DTIC FILE COPY

(3)

AD-A225 323

Technical Report 1350
June 1990

Super High Frequency (SHF) Link Analysis Model (SLAM) for Nonsatellite Applications

R. R. James
J. W. Rockway

Approved for public release; distribution is unlimited.

NAVAL OCEAN SYSTEMS CENTER
San Diego, California 92152-5000

J. D. FONTANA, CAPT, USN
Commander

R. M. HILLYER
Technical Director

ADMINISTRATIVE INFORMATION

This work was performed by the Electro-optic Systems Branch, Code 844, Naval Ocean Systems Center, for the Office of Chief of Naval Research.

Released by
R. P. Schindler, Head
Electro-optic Systems Branch

Under authority of
M. S. Kvigne, Head
Satellite Communications
Division

JG

SUMMARY

A point-to-point link analysis model has been developed for the Super High Frequency (SHF) Band. It was developed to evaluate ship-to-ship and ship-to-air links. The SHF Link Analysis Model (SLAM) evalutes a communication link and determines system margin. The link margin is determined after a user defines the transmitter subsystem, the receiver subsystem, the specified level of system performance, and the propagation channel. The propagation channel incorporates the Engineer's Refractive Effects Prediction System (EREPS) and includes the effects of the evaporation duct. A rain model developed by NASA is also included in the channel.

SLAM provides a detailed discussion of the link equation, the propagation effects, the rain model, and the antenna characteristics. In addition, a detailed explanation of the operation of the SLAM computer program is given. Two communication links are evaluated and these examples are used to demonstrate the computer program's capabilities.

CONTENTS

1.0 INTRODUCTION 1

2.0 MODELS 3
2.1 LINK EQUATION 3
2.2 PROPAGATION 5
2.2.1 Line of Sight 6
2.2.2 Over the Horizon 7
2.2.2.1 Diffraction 7
2.2.2.2 Ducting 7
2.2.2.3 Scattering 8
2.2.2.4 Fading 9
2.3 RAIN 9
2.4 ANTENNAS 11

3.0 OPERATION 14
3.1 MAIN MENU-[F1] 14
3.2 ANALYSIS OPTIONS 15
3.2.1 LINK DESCRIPTION-[F2] 16
3.2.1.1 Transmitter subsystem 16
3.2.1.1.1 Description. 16
3.2.1.1.2 Parameters. 17
3.2.1.2 Receiver Subsystem 20
3.2.1.2.1 Description. 20
3.2.1.2.2 Parameters. 21
3.2.1.3 System Performance 23
3.2.1.3.1 Description. 23
3.2.1.3.2 Parameters. 23
3.2.1.4 Environment 24
3.2.1.4.1 Description. 24
3.2.1.4.2 Parameters. 31
3.2.2 Margin Calculation - [F3] 33
3.2.3 SPREAD SHEET - [F4] 35
3.2.4 SUPPLEMENTARY CALCULATIONS - [F5] 40
3.2.4.1 Bit Energy-to-Noise Density Requirement - [1] 40
3.2.4.2 Parabolic Circular Antenna - [2] 46
3.3 SUPPORT OPTIONS 47
3.3.1 Load Link Description - [F6] 48
3.3.2 Save Link Description - [F7] 48
3.3.3 Calculator - [F8] 48
3.3.4 Help Screens - [F9] 48
3.3.5 Exit to DOS - [F10] 48

4.0 APPLICATIONS 49
4.1 SHIP-TO-AIR LINK EXAMPLE 49
4.2 SHIP-TO-SHIP LINK EXAMPLE 53

REFERENCES 58

FIGURES

3-1. MAIN MENU screen. 14
3-2. MAIN MENU HELP screen. 15
3-3. LINK DESCRIPTION screen. 16
3-4. LINK DESCRIPTION HELP SCREEN #1. 19
3-5. LINK DESCRIPTION HELP SCREEN #2. 19
3-6. LINK DESCRIPTION HELP SCREEN #3. 22
3-7. LINK DESCRIPTION HELP SCREEN #4. 24
3-8. Map of Marsden squares. 25
3-9. SDS world average screen. 26
3-10. Rain climate regions. 30
3-11. LINK DESCRIPTION HELP SCREEN #5. 32
3-12. LINK DESCRIPTION HELP SCREEN #6. 32
3-13. MARGIN CALCULATION screen. 34
3-14. MARGIN CALCULATION help screen. 34
3-15. SPREAD SHEET INPUT with dependent variables. 35
3-16. SPREAD SHEET INPUT with independent variables. 36
3-17. SPREAD SHEET INPUT example. 37
3-18. SPREAD SHEET output example. 38
3-19. GRAPH OPTIONS screen example. 39
3-20. Example of graph screen. 39
3-21. SUPPLEMENTARY CALCULATIONS help screen. 40
3-22. QPSK modulator. 41
3-23. QPSK demodulator. 42
3-24. QPSK carrier recovery subsystem. 42
3-25. BPSK and QPSK probability of symbol error. 44
3-26. BPSK and QPSK probability of bit error. 45
3-27. Sample BER requirement screen. 46
3-28. Sample parabolic antenna calculation screen. 47
4-1. LINK DESCRIPTION for ship-to-air example. 50
4-2. MARGIN CALCULATION for ship-to-air example. 50
4-3. SPREAD SHEET INPUT for ship-to-air example. 51
4-4. GRAPH OPTIONS for ship-to-air example. 51
4-5. First sheet of spread sheet output. 52
4-6. Second sheet of spread sheet output. 52
4-7. Example of ship-to-air graph screen. 53
4-8. LINK DESCRIPTION for ship-to-ship example. 54
4-9. MARGIN CALCULATION for ship-to-ship example. 54
4-10. SPREAD SHEET INPUT for ship-to-ship example. 55
4-11. GRAPH OPTIONS for ship-to-ship example. 55
4-12. First sheet of spread sheet output. 56
4-13. Second sheet of spread sheet output. 56
4-14. Example of ship-to-ship graph screen. 57

TABLES

1-1. SLAM program files. 2
2-1. Radio horizon for various receiver antenna heights. 7
2-2. Rain attenuation loss rate-dB/nmi. 10
3-1. Duct height occurrence statistics (worldwide). 27
3-2. Duct height occurrence statistics (Pacific). 28
3-3. Duct height occurrence statistics (Atlantic). 29
3-4. Rain Rates - mm/hr. 30

1.0 INTRODUCTION

The SHF (Super High Frequency) Link Analysis Model (SLAM) supports the power budget analysis of SHF ship-to-air, air-to-ship, and ship-to-ship communication links. The power budget or link budget analysis is fundamental to the system design of any communication link. In the conceptual design stage, tentative data entries are used to establish link feasibility. As planning matures, these tentative data become link requirements. Throughout the development process, the link budget is refined. During development, system parameters change and the link budget is used to project system performance. Finally, using the link budget tool for verification testing of the communication link permits validation of the tool. This process validates the projection of system performance.

In its simplest form, SLAM evaluates a communication link and determines the system margin. The link margin is determined after the user defines the transmitter subsystem, the receiver subsystem, the specified level of system performance, and the propagation channel. Margin is the excess over that required to nominally ensure a specified level of system performance. Margin accounts for uncertainties in the system and ensures the availability of the link. SLAM uses the propagation algorithm of the Engineer's Refractive Effects Prediction System (EREPS) (Patterson, et al., 1990). The Surface Duct Summary (SDS) program of the EREPS system is used as a source of information for the environmental data. SDS displays an annual historical summary of the evaporation duct, the surface-based duct, and other meteorological parameters into 10- by 10-degree squares covering the earth's oceans. Ippolito, et al. (1989) is used as a source of data for rain rates. An effort has been initiated to enhance the SDS program for the SLAM application. At this time, only the evaporation duct height is given as an annual probability distribution. In this new effort, other meteorological parameters including rain rate will be available as probability distributions for both day-night and monthly intervals.

Section 2.0 describes the principal algorithms used in the SLAM program. The link equation, the rain attenuation model, and the calculation of the gain and beamwidth for a circular parabolic antenna are described in detail. An overview of the propagation phenomenon is given, and the specific details are referred to the EREPS documentation (Patterson, et al., 1990). Section 3.0 provides a detail description of the various options of SLAM. The program options fall into two principal categories (Analysis Options and Support Options). The Analysis Options allow the user to perform the actual power budget analysis. The Support Options do not directly support the calculations of link budgets. These options allow the user easier interaction with SLAM. Section 4.0 shows examples of typical SLAM applications.

The SLAM program was developed using Microsoft QuickBASIC Version 4.5 and is available as an executable file. The files necessary to run the SLAM program are listed in table 1-1. The executable file is SLAM.EXE. The library of screen files is designated with the .QSL extension. Those screen files requiring user interaction are designated with the .FRM extension. The files used for data graphing are designated with the .GFN extension. The SLAM files should be copied onto a hard disk into a directory named C:\SLAM. There the program is executed with the command SLAM. Files generated by the SLAM program are designated with the .DES extension.

Table 1-1. SLAM program files.

File Name	Size (bytes)
SLAM.EXE	155686
SHELP.QSL	40250
SLAM.QSL	48294
BER.FRM	88
DESCRIB.FRM	1048
GRAPH.FRM	448
LOAD.FRM	88
PARA.FRM	168
SAVE.FRM	128
SPDF.FRM	5048
SPDO.FRM	408
CGA.GFN	4512
EGA.GFN	5280
HELV8.GFN	2976
HELV12.GFN	14304
TROM12.GFN	16416

2.0 MODELS

This section discusses the principal algorithms used in the SLAM program. The link equation is discussed in detail. An overview of the propagation phenomena is presented. For specific algorithms of the link propagation, the reader should refer to the EREPS program (Patterson, et al., 1990). The rain and antenna algorithms are presented in detail.

2.1 LINK EQUATION

Consider a transmitter that has the capability of delivering P_{te} watts of effective power to the transmitting antenna. P_{te} is the transmitter power reduced by the line losses in the transmitting subsystem. In free space at a distance of r from the transmitting antenna, the signal power density for an isotropic radiator (i.e., uniform radiation in all directions) will be

$$P_D = \frac{P_{te}}{4\pi r^2}. \qquad (2-1)$$

For a nonisotropic radiator, the effective antenna gain G_{te} is used to describe the increase of directional power as referenced to the isotropic radiator. G_{te} is the transmitter antenna gain reduced by the radome loss. The signal power density then becomes

$$P_D = \frac{P_{te}G_{te}}{4\pi r^2}. \qquad (2-2)$$

At the receiver an antenna is used to intercept or capture the transmitted power. The net signal power flow into the receiving antenna is

$$S = P_D A_{re} = \frac{P_{te}G_{te}A_{re}}{4\pi r^2} \qquad (2-3)$$

where A_{re} is the effective intercept area of the receiver.

The effective receiver antenna gain is related to the receiver capture area by

$$G_{re} = \frac{4\pi}{\lambda^2}\varepsilon A, \qquad (2-4)$$

where

- A = actual area of the receiving antenna
- ε = antenna efficiency
- A_{re} = εA = effective area of the receiving antenna including radome loss
- λ = wavelength.

Again, G_{re} is the receiver antenna gain reduced by the radome loss. By rearranging the terms in equation (2-4), the effective area of the receiving antenna is

$$A_{re} = \varepsilon A = \frac{\lambda^2}{4\pi} G_{re}. \qquad (2-5)$$

Substituting equation (2-5) into equation (2-3), the received signal power becomes

$$S = \frac{P_{te} G_{te} G_{re}}{(4\pi r/\lambda)^2}. \qquad (2-6)$$

To express equation (2-6) as a function of frequency, the wavelength is converted to frequency using the formula, $\lambda f = c$, where c equals the speed of light. Thus, the received signal power is

$$S = \frac{P_{te} G_{te} G_{re}}{(4\pi r f/c)^2} = P_{te} G_{te} G_{re} \tau_{fs}. \qquad (2-7)$$

The free-space path loss τ_{fs} is

$$\tau_{fs} = \frac{1}{(4\pi r f/c)^2}. \qquad (2-8)$$

An additional propagation factor τ_{pf} is required to account for effects on propagation such as sea-surface reflection, atmospheric refraction, scattering from inhomogeneities in the atmosphere, and diffraction from the earth's surface. The propagation factor τ_{pf} is defined as the ratio of the actual signal at a point in space to the signal that would exist at the same range under free-space conditions. Finally the effect of rain can be included with the factor τ_r. The modification of equation (2-7) gives

$$S = P_{te} G_{te} G_{re} \tau_{fs} \tau_{pf} \tau_r. \qquad (2-9)$$

The noise energy density N_d is given by

$$N_d = kT \qquad (2-10)$$

where

k - Boltzmann's constant,
T - noise temperature (°K).

The relationship of the receiver noise temperature to the receiver noise factor is discussed in section 3.2.1.2.1.

The resulting received signal power-to-noise energy density ratio is

$$\frac{S}{N_d} = \frac{P_{te}G_{te}G_{re}\tau_{fs}\tau_{pf}\tau_r}{kT}. \qquad (2-11)$$

The signal power S can be related to the signal energy per bit E_b by

$$S = E_b D_r \qquad (2-12)$$

where D_r is the data rate in bits per second. Using equation (2-12), equation (2-11) can be written

$$\frac{E_b}{N_d} = \frac{P_{te}G_{te}G_{re}\tau_{fs}\tau_{pf}\tau_r}{kTD_r}. \qquad (2-13)$$

The link equation, equation (2-13), can expressed in decibels as

$$\left(\frac{E_b}{N_d}\right)_{dB} = P_{TE} + G_{TE} + G_{RE} - L_{FS} - L_{PF} - L_R - N_D - D_R - M_{dB} \qquad (2-14)$$

where P_{TE}, G_{TE}, G_{RE} and D_R are the dB equivalents for P_{te}, G_{te}, G_{re}, and D_r respectively. N_D is the dB equivalent of kT. M_{dB} is introduced as margin and accounts for miscellaneous loss factors. The free-space loss factor is

$$L_{FS} = 10\log\left(\frac{1}{\tau_{fs}}\right) \qquad (2-15)$$

or

$$L_{FS} = 32.45 + 20\log(r) + 20\log(f) \qquad (2-16)$$

where r is in kilometers and f is in megahertz (MHz). The remaining loss factors are

$$L_{PF} = 10\log\left(\frac{1}{\tau_{pf}}\right) \qquad (2-17)$$

and

$$L_R = 10\log\left(\frac{1}{\tau_r}\right). \qquad (2-18)$$

2.2 PROPAGATION

The EREPS program was developed by the Naval Ocean Systems Center as a collection of individual programs for evaluating the effect of the atmosphere on propagation (Patterson, et al., 1990). EREPS is a follow-on to the Integrated Refractive Effects Prediction System (IREPS) described by Patterson, et al. (1987). EREPS consists of three individual programs: PROPR, SDS, and RAYS. PROPR calculates the path loss for a variety of environmental conditions. SDS displays an annual historical summary of the evaporation duct, surface-based duct, and other meteorological parameters for many 10- by 10-degree squares of the earth's surface. SDS is used as the primary source of environmental data for the PROPR program. RAYS is a ray trace program for displaying trajectories of a series of rays for any user-supplied refractive index profile. The EREPS model was incorporated into the SLAM model and serves as the principal means of evaluating propagation variables L_{FS} and L_{PF} with exception of the atmospheric attenuation model. SLAM uses the attenuation model described by Ippolito, et al. (1986). For a path below the scale height of the atmosphere, the Ippolito attenuation model compares favorably with EREPS model. The following sections serve only to explain the propagation phenomena that are being modeled.

2.2.1 Line of Sight

At radio frequencies above 30 MHz, the ionosphere is not able to refract energy and the ground wave propagation attenuates to a negligible amplitude in a very short distance. Propagation is achieved by means of the space wave traveling between the transmitting and receiving antennas. This space wave has two components. The first component is the signal traveling directly from the transmitting antenna to the receiving antenna. The second component reaches the receiving antenna after reflecting from the surface. As these individual signals travel through space, the signals are attenuated by spreading. This spreading is characterized by an inverse square falloff with range. Within the horizon, coherent interference occurs between the direct and reflected signals. In a marine environment, these multipath effects are the result of interference of the sea-reflected path with the direct path. The effects of the rough sea surface on reducing the reflection coefficient is important in determining the total amount of interference between the two paths.

As the distance between the transmitting and receiving antennas becomes greater, the curvature of the earth must be considered. Because of the earth's curvature, the effective antenna height is reduced below the actual antenna height. In addition, the curvature of the earth causes the ground-reflected signal to be a diverging wave rather than a plane wave. As a result, the reflected signal at the receiving antenna is weaker than if the reflection were from a flat surface.

The radio horizon R_h in nautical miles is related to the heights of the transmitting and receiving antennas by the following equation

$$R_h = 1.065(\sqrt{r_k H_t} + \sqrt{r_k H_r}) \qquad (2-19)$$

where r_k is the effective earth radius factor. A nominal value for r_k is 4/3. H_t is the height of the transmitting antenna in feet, and H_r is the height of the receiving antenna in feet. The radio horizon is 24.6 nautical miles for transmitting and receiving antennas at 100 feet. The radio horizon for a transmitting antenna at 100 feet, and the receiving antenna at various ascending heights is given in table 2-1.

Table 2-1. Radio horizon for various receiver antenna heights (transmit antenna at 100 feet).

Rx Antenna Height (feet)	Radio Horizon (nmi)
5,000	99
10,000	135
15,000	163
20,000	186
25,000	206
30,000	225
35,000	242
40,000	258
45,000	273
50,000	287
55,000	301
60,000	314
65,000	326
70,000	338

2.2.2 Over the Horizon

When the receiving antenna is below the radio horizon, neither the direct signal nor the ground reflected signal are received. The receiving antenna is considered to be in a shadow zone. Several mechanisms exist whereby some of the transmitter energy can still reach the receiver.

2.2.2.1 Diffraction

The signal can diffract into the shadow zone. The strength of the diffracted field in the shadow zone depends on the roughness of the earth's surface.

2.2.2.2 Ducting

The atmosphere through which the signal energy travels is able to influence the propagation to a significant degree. The presence of gas molecules, especially water vapor, causes the air of the troposphere to have a dielectric constant greater than one. The refractive index of air will vary with height and will in general decrease with increasing height. In accordance with Snell's Law, energy traveling in the atmosphere will bend away from regions of low refractive index and toward regions of high refractive index. Thus, the electromagnetic energy will be bent downwards and be ducted to receivers at points beyond line of sight.

In a marine environment there are three distinct types of ducts:

- Elevated ducts
- Surface-based ducts
- Evaporation ducts.

An elevated duct is created when a trapping layer is sufficiently high that no rays from a source at the surface will be trapped (Hitney, et al., 1985). Elevated ducts are most important when addressing airborne systems. A surface-based duct is created by trapping layers that occur up to several hundred meters in height and extend to the surface. These ducts occur with annual frequencies up to 50% in areas such as the eastern Mediterranean and northern Indian Ocean. These ducts are responsible for most reports of extremely long over-the-horizon radar detection and communication ranges. However, such ducts occur annually only 8% of the time worldwide with only 1% occurrence in the North Atlantic. The third type of duct is the evaporation duct. Evaporation ducts are created by the extremely rapid decrease of moisture immediately adjacent to the sea surface. The strength of the evaporation duct is determined by the parameter "duct height," which is a function of sea temperature, air temperature, relative humidity, and wind speed. The height of an evaporation duct varies between 0 and 40 meters. The worldwide average is 13 meters. The evaporation duct is a "leaky" wave guide. Antennas both above and below the evaporation duct height will be affected.

2.2.2.3 Scattering

When no ducting occurs, the strength of a microwave signal may be greater than would be expected on the basis of diffraction. Because of turbulence and other more gradual changes in the troposphere, small irregularities occur in the refractive index (ITT, 1969; Panter, 1972). The signal energy passing through the troposphere will be scattered into the shadow zone. Propagation from a transmitter to a receiver can be achieved using these irregularities in the troposphere. Long-distance communication links of several hundred miles can be established using large power and high-gain antennas.

A scattered signal at a particular instant in time appears to be the result of a number of individual signals arriving with random phase differences. Consider the transmitter and receiver antenna beams intersecting on a common volume in the troposphere. Different parts of the scatter volume contribute to the scattered wave. The received signal consists of many components that have traveled slightly different paths. Thus, the signal is always varying. Over a period of a few minutes, this random variation in signal appears to be Rayleigh distributed. For longer periods, the distribution is log normal.

Very narrow beamwidths, diversity techniques (frequency and spatial), and careful selection of modulation techniques are used to overcome the effects of short-term fading (Panter, 1972). The long-term signal variations are on the average of 10 dB. The summer signal levels average 10 dB higher than in the winter. The atmosphere is well mixed during the afternoon. The signal fade is 5 dB lower than in the morning or evening. Finally, the longer paths exhibit less variability.

Several different approaches exist for the estimation of troposcatter loss. There is no exact method. The loss models are usually estimates of empirical data. EREPS uses a combination of methods discussed in Panter (1972).

2.2.2.4 Fading

As a transmission medium for the signal energy, the atmosphere is inhomogeneous. Variations in the index of refraction are caused by spatial variations in temperature, pressure, humidity, and turbulence. Because of this differential refraction, rays will travel over slightly different path lengths between the transmitter and the receiver. At the receiver, the rays may be out of phase with each other. Since the received signal is the vector sum of the rays, the rays can interfere with each other and reduce the signal below the median value. The resultant multipath propagation can produce a loss that varies with frequency within the radio channel. This effect is often called selective fading. The SLAM program with its EREPS algorithm does not consider fading. The propagation loss calculation should be considered to be a nominal value.

2.3 RAIN

In addition to clear air atmospheric absorption, rain and fog will also affect absorption. Ice or snow do not produce significant attenuation. Only regions with liquid water precipitation particles are of interest in the estimation of attenuation. Rain attenuation at SHF frequencies can be high. The specific attenuation in decibels per kilometer, α, is the quantity of concern for calculation of rain attenuation.

SLAM uses an empirical algorithm (Olsen, et al., 1978) based on the approximate relation between α and the rain rate RR,

$$\alpha = a(f) RR^{b(f)} \qquad (2-20)$$

where $a(f)$ and $b(f)$ are functions of frequency and rain temperature. For most applications, 0 degrees centigrade should be the most appropriate. The parameter $a(f)$ at 0 degrees centigrade is given by

$$a(f) = G_a f^{E_a} \qquad (2-21)$$

where

$G_a = 6.39x10^{-5}$	$E_a = 2.03$	*for* $f < 2.9GHz$
$G_a = 4.21x10^{-5}$	$E_a = 2.42$	*for* $2.9GHz \le f < 54GHz$
$G_a = 4.09x10^{-2}$	$E_a = 0.699$	*for* $54GHz \le f < 180GHz$
$G_a = 3.38$	$E_a = -0.151$	*for* $f \ge 180GHz.$

The parameter $b(f)$ at 0 degrees centigrade is given by

$$b = G_b f^{E_b} \qquad (2-22)$$

where

$G_b = 0.851 \qquad E_b = 0.158 \qquad for \quad f < 8.5GHz$

$G_b = 1.41 \qquad E_b = -0.0779 \qquad for \quad 8.5GHz \leq f < 25GHz$

$G_b = 2.63 \qquad E_b = -0.272 \qquad for \quad 25GHz \leq f < 164GHz$

$G_a = 0.616 \qquad E_b = 0.0126 \qquad for \quad f \geq 164GHz.$

This empirical procedure is based on the Laws and Parsons (1943) drop size distribution. The Laws and Parsons distribution is probably the most widely tested distribution. It is a reasonable choice for a mean drop size spectrum in continental temperate rainfall (Laws and Parsons, 1943; Medhurst, 1965; Ippolito, et al., 1989). In the frequency range between 7 and 32 GHz, the parameter $a(f)$ and to some extent the parameter $b(f)$ are least sensitive to drop size distribution.

The loss in decibels per nautical mile for different rain rates is given in table 2-2. The effective attenuation losses are for 4.5, 9, and 18 GHz. The rain rates are in millimeters per hour and are characterized from drizzle to heavy rain.

Table 2-2. Rain attenuation loss rate-dB/nmi.

Rate (mm/hr)	Rain Type	4.5 GHz	9 GHz	18 GHz
0.25	Drizzle	0.0002	0.0009	0.0052
1.15	Light	0.0010	0.0055	0.0290
12.50	Medium Heavy	0.0130	0.0930	0.4300
25.00	Heavy	0.0270	0.2100	0.9300

For total loss in an SHF link, the rain rate along the path would be multiplied by the length of the path. However, the spatial distribution of rain is the most difficult parameter of the rain attenuation model to characterize. Generally, precipitation systems are combinations of both stratiform and convective rain structures. Radar measurements indicate that most precipitation is characterized by large areas of low rates with a number of smaller regions of high rain rates (Crane, 1977). Because rain rate statistics are usually available for point rain rates (Ippolito, et al. 1989), an "effective" spatial rain distribution model (or rain profile) must be developed that will relate the rainfall along a path to the rainfall at a point. This rain profile is not applicable to single event analysis but is useful for determining the long-term performance. Long-term performance is the objective in the link budget analyses.

The SLAM rain profile uses the rain profile model developed by Stutzman and Dishman (1982) and includes both the horizontal and vertical spatial variations of rain. Stutzman and Dishman assume a uniform rain structure from the ground to an effective rain height H_e. Radar observations show the vertical structure of precipitation is characterized by two different regions. The upper region consists of a mixture of ice and snow. This region does not contribute significantly to attenuation at frequencies below 60 GHz. The lower region is mostly rain and is the primary source of attenuation. The transition height between these two regions is defined as the effective rain height. Attenuation above the effective rain height is ignored. The effective rain height is given by

$$H_e = H_i \quad for \quad RR \leq 10 \quad mm/hr, \tag{2-23}$$

and

$$H_e = H_i + \log\left(\frac{RR}{10}\right) \quad for \quad RR > 10 \quad mm/hr. \tag{2-24}$$

H_i is the 0 degree Centigrade isotherm height in kilometers and is a function of latitude. However, for this analysis, a constant 4-kilometer height is assumed.

Convective cells imbedded in stratiform rain render the distribution of rain nonuniform in the horizontal direction. Data suggest that point- and path-averaged rain rates are the same up to rates of 10 mm/hr. For rain rates in excess of 10 mm/hr, the path-averaged rain rate decreases as the point rain rates increase and as path lengths increase. Stutzman and Dishman (1982) proposed a simple model for A_T, the total attenuation in decibels, due to a point rainfall rate RR. For rain rates less than or equal to 10 mm/hr, the total attenuation is

$$A_T = a(f)RR^{b(f)}R. \tag{2-25}$$

For rain rates greater than 10 mm/hr, the total attenuation in dB is

$$A_T = a(f)RR^{b(f)}\frac{1-\exp[-\gamma b(f)\ln(RR/10)R\cos\varepsilon]}{\gamma b(f)\ln(RR/10)\cos\varepsilon} \tag{2-26}$$

where R is the path length in kilometers, and ε is the elevation angle of the path. γ is a parameter controlling the rate of decay of the profile. A value of $\gamma = 1/22$ gives a best fit to the data. The path length is the smaller of the range of the two antennas or the range from the lowest antenna to the rain effective height.

In SLAM, to ensure some continuity between equations (2-25) and (2-26) for long ranges, equation (2-26) is used only for a horizontal distance of 22 kilometers. After 22 kilometers, the rain rate is assumed to be 10 mm/hr. These assumptions imply only one large cell within the path. For rain rates below 10 mm/hr, the rain is considered constant along the entire path as implied in equation (2-25).

2.4 ANTENNAS

The normalized antenna pattern factor $f(\mu)$ will affect the calculation of the propagation factor given by equation (2-17) of section 2.1. The primary effect occurs in the line-of-sight region. $f(\mu)$ is a function of the antenna pattern type, beamwidth, and pointing angle. Five different antenna types are used in the EREPS algorithm. These antenna types are omnidirectional, $\sin(x)/x$, cosecant-squared, generic height-finder, and the Gaussian beam. The omnidirectional antenna is the simplest case. This antenna has unity gain in all directions. Hence,

$$f(\mu) = 1 \tag{2-27}$$

for all angles μ.

The second case is the $\sin(x)/x$ antenna type. The radiation pattern of this antenna is symmetrical about the elevation angle of the antenna. The pattern factor is given by

$$f(\mu) = \sin(x)/x \tag{2-28}$$

where

$$x = c\sin(\mu - \mu_0) \tag{2-29}$$

and μ_0 is the elevation angle. The value of c is chosen so that $f(\mu) = 0.7071$ when $\mu = \mu_0 \pm BW/2$ and BW is the beamwidth. This normalization ensures that the antenna half-power points occur at $\mu = \mu_0 \pm BW/2$. Thus,

$$c = 1.39157/\sin(BW/2). \tag{2-30}$$

The pattern factor calculations are limited to those angles within the main beam of the antenna down to the -30 dB level. Angles greater than

$$\mu_{max} = \mu_0 \pm \tan^{-1}(A/\sqrt{1+A}) \tag{2-31}$$

where $A = \pi/x$ are limited to a pattern factor of 0.03. This is equivalent to an antenna having its first sidelobes at -30 dB.

The generic height-finder antenna is a special case of the $\sin(x)/x$antenna. Height-finder antennas typically sweep the beam upward in elevation. This is simulated by substituting the direct ray angle, μ, for the elevation angle μ_0. Then $f(\mu) = 1$ for all values of the direct ray set. As the antenna beam is swept upward, the pattern factor for the reflected ray gradually tapers to the -30 dB level.

A fourth antenna type is the cosecant-squared antenna. This antenna pattern is not symmetrical about the elevation angle and is calculated as

$$f(\mu) = 1 \qquad for \quad \mu_0 \le \mu \le \mu_0 + BW, \tag{2-32a}$$

and

$$f(\mu) = \sin(BW)/\sin(\mu) \qquad for \quad \mu > \mu_0 + BW. \tag{2-32b}$$

For $f(\mu) \ge 0.03$,

$$f(\mu) = [1 - (\mu_0 - \mu)/BW] \qquad for \quad \mu < \mu_0. \tag{2-32c}$$

This antenna pattern is different from the $\sin(x)/x$ beam antenna since the beamwidth of this antenna does not coincide with the -3 dB, or half-power points of the antenna.

The fifth and final antenna option is the Gaussian beam antenna. The pattern factor for this antenna is symmetrical about the pointing angle. For $f(\mu) \geq 0.03$

$$f(\mu) = \exp[-w^2(P-P_0)^2/4] \quad for \quad -\mu_{max} \leq \mu \leq \mu_{max} \tag{2-33}$$

where

$$P = \sin(\mu). \tag{2-34}$$

$$P_0 = \sin(\mu_0), \tag{2-35}$$

and

$$W = \sqrt{2\ln(2)}/\sin(BW/2). \tag{2-36}$$

The normalization factor W is chosen such that $f(\mu) = 0.7071$ when $\mu = \mu_0 \pm BW/2$. The maximum angle is

$$A = 3.18\sin(BW/2). \tag{2-37}$$

3.0 OPERATION

The SHF Link Analysis Model (SLAM) begins with a title page. The title page shows the version number and date of the version. The title page is immediately followed by the MAIN MENU.

3.1 MAIN MENU-[F1]

The screen for the MAIN MENU is shown in figure 3-1. Each of the Options can be accessed by pressing the indicated FUNCTION KEY. The FUNCTION KEY [F1] will always return the program to the MAIN MENU. There are two program options, ANALYSIS OPTIONS and SUPPORT OPTIONS, and each is described in the following sections.

The help screen for the MAIN MENU is shown in figure 3-2. This help screen indicates a point of contact for the indicated version of the SLAM program and includes a brief description of what the program does.

```
                              MAIN MENU

                        [F1]  -  MAIN MENU

                         ANALYSIS OPTIONS

                 [F2]  -  LINK DESCRIPTION

                 [F3]  -  MARGIN CALCULATION

                 [F4]  -  SPREAD SHEET

                 [F5]  -  SUPPLEMENTARY CALCULATIONS

                          SUPPORT OPTIONS

   [F6]  -  Load Link Description        [F7]  -  Save Link Description

   [F8]  -  Calculator                   [F9]  -  Help Screens

                    [F10]  -  Exit to DOS

              Press FUNCTION KEY for Desired Option
```

Figure 3-1. MAIN MENU screen.

```
MAIN MENU HELP SCREEN

              SHF Link Analysis Model (SLAM)
                 Version 2.0    June 1990

                          Code 80
                 Naval Ocean Systems Center
                 San Diego, California 92152

       Contacts: J. W. Rockway, (619) 553 - 5688
                 R. R. James,   (619) 553 - 6131

DESCRIPTION:  SLAM supports the power budget analysis of SHF
              ship-to-ship, air-to-ship, and ship-to-ship
              communication links.  The model was developed
              using the EREPS program of NOSC Technical
              Document 1342 of July 1988.

Each of the Options can be accessed by pressing the indicated
FUNCTION KEY.  The FUNCTION KEY [F1] will always return the
program to the MAIN MENU.

                    Hit [ESC] key to Exit.
```

Figure 3-2. MAIN MENU HELP screen.

3.2 ANALYSIS OPTIONS

The Analysis Options section allows the user to perform the actual power budget analyses. The LINK DESCRIPTION prompts the user to specify the baseline SHF communication link in terms of the transmitter subsystem, the receiver subsystem, the level of system performance, and environment characterization (channel description). The MARGIN CALCULATION calculates the link margin for the baseline link specified in the LINK DESCRIPTION. The SPREAD SHEET function allows the user to perform parametric analyses using the parameters of the baseline link description. The SUPPLEMENTARY CALCULATIONS give the user supporting analytical capabilities. The user can calculate the bit energy-to-noise density requirement in decibels for ideal biphase shift keying (BPSK) or quaternary phase shift keying (QPSK) assuming white Gaussian noise and a given bit error rate (BER). In addition, the user can calculate the gain and beamwidth of a circular parabolic antenna for a given diameter and antenna efficiency.

3.2.1 LINK DESCRIPTION-[F2]

The screen for LINK DESCRIPTION is shown in figure 3-3. The user is prompted to describe the transmitter subsystem, the receiver subsystem, the level of system performance, and the environmental characteristics. Each of the descriptive parameters can be changed or the present baseline values accepted. The [ENTER] key will cause the parameters to be accessed going down the LINK DESCRIPTION list. A [DOWN] arrow will accomplish the same action. An [UP] arrow will cause the parameters to be accessed going up the LINK DESCRIPTION list. When the bottom of the list is reached, an action down will cause the parameter at the top of the list to be accessed. An [UP] arrow at the top of the list will cause the parameter at the bottom of the list to be accessed.

```
LINK DESCRIPTION HELP SCREEN #5

ENVIRONMENT:

Evaporation duct height. Caused by the extremely rapid decrease of
moisture immediately adjacent to the sea surface and characterized by
the duct height in meters. Results are unreliable for

          S-band  (3 GHz)  heights greater than 30 meters
          C-band  (5 GHz)  heights greater than 22 meters
          X-Band (10 GHz)  heights greater than 14 meters
          K-Band (18 GHz)  heights greater than 10 meters

Surface-based duct height. Created by trapping layers which extend
from the surface and up to several hundred meters in height. These
ducts occur annually only 8% of the time worldwide.

Effective earth radius factor. Ratio of the radius of the earth modified
so that the relative curvature between the ray and the earth remains
unchanged and the true earth radius. Variations only affect the position
of nulls in the optical region. As a general rule, the effective earth
radius factor should be kept at a value near 1.33. Limits are 0 to 5.

Press [SPACE] bar to display next Help Screen. Hit [ESC] key to Exit.
```

Figure 3-3. LINK DESCRIPTION screen.

3.2.1.1 Transmitter subsystem

3.2.1.1.1 Description. In general the microwave amplifier, or transmitter, contributes more to the overall performance and system gain than most of the other components comprising the transmission system. The microwave power amplifier must deliver a signal of sufficient power to produce an easily detectable output at the end of the transmission channel. This signal should be produced with maximum efficiency, maximum reliability, and minimum distortion.

The characteristics of the microwave power amplifier are identified by

- the output power level and flatness
- the gain
- the operating bandwidth
- the overall efficiency
- the harmonic and intermodulation distortion
- the AM to PM conversion (phase shift of amplified signal)
- the noise.

To maximize transmission power and yet keep the system complexity at a minimum (i.e., avoid the addition of a water cooling system), a nominal 1-kilowatt microwave transmitter is used for maximum power. Because the system is required to operate at high data rates (using a bandwidth of up to 5% of the carrier frequency), the microwave transmitter must be able to operate over large bandwidth excursions. As long as the transmitter can be operated in the linear mode, the harmonic and intermodulation distortion can be controlled. However, the efficiency of the microwave amplifier is better (that is, a higher transmitted power is obtained) in the nonlinear region at close to saturation. Unfortunately, the nonlinear amplifier causes spectral spreading and increases the AM to PM conversion (increased phase fluctuations) which degrades the system performance.

3.2.1.1.2 Parameters. The transmitter subsystem is described in terms of its transmitter or amplifier power, line loss, antenna gain, radome loss, antenna height, frequency, polarization, antenna type, beamwidth, and elevation. Each of these parameters is discussed below.

Power (watts) -- The total transmitter power output in watts. An important constraint on higher transmitter power is higher implementation cost. As an example, above 1 kilowatt a microwave transmitter amplifier may have to be water-cooled.

Line loss (dB) -- Any losses occurring between the transmitter and the radiating antenna. Typical loss components include transmission filters and the transmission line. Minimization of this loss is important both in terms of link availability and heat dissipation.

Antenna gain (dB) -- The ratio of the power radiated in a given direction to the power radiated in the same direction by an isotropic radiator. Calculation of antenna gains are discussed in section 3.2.4. If this parameter is set to a negative value, the value entered will assume the diameter of a circular parabolic antenna in feet. The gain of a circular parabolic antenna with the diameter specified is then used in the link budget calculation.

Radome loss (dB) -- A radome is a dielectric cover, which may be required to protect the transmitting antenna from weather. This parameter in decibels accounts for any losses attributable to the radome. These losses may occur because the radome may either reflect or absorb the radiating energy.

Antenna height (ft) -- This parameter is the height of the transmitting antenna above sea level in feet. Antenna heights are acceptable from 3 to 70,000 feet. At least one antenna must be lower than 300 feet. If the receiving antenna is more than 300 feet, the transmitting antenna must be below 300 feet. The recommended height is 100 feet to assure a ship-to-ship line-of-sight (LOS) range (Goodbody, et al., 1974). If link calculations are being performed for beyond LOS, the limits on the heights are approximately 30,000 feet.

Frequency (GHz) -- This parameter is the system operating frequency in gigahertz. The limits of the program are 100 MHz to 20 GHz. These limits are set by the loss propagation calculation performed by the EREPS portion of the SLAM program.

Polarization -- Polarization identifies the position of the electric field. An electromagnetic wave is linearly polarized when the electric field lies in the plane containing the direction of propagation. For horizontal polarization, the electric field lines are in a plane parallel to the earth's surface. For vertical polarization, the electric field is in a plane perpendicular to the earth's surface. For circular polarization, the electric field vector describes a circle in a plane perpendicular to the direction of propagation, making one complete revolution during one period of the wave. Horizontal, vertical, and circular polarization are the only options for this parameter.

Antenna type -- There are five different antenna types that may be selected for this parameter. The antenna pattern is important to the calculation of the propagation loss. The OMNI antenna has a gain of unity in all directions. The radiation pattern of SIN(X)/X is symmetric about the elevation angle of the antenna. The generic HEIGHT-FINDER antenna is a special case of the SIN(X)/X antenna. HEIGHT-FINDER antennas typically sweep the beam upward in elevation. The COSECANT-SQUARED antenna is not symmetric about the elevation angle. The *GAUSSIAN BEAM antenna is a Gaussian* function, which is symmetric about the elevation angle. With OMNI there is no pointing loss due to misalignment of the antennas. All of these antenna types are discussed in detail in section 2.5.

Beamwidth (deg) -- This parameter is the angle in degrees between the 3-dB points in the main beam. The importance of this angle is discussed in more detail in section 2.5. Program limits are again set by the EREPS propagation algorithm and are 0.5 to 45 degrees.

Elevation -- This parameter is the pointing angle for the antenna. The elevation angle is 0 degrees at horizontal. The importance of this angle is discussed in more detail in section 2.5. The program limits are set by the EREPS propagation algorithm and are -10 to 10 degrees.

The help screens for the transmitter subsystem are displayed in figures 3-4 and 3-5.

```
LINK DESCRIPTION HELP SCREEN #1

TRANSMITTER SUBSYSTEM:
Radiated power.  Total power out of the transmitter in watts.

Line loss.  Losses between transmitter and transmitting antenna in dB.

Antenna gain.  The ratio of the power radiated in a given direction to the
power radiated in the same direction by an isotropic radiator.  If a
negative value is entered, the gain of a parabolic antenna with a diameter
of the value in feet (efficiency = 50%) is used in the link budget.

Radome loss.  Loss due to antenna radome.

Antenna height.  Height of the antenna above sea level in feet.  Antenna
heights are acceptable from 3 to 70,000 feet.  If the receiving antenna
is greater than 300 feet, then this antenna must be less than 300 feet.

Frequency.  System operating frequency in GHz.  Limits are 0.1 to 20 GHz.

Polarization.  Position of the electric field.  An EM wave is linearly
polarized when the electric field lies in the plane containing the
direction of propagation.  For horizontal polarization the electric field
lies in a plane parallel to the earth's surface.  For vertical polarization
  Press [SPACE] bar to display next Help Screen.  Hit [ESC] key to Exit.
```

Figure 3-4. LINK DESCRIPTION HELP SCREEN #1.

```
LINK DESCRIPTION HELP SCREEN #2
the electric field is in a plane perpendicular to the earth's surface.  For
circular polarization the electric field vector describes a circle in a
plane perpendicular to the direction of propagation, making one complete
revolution during one period of the wave.

Antenna type.  Five different antenna types are options.  The antenna
pattern is important to the calculation of the propagation loss.  The OMNI
antenna has a gain of unity in all directions.  The radiation pattern of
the SIN(X)/X is symmetric about the elevation angle of the antenna.  The
generic HEIGHT-FINDER antenna is a special case of the SIN(X)/X antenna.
HEIGHT-FINDER antennas typically sweep the beam upward in elevation.  The
COSECANT-SQUARED antenna is not symmetric about the elevation angle.  The
GAUSSIAN beam antenna is a Gaussian function which is symmetric about the
elevation angle.  With OMNI there is no propagation loss due to antenna.

Beamwidth.  Angle in degrees between the 3-dB points in the main beam.
Program limits are 0.5 to 45 degrees.

Elevation.  Pointing angle for antenna.  Elevation angle is 0 degrees at
horizontal.  Program limits are -10 to 10 degrees


  Press [SPACE] bar to display next Help Screen.  Hit [ESC] key to Exit.
```

Figure 3-5. LINK DESCRIPTION HELP SCREEN #2.

3.2.1.2 Receiver Subsystem

3.2.1.2.1 Description. At the reception end of the communication link, the small-signal microwave amplifier must increase the power of a weak signal sufficiently for added processing. The amplifier must add as little noise as possible to the signal. Efficiency is usually of secondary concern. The dominate concern is reliability and linearity.

Small-signal amplifiers are evaluated in terms of the following characteristics:

- the gain
- the operating bandwidth
- the noise level specified by the noise figure (NF).

The third specification is of particular importance. The NF, or noise temperature (T_e), describes the deterioration of the signal-to-noise ratio (SNR) due to the presence of a noisy amplifier. The noise figure is defined as

$$NF(dB) \quad = \quad 10\log\left[\frac{P_{si}/P_{ni}}{P_{so}/P_{no}}\right] \tag{3-1}$$

where

P_{si} = available input signal power (watts),

P_{so} = available output signal power (watts),

P_{ni} = available input noise power (watts),

P_{no} = available output noise power (watts).

The output noise power is composed of both the amplified input noise, and the inherent amplifier noise P_{inh}. P_{inh} originates in the active and passive elements of the receiver. Mathematically, the output noise power can be expressed as

$$P_{no} \quad = \quad GP_{ni} + P_{inh} \tag{3-2}$$

where

$$G \quad = \quad \frac{P_{so}}{P_{si}}. \tag{3-3}$$

After combining equations (3-1), (3-2), and (3-3), the noise figure can be written

$$NF(dB) \quad = \quad 10\log\left[\frac{P_{no}}{GP_{ni}}\right] \quad = \quad 10\log\left[1+\frac{P_{inh}}{GP_{ni}}\right]. \tag{3-4}$$

The inherent noise of an amplifier is also be expressed in terms of an equivalent T_e which can be represented by

$$P_{inh} \quad = \quad GP_n \tag{3-5}$$

where P_n is the thermal noise power produced by the matched input load at the T_e such that

$$P_n = kT_eB \tag{3-6}$$

where

k = Boltzmann's constant ($1.38 \cdot 10^{-23}$ joules/°Kelvin),
T_e = equivalent noise temperature (°K),
B = amplifier bandwidth (Hz).

Assuming the input noise power P_{ni} of the amplifier is produced by the same matched load at an ambient temperature of T_{amb}, the input noise power is

$$P_{ni} = kT_{amb}B. \tag{3-7}$$

The noise figure now becomes

$$NF(dB) = 10\log\left[1 + \frac{T_e}{T_{amb}}\right]. \tag{3-8}$$

Equation (3-8) can also be written as

$$T_e = T_{amb}(10^{NF/10} - 1). \tag{3-9}$$

In communication systems having low-noise figure requirements, low-noise GaAs field effect transistors (FET) have sufficient capabilities to satisfy the requirements in digital communication systems. Typical noise figures at SHF operating frequencies are 5 db or less (Castro and Major, 1988). According to equation (3-9), a noise figure of 5 dB corresponds to an equivalent noise temperature of 627 °K.

The system thermal noise density N_d at the receiver is

$$N_d = kT_{sys} = k(T_{ant} + T_e) \tag{3-10}$$

where T_{ant} is the antenna noise temperature at the receiver. The antenna noise temperature includes the external noise temperature and the noise temperature due to ohmic losses between the antenna and the receiver.

3.2.1.2.2 Parameters. The receiver subsystem is described in terms of the noise figure, antenna gain, line loss, radome loss, and antenna height. Each of these parameters is discussed in the following.

Noise figure (dB) -- The noise figure describes the deterioration of the SNR due to the presence of a noisy amplifier. Typical noise figures at SHF operating frequencies are 5 dB or less.

Line loss (dB) -- Any losses that occur between the receiving antenna and the receiver. A typical loss component is the transmission line to the receiver.

Antenna gain (dB) -- The ratio of the power received in a given direction to the power received in the same direction by an isotropic receiver. Calculation of antenna gains are discussed in section 3.2.4. If this parameter is set to a negative value, the value entered assumes the diameter of a circular parabolic antenna in feet. The gain of a circular parabolic antenna with the diameter specified is used in the link budget calculation.

Radome loss (dB) -- A radome is a dielectric cover which may be required to protect the receiving antenna from the weather. This parameter in decibels accounts for any losses attributable to the radome. These losses may occur because the radome may either reflect or absorb the received energy.

Antenna height (ft) -- This parameter is the height of the receiving antenna above sea level in feet. Antenna heights are acceptable from 3 to 70,000 feet. At least one antenna must be lower than 300 feet. If the transmitting antenna is more than 300 feet, the receiving antenna must be below 300 feet. The recommended height is 100 feet to assure ship-to-ship LOS range. If link calculations are being performed for beyond line-of-sight (BLOS) ranges, the limits on the heights are 30,000 feet.

The help screen for the receiver subsystem is displayed in figure 3-6.

```
LINK DESCRIPTION HELP SCREEN #3

RECEIVER SUBSYSTEM:

Noise figure.  The noise figure describes the deterioration of the signal-
to-noise ratio due to the presence of an amplifier.  Typical noise figures
at SHF operating frequencies are 5 dB or less.

Line loss.  Losses between receiving antenna and receiver in dB.

Antenna gain.  The ratio of the power received in a given direction to the
power received in the same direction by an isotropic receiver.  If a
negative value is entered, the gain of a parabolic antenna with a diameter
of the value in feet (efficiency = 50%) is used in the link budget.

Radome loss. Loss due to receiving antenna radome in dB.

Antenna height.  Height of the antenna above sea level in feet.  Antenna
heights are acceptable from 3 to 70,000 feet.  If the transmitting antenna
is greater than 300 feet, this antenna must be less than 300 feet.



Press [SPACE] bar to display next Help Screen. Hit [ESC] key to Exit.
```

Figure 3-6. LINK DESCRIPTION HELP SCREEN #3.

3.2.1.3 System Performance

3.2.1.3.1 Description. In SLAM the performance of the communication system is described in terms of the capacity, quality, and connectivity (Goodbody, et al., 1976). For a given communications link, the volume of data that can be transferred per unit time is capacity. In SLAM, the user specifies the data rate in megabits per second. Quality is the accuracy with which the communication system reproduces the data at the receiver. In SLAM, the user specifies the bit energy-to-noise density requirement in decibels to assure a certain bit error rate (see section 3.2.4.1). Finally, connectivity is the range between the transmitting and receiving antennas.

3.2.1.3.2 Parameters. The system performance is described in terms of data rate, requirement, and range. Each of these parameters is discussed in the following.

Data rate (Mbps) -- This parameter is the rate at which the information is being passed over the link. Data rate is given in megabits per second (Mbps).

Requirement (dB) -- This parameter includes the required bit energy-to-noise power density for the required quality of digital communications. An addition requirement can include more margin to account for any miscellaneous factors that degrade the ideal performance.

Range (nmi) -- This parameter is the distance from the transmitting antenna to the receiving antenna. The program limits are set by the EREPS program and are 1 to 1800 nautical miles. There are two distinct regions of propagation. The first region is called the LOS region. This region extends from the transmitter to the radio horizon and is dominated by two-path coherent interference between direct and surface-reflected waves. The other distinct region is the over-the-horizon region with propagation mechanisms using diffraction, troposcatter, and ducting. This region begins just beyond the radio horizon.

The help screen for the system performance is displayed in figure 3-7.

```
LINK DESCRIPTION HELP SCREEN #4

SYSTEM PERFORMANCE:

Data rate. Information rate in megabits per second.

Requirement. Includes the required bit energy-to-noise power density for
acceptable digital communications. In addition, Requirement can include
margin which accounts for any miscellaneous factors which degrade the
ideal requirement.

Range. Distance from the transmitter to the receiver. The program
limits are 1 to 1800 nautical miles. There are two distinct regions of
propagation. The first region is called the optical region. This
region extends from the transmitter to the radio horizon and is
dominated by two-path coherent interference between direct and surface-
reflected waves. The other distinct regions are diffraction,
troposcatter, and ducting which begin just beyond the radio horizon.

Press [SPACE] bar to display next Help Screen. Hit [ESC] key to Exit.
```

Figure 3-7. LINK DESCRIPTION HELP SCREEN #4.

3.2.1.4 Environment

3.2.1.4.1 Description. The Surface Duct Summary (SDS) program of the Engineer's Refractive Effects Prediction System (EREPS) (Hitney, et al., 1988) provides annual historical summaries of evaporation duct, surface-based duct, and other meteorological parameters for many 10- by 10-degree squares of the earth's surface. The SDS program is being extended to include seasonal and day-night summaries of the environmental data required for SLAM. As an example of the data available in the present SDS program, a discussion of the evaporation duct heights is presented. The evaporation duct heights are especially important for any ship-to-ship communications.

The evaporation duct height is statistical in nature and depends on the geographical area, season, and time of day. Typical values of duct height are from 0 to 30 meters. Higher duct heights tend to occur in the daytime, in the warmer seasons, and in the more equatorial latitudes. The occurrence statistics of the evaporation duct height for different geographical regions can be obtained from the SDS program of EREPS (Hitney, et al., 1988). A display of these different geographic regions, called Marsden squares, is given in figure 3-8.

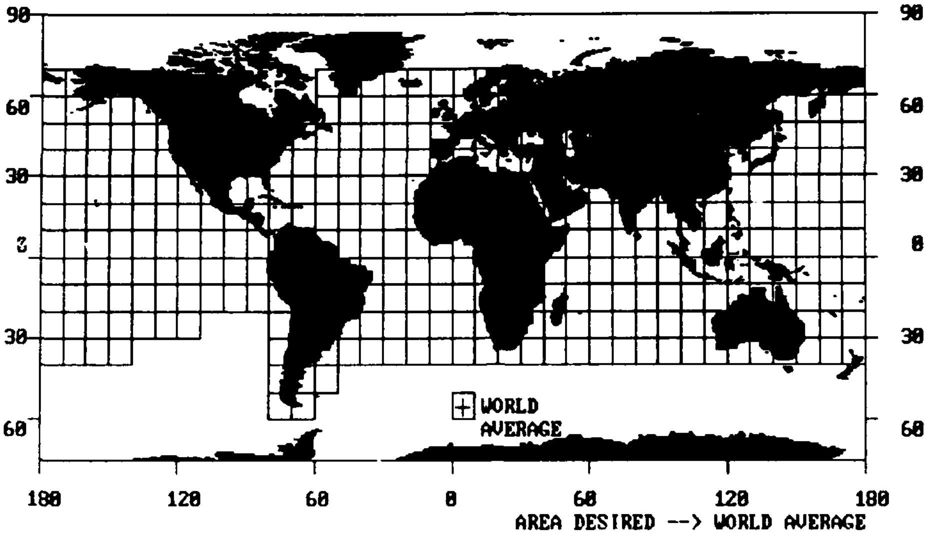

Figure 3-8. Map of Marsden squares.

The SDS data summary screen for the world average is shown in figure 3-9. The SDS data base shows average duct heights vary from around 5 meters in high-latitude areas to around 16 meters in tropical areas, with the worldwide average being 13.1 meters. The worldwide occurrence statistics are given in table 3-1. The average is given at the end of the table. The occurrence statistics for selected regions of the Western Hemisphere are given in table 3-2. The occurrence statistics for selected regions of the Eastern Hemisphere are displayed in table 3-3. The duct height that occurs at least 75% of the time worldwide is about 8 meters. For the selected Western Hemisphere areas, the average duct heights range from 5.3 to 16.5 meters. The 75% occurrence duct height is for Hawaii about 12 meters, the Gulf of Alaska is about 2 meters, the Northwest Pacific about 2 meters, and New Guinea about 12 meters. For the selected areas of the Eastern Hemisphere, the average duct heights range from 7.6 to 14.4 meters. The 75% occurrence duct height is for the Western Atlantic off the east shores of the United States about 9 meters, the North Atlantic near Iceland about 4 meters, the Atlantic near the equator about 12 meters, and the eastern Mediterranean about 8 meters.

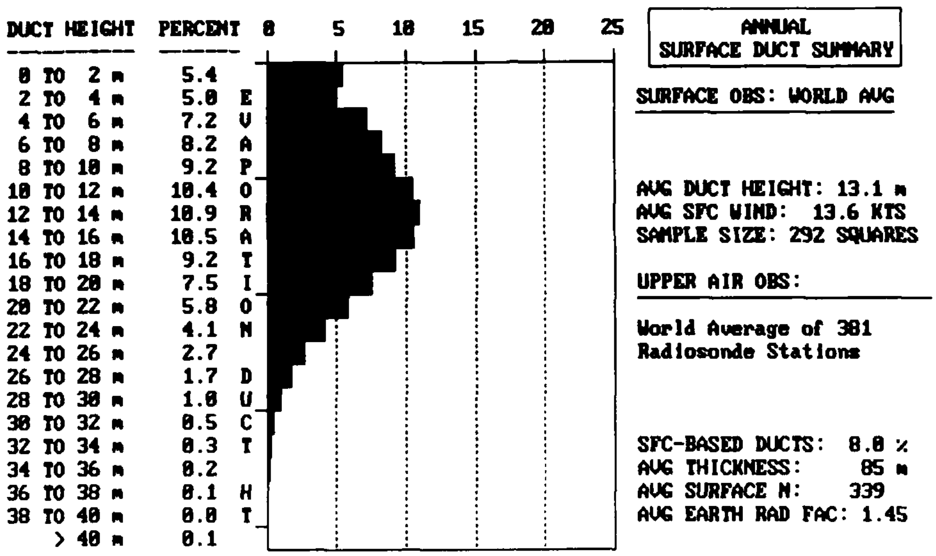

Figure 3-9. SDS world average screen.

Table 3.1 Duct height occurrence statistics (worldwide).

Duct Height (meters)	Worldwide (%)
0 to 2	5.4
2 to 4	5.0
4 to 6	7.2
6 to 8	8.2
8 to 10	9.2
10 to 12	10.4
12 to 14	10.9
14 to 16	10.5
16 to 18	9.2
18 to 20	7.5
20 to 22	5.8
22 to 24	4.1
24 to 26	2.7
26 to 28	1.7
28 to 30	1.0
30 to 32	0.5
32 to 34	0.3
34 to 36	0.2
36 to 38	0.1
38 to 40	0.0
>40	0.1
Average	13.1 meters

Table 3-2. Duct height occurrence statistics (selected Pacific areas).

Duct Height (meters)	Hawaii (%)	Gulf of Alaska (%)	Northwest Pacific (%)	New Guinea (%)
0 to 2	1.3	20.5	22.2	0.6
2 to 4	1.0	17.7	16.6	0.6
4 to 6	2.4	21.9	18.8	2.6
6 to 8	3.5	17.9	15.2	4.0
8 to 10	5.8	11.7	10.9	6.6
10 to 12	8.7	5.9	7.1	10.6
12 to 14	11.7	2.7	4.3	14.1
14 to 16	13.2	1.1	2.4	14.3
16 to 18	13.2	0.4	1.3	13.2
18 to 20	11.8	0.1	0.7	10.5
20 to 22	9.6	0.1	0.3	8.0
22 to 24	6.9		0.1	
24 to 26	4.6		0.1	
26 to 28	2.8			
28 to 30	1.7			
30 to 32	0.9			
32 to 34	0.4			
34 to 36	0.2			
36 to 38	0.1			
38 to 40	0.1			
>40	0.1			
Average	16.5 m	5.3 m	5.8 m	15.9 m

Table 3-3. Duct height occurrence statistics
(selected Atlantic areas).

Duct Height (meters)	Western (USA) (%)	North (Iceland) (%)	Atlantic (Equator) (%)	Eastern (Med) (%)
0 to 2	5.9	12.1	0.7	2.0
2 to 4	2.9	10.6	0.9	3.4
4 to 6	4.8	13.4	2.5	6.7
6 to 8	6.2	16.8	4.1	9.5
8 to 10	7.8	16.7	7.5	11.8
10 to 12	9.5	13.9	10.9	13.4
12 to 14	10.7	8.9	13.1	12.9
14 to 16	10.9	4.7	14.0	11.2
16 to 18	10.5	2.0	13.4	8.7
18 to 20	8.9	0.6	11.3	6.7
20 to 22	7.2	0.2	8.8	4.6
22 to 24	5.3	0.1	6.0	3.2
24 to 26	3.5		3.4	2.1
26 to 28	2.3		1.7	1.4
28 to 30	1.4		1.0	0.9
30 to 32	0.9		0.4	0.5
32 to 34	0.5		0.2	0.4
34 to 36	0.3		0.1	0.2
36 to 38	0.2			0.1
38 to 40	0.1			0.1
>40	0.2			0.2
Average	14.4 m	7.6 m	15.6 m	13.1 m

The Global Prediction Model (Ippolito, et al., 1989) can be used to provide rain rate information. This model uses cumulative rain rate data to develop cumulative attenuation statistics. The Global Prediction Model provides distribution estimates of the instantaneous point rain rate, *RR*, for broad geographical regions. Eight climate regions A through H are designated to classify regions covering the entire globe. Figure 3-10 shows the geographical rain climate regions for the continental and ocean areas of the earth. The point rain rate distribution values (mm/hr) versus percent of year rain rate is exceeded is given in table 3-4.

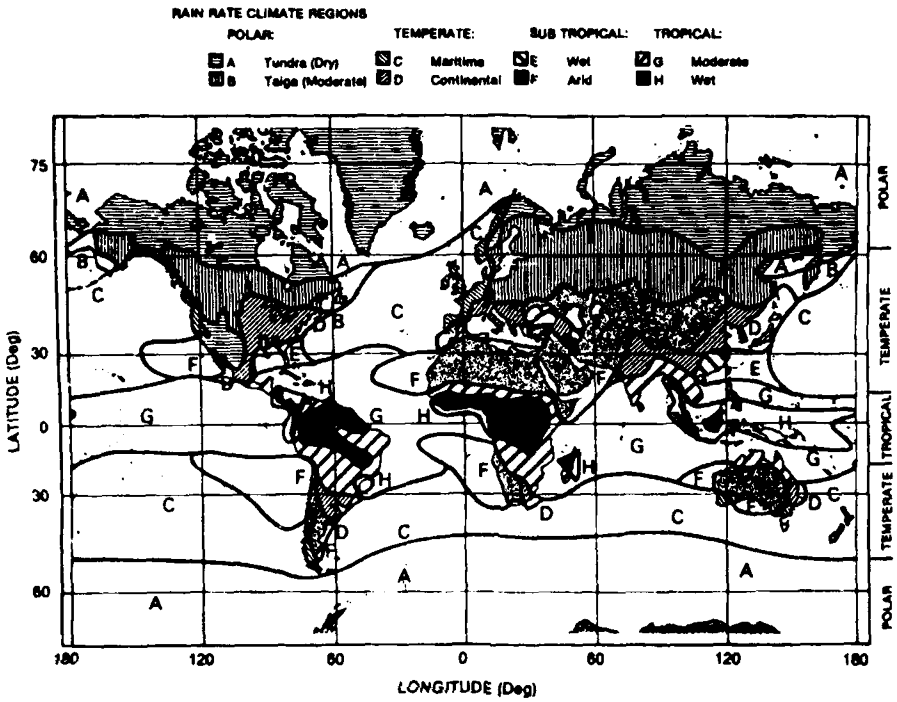

Figure 3-10. Rain climate regions.

Table 3.4 Rain Rates - mm/hr

Climate Region	Percentage of year		
	0.01%	0.1%	1.0%
A	10.0	2.5	0.4
B	19.5	5.2	1.3
C	28.0	7.2	1.8
D	49.0	14.5	3.0
E	98.0	35.0	6.0
F	23.0	5.2	0.7
G	94.0	32.0	8.0
H	147.0	64.0	12.0

3.2.1.4.2 Parameters. The environment is described in terms evaporation duct height, surface-based duct height, effective earth radius factor, surface refractivity, absolute humidity, wind speed, and rain rate. Each of these parameters is discussed below.

Evaporation duct height (meters) -- The evaporation duct is caused by the extremely rapid decrease of moisture immediately adjacent to the sea surface and characterized by the duct height in meters. The EREPS algorithm results are unreliable for

S-band	(3 GHz)	heights greater than 30 meters
C-band	(5 GHz)	heights greater than 22 meters
X-band	(10 GHz)	heights greater than 14 meters
K-band	(18 GHz)	heights greater than 10 meters

Surface-based duct height (meters) -- The surface-based duct is created by trapping layers that extend from the surface and up to several hundred meters in height. These ducts occur annually only 8% of the time worldwide.

Effective earth radius factor -- The effective earth radius factor is the ratio of the radius of the earth (modified so the relative curvature between the ray and the earth remains unchanged) and the true earth radius. Variations only affect the position of nulls in the optical region. As a general rule, the effective earth radius factor should be kept at a value near 4/3. The programs limits are set by the EREPS algorithm and are 0 to 5.

Surface refractivity (N-units) -- The surface refractivity is the refractivity at the earth's surface in N-units. Refractivity affects the troposcatter loss. The program limits are 0 to 450 N-units and are again a result of the EREPS algorithm. The world average value is 339 N-units.

Absolute humidity (g/m^3) -- The absolute humidity determines the absorption by water vapor molecules with units of grams per meter cubed. The EREPS program limits the values to between 0 and 14 gm/m^3. The world average value is 7.5 gm/m^3.

Wind speed (knots) -- The wind speed is required at the earth's surface in knots. The wind speed affects the depths of the nulls in the interference region. The EREPS program limits the values to between 0 and 100 knots.

Rain rate (mm/hr) -- The rain rate is the instantaneous point rain rate in millimeters per hour. The rain loss was discussed in section 2.3. The rain rate is used to calculate the loss due to rain.

External noise temperature -- The external noise temperature includes the external sources of noise including galatic noise, sky noise, and atmospheric noise in degrees Kelvin.

Ambient temperature -- Ambient temperature is used to determine the contribution of the losses in the receive antenna to the thermal noise in degrees Kelvin. It is also used to relate the receiver noise figure to the receiver noise temperature. The standard ambient temperature is 290 degrees Kelvin.

The help screens for the environment are displayed in figures 3-11 and 3-12.

```
LINK DESCRIPTION HELP SCREEN #5

ENVIRONMENT:

Evaporation duct height.  Caused by the extremely rapid decrease of
moisture immediately adjacent to the sea surface and characterized by
the duct height in meters.  Results are unreliable for

             S-band  (3 GHz)  heights greater than 30 meters
             C-band  (5 GHz)  heights greater than 22 meters
             X-Band (10 GHz)  heights greater than 14 meters
             K-Band (18 GHz)  heights greater than 10 meters

Surface-based duct height. Created by trapping layers which extend
from the surface and up to several hundred meters in height.  These
ducts occur annually only 8% of the time worldwide.

Effective earth radius factor.  Ratio of the radius of the earth modified
so that the relative curvature between the ray and the earth remains
unchanged and the true earth radius.  Variations only affect the position
of nulls in the optical region.  As a general rule, the effective earth
radius factor should be kept at a value near 1.33.  Limits are 0 to 5.

Press [SPACE] bar to display next Help Screen. Hit [ESC] key to Exit.
```

Figure 3-11. LINK DESCRIPTION HELP SCREEN #5.

```
LINK DESCRIPTION HELP SCREEN #6

Surface refractivity.  The refractivity at the earth'surface in N-units.
Refractivity affects the troposcatter loss.  The program limits are 0 to
450 N-units.  The world average value is 339 N-units.

Absolute humidity.   Determines absorption by water vapor molecules with
units of grams per meter cubed.  The program limits are 0 to 14.  The
world average value is 7.5.

Wind speed.   Wind speed at the earth's surface in knots.  This affects the
depths of the nulls in the optical region.  Limits are 0 to 100 knots.

Rain rate.  Instantaneous point rain rate in millimeters per hour.  This
is used to calculate the loss due to rain.

External noise temperature.  Galatic noise and atmospheric noise in
degrees Kelvin.

Ambient temperature.  Ambient temperature used to determine the
contribution of the losses in the receive antenna to the thermal noise
in degrees Kelvin and relates the noise figure to the receive noise
temperature.  The standard ambient temperature is 290 °K.

Press [SPACE] bar to display next Help Screen. Hit [ESC] key to Exit.
```

Figure 3-12. LINK DESCRIPTION HELP SCREEN #6.

3.2.2 Margin Calculation - [F3]

In its simplest form, SLAM will calculate the link margin M_{dB} for a SHF communication system. The equation for M_{dB} can be determined from equation (2-14) for the following

$$M_{dB} = P_{TE} + G_{TE} + G_{RE} - L_{FS} - L_{PF} - L_R - N_D - D_R - REQ \qquad (3-11)$$

where

P_{TE} is the effective power in dB of the transmitting system. P_{TE} equals the transmitter power reduced by the line losses in the transmitting system.

G_{TE} is the effective transmitter antenna gain in dB. G_{TE} equals the transmitter antenna gain reduced by the radome loss.

G_{RE} is the effective receiver antenna gain in dB. G_{RE} equals the receiver antenna gain reduced by the radome loss.

L_{FS} is the free space loss in dB of the link.

L_{PF} is the additional propagation loss above free space loss in dB. Both of the propagation loss values are discussed in more detail in section 2.2.

L_R is the additional attenuation loss due to rain. This calculation is discussed in section 2.3.

N_D is the receiver noise density in dB. N_D can be calculated from the receiver noise figure using equations (3-9) and (3-10) of section 3.2.1.2.1.

D_R is the data rate in dB.

REQ is the required bit energy-to-noise density requirement in dB for the desired quality of digital communications. An addition to the requirement can include more margin to account for any miscellaneous factors which degrade the ideal performance. In equation (2-14)

$$REQ = \left[\frac{E_b}{N_d}\right]_{dB}. \qquad (3-12)$$

Margin is the contingency guard or safety factor in the data link design. Signal margin provides continued link operation when nominal design conditions are exceeded.

The margin screen for the link description of figure 3-3 is shown in figure 3-13. Those parameters that reduce the margin are noted by a negative sign. In addition, a color screen will show red. For this example the margin is 47.4 dB. The range of the calculation, the radio horizon, and the optimal elevation angle are also displayed. In this example, the range is well within the radio horizon. Because an omnidirectional antenna type was used, the elevation angle has no effect. The help screen for the MARGIN screen is displayed in figure 3-14.

```
                        MARGIN CALCULATION

TRANSMITTER    (EIRP =        50.00 dB)
     Effective transmitter power                    20.00      dBW
     Effective antenna gain                         30.00      dBi
RECEIVER       ( G/T =         0.38 dB)
     Noise density                                 198.98      dBW/Hz
     Effective antenna gain                         30.00      dBi
SYSTEM
     Data rate                                     -73.01      dBHz
     Requirement                                   -14.00      dB
ENVIRONMENT
     Free space attenuation                       -143.82      dB
     Propagation factor                             -0.79      dB
     Rain attenuation                                0.00      dB
                                               ------------

               MARGIN                               47.36      dB

               Range                                20.00      nmi
               Radio horizon                       206.45      nmi
               Optimal elevation angle              11.70      deg

              Press [F1] for MAIN MENU, [F2] . . . [F10]
```

Figure 3-13. MARGIN CALCULATION screen.

```
                 MARGIN CALCULATION HELP SCREEN

The margin M in dB is calculated by

          M = PTE + GTE - ND + GRE - DR - REQ - LFS - LPF - LR
where
     PTE -  Effective transmitter power in dB
            [Transmitter power (dB) - line loss]
     GTE -  Effective transmitter antenna gain in dB
            [Transmitter antenna gain - radome loss]
     ND  -  Receiver noise density at the receiver in dB
     GRE -  Effective receiver antenna gain in dB
            [Receiver antenna gain - line loss - radome loss]
     DR  -  Data rate in dB
     REQ -  Requirement in dB
     LFS -  Free space attenuation in dB
            [97.80 + 20 * log[Frequency(GHz)] + 20 * log[Range (nmi)]]
     LPF -  Propagation factor in dB.  NOSC EREPS code of NOSC TD 1342
     LR  -  Rain attenuation in dB
            Method of calculation is described in References:
              Ippolito, et al., NASA Reference Publication 1082(3), 1983
              Stutzman, et al., Radio Science, Vol 17, No.6, Dec 1982

                      Hit [ESC] key to Exit.
```

Figure 3-14. MARGIN CALCULATION help screen.

3.2.3 SPREAD SHEET - [F4]

The SPREAD SHEET function allows the user to perform parametric analyses using the parameters of the baseline link description. The user defines a single dependent variable and two independent variables. A "two-dimensional spread sheet" is produced with the dependent variable displayed for the defined variations of the two independent variables. All other parameters appropriate to the analysis are fixed and have the values displayed in the LINK DESCRIPTION of section 3.2.1.

One of five dependent variables may be chosen. Figure 3.15 displays the SPREAD SHEET screen with the dependent variable list displayed. The dependent variables include margin (dB), free space loss (dB), propagation factor (dB), rain loss (dB), total loss (dB), data rate (Mbps), and range (nmi). The calculation of margin (dB) is given by equation (3-10) in section 3.2.2. The next three dependent variables are concerned with the losses from propagation of the signal in the channel. The free space loss (dB) is given by equation (2-16) of section 2.1. The propagation factor (dB) is given by equation (2-17) of section 2.1. The rain loss (dB) are determined using equations (2-25) and (2-26) of section 2.3. The total loss (dB) is the sum of all the signal losses due to the channel: free space loss (dB), propagation factor (dB), and rain loss (dB). In the calculation of data rate in megabits per second the margin is set to zero in the link equation (3-10) by appropriately increasing or decreasing the data rate. The dependent variable is the data rate (Mbps) when the margin is zero. The dependent variable range in nautical miles (nmi) is determined in a similar manner to data rate (Mbps). The range is increased or decreased appropriately until the margin is again zero.

```
                        SPREAD SHEET INPUT

 Dependent variable       MARGIN (dB)
                          FREE SPACE LOSS (dB)
                          PROPAGATION FACTOR (dB)
 Independent #1           RAIN LOSS (dB)
                          TOTAL LOSS (dB)
                          DATA RATE (Mbps)            100.00
                          RANGE (nmi)                   0.00
                                                           1

 Independent #2           FREQUENCY (GHz)

                         Initial value                10.00
                         Increment                     0.00
                         No. of values                    1

             Press [F4] for SPREAD SHEET CALCULATION
```

Figure 3-15. SPREAD SHEET INPUT with dependent variables.

Figure 3-16 displays the SPREAD SHEET screen with the first independent variable list displayed. Both of the independent variables may be any of the parameters discussed in section 3.2.1, LINK DESCRIPTION. The exceptions are polarization, antenna type, and data rate. The transmitter parameters power, line loss, antenna gain, radome loss, antenna height, frequency, beamwidth, and elevation can be independent variables. The possible receiver independent variables include noise figure, line loss, antenna gain, radome loss, and antenna height. The system parameters requirement and range may be independent variables. Finally, the independent variables for the environment include evaporation duct height, surface-based duct height, effective earth radius, surface refractivity, absolute humidity, wind speed, and rain rate. The two independent variables cannot be the same parameter. The initial value, increment value, and number of values must be provided for the user for each of the two independent variables. There are limits to the number of values for the independent variables. The number of values of one of the independent variables must be less than or equal to 5. The number of values of the other independent variable must be less than or equal to 175. If the number of values of both of the independent variables are specified to be over 5, the program will limit the minimum specified number of values to 5.

```
                        SPREAD SHEET INPUT

Dependent variable     MARGIN (dB)

Independent #1         TX POWER (watts)           RX RADOME LOSS (dB)
                       TX LINE LOSS (dB)          RX ANTENNA HEIGHT (ft)
                       TX ANTENNA GAIN (dB)       REQUIREMENT (dB)
                       TX RADOME LOSS (dB)        RANGE (nmi)
                       TX ANTENNA HT (ft)         EVAPORATION DUCT HT (m)
                       FREQUENCY (GHz)            SURFACE-BASED DUCT HT (m)
                       BEAMWIDTH (deg)            EFFECTIVE EARTH RADIUS
Independent #2         ELEVATION (deg)            SURFACE REFRACTIVITY (N)
                       NOISE FIGURE (dB)          ABSOLUTE HUMIDITY (g/m3)
                       RX ANTENNA GAIN (dB)       WIND SPEED (kts)
                       RX LINE LOSS (dB)          RAIN RATE (mm/hr)

                       No. of values              1

              Press [F4] for SPREAD SHEET CALCULATION
```

Figure 3-16. SPREAD SHEET INPUT with independent variables.

The user has three different means for viewing the spread sheet. First, the user must again press the function key [F4], and the spread sheet is displayed on the screen. For the example SPREAD SHEET screen of figure 3-17, the SPREAD SHEET output screen is displayed in figure 3-18. The user can move up and down the spread sheet by using the page up [PGUP] and page down [PGDN] keys. The user can get a hard copy of the baseline link description and the spread sheet by using the two keys [ALT] and [F4] simultaneously. The hard copy is not printed until the screen has been filled with the results of the spread sheet calculations.

```
                         SPREAD SHEET INPUT

Dependent variable     MARGIN (dB)


Independent #1         RANGE (nmi)

                       Initial value              20.00
                       Increment                  10.00
                       No. of values                15


Independent #2         FREQUENCY (GHz)


                       Initial value               2.00
                       Increment                   2.00
                       No. of values                  5




               Press [F4] for SPREAD SHEET CALCULATION
```

Figure 3-17. SPREAD SHEET INPUT example.

RANGE (nmi)	MARGIN (dB) FREQUENCY (GHz) 2.00	4.00	6.00	8.00	10.00
20.00	61.87	56.32	52.75	49.70	47.36
30.00	59.54	51.73	49.19	45.89	44.47
40.00	53.19	48.95	45.98	43.77	42.05
50.00	54.29	49.13	44.01	40.72	39.80
60.00	52.46	47.86	42.87	38.76	37.51
70.00	50.53	46.72	42.53	38.42	35.22
80.00	52.97	43.98	38.30	38.68	33.77
90.00	52.35	42.65	37.20	37.82	32.11
100.00	50.39	44.68	32.91	35.36	34.50
110.00	50.28	42.93	30.75	36.64	31.83
120.00	49.76	42.13	29.17	36.36	31.07
130.00	42.19	41.08	39.16	36.25	32.21
140.00	45.54	42.81	37.96	28.29	24.33
150.00	48.60	32.76	37.40	31.46	29.58
160.00	47.86	34.37	35.98	32.65	26.17

Press [PgUp]/[PgDn], [ALT-F4]-hardcopy, [SHIFT-F4]-graph, [F1]...[F10]

Figure 3-18. SPREAD SHEET output example.

For the final viewing option, the user can generate a graph of the data on the screen by using the two keys **[SHIFT]** and **[F4]** simultaneously. This action results in a display of the GRAPH OPTIONS screen. When viewing the GRAPH OPTIONS screen, the user can press the two key **[SHIFT]** and **[F4]** simultaneously to display a graph of the data in the spread sheet. While viewing the graph, the user may press the two key **[ALT]** and **[F4]** to get a hard copy of the graph. Any key will return the user to the GRAPH OPTIONS screen. With the GRAPH OPTIONS screen the user may choose several options to change the display of the data. Different types of line graphs may be displayed. The ordinate may be either linear or log. Two different printer types are supported: Hewlett Packard Laser Jet with different dots per inch and the Epson dot matrix. The ranges for both the abscissa and the ordinate may be changed, and the number axis step may be varied. Finally, the user has the option of printing or not printing the legend. An example GRAPH OPTIONS screen is displayed in figure 3-19. In figure 3-20 the resulting screen display of the graph is shown.

```
GRAPH OPTIONS

Graph type    X-linear Y-linear        Printer type    LJ 075 dpi




                RANGE (nmi)                          MARGIN (dB)

  Highest value               160.00                          70.00
  Lowest value                 20.00                          20.00
  Number of steps                 14                             10

              IF ALL VALUES ARE ZERO, DEFAULTS ARE USED!

  Title      Margin (dB) vs Range (nmi) and Frequency (MHz)

                     Show Legend      (Y/N)    Y

              Press [SHIFT F4] for graph, [F1] . . . [F10]
   [ALT F4] for hardcopy of graph, any key will return to this screen
```

Figure 3-19. GRAPH OPTIONS screen example.

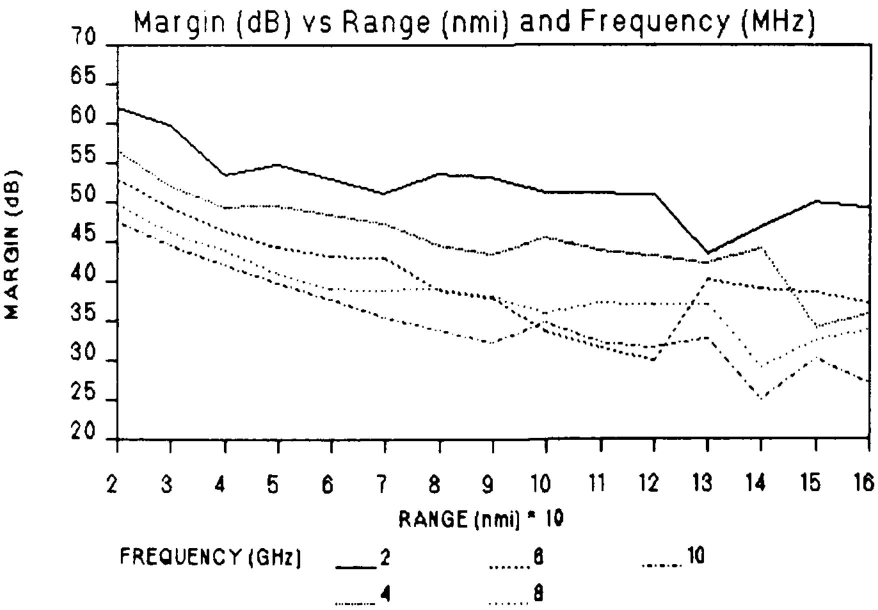

Figure 3-20. Example of graph screen.

3.2.4 SUPPLEMENTARY CALCULATIONS - [F5]

SUPPLEMENTARY CALCULATIONS give the user supporting analytical capabilities. The user can calculate the bit energy-to-noise density requirement in decibels for ideal biphase shift keying (BPSK) or quaternary phase shift keying (QPSK) in white Gaussian noise and for a given bit error rate (BER). In addition, the user can calculate the gain and beamwidth for a circular parabolic antenna of a given diameter and antenna efficiency. The help screen for the SUPPLEMENTARY CALCULATIONS is given in figure 3-21.

```
SUPPLEMENTARY CALCULATIONS HELP SCREEN

Bit energy-to-noise density requirement

The requirement in dB is calculated for ideal biphase shift keying (BPSK)
and quadrature shift keying (QPSK) in white Gaussian noise and the desired
bit error rate (BER).


Circular parabolic antenna gain and beamwidth

The geometric properties of a parabola yield an excellent microwave
radiator.  For a parabolic reflector with a circular aperture the
gain and beamwidth are calculated for a given antenna efficiency and
incremented values of antenna diameter.

Hit [ESC] key to Exit
```

Figure 3-21. SUPPLEMENTARY CALCULATIONS help screen.

3.2.4.1 Bit Energy-to Noise Density Requirement - [1]

Because of the importance in transferring information at a high data rate and containing it within a minimal bandwidth, the employment of bandwidth-efficient modulation techniques becomes necessary. A number of modulation techniques exist, but QPSK modulation is widely used in a number of digital terrestrial microwave and satellite systems (Feher, 1981).

The modulator is described by referring to figure 3-22. The inputs, in-phase (I) and quadrature (Q), represent the sequences of data to be modulated. The digital-to-analog (D/A) converters change the data into analog sequences (a_n) and (b_n), which are then put through a low-pass filter to form the pulse streams $\sum a_n h(t-nT)$, $\sum b_n h(t-nT)$. The low-pass filter has an impulse response h(t) and is in the form of a raised cosine for the purpose of reducing intersymbol interference (ISI). The local oscillator (LO) produces a sinusoidal carrier at frequency (f_c) and is usually the intermediate frequency (IF) of the radio (although direct modulation at radio frequency (RF) may also be used). The local oscillator along with its quadrature component are used to modulate the I and Q pulse streams respectively. These outputs are added together and then bandpass filtered to produce the signal

$$s(t) = \sum_n a_n h(t-nT)\cos\omega_c t - \sum_n b_n h(t-nT)\sin\omega_c t \qquad (3-13)$$

at the IF or RF (Ivanek, 1989).

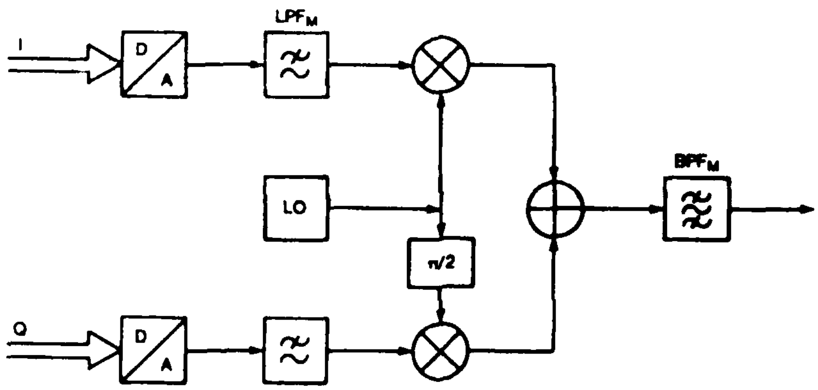

Figure 3-22. QPSK modulator.

The demodulation process is shown in figure 3-23. The incoming modulated signal is passed through a bandpass filter (BPF) to eliminate out-of-band noise and adjacent channel interference. The signal is split into an I and Q demodulation path where the carrier recovery (CR) subsystem regenerates the unmodulated sinusoidal carrier. The reconstituted carrier and its quadrature component are mixed with the I and Q demodulated lines respectively. These lines are low-pass filtered and analog-to-digitally (A/D) converted under the control of the timing recovery (TR) circuitry, to reproduce the I and Q sequences of data originally modulated (Ivanek, 1989).

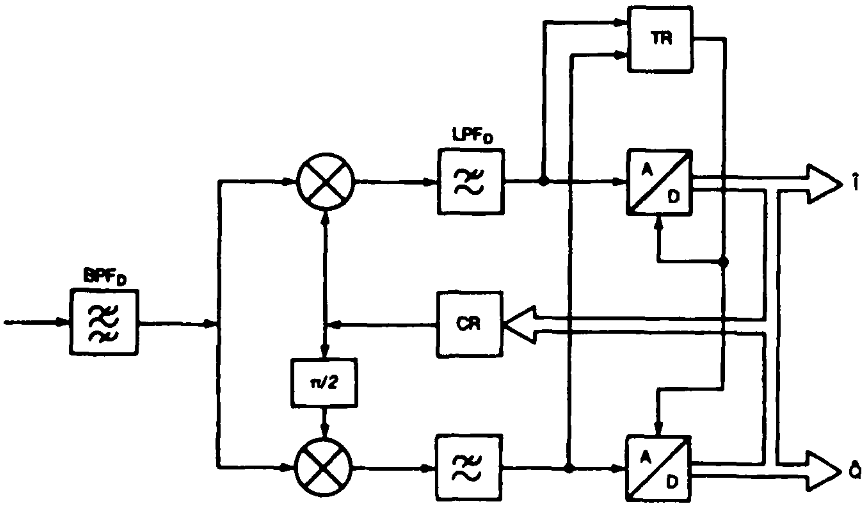

Figure 3-23. QPSK demodulator.

Figure 3-24 depicts the CR subsystem. The CR is accomplished by passing the IF signal through a nonlinear circuit made up of an nth order squarer (i.e., for QPSK M=4), which removes the modulation from the carrier. The desired spectral component is bandpass filtered. A phase lock loop (PLL) is used to track and produce a clean sinusoidal output, which is divided down by n to the original modulated frequency. The TR subsystem is accomplished by squaring the output of the low-pass filters, extracting from the square a spectral line component at $1/T$ with the aid of a bandpass filter, and then tracking and cleaning it with a PLL (Ivanek, 1989).

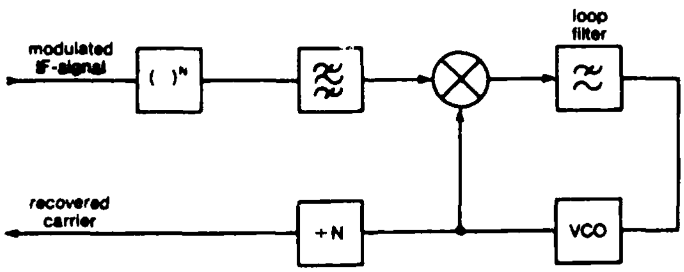

Figure 3-24. QPSK carrier recovery subsystem.

The error performance of this modulator-demodulator (modem) is derived in the following manner. For M-ary PSK system in additive white Gaussian noise (AWGN), an ideal, coherent, digital phase detector observes a sinewave with one of M phases. For QPSK M equals four. For binary phase shift keying, BPSK, M equals two. The detector may be characterized as a device that performs a phase measurement during a T-second interval. The received wave plus noise is

$$r(t) \;=\; A\cos(\omega_c t+\phi)+n_c(t)\cos(\omega_c t+\phi)+n_s(t)\sin(\omega_c t+\phi) \qquad (3-14)$$

where $\phi = m(2\pi/M), m = 1,2,\ldots,M$, and $n_c(t)$ and $n_s(t)$ are the in-phase and quadrature Gaussian noise components, respectively, with average power N. Since the transmitted phases are constant over this T-sec interval, the composite phase is

$$\alpha \;=\; \phi+\tan^{-1}\left[\frac{n_s(t)}{A+n_c(t)}\right]. \qquad (3-15)$$

In the absence of noise, the ideal phase detector measures ϕ at the end of the signaling interval. Because of noise, errors are committed whenever the device measures a phase outside of the region

$$\phi-\frac{\pi}{M} \;\le\; \theta \;<\; \phi+\frac{\pi}{M}. \qquad (3-16)$$

The probability density of the received wave plus noise phase has been derived (Lucky, 1968) and is

$$p(\theta) \;=\; \frac{1}{2\pi}e^{-S/N}\left[1+\sqrt{4\pi S/N}\cos\alpha e^{S/N\cos^2\alpha}Q(\sqrt{2S/N}\cos\alpha)\right] \qquad (3-17)$$

where

$$Q(x) \;=\; \frac{1}{\sqrt{2\pi}}\int_x^{\infty}e^{-t^2/2}dt, \qquad (3-18)$$

and $S/N = A^2/2/N$ is the SNR.

Assuming all the phase modulations are equally likely, the probability of a phase-detected error P_{SE} is given by

$$P_{SE} \;=\; \int_{\pi/M}^{\pi}p(\alpha)d\alpha+\int_{-\pi}^{-\pi/M}p(\alpha)d\alpha \;=\; 2\int_{\pi/M}^{\pi}p(\alpha)d\alpha. \qquad (3-19)$$

For BPSK and QPSK, there exists a closed form solution. These solutions are shown in figure 3-25 and are mathematically represented for BPSK as

$$P_{SE}(M=2) \;=\; Q(\sqrt{2S/N}), \qquad (3-20)$$

and for QPSK as

$$P_{SE}(M=4) \;=\; 1-[1-Q(\sqrt{S/N})]^2. \qquad (3-21)$$

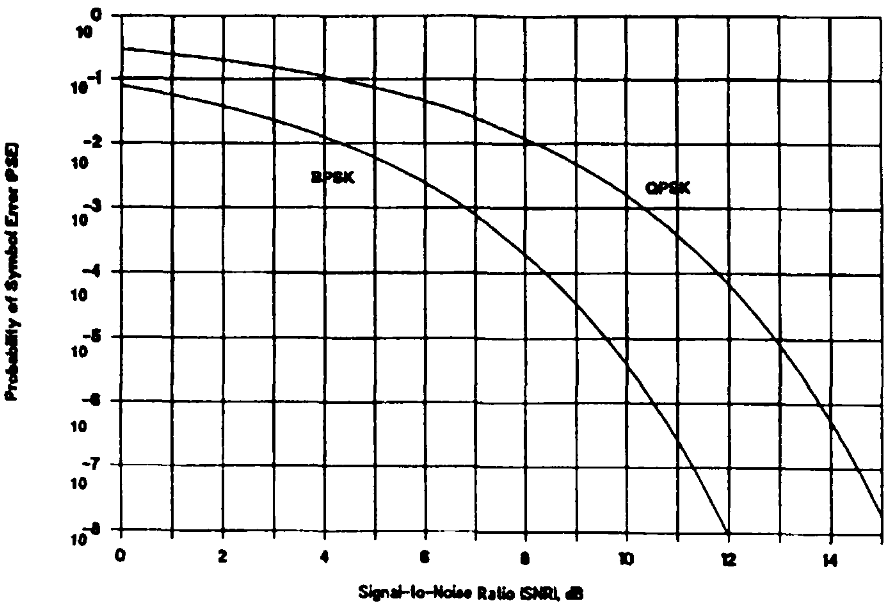

Figure 3-25. BPSK and QPSK probability of symbol error.

For the probability of a bit error P_{BE}, the symbol error rate and bit error rate are related as follows

$$P_{BE} = \frac{M/2}{M-1} P_{SE}. \qquad (3-22)$$

The bit energy, E_b, to noise power density, N_0, is related the received SNR by

$$\frac{E_b}{N_0} = \frac{W}{R}\frac{S}{N} = \frac{S/R}{N_0} \qquad (3-23)$$

where

$$R = \frac{\log_2 M}{T} \qquad (3-24)$$

is the information bit rate (bps), and W is twice the amplifier bandwidth B. Figure 3-26 shows the probability of a bit error given the energy-per-bit to noise-power density for both BPSK and QPSK. For acceptable digital communications, the bit error rate usually ranges from 10^{-3} to 10^{-6}. A bit error rate of 10^{-6} implies a bit energy-to-noise power density of 10.5 dB. These curves are theoretical limits, and some additional decibels should be added for practical implementation in a modem.

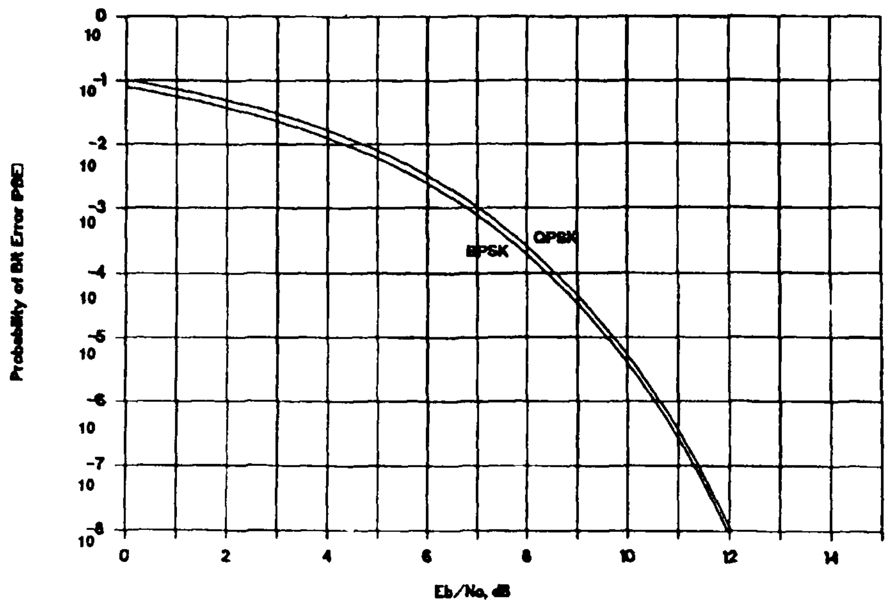

Figure 3-26. BPSK and QPSK probability of bit error.

In the Requirement Option of the SUPPLEMENTARY CALCULATIONS, the user specifies the desired probability of bit error and the program solves for the required bit energy-to-noise density using equations 3-20 through 3-24. A sample screen for this option is shown in figure 3-27.

```
BIT ENERGY-TO-NOISE DENSITY REQUIREMENT (dB)

Enter desired BER and then [RETURN] for calculation

Bit error rate (BER)        1.00E-06


Bit Energy-to-Noise Density Requirement (dB)

QPSK =        10.64     dB

BPSK =        10.53     dB


Press [F1] for MAIN MENU, [F2] . . . [F10]
```

Figure 3-27. Sample BER requirement screen.

3.2.4.2 Parabolic Circular Antenna - [2]

The geometric properties of a parabola yield an excellent microwave radiator. The plane at which the reflector is cut off is called the aperture plane. The surface generated by the revolution of parabola around its axis is called a paraboloid. A paraboloid can be used to concentrate the radiation from an antenna located at the focus to form a beam in the same way that a searchlight reflector produces a light beam. The action of a paraboloid is to convert a spherical wave originating at the focus into a plane wave at the mouth or aperture of the parabolic antenna.

For a parabolic reflector with a circular aperture, the equations for gain G and beamwidth BW are

$$G = 9.934 + 10\log(\eta/100) + 20\log(D/\lambda), \qquad (3-25)$$

and

$$BW = \frac{58}{(D/\lambda)} \qquad (3-26)$$

where η is the antenna efficiency in percent, D is the diameter of the circular aperture, and λ is the wavelength (Johnson and Jasik, 1984).

In the CIRCULAR PARABOLIC GAIN AND BEAMWIDTH of the SUPPLEMENTARY CALCULATIONS, the user is requested to supply the antenna efficiency in percent. An antenna efficiency of 50% is a reasonable value. Next, an initial value for diameter and a stepping increment are requested. When the user hits any FUNCTION KEY, a table of gain in decibels and beamwidth in degrees are listed for the specified diameters. Figure 3-28 displays the screen for a sample calculation for a circular parabolic antenna.

CIRCULAR PARABOLIC ANTENNA GAIN AND BEAMWIDTH

FREQUENCY = 10 GHz

Efficiency (%) 50.00

Antenna Diameter

Initial value 0.50 ft

Increment 0.50 ft

DIAMETER (ft)	GAIN (dB)	BEAMWIDTH (deg)
0.50	21.05	11.41
1.00	27.07	5.70
1.50	30.59	3.80
2.00	33.09	2.85
2.50	35.02	2.28
3.00	36.61	1.90
3.50	37.95	1.63
4.00	39.11	1.43
4.50	40.13	1.27
5.00	41.05	1.14
5.50	41.87	1.04
6.00	42.63	0.95
6.50	43.32	0.88
7.00	43.97	0.81

Press [F1] for MAIN MENU, [F2] . . . [F10]

Figure 3-28. Sample parabolic antenna calculation screen.

3.3 SUPPORT OPTIONS

The Support Options are the second of the two principal types of options in SLAM. The Support Options do not directly support the calculations of link budgets. Instead, these options allow the user to use SLAM more easily. Load Link Description and Save Link Description allow the user to save and load baseline descriptions of the communication system. This will allow the user to save system descriptions for future analysis and avoid having to enter directly all system descriptions. The calculator allows the user to make arithmetic calculations while using SLAM. The Help screens are accessible directly from the user's current screen. These screens are meant to be an aid to the user's understanding of the different options. Finally, the FUNCTION KEY [F10] will always return the user directly to the DOS environment.

3.3.1 Load Link Description - [F6]

This option allows the user to load a previously saved baseline system description. The [ESC] key will return the user directly to the LINK DESCRIPTION screen without loading a file. The default directory for these files is C:\SLAM. The user, however, can specify any legitimate directory. Once the directory is specified, files with the designation .DES are listed. Using the cursor, the user designates one of the files. Pressing the [RETURN] key will load the desired file and return the user to the LINK DESCRIPTION screen.

3.3.2 Save Link Description - [F7]

This option allows the user to save the baseline system description, which is currently displayed on the LINK DESCRIPTION screen. The [ESC] key will return the user directly to the LINK DESCRIPTION screen without saving a file. The default directory is C:\SLAM. The user, however, can specify any legitimate directory. Once the directory is specified, the file name is specified. The file name must not have a designator. The SLAM program will automatically add .DES to the file. When the user presses any FUNCTION KEY, the baseline system description is saved and the user is returned to the LINK DESCRIPTION screen.

3.3.3 Calculator - [F8]

This option allows the user to make arithmetic calculations while using SLAM. The [+] key will add two numbers. The [-] will subtract two numbers. The [*] will multiply two numbers, and the [/] key will divide two numbers.

3.3.4 Help Screens - [F9]

3.3.5 Exit to DOS - [F10]

The FUNCTION KEY [F10] will return the user directly to the DOS environment from anywhere in the program.

4.0 APPLICATIONS

Ship-to-air and ship-to-ship links are provided as examples to show how the SLAM program can be applied. These examples give the user insight into the utility of the SLAM program. In addition, these examples provide a permanent record of the configuration for Version 2.0 of the SLAM program.

4.1 SHIP-TO-AIR LINK EXAMPLE

For this example, a shipboard transmitter and an aircraft receiver are used. The transmitter subsystem transmits 100 watts at 10 GHz into an omnidirectional, circular polarized antenna with an effective radiated area of a 3-foot dish and located at a height of 100 feet. The receiving subsystem collects this energy with a 3-foot-diameter antenna, located at 25,000 feet. The receiver noise figure is 5 db. The system operates at 20 Mbps and communicates to 20 nautical miles. The quality of transmission is specified at an energy-per-bit to noise-density ratio of 14 db. The environment consists of standard atmospheric propagation and includes 10 millimeters of rain per hour and the wind speed is 10 knots. The LINK DESCRIPTION is shown in figure 4-1. The resulting MARGIN CALCULATION is displayed in figure 4-2. Because the link is well within the radio horizon, the resulting margin is large.

To demonstrate some other features of the SLAM program, a parametric analysis is performed with range and frequency. The desired spread sheet input is shown in figure 4-3. The graph options for displaying the results of the spread sheet are shown in figure 4-4. The spread sheet output generates 37 range values and results in two pages of output. This output is shown in figures 4-5 and 4-6. A graph of the spread sheet output is shown in figure 4-7. If a margin of 20 dB is required, a communication range of 185 miles is possible. As the frequency is increased, the range is reduced. At 10 Mhz, the range is limited to 130 miles. This reduction in range is primarily due to rain.

LINK DESCRIPTION

TRANSMITTER SUBSYSTEM			RECEIVER SUBSYSTEM	
Power (watts)		100.00	Noise figure (dB)	5.00
Line loss (dB)		0.00	Line loss (dB)	0.00
Antenna gain (dB)		-3.00	Antenna gain (dB)	-3.00
Radome loss (dB)		0.00	Radome Loss (dB)	0.00
Antenna height (ft)		100.00	Antenna height (ft)	25,000.00
Frequency (GHz)		10.00		
Polarization	CIRCULAR		SYSTEM PERFORMANCE	
Antenna type	OMNI		Data rate (Mbps)	20.00
Beamwidth (deg)		3.00	Requirement (dB)	14.00
Elevation (deg)		0.00	Range (nmi)	20.00

ENVIRONMENT	
Evaporation duct height (meters)	0.00
Surface-based duct height (meters)	0.00
Effective earth radius factor	1.33
Surface refractivity (N-units)	339.00
Absolute humidity (g/m3)	7.50
Wind speed (knots)	10.00
Rain rate (mm/hr)	10.00
Ambient temperature (°K)	290.00
External noise temperature (°K)	290.00

Press [F1] for MAIN MENU, [F2] . . . [F10]

Figure 4-1. LINK DESCRIPTION for ship-to-air example.

MARGIN CALCULATION

TRANSMITTER (EIRP = 56.62 dB)		
Effective transmitter power	20.00	dBW
Effective antenna gain	36.62	dBi
RECEIVER (G/T = 6.99 dB)		
Noise density	198.98	dBW/Hz
Effective antenna gain	36.62	dBi
SYSTEM		
Data rate	-73.01	dBHz
Requirement	-14.00	dB
ENVIRONMENT		
Free space attenuation	-143.82	dB
Propagation factor	-0.79	dB
Rain attenuation	-3.25	dB

MARGIN	57.35	dB
Range	20.00	nmi
Radio horizon	206.45	nmi
Optimal elevation angle	11.70	deg

Press [F1] for MAIN MENU, [F2] . . . [F10]

Figure 4-2. MARGIN CALCULATION for ship-to-air example.

```
                        SPREAD SHEET INPUT

Dependent variable     MARGIN (dB)


Independent #1         RANGE (nmi)

                       Initial value             20.00
                       Increment                  5.00
                       No. of values                37


Independent #2         FREQUENCY (GHz)


                       Initial value              6.00
                       Increment                  2.00
                       No. of values                 5




              Press [F4] for SPREAD SHEET CALCULATION
```

Figure 4-3. SPREAD SHEET INPUT for ship-to-air example.

```
                          GRAPH OPTIONS

Graph type    X-linear Y-linear       Printer type    LJ 075 dpi




              RANGE (nmi)                        MARGIN (dB)

 Highest value                200.00                        60.00
 Lowest value                  20.00                       -60.00
 Number of steps                   9                           12


              IF ALL VALUES ARE ZERO, DEFAULTS ARE USED!

 Title       MARGIN (dB) vs RANGE (nmi)

                   Show Legend      (Y/N)    Y


              Press [SHIFT F4] for graph, [F1] . . . [F10]
     [ALT F4] for hardcopy of graph, any key will return to this screen
```

Figure 4-4. GRAPH OPTIONS for ship-to-air example.

MARGIN (dB)

RANGE (nmi)	FREQUENCY (GHz) 6.00	8.00	10.00	12.00	14.00
20.00	56.27	57.15	57.35	57.63	57.48
25.00	54.23	55.19	54.89	53.98	52.84
30.00	52.28	52.37	52.80	51.58	49.88
35.00	50.04	50.18	50.73	49.47	46.11
40.00	48.63	49.25	48.69	47.12	44.36
45.00	48.21	47.29	45.46	43.89	41.35
50.00	46.21	45.18	44.69	42.48	37.47
55.00	43.85	43.65	41.73	38.61	34.12
60.00	44.60	42.17	40.61	38.09	32.66
65.00	44.39	43.08	39.78	35.09	28.77
70.00	43.77	40.72	36.44	32.33	27.13
75.00	38.93	37.68	34.53	29.79	22.97
80.00	39.04	39.83	33.03	29.05	21.71
85.00	39.39	37.62	33.61	27.66	19.45
90.00	37.41	37.76	29.32	25.01	16.16
95.00	38.52	36.05	27.55	23.77	11.56
100.00	32.56	34.05	29.56	18.65	9.68
105.00	33.09	31.74	28.26	17.64	5.51
110.00	29.82	34.00	24.64	14.11	5.81
115.00	38.66	27.09	24.82	12.42	2.02

Press [PgUp]/[PgDn], [ALT-F4]-hardcopy, [SHIFT-F4]-graph, [F1]...[F10]

Figure 4-5. First sheet of spread sheet output.

MARGIN (dB)

RANGE (nmi)	FREQUENCY (GHz) 6.00	8.00	10.00	12.00	14.00
120.00	27.62	32.33	21.52	9.23	0.11
125.00	37.41	31.72	21.98	8.82	-7.31
130.00	36.97	30.77	20.19	5.68	-11.39
135.00	35.38	26.67	16.26	6.72	-14.33
140.00	35.10	21.30	9.72	4.06	-11.29
145.00	35.50	27.43	13.91	-5.83	-22.60
150.00	33.84	22.89	1[illegible].29	-0.09	-24.09
155.00	20.71	14.53	4.53	-8.96	-26.89
160.00	31.70	22.44	6.09	-3.60	-38.05
165.00	30.78	22.97	10.66	-5.81	-27.61
170.00	28.12	21.86	-9.78	-8.36	-35.68
175.00	27.67	19.28	6.31	-10.86	-33.43
180.00	30.37	10.25	4.40	-19.94	-38.46
185.00	23.68	14.50	0.60	-17.62	-41.48
190.00	15.04	14.91	0.08	-31.02	-47.32
195.00	18.10	14.63	-5.29	-28.81	-49.23
200.00	24.88	12.69	-5.06	-28.19	-58.37

Press [PgUp]/[PgDn], [ALT-F4]-hardcopy, [SHIFT-F4]-graph, [F1]...[F10]

Figure 4-6. Second sheet of spread sheet output.

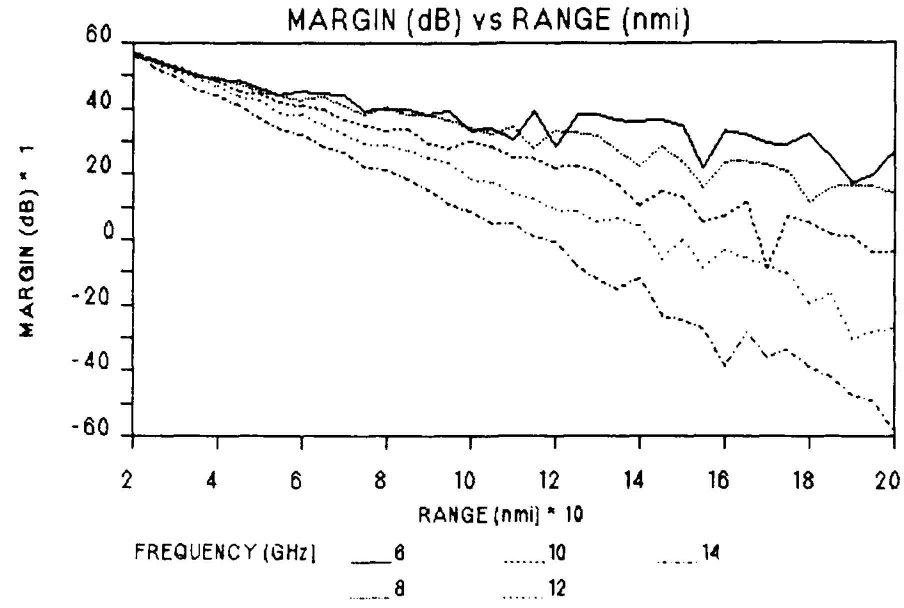

Figure 4-7. Example of ship-to-air graph screen.

4.2 SHIP-TO-SHIP LINK EXAMPLE

For this example, both the transmitter subsystem and receiver subsystem are on ships. The transmitting subsystem has 1000 watts of power with 3 dB of line loss. The antenna is 3 feet in diameter and located at 100 feet. The antenna type is omnidirectional and circular polarized. The receiving subsystem has a noise figure of 5 dB. The receiving antenna is also 3 feet in diameter and is located at 100 feet. The operating frequency is 10 GHz. The system performance requirements include a data rate of 1.5 Mbps and a range of 40 nmi. The quality of transmission is insured by a requirement of 14 dB energy-per-bit to noise-density ratio. The environment assumes standard atmospheric propagation and a wind speed of 10 knots. The LINK DESCRIPTION is shown in figure 4-8. The resulting MARGIN CALCULATION is displayed in figure 4-9. Because the link is beyond the radio horizon, the resulting margin is below 20 dB.

For this example a parametric analysis is performed with range and evaporation duct height. The desired spread sheet input is shown in figure 4-10. The graph options for displaying the results of the spread sheet are shown in figure 4-11. The spread sheet output generates 33 range values and, therefore, requires two pages of output. These pages are shown in figures 4-12 and 4-13. A graph of the spread sheet output is shown in figure 4-14. Again, consider that the required margin is 20 dB. The impact of evaporation duct becomes quite apparent. For an evaporation duct height of 10 meters, the range is extended to almost 130 nmi.

LINK DESCRIPTION

TRANSMITTER SUBSYSTEM		RECEIVER SUBSYSTEM	
Power (watts)	1,000.00	Noise figure (dB)	5.00
Line loss (dB)	3.00	Line loss (dB)	0.00
Antenna gain (dB)	-3.00	Antenna gain (dB)	-3.00
Radome loss (dB)	0.00	Radome Loss (dB)	0.00
Antenna height (ft)	100.00	Antenna height (ft)	100.00
Frequency (GHz)	10.00		
Polarization	CIRCULAR	**SYSTEM PERFORMANCE**	
Antenna type	OMNI	Data rate (Mbps)	1.50
Beamwidth (deg)	3.00	Requirement (dB)	14.00
Elevation (deg)	0.00	Range (nmi)	40.00

ENVIRONMENT	
Evaporation duct height (meters)	0.00
Surface-based duct height (meters)	0.00
Effective earth radius factor	1.33
Surface refractivity (N-units)	339.00
Absolute humidity (g/m3)	7.50
Wind speed (knots)	10.00
Rain rate (mm/hr)	0.00
Ambient temperature (°K)	290.00
External noise temperature (°K)	290.00

Press [F1] for MAIN MENU, [F2] . . . [F10]

Figure 4-8. LINK DESCRIPTION for ship-to-ship example.

MARGIN CALCULATION

TRANSMITTER (EIRP = 63.62 dB)		
Effective transmitter power	27.00	dBW
Effective antenna gain	36.62	dBi
RECEIVER (G/T = 6.99 dB)		
Noise density	198.98	dBW/Hz
Effective antenna gain	36.62	dBi
SYSTEM		
Data rate	-61.76	dBHz
Requirement	-14.00	dB
ENVIRONMENT		
Free space attenuation	-149.85	dB
Propagation factor	-55.21	dB
Rain attenuation	0.00	dB

MARGIN	18.41	dB
Range	40.00	nmi
Radio horizon	24.56	nmi

Press [F1] for MAIN MENU, [F2] . . . [F10]

Figure 4-9. MARGIN CALCULATION for ship-to-ship example.

```
                    SPREAD SHEET INPUT

Dependent variable      MARGIN (dB)

Independent #1          RANGE (nmi)

                        Initial value               40.00
                        Increment                    5.00
                        No. of values                  33

Independent #2          EVAPORATION DUCT HT (m)

                        Initial value                0.00
                        Increment                    5.00
                        No. of values                   5

            Press [F4] for SPREAD SHEET CALCULATION
```

Figure 4-10. SPREAD SHEET INPUT for ship-to-ship example.

```
                         GRAPH OPTIONS

Graph type    X-linear Y-linear        Printer type    LJ 075 dpi

              RANGE (nmi)                          MARGIN (dB)

  Highest value              200.00                          80.00
  Lowest value                40.00                         -20.00
  Number of steps                 8                             10

              IF ALL VALUES ARE ZERO, DEFAULTS ARE USED!

  Title      MARGIN (dB) vs RANGE (nmi)

                    Show Legend      (Y/N)    Y

              Press [SHIFT F4] for graph, [F1] . . . [F10]
   [ALT F4] for hardcopy of graph, any key will return to this screen
```

Figure 4-11. GRAPH OPTIONS for ship-to-ship example.

RANGE (nmi)	MARGIN (dB) EVAPORATION DUCT HT (m) 0.00	5.00	10.00	15.00	20.00
40.00	18.41	44.56	71.46	47.84	30.04
45.00	14.17	34.78	68.27	47.19	29.19
50.00	12.52	26.89	65.13	46.60	28.42
55.00	10.95	19.46	62.04	46.05	27.71
60.00	9.45	13.81	58.98	45.54	27.06
65.00	8.01	9.98	55.96	45.06	26.46
70.00	6.62	6.62	52.96	44.60	24.90
75.00	5.27	5.27	49.98	44.17	24.46
80.00	3.96	3.96	47.02	43.75	24.05
85.00	2.69	2.69	44.08	43.35	23.65
90.00	1.44	1.44	41.15	42.97	23.27
95.00	0.22	0.22	38.24	42.60	22.90
100.00	-0.97	-0.97	35.34	42.24	22.54
105.00	-2.15	-2.15	32.44	41.90	22.19
110.00	-3.30	-3.30	29.56	41.56	21.86
115.00	-4.44	-4.44	26.69	41.23	21.53
120.00	-5.56	-5.56	23.83	40.91	21.21
125.00	-6.67	-6.67	20.97	40.60	20.90
130.00	-7.76	-7.76	18.12	40.30	20.59
135.00	-8.84	-8.84	15.28	40.00	20.30

Press [PgUp]/[PgDn], [ALT-F4]-hardcopy, [SHIFT-F4]-graph, [F1]...[F10]

Figure 4-12. First sheet of spread sheet output.

RANGE (nmi)	MARGIN (dB) EVAPORATION DUCT HT (m) 0.00	5.00	10.00	15.00	20.00
140.00	-9.90	-9.90	12.44	39.71	20.00
145.00	-10.96	-10.96	9.61	39.42	19.72
150.00	-12.01	-12.01	6.79	39.14	19.43
155.00	-13.04	-13.04	5.11	38.86	19.16
160.00	-14.07	-14.07	2.54	38.59	18.89
165.00	-15.09	-15.09	0 01	38.32	18.62
170.00	-16.10	-16.10	-2.45	38.06	18.35
175.00	-17.10	-17.10	-4.85	37.80	18.09
180.00	-18.10	-18.10	-7.17	37.54	17.84
185.00	-19.09	-19.09	-9.42	37.28	17.58
190.00	-20.07	-20.07	-11.57	37.03	17.33
195.00	-21.05	-21.05	-13.64	36.79	17.08
200.00	-22.02	-22.02	-15.61	36.54	16.84

Press [PgUp]/[PgDn], [ALT-F4]-hardcopy, [SHIFT-F4]-graph, [F1]...[F10]

Figure 4-13. Second sheet of spread sheet output.

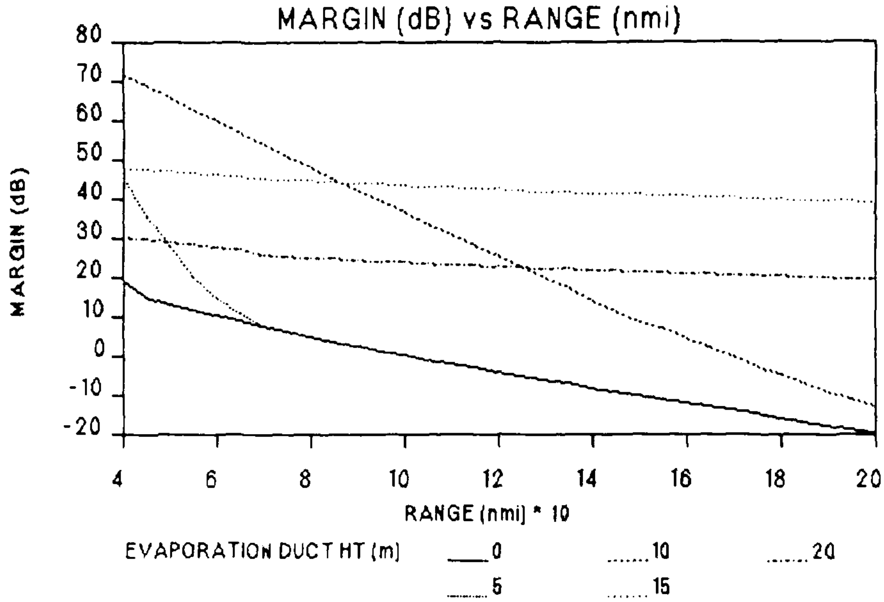

Figure 4-14. Example of ship-to-ship graph screen.

REFERENCES

Castro, C. R., and R. Major. 1988. "Improved USMC Antenna Farm Downlink," NOSC TN 1557 (November). Naval Ocean Systems Center, San Diego, CA. *

Crane, R. K. 1977. "Prediction of the effects of rain on satellite communication systems," *Proceedings of IEEE, vol.* 65(3).

Feher, K. 1981. *Digital Communications: Microwave Applications*, Prentice-Hall, Englewood Cliffs, New Jersey.

Goodbody, R. L., V. J. Monteleon, et al. 1976. "Navy Command Control and Communcations System Design Principles and Concepts, Volume I: C^3 Principles and Concepts." NELC TD 504 (August). Naval Electronics Laboratory Center, San Diego, CA.

Hitney, H. V., J. H. Richter, R. A. Pappert, K. D. Anderson, and G. B. Baumgartner, Jr. 1985. "Tropospheric Radio Propagation Assessment," *Proceedings of the IEEE, vol.* 73(2).

Hitney, H. V., A. E. Barrios, and G. E. Lindem. 1988. "Engineer's Refractive Effects Prediction Systems (EREPS) - Revision 1.00 User's Manual." NOSC TD 1342 (July). Naval Ocean Systems Center, San Diego, CA.

International Telephone and Telegraph Corporation. 1969. *Reference Data for Radio Engineers: Fifth Edition*, Howard W. Sams & Co., Inc., New York.

Ippolito, L., R. D. Kaul, and R. G. Wallace. 1989. "Propagation Effects Handbook for Satellite Systems Design: A summary of Propagation Impairments on 10 to 100 GHz Satellite Links with Techniques for System Design." NASA Reference Publication (PR) 1082(04). National Aeronautics and Space Administration, Washington, DC.

Ippolito, L. J. 1986. *Radio Propagation in Satellite Communications*, Van Nostrand Reinhold Company, New York.

Ivanek, F. 1989. *Terrestrial Digital Microwave Communications*, Artech House.

Johnson, R. C., and H. Jasik. 1984. *Antenna Engineering Handbook - Second Edition*, McGraw-Hill Book Company, New York.

Laws, J. O., and D. A. Parsons. 1943. "The relation of raindrop-size to intensity," *Transactions of American Geophysical Union, vol.* 24, pp 452-460.

Lucky, R. W., J. Salz, and E. J. Weldon, Jr. 1968. *Principles of Data Communication*, McGraw-Hill Book Company, New York.

Medhurst, R. G. 1965. "Rainfall attenuation of centimeter waves: Comparison of theory and measurement," *IEEE Transactions on Antennas and Propagation, AP*-13, July.

Olsen, R. L., D. V. Rodgers, and D. B. Hodge. 1978. "The aR^b Relation in the Calculation of Rain Attenuation," *IEEE Transactions on Antennas and Propagation, AP*-26, March.

* NOSC Technical notes are working documents and do not represent an official policy statement of the Naval Ocean Systems Center. For further information, contact the author.

REFERENCES (CONTINUED)

Panter, P. F. 1972. *Communication System Design: Line-of-sight and Tropo-scatter Systems*, McGraw-Hill Book Company, New York.

Patterson, W. L., C. P. Hatton, H. V. Hitney, R. A. Paulus, K. D. Anderson, and G. E. Lindem. 1987. "IREPS 3.0 User's Manual." NOSC TD 1151 (September). Naval Ocean Systems Center, San Diego, CA.

Patterson, W. L., C. P. Hatton, H. V. Hitney, R. A. Paulus, A. E. Barrios, G. E. Lindem, and K. D. Anderson. 1990. "Engineer's Refractive Effects Prediction Systems (EREPS) - Revision 2.00." NOSC TD 1342 (February). Naval Ocean Systems Center, San Diego, CA.

Stutzman, W. L., and W. K. Dishman. 1982. "A simple model for the estimation of rain-induced attenuation along earth-space paths at millimeter wavelengths," *Radio Science*, Volume 17, Number 6, November-December.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 1990

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
SUPER HIGH FREQUENCY (SHF) LINK ANALYSIS MODEL (SLAM) FOR NONSATELLITE APPLICATIONS

5. FUNDING NUMBERS
0602232N
R3211
DN300067

6. AUTHOR(S)
R. R. James and J. W. Rockway

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Ocean Systems Center
San Diego, CA 92152-5000

8. PERFORMING ORGANIZATION REPORT NUMBER
NOSC TR 1350

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Chief of Naval Research
Arlington, VA 22217

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report describes the principal algorithms used in the Super High Frequency (SHF) Link Analysis Model (SLAM) program, gives detailed descriptions of the various options of SLAM, and shows examples of typical SLAM applications.

14. SUBJECT TERMS
ship-to-air, air-to-ship, and ship-to-ship communications links
Engineer's Refractive Effects Prediction System (EREPS)
Surface Duct Summary (SDS)

15. NUMBER OF PAGES
67

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAME AS REPORT