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SPECTRUM ORBIT UTILIZATION PROGRAM TECHNICAL MANUAL
SOUP5 VERSION 3.8

CR-174944

13 DECEMBER 1984

(NASA-CR-174944) SPECTRUM ORBIT UTILIZATION
PROGRAM TECHNICAL MANUAL SOUP5 VERSION 3.8
(Operations Research, Inc.) 77 p
HC A05/MF A01

N86-26489

CSCL 17B

Unclas

G3/32 43458

BY

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F. S. ZUSMAN

PREPARED UNDER CONTRACT No. NAS3-22885
FOR NASA LEWIS RESEARCH CENTER

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Silver Spring, Maryland 20910

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I. INTRODUCTION

1.1 PURPOSE AND SCOPE

The purpose of the SOUP5 Version 3.8 Technical Manual is to describe the underlying engineering and mathematical models as well as the computational methods used by the SOUP5 analysis programs, which are a part of the R2BCSAT-83 Broadcast Satellite Computational System. This system was developed for use at the Regional Administrative Radio Conference (RARC-83) held in Geneva in June of 1983. Version 3.8 is equivalent to the program used to establish the Region 2 plan at the conference. However, it should be noted that the International Frequency Registration Board was empowered by RARC-83 through its Resolution COM 5/1 to further modify the software for the purpose of preparing a final prediction of mutual interference levels for applications under the plan agreement. This may result in predictions that differ from those made at the RARC-83.

Included in this manual are the algorithms used to calculate the technical parameters and references to the relevant technical literature. Not included are a detailed discussion of how to use and interpret the output of the SOUP5 analysis programs, detailed descriptions of the inputs and hardcopy (printed) outputs of the SOUP5 program, nor summary descriptions of the program themselves. These are fully documented in the SOUP5 Version 3.8 User Manual. Nor is there a description of the program code and structure or the program's data structures (including the COMMON blocks and binary file interfaces). These are documented in the SOUP5 Version 3.8 Programmer's Manual.⁶

1.2 R2BCSAT-83 COMPUTATIONAL SYSTEM OVERVIEW

The SOUP5 programs provide the plan analysis capability of the R2BCSAT-83 Computational System. The R2BCSAT-83 Computational System was designed to satisfy the computational requirements of the 83 RARC. The system provides the following capabilities:

- Requirements File Maintenance
- Data Base Maintenance
- Elliptical Satellite Beam Fitting to Service Areas
- Plan Synthesis from Specified Requirements
- Plan Analysis (System Performance and Inter-System Interference)
- Report Generation/Query

This section provides a brief description of each of these functions.

Prior to RARC-83, the ITU collected the broadcast satellite service requirements information from each ITU Region 2 administration. This includes such information as the locations and rain zones of performance/interference test points for the service areas in the plans to be developed. These data have been keyed and are now maintained in a data base. They are available for report generation, querying, and as input to the computational routines.

The technical parameters for the conference as well as plans under consideration are maintained in a data base which is accessible for report generation, querying, and input to computational routines. The data base also includes the results of the Beam Fitting and Synthesis Modules.

The Beam Fitting Module of the system computes the parameters of the satellite antenna beam from a specified satellite location which best fits a set of points defining a service area. The outputs of this program are in the data base.

The Plan Synthesis Module assists a planner in the development of downlink plans. These prospective plans are stored in the data base and are used as input to the Plan Analysis Module by means of an interface program.

The Plan Analysis Module consists of the SOUP5 system described in this manual. SOUP5 computes the aggregate interference (uplink, downlink, and total including co-channel, adjacent channel and second adjacent channel) for all the service areas in a plan. A plan can come from the Plan Synthesis Module or be generated manually by a planner. The latter was necessary at RARC-83 because the synthesis module could not process the large number of requirements with sufficient speed. The printed outputs of the SOUP5 module are summary and detailed reports as well as diagnostic information. The module also generates a binary output file for use by the Report Generation/Query Module. SOUP5 is written in FORTRAN and currently runs on the PRIME 400, IBM 370 compatible computers, the VAX 11/780 and the SEIMENS computer at the ITU.

The Report Generation/Query Module permits a planner to query the data base to determine the values of selected parameters or to generate reports on a preformatted or ad hoc basis using data from any part of the data base - Requirements, Technical Parameters, Results, or Analysis Results.

1.3 SOUP5 SYSTEM SUMMARY

The principal purpose of SOUP5 is to compute the mutual interference between a large number of broadcast satellite links for ground stations at specified locations operating through satellites in specified orbital positions. Since mutual interference is the main limiting factor in the use of the geostationary arc by many systems operating in the same frequency band, SOUP5 is a most valuable tool in the planning or analysis of spectrum-orbit utilization.

An additional purpose of SOUP5 is to compute certain associated performance parameters, such as power flux density and received power, which, while not directly related to mutual interference, nevertheless are useful in the analysis of satellite communication systems.

SOUP5 is designed to be used for systems in the Broadcasting-Satellite Service (BSS) with 17 GHz uplinks and 12 GHz downlinks. The propagation model, channelization characterization, antenna types, and/or

interference interaction evaluation methodologies could require modification for other applications. The program handles as many as 300 service areas, 2400 feederlink transmitters (FLT) and 2400 earth station receivers (ESR) in one run. Each link must be described in terms of its geometrical and communication parameters. Some of the more significant input parameters considered are carrier frequency, polarization, channelization schemes, antenna off-axis gain patterns, antenna diameters or beamwidths, and ground terminal and satellite locations.

The standard output is a set of interference reports for up, down, and total aggregate interference. A report giving intermediate results is optionally available. Extensive detailed printout for the subprograms in the system are available as debug options.

1.4 HISTORY

The Spectrum Orbit Utilization System (SOUP) was originally developed by General Electric, Space Systems Organization, Valley Forge Space Center, in 1969/70 as part of a study of the technical and economic aspects of spectrum-orbit utilization under Contract No. OEP-SE-69-102.¹ This work was first monitored by the Office of Telecommunications Policy, Executive Office of the President, with funding also supplied by NASA and the FCC. Later, the responsibility for this effort was transferred to NASA. The system was written for use on the IBM 360/44 computer. In June 1971, ORI, primarily under NASA sponsorship with some assistance from the NTIA, started to adapt the system for use on the IBM 360/95 computer and to make several modifications to enhance its utility as a tool in a study of domestic communication satellite systems. A document describing the modified SOUP was published in 1974.² A 1980 document describes further enhancements.³ An updated document describing the enhanced version (SOUP3), which can be used to analyze the interference between systems transmitting television, telephony and data, was published in 1981.⁴ This manual describes the technical details of the version of the system which is called SOUP5* Version 3.8 which has been designed to handle broadcast satellite systems only.

1.5 FORMAT OF THIS REPORT

Section II, (Overview) describes the organization, capabilities, processing sequences, and processing and data options of the SOUP5 system. Section III (Geometry) gives the details of the geometric calculations. Section IV (Antenna Gains) describes the various antenna gain algorithms used. Section V (Rain Attenuation) discusses the rain attenuation and depolarization calculations. Section VI (Equivalent Gain, Transmitter Power and Received Power) details the calculations of transmitter power and resulting power flux density. Section VII (Channelization and Protection Ratio) describes the channelization options, interference categories, and protection ratio calculations. Section VIII (Margins, Aggregate Interference and Grouping) describes the generation of aggregate interference and margins. Appendix A describes the equivalent gain calculation in detail.

*SOUP4, an enhanced version of SOUP3, was superseded by SOUP5 Version 1 before it was distributed to the user community.

II. SOUP5 TECHNICAL OVERVIEW

The SOUP5 analysis system currently consists of three programs and their associated input and output files. The flow chart in Figure 1 shows the input and output files used by SOUP5. Each file is labeled with the Data Set Name (DSN) used in the JCL which accompanies the program (see Appendix C of the User's Manual). For files without a DSN (i.e., Sysout = A for printout, or DD * for input in JCL stream) a descriptive name is enclosed in parentheses. Each arrow is labeled with the FORTRAN unit number of the file as implemented on IBM computers and the name of the internal program variable containing the FORTRAN unit number. The unit numbers themselves are read from files P1.DATA, P2.DATA and P3.DATA so that individual installations may change them to suit their own conventions. The following paragraphs summarize the components -- both programs and data -- of the system.

2.1 INPUT FILES

SOUP5 reads six input files in program P1 and one in Program P3 to assemble the data necessary to perform subsequent calculations. These files (except those written by the IFRB) contain sequentially organized, card image data. The Program 1 input files are the following:

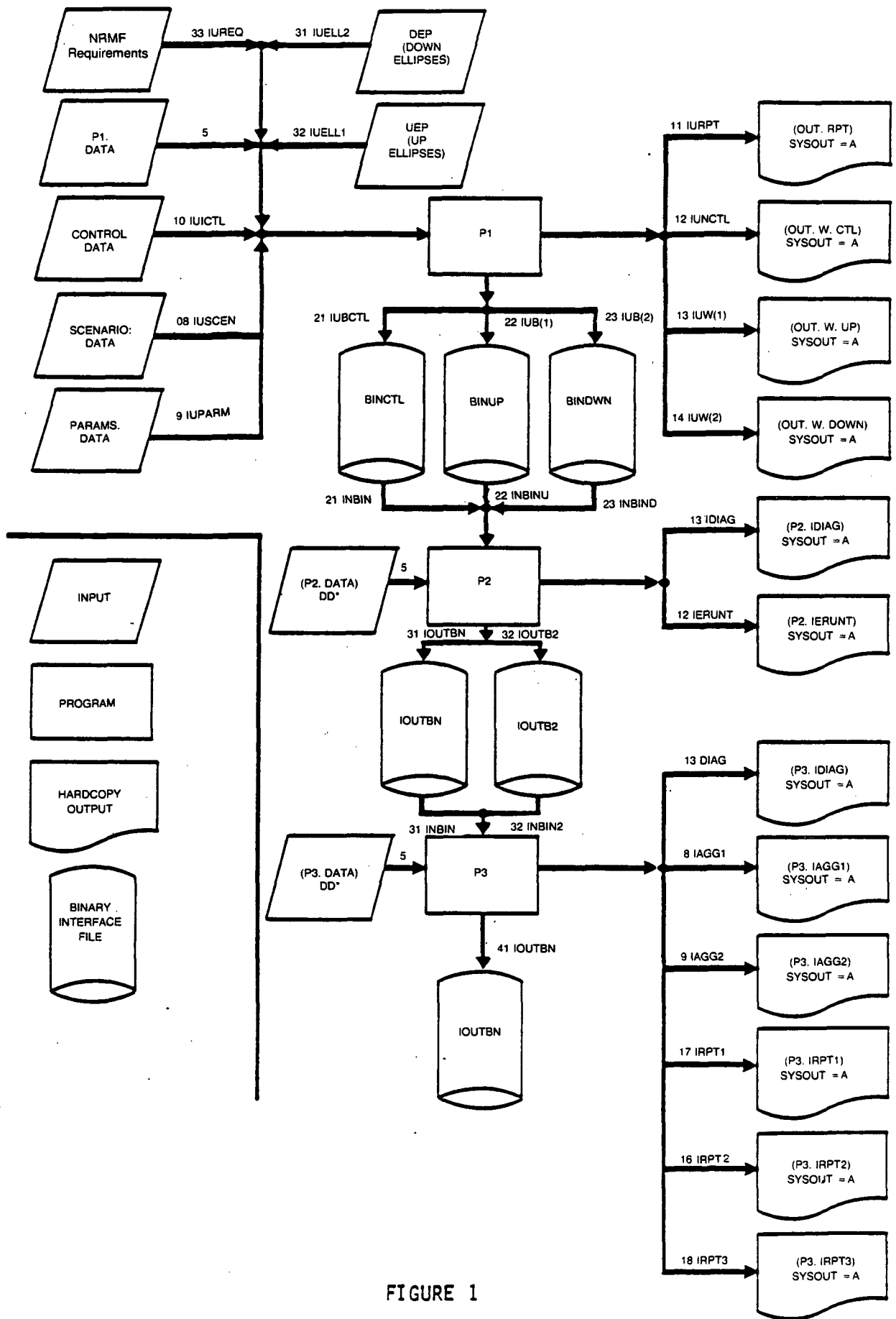


FIGURE 1
SOUP5 - SYSTEM FLOWCHART

- System and Run Control Data:

- DATA.P1 - Contains error message formats, file unit assignments, and other internal program P1 data.
- DATA.CONTROL - Contains
 - Name of scenario-plan for this run
 - Process up and/or down option
 - Reports to be written
 - Debug printout flags for programs P1 through P3.

- R2BCSAT-83 Data Base Data:

- DATA.SCENARIO contains a set of scenario-plans. Program P1 selects and processes one of them. Up to 300* service areas, 2400* feederlinks and 2400* earth station receivers can be accommodated in any one plan.
- DATA.PARAMETERS contains
 - RARC Parameters
 - Channelizations
 - Protection Ratio Sets
 - Point Sets (alternatives for the Requirements files)
 - Ellipses (alternatives for the official ellipse files)
 - Antenna Characteristics Sets
 - Gain Tables
- ELLIPSE FILES (one for up and one for down) contain official IFRB ellipses
- REQUIREMENTS FILE contains data from requirements forms submitted to the IFRB.

* Numbers can be changed during installation.

Input file P3.IMATRX is read in Program P3. This file allows the user to inhibit the interference calculations between specified service areas in either direction. It may be created by the user, or by the synthesis program.

Each of these files is fully described in Chapter 3 of the SOUP5 Version 3.8 User's Manual.⁵

2.2 PROGRAMS

The three programs comprising SOUP5 are:

Program 1 - Selects the data from the data base which are needed for the run and assembles them into a form usable by programs P2 and P3, echo printing the selected data while checking and editing them for completeness and consistency.

Program 2 - Perform intra-system calculations: unit conversions (e.g., dB to numerics); transformation to Cartesian coordinates; calculations of protection ratios by interference category; determination of interference categories by channel family; computations of on-axis gains, transmitter power, etc.

Program 3 - Performs "cross" calculations (i.e., for up, each satellite vs. all feederlink test points; for down, each earth station receiver test point vs. all satellites). Calculations performed include: gain, received signal power, attenuation, C/I and margins. Produces summary aggregate interference reports for up, down, and total.

Each of these programs is summarized below.

2.2.1 Program 1

As explained above, Program 1 reads the six input files, selects the needed data, checks and edits them, and assembles them into a form usable by Program 2 and 3.

The main program in Program 1 invokes in sequence the following top-level subroutines:

- INIT - Read DATA.P1 and initialize the run
- PRCTL - Process control inputs in DATA.CONTROL
- PRSCEN - Process scenario level data and scenario description in DATA.SCENARIO
- PRRARC - Process RARC parameters in DATA.PARAMS
- PRSERV - Process scenario service areas and point overrides in DATA.SCENARIO
- PRCHAN - Process channelization data in DATA.PARAMS
- PRPROT - Process protection ratio data in DATA.PARAMS
- PRPNTS - Process points sets and points in DATA.PARAMS and Requirements
- PRBEAM - Process ellipse data in DATA.PARAMS and the Ellipse File
- PRANG - Process antenna characteristics in DATA.PARAMS
- PRGAIN - Process gain tables in DATA.PARAMS
- PRSIZE - Process up/down table sizes.

Typically these top-level subroutines incorporate the steps delineated in the following algorithm, depending on the type of data being processed:

PRXXXX (Process data type XXXX)

- Initialize - Write the input and binary echo report subheadings; initialize the control and table data
- Get the next needed key from the program key storage tables

- Read through the sequential input file until the record(s) with the needed key are located. If any are not located, report the error
- Write the input report entries to OUT.RPT
- Resolve data overrides from the tabled overrides
- Put the referenced keys into the program key storage tables, returning indices
- Perform data lookups, conversions, edits and verifications, while reporting any errors which occur
- Table the data required by program P2 with all overrides, indices, and edits
- Continue the above subprocesses until all the needed data are located, reported, edited, and tabled
- Skip to the end of the data of type XXXX in the parameter input file
- Write the binary data needed for program P2 and the corresponding binary echo report records from tabled data.

Below we list and summarize the Program 1 subroutines and their calling hierarchy. The subroutines are listed in two sections. The first section presents a hierarchical listing of the highest level subroutines. The listing shows the flow of processing but does not list or describe the "tool" subroutines. These subroutines perform various housekeeping functions, but do not participate in the logic flow of Program 2. These subroutines are listed below the higher level subroutines. Each subroutine is documented more fully in section II-E of the SOUP5 Programmer's Manual.⁶

Main - Drives Program 1

- 2.1 INIT - Initializes constants and tables
- 2.2 PRCTL - Process Control Cards
 - 3.1 PRNCTL - Process P2 to P5 Control Cards
- 2.3 PRSCEN - Process Scenario and Description
 - 3.2 PRSCDS - Process Scenario Description
- 2.4 PRRARC - Process RARC Parameters
- 2.5 PRSERV - Process Service Area

- 3.3 RRSERV - Read and Report Service Area Cards
- 3.4 PRPATH - Process Up and Down Path Data
 - 4.1 PPRTOV - Process point overrides
- 2.6 PRCHAN - Process Channelization Cards
 - 3.5 RDCHNZ - Process Channelization Cards
 - 3.6 RDCHF - Process Channel Family Records
 - 3.7 WBCHAN - Write Channelization Data
- 2.7 PPROT - Process Protection Ratio Templates
 - 3.8 RRPROT - Read, Report and Template Protection Ratio Tables
 - 3.9 WBPROT - Write Protection Ratio Tables
- 2.8 PRPNTS - Process point set input cards
 - 3.10 RDPSET - Process needed point set
 - 3.11 RDPNTS - Process needed points
 - 3.12 WBPNTS - Write point set tables
- 2.9 PRBEAM - Process Ellipse Input and create Ellipse Table
 - 3.13 RDBEAM - Read, Report and Table Beam Data
- 2.10 PRANT - Process Antenna Input and create Tables
 - 3.14 RDANT - Read and Report needed Antenna records
- 2.11 PRGAIN - Process Gain Tables
 - 3.15 RRGAIN - Read, Report and Store needed Gain tables
 - 4.2 RRGR1 - Read, Table, and Report Gain Record Type 1
 - 4.3 RRGR2 - Read, Table, and Report Gain Record Type 2
 - 3.16 WBGAIN - Write Gain Tables
- 2.12 PRSIZE - Process and Write Up and Down Table Sizes

2.2.2 Program 2

Program P2 converts all the variables to units suitable for use in Program P3, does all the intra-system calculation involving each service area at a time, and checks for errors.

The program performs the following functions:

- Transforms all ground and satellite positions from latitude and longitude to earth-centered Cartesian coordinates.

- Converts all values expressed in decibels to numerical values where necessary.
- Reads the control and table files and, after necessary conversions, writes them out for use by Program 3.
- If the user desires, prints a graph of gain as a function of off-axis angle for each antenna gain table used in the run.
- Produces extensive diagnostic output at the user's option.
- Checks for errors in the data, prints warnings when an error is found, and sets the stop code to values depending on the seriousness of the error.
- Calculates the on-axis gains and beamwidths of all antennas.
- Calculates the basis vectors of the antennas, and the orientation angle of the beam major axis in the beam plane. The orientation angle may be specified directly as an input or by use of a reference point latitude and longitude.
- Calculates transmitter power if the user has specified EIRP, receiver C/N or impinging PFD as input. Antenna noise temperature can be specified as an input or determined from an input figure of merit (G/T).
- Calculates on-axis beam unit vectors.
- Calculates a nominal wavelength for each assigned channel family and relevant interference categories (e.g., co-channel, upper adjacent) between channel families. Checks to ensure the RARC channelization parameters have not been violated.

- Calculates the protection ratio for each interference category using the selected template.
- Writes out all the data needed by Program 3.

The calling hierarchy of the subroutines in Program 2 is listed below. Each routine is called by the last preceding subroutine of the next (numerically) lower level.

MAIN - Drives Program 2

- 1.1 INIT - Initiates constants and I/O Unit numbers
 - 2.1 CTBLRW - Drives reads and writes of control and tables
 - 3.1 RWCNTL - Reads and writes control tables
 - 3.2 RWSNRA - Reads and writes scenario data
 - 3.3 RWSNDS - Reads and writes scenario description
 - 3.4 RWRARC - Reads and writes RARC Parameters
 - 3.5 RWSVA - Reads and writes service area data
 - 3.6 RDPRAT - Reads protection ratio template
 - 3.7 RDBEAM - Reads beam tables
 - 3.8 RWANT - Reads and writes antenna tables
 - 3.9 RWGTBL - Reads and writes gain tables
 - 3.10 RWGETB - Reads and writes gain entry table
 - 4.1 PRGRA - Print graphs of gain table
 - 5.1 GAINA - Calculates off-axis antenna gains
 - 3.11 RWRATN - Reads and writes rain attenuation tables
 - 3.12 RWTBSZ - Reads and writes up/down table sizes
- 1.2 TPATH - Drives reads, calculations and writes of Path and Point data
 - 2.2 RDPATH - Reads Path related data
 - 2.3 RDCHNL - Reads, converts, and edits channel data
 - 3.13 INCAT2 - Calculates nominal frequencies and interference category tables
 - 2.4 GENPRT - Calculates Protection ratios
 - 3.14 CPRAT - Interpolates protection ratio templates
- 2.5 PRPTH - Process path related data

- 3.15 POSITN - Finds satellite Cartesian Coordinates
- 3.16 POSITN - Finds aimpoint Cartesian coordinates
- 3.17 RANGE - Finds satellite on-axis beam
- 3.18 ORIENT - Drives Orientation angle calculation (for non-circular satellite antennas)
 - 4.2 ELPSE - Sets Ellipse orientation angle
 - 5.2 LATLON - Finds reference point antenna coordinates
 - 5.3 ELTLN - Finds orientation angle reference points
 - 5.4 TRNFRM - Finds antenna beam plane base vectors
- 3.19 BMWGOA - Finds on-axis gain of satellite antennas
- 3.20 POWER - Finds satellite transmitter power
- 2.5 WRFRBW - Writes nominal wavelength and interference category tables
- 2.6 WRPRAT - Writes protection ratio ratios
- 2.7 RWPST - Reads and writes end point table
- 2.8 RWPOIN - Reads, calculates and writes ground point data
 - 3.21 POSITN - Finds Cartesian coordinates of earth stations
 - 3.22 BMWGOA - Finds earth station on-axis gains and antenna beamwidths
 - 3.23 RANGE - Finds earth station on-axis beams
 - 3.24 POWER - Finds earth station transmitter powers
 - 4.3 RPWCN Finds Received power for C/N and PFD calculations
 - 5.5 RANGE - Finds earth-station-satellite range
 - 5.6 PHIS - Finds satellite antenna off-axis angles
 - 5.7 SIGMA - Finds relative orientation angle
 - 5.8 GAINA - Finds off axis antenna gains
 - 5.9 PHIS - Finds elevation angle
 - 5.10 ATTENU - Finds rain attenuation
 - 5.11 GNEQU - Finds equivalent gain
- 2.9 WRPATH - Writes path related data

2.2.3 Program P3

Program P3 reads the user-specified non-interference matrix (i.e., specification of interference interactions to be disregarded) and then performs the following inter-system calculations:

- For each satellite vs. ground point
 - Looks up the interference category (e.g., co-channel, upper-adjacent).
 - Does no calculations where the channels are non-interfering (e.g., channel separations greater than second adjacent channel).
 - Does no calculations when the interference matrix specifies inhibition of interference between the service areas.
 - At the user's option, does no interference calculation for same administration, same satellite position, same channel family.
 - Calculates slant range, off-axis angle and orientation angle relative to the major axis of the ellipse.
 - Calculates the co-polarized and cross-polarized transmit and receive antenna gains using the selected gain tables.
 - Calculates the equivalent gain, rain attenuation and received power.
 - Allows the user to specify up and down parameters (e.g., frequency, channelization) independently.

For up calculations only

- Determines the weakest feederlink transmitter (FLT) in the satellite's own ground point set to determine carrier power and the strongest FLT's in the other ground point sets to determine the interfering powers for use in the carrier-to-interference calculations.

- For both up and down
 - Sums all the interference powers taking grouping into account.
 - Calculates the carrier to interference power ratio ratios and interference margins for all the interference categories.
 - Determines the worst interfering service areas in all five interference categories.
 - Produces summary reports for up, down, and total aggregate interference.
 - Writes all inputs, intermediate results and final results to a binary file for use by a report generator.

The calling hierarchy of the subroutines in Program 3 is listed below. Each routine is called by the last subroutine of the next higher lower level.

- Main - Reads interference matrix and drives Part 3
 - 1.1 INIT - Initiates constants and I/O
 - 2.1 CTBLRW - Drives reads and writes control tables
 - 3.1 RWCNTL - Reads and writes control tables
 - 3.2 RWSNRA - Reads and writes scenario data
 - 3.3 RWSNDS - Reads and writes scenario description
 - 3.4 RWRARC - Reads and writes RARC parameters
 - 3.5 RWSVA - Reads and writes service area data
 - 3.6 RWANT - Reads and writes antenna table
 - 3.7 RWGTBL - Reads and writes gain tables
 - 3.8 RWGETB - Reads and writes gain entry table
 - 3.9 RWRATN - Reads and writes rain attenuation tables
 - 3.10 RWTBSZ - Reads and writes up/down table sizes
 - 1.2 UP - Drives uppath calculations

- 2.2 READIN - Drives reads of path and point related data
 - 3.11 RDPSD3 - Reads path related data
 - 3.12 RWFRBW - Reads and writes interference category and nominal wavelength tables
 - 3.13 RWPRAT - Reads and writes protection ratios
 - 3.14 RWPST - Reads and writes endpoint tables
 - 3.15 RDPOIN - Reads point set data
- 2.3 INIT3G - Initializes aggregate interference results
- 2.4 INIT3P - Initializes cross calculation results
- 2.5 CHKCRD - Checks if maximum Φ/Φ_0 is exceeded
- 2.6 RPOWER - Finds received power relative to one watt transmitter power
 - 3.16 RANGE - Finds slant range
 - 3.17 PHIS - Finds off-axis angle for earth antenna
 - 3.18 SIGMA - Finds relative orientation angle
 - 3.19 PHIS - Finds off axis angle for satellite antenna
 - 3.20 GAINA - Finds off axis antenna gains
 - 3.21 PHIS - Finds elevation angle
 - 3.22 ATTENU - Finds rain attenuation
 - 3.23 GNEQU - Finds equivalent gain
- 2.7 BSTWST - Selects feederlink to be used in interference calculations
- 2.8 WRSLTS - Writes intermediate cross calculation results
- 2.9 WRTAGU - Prints up aggregate interference report
 - 3.24 ERLOC - Calculates Earth station Latitude and Longitude
- 1.3 DOWN - Reads point data and drives downpath calculations
 - 2.10 READIN - Drives reads of path and point related data
 - 3.25 RDPSD3 - Reads path related data
 - 3.26 RWFRBW - Reads and writes interference category and nominal wavelength tables
 - 3.27 RWPRAT - Reads and writes protection ratios
 - 3.28 RWPST - Reads and writes endpoint tables
 - 2.11 INIT3P - Initializes cross calculation results
 - 2.12 CHKCRD - Checks if maximum Φ/Φ_0 exceeded
 - 2.13 RPOWER - Finds received power relative to one watt transmitter power

- 3.29 RANGE - Finds slant range
- 3.30 PHIS - Finds off-axis angle for earth antenna
- 3.31 SIGMA - Finds relative orientation angle
- 3.32 PHIS - Finds off-axis angle for satellite antenna
- 3.33 GAINA - Finds off-axis antenna gains
- 3.34 PHIS - Finds elevation angle
- 3.35 ATTENU - Finds rain attenuation
- 3.36 GNEQU - Finds equivalent gain
- 2.14 WRSLTS - Writes intermediate cross calculation results
- 2.15 WRTAGD - Prints down aggregate interference report
 - 3.37 ERLOC - Calculates Earth station Latitude and Longitude
- 2.16 WRATGT - Prints total aggregate interference report
 - 3.38 ERLOC - Calculates Earth station Latitude and Longitude

2.3 HARDCOPY AND BINARY OUTPUTS

Each of the programs produce various hardcopy and binary outputs, as summarized below:

There are two types of outputs from Program 1:

- Formatted reports echoing the card image inputs and the binary outputs
- Binary outputs to Program 2

Specifically, the outputs of Program 1 are:

- OUT.RPT - Formatted report echoing the selected card image inputs, with error messages to assist in debugging the data, including:

- Control Data	- Antenna Characteristics Table
- Scenario Level Data	- Gain Table
- Scenario Description	- Gain Entry Table
- RARC Parameter	- Up/Down Table Sizes
- Protection Ratio	

- Template Table
- Protection Ratio
- Entry Table
- Beam Table

- OUT.B.UP and OUT.W.UP

- OUT.B.DOWN and OUT.W.DOWN

Binary outputs for Program 2 and their corresponding formatted reports for up/down dependent data including:

- Feederlink/Downpath Table
- Channelization Table
- Channel Family Table
- Channel Table
- Point Set Table
- Points Table

Each of the report outputs is discussed in detail in Chapter 4 of the SOUP5 Version 3.4 User's Manual⁵.

There are three types of outputs from Program 2:

- Hardcopy diagnostic outputs
- Hardcopy error message outputs
- Binary outputs to Program 3

Specifically the outputs of Program 2 are:

- P2.IERUNT - A formatted report containing messages to warn the user of errors in the input data

- P2.IDIAG - A formatted report containing diagnostic output requested by the user

- P2.IOUTBN and P2.IOUTB2 - Binary output for Program 3 containing all control and data variables.

The error messages and gain table graphs are described in detail in Chapter 4 of the SOUP5 Version 3.8 User's Manual⁵. Chapter 4 of the Programmer's Manual describes the P2.IDIAG outputs.

There are four types of outputs from Program 3:

- Hardcopy diagnostic outputs
- Hardcopy aggregate interference summary reports
- Hardcopy detail reports
- Binary outputs for yet-to-be-defined report generators.

Specifically, the outputs from Program 3 are:

- P3.IDIAG - A report containing the diagnostic output requested by the user
- P3.IAGG1 - The aggregate interference summary reports for up and total interference
- P3.IAGG2 - The aggregate interference summary report for down interference
- P3.IRPT1, P3.IRPT2, P3.IRPT3 - Detail reports giving the detail results of each link equation calculation. The last, P3.IRPT3, is only written for scenarios using grouping
- P3.IOUTBN - Binary output for use by report writing programs containing the results of the link equations.

Program 3 outputs are fully documented in Chapter 4 of the SOUP5 Version 8 User's Manual⁵; P3.IDIAG in Chapter 4 of the Programmer's Manual.

2.4 TECHNICAL CAPABILITIES

The SOUP5 Version 3.8 system can handle aggregate interference calculations involving up to 300* service areas, with up to 2400* FLTs and 2400* ESRs.

The FLTs and ESRs can be allocated to the service areas in any manner except that no one area can have more than 50 ESRs and 50 FLTs. A service area may be totally independent of the others, or sets of service areas may be combined into groups which may, at a later date, coordinate their system characteristics to assure compatibility. Grouping is described in Section VIII.

Calculations for up and down interference are totally independent so that a service area may have different channelizations, satellite positions (for possible future implementation of intersatellite links), satellite antenna ellipses, polarizations, and ground point sets for up and down. If both up and down interference are calculated in the same run, the aggregate results are totalled.

2.5 TECHNICAL PROCESSING SEQUENCE

First all calculations involving only one service area are done in SOUP5 Program 2. These include:

- Antenna on-axis gains
- Transmitter power
- Antenna beamwidth
- Channelization, nominal wavelength and interference categories
- Protection ratios
- Satellite elliptical antenna beam base vectors, and ellipse major axis orientation.

*Numbers can be changed on implementation.

Next, in Program 3, all inter-system calculations, (i.e., those calculations involving more than one service area) are done. The order in which each pair of service areas is processed differs between the up and down calculations, as explained below, but the sequence of the inter-system calculations is the same, and is the following:

- Initialize all computed outputs to default values.
- Set interference categories. If the two service areas have non-interfering channelizations, no further inter-system calculations are done.
- If the interference matrix (an input) indicates no interference should be considered between the system, no further calculations are done.
- Calculate slant range. If the satellite and the ground point are over the Earth horizon from each other by more than a distance HORIZ (an input parameter), no further calculations are done*.
- Calculate satellite and ground antenna off-axis angles. Pointing tolerances are incorporated in such a way as to minimize the C/I power ratios.
- For satellite elliptical antenna beams, calculate the relative orientation angle between the ellipse major axis and the projection of the ground point in a plane orthogonal to the antenna beam.
- Calculate satellite and earth station antenna gains.
- Calculate earth station antenna elevation angles.

*If a ground point (ESR or FLI) is over the horizon from its own satellite, the user is warned and the calculation continues. No valid results (i.e. not involving the over-the-horizon points) are affected.

- Calculate rain attenuation and depolarization.
- Calculate equivalent link antenna gain.
- Calculate received power.
- Increment total interference.

Uplink inter-system calculations are done in the following sequence:

- Fix on one satellite.
- Calculate the received power from all FLT's in its own service area (carrier power).
- In reality only one carrier FLT can transmit on a given channel at a time, so we choose which one to use as follows:
 - If the FLT transmitter power is set directly as watts, or calculated from a desired EIRP, the FLT yielding the weakest received power is selected. This is consistent with SOUP's worst-case-analysis design.
 - If the FLT transmitter power is calculated from a desired PFD or C/N, then the received power from all FLT's will be equal unless the rain attenuation at one or more FLT's exceeds the allowable rain margin (an input value). In this case, the received power from these rain-limited FLT's will be less than that needed for the desired C/N or PFD. We disregard these FLT's and assume the faded threshold carrier-power level for the desired signal.
 - If the FLT transmitter power is set from desired PFD, we use the strongest received power as the carrier.

- From each interfering service area we calculate the received power from all FLT's under clear sky conditions and designate the strongest signal as the interference from that service area.
- The signal from the satellite's own carrier FLT is also incremented into the total interference in all appropriate non-cochannel categories.
- After summing all the uplink interference into one satellite, go on to the next satellite.

The downlink processing sequence is as follows:

- Fix on one Earth Station Receiver (ESR).
- Calculate the received desired signal power from the satellite under faded conditions and designate this as the carrier.
- Calculate the received interference power from the other satellites and increment the power into the total interference. Also increment any non-cochannel signal from own satellite into the total interference.

After all the inter-system calculations are done for each satellite (for up) or ESR (for down), the interference powers are summed separately in co-channel, upper and lower adjacent and second adjacent channel categories before calculating aggregate interference.

Details of the calculations summarized above are given in Section III through VIII.

2.6 TECHNICAL OPTIONS

The SOUP5 system gives the user a large number of calculation and input options. These are described in detail in the SOUP5 Version 3.8 User's Manual⁵ but those relevant to this document are shown below. In parentheses after each item is a note showing where in the input data the option is specified. Further details on each specification can be found in Chapter 4 of the User's Manual.

- Calculations in a run may be made for up only, down only, or both. In the latter case, total aggregate interference is calculated. (Record 1 of Control file)
- Transmitter power may be specified directly or it may be set indirectly by EIRP, by Power Flux Density (PFD) at the input to the receiving antenna or by carrier to noise ratio (C/N) at the output of the receiving antenna. (Records 2, 5-3, 5-5, and 5-7 of Data.Scenario. If C/N is specified, noise temperature can be specified directly, or as the figure of merit (G/T). A maximum rain margin to be used in the C/N and PFD calculation may also be specified. See Section VI for details. Antenna noise temperature is set in the antenna section of the parameter file. Maximum rain margin for up calculations is set in Record 2 of the scenario file. For down, the maximum rain margin is set in Record 3 of the RARC section of the parameter file.)
- Gain fall-off at the satellite beam edge (ΔG) is specified for the whole scenario but can be overridden at the service area level. (Records 1, 5-3, and 5-5 of Data.Scenario, and Record 1 of RARC section of parameter file.)
- Earth station antenna pointing tolerance is specified in units of the antenna beamwidth. (Records 1, 5-3 and 5-5 of Data.Scenario and Record 1 of RARC section of parameter file.)

- Satellite antenna pointing error is specified as an angle. (Records 1, 5-3 and 5-5 of Data.Scenario and Record 1 of RARC section of parameter file.)
- Antenna aperture efficiency is specified for each antenna. (Antenna Record of Data.Params.)
- Antenna gain patterns may be specified in a number of ways. See Section IV for details. (Antenna and Gain Pattern section of Data.Params.)
- The nominal frequency used for all calculations, can be set to the lowest, highest or median channel center frequency of a family. (Record 3 of Data.Scenario.)
- Peak-to-peak deviation, bandwidths, noise bandwidths and top baseband frequency may be specified. (Channelization section of Data.Params.)
- Protection ratio curves for non-cochannel situations can be specified. (Protection Ratio section of Data.Params and Record 1 of Scenario file.)
- Group assignment can be specified. See Section VIII for details. (Option to use grouping on record 3 of Scenario file. Individual group assignments on Record 5-1 of same file.)
- For non-group assignment runs the user may choose not to include any interferer with the same administration code, satellite longitude, and channel family. (Record 3 of Data.Scenario.)
- The user may request that no interference be calculated if the Φ/Φ_0 for either antenna is greater than an input value (Record 3 of Data.Scenario)

- Through the use of a non-interference matrix, the user can inhibit interference calculations between any two service areas in either direction. (Interference matrix file.)
- Circular or linear polarization can be specified, along with the polarization angle (linear) or handedness (circular). (Record 2 of Data.Scenario for circular/linear; Records 2, 5-3 and 5-5 of Data.Scenario for angle.)
- The percent of worst month number is specified for the rain attenuation calculations. (Record 1 of Data.Scenario.)
- The user may choose to include or not to include rain attenuation in the received power calculation. (Record 2 of Data.Scenario.)
- The polarization reference point may be set at either the subsatellite point or the satellite antenna aim point (only relevant when using rain attenuation with linear polarization). (Record 2 of Data.Scenario.)
- The user may specify calculation of interference into one specific channel only. (Record 3 of scenario file.)
- The user may request the SOUP only calculate interference into a selected set of service areas. (Records 9-11 of Data.Control.)

III. GEOMETRY

3.1 COORDINATES AND POSITIONS

In order to minimize the use of trigonometric functions (which slows the computations), all satellite and ground positions are transformed to Earth-centered Cartesian coordinates by subroutine POSITN in Program 2. Below is a table defining the geocentric axes in terms of the longitude and latitude of their intersection with the Earth's surface.

AXIS	INTERSECTION OF AXIS
X	0° Latitude 90° E Longitude
Y	0° Latitude 0° Longitude
Z	90° N Latitude

All distances are measured in Earth radii, defined as 6.3782×10^6 meters.^{7,8} We assume the earth is spherical, that is all ground points are 1 earth radius from the center. All satellites are placed 6.6105 earth radii from the Earth's center (nominal geostationary orbital height)⁸. Both the latitude and longitude of the satellite are set by input values. The transformations are done using the following equations:

$$\begin{aligned} X &= R \cos \theta \cos \phi && 3-1 \\ Y &= R \cos \theta \sin \phi && 3-2 \\ Z &= R \sin \theta && 3-3 \end{aligned}$$

where

θ is North Latitude

ϕ is East Longitude

R is 1 for ground points, or 6.6105 for satellites.

3.2 RANGE

The range between two points denoted by their position vectors

$$P_1 = (P_{1x}, P_{1y}, P_{1z}) \text{ and } P_2 = (P_{2x}, P_{2y}, P_{2z}) \quad 3-4$$

is

$$R_{12} = \sqrt{(P_{2x} - P_{1x})^2 + (P_{2y} - P_{1y})^2 + (P_{2z} - P_{1z})^2} \quad 3-5$$

The unit range vector between the two points is

$$R_{12} = (P_2 - P_1) / R_{12} \quad 3-6$$

The on-axis beam unit vector for an antenna is $R_{oa} = R_{12}$ where the antenna is at P_1 and the aim point is at P_2 . Satellite antennas are "aimed" at their beam aimpoint with some specified tolerance. Earth station antennas are "aimed" at their own satellite with a specified tolerance.

These range calculations are done using subroutine RANGE.

3.3 OFF-AXIS ANGLES

The antenna off-axis gain angle, ϕ , towards an interference victim is found by subroutine PHIS in the following manner.

$$\phi = \cos^{-1} (R_{oa} \cdot R_{12}) \quad 3-7$$

where R_{oa} is the unit on-axis beam vector mentioned above and R_{12} is the unit range vector between the two antennas.

Desired signal power at the satellite assumes the full earth station antenna mispointing. Before the off-axis angle is used for gain calculation, the pointing errors are introduced to decrease the carrier-to-interference power ratio (C/I) to the worst-case extent. The earth station antenna pointing tolerance is specified in beamwidths.

The satellite antenna pointing error is a direct input and the full pointing error is included in desired signal calculations. For interference signals the error is subtracted from the off-axis angle (worst-case). However, if the pointing error to be subtracted is larger than the off-axis angle, the off-axis angle is set to 0.

3.4 ELEVATION ANGLE

The elevation angle of the satellite as seen by the earth station antenna is computed as follows:

$$\phi_{el} = \phi_g - \pi/2, \quad 3-8$$

where ϕ_g is the angle between the ground point position vector and the ground antenna on-axis vector, as found by subroutine PHIS.

3.5 ELLIPSE ORIENTATION

In order to find the relative ellipse orientation, the following steps are taken:

1. The antenna beam plane base vectors are calculated (see definition below)
2. The orientation of the ellipse major axis relative to the X base vector are calculated.
3. The orientation angle of the vector (in the beam plane) connecting the beam aim point and the X projection of the ground point into the plane is calculated relative to the base vector.

4. The difference between the two orientation angles calculated above (steps 2 & 3) is used for the satellite antenna gain calculations.

The present implementation of this algorithm in SOUP5 uses code from SOUP3 for the above calculations. This adds complications, because the definitions of the antenna beam base vectors, and consequently the values of the ellipse orientation angle, differ between those used for input, and those used for internal computation. The final value of σ , which is the difference between two angles, is not affected by the choice of base vectors.

Before going into more detail, it is necessary to give some definitions, below.

- Antenna beam plane (cross section).
A plane orthogonal to the satellite antenna on-axis beam center passing through the beam aim point (which is on the Earth's surface).
Note: not to be confused with Antenna Plane.
- Antenna beam coordinate system.
A coordinate system with its origin at the beam aim point. Units are unimportant, because these coordinates are used only to calculate angles.
 - System used for internal computation (Internal system)
The Y-axis is defined by the orthogonal projection of the subsatellite point on the antenna beam plane.
 - System used for input (Input system)
The Y-axis is defined to be parallel to the intersection of the antenna beamplane and Earth's equatorial plane. This is the system used by the SOUP user community. In both systems, the X-axis is the beam on-axis vector, and the unit vector along the Z-axis is defined as $Z = X \times Y$ (vector cross product).

- Orientation angle.
The angle between a vector in the antenna beam plane and the Y-axis of the antenna beam coordinate system. The orientation angle of a ground point refers to the orientation angle of a vector connecting the origin and the satellite ray projection of the ground point on the plane.
- Antenna plane.
A plane orthogonal to the line connecting the antenna (i.e., satellite) to the center of the Earth.
Note: not to be confused with Antenna Beam Plane.
- Antenna coordinate system.
A two-dimensional coordinate system in the antenna plane, with its origin at the subsatellite point, and its X-axis defined to be parallel to the intersection of the antenna plane and the Earth's equatorial plane and its Y-axis perpendicular to the X-axis. Distance is measured in radians, as seen from the satellite.

The user may specify the elliptical antenna beam orientation in one of the two ways:

1. Orientation angle in the coordinate system used for input.
2. Ellipse reference point; the latitude and longitude of an arbitrary point on the ellipse major axis' projection on the Earth's surface (except the beam aim point).

If ellipse orientation angle is given, it is translated into the internal ellipse orientation angle. The method is implemented because it uses existing proven code.

The first step is to use subroutine LATLON (called by ELPSE) which finds the antenna plane coordinates of the beam aim point using the following algorithm.

$$SX = \text{Tan}^{-1} \left(\frac{\text{Cos}(\theta_c) * \text{Sin}(\phi_c - \phi_s)}{R_s - \text{Cos}(\theta_c) * \text{Cos}(\phi_c - \phi_s)} \right) \quad 3-9$$

$$SY = \text{Tan}^{-1} \left(\frac{\text{Sin} \theta_g}{\left(\text{Cos}^2(\theta_c) * \text{Sin}^2(\phi_c - \phi_s) + (R_s - \text{Cos}(\phi_c)) * \text{Cos}(\phi_c - \phi_s) \right)^{1/2}} \right) \quad 3-10$$

Where

ϕ_s = satellite longitude

ϕ_c = beam aimpoint longitude

θ_c = beam aimpoint latitude

R_s = geosynchronous orbital radius in earth radii

SX = the X coordinate of the satellite ray projection of the aimpoint on the antenna plane

SY = the Y coordinate of above.

All coordinates are in units of angle between the point in the antenna beam plane and the origin as seen by satellite.

Next subroutine ELTLN is used to find the X and Y distances from the beam axis SX2, SY2, in the antenna plane, of a reference point on the ellipse major axis, one half semimajor axis from the beam aimpoint.

$$SX2 = (A_{maj}/2) * \text{Cos}(e) \quad 3-11$$

$$SY2 = (A_{maj}/2) * \text{Sin}(e) \quad 3-12$$

Where

A_{maj} is the ellipse major axis (in radians)

e is the ellipse orientation angle as specified by the user

Using the numbers, SX, SX2, SY and SY2, subroutine ELTLN finds a reference point of the ellipse major axis, using the following methods. First, it finds a reference point in the antenna plane

$$X1 = SX + SX2$$

$$Y1 = SY + SY2$$

then it calculates

$$T = R * \text{Sin} (\text{Cos}^{-1} (\text{Cos} (X1) * \text{Cos} (Y1))) \quad 3-13$$

If $T > 0$, (i.e., the reference point does not intersect the Earth surface), $X1$ is reset to $SX - SX2$ and $Y1$ is reset to $SY - SY2$; that is, the reference point is placed on the other side of the ellipse major axis.

If after resetting the reference point to the other half of the ellipse major axis T is still > 1 , an error exists, the ellipse aimpoint does not intersect the earth.* Subroutine ELTLN prints an error message and sets the Program 2 Stop code to a level which warns that Program P3 will not work.

Assuming no error, the calculations continue.

$$PX = \text{Sin}^{-1} (\text{Sin} (Y1) / \text{Sin} (\text{Cos}^{-1} (\text{Cos}(X1) \text{Cos}(Y1)))) \quad 3-14$$

$$\text{If } X1 < 0, PX = \pi - PX$$

$$D = \text{Sin}^{-1} (T) \quad 3-15$$

$$BLAM = D - \text{Cos}^{-1} (\text{Cos} (X1) \text{Cos} (Y1)) \quad 3-16$$

$$\theta_r = \text{Sin}^{-1} (\text{Sin} (BLAM) \text{Sin} (PX)) \quad 3-17$$

Where θ_r = the reference point longitude

$$AL = \text{Cos}^{-1} (\text{Cos}(BLAM) / \text{Cos} \theta_r) \quad 3-18$$

$$\text{If } PX > \pi/2, AL = -AL \quad 3-19$$

$$\phi_r = \phi_s + AL \quad 3-20$$

*This will not happen with a valid ellipse, but can inadvertently happen when the satellite position used in the scenario differs considerably from the satellite position used to generate the ellipse.

Where ϕ_r = the reference point longitude.

Using the reference point, which was either computed above or entered by the user, subroutine ELPSE finds the vector connecting the beam aimpoint and the reference point, $(X_{elp}, Y_{elp}, Z_{elp})$. (Later this vector will be projected onto the antenna beam plane).

$$X_{elp} = \cos \theta_r * \cos \phi_r - X_{beam} \quad 3-21$$

$$Y_{elp} = \cos \theta_r * \sin \phi_r - Y_{beam} \quad 3-22$$

$$Z_{elp} = \sin \theta_r - Z_{beam} \quad 3-23$$

Where

θ_r = latitude of reference point

ϕ_r = longitude of reference point

$X_{beam}, Y_{beam}, Z_{beam}$ = the Cartesian coordinates of the beam aimpoint.

Subroutine TRNFRM then finds the internal base vectors and the orientation angle of the ellipse in the antenna beam plane. The three vectors are defined as:

A_1 = Parallel to beam axis

A_2 = The line running through the origin and the satellite ray projection of the subsatellite point on the antenna beam plane. (This is the Y axis in the antenna beam plane)

A_3 = $A_1 \times A_2$ (vector cross product) (This is the Z axis in the antenna beam plane)

A_1 is not computed as we only need to know angles in the antenna beam plane, not perpendicular to it. The three components (in Earth centered Cartesian coordinates) of the two vectors A_2 and A_3 are computed by

$$\begin{aligned}
\tan \theta &= \sin(w) / (R - \cos w) \\
\cos w &= \cos(\theta_c) * \cos(\theta_s) * \cos(\phi_s - \phi_c) + \sin(\theta_c) \\
&\quad * \sin(\theta_s) \\
\sin a &= \cos(\theta_c) * \sin(\phi_c - \phi_s) / \sin w \\
A_{2X} &= -\cos(a) * \sin(\phi_s) + \sin(a) * \sin(-\theta_s) * \cos(\sigma_s) \\
A_{2Y} &= \cos(a) * \cos(\phi_s) + \sin(a) * \sin(-\theta_s) * \sin(\phi_s) \\
A_{2Z} &= \sin(a) * \cos(\theta_s) \\
A_{3X} &= \sin(\theta) * \cos(\phi_s) * \cos(\theta_s) + \cos(\theta) * \sin(a) \\
&\quad * \sin(\phi_s) + \cos(\theta) \\
A_{3Y} &= \sin(\theta) * \cos(\phi_s) * \sin(\phi_s) - \cos(\theta) * \sin(a) \\
&\quad * \cos(\phi_s) + \cos(\theta) * \cos(a) * \sin(-\theta_s) * \sin(\phi_s) \\
A_{3Z} &= -\sin(\theta) * \sin(-\theta_s) + \cos(\theta) * \cos(a) * \cos(\theta_s)
\end{aligned}$$

Here, θ_s and θ_c are the latitudes of the satellite and the satellite antenna aimpoint with the surface of the earth, respectively; ϕ_s and ϕ_c are the corresponding longitudes, and R is the radius of the geostationary orbit in earth radii.

The orientation angle of the ellipse is computed by subroutines TRNFRM and ELPSE

$$ORAN1 = \tan^{-1} ((A_3 \cdot R_{elp}) / (A_2 \cdot R_{elp})) \quad 3-24$$

Where $R_{elp} = (X_{elp}, Y_{elp}, Z_{elp})$ is the vector connecting the beam aimpoint and the ellipse reference point.

In Program 3, subroutine SIGMA calculates the relative orientation angle using the following computation.

$$\sigma = \tan^{-1} ((A_3 \cdot R_{12}) / (A_2 \cdot R_{12})) - ORAN1 \quad 3-25$$

The calculation of the elliptical antenna beamwidth at a relative ellipse orientation is:

$$DG = \cos^2 \sigma + AXR * \sin^2 \sigma \quad 3-26$$

where AXR is the axial ratio of the antenna. The beamwidth used in the gain calculations in subroutine RPWCN (Program 2) and RPOWER (Program 3) is

$$\phi_z = A_{\text{maj}}/DG$$

where ϕ_z is the beamwidth used for gain calculations, and A_{maj} is the major axis beamwidth.

IV. ANTENNA GAINS

4.1 BEAMWIDTH

The user may characterize an antenna either by a diameter (earth station antennas only), or by a beamwidth (ground or satellite antennas).* In the case of an elliptical antenna beam (satellite only) both the major and minor axis beamwidth are specified. The satellite beamwidth is specified for a coverage area edge gain contour of ΔG dB down from mainbeam gain.** SOUP5 converts all satellite's beamwidths to a 3dB beamwidth by the following formula

$$\phi_z \text{ 3dB} = \phi_z \Delta G (3/\Delta G)^{1/2} \quad 4-1$$

All ground station antenna beamwidths must be specified as half-power beamwidths.

If diameter is specified, half-power beamwidth is calculated by the following formula.

$$\phi_z = (223/180) * (\lambda/D) \quad 4-2$$

*Antenna diameter or beamwidth are set in the Antenna Section of the parameter file.

** ΔG can be set in record 1 of the RARC section of the parameter file, or records 1, 5-3 and 5-5 of the scenario file.

where ϕ_z is the antenna half-power beamwidth in radians, λ is the nominal wavelength in meters (see Section VII), and D is the antenna diameter in meters. This is equivalent to the CCIR value of $21.28/fD$ degrees where f is the frequency in Ghz.⁹

4.2 ON-AXIS GAIN

The on-axis gain of an antenna is calculated by subroutine BMWGOA as

$$G_{oa} = EAP \left(\frac{\pi}{\phi_z} \right) \cdot (223/180))^2 AXR \quad 4-3$$

where G_{oa} = the numerical on axis gain
 ϕ_z = ϕ_z is the beamwidth in radians (see Eq. 4-1 above)
 AXR = AXR is the voltage axial ratio of an elliptical antenna (for elliptical antennas ϕ_z is the major axis beamwidth)*,
 EAP = EAP is the antenna aperature efficiency.

4.3 OFF-AXIS GAIN**

The off-axis gain is given by

$$G = G_{oa} 10^{-.1f} \quad 4-4$$

where G is the numerical off-axis gain; G_{oa} is the numerical on-axis gain; and f, the discrimination or gain fall off (dB), is discussed below.

SOUP5 allows the user to specify the use of any number of antenna patterns in terms of five gain pattern types, designated types 1, 2, 3, 4 and 5. Two of the types, 2 and 3, were not used at RARC-83 and are not considered here. (They are kept as an aide to users who have not yet converted their data to current gain patterns). The five types are listed below:

*Antenna beam major and minor axes are set in Antenna section of parameter file

**Antenna gain types are specified in the Antenna section of the parameter file, and defined in the Gain Table section of the same file.

- Type 1 - Segmented gain pattern.
- Type 2 - A special case of type 1.
- Type 3 - 1982 Fast Rolloff Satellite Antenna.
- Type 4 - 1982 CPM Feederlink (Earth Station) Transmit Antenna
- Type 5 - 1983 RARC Fast Rolloff Satellite Antenna

Type 1, which has been used to model many standard and proposed antenna patterns, allows the user to define f as a composite of any number of segments. The values of ϕ or ϕ_a (defined below) delineating the segment boundaries are read from the gain entry table section of the data base. The value of discrimination f in each segment is defined by one of five user designated functions. The segment types can be used in any combination.

$$1) \quad f = C_1 \quad 4-5$$

$$2) \quad f = C_1 (\phi_a - C_2)^{C_3} \quad 4-6$$

$$3) \quad f = C_1 + C_2 \log (C_3 (\phi_a - C_4)) \quad 4-7$$

$$4) \quad f = C_1 + 10 \log (G_{oa}) + C_2 \log (\phi) + C_3 \phi^2 \quad 4-8$$

$$5) \quad F = C_1 + C_2 \phi_a^2 + C_3 \phi_a^4 + \dots C_n \phi_a^{2(n-1)} \quad 4-9$$

$$f = -10 \log F$$

where ϕ = off axis angle in degrees

ϕ_z = antenna beamwidth (corrected for ellipse orientation if antenna is elliptical)

$$\phi_a = \phi / \phi_z$$

and n (the number of coefficients) and the coefficients $C_1 \dots C_n$ are taken from the gain entry table section of the data base.

For each segment, the user specifies the segment limit, whether the limit is on ϕ , or ϕ_a , the segment equation type (1 to 5) and the values of the C_i 's.

Type 4, the CPM 82 Feederlink Transmit antenna uses a parameter, D_{\min} (minimum antenna diameter in meters), which is entered on the RARC parameter section of the parameters file. The equation has four segments which are functions of ϕ , ϕ_a and V

$$\text{where } V = D/D_{\min}$$

and D is the antenna diameter in meters. The equations are shown on the following page. Various antenna patterns may be modeled by setting the values of the C_i 's appropriately.

Arbitrary-Gain-Function Table For CPM Feederlink Transmit (Type-4)

$V = D/D_{\min}$; where D is antenna diameter in meters

D_{\min} is minimum antenna diameter (m)

G is absolute gain in dB

G_{oa} is on-axis gain

Equation	Limits
$G = G_{oa} + C_2 \left(\frac{\theta}{\theta_0}\right)^2 + C_3$	$0 \leq \frac{\theta}{\theta_0} \leq C_1$
$G = C_8 + C_9 \log \theta$	$C_1 < \frac{\theta}{\theta_0} \leq C_4, V$
$G = \begin{cases} C_8 + C_9 \log (V\theta_0) + \frac{C_{10}}{V^2} \left(\frac{\theta}{\theta_0}\right)^2 \\ C_{11} + C_{12} \log \theta \end{cases}$ maximum	$C_4, V < \frac{\theta}{\theta_0} \leq \frac{C_7}{\theta_0}$
$G = C_{13}$	$\frac{C_7}{\theta_0} < \frac{\theta}{\theta_0}$

Note: If $C_8 = -999$ then 2nd equation is used

The following values of the C_i parameters for gain type 4 will produce the 1982 CPM recommended feederlink transmit antenna pattern.

PARAMETER	CO-POLARIZED GAIN PATTERN	CROSS-POLARIZED GAIN PATTERN
C_1	.5	.493
C_2	-12.	0.
C_3	0.	-30.
C_4	.635	0.
C_5	36.	0.
C_6	-20.	0.
C_7	36.3	8.91
C_8	45	-999.
C_9	-20.	0.
C_{10}	-12.6	0.
C_{11}	29.	9.0
C_{12}	-25.0	-20.
C_{13}	-10.	-10.

Type 5, 1983 RARC Satellite Fast Roll-off, has segment boundaries which are functions of ΔG and ϕ_a , which is a function of ϕ_z . The segment boundaries and equations are shown on the following table.

Arbitrary-gain-function table for Fast Roll-Off (Pattern Type 5)

Let $G(f) = GOA - f$

f = fall-off in dB from on-axis gain;

GOA = on-axis gain (dB)

$$x = \sqrt{\frac{\Delta G_3}{12} \left(1 - \frac{C_2}{B_0}\right)}$$

ΔG_3 = maximum of $(3, \Delta G)$ where

ΔG is the gain fall-off at ellipse edge (dB)

Equation	Limits	Description
$f = 12 \left(\frac{B}{B_0}\right)^2$	$0 \leq \frac{B}{B_0} \leq \sqrt{\frac{\Delta G_3}{12}}$	Gaussian
$f = 12 \left(\frac{B_0}{C_2}\right)^2 \left(\frac{B}{B_0} - x\right)^2$	$\sqrt{\frac{\Delta G_3}{12}} < \frac{B}{B_0} \leq \frac{C_2}{B_0} \sqrt{\frac{C_2 + x}{12}}$	Fast roll-off
$f = C_3$	$\frac{C_2}{B_0} \sqrt{\frac{C_2 + x}{12}} < \frac{B}{B_0} \leq \sqrt{\frac{C_2}{12}}$	Upper Limit
$f = C_4 + C_5 \log_{10} \left(\frac{B}{B_0}\right)$	$\sqrt{\frac{C_2}{12}} < \frac{B}{B_0}$	Beamlet roll-off
$f = C_6 + GOA$	upper limit value of f	Plateau

The following values of the C_i parameters in Type 5 gives the 83-WARC Fast Roll-off Satellite Antenna Pattern.

PARAMETER		CO-POLARIZED GAIN PATTERN
C_1	=	0.
C_2	=	.8
C_3	=	25.23
C_4	=	22.
C_5	=	20.
C_6	=	0.

V. RAIN ATTENUATION AND DEPOLARIZATION

5.1 GENERAL DESCRIPTION

The rain attenuation and depolarization subroutine ATTENU which is documented below is an adaptation of a subroutine developed by J. Royce Trenholm of Canada. It contains the necessary specific attenuation coefficients for the 12 GHz downlink and 17 GHz uplinks. As previously mentioned, the user who wants clear weather margins may deactivate rain attenuation calculations. It should be noted that atmospheric absorption is not included in the calculations (RARC-83 Resolution COM 4/1). Even when the user specifies rain attenuation, the uplink interference (but not desired signal) is calculated without rain attenuation. The algorithms developed to estimate the rain attenuation and cross polarization discrimination are generally based on information contained in the CCIR CPM report, as modified at RARC-83.

5.2 AVERAGE YEAR AND WORST MONTH STATISTICS

Since the RARC-83 performance criteria were specified in terms of percent of the worst month that the attenuation will be exceeded (i.e., 1 percent of the worst month at RARC-83)* and the rain rate data given in Study Group 5 is in terms of annual statistics, the program converts predicted annual statistics to worst-month based on the following approximate relationship:

*Specified on record 1 of scenario file.

$$P_{yr} = .29 (P_{mn})^{1.15}$$

where P_{yr} is percent of year and P_{mn} is percent of worst month. At RARC-83, an annual rain fade exceedance time percentage of 0.29 was used independently of the rain climate zone. This is done in subroutine RWSNRA.

5.3 ESTIMATED HEIGHT OF RAIN ABOVE MEAN SEA LEVEL (H_R) AND SLANT PATH LENGTH THROUGH THE RAIN (L_S)

This is based upon the data given in Report 563 and algorithms modified at the CPM. The heights corresponding to .01 average year exceedance percent are used:

$$H_R \text{ (Km)} = (5.1 - 2.15 \log_{10} (1 + 10 (\frac{L-27}{25})))$$

where L = the absolute value of the test point latitude in degrees, and takes the following values)

$$\begin{aligned} \rho &= .6 && , 0 \leq L \leq 20^\circ \\ \rho &= .6 + 0.02 (L - 20^\circ) && , 20^\circ < L \leq 40^\circ \\ \rho &= 1. && , 40^\circ < L \end{aligned}$$

The equations apply to latitudes up to 70°

5.4 SLANT PATH DISTANCE THROUGH RAIN

Once the rain height is determined, the slant path distance is calculated using the following equation:

$$L_S = (H_R - h_0) / (A + \sin \theta)$$

Where $A = (\sin^2 \theta + 2 (H_R - h_0) / R_E)^{1/2}$

θ = elevation angle at test point

h_0 = height of test point above mean sea level

R_E = Effective earth radius (8500 Km)

5.5 SLANT PATH REDUCTION FACTOR

The slant path reduction factor is determined using the expression:

$$RP = \frac{90}{90 + 4 L_s \cos \theta}$$

Where

$P = \text{Log}_{10}$ (annual Probability (percent))
 $L_s =$ slant path distance (see step (2))
 $\theta =$ elevation angle of test point.

5.6 SPECIFIC ATTENUATION CORRESPONDING TO THE PARTICULAR CLIMATIC ZONE

The equations used to determine the specific attenuation are as follows (based on data in Report 721 (Mod F)):

$$S_a = k(RR^a)$$

$$k = (k_H + k_V + (k_H - k_V) \cos^2(\theta) \cos(2t))/2$$

$$a = (k_H \alpha_H + k_V \alpha_V + (k_H \alpha_H - k_V \alpha_V) \cos^2(\theta) \cos(2t))/2k$$

where $k =$ elevation angle at test point

$t =$ polarization tilt angle at test point (see below)

$RR =$ rain rate (mm/hr)

$k_H, k_V, \alpha_H, \alpha_V$ are coefficients which depend on frequency and spatial rain rate distribution, (subscripts H and V stand for horizontal and verticle polarization).

For the nominal 12.5 GHz and 17.5 GHz frequencies the coefficient values were estimated to be:

GHz	k_H	k_V	H	V
12.5 GHz	0.0217	0.019	1.205	1.186
17.5 GHz	0.053	0.516	1.116	1.096

The rain intensity data for .01 percent of the average year for each climatic zone RR (mm/hr) is taken from Report 563-1 Table 1. The nominal-frequency specific attenuation for the zone for circular polarization is given by:

$$SA = 2.0202 \cdot 10^{-2} (RR^{1.198}) \text{ at } 12.5 \text{ GHz}$$

$$SA = 5.21 \cdot 10^{-2} (RR^{1.114}) \text{ at } 17.5 \text{ GHz}$$

5.7 POLARIZATION TILT ANGLE

The tilt angle for a vertically defined polarized wave, t , is the angle the received polarization vector makes with the plane containing the local vertical and the line joining the earth station and the satellite. It can be obtained using the following expression: (i.e., for a vertically polarized wave $t=0^\circ$ when the earth station is at the reference point, i.e., $\phi_p, \lambda_p = \phi_R, \lambda_R$):

$$t = \tan^{-1} \frac{\sin \phi_R \cos \phi_p \sin (\lambda_p - \lambda_S) - \cos \phi_R \sin (\lambda_R - \lambda_S) \sin \phi_p}{\sin \phi_R \sin \phi_p - \cos \phi_R \sin (\lambda_R - \lambda_S) \cos \phi_p \sin (\lambda_p - \lambda_S)}$$

where:

ϕ_R, λ_R = latitude, longitude of reference point defining the sense of polarization. There are basically two alternatives in the selection of the reference polarization vector:

- a) Each beam has its polarization vector rotated so that it appears parallel to the projection of the local vertical onto the antenna beam plane at a point within the service area - usually this point is selected as the aim point (i.e., $\phi_R, \lambda_R = \phi_B, \lambda_B$)
- b) The polarization vectors of every beam can be made parallel (or perpendicular) at the satellite irrespective of the apparent orientation of the earth stations. In this case $\lambda_R = \lambda_S$ and the equation simplifies to:

$$t = \tan^{-1} (\cot \phi_p \sin (\lambda_p - \lambda_s))$$

Where ϕ_p, λ_p = coordinates of the earth station (test point)
 λ_s = satellite longitude

The user can choose either option a) or b) above at the scenario level.

Note that since the tilt angle value used in Report 721 to determine specific attenuation coefficients, K, uses the horizontal line at the earth station as the reference line, the complement of t obtained in the above expression is used. For circular polarization, $t = 45^\circ$.

5.8 RAIN ATTENUATION

The RARC-83 rain model applies an 88 percent fade reduction to the CPM model based on last-minute purported experience/observations.

$$A_{tn01} = 0.88 (SA) (RP) (L_s)$$

Then the attenuation for the input average year fade exceedance percentage (Pan) is calculated by:

$$A_{tn} = C \cdot A_{tn} \cdot (.01/Pan)^A$$

Where C and A are set as follows:

C = 1.	A = .33	.001 ≤ Pan < .01
C = 1.	A = .41	.01 ≤ Pan < .1
C = 1.3	A = .5	1. ≤ Pan < .1

For attenuation exceeded for 1 percent of the worst month, Pan = 0.29 (Section 5.2).

5.9 FREQUENCY SCALING

Since the rain attenuation is estimated at one specific frequency in the particular band (12.5 GHz or 17.5 GHz), a frequency scaling equation is used to determine the attenuation for other frequencies in the respective

bands. The frequency scaling method used is based on the method of Report 564 (this was not endorsed by the CPM, but nevertheless used at RARC-83):

$$A_f = g(f)/g(f_R)A_R$$

where:

$$g(x) = x^{1.72} / 1 + 3 \times 10^{-7} (x^{1.72})^2$$

A_f = Rain attenuation at desired frequency, f, (dB)

f_R = Reference frequency (12.5 GHz or 17.5 GHz)

A_R = Rain attenuation at reference frequency (dB)

x = desired frequency (GHz).

5.10 CROSS POLARIZATION DISCRIMINATION

The cross polarization due to propagation through hydrometers (rain only, atmospheric ice was disregarded) is estimated using the following general equation:

$$XPDDB = U - V \text{Log}_{10} (A_f) \quad \text{dB}$$

Where U is estimated by:

$$U = K^2 - 10 \log_{10} \left[\frac{1}{2} (1 - \cos^2 4t(e^{-K_m})) \right] + 30 \log_{10}(f) - 40 \log(\cos \theta)$$

and

K , K_m are effective parameters of the raindrop canting angle distribution. The values used in the program are:

$$K = 0, K_m = 0.25^\circ \text{ (CPM)}$$

t = tilt angle (=45° for circular polarization.)

θ = elevation angle (In the program the upper limit of 60° is substituted for higher elevation angles and a lower limit is not observed.)

V = a constant over the specified frequency range as follows:

20 , 8 GHz < f ≤ 15 GHz

23 , 14 GHz < f ≤ 35 GHz

Atten = Rain attenuation in dB corresponding to the case for circular polarization even if linear polarization is used.

Note that the XPD used in the equivalent gain calculation (see Section 6-1) is given by $XPD = 10^{.1 * XPDDB}$.

VI. EQUIVALENT GAIN, TRANSMITTER POWER AND RECEIVED POWER

A. EQUIVALENT GAIN

The equivalent gain is computed using the following antenna parameters: 1) the earth station copolarized gain, G_{gc} ; 2) the earth station cross-polarized gain, G_{gx} ; 3) the satellite copolarized gain, G_{sc} ; and 4) the satellite cross-polarized gain, G_{sx} (all gains numerical). The equivalent gain is given by

$$G_{eq} = G_1 \cos^2 \beta + G_2 \sin^2 \beta \quad 6-1$$

Where

$$G_1 = G_{gc} G_{sc} + G_{gx} G_{sx} + (G_{gx} G_{sc} + G_{sx})/XPD \quad 6-2$$

$$G_2 = (G_{gc} G_{sx} + G_{gx} G_{sc})^2 + (G_{gc} G_{sc} + G_{gx} G_{sx})/XPD \quad 6-3$$

β is the relative linear polarization of the two linear polarizations (If both polarizations are circular $\beta = 0^\circ$ or 90° ; if one is circular, and the other linear, $\beta = 45^\circ$)

XPD is (numerical) rain depolarization as defined in the previous chapter. If the user requests clear weather margins (i.e., no rain attenuation calculations) the last terms of G_1 and G_2 are set to 0. Further details on this algorithm are provided in Appendix A.

6.2 TRANSMITTER POWER**

Transmitter power may be computed in one of four ways:

- o Given as an input in Watts
- o From desired EIRP
- o From required receiver carrier-to-noise ratio (C/N) at the receiving antenna
- o From required power flux density (PFD - Watts/m²) at the receiving antenna.

Below we discuss how SOUP computes the transmitter power in Watts for the last three options.

If the user specifies the EIRP of the transmitter, Subroutine POWER calculates the power in the following manner:

$$P = \text{EIRP} / G_{\text{oa}}$$

6-4

where P is the power (in Watts), EIRP is in Watts and G_{oa} is the antenna on-axis gain (numerical). See Section 4.2 for details of G_{oa} .

In order to compute power from desired C/N or desired PFD the link equation given below is used. For up calculations each possible feederlink transmitter (FLT) is given its appropriate calculated power.* However, the satellite (downpath transmitter) power calculations can give a different power for each earth station received (ESR). SOUP sets the satellite power to the minimum value required to produce at least the specified PFD or C/N at all ESRs. This means that all ESRs will receive at least the requested C/N or PFD unless rain margin limitations (see below) intervene.

*For service areas with more than one possible FLT there is an entirely different problem - which FLT should be used for carrier power and which for interferer power in the C/I calculations. This problem is discussed in Section 8.1.

**Specified on Records 2, 5-3, 5-5 and 5-7 of scenario file.

If the user specifies C/N, the following power calculations are done. First, the receiver system noise temperature may be specified directly or in terms of the figure of merit (G/T)*. In the latter case, the temperature is computed as:

$$T = G_{oa} 10^{-0.1 (G/T)} \quad 6-5$$

where G_{oa} is the numerical antenna on-axis gain, T is the noise temperature in °K, and (G/T) is in units of dBK. Next the link equation (see Section 6-3 below) is used to calculate $RCVPWR_1$, the received carrier power divided by the transmitter power. If the calculated rain attenuation is greater than the maximum rain margin** then $RCVPWR_1$ is calculated by setting the rain attenuation value to the user-specified maximum rain margin.

Finally, the transmitter power is calculated as follows:

$$P = (C/N) * K * T * BW / RCVPWR_1 \quad 6-6$$

Where

- P = transmitter power (watts)
- C/N = Carrier-to-noise power ratio (numerical)
- K = Boltzman's constant (joules/K)
- T = Antenna noise temperature (K) (antenna input)
- BW = channel noise bandwidth (Hz) (channelization input)
- $RCVPWR_1$ = Received power divided by transmitter power (see below)

If the user specifies the power by the receiver's power flux density (PFD) the following calculation is done.

$$P = (PFD) 4 \pi R^2 A_f / G_{tr} \quad 6-7$$

*The antenna key is specified on Records 2, 5-3, 5-5, 5-6 and 5-7 of the scenario file. The temperature or G/T is specified in the antenna record of the parameter file.

**The maximum up margin is set on Record 2 of the scenario file. The maximum down margin is set in Record 3 of the RARC section of the parameter file.

Where

P = transmitter power (Watts)
PFD = user specified PFD (converted to numerical value)
R = slant range (m)
A_f = rain attenuation (numerical)
G_{tr} = transmitter antenna gain (numerical) in the direction

6.3 RECEIVED POWER

To calculate the received power we use the following formula:

$$\text{RCVPWR} = P \cdot G_{\text{eq}} (\lambda/4\pi R)^2 / A_f$$

Where

P = transmitter power (watts)
G_{eq} = equivalent gain (numerical)
λ = the wavelength (m)
R = slant range (m)
A_f = rain attenuation (numerical); if user requests clear weather margin, A_{tn} is set to 1.

The calculation of the RCVPWR₁ is done in subroutine RPOWER in Program 3 for use in setting C/I values, and RPWCN in Program 2 to calculate transmitter power when C/N or PFD is specified.

VII. CHANNELIZATION AND PROTECTION RATIOS

7.1 NOMINAL WAVELENGTH

The nominal wavelength, λ , is the wavelength (in meters) used for all gain and attenuation calculations. It is given by

$$C/f_{\text{nom}}$$

VII-A1

Where C is the speed of light in meters/nanosecond (= .299796)
and f_{nom} is the nominal frequency (GHz).

At the user's option* f_{nom} is the center frequency of either the lowest, highest or median channel used by the service area.

7.2 INTERFERENCE CATEGORIES

Each interference interaction is given one of six (6) interference categories, except between systems in a group or for which the interference matrix precludes consideration. For treatment of interference category in grouping, see Section 8.3.

- 1 = Co-channel interference
- 2 = Upper adjacent interference
- 3 = Lower adjacent interference
- 4 = Next upper adjacent interference

* This option is set on Record 3 of the scenario file.

- 5 = Next lower adjacent interference
- 6 = No interference

If the channel assignments of two systems have more than one category, all categories are used in determining interference. For example, a system with channels 2, 6 and 10 interfering with a system with channels 6 and 8 will be included in co-channel (6 into 6), next upper adjacent (10 into 8), and next lower adjacent (6 into 8) interference.

If the scenario contains more than one channelization scheme (i.e., there is more than one definition of the center frequency and bandwidth of each channel), SOUP5 cannot make meaningful interference category assignments. In this case SOUP5 sets all interference categories to 1 (co-channel) and warns the user.

7.3 CHANNELIZATION SCHEME (RARC PARAMETERS*)

If the channelization scheme violates the RARC parameters, SOUP5 warns the user. It uses the tests below to check for violations

1. $F_L - B/2 < R_L + G_L$
2. $F_L + (N - 1)S + B/2 > R_U - G_U$

Where

F_L	= lowest center frequency in channelization
B	= bandwidth of channel
R_L	= RARC lower bandedge frequency
R_U	= RARC upper bandedge frequency
S	= separation between channels
N	= number of channels
G_L	= lower guard bandwidth
G_U	= upper guard bandwidth.

*The RARC parameter set key is specified on record 1 of the scenario file. The parameters themselves are in the RARC section of the parameter file.

The channel bandwidth is an input parameter in the channelization record of the parameters. All other parameters are inputs in the RARC parameter record.

7.4 PROTECTION RATIOS*

SOUP5 allows the user to specify separate protection ratios for uplinks, downlinks, and total aggregate interference (single entry protection ratios are not used).

The protection ratios are supplied by the user as a co-channel protection ratio (PR_0) in dB and a template which gives the fall-off (in dB) from the co-channel value as a function of normalized frequency offset. The normalized frequency offset is the frequency offset divided by the Carson's rule bandwidth (peak-to-peak-deviation + 2 x top-baseband-frequency). For total protection ratio calculations the Carson's bandwidth of the down channelization is used. Adjacent channels are typically interleaved and cross-polarized. If more than one channelization is used in a scenario all interference categories are set to co-channel and the co-channel protection ratio is set to 0 dB.

Each template is specified as a series of line segments in order by increasing upper frequency limit**. Each segment in the template is specified by four numbers:

- Upper limit, the highest normalized frequency to which this line segment applies. (This limit is not needed for the last segment.)
- Segment-value-at-offset. The value (in dB) of the protection ratio fall-off when the normalized frequency offset equals the offset (see below)

* The protection ratio template key and the co-channel protection ratios are specified on record 3 of the scenario file.

**Specified in the Protection Ratio section of the parameter file.

- o Slope. The slope of the line segment in dB/normalized-frequency-offset
- o Offset. The frequency offset at which the protection ratio fall-off has the value specified by the segment-value-at-offset.

The formula used is:

$$PR = PR_0 + \text{Segment-value-at-offset} + \text{Slope} * (\text{FD} - \text{offset})$$

where

PR is protection ratio (dB)

FD is normalized frequency offset

PR₀ is co-channel protection ratio

The segment used in the above formula is the one in which the upper limit of the previous segment FD upper limit of the segment. For all values of FD greater than the upper limit of the next to the last segment, the last segment is used. For all values of FD less than the upper limit of the first segment, the first segment is used.

7.5 CHANNELIZATION SCHEME* AND CHANNEL FAMILY**

The channelization scheme data contain the following information:

- o Lowest Center Frequency: the center frequency of channel 1.
- o Number of Channels: used only to determine whether the RARC parameters are violated.

*The channelization scheme key is set on records 2, 5-3 and 5-5 of the scenario file. The scheme itself is defined in the channelization section of the parameter file.

**The family key is set on record 5-3 and 5-5 of the scenario file. The family itself is defined in the Channelization section of the Parameter file.

- o Channel Bandwidth: also used only to determine whether the RARC parameters are violated.
- o Channel Separation: used to determine the center frequency of all channels except channel 1.
- o Channel Noise Bandwidth: used only to determine carrier to noise ratio.
- o Top Baseband Frequency and Peak-to-Peak Deviation: used to determine Carson's Rule Bandwidth for protection ratio calculations.

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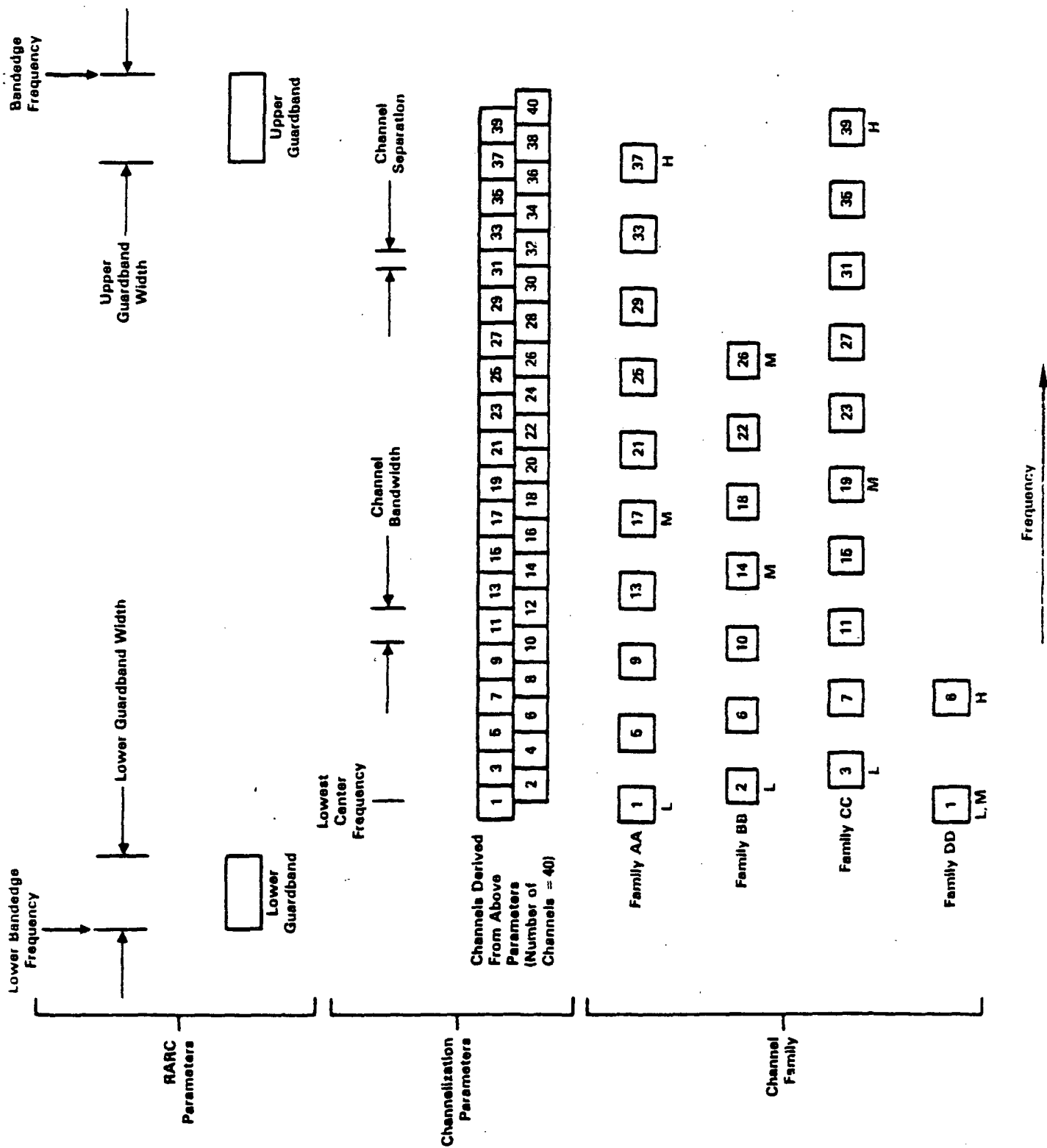


FIGURE 7.1

Figure 7.1 gives a sample of a set of RARC parameters, a channelization scheme and a set of channel families.

A violation of the RARC parameters would occur only if a channel in the family overlaps one of the two guard bands. Channel one does not overlap the guard band, but if the number of channels in the channelization is too great, the upper channels will overlap the upper guard band and the user will be warned. The L, M, and H on each channel family illustrate the nominal frequency the user will get for each channel family by specifying the low, median, or high nominal frequency option. This frequency is used for all gain and attenuation calculations.

The interference categories between families are calculated using the channel numbers only (the effect of the bandwidth is taken into account during the calculation of protection ratio from the template).

VIII. AGGREGATE AND TOTAL INTERFERENCE AND MARGINS

For this discussion, "total" means the sum of up and down, "aggregate" means sum over all interferers. All C/I and margin calculations are performed in subroutine WRTAGU for up, WRTAGD for down, and WRTAGT for total.

For the uppath C/I calculation, if power is specified directly or in terms of EIRP, the feederlink transmitter (FLT) giving the weakest received signal at the satellite yields the desired carrier signal. If power is calculated from C/N or PFD, the FLT producing the strongest received signal power is used. In all cases, the FLT from each service area giving the strongest interfering signal is used for the interference calculation. When the user specifies rain attenuation, it is only used in uppath calculations for the desired carrier signal calculations and user-specified rain fade margin limits are never exceeded. All interferers are assumed to be in clear weather.

8.1 AGGREGATE AND TOTAL INTERFERENCE

Defining $(C/I)_{U/Dij}$ as the carrier-to-interference ratio in dB for up or down in the i th interference category due to the j th interferer, then the aggregate interference up or down in category i is:

$$(C/I)_{U/Di} = \sum_j (C/I)_{U/Dij} \quad \text{dB*} \quad 8-1$$

dB* = -10 log of inverted numerical power ratios.

The total aggregate C/I in category i is then defined as:

$$(C/I)_{Ti} = \sum_{U/D}^{dB} (C/I)_{U/Di} \quad 8-2$$

Non co-channel intra-system interference is included in aggregate interference.

8.2 AGGREGATE AND TOTAL MARGINS

At the user's option, no interference from between systems of the same administration, same satellite longitude and same channel family will be added to the aggregate.

The aggregate margin for the i^{th} interference category for either up or down is computed as:

$$M_{U/Di} = (C/I)_{U/Di} - PR_{U/Di} \quad 8-3$$

where $(C/I)_{U/Di}$ is the aggregate carrier-to-interference ratio (up or down) for the i^{th} interference category and $PR_{U/Di}$ is the aggregate protection ratio (up or down) in dB for the i^{th} interference category.

The aggregate margin for up or down is computed as:

$$M_{U/D} = \sum_i^{dB} M_{U/Di} \quad 8-4$$

The total aggregate Margin in category i is computed as:

$$M_{Ti} = (C/I)_{Ti} - PR_{Ti} \quad 8-5$$

where PR_{Ti} is the total protection ratio in category i . Finally, the total aggregate Margin is computed as

$$M_T = \sum_i M_{Ti} \quad \text{dB} \quad 8-6$$

8.3 GROUPING*

Two or more service areas may be combined into a group. Each group of areas will be usually given a block of channels, to be divided however the administrations of the grouped service areas see fit.

SOUP5 uses the following rules for grouping:

- o All interference categories calculated from channelizations are ignored.
- o The aggregate interference is calculated with the following rules:
 - Co-channel interference
The sum of the highest co-channel interference power levels from each group except its own.
 - Upper and lower adjacent channel interference
The sum of the highest adjacent channel interference power levels from each group including those within its own group (or system).

* The grouping option is specified on Record 3 of the scenario file. Group membership for each service area is specified on record 5-1 of the same file.

- Next upper and next lower adjacent channel interference
The sum of the highest second adjacent channel interferences from each group including its own group (and system).

8.4 NON-INTERFERENCE MATRIX

This matrix contains arbitrary flags indicating that specified service areas cannot interfere with other specified service areas. This matrix permits the selection of one service area from a set of related service areas for the calculation of the interfering signal from the set of areas. An example of this would be only one service area of a multi-service area country interfering into the service areas of another country.

SOUP 5
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2. Spectrum/Orbit Utilization Program, User's Manual, by P. Sawitz and N. Shusterman, 16 May 1974, ORI Technical Report 831.
3. Modification of the Spectrum-Orbit Utilization Program - Final Report, Joyce Kerr, Peter Sawitz, Fred Zusman, ORI Technical Report 1812, October, 1981.
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5. SOUP5 Version 3 User's Manual, ORI Technical Report No. 2139
6. SOUP5 Programmer's Manual
7. CCIR Report 215-4, Volume XI, Table 1, p. 164
8. Ibid page 172, line 8
9. Ibid page 171, line 3

APPENDIX A
EQUIVALENT GAIN FOR EACH PARTIAL LINK

There are two antennas involved in each partial link, these have both co-polar and cross-polar transmission and reception characteristics. In addition atmospheric propagation effects, represented principally by co-polar attenuation and cross-polar discrimination, influence the net received signal power level.

The equivalent gain for one partial link can be represented by the following approximation:

$$G = G_1 \cos^2 \beta + G_2 \sin^2 \beta$$

$$G_1 = G_{tp} G_{rp} + G_{tc} G_{rc} + G_{tp} G_{rc} X + G_{tc} G_{rp} X$$

$$G_2 = (G_{tp} G_{rc} + G_{tc} G_{rp})^2 + G_{tp} G_{rp} X + G_{tc} G_{rc} X$$

where β , for linear polarization, is the relative alignment angle between the transmitted and received polarization planes, this includes the effects of antenna misalignment (both incidental and unavoidable), satellite yaw motion, Faraday rotation (if any), etc. For circular polarization, $\beta = 0^\circ$ is assumed to correspond to co-polar transmission and reception and $\beta = 90^\circ$ is assumed to correspond to mutually cross-polarized transmission and reception.

A = attenuation (dB)

X = cross-polar discrimination (as a power ratio < 1)

$$= 10^{0.1 (u - v \log A)} \text{ for circular polarization}$$

Subscripts:

t denotes transmission

r denotes reception

p denotes co-polar characteristic

c denotes cross-polar characteristic

In the expression for G_1 , power summation of the terms is assumed throughout. Near the mainbeam of the wanted transmission a voltage addition of the first two terms may be more appropriate due to phase alignment whilst away from this axis random effects would dictate power addition. However, since the second term is insignificant near the mainbeam axis the assumption of power addition does not compromise the approximation. Atmospheric depolarization is a random effect, thus the last two terms are power summed.

In the expression for G_2 , voltage addition of the first two terms is assumed since, near the mainbeam axis, either term could be dominant and phase alignment of these terms would dictate voltage addition. A power addition of the first two terms is perhaps more appropriate away from the mainbeam axis, but the validity of the assumed model is not unduly compromised by the maintaining voltage addition in all regions. The above expressions, in view of the arguments presented, are a reasonable compromise between accuracy and simplicity.

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