THESIS

COMPUTER INVESTIGATION OF VHF, UHF
AND SHF FREQUENCIES FOR
MARINE CORPS PACKET RADIO USAGE

by

Thomas George Kane

Dec 1980

Thesis Advisor: J. M. Wozencraft

Approved for public release; distribution unlimited.
Computer Investigation of VHF, UHF and SHF Frequencies for Marine Corps Packet Radio Usage

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Packet Radios
Frequency Determination
Link Equations
Marine Amphibious Brigade
Network Connectivity

This thesis is a computer investigation of the VHF, UHF and SHF frequency bands for possible use by Marine Corps Packet Radio systems. It uses the STAR Terrain Model to analyze the different connectivity patterns that appear as the units of the Marine Amphibious Brigade move across the battlefield. The problem of enemy intercept of friendly traffic is also discussed and the units with a high probability of being intercepted are displayed pictorially.
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Computer Investigation of VHF, UHF and SHF Frequencies for Marine Corps Packet Radio Usage

by

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Captain, U.S. Marine Corps
B.S.I.M., Purdue University, 1974

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ABSTRACT

This thesis is a computer investigation of the VHF, UHF and SHF frequency bands for possible use by Marine Corps Packet Radio systems. It uses the STAR Terrain Model to analyze the different connectivity patterns that appear as the units of the Marine Amphibious Brigade move across the battlefield. The problem of enemy intercept of friendly traffic is also discussed and the units with a high probability of being intercepted are displayed pictorially.
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I. INTRODUCTION

Packet Radio (PR) is a technology that extends the application of packet switching, which evolved for networks of point-to-point communication lines, into the area of broadcast radio. It offers a highly effective way of using a multiple-access radio channel, with potentially large numbers of mobile users, to support digital communications over a wide geographic area.

Users in a packet radio network are assumed to share common radio channels, access to which is controlled by microprocessors in the packet radios. The unit of transmission in a packet radio network is called a packet. It contains a number of data bits and is usually variable in length. A packet includes all addressing and control information necessary to correctly route the packet to its final destination. Each packet wends its way from node to node through the network until it arrives at its final destination and is delivered.

An essential attribute of any network is its ability to provide full connectivity among all network nodes [Ref. 1]. It is this connectivity that will be examined in this report. The nodes in this network will be the units that comprise the Marine Amphibious Brigade (MAB). The units will be spread over a battlefield such that their positions relative to one another will be in keeping with current doctrine. The battlefield will
be the STAR model of the Fulda Gap region in West Germany, which is currently being used by the U.S. Army for combat simulation [Ref. 2].
II. LINK EQUATIONS FOR PACKET RADIOS

A. GENERAL

Ground radio links are subject to severe variations in received signal strength due to local variations in terrain and foliage. In addition, reflections give rise to multiple signal paths which lead to distortion and fading as signals with different delays interfere at a receiver. As a result, RF connectivity is difficult to predict in detail and may change abruptly as units move about the battlefield.

If a packet radio network existed such that all radios were sited with a radio line-of-sight path to nearby neighbors, then the predictability and reliability of such a network would be greatly increased. Particularly if a packet radio network existed such that all radios possessed an optical line-of-sight to nearby neighbors, then analysis of the network would be greatly simplified. The stringent requirement for an optical line-of-sight over the earth will be used in this report to simplify the calculations.

---

1An optical line-of-sight exists when a straight line can be drawn between the two antennas, and the line is not intersected by the earth. A radio line-of-sight is an RF path between a transmitter and a receiver. This path can exist in the absence of an optical line-of-sight because of obstacle gain and diffraction.
B. LINK EQUATION

The link equation used in this report is:

\[
\frac{P_T G_T G_R}{k T_o B_{Rf} F_s L} > \text{SNR}_{\text{min}}
\]

where 

- \(P_T\) = transmitter output power (watts)
- \(G_T\) = transmitting antenna gain
- \(G_R\) = receiving antenna gain
- \(L\) = link loss
- \(k\) = Boltzman's constant (-228.6 dB)
- \(T_o\) = noise temperature (24.6 dB)
- \(B_{Rf}\) = RF bandwidth of receiver
- \(F_s\) = system noise figure
- \(\text{SNR}_{\text{min}}\) = signal-to-noise ratio at receiver input corresponding to minimum acceptable message quality

The link loss can consist of the following losses.

\[
L = [L_s] (L_{O_2} - H_2O) (L_{\text{Rain}}) (L_T) (L_R) (L_p) (L_F)
\]

Here:

- \(L_s = \left(\frac{4\pi d}{\lambda}\right)^2\) is the spreading loss (for free-space),
- \(L_{O_2} - H_2O\) is the loss due to oxygen and water vapor absorption at frequencies above about 10 GHz,
. $L_{\text{Rain}}$ is the loss due to rainfall attenuation at frequencies above about 3 GHz.

. $L_T$ and $L_R$ are the losses associated with the transmitting and receiving stations.

. $L_p$ includes incidental losses, and

. $L_F$ is the loss associated with foliage penetration.

Therefore the link equation is:

$$\frac{P_T G_T G_R}{k T_0 B_{\text{rf}} F_s [L_s (L_{O_2} - H_2O) (L_{\text{Rain}})(L_T)(L_R)(L_p)(L_F)] > \text{SNR}_{\text{min}}$$

For the analysis of the connectivity of the MAB's radio network the following parameters were given.

(1) Both transmit and receive antennas were omnidirectional in the horizontal plane and had a $30^\circ$ beamwidth in the vertical plane.

(2) The transmit power was 1 watt.

(3) The data rate was 16 kbs with $P_e < 10^{-6}$.

(4) The system noise figure was 15 dB, $(L_T)(L_R)$ was 3 dB, and $L_p$ was 1 dB.

To find the $\text{SNR}_{\text{min}}$ that will give a $P_e < 10^{-6}$ we have

$$P_e \leq \frac{1}{2} \text{erfc} \sqrt{2}$$
where $z$ is the SNR$_{\text{min}}$ [Ref. 3]. This gives a SNR$_{\text{min}}$ of 10.53 dB, or about 11 dB for PRK.

To get the gain of the transmit and receive antennas, which are omni-directional in the horizontal plane and have a 30° beamwidth in the vertical plane we have the following equation.

**Directive Gain $G_T$, $G_R$**

$$G_T = G_R = \frac{4\pi r^2}{\text{area}} = \frac{4\pi r^2}{(\theta r)(\phi r)} = \frac{4\pi}{\theta \phi} \text{ in radians}$$

or

$$G_T = G_R = \frac{4\pi}{\left[\frac{2\pi}{360} \theta^\circ \right] \left[\frac{2\pi}{360} \phi^\circ \right]} = \frac{360^2}{\pi \theta^\circ \phi^\circ} = \frac{41253}{\theta^\circ \phi^\circ} \text{ in degrees}$$

$$G_T = G_R = \frac{41253}{(30)(360)} = 3.8197 = 5.82 \text{ dB}.$$ 

Thus for $P_T = 1 \text{ watt} = 0 \text{ dBw}$ and $B_{RF} = 2 \times 16 \text{ kbps}$ the link equation becomes

$$0 \text{ dB} + 5.82 \text{ dB} + 5.82 \text{ dB}$$

$$-228.6 \text{ dB} + 24.6 \text{ dB} + 45 \text{ dB} + 15 \text{ dB} + L_s + L_{O_2 - H_2 O} + L_{\text{Rain}} + 3 \text{ dB} + 1 \text{ dB} + (L_F) \text{ dB} \geq 11 \text{ dB}$$

10
or

\[ L_{dB} = [L_s(L_{O_2} - H_2O)]_{dB} + [L_{Rain}]_{dB} + [L_F]_{dB} \leq 140.64 \text{ dB} \]

Therefore, the attenuation due to path loss, rain, and foliage must be less than or equal to about 141 dB. It is this link loss of 141 dB that was used in the model to determine whether or not a link "existed." All combinations of transmitters and receivers were analyzed to find links that had losses of less than 141 dB.

C. PATH LOSS

The minimum theoretical path loss on a radio link in free-space is given by the following formula.

\[ L_s = \text{Loss}_{fs} = \left(\frac{4\pi d}{\lambda}\right)^2 \]

For a ground radio link, the path loss of free-space may be approached on a link having a radio line-of-sight, although even under this desirable condition diffraction and multipath phenomena can greatly reduce received signal power. Average path attenuation exceeds that of a free-space radio link by a significant amount in the ground radio environment, depending on the type of terrain and the elevation of the radio antenna. The curves in Figures 1 and 2 show average path loss as a
function of link range for a frequency of 1.080 GHz, and illustrate these dependencies for two different transmitter heights [Ref. 4]. These curves are typical also of propagation at UHF.

It is worth noting that the variation of mean path loss as a function of frequency is typically much less than the variations due to terrain at a particular frequency [Ref. 1]. The curves shown reflect average values of path loss which apply to a link of given length which is randomly selected without regard to user sitting. Well sited radios will typically encounter less path loss than shown in the curves [Ref. 1].

Bullington [Ref. 5] and later Jordan and Balmain [Ref. 6] have developed a simplified propagation formula for transmission in the VHF/UHF range when the elevated transmitting and receiving antennas are far apart. Their approximations are:

1. The surface wave can be neglected in comparison with the space wave.
2. The angle of incidence of the wave with the earth (hence the angle of reflection) is very small so that the reflection factor equals -1.

When the approximations used are valid, the received field strength is proportional to the height of the transmitting antenna, the height of the receiving antenna, and inversely proportional to the square of the distance between them [Refs. 5 and 6].
Figures 1 and 2. Path loss versus range [Ref. 4].
where \( h \) represents the heights of the antennas and \( d \) represents the distance between them. This relation is independent of frequency and is valid as long as the loss is more than the free-space loss. Figure 3 shows the free-space loss, the loss encountered over "smooth plains" from Figure 1, and the loss associated with Bullington's equation for a transmit antenna height of 15.2 meters and a receive antenna height of two meters. Figure 4 represents the same data but with a transmit antenna height of two meters. For both graphs, the error is less than 5 dB over the range of interest, which is from a few to about 10 km. Therefore Bullington's equation was used in this thesis to predict path losses in the VHF and UHF regions. The equation is valid as long as it produces losses greater than the free-space loss. Therefore, the model uses the larger of the two losses in calculating link loss.

D. ATTENUATION BY FOLIAGE

Another factor that affects the link loss is the attenuation caused by foliage penetration. Nathanson [Ref. 7] referenced a previously defined equation by Saxton and Lane [Ref. 8] for attenuation in the frequency range from 100 MHz to 3 GHz. He stated that for either antenna polarization, attenuation by trees with leaves in that range is given
Figure 3. Comparison of Bullington's loss equation vs. free space loss, for a transmitter height of 15.2 meters

A - Smooth plains  
B - Bullington's loss equation  
C - Free Space loss
Figure 4. Comparison of Bullington's loss equation vs. free space loss, for a transmitter height of 2 meters

A - Smooth plains
B - Bullington's loss equation
C - Free Space loss
approximately by

\[ A = 0.25 f^{3/4} \text{ (dB/m)} \]

where \( f \) is the carrier frequency in gigahertz and \( A \) is attenuation in dB per meter. This equation is used to calculate attenuation from foliage penetration in the model.

\[ \Sigma. \] ATTENUATION OF MILLIMETER WAVES

As shown in Figure 5, at frequencies above about 10 GHz, transmission of millimeter waves through the atmosphere is subject to attenuation caused by resonances of oxygen and water vapor molecules. Attenuation by precipitation, primarily rain, and attenuation associated with penetrating tree foliage also play a key role.

For highly reliable operations at millimeter waves, attenuation by rain is the dominant factor in determining the reliability of the circuit. Figures 6a, b and c were developed by Dudzinsky [Ref. 9] and give required margins for three different levels of reliability. For various frequencies, Figure 6a has as abscissa the path length and gives as an ordinate the margin that will not be exceeded by attenuation due to rain for 99.9% of the time.

The attenuation over a free-space path through a clear atmosphere is simply the sum of the spreading loss \((4\pi d/\lambda)^2\) and the loss due to oxygen and water vapor absorption. The
Figure 5. Horizontal attenuation due to oxygen and water vapor [Ref. 9].
Figure 6a. Attenuation by rain as a function of path length for 99.9% reliability [Ref. 9].
Figure 6b. Attenuation by rain as a function of path length for 99.99% reliability [Ref. 9].
Figure 6c. Attenuation by rain as a function of path length for 99.999% reliability [Ref. 9].
dependence of this attenuation on path length can be represented by curves such as those of Figure 7 [Ref. 9]. These curves can be used together with curves from Figures 6 to estimate the performance of millimeter-wave communications links operating through the atmosphere and in the presence of rainfall.
Figure 7. Total attenuation through a clear atmosphere at sea level [Ref. 9].
III. THE STAR TERRAIN MODEL

The STAR (Simulation of Tactical Alternative Responses) ground-air combat model is a computer simulation program developed at the Naval Postgraduate School during 1978-1979. STAR is written in SIMSCRIPT II.5 simulation language. The idea for the STAR terrain representation -- called parametric terrain -- was originally proposed by Major Chris Needels in his 1976 Master of Science Thesis at the Naval Postgraduate School [Ref. 10]. The model as used in this report is the work of Professor James K. Hartman [Ref. 2]. The subroutines that were developed specifically to analyze the MAB radio links are outlined in detail in Appendix A.

The basic function which any terrain representation must provide for a high-resolution combat simulation is, "for any x,y map coordinates on the battlefield, compute the elevation z of the terrain, and the height h of the forest if one exists." The elevation z is generally called the macro terrain.

The parametric terrain model used in STAR involves storing a function f(x,y). The process of determining z for a given x,y then reduces to computing the function z = f(x,y). Parametric terrain has the advantage that the function f can be stored using only a modest amount of computer storage. In addition, the parametric terrain is inherently continuous, so no interpolation is required for smoothing.
The parametric terrain model proposed by Needels represents terrain by modeling individual hill masses. Each hill mass is represented mathematically as a scaled bivariate normal probability density function. This gives a characteristic elliptic bell-shaped hill mass cross section as shown in Figure 8. By varying the parameters, a wide variety of different hill locations, sizes, and shapes can be modeled. By superposing several hill masses, the contour map can be fitted to real map contours remarkably well by using the maximum macro terrain.

In addition to the macro terrain, another factor that influences line-of-sight computations in the STAR model is the presence of forests. Forests in the model are represented by cover ellipses on the ground. Each ellipse has a tree height associated with it, and the forest is thus an elliptical "cylinder" with that fixed height above the ground. Actual forests with non-elliptical shapes and non-constant heights can be approximated by combining several overlapping ellipses. The tree height at a given point x,y is the maximum tree height for all the forest ellipses containing the point x,y.

Figures 11, 12, and 13 show the terrain model on which all computations have been performed. They are a 10 by 30 km section of terrain near the town of Hunfeld, West Germany. Hunfeld is located near the East German border in the Fulda Gap region of central West Germany.

The map symbols that resemble capital Y's represent forested areas. The contour lines are drawn every 10 meters with
Figure 8. MACRO terrain is the maximum over all the hill masses.
Figure 11. MAB Unit locations for the first set of data points.
Figure 12. MAB Unit locations for the second set of data points.
Figure 13. MAB Unit locations for the third set of data points.
100-meter contour lines accented. Grid lines in both the horizontal and vertical directions are every 1000 meters. The valley located at 41000 19000 has an elevation of 230 meters above sea level. The other two major valleys, located at 53000 15000 and 76000 19000, have elevations of 250 and 280 meters, respectively. The terrain represented in the model is highly forested and very irregular and is representative of many areas of the world.

The use of the STAR model has been simplified by the subroutine RES.TERR developed by Professor Hartman. This subroutine is called by the main program first and is set up to dynamically reserve and dimension the various arrays so that core requirements are minimized. The input to RES.TERR is parameter information on the hill masses and forest ellipses. This parameter information is currently stored on disk.

To use the model all that is needed is to read in two ten-digit grid coordinates and assign them to the variables XA.LS, YA.LS, XB.LS and YB.LS. The variable XA.LS is the five-digit x coordinate of the first point A and YA.LS is the five-digit y coordinate. Now the macro terrain elevation can be found by calling subroutine ELEV, or the height of the trees at point A can be found by calling the subroutine TREES.

To calculate the line-of-sight (LOS), the following information must be available for both points A and B:

(1) The x and y coordinates on the battlefield expressed as XA.LS and YA.LS.
(2) The macro terrain elevation (TMACA.LS) computed from the ELEV subroutine.

(3) A micro terrain offset (TMICA.LS) of + or - from the macro terrain. The offset is used to place some of the antennas above the surrounding forest.

(4) The last piece of information that is needed is the size of the antenna (SIZE.LS), which is specified as three meters in this report.

Now the LOS subroutine can be called which will return the percent visible of antenna B, i.e., the fraction of antenna B that can be seen from the top of antenna A. This is depicted in Figure 9 where point A's antenna is mounted on top of the radio and point B's antenna is mast mounted.

The preceding paragraphs provide an overview of Professor Hartman's report. Anyone wishing to use the STAR model should become familiar with Ref. 2 before proceeding.

Four routines were written as part of this thesis specifically to analyze the MAB's radio links. They are MAIN, REPORT.PRINT, LPI and FOREST. The purpose of the MAIN program is to determine if a radio transmission path exists between points A and B, at the specified high frequency, at the specified low frequency, or if no path exists at all. The program defines a low frequency (FREQ.L) and high frequency (FREQ.H). The maximum allowable loss between points A and B, as given in Chapter I, is then specified. The line-of-sight is specified as being from A to B (LATOB.LS=1).
Figure 9. A Line-of-Sight Exists if the Top of Antenna A Can See the Top of Antenna B.
All of the points to be analyzed are read in at once with the x coordinate first followed by the y coordinate, the node number, the printing symbol code, and the "Mobility Factor."\(^2\) Then each pair of points is analyzed. Since all pairs of points make up a symmetric matrix, only the upper half of the matrix is analyzed. The offset (TMICA.LS) is initially set to zero, but it can be changed to the tree height if the mobility factor is "1."

The macro terrain elevation is found along with the tree height at each pair of points. Antenna heights are also computed and some redefining is done in preparation for the first call of the LOS subroutine. The first call of LOS is done over a terrain model that is void of trees. If a line-of-sight exists over the ground then the forest ellipses are reinstated and another line-of-sight is shot. The loss for free-space and the loss associated with Bullington’s equation are both computed and the greater loss is used. If a line-of-sight exists over the ground but not over the trees, then the subroutine FOREST is called. The output of FOREST is the amount of forests that lie between points \(A\) and \(B\).

Now the total losses between \(A\) and \(B\) can be computed, since it is a function of the distance, frequency and amount of trees that intersect the line-of-sight. For each link, analysis is

---

\(^2\) The Mobility Factor describes the unit's ability to erect a large antenna and is described in Chapter II.
done to determine if the link can operate at the high frequency, and then at the low frequency. For links that exist, the fading margin is given as the number of dBs above the required 11 dB, for a required $P_e = 10^{-6}$. If neither frequency produces a favorable margin, then the link is discarded and another pair of points (A,B) is looked at. For links that do exist, the distance between the two points is stored in matrix form for both (A,B) and (B,A). The distance is stored as a truncated number if the link is being carried by the higher frequency, and point one is added to the distance if it is being carried by the lower frequency.

Next, the matrix of distance is sorted and the five nearest neighbors to each point are displayed in table form. The nearest neighbor would appear in the table as 10 if it was accessible at the higher frequency and 11 if it was accessible by the lower frequency. Other valid entries in the table are 20, 21, 30, 31, 40, 41, 50, and 51.

The subroutine REPORT.PRINT prints out the contents of the matrix that contains the listing of the five nearest neighbors. It prints out the matrix in two separate formats. The first format is larger and easier to work with, while the second format is compatible with an 8-1/2" x 11" piece of paper.

The subroutine LPI determines the signal-to-noise ratio that an enemy listening post would receive if it used an antenna with a gain of 3.8 dB. This subroutine follows the
same procedures as the MAIN program except its output is the SNR and not the fading margin that the main program calculates.

The FOREST subroutine was designed to calculate the amount of forests that lie between points A and B. The routine checks the heights of the trees every 1/100 of the distance between the two end points. Every time that the height of the trees intersects the line-of-sight, it adds one more percent to its counter. When the routine is completed, it has a number that expresses the percent of the distance that the tree height exceeded the line-of-sight. This percent is returned to the main program where the depth of the forest in meters is determined by multiplication by the distance.
IV. UNIT LOCATIONS

On the battlefield are positioned sixty-six units that comprise the Marine Amphibious Brigade (MAB). There is also one point that represents an external connection with higher headquarters plus seven repeater stations. In addition to the one special point, any node near the boundary of the MAB could be used as an external connection point. These seventy-four points and their relative positions were furnished by Ref. 11. In their original form they had a frontage of 16 km and a depth of 26 km. Position number 1 was the Regimental Headquarters and also grid center for the map. All other positions were given coordinates relative to the Regimental Headquarters as shown in Table 1.

Since the STAR terrain model map of Hunfeld, West Germany, was only 10 km wide by 30 km in depth, there existed a need to decrease the frontage of the MAB. Each unit's lateral distance from grid center was decreased by 5/8 and it was given coordinates that made it compatible with the Hunfeld map. Table 2 lists the new coordinates and Figure 10 shows the relative positions of all points on the map.

The reduced frontage of the MAB does make connectivity easier on this terrain model because of the reduction in the average amount of trees between nodes. Whether or not this frontage is realistic is a question that cannot be answered without knowledge of the density of the enemy units. It is
Figure 10. MAB Unit locations for the first set of data points, nodes.
worth noting that the 16 km front was for a situation in southern California where the lack of trees would have made the connectivity easier.

The points went through another transition when they were actually placed on the map. A term was used, called "antenna sight selection," whereby each antenna was placed within 200 - 300 meters from the unit's location in an area that was conducive to radio frequency communications. This kept the antennas out of the bottom of ravines and also prevented enemy direction finding systems from pinpointing unit locations, since the antenna and unit were not colocated.

A list of final coordinates is given as Table 3 along with their "Mobility Factor." Each unit has been given a mobility factor of either one or zero. If a unit has a mobility factor of zero, then it is assumed to be in almost constant motion and unable to erect an external antenna. Its antenna is defined as being three meters above the ground. If a unit has a mobility factor of one, then it is using an external antenna that is either three meters above the ground when the unit is in a clearing, or three meters above the forest when the unit is in a forest. Mobility factors of one have been given to units of battalion size and larger.

After all the units of the MAB were analyzed for connectivity in the first set of positions, described in Table 3 and Figure 11, they were moved back from the FEBA. The FEBA is near the grid line 40000. They were again analyzed in the second set of positions, described in Table 4 and
Figure 12, and moved again. The final set of positions used is described in Table 5 and Figure 13. Each time that the set of units was moved, their relative positions to one another were maintained. This was accomplished by requiring each unit to move backward into the next adjoining grid square. The units were permitted, however, to find an optimum position in that adjoining grid square. The movement of the repeaters, nodes 68 through 74, were not as strictly controlled as the units. When the units were moved into their second set of positions, the repeaters were not moved. The repeater positions were changed when the units were moved into the third set of positions. They were positioned on key terrain in positions relative to where they were at the start of the problem. Thus, their role of bridging the gap between distant units was again reinstated.

Three enemy listening posts were established along the FEBA and they were used to analyze what units could be intercepted. Analysis of RF interception is discussed in Chapter V.
Table 1. Marine Amphibious Brigade (MAB) Unit locations, all points relative to the infantry regiment.

<table>
<thead>
<tr>
<th>NODE</th>
<th>NAME</th>
<th>LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inf Regt</td>
<td>000 000</td>
</tr>
<tr>
<td>2</td>
<td>Inf Bn</td>
<td>-040 040</td>
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<td>3</td>
<td>Inf Bn</td>
<td>040 040</td>
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<td>4</td>
<td>Inf Bn</td>
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<tr>
<td>74</td>
<td>Repeater 7</td>
<td>1</td>
<td>56100 16800</td>
<td></td>
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</tbody>
</table>
V. CONNECTIVITY

A. GENERAL

The operational characteristics of the radio frequency band have a major impact on the connectivity of the MAB's packet radio system. The lowest and highest frequencies which can be used for a packet radio system are determined primarily by considerations of bandwidth and propagation link loss. Practical, cost-effective radio equipment is difficult to find if the ratio of RF bandwidth to RF center frequency is much larger than about 15%. With a 16 kbs data rate and a 32 kHz RF bandwidth, this puts the lower bound of RF center frequencies at about 200 kHz. With pseudonoise modulation, the lowest usable frequency will be multiplied by the "spreading factor."

The upper limits of usable frequencies are determined by total link losses. As the operating frequency rises above about 10 GHz, absorptive losses due to the atmosphere, rain, and foliage penetration rapidly increase, and the resulting range is reduced accordingly.

B. SHF CONNECTIVITY

For a center frequency of 40 GHz and a percent reliability of 99.9%, Figures 6a and 7 give the maximum single hop distance such that the path loss does not exceed 141 dB as described in Chapter I.
\[ 141 \, \text{dB} \geq \left( \frac{4\pi d}{\lambda} \right)^2 \cdot \left( L_{O_2} - L_{H_2O} \right) \, \text{dB} + L_{\text{Rain}} \, \text{dB} \]

\[ 141 \, \text{dB} \geq 132 \, \text{dB} + 8 \, \text{dB} \]

For a maximum distance of 2.5 km a link can exist in the absence of any trees. From Figure 14 for a frequency of 40 GHz the attenuation due to trees is between 2 and 5 dB per meter of forest. At this frequency, a single tree could produce almost 50 dB of attenuation. Therefore, Figure 15 displays all links that are less than 2.5 km and whose line-of-sight is not obstructed by any trees. Only 53\% of the units have a connection, and these connections are broken down into eight disjointed sets. It is obvious at 40 GHz that connectivity does not exist.

If 20 GHz is used as the center frequency with the same percent reliability, Figures 6a and 7 give the maximum single hop distance as 5 km. From Figure 14 for a frequency of 20 GHz, the attenuation due to trees is still about 2 to 5 dB per meter. Figure 16 displays all the links that are less than 5 km and whose line-of-sight is not obstructed by any trees. This is a noticeable improvement in that 69\% of the units have a connection, but connectivity does not exist since there is a limited capability to pass traffic from the forward units to the units in the rear. A loss of key nodes
Figure 15. Connectivity at 40 GHz for the first data set.
Figure 16. Connectivity at 20 GHz for the first data set.
such as 54 and 56 would cause the system to become disjointed. From Figure 16, it is obvious that a greater reduction in center frequency is still needed. Connectivity of the MAB's units in the SHF band is limited by the poor tree penetration quality and by the requirement to have short links. Units with antennas below the forest ceiling will never be able to connect at frequencies above about 10 GHz. Further analysis was therefore directed not only to finding a good frequency for connectivity but also to finding one with good tree penetration qualities.

C. UHF AND VHF CONNECTIVITY

At frequencies below SHF, Figures 6a, b, and c, and 7 cannot be used to determine path loss. At these lower frequencies the path loss is more accurately approximated by Bullington's equation as shown in Figures 3 and 4. The attenuation due to foliage penetration at VHF and UHF can be determined by Nathanson's equation. Therefore the link loss equation is

\[
(\text{Attenuation})_{\text{dB}} = \left[ \frac{d^2}{h_1 h_2} \right]^2 + 0.25 f^{3/4}
\]

Figure 17 displays the five nearest neighbors at a center frequency of 1.5 GHz that have a total link loss of less than or equal to 141 dB. The five nearest neighbors concept was
Figure 17. Connectivity for the five nearest neighbors at 1.5 GHz for the first data set.
developed because some nodes see over 20 other nodes. The five nearest neighbors concept functions such that a node displays the five nearest of all the links that it has. Nearest is determined as a function of the x and y coordinates only, and does not take into account changes in elevation. Figure 17 has only five nodes that do not have a single connection with another node, and all of these five have a mobility factor of zero. To connect these nodes, a lower frequency with a better tree penetration quality is needed.

In order to provide a high frequency with ample bandwidth for multi-channel operations, and a low frequency for tree penetration, a frequency pair was analyzed. The high frequency was 1.5 GHz and the low frequency was either 150 MHz or 300 MHz. These three frequencies were used throughout the remainder of the report. The five nearest neighbors concept was still used without regard to whether the link was being carried on the high or low frequency. One of the problems with this concept is that, as the number of low-frequency links increased, there was a decrease in the number of high-frequency links that fell within the five nearest neighbors rule. Though the use of lower-frequency links produced more of a direct path through the network, they were not beneficial to all nodes. Some nodes had high-frequency links capable of carrying multiple channels replaced by narrow-band, short links, capable of carrying only a few channels. This is evident when one compares Figures 17 and 18. Figure 17 is the five nearest high-frequency links, and
Figure 18. Connectivity for only the 1.5 GHz links from among the five nearest neighbors for 300 MHz and 1.5 GHz, for the first data set.
Figure 18 is the high-frequency links that fit the five nearest neighbors rule when the lower frequency is 300 MHz. There is a 21% reduction in the number of high-frequency links but a 27% increase in the number of total links. The total link connectivity is displayed in Figure 19 where the solid line represents a link that is being carried on the high frequency, and a solid line with a tick mark on it represents a link that is being carried on the low frequency. This is the first connection pattern that includes all the nodes. Figure 19 was generated from Table 6. Table 6 displays the transmit station on the left, the number of links that exist, and the five nearest receiving stations. The second digit under the receiving stations is a zero if the link is being carried on the high frequency and a one if the link is being carried on the low frequency.

If the low frequency is 150 MHz and the high frequency is maintained at 1.5 GHz the connectivity is described in Figure 20. On the average this produces more low-frequency links and reduces the number of high-frequency links that make up the backbone of wideband multi-channel links. The connectivity of the units near the FEBA is increased by the use of 150 MHz, but at the expense of channel capacity throughout the entire network. This decrease in high-frequency links can be seen by comparing Figure 18 for 300 MHz and 1.5 GHz, with Figure 21 for only 150 MHz and 1.5 GHz.
Figure 19. Connectivity for the five nearest neighbors for 300 MHz and 1.5 GHz, for the first data set. Links with tick marks are carried at the lower frequency.
Figure 20. Connectivity for the five nearest neighbors for 150 MHz and 1.5 GHz, for the first data set. Links with tick marks are carried at the lower frequency.
Figure 21. Connectivity for only the 1.5 GHz links from among the five nearest neighbors for 150 MHz and 1.5 GHz, for the first data set.
Both of these figures display the high-frequency links that meet the five nearest neighbors rule. By using 150 MHz as the low frequency vice 300 MHz, a 10% reduction in the number of high-frequency links is created.

D. CONNECTIVITY WITH UNIT MOVEMENT

In order to check the MAB's connectivity under different terrain conditions, all units were moved back off the FEBA into the next adjoining grid squares. Figure 22 displays the connectivity for a low frequency of 300 MHz and a high frequency of 1.5 GHz, with unit positions as described in Table 4 and Figure 12. Figure 23 also displays the five nearest neighbors but with a low frequency of 150 MHz. Both figures show evidence of the connectivity problem caused by the 6 km ridge that runs along grid line 59000, just forward of node 59. The connectivity problem caused by ridges and ravines will not be overcome solely by using packet radios. Care must be taken when assigning unit locations so that a repeater or unit is located with connectivity to both sides of the ridge.

The MAB units were moved a second time back into the next adjoining grid squares. The unit locations are described in Table 5 and Figure 13. The connectivity problem encountered by the ridge running along grid line 59000 has been eliminated by positioning repeater number 73 on top of the ridge. Figure 24 displays the five nearest neighbors when only the high frequency of 1.5 GHz is used. Figure 25 shows the
Figure 22. Connectivity for the five nearest neighbors for 300 MHz and 1.5 GHz, for the second data set. Links with tick marks are carried at the lower frequency.
Figure 23. Connectivity for the five nearest neighbors for 150 MHz and 1.5 GHz, for the second data set. Links with tick marks are carried at the lower frequency.
Figure 24. Connectivity for the five nearest neighbors at 1.5 GHz, for the third data set.
Figure 25. Connectivity for only the 1.5 GHz links from among the five nearest neighbors for 300 MHz and 1.5 GHz, for the third data set.
connectivity by the high-frequency links when the five nearest neighbors rule is employed with a low frequency of 300 MHz and a high frequency of 1.5 GHz. The total connectivity for these two frequencies is displayed in Figure 26.

These figures show good connectivity at the high frequency, which is the backbone of the high-volume, multi-channel system. They also provide ample routing capability for all nodes, even the units located near the FEBA with mobility factors of zero.
Figure 26. Connectivity for the five nearest neighbors for 300 MHz and 1.5 GHz, for the third data set.
Links with tick marks are carried at the lower frequency.
Table 6. The five nearest neighbors for 300 MHz and 1.5 GHz, for the first data set.
VI. ENEMY INTERCEPT

Three enemy listening posts (LP) were established in order to determine which units were capable of transmitting across the FEBA. The listening posts were numbered 90, 91 and 92, and were located at 40050 11650, 40050 13500, and 40050 19500. For each LP, an analysis was done to determine if an RF link existed to any one of the 74 nodes. If a link existed, then the SNR at the receiver input for an antenna gain of 5.83 dB was given. This SNR was given for both the low and high frequencies that the transmitter might be using. The distance between the LP and node was also given along with the amount of forests penetrated.

Table 7 shows all the links that exist for a low frequency of 150 MHz and a high frequency of 1.5 GHz. The units are located at the first set of data points as described in Figure 11. Figure 27 displays all the nodes that produce an SNR of greater than -30 dB at any one of the listening posts. The nodes with the large dots are the ones that can be intercepted. If the high frequency only is displayed as in Figure 28, there is a noticeable reduction in the number of nodes that produce an SNR > -30 dB at the FEBA. Therefore the high frequency is again recommended because of its bandwidth and low probability of intercept.

If the units are moved back off the FEBA one grid square to locations as in Figure 12, the stations that can be
Table 7. The nodes that can be intercepted for 163 MHz and 1.5 GHz, for the first data set. The distance and amount of forest between nodes is also displayed.
Figure 27. The nodes with the large dots can be intercepted with a SNR greater than -10 dB if they are transmitting at 150 MHz, first data set.
<table>
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<th>UNCLASSIFIED</th>
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<tbody>
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<tbody>
<tr>
<td>3-88</td>
</tr>
<tr>
<td>TAC</td>
</tr>
</tbody>
</table>
Figure 28. Links that can be intercepted with a SNR greater than -30 dB if they are transmitting at 1.5 GHz, first data set.
intercepted at the low frequency appear in Figure 29 and the high frequency in Figure 30. Finally, if the units are again moved as in Figure 13, the units that can be intercepted at the low frequency appear in Figure 31 and the high frequency in Figure 32. These figures show that the probability of intercept decreases with increasing distance and frequency, as was expected. It is evident that, in order to decrease the amount of traffic intercepted, the low, tree-penetration frequencies should be used sparingly.
Figure 29. The nodes with the large dots can be intercepted with a SNR greater than -30 dB if they are transmitting at 150 MHz, second data set.
Figure 30. Links that can be intercepted with a SNR greater than -30 dB if they are transmitting at 1.5 GHz, second data set.
Figure 31. The nodes with the large dots can be intercepted with a SNR greater than -30 dB if they are transmitting at 150 MHz, third data set.
Figure 32. Links that can be intercepted with a SNR greater than -30 dB if they are transmitting at 1.5 GHz, third data set.
VII. CONCLUSIONS AND RECOMMENDATIONS

From the data presented in this report, it can be concluded that connectivity to support a practical packet radio system can be provided for terrain typical of western Europe. The system should have the capability of transmitting on at least two frequencies in the VHF and UHF bands. One of these frequencies should be in the high VHF range and would be needed as the tree-penetration frequency. The other frequency could be near 1.5 Hz and would be used as the wide-band, multi-channel frequency.

The algorithm used for selecting the frequency in the packet radio should make maximum use of the high frequency. The low frequency need only be used where the high frequency fails to connect with another node. Relying on the high frequency will not only increase the total system's channel capacity, but will also decrease the probability of being intercepted.

Figure 33 shows the connectivity under these constraints. The system is based on the five nearest neighbors rule for the third set of data points and a high frequency of 1.5 GHz. Then only the nodes without connectivity were permitted to use the lower frequency of 300 MHz. This network has 95% of the links being carried on the high frequency and only 35% of the nodes with the capability of being intercepted, as shown in Figure 34.
Figure 33. Connectivity for the five nearest neighbors at 1.5 GHz with selected nodes using 300 MHz, third data set. Links with tick marks are carried at the lower frequency.
Figure 34. Links that can be intercepted with a SNR greater than -30 dB for 300 MHz and 1.5 GHz, third data set.
GLOBAL DEFINITIONS FOR TERRAIN AND FOREST

GLOBAL DEFINITIONS FOR LOS AND ASSOCIATED ROUTINES -- ALL END WITH .LS

DEFINE CS1.LS, CS2.LS AS 1-DIMENSIONAL REAL ARRAYS
DEFINE AX, AY AS 1-DIMENSIONAL REAL ARRAYS
DEFINE NODE, ND AS A 1-DIMENSIONAL INTEGER ARRAY
DEFINE NO, OF, PTS AS INTEGER VARIABLES
DEFINE NO, PER, ROW AS 1-DIMENSIONAL INTEGER ARRAY
DEFINE MATIX, ORDER AS A 2-DIMENSIONAL INTEGER ARRAY
DEFINE FOREST, PERCENT, WOODS, LINK, LOSS, FREQ, FREQ.H, LAMDA, LAMDA.H,
TREE.E, HT, TREE.B, HT AS REAL VARIABLES
DEFINE KREP, TEMP, NCVESS AS INTEGER VARIABLES
DEFINE LINES, V AS A INTEGER VARIABLE
DEFINE MOBILITY AS 1-DIMENSIONAL INTEGER ARRAY
DEFINE ANT.A, HT, ANT.B, HT AS REAL VARIABLES

END
MAIN

DEFINE MAXLOS*DISTANCE AS REAL VARIABLES
DEFINE LAND*VISIBILITY AS REAL VARIABLE
DEFINE T, J, K, II, JJ, SMALLEST, KK, 
NODE, J, NODE, K, X, JX, XZ AS INTEGER VARIABLES
DEFINE MATRIX, DISTANCE AS A 2-DIMENSIONAL REAL ARRAY
DEFINE FREE_SPACE, L, FREE_SPACE, H, BULLINGTON, LOSS, MARGIN, LOSS, L, LOSS, H
AS REAL VARIABLES
LET LINES, V = 80
CALL RES, TERR
LET TEMP, NCVELS = NCVELS
READ SIZEA, LS, SIZEB, LS
READ MAXLOS, NO, OF, PTS
RESERVE AX(*), AY(*), NODE, NO(*), NO, PER, ROW(*), MOBILITY(*), AS NO, OF, PTS
RESERVE MATRIX, DISTANCE(*, *), MATRIX, ORDER(*, *), AS NO, OF, PTS BY NO, OF, PTS
LET FREQ, L = 0.3 / 3FREQ, L
LET FREQ, H = 1.5 ** G H Z
LET LAMDA, L = 0.3 / FREQ, L
LET LAMDA, H = 0.3 / FREQ, H
LET LINK, LOSS = 141 ** DB
LET LAGA, LS = 1
LET LAGB, LS = 1
LET LTOA, LS = 0
LET LATB, LS = 1
FOR I = 1 TO NO, OF, PTS, READ AX(I), AY(I), NODE, NO(I), J, MOBILITY(I)
FOR J = 1 TO NO, OF, PTS - 1, DO
LET MATRIX, DISTANCE(J, J) = MAXLOS*10
LET MATRIX, DISTANCE(NO, OF, PTS, NO, OF, PTS) = MAXLOS*10
FOR K = J + 1 TO NO, OF, PTS, DO
LETK = K = NODE, NO(J)
LET NODE, J = NODE, NO(J)
LET NCVELS = TEMP, NCVELS
LET TMICA, LS = 0
LET TMICB, LS = 0
LET MATRIX, DISTANCE(NODE, K, NODE, J) = MAXLOS*10
LET MATRIX, DISTANCE(NODE, J, NODE, K) = MAXLOS*10
LET DISTANCE = SQRT.(X(JI) - X(K))**2 + (Y(J) - Y(K))**2
CALL ELEV GIVEN AX(I), AY(I) YIELDING TMICA, LS
CALL ELEV GIVEN AX(K), AY(K) YIELDING TMICB, LS
CALL TREES GIVEN AX(J), AY(J) YIELDING TREE, A, HT
CALL TREES GIVEN AX(K), AY(K) YIELDING TREE, B, HT
IF MOBILITY(J) EQ 1
LET TMICA, LS = TREE, A, HT
ALWAYS
IF MOBILITY(K) EQ 1
LET TMICB, LS = TREE, B, HT
ALWAYS
LET ANI.A.HI = SIZEA.LS + THICA.LS
LET ANI.B.HI = SIZEB.LS + THICB.LS
LET XA.LS = AX(IJ)
LET YA.LS = AY(IJ)
LET XB.LS = AX(KI)
LET YB.LS = AY(KI)
LET NCLEVELS = 0
CALL LOS
IF VISFRB.LS LE 0, CYCLE
ALWAYS
LET FREESPACE.L = 10*LOG.10.F(14*PI.C*DISTANCE/LAMDA.L)**2
LET FREESPACE.H = 10*LOG.10.F(14*PI.C*DISTANCE/LAMDA.H)**2
LET BULLINGTON.LOSS = 10*LOG.10.F(DISTANCE**2)(ANT.A.HI*ANT.B.HI)**2
LET LOSS.L = FREESPACE.L
IF BULLINGTON.LOSS GT LOSS.L, LET LOSS.L = BULLINGTON.LOSS ALWAYS
LET LOSS.H = FREESPACE.H
IF BULLINGTON.LOSS GT LOSS.H, LET LOSS.H = BULLINGTON.LOSS ALWAYS
LET LAND.VISFRB = VISFRB.LS
LET NLEVELS = TEMP.NLEVELS
CALL LOS
LET DISTANCE = DISTANCE-FRAC.F(DISTANCE)
LET WOODS = 0
IF VISFRB.LS LE 0.0, CALL FOREST YIELDING FOREST.PERCENT
LET FOREST.PERCENT = 0.01 ALWAYS
LET WOODS = FOREST.PERCENT * DISTANCE
LET DISTANCE = DISTANCE + 0.1
IF LINK.LOSS LT LOSS.L + WOODS*0.25*FREQ.L**0.75 CYCLE ALWAYS
LET MARGIN = LINK.LOSS - LOSS.L - WOODS*0.25*FREQ.L**0.75
ALWAYS
IF LINK.LOSS GT LOSS.H + WOODS*0.25*FREQ.H**0.75,
LET MARGIN = LINK.LOSS - LOSS.H - WOODS*0.25*FREQ.H**0.75
LET DISTANCE = DISTANCE - FRAC.F(DISTANCE) ALWAYS
PRINT 4 LINES WITH XA.LS, YA.LS, NODE.NO(IJ), TMACA.LS, TREE.A.HT, ANTI.A.HT, XB.LS, YB.LS, NODE.NO(KI), TMACB.LS, TREE.B.HT, ANTI.B.HT, LAND.VISFRB, DISTANCE, WOODS, VISFRB.LS, MARGIN AS FOLLOWS
X = *****.**** NODE = ** ELEV = *****.*** TREE HT = *****.*** ANT HT = *****.****
Y = *****.**** NODE = ** ELEV = *****.*** TREE HT = *****.*** ANT HT = *****.****
SIM.L = *****.**** DISTANCE = *****.**** TREE HT = *****.**** ANT HT = *****.****
SIM.T = *****.**** MARGIN = *****.**** DB
SKIP OUTPUT LINE
LET MATRIX.DISTANCE(NODE.K,NODE.J) = DISTANCE
LET MATRIX.DISTANCE(NODE.J,NODE.K) = DISTANCE
LET NO.PER.ROW(NODE.K) = NO.PER.ROW(NODE.J) + 1
LET NO.PER.ROW(NODE.K) = NO.PER.ROW(NODE.K) + 1
LOOP "K"
LOOP "J"
FOR II = 1 TO NO.OF.PTS, DO
FOR JJ = 1 TO 5, DO
  LET SMALLEST = 1
  FOR KK = 2 TO NO. OF. PTS, DO
    IF MATRIX.DISTANCE(II, SMALLEST) LE MATRIX.DISTANCE(II, KK), CYCLE
      ALWAYS
    LET SMALLEST = KK
  LOOP **KK**
  IF MATRIX.DISTANCE(II, SMALLEST) EQ MAXLOS*10, CYCLE
    ALWAYS
    LET MATRIX.ORDER(II, SMALLEST) = JJ*10 +
    INT(FRFAC.F(MATRIX.DISTANCE(II, SMALLEST)))*10
    LET MATRIX.DISTANCE(II, SMALLEST) = MAXLOS*10
  LOOP **II**
CALL REPORT.PRINT
CALL LPI
STOP
END

ROUTINE REPORT.PRINT

DEFINE IJ, JI AS INTEGER VARIABLES
BEGIN REPORT PRINTING FOR IJ = 1 TO NO. OF. PTS IN GROUPS OF 25 PER PAGE
BEGIN HEADING
PRINT 1 LINE AS FOLLOWS
XT NO RECEIVERS
SKIP 1 OUTPUT LINE
PRINT 1 LINE WITH A GROUP OF IJ FIELDS THUS

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PRINT 1 LINE AS FOLLOWS
XT NO RECEIVERS
SKIP 1 OUTPUT LINE
PRINT 1 LINE WITH A GROUP OF IJ FIELDS THUS
** ** ** ** ** ** ** ** ** ** ** ** ** ** **
SKIP 1 OUTPUT LINE
END ** HEADING
FOR J1 = 1 TO NDFSPTS, PRINT 1 LINE WITH J1, NO.PER.ROW(J1),
AND A GROUP OF MATRIX.ORDER(J1,IJ) FIELDS THUS
** ** ** ** ** ** ** ** ** ** ** ** ** ** **
END ** REPORT
START NEW PAGE
RETURN
END

ROUTINE LPI

DEFINE I, SYMBOL AS INTEGER VARIABLES
DEFINE X, Y, NODE, MOBILITY.LPI, DISTANCE, SNR.L, SNR.H AS REAL VARIABLES
LET LINES.Y = 80
START NEW PAGE
SKIP 4 OUTPUT LINES
PRINT 1 LINE AS FOLLOWS
LP XMTX SNR.L SNR.H DISTANCE FOREST
SKIP 1 OUTPUT LINE
*START* READ X, Y, NODE, SYMBOL, MOBILITY.LPI
IF X EQ 99999 RETURN ALWAYS
FOR I = 1 TO NODFSPTS, DO
LET TMICA.LS = 0.
LET TMICB.LS = 0.
LET DISTANCE = SQRT.F((X-AX(I))**2+(Y-AY(I))**2)
CALL ELEV GIVEN X, Y YIELDING TMICA.LS
CALL ELEV GIVEN AX(I), AY(I) YIELDING TMICB.LS
CALL TREES GIVEN X, Y YIELDING TREE.A,HT
CALL TREES GIVEN AX(I), AY(I) YIELDING TREE.B,HT
IF MOBILITY.LPI EQ 1 LET TMICA.LS = TREE.A,HT ALWAYS
IF MOBILITY(I) EQ 1 LET TMICB.LS = TREE.B,HT ALWAYS
LET XA.LS = X LET YA.LS = Y LET XB.LS = AX(I) LET YB.LS = AY(I)
LET NCVELS = 0
CALL LOS
IF VISIFB.LS LE 0.0, CYCLE ALWAYS
LET NCVELS = TEMP.NCVELS
CALL LOS
LET WOODS = 0.0
IF VISIFB.LS LE 0.0, CALL FOREST YIELDING FOREST.PERCENT
IF FOREST.PERCENT LE 0.0, LET FOREST.PERCENT = 0.01 ALWAYS
LET WOODS = FOREST.PERCENT * DISTANCE ALWAYS
LET SNR.L = LINK.LOS*11-10*LOG.10.F(DISTANCE**4/(ANT.A.HT*ANT.B.HT)**2)-WOODS*0.25*FREQ.L**0.75
LET SNR.H = LINK.LOS*11-10*LOG.10.F(DISTANCE**4/(ANT.A.HT*ANT.B.HT)**2)-WOODS*0.25*FREQ.H**0.75
PRINT I LINE WITH NODE, NODE.NO(I), SNR.L, SNR.H, DISTANCE, WOODS AS FOLLOWS
*** *** *** *** *** *** *** ***
LOOP ** I**
GO TO START
END

ROUTINE FOR ELEV GIVEN X,Y YIELDING Z
** ROUTINE TO COMPUTE GIVEN ELEVATION Z FOR GIVEN X,Y COORDINATES
DEFINE I, IX, IY, KOUNT, LS AS INTEGER VARIABLES
DEFINE X,Y, Z, XS, YS, Q1, FI AS REAL VARIABLES
DEFINE DUM.I AS A 1-DIMENSIONAL INTEGER ARRAY
LET IX=1+TRUNC.F((X-X.LQ.BDRY)/GSIZE)
LET IY=1+TRUNC.F((Y-Y.LQ.BDRY)/GSIZE)
IF IX LT 1 LET IX=1 ALWAYS
IF IX GT NGRIDX LET IX = NGRIDX ALWAYS
IF IY LT 1 LET IY=1 ALWAYS
IF IY GT NGRIDY LET IY = NGRIDY ALWAYS
LET DUM.1(I*1) = LIST.HX, IY, I*1 ** DUMMY ARRAY TO SIMPLIFY INDEXING
LET KOUNT = DIM.F(DJ, I*1)
LET Z = DUM.I(I)
FOR L = 2 TO KOUNT DO
LET I = DUM.I(I)
LET XS=X-XC.H(I)
LET QI=PXX.H(I)*XS*XS + PYY.H(I)*YS*YS + PXY.H(I)*XS*YS
IF QI LT CRIT.H(I) CYCLE
ELSE LET FI=PEAK.H(I)+HT.H(I)*(EXP.FQI)-1.)
IF FI GT Z LET Z=FI ALWAYS
LOOP RETURN END
**ROUIN ACE KOVER GIVEN ZO,TMCT,SIZJZT,SHTS,VS,S,NSFN YIELDING VIJSOUT**

**DEFINE ZO,TMCT,SIZET,IT,S,HTS,VS,NSFIN,VIJSOUT,EVIS T AS RCAL VARIABLES**

**LET VIJSOUT = VSFIIV**

**IF S NE 0**

**IF HTS GE ZS GO TO BLOKED ELSE**

**LET EVIS T = MAX.F(TMCT,ZO+(HTS-ZO)/S)**

**IF EVIS T GE ZT GO TO BLOKED ELSE**

**IF EVIS T LE ZT-SIZET RETURN ELSE**

**LET VIJSOUT = MIN.F(VIJSOUT,(ZT-EVIS T/ SIZET)) RETURN**

**ELSE IF HTS LT ZD RETURN ELSE**

**BLOCKED* LET VIJSOUT = 0. RETURN END**

**ROUIN ACE TREES GIVEN X AND Y YIELDING T**

**. ROUTINE TO COMPUTE TREE HEIGHT GIVEN A POINT ON THE BATTLEFIELD**

**DEFINE X,1,T,LS,VS,GI,T AS REAL VARIABLES**

**DEFINE IC,IX,IY,N,L AS INTEGER VARIABLES**

**DEFINE DUM.1 AS A 1-DIMENSIONAL INTEGER ARRAY**

**LET T = 0.**

**IF NCVELS EQ 0 RETURN ELSE**

**LET IX = 1 + TRUNC.F((X-X.LO, BDY1)/GSIIZE)**

**LET IY = 1 + TRUNC.F((Y-Y.LO, BDY1)/GSIIZE)**

**IF IX LT 1 LET IX = 1 ALWAYS**

**IF IX GT NGRIDX LET IX = NGRIDX ALWAYS**

**IF IY LT 1 LET IY = 1 ALWAYS**

**IF IY GT NGRIDY LET IY = NGRIDY ALWAYS**

**IF (IX LT 1) OR (IX GT NGRIDX) OR (IY LT 1) OR (IY GT NGRIDY) RETURN**

**ELSE LET DUM.1[(*)]= LIST.C(IX,IY,*)**
LET N = DUM.I(1) + 1
IF N EQ 1 RETURN ELSE
FOR L = 2 TO N DO
  LET IC = DUM.I(L) LET HT = HT.E(IC)
  IF HT LE 1 CYCLE
  ELSE
    LET XS = X-XC.E(IC) LET VS = Y-VC.E(IC)
    LET Q1 = PX.E.IC1*XS**2 + PXY.E.IC1*VS**2 + PXY.E.IC1*XS*VS
    IF Q1 GE 1 CYCLE
    ELSE LET I = HT
  LOOP
RETURN
END

ROUTINE LSO

DEFINE I,K,N,L,IC,M AS INTEGER VARIABLES
** ALL VARIABLES EXCEPT THOSE DECLARED ABOVE ARE GLOBAL FOR USE IN LOS AND **
** ITS ASSOCIATED ROUTINES.
LET VISFRA.LS = 1.0 LET VISFRB.LS = 1.0
LET XBA.LS = XB.LS - XA.LS LET YBA.LS = YB.LS - YA.LS
IF XBA.LS EQ 0 AND YBA.LS EQ 0 RETURN ELSE
IF (SIZEA.LS + TMICA.LS LE 0.) OR (SIZEB.LS + TMICB.LS LE 0.) GO TO NO.LOS ELSE
IF TMICA.LS LT 0. LET VISFRA.LS = 1. + TMICA.LS / SIZEA.LS ALWAYS
IF TMICB.LS LT 0. LET VISFRB.LS = 1. + TMICB.LS / SIZEB.LS ALWAYS
LET ZA.LS = TMACA.LS + TMICA.LS + SIZEA.LS
LET ZB.LS = TMACB.LS + TMICB.LS + SIZEB.LS
LET ZBA.LS = ZB.LS - ZA.LS ADD 1 TO <IREP
LET XBSQ.LS = XBA.LS **2 LET YBSQ.LS = YBA.LS **2
LET XVB.LS = XBA.LS + YBA.LS
LET XNYBA.LS = 2. * XBA.LS
LET YVYBA.LS = 2. * YBA.LS
LET LAG.LS = LAGA.LS + LAGB.LS LET CMYAX.LS = 0.
** COMPUTE LIST OF GIDSQUARES CROSSED BY A TO B LINE **
LET NGRS.LS = 0
IF XBA.LS EQ 0. LET XBA.LS = 0.1 ALWAYS
IF XBA.LS GT 0.
  LET ISG.XS = -1 LET XINC.LS = GSIZE/XBA.LS JUMP AHEAD
ELSE LET ISG.XS = 1 LET XINC.LS = -FSIZE/XBA.LS
HERE IF YBA.LS EQ 0. LET YBA.LS = 0.1 ALWAYS
IF YBA.LS GT 0
   LET ISGY.LS = -1   LET YINC.LS = GSIZE/YBA.LS   JUMP AHEAD
ELSE LET ISGY.LS = 1   LET YINC.LS = -GSIZE/YBA.LS
HERE
LET IX.LS = 1 + TRUNC.F([IX.LS-X.LO.BDRY]/GSIZE)
LET IY.LS = 1 + TRUNC.F([IY.LS-Y.LO.BDRY]/GSIZE)
LET XSTEP.LS = (X:LS-X.LO.BDRY-1*GSIZE*([IX.LS-0.5][ISGY.LS-1.5]))/XBA.LS
LET YSTEP.LS = (Y:LS-Y.LO.BDRY-1*GSIZE*([IY.LS-0.5][ISGY.LS-1.5]))/YBA.LS
GRID.LOOP
IF IX.LS LT 1 OR (IX.LS GT NGRIDX) OR (IY.LS LT 1 OR (IY.LS GT NGRIDY))
   JUMP AHEAD
ELSE ADD 1 TO NGRSQ.LS
   LET IGX.LS(INGRSQ.LS) = IX.LS
   LET IGY.LS(INGRSQ.LS) = IY.LS
HERE
IF XSTEP.LS LE 1 OR YSTEP.LS LE 1,
   IF XSTEP.LS LT YSTEP.LS
      ADD ISGX.LS TO IX.LS
      ADD XINC.LS TO XSTEP.LS
      GO TO GRID.LOOP
   ELSE
      IF XSTEP.LS GT YSTEP.LS JUMP AHEAD
   HERE
   ADD ISGY.LS TO IY.LS
   ADD YINC.LS TO YSTEP.LS
   GO TO GRID.LOOP
ALWAYS **GRID LIST NOW COMPLETE IN IGX.LS, IGY.LS WITH NGRSQ.LS ENTRIES
IF NGRSQ.LS EQ 0 GO TO NO.LOS ELSE
IF NOW FIND WHICH COVER ELLIPSES INTERSECT THE A TO B LINE
** AND CHECK LOS AT S1 AND S2 FOR EACH SUCH ELLIPSE
LET MELS = 0
IF MCVELS EQ 0 GO TO HILL.PROCESSING ELSE
FOR K = 1 TO NGRSQ.LS DO
   LET IY.LS = IGX.LS(IK)
   LET IX.LS = IGY.LS(K)
   LET DUM.1(1) = LIST.CIT(IX.LS, IY.LS, *)
   LET N = DUM.1(1) + 1
   IF N EQ 1 CYCLE ELSE
   FOR L = 2 TO N
      LET IC = DUM.1(1)
      LET CPK.LS = HT.E(IC)
      IF KCREP.E(IC) EQ KTREP CYCLE ELSE
      LET KCREE.PIC = KTREP
      LET RX.LS = XA.LS - X.C.E(IC)
      LET RY.LS = YA.LS - Y.C.E(IC)
      LET PX.X.LS = PX.E(IC)
      LET PY.Y.LS = PY.E(IC)
      LET PX.Y.LS = PXY.E(IC)
      LET AA.LS = PX.X.LS*PX.X.LS + PY.Y.LS*PY.Y.LS + PXY.LS*PXY.LS
      LET BB.LS = PXX.LS*PXX.LS + PYY.LS*PYY.LS + PXY.LS*PXY.LS
      LET CC.LS = PXX.LS*PXX.LS + PXX.LS*PXX.LS + PYY.LS*PYY.LS + PXY.LS*PXY.LS
      LET AREG.LS = BB.LS*CC.LS - 4.0*AA.LS*CC.LS
      LET ARG.LS = BB.LS*CC.LS - 4.0*AA.LS*CC.LS
      IF ARG.LS LE 0 CYCLE ELSE
      LET SQ.LS = SORT.F(ARG.LS)
      LET S1.LS = -[BB.LS+SQ.LS]/12.0*AA.LS
      LET S2.LS = (SQ.LS-BB.LS)/(12.0*AA.LS)
IF S1.LS GE 1.0 CYCLE ELSE
IF S2.LS LE 1.0 CYCLE ELSE
**BOTH A AND B ARE GROUND PLATFORMS**
IF LAG.LS NE 0. GO TO AIR ELSE
**FOREST IS BETWEEN A AND B**
*GROUND* LET SS.LS = S2.LS CALL TREE.CHECK
LET SS.LS = S1.LS CALL TREE.CHECK
GO TO SAVE.ELL
*AIR* IF S1.LS LE 3. AND S2.LS LE 3. GO TO GROUND ELSE
**BOTH A AND B ARE IN OR OVER TREES, IF LAG.LS LE 0. GO TO NO.LOS ELSE**
**GO TO SAVE.ELL**
**A.IS.IN** A IS IN OR OVER TREES, B IS NOT
IF LAG.LS EQ O OR TMICA.LS LT CPK.LS GO TO NO.LOS ELSE
LET SS.LS = S2.LS CALL TREE.CHECK
GO TO SAVE.ELL
**B.IS.IN** B IS IN OR OVER TREES, A IS NOT
IF LAG.LS EQ O AND TMICA.LS LT CPK.LS GO TO NO.LOS ELSE
LET SS.LS = S1.LS CALL TREE.CHECK
*SAVE.ELL* IF LATOB.LS EQ O AND VISFRB.LS LE 0. GO TO NO.LOS ELSE
IF LATOA.LS EQ O AND VISFRAL.LS LE 0. GO TO NO.LOS ELSE
ADD 1 TO NELS.LS LET IEL.LS(NELS.LS) = IC
LET C1.LS(NELS.LS) = S1.LS LET CS2.LS(NELS.LS) = S2.LS
IF CPK.LS GT CHTMAX.LS LET CHTMAX.LS = CPK.LS ALWAYS
LOOP **BACK FOR NEXT ELLIPSE IN THIS GRID SQUARE**
**ALL ELLIPSES CHECKED AND SAVED**
**NOW START ON THE HILLS**
*HILL PROCESSING*
FOR K = 1 TO NGRSQ.LS DO
LET IX.LS = IGR.LS(K) LET IV.LS = IGY.LS(K)
LET DUM.([k]) = LIST.H([x.LS],[y.LS],*)
LET N = DIM.F(DUM.([k]))
LET BASE = DUM.([k])
FOR L = 2 TO N DO
LET I = DUM.([k]) ** GIVING THE HILL NUMBER**
IF K.REP([k]) EQ KTREP CYCLE ELSE
LET KHREP([k]) = KTREP
**COMPUTE W = TOP OF HILL I ALONG A TO B LINE**
LET PX.LS = PXH.LI LET PY.LS = PYH.LI LET PXH.LS = PXH.LI
LET RX.LS = XA.LS - XC.H.II LET RY.LS = YA.LS - YC.H.II
LET GQ.LS = PX.LS*YBASQ.LS + PY.LS*YBASQ.LS + PX.LS*YBASQ.LS
LET FQ.LS = 2.0*(PX.LS*RX.LS*YBA.LS + PY.LS*RY.LS*YBA.LS) +
PX.LS*(RX.LS*YBA.LS + RY.LS*YBA.LS)
IF GQ.LS EQ 0 THEN CYCLE ELSE
   LET W.LS = -F9.LS / (2.0*GQ.LS)
   IF ABS.FW.LS > GT 5 THEN CYCLE ELSE
   LET FSQ.LS = FO.LS**2
   LET EQ.LS = PXX.LS*RX.LS**2 + PYY.LS*RY.LS**2 + PXY.LS*RX.LS*RY.LS
   LET POW.LS = EQ.LS - FSQ.LS / (4.0*GQ.LS)
   IF POW.LS LT 4.0 THEN CYCLE ELSE
   LET PK.LS = PEAK.HII
   LET HT.LS = HT.LS + (EXP.F(Pow.LS)-1.)
   IF HHW.LS LE BASE.LS CYCLE ELSE
   LET ZW.LS = ZA.LS + W.LS*ZBA.LS
   IF W.LS LT 0 OR W.LS LT 1. THEN JUMP AHEAD ELSE
   IF HHW.LS GO TO NO.LOS ELSE
   IF NELS.LS EQ 0 THEN JUMP AHEAD ELSE
   LET CVHTW.LS = 0
   FOR Y = 1 TO NELS.LS DO
      IF CS1.LS(M) GE W.LS OR CS2.LS(M) LE W.LS CYCLE ELSE
      LET IC = IEL.LS(M)
      IF CVHTW.LS LT HT.E(IC) THEN CYCLE ELSE
      loop
      IF HHW.LS + CVHTW.LS GE ZW.LS GO TO NO.LOS ELSE
      HERE IF WE GET TO HERE, THEN NEED TO FIND LOWEST SIGHT LINE OVER HILL
   """ NEWTON ITERATION FROM A TO B GIVING VISFRA.LS
      IF LATOB.LS EQ 1
         LET ZZ.LS = ZA.LS + HT.LS - PK.LS
         CALL NEWTON
      IF VISFRA.LS LE 0 THEN NO.LOS ELSE
      ALWAYS
   """ NEWTON ITERATION FROM B TO A GIVING VISFRA.LS
      IF LBTOA.LS EQ 1
         LET ZZ.LS = ZB.LS + HT.LS - PK.LS
         CALL NEWTON
      IF VISFRA.LS LE 0 THEN NO.LOS ELSE
      ALWAYS
   always
   loop """ back for next hill
   loop """ back for next grid square
   return
   *NO.LOS* LET VISFRA.LS = 0.
   LET VISFRA.LS = 0.
   return
   routine newton
   define M, NCT.LS, IC AS INTEGER VARIABLES
   ** ALL VARIABLES ARE REAL AND GLOBAL EXCEPT M, IC AS ABOVE AND
   ** NCT.LS, NELS.LS, IEL.LS WHICH ARE INTEGER GLOBAL
   LET NCT.LS = 0
   LET V.LS = W.LS
   LET VM.LS = V.LS - VSUB.LS
   LET HHW.LS = HHW.LS + HT.LS - PK.LS
   LET TWDGV.LS = 2.*GQ.LS * V.LS
*TOP* LET FCNV.LS = ZZ.LS + HHV.LS*((FQ.LS+TWOGV.LS)*VM.LS-L.L)
LET DFCNV.LS = HHV.LS*VM.LS*(TWOGV.LS**2 + 2.*((GQ.LS + TWOGV.LS*FQ.LS)+FSQ.LS))
IF ABS.FIDFCNV.LS LT 0.0000000001 RETURN ELSE
LET V.LS = V.LS - FCNV.LS/DFCNV.LS
IF ABS.FIV.LS) GT 5. RETURN ELSE
LET V-.LS = V.LS - VSUB.LS
LET TWOGV.LS = 2.*GQ.LS*V.LS
LET POW.LS = EQ.LS + FQ.LS*V.LS + GQ.LS*V.LS**2
IF POW.LS LT -4. RETURN ELSE
LET HHV.LS = HT.LS*EXP.F(POW.LS)
LET ELV.LS = ZZ.LS + VM.LS*(HHV.LS*(FQ.LS+TWOGV.LS))
IF ABS.FIELV.LS - HHV.LS) GT 1.
LET NCT.LS = NCT.LS + 1
IF NCT.LS LT 10 GO TO TOP ELSE
ALWAYS
IF V.LS LT 0. OR V.LS GT 1. RETURN ELSE
** WE HAVE A GOOD VALUE OF V -- CHECK IT FOR FOREST COVERAGE
LET CVHTV.LS = 0.
FOR M = 1 TO NELS.LS DO
  IF CSL.LS(N) GE V.LS OR CS2.LS(N) LE V.LS CYCLE ELSE
  LET IC = IEL.LS(N)
  IF CVHTV.LS LT HT.E(IC) LET CVHTV.LS = HT.E(IC) ALWAYS
END LOOP
LET HTY.LS = HHV.LS + PK.LS + CVHTV.LS - HT.LS
LET ZV.LS = ZA.LS + V.LS*ZBA.LS
IF VSUB.LS EQ 0. CALL COVER(ZA.LS, TMACB.LS, SIZE0.LS, ZB.LS, V.LS, HTY.LS, ZV.LS, VISFRB.LS) YIELDING VISFRB.LS
ALWAYS RETURN END
**ROUTINE RES.TERR**

**ROUTINE TO RESERVE AND READ IN DATA ARRAYS FOR TERRAIN HILLS, COVER ELLIPSES, AND BATTLEFIELD COORDINATES**

NORMALLY MODE IS REAL

DEFINE I,X,Y,KOUNT,J,JX,JY

USE UNIT 14 FOR INPUT

READ NGRIDX,NGRIDY,CSIZE,X,LO.BDRY,Y,LO.BDRY,NHILLS **ALL GLOBAL

RESERVE IX,LS(*),IY,LS(*) AS NGRIDX + NGRIDY

RESERVE EL,LS(*),CS1,LS(*),CS2,LS(*) AS 100

RESERVE LIST,H(*,*,*),KREP(*) AS NGRIDX BY NGRIDY BY *

RESERVE XC,M(*),YC,M(*),PEAK.H(*),HT.H(*),PXX.H(*),PYY.H(*),PXY.H(*),CRIT.H(*)

AS NHILLS

RESERVE KREP(*) AS NHILLS

LET KREP=-INF,C

FOR I=1 TO NHILLS DO

READ J

IF I NE J PRINT 1 LINE WITH I AS FOLLOWS

XXXXX INPUT DATA SEQUENCE ERROR IN HILL DATA FOR HILL ***** XXXXX

ALWAYS

READ XC,YC,PEAK.H(*),ANG,ECC,SPRD,HT.H(*),CUTOFF

LET A=LOG.E.FHT.H(I)/HT.H(I)-50.

LET B=A*ECC**2

LET SINC=SIN.F(ANG)

LET CANG=COS.F(ANG)

LET PX.H(*)=-(A*CANG**2 + B*CANG**2)/(SPRD**2)

LET PY.H(*)=A*SANG**2 + B*CANG**2)/(SPRD**2)

LET PX.H(*)=(2*A*SANG**2+B-CANG*SANG*(B-A))/(SPRD**2)

LET XC.H(I)=XC*100

LET YC.H(I)=YC*100

LET KREP(I)=INF.

IF CUTOFF GE HT.H(I) LET CRIT.H(I)=5.

ELSE LET CRIT.H(I)=LOG.E.F(H.T.H(I)-CUTOFF)/HT.H(I)

ALWAYS

LOOP

FOR IX = 1 TO NGRIDX DO

FOR IY = 1 TO NGRIDY DO

READ JX,JY,KOUNT

IF IX NE JX OR IY NE JY PRINT 1 LINE WITH IX, IY AS FOLLOWS

XXXXX INPUT DATA SEQUENCE ERROR IN LIST.H DATA FOR GRID **** **** XXXXX

ALWAYS

RESERVE LIST,H(IX,IY,*) AS KOUNT+1

FOR I = 1 TO KOUNT+1 READ LIST,H(IX,IY,*)

LOOP

READ NCLEVELS

IF NCLEVELS EQ 0 USE UNIT 5 FOR INPUT RETURN

ELSE RESERVE LIST,C(*,*,*),* AS NGRIDX BY NGRIDY BY *

RESERVE XC,E(*),Y,E(*),HT.E(*),PXX.E(*),PYY.E(*),PXY.E(*),KCREP(*) AS NCLEVELS

FOR I = 1 TO NCLEVELS DO

READ J

IF I NE J PRINT 1 LINE WITH I AS FOLLOWS
XXXXX INPUT DATA SEQUENCE ERROR IN COVER ELLIPSE NUMBER ***** XXXXX
ALWAYS
READ XC,YC,HT, E(I), ANG,AMAJ,AMIN
LET ANG = ANG/RADIAN.C LET SANG = SIN.F(ANG) LET CANG = COS.F(ANG)
LET PXX.E(I) = (CANG/AMAJ)**2 + (SANG/AMIN)**2
LET PYY.E(I) = (SANG/AMAJ)**2 + (CANG/AMIN)**2
LET PXY.E(I) = 2.*SANG*CANG*(1./AMAJ**2 - 1./AMIN**2)
LET XC.E(I) = XC * 100. LET YC.E(I) = YC * 100.
LET KCREP(I) = -INF.C
LOOP
FOR IX = 1 TO NGRIDX DO
FOR IY = 1 TO NGRIDY DO
READ JX,JY,KOUNT
IF IX NE JK OR IY NE JY PRINT 1 LINE WITH IX,IY AS FOLLOWS
XXXXX INPUT DATA SEQUENCE ERROR IN LIST.C DATA FOR GRID ***** **** XXXXX
ALWAYS RESERVE LIST.C(IX,IY,*) AS KOUNT+1
LET LIST.C(IX,IY,1) = KOUNT
FOR I = 2 TO KOUNT + 1 READ LIST.C(IX,IY,I)
LOOP LOOP
USE UNIT 5 FOR INPUT
RETURN END

ROUTINE TRE.CHECK
LET XS.LS = XA.LS + SS.LS*XBA.LS LET YS.LS = YA.LS + SS.LS*YBA.LS
CALL ELEV GIVEN XS.LS; YS.LS YIELDING HTS.LS
ADD GPK.LS TO HTS.LS
LET ZS.LS = ZA.LS + SS.LS * ZBA.LS
IF LATOB.LS EQ 1 CALL KOVER(ZA.LS,MACB.LS,SIZEB.LS,ZB.LS,SS.LS,HTS.LS,ZS.LS,VISFRB.LS)
YIELDING VISFRB.LS
ALWAYS
IF LATOA.LS EQ 1 CALL KOVER(ZB.LS,MACA.LS,SIZEA.LS,ZA.LS,1.0-SS.LS,HTS.LS,ZS.LS,VISFRA.LS)
YIELDING VISFRA.LS
ALWAYS RETURN END
ROUTINE FOREST YIELDING FOREST.ATOB

DEFINE I AS INTEGER VARIABLE
DEFINE FOREST.ATOB, X,Y,ELEV.XY, TREE.XY, Z,Z.OT.LINE,DIF AS REAL VARIABLES
LET FOREST.ATOB = 0.0
FOR I = 1 TO 100, DO
    LET X = XA.LS + I/100*(XB.LS - XA.LS)
    LET Y = YA.LS + I/100*(YB.LS - YA.LS)
    CALL ELEV.GIVEN X,Y YIELDING ELEV.XY
    CALL TREES GIVEN X,Y YIELDING TREE.XY
    LET Z = ELEV.XY + TREE.XY
    LET Z.OT.LINE = ZA.LS + I/100*(ZB.LS - ZA.LS)
    LET DIF = Z.OT.LINE - Z
    IF DIF LE 0.0, LET FOREST.ATOB = FOREST.ATOB + 0.01 CYCLE
    ALWAYS
LOOP *"I
RETURN
END

//GU.SIMUL4 DO UNIT=2314, VOL=SER=PATO01,
// DSN=HUNTER,T, DISP=SHR
3 3 74
5000 74

99999 99999 99 99 9
//TGKL015 JOB (1420, 0238, DC91, 15), 'TRY ONE', TIME=10
// EXEC FORTCLOW
//FORT SYMIN DD *
C PLOT FOR 10 BY 30 KM HUNFELD TERRAIN BOX
DIMENSION IOP1(10), BX(7), BY(7), EX(7), EY(7), XI(3600), Y(3600),
   ITR(100), TITLE(20)
DATA BX/-500., -30500., 30500., -500., -500., 0., 1.,/
   BY/-500., -10500., 10500., -10500., -10500., 0., 1.,/
   EX/0., 30000., 30000., 0., 0., 0., 1.,/
   EY/0., 10000., 10000., 0., 0., 0., 1.,/
DATA L4ASKI/2DFOF/
C INPUT OPTIONS AS 1 = DESIRED, 0 = NOT DESIRED
C IOPT(1) -- COORDINATE GRID
C (2) -- LABEL COORDINATES
C (3) -- TERRAIN CONTOUR MAP
C (4) -- ACCENT CONTOURS DIVISIBLE BY 100.
C (5) -- FORESTS SHADED
C (6) -- DRAW LINES (EG. ROUTES)
C (7) -- DRAW SYMBOLS (EG. POSITIONS)
C (8) -- TITLE
C READ(S, 7) IOPT
C FORMAT(IOPT)
C BATTLEFIELD LOWER LEFT CORNER COORDS IN METERS
XLOBY=40000.
YLOBY=10000.
C PLOT FRAME
C CALL PLOTS(0, 0, 0)
CALL NEWPEN(5)
CALL LINE(BX, BY, 5, 1, 0, 0)
CALL LINE(EX, EY, 5, 1, 0, 0)
CALL NEWPEN(1)
C PLOT COORDINATE GRID
C IF (IOPT(1).NE.1) GO TO 200
WRITE(6, 107)
107 FORMAT(' OPTION 1 -- COORDINATE GRID')
CALL GRID(0., 0., 30, 1000., 10, 1000., L4ASK1)
C PLOT COORDINATE LABEL NUMBERS
C 200 IF (IOPT(2).NE.1) GO TO 300
C
```
WRITE(*,1207)
FORMAT(*, OPTION 2 -- COORDINATE LABELS*)
CX=-100.
CY=-315.
CYT=101.85.
DX=-445.
DXT=300.95.
DY=-65.
X8=XLOBY/1000.
YB=YLOBY/1000.
HT=130.
DO 230 I=1,31
CALL NUMBER(CX, CY, HT, X8, 0, 0, -1)
CALL NUMBER(CX, CYT, HT, X8, 0, 0, -1)
CX=CX+1000.
X8=X8+1.
DO 250 I=1,11
CALL NUMBER(DX, DY, HT, YB, 0, 0, -1)
CALL NUMBER(DX, DYT, HT, YB, 0, 0, -1)
DY=DY+1000.
YB=YB+1.
C PLOT TERRAIN CONTJR MAP
C
300 IF(10PT(3), NE.1) GO TO 500
WRITE(*,307)
307 FORMAT(*, OPTION 3 -- TERRAIN CONTOUR LINES*)
IF (10PT(4), EQ.1) WRITE(6,407)
407 FORMAT(*, OPTION 4 -- ACCENT 100 M. CONTOURS*)
310 READ(3,317,END=390) NP,CV
317 FORMAT(15,F10.0)
327 FORMAT(8F10.2)
X(NP)=0.
X(NP+1)=1.
Y(NP)=0.
Y(NP+1)=1.
CALL NEWPEN(1)
IF(10PT(4), NE.1) GO TO 350
C ACCENT CONTOURS DIVISIBLE BY 100.
C
ICV=CV/100.
XXCV=CV-ICV*100.
IF(ABS(XXCV), LT. 0.1) CALL NEWPEN(4)
350 CALL LINE(Y, X, NP, 1, 0, 0)
GO TO 310
C OUT OF DATA
```
CALL NEWPEN(1)

SHADE FORESTED AREAS

IF(IOPT(5).NE.1) GO TO 600
WRITE(6,'(5F8.0)')
517 FORMAT(' OPTION 5 -- SHADE FORESTS'
HT=75.
XC=50.
DO 520 I=1,300
READ(2,507) (ITR(J),J=1,100)
507 FORMAT(5D11.3)
YC=50.
DO 540 J=1,100
IF(ITR(J).EQ.0) GO TO 520
CALL SYMBOL(XC,YC,HT,9,0.,-1)
520 YC=YC+100.
540 CONTINUE
XC=XC+100.
570 CONTINUE

PLOT LINES (EG. ROJTES)

600 IF(IOPT(6).NE.1) GO TO 700
WRITE(6,'(5F8.0)')
627 FORMAT(' OPTION 6 -- PLOT LINES'
CALL NEWPEN(2)
610 READ(5,507) NP
607 FORMAT(5I1)
IF(NP.EQ.999) GO TO 690
617 FORMAT(8F10.0)
X(NP)=0.
X(NP+2)=1.
Y(NP)=0.
Y(NP+2)=1.
CALL LINE(X,Y,NP,1,0,0)
GO TO 610
690 CALL NEWPEN(1)

PLOT SYMBOLS (EG. POSITIONS)

700 IF(IOPT(7).NE.1) GO TO 800
WRITE(6,'(5F8.0)')
707 FORMAT(' OPTION 7 -- PLOT POSITIONS'
HT = 100.
CALL NEWPEN(4)
710 READ(5,717) XC, YC, I, ISYM
717  FORMAT(F5.0,4X,F5.0,4X,I2,4X,I3)
   IF(ISYM.EQ.999) GO TO 800
   XC = XC - XLOBY
   YC = YC - YLOBY
   CALL_SYMBOL(XC,YC,HT,ISYM,0.,-1)
   I = 1
   XC = XC + 50.
   YC = YC + 50.
   CALL_NUMBER(XC,YC,HT,I,0.0,-1)
   GO TO 710

C  PLOT TITLE
C
800  IF(IOPT(8).NE.1) GO TO 900
   CALL_NEWPEN(1)
   READ (5,807) ITITLE
807  FORMAT(20A4)
   WRITE(6,817) ITITLE
817  FORMAT(' OPTION 8 -- TITLE ','20A4)
       XC=700.
       YC=-400.
       HT=135.
   CALL_SYMBOL(XC,YC,HT,ITITLE,90.0,80)
900  CONTINUE
   CALL_PLOT(0.,0.,999)
   STOP
END

GO,PLOTPARM DD *
&PLOT XMIN=-999.,XMAX=32000.,YMIN=-999.,YMAX=12000.,UNITS=.0254,
   SCALE=.00004,STRIP=14000.,&END
GO,FT02F001 DD UNIT=2314,VOL=SER=PATO01,DSN=PLTHMTR,DISP=SHR
GO,FT03F001 DD UNIT=2314,VOL=SER=PATO01,DSN=PLTHNCL,DISP=SHR
GO,SYSIN DD *
1111101100

00000  00000  02  999
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