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# FAA REMOTE TERMINAL SYSTEM

IIT Research Institute
Under Contract to
DEPARTMENT OF DEFENSE
Electromagnetic Compatibility Analysis Center
Annapolis, Maryland 21402

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FINAL REPORT

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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
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16. Abstract

A system of interactive analysis programs was developed by the Electromagnetic Compatibility Analysis Center (ECAC) for the Federal Aviation Administration (FAA). This system provides automated, quick-response capabilities for use by the FAA frequency managers to solve daily frequency management problems.

The system can be used to display records from the FAA Air Traffic Control (ATC) data base, provide electromagnetic compatibility (EMC) analyses, make frequency assignments, and plot service volumes. The typical program inputs and sample results are shown in the appendixes.

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# PREFACE

The Electromagnetic Compatibility Analysis Center (ECAC) is a Department of Defense facility, established to provide advice and assistance on electromagnetic compatibility matters to the Secretary of Defense, the Joint Chiefs of Staff, the military departments and other DoD components. The Center, located at North Severn, Annapolis, Maryland 21402, is under executive control of the Assistant Secretary of Defense for Communication, Command, Control, and Intelligence and the Chairman, Joint Chiefs of Staff, or their designees, who jointly provide policy guidance, assign projects, and establish priorities. ECAC functions under the direction of the Secretary of the Air Force and the management and technical direction of the Center are provided by military and civil service personnel. The technical operations function is provided through an Air Force sponsored contract with the IIT Research Institute (IITRI).

This report was prepared for the Systems Research and Development Service of the Federal Aviation Administration in accordance with Interagency Agreement DOT-FA76WAI-612, as part of AF Project 649E under Contract F-19628-78-C-0006, by the staff of the IIT Research Institute at the Department of Defense Electromagnetic Compatibility Analysis Center.

To the extent possible, all abbreviations and symbols used in this report are taken from American Standard Y10.19 (1967) "Units Used in Electrical Science and Electrical Engineering" issued by the USA Standards Institute.

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# METRIC CONVERSION FACTORS

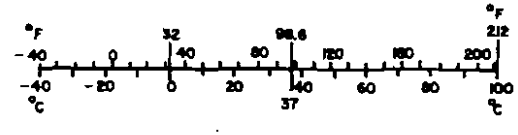
## Approximate Conversions to Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



## FEDERAL AVIATION ADMINISTRATION
## SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
## SPECTRUM MANAGEMENT STAFF

### STATEMENT OF MISSION

The mission of the Spectrum Management Staff is to assist the Department of State, Office of Telecommunications Policy, and the Federal Communications Commission in assuring the FAA's and the nation's aviation interests with sufficient protected electromagnetic telecommunications resources throughout the world to provide for the safe conduct of aeronautical flight by fostering effective and efficient use of a natural resource--the electromagnetic radio-frequency spectrum.

This objective is achieved through the following services:

- Planning and defending the acquisition and retention of sufficient radio-frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.

- Providing research, analysis, engineering, and evaluation in the development of spectrum related policy, planning, standards, criteria, measurement equipment, and measurement techniques.

- Conducting electromagnetic compatibility analyses to determine intra/inter-system viability and design parameters, to assure certification of adequate spectrum to support system operational use and projected growth patterns, to defend the aeronautical services spectrum from encroachment by others, and to provide for the efficient use of the aeronautical spectrum.

- Developing automated frequency-selection computer programs/routines to provide frequency planning, frequency assignment, and spectrum analysis capabilities in the spectrum supporting the National Airspace System.

- Providing spectrum management consultation, assistance, and guidance to all aviation interests, users, and providers of equipment and services, both national and international.

# EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) required an analysis tool that would assist the FAA frequency managers in solving daily frequency management problems. The analysis tool had to provide quick response and the flexibility to be adapted to an FAA computer. This report describes a package of analysis programs satisfying the above criteria that was developed on the Electromagnetic Compatibility Analysis Center's (ECAC) UNIVAC 1110 computer and executed from remote terminals at ECAC. These capabilities are available to the FAA through a mode of operation that requires the user to request an analysis from ECAC via telephone or telecopier. Personnel at ECAC utilize the programs to perform analyses and then return the results via telecopier or telephone.

The included programs provide electromagnetic compatibility (EMC) analyses, FAA data base retrieval and display, cosite analysis, frequency assignments, and graphic analyses. These programs operate in conjunction with an FAA-supplied data base which is maintained by ECAC.

The data base is developed from the Interdepartment Radio Advisory Committee's Government Master File (IRAC GMF) and the Adaptation Controlled Environment System (ACES) data tapes that are periodically produced by the FAA Air Route Traffic Control Centers.

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# GLOSSARY OF ACRONYMS

| | |
|---|---|
| ACES | - Adaptation Controlled Environment System |
| ARINC | - Aeronautical Radio, Inc. |
| ARTCC | - Air Route Traffic Control Center |
| ATC | - Air Traffic Control |
| BLOS | - Beyond Line-of-Sight |
| DFSRF | - Distance to Maximum Free Space and Reflection Field |
| ECAC | - Electromagnetic Compatibility Analysis Center |
| EFFDBL | - Effective Double Knife-Edge Loss |
| EFFKE | - Effective Knife Edge |
| EMC | - Electromagnetic Compatibility |
| EPM-73 | - Empirical Propagation Loss Model |
| FAA | - Federal Aviation Administration |
| FCC | - Federal Communications Commission |
| IM | - Intermodulation |
| IPS | - Integrated Propagation System |
| IRAC GMF | - Interdepartment Radio Advisory Committee Government Master File |
| KEBLS | - Knife Edge Beyond Line-of-Sight |
| LOS | - Line-of-Sight |
| RED | - Rough Earth Diffraction |
| SCSE | - Smooth Curve Smooth Earth |
| SSV | - Standard Service Volume |
| STGW-1 | - Simplified Theoretical Groundwave |
| TCV | - Tailored Circular Volume |
| TIREM | - Terrain Integrated Rough Earth Model |
| TROSC | - Tropospheric Scatter Loss |
| TSV | - Tailored Service Volume |
| VHF | - Very High Frequency (118-136 MHz) |
| YEH | - Yeh Troposcatter |

# GLOSSARY OF TERMS

| | |
|---|---|
| Actual Frequency | - the frequency in MHz that is presently being used for the ATC requirement. |
| Air Traffic Control (ATC) Function | - communication responsibility of each site (e.g., high en route). |
| ATC Requirement | - the requirement for an air traffic control frequency, in order to serve an ATC function at a specific site. |
| Background ATC Assignment | - an ATC assignment whose assigned frequency is not a candidate for reassignment by the assignment system (e.g., a Canadian assignment). |
| Background File | - a file containing frequency assignments that can contribute interference to FAA ATC frequency assignments and therefore must be considered in the assignment process. |
| Combined File | - a file containing data on each FAA ground-to-air communications ATC requirement and the service volume associated with each ATC requirement. |
| Default Value | - the value of a parameter which is automatically used by a model should the value not be specified by the user. |
| Desired-to-Undesired Signal Ratio (D/U) | - the ratio of desired-to-undesired signal. |
| IRAC GMF ID | - a 6-digit identifier placed in each Government Master File record by the agency utilizing the frequency assignment. |
| Link Number | - an identifier associating those ATC requirements that must be assigned identical frequencies. Such requirements are called "selective keyed" requirements. |
| Master File | - a file containing information that is subject to a well-defined updating and verification process. |

GLOSSARY OF TERMS (Continued)

| | |
|---|---|
| On-Line | - data or programs that are always available on demand within the computer. |
| Operational Year | - the activation date for a given requirement. |
| Ordering | - the process of sorting and sequencing requirements. |
| Pre-Assigned ATC Requirement | - a definite FAA frequency assignment that will not be changed. |
| Protection Criteria | - the desired-to-undesired (D/U) signal ratio that is the minimum ratio to be provided for ATC requirements. |
| Remote Terminal | - a device that is connected to a computer via cables or telephone lines and permits the computer to be used without any direct physical contact; commonly used with time-shared computers. |
| Remote Terminal System | - a computer system wherein the user (FAA) communicates with personnel at ECAC via a telephone or telecopier; these personnel then use the ECAC computer to perform the analyses. |
| Service Volume | - the geometrical volume associated with each ATC site for which radio coverage is provided. Also referred to as Sector. |
| Tailored Service Volume (TSV) | - a file containing a description of the perimeter boundary for each multi-point ATC service volume. |

# SECTION 1

# INTRODUCTION

## BACKGROUND

The Federal Aviation Administration (FAA) required a quick response frequency management system that would permit the FAA frequency management community to use the Electromagnetic Compatibility Analysis Center (ECAC)-developed electromagnetic compatibility (EMC) analysis and VHF frequency assignment programs and the ECAC-maintained FAA VHF air traffic control (ATC) data base. ECAC investigated typical computer configurations that could be used to provide this frequency management system.[1] The report recommended that the FAA regions be provided direct access to an FAA purchased/leased minicomputer located at and operated by ECAC. In addition, it was proposed that in the interim (Phase 1) a quick response capability be developed to provide an analysis package developed by ECAC on the UNIVAC 1110 computer.

This report describes the ECAC-developed remote terminal capability and the supporting data base system. The appendixes list the specific data requirements for each analysis capability and show examples of typical output.

## OBJECTIVE

The objective was to provide a quick response package of analysis capabilities for use by the FAA.

---

[1]Bode, T. J., *Investigation of Methods for Providing FAA Remote Terminal Capabilities for VHF ATC Frequency Management*, ECAC-PR-74-056, ECAC, Annapolis, MD, November 1974 (draft).

## APPROACH

The approach was divided into two steps: first, to determine capabilities that would be of use to the FAA and second, to program these capabilities on the UNIVAC 1110 Remote Terminal System at ECAC. The selection of capabilities was accomplished by reviewing FAA ATC capabilities developed under contract DOT-FA70WAI-175, Task 14.[2,3] To solve large scale VHF assignment problems, these capabilities were developed to generate new assignment plans and to analyze existing assignments. Present ECAC remote terminal analysis capabilities were also reviewed to determine the models that should be included among the FAA capabilities. Those capabilities proposed for the Remote Terminal System were reviewed and approved by the FAA.

Implementation of the selected capabilities involved the modification of existing programs and the development of new capabilities. Most ECAC analysis capabilities required only a limited reprogramming effort to be incorporated into the FAA Remote Terminal System. The frequency assignment programs and the data retrieval and display capabilities, were completely redesigned to conform to the requirements of a quick response Remote Terminal System. In addition, several new data files were constructed to increase the efficiency of remote terminal operation.

A graphic capability is an added feature of the FAA Remote Terminal System. Through the use of a Tektronix Model 4014-1 terminal, it is possible to plot ATC service volumes and the terrain profile between specified locations.

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[2]Beall, L., et al, *An Automated FAA Air Traffic Control Frequency Assignment Model*, FAA-RD-73-184, ECAC, Annapolis, MD, December 1973.

[3]Hensler, T., *Automated VHF Frequency Assignment System (FAS) For Air Traffic Control Communications*, FAA-RD-76-14, ECAC, Annapolis, MD, February 1976.

# SECTION 2

# REMOTE TERMINAL SYSTEM DESCRIPTION

## GENERAL DESCRIPTION

The capabilities that constitute the FAA frequency management Remote Terminal System are divided into four areas:

1. EMC support routines
2. FAA data analysis
3. Frequency assignment and cosite analysis
4. Graphic analyses.

The routines in each of the four analysis areas are subsequently described.

The Remote Terminal System is supported by an FAA-supplied data base and the ECAC Topographic File. The analysis programs permit the user to experiment with changes and updates in relationship to existing or modified ATC requirements. All such changes are temporary program-handled modifications and do not actually alter the data base.

The FAA data is selected from the Interdepartment Radio Advisory Committee Government Master File (IRAC GMF) and the Adaptation Controlled Environment System (ACES) data tapes which are periodically produced by the FAA centers. For the purposes of the Remote Terminal System, this data is organized into three files.

1. Tailored Service Volume (TSV) File - gives a description of the perimeter boundary for each multipoint ATC service volume.
2. Combined File - contains data on each FAA ATC communications requirement and its associated service volume.

3. Background File - describes frequency assignments that may interfere with ATC frequency assignments and therefore must be considered in the assignment process. A more detailed description of these data files and the Topographic File is given in Section 3.

## ELECTROMAGNETIC COMPATIBILITY (EMC) SUPPORT ROUTINES

The four EMC support routines are as follows:

1. Intermodulation and harmonic analysis
2. Airframe coupling loss prediction
3. Bearing and distance calculation
4. Propagation loss prediction.

APPENDIX A gives instructions for the use of these programs.

### The Intermodulation and Harmonic Analysis Routine

This program searches transmitter and receiver frequency lists for potential intermodulation and harmonic problems. Intermodulation analysis may be performed for any combination of two-signal second- , third- , fifth- , seventh-orders, and three-signal, third- and fifth-orders. Harmonic analysis may be performed up to the ninth-order.

The user may input both transmitter and receiver lists or only a transmitter list for simplex transceivers. The program returns intermodulation-free transmitter and receiver lists or an intermodulation-free transceiver list. The user may force specified frequencies to be included in the final intermodulation-free list(s). A discussion of the equations (and variables) used in this routine is given in APPENDIX H.

## The Airframe Coupling Loss Prediction Routine

This routine calculates the theoretical transmission path loss between two points on or near the surface of a conventional airframe.[4] The two points represent the locations of two isotropic antennas with respect to a fuselage. The fuselage is assumed to be a perfectly conducting right circular cylinder or in some instances, a conical section.

The data required to use the routine includes a description of the fuselage, the locations of the antennas, and the frequency. The transmitter frequency must be greater than or equal to 30 MHz. An option permits the inclusion of a bulkhead that may obstruct the transmission path between the antennas. A detailed description of this routine is given in APPENDIX I.

## Bearing and Distance Calculation Routine

This program calculates the great circle distance between two points on the earth's surface and the bearing to each point from the other, relative to true north. The user provides the latitudes and longitudes of the points of interest, or the IRAC identifications (ID's) of the sites; distance and bearing are returned.

## Propagation Loss Prediction Routines

These routines combine the capabilities of four propagation models: TIREM, IPS, NLAMBDA and EPM-73. These models are discussed in detail in APPENDIX E.

The user determines the appropriate model to be used in the calculation of the predicted loss depending upon the parameters of the

[4]Dwyer, P. A., *A Model to Predict Mutual Interference Effects on an Airframe*, FAA-RD-76-050, ECAC, Annapolis, MD, October 1976.

particular problem. It also requires a large number of input values. Many of these values, particularly the ground and atmospheric constants, are preset in the program, but may be changed during the run. Required input values are as follows: transmitter and receiver locations (or path distance), IRAC ID's, antenna height, site elevations, and frequency.

Path loss in dB for each of the four models and transmitter and receiver effective antenna heights are returned by the program.

Some general guidelines regarding model selection are presented below.

TIREM is recommended whenever all of the following conditions are met.

1. The frequency is in the 40 MHz-20 GHz band.
2. The actual locations of the transmitter and receiver are known. (If one of the terminals is mobile, a series of locations can be used.)
3. Terrain information is available, either from the automated topographic data base or in the form of contour maps from which profiles can be extracted.
4. Antenna heights are between 10 and 10,000 feet.

EPM-73 is recommended whenever all of the following conditions are met.

1. TIREM cannot be used because: frequency restraints prevent it, the circuit end points are not known, or because no terrain information is available.

2. The predicted effects of moderately irregular ("rolling plains") terrain on path loss are desired.

3. The frequency is between 1 MHz and 10 GHz.

4. Antenna heights are less than 3 km.

NLAMBDA and IPS should be used whenever any of these three situations exists.

1. The path between the transmitter and the receiver is over very smooth terrain, e.g. a lake or flat plain.

2. The user desires a solution to the classical problem of propagation over a smooth spherical earth.

3. Neither TIREM nor EPM-73 can be applied. This may be because: the circuit end points are not known, or terrain information is not available, or the frequency is too low (NLAMBDA useful as low as 100 kHz) or the antenna heights are too high. (NLAMBDA and IPS are used with heights up to 100,000 feet.)

The choice between using IPS and NLAMBDA is generally arbitrary. Some features that may aid the selection are:

1. NLAMBDA is useful from 100 kHz to 20 GHz. IPS applies from 1 MHz to 20 GHz.

2. Below 50 MHz, NLAMBDA can give predictions for a higher range of antenna heights than IPS. The specific limits are a function of frequency and path distance.

3. IPS uses less computer time.

4. IPS has the "envelope option." (See APPENDIX E, FIGURE E-3.)

## FAA DATA ANALYSIS ROUTINES

There are four routines that display data or analyze the FAA VHF ATC data base:

1. The Combined File Select and Display Routine
2. The TSV File Select and Display Routine
3. The Desired-to-Undesired Signal Ratio (D/U) Routine
4. The Background File Select and Display Routine.

Instructions for the use of these programs are given in APPENDIX B.

### The Combined File Select and Display Routine

This routine selects and displays the records that comprise the FAA ATC requirements as entered in the IRAC file. The select parameters that may be used to display the requirements are shown below.

IRAC ID
Frequency
FAA region
Air traffic control (ATC) function
Operating agency
State (for non-en route requirements)
Air Route Traffic Control Center (ARTCC) (for en route requirements)
Service volume parameters (radius and/or altitude)

These select parameters may be used in combinations to display specified records. Typical examples of select combinations are all approach control requirements in a given state or all low en route requirements in a given FAA region.

## The Tailored Service Volume (TSV) File Select and Display Routine

This routine displays the latitude and longitude points that describe the multipoint service volumes served by the en route FAA requirements. The routine also displays the latitude and longitude of the estimated TSV center, and the radius of the circle which circumscribes the TSV. TSV records may be selected for display in one of three ways by: the IRAC ID of the specific record, the FAA center and sector number, or the TSV ID contained in the requirement file records. If a requirement is selected that has no multipoint TSV, the receive center latitude and longitude and the service volume radius are displayed.

## The Desired-to-Undesired Signal Ratio (D/U) Routine

This program calculates the D/U between all pairs of requirements on the same frequency. The requirements may consist of existing and/or proposed assignments. Proposed assignments in the analysis provide an automated method for validating these assignments prior to formal submission.

The D/U calculations may be made using any one of three options. The closest-point option calculates the D/U using the point on the victim's circular service volume that is closest to the interferer's service volume. The worst-case point option calculates the D/U using the point on the victim's circular service volume that yields the minimum D/U. Finally, the multipoint option applies only to those requirements that have multipoint (noncircular) service volumes, namely en route requirements. This option uses the vertices of the TSV as a series of "worst-case" points to determine the minimum D/U. When the multipoint option is chosen, the user must choose between



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the closest-point and the worst-case point options for the circular service volumes. The D/U calculations for each requirement pair are made by treating each requirement alternately as victim and interferer. The worst-case point calculations are discussed in APPENDIX F.

### The Background File Select and Display Routine

This routine displays all frequencies in the Background File within a specified area. The circular area is defined by a center point and a radius. If interference problems exist at an FAA site, the site coordinates and specified radius value would yield the Background File frequencies in use within that area. Additional analyses could then be performed on these frequencies using the Intermodulation and Harmonic Analysis Routine. See Section 3 for a summary of the files available for display and the sources of the data.

## FREQUENCY ASSIGNMENT AND COSITE ANALYSIS PROGRAM

The Frequency Assignment and Cosite Analysis Program is designed to handle the addition or reassignment of up to 10 requirements, given an existing assignment plan. To modify the background environment, requirements in the data base may be added, deleted, or modified. This gives the user flexibility with the data base that might be necessary to make new assignments among closely-packed existing assignments. Cosite and intersite analyses are performed on each requirement to be assigned. Instructions for the use of this program are shown in APPENDIX C.

The cosite analysis is used to assure that the new assignment will not receive interference on the ground (transmitter site) from facilities at or very near the same location. The intersite analysis is used to provide protection from distant aircraft and ground sites. The results of both analyses must meet the criteria for an assignment to be acceptable.

## Cosite Analysis

The cosite analysis is performed for each site to be assigned a new frequency. For the cosite analysis, potential intermodulation, harmonic and adjacent-signal interference are considered. Frequencies used in the analysis are selected from the Background File. Intermodulation calculations are the third-order two-signal type considered by the FAA to be the most likely intermodulation annoyance to ATC facilities. Frequencies in the intermodulation analysis include FM radio and television station frequencies, administrative and emergency frequencies, and in-band (118-136 MHz) military frequencies. As an option, third-order three-signal intermodulation can be considered by the model when at least one of the signals is a continuously operating transmitter, such as a television station.

Harmonic analysis is performed on UHF (225-400 MHz) frequencies. Selected transmit and receive frequencies used within a specified distance (2 nmi for all frequencies except for broadcast stations where 15 nmi is used) of each ATC site are considered in the intermodulation and harmonic analysis.

For adjacent-signal analysis, possible interfering assignments are denied by making a geographical select of collocated equipments at each ATC site and eliminating candidate frequencies within a specified guard band (500 kHz) of any assigned frequency in the 117.5-136.5 MHz band. These analyses are shown in a summary chart that indicates for each specified resource frequency the availability for assignment or the reason for which it was rejected.

## Intersite Analysis

The intersite analysis is performed after the cosite analysis. All requirements on or adjacent to each of the remaining specified

resource frequencies are used in the intersite analysis. Both co-channel and adjacent-channel constraints must be met before an assignment is made. These constraints are specified by the user, guidelines for which may be found in an FAA handbook.[5] The co-channel test can be performed in a probabilistic manner in which probability of simultaneous transmissions is considered in the calculations. As requirements are assigned new frequencies, the environment is updated before the next requirement undergoes the cosite and intersite analyses. These file changes and updates are made in temporary files that are kept only for the duration of the program execution. Changes to the permanent files result only from changes in the GMF IRAC and ACES tape files. A more detailed description of the intersite analysis is given in APPENDIX F.

## GRAPHIC ANALYSES

There are two programs that provide a graphic output to the user. These programs are the TSV Plot Program and the Point-to-Point Terrain Analysis Program. Instructions for the use of these programs, the data required of the user, and typical results are shown in APPENDIX D.

### TSV Plot Program

This program plots tailored service volumes used by the FAA ATC requirements. There are four options available. The first option will plot the service volume requested by a user-specified TSV ID. The second option plots all service volumes for requirements using the same frequency. The third option plots the service

[5]Federal Aviation Administration, *VHF-UHF Air/Ground Communications Frequency Engineering Handbook*, Washington, DC, June 1965.

volume for a selected FAA ATC requirement specified by IRAC ID. For a given FAA region or center, the fourth option plots all multipoint service volumes used for a specific type of ATC function. If desired, the second and third options will also plot the FAA ground site location with the service volume. All plots include a background map of the political boundaries of the United States.

Point-to-Point Terrain Analysis Program

This routine plots the terrain profile between any two user-specified sites. A linear plot can be made showing the actual elevation along the profile or a spherical plot can be chosen showing the effect of the refractivity of the atmosphere on the path of the radio waves. The user provides a pair of points by entering two specific coordinates or two IRAC ID's. Antenna heights for each location may also be considered. The output consists of a profile plot of the terrain indicating the line-of-sight point. Elevations at various distances from the sites are also provided. APPENDIX G explains in detail the methods used to generate profiles and determine the line-of-sight.

# SECTION 3

## FAA REMOTE TERMINAL DATA BASE AT ECAC

The Remote Terminal System's data base consists of four distinct data files: the TSV File, the Combined File, the Background File, and the ECAC Topographic File. Each of these files is discussed in detail below.

### TAILORED SERVICE VOLUME (TSV) FILE

The TSV File contains specific service-volume data for FAA-controlled sectors. This data includes latitude and longitude point descriptions used to describe sectors. The multipoint sector data is derived from the Adaptation Controlled Environment System (ACES) tapes that are provided by the FAA centers on a periodic basis. Data representing geographical nodes is combined to form sectors that are defined by a series of latitude and longitude points. These sectors become the TSV's used by the programs. Each record in the TSV file contains the following data items:

1. TSV ID - unique identification for each record
2. Number of points - number of points describing the TSV polygon (maximum = 25)
3. Center latitude - latitude for the center of the circle that encloses the TSV, in seconds
4. Center longitude - longitude for the center of the circle that encloses the TSV, in seconds
5. Radius - radius for the circle that encloses all of the TSV points, in statute miles (converted to nautical miles by the programs)
6. Latitude/longitude points - points corresponding to the vertices of the TSV polygon

7. Sector name - six-character descriptor from ACES tape.

8. Sector use code - single-character identifier indicating sector use (e.g., H = high altitude, L = low altitude).

COMBINED FILE

The Combined File contains all information pertinent to the VHF ATC requirements in the 118-136 MHz band. The data in each record is listed below:

1. Requirement ID - an ECAC-generated identification
2. Site/terminal name - the name of the site in the GMF data file
3. Site latitude - geographic site latitude, in seconds
4. Site longitude - geographic site longitude, in seconds.
5. TSV ID - an identification link to the TSV File
6. ATC function - a one-character function descriptor (e.g., H = high, A = approach control)
7. Altitude - height above sea level, in thousands of feet
8. Operational year - year of activation
9. Channel number - channel number corresponding to Item 15
10. Sort key - a value placed in the file to permit sorting the file by ATC function
11. Link number - an identifier associating those requirements that must be assigned identical frequencies (selective keyed requirements)
13. D/U - the specified minimum ratio of desired-to-undesired signal (desired protection criteria), in dB

14. Date of latest entry - year, month, day

15. Background/preassigned frequency - the frequency (Item 16) for a requirement that is to be considered as preassigned by the assignment system, in MHz

16. Actual frequency - the actual frequency that is presently being used to satisfy this requirement, in MHz

17. Operating agency - a one-character agency descriptor (e.g., A = FAA, C = Canadian)

18. Service volume radius - the radius of the circular service volume as shown in the GMF, in nautical miles

19. GMF Identification (GMF IRAC ID) - the agency serial number taken from the GMF data file

20. Receiver latitude - geographic service volume center latitude, in seconds

21. Receiver longitude - geographic service volume center longitude, in seconds

22. Region code - a code placed in the file to permit sorting the file by FAA region

23. Radius - radius of circular service volume, in nautical miles

24. Number of points - number of points that describe the TSV polygon (maximum = 25)

25. Center latitude - latitude for the center of the circle that encloses the TSV, in seconds

26. Center longitude - longitude for the center of the circle that encloses the TSV, in seconds

27. Radius - radius for the circle that encloses all of the TSV points, in statute miles (converted to nautical miles by the programs)

28. Latitude/longitude points - points that describe the TSV polygon

29. Sector name - six-character descriptor from ACES tape

30. Sector use code - single-character identifier indicating sector use (e.g., H = high altitude, L = low altitude).

A major concern with an on-line computer system is file-accessing speed. The Combined File is ordered by frequency, and has two indices that curtail lengthy file searches and improve system response time.

The first index lists the frequency and record location of every 100th requirement in the file to expedite frequency searches. The second index table gives the GMF IRAC ID and its record location. Since these ID's are in numerical sequence, the location of a specific record in the file using the GMF IRAC ID is a relatively simple process.

BACKGROUND FILE

The Background File contains all existing frequency assignments that are considered in the cosite analysis. Frequency data from the three sources listed below are used to develop the file.

FCC: 54-72 MHz, 76-108 MHz, and 174-216 MHz (FM and TV broadcast bands)

ARINC: 108-136 MHz

GMF: 108-136 MHz and 215-410 MHz

Since part of the cosite analysis requires collection of all frequencies within a specified distance of the ATC site, quick access by site location is a requirement. Therefore, the records are

ordered by longitude and are referenced via a longitude index table appended to the file. The records in this file contain only frequency, latitude, longitude and an identifier. The identifier is composed of the GMF IRAC ID (for records from the GMF file), the ATC function code, and the operating agency code.

## TOPOGRAPHIC FILE

ECAC's Topographic File contains digitized terrain elevations for the continental United States (CONUS). The file is based on a spherical-coordinate system designed to accommodate data of variable grid spacing. The data has a grid spacing of 30 seconds (approximately ½ mile between data points), and consists of latitude, longitude, and elevation values. However, foilage and man-made structures are not included in this file. Terrain elevations are also available for Hawaii and portions of Alaska.

## SUMMARY OF FILES

The data below lists the frequency bands available for display using the data analysis routines.

| Frequency Band (MHz) | Data Source | Data File |
|---|---|---|
| 54-72 | FCC | Background |
| 76-108 | FCC | Background |
| 108-136 | GMF | Background |
| 118-136 (U.S.) | GMF | Combined |
| 118-136 (Canada) | Canadian Tape | Combined |
| 118-136 (Mexico) | ICAO[a] | Combined |
| 108-136 (ARINC) | ARINC Tape | Background |
| 174-216 | FCC | Background |
| 215-410 | GMF | Background |

[a]International Civil Aviation Organization.

# SECTION 4

## RESULTS

The FAA VHF Remote Terminal System provides quick response for analyses that are related to FAA air traffic control (ATC) functions. The analysis is performed at ECAC in response to FAA requests that are communicated to ECAC via telephone or telecopier; results are returned in the same way. The system consists of a group of computer programs that incorporate the following capabilities:

1. Generate frequency assignments for new or existing requirements. These assignments meet all cosite and intersite constraints and are compatible with the existing environment.
2. Select and display records from the FAA data base.
3. Provide an analysis of new and existing assignments by calculating D/U's.
4. Provide EMC analyses at FAA sites by calculating intermodulation products, terrain profiles, and propagation path losses.
5. Provide plots of the terrain profiles and the service volumes controlled by the FAA sites.
6. Provide a system that can be easily expanded to include additional analysis capabilities.

# APPENDIX A

## ELECTROMAGNETIC COMPATIBILITY (EMC) ANALYSIS PROGRAM

The EMC Analysis Program is comprised of four separate routines:

1. Intermodulation and Harmonic Analysis Routine
2. Airframe Coupling Loss Routine
3. Bearing and Distance Routine
4. Propagation Loss Prediction Routine.

Depending on the routine the user selects to run, certain data inputs are required to perform the analyses. The required as well as the optional data inputs are listed for each routine.

### INTERMODULATION AND HARMONIC ANALYSIS ROUTINE

The Intermodulation and Harmonic Analysis Routine provides an intermodulation-free list of frequencies. If the user enters both receivers and transmitters, two intermodulation-free lists are produced. APPENDIX H lists all equations in the Intermodulation and Harmonic Analysis Routine and explains the variables used in the equations.

#### Required Data Inputs

1. Transmitter frequency list and number of frequencies in list
2. Receiver frequency list and number of frequencies in list (if not transceivers)
3. Calculations desired: intermodulation products, harmonic order or both
4. Epsilon (usually one half of the IF bandwidth) - default value is 0.0 MHz.

Optional Data Inputs

1. Delta (maximum frequency separation)[a]
2. Gamma (maximum fraction of receiver frequency)[a]
3. Desire to print intermodulation problem list.

AIRFRAME COUPLING LOSS ROUTINE

The Airframe Coupling Loss Routine gives the path loss between any two points on an airframe.

Required Data Inputs

1. Frequency (MHz), must be greater than 30 MHz
2. Maximum fuselage radius (in feet or inches)
3. Height (antennas 1 and 2) with respect to fuselage centroid (feet or inches)
4. Angle (antennas 1 and 2), position of the point with respect to the vertical stabilizer, referenced in a clockwise direction in the front view (degrees)
5. Z-axis (antennas 1 and 2) location along fuselage centroid (feet or inches).

Optional Data Input

Airframe bulkhead

Z-axis location along fuselage centroid (feet or inches)
Height with respect to fuselage centroid (feet or inches)

[a]Default value is 0.0 MHz.

## BEARING AND DISTANCE ROUTINE

The Bearing and Distance Routine yields the great circle distance between any two points and the bearing (relative to true north) from each point to the other. The required data input is IRAC ID or latitude/longitude (transmitter and receiver).

## PROPAGATION LOSS PREDICTION ROUTINE

There are four propagation models included in this routine: Terrain Integrated Rough Earth Model (TIREM), Integrated Propagation System (IPS), NLAMBDA Ground Wave Model, and the Empirical Propagation Loss Model (EPM-73). All models provide the user with the predicted propagation path loss between any two locations.

APPENDIX E explains the calculations used to determine the propagation path loss by each of the four models.

### Required Data Inputs For All Propagation Models

1. IRAC ID or latitude/longitude (TX and RX or path distance)
2. Antenna height (TX and RX)
3. Site elevation (TX and RX)
4. Frequency MHz (TX only)
5. All inputs in English or Metric.

### Optional Data Inputs For All Propagation Models

The optional data input that applies to all propagation models is antenna aperture size.

Required Data Inputs for TIREM

1. Permittivity (default value is 15)
2. Refractivity (default value is 301)
3. Conductivity (default value is .0278 mho-m/$m^2$)
4. Humidity (default value is 10 g/$m^3$)
5. Topographic area (default is CONUS)
6. Polarization (default value is vertical).

Required Data Inputs for IPS and NLAMBDA

1. Permittivity (default value is 15)
2. Refractivity (default value is 301)
3. Conductivity (default value is .0278 mho-m/$m^2$)
4. Polarization (default value is vertical).

Required Data Inputs for EPM-73

1. Terrain type (default value is rolling plains)
2. Polarization (default value is vertical).

The default values shown for input parameters in TIREM and IPS are representative values for the U.S. If available, more accurate values should be used. The atmospheric refractivity ($N_s$) value is calculated using:

$$N_s = N_o \exp(-0.1057 h_s) \qquad \text{(A-1)}$$

where

$N_o$ = refractivity reduced to sea level

$h_s$ = terrain elevation, in km.

Absolute humidity values can be determined using data from the weather bureau or from world weather charts.

TABLE A-1 lists typical values of permittivity and electrical conductivity.

TABLE A-1

TYPICAL VALUES OF RELATIVE PERMITTIVITY AND ELECTRICAL CONDUCTIVITY

| Earth Surface Type | Permittivity (numeric) | Conductivity $\left(\frac{\text{mho-m}}{\text{m}^2}\right)$ |
|---|---|---|
| Marsh Land | 30 | .111 |
| Average Land | 15 | .0278 |
| Desert Land | 3 | .0111 |
| Fresh Water | 81 | .005 |
| Tundra | 5 | .0004 |
| Artic Ice | 3 | .000025 |
| Sea Water | 81 | 4.64 |
| Jungle Earth Characteristics | | |
| Poor | 10 | .002 |
| Medium | 13 | .01 |
| Good | 15 | .03 |

# APPENDIX B

## FAA REMOTE TERMINAL DATA BASE PROGRAM

The FAA Remote Terminal Data Base Program contains four separate routines.

1. IRAC GMF File Select and Display Routine
2. Desired-to-Undesired Signal Ratio (D/U) Calculation Routine
3. Tailored Service Volume (TSV) File Select and Display Routine
4. Background File Select and Display Routine.

The data inputs for each of the routines are listed below.

### IRAC GMF FILE SELECT AND DISPLAY ROUTINE

Any or all records contained in the IRAC GMF file can be examined. If in the select, more than 15 records result from the option chosen, the records may be sent to an on-site printer. Fifteen or less records will be displayed on the remote terminal. The select options are as follows:

1. Specific IRAC ID
2. Frequency
3. FAA regions
4. Air Traffic Control (ATC) function
5. Operating agency
6. State
7. Air Route Traffic Control Center (ARTCC)
8. Service volume parameters (radius and/or altitude)
9. CONUS environment only.

## DESIRED-TO-UNDESIRED SIGNAL RATIO (D/U) CALCULATION ROUTINE

The user must first specify the requirements by indicating a frequency and an IRAC ID or a latitude/longitude, service volume type, frequency, and a site name. If a TSV is used, the center and sector number must be given. The user receives all requirements, on the specified frequency, that fail to meet the criteria D/U value. This value can be changed by the user from its default value of 14 dB.

## TAILORED SERVICE VOLUME (TSV) FILE SELECT AND DISPLAY ROUTINE

This routine selects and then displays the latitude and longitude points that describe the sector. The select parameters are:

1. Air Route Traffic Control Center (ARTCC)
2. IRAC ID
3. TSV ID.

If the first parameter is selected, the user must input center name and sector number.

## BACKGROUND FILE SELECT AND DISPLAY ROUTINE

All records in the Background File within the radius of the point selected are displayed to the user.

The select parameters for this program are:

1. Latitude/longitude
2. Radius
3. Frequency range.

The radius parameter default value is 15 nautical miles and the frequency parameter defaults to all frequencies available in the Background File.

# APPENDIX C

## FREQUENCY ASSIGNMENT/COSITE PROGRAM

The Frequency Assignment/Cosite Program provides the user with a cosite analysis for the site chosen and a frequency assignment for the site that meets all the specified criteria. This program allows the user to *add*, *delete*, or *modify* records to the FAA requirement file before proceeding with the assignment process. Cosite analyses about a specified site may be performed if an assignment is not desired. Requirement inputs for each type of file modification as well as the cosite and assignment parameters are listed below. APPENDIX F explains the intersite analysis used by this assignment program.

To delete records, use:

1. IRAC ID
2. Agency Code, if not an FAA record.

To modify or add records, use:

1. IRAC ID or unique site name (for non-IRAC records)
2. Site ID
3. Frequency (in MHz)
4. Site latitude (degrees, minutes, seconds)
5. Site longitude (degrees, minutes, seconds)
6. Receiver latitude (degrees, minutes, seconds)
7. Receiver longitude (degrees, minutes, seconds)
8. ATC function abbreviation
9. Altitude (thousands of feet)
10. Service volume radius (nautical miles)
11. TSV ID.

COSITE PROTECTION CRITERIA

1. Radius of concern for non-Federal Communications Commission (FCC) background records to be treated in the harmonic and intermodulation analysis (nautical miles)--default value is 2 nmi

2. Radius of concern for FCC background records to be treated in the harmonic and intermodulation analysis (nautical miles)--default value is 15 nmi

3. Intermodulation analysis types to be performed (2- or 3-signal)--default value is 2-signal

4. Radius of concern for all background records to be treated in the adjacent-signal analysis (nautical miles)--default value is .2 nmi

5. Adjacent-signal protection bandwidth (kHz)--default value is 500 kHz.

INTERSITE PROTECTION CRITERIA

1. Type of cochannel analysis desired (default is multipoint)

   a. Multipoint
   b. Circular-worst case point
   c. Circular-closest point

2. D/U ratios to be used by ATC function (default values are 14 dB except ATIS is 12 dB)

3. ATC functions using probability (default is none)

4. Probability values (if 3 is nonblank)

5. ATC functions eligible for 25 kHz assignment (default is none)

6. Adjacent-channel criteria

   a. Adjacent-channel service volume separation (default value is 2 nmi)

b. D/U protection value for a mixed environment (default value is 14 dB)

c. dB rejection assumed for 25 kHz off-tuning (default value is 6 dB).

FREQUENCY RESOURCE DEFINITION

1. Channelization desired (25, 25 & 50, 50, 50 & 100, or 100 kHz)--default value is 50 kHz

2. Frequency range(s) available, in MHz

3. Specific frequencies, in MHz.

Both the second and third options may be used.

RECORD SELECTION FOR ASSIGNMENT/COSITE ANALYSIS

1. Next record to be assigned by IRAC ID or site ID

2. IRAC ID's and/or site ID's of those records in a net, if this option is chosen for assignment

3. Next record for which a cosite analysis is to be performed by IRAC ID or site ID.

# APPENDIX D

# GRAPHICS PROGRAMS

## TAILORED SERVICE VOLUME (TSV) PLOT PROGRAM

The TSV Plot Program provides to the user any one of the four plots listed below, depending on the selected option.

1. All service volumes for requirements using the same frequency (see FIGURE D-1).
2. The multipoint service volumes for a given FAA region or center (see FIGURE D-2).
3. Any service volume requested by the user.
4. The service volume used by an FAA ATC requirement.

### Required Data Inputs

OPTION 1. frequency (MHz)
OPTION 2. FAA region(s) or center(s)
ATC function code
OPTION 3. Tailored service volume (TSV) ID
OPTION 4. IRAC ID

### Optional Data Inputs

1. Plot title
2. Along with each plot a map of the United States is given if desired. The user may change the center of the plot by inputting the center latitude and longitude. If the center location is changed, the upper and lower standard parallels must also be given.

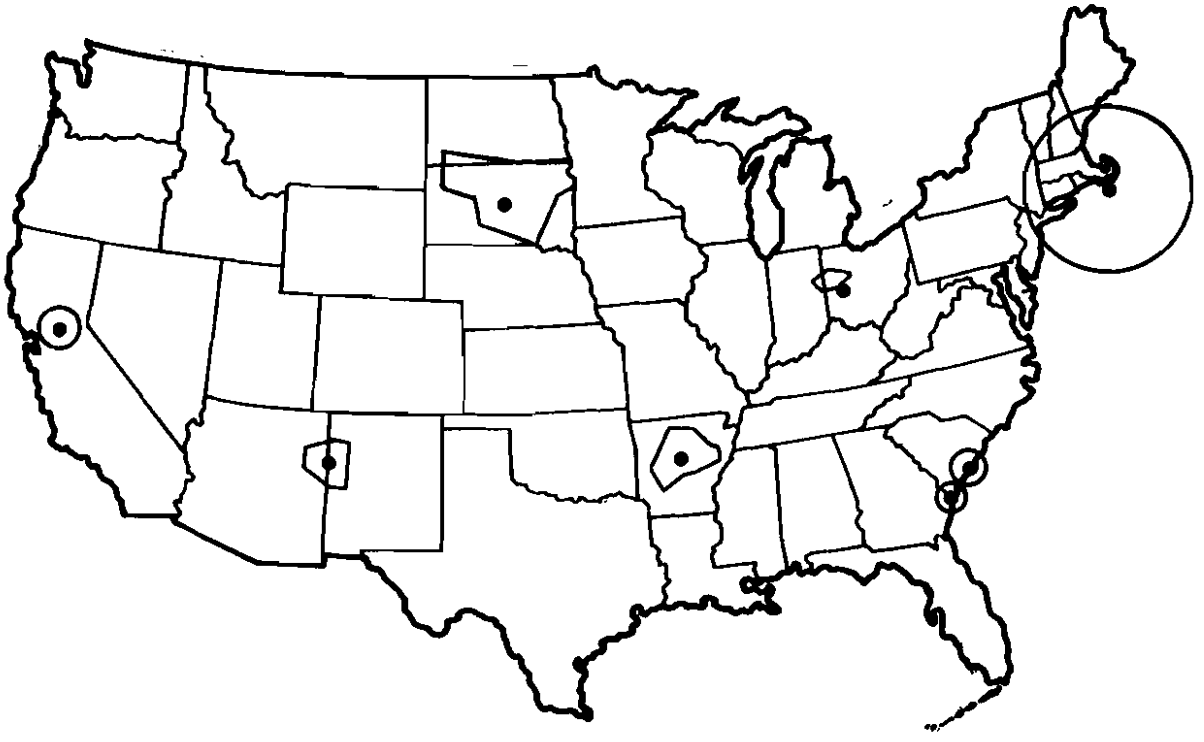


FIGURE D-1. PLOT OF SERVICE VOLUMES ON SAME FREQUENCY.

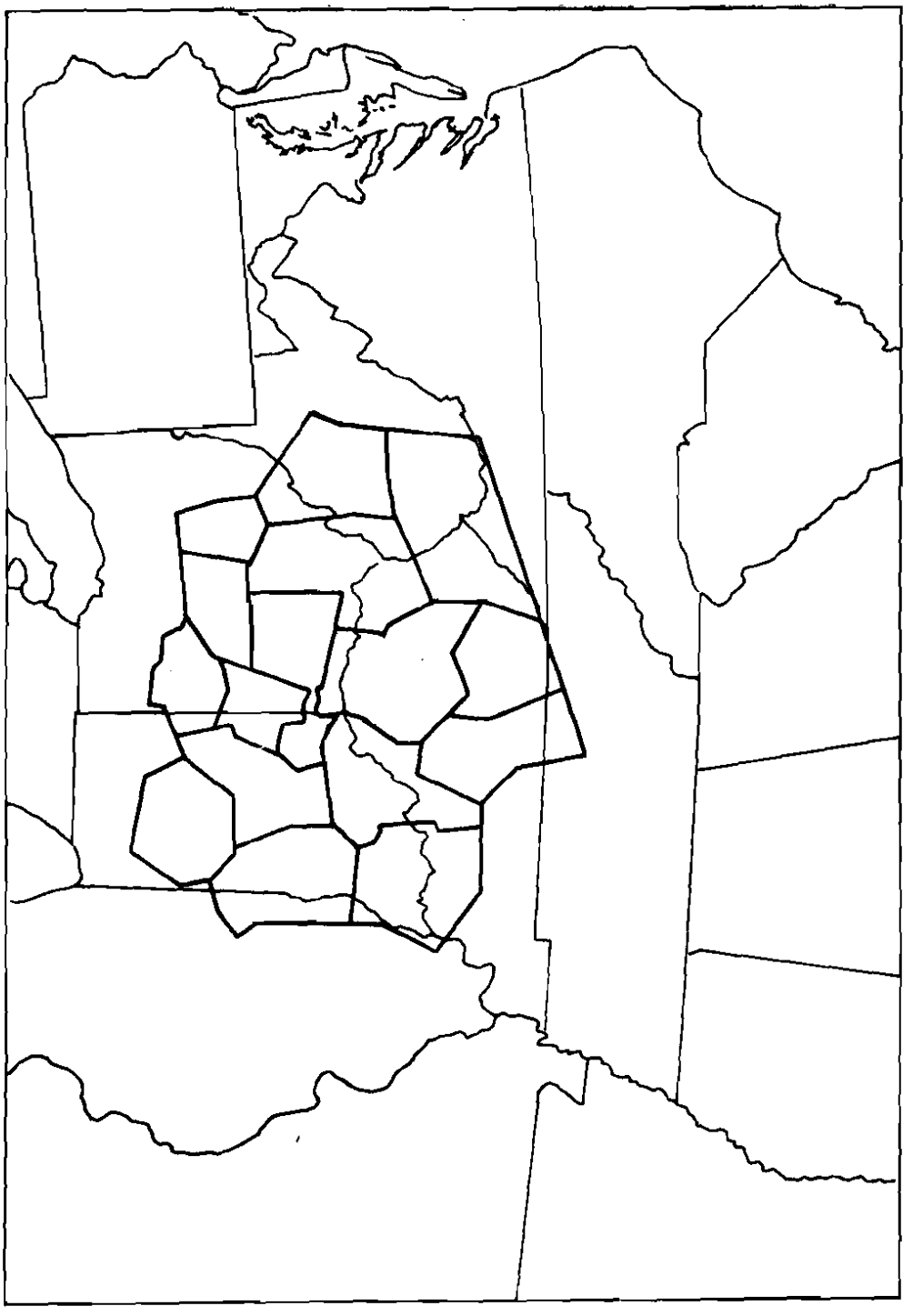


FIGURE D-2. PLOT OF SERVICE VOLUMES FOR INDIANAPOLIS ARTCC.

## POINT-TO-POINT TERRAIN ANALYSIS PROGRAM

This program permits the user to plot the terrain profile between two given sites using either a linear or a 4/3 earth scale. Inputs can be in meters or feet, and outputs are in kilometers, statute or nautical miles. The site locations are specified by either latitude and longitude or IRAC ID. A hard copy is given of the terrain plot and the line-of-sight distance between the two sites. Example outputs are shown in FIGURES D-3 and D-4.

APPENDIX G explains in detail the method used by the program to generate profiles to determine the line-of-sight (LOS).

### Required Data Inputs

1. Option for linear or 4/3 earth plot
2. Option to input data (meters or feet)
3. Refractivity Index (between 290 and 330, for U.S.)
4. Option for distance units (kilometers, statute, nautical)
5. Transmitter latitude and longitude or IRAC ID
6. Receiver latitude and longitude or IRAC ID
7. Elevation interpolation option (nearest point or 4-point interpolation).

### Optional Data Inputs

1. Plot title
2. Transmitter antenna height
3. Receiver antenna height
4. LOS distance from receiver to transmitter
5. Transmitter elevation options
6. Receiver elevation options.

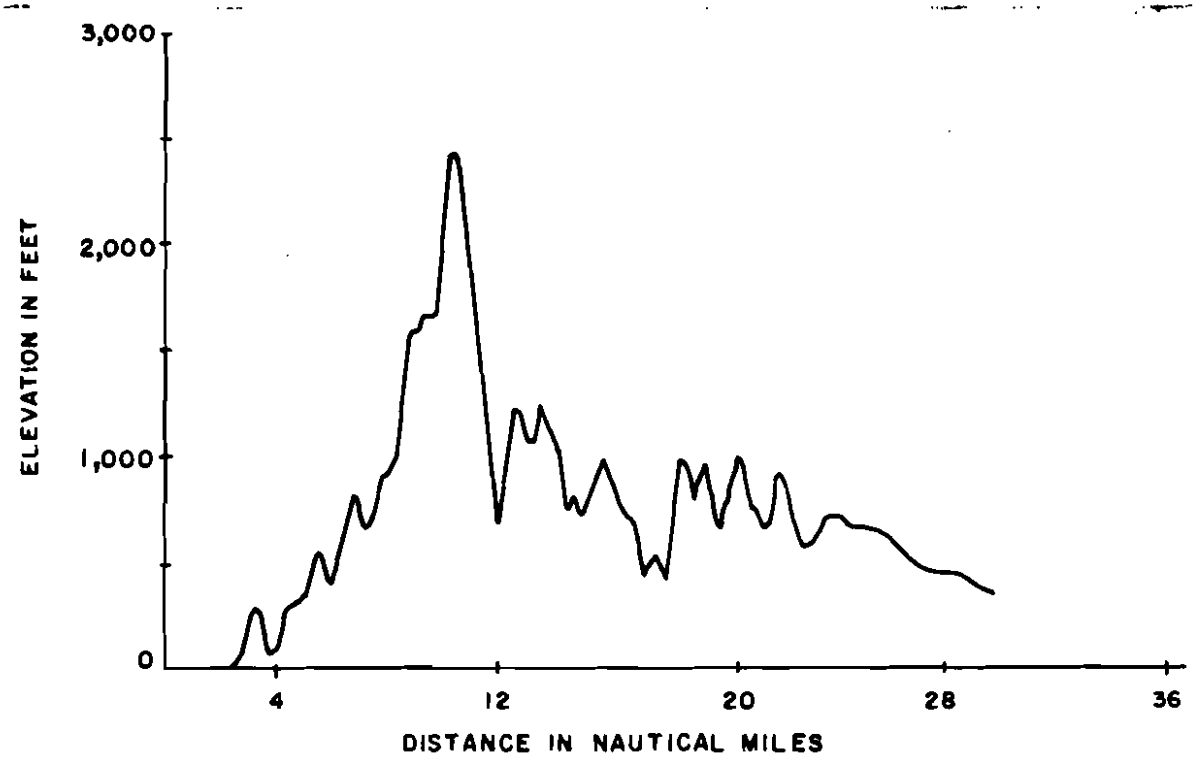



FIGURE D-3. TERRAIN PROFILE BETWEEN TWO POINTS (FLAT EARTH).

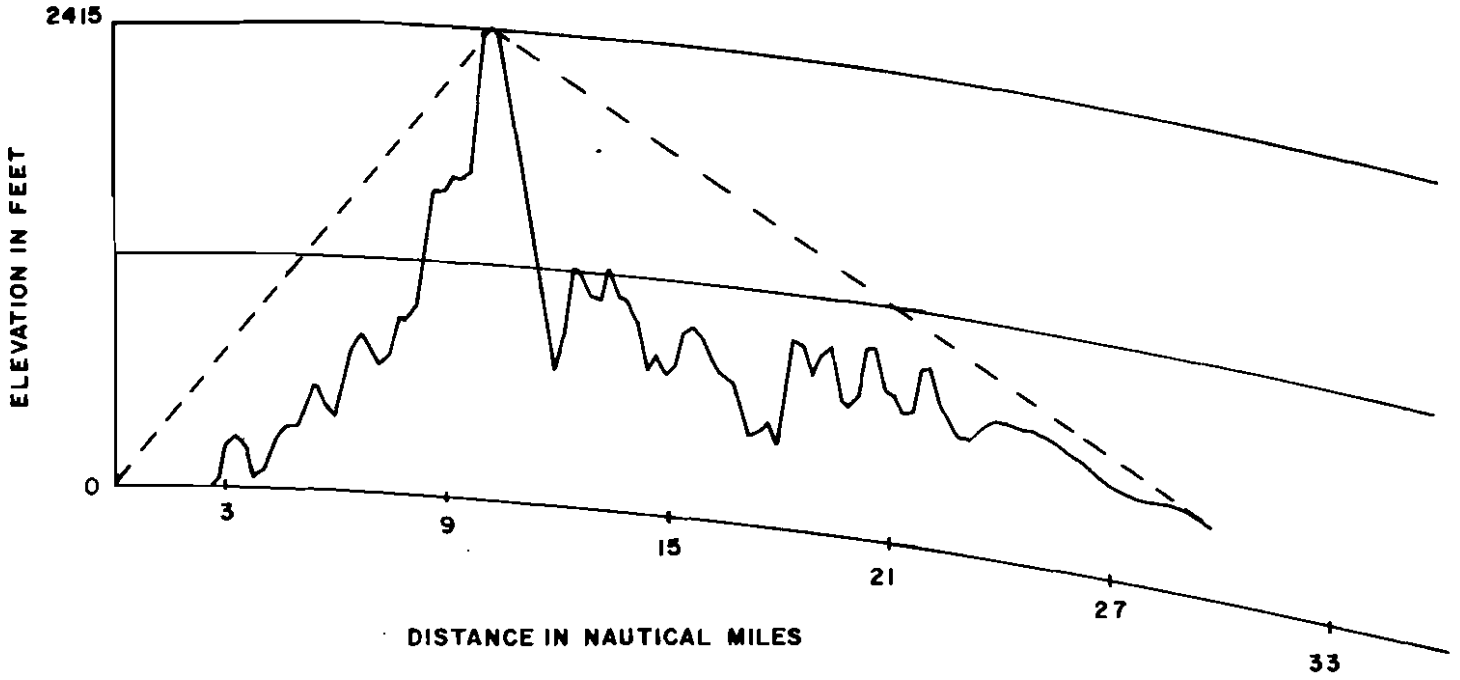



FIGURE D-4. TERRAIN PROFILE BETWEEN TWO POINTS (4/3 EARTH'S RADIUS).

# APPENDIX E

# DESCRIPTION OF PROPAGATION MODELS

This appendix discusses the four propagation models used in the electromagnetic compatibility (EMC) support program which is part of the FAA on-line computer system. The four models are: Terrain Integrated Rough Earth Model (TIREM), Integrated Propagation System (IPS), NLAMBDA Ground Wave Model, and Empirical Propagation Loss Model (EPM-73). The data input required to drive these models is presented in APPENDIX A.

## TERRAIN INTEGRATED ROUGH EARTH MODEL (TIREM)

### Introduction and General Discussion

The Terrain Integrated Rough Earth Model (TIREM) is a propagation analysis system which utilizes a digitized topographic data base to determine path losses. The model is valid for tropospheric propagation at frequencies in the range of 40 MHz to 20 GHz over both within and beyond line-of-sight (BLOS) paths. The decibel values of basic median transmission loss and long term power fading ranges are predicted. The model and the terrain data base are fully computer automated with several options for input and output format. Ionospheric modes are not included in the TIREM model.

### Synopsis of Model Theory

TIREM is an automated rough-earth propagation model that automatically calculates the necessary profile parameters to be used in a propagation analysis. The primary output of TIREM is a propagation loss which includes absorption and power fading statistics. FIGURE E-1 is a flow chart of TIREM.

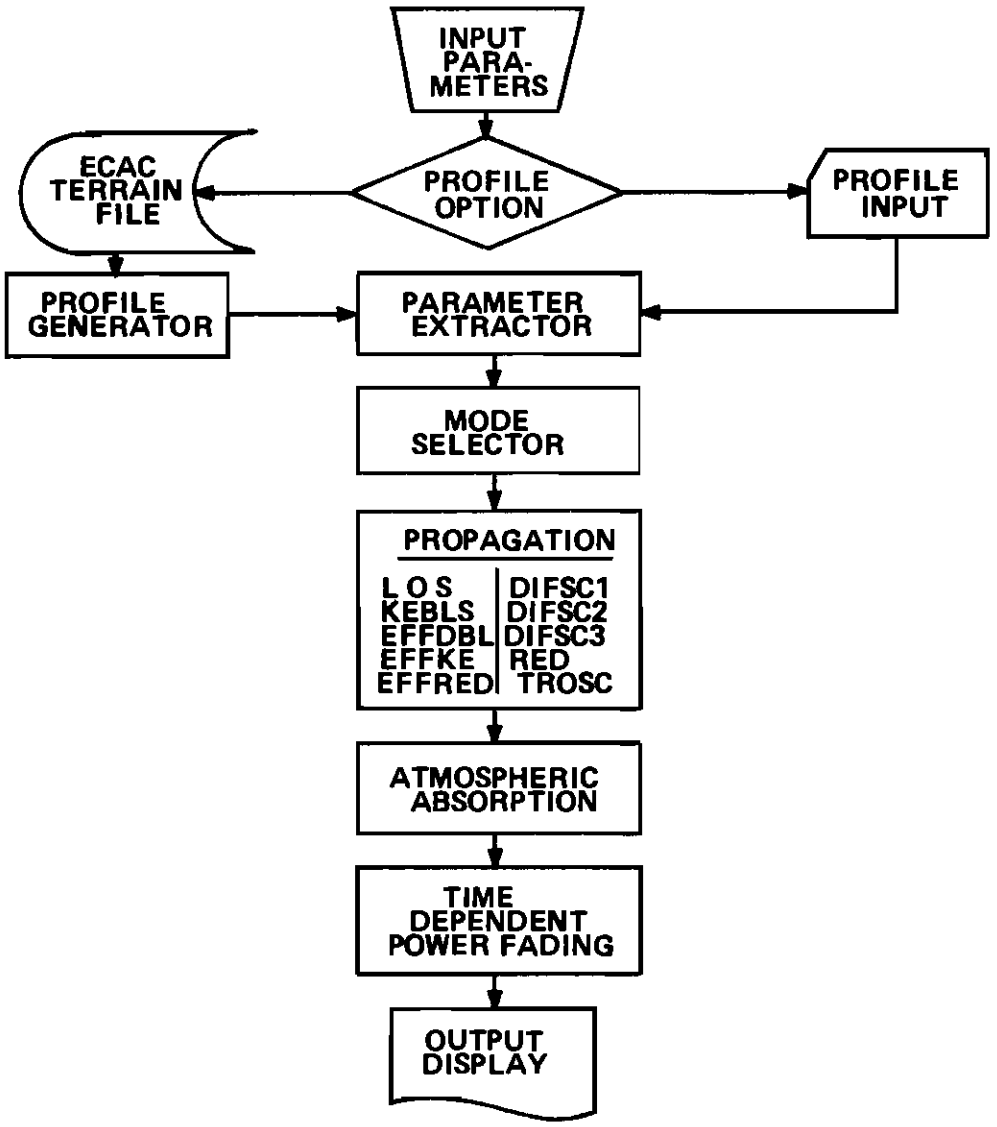



FIGURE E-1. TERRAIN INTEGRATED ROUGH-EARTH MODEL FLOW CHART.

The input parameters to TIREM consist mainly of antenna height, frequency, atmospheric conditions, ground constants, and the transmitting and receiving site coordinates. ECAC maintains an extensive data file consisting of terrain information for areas throughout the world.

The profile generator automatically generates the propagation path profile from the ECAC terrain file. The profile is generated along a great circle path between the transmitting and receiving sites. Starting at the transmitting site, the profile generator obtains the four terrain points nearest to the site and appropriately weights them before selecting the site elevation. Then, moving equal increments along the great circle path, the profile generator performs the same computations to obtain each elevation. The increment or distance between elevations along the great circle path is equal to one-half the element spacing of the terrain file being used. A more detailed explanation of the profile generator is given in APPENDIX G.

The parameter extractor automatically calculates: the parameters to be used for selecting the applicable propagation mode, the radio horizon of the transmitter and receiver, effective antenna heights, and various angles and distances that are used in the propagation models.

Using the values calculated by the parameter extractor, the appropriate propagation mode is determined. Mode selection is begun by determining whether the transmitter and receiver are within LOS.

For all LOS cases, one mode is chosen: LOS-RE, LOS-FS, or LOS-TR. Beyond line-of-sight (BLOS) analysis consists of selecting knife-edge beyond line-of-sight (KEBLS) if the radio horizons coincide at the same terrain point. The effective knife-edge (EFFKE) mode is selected if there

are two distinct radio horizons, and the scattering angle is less than a calculated minimum. If the scattering angle is greater than this minimum, the rough earth diffraction (RED) mode is compared with the troposcatter (TROSC) mode. The result is either RED, TROSC, the effective double knife-edge loss (EFFDBL) or a combination of these modes called EFFRED, DIFSC1, DIFSC2, or DIFSC3. Brief descriptions of the TIREM propagation mode computer models are given below:

LOS-RE - a computer routine that calculates the line-of-sight rough earth propagation loss using empirically derived techniques. It applies to cases where the ray path is close to the earth.
LOS-FS - the computer routine that calculates free space (inverse square) loss used when the ray path is more than 1.5 first Fresnel zones above the earth.
LOS-TR - the computer routine that calculates a weighted combination of LOS-RE and LOS-FS predictions for transitional geometry.
KEBLS - the computer routine that calculates the single knife-edge BLOS diffraction loss using the Fresnel-Kirchhoff computations.
EFFKE - the computer routine that calculates the effective single knife-edge diffraction loss for the intermediate region at or just beyond the radio horizon.
RED - the computer routine that calculates the rough earth diffraction loss using Norton's four arc method.
TROSC - the computer routine that calculates the tropospheric scatter loss using a model developed for rough terrain.
DIFSC1 - the computer routine that combines the diffraction loss with the scattering loss when the two field strengths are comparable.
EFFDBL - the computer routine that calculates the effective double knife-edge diffraction loss using the Sacco formulation.
EFFRED - is the computer routine which combines the RED and KEBLS loss values.

DIFSC2 - the computer routine that makes an interpolation between the EFFDBL calculation and the one given by the DIFSC1 mode.
DIFSC3 - the computer routine that makes an interpolation between the EFFDBL calculation and the one given by the TROSC mode.

The absorption computer routine (ABSBLS) is capable of calculating the additional absorption loss due to oxygen and water vapor in the atmosphere. The time dependent power fading computer routine (FADING) is composed of statistical and empirical functions. This model gives the expected long-term variation of propagation loss over tropospheric paths. Structural antenna height ($h_{st}$, $h_{sr}$) and site elevation ($h_{tt}$, $h_{tr}$) input parameter values should be determined as accurately as possible.

Providing an accurate figure for the transmitted frequency ($f_{MHz}$) is also of primary importance. In TIREM, the input frequency must be between 40 MHz and 20 GHz.

The atmospheric refractivity ($N_s$) value should be determined with reasonable care. Corresponding values of $N_s$ are calculated by the equation, $N_s = N_o \exp(-0.1057\ h_s)$, where $h_s$ is the terrain elevation in kilometers. TIREM will recover a value of 301 if this parameter is not specified. Relative permittivity ($\varepsilon_r$) and electrical conductivity ($\sigma$) should also be specified when possible. TIREM will use a permittivity value of 15 if no other value is specified. TIREM will recover a value of 0.0278 mho-meter/square meter for conductivity if this parameter is unspecified. Finally, it is desirable to specify a value of absolute humidity (H), but a figure of 10 grams/cubic meter is used if not supplied.

The output of the model includes a printout of the input parameters, the path loss according to the TIREM model (LB), the free-space loss (LBFS), and other ancillary data that is of value for a very detailed analysis of the propagation calculations.

## INTEGRATED PROPAGATION SYSTEM (IPS)

### Introduction and General Discussion

The Integrated Propagation System is a collection of ECAC smooth earth propagation models within a single routine that selects the appropriate model based on the problem input parameter values. The system is applicable for frequencies in the range of 1.0 MHz to 20 GHz for both within and BLOS tropospheric paths. The system is designed to provide a rapid calculation of the decibel value of basic transmission loss for the range of parameters of all the included models. Ionospheric modes of propagation are not included in the model.

### Synopsis of Model Theory

The Integrated Propagation System (IPS) incorporates five smooth earth propagation models. FIGURE E-2 shows these five models: the Smooth Curve Smooth Earth (SCSE), Simplified Theoretical Groundwave (STGW-1), Distance to Maximum Free Space and Reflection Field (DFSRF), modified Yeh Troposcatter (YEH), and Free Space.

One objective of the system is to provide a single routine which automatically selects the valid model for a particular combination of the input parameters. The input parameters are shown in FIGURE E-2 as frequency, distance, antenna heights, polarization, ground type, and atmospheric refractivity.

If the frequency is $1.0 \leq f_{MHz} \leq 1000$ and the antenna heights are relatively low, the STGW-1 ground wave model is selected. The YEH troposcatter model will also be selected when $f_{MHz} > 40$. If

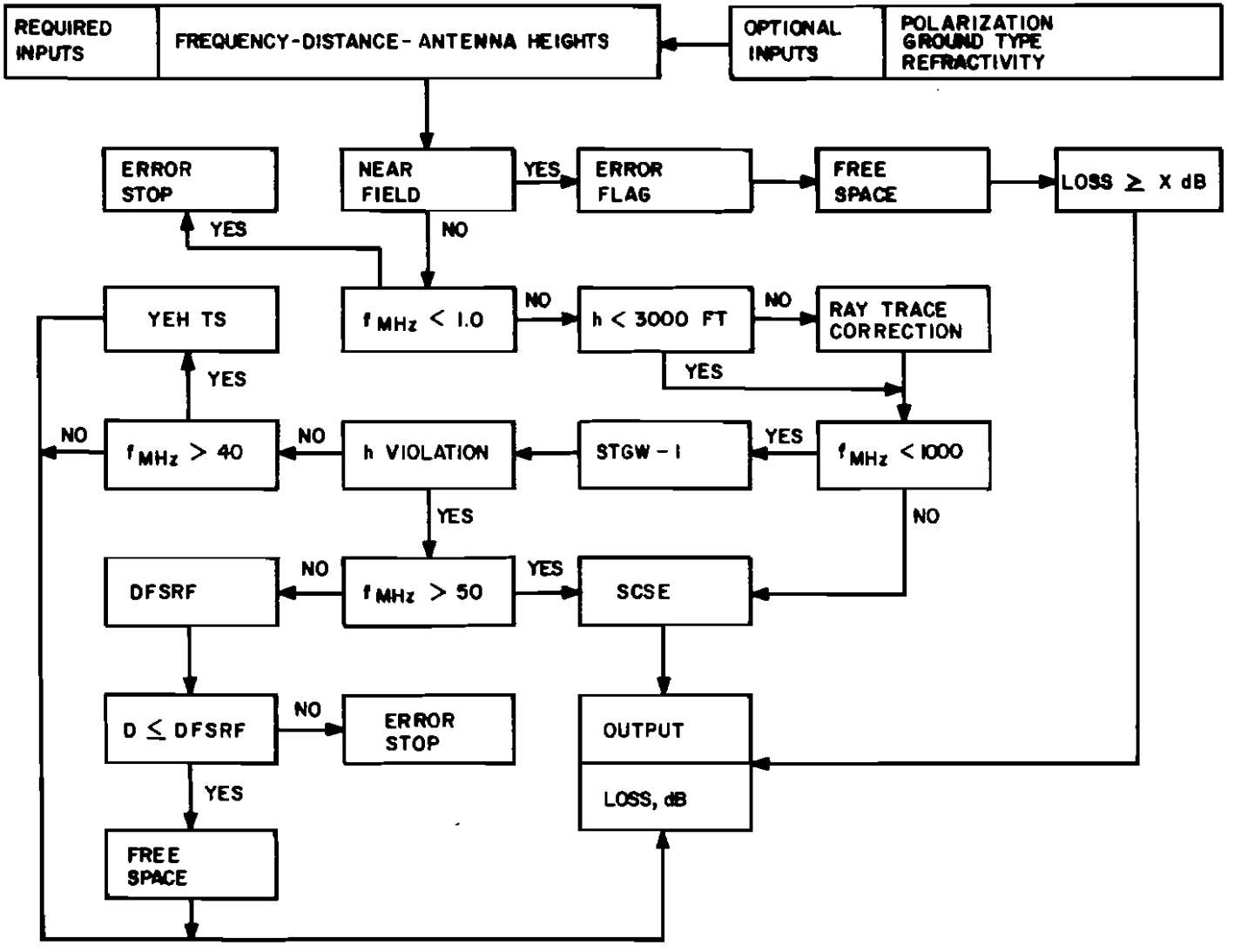



FIGURE E-2. INTEGRATED PROPAGATION SYSTEM (IPS).

however, the antenna heights are high and $f_{MHz} < 50$, the maximum free space distance model DFSRF is selected and the Free Space model may be selected.

When the frequency is >1000 MHz, the SCSE model is selected. It is also selected when $f_{MHz} > 50$ for high antenna heights. The SCSE has three modes that include reflection (SCSE-R), intermediate (SCSE-I), and diffraction (SCSE-D) region calculations.

The IPS uses an algorithm based on relative antenna heights, frequency, antenna polarization, ground permittivity, and conductivity to determine whether to treat these antenna heights as "low" or "high" heights. The IPS automatically makes this determination for the user in the process of selecting the propagation model to be exercised.

If the antenna heights are more than 3000 feet for any selected model, a ray tracing correction is applied along with the effective earth modeling already included in the system. The system output is a predicted value of basic transmission loss in decibels.

IPS has a capability that is useful for conservative estimates of interfering signal levels. The capability is an option regarding the type of predictions done by the SCSE-R mode. This mode gives predictions for problems in which the signal strength (and path loss) are determined solely by a direct and a ground-reflected radio ray. If the user selects the "envelope option," the program calculations will be done assuming that the two rays are always in phase. This results in a prediction of the strongest signal that is possible in this region. The user can also choose the "null option," in which case the theoretical phase relationship between the two rays is factored into the predictions.

FIGURE E-3 illustrates path loss versus distance plots using the envelope option and the null option. The plot suggests another useful feature of the envelope option. Because the curve has only one distance corresponding to a given loss, a scheme can be devised to do a reverse solution. The reverse solution would give the distance separation required for a specified loss value.

## NLAMBDA GROUND WAVE MODEL

### Introduction and General Discussion

The NLAMBDA Ground Wave Model is a sophisticated theoretical propagation analysis model. The model is valid for tropospheric propagation at frequencies in the range from 100 kHz to 20 GHz and is applicable for any smooth, spherical earth radius. The decibel value of basic median transmission loss is predicted. The model incorporates automatic mode selection for both within and BLOS paths. In general, the NLAMBDA model should be used when low frequencies and low antenna heights are employed for either large or small environments, and particularly when a theoretical smooth earth analysis is required.

### Synopsis of Model Theory

The NLAMBDA ground wave propagation model provides a far-field propagation loss prediction routine that is based on smooth earth theory. The model utilizes the average surface refractivity of the earth's atmosphere to determine an effective earth radius and to compute the basic median transmission loss (path loss between isotropic antennas). The propagation regions represented in this model include LOS and BLOS paths.

The NLAMBDA model automatically selects the appropriate mode based on the input parameters. It then applies the correct formulation

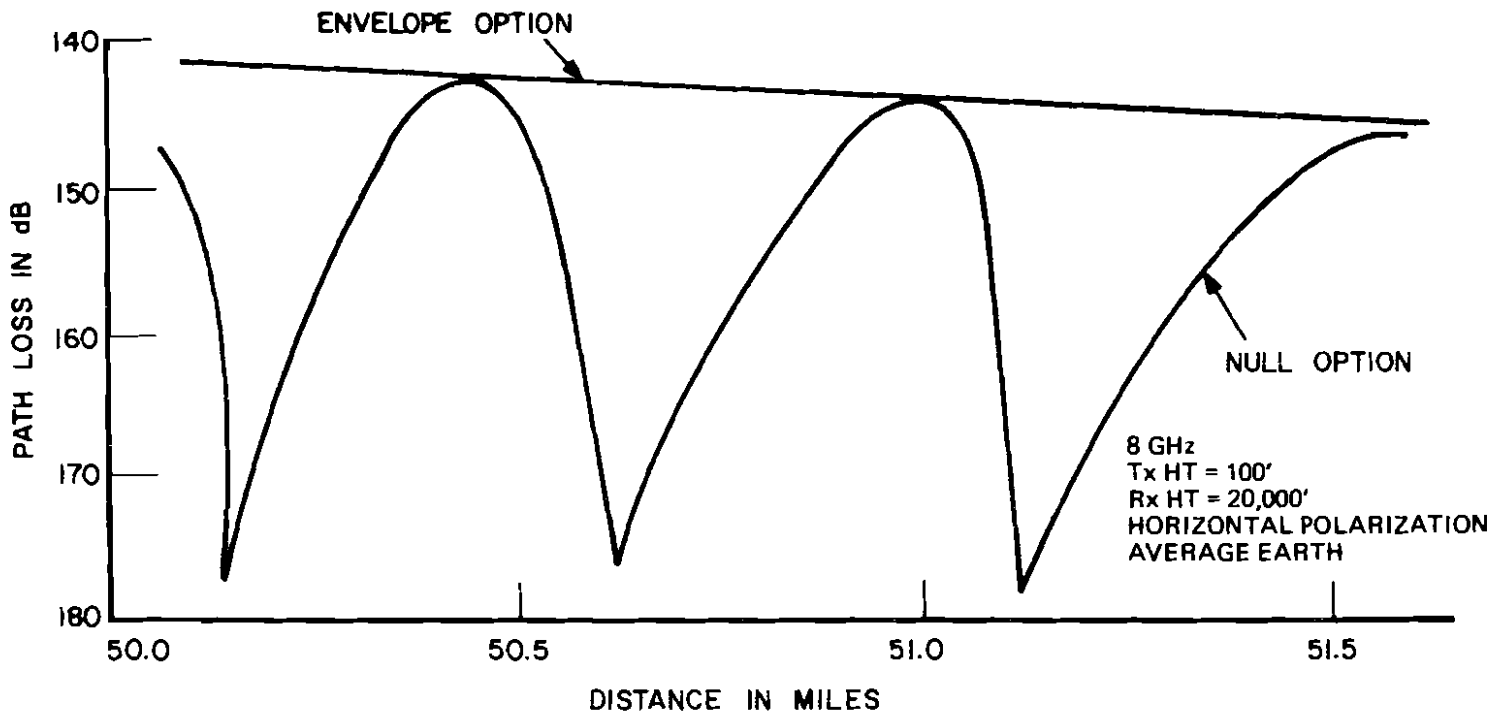



FIGURE E-3. PATH LOSS VERSUS DISTANCE PLOTS ILLUSTRATING THE ENVELOPE OPTION OF IPS.

to compute the path loss for either horizontal or vertical polarization. The model was designed to analyze problems involving frequencies from 100 kHz to 20 GHz.

The NLAMBDA ground wave model makes use of four computer routines--PONE, MLINOS, BREMER, and YEH--to calculate propagation losses. These automatically selected routines depend on the input parameters.

The PONE Program assumes a plane earth, and is therefore restricted to short distances such that this assumption is reasonable. Calculations are made to determine the contributions of the surface wave and the space wave. The space wave consists of a direct wave and a wave reflected off the surface of the assumed plane earth.

The MLINOS Program calculates the propagation loss of a space wave over a spherical earth. Unlike program PONE, MLINOS does not include the effects of the surface wave, and is therefore limited to cases where the surface wave is known to have negligible effects, such as horizontally polarized fields or sufficiently high antennas. Another important limitation is that for given antenna heights, frequency, etc., the path distance is such that the angle of reflection of the reflected space wave is greater than a certain specified minimum.

The BREMER Program can theoretically calculate losses for both LOS paths and diffraction mode paths. But for practical reasons, program BREMER is limited to paths near or beyond the radio horizon. This is primarily due to the existance of an infinite series in the prediction equation of BREMER. This infinite series converges quickly for paths in the diffraction region, thus requiring the computation of relatively few terms (less than a few hundred) for reasonable accuracy. In the computations for shorter paths (within-the-horizon or near-the-horizon), convergence is much slower and the required number of terms for the same accuracy quickly passes one thousand and computer time required increases

considerably. This is mainly due to the shorter distances and/or higher antenna. Thus the maximum number of terms summed in BREMER is limited to 250. Therefore, the mode selector in the NLAMBDA ground wave model was designed to make maximum use of programs PONE and MLINOS.

The YEH model is used as an alternative to the BREMER model. The YEH model calculates propagation loss for BLOS paths based on tropospheric scatter (atmospheric conditions) of the transmitted signals as opposed to the diffraction mode paths as in BREMER. Whenever BREMER is selected for a BLOS path, the YEH loss is also calculated, and the lesser loss value is chosen as the more representative path loss prediction.

As with TIREM and IPS, power fading statistics and power density calculations are optional. The output includes a printout of the input parameters, basic median transmission loss according to the NLAMBDA model and the free space loss.

## EMPIRICAL PROPAGATION LOSS MODEL (EPM-73)

### Introduction and General Discussion

The Empirical Propagation Loss Model (EPM-73) is a propagation analysis computer program which does not require deterministic earth profiles or a digitized topographic data base to provide a prediction. The EPM-73 can be thought of as an "area" model used for a group of paths sharing a common geographical area. The model is intended for use at frequencies in the range of 1 MHz to 10 GHz over paths both within and BLOS. The model is intended for use with antenna heights below 3 km. ($\approx$10,000 feet).

The method used to calculate basic transmission loss might be described as a "ground wave" model augmented by troposcatter calculations for long distances. Ground wave in this case is meant to include the effects of the surface wave and multipath phenomena. The model considers a combination of direct wave, reflected wave, surface wave, diffraction, and troposcatter phenomena and is applicable over all distances within its range (approximately 1 to 300 statute miles). The model is not applicable for skywave propagation, nor does it consider the effects of ducting phenomena, or long term power fading.

Synopsis of the Empirical Propagation Loss Model

The EPM-73 consists of two subroutines: a low-h/λ submodel and a high-h/λ submodel (h is the antenna height and λ is the wavelength of the transmitted frequency). The transmission loss is calculated using both routines, and the program selects the output predicted loss value.

The low-h/λ model first computes a minimum effective antenna height from information on the type of terrain and antenna polarization. Using this and the structural antenna height, an effective antenna height is then calculated. With that information and the given transmitter frequency, three reference distance points are determined. They include the minimum boundary, $d_{cf}$, the plane earth/spherical earth boundary, $d_c$, and the tropospheric scatter boundary, $d_2$.

The boundary values are used to choose one of three loss prediction equations. The corresponding output loss values are associated with the L1, L2, or L3 modes in the low-h/λ model as follows:

| Mode | Region |
|---|---|
| L1 | $d_{cf} \leq d \leq d_c$ |
| L2 | $d_c < d \leq d_2$ |
| L3 | $d > d_2$ |

The high-h/λ model also considers three regions of separation between antennas. These regions might be described as the reflection region, the diffraction region, and the tropospheric scatter region. As in the low-h/λ model, a calculation is made corresponding to the region in which the separation distance lies. The regions are separated or defined by two distance marks, $d_1$ and $d_2$.

The first mark, $d_1$, is a parameter which is slightly larger than $d_{FSRF}$, the distance at which diffraction effects become noticeable. The $d_2$ boundary is the same as calculated in the low-h/λ model. The boundary values are used to choose prediction equations corresponding to the H1, H2, or H3 modes in the high-h/λ model as follows:

| Mode | Region |
|---|---|
| H1 | $d \leq d_1$ |
| H2 | $d_1 < d \leq d_2$ |
| H3 | $d > d_2$ |

The output of the model includes a printout of the input parameters, the basic mean transmission loss according to the EPM-73 model, the free space loss, and other ancillary data that is of value for a detailed analysis of the propagation calculations.

# APPENDIX F

## INTERSITE ANALYSIS

The intersite analysis used in the Frequency Assignment Program involves calculating the signal ratio between the requirement to be assigned and all requirements presently using the frequency under consideration.

The decision-making process depends on calculations involving three types of service volume descriptors: Tailored Service Volume (TSV), Tailored Circular Volume (TCV), and Standard Service Volume (SSV). En route functions generally control multipoint TSV's while non-en route functions control a TCV or SSV.

Each TSV may be described by a maximum of 25 boundary points joined to form a polygon. The radius and center of a TCV or an SSV are extracted from the GMF and stored in the requirements file. The center of a TCV is not necessarily located at the site and its radius value is tailored for the particular site. The center of an SSV is located at the site and the radius defined according to ATC function.

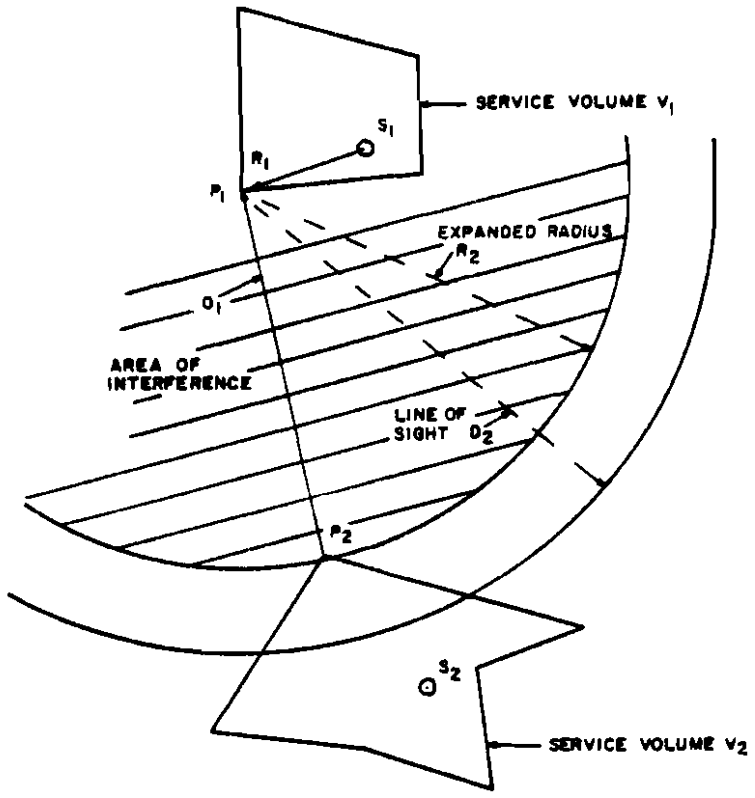
### COCHANNEL TSV ANALYSIS

The cochannel TSV analysis involves two sites ($S_1$, $S_2$) and their associated service volumes ($V_1$, $V_2$). Three types of interference are considered: air-to-air, ground-to-air, and air-to-ground. All calculations assume free-space path loss.

#### Air-to-Air

It is assumed that the desired signal is transmitted from site $S_1$ and received by an airplane located at a vertex $P_1$ of the associated

TSV $V_1$ (see FIGURE F-1). The undesired signal is transmitted from an airplane at $P_2$ of the associated TSV $V_2$.




Note: In this example, the cochanneling of $S_1$ and $S_2$ is prohibited.

FIGURE F-1. AIR-TO-AIR INTERFERENCE.

$R_1$ equals the distance from $S_1$ to $P_1$ corrected by the altitude of the sector. An expanded radius corresponding to the prescribed D/U ratio is calculated using:

$$R_2 = R_1 \cdot 10^{(D/U)/20}, \text{ in nmi} \qquad \text{(F-1)}$$

To describe a circle of interference about $P_1$, the line-of-sight distance between airplanes that are located in $V_1$ and $V_2$ is calculated using:

$$D_2 = (\sqrt{2A_1} + \sqrt{2A_2}) \cdot (.87), \text{ in nmi} \qquad \text{(F-2)}$$

where

$A_1$ = the altitude in feet of $V_1$

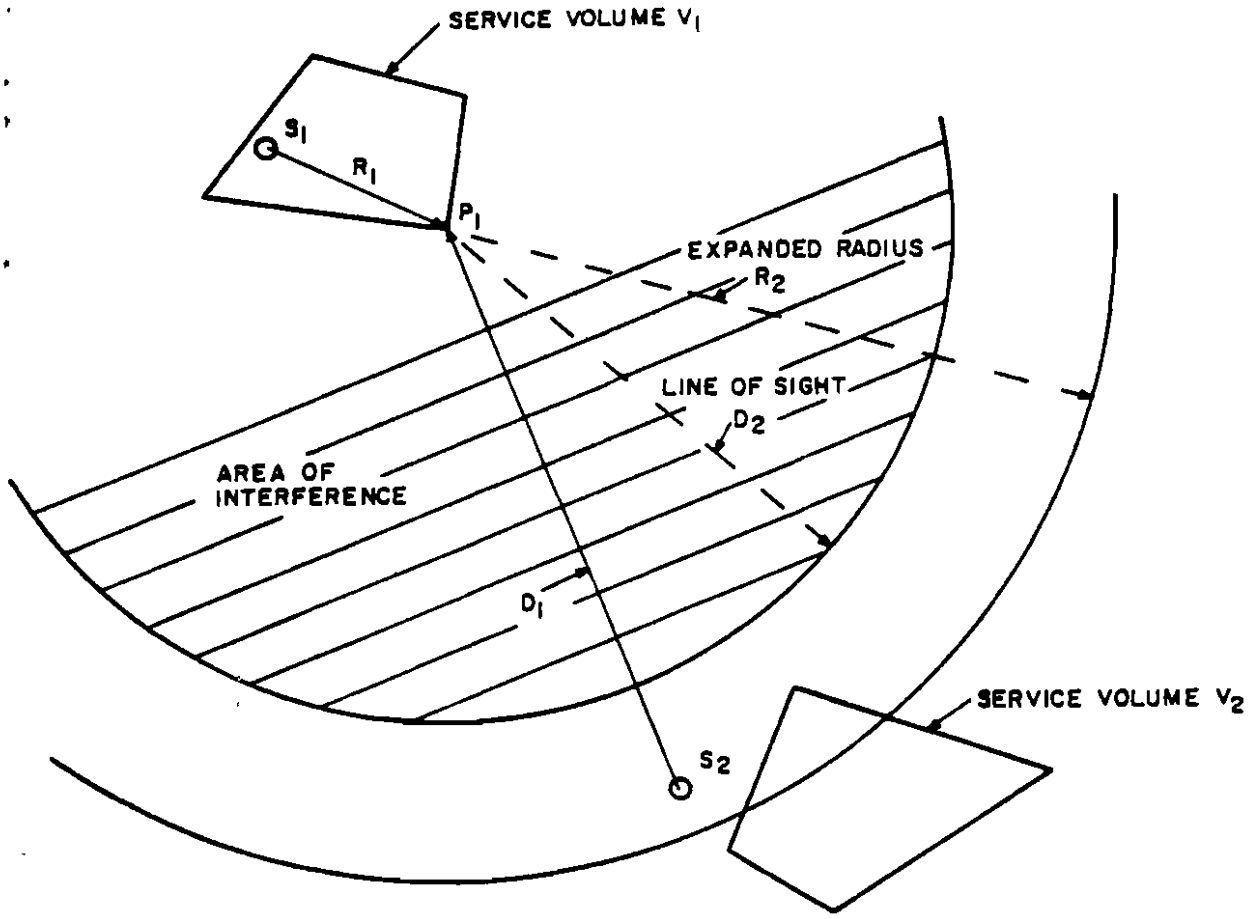
$A_2$ = the altitude in feet of $V_2$.

The radius $R_{Int} = \min (R_2, D_2)$ defines a circle of interference about the point $P_1$; i.e., if any interfering airplane lies within this circle, the given protection criterion is violated which results in failure to pass this cochannel test. To determine if this is indeed the case, the distance ($D_1$) from $P_1$ to each vertex of the interfering polygon ($V_2$) is calculated and compared against $R_{Int}$. Each vertex of $V_1$ is considered in a similar manner. If this test fails for any combination of vertices, the analysis is terminated which indicates that the sites must be separated by at least one channel.

If every test is passed, using the sites and service volumes in the manner described above, their roles are interchanged ($S_2$ generates the desired signal) and the process is repeated. If every test is again passed, the sites may be cochanneled.

Ground-to-Air

This analysis assumes that the desired signal is transmitted from $S_1$ and the undesired signal is radiated from $S_2$ (see FIGURE F-2). Both signals are received by an airplane located at $P_1$ in TSV $V_1$. A circle




Note: In this example, the cochanneling of $S_1$ and $S_2$ is not prohibited.

FIGURE F-2. GROUND-TO-AIR INTERFERENCE.

of interference is drawn about each vertex of $V_1$. Using the radius, $R_{Int} = \min (R_2, D_2)$ nmi, $R_2$ is defined as above and $D_2$ is the line-of-sight distance from an airplane located at $P_1$.

$$D_2 = .87 \cdot \sqrt{2A_1} + 8.7, \text{ in nmi} \qquad \text{(F-3)}$$

Ground antenna height is assumed to be 50 feet.

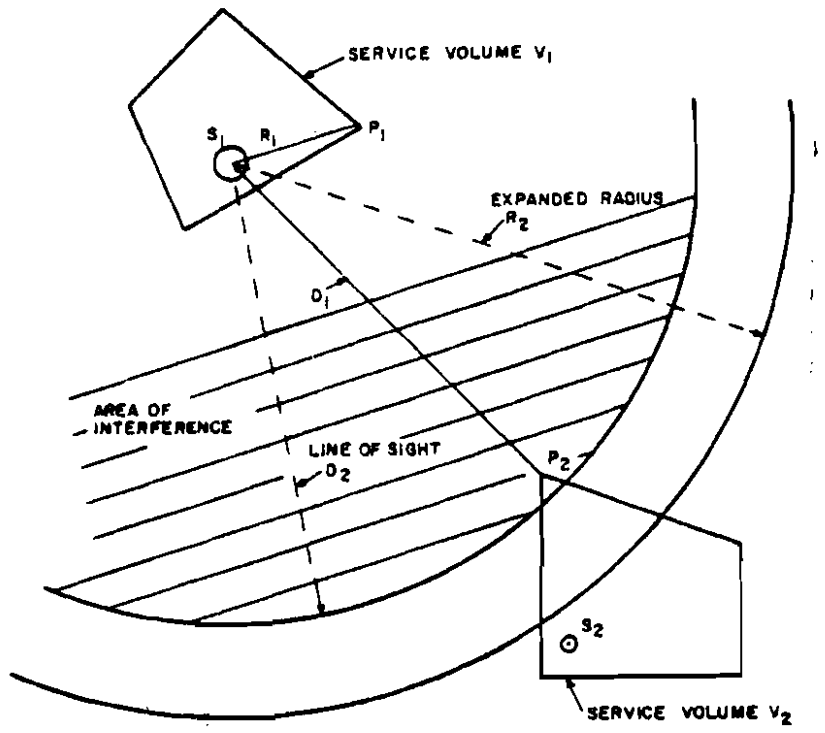
The possibility of ground-to-air interference is then determined by computing the distance ($D_1$) from $P_1$ to $S_2$. If $D_1$ is less than $R_{Int}$, $S_2$ lies within the circle of interference and the co-channel protection criterion is violated. To test for ground-to-air interference where $S_2$ emits the desired signal, the analysis is reversed.

Air-to-Ground

In this case, the desired signal is transmitted from an aircraft located at vertex $P_1$ of $V_1$, and the undesired signal is transmitted from an aircraft at $P_2$ of TSV $V_2$ (see FIGURE F-3). The interference takes place at site $S_1$.

A circle of interference is drawn about $S_1$ using the radius $R_{Int}$. The possibility for interference is determined by calculating the distance ($D_1$) from $S_1$ to $P_2$ and comparing it with the radius $R_{Int}$. If $P_2$ is found to lie within the circle of interference, $S_1$ and $S_2$ cannot be cochanneled. This process is repeated for each vertex of $V_1$. To determine the possibility of air-to-ground interference at $S_2$, the role of arguments is reversed.

$$D_2 = .87 \cdot \sqrt{2A_2} + 8.7, \text{ in nmi} \qquad \text{(F-4)}$$




Note: In this example, the cochanneling of $S_1$ and $S_2$ is prohibited.

FIGURE F-3. AIR-TO-GROUND INTERFERENCE.

## COCHANNEL CYLINDRICAL SERVICE-VOLUME ANALYSIS

Some sites serve airspaces that have circular plots in lieu of polygon plots. The basic concepts used in TSV cochannel analysis are modified to accommodate circular service-volume description. For TSV analysis, computations were made assuming that the airplanes were located at the vertices of the polygon service area descriptions. When a cochannel analysis is conducted for circular volumes, airplanes are assumed to be at worst-case position; i.e., the ratio of the distance from the desired signal to the distance from the undesired signal is maximized.

AN ALGORITHM FOR FINDING WORST-CASE LOCATION ON A CIRCLE

This analysis determines the worst-case position of an aircraft located in a sector V served by a site S. The location of the site is arbitrary and the sector is circular with radius $r_1$. FIGURE F-4 describes a typical orientation of the site, its service volume, and the location of an interfering transmitter.

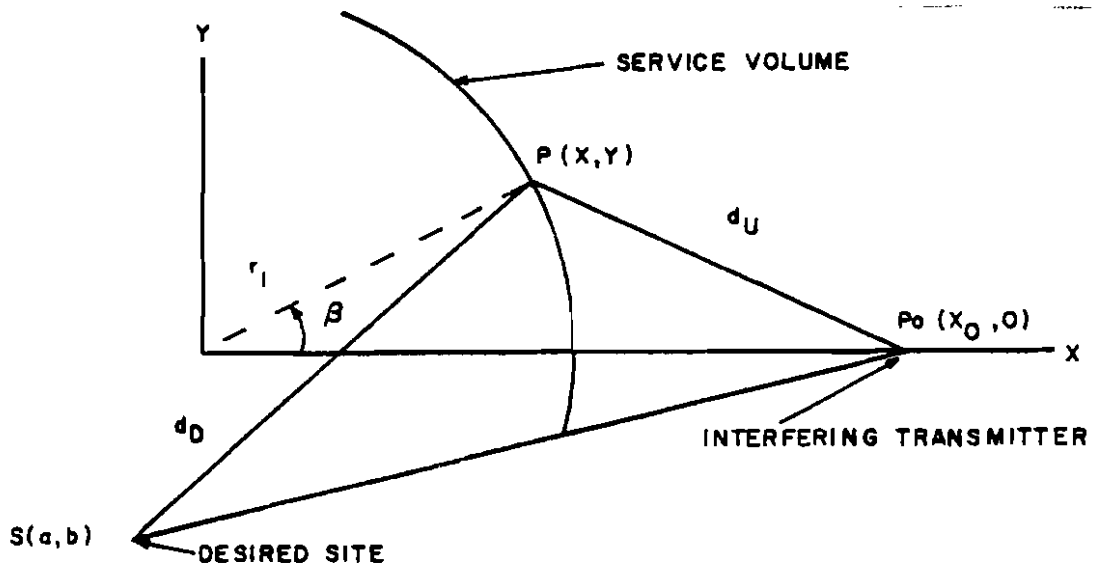



FIGURE F-4. WORST-CASE CONFIGURATION.

The problem is to find the coordinates of P such that the ratio of $d_D/d_U$ is maximized (thereby minimizing D/U signal ratio),

where

$d_D$ = desired distance

$d_U$ = undesired distance

which gives the following:

$S\ (a,b)$ = site location (desired transmitter)

$Po\ (x_o,\ 0)$ = undesired signal transmitter location

$r_1$ = radius of sector

Knowing that P is on the perimeter of the circle we have,

$$x^2 + y^2 = r_1^2$$

The following distances can then be calculated using:

$$d_D = \sqrt{(x-a)^2 + (y-b)^2} \qquad \text{(F-5)}$$

$$d_U = \sqrt{(x-x_o)^2 + (y-o)^2} \qquad \text{(F-6)}$$

Now squaring, we have

$$d_D^2 = r_1^2 + a^2 + b^2 - 2(ax + by)$$

by letting

$$c^2 = r_1^2 + a^2 + b^2 \qquad \text{(constant)}$$

then

$$d_D^2 = c^2 - 2(ax + by) \qquad \text{(F-7)}$$

Now, squaring $d_U$ we have

$$d_U^2 = r_1^2 + x_o^2 - 2x_o x \qquad \text{(F-8)}$$

by letting

$$e^2 = r_1^{\,2} + x_o^{\,2} \qquad \text{(constant)}$$

we have

$$d_U^{\,2} = e^2 - 2x_o x$$

Let

$$R = d_D/d_U$$

then

$$R^2 = \frac{c^2 - 2ax - 2by}{e^2 - 2x_o x} \qquad \text{(F-9)}$$

and

$$2 \ln R = \ln (c^2 - 2ax - 2by) - \ln (e^2 - 2x_o x)$$

But

$$y = \sqrt{r_1^{\,2} - x^2}$$

Therefore,

$$2 \ln R = \ln \left(c^2 - 2ax - 2b\sqrt{r_1^{\,2} - x^2}\right) - \ln (e^2 - 2x_o x) \qquad \text{(F-10)}$$

Now, taking the derivative with respect to x and setting it equal to zero we have

$$\frac{dR}{dx} = \left[\frac{-2a + 2bx(r_1{}^2 - x^2)^{-\frac{1}{2}}}{c^2 - 2ax - 2b\sqrt{r_1{}^2 - x^2}} + \frac{2x_o}{e^2 - 2xx_o}\right]\frac{R}{2} = 0$$

on simplifying, we obtain

$$(c^2x_o - e^2a)\sqrt{r_1{}^2 - x^2} = 2bx_or_1{}^2 - e^2bx \qquad \text{(F-11)}$$

Letting

$$x = r_1 \cos\beta$$

we have

$$(c^2x_o - e^2a)\sin\beta + e^2b\cos\beta = 2bx_or_1$$

Now, set

$$c^2x_o - e^2a = f$$

and

$$e^2b = g.$$

And substituting into the above

$$f\sin\beta + g\cos\beta = 2bx_or_1 \qquad \text{(F-12)}$$

then

$$\frac{f}{\sqrt{f^2 + g^2}}\sin\beta + \frac{g}{\sqrt{f^2 + g^2}}\cos\beta = \frac{2bx_or_1}{\sqrt{f^2 + g^2}} \qquad \text{(F-13)}$$

and

$$\sin\psi = \frac{g}{\sqrt{f^2 + g^2}} \; ; \; \cos\psi = \frac{f}{\sqrt{f^2 + g^2}}$$

then

$$\sin(\beta + \psi) = \frac{2bx_o r_1}{\sqrt{f^2 + g^2}} \qquad \text{(F-14)}$$

or

$$\beta = \sin^{-1}\left(\frac{2bx_o r_1}{\sqrt{f^2 + g^2}}\right) - \psi \qquad \text{(F-15)}$$

together with the radius $r_1$ define the point P (x,y).

INTERSITE ADJACENT-CHANNEL ANALYSIS

Adjacent-channel assignment, by FAA practice, requires at least a 2-nmi separation between aircraft. For two requirements, this test is made by calculating the distance between the centers and subtracting the sum of the two radii. If the result is 2 nmi or more, the requirements may be assigned adjacent-channels (see FIGURE F-5).

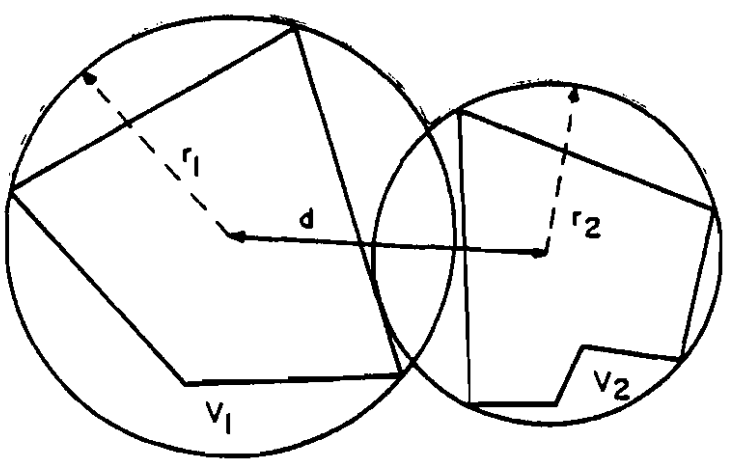



FIGURE 5. ADJACENT-CHANNEL ANALYSIS.

# APPENDIX G

## PROFILE GENERATION AND LINE-OF-SIGHT (LOS) DETERMINATION

### PROFILE GENERATION

A profile is generated between two points by calculating elevation values through interpolation of topographic data at a given increment along a great circle path from the first point to the second. A 30-second interval results in elevations being calculated approximately every half mile along the path, while a 15-second interval yields elevations at approximately every quarter mile.

### GREAT-CIRCLE PATH COMPUTATION

Calculation of coordinates along a great-circle path is based on a unit sphere with the coordinate system shown in FIGURE G-1. The i, j, and k vectors are of unit length in X, Y, and Z directions, respectively.

Transformations involved are:

Spherical to rectangular:

$$X = \cos\phi \cos\lambda$$
$$Y = \sin\phi \cos\lambda$$
$$Z = \sin\lambda \qquad \text{(G-1)}$$

Rectangular to spherical:

$$\lambda = \tan^{-1} \frac{Z}{\sqrt{X^2 + Y^2}}$$
$$\phi = \tan^{-1} (Y/X) \qquad \text{(G-2)}$$

where

$\lambda$ = latitude (positive north)

$\phi$ = longitude (positive west)

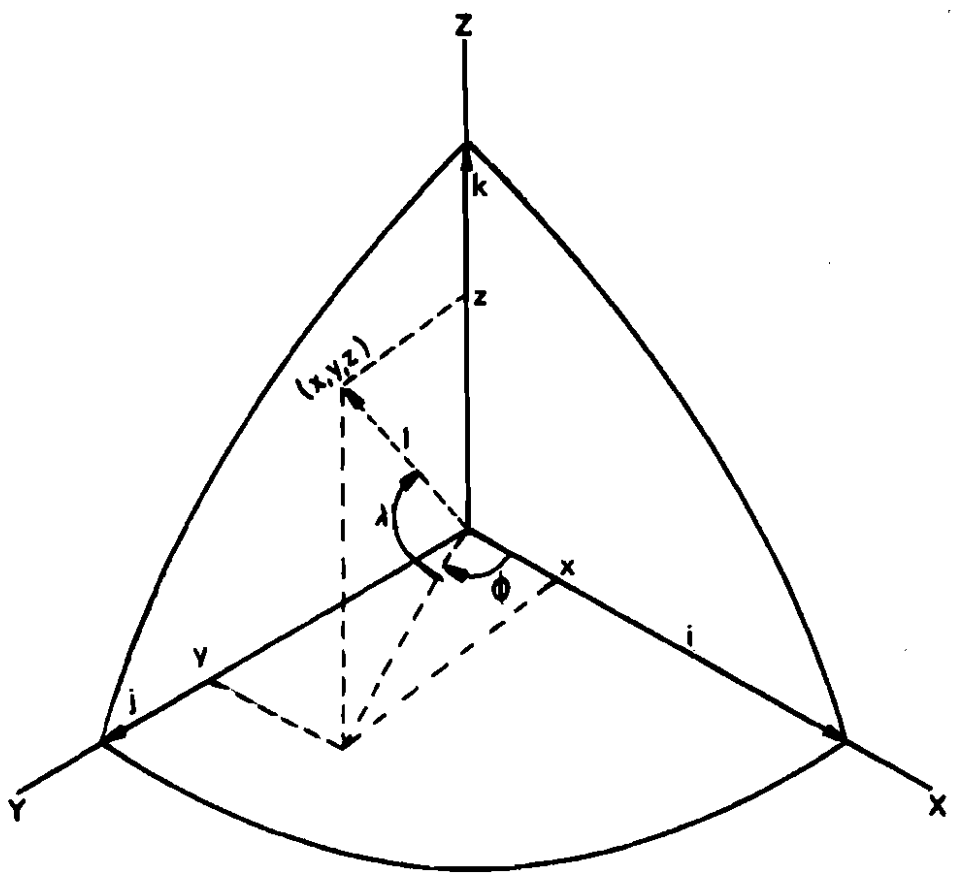



FIGURE G-1. COORDINATE SYSTEM FOR GREAT-CIRCLE PATH CALCULATIONS.

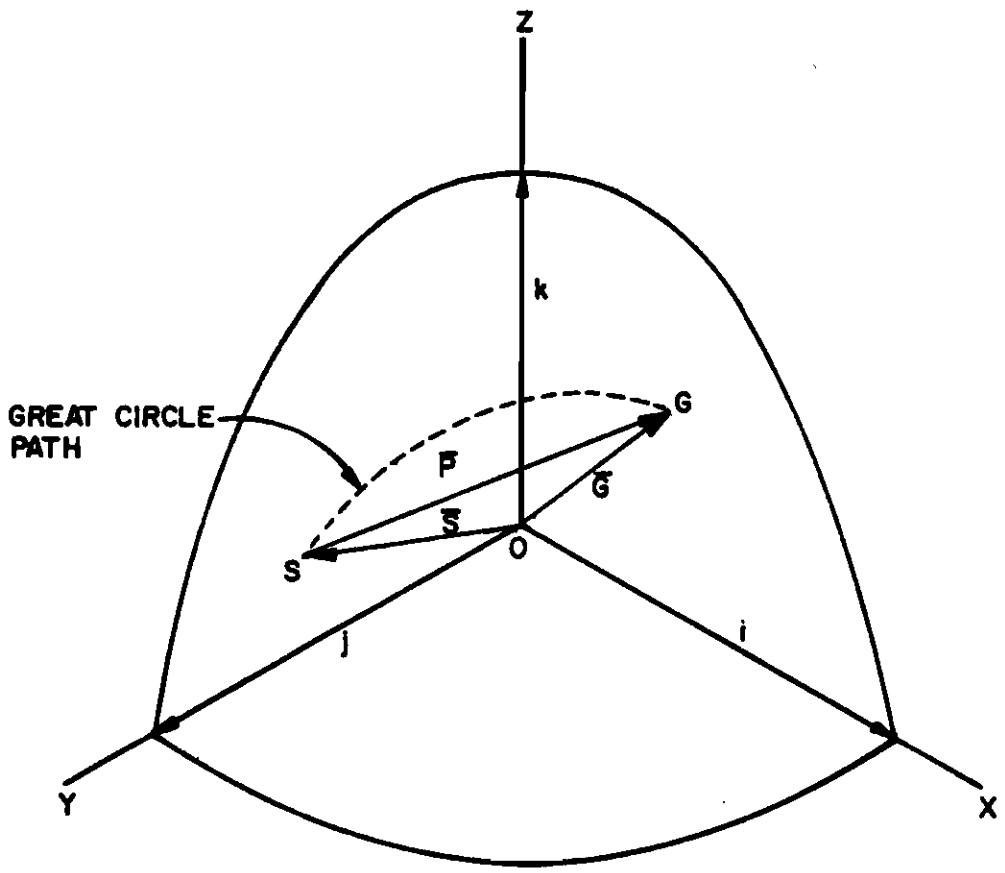



FIGURE G-2. THE VECTORS $\overline{S}$, $\overline{G}$ AND $\overline{P}$.

Given a site shown in FIGURE G-2 as point S on the unit sphere (latitude $\lambda_s$, longitude $\phi_s$), a vector $\overline{S}$ from the center of the sphere to point S is constructed as:

$$\overline{S} = s_1 \, i + s_2 \, j + s_3 \, k \qquad \text{(G-3)}$$

where $s_1$, $s_2$, and $s_3$ are scalers calculated from Equation G-1 with $\lambda_s$, $\phi_s$. Similarly, a vector $\overline{G}$ from the center of the sphere to a grid point $G(\lambda_G, \phi_G)$ is constructed using:

$$\overline{G} = g_1\ i + g_2\ j + g_3\ k \tag{G-4}$$

The vector $\overline{P}$ from S to G is then calculated using:

$$\overline{P} = \overline{G} - \overline{S} = (g_1 - s_1)\ i + (g_2 - s_2)\ j + (g_3 - s_3)\ k$$

$$= p_1\ i + p_2\ j + p_3 k \tag{G-5}$$

The unit vector $\overline{U}$ in the direction of $\overline{P}$ is:

$$\overline{U} = \frac{\overline{P}}{|\overline{P}|} = \frac{p_1\ i + p_2\ j + p_3\ k}{\sqrt{p_1^2 + p_2^2 + p_3^2}} \tag{G-6}$$

$$= u_1\ i + u_2\ j + u_3\ k.$$

Equal spacing along the great circle path from S to G is achieved through the calculation of the angle $\gamma_n$ (shown in FIGURE G-3) as follows:

$$\theta = \mathrm{Cos}^{-1}\left[\mathrm{Sin}\ \lambda_s\ \mathrm{Sin}\ \lambda_G + \mathrm{Cos}\ \lambda_s\ \mathrm{Cos}\ \lambda_G\ \mathrm{Cos}\ (\phi_G - \phi_s)\right]$$

$$d_o = C\ \Delta_s \tag{G-7}$$

$$N = \left\langle \frac{\theta}{d_o} + 1 \right\rangle$$

$$\gamma_n = \frac{\theta}{N}\ n,\ n = 0,\ 1,\ \ldots,\ N$$

where

$\Delta_s$ = user specified spacing in seconds

C = seconds to radians conversion factor, other variables are as previously defined

$\langle\ \rangle$ = denotes truncation to nearest integer value.

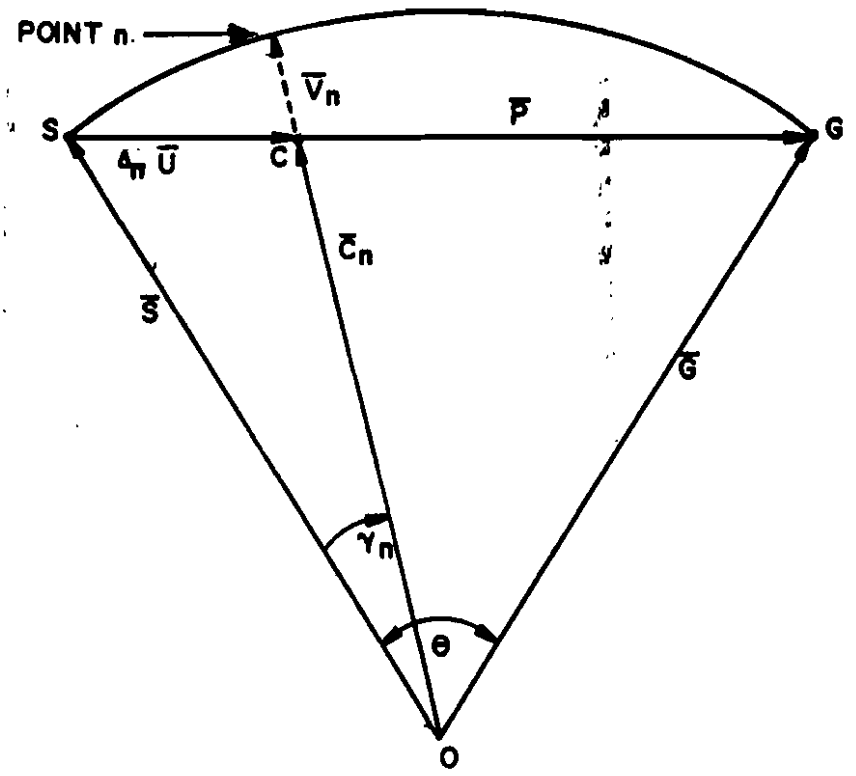



FIGURE G-3. SPACING ANGLE $\gamma_n$.

Coordinates $(\lambda_n, \phi_n)$ at equal spacing along the great circle path from S to G are then calculated as follows (see FIGURE G-4):

$$h = \text{Cos}\left(\frac{\theta}{2}\right) \qquad \text{(G-8)}$$

$$b = \text{Sin}\left(\frac{\theta}{2}\right)$$

$$r_n = h \tan\left(\frac{\theta}{2} - \gamma_n\right)$$

$$\Delta_n = b - r_n$$

$$\overline{C}_n = \overline{S} + \Delta_n \overline{U} = c_{1n} i + c_{2n} j + c_{3n} k, \text{ for } n = 0, 1, \ldots, N$$

Equation G-2 with $c_{1n}$, $c_{2n}$, $c_{3n}$ then gives $\lambda_n$, $\phi_n$. These coordinates apply equally to the unit vector $\overline{V}_n$ (FIGURE G-3), in the direction of $\overline{C}_n$, which is the vector from the center of the unit sphere to the nth point on the great circle path from S to G.

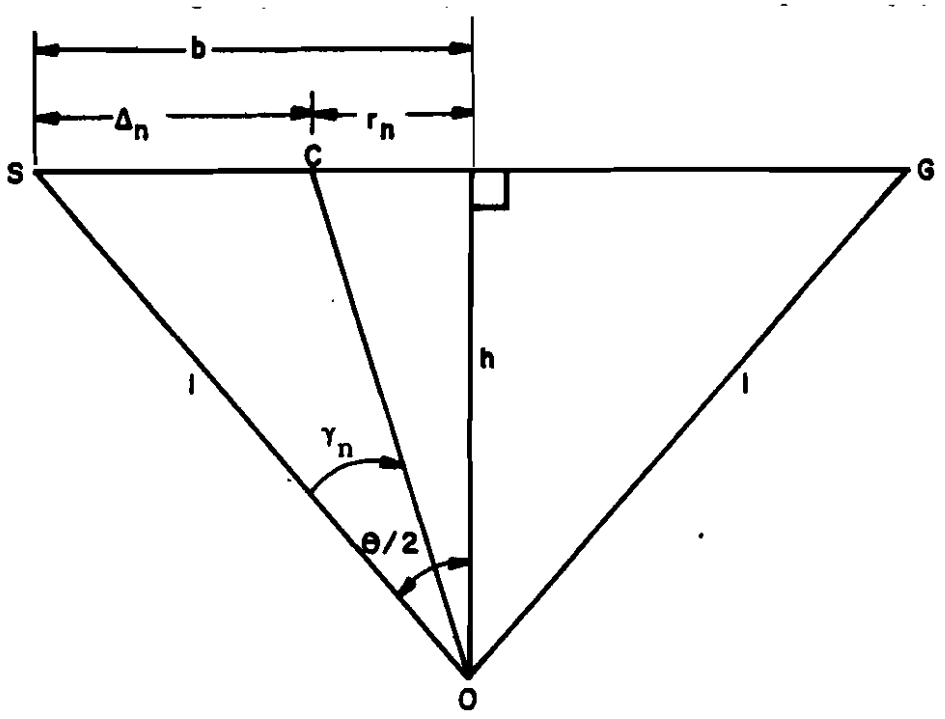



FIGURE G-4. THE SCALAR, $\Delta_n$.

DATA RETRIEVAL

It is, of course, necessary to determine which topographic data block is needed to obtain the elevation of a given point, and then to retrieve it from drum. In order to minimize drum access time, two data blocks are always retained in computer memory during profile generation from a given site. One array is reserved for the block area containing the site location. The second array is used to store other data blocks which are required for grid points not contained in the site block area (see FIGURE G-5).

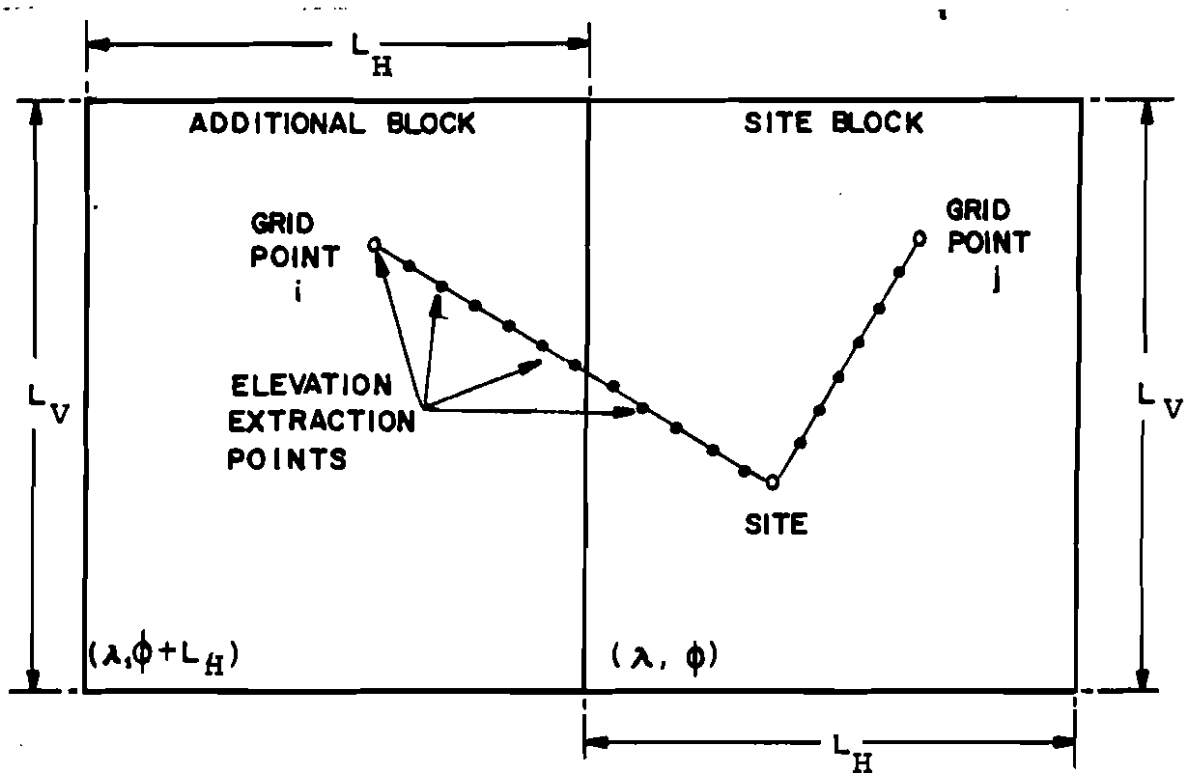



FIGURE G-5. DATA RETRIEVAL SITUATION.

Let $\lambda_n$, $\phi_n$ be the latitude and longitude (in radians) of the $n^{th}$ point along the great circle path from the site to a given grid point. Since topographic data blocks are referenced by latitude and longitude of the southwest corner in minutes, the block reference ($\lambda_{sw}$, $\phi_{sw}$) for $\lambda_n$, $\phi_n$ and additional measures (x, y) used in elevation extraction are determined as follows:

For $\lambda_n > 0$

$$\lambda_{sw} = \lambda_T$$

$$y = \lambda_c - \lambda_T$$

For $\lambda_n \leq 0$

$$\lambda_{sw} = \lambda_T - L_V \qquad \text{(G-9)}$$

$$y = \lambda_c - \lambda_T + L_V$$

For $\phi_n > 0$

$$\phi_{sw} = \phi_T + L_H$$

$$x = \phi_T - \phi_c + L_H$$

For $\phi_n \leq 0$

$$\phi_{sw} = \phi_T$$

$$x = \phi_T - \phi_c$$

where

$\lambda_{sw}, \phi_{sw}$ = latitude and longitude of the southwest corner, in minutes

$\lambda_c, \phi_c$ = latitude $\lambda_n$ and longitude $\phi_n$ converted to minutes

$\lambda_T = \left\langle \frac{\lambda_c}{L_V} \right\rangle \cdot L_V$, in minutes

$\phi_T = \left\langle \frac{\phi_c}{L_H} \right\rangle \cdot L_H$, in minutes

$L_V, L_H$ = vertical and horizontal topographic block lengths, in minutes

$x, y$ = extraction measures, in minutes (see FIGURE G-6), and $\langle\ \rangle$ denotes truncation to nearest integer value.

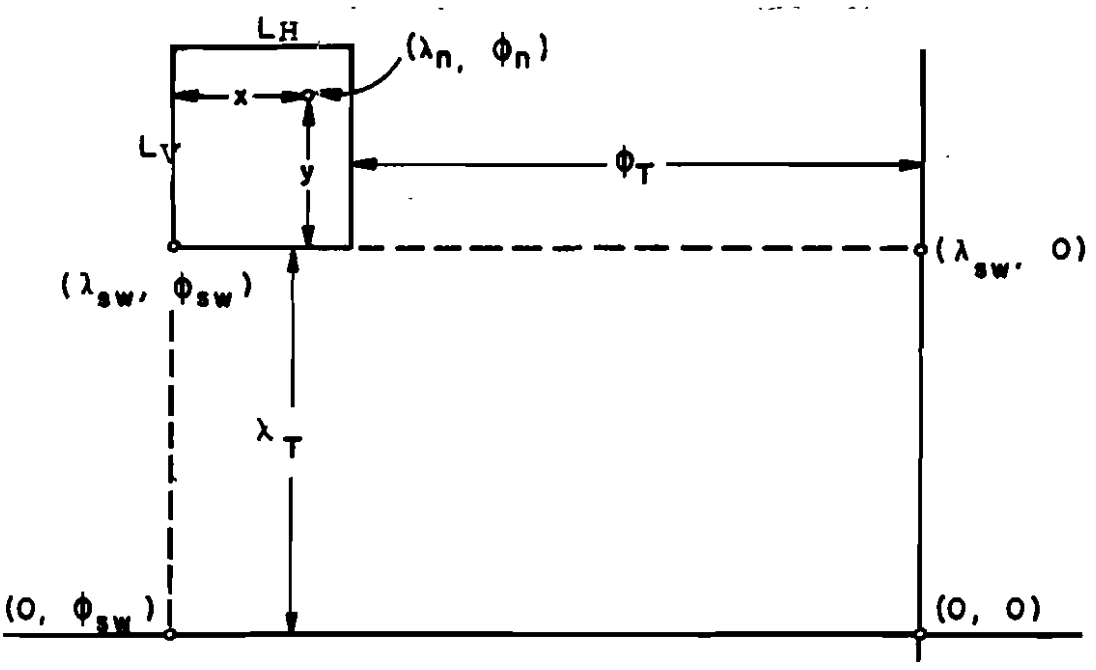



FIGURE G-6. SOUTHWEST CORNER DETERMINATION.

The necessary block reference point $(\lambda_{sw}, \phi_{sw})$ is then compared with those of the two data blocks in the computer. If the required data is already available, the elevation at $(\lambda_n, \phi_n)$ may then be extracted; if not present, the data is first retrieved from drum storage.

ELEVATION EXTRACTION

Two methods of deriving an elevation are available. The first procedure assumes the same elevation for the location in question as is recorded in the topographic data file for the location nearest to it. The second method performs a linear interpolation in two directions using the elevations of the four proximal points with the resultant being the desired elevation.

The required row(s) and column(s) of the 121 x 121 topographic data matrix are first determined using:

$$m = \langle M \rangle$$
$$n = \langle N \rangle \qquad \text{(G-10)}$$

where

$m$ = the number of the nearest matrix row south of the location in question

$n$ = the number of the nearest matrix column west of the location in question

$$M = \frac{120 \cdot y}{L_V} + 1$$

$$N = \frac{120 \cdot x}{L_H} + 1$$

and other variables are as previously defined.

The relation of the proximal elevations shown in FIGURE G-7 to the desired elevation, $E_d$, is determined by the following weights:

$$\Delta_1 = N - n$$
$$\Delta_2 = 1 - \Delta_1$$
$$\delta_1 = M - m$$
$$\delta_2 = 1 - \delta_1$$

The desired elevation, $E_d$, is then extracted by one of two methods.

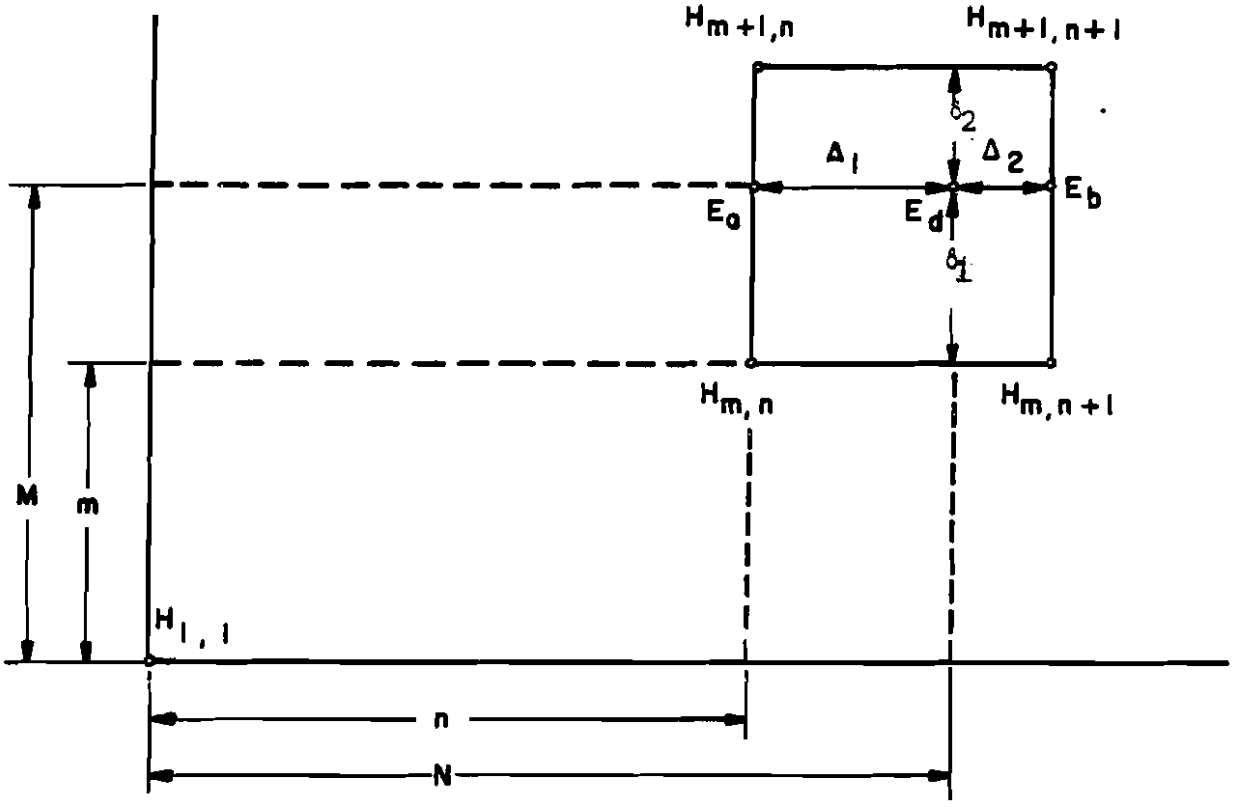



FIGURE G-7. ELEVATION DETERMINATION.

1. Nearest Point Option

If $\delta_1 < \delta_2$, $i = m$; otherwise, $i = m + 1$

If $\Delta_1 < \Delta_2$, $j = n$; otherwise, $j = n + 1$

The desired elevation is then obtained using:

$$E_d = H_{i,j} \tag{G-11}$$

2. Four Point Option

Interpolation in the north-south direction gives

$$E_a = \delta_2 H_{m,n} + \delta_1 H_{m+1,n} \tag{G-12}$$

$$E_b = \delta_2 H_{m,n+1} + \delta_1 H_{m+1,n+1}$$

Interpolation in the east-west direction then results in the desired elevation using:

$$E_d = \Delta_2 E_a + \Delta_1 E_b \tag{G-13}$$

Since the elevation values are initially biased by a quantity $\Delta E$, quantized by a factor Q and stored in compressed form in the topographic data file, the elevation derived from either method must be converted to feet above sea level by the equation:

$$E = Q E_d + \Delta E \tag{G-14}$$

The extracted elevation, E, is thus one of any number of elevations that constitute an elevation profile from a site to a given grid point.

LINE-OF-SIGHT (LOS) DETERMINATION

Before LOS can be determined along a profile, two factors must be taken into consideration: the effect of refractivity or bending of radio waves as they are transmitted through the atmosphere and the effect of earth's curvature with respect to the elevations.

Atmospheric refractivity is accounted for by assuming an effective earth's radius, $a_e = ka$, where k is the effective earth's radius factor and a is the true radius of the earth. This allows radio waves to be drawn as straight lines over an earth with effective radius $a_e$.

The value of k, for rays leaving a transmitter at low angles to the horizon, is given using:

$$k = \frac{1 + 10^{-6}N}{1 + 10^{-6}N + 10^{-6}\, a\Delta N} \qquad \text{(G-15)}$$

where

N = local refractivity index

a = true earth's radius

$\Delta N$ = change in refractivity with respect to altitude.

In general, the change of refractivity varies exponentially and is given as $\Delta N = -7.32\, e^{0.005577N}$. Taking a = 6370 kilometers yields

$$k = \frac{1 + 10^{-6}N}{1 + 10^{-6}\, N - 0.04663\, e^{0.005577N}} \qquad \text{(G-16)}$$

Assuming that the effective earth's radius is ka, each elevation, En, is now reduced by an appropriate amount, $\Delta hn$, which corrects the elevation for earth's curvature. Using FIGURE G-8, it is shown that:

$$\Delta hn = -ka + \sqrt{(ka)^2 + Xn^2} \qquad \text{(G-17)}$$

dn is a reasonable approximation for Xn as Xn differs from dn by less than one mile for path lengths up to 425 miles. A binomial series expansion of the radical in Equation G-17 yields the following equation:

$$\Delta hn = \frac{dn^2}{2ka} \qquad \text{(G-18)}$$

The corrected elevation, Ec, is:

$$Ec = En - \frac{dn^2}{2ka} \qquad \text{(G-19)}$$

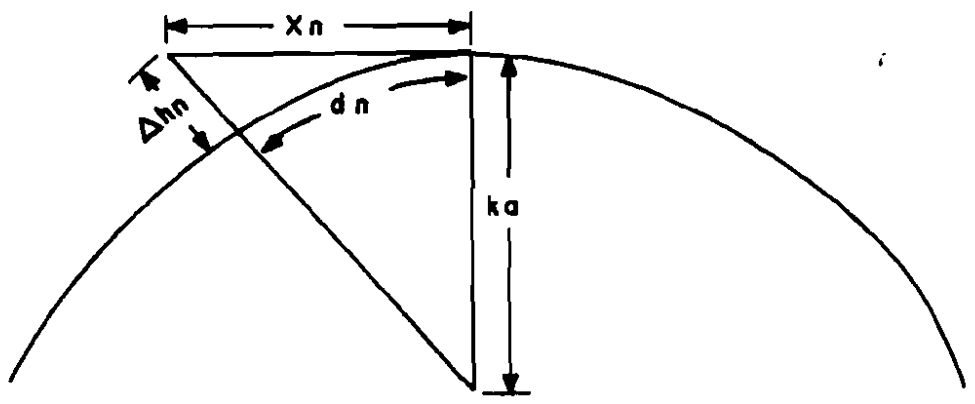



FIGURE G-8. ELEVATION CORRECTED FOR ATMOSPHERIC REFRACTIVITY AND EARTH'S CURVATURE.

The vertical angle, $\theta_n$, is then calculated (FIGURE G-9) from the site to each corrected elevation along the profile by the following equation:

$$\theta_n = \tan^{-1} \frac{E_c - (E_s + H)}{d_n} \qquad \text{(G-20)}$$

where

$E_s$ = site elevation above sea level (feet)

$H$ = antenna height (feet).

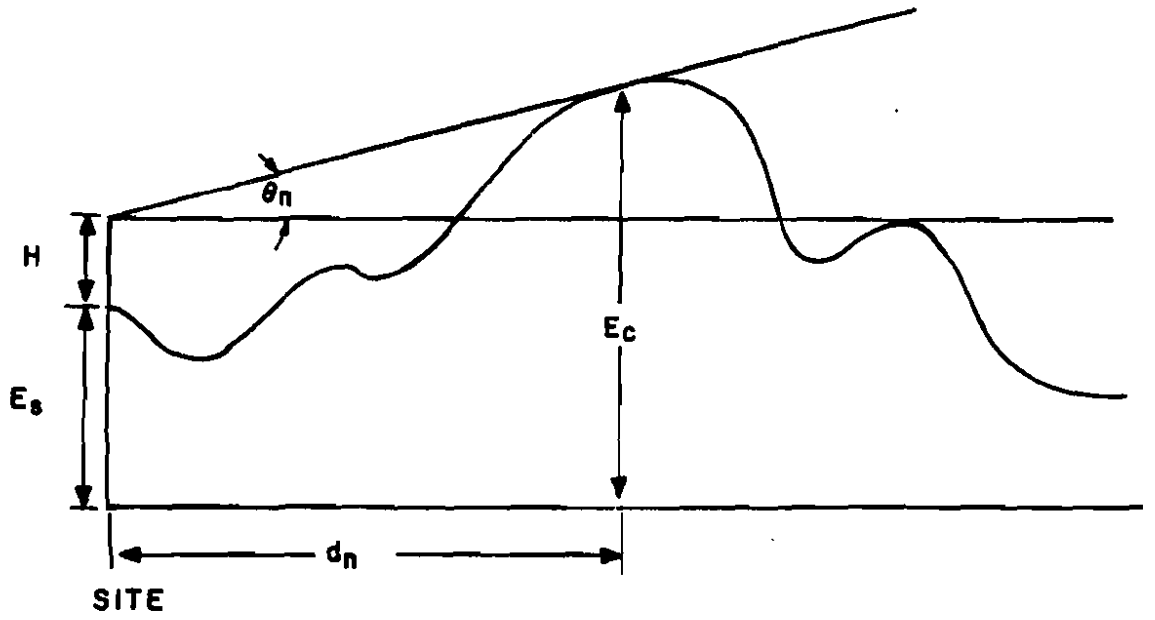



FIGURE G-9. RADIO HORIZON ANGLE, $\theta_n$.

As shown in FIGURE G-10, the limiting LOS will occur at the values of $d_n$ and $E_c$ which correspond to the maximum value of the vertical angle $\theta_n$ or the radio horizon angle.

The LOS determination described in this appendix assumes that radio wave bending has a linear dependence of the refractive index on height above the earth. For heights greater than one kilometer above sea level, the calculations are adjusted to take into account the exponential decay of the atmosphere's density.[6]

[6]Bean, B. R., Thayer, G. D., *CRPL Exponential Reference Atmosphere*, NBS Monograph 4, 29 October 1959.

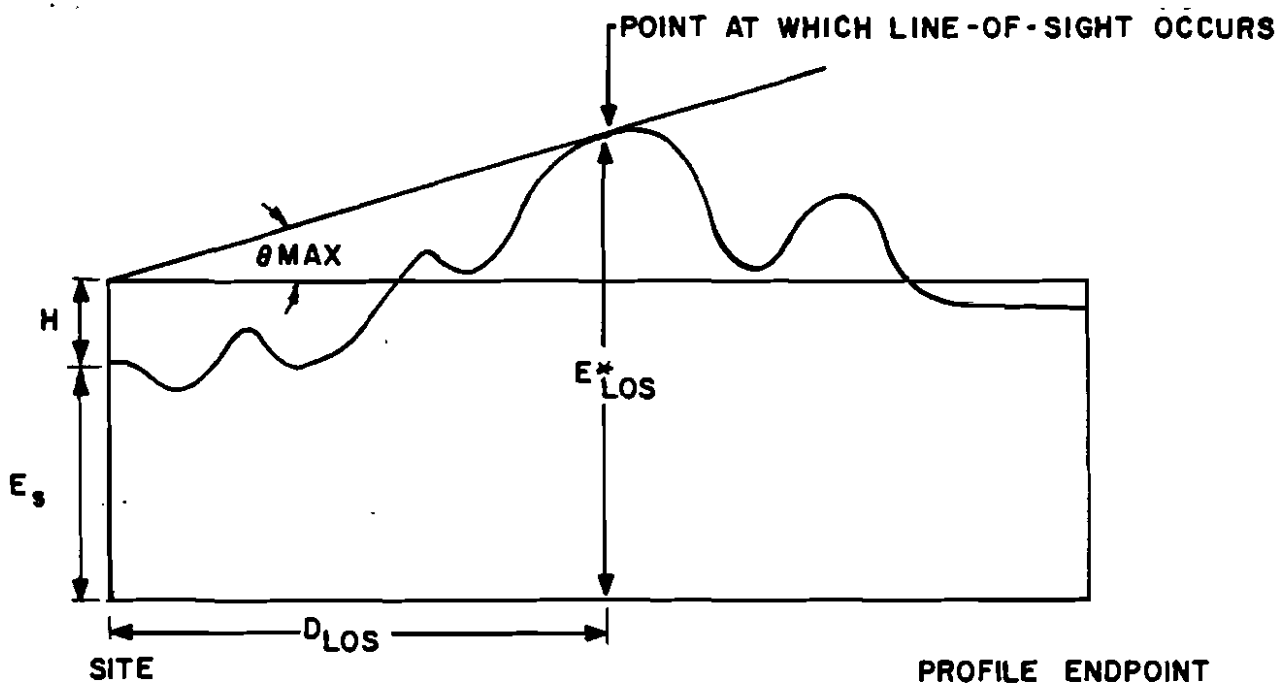



FIGURE G-10. DETERMINATION OF LOS FOR A PROFILE.

# APPENDIX H

## THE INTERMODULATION AND HARMONIC ANALYSIS ROUTINE

The Intermodulation and Harmonic Analysis Routine performs intermodulation (IM) and harmonic analysis for sets of frequencies provided by the user. The routine returns IM and harmonic free list(s) to the user.

Intermodulation analysis may be performed for any combination of two-signal second- , third- , fifth- and seventh-orders, and three-signal, third- and fifth-orders using the equations:

two-signal $f_o - (a*f_1+b*f_2) \leq \text{epsilon}$ (H-1)

three-signal $f_o - (c*f_1+d*f_2+e*f_3) \leq \text{epsilon}$ (H-2)

where

$f_o$ = receiver frequency, in MHz

$f_1, f_2, f_3$ = transmitter frequencies, in MHz

a,b = two-signal mix coefficients

c,d,e = three-signal mix coefficients

epsilon = tolerance, in MHz = one-half of the IF bandwidth.

The coefficients are set in the program, but they may be changed, provided that the sum of the absolute values of the coefficients is equal to that order.

Harmonic analysis may be performed up to the ninth order, using the equation:

$f_1 - N*f_2 \leq \text{epsilon}$ (H-3)

where

$f_1$ = transmitter frequency, in MHz

$f_2$ = receiver frequency, in MHz

N = harmonic order (2 to 9)

epsilon = tolerance, in MHz.

The user may input both transmitter and receiver frequency lists, or for transceivers only a transmitter list is required. Problems are predicted between the transmitter and receiver lists, and thus give both a problem-free transmitter list and receiver list. For transceivers, problems will be predicted among frequencies within that list, and thus give a problem-free transceiver list only. In each case, problem sets are calculated and the frequency that occurs most in these problems is deleted. This process is then repeated until there are no problems predicted, and the problem-free lists are given.

Each transmitter and receiver frequency list may contain a maximum of 44 frequencies. Any of these frequencies may be input as negative to prevent them from being deleted. If these saved frequencies occur together in an intermodulation or harmonic problem so that none can be deleted, a warning will be printed.

For intermodulation analysis, the user has the option of printing out a list of the IM problems. Otherwise only an IM-free frequency list will be given. For harmonic analysis, only a harmonic-free frequency list is given.

If the user has enough data to make some simple power calculations before running the program, and the estimated attenuation is sufficiently large for wide frequency spacings, the program can be instructed to ignore

intermodulation combinations that exceed certain limits on frequency spread. Two limits are calculated. The first limit calculated is the difference between the highest and lowest frequency involved (delta) and the second is the ratio of the spread to the tuned frequency of the receiver (gamma). The calculations performed are as follows:

$$\mathrm{Max}(f_0, f_1, f_2, f_3) - \mathrm{MIN}\ (f_0, f_1, f_2, f_3) \leq \mathrm{delta} \qquad \text{(H-4)}$$

$$\frac{\mathrm{MAX}(f_0, f_1, f_2, f_3) - \mathrm{MIN}\ (f_0, f_1, f_2, f_3)}{f_0} \leq \mathrm{gamma} \qquad \text{(H-5)}$$

where

$f_0$ = receiver frequency, in MHz

$f_1, f_2, f_3$ = transmitter frequencies, in MHz

delta = maximum frequency separation tolerance, in MHz

gamma = maximum fraction tolerance.

# APPENDIX I

## THE AIRFRAME COUPLING ROUTINE

The methods used to calculate the theoretical transmission path loss are discussed in this appendix. The discussion and figure that follows is found in Reference 4.

The path loss between isotropic radiators on an airframe is calculated using the technique reported by Hasserjian and Ishimaru[7] and extended by Khan, et al.[8] These efforts have shown that the path loss along a conducting curved surface can be calculated by:

$$L_{PC} = L_{PF} + F(y) \qquad \text{(I-1)}$$

where

$L_{PC}$ = the path loss along the curved surface of the airframe

$L_{PF}$ = the path loss if the same surface were flattened into a plane

$F(y)$ = the loss factor due to the curvature of the surface i.e., the curvature factor.

The curvature factor $F(y)$ was expressed by Hasserjian (Reference 7) in the form of two different infinite series as an approximate solution to Maxwell's equation with boundary conditions. One series expression

[7]Hasserjian, G., and Ishimaru, A., "Excitation of a Conducting Cylindrical Surface of Large Radius of Curvature," *IRE Transactions on Antennas and Propagation*, Vol. AP-10, May 1962.

[8]Khan, P. J., et al, *Derivation of Aerospace Antenna Coupling Factor Interference Prediction Techniques*, Colley Electronics Laboratory, University of Michigan, 1964.

was derived for "large values" of the parameter y and the other series was derived for "small values" of y. The numerical evaluation of these series for the magnitude of F(y) versus y in decibels was done at the University of Michigan (Reference 8), and is presented as a tabulation of points of the graph of F(y) versus y in FIGURE I-1. This tabulation is used with an interpolation subroutine and the formula for y.

The independent variable, y, of this function is in itself a function of the "ray path" of length $R_1$ and of curvature $\rho_1$. The function y is:

$$y = \left[(R_1)^{3/2}\right]/\rho_1 \qquad \text{(I-1)}$$

where

$R_1$ = the length of the curved ray path as normalized to the wave number, k (where $k = 2\pi/\lambda$, and $\lambda$ is the wavelength). That is, $R_1 = k\ D_1$, where $D_1$ is the length of the curved ray path

$\rho_1$ = the curvature of the ray path as normalized by the wave number.

The value of y for a cylinder is determined using:

$$y = \frac{k^{\frac{1}{2}}\ a\phi^2}{[(\Delta Z)^2 + (a\phi)^2]^{\frac{1}{4}}} \qquad \text{(I-3)}$$

where

a = the radius of the cylinder

$\Delta Z$ = the distance between the antennas along the axis of the cylinder

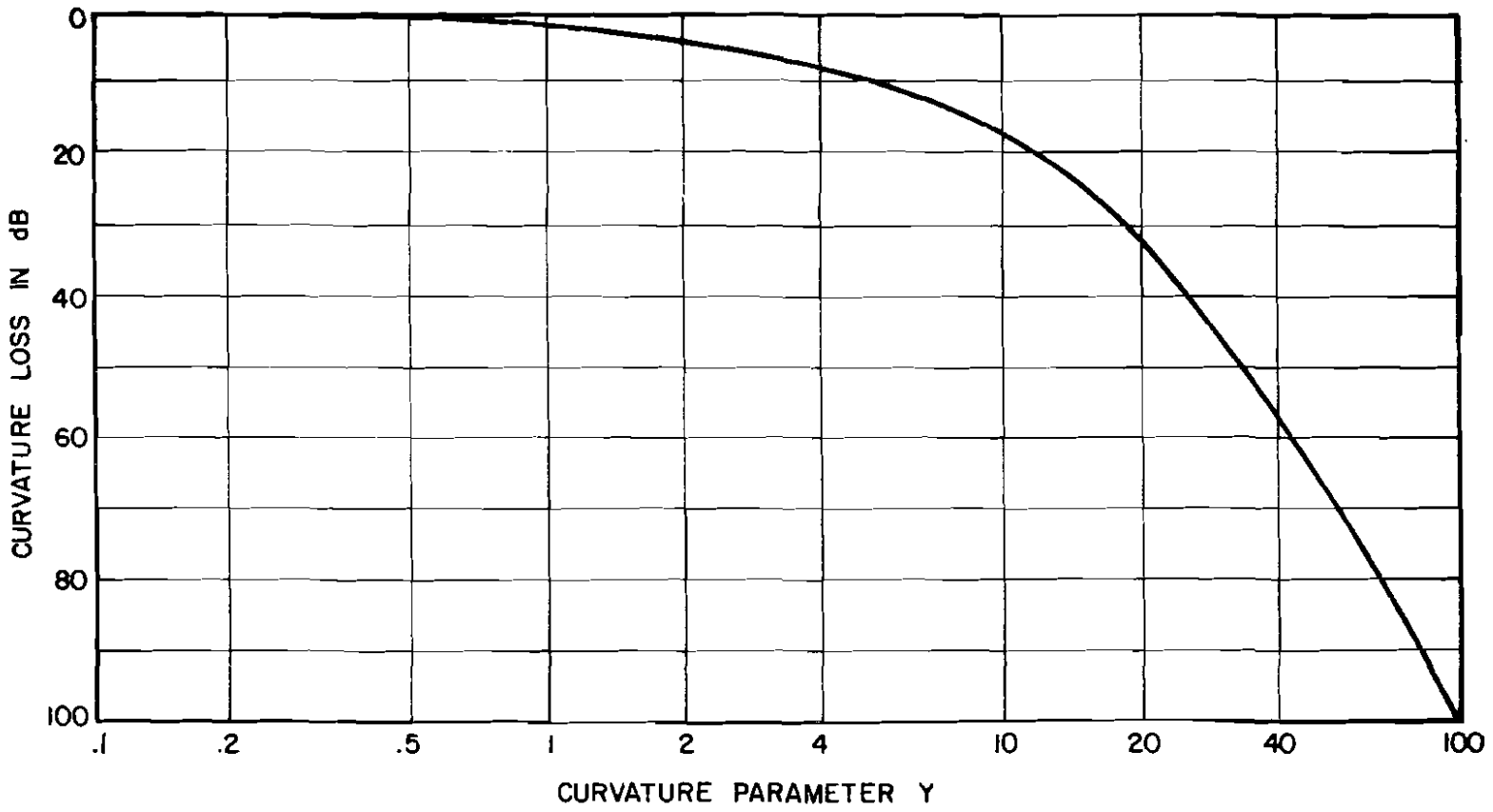



FIGURE I-1. PLOT OF THE FUNCTION F(Y), DESCRIBING THE MAGNITUDE OF THE CURVATURE LOSS CONTRIBUTION CORRESPONDING TO THE CALCULATED VALUE OF PARAMETER Y.

$\phi$ = the angle in radians between the antennas on a plane, defined by the two antennas and the center of the airframe.

The path loss between the antennas if the surface is assumed to be planar is calculated using the free-space formula:

$$L_{PF} = 20 \log f + 20 \log D_1 - 38 \qquad \text{(I-4)}$$

where

$L_{PF}$ = the free-space loss between isotropic radiators, in dB

$f$ = the transmitted frequency, in MHz

$D_1$ = the ray path distance along the surface between the antennas, in feet.

The distance, $D_1$, for a cylinder is:

$$D_1 = [(\Delta Z)^2 + (a\phi)^2]^{\frac{1}{2}} \qquad \text{(I-5)}$$

where all terms have been previously defined.

One of the restrictions in the technical development of the curvature factor is a requirement that the curvature along the ray path between the antennas remain constant. If the antennas lie on a conical surface, the requirement is not completely satisfied. In practical airframes, however, it can be shown that the ray-path length can be calculated with a high degree of accuracy by treating the cone as a modified cylinder with a radius equal to the geometric mean of

the radii of the cone at the locations of the antennas. The limitation of this approximation is that the apex angle of the cone cannot exceed 20 degrees.

It can be shown that the curvature factor between two antennas on a cone lies between the two F(y)'s which would be calculated if the cone was replaced by two different cylinders having radii equal to the cone radii at each of the two antenna locations.

The remaining restrictions which affect the application of this technique include geometrical limitations which ensure that the respective antennas do not lie within each other's Fresnel (near-field) region. These geometrical restrictions place a lower limit on the frequencies at which the coupling loss can be calculated. For example, if an HF wire antenna, the resulting radiating high frequency wavelengths, and an airframe length are all of comparable magnitudes, then the entire airframe can be expected to be a part of the HF antenna system. Any consideration of the coupling loss to be expected along the airframe, consequently, becomes an intra-antenna (near-field) consideration. Thus, this technique cannot be applied to HF systems.

In addition to the parameters discussed above, other factors must be considered for certain paths between antennas on an airframe. When one antenna is located in front of the metal nose bulkhead and the other is behind the bulkhead, a knife-edge diffraction loss can be expected due to the obstruction created by the bulkhead. Bullington presents a nomograph which can be used to calculate these losses (Reference 9, Chapter 33). This nomograph has been automated in equation form and this additional loss factor is automatically included when the transmission path crosses the nose bulkhead. The equation used is:

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[9]Jasik, H., ed., *Antenna Engineering Handbook*, McGraw-Hill, New York, NY, 1961.

$$L_k = 10 \log (h^2 f/20d) \qquad \text{(I-6)}$$

where

$L_k$ = the knife-edge diffraction loss, in dB

$h$ = the height of the obstruction above the straight-line path, in feet

$f$ = the transmitted frequency, in MHz

$d$ = the distance between the bulkhead and the antenna nearest the bulkhead, in feet.