can be selected and designed. A micro-computer based program was developed to accomplish this task.

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ACKNOWLEDGEMENT

I wish to express my appreciation to the many people who took part in the preparation of this thesis. A special thanks goes to Prof Hung Mou Lee and Dr. Richard Adler, two individuals who have given me countless hours of discussion, assistance, and encouragement throughout the thesis development process.

I. INTRODUCTION

A. BACKGROUND

Before the advent of satellites, long range communications were routed over HF skywave paths. Today few military communicators possess the knowledge and expertise required to set-up and maintain reliable long haul HF communications. Since the early 1970's, this technology has been relatively neglected as satellite communications are more reliable and the data rate is much higher than is possible over HF links. However, one cannot afford to ignore the eventual vulnerability of satellites.

President Reagan warned the public that the battlefield will soon extend into space, in which case the satellites may very well be the first casualties. In addition to the growing threat of satellite destruction, satellite communications are vulnerable to jamming.

Communicators need HF capabilities. An HF communicator must be able to accomplish the following tasks:

1. Analyze or obtain analysis of the propagation path between the local station and the outstation. The most important products of the analysis are:
    a. Desired take-off angle[1] (TOA) at transmitting station
    b. Azimuth to the outstation
    c. Propogation loss over the path on each frequency
2. Select the best antenna, whether it is the standard type (Whip, AS-2259, etc.) or a directional wire antenna.

---

[1] Take-off angle -- angle above the horizon at which the largest amount of power must radiate if the receiver is to receive the strongest signal possible.

3. Design and construct a wire antenna when those available are inadequate.

4. Choose the best available frequency for operation during each hour of the day to obtain the highest possible communications reliability.

The importance of each of these capabilities should become apparent in the discussion that follows.

Each time a link is established, the characteristics of the path will change. The ionosphere varies in density over a 24 hour cycle, a four season cycle and on an eleven year cycle as well as randomly due to solar disturbances. As a result, on a link between two given stations, the range of useful frequencies and transmission losses will vary. The best communication can be obtained only by first analyzing the propagation path each time one establishes a link.

Each antenna, whether it be a stock antenna or a wire antenna, will have certain characteristics that make it right for a particular link. Of primary importance is that the antenna radiates a sufficient amount of power along the azimuth to the outstation and at the proper take-off-angle (TOA). After subtracting the transmission losses over the path, the received signal at the outstation must be intelligible.

An antenna will develop a radiation pattern, an example of which is shown in figure 1.1. One's objective when selecting an antenna is to choose one which developes a major lobe that can be aligned with the azimuth to the outstation and the TOA. Referring to the example radiation pattern,[2] this antenna will be adequate if the TOA is between 15 and 45 degrees.

---

[2] All radiation patterns presented in this thesis are from antennas modeled over fair ground unless otherwise stated.

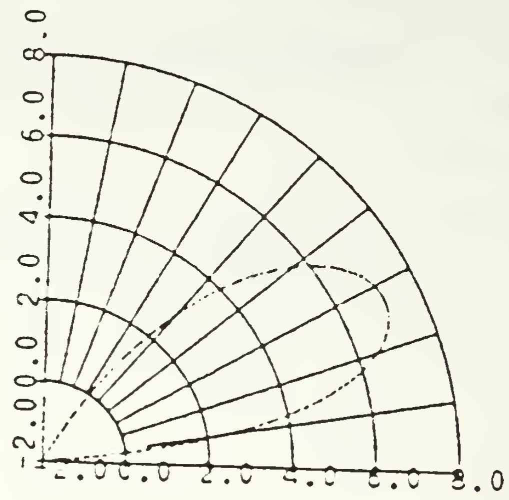


Figure 1.1 Dipole radiation pattern (height = 1/2 wavelength).

The chosen antenna must be designed and constructed. One must determine the following in the design process:

1. How high and long the antenna should be.
2. How the antenna should be oriented.
3. What type of transmission line (if any) is needed.
4. What matching devices (baluns, transformers, or resistors) are needed and how to connect these.

In determining these specifications, in addition to the propagation path parameters, one must consider the physical limitations at the local antenna site -- area and materials available.

During operations the most important task that the communicator carries out is the selection of the best available frequency for each hour of the day. Three factors are considered when choosing the frequency. The operator should choose:

a frequency over which the signal will be attenuated the least over the propagation path.

a frequency on which the antenna will efficiently radiate power in the desired direction (along the azimuth to the outstation and at the desired take-off angle).

a frequency over which the environmental noise level at the receiver is low.

B. ENGINEERING AIDS PRESENTLY AVAILABLE

Several engineering aids are available that the communicator can use to engineer his HF links.

1. Propagation Path Analysis

The communicator can choose to use PROPHET or task the Environmental Capability Analysis Center (ECAC) to obtain needed information about the propagation path.

a. PROPHET

This is a stand alone micro-computer based program in basic. While many different products can be obtained, those of most interest to the operator are the field strength plot, ray-trace, and environmental noise report. [Ref. 1]

(1) Field Strength Plot. From this product (an example which is shown in Figure 1.2) one can determine the best frequency to operate on during each hour of the day. The communicator would simply look vertically down the graph on the hour of operation and choose a frequency available which corresponds to the highest signal power received. The information considered in generating this plot includes the antenna type and its radiation pattern. One can specify any of seven antennas to the program but each is of a set design and no allowance is made for the operator's need to modify the antenna and its pattern for a particular link.

(2) Ray-Trace. As may be noted in Figure 1.3, one can obtain the TOA and azimuth to the outstation from this product. The arrow at the bottom of the graph indicates the receiver location. In this example, the proper TOA is 14 degrees. Over a 24 hour operation period, a new TOA is needed at least every two hours, so one should run this module twelve times.

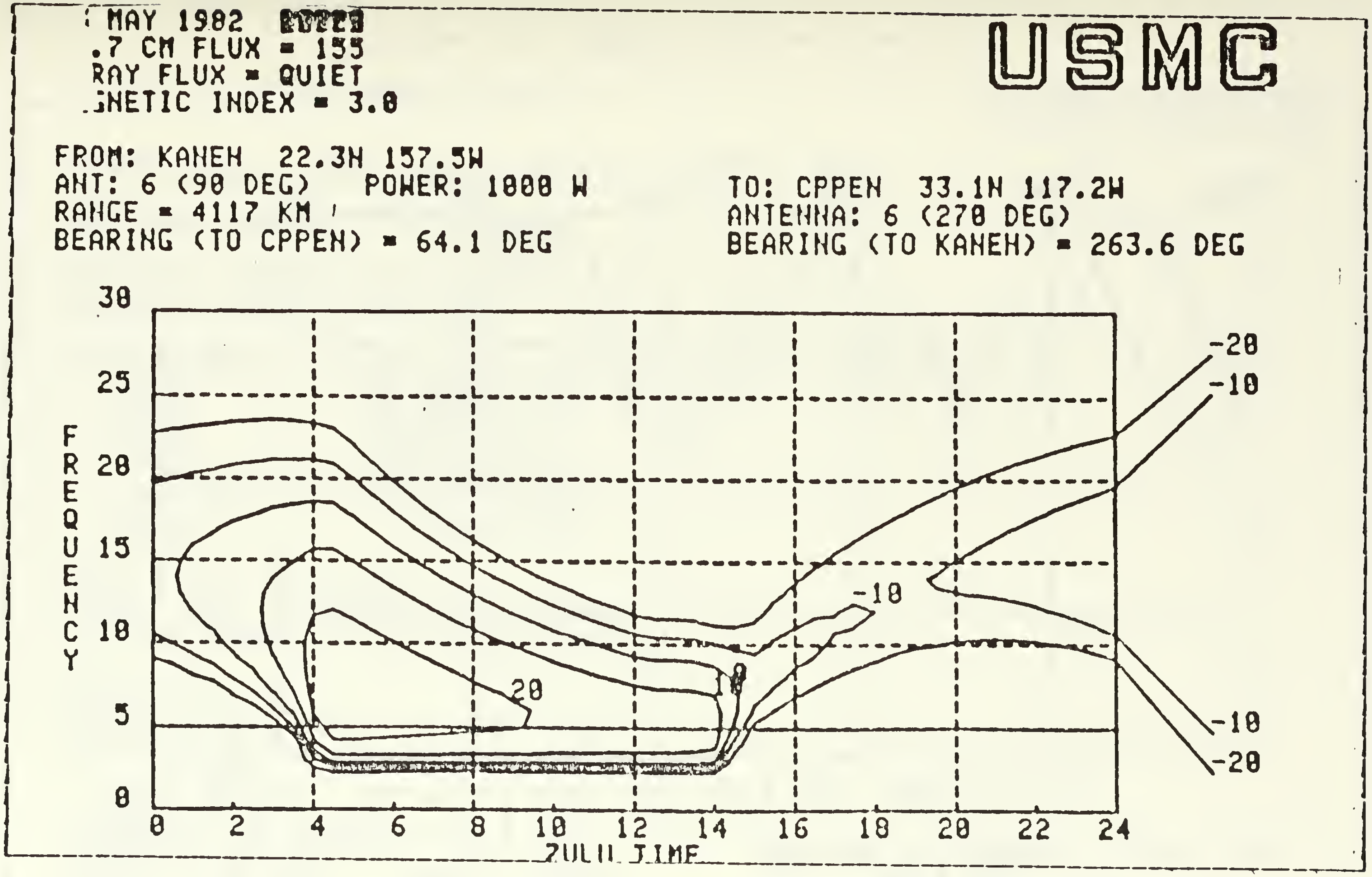
(3) Environmental Noise Report. An example of this report is shown in figure 1.4 Note that the total noise indicated is for a specific time and frequency. One would run this program for every two hour period and on each frequency available to obtain all the noise information needed. [Ref. 2]

b. ECAC Reliability Report.

The communicator can request the reliability report from the Environmental Compatibility Analysis Center (ECAC). In the request he should specify the local station coordinates, outstation coordinates, radio power, and antenna that he will employ. The report as shown in figure 1.5 from [Ref. 3:p 153] lists the reliability[3] of communications one should expect during each hour of the day across the HF band. Optimum TOA is listed in the right hand column.

---

[3] Reliability is the probability of obtaining the required signal-to-noise ratio at the receiver.

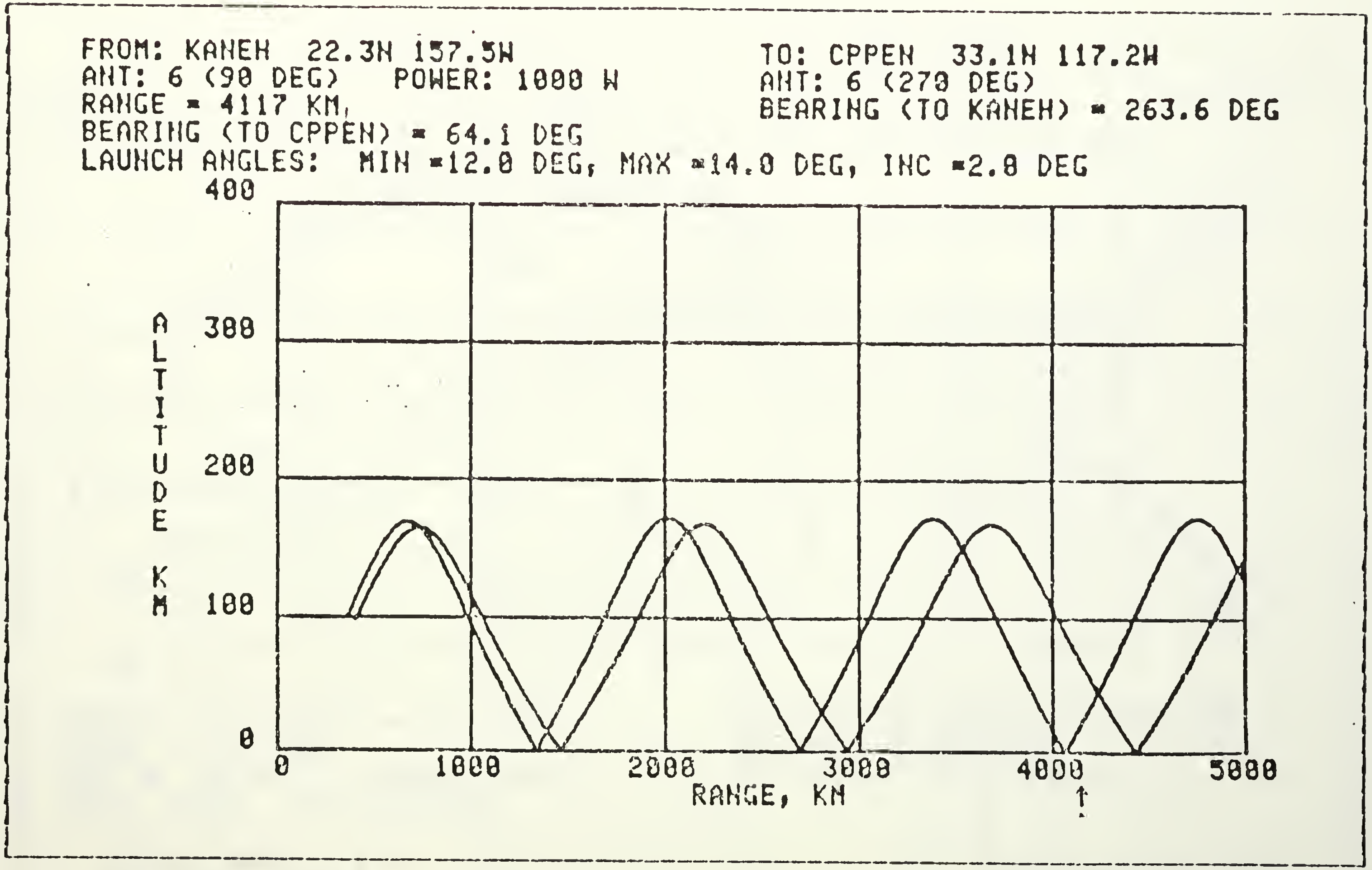


MAY 1982
.7 CM FLUX = 155
RAY FLUX = QUIET
GNETIC INDEX = 3.0

FROM: KANEH 22.3N 157.5W
ANT: 6 (90 DEG) POWER: 1000 W
RANGE = 4117 KM
BEARING (TO CPPEN) = 64.1 DEG

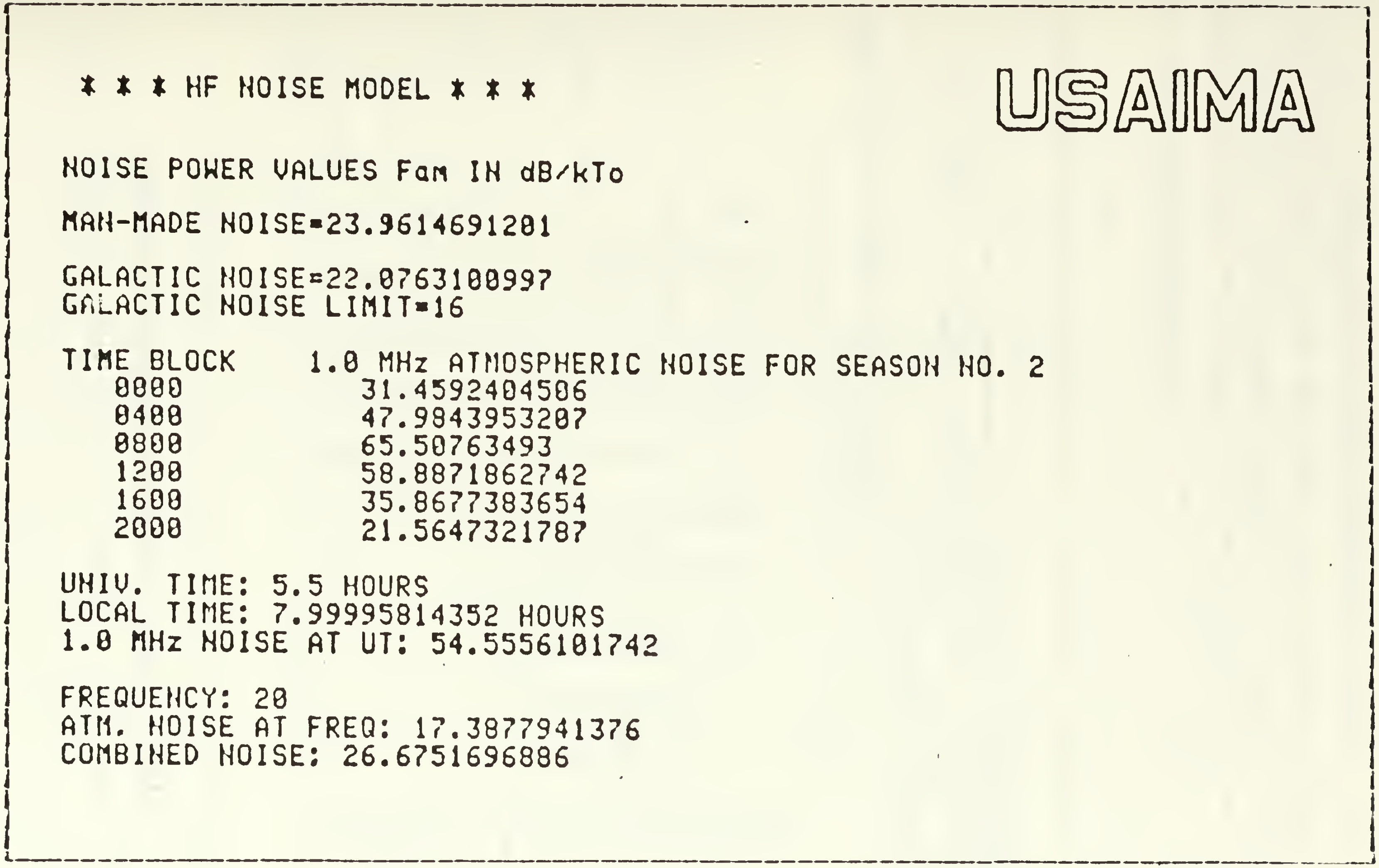
TO: CPPEN 33.1N 117.2W
ANTENNA: 6 (270 DEG)
BEARING (TO KANEH) = 263.6 DEG

Figure 1.2 Field Strength Plot from PROPHET.



```
FROM: KANEH  22.3N 157.5W                     TO: CPPEN  33.1N 117.2W
ANT: 6 (90 DEG)   POWER: 1000 W               ANT: 6 (270 DEG)
RANGE = 4117 KM,                              BEARING (TO KANEH) = 263.6 DEG
BEARING (TO CPPEN) = 64.1 DEG
LAUNCH ANGLES:  MIN =12.0 DEG, MAX =14.0 DEG, INC =2.0 DEG
```

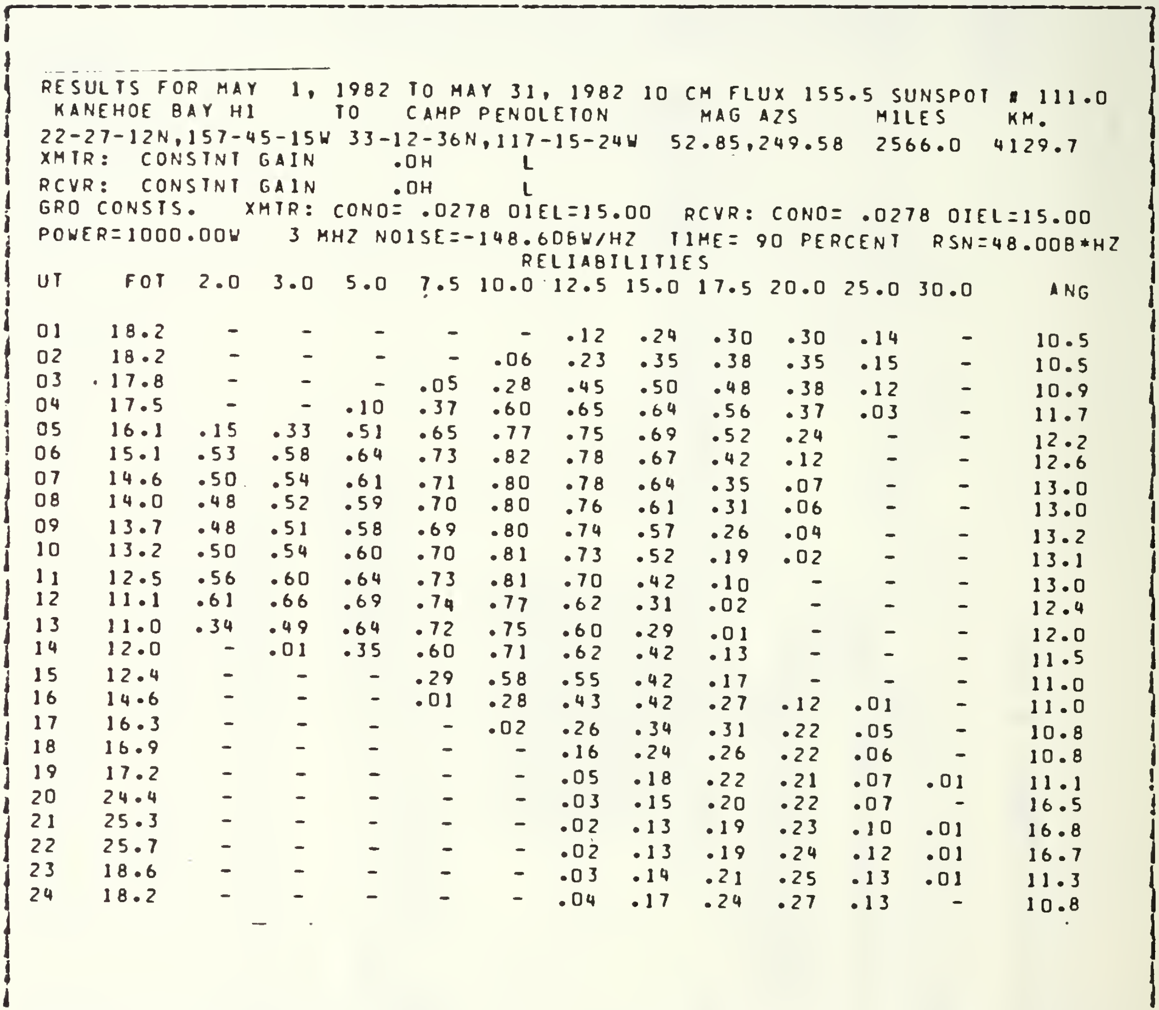
Figure 1.3 PROPHET Raytrace product.



```
* * * HF NOISE MODEL * * *                                    USAIMA

NOISE POWER VALUES Fam IN dB/kTo

MAN-MADE NOISE=23.9614691201

GALACTIC NOISE=22.0763100997
GALACTIC NOISE LIMIT=16

TIME BLOCK    1.0 MHz ATMOSPHERIC NOISE FOR SEASON NO. 2
   0000           31.4592404506
   0400           47.9843953207
   0800           65.50763493
   1200           58.8871862742
   1600           35.8677383654
   2000           21.5647321787

UNIV. TIME: 5.5 HOURS
LOCAL TIME: 7.99995814352 HOURS
1.0 MHz NOISE AT UT: 54.5556101742

FREQUENCY: 20
ATM. NOISE AT FREQ: 17.3877941376
COMBINED NOISE: 26.6751696886
```

Figure 1.4   Environmental Noise Report from PROPHET.

When using this report, the operator would look horizontally accross the row for the particular hour of operation to find the highest reliability. He would then select an available frequency closest to the one at the top of the column in which the highest reliability was found. [Ref. 3]



```
RESULTS FOR MAY  1, 1982 TO MAY 31, 1982 10 CM FLUX 155.5 SUNSPOT # 111.0
 KANEHOE BAY HI      TO   CAMP PENOLETON        MAG AZS      MILES     KM.
22-27-12N,157-45-15W 33-12-36N,117-15-24W  52.85,249.58  2566.0  4129.7
XMTR:  CONSTNT GAIN       .OH      L
RCVR:  CONSTNT GAIN       .OH      L
GRO CONSTS.   XMTR: CONO= .0278 OIEL=15.00  RCVR: CONO= .0278 OIEL=15.00
POWER=1000.00W   3 MHZ NOISE=-148.6DBW/HZ  TIME= 90 PERCENT  RSN=48.008*HZ
                                   RELIABILITIES
UT    FOT  2.0  3.0  5.0  7.5 10.0 12.5 15.0 17.5 20.0 25.0 30.0    ANG

01   18.2    -    -    -    -    -  .12  .24  .30  .30  .14    -    10.5
02   18.2    -    -    -    -  .06  .23  .35  .38  .35  .15    -    10.5
03  .17.8    -    -    -  .05  .28  .45  .50  .48  .38  .12    -    10.9
04   17.5    -    -  .10  .37  .60  .65  .64  .56  .37  .03    -    11.7
05   16.1  .15  .33  .51  .65  .77  .75  .69  .52  .24    -    -    12.2
06   15.1  .53  .58  .64  .73  .82  .78  .67  .42  .12    -    -    12.6
07   14.6  .50  .54  .61  .71  .80  .78  .64  .35  .07    -    -    13.0
08   14.0  .48  .52  .59  .70  .80  .76  .61  .31  .06    -    -    13.0
09   13.7  .48  .51  .58  .69  .80  .74  .57  .26  .04    -    -    13.2
10   13.2  .50  .54  .60  .70  .81  .73  .52  .19  .02    -    -    13.1
11   12.5  .56  .60  .64  .73  .81  .70  .42  .10    -    -    -    13.0
12   11.1  .61  .66  .69  .74  .77  .62  .31  .02    -    -    -    12.4
13   11.0  .34  .49  .64  .72  .75  .60  .29  .01    -    -    -    12.0
14   12.0    -  .01  .35  .60  .71  .62  .42  .13    -    -    -    11.5
15   12.4    -    -    -  .29  .58  .55  .42  .17    -    -    -    11.0
16   14.6    -    -    -  .01  .28  .43  .42  .27  .12  .01    -    11.0
17   16.3    -    -    -    -  .02  .26  .34  .31  .22  .05    -    10.8
18   16.9    -    -    -    -    -  .16  .24  .26  .22  .06    -    10.8
19   17.2    -    -    -    -    -  .05  .18  .22  .21  .07  .01    11.1
20   24.4    -    -    -    -    -  .03  .15  .20  .22  .07    -    16.5
21   25.3    -    -    -    -    -  .02  .13  .19  .23  .10  .01    16.8
22   25.7    -    -    -    -    -  .02  .13  .19  .24  .12  .01    16.7
23   18.6    -    -    -    -    -  .03  .14  .21  .25  .13  .01    11.3
24   18.2    -    -    -    -    -  .04  .17  .24  .27  .13    -    10.8
```

Figure 1.5 Reliability Report from ECAC.

This single report contains all the information which would have to be compiled from the three Prophet products discussed above. Although ECAC's report is better, one must allow days between request and receipt.

2. Antenna analysis.

One may use one of three methods to determine the radiation patterns of antennas -- Numerical Electromagnetics Code (NEC) developed at the Lawrence Livermore Laboratory for large computer installations, MININEC a cut down version of NEC written in basic for microcomputer analysis and the Accessible Antenna Package (APACK) another microcomputer based program developed for ECAC.

a. Numerical Electromagnetics Code (NEC)

The technique used to analyze the antennas in NEC is the Method of Moments (MOM). In the program the functional electromagnetic field equations are reduced to a set of equations that can be handled in a straight-forward fashion using matrix manipulation on a digital computer [Ref. 4]. This method is used for modeling the antenna and its immediate environment. First the input impedance and current distribution on the antenna are found, from this the antenna gain and radiation pattern can be determined. The NEC program provides performance estimates on antennas in free space, over perfectly conducting ground or finite conducting ground which is a good approximation to the true field condition. [Ref. 5]

b. MININEC

The most commonly used options in NEC are available in MININEC. [Ref. 6] It cannot estimate radiation patterns over finite ground.

c. Accessible Antenna Package (APACK)

This is a set of subroutines which evaluate analytic expressions to determine the radiation patterns of several wire antennas. The routines can evaluate antenna modeled in free space, over perfect conducting and finite conducting ground. The routines can be installed in a microcomputer. [Ref. 7]

C. STUDY OBJECTIVES

Propagation analysis, antenna design, and frequency selection are skills that require detailed training to master. Although several computer based tools are available, the outputs of each must be analyzed and fed to others and only a skilled communicator can apply the information and engineer a reliable communications link.

The objective of this study is to develop a microcomputer based program which combines the capabilities of propagation path analysis, antenna design and frequency selection. It will require only a limited amount of input, listed in table 1 and its output will be instructions on antenna construction and frequency useage.

The program can be divided into two distinct areas. Chapter II covers the first area -- propagation path and noise analysis. The procedure for carrying out this analysis is shown in the flow chart of figure 1.6 The second area, antenna design and evaluation is discussed in Chapter III; figures 1.7 and 1.8 show the processes developed in that Chapter.

Chapters II and III cover the computer algorithm in a general manner and the theory behind the processes are discussed. The detailed algorithm appears as Appendix B.

TABLE 1

Computer program input

Frequencies available for operation
Location and names of the local station and outstation
Link start time and stop time
Date link is to be operated
10.7 cm Flux
Height of masts available
Length of the antenna site along the azimuth
    to the outstation
Length of Wire available
Type of wire available
WD-1/TT or copper/phosphur Bronze
Resistors and Baluns available
    (i.e., antenna tuning devices)
Transmitter Power
Man-Made Noise Level
    Shipboard
    Business
    Residential
    Rural
    Quiet-Rural
    Quasi-Minimum

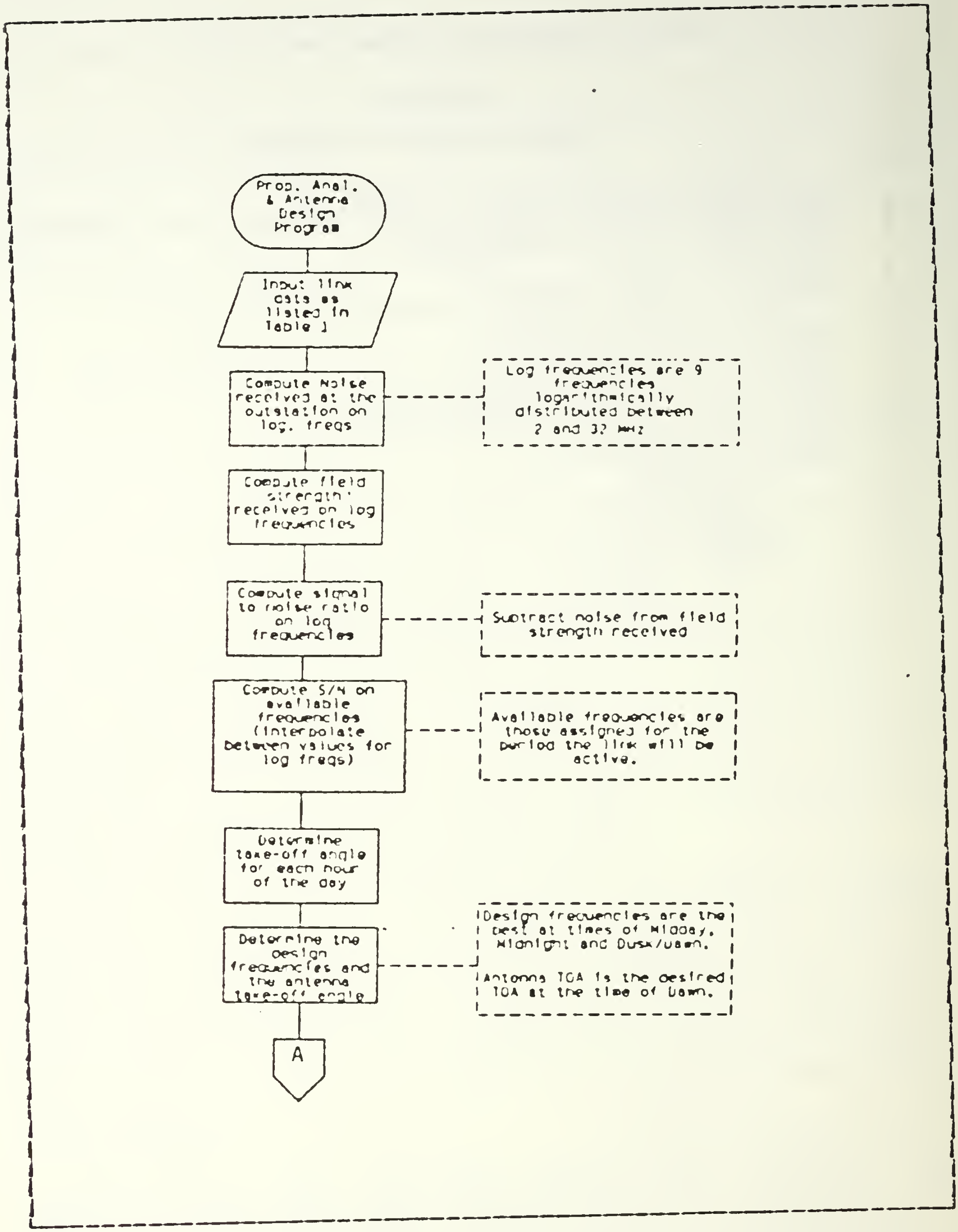


Figure 1.6 Flow chart for propagation and noise analysis.

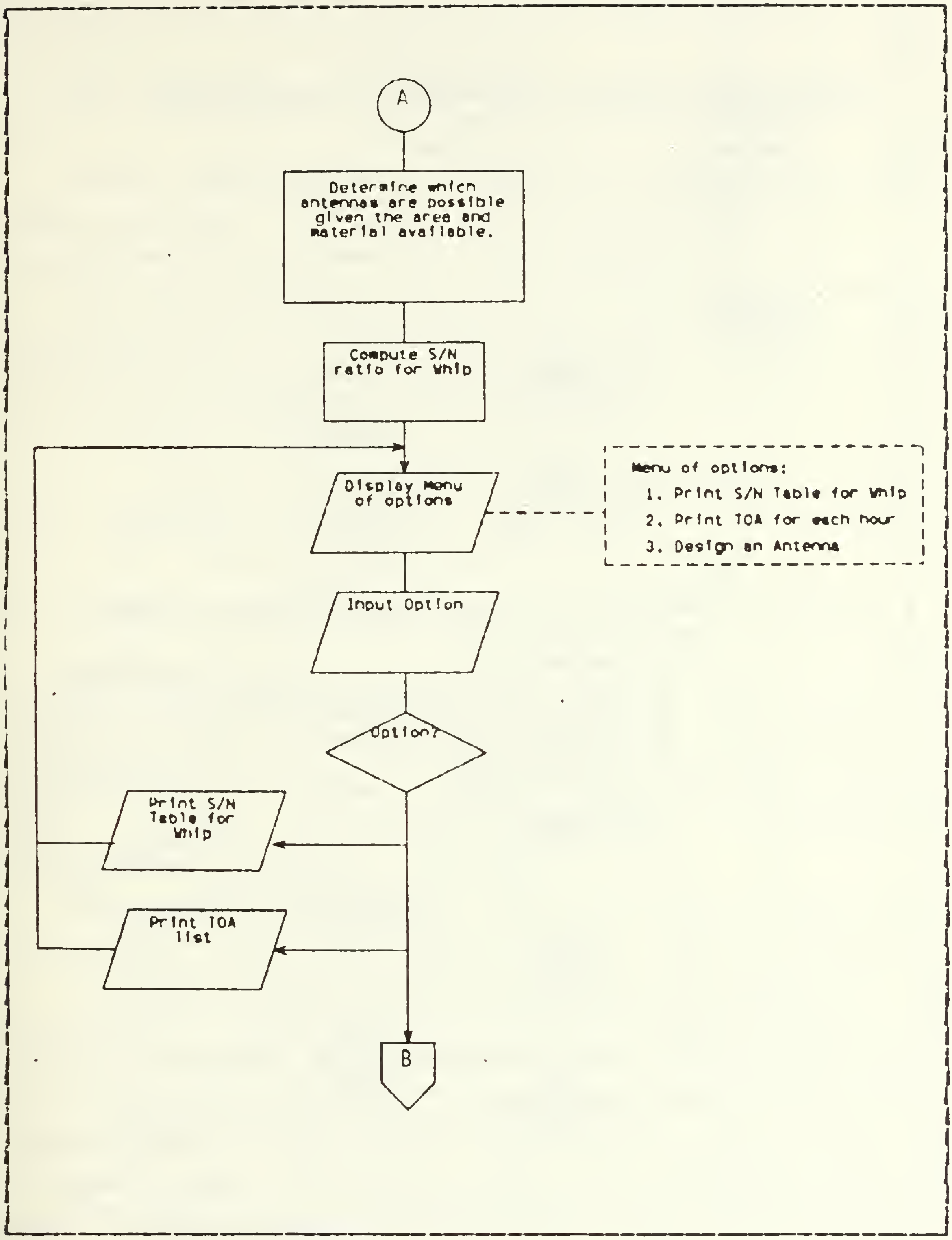


Figure 1.7 Flow Chart of preliminary antenna analysis.

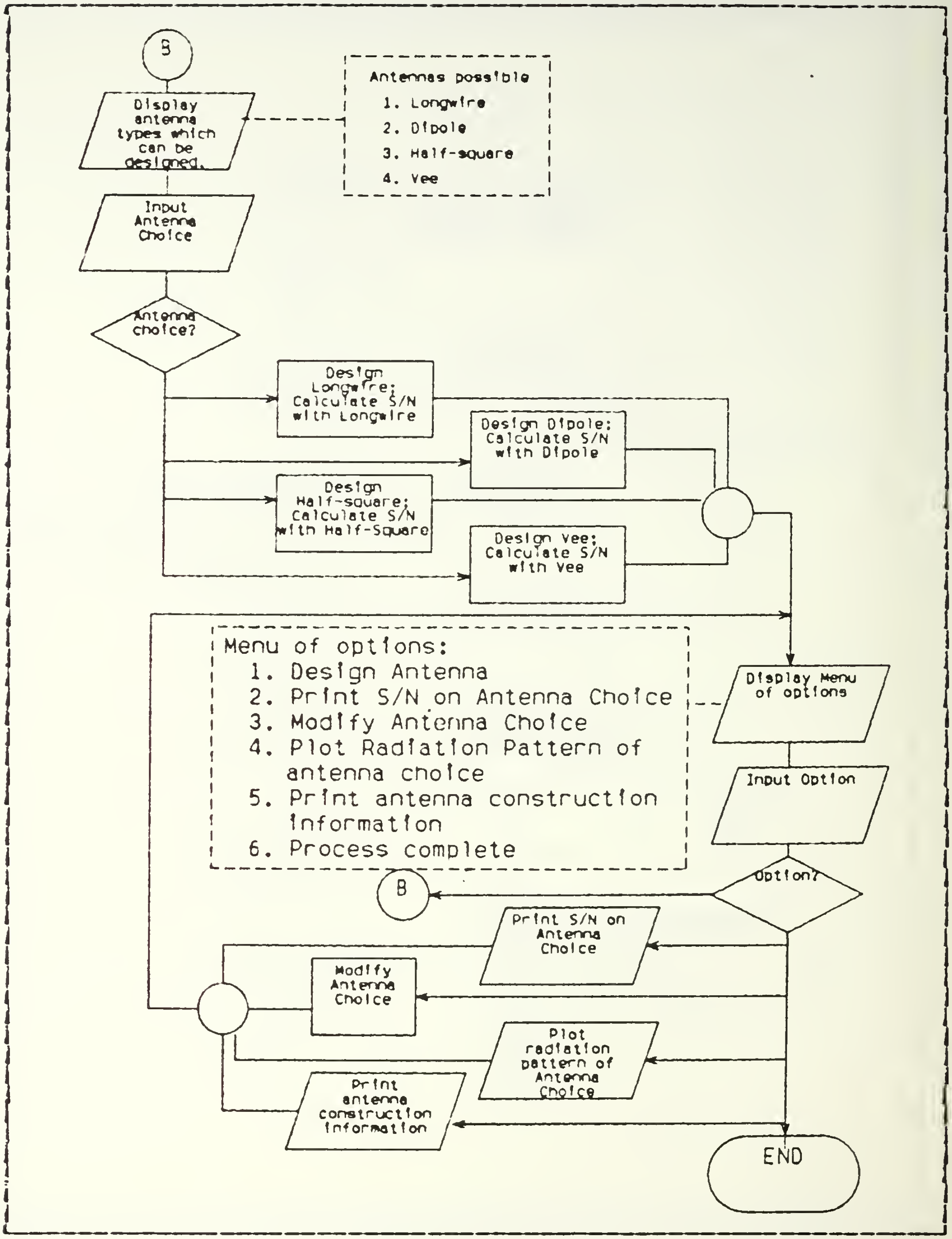


Figure 1.8 Flowchart of antenna design and analysis.

II. PROPAGATION PATH AND NOISE ANALYSIS ALGORITHMS

Within this algorithm all times are local unless otherwise indicated. The local station is referred to as the transmitter and the receiver is the outstation.

The term logarithmic frequencies refers to 9 frequencies logarithmically distributed between 2 and 32 Mhz. Each frequency is determined using equation 2.1 where I is indexed from 2 to 10.

$$f = SQRT(2**I) \qquad (2.1)$$

A. COMPUTE ENVIRONMENTAL NOISE AT THE RECEIVING STATION

The environmental noise is computed for the nine logarithmic frequencies during each hour of the day at the receiver. Sailor's [Ref. 2] noise model is employed to obtain the noise values. This model considers the external noise as being composed of three types -- atmospheric, galactic and man-made.

Atmospheric noise usually dominates below 30 Mhz. It is a function of season, location, time of day and frequency.

Galactic noise may contribute if the noise at the frequency of operation can penetrate the ionosphere. The cut off frequency is determined from the Maximum Useable Frequency Frequency[4] (MUF) corresponding to the Sunspot number (SSN). If galactic noise will contribute to the external noise level on the logarithmic frequency then the median galactic noise is calculated.

---

[4] Signals transmitted on frequencies above the MUF will pass through the ionosphere.

Man-made noise calculations are based on the level specified by the operator to fall into one of six categories that are defined in [Ref. 8] and below:

Rural--locations where land useage
is primarily for agricultural
or similar pursuits, and dwellings
are not more than one every five acres.

Residential-any area used predominantly
for single or multiple family dwellings
with a density of at least two family
units per acre and no large or busy
highways.

Business--any area where the predominant
useage throughout the area is
for any type of business
(e.g., shopping centers,
main streets, or highways
lined with various business
enterprises, etc.)

Shipboard--Aboard ship, noise is
considered equivalent to business

Quiet Rural--less density of human
activity than rural.

Quasiminimum--Less activity than
Quiet Rural.

Each of the three types of noise -- Atmospheric (Na), Galactic (Ng) and Man-made (Nm) are expressed in terms of decibels of respective noise power to the thermal noise density at the outstation. For example the value of Na is given by equation 2.2, where k is Boltzman's constant and T is the absolute temperature (room temperature is 290 degrees Kelvin). The three sources of noise are combined to form a single noise figure (N) in equation 2.3

$$N_a = 10 \, \mathrm{Log}_{10}\left(\frac{\text{Atmospheric Noise Power}}{kT_o}\right) \qquad (2.2)$$

$$N = 10 \, \mathrm{Log}_{10}\left(10^{N_a/10} + 10^{N_g/10} + 10^{N_m/10}\right) \qquad (2.3)$$

B. COMPUTE POWER OF SIGNAL RECEIVED.

Field strength of the received signal is computed for the nine logarithmic frequencies. This process is repeated for each hour of the day. Calculations are made using Martin's [Ref. 1] Field strength module. Damboldt's equation (equation 2.4 (derived in [Ref. 9]) provides the field strength (F) at the antenna in microvolts/meter; given the free space field strength (Fo), Maximum useable frequency (MUF=fm) Lowest Useable Frequency (LUF=fl)[5] and frequency of

$$F = \frac{F_o(1 - f_m^2 x I)}{F_m^2 + F_1^2} \qquad \text{where:} \quad I = (F_1/F_m)^2 + (F/F_m)^2 \qquad (2.4)$$

operation (f). Free space field strength is computed using equation 2.5 given transmitted power in watts (P) and path

$$Fo = 20 \, \mathrm{Log}_{10}(300000 \sqrt{P}/R) \qquad (2.5)$$

length in kilometers (R). Equation 2.6 relates F to the signal power (S) at the receiver relative to kTo. In this equation η is free space impedance (120 * pi) with units of ohms, Aeff is the effective aperture of the antenna given by equation 2.7 and GdBi equals the antenna gain over an isotropic radiator.

---

[5] Signals transmitted on frequencies below the LUF will be absorbed by the ionosphere.

$$S = \left[F-120\right]_{dBW} + A_{eff} - 10\, Log_{10}(KT_o) \qquad (2.6)$$

$$A_{eff} = G_{dBi} + 10\, Log_{10}(\lambda^2/4\pi) \qquad (2.7)$$

C. COMPUTE SIGNAL TO NOISE RATIO

Using equation 2.8 the signal to noise ratio is computed for each of the logarithmic frequencies for each hour of the day, the results are stored in the matrix variable S/N_RATIO_ON_LOG_FREQUENCIES. By interpolating between adjacent logarithmic frequencies a signal to noise figure is computed for the available frequencies and the results of this process are stored in the matrix variable S/N_RATIO_ON_AVAILABLE_FREQUENCIES. An example of the latter table is listed in table 2.

$$S/N = S - N \qquad (2.8)$$

D. DETERMINE TAKE-OFF ANGLES

Given the ionosphere layer height and great circle distance the TOA is determined using table 3 (derived from [Ref. 10).] The height is obtained from a process Martin used in his Ray Trace module. Ref. 1]In the process, the height is calculated at seven points along the propagation path; the value used in the program is the average of those heights calculated.

E. DETERMINE THE DESIGN FREQUENCY AND ANTENNA TOA.

Three design frequencies are determined in this process. The first is the best frequency for which highest S/N is predicted at midday, the second design frequency is the best at Midnight, and the third is the average of the best frequencies for a 24 hour period.

TABLE 2

S/N_RATIO_ON_AVAILABLE_FREQUENCIES, (example)

		3.2	4.5	6.4	10.0	17.0	25.0
	1	8	8	12	14	7	7
	2	9	10	13	14	3	-30
	3	10	11	14	14	1	-33
	4	5	8	13	13	0	-34
	5	0	5	11	12	2	-35
T	6	-8	-7	3	10	2	-37
I	7	-9	-8	-1	3	4	-9
M	8	-15	-14	-13	-1	3	-1
E	9	-20	-18	-15	-9	3	0
	10	-25	-20	-17	-10	3	0
	11	-30	-25	-18	-11	2	1
L	12	-35	-28	-20	-12	2	2
O	13	-35	-28	-20	-11	2	1
C	14	-35	-30	-18	-6	2	2
A	15	-30	-28	-18	-5	2	2
L	16	-25	-20	-16	-2	4	2
	17	-20	-18	-12	0	5	2
	18	-15	-12	-5	4	7	1
	19	-8	0	4	12	10	0
	20	2	5	12	14	10	-2
	21	6	7	12	15	9	-15
	22	5	9	14	7	3	-20
	23	6	7	14	14	1	-12
	24	7	7	10	12	5	5

TABLE 3

Take-off Angle

DISTANCE IN KILOMETERS	Ionosphere Layer Height								
	100	150	200	250	300	350	400	450	500
2000	3	3	6	9	12	15	15	18	18
1370	6	12	15	18	21	24	27	30	33
945	9	15	21	27	30	33	39	42	42
650	15	24	30	36	42	45	48	54	57
445	24	33	42	45	51	57	60	63	66
305	33	42	51	57	60	66	69	69	72
210	42	54	60	66	69	72	75	75	78
145	57	66	72	75	75	78	81	81	81
100	66	72	75	78	81	81	81	84	84

Analysis is first carried out on the S/N values for the logarithmic frequencies. The best frequency for each hour of operation is determined and their average is calculated. One can assume that the best frequency will be low (below the average value) at night and high during the day. A low to high transition of best frequency through the average value indicates the time is dawn; a high to low transition indicates time is dusk. The time halfway between dawn and dusk is taken to be midday; and midnight is halfway between dusk and dawn.

An available frequency closest to the best logarithmic frequency at midday is chosen as the first design frequency; similarly the second design frequency is chosen at midnight. The available frequency closest to the average value is chosen as the third design frequency.

The program bases initial antenna designs on the antenna-TOA which is also calculated in this routine. It is simply the preferred TOA at the time of dawn.

III. ANTENNA DESIGN AND EVALUATION ALGORITHM

A. GENERAL

Output from that portion of the algorithm covered in the last chapter is required as input into the antenna design and evaluation processes. Initial design on all the antennas will be based on the design frequencies and antenna take-off angle previously determined. As a measure to evaluate each antenna a signal to noise table (S/N_RATIO_ON_ANTENNA) will be developed by adding the antenna gain (at the TOA and along the azimuth to the out-station) to the corresponding (frequency and hour) value in the table -- S/N_RATIO_ON_AVAILABLE_FREQUENCIES. The S/N_RATIO_ON_ANTENNA table will be of the same format as table 2.

For the whip S/N_RATIO_ON_ANTENNA is automatically generated immediately after the propagation path and noise analysis is complete. A new S/N_RATIO_ON_ANTENNA will automatically be generated immediately after other antennas are designed or modified. These S/N_RATIO_ON_ANTENNA tables should be compared to determine the benefits of constructing each antenna.

Several options are available to the operator for design and evaluation on four antennas -- longwire, dipole, half-square and vee. Each antenna is handled by the program in a unique manner. In the following presentation the procedures for designing and evaluating each antenna will be covered in a separate section. Example instructions for the construction and use of each antenna appears in Appendix C.

Appendix A describes the computer models and procedures used to obtain the pattern data for each antenna.

B. LONGWIRE

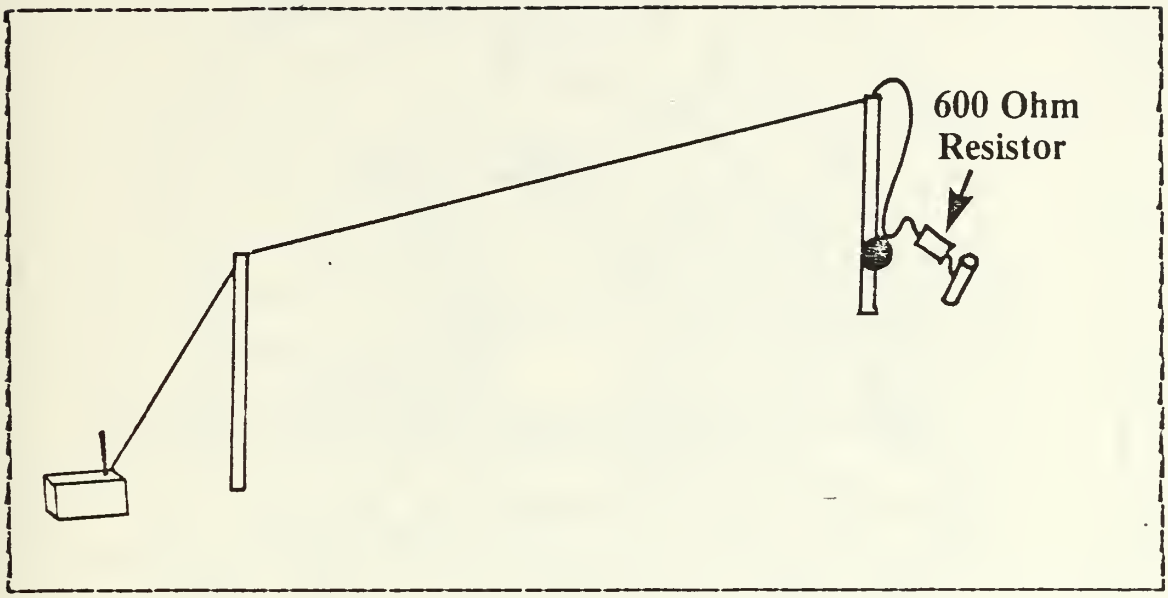


Figure 3.1 Longwire Antenna Field Configuration.

1. General.

Figure 3.2 depicts the one dimensional radiation pattern of a Longwire antenna in freespace. The number of lobes and the magnitude of the main lobe increase with an increase[6] in the length of the wire. [Ref. 11:pp. 7-1,7-3] Also the angle (wave angle) between the center of the main lobe and the antenna decreases as the length of the wire is increased. One can determine the waveangle for a given length (in wavelengths) by using the aid depicted in Figure 3.3.

To obtain the three dimensional radiation pattern one would rotate the pattern of figure 3.2, around the

---

[6] In this context increase in the number of wavelengths.

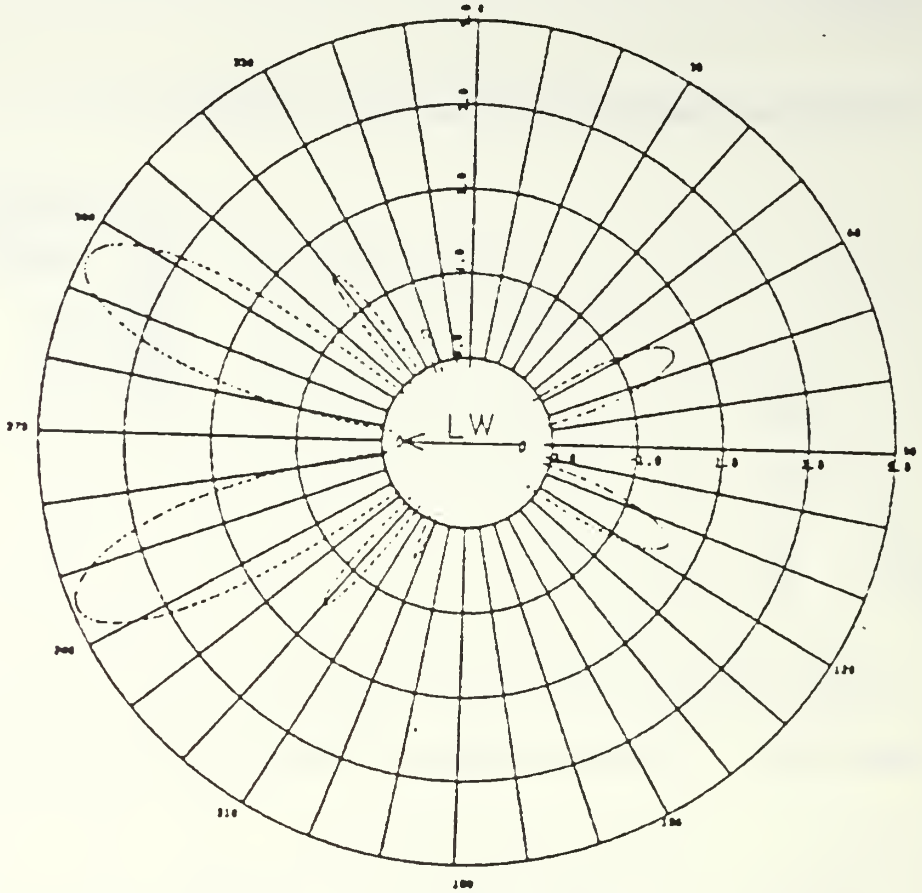


Figure 3.2   Longwire radiation pattern in free space.

antenna axis. In so doing a line through the center of the main lobe would trace out a hollow cone as shown in Figure 3.4.

The half cone depicted in Figure 3.5 represents (approximately) the location of the main lobe when the longwire is mounted horizontally over ground. For best communication a portion of the mainlobe should be aligned with the path (along the azimuth and at the desired take-off angle) to the outstation. To accomplish this, one must orient the antenna off the azimuth to the outstation by a degree

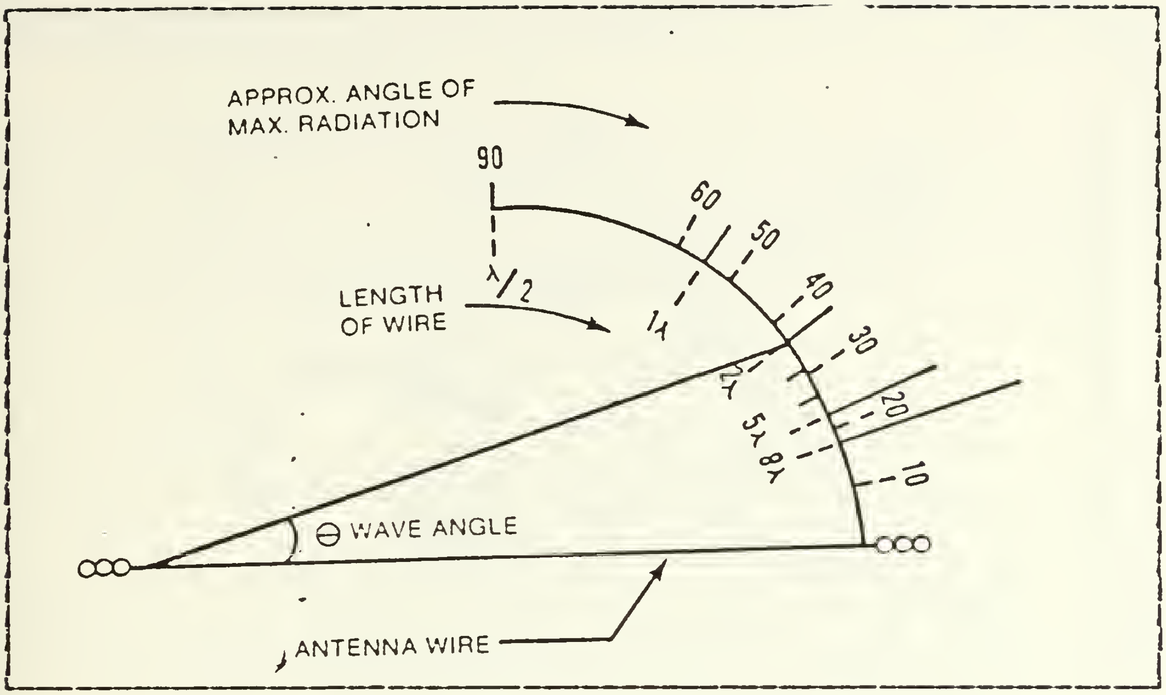


Figure 3.3 Aid to determine wave angle given the longwire length.

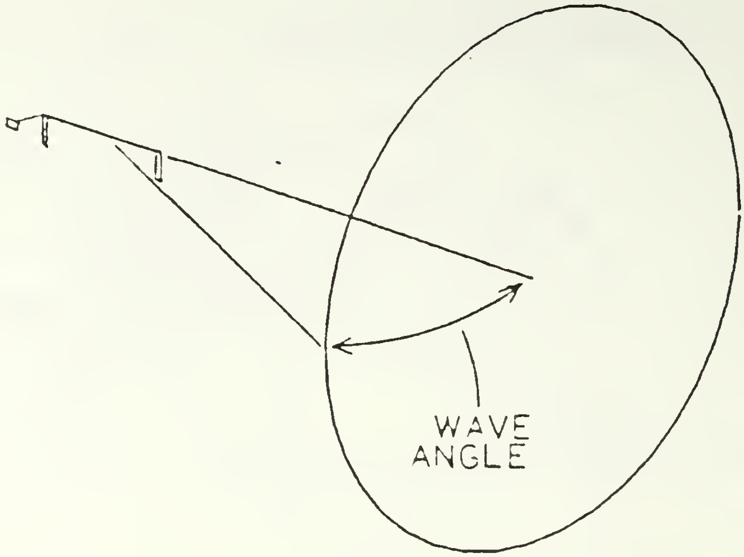
measurement equal to the orientation angle. The law of cosines as specified in equation 3.1 can be used to calculate this angle.

2. Design

Throughout the design process the longwire will be optimized to perform best on the best frequency (DESIGN_FREQ(3)) during the time of dusk and dawn and for the desired take-off angle at dawn (ANTENNA_TOA).

a. Dimensions

(1) Height. Each end of the longwire should be erected as high as possible. The end closest to the radio will be set at the tallest mast (Mast (1)) height and the far end will be set at the next tallest mast (Mast (2)) height.



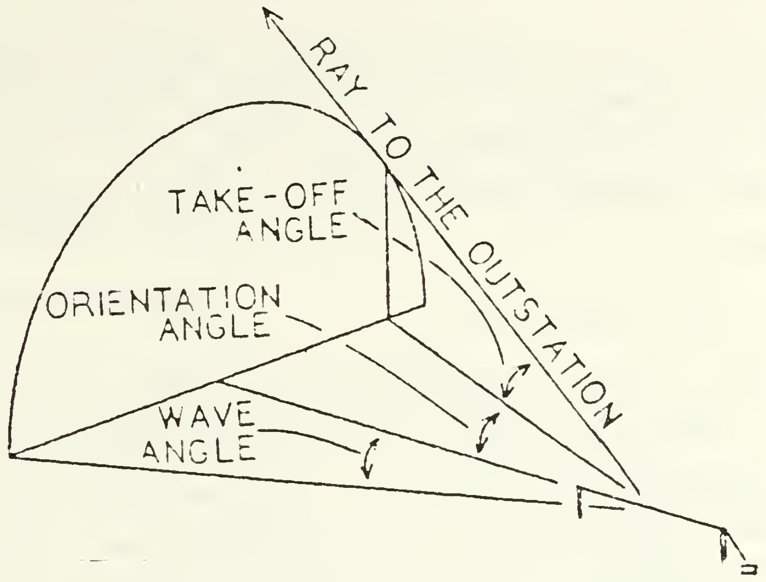
(Cone representing the center of the main lobe rotated around the longwire)

Figure 3.4 Main lobe trace (3 dimensional) for longwire.

(2) Length. One should construct the longwire as long as possible to obtain the highest gain. Maximum length is determined by first considering the desired take-off angle; the antenna should be sufficiently short that the take-off angle is less than or equal to the wave angle, otherwise regardless of the antenna orientation the main lobe will under shoot the path trace to the outstation.

The second criteria for establishing the maximum length, is the actual length of wire available and length of the operation site.

Given the maximum length of the longwire, the electrical length can be determined. A single wavelength is calculated using equation 3.2. The variable FACTOR



(Half cone representing the main lobe trace of a longwire erected over ground.)

Figure 3.5 Longwire orientation diagram.

$$\text{ORIENTATION\_ANGLE} = \text{Arccos}(\text{Cos}(\text{WAVE\_ANGLE})/\text{Cos}(\text{TAKE\_OFF\_ANGLE})) \tag{3.1}$$

is determined by equation 3.3 if the antenna wire is 'WD-1/TT'.[7] For copper or phosphur bronze antenna wire, FACTOR equals 984.

$$\text{WAVELENGTH} = \text{FACTOR}/\text{DESIGN\_FREQUENCY} \tag{3.2}$$

---

[7] This formula was determined experimentally.

FACTOR = 973 - (.328*DESIGN_FREQUENCY) (3.3)

It is desired that the electrical length be an odd multiple of a quarter wavelength minus five percent for end effects (e.g., 1.2, 1.7, 2.2, 2.7, etc.). At these lengths the radio will most easily tune to the antenna.

b. Orientation

Once the electrical length of the antenna is known, the wave angle can be determined from figure 3.3 and the orientation angle in turn can be calculated using figure 3.5 and equation 3.2 The azimuth along which the antenna should be aligned is the azimuth to the outstation plus or minus the orientation angle.

c. Terminating Resistor

If a 300-600 ohm resistor is available it can be connected between the far end of the longwire and a ground stake. The resistor must be rated to dissipate at least 1/3 of the output power of the transmitter. One might additionally connect a counterpoise (a wire) between the radio ground and the low end of the terminating resistor. The resistor will cause four major changes to the antenna's characteristics:

(1) The input impedance of the antenna will increase to 300-600 ohms.

(2) The antenna will be broader banded making it possible for the radio to easily tune to many more frequencies.

(3) The radiated power in the major lobe will decrease by approximately 2 dB.

(4) The antenna will poorly transmit and receive signals to and from the rear.

3. Modifications

After the longwire is initially designed the program accepts instructions to reset the height of each end, the antenna length, and/or the azimuth along which the antenna will be aligned. After each modification the program reevaluates communications.

4. Radiation patterns

Gain data is stored for longwires .125, .25, .45, .75 and 1.5 wavelengths above the ground, and for 1, 2, 3, 4, 6 and 8 wavelengths long. The pattern data for each model represents 11 vertical cuts through the calculated pattern, with a cut taken every 3 degrees from 0 out to 30 off the vertical plane passing through the wire axis.

The program retrieves the particular pattern data for the longwire which most closely approximates the dimensions of the one designed for the link, and the cut within the pattern data corresponds to the angle which approximates the orientation angle.

5. Antenna Feed

The input impedance of the longwire antenna (when it is an odd multiple of one quarter wavelength long) is between 100 and 200 ohms if the antenna is unterminated, otherwise it is between 300 and 500 ohms. This antenna is usually connected directly to the output of the radio coupler, an impedance matching device. If the antenna is to be fed with a coaxial cable (characteristic impedance is 50-75 ohms), then a 4:1 transformer is needed between the coaxial cable and the antenna when the longwire is unterminated, and a 9:1 transformer is needed when the antenna is terminated.

C. DIPOLE

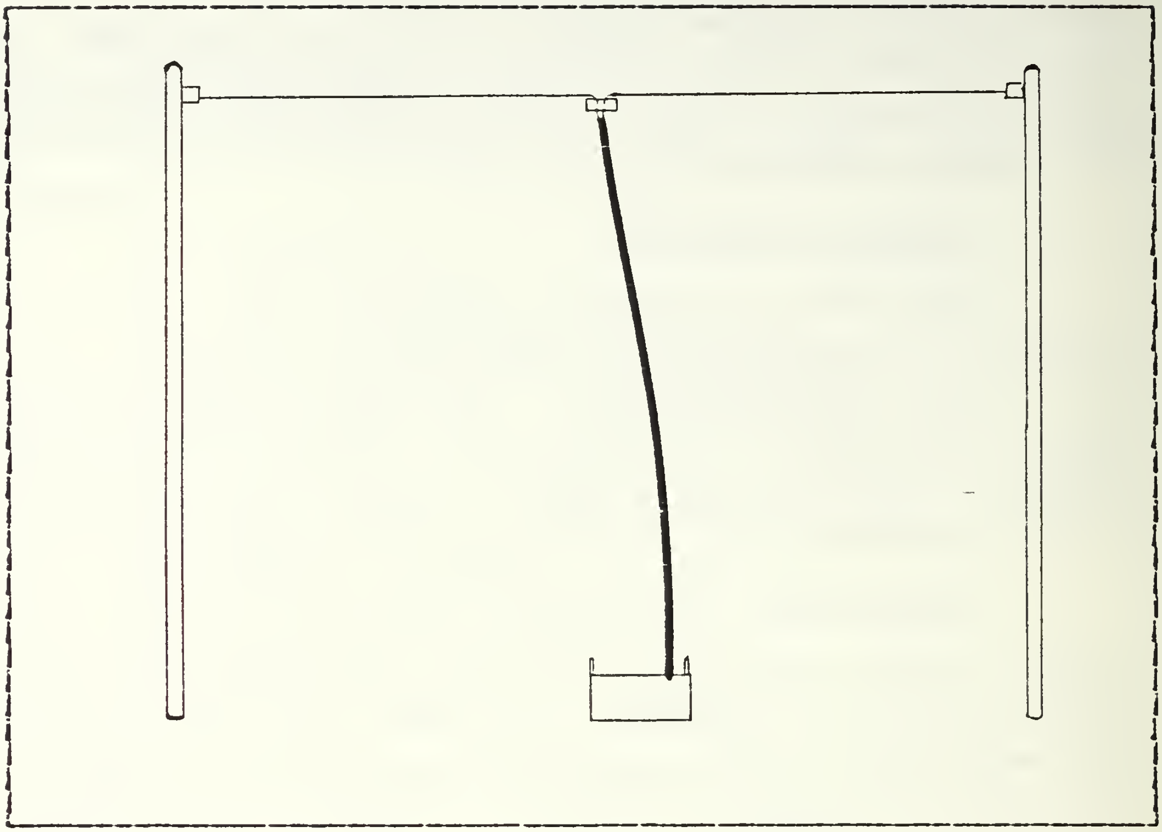


Figure 3.6 Dipole antenna Field configuration.

1. General

Figure 3.7 depicts the radiation pattern of the dipole in free space. A dipole constructed 1/2 wavelength above ground would create the radiation pattern of figure 3.8. Note from figure 3.8 b) that if the take-off angle to the outstation is between 10 and 50 degrees (distance to the outstation is greater than 400 kilometers) then this antenna will enhance communications.

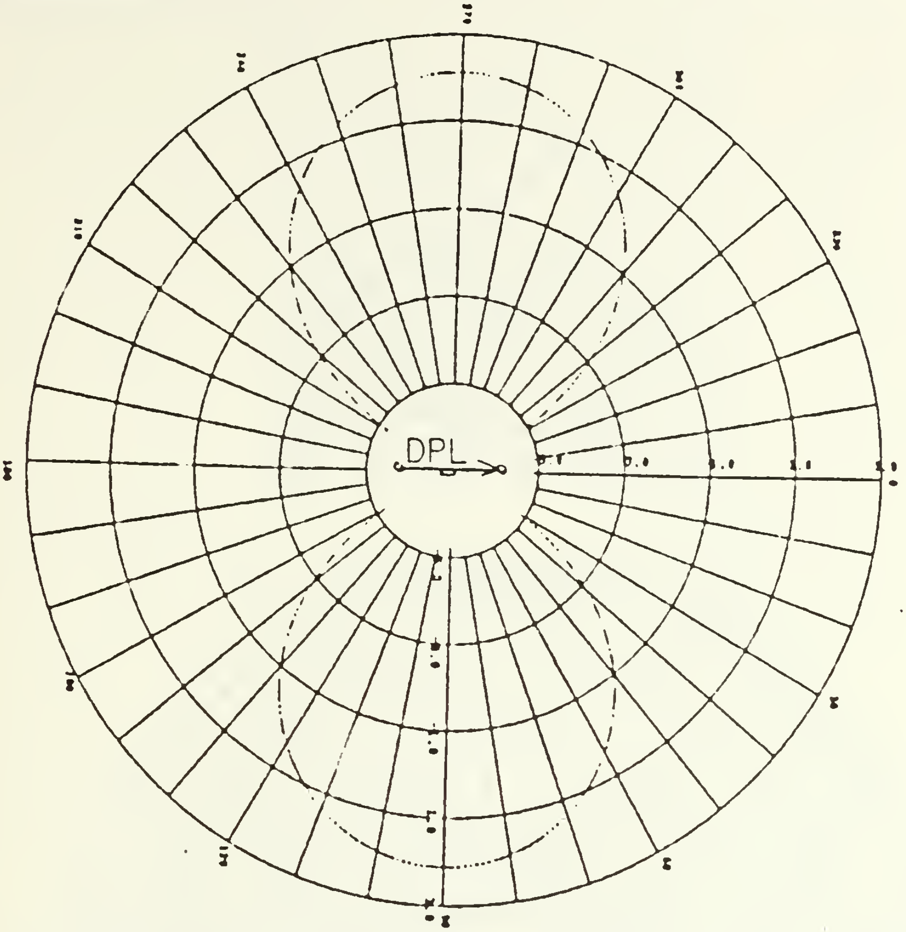
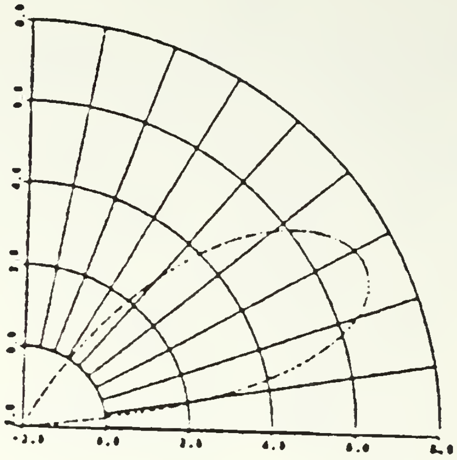


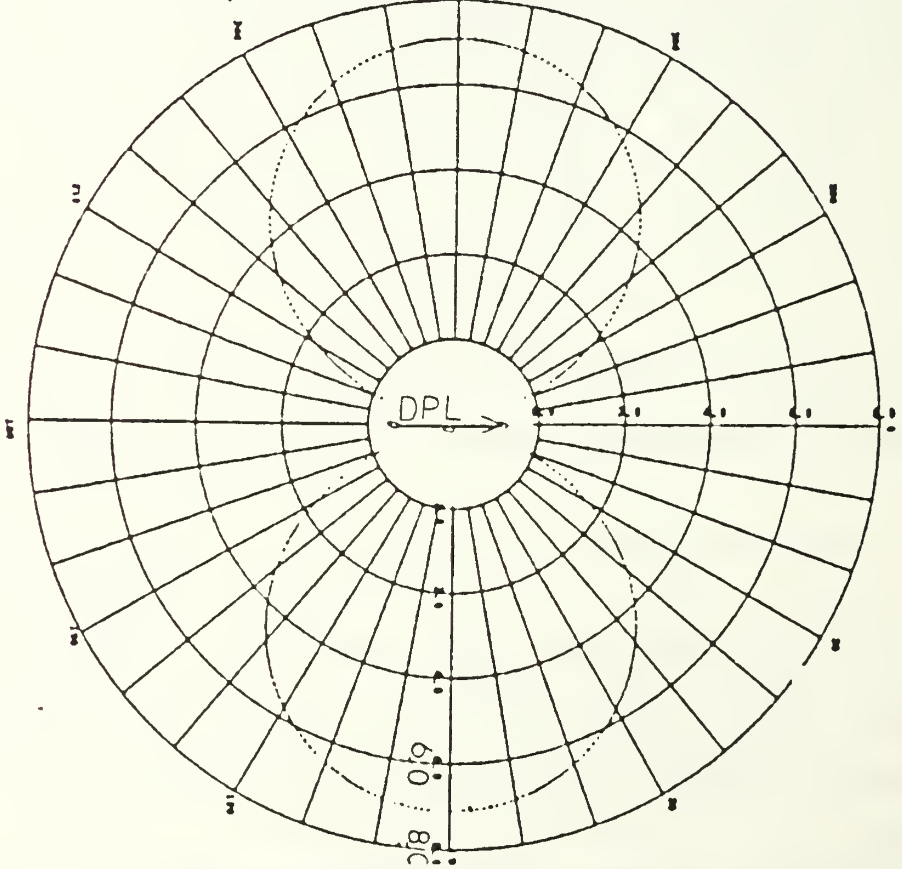
Figure 3.7 Radiation pattern of dipole in free space.

When the antenna is constructed close to ground the majority of the power is reflected upward. This is moreso true if the antenna is less than 1/4 wavelength high. Figure 3.9 depicts the radiation pattern of a dipole 1/10 wavelength above ground. It will enhance communications if the take-off angle to the outstation is between 50 and 90 degrees.

Comparing figure 3.8 a) and Figure 3.9 a), one may note that a dipole constructed for longhaul communications (greater than 400 kilometers) is bidirectional while one for shorthaul is essentially omnidirectional. [Ref. 12]

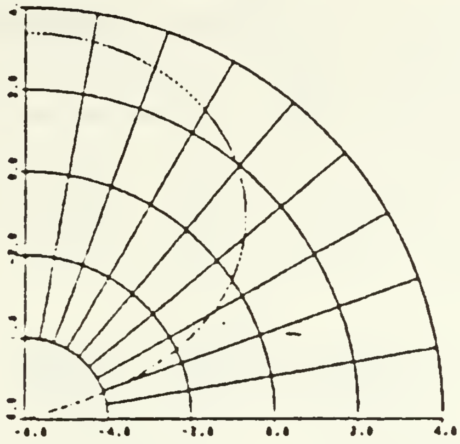


a) Vertical Cut

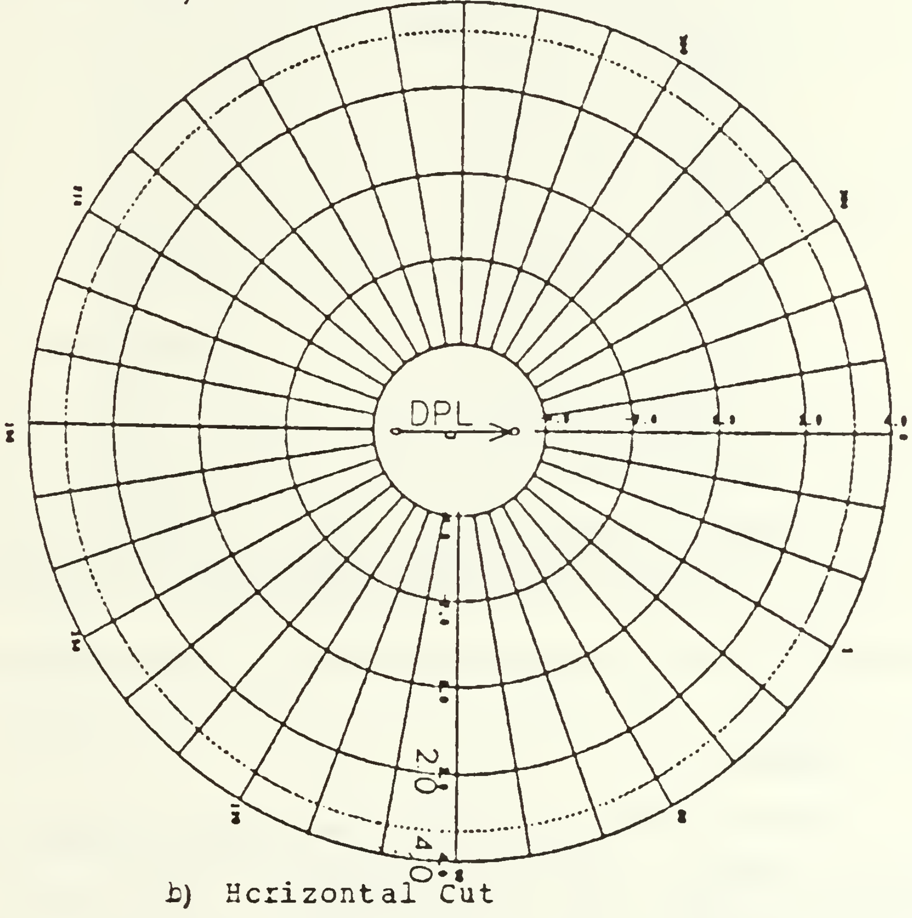


b) Horizontal Cut

Figure 3.8 Dipole radiation pattern (height = 1/2 wavelength).



a) Vertical Cut



b) Horizontal Cut

Figure 3.9 Dipole radiation pattern (height = 1/10 wavelength).

The dipole is a highly selective antenna. From table 4 [Ref. 13: p. 21] one can see that a dipole operated on a frequency just 11 percent below or 6 percent above the design frequency will have an efficiency of less than 50 percent.

TABLE 4

Dipole Selectivity

Transmitter Frequency	Power Radiated by Dipole (watts)
F(design Frequency)	100
0.98F or 1.01F	89
0.96F or 1.02F	75
0.94F or 1.04F	64
0.92F or 1.05F	56
0.89F or 1.06F	49
0.87F or 1.07F	44
0.85F or 1.09F	40
0.83F or 1.10F	36
0.81F or 1.11F	33

Power radiated by a dipole connected to a 100 watt transmitter operated on frequencies around the design frequency.

2. Design

In the design processes the dipole is optimized for the best frequency (DESIGN_FREQUENCY(3)) during the time of dusk and dawn and for the desired take-off angle at dawn. Dimensions of two other dipoles are determined: one set is for DESIGN_FREQUENCY(1) for day operations and DESIGN_FREQUENCY(2) for the night.

a. Dimensions

(1) Height. For links where the take-off angle is less than 50 degrees, the height of the antenna is set by the shorter of the two tallest masts (height of MAST (2)). If the take-off angle is greater than 50 degrees three heights are found, each is set as the lesser of 1/10 of a wavelength (on the three design frequencies) and the height of Mast (2).

(2) Length. Three antenna lengths are found one for each of the three design frequencies.

(3) Orientation. Proper orientation of the antenna is 90 degrees off the azimuth to the outstation. There is some leeway in the manner the dipole is oriented. If the take-off angle is less than 50 degrees then the dipole is bidirectional and the antenna must be properly oriented plus or minus 40 degrees. When the take-off angle is greater than 50 degrees the dipole is omnidirectional and thus it may be oriented along any azimuth.

3. Modifications

After the dipole is first designed by the computer it accepts instructions to reset the design frequencies and/or the height of the antenna. On the new design frequencies the program recalculates the antenna length and height (if it is not already reset by the operator). The communications link is then reevaluated and the results of the modifications can be detected in the table S/N_ON_ANTENNA.

4. Radiation patterns

Gain data is stored for the dipole erected at heights of .125, .25, .45, 0.75 and 1.50 wavelengths. The pattern data for each model is a single vertical cut through the center of the main lobe. The program retrieves the pattern data for the modeled dipole which is closest in height to the one designed for the link.

5. Antenna Feed

The input impedance of the dipole is approximately 60 ohms so a 50 ohm transmission line (coaxial cable) can be used between the radio and the antenna. Although the dipole is a balanced antenna and the coaxial cable is an unbalanced transmission line, a balun (balanced to unbalanced transformer) should not be used[8] between the two; the outer shield of the coaxial cable should be connected to one dipole element and the inner conductor of the cable to the other element.

D. HALF-SQUARE

1. General

Figure 3.11 depicts the radiation pattern of the half-square at 10 degrees above the horizon. the predominance of power radiated is vertically polarized so the angle between the main lobe and the horizon is less than the other antennas (which radiate horizontally polarized signals) discussed in this chapter. This antenna is ideal for long haul communications; for these links the desired TOA is small. [Ref. 15]

Because this antenna is relatively small it is simpler than others to erect. A disadvantage though is that it is narrow banded like the dipole. A different half-square must be cut for each frequency of operation.

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[8] Tests using an airborne transmitter have shown that balanced and unbalanced horizontal half-wave dipole antennas have similar radiation patterns. [Ref. 14]

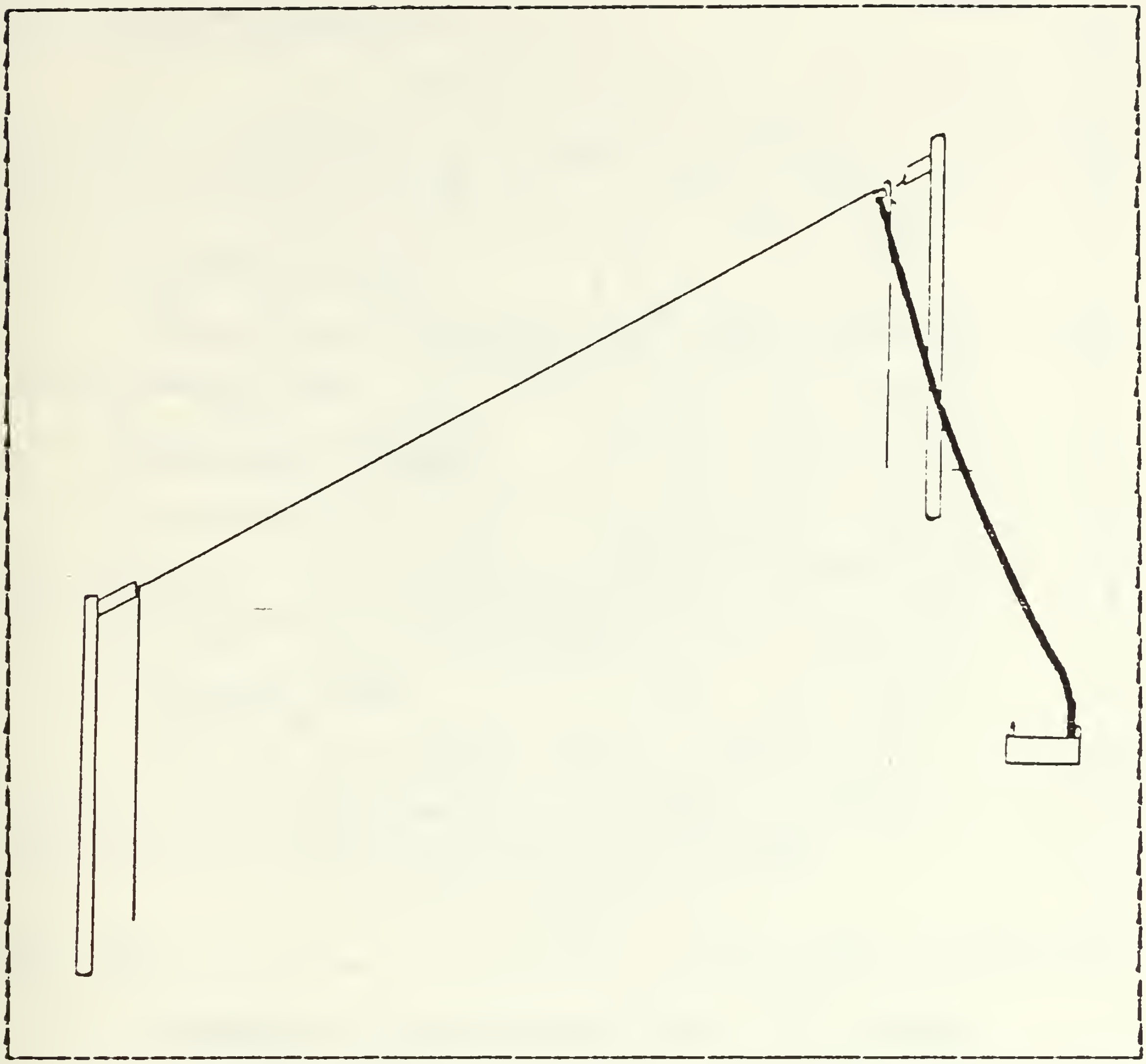


Figure 3.10 Half-square field configuration.

2. Design

In the design process the half square will be optimized for the best frequency (DESIGN_FREQUENCY(3)) at the time of dusk and dawn. Dimensions of two other half-squares will also be determined: one set is for DESIGN_FREQUENCY(1) for day operations and DESIGN_FREQUENCY(2) for the night.

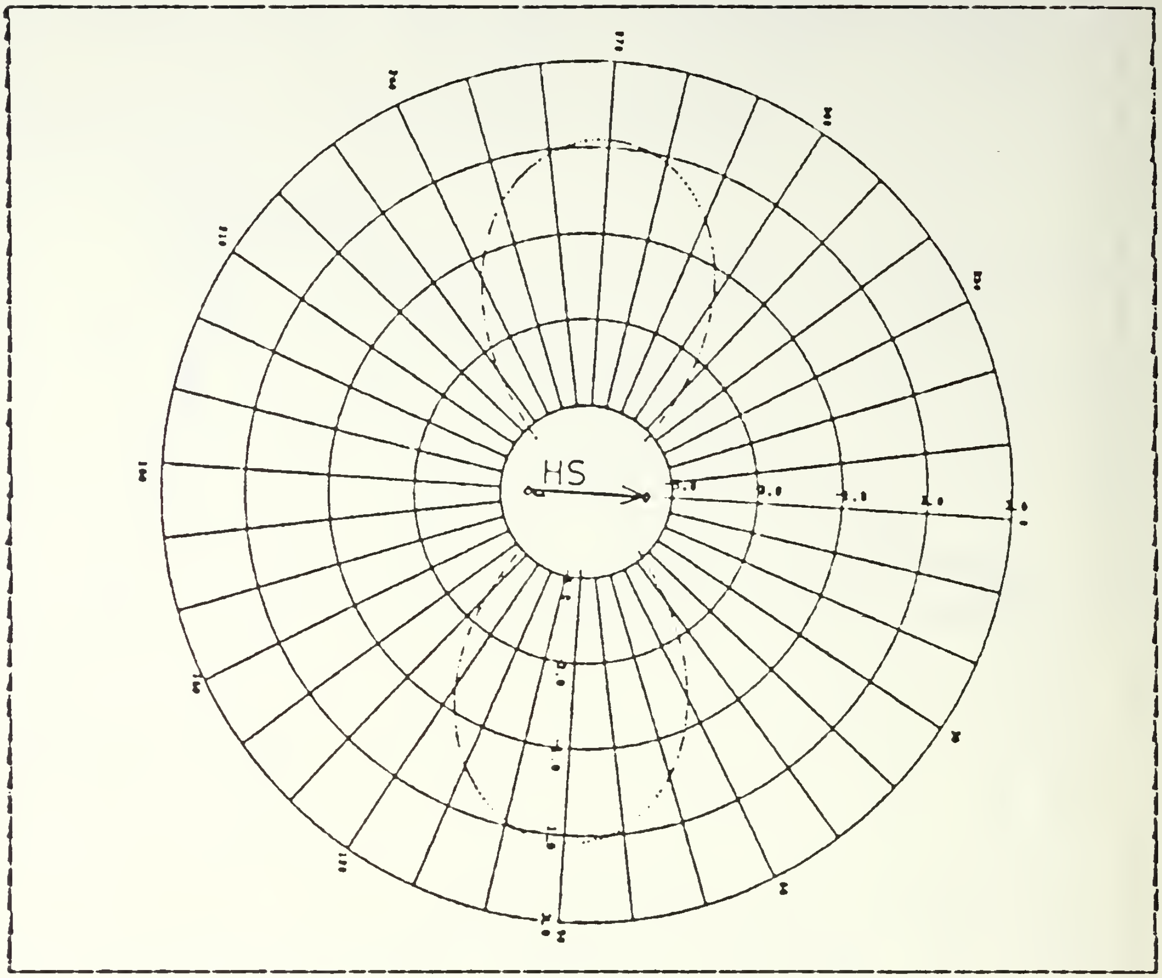


Figure 3.11 Half-square radiation pattern.

a. Dimensions.

The height of the antenna is set to be the shortest of the two tallest masts (MAST(2)). Length of the down legs is 1/4 wavelength[9] and the length of the cross member is 1/2 wavelength. End effects should not be considered in the Calculations.[10]

---

[9] Wavelength is determined using equation 3.2

[10] In field experiments the half-square was found to resonate when the dimensions were calculated using the same factor as for the longwire.

b. Orientation

Proper orientation of the antenna is 90 degrees off the azimuth to the outstation (broadside). One can be off in the orientation by plus or minus 35 degrees.

3. Modifications

The operator is given the option to change only the design frequencies.

4. Radiation Pattern

Gain data is stored for a single version of the half-square. The same pattern data is used to characterize the half-square on all frequencies.

5. Antenna Feed

The input impedance of the half square is approximately 50 ohms [Ref. 16] so a coaxial transmission line can be used between the radio and the antenna.

E. VEE

1. General

The vee antenna is merely a combination of two longwires, the patterns of which combine to form a single major lobe of the shape shown in figure 3.13.

2. Design

a. Dimensions

In so far as the determination of the vee dimensions are concerned, procedures described under "Longwire" above apply.

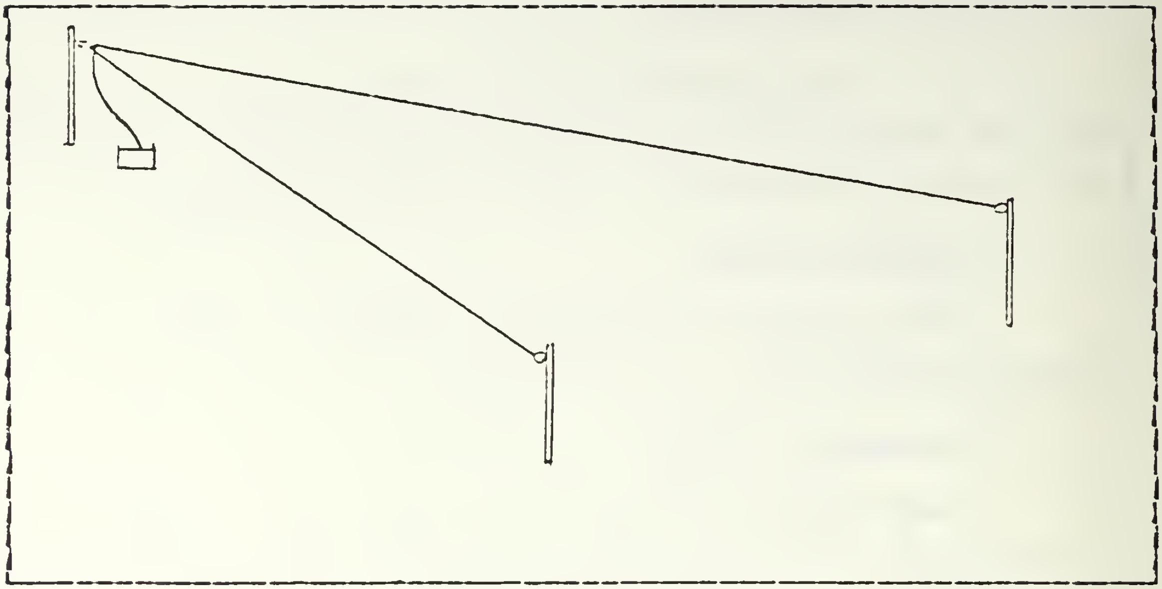


Figure 3.12 Vee antenna field Configuration.

b. Orientation

The vee should be oriented such that the azimuth to the outstation bisects the apex angle.

c. Apex angle

To determine the apex angle one should determine the orientation angle for a single longwire and then multiply this value by two.

d. Terminating Resistor

If two 300-600 ohm resistors are available they can be connected between the far end of the antenna legs and ground stakes. The resistors must be rated to dissipate at least 1/3 of the output power of the transmitter. The resistor will cause four major changes to the antenna's characteristics

(1) The input impedance of the antenna will increase to 300-600 ohms.

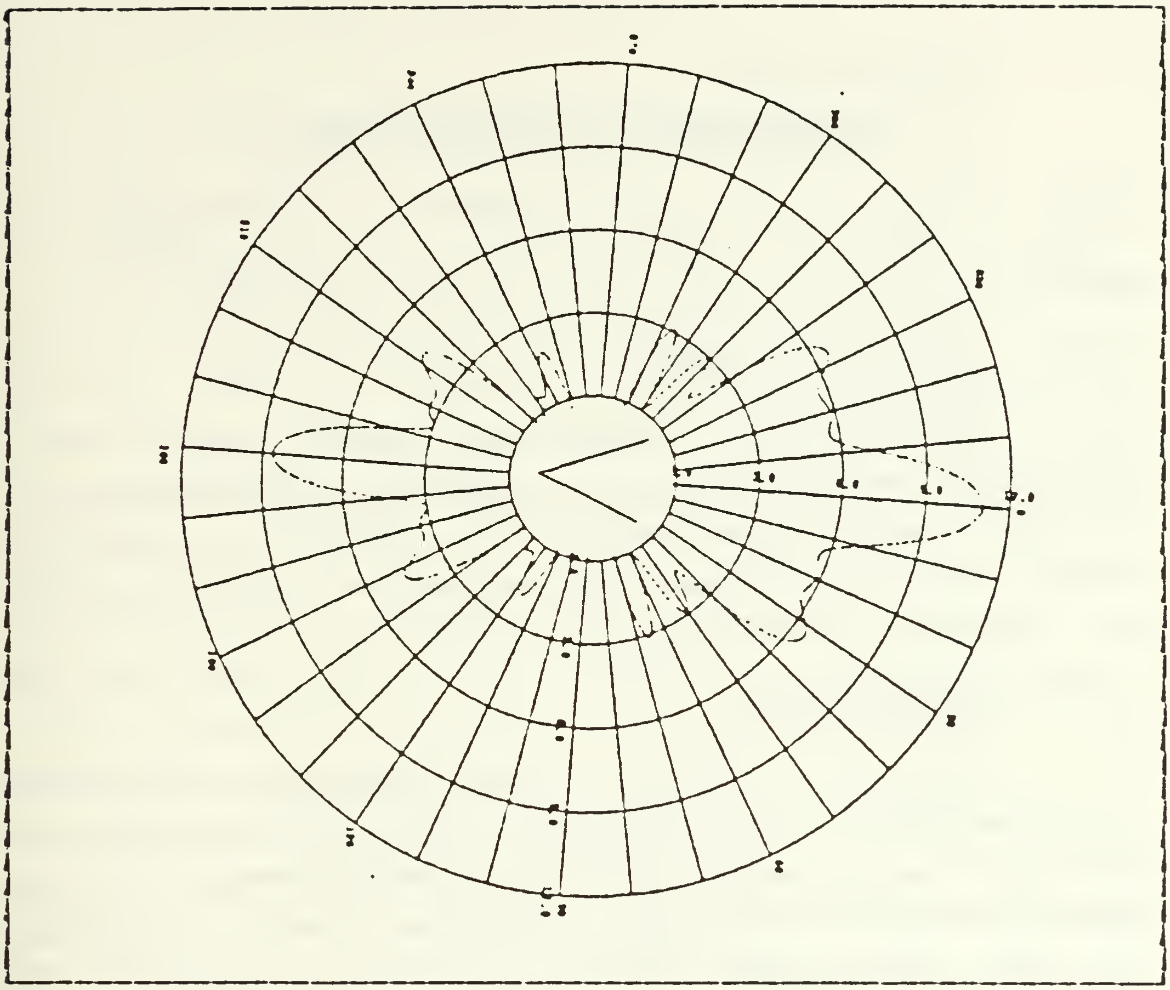


Figure 3.13 Radiation pattern of the Vee.

(2) The antenna will be broader banded making it possible for the radio to easily tune to many more frequencies.

(3) The radiated power in the major lobe will decrease by approximately 2 dB.

(4) The antenna will poorly transmit and receive signals to and from the rear.

3. Modifications

The operator is provided the option to alter the basic design of the Vee by changing the apex angle, leg length and/or the antenna height at either end of the antenna.

4. Radiation Patterns

Gain data is stored for the 30 combinations of height and length previously indicated for the longwire. A third dimension (apex angle) is added to the matrix of combinations for the vee; the values of the apex angle are 33, 39, 45, 51 and 60 degrees.

5. Antenna Feed

The input impedance of the unterminated vee antenna is between 200 and 400 ohms and and a vee terminated into a resistor has an input impedance between 300 and 600 ohms. Another feed consideration is that the antenna is balanced (the two fed elements are the same electrically). This antenna is usually connected to the radio through a coaxial cable, an unbalanced transmission line whose characteristic impedance is 50-75 ohms. To transform the impedance a 4:1 balun should be connected between the coaxial cable and the vee.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. GENERAL

The program developed in this study processes a limited amount of raw information into the instructions an operator needs to set-up and maintain an HF skywave communications link. Prior to this; propagation path, noise and take-off angle information has been available from a microcomputer based system (PROPHET) in three seperate reports and from ECAC in a single report, but only a well trained and experienced operator could make full use of these. Antenna design programs (specifically NEC) which take into consideration finite conducting ground are limited to large computer systems and are not available to the general user. This program ties all these capabilities into a single tool.

The program is written in algorithmic language making it possible to easily convert to any programming language on any system.

This is only the first iteration of a solution. First improvements to the program should include an update in the antenna data base to include the effects on the longwire and vee radiation patterns when ground stakes are employed. Also, the take-off angle look-up table (also with the data base) should be updated based on reports published after [Ref. 10].

Other recommendations related to computer applications in communications engineering follows.

B. NEW COMPUTER PROCUREMENT

An investigation should be initiated to identify a new standard computer for communicators. Characteristics should include: lightweight, inexpensive (less than $3,000.00), 64K of RAM, battery operation, integral secondary storage capability (tape preferred), and at least 40 column hardcopy printout. A graphics capability is desireable but not required.

Distribution of the computer should be to all units with the requirement to establish skywave HF circuits.

Future program development as described below may justify this need.

C. COMPUTER AIDED ANTENNA DESIGN AND FREQUENCY SELECTION BASED ON ECAC PREDICTIONS

The program developed during this study is based on a microcomputer analysis of propagation. As such the considerations are limited to a small number of variables and should be considered a first approximation. A higher order approximation can be obtained from ECAC. Their reliability report, an example of which is shown in Table 1.5 can be used as input to a program that can carry out the process, described below. It is similar to the computer aided design (CAD) program of this thesis.

1. Design frequencies would be chosen for the three periods of day, night and transition (dawn/dusk).
2. An antenna would be designed based on the design frequencies, and link parameters--dimensions of the antenna site and materials available.
3. The reliabilities would be adjusted to take into account the gain of the antenna designed.
4. An output report would be generated similar to that of the present CAD program. The format of the operator's table would be changed to that shown in Table 5.

TABLE 5

Operators Reliability Table

TIME	FREQ/REL	FREQ/REL	FREQ/REL	FREQ/REL	FREQ/REL
11	25.0/.48	26.5/.48	24.0/.45	21.5/.38	19.2/.20
12	25.0/.48	26.5/.45	24.0/.42	21.5/.36	19.2/.16
13	26.5/.50	25.0/.45	24.0/.40	21.5/.30	19.2/.14
14	26.5/.48	25.0/.45	24.0/.40	21.5/.30	19.2/.11
15	25.0/.45	26.5/.42	24.0/.40	21.5/.30	19.2/.11
16	25.0/.48	26.5/.48	24.0/.42	21.5/.30	19.2/.11
17	26.5/.51	25.0/.50	24.0/.45	21.5/.30	19.2/.11
19	25.0/.58	26.5/.58	24.0/.54	21.5/.43	19.2/.20
20	25.0/.62	26.5/.61	24.0/.59	21.5/.53	19.2/.29
21	25.0/.62	24.0/.64	26.5/.62	21.5/.60	19.2/.43
22	24.0/.64	25.0/.63	21.5/.63	26.5/.60	19.2/.52

Operator's reliability table for link between Kaneohe, Hi and Camp Courtney, Okinawa. The link was active between 1100-2200 Kaneohe local time.

D. COMPUTER AIDED DESIGN ON THE ADPE-FMF (GREEN MACHINE)

Up to this point, the discussion has been limited to the development of programs written in BASIC programming language. The program as described in paragraph A.2 above can be written in COBOL which is a language the Green Machine can process. This researcher has already implemented a version of the program in COBOL on the IBM 3033 at NPS.

It is recommended that the program as described in paragraph A.2 above be implemented on the Green Machine and distributed for communicators' use.

E. COMPUTER AIDED DESIGN USING ECAC'S ACCESSIBLE ANTENNA PACKAGE

The Accessible Antenna Package (APACK) [Ref. 7] is a set of computer subroutines which may be used to determine the radiation patterns of several wire antennas. In that the routines of APACK would be implemented on a microcomputer the patterns they generate will not be as accurate as can be computed using the larger NEC (NEC was used to generate the data base in the present CAD program). In some cases though the patterns computed by each program will be similar.

It is recommended that the APACK routines for the long-wire, vee, and dipole be acquired and that the patterns generated by these be compared to NEC results. The APACK routines should then be included in the present CAD program and used to generate pattern data in those cases where the results are sufficiently accurate.

F. COMPUTER AIDED ANTENNA DESIGN FOR GROUNDWAVE COMMUNICATIONS

Megatek's [Ref. 17] groundwave analysis program can be used to determine signal strength loss over various types of terrain, on frequencies of 2-75 MHz and for horizontally (40-75 MHz) and vertically polarized radio waves.

Further development might include the automation of the basic radio plan (for radio nets using groundwave). An operator would enter his list of frequencies available, radios available, breakdown of the nets required, and the location of the units on the nets. The computer would then determine best use of frequencies and recommend radios and antennas to be used by each station of each net.

APPENDIX A

NEC COMPUTER ANTENNA MODELS

A. DATA STRUCTURE.

The data necessary to represent the radiation patterns for each antenna is stored in the tape file. Each group of 28 numbers in the file represents a vertical cut through a radiation pattern with gain values from 3 to 84 degrees zenith.

Only a single vertical cut represents the pattern for each variation of the whip, vee, dipole and half-square for the following reasons:

-The whip and shorthaul dipole are omnidirectional and so a single vertical cut can represent the pattern in all directions.

-Proper orientation of the vee is such that the azimuth to the outstation bisects the apex; the dipole (for longhaul applications) and half square should be oriented broadside to the direction of the outstation; and so the single cut along the direction of maximum radiation is the only portion of the pattern needed for analysis of these antennas.

A total of eleven vertical cuts are needed to represent the patterns for each longwire variation. The longwire, unlike the other antennas, should be oriented differently based on its electrical dimensions; gain along any of the azimuthal angles (out to 30 degrees off the azimuth to the outstation) may be required for analysis.

To obtain the data for the file, a specified number of variations of each antenna were modeled on NEC and these appear below. The antennas are modeled over fair conducting soil (Epsilon = 10, Sigma = 0.003). Values of total gain (combined vertical and horizontal polarized power) is stored in the data files.

For the longwire and the whip the computer model includes a metal box that is the same approximate size of a jeep body (e.g., a MRC-138). The box is represented by a wire grid as shown in figure A.1 and the data generating the box is listed in table 6 This box does not appear in the models of the vee or half-square because these antennas are fed through a coaxial cable (unlike the longwire and whip) and thus the body vehicle carrying the radio will have minimal effect on the radiation pattern.

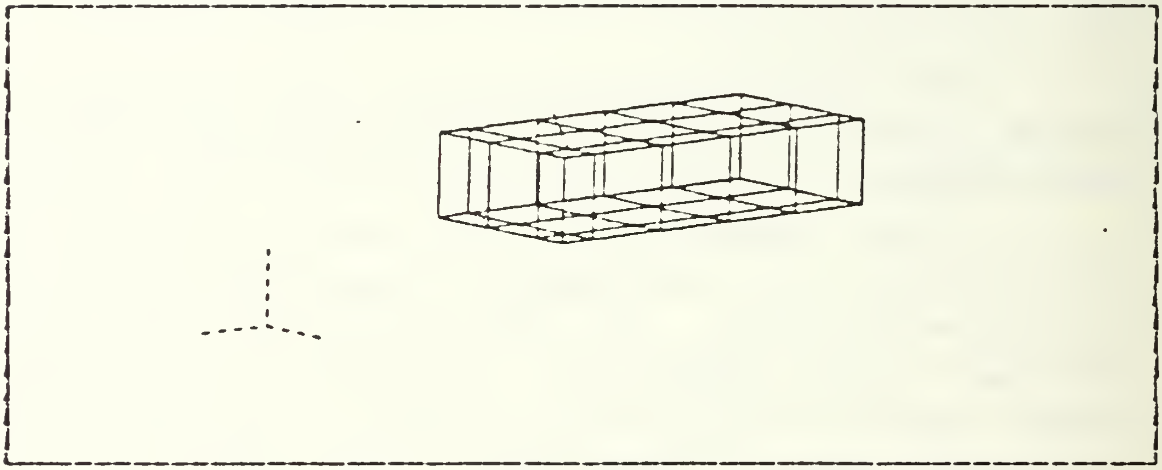


Figure A.1 Wire grid computer model of jeep-size metal box.

TABLE 6

NEC data to generate jeep-size metal box

```
CE
GW 500,1, -1,-1,0, 0,-1,0, .1        RIGHT TOP
GW 500,4, 0,-1,0, 9.08,-1,0, .1          "
GM 5,1, 0,0,0, 0,1,0, 500.500     MV TO LFT FR CONNECTION
GM 5,2, 0,0,0, 0,2,0, 505.505     2 MORE TO THE LFT/TP
GW 520,1, -1,-1,0, -1,0,0, .1        REAR TOP
GW 520,2, -1,0,0, -1,4,0, .1             "
GM 5,1, 0,0,0, 1,0,0, 520.520        MV FWD FR CONNECTION
GM 5,4, 0,0,0, 2.27,0,0, 525.525   4 MORE FWD
GM 0,0, 0,0,0, 0,0,3.83, 500.550   RAISE UP TO TOP LEVEL
GM 100,1, 0,0,0, 0,0,-2.33, 500.550  TO THE BOT LVL
GW 700,1, -1,-1,1.5, -1,-1,3.83, .1  RT RR CRNR VERTICAL
GM 100,1, 0,0,0, 0,1,0, 700.700      MOVE LEFT ONE CELL
GM 5,1, 0,0,0, 0,2,0, 800.800        1 MORE TO THE LEFT
GM 5,1, 0,0,0, 10.08,0,0, 800.810  MAKE CNTR FRONT VERTS.
GM 5,1, 0,0,0, 1,0,0, 700.700        MOVE FWD ONE CELL
GM 5,4, 0,0,0, 2.27,0,0, 705.705   4 MORE FWD
GM 5,1, 0,0,0, 0,5,0, 700.750
GM 0,0, 0,0,180, 0,0,0, 500.999      ROTATE AROUND Z-AXIS
GS 1                                 FEET TO METERS
GE 1
```

B. WHIP MODEL

The whip was modeled as shown in figure A.2. An example data set used to generate this model is listed in table 7. A version of the data was run on the frequencies listed in the table 8 and the patterns were stored in files corresponding to the electrical length at each frequency.

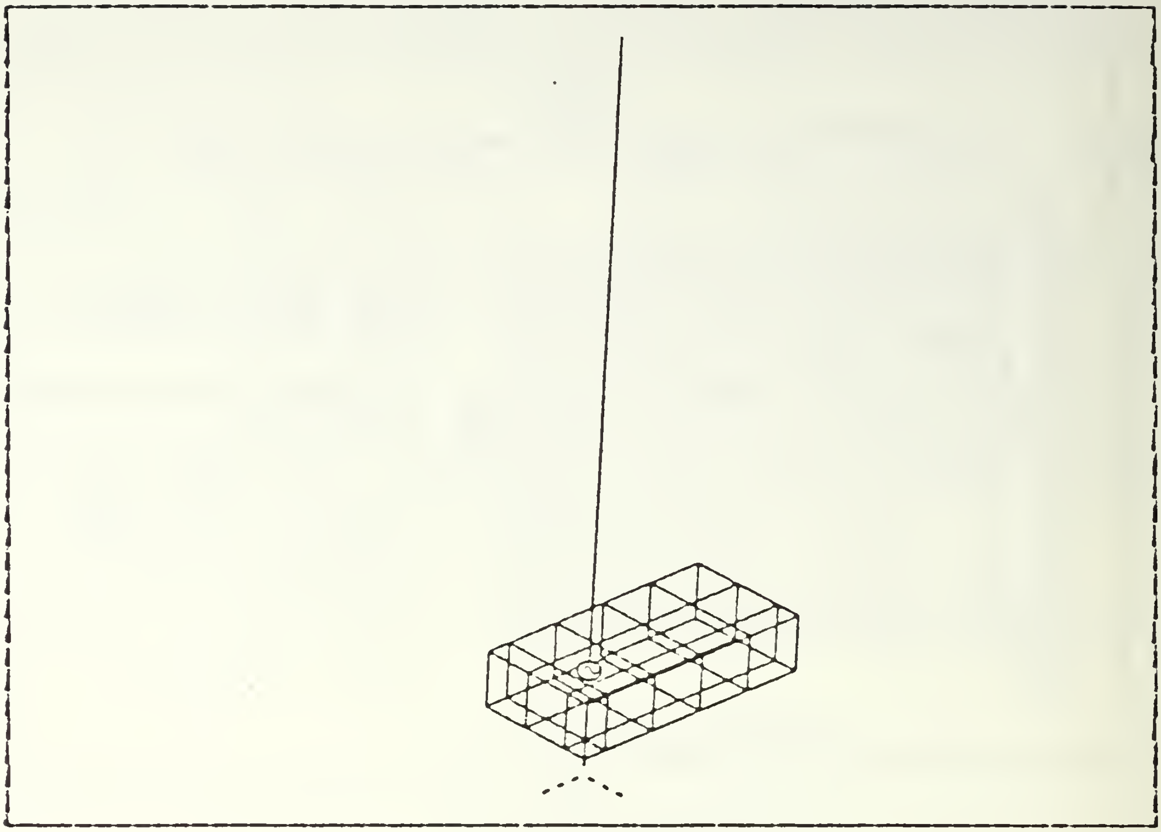


Figure A.2 Jeep mounted whip antenna (NEC model).

C. LONGWIRE MODEL

A computer model of the longwire is shown in figure A.3 and an example of the data generating this model is listed in table 9.

Based on the experiences of this researcher the limiting physical dimensions of the longwire are:

10' < Height < 60'
80' < Length < 500'

These translate to the folowing electrical dimensions over the HF band.

0.125 wavelengths < Height < 1.5 wavelengths
1 wavelength < Length < 8 wavelengths

TABLE 7

NEC data (sample) to generate Whip radiation patterns

```
CE
GW 1,15, 0,0,0, 0,0,32, 0         THE WHIP
GC 0,0, 1,.125,.01        TAPERED FROM 3" D. TO 1/2" D.
GM 0,0, 0,0,0, 0,0,3.83, 001.001  UP TO FD PNT ON JEEP
(Data from 6 is placed in this location)
GS 1                              FEET TO METERS
GE 1
GN 2,0,0,0, 10,.003              FAIR SOMMERFELD GROUND
EX 0,1,1                          FEED BOTTOM SEGMENT
FR 0,0,0,0, 3.9
PI 3,1,0,3
RP 0,91,1,1000, 0,0,1      VERT PATT, 0-90 DEG EL ANGLE
```

TABLE 8

Frequencies and electrical lengths of the whip (modeled on NEC)

Length in Wavelengths	0.125	0.250	0.375	0.50	0.625	0.75	0.875	1.0
Frequency in Megahertz	3.9	7.7	11.6	15	19.0	23	27.0	30

The frequencies the longwire can be built to operate on are listed in table 10 for each combination of electrical height and length.

To reduce the complexity of the program runs, only two frequencies of design were considered. For longwire variations with heights less than 0.50 wavelengths and lengths less than 4 wavelengths the longwire's physical dimensions

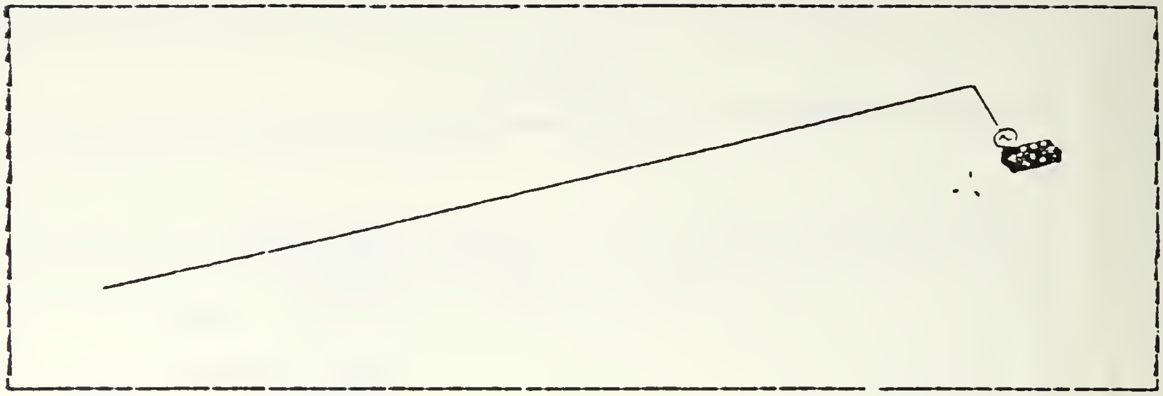


Figure A.3 Longwire connected to a jeep (NEC Model).

TABLE 9

NEC data (sample) to generate longwire radiation patterns

```
CM
CM        L = 1, 2, 3, 4, 6, & 8 LAMBDA
CM
CM        H = .125, .250, .45, .75, 1.5 LAMBDA
CM
CM        F = 5.3 & 17 MHZ
CM
CM        PATTERNS: THETA CUTS OF 28 VALUES
CM                  3 TO 84 DEGREES, EVERY 3 DEGREES
CM                  11 PHI VALUES
CM                  0 TO 30 DEGREES, EVERY 3 DEGREES
CE
GW 1,100, 0,0,87, 463,0,87, 0       HORIZONTAL RUN
GC 0,0, 1.0055,.002666,.002666     VARIABLE SEGMENTS
GW 2,36, 0,0,87, -10,0,3.83, 0      DOWNLEAD TO JEEP
GC 0,0, 1.,.005,.1                 TAPERED RADIUS
(Data from 6 is placed in this location)
GM 0,0, 0,0,0, -10,0,0, 500.999 MVE JEEP TO END OF LW
GS 1                               FEET TO METERS
GE 1
GN 2,0,0,0, 10,.003                          SOMMERFELD GROUND
FR 0,0,0,0, 17
EX 0,2,4
PL 3,1,0,3
RP 0,91,11,1000, 0,0,1,3
```

TABLE 10

Frequency bands (MHz) for each set of electrical dimensions (Wavelengths)

		HEIGHT					
L		1	2	3	4	6	8
E	.125	2-30	4-30	6-30	12-30	16-30	16-30
N	.25	4-30	4-30	6-30	8-30	12-30	16-30
G	.45	7.3-30	7.3-30	7.3-30	8-30	12-30	16-30
T	.75	12-30	12-30	12-30	12-30	12-30	16-30
H	1.50	24-30	24-30	24-30	24-30	24-30	24-30

were based on a frequency of 5.3 MHz. All other models were based on a frequency of 17 MHz. The antenna dimensions of the models are shown in table 11

The data is stored according to the following Heirarchy:

Orientation off of boresight
Electrical Length
Electrical Height
Vertical Cut (28 points)

TABLE 11

Physical dimensions (L,H) of longwire NEC models and frequencies (f) of operation

Electrical Height	Electrical Length 1	2	3	4	6	8
0.125	L=186 H=23 f=5.3	L=371 H=23 f=5.3	L=557 H=23 f=17	L=231 H=7.2 f=17	L=347 H=7.2 f=17	L=463 H=7.2 f=17
0.25	L=186 H=46 f=5.3	L=371 H=46 f=5.3	L=557 H=46 f=17	L=231 H=14.5 f=17	L=347 H=14.5 f=17	L=463 H=14.5 f=17
0.45	L=186 H=83 f=5.3	L=371 H=83 f=5.3	L=557 H=83 f=5.3	L=231 H=26 f=17	L=347 H=26 f=17	L=463 H=26 f=17
0 .75	L=58 H=43 f=17	L=116 H=43 f=17	L=174 H=43 f=17	L=123 H=43 f=17	L=347 H=43 f=17	L=463 H=43 f=17
1.5	L=58 H=87 f=17	L=116 H=87 f=17	L=174 H=87 f=17	L=231 H=87 f=17	L=347 H=87 f=17	L=463 H=87 f=17

L=length in feet, H= height in feet
f=frequency in MHz
Electrical Length and Height are in wavelengths

D. DIPOLE MODEL

The only variation of the dipole is in height values, which are: 0.125, 0.250, 0.45, 0.75 and 1.5 wavelengths. The design frequency of the model is 9.3 MHz (logarithmic mean between 3 and 30 MHz). In that the NEC model of the dipole is simple, it is not illustrated in this section.

E. HALF-SQUARE MODEL

A single configuration of the half square was modeled on a frequency of 9.3 MHZ. The data producing the radiation pattern of the half-square is listed in table 12

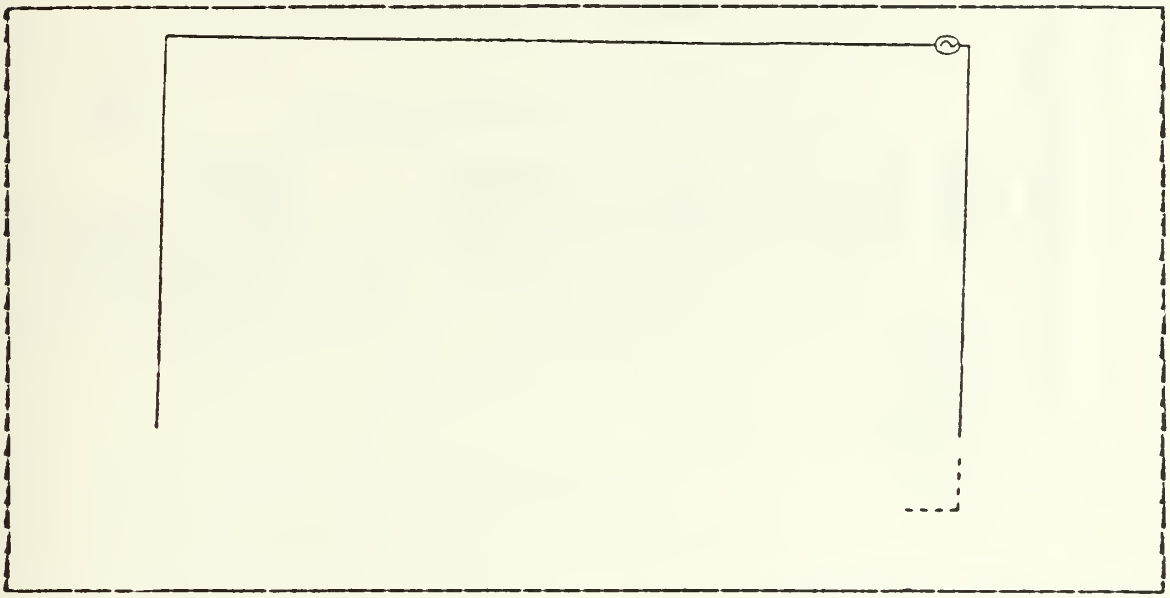


Figure A.4 Half-Square (NEC Model).

TABLE 12

NEC data to generate half-square radiation patterns

```
CM
CM        L = .5 LAMBDA
CM
CM        H = .25 LAMBDA
CM
CM        F = 9.3 MHZ
CM
CM        PATTERNS: 0 TO 90 DEG. IN THETA
CE
GW 1,9, 0,-26,0, 0,26,0, .002666          DIPOLE
GM 0,0, 0,0,0, 0,0,26.4, 001.003          HEIGHT
GW 2,4, 0,0,.1, 0,0,26.4, .002666         THE VERTICAL LEG
GM 1,0, 0,0,0, 0,26,0, 002.002            MOVE TO ONE END
GM 0,1, 0,0,0, 0,-52,0, .002.002          ANOTHER END ONE
GS 1                                 FEET TO METERS
GE 1
GN 2,0,0,0, 10,.003                       SOMMERFELD GROUND
FR 0,0,0,0, 9.3
EX 0,1,5
PL 3,1,0,3
RP 0,91,1,1000, 0,0,1
```

F. VEE MODEL

There are three dimensions to the permutation table for the Vee -- height, length, and apex angle. Variations of height and length are the same as for the longwire listed in table 11 For each height and length, five apex angles are considered -- 33, 39, 45, 51 and 60 degrees. A sample of the data used to generate the radiation patterns for the vee is listed in table 13.

The data is stored according to the follwoing heirarchy:

Apex Angle
Electrical Length
Electrical Height
Group (28 points)

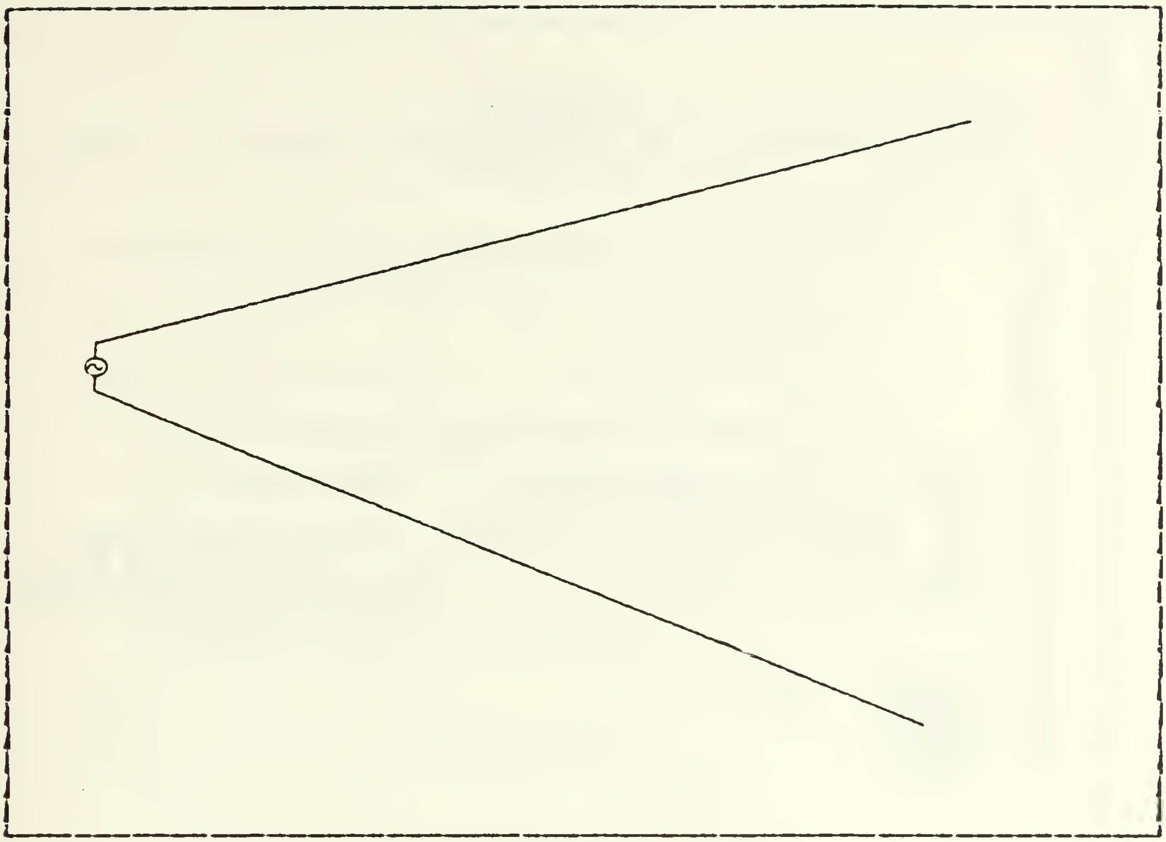


Figure A.5   Vee (NEC Model).

TABLE 13

NEC data (sample) to generate Vee radiation patterns

```
CM
CM        APEX ANGLES: 33, 39, 45, 51 & 60 DEGREES
CM
CM        L = 1, 2, 3, 4, 6, & 8 LAMBDA
CM
CM        H = .125, .250, .45, .75, 1.5 LAMBDA
CM
CM        F = 5.3 & 17 MHZ
CM
CM        PATTERNS: 0 TO 90 DEG. IN THETA
CE
GW 1,127, 0,0,0, 463,0,0, 0      FIRST LEG
GC 0,0, 1.0088,.002666,.002666
GM 0,0, 0,0,16.5, C,1,0, 001.001  ROTATE HALF ANGLE
GW 2,1, C,0,0, 0,1,0, .002666          HALF OF FEED
GM 0,0, C,0,0, 0,0,26, 001.003  RAISE TO PROPER HEIGHT
GX 0,010                        REFLECT FOR OTHER HALF
GS 1                            FEET TO METERS
GE 1
GN 2,C,0,0, 1C,.003             SOMMERFELD GROUND
FR C,C,0,0, 17
EX 0,2,1
EX 0,2,2,0, -1
PI 3,1,0,3
RP 0,91,1,1000, 0,C,1
```

APPENDIX B
COMPUTER ALGORITHM

A. SUBROUTINE CALLING STRUCTURE

```
GCRAZ
GENERATE_NOISE-TABLE
   DETERMINE_FIRST_FACTOR_ATM_NOISE
   DETERMINE_GALACTIC_NOISE_LIMIT
   DETERMINE_TIME_INDEX
   GMT_TO_LOCAL_TIME
   DETERMINE_SECOND_FACTOR_ATM_NOISE


GENERATE_FIELD_STRENGTH_TABLE
   PATH
      RAZGC
      GCRAZ
   GMT_TO_LOCAL_TIME
   MINIMUF
      RAZGC
   QLCF
      ABSORB
         CHAPMAN
            CHAPMAN_INTEGRAND
      ADJUST_LUF
GENERATE_TOA_LIST
   PATH
      GCRAZ
      RAZGC
   RAZGC
   MINIMUF
      RAZGC
   GMT_TO_LOCAL_TIME
```

```
FIND_S/N_FOR_WHIP
DESIGN_ANTENNA
   DESIGN_LONGWIRE
      DETERMINE_LW_LENGTH_AND_ORIENTATION
      FIND_S/N_FOR_LONGWIRE
         FIND_LW_PATTERN
   DESIGN_DIPOLE
      DETERMINE_DIPOLE_HEIGHT_AND_ORIENTATION
      FIND_S/N_FOR_DIPOLE
         FIND_DIPOLE_PATTERN
   DESIGN_HALF_SQUARE
      DETERMINE_HS_DIMENSIONS_AND_ORIENTATION
      FIND_S/N_FOR_HS
         FINE_HS_PATTERN
   DESIGN_VEE
      DETERMINE_VEE_DIMENSIONS_AND_APEX_ANGLE
      FIND_S/N_FOR_VEE
         FIND_VEE_PATTERN
MODIFY_LONGWIRE
   FIND_S/N_FOR_LONGWIRE
      FIND_LW_PATTERN
MODIFY_DIPOLE
   FIND_S/N_FOR_DIPOLE
      FIND_DIPOLE_PATTERN
MODIFY_HALF_SQUARE
   FIND_S/N_FOR_HS
      FINE_HS_PATTERN
PLOT_RADIATION_PATTERN
   FIND_LONGWIRE_PATTERN
   FIND_VEE_PATTERN
   FIND_DIPOLE_PATTERN
   FIND_HS_PATTERN
MODIFY_VEE
```

```
      FIND_S/N_FOR_VEE
         FIND_VEE_PATTERN
   PRINT_ANTENNA_INSTRUCTIONS
      DIAGRAM_LONGWIRE
      DIAGRAM_DIPOLE
      DIAGRAM_HALF_SQUARE
      DIAGRAM_VEE
```

B. VARIABLE DEFINITIONS

ANTENNA_AZIMUTH(2)......Azimuth along which each antenna element may be aligned

ANTENNA_GAIN(28).......Gain of the antenna along a vertical cut starting at 3 degrees above the horizon and ending at 84 degrees, values are at every 3 degrees.

ANTENNA_HEIGHT(3)......Height of each end of the antenna ANTENNA_HEIGHT(1)=Height of half-square, longwire or vee (whichever of these has been chosen for design). ANTENNA_HEIGHT(1:3)= heights of 3 dipoles designed for DESIGN_FREQ(1:3) if the dipole was chosen for design.

ANTENNA_LENGTH(3)......Length of the antenna on three different design frequencies.

DATE(3)................DATE(1)=Year,DATE(2)=Month,DATE(3)=Day. All valu are 2 digits. Date the link will take place.

DESIGN_FREQ(3).........Best frequencies (those which have the highest signal to noise ratio at the receiver) for Midday, Midnight, and Dusk/Dawn.

FIELD_STRENGTH(24,9)...Received field strength in dBm at the outstation during each hour of the day on 9 frequencies logarithmically distributed between 2 and 32 MHz.

FREQ_AVAIL(15).........Frequencies (the operator must provide) which can be operated on during the link.

MAST_HEIGHT(3).........Height of masts available to support the antenna Tallest to shortest, 1 --> 3

NOISE(24,9)............Noise level in dBm at the outstation during each hour of the day on 9 frequencies logarithmically distributed between 2 and 32 Mhz

OPERATOR_FREQ(24,5)....The five best frequencies (those with the highes signal to noise ratio) during each hour of operation.

RCVR_LOC(2).............Location of the Outstation in radians. RCVR(1)=latitude (negative value ==> south of equator) RCVR(2)=longitude (negative value ==> west of Greenwiche)

S/N_ON_ANTENNA(24,15)..The difference in power levels in dB between the received signal strength and the noise level at the outstation on the available frequencies during each hour of the day. The calculations are based on a particular antenna at the local station.

S/N_CN_AVAIL_FREQ(24,15)...The difference in power levels in dB between received signal strength and the noise level at the outstation on the available frequencies during each hour of the day. The calculations are based on an isotropic antenna at the local station.

S/N_CN_LOG_FREQ(24,9)..The difference in power levels in dB between th received signal strength and the noise level at the outstation on 9 frequencies logarithmically distributed between 2 and 32 MHz, during each hour of the day. The calculations are based on an isotropic antenna at the local station.

TOA(24)................Take-off angle for each hour of the day. Values are evenly divisible by 3.

XMTR_LOC(2).............Location of the local station in radians. XMTR(1)=latitude (negative value ==> south of equator) XMTR(2)=longitude (negative value ==> west of Greenwiche)

ANTENNA_CHOICE.........Antenna chosen for design by the operator.

1 ==> longwire
2 ==> dipole
3 ==> half-square
4 ==> vee

ANTENNA_NAME...........Name of the antenna chosen by the operator to be designed.

ANTENNA_SITE_LENGTH.....Length in feet of the local station's antenna site in the direction of the outstation.

ANTENNA_TOA............Best take-off angle (angle above the horizon) at which the antenna will be designed to have a major lobe aligned with) at the time of dawn.

BALUNS ....Flag to indicate whether or not baluns or transformers (transmission line to antenna matching devices) are available. (1=Yes, 0=No)

COAXIAL_CABLE_LENGTH...Length of coaxial cable available.

DAWN....................Time of transition between night and day frequencies

DUSK....................Time of transition between day and night frequencies

FLUX....................10.7 cm Flux, default value is 11

MIDDAY.................Time halfway between DAWN and DUSK

MIDNIGHT...............Time halfway between DUSK and DAWN

MODE_OF_TRANSMISSION...TTY, or voice

NUMBER_OF_FREQS_AVAIL..Number of frequencies available to the operator for communications during the day of the link

ORIENTATION_ANGLE......For longwire and vee--> Angle between XMTR_RCVR_AZIMUTH and ANTENNA_AZIMUTH. For dipole and half-square --> variation from antenna azimuth the antenna can be oriented before depreciable losses of performance will be realized.

RCVR_BW................Bandwidth of the receiver in KHz (default is 3 KHz)

RCVR_NAME..............Name of the outstation in 5 characters

RESISTORS..............Flag to indicate whether or not Terminating resistors are available. (1=Yes,0=No)

START_TIME.............Time operations will begin, 2 digits

STOP_TIME..............Time operations will terminate, 2 digits

TYPE_OF_ANTENNA_WIRE...1==>Copper/Phosphur Bronze, 0==> WD-1/TT

RADIO_POWER............Rated output power of the local station radio

WIRE_LENGTH............Length of wire available to construct the antenna

XMTR_NAME..............Name of the local station, 5 characters

XMTR_RCVR_DIST.........Distance in kilometers

XMTR_RCVR_AZIMUTH......Grid azimuth in radians from the local station to the outstation

ANTENNA_DESIGN_INFO <-- DESIGN_FREQ, FREQ_AVAIL, MAST_HEIGHT, S/N_ON_AVAIL. FREQ, TOA, ANTENNA_CHOICE, MAX_LENGTH, ANTENNA_TOA NUMBER_OF_FREQS_AVAIL, TYPE OF ANTENNA_WIRE,

ANTENNA_CONSTRUCTION_INFO <-- ANTENNA_AZIMUTH, ANTENNA_HEIGHT, ANTENNA_LENGTH, S/N_ON_ANTENNA, ORIENTATION_ANGLE

```
C.   ALGORITHM COMPUTER_AIDED_ANTENNA_DESIGN
     (Initialize Link Parameters)
        INPUT DATE (1:3) (In six digits.  Ex:  840529)
        OUTPUT "INITIALIZE FROM TAPE OR KEYBOARD?"
        INPUT OPTION (TAPE OR KEYBOARD)
        IF OPTION = "TAPE" THEN
           OUTPUT (LIST OF LINKS CHARACTERIZED BY LOCAL STATION AND OUTSTATION
           NAMES FROM FILE)
           OUTPUT "IF TAPE FILE FOR LINK DOES NOT EXIST ENTER NONE."
           INPUT STATION_NAMES
        END IF
        IF OPTION = "KEYBOARD" OR STATION_NAMES = "NONE"
           INPUT NUMBER_OF_FREQS_AVAIL (MINUMUM OF 1; MAXIMUM OF 15)
           DO FOR I <-- 1 TO NUMBER_OF_FREQS_AVAIL
              INPUT FREQ_AVAIL(I)
           END DO
           INPUT XMTR_NAME
           (GET XMTR LATITUDE AND LONGITUDE)
           (LATITUDE SOUTH OF EQUATOR IS NEGATIVE)
           (LONGITUDE WEST OF GREENWICH IS NEGATIVE)
           INPUT LATITUDE
           INPUT LONGITUDE
           (CONVERT DEGREES TO RADIANS)
```

```
   XMTR_LOC(1) <-- LATITUDE * (2 * PI/360)
   XMTR_LOC(2) <-- LONGITUDE * (2 * PI/360)
INPUT RCVR_NAME
   (GET RCVR LATITUDE AND LONGITUDE)
   INPUT LATITUDE
   INPUT LONGITUDE
   (CONVERT DEGREES TO RADIANS)
      RCVR_LOC(1) <-- LATITUDE * (2 * PI/360)
      RCVR_LOC(2) <-- LONGITUDE * (2 * PI/360)
   INPUT RCVR_BW (DEFAULT TO 3 KHZ)
   DO FOR I <--1 TO 3
      INPUT MAST_HEIGHT(I)
      (MINIMUM HEIGHT FOR FIRST AND SECOND MAST IS 14 FEET, IF THIRD
      MAST IS NOT AVAILABLE THE OPERATOR ENTERS "0")
   END DO
   INPUT START_TIME (LOCAL)
   INPUT STOP_TIME (LOCAL)
   (IF LINK IS TO RUN AROUND THE CLOCK, THE OPERATOR SHOULD ENTER
   START_TIME = 001, STOP_TIME = 2400)
   INPUT WIRE_LENGTH (MINIMUM OF 50 FEET MAXIMUM OF 1000 FEET)
   INPUT RADIO_POWER
   (Get information about availability of antenna matching devices)
      OUTPUT "Are 300 or 600 ohm resistors available?  These devices
```

```
         must be able to dissipate at least " RADIO_POWER/3
         "Watts of power."
         INPUT RESISTORS (1 = Yes, 0 = No)
         OUTPUT "Is a balun or transformer available?"
         INPUT BALUN (1 = Yes, 0 = No)
      INPUT CCAXIAL_CABLE_LENGTH
      INPUT TYPE_OF_ANTENNA_WIRE (0 = WD-1/TT,
         1 = Phosphur bronze or copperwire)
      INPUT FLUX (10.7 cm flux; default value is 110)
      INPUT RADIO_POWER
      CALL GCRAZ
      (In:  XMTR_LOC(1:2), RCVR_LOC(1:2))
      (Out:  XMTR_RCVR_DIST, XMTR_RCVR_AZIMUTH)
      (Convert radian azimuth to degrees)
         AZIMUTH <-- XMTR_RCVR_AZIMUTH * (360/(2 * PI))
      OUTPUT "Enter the antenna site length along" AZIMUTH "(grid
         azimuth)"
      INPUT ANTENNA_SITE_LENGTH (MAX value 500)
   END IF
OUTPUT "Do you wish to edit the link parameters? Y/N"
INPUT ANSWER
IF ANSWER = "Y" THEN
   DO UNTIL ANSWER = "N"
```

```
            (List all parameters)
            (Input parameter the operator wishes to change)
            OUTPUT "Do you wish to change any other parameters? Y/N
            INPUT ANSWER
         END DO
      END IF
   CALL GENERATE_NOISE_TABLE
   (In:  DATE, RCVR_LOC(1:2))
   (Out:  NOISE(1:24,1:9))
   CALL GENERATE_FIELD_STRENGTH_TABLE
   (In:  DATE, RADIO_POWER, RCVR_LOC(1:2), XMTR_LOC(1:2))
   (Out:  FIELD_STRENGTH(1:24,1:9))
   (Combine FIELD_STRENGTH and NOISE into S/N_ON_LOG_FREQ
      DO FOR I <-- 1 TO 24
         DO FOR J <-- 1 TO 9
            S/N_ON_LOG_FREQ (I,J) <-- FIELD_STRENGTH (I,J) - NOISE (I,J)
         END DO
      END DO
   (Calculate S/N_ON_AVAIL_FREQ from S/N_ON_LOG_FREQ)
   (The values in 24x9 array S/N_ON_LOG_FREQ are for frequencies
   logarithmically distributed between 2 and 32.  In the following process
   the values are changed to represent the S/N on up to 15 available
   frequencies.)
```

```
  DO FOR I <-- 1 TO NUMBER_OF_FREQS_AVAILABLE
    DO FOR J <-- 2 TC 10
      FREQUENCY_B <-- SQRT(2**(J - 1))
      FREQUENCY_A <-- SQRT(2**J)
      IF FREQ_AVAIL(I) < FREQUENCY_A
        (Interpolate to find S/N ratio on the frequencies available)
        INTERPOLATION_FACTOR <-- (FREQ_AVAILABLE(I) - FREQUENCY_B)/
          (FREQUENCY_A - FREQUENCY_B)
        DO FCR K <-- 1 TO 24
          S/N_ON_AVAIL_FREQ(I) <--
            INTERPOLATION_FACTOR*(S/N_ON_LOG_FREQ(K,J - 1) -
            S/N_CN_LOG_FREQ(K,J - 2)) + S/N_CN_LOG_FREQ(K,J - 2)
        END DO
      END IF
    END DO
  END DO
CALL GENERATE TAKE_OFF_ANGLE_LIST
(In:  RCVR_LOC(1:2), XMTR_LOC(1:2), FLUX, DATE(2))
(Out: TOA(1:24))
CALL DETERMINE_DESIGN_FREQUENCIES
(In: S/N_ON_LOG_FREQ, TOA, START_TIME,STOP_TIME, FREQ_AVAIL)
(Out:  DESIGN_FREQ(1:3), ANTENNA_TOA)
(Determines design frequencies for each of three times midday, midnight and
```

```
dusk/dawn, and determines best TOA for dusk/dawn periods)
   IF (ANTENNA_SITE_LENGTH - MAST_HEIGHT(1)) > 200 AND WIRE_LENGTH >200
      and Antenna_TOA < 38 THEN
         (Longwire is possible)
         ANTENNA(1) <-- 1
         IF WIRE_LENGTH > 400 AND COAXIAL_CABLE_LENGTH > MAST_HEIGHT(1)
            AND MAST_HEIGHT(3) > 0 THEN
               (Vee is possible)
               ANTENNA(4) <-- 1
         END IF
   END IF
   IF COAXIAL_CABLE_LENGTH > MAST_HEIGHT(1)  THEN
      (Dipole and half-square can be built)
      ANTENNA(2:3) <-- 1
   END IF
CALL FIND_S/N_FOR_WHIP (S/N_ON_AVAIL_FREQ, TOA, S/N_ON_ANTENNA)
(In:  S/N_ON_AVAIL_FREQ, TOA)
(Out:  S/N_ON_ANTENNA)
DO UNTIL OPTION = "Design-Antenna"
   OUTPUT "INITIAL ANALYSIS BETWEEN:"  XMTR_NAME, RCVR_NAME
   OUTPUT "DISTANCE BETWEEN STATIONMS:" XMTR_RCVR_DIST
   OUTPUT "PRIMARY FREQUENCIES OF OPERATION:"
      OUTPUT "DAY:" DESIGN_FREQ(1)
```

```
      OUTPUT "NIGHT:" DESIGN_FREQ(2)
      OUTPUT "DUSK/DAWN:" DESIGN_FREQ(3)
   OUTPUT "AZIMUTH FROM " LOCAL_STATION_NAME ":" AZIMUTH
   OUTPUT "ANTENNAS WHICH CAN BE BUILT:"
   IF ANTENNA(1) = 1 THEN OUTPUT "Longwire"
   IF ANTENNA(2) = 1 THEN OUTPUT "Dipole"
   IF ANTENNA(3) = 1 THEN OUTPUT "Half-Square"
   IF ANTENNA(4) = 1 THEN OUTPUT "Vee"
   OUTPUT "Menu of Options:
   OUTPUT "Print Signal to Noise Table for Whip Antenna"
   OUTPUT "Print Take-Off Angle List"
   OUTPUT "Design Antenna"
   INPUT OPTION
   IF OPTION = "Print S/N Table" THEN
      OUTPUT "Antenna Type is Whip"
      OUTPUT S/N_ON_ANTENNA
   ELSE IF OPTION = "Print TOA List" THEN
      OUTPUT TOA
   END IF
END DO
CALL DESIGN_ANTENNA
(IN:  ANTENNA_DESIGN_INFO)
(OUT:  ANTENNA_CONSTRUCTION_INFO)
```

```
DO UNTIL OPTION = "Process Complete"
   OUTPUT "Menu of Options"
   OUTPUT "Design Antenna"
   OUTPUT "Print Signal to Noise Table for" ANTENNA_NAME
   OUTPUT "Modify"  ANTENNA_NAME
   OUTPUT "Plot Radiation Pattern of" ANTENNA_NAME
   OUTPUT "Print Antenna Construction Information"
   OUTPUT "Process Complete"
   INPUT OPTION
   IF OPTION = "Design Antenna"
      CALL DESIGN_ANTENNA
      (In:  ANTENNA_DESIGN_INFO)
      (Out:  ANTENNA_CONSTRUCTION_INFO)
   ELSE IF OPTION = "Modify Antenna"
      IF ANTENNA_CHOICE = 1 THEN
         CALL MODIFY_LONGWIRE
         (In:  FREQ_AVAIL, TYPE_OF_ANTENNA_WIRE, TOA, S/N_ON_AVAIL_FREQ,
         XMTR_RCVR_AZIMUTH, XMTR_RCVR_DIST)
         (In/Out:  ANTENNA_CONSTRUCTION_INFO)
      ELSE IF ANTENNA_CHOICE = 2 THEN
         CALL MODIFY_DIPOLE
         (In:  FREQ_AVAIL, TYPE_OF_ANTENNA_WIRE, TOA, S/N_ON_AVAIL_FREQ,
         XMTR_RCVR_AZIMUTH, XMTR_RCVR_DIST)
```

```
        (In/Out:  ANTENNA_CONSTRUCTION_INFO)
      ELSE IF ANTENNA_CHOICE = 3 THEN
        CALL MODIFY_HALF_SQUARE
        (In:  FREQ_AVAIL, TYPE_OF_ANTENNA_WIRE, TOA, S/N_ON_AVAIL_FREQ,
        XMTR_RCVR_AZIMUTH, XMTR_RCVR_DIST)
        (In/Out:  ANTENNA_CONSTRUCTION_INFO)
      ELSE
        CALL MODIFY_VEE
        (In:  FREQ_AVAIL, TYPE_OF_ANTENNA_WIRE, TOA, S/N_ON_AVAIL_FREQ,
        XMTR_RCVR_AZIMUTH, XMTR_RCVR_DIST)
        (In/Out:  ANTENNA_CONSTRUCTION_INFO)
    ELSE IF OPTION = "Plot Pattern" THEN
      CALL PLOT_RADIATION_PATTERN
      (In:  ANTENNA_HEIGHT, ANTENNA_LENGTH, ANTENNA_AZIMUTH, XMTR_RCVR_AZIMUTH,
      ANTENNA_CHOICE, FREQ_AVAIL, TOA)
    ELSE IF OPTION = "Print Antenna Instructions" THEN
      CALL PRINT_ANTENNA_INSTRUCTIONS
      (In:  ANTENNA_HEIGHT, ANTENNA_LENGTH, ANTENNA_AZIMUTH, DESIGN_FREQ,
      S/N_ON_ANTENNA, FREQ_AVAIL, START_TIME, STOP_TIME, XMTR_NAME,
      XMTR_LOC, RCVR_NAME, RCVR_LOC, XMTR_RCVR_AZIMUTH, XMTR_RCVR_DIST.
      NUMBER_OF_FREQS_AVAIL, DATE, ANTENNA_CHOICE)
    END IF
  END DO
END COMPUTER_AIDED_ANTENNA_DESIGN
```

```
SUBROUTINE GENERATE_NOISE_TABLE
(IN:  FLUX, RCVR_LOC, MONTH, RCVR_BW, XMTR_LOC)
(OUT:  NOISE)
   OUTPUT "Choose Man Made Noise Level"
   OUTPUT "Shipboard/Business,Residential"
   OUTPUT "Rural, Quiet_Rural, Quasi_Minimum"
   OUTPUT "Unknown"
   INPUT MM_NOISE_LEVEL
   IF MM_NOISE_LEVEL = "Unknown" THEN
      MM_NOISE_LEVEL <-- "Quasi-Minimum"
   (Convert RCVR_LOC to polar radians)
      (Convert Latitude)
         THETA <-- ABS(RCVR_LOC(1))
      (Convert Longitude)
         IF RCVR_LOC(2) < 0 THEN
            PHI <-- 2*PI + RCVR_LOC(2)
         ELSE
            PHI <-- RCVR_LOC(2)
         END IF
      (Convert PHI to WEST LONGITUDE)
         WEST_LONGITUDE <-- 2*PI - PHI
   (Find Season_Index)
      IF MONTH = 1 OR MONTH = 2 OR MONTH = 12 THEN
```

```
    SEASON_INDEX <-- 1
  ELSE IF MONTH = 3 OR MONTH = 4 OR MONTH = 5 THEN
    SEASON_INDEX <-- 2
  ELSE IF MONTH = 6 OR MONTH = 7 OR MONTH = 8 THEN
    SEASON_INDEX <-- 3
  ELSE
    SEASON_INDEX <-- 4
  END IF
(Find the FIRST_FACTOR_ATM_NOISE;
this factor is a function of the season only)
  H1 <-- 5
  M5 <-- 7
  CALL DETERMINE_FIRST_FACTOR_ATM_NOISE
  (IN:  SEASON_INDEX, THETA, WEST_LONGITUDE, H1, M5)
  (OUT:  FIRST_FACTOR_ATM_NOISE(1:6) = Atmospheric noise
  at 1 MHz  at 0, 4, 8, 12, 16, 20 GMT)
(Determine noise for each frequency)
  DC FOR I4 <-- 2 TO 10
    FREQUENCY <-- SQRT(2**I4)
    (Calculate Man-Made Noise)
    Median Man-Made noise for a short
    vertical antenna over a 1 Hz bandwidth)
      IF MM_NCISE_LEVEL = "Shipboard" OR
```

```
          MM_NCISE_LEVEL = "Business" THEN
             MM_NOISE <-- -27.7*LOG(FREQUENCY) + 76.8
       ELSE IF MM_NOISE_LEVEL = "Residential" THEN
          MM_NCISE <-- -27.7*LOG(FREQUENCY) + 72.5
       ELSE IF MM_NOISE_LEVEL = "Rural" THEN
          MM_NCISE <-- -27.7*LOG(FREQUENCY) + 67.2
       ELSE IF MM_NOISE_LEVEL = "Quiet Rural" THEN
          MM_NCISE <-- -28.6*LOG(FREQUENCY) + 53.6
       ELSE
          MM_NCISE <-- -27.7*LOG(FREQUENCY) + 60
       END IF
    (Calculate Galactic Noise)
    (Median galactic noise for a short
    vertical electric dipole above a
    perfectly conducting ground screen
    over a 1 Hz Bandwidth
       CALL DETERMINE_GALACTIC_NOISE_LIMIT
       (IN:  DATE(2) FLUX, SEASON INDES)
       (OUT:  GALACTIC_NOISE_LIMIT)
       IF FREQUENCY > GALACTIC_NOISE_LIMIT THEN
          GALACTIC_NOISE <-- 52 - 23*LOG(FREQUENCY)
       ELSE
          GALACTIC_NOISE <-- 0
```

```
    END IF
DO FOR I3 <-- 1 TO 24
    GMT <-- I3
    CALL DETERMINE_TIME_INDEX
    (IN:  GMT)
    (OUT:  TIME_INDEX_1, TIME_INDEX_2, INTERPOLATION_FACTOR)
    ATM_NOISE_FACTOR <-- FIRST_FACTOR_ATM_NOISE(TIME_INDEX_1) +
       (FIRST_FACTOR_ATM_NOISE(TIME_INDEX_2) -
       FIRST_FACTOR_ATM_NOISE(TIME_INDEX_1) * INTERPOLATION_FACTOR
    Call GMT_TO_LOCAL_TIME
    (IN:  GMT, XMTR_LOC(2))
    (OUT:  LOCAL_TIME
    CALL DETERMINE_SECOND_FACTOR_ATM_NOISE
    (IN:  SEASON_INDEX, THETA, FREQUENCY, TIME_INDEX_1, ATM_NOISE_FACTOR)
    (OUT:  SECOND_FACTOR_ATM_NOISE)
    A9 <-- SECOND_FACTOR_ATM_NOISE
    (IN:  SEASON_INDEX, THETA, FREQUENCY, TIME_INDEX_2,ATM_NOISE_FACTOR)
    (OUT:  SECOND_FACTOR_ATM_NOISE)
    A8 <-- SECOND_FACTOR_ATM_NOISE
    A9 <-- A9 + (A8 - A9)*INTERPOLATION_FACTOR
    NOISE(LOCAL_TIME,I4) <-- 10*LOG(10**(A9*0.1) +
       10**(GALACTIC_NOISE*0.1) + 10**(MAN_MADE_NOISE*0.1))
       (dB above k To over 1 Hz band)
```

```
            NOISE(LOCAL_TIME,I4) <-- NOISE(LOCAL_TIME,I4) + (10*LOG(RCVR_BW) + 30)
            (Account for the Receiver bandwidth in kHz)
            (Still need to adjust for db above K To to dbm)
         END DO
      END DO
   RETURN
END GENERATE_NOISE_TABLE
```

```
SUBROUTINE DETERMINE_GALACTIC_NOISE_LIMIT
(IN:  MONTH, FLUX, SEASON_INDEX)
(OUT:  GALACTIC_NOISE_LIMIT)
   (G2 = Frequencies above which galactic noise is significant)
   G2(1:3,1:4) <-- 11.3, 12.3, 10, 12, 15, 15.3, 13.7, 16.7, 16, 16, 14, 17.3
   (S2 = FLUX thresholds)
   S2(1:4) <-- 10, 110, 160, 302
   N3 <-- 0
   DO UNTIL FLUX < S2(N3)
      N3 <-- N3 + 1
   END DO
   IF N3 < 4 THEN
      N4 <-- N3 - 1
      INTERPOLATION_FACTOR <-- (FLUX - S2(N4)/(S2(N3) - S2(N4))
      GALACTIC_NOISE_LIMIT <-- G2(N4,SEASON_INDEX) +
         ((G2(N3,SEASON_INDEX) - G2(N4,SEASON_INDEX)) * INTERPOLATION_FACTOR
   ELSE
      GALACTIC_NOISE_LIMIT <-- G2(3,4)
   END IF
   RETURN
END DETERMINE_GALACTIC_NOISE
```

```
SUBROUTINE DETERMINE_TIME_INDEX
(IN:  GMT)
(OUT:  TIME_INDEX_1, TIME_INDEX_2, INTERPOLATION_FACTOR)
(Routine assigns the indices according to the following)
(criteria:                                              )
(   0 < GMT < 4:  TIME_INDEX_1 <--1; TIME_INDEX_2 <-- 2)
(                 INTERPOLATION_FACTOR <-- GMT/4        )
(   4 < GMT < 8:  TIME_INDEX_1  2; TIME_INDEX_2  3;     )
(                 INTERPOLATION_FACTOR <-- (GMT - 4)/4 )
(                 .                                     )
(                 .                                     )
(                 .                                     )
(  20 < GMT < 24  TIME_INDEX_1 <-- 6; TIME_INDEX_2 <--1)
(                 INTERPOLATION_FACTOR <-- (GMT - 20)/4)
   IF GMT = 24 THEN
      TIME_INDEX_1 <-- 1
      TIME_INDEX_2 <-- 2
      INTERPOLATION FACTOR <-- 0
   ELSE
      TIME_INDEX_1 <-- INT(GMT/4 + 1)
      TIME_INDEX_2 <-- TIME_INDEX_1 + 1
      IF TIME_INDEX_2 > 6 THEN
         TIME_INDEX_2 <-- 1
```

```
        INTERPOLATION FACTOR <-- (GMT - 4*(TIME_INDEX_1 - 1))/4
    END IF
    RETURN
END DETERMINE_TIME_INDEX
```

```
SUBROUTINE DETERMINE_FIRST_FACTOR_ATM_NOISE
(IN:  SEASON_INDEX, THETA, WEST_LONGITUDE, H1, M5)
(OUT:  FIRST_FACTOR_ATM_NOISE)
   CASE SEASON_INDEX OF
   1:
      I2 <-- 1
   2:
      I2 <-- 7
   3:
      I2 <-- 13
   4:
      I2 <-- 19
   END CASE
   I3 <-- 1
   (Obtain noise from data files 2-7 for winter, 8-13 for spring, 14-19 for
   summer and 20-25 for fall)
      FOR I1 <-- 1 TO 6
         (Locate file I1+I2)
         (Input from file D2(1:11, 1:7)
         F5 <-- 2*H1+I2
         M6 <-- M5
         T3 <-- SIN(THETA)
         T2 <-- COS(THETA)
```

```
DO FOR I <-- 1 TO F5
   J1 <-- INT(I/2)
   S3 <-- 0
   IF I <= 16 THEN
      M5 <-- 7
   DO FOR K <-- 1 TC M5
      K1 <-- K - 1
      S3 <-- S3 + D2(I,K) * (T3**K1) * (T2**J)
   END DO
   D4(I) <-- S3
END DO
M5 <-- M6
S3 <-- D4(1)
C4 <-- COS(WEST_LONGITUDE)
F6(1) <-- C4
S4 <-- SIN(WEST_LONGITUDE)
F7(1) <-- S4
DO FOR I <-- 2 TO H1
   F6(I) <-- C4*F6(I - 1) - S4 * F7(I - 1)
   F7(I) <-- C4*F7(I - 1) + S4 * F6(I - 1)
END DO
DO FOR J <-- 1 TC H1
   S3 <-- S3 + D4(2 * J) * F7(J) + D4(2*J + 1) * F6(J)
```

```
         END DO
         FIRST_FACTOR_ATM_NOISE(I1) <-- S3
      END DO
   RETURN
END DETERMINE_FIRST_FACTOR_ATM_NOISE
```

```
SUBROUTINE DETERMINE_SECOND_FACTOR_ATM_NOISE
(IN:  SEASON_INDEX, THETA, FREQUENCY, TIME_INDEX_1)
(OUT:  SECOND_FACTOR_ATM_NOISE)
  (Locate File (25+SEASON_INDEX)
  INPUT FROM TAPE FILE F9(1:14, 1:12)
  IF FREQUENCY < 30 THEN
    F3 <-- LOG(FREQUENCY)
    T7 <-- TIME_INDEX_1
    X3 <-- -0.75
    DO FOR J <-- 1 TO 2
      P3 <-- 9
      P4 <-- 0
      DO FOR I <-- 1 TO 7
        P3 <-- X3*P3 + F9(I,T7)
        P4 <-- X3*P4 + F9(I+7,T7)
      END DO
      IF X3 = -0.75 THEN
        C3 <-- A5*(2 - P3) - P4
        X3 <-- (8*(2**F3) - 11)/4
      END IF
    END DO
    SECOND_FACTOR_ATM_NOISE <-- C3*P3 + P4
  ELSE
```

```
        SECOND_FACTOR_ATM_NOISE <-- -10
    END IF
    RETURN
END DETERMINE_SECOND_FACTOR_ATM_NOISE
```

```
SUBROUTINE GENERATE_FIELD_STRENGTH_TABLE
(IN:  DATE, RADIO_POWER, RCVR_LOC, XMTR_LOC)
(OUT:  FIELD_STRENGTH(1:24,1:9)
   CALL PATH
   (IN:  XMTR_LOC, RCVR_LOC)
   (OUT:  XMTR_RCVR_AZIMUTH, XMTR_RCVR_RADIAN_DIST, COORDINATES_MIDPOINT,
   COORDINATES_1000_KM_FROM_XMTR, COORDINATES_1000_KM_FROM_RCVR,
   RCVR_XMTR_AZIMUTH)
   (Set flux to quiet)
   X_RAY_FLUX <-- .0001
   DO FOR I3 <-- 1 TO 24
      CALL GMT_TO_LOCAL_TIME
      (IN:  GMT,XMTR_LOC(2))
      (OUT:  LOCAL_TIME)
      HOUR <-- GMT
      MINUTE <-- 0
      CALL MINIMUF
      (IN:  XMTR_RCVR_RADIAN_DIST, HOUR, MINUTE, DATE(1:2), XMTR_LOC(1),
      RCVR_LOC(1:2), RCVR_XMTR_AZIMUTH, SSN)
      (OUTPUT:  MUF)
      CALL QLOF
      (INPUT:  XMTR_RCVR_AZIMUTH, XMTR_RCVR_RADIAN_DIST, COORDINATES_MIDPOINT,
      COORDINATES_1000_KM_FROM_XMTR, COORDINATES_1000_KM_FROM_RCVR,
```

```
RCVR_XMTR_AZIMUTH, DATE(2))
(OUTPUT:  LUF)
EARTH_RADIUS <-- 6371
DO FOR I4 <-- 2 to 10
   FREQUENCY <-- SQRT(2**I4)
   IF LUF < FREQUENCY < MUF
      XMTR_RCVR_DISTANCE <-- XMTR_RCVR_RADIAN_DIST_ * EARTH_RADIUS
      FREE_SPACE_FIELD_STRENGTH <--
         20 * LOG(300000 * SQRT(RADIO_POWER)/XMTR_RCVR_DIST
      F5 <-- FREE_SPACE_FIELD_STRENGTH
      F3 <-- LUF
      F4 <-- MUF
      F0 <-- FREQUENCY
      A6 <-- (F3/F4)**2 + (F0/F4)**2
      (Use Damboldt's equation to calculate field strength received)
         FIELD_STRENGTH(I3,I4 - 1) <-- (F5 * (1 - (F4**2) * A6)/
            (F4**2 + F3**2)
      (Adjust to dBwatts at the receiver input with isotropic antenna)
         FIELD_STRENGTH(I3,I4 - 1) <-- FIELD_STRENGTH(I3,I4 -1) -
            10*LOG(240*PI) + 10*LOG(WAVELENGTH**2/(4*PI))
      (Adjust to dB KTo)
         FIELD_STRENGTH(I3,I4 - 1) <-- FIELD_STRENGTH(I3,I4 -1) +
            10*LOG(1.38E-23 * 290)
```

```
      ELSE
        FIELD_STRENGTH(LOCAL_TIME,I4 - 1) <-- 0
      END IF
    END DO
  END DO
  RETURN
END GENERATE_FIELD_STRENGTH_TABLE
```

```
SUBROUTINE GENERATE_TOA_LIST
(IN:  XMTR_LOC, RCVR_LOC, FLUX, DATE)
(OUT:  TCA(1:24))
   SSN <-- SQRT(0.53 - 0.00356*(63.75 - FLUX)) - 0.728)/0.00178
   CALL PATH
   (IN:  XMTR_LOC, RCVR_LOC)
   (OUT:  XMTR_RCVR_AZIMUTH, XMTR_RCVR_RADIAN_DIST, COORDINATES_MIDPOINT,
   COORDINATES_1000_KM_FROM_XMTR, COORDINATES_1000_KM_FM_RCVR,
   RCVR_XMTR_AZIMUTH)
   XMTR_RCVR_DISTANCE <-- XMTR_RCVR_RADIAN_DIST * EARTH RADIUS
   RADIAN_DIST_2000_KM <-- 0.31392
   CALL RAZGC
   (IN:  COORDS_2000_KM, POINT_2000_KM_TO_XMTR_AZIMUTH)
   (OUT:  RADIAN_DIST_2000_KM, POINT_2000_KM_TO_XMTR_AZIMUTH)
   RADIAN_DISTANCE_100_KM <-- 0.015696
   CALL RAZGC
   (IN:  RADIAN_DISTANCE_100_KM_FROM_XMTR)
   (OUT:  COORDS_100_KM_FROM_XMTR)
   C6 <-- COS(XMTR_RCVR_AZIMUTH - 1.5 * PI)
   DO FOR I3 <-- 1 TO 24
      TIME <-- I3
      (Find MUF at 7 points along the path between the XMTR and RCVR)
         DO FOR I0 <-- 1 TO 7
```

```
         TIME_AT_POINT <-- TIME - .000153*(XMTR_RCVR_DISTANCE - 1000)*(IO - 1)*C5
         IF TIME_AT_POINT > 24 THEN
            TIME_AT_POINT <-- TIME_AT_POINT_24
         IF TIME_AT_POINT < 0 THEN
            TIME_AT_POINT <-- TIME_AT_POINT + 24
         HOUR <-- INT(TIME_AT_POINT)
         MINUTE<-- (TIME_AT_POINT - HOUR) * 60
         CALL MINIMUF
         (IN:  RADIAN_DIST_2000_KM, HOUR, MINUTE, DATE(1:2), XMTR_LOC,
         COORDS_2000_KM_FM_XMTR(1:2), POINT_2000_DM_TO_XMTR_AZIMUTH, SSN)
         (OUT: MUF)
         MUF_AT_FIRST_POINT(IO) <-- MUF
      END DO
   (Find F_LAYER_HEIGHT at 7 points along path between XMTR and RCVR)
      HEIGHT_SUM <-- 0
      DO FOR IO <-- 1 TO 7
         D1 <-- XMTR_RCVR_DISTANCE
         TIME_AT_POINT <-- TIME - .000153*D1*(IO - 1)*C6
         IF TIME_AT_POINT > 24 THEN
            TIME_AT_POINT <-- TIME_AT_POINT - 24
         IF TIME_AT_POINT < 0 THEN
            TIME_AT_POINT <-- TIME_AT_POINT + 24
         HOUR <-- INT(TIME_AT_POINT)
```

```
        MINUTE <-- (TIME_AT_POINT_HOUR)*60
        CALL MINIMUF
        (IN:  RADIAN_DIST_100_KM, HOUR, MINUTE, DATE(1:2), XMTR_LOC(1),
        COORDS_100_KM_FM_XMTR, POINT_2000_KM_TO_XMTR_AZIMUTH, SSN)
        (OUT:  MUF)
        L1 <-- MUF_AT_FIRST_POINT(I0)
        HEIGHT <-- 1.34*LN(2*MUF/L1)+LN(385)
        HEIGHT <-- EXP(HEIGHT)
        HEIGHT_SUM <-- HEIGHT_SUM + HEIGHT
      END DO
    F_LAYER_HEIGHT <-- HEIGHT_SUM/7
    (Find TOA for each hour of the day)
      CALL GMT_TO_LOCAL_TIME
      (IN:  TIME, XMTR_LOC(2))
      (OUT:  LOCAL_TIME)
      (Look up TOA in table derived from Davies Figure 7.2)
      (Table coordinates are:  F_LAYER_HEIGHT and XMTR_RCVR_DISTANCE)
      (If the path distance exceeds 2000 miles
      the path length is taken as 1/2 XMTR_RCVR DISTANCE.)
      TOA(I3) <-- DAVIES_TOA
  END DO
  RETURN
END GENERATE_TOA_LIST
```

```
SUBROUTINE DETERMINE_DESIGN_FREQUENCIES
(IN:  S/N_ON_LOG_FREQ, TOA, START_TIME, STOP_TIME, FREQ_AVAIL)
(OUT:  DESIGN_FREQ, ANTENNA_TOA)
   (Determine the best frequency for each hour of the day)
   (BEST_FREQ = => Frequency over which the greatest S/N will be realized.)
      DO FOR I <-- 1 TO 24
         (Initialize Variable)
            BEST_S/N <-- -100
         DO FOR J <-- 1 TO 9
            IF S/N_ON_LOG_FREQ(I,J) > BEST_S/N THEN
               (Set BEST_FREQUENCY = Log Value of Frequency)
                  BEST_FREQ(I) <-- J+1
               BEST_S/N <-- S/N_ON_LOG_FREQ(I,J)
            END IF
         END DO
      END DO
   (Determine the mean of the best logarithmic frequencies)
      TOTAL <-- 0
      DO FOR I <-- 1 TO 24
         TOTAL <-- TOTAL + BEST_FREQ(I)
      END DO
   MEAN_FREQ <-- TOTAL/24
   (Convert from the logarithmic value)
```

```
   MEAN_FREQ <-- SQRT(2**MEAN_FREQ)
(Determine time of dusk and dawn)
(Assume that the best frequency of operation will be low at night and high
during the day.  The best frequency will coincide with the mean frequency
at dawn and dusk.)
   DAWN,DUSK <-- 0
   DO FOR I <-- 1 TO 24
   BEST_FREQ(I) <-- SQRT(2**BEST_FREQ(I))
         IF DAWN = 0 AND BEST_FREQ(I) > MEAN_FREQ THEN
            DAWN <-- I
         IF DUSK = 0 AND DAWN > 0 AND BEST_FREQ(I) < MEAN_FREQ THEN
            DUSK <-- I
         END IF
   END DO
MIDNIGHT <-- INT((DUSK + DAWN + 24.5)/2) - 24
IF MIDNIGHT < 0 THEN MIDNIGHT <-- 24 + MIDNIGHT
MIDDAY <-- INT(DUSK+DAWN)/2 +.5)
DAY_FREQ <-- SQRT(2**BEST_FREQ(MIDDAY))
NIGHT_FREQ <-- SQRT(2**BEST_FREQ(MIDNIGHT))
(Determine which of the available frequencies best coincides with the
Day, Night, and Mean Frequencies)
DIFFERENCE_1 <-- 30
DIFFERENCE_2 <-- 30
```

```
DIFFERENCE_3 <-- 30
DO FOR J <-- 1 TO NUMBER_OF_FREQS_AVAIL
   DELTA <-- ABS(FREQ_AVAIL(J) - DAY_FREQ)
   IF DELTA < DIFFERENCE_1
      DIFFERENCE_1 <-- DELTA
      DESIGN_FREQ(1) <-- FREQ_AVAIL(J)
   END IF
   DELTA <-- ABS(FREQ_AVAIL(J) - NIGHT_FREQ)
   IF DELTA < DIFFERENCE_2 THEN
      DIFFERNCE_2 <-- DELTA
      DESIGN_FREQ(2) <-- FREQ_AVAIL(J)
   END IF
   DELTA <-- ABS(FREQ_AVAIL(J) - MEAN_FREQ
   IF DELTA < DIFFERENCE_3 THEN
      DIFFERENCE_3 <-- DELTA
      DESIGN_FREQ(3) <-- FREQ_AVAIL(J)
   END IF
END DO
ANTENNA_TOA <-- TOA(DAWN)
IF START_TIME > DAWN AND STOP_TIME < DUSK THEN
   (Operations are during the day only)
   DESIGN_FREQ(3), DESIGN_FREQ(2) <-- DESIGN_FREQ(1)
   ANTENNA_TOA <-- TOA(MIDDAY)
```

```
   IF STOP_TIME < DAWN and START_TIME > DUSK THEN
      (Operations are during the night only)
      DESIGN_FREQ(3), DESIGN_FREQ(1) <-- DESIGN_FREQ(2)
      ANTENNA_TOA <-- TOA(MIDNIGHT)
   RETURN
END DETERMINE_DESIGN_FREQUENCIES
```

```
SUBROUTINE RAZGC
(IN:  POINT_1_2_RADIAN_DIST, POINT_1_LOC(1:2), POINT_1_2 RADIAN_AZIMUTH)
(OUT:  POINT_2_LOC(1:2))
   C <-- POINT_1_2_RADIAN_DIST
   D <-- POINT_1_2_RADIAN_AZIMUTH
   (Calculate R & S as in Prophet RAZGC)
   POINT_2_LOC(1)  <-- R (LATITUDE)
   POINT_2_LOC(2)  <-- S (LONGITUDE)
   RETURN
END RAZGC
```

```
SUBROUTINE GCRAZ
(IN:  POINT_1_LOC(1:2), POINT_2_LOC(1:2)
(OUT:  POINT_1_2_RADIAN_DIST, POINT_1_2_RADIAN_AZIMUTH)
   A <-- POINT_1_LOC(1) (LATITUDE)
   B <-- POINT_1_LOC(2) (LONGITUDE)
   C <-- POINT_2_LOC(1)
   D <-- POINT_2_LOC(2)
   (Calculate R & S using Prophets GCRAZ)
   POINT_1_2_RADIAN_DIST <-- R
   POINT_1_2_RADIAN_AZIMUTH <-- S
   RETURN
END GCRAZ
```

```
SUBROUTINE MINIMUF
(IN:  POINT_1_2_RADIAN_DIST, HOUR, MINUTE, DATE(1:2), POINT_1_LOC(1)
POINT_2_LOC(1:2), POINT_2_1_AZIMUTH, SSN)
(OUT:  MUF)
   M1 <-- DATE(2)
   D0 <-- DATE(1)
   H0 <-- HOUR
   M0 <-- MINUTE
   Z3 <-- POINT_1_LOC(1)          (Latitude)
   Z5 <-- POINT_2_LOC(1)          (Latitude)
   Z6 <-- POINT_2_LOC(2)          (Longitude)
   Z0(1) <-- POINT_1_2_RADIAN_DISTANCE
   Z0(2) <-- POINT_2_1_AZIMUTH    (In Radians)
   S9 <-- SSN                      (SSN = Sunspot number)
   (Calculate MUF = J9 as in PROPHET MINIMUF)
   MUF <-- J9
   RETURN
END MINIMUF
```

```
SUBROUTINE GMT_TO_LOCAL_TIME
(IN:  GMT, LONGITUDE)
(OUT:  LOCAL_TIME)
(West longitude is negative)
   LOCAL_TIME <-- INT(GMT + LONGITUDE/0.262 + .5)
   IF LOCAL_TIME < 0 THEN
      LOCAL_TIME <-- LOCAL_TIME + 24
   ELSE IF LOCAL_TIME > 24 THEN
      LOCAL_TIME <-- LOCAL_TIME - 24
   END IF
   RETURN
END GMT_TO_LOCAL_TIME
```

```
SUBROUTINE QLOF
(IN:  XMTR_RCVR_AZIMUTH, XMTR_RCVR_RADIAN_DIST, COORDS_MIDPOINT,
COORDS_1000_KM_FROM_XMTR,
COORDS_1000_KM_FROM_RCVR, RCVR_XMTR_AZIMUTH, MONTH)
(OUT:  LUF)
   Z0(1) <-- XMTR_RCVR_RADIAN_DIST
   Z0(2) <-- RCVR_XMTR_AZIMUTH
   Z0(3) <-- COORDS_MIDPOINT(1)
   Z0(4) <-- COORDS_MIDPOINT(2)
   Z0(5) <-- COORDS_1000_KM_FROM_RCVR(1)
   Z0(6) <-- COORDS_1000_KM_FROM_RCVR(2)
   Z0(7) <-- COORDS_1000_KM_FROM_XMTR(1)
   Z0(8) <-- COORDS_1000_KM_FROM_XMTR(2)
   (Process as in QLOF of PROPHET)
   LUF <-- L
   RETURN
END QLOF
```

```
SUBROUTINE PATH
(IN:  XMTR_LOC, RCVR_LOC)
(OUT:  XMTR_RCVR_AZIMUTH, XMTR_RCVR_RADIAN_DISTANCE, COORDINATES_MIDPOINT,
COORDS_1000_KM_FROM_XMTR, COORDS_1000_KM_FROM_RCVR, RCVR_XMTR_AZIMUTH)
   CALL GCRAZ
   (IN:  XMTR_LOC, RCVR_LOC)
   (OUT:  XMTR_RCVR_RADIAN_DIST, XMTR_RCVR_AZIMUTH)
   XMTR_MIDPOINT_RADIAN_DIST <-- XMTR_RCVR_RADIAN_DIST/2
   CALL RAZGC
   (IN:  XMTR_MIDPOINT_RADIAN_DIST, XMTR_LOC, XMTR_RCVR_AZIMUTH)
   (OUT:  COORDINATES_MIDPOINT)
   IF XMTR_RCVR_RADIAN_DIST > PI/5 THEN
      RADIAN_DISTANCE_1000_KM <-- 0.15696
      CALL RAZGC
      (IN:  RADIAN_DISTANCE_1000_KM, XMTR_LOC, XMTR_RCVR_AZIMUTH)
      (OUT:  COORDS_1000_KM_FROM_XMTR)
      XMTR_RCVR_RAD_DIST_1000_KM <-- XMTR_RCVR_RADIAN_DIST - 0.15696
      CALL RAZGC
      (IN:  XMTR_RCVR_RAD_DIST_LESS_1000_KM, XMTR_LOC, XMTR_RCVR_AZIMUTH)
      (OUT:  COORDS_1000_KM_FROM_RCVR)
   END IF
   CALL GCRAZ
   (IN:  RCVR_LOC, XMTR_LOC)
```

```
     (OUT:  RCVR_XMTR_RADIAN_DIST, RCVR_XMTR_AZIMUTH)
     RETURN
  END PATH
```

```
SUBROUTINE FIND_S/N_FOR_WHIP
(IN:  FREQ_AVAIL, NUMBER_OF_FREQS_AVAIL, S/N_ON_AVAIL_FREQS, TOA)
(OUT:  S/N_ON_ANTENNA)
   DO FOR I <-- 1 TO NUMBER_OF_AVAIL_FREQS
      (Determine length of 32' whip in wavelengths for Frequency I)
         LENGTH <-- 32/(984/FREQ_AVAILABLE(I))
      (Find radiation pattern for whip antenna of electrical length = LENGTH,
      results into 28 element array GAIN which represents the radiation
      pattern of the antenna from 3 degrees to 84 degrees above the horizon
      in 3 degree increments)
      DO FOR J <-- 1 TO 24
         S/N_ON_ANTENNA(J,I) <-- S/N_ON_FREQ_AVAIL(J,I) +
            ANTENNA_GAIN(TOA(J)/3)
      END DO
   END DO
   RETURN
END FIND_S/N_FOR_WHIP
```

```
SUBROUTINE DESIGN_ANTENNA
(IN:  ANTENNA_DESIGN_INFO)
(OUT:  ANTENNA_CONSTRUCTION_INFO)
   OUTPUT "Which antenna do you want designed?"
   IF ANTENNA(1) = 1 THEN OUTPUT "1 ... Longwire"
   IF ANTENNA(2) = 1 THEN OUTPUT "2 ... Dipole"
   IF ANTENNA(3) = 1 THEN OUTPUT "3 ... Half-Square"
   IF ANTENNA(4) = 1 THEN OUTPUT "4 ... Vee"
   INPUT ANTENNA_CHOICE
   CASE ANTENNA_CHOICE OF
   1:
      CALL DESIGN_LONGWIRE
      (IN:  ANTENNA_DESIGN_INFO)
      (OUT:  ANTENNA_CONSTRUCTION_INFO)
      ANTENNA_NAME<-- "Longwire"
   2:
      CALL DESIGN_DIPOLE
      (IN:  ANTENNA_DESIGN_INFO)
      (OUT:  ANTENNA_CONSTRUCTION_INFO)
      ANTENNA_NAME <-- "Dipole"
   3:
      CALL DESIGN_HALF_SQUARE
      (IN:  ANTENNA_DESIGN_INFO)
```

```
      (OUT:  ANTENNA_CONSTRUCTION_INFO)
      ANTENNA_NAME <-- "Half-Square"
   4:
      CALL DESIGN_VEE
      (IN:  ANTENNA_DESIGN_INFO)
      (OUT:  ANTENNA_CONSTRUCTION_INFO)
      ANTENNA_NAME <-- "VEE"
   END CASE
   RETURN
END DESIGN_ANTENNA
```

```
SUBROUTINE DESIGN_LONGWIRE
(IN:  ANTENNA_DESIGN_INFO)
(OUT:  ANTENNA_CONSTRUCTION_INFO)
   (Determine the maximum length possible for the longwire)
      MAX_LENGTH <-- MAX(ANTENNA_SITE_LENGTH,(WIRE_LENGTH - MAST_HEIGHT(1))
      MAX_LENGTH <-- MAX_LENGTH + MAST_HEIGHT(1)
   (Determine length of the longwire antenna for DESIGN_FREQ(3))
      CALL DETERMINE_LONGWIRE_LENGTH_AND_ORIENTATION
      (IN:  MAX_LENGTH, DESIGN_FREQ(3), XMTR_RCVR_AZIMUTH, ANTENNA_TOA,
      ANTENNA_WIRE_TYPE)
      (OUT:  ANTENNA_LENGTH, ANTENNA_AZIMUTH, ORIENTATION_ANGLE)
   ANTENNA_HEIGHT(1) <-- MAST_HEIGHT(1)
   ANTENNA_HEIGHT(2) <-- MAST_HEIGHT(2)
   CALL FIND_S/N_FOR_LONGWIRE
   (IN:  S/N_ON_AVAIL_FREQ, ANTENNA_LENGTH(1), FREQ_AVAIL,
   ANTENNA_HEIGHT, ORIENTATION_ANGLE, NUMBER_OF_FREQS_AVAIL, TOA)
   (OUT:  S/N_ON_ANTENNA)
   RETURN
END DESIGN_LONGWIRE_ANTENNA
```

```
SUBROUTINE MODIFY_LONGWIRE_ANTENNA
(IN:  TOA, FREQ_AVAIL, NUMBER_OF_FREQ_AVAIL, XMTR_RCVR_AZIMUTH)
(IN/OUT:  ANTENNA_LENGTH, ANTENNA_AZIMUTH, S/N_ON_ANTENNA, ORIENTATION_ANGLE)
  OUTPUT "Enter the antenna height at the radio end."
  INPUT ANTENNA_HEIGHT(1)
  OUTPUT "Enter the antenna height at the far end."
  INPUT ANTENNA_HEIGHT(2)
  OUTPUT "Enter the antenna length -- distance between supporting masts."
  INPUT ANTENNA_LENGTH(1)
  ANTENNA_LENGTH(1) <-- ANTENNA_LENGTH(1) + ANTENNA_HEIGHT(1)
  DO UNTIL ORIENTATION_ANGLE < 31
    OUTPUT "Enter the azimuth along which the antenna will be aligned."
    INPUT ANTENNA_AZIMUTH(1)
    AZIMUTH <-- XMTR_RCVR_AZIMUTH * (360/(2*PI))
    ORIENTATION_ANGLE <-- ABS(ANTENNA_AZIMUTH(1) - AZIMUTH)
    IF ORIENTATION_ANGLE > 180 THEN
      IF ANTENNA_AZIMUTH(1) > 180 THEN
        ORIENTATION_ANGLE <-- ABS(ANTENNA_AZIMUTH(1) + 360 - AZIMUTH)
      ELSE
        ORIENTATION_ANGLE <-- ABS(ANTENNA_AZIMUTH(1) - 360 - AZIMUTH)
      END IF
  END DO
  ANTENNA_AZIMUTH(2) <-- ANTENNA_AZIMUTH(1)
```

```
    CALL FIND_S/N_FOR_LONGWIRE
    (IN:  S/N_ON_AVAIL_FREQ, ANTENNA_LENGTH(1), FREQ_AVAIL, ANTENNA_HEIGHT,
    ORIENTATION_ANGLE, NUMBER_OF_FREQS_AVAIL, TOA)
    (OUT:  S/N_ON_ANTENNA)
    RETURN
END MODIFY_LONGWIRE_ANTENNA
```

```
SUBROUTINE DETERMINE_LONGWIRE_LENGTH_AND_ORIENTATION
(IN:  MAX_LENGTH, DESIGN_FREQUENCY(3), XMTR_RCVR_AZIMUTH, ANTENNA_TOA,
ANTENNA_WIRE_TYPE)
(OUT:  ANTENNA_LENGTH, ANTENNA_AZIMUTH, ORIENTATION_ANGLE)
   (Determine the length of a longwire designed for DESIGN_FREQ(3))
   (Determine factor required for wavelength calculation
      IF TYPE_OF_ANTENNA_WIRE = 0 THEN
         (WIRE TYPE IS WD-1/TT)
         FACTOR <-- 973 -  (0.328*DESIGN_FREQ(3))
      ELSE
         (Wire type is copper or phosphur bronze)
         FACTOR <-- 984
      END IF
      WAVELENGTH <-- FACTOR/DESIGN_FREQ(3)
      IF ANTENNA_TCA > 21 THEN
         IF ANTENNA_TOA < 23 THEN
            MAX_LENGTH <-- MIN(MAX_LENGTH,5.4 * WAVELENGTH)
         ELSE IF ANTENNA_TOA < 26 THEN
            MAX_LENGTH <-- MIN(MAX_LENGTH,4.4 * WAVELENGTH)
         ELSE IF ANTENNA_TOA < 30 THEN
            MAX_LENGTH <-- MIN(MAX_LENGTH,3.4 * WAVELENGTH)
         ELSE IF ANTENNA_TOA < 38 THEN
            MAX_LENGTH <-- MIN(MAX_LENGTH,2.4 * WAVELENGTH)
```

```
      END IF
   END IF
   ELECTRICAL_LENGTH <-- 1.2
   LONGWIRE_LENGTH <-- 0
   ANTENNA_LENGTH(1) <-- ELECTRICAL_LENGTH * WAVELENGTH
   DO UNTIL LONGWIRE_LENGTH > MAX_LENGTH
      ANTENNA_LENGTH(1) <-- LONGWIRE_LENGTH
      ELECTRICAL_LENGTH <-- ELECTRICAL_LENGTH + .5
      LONGWIRE_LENGTH <-- ELECTRICAL_LENGTH * WAVELENGTH
   END DO
   ELECTRICAL_LENGTH <-- ELECTRICAL_LENGTH - 0.5
(Determine WAVE_ANGLE, angle at which maximum power is radiated from the
antenna)
   IF ELECTRICAL_LENGTH < 2.5
      WAVE_ANGLE <-- 38
   ELSE IF ELECTRICAL_LENGTH < 3.5
      WAVE_ANGLE <-- 30
   ELSE IF ELECTRICAL_LENGTH < 4.5
      WAVE_ANGLE <-- 26
   ELSE IF ELECTRICAL_LENGTH < 5.5
      WAVE_ANGLE <-- 23
   ELSE
      WAVE_ANGLE <-- 20
```

```
      END IF
    (Determine ORIENTATION_ANGLE, angle between the antenna and the azimuth to
    the outstation)
      CRIENTATION_ANGLE <-- ARCOS(COS(WAVE_ANGLE)/COS(ANTENNA_TOA)
      AZIMUTH <-- XMTR_RCVR_AZIMUTH * 360/(2*PI)
      IF ORIENTATICN_ANGLE > 5 THEN
        ANTENNA_AZIMUTH(1) <-- AZIMUTH + ORIENTATION_ANGLE
        IF ANTENNA_AZIMUTH(1) > 360 THEN
          ANTENNA_AZIMUTH(1) <-- ANTENNA_AZIMUTH(1) - 360
        ANTENNA_AZIMUTH(2) <-- AZIMUTH - ORIENTATION_ANGLE
        IF ANTENNA_AZIMUTH(2) < 0 THEN
          ANTENNA_AZIMUTH(2) <-- ANTENNA_AZIMUTH(2) + 360
    ELSE
      CRIENTATION_ANGLE <-- 0
      ANTENNA_AZIMUTH(1:2) <-- AZIMUTH
    END IF
    RETURN
  END DETERMINE_LONGWIRE_LENGTH_AND_ORIENTATION
```

```
SUBROUTINE FIND_S/N_FOR_LONGWIRE
(IN:  S/N_ON_AVAIL_FREQ, ANTENNA_LENGTH(1), FREQ_AVAIL, ANTENNA_HEIGHT,
ORIENTATION_ANGLE)
(OUT:  S/N_ON_ANTENNA)
  DO FOR I <-- 1 TO NUMBER_OF_FREQS_AVAIL
    WAVELENGTH <-- 984/FREQ_AVAIL(I)
    ELECTRICAL_LENGTH <-- INT(.5 + (ANTENNA_LENGTH(1) - ANTENNA_HEIGHT(1))/
      WAVELENGTH)
    ELECTRICAL_HEIGHT <-- (ANTENNA_HEIGHT(1) + ANTENNA_HEIGHT(2))/
      (2 * WAVELENGTH)
    CALL FIND_LONGWIRE_PATTERN
    (IN:  ELECTRICAL_LENGTH, ELECTRICAL_HEIGHT, ORIENTATION_ANGLE)
    (OUT:  ANTENNA_GAIN)
    DO FOR J <-- 1 TO 24
      S/N_ON_ANTENNA(J,I) <-- S/N_ON_FREQ_AVAIL(J,I) +
        ANTENNA_GAIN(TOA(J)/3)
    END DO
  END DO
  RETURN
END FIND_S/N_FOR_LONGWIRE
```

```
SUBROUTINE FIND_LONGWIRE_PATTERN
(IN:  ELECTRICAL_LENGTH, ELECTRICAL_HEIGHT, ORIENTATION_ANGLE)
(OUT:  ANTENNA_GAIN)
   (Find the file on tape containing the pattern data for a longwire of the
   dimensions ELECTRICAL_LENGTH and ELECTRICAL_HEIGHT, strip out the pattern
   data for the ORIENTATION_ANGLE)
   RETURN
END FIND_LONGWIRE_PATTERN
```

```
SUBROUTINE DIAGRAM_LONGWIRE
(IN: XMTR_RCVR_AZIMUTH, ANTENNA_AZIMUTH, ANTENNA_HEIGHT,
ANTENNA_LENGTH, RESISTOR, BALUN)
   (Scale antenna dimensions to fill plot window)
      (Set SCALE_FACTOR, antenna length will be 3/4 the width of the plot window)
         SCALE_FACTOR <-- ANTENNA_LENGTH * 1.33
      LENGTH <-- ANTENNA_LENGTH/SCALE_FACTOR
      HEIGHT(1) <-- ANTENNA_HEIGHT(1)/SCALE_FACTOR
      HEIGHT(2) <-- ANTENNA_HEIGHT(2)/SCALE_FACTOR
   (Diagram the antenna)
   IF RESISTOR = 1 THEN
      (Add resistor to diagram)
   (Plot orientation diagram)
   IF ANTENNA_AZIMUTH(2) = ANTENNA_AZIMUTH(1) THEN
      (Do not plot second azimuth)
      "The longwire should be oriented along either
      azimuth shown above."
   RETURN
END DIAGRAM_LONGWIRE
```

```
SUBROUTINE DESIGN_DIPOLE
(IN:  ANTENNA_DESIGN_INFO)
(OUT:  ANTENNA_CONSTRUCTION_INFO)
(This routine will determine the dimensions of three dipoles, one for each
design frequency.)
   DO FOR I <-- 1 TO 3
      (Determine the antenna length)
         IF TYPE_OF_ANTENNA_WIRE = 1 THEN
            (WD-1/TT FORMULA)
            ANTENNA_LENGTH(I) <-- 440/DESIGN_FREQ(I)
         ELSE
            (Wire is copper or phosphur bronze)
            ANTENNA_LENGTH(I) <-- 460/DESIGN_FREQ(I)
      END IF
   END DO
   CALL DETERMINE_DIPOLE_HEIGHT_AND_ORIENTATION)
   (IN:  TOA, DESIGN_FREQ, MAST_HEIGHT, ANTENNA_TOA)
   (OUT:  ANTENNA_HEIGHT, ORIENTATION_ANGLE)
   CALL FIND_S/N_FOR_DIPOLE
   (IN:  S/N_ON_AVAIL_FREQ, FREQ_AVAIL,
   NUMBER_OF_FREQ_AVAIL, ANTENNA_HEIGHT, DESIGN_FREQ, TOA)
   (OUT:  S/N_ON_ANTENNA)
   RETURN
END DESIGN_DIPOLE
```

```
SUBROUTINE MODIFY_DIPOLE_ANTENNA
(IN:  TOA, FREQ_AVAIL, S/N_ON_AVAIL_FREQ, NUMBER_OF_FREQS_AVAIL)
(IN/OUT:  ANTENNA_HEIGHT, DESIGN_FREQ, S/N_ON_ANTENNA)
   OUTPUT "Enter the new frequencies of design.  Presently the
      frequencies the three dipoles were designed to operate
      on are "DESIGN_FREQ(1:3)
   OUTPUT "The new frequencies must be taken from the following list:"
   OUTPUT FREQ_AVAIL(1:NUMBER_OF_FREQ_AVAIL)
   INPUT DESIGN_FREQ(1:3)
   OUTPUT "Do you wish to specify the antenna heights? Y/N"
   INPUT ANSWER
   IF ANSWER = "Y" THEN
      DO FOR I <-- 1 TO 3
         OUTPUT "Enter the height for the dipole to operate on "
         OUTPUT DESIGN_FREQ(I)
         INPUT ANTENNA_HEIGHT(I)
      END DO
      WAVELENGTH <-- 984/DESIGN_FREQ(3)
      IF ANTENNA_HEIGHT(3) < .2 * WAVELENGTH THEN
         ORIENTATION_ANGLE <-- 90
      ELSE
         ORIENTATION_ANGLE <-- 40
      END IF
```

```
  ELSE
     CALL DETERMINE_DIPOLE_HEIGHT_AND_ORIENTATION
      (IN:  TOA, DESIGN_FREQ, MAST_HEIGHT)
      (OUT:  ANTENNA_HEIGHT, ORIENTATION_ANGLE)
  END IF
  CALL FIND_S/N_FOR_DIPOLE
  (IN:  S/N_ON_AVAIL_FREQ, FREQ_AVAIL, NUMBER_OF_FREQS_AVAIL, ANTENNA_HEIGHT,
  DESIGN_FREQ,TOA)
  (OUT:  S/N_ON_ANTENNA)
  RETURN
END MODIFY_DIPOLE_ANTENNA
```

```
SUBROUTINE FIND_S/N_FOR_DIPOLE
(IN:  S/N_ON_AVAIL_FREQ, FREQ_AVAIL, NUMBER_OF_FREQS_AVAIL,
ANTENNA_HEIGHT, DESIGN_FREQ, TOA)
(OUT:  S/N_ON_ANTENNA)
   DO FOR I <-- 1 TO NUMBER_OF_FREQS_AVAIL
      ANTENNA_GAIN(1:28) <-- -30
      IF FREQ_AVAIL(I) = DESIGN_FREQ(1) OR FREQ_AVAIL(I) = DESIGN_FREQ(2) OR
         FREQ_AVAIL(I) = DESIGN_FREQ(I) THEN
            WAVELENGTH <-- 984/FREQ_AVAIL(I)
            ELECTRICAL_HEIGHT <-- (ANTENNA_HEIGHT(1) + ANTENNA_HEIGHT(2))/
                2 * WAVELENGTH)
            CALL FIND_DIPOLE_PATTERN
            (IN:  ELECTRICAL_HEIGHT)
            (OUT:  ANTENNA_GAIN)
      END IF
      DO FOR J <-- 1 TO 24
         S/N_ON_ANTENNA <-- S/N_ON_FREQ_AVAIL(J,I) +
            ANTENNA_GAIN(TOA(J)/3)
      END DO
   END DO
   RETURN
END FIND_S/N_ON_DIPOLE
```

```
SUBROUTINE FIND_DIPOLE_PATTERN
(IN:  ELECTRICAL_HEIGHT)
(OUT:  ANTENNA_GAIN)
   (Find the file on tape containing the pattern data for a dipole antenna
   ELECTRICAL_HEIGHT wavelengths above the ground, the data goes into
   ANTENNA_GAIN(1:28))
   RETURN
END FIND_DIPOLE_PATTERN
```

```
SUBROUTINE DETERMINE_DIPOLE_HEIGHT_AND_ORIENTATION
(IN:  TOA, DESIGN_FREQ, MAST_HEIGHT, ANTENNA_TOA)
(OUT:  ANTENNA_HEIGHT, ORIENTATION_ANGLE)
   (Determine best antenna height.)
      IF ANTENNA_TOA > 50 THEN
         (The dipole should be constructed close to the ground)
         DO FOR I <-- 1 TO 3
            WAVELENGTH <-- 984/DESIGN_FREQ(I)
            ANTENNA_HEIGHT(I) <-- MIN(.1*WAVELENGTH, MAST_HEIGHT(2))
         END DO
         ORIENTATION_ANGLE <-- 90
      ELSE
         (The dipole should be constructed as high as possible.)
         ANTENNA_HEIGHT(1:3) <-- MAST_HEIGHT(2)
         ORIENTATION_ANGLE <-- 40
      ELSE IF
   RETURN
END DETERMINE_DIPOLE_HEIGHT
```

```
SUBROUTINE DESIGN_VEE
(IN:  ANTENNA_DESIGN_INFO)
(OUT:  ANTENNA_CONSTRUCTION_INFO)
   (Determine the maximum length possible for each leg of the vee)
      MAX_LENGTH <-- MAX(ANTENNA_SITE_LENGTH,(WIRE_LENGTH/2))
   (Determine length of the vee legs for DESIGN_FREQ(3).  Vee is two longwires.)
      CALL DETERMINE_LONGWIRE_LENGTH_AND_ORIENTATION
      (In: MAX_LENGTH, DESIGN_FREQ(3), XMTR_RCVR_AZIMUTH, ANTENNA_TOA
      ANTENNA_WIRE_TYPE)
      (OUT:  ANTENNA_LENGTH, ANTENNA_AZIMUTH, ORIENTATION_ANGLE)
   ANTENNA_HEIGHT(1) <-- MAST_HEIGHT(1)
   ANTENNA_HEIGHT(2) <-- MAST_HEIGHT(3)
   CALL FIND_S/N_FOR_VEE
   (IN:  S/N_ON_AVAIL_FREQ, ANTENNA_LENGTH(1), FREQ_AVAIL,
   ANTENNA_HEIGHT, ORIENTATION_ANGLE, NUMBER_OF_FREQS_AVAIL, TOA)
   (OUT:  S/N_ON_ANTENNA)
   RETURN
END DESIGN_VEE_ANTENNA
```

```
SUBROUTINE MODIFY_VEE
(IN: TCA, FREQ_AVAIL, S/N_ON_AVAIL_FREQ, NUMBER_OF_FREQ_AVAIL, XMTR_RCVR_AZIMUTH)
(IN/OUT:  ANTENNA_LENGTH, ANTENNA_HEIGHT,
ANTENNA_AZIMUTH, S/N_ON_ANTENNA, ORIENTATION_ANGLE)
   OUTPUT "Enter the antenna height at the radio end."
   INPUT ANTENNA_HEIGHT(1)
   OUTPUT "Enter the antenna height at the far end."
   INPUT ANTENNA_HEIGHT(2)
   OUTPUT "Enter the antenna length."
   INPUT ANTENNA_LENGTH(1)
   OUTPUT "Enter the angle between the antenna legs."
   INPUT APEX_ANGLE
   ORIENTATION_ANGLE <-- APEX_ANGLE/2
   AZIMUTH <-- XMTR_RCVR_AZIMUTH * (360/(2*PI))
   ANTENNA_AZIMUTH(1) <-- AZIMUTH - ORIENTATION_ANGLE
   IF ANTENNA_AZIMUTH(1) < 0 THEN
      ANTENNA_AZIMUTH(1) <-- 360 + ANTENNA_AZIMUTH(1)
      ANTENNA_AZIMUTH(2) <-- AZIMUTH + ORIENTATION_ANGLE
   ELSE
      ANTENNA_AZIMUTH(2) <-- AZIMUTH + ORIENTATION_ANGLE
      IF ANTENNA_AZIMUTH(2) > 360 THEN
         ANTENNA_AZIMUTH(2) <-- ANTENNA_AZIMUTH(2) - 360
      END IF
```

```
    CALL FIND_S/N_FOR_VEE
    (IN:  S/N_ON_AVAIL_FREQ, ANTENNA_LENGTH(1),
    FREQ_AVAIL, ANTENNA_HEIGHT, ORIENTATION_ANGLE,
    NUMBER_OF_FREQS_AVAIL, TOA)
    (OUT:  S/N_ON_ANTENNA)
    RETURN
END MODIFY_VEE
```

```
SUBROUTINE FIND_S/N_FOR_VEE
(IN: S/N_ON_AVAIL_FREQ, ANTENNA(1), FREQ_AVAIL, ANTENNA_HEIGHT, ORIENTATION_ANGLE,
NUMBER_OF_FREQS_AVAIL, TOA)
(OUT:  S/N_ON_ANTENNA)
   DO FOR I <-- 1 TO NUMBER_OF_FREQS_AVAIL
      WAVELENGTH <-- 984/FREQ_AVAIL(I)
      ELECTRICAL_LENGTH <-- INT(.5 + ANTENNA_LENGTH(1)/WAVELENGTH)
      ELECTRICAL_HEIGHT <-- (ANTENNA_HEIGHT(1) + ANTENNA_HEIGHT(2))/
         (2*WAVELENGTH)
      APEX_ANGLE <-- 2*ORIENTATION_ANGLE
      CALL FIND_VEE_PATTERN
      (IN:  ELECTRICAL_LENGTH, ELECTRICAL_HEIGHT, APEX_ANGLE)
      (OUT:  ANTENNA_GAIN)
      DO FOR J <-- 1 TO 24
      S/N_ON_ANTENNA(J,I) <-- S/N_ON_AVAIL_FREQ(J,I) +
         ANTENNA_GAIN(TOA(J)/3)
      END DO
   END DO
   RETURN
END FIND_S/N_FOR_VEE
```

```
SUBROUTINE FIND_VEE_PATTERN
(IN:  ELECTRICAL_LENGTH, ELECTRICAL_HEIGHT,
APEX_ANGLE)
(OUT:  ANTENNA_GAIN)
   (Find tape file with pattern data
   for APEX_ANGLE.  Strip out the particular
   pattern pointed to by ELECTRICAL_LENGTH
   and ELECTRICAL_HEIGHT
   RETURN
END FIND_VEE_PATTERN
```

```
SUBROUTINE DESIGN_HALF_SQUARE
(IN:  ANTENNA_DESIGN_INFO)
(OUT:  ANTENNA_CONSTRUCTION_INFO)
(This routine will determine the dimensions
of three Half Square antennas, one for each design frequency)
   DO FOR I <-- 1 TO 3
      (Determine overall antenna length)
      IF TYPE_OF_ANTENNA_WIRE = 0 THEN
         (WIRE TYPE IS WD-1/TT)
         FACTOR <-- 973 -  (.328 * DESIGN_FREQ(I))
      ELSE
         (Wire type is copper or phosphur bronze.)
         FACTOR <-- 984
      END IF
      ANTENNA_LENGTH(I) <--FACTOR/WAVELENGTH
   END DO
   ANTENNA)HEIGHT(1:2) <-- MAST_HEIGHT(2)
   CALL FIND_S/N_FOR_HS
   (IN:  S/N_ON_AVAIL_FREQ, FREQ_AVAIL, NUMBER_OF_FREQS_AVAIL, TOA)
   (OUT:  S/N_ON_ANTENNA)
   RETURN
END DESIGN_HALF_SQUARE
```

```
SUBROUTINE FIND_S/N_FOR_HS
(IN:  S/N_ON_AVAIL_FRQ, FREQ_AVAIL, NUMBER_OF_FREQS_AVAIL, TOA)
(OUT:  S/N_ON_ANTENNA)
   CALL FIND_HS_PATTERN
   (OUT:  ANTENNA_GAIN)
   DO FOR I <-- 1 TO NUMBER_OF_FREQS_AVAIL
      IF FREQ_AVAIL(I) = DESIGN_FREQ(1) OR FREQ_AVAIL(I) = DESIGN_FREQ(2)
         OR FREQ_AVAIL(I) = DESIGN_FREQ(3) THEN
         DO FOR J <-- 1 TO 24
         S/N_ON_ANTENNA(J,I) <-- S/N_ON_FREQ_AVAIL(J,I) + ANTENNA_GAIN(TOA(J)/3)
         END DO
      ELSE
         DO FOR J <-- 1 TO 24
            S/N_ON_ANTENNA <-- S/N_ON_AVAIL_FREQ(J,I) - 30
         END DO
      END IF
   END DO
   RETURN
END FIND_S/N_FOR_HS
```

```
SUBROUTINE FIND_HS_PATTERN
(OUT:  ANTENNA_GAIN)
   (Find the single set of data on tape
   characterizing the Half Square
   radiation pattern.)
   RETURN
END FIND_HS_PATTERN
```

```
SUBROUTINE PLOT_RADIATION_PATTERN
(IN: ANTENNA_HEIGHT, ANTENNA_LENGTH, ORIENTATION_ANGLE,
ANTENNA_CHOICE, FREQ_AVAIL, TOA, ANTENNA)
   CASE ANTENNA_CHOICE OF
   1:
      OUTPUT "Enter frequency of operation"
      OUTPUT "Available frequencies are:"  FREQ_AVAIL(1:NUMBER_OF_FREQS_AVAIL)
      INPUT FREQUENCY
      WAVELENGTH <-- 984/FREQUENCY
      ELECTRICAL_LENGTH <-- INT(.5 + (ANTENNA_LENGTH - ANTENNA_HEIGHT(1))/WAVELENGTH)
      ELECTRICAL_HEIGHT <-- (ANTENNA_HEIGHT(1) + ANTENNA_HEIGHT(2))/(2*WAVELENGTH)
      CALL FIND_LONGWIRE_PATTERN
      (IN:  ELECTRICAL_LENGTH, ELECTRICAL_HEIGHT, ORIENTATION_ANGLE)
      (OUT:  ANTENNA_GAIN)
   2:
      OUTPUT "Enter Frequency of operation
      OUTPUT "Design frequencies are:" DESIGN_FREQ(1:3)
      INPUT FREQUENCY
      WAVELENGTH <-- 984/FREQUENCY
      ELECTRICAL_HEIGHT <-- ANTENNA_HEIGHT(2)/WAVELENGTH
      CALL FIND_DIPOLE_PATTERN
      (IN:  ELECTRICAL_HEIGHT)
      (OUT:  ANTENNA_GAIN)
```

```
3:
   CALL FIND_HS_PATTERN
   (OUT:  ANTENNA_GAIN)
4:
   OUTPUT "Enter frequency of operation"
   OUTPUT "Available Frequencies are:"
      FREQ_AVAIL(1:NUMBER_OF_FREQS_AVAIL)
   INPUT FREQUENCY
   WAVELENGTH <-- 984/FREQUENCY
   ELECTRICAL_LENGTH <-- INT(.5 + ANTENNA_LENGTH/WAVELENGTH)
   ELECTRICAL_HEIGHT <-- (ANTENNA_HEIGHT(1) + ANTENNA_HEIGHT(2))/(2 * WAVELENGTH)
   CALL FIND_VEE_PATTERN
   (IN:  ELECTRICAL_LENGTH, ELECTRICAL_HEIGHT, ORIENTATION_ANGLE)
   (OUT:  ANTENNA_GAIN)
END CASE
(Print out Heading)
   OUTPUT "The below pattern is for the" ANTENNA_NAME
   OUTPUT "Overall length of the antenna is:" ANTENNA_LENGTH
   OUTPUT "Height of the antenna is:"
   OUTPUT "END ONE" ANTENNA_HEIGHT(1)
   OUTPUT "END TWO" ANTENNA_HEIGHT(2)
   OUTPUT "The pattern is a vertical cut along the azimuth to the outstation"
   IF ANTENNA_CHOICE = 3 THEN
```

```
      OUTPUT "Frequency of operation is "FREQUENCY
  CASE ANTENNA_CHOICE OF
  1:
     "The angle between the longwire and the
     outstation is "ORIENTATION_ANGLE"
  2:
     "The angle between the dipole and the outstation is 90 degrees
     plus or minus" ORIENTATION_ANGLE"
  3:
     "The half-square is perpendicular to the azimuth
     to the outstation plus or minus 30 degrees"
  4:
     "The azimuth to the outstation bisects
     the angle between the Vee legs -- apex angle;
     the apex angle is" 2*ORIENTATION_ANGLE
  END CASE
     (Determine the Minimum and Maximum TOA's for 24 hour operation)
        MIN_TOA <-- 90
        MAX_TOA <-- 0
        DO FOR I <-- 1 TO 24
           MIN_TOA <-- MIN(MIN_TOA, TOA(I))
           MAX_TOA <-- MAX(MAX_TOA, TOA(I))
           END DO
```

```
    (Determine the maximum gain)
      MAX_GAIN <-- -100
      DO FOR I <-- 1 TO 28
         MAX_GAIN <-- MAX(MAX_GAIN, ANTENNA_GAIN(I))
      END DO
    (Draw out the graticule with one quadrant of a polar plot with 4
    concentric lines in 3 dB increments; outer ring is INT(MAX_GAIN + 1)
    (Plot Radiation Pattern)
    (Draw MIN_TOA AND MAX_TOA lines)
    RETURN
END PLOT_RADIATION_PATTERN
```

```
SUBROUTINE PRINT_INSTRUCTIONS
(IN:  ANTENNA_CONSTRUCTION_INFO, DESIGN_FREQ,
FREQ_AVAIL, START_TIME, STOP_TIME, XMTR_NAME, XMTR_LOC, RCVR_ NAME,
RCVR_LOC, XMTR_RCVR_AZIMUTH, XMTR_RCVR_DIST,
NUMBER_OF_FREQS_AVAIL, DATE, ANTENNA_CHOICE, ANTENNA_NAME)
   (For each hour of the day, sort FREQ_AVAIL list according to the
   signal to noise ratio as already calcualted in the S/N_ON_ANTENNA
   MATRIX.  Sort the frequencies in OPERATOR_FREQ MATRIX)
      DO FOR I <-- 1 TO 24
         (Move FREQ_AVAILABLE Into working list FREQ_SORT)
            DO FOR J <-- TO NUMBER_OF_FREQS_AVAIL
               FREQ_SORT(J) <-- FREQ_AVAIL(J)
            END DO
         DO FOR J <-- 1 TO 5
            BEST_FREQ <-- FREQ_SORT(J)
            BEST_S/N(I,J) <-- S/N_ON_ANTENNA(I,J)
            DO FOR K <-- J+1 TO NUMBER_OF_FREQS_AVAIL
               IF S/N_ON_ANTENNA(I,K) > BEST_S/N THEN
                  S/N_ON_ANTENNA(I,J) <-- S/N_ON_ANTENNA(I,K)
                  S/N_ON_ANTENNA(I,K) <-- BEST_S/N
                  BEST_S/N <-- S/N_ON_ANTENNA(I,J)
                  FREQ_SORT(J) <-- FREQ_SORT(K)
                  FREQ_SORT(K) <-- BEST_FREQ
```

```
          BEST_FREQ <-- FREQ_SORT(J)
        END IF
      END DO
    END DO
  (Save 5 best frequencies)
    DO FOR J <-- 1 TO 5
      OPERATOR_FREQ(I,J) <-- FREQ_SORT(J)
    END DO
END DO
(Print out the header information)
  OUTPUT "A" ANTENNA_NAME "was designed to operate between " XMTR_NAME "
  and " RCVR_NAME " for a communications link to be conducted on " DATE"."
  OUTPUT "Distance between the stations:"  XMTR_RCVR_DIST " Kilometers"
  AZIMUTH <-- XMTR_RCVR_AZIMUTH*(360/(2*PI))
  OUTPUT "Grid azimuth from the local station to the outstation:" AZIMUTH
  OUTPUT "Dimensions of the antenna and orientations can be obtained from
          the diagrams below."
  CASE ANTENNA_CHOICE OF
  1:
    CALL DIAGRAM_LONGWIRE
    (IN:  XMTR_RCVR_AZIMUTH, ANTENNA_AZIMUTH,
     ANTENNA_HEIGHT, ANTENNA_LENGTH, RESISTOR)
  (Print longwire instructions as listed in Appendix c)
2:
  CALL DIAGRAM_DIPOLE
```

```
    (IN:  XMTR_RCVR_AZIMUTH,
    ANTENNA_HEIGHT, ANTENNA_LENGTH)
    (Print dipole instructions as listed in Appendix c)
3:
    CALL DIAGRAM_HALF_SQUARE
    (IN:  MAST_HEIGHT, ANTENNA_LENGTH,
    DESIGN_FREQ, XMTR_REVR_AZIMUTH)
    (Print half-square instructions as listed in Appendix c)
4:
    CALL DIAGRAM_VEE
    (IN:  XMTR_RCVR_AZIMUTH, ANTENNA_AZIMUTH, ANTENNA_HEIGHT, ANTENNA_LENGTH, RESISTOR)
    (Print Vee instructions as listed in Appendix c)
END CASE
OUTPUT INSULATORS_GUYLINES_INSTRUCTIONS
IF ANTENNA_CHOICE  = 1 OR ANTENNA_CHOICE = 4 THEN
    (Print instructions for frequency selection on wideband antennas)
    (These are the same for the longwire and vee. See Appendix C)
    NUMBER_OF_FREQS <-- MIN(5,NUMBER_OF_FREQS_AVAIL)
ELSE
    (Print instructions for frequency selection on narrow band antennas)
    (These are the same for the half-square and dipole.  See Appendix C)
```

```
  (Print out Operator's Frequency Table)
     CUTPUT "Operator's Frequency Table)
     DO FOR I <-- 1 TO 24
        (Output a line in the table)
           OUTPUT I*100
           DO FOR J <-- 1 TC NUMBER_OF_FREQS
              OUTPUT OPERATOR_FREQ(I,J)"/"S/N_ANTENNA(I,J)
           END DO
     END DO
  RETURN
END PRINT_INSTRUCTICNS
```

APPENDIX C

COMPUTER OUTPUT

A. SIGNAL TO NOISE RATIO FOR THE ANTENNA

After evaluating the propagation path and noise at the receiver the program automatically analyzes the whip. Results of this analysis are available to the operator in the form of a signal to noise table for the whip. An example of this output is shown in table 14 A different signal to noise table can be obtained for each antenna designed or modified.

B. TAKE-OFF ANGLE LIST

The desired take-off angle for each hour of the day is stored in the TOA list which can be output in the form of table 15.

C. ANTENNA RADIATION PATTERN

A radiation pattern for each antenna can be obtained in the form of figure C.1 The headings for the antennas will contain the information listed in table 16.

D. ANTENNA CONSTRUCTION INFORMATION

1. General

Each set of instructions will begin with a general description of the link and will appear as follows.

"A Longwire was designed to operate between KANEO and CPPEN for a communications link to be conducted on 820515. Distance between the stations is 4129 kilometers.

TABLE 14

Signal to noise ratio for the 32 foot whip

		3.2	4.5	6.4	10.0	17.0	25.0
	1	1	2	10	12	7	6
	2	2	3	11	12	2	-29
	3	3	4	12	12	0	-32
	4	-5	6	7	11	-1	-33
	5	-8	5	6	10	2	-35
T	6	-13	-16	-2	8	2	-37
I	7	-17	-12	-4	3	4	-9
M	8	-23	-20	-18	-3	3	-1
E	9	-28	-24	-20	-9	3	0
	10	-33	-26	-22	-13	3	0
	11	-41	-31	-23	-14	2	1
L	12	-42	-34	-25	-15	2	2
O	13	-49	-34	-25	-14	2	1
C	14	-42	-36	-23	-8	2	2
A	15	-38	-34	-23	-7	2	2
L	16	-33	-26	-21	-4	4	2
	17	-28	-24	-17	0	5	2
	18	-23	-18	-9	3	7	1
	19	-16	-8	0	10	10	0
	20	-6	-13	7	12	10	-2
	21	-2	1	7	13	9	-15
	22	-3	3	9	5	3	-20
	23	-2	1	9	12	1	-12
	24	-1	1	5	10	5	5

The grid azimuth from the local station to the outstation is 43 degrees. Dimensions of the antenna and orientation can be obtained from the diagrams below."

TABLE 15

Take-off angle in degrees for each hour of the day

TIME	TOA	TIME	TOA	TIME	TOA
0100	12	0900	15	1700	12
0200	12	1000	15	1800	12
0300	12	1100	15	1900	12
0400	12	1200	15	2000	12
0500	12	1300	15	2100	12
0600	12	1400	12	2200	12
0700	12	1500	12	2300	12
0800	12	1600	12	2400	12

In the following subsections all information peculiar to the particular antenna is listed as the operator would see it.

2. Longwire

"The longwire can be oriented along either of the azimuths shown in the orientation diagram."

If a resistor were available then figure C.4 would also be provided in addition to the following instructions:

"The resistor on the end of the antenna has the following effects on the antenna characteristics:

a. It becomes a wider band antenna; the radio will tune to a greater number of frequencies.

b. Communications to the rear of the antenna will be degraded.

c. A loss of 2 dB (30% efficiency) will result.

One may choose to use a counterpoise. This is a wire connected between the radio ground and the ground stake at the lower end of the terminating resistor. This modification can improve antenna performance."

Standard longwire instructions continue: "Connect the antenna wire directly to the whip base of the antenna.

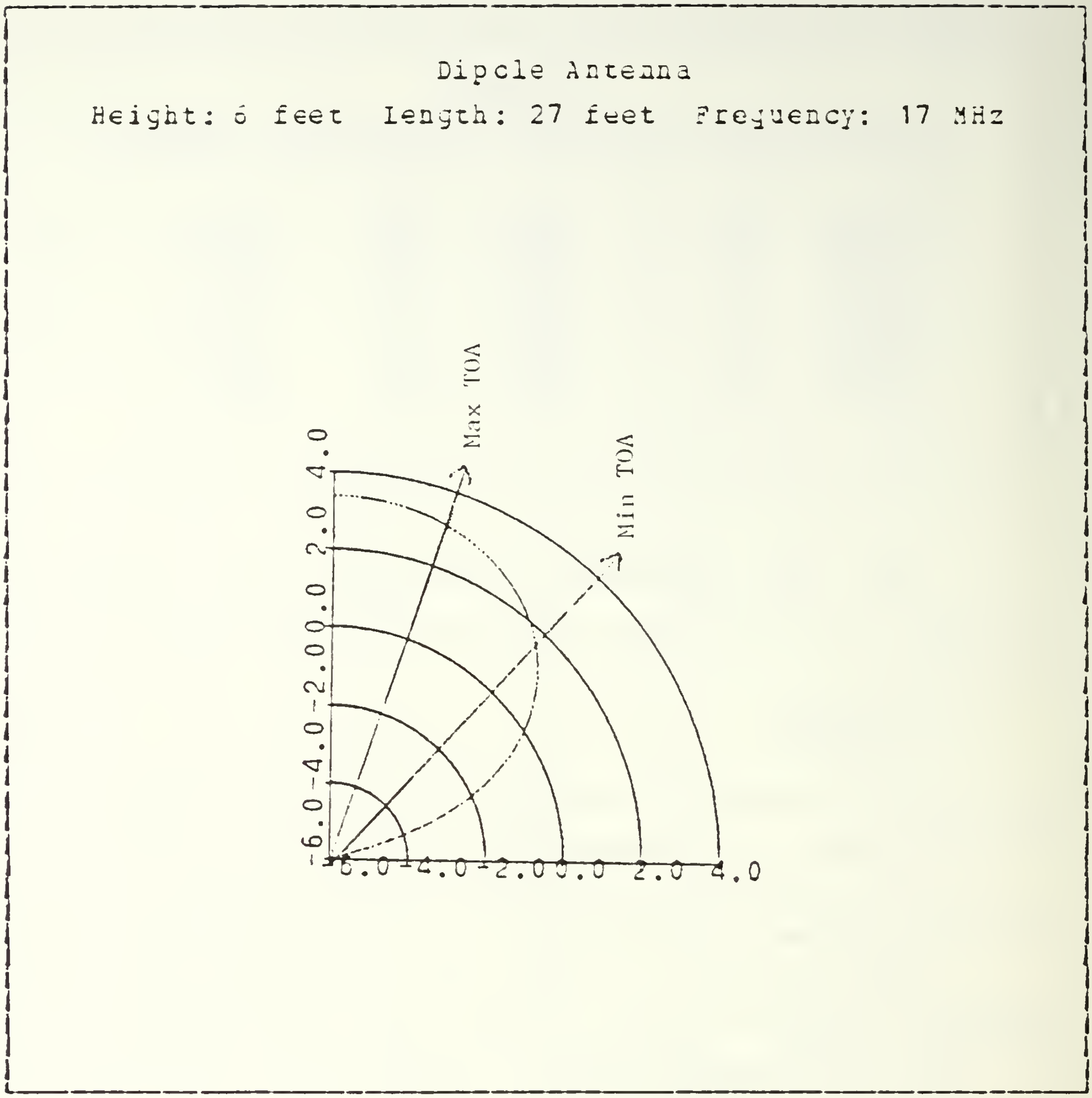


Figure C.1 Antenna Radiation Pattern for Dipole.

For the best results, clean the brass threads of the base with steel wool then wrap several turns of bared antenna wire around it. A hose clamp can be used to secure the wire."

If transformer building material is available the program would provide figure C.5 and the following instructions:

TABLE 16

Information in radiation pattern headings for all antennas

Antenna	Information
Longwire	Height of radio-end mast, Height of far end mast, Length, Frequency, Azimuth to the outstation, Azimuth along which antenna is aligned, Orientation angle
Dipole	Height, Length, Frequency
Half-square	(no information)
Vee	Height of radio-end mast, Height of far-end masts, Apex angle, Length of antenna legs, Frequency

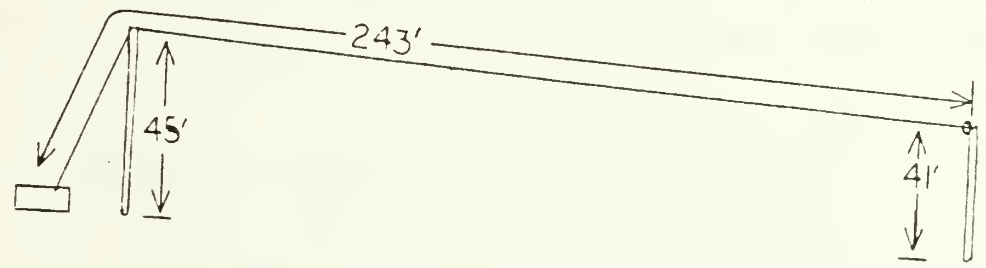


Figure C.2 Longwire Design Diagram.

"For improved performance connect a 4:1 or 9:1 transformer between the radio and the antenna. A 9:1 transformer is preferred if the antenna is terminated in a

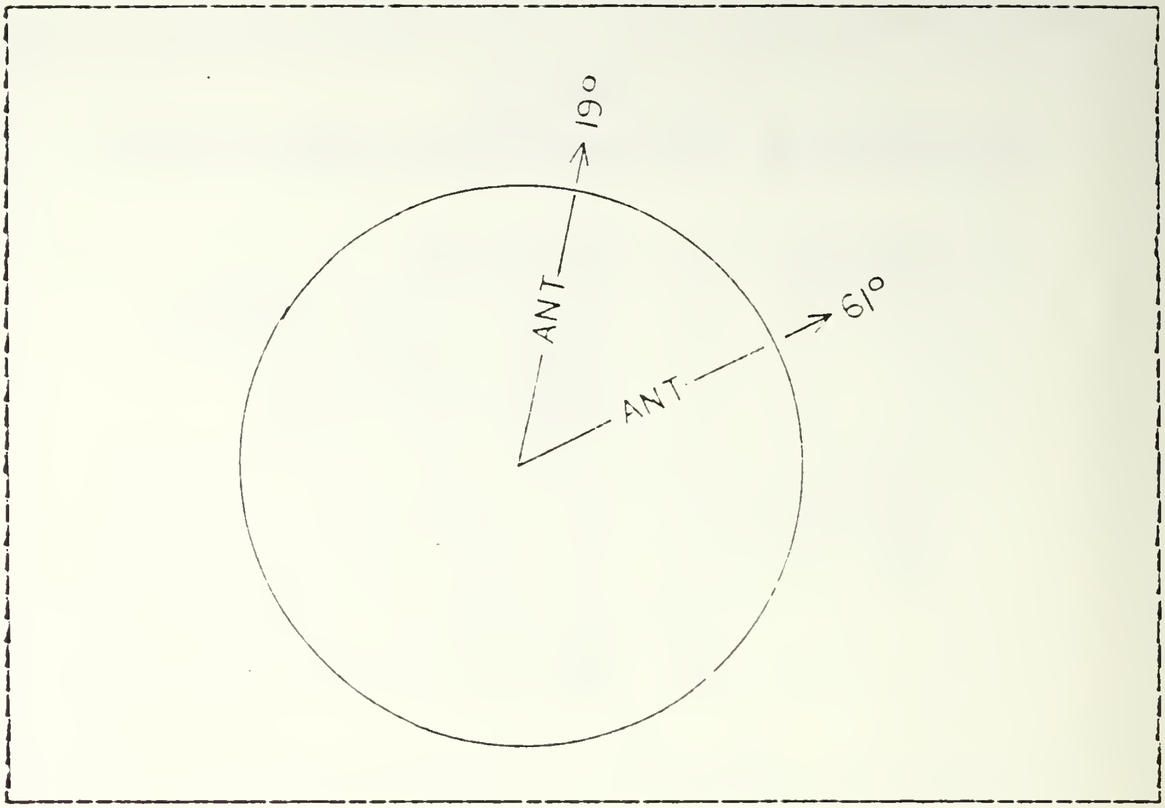


Figure C.3 Longwire Orientation Diagram.

resistor and a 4:1 if it is unterminated. This device can be connected at the radio or at the top of the antenna mast if one uses a coaxial cable to convey the power from the radio."

"For the first hour of operations select the left most frequency listed in the operator's frequency table. If at a later time communications drop to an unacceptable quality, switch to the best frequency for that hour of operation, the next best if communications do not improve, and so on until all frequencies are tried.

3. Dipole

If the dipole take-off angle is less than 50 degrees then figure C.7 and the following orientation instructions

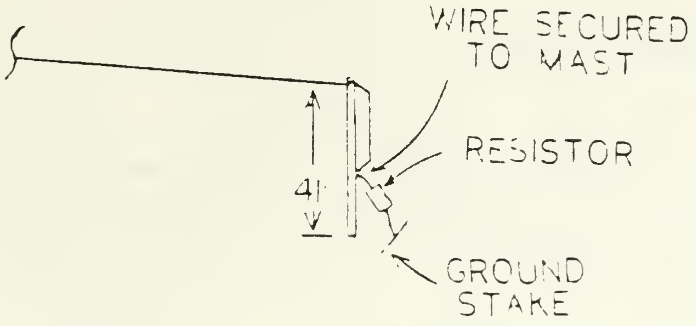


Figure C.4 Terminated Longwire connection.

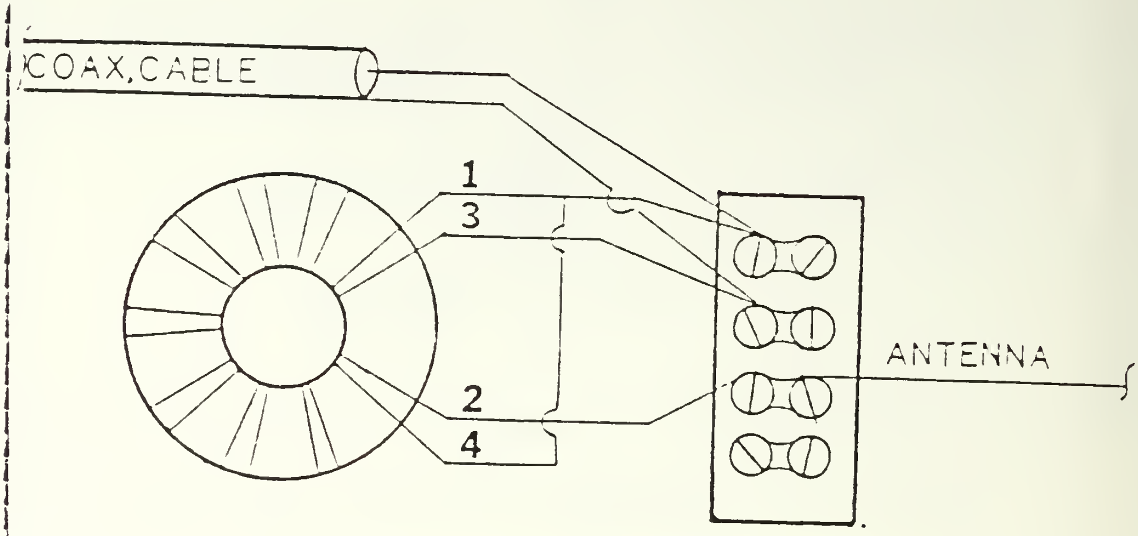
are output. "The dipole should be oriented such that the two supporting masts are aligned with the azimuth (solid line) as shown in the orientation diagram. Some leeway is permitted though, the antenna can be off oriented along any azimuth between the dashed lines without a serious loss of link performance."

For the case where the take-off angle is greater than 50 degrees then antenna would be erected closer to the ground and the following instructions would pertain.

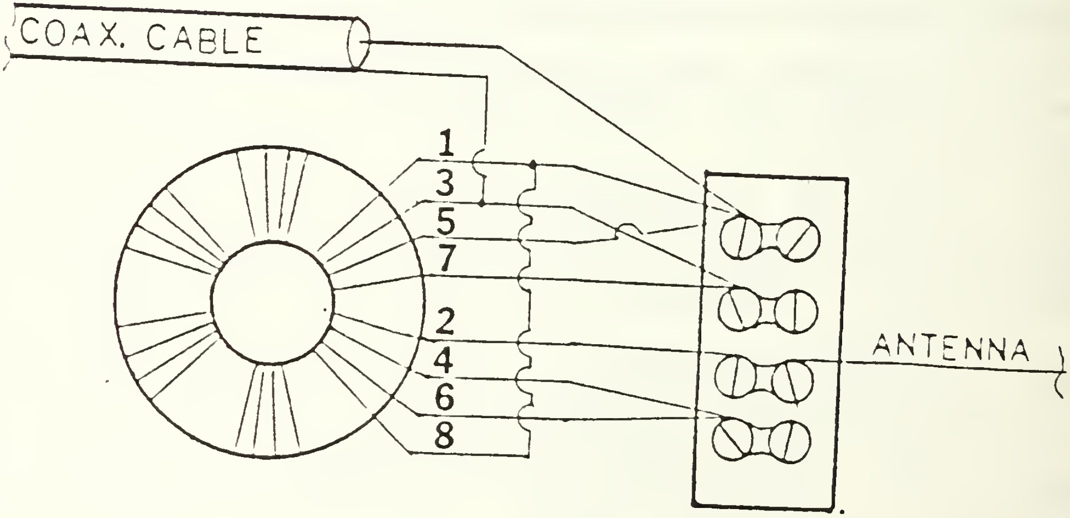
"Orient the dipole in any convenient manner for it is an omnidirectional antenna in this application."

The dipole standard instructions continue: "In addition to the dipole shown in the dipole design diagram two others were designed. The critical information for all the dipoles are listed in table 18."

"For the first hour of operations erect a dipole designed for the left most frequency listed in the operator's frequency table. If at a later time communications drop to an unacceptable quality, switch to the best frequency for that hour of operation, the next best if



a) 4:1 transformer



b) 9:1 transformer

Figure C.5 Impedance transformers for Longwire.

TABLE 17

Operator's frequency table for the longwire

Time	Freq/SN	Freq/SN	Freq/SN	Freq/SN	Freq/SN
1	10.0/14	6.4/12	17.0/11	25.2/6	4.5/8
2	10.0/13	6.4/11	17.0/8	25.2/-20	4.5/8
3	10.0/14	17.0/11	6.4/8	25.2/-30	4.5/6
.etc.					

communications do not improve, and so on until all frequencies are tried. If the radio will not tune to the best frequency or signal quality is poor on all other frequencies, modify the antenna dimensions to those appropriate for the best frequency."

4. <u>Half-square</u>

"Orient the half-square along the azimuth pointed to by the solid line in the orientation diagram, one can be off in the proper orientation out to the azimuths pointed to by the dashed lines."

"In addition to the half-square shown in the half-square design diagram two others were designed. The critical information for all the half-squares are listed in table C.8."

"Erect the half-square at a convenient height greater than the short element length shown in the table."

An operator's frequency table similar to that shown in table 19 would be provided in addition to the instructions accompanying it in the dipole section above.

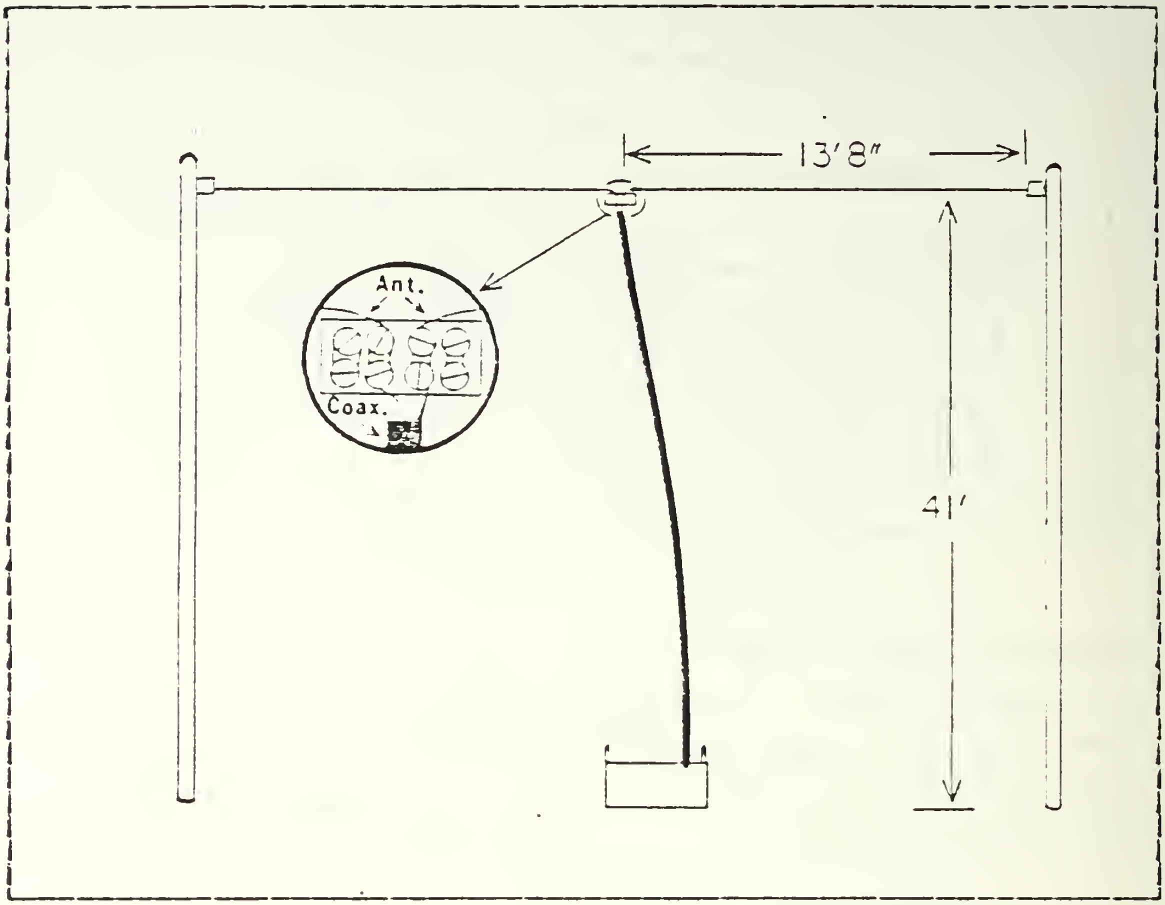


Figure C.6 Dipole design diagram.

5. <u>Vee</u>

"Align a vee leg with each of the azimuths shown in the orientation diagram."

The program outputs an operator's frequency table similar to that shown in table 17 and the instructions to accompany this.

6. <u>Final Instructions</u>

After the information peculiar to the antenna is output the program will follow this with more general instructions pertaining to all antennas.

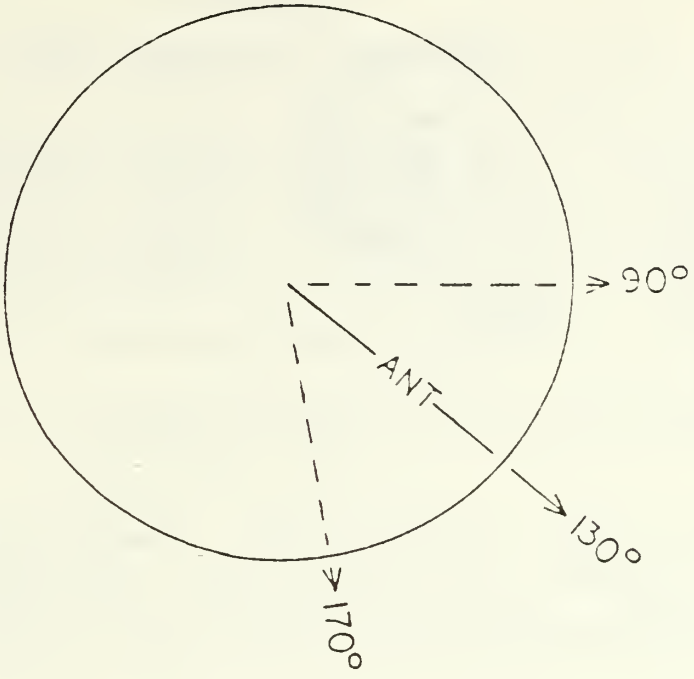


Figure C.7 Dipole orientation diagram.

TABLE 18

Dipole dimensions and operating frequencies

Period	Frequency	Height	Element Length
Day	25.2	41'	9' 1"
Transition	17.0	41'	13' 8"
Night	10.0	41'	23'

"The antenna must be insulated from the supporting structure (Masts). For insulators one can use rope, twine,

TABLE 19

Operator's frequency table

Time	Freq/SN	Freq/SN	Freq/SN
1	10.0/12	17.0/10	25.2/9
2	10.0/12	17.0/7	25.2/-20
3	17.0/11	10.0/10	25.2/-30
.etc.			

electrical tape, fishing line, ammo straps, etc. The guylines holding the antenna masts must also consist of a non-conducting material such as rope or engineer's tape."

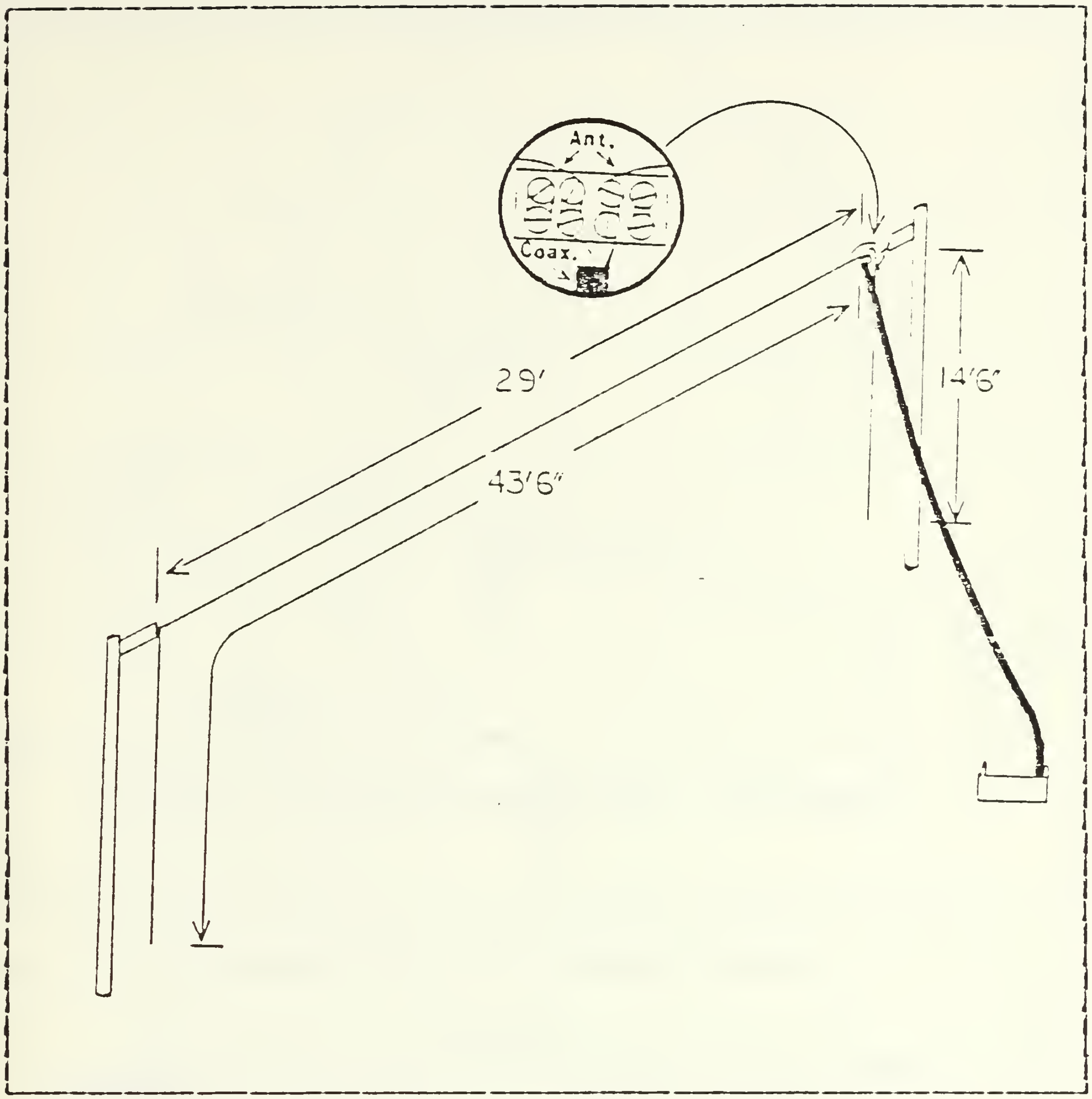


Figure C.8 Half-square design diagram.

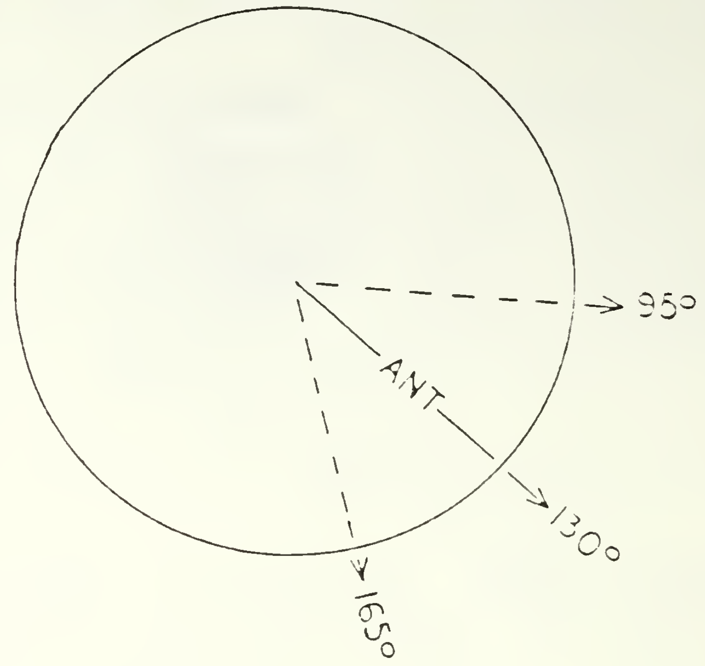


Figure C.9 Half-square orientation diagram.

TABLE 20

Half-square dimensions and operating frequencies

Period	Frequency	Mast Seperation	Short Element Length	Long Element Length
Day	25.2	19'6"	9'9"	29'3"
Transition	17.0	29'	14'6"	43'6"
Night	10.0	49'2"	24'7"	73'9"

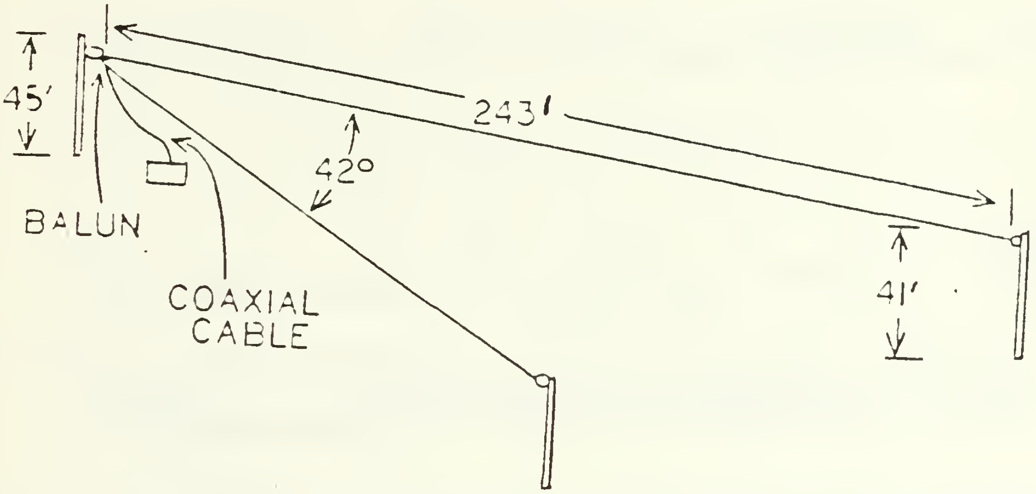


Figure C.10 Vee design diagram.

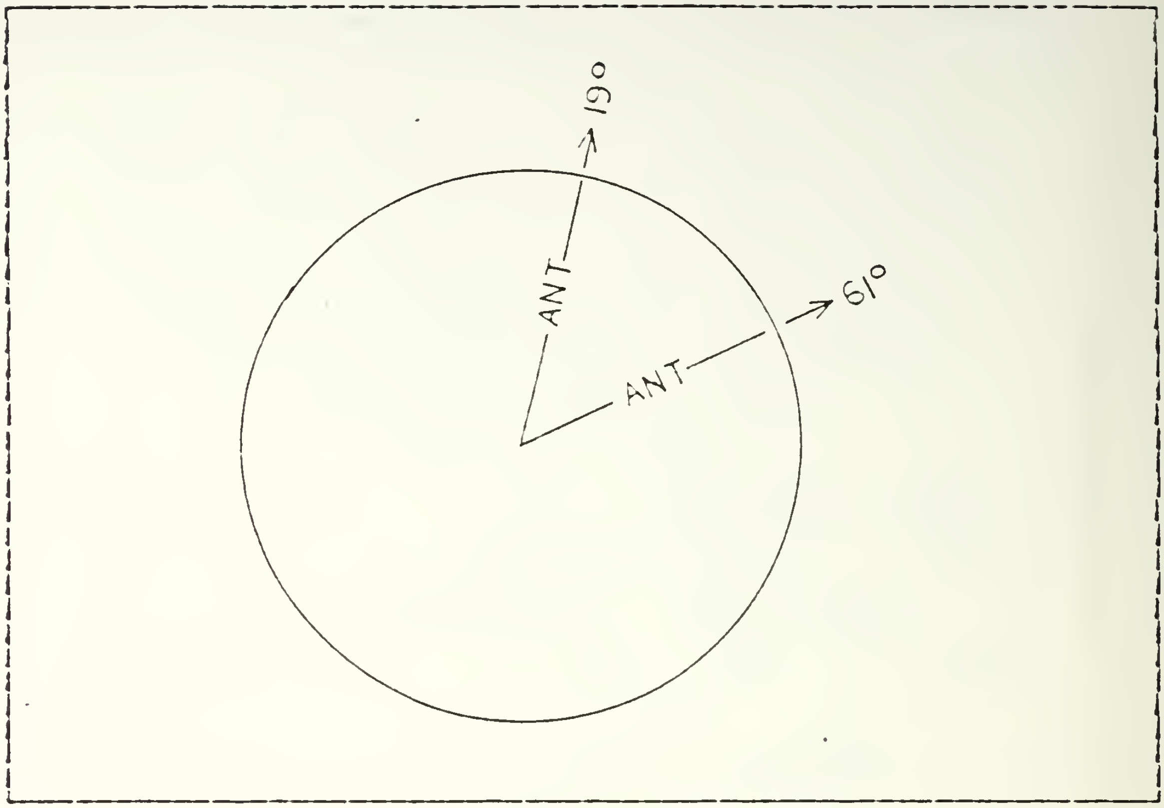


Figure C.11 Vee orientation diagram.

LIST OF REFERENCES

1. Naval Oceans Systems Center, Technical Document 441, *Army Prophet Evaluation System*, by J.N. Martin, 23 April 1981

2. Naval Oceans System Center, Technical Document 642, *The New U. S. Army PROPHET Evaluation System (APES) Models*, by D. B. Sailors, W. K. Moision, and T. N. Roy, pp. 42-52, December 1983

3. Environmental Compatability Analysis Center; ECAC-CR-79-010, Supp. 2(P) *ECAC Consultative Report*, May-June 1982

4. Harrington, R. F., *Field Computation by Moment Method* McMillan Co., New York, 1968

5. Burke, G. J., and Pogio, A. J., *Numerical Electromagnetics Code -- Method Moments*, Lawrence Livermore Laboratory, January 1981

6. Naval Ocean Systems Center, Technical Document 516, *MININEC: A Mini-Numerical Electromagnetics Code*, by A. J. Julian, J. C. Logan and J. W. Rockway, 6 September 1982

7. IIT Research Institute, ESD-TR-80-102, *APACK, a Combined Antenna and Propogation Model*, by S. Chang, and H.C. Maddocks, July 1981

8. Office of Telecommunications Report 74-38, *Man-Made Noise Part 1: Estimates for Business, Residential and Rural Areas*, by A. D. Spaulding and R. T. Disney, June 1974

9. Damboldt, T., *A Comparison between the Deutche Bundepost Ionospheric HF Radio Propagation Predictions and Measured Field Strengths*, a paper presented at NATO, AGARD, Radio Systems and the Ionosphere, Conf. Proc. 173, Athens, Greece, 26-30 May 1975

10. National Bureau of Standards Monograph 801 *Ionospheric Radio Propagation*, by Kenneth Davies April 1965, Figure 7.2

11. American Radio Relay League, *The ARRL Antenna Book* 14th Ed., 1984

12. Fiedler, D. M., and Hagn, G. H., "Beyond-line-of-sight Propagation Modes and Antennas," *Army Communicator* pp. 14-22, Fall 1983

13. Barnes, C., Hudick, J. A., and Mills, A. E., *A Field Guide to Simple Dipoles*, Stanford Research Institute, Menlo Park, CA, March 1967

14. Stanford Research Institute, SRI Project 4240, Special Report 10, Contract DA-36-039 AMC_00040(E), *Full-Scale Pattern Measurements of Simple HF Antennas*, by W. A. Ray, 1 Sept. 1967

15. Vestere, B., "The Half Square Antenna," *The ARRL Antenna Anthology*, pp. 81-83; undated

16. Campbell, D. V., "Personal Computer Applications of MININEC", *Antennas & Propogation Society Newsletter*, IEEE, February 1984

17. MEGATEK Corporation, Contract No. N00123-78-C-0191, *Coverage Estimation in Tactical LPI Communications Analysis*, by P.H. Levine, 30 September 1978

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