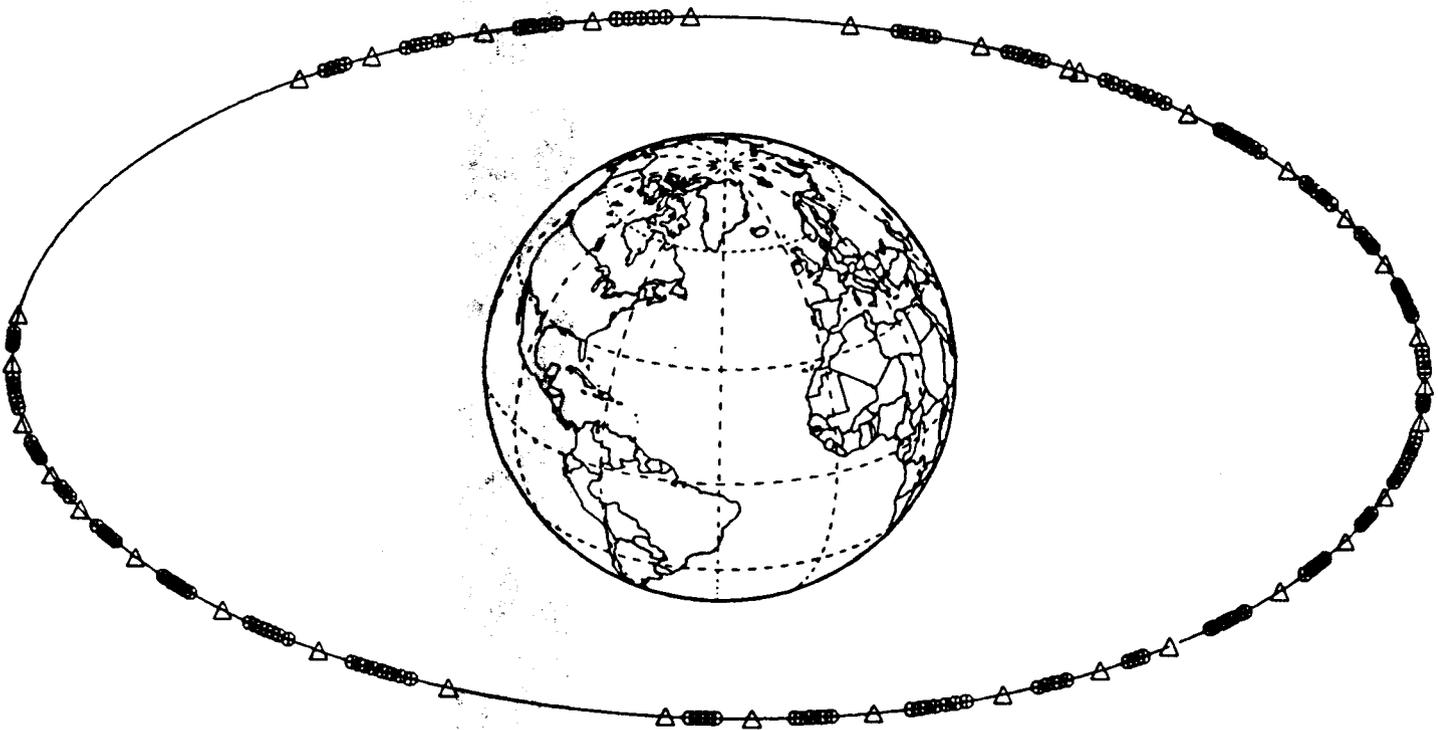


NASA Technical Memorandum 100160

# *Numerical Arc Segmentation Algorithm for a Radio Conference – NASARC (Version 2.0)*

## *Technical Manual*

Wayne A. Whyte, Jr., Ann O. Heyward, Denise S. Ponchak,  
Rodney L. Spence, and John E. Zuzek



National Aeronautics and Space Administration  
Lewis Research Center  
Cleveland, Ohio  
October 16, 1987

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ALGORITHM FOR A RADIO CONFERENCE-NASARC  
(VERSION 2.0) TECHNICAL MANUAL (NASA)  
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## PREFACE

The information contained in the *NASARC (Version 2.0) Technical Manual* (NASA TM-100160) and *NASARC (Version 2.0) User's Manual* (NASA TM-100161) relates to the state of NASARC software development through October 16, 1987. The technical manual describes the Numerical Arc Segmentation Algorithm for a Radio Conference (NASARC) concept and the algorithms which are used to implement the concept. The *User's Manual* provides information on computer system considerations, installation instructions, description of input files, and program operation instructions. Significant revisions have been incorporated in the Version 2.0 software over prior versions. These revisions have enhanced the modeling capabilities of the NASARC procedure while greatly reducing the computer run time and memory requirements. Array dimensions within the software have been structured to fit within the currently available 6-megabyte memory capacity of the International Frequency Registration Board (IFRB) computer facility. A piecewise approach to predetermined arc generation in NASARC (Version 2.0) allows worldwide scenarios to be accommodated within these memory constraints while at the same time effecting an overall reduction in computer run time.

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3.1.2.3.10	Satellite Antenna IWP4/1 .....	35
3.1.2.3.11	Satellite Antenna IWPIMP .....	36
3.1.2.4	Grouping Criterion .....	37
3.1.2.5	Minimum Half-Power Beamwidth .....	37
3.1.3	Input Parameter Constraints .....	55
3.2	NASARC1: Grouping Program .....	56
3.2.1	Intersection of Arcs .....	56
3.2.2	Pairwise Compatibility Matrix .....	63
3.2.2.1	Determination of <i>Worst-Case</i> Polygon Point .....	63
3.2.2.2	Calculation of Antenna On-Axis Gain .....	65
3.2.2.3	Calculation of Antenna Off-Axis Angles .....	66
3.2.2.4	Half-Power Beamwidth in Direction of Interest .....	67
3.2.2.5	Determination of Pairwise Compatibility .....	69
3.2.3	Enumeration of Compatible Groups .....	69
3.2.4	Determination of Group Arcs .....	72
3.3	NASARC2: Arc Determination Program .....	75
3.3.1	Generation of Service Area Information .....	75
3.3.2	Prioritization of Service Areas .....	80
3.3.3	Selection of Critical Service Area .....	80
3.3.4	Selection of Critical Grouping .....	81
3.3.4.1	Sorting of Grouping Containing Critical Service Area .....	81
3.3.4.2	Determination of Predetermined Arc Length .....	82
3.3.5	Updating and Arc Adjustment of Groups and Group Arcs .....	83
3.3.5.1	Updating and Arc Adjustment of the Master Groups List .....	83
3.3.5.2	Subset Arc Extension in the Critical Groups Sublist .....	85
3.3.6	Allotted Arc Determination Procedures .....	87
3.3.6.1	Zero Density Allotted Arc Routine .....	88
3.3.6.2	Pairwise Check Routine .....	88
3.3.6.3	Push Allotted Arc Routine .....	92
3.3.6.4	Shuffle Allotted Arc Routine .....	97
3.3.7	Special Handling of Unallottable Service Areas .....	100
3.4	NASARC3: Group Arc Extension Program .....	101
3.4.1	Determination of Candidate Groupings, Extension Direction, and Feasible Arc Limits .....	101
3.4.2	Extending Group Arc for Allotted Groups .....	102
3.4.3	Other NASARC3 Functions .....	103
3.5	Technical Assumptions Inherent in NASARC Software .....	103
3.5.1	Introduction .....	103
3.5.2	Assumptions .....	103
3.5.2.1	Shared Predetermined Arcs .....	103
3.5.2.2	Downlink Interference .....	109
3.5.2.3	Clear-Sky Conditions .....	109
3.5.2.4	Constant Power Flux Density .....	109
3.5.2.5	Use of Minimum Area Ellipses .....	109
3.5.2.6	Homogeneous Antenna Patterns .....	109
3.5.2.7	Uniform Single-Entry Downlink Carrier-to-Interference Ratio .....	109
3.5.2.8	Single Downlink Frequency .....	109
3.5.3	Summary of Assumptions .....	110

## 1.0 INTRODUCTION

### 1.1 Purpose and Scope

The purpose of the *Numerical Arc Segmentation Algorithm for a Radio Conference (NASARC Version 2.0) Technical Manual* is to describe the underlying engineering and mathematical models as well as the computational methods used in the NASARC programs. NASARC was developed to provide a method of generating predetermined arc segments for use in the development of an allotment planning procedure to be carried out at the 1988 World Administrative Radio Conference (WARC-88) on the Use of the Geostationary-Satellite Orbit and the Planning of Space Services Utilizing It. NASARC, in configuration with a synthesis program, can be used to develop an allotment plan which is in conformity with decisions of WARC-85 and set forth in its *Report to the Second Session of the Conference* while remaining flexible enough to accommodate the specification of key technical parameters decided on by WARC-88.

This manual includes a description of the NASARC concept and details of the various algorithms used in the software implementation of the concept. Information related to computer system considerations, installation instructions, description of input files, and program operation instructions is contained in the *NASARC Version 2.0 User's Manual*. Also included in the manual is a discussion of interface considerations between NASARC and the synthesis program ORBIT developed by Kokusai Denshin Denwa, Tokyo, Japan, and selected for use at WARC-88.

### 1.2 Approach to Allotment Planning

The general approach proposed for allotment planning consists of two phases. The first is the use of NASARC to identify predetermined arc segments common to groups of administrations. Those administrations within a group and sharing a common predetermined arc segment would be able to position individual space stations at any one of a number of orbital positions within the arc segment. The second phase is the use of the synthesis program ORBIT to identify example scenarios of space station placements. Given  $N$  space stations to be placed in a predetermined arc of  $X$  degrees, repeated runs of the synthesis program would identify acceptable space station placement scenarios within the arc segment, subject to other constraints such as allowable carrier-to-interference ratio, space and ground antenna characteristics, and other technical parameters. Completion of these two phases of the allotment planning approach will have identified an allotment plan that would permit each administration to satisfy its requirements from **any one of a number of orbital positions within a predetermined arc.**

Of course, any trial allotment plan obtained is a function of the technical parameters used, the number of separate geographical areas served, and a large number of other factors, all of which are subject to the decisions of WARC-88. The approach proposed has the flexibility to accommodate the specification of key technical parameters decided upon by WARC-88.

Additionally, subregional groupings of administrations could be accommodated in the initial allotment planning process by defining appropriate service areas that include the participating administrations. After WARC-88, subregional groupings could be formed within the arc segment of any of the participating administrations. Existing systems can be accommodated during the development of the plan by identifying the appropriate orbital positions, service areas, and technical parameters as part of the initial requirements.

### 1.3 NASARC Concept Overview

Through careful selection of predetermined arcs for each administration, flexibility can be increased in terms of choice of system technical characteristics and specific orbit location while the need for coordination among administrations is reduced.

The principal purpose of NASARC is to generate predetermined arc segments (PDA's) within which each administration may be guaranteed the availability of an orbit location to fulfill its requirements under the allotment plan. The technique used is based on examining pairwise (single-entry) space station separation requirements to achieve a user supplied protection requirement. The carrier-to-interference ratio  $C/I$  is calculated on the basis of antenna discrimination on the downlink. Systems are generally assumed homogeneous, with prescribed space station and earth station antenna characteristics. (The capability also exists for individual specification of antenna characteristics if the user so decides.)

The NASARC grouping program (NASARC1) determines an exhaustive list of *compatible* groups of space station service areas and a potential PDA associated with each group over which the group may exist. Pairwise (single-entry) compatibility between systems is assessed on the basis of the space station separation required to allow systems serving each service area to meet the desired  $C/I$ . Each pair of systems is compatible if the required  $C/I$  is achieved at the orbital separation defined by a user specified *grouping criterion*. The grouping criterion expresses, in degrees of orbital arc, the maximum allowable required space station separation at which the required  $C/I$  may be met. Compatibility is assessed between each pair of space stations at discrete points across the intersection of their service arcs. Space stations which can be colocated or nearly colocated (e.g., requiring separations less than the grouping criterion) are identified and grouped where commonality of service arc exists. Members of a group are geographically separated from one another in order to achieve the necessary isolation such that near colocation is possible. These groupings take advantage of north-south as well as east-west geographical separation of service areas. The common arc associated with each grouping then defines the maximum boundaries on the predetermined arc associated with the members of the group. Since all systems within any group can be colocated, or nearly so, little coordination is necessary at the time an actual system is to be implemented. Provided each group has several members, the arc segment available to any one group can be sufficiently large to allow flexibility of orbital position. Additionally, each arc segment can contain a buffer arc to provide enhanced isolation between networks in abutting predetermined arcs.

The arc determination program (NASARC2) selects appropriate groupings from among the exhaustive list of potential groupings generated by NASARC1. The members of the selected groupings are each allotted a predetermined arc segment, common to all members of a particular grouping, within which they are guaranteed the availability of an orbital position for implementation of a system to meet their requirements. The selection procedure in NASARC2 is a heuristic approach which uses figures of merit to try to accommodate the most difficult allotment problems first.

User prompted inputs are passed to the grouping and arc determination programs by way of a file generated by the NASARC input program (NASARC0).

#### 1.4 Structure of the Technical Manual

Section 2.0 discusses the various aspects of the NASARC concept and how the software accomplishes specific features of allotment planning as described in the WARC-85 *Report to the Second Session of the Conference*. Section 3.0 contains a detailed description of the NASARC software package, including the algorithms and equations used, the various inputs which are required, and the fundamental assumptions inherent in the software.

The *NASARC Version 2.0 User's Manual* provides information related to computer system considerations, installation procedures, input file description, and program operation instructions as well as a discussion of NASARC/ORBIT interface considerations.

## 2.0 GENERAL DESCRIPTION OF THE NASARC SOFTWARE PACKAGE

### 2.1 NASARC Concept

In response to the decisions of WARC-85 regarding allotment planning for the fixed satellite service, the Numerical Arc Segmentation Algorithm for a Radio Conference (NASARC) software package has been developed for the purpose of identifying and selecting predetermined arcs (PDA's) for use by each administration in an allotment plan.

The NASARC software determines an exhaustive list of *compatible* groups of space station service areas and an arc segment over which each group may exist. From this list, appropriate groups are selected and allotted predetermined arcs for use in the development of an allotment plan. Single-entry carrier-to-interference values ( $C/I$ ) are calculated at an orbital separation equal to a user supplied grouping criterion for all possible pairs of service areas at discrete arc locations. The calculated values are compared against a target  $C/I$  to determine compatibility between service area space stations. Groups of compatible service areas are enumerated where each member of a given group is compatible with every other member in the same group. The boundaries of the arc segment over which each compatible group may exist are identified.

Appropriate groups are selected from a list of all such compatible groups and corresponding arc segments, and each group is given a PDA within its corresponding arc segment. Members of the same group share a common PDA with all other members of the group. Given suitable input parameters, the final result of the NASARC process is a listing of the groups which contain all of the service areas represented in the input scenario and the boundaries of the unique predetermined arc segments associated with those groups.

#### 2.1.1 Grouping of Service Areas

Fundamental to the generation of predetermined arc segments via NASARC is the grouping of service areas into common PDA's. PDA formulations can fall into three categories: individual nonoverlapping arc segments, individual overlapping arc segments, and groups of common overlapping arc segments. Nonoverlapping arc segments, along with certain rules concerning positioning near a segment boundary, have the advantage of minimal or no coordination required between service areas. The disadvantage of this method is the inherent lack of real flexibility due to the small size of each segment. Individual overlapping arc segments have the ability to utilize collocation of satellites whose service areas are greatly separated, thereby relieving some of the congestion and allowing greater flexibility. This method, however, requires a significant increase in the amount of coordination required compared to nonoverlapping arc segments.

The third method for choosing predetermined arcs involves groups of common overlapping arcs. Service areas, having sufficient geographical separation such that collocation or near collocation of space stations covering each service area would be possible, could share a common arc segment. Each common arc segment would be larger than the minimum necessary for all members of the group to simultaneously operate. This would allow for flexibility in positioning each system as well as flexibility in the choice of system technical characteristics. Additionally, only minimal coordination would be required within a group.

The NASARC concept falls into the third category of PDA formulation, i.e., a group of *compatible service areas* sharing a common PDA. Each *compatible* group consists of several service areas that are sufficiently separated geographically so that collocation or near collocation of their corresponding space stations will result in achieving a specified single-entry  $C/I$ . A service area could consist of the political boundaries of an individual administration or the combined boundaries of neighboring administrations for subregional service. (Group members will hereafter be referred to as *service areas*, whether individual or subregionally combined.)

### 2.1.2 Determination of Pairwise Compatibility

The first major element of the NASARC software package, the grouping program (NASARC1), determines the list of compatible groups of space stations and the arc segment associated with each group. Each compatible group consists of several service areas that are sufficiently separated geographically so that colocation or near colocation of their space stations will result in achieving a user-specified single-entry downlink  $C/I$ .

Pairwise (single-entry) compatibility between systems is assessed on the basis of the satellite separation required to allow systems serving each service area to meet the desired  $C/I$ . A user-supplied grouping criterion is utilized as the basis of this assessment. The grouping criterion expresses, in degrees of orbital arc, the maximum allowable required satellite separation defining pairwise compatibility between systems. Each pair of systems is compatible if the required  $C/I$  is achieved at the orbital separation defined by the grouping criterion, when each system in turn is regarded as wanted and interfering. The  $C/I$  achieved is calculated on the basis of antenna discrimination on the downlink. That is, the falloff from on-axis gain of the interfering satellite transmit antenna in the direction of the wanted earth station receiver is combined with the falloff of the earth station receive antenna in the direction of the interfering satellite to obtain the total antenna discrimination available for the given satellite separation. NASARC (Version 2.0) has the capability for individual specification of space station and earth station antenna types and their corresponding characteristics. This is done by supplying the required data in the service area file. When individual parameters are specified, those values are used in the interference calculation in place of the user prompted default antenna parameters. All service areas not having individual antenna specifications will use the default values.

Compatibility is assessed, in the manner described previously, for all possible pairings of satellite systems at a discrete arc location. This assessment is followed by construction of a corresponding compatibility matrix for the current arc location.

### 2.1.3 Enumeration of Compatible Groups

The compatibility matrix for a given arc location may be regarded as a collection of vectors that expresses, for each system, all possible pairwise compatibilities with other systems. All possible groups of service areas, whose members are each compatible with all other group members, may be found by exhaustive examination of each vector. Thus, unique compatible groupings are enumerated at each discrete arc location considered by the program.

The span of arc locations over which each unique grouping may occur is determined by merging the lists of groupings generated at each arc location. The output of the first program element of the NASARC software package, therefore, consists of a listing of all unique compatible groupings of service areas and the east and west longitudinal boundaries over which each grouping may exist. These arc spans, referred to as group arcs, may be considered as upper bounds on the predetermined arc available to each grouping.

### 2.1.4 Group Selection and Arc Determination

The second major element of the NASARC software package, the arc determination program (NASARC2), examines all the available groups with their corresponding arc segments and computes a common PDA for members of each selected grouping. The software proceeds through a heuristic process of choosing an appropriate grouping, computing the PDA length, and placing the group of compatible service areas in an open area on the geostationary orbit within the constraints of the group's available group arc. This process is repeated until all administrations have been considered and the requirements of the allotment plan, to "permit each administration to satisfy requirements for national service from at least one orbital position within a predetermined arc," have been satisfied. The process of selecting groups and predetermined arc sizes is performed using several figures of

merit (FOM) or selection criteria designed to solve the most difficult allotment problems first, to maintain as much flexibility as possible, and to provide a reasonable opportunity for a successful allotment plan to be found. The entire heuristic process is highly dependent on the choice of technical parameters initially used to find compatible groups.

The first figure of merit is used to select a *critical* service area. This is done by choosing the service area which appears in the least number of groups. Selection of this service area preserves the maximum number of remaining groupings for subsequent allotments. It also allows the most limited service area, in terms of available groupings, to be handled first, which preserves the possibility of accommodating all service areas in the planning process. If there is a tie at this step of the selection process, the service area with the smallest service arc is handled first.

The next step is to select a group which contains the critical service area, as determined by the first figure of merit (FOM1). Selection of the critical grouping is a two-stage process employing two figure of merit factors (FOM2 and FOM3) simultaneously. The first of these selection criteria (FOM2) is related to the desired grouping size, in terms of number of members, and the second criterion (FOM3) sets the predetermined arc length for a given grouping. The grouping selection process is configured such that the largest size grouping containing the critical service area which meets the predetermined arc length constraint is selected. If two or more groupings are of the same size and have group arcs which meet the predetermined arc length constraint, the grouping which has the largest available group arc is selected. The predetermined arc length is determined by the number of members within the grouping and by certain technical characteristics. The technical characteristics which can affect the PDA length include the earth station antenna diameter, the required single-entry  $C/I$ , and the grouping criterion (i.e., the specified orbital separation requirement for near colocation). The specification of an appropriate set of technical characteristics will be decided at WARC-88 with the guidance of activities to be carried out during the intersessional period by the IFRB.

Once an appropriate grouping has been selected, it is given a temporary predetermined arc within its corresponding group arc. As subsequent critical service areas and critical groupings are selected, each is given a PDA of the calculated arc length in an open area of the orbital arc, somewhere within its group arc. These PDA's are temporary in that they are moved around within their group arcs during the arc determination process in order to make room for subsequent PDA's as necessary. When all the service areas have been accommodated, the temporary PDA's become the final predetermined arcs for the allotment plan. Thus, with predetermined arcs defined in this manner, service areas would be able to position individual space stations at any one of a number of possible orbital positions within their allotted arc segments.

#### 2.1.5 NASARC Piecewise Approach

For very large scenarios (as is the case with a worldwide allotment planning process) the number of groups which are exhaustively enumerated in NASARC1 can become prohibitively large, so as to exceed the memory capabilities of the computer system. One of the significant differences between NASARC (Version 2.0) and previous versions of the NASARC software is the application of a piecewise approach to the selection of groups and their PDA's. There are three ways of limiting the number of groupings which will be enumerated by NASARC1. These are (1) change the input technical parameters (e.g., a grouping criterion of 0.0 will produce far less groups than a grouping criterion of 1.0 because the effect of the earth station discrimination is eliminated), (2) reduce the number of service areas to be considered, or (3) reduce the orbital arc over which groupings are to be enumerated. None of these methods, in and of themselves, is an acceptable way to limit the number of groupings. Restricting the technical parameters to too narrow of a set would not allow full examination of the possible impact of those parameters and may also preclude obtaining a successful outcome. Similarly, reducing the number of service areas to be considered may limit the number of groupings, but it also prohibits the development of PDA's for a worldwide scenario. Finally, reducing the orbital arc is of limited use in the high-density portions of the orbit as is the case for parts of Region 1. Figure 2.1-1 presents a typical orbit density curve for worldwide service areas. As can be seen from the figure, the number of service areas which can be covered from a single orbit location is in excess of 100 for a significant portion of the orbital arc. Since

# SERVICE ARC DENSITY

WORLD ARCS FILE

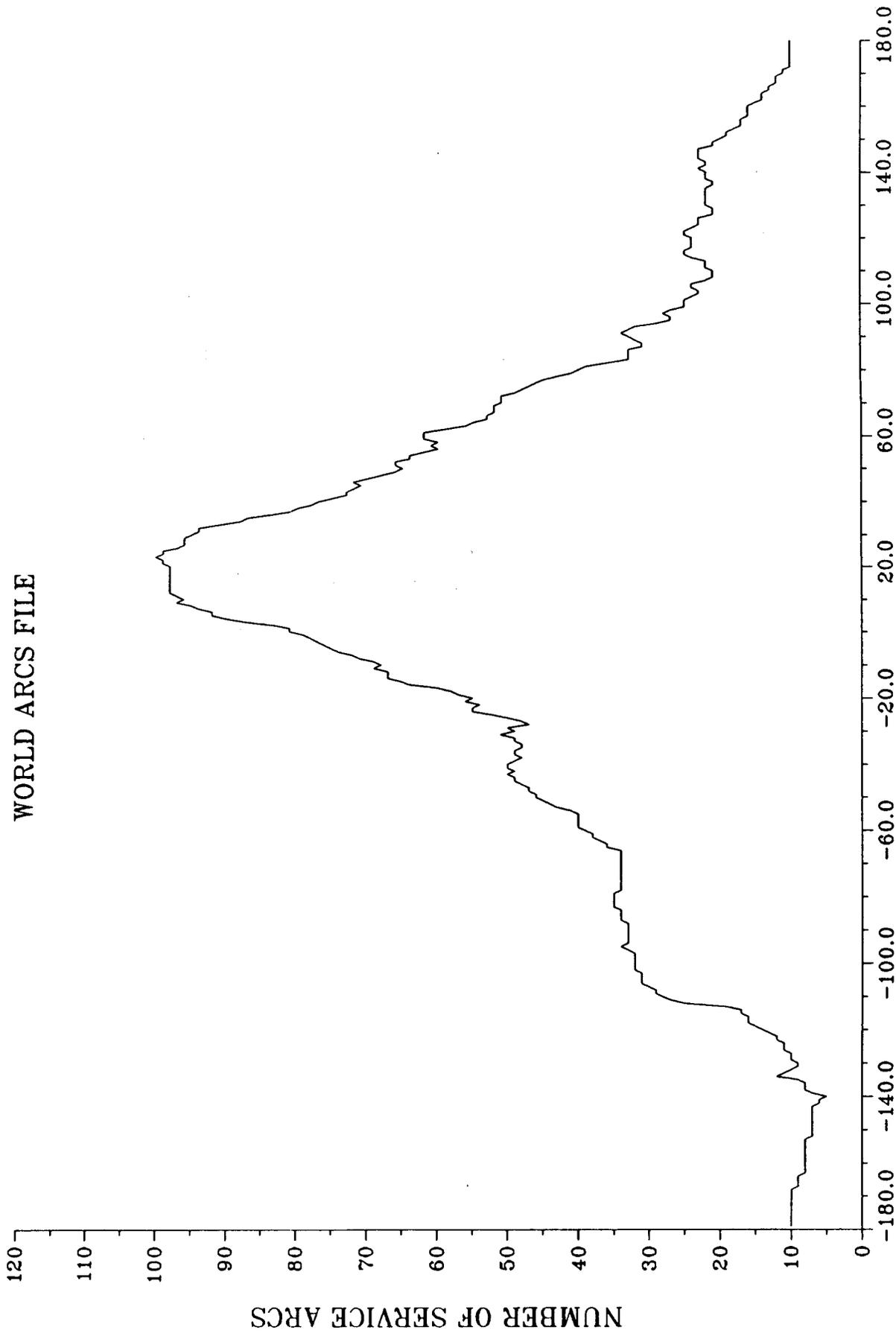


Figure 2.1-1.

NASARC1 examines all possible intersections at every integral degree across the orbital arc in the process of enumerating compatible groupings, the number of possible groupings in the high density areas can be very very large.

The piecewise approach incorporated in NASARC (Version 2.0) works to reduce the density of the quantity of service areas which can be seen from a given orbit location. The NASARC process (as explained in sections 2.1.3 and 2.1.4) is repeatedly executed over segments of the orbit until the entire orbital arc has been examined. Rather than allowing NASARC1 to enumerate groupings over the entire arc, as has been done in previous versions of NASARC, and then perform the NASARC2 arc determination process on those groupings, NASARC1 and NASARC2 are repeatedly executed in a looping fashion over limited arc segments. A segment of orbit is selected where the relative density of service areas is low by using an orbit density figure like the one shown in figure 2.1-1. The NASARC1 program is executed over this segment enumerating all possible groupings for the administrations whose service arcs intersect the segment boundaries. These groupings are provided to the NASARC2 program for selection of groupings and their PDA's within the segment. Once a service area has been allotted, it no longer needs to be considered in future segments which its service arc may have intersected. The number of service areas which will need to be considered in the higher density segments will be reduced by progressively working from the areas of lowest density to those of highest density. This results in the desired effect of reducing the number of NASARC1 groupings without sacrificing the capability of examining large scenarios. An added benefit of the piecewise approach is an overall reduction of run time for large scenarios, because the NASARC program elements operate more efficiently when the number of NASARC1 enumerated groupings is reduced.

Details on the specification of segment boundaries can be found in the *NASARC (Version 2.0) User's Manual*. If the user so chooses, a single segment can be specified which encompasses the service arcs of all service areas in the scenario. For this case, the NASARC procedure is essentially the same as in previous versions of the software. This is, in fact, the best way to process a small scenario where extremely large grouping files will not be generated.

Additional information regarding the segment file and choosing segment boundaries can be found in section 3.1.1.5 of this manual.

Processing multiple segments using the piecewise approach requires a couple of changes to the overall NASARC procedure in order to maintain as much flexibility as possible in grouping selection and PDA generation. First, it becomes necessary to associate a priority level with each service area related to the criticality of being accommodated within the segment being processed. This determination is done in NASARC2 and is based solely on the amount of service arc remaining for each service area outside of the cumulative arc.

The cumulative arc is the portion of orbital arc encompassed by the current segment and all prior segments in which groups have been allotted PDA's. Unallotted service areas whose service arcs are completely contained within the cumulative arc are given a priority P1 which indicates that these service areas must be accommodated within the current segment. A priority P2 is given to service areas that have less than 20° of remaining service arc outside of the cumulative arc. And a priority P3 is given to service areas with greater than 20° of remaining service arc outside of the cumulative arc. The priorities are determined each time a new segment is handled in the looping process. Assigning the priorities in no way restricts the selection of a P2 or P3 service area within a given segment. It merely ensures that the service areas which must be accommodated within the current segment are handled first. The priorities become an additional FOM in determining the critical service area, as was outlined in section 2.1.4.

The second change to the NASARC procedure, due to the piecewise approach, involves the handling of groupings from the NASARC1 output for a given segment which were not allotted to a PDA in the segment by NASARC2. Those groups whose group arc touches the cumulative arc boundary are retained in an unallotted groups file for later merging with groups from subsequent segments. This is done so that a group's group arc may span a segment boundary and allow NASARC2 to allot groupings, being considered in the current segment, in unused portions of prior segments within the cumulative arc.

The final change to the NASARC procedure involves the creation of a new program element, NASARC3, the group arc extension program. The operation of this program element is very similar to NASARC1. The purpose of NASARC3 is to extend the group arcs of groupings which have been allotted PDA's by NASARC2 into the orbital arc of the next segment to be processed. All allotted groupings, whose group arcs touch the boundary of the next segment to be processed, are examined for possible extension of their group arc into the new segment. That is, a NASARC1 type of procedure is applied to the members of each allotted group to assess the compatibility of the group over arc locations encompassed by the next segment. This procedure is done to maintain the flexibility of repositioning temporary PDA's within their group arcs during the NASARC2 arc determination process. It allows NASARC2 to reposition temporary PDA's across segment boundaries so that the orbital arc can be used as efficiently as possible.

In summary, the NASARC piecewise approach is a major enhancement to the NASARC procedure, allowing PDA's to be generated for very large scenarios with total flexibility in the choice of input technical parameters.

#### 2.1.6 NASARC Concept Summary

The purpose of the NASARC software package is to generate a list of compatible groupings and arc segments and determine selections of predetermined arc segment sizes and service area members that will satisfy the requirements of the allotment plan, to "... permit each administration to satisfy requirements for national services from at least one orbital position within a predetermined arc." The selection of particular groupings of service areas and their associated predetermined arcs is made according to a heuristic approach using several figures of merit designed to attack the most difficult allotment problems first. The task is to select groupings and predetermined arc sizes such that the requirements of all administrations are met before the available arc is exhausted. For some sets of technical parameters this will be possible, with some degree of flexibility remaining. For other choices of technical parameters solutions may not be found.

The NASARC-generated predetermined arcs, which are based on grouping compatible service areas into common arc segments, provide a means of generating a highly flexible allotment plan with a reduced need for coordination among administrations. The PDA's allow considerable freedom of choice in the positioning of space stations for all members of any grouping.

#### 2.2 Relationship of NASARC Concept to WARC-85 Decisions

WARC-85 was the first of a two session "World Administrative Radio Conference on the Use of the Geostationary—Satellite Orbit and the Planning of Space Services Utilizing It." Part of the overall objective of the Conference is to "guarantee in practice for all countries equitable access to the geostationary satellite orbit and the frequency bands allocated to space services." One goal of WARC-85 was to determine the bands and services which would be planned at the second session of the Conference (WARC-88). WARC-85 adopted a report for submission to the second session which include decisions related to the planning of space services. The report indicates that "[t]he planning shall concern only the FSS in the bands 6/4 GHz [and] 14/11-12 GHz." The report also cites certain planning principles to be incorporated in the planning methods to be implemented. The planning method is to consist of two parts: (1) an allotment planning procedure to be used in planning the FSS expansion bands near the standard FSS C and Ku band allocations, and (2) *improved procedures* to be used in planning the remaining FSS bands under consideration by the Conference.

NASARC addresses the part of the planning method dealing with the development of an allotment plan to be established in the bands:

- 4,500 to 4,800 MHz and 300 MHz to be selected in the 6,425 to 7,075 MHz band
- 10.70 to 10.95 GHz, 11.20 to 11.45 GHz, and 12.75 to 13.25 GHz

The following subsections will relate the various aspects of the NASARC concept to points addressed in section 3.3.4 of the *Report to the Second Session of the Conference* which deals with the development of an allotment plan.

### 2.2.1 Service Area

The report indicates that "[t]he allotment plan shall be limited to national systems providing domestic services. The procedures associated to this plan should contain provisions permitting administrations with adjacent territories to combine all or part of their allotments with the view to ensure a subregional service."

NASARC identifies a service area by a set of longitude/latitude points which define the geographic boundaries of the service area sufficiently so that a minimum area ellipse can be generated to cover the service area. A service area so identified could consist of the political boundaries of an individual administration or the combined boundaries of neighboring administrations. Administrations will be asked during the plan generation phase (prior to and at WARC-88) to submit certain requirements which will include the specification of the longitude/latitude points which define the service area. Administrations wishing to combine their individual service areas into a subregional coverage area may request a single allotment to provide such coverage. The longitude/latitude points required to define the subregional coverage area would be input to NASARC in the same manner as the points used to describe an individual administration's service area. A PDA would then be generated by NASARC for the combined coverage area at the same time that PDA's are generated for all other service areas. The combined coverage area would be grouped with other compatible service areas in sharing a common PDA (compatibility being based on space stations meeting the near colocation grouping criterion).

Additionally, administrations may wish to illuminate several affiliated, but geographically separated, service areas from a single space station location within the administration's allotted arc. An affiliated set would consist of several nonadjacent service areas to be served from a single orbital location. This could be a single administration and its dispersed territories or could be extended to the case of subregional coverage where the combining administrations are not adjacent territories but are geographically separated. The NASARC (Version 2.0) software can respond to the desire for affiliations of service areas on the part of administrations. It is assumed that some form of channelization or multibeam antenna technology would be implemented for such systems and therefore interference aspects within an affiliated set are not examined (i.e., service areas making up the affiliated set are assumed to be compatible with each other). However, in examining the compatibility between service areas in the affiliated set and any other service areas with which the affiliated set may be grouped, the interference analysis is done with respect to each and every individual service area making up the affiliated set. Therefore, service areas which are found to be compatible with the affiliated set are compatible with every service area making up the affiliated set over the full bandwidth. One additional application of the affiliated set capability would be for systems covering very large geographical areas where multiple beams are used to maintain a higher EIRP. Several of the existing systems use such a technology for global coverage. Each beam could be interpreted as a separate service area in an affiliated set when being input to NASARC. Sections 3.1.1.2.2 and 3.1.1.4 provide additional information on the application of affiliated sets in the NASARC process.

WARC-88 might decide that individual administrations may choose to identify subregional coverage requirements that were not indicated during the plan development process. That is, administrations may be allowed to go through the planning process and receive an individual allotment to serve solely their own domestic service area. Then, during the implementation of the plan, multiple administrations may elect to combine their service areas to be served by one subregional coverage. The NASARC grouping concept is well suited to accommodating such subregional coverages. The coverage areas could consist of several administrations' service areas requiring a very large beam or as few as two administrations' service areas requiring a beam which is not significantly larger than the service area of either of the combining administrations. In the case of a small subregional coverage, since members of the original grouping are geographically separate from each other, the formation of a subregional coverage area involving any one of the group's members with territories adjacent to it would not significantly impact the remaining members of the original grouping. In most situations, only the member(s) of the original grouping closest to the added territory in the subregional coverage would be affected at all. The extent to which

they are affected (i.e., the separation necessary to meet the interference criteria) is a function of how large the subregional coverage area becomes and how closely it extends toward members of the original grouping. Additionally, the combining administrations could have the flexibility of choosing to locate the space station serving the subregional coverage in any of the predetermined arcs in which their individual allotments were originally given. The additional interference constraints resulting from the subregional coverage space station could therefore be minimized by choosing the predetermined arc whose members are least affected by the subregional space station. This interference effect tradeoff could be performed by a synthesis program during the implementation of the plan when the subregional coverage is proposed. Particular subregional groupings would need to be examined on a case by case basis when specific groupings are proposed. It may be desirable at the time of plan development to include a small interference margin to allow increased flexibility in the formation of subregional coverage areas. Procedures related to accommodation of subregional coverage areas after plan development will need to be agreed on at WARC-88.

### 2.2.2 Guarantee of Access

The *Report to the Second Session of the Conference* states that the planning method "shall guarantee in practice for all countries equitable access to the geostationary satellite orbit." This is to be accomplished in the allotment plan by providing to all ITU members "at least one orbital position, within a predetermined arc and predetermined band(s)."

The NASARC concept is specifically aimed at generating a predetermined arc for every service area for a given set of technical parameters. The method uses no prejudgment of individual administration preferences and formulates groupings and their associated predetermined arcs solely on technical considerations. All service areas (administrations/subregional coverage) are considered on an equal basis. The grouping enumeration is exhaustive and therefore generates all possible unique groupings and associated group arcs resulting from a given set of technical parameters. The heuristic used in selecting appropriate groupings and their PDA's functions on the basis of increasing the likelihood of obtaining a successful plan by attacking the most difficult allotment problems first. A plan is considered successful only if one full bandwidth allotment is given to each ITU member.

NASARC attempts to provide the PDA for one allotment for each service area input to the program. If geographical considerations necessitate multiple allotments for a given administration (e.g., very large service area), the overall service area would be partitioned into smaller service areas, each of which could be included in one nonoverlapping common predetermined arc.

All calculations within NASARC which are frequency dependent are based on a single downlink frequency to be input by the user. Thus, interference is examined on a cochannel basis only. This is consistent with full bandwidth allotments as no frequency discrimination will be available. The user specified frequency may be anywhere in the allotment planning bands allocated for downlink use (although operation only in these bands is not an inherent limitation of the programming). Further information on the frequency input parameter is given in section 3.1.2.2.

The *Report to the Second Session of the Conference* refers to a predetermined arc "as a means of increasing the flexibility of the plan." The NASARC concept of grouping compatible service areas within common PDA's provides such flexibility. Allowance is made for each member of the group to be separated from its nearest neighbors in orbit by the amount of the grouping criterion (GRP). In practice some space stations may be colocated with others or may be separated from others by distances less than GRP. The mutual ability to nearly colocate space stations within a PDA allows each system increased flexibility of location within the PDA. The added flexibility may also be available for changing system technical parameters from those used for planning purposes. (Of course, any such changes would be subject to the plan modification procedures established by WARC-88.)

### 2.2.3 Consideration of Existing Systems

The *Report to the Second Session of the Conference* indicates that "the planning methods shall take into account the existing systems. If necessary, these systems may be subjected to some adjustments to allow for the accommodation of new systems. The degree of adjustment to which a system would be subjected would depend upon the state of development of the system."

The method by which existing systems are accommodated in the NASARC procedure depends to some extent on the adjustment criteria to be decided at WARC-88. If it is decided that existing systems shall be entitled to the specific orbit locations for which they had previously filed, they could be accommodated in at least two different ways. They could be given that orbit location as an assignment, with sufficient guard zones to provide interference isolation. Or, they could be given that specific orbit location within a PDA containing grouping members that are compatible with the service area associated with the existing system. This second approach would reduce overall orbit usage; however, members of the grouping in the affected PDA would lose a small degree of flexibility in position due to the priority of the existing system.

Existing systems whose orbit locations are not fixed can be accommodated in the same manner as any administration. The service area would be defined for the existing system coverage. It would then be treated as any other service area and grouped into a PDA containing other compatible service areas. It could have the same freedom of movement within the PDA as the planned allotments. The exact method of accommodating existing systems in the allotment planning process is subject to the decisions of WARC-88.

Existing systems will in general have technical characteristics which may differ from those to be decided on at WARC-88 for the systems subject to allotment planning. To accommodate this, NASARC (Version 2.0) has the capability of specifying individual space station and earth station antenna parameters. These include the antenna codes, any parameters required in specifying a particular antenna type (such as diameter or sidelobe level), and antenna efficiency. Since these parameters are specified in the service area input file (see section 3.1.1.2) the capability for individual antenna specification is not restricted solely for use with existing systems. When performing the pairwise interference analysis, NASARC1 uses the individually specified antenna parameters for all service areas having such parameters and uses the user-prompted default antenna parameters for all service areas not having individual specifications. For existing systems, the antenna type most closely approximating the actual antenna would be selected by the user from among those available (see section 3.1.2.3). (The creation of a new antenna type is also a possibility but would require software coding of the falloff envelope.)

Another area in which the technical characteristics of existing systems may differ from those for systems subject to allotment planning is the incident power flux density (pfd) resulting from differing space station transmit power levels. In the NASARC process it is assumed that the level of power flux density at the edge of the minimum area ellipse covering each service area is constant for all systems. In other words, systems are assumed to be homogeneous with respect to pfd. While this assumption is not unreasonable for planning purposes, it may be desirable to have the capability of introducing some degree of inhomogeneity into the planning process. Planners may wish to examine the effect of constant space station transmitter power rather than constant pfd or the effect of nonuniform  $C/I$  levels among space stations in a given scenario. The effect that rain attenuation has on the compatibility (and therefore groupability) of space stations may also be of interest. NASARC (Version 2.0) allows for the introduction of an inhomogeneity factor to be associated with each service area which would modify the threshold  $C/I$  required between each pair of space stations. The specification and applications of the inhomogeneity factors are described in sections 3.1.1.2.3 and 3.2.2.5 of this manual.

Methods of introducing inhomogeneities in the planning process should be handled cautiously. The primary reason that planning has commonly been done with a homogeneous set of parameters is that it is difficult to assess the specific parameter values to associate with each space station before the intended purpose of the system has been identified. This is especially true of the varied systems in the fixed satellite service. Different signal types may require different levels of interference protection. However, without specific knowledge of the levels required for each system, results obtained for random inhomogeneities could be misleading. Therefore, caution needs to be exercised in selecting the inhomogeneity factors.

### 3.0 DETAILED DESCRIPTION OF NASARC (VERSION 2.0) SOFTWARE PACKAGE

The previous section gives a general description of the NASARC concept and the software package which implements that concept. In this section, a more detailed view of the software is presented. Five major topics are to be covered. First, a description and discussion of the inputs to the NASARC software package are given, including both the prestored data files and the prompted user inputs to NASARC0, the input program. The second major topic concerns the operation of NASARC1, the grouping program. A detailed description of how potential groups of compatible service areas and their associated arcs are determined is presented along with explanations of the algorithms and assumptions used in the grouping program. The third topic is a detailed review of the operation of NASARC2, the arc determination program. This module, the third program in the NASARC software package, uses a heuristic approach in the determination of the predetermined arcs for the selected groups. The fourth topic is a description of the fourth program in the NASARC software package, NASARC3, the group arc extension program. The functions of NASARC3 are to extend group arcs in the piecewise approach used in NASARC (Version 2.0) and to output all of the NASARC final results. The fifth and final topic gives a discussion of the various technical assumptions inherent in the NASARC software.

#### 3.1 Inputs to NASARC Software

The inputs to the NASARC software are divided into two types: prestored file inputs and user-specified inputs to NASARC0, the input program. Each is addressed in the following sections. Additionally, the modules NASARC1, NASARC2, and NASARC3 all take inputs from intermediate files created by the various modules of the NASARC software package used in the NASARC piecewise approach. These files are described briefly in the *User's Manual* for completeness, but they require no input from the user.

##### 3.1.1 Prestored Files

There are five prestored input files used in the NASARC (Version 2.0) software package: the Point Sets file containing polygon point information, the Service Area file which contains scenario information, the Ellipse file with all possible required ellipse parameters, the Affiliated Sets file containing set information, and the Segments file containing the segment information needed for the NASARC piecewise approach. Typical input values as well as the organization of some of the prestored data are provided where appropriate.

###### 3.1.1.1 Point Sets

In NASARC (Version 2.0), the Point Sets file consists of the polygon point sets for each service area (used in NASARC1 and NASARC3) and the coefficients utilized in the determination of the allotted arc length (used in NASARC2). For each service area contained in the Point Sets file, three to six polygon points are given. The minimum number of points required for the calculation of a minimum area ellipse corresponding to a service area is three; hence, this is the minimum number of polygon points contained in the Point Sets file for any service area. Presently, a maximum of six polygon points are given in the Point Sets file to correspond with an earlier version of the ORBIT-II synthesis program, which is another key element used in the allotment planning process. However, NASARC is not limited to using only six polygon points. In addition to the polygon points, NASARC can accept a number of test points if necessary.

The points set data are expressed in the same format utilized in the Spectrum Orbit Utilization Program (SOUP). Polygon points are expressed in decimal degrees and use the convention of positive latitudes being north of the equator and negative latitudes being south of the equator. Similarly, positive longitudes are east of the prime meridian while negative longitudes are west of that meridian.

There are currently three sources for the polygon point data contained in the Point Sets file: a 151 service area test scenario provided by KDD of Japan with the ORBIT-II synthesis program; polygon point set data received from the IFRB from WARC-77 data; and the NASA-generated polygon point data. Since the IFRB points are for

ITU Regions 1 and 3 only, most of the Region 2 point set data comes from the ORBIT-II scenario or has been generated by NASA. In addition, any of the points which did not form a convex set of points for a given service area were replaced by NASA point set data. A set of points for any service area must form a convex polygon in order to conform with some of the various minimum ellipse routines available.

It should be noted that the current point set data does not include the elevation above sea level or the CCIR rain zone since NASARC assumes a spherical earth and performs only clear-sky calculations (unless the inhomogeneity factor is utilized to include propagation effects). It is recognized that the IFRB will make available a requirements file which will be used to update the Point Sets file for NASARC as soon as these new data are available.

In addition to the points set data, the Point Sets file used by NASARC (Version 2.0) also contains the coefficients used in the computation of the allotted arc length in NASARC2. The allotted arc length equation is described in detail in section 3.3.4.2 of this manual.

#### 3.1.1.2 Service Area File

Of the five prestored files utilized by the NASARC software package, three files are used to define the specific scenario to be examined: the Service Area file, the Affiliated Sets file, and the Segments file. The other two prestored files, the Point Sets file and the Ellipse file, contain global information which need not be changed. The Service Area file contains the basic scenario information required by the NASARC software. As a minimum, this file will contain the individual ITU codes for each service area in the given scenario and the western and eastern boundaries of each service area's service arc. The service arcs may be based on some desired minimum elevation angle as described in section 3.1.1.2.1 or may be defined in some other manner as long as the entire service area is visible from all orbital locations within and including the boundaries defining this arc.

In addition to the service area codes and service arc boundaries, there are three other types of information which appear in the Service Area file if the user chooses to exercise certain options in forming a given scenario. The affiliated set number is placed in this file to designate groups of service areas to be placed in an affiliated set. This option is explained further in section 3.1.1.2.2 of this manual. Inhomogeneities for individual service areas in the form of a differential number of decibels from a chosen baseline are also placed in this file. Section 3.1.1.2.3 gives a more detailed explanation of the use of inhomogeneities as well as some guidance in the application of this option. Another option available in forming a scenario for NASARC (Version 2.0) is the use of individually specified antennas for the space station and/or the earth station. The individual antenna types and corresponding parameters including the aperture efficiency are specified in the Service Area file. This process is further described in section 3.1.1.2.4 while details on the various antenna types and required parameters is given in sections 3.1.2.3.1 through 3.1.2.3.11 of this manual.

The Service Area file along with the Affiliated Sets file and the Segments file is used in concert with the user-specified technical inputs in NASARC0 to fully specify a NASARC scenario. Through the use of these tools, the user is able to define a wide range of scenarios which the NASARC (Version 2.0) software package will utilize to determine the predetermined arcs for the given set of service areas.

#### 3.1.1.2.1 Service Arcs

In the Service Area file, the service arcs identify, for each service area, boundaries on predetermined arc segments. Pairwise compatibility is then determined, based on the intersection of arcs from the service arcs in this file, and the segment boundaries being considered. Service arc data are derived from polygon point data for each service area. NASARC is currently being accessed with service arcs based on a minimum elevation angle of 30° wherever possible. Exceptions to this guideline are certain service areas having a very large geographical area and/or polygon points at relatively high latitudes. In these cases an elevation angle was chosen, whenever possible, to yield an arc span of 30°.

While 30° was selected for use as the minimum elevation angle, any desired elevation angle can be used to create the service arcs used in NASARC. It should be noted that smaller elevation angles, resulting in larger service arcs, will generally yield more potential groupings in the grouping program.

The currently used service arcs were calculated as follows:

- (1) All polygon and test points were considered for a given service area.
- (2) For each point (latitude-longitude pair), the following calculation was made:

$$\Delta = \cos^{-1} \left[ \frac{\cos^2 \epsilon + \sin \epsilon (R^2 - \cos^2 \epsilon)^{1/2}}{R \cos \beta} \right] \quad (3.1-1)$$

where

- $\Delta$  maximum allowable longitudinal distance, from the subsatellite point, which meets the minimum elevation angle criterion (This may be referenced to the east or to the west of the subsatellite point.)
- $\epsilon$  minimum desirable elevation angle
- $R$  geostationary orbit radius, in earth radii (6.6105)
- $\beta$  polygon/test point latitude

- (3) A service arc for each point is formed by determining the eastern and western boundaries of each by

$$\begin{aligned} E &= \alpha + \Delta \\ W &= \alpha - \Delta \end{aligned}$$

where

- $\Delta$  as previously defined
- $\alpha$  polygon/test point longitude
- $E$  eastern limit of service arc
- $W$  western limit of service arc

(4) Once a service arc has been defined for each polygon/test point, all arc segments for a service area are intersected (as in fig. 3.1-1) to yield a resultant service arc in which each point achieves or exceeds the minimum elevation angle over the entire arc length.

(5) The resultant arc is then truncated to facilitate computation. For example, an arc of -102.6 to +15.3 would be truncated to -102 to +15.

#### 3.1.1.2.2 Affiliated Sets

As described in section 2.2.1, some administrations may wish to illuminate several affiliated, but geographically separated, service areas from a single space station location within that administration's allotted arc. Thus, the affiliated set would be defined by a number of nonadjacent service areas to be served from a single orbital location. There are several possible uses for this option. For example, affiliated sets could be used for specifying a single administration and its dispersed territories. Similarly, the affiliated set option could be used for the case of nonadjacent administrations wishing to combine their requirements in a subregional grouping. Adjacent administrations in a subregional grouping would simply be handled as a single combined service area as mentioned in section 2.2.1. Another potential use of the affiliated set option is to synthesize the use of a multiple beam system. Each beam coverage area could be specified as a separate service area and then affiliated to examine the multiple beam interference effects with other service areas. Interference aspects between beams are not examined because service areas within an affiliated set are assumed to be compatible with each other. The affiliated set is only considered compatible with another service area if each of its members are individually compatible with the other service area in question and vice-versa.

### Derivation of Resultant Service Arcs

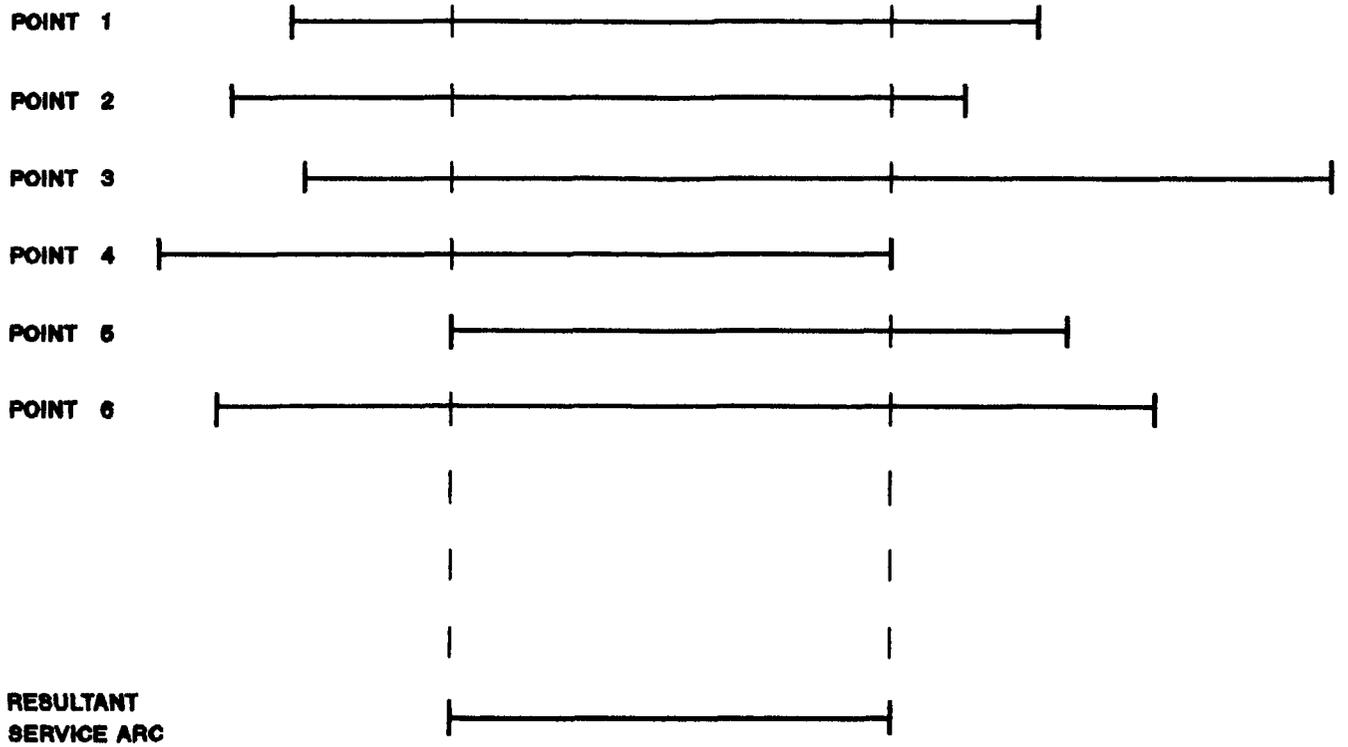


Figure 3.1-1.

Affiliated sets are specified in the Service Area file which describes many aspects of the given NASARC scenario. In the Service Area file, numbers are used to indicate which of the individual service areas are members of affiliated sets. In general, there is no set number of members for specifying an affiliated set nor is there a set number of affiliated sets which one can specify. Each member of a given affiliated set will have a number associated with it which will correspond to that affiliated set with these numbers occurring in ascending order beginning with the number 1. For example, if AAA, BBB, and CCC are all members of the same affiliated set, they might have the number 1 associated with them while WWW, XXX, YYY, and ZZZ might be in a different affiliated set designated by the number 2. If affiliated sets are specified in the Service Arc file, additional information is required in another file known as the Affiliated Sets file which is described in section 3.1.1.4. The formatting and setup of these files are described in sections 2.3.1.2 and 3.2.2 of the *NASARC (Version 2.0) User's Manual*.

The NASARC software treats the members of an affiliated set as separate entities when determining pairwise compatibility but does not determine the compatibility between the set members since this has been assumed to exist. The software later combines this compatibility information into a single row and column in the compatibility matrix, as if the affiliated set were indeed a single service area. An affiliated set code, similar to the ITU codes, which is specified in the Affiliated Set file, is used to represent the affiliated set in the compatible groupings themselves. This compatibility procedure is described in more detail in the subsections of section 3.2.

### 3.1.1.2.3 Inhomogeneities

The inhomogeneity factor is the second optional input in the Service Area file. This factor may be used to introduce a degree of inhomogeneity into the planning process. A real value in decibels can be individually specified for each service area by the user at the time the Service Area file is generated. The default value is 0.0 dB. The default value is assumed if the input field in the Service Area file is left blank. When this parameter is defaulted for all service areas (i.e., no inhomogeneity), the interference calculations performed in NASARC1 assume that the level of pfd at the edge of the minimum area ellipse covering each service area is constant for all systems. This assumption is not unreasonable for planning purposes, though it may be desirable to examine the effect of introducing some degree of inhomogeneity into the planning process. Planners may wish to examine the effect of constant space station transmitter power rather than constant pfd among space stations in a given scenario. The effect that rain attenuation has on the compatibility (and therefore groupability) of space stations may also be of interest.

As the inhomogeneity factor can be used to examine the effect of a number of inhomogeneous situations which may arise between systems, its specification and application need to be carefully understood by the user. The method which has been incorporated into the NASARC process, involves modifying the threshold  $C/I$  requirement by inhomogeneity factors related to the wanted and interfering systems. The threshold  $C/I$  is the value input by the user in response to prompting from the NASARCO program module. The inhomogeneity factors can be thought of as deltas, since they act to change the threshold  $C/I$  to a target  $C/I$  value which is used for the determination of compatibility. The target  $C/I$  has the form

$$C/I_{\text{target}} = C/I_{\text{thr}} + \Delta_w - \Delta_i \quad (3.1-2)$$

where

$C/I_{\text{target}}$  required  $C/I$  (specific to each space station pair)  
 $C/I_{\text{thr}}$  uniform value of threshold  $C/I$  (user specified input)  
 $\Delta_w$  wanted system inhomogeneity factor  
 $\Delta_i$  interfering system inhomogeneity factor

The values of  $\Delta_w$  and  $\Delta_i$  are obtained from the Service Area file. If all systems are defaulted (i.e.,  $\Delta_w = \Delta_i = 0.0$ ), then the target  $C/I$  is simply the threshold  $C/I$  supplied by the user and calculations are performed on a constant pfd basis.

As mentioned previously, a number of applications exist for the inhomogeneity factor. One of these is the simulation of constant space station transmit power levels for all systems rather than constant pfd. Space station transmit power is a function of the effective isotropic radiated power (*EIRP*) and the gain of the space station transmit antenna in the following manner:

$$P_{sat} = EIRP - G_{sat} \quad (3.1-3)$$

where

$P_{sat}$  space station transmit power, dB  
 $G_{sat}$  gain of space station transmit antenna, dB

and

$$EIRP = C/N + L_{FS} + k + B - G/T \quad (3.1-4)$$

where

$EIRP$  effective isotropic radiated power, dB  
 $C/N$  carrier-to-noise ratio, dB  
 $L_{FS}$  free space loss, dB  
 $k$  Boltzmann's constant, dB  
 $B$  channel bandwidth, dB  
 $G/T$  earth station receive antenna figure of merit, dB

If constant values are assumed for all systems, for  $C/N$ ,  $L_{FS}$ ,  $B$ , and  $G/T$  the space station transmit power becomes a factor solely of the space station transmit antenna gain. (Individual parameters could be assumed in determining value of  $EIRP$  for each system if so desired.) Therefore, to equalize space station transmit power between systems, the inhomogeneity factor can be used to equalize the gains of the space station transmit antenna as follows:

$$P_{sat} = EIRP - G_{sat}(N) - \Delta(N) \quad (3.1-5)$$

where

$P_{sat}$  space station transmit power (constant)  
 $EIRP$  constant  $EIRP$  for all systems  
 $G_{sat}(N)$  gain of space station transmit antenna for service area  $N$   
 $\Delta(N)$  inhomogeneity factor for service area  $N$

and, in dB,

$$G_{sat} = 10 \log \left( \eta \frac{49729}{\theta_1 \theta_2} \right) \quad (3.1-6)$$

where

$\eta$  space station transmit antenna efficiency  
 $\theta_1$  major axis half-power beamwidth (HPBW), deg  
 $\theta_2$  minor axis HPBW, deg

The major and minor axis half-power beamwidth (HPBW) values can be obtained by examining the Ellipse file (see section 3.1.1.3) at a representative orbit location within each service area's service arc. (Typical gain variations across the service arcs are in the range 0 to 2 dB.)

Given specific values for  $P_{sat}$  and  $EIRP$ , equation (3.1-5) could be used to determine the values of the inhomogeneity factors for each system. However, specific values are not required because  $P_{sat}$  and  $EIRP$  are constant for all systems. Since the inhomogeneity factors are themselves decibel quantities, the inhomogeneity factor for each service area can be determined with respect to a reference. If, for the case of constant power, the service areas requiring major and minor axis HPBW values equal to the minimum HPBW are each given an inhomogeneity factor of 0.0 dB and considered as the reference, the inhomogeneity factor for the remaining service areas is equal to the difference in space station transmit antenna gains between the reference service area  $A$  and each of the other service areas; that is, in dB,

$$\Delta(N) = G_{sat}(REF) - G_{sat}(N) \quad (3.1-7)$$

where

- $\Delta(N)$  inhomogeneity factor for service area  $N$
- $G_{sat}(REF)$  space station transmit antenna gain for minimum HPBW
- $G_{sat}(N)$  space station transmit antenna gain for service area  $N$

and

$$\Delta(REF) = 0.0 \text{ dB}$$

Inhomogeneity factors calculated in this manner would be placed in the Service Area file by the user and used by NASARC1 when determining compatibility between service areas using equation (3.1-2). While the calculation of the inhomogeneity factor may appear cumbersome, it is relatively straightforward and repetitive for each service area.

An alternate use of the inhomogeneity factor is in taking account of propagation loss differences between the service areas. The approach would assume that differences in average rain attenuation levels would be compensated for by the space station transmitter power. That is, a space station providing coverage for a service area with an average rain attenuation level of 5 dB would be compensated with 5 dB more transmit power than would be required under clear sky conditions. If equation (3.1-2) is re-examined and we assume system  $A$  requires 10 dB of rain attenuation compensation and system  $B$  requires 4 dB of rain attenuation compensation, when system  $A$  acts as the wanted system and system  $B$  as the interference,  $C/I_{target}$  must be less than  $C/I_{thr}$  by the difference of 6 dB. Conversely, when system  $B$  acts as the wanted system and system  $A$  as the interference,  $C/I_{target}$  must be greater than  $C/I_{thr}$  by the difference of 6 dB. For these situations to be correctly represented, the inhomogeneity factors must be input as negative values (i.e.,  $\Delta(A) = -10$  dB and  $\Delta(B) = -4$  dB).

Any method of introducing inhomogeneities in the planning process should be handled cautiously. The primary reason that planning is commonly done with a homogeneous set of parameters is that it is difficult to assess the specific parameter values to associate with each space station before the intended purpose of the system has been identified. This is especially true of the varied systems in the fixed satellite service. Different signal types may require different levels of interference protection. However, without specific knowledge of the levels required for each system, results obtained for random inhomogeneities could be misleading. Therefore, caution needs to be exercised in selecting the inhomogeneity factors.

The user is reminded that the inhomogeneity factor is an optional input to the Service Area file. All, some, or none of the service areas may use the factor in any given scenario. A blank input in the appropriate field of each record in the Service Area file will be interpreted by the program as 0 dB (i.e., having no inhomogeneity related to the service area). Section 2.3.1.2 of the *NASARC (Version 2.0) User's Manual* provides information for the specification of the inhomogeneity factor in the Service Area file.

#### 3.1.1.2.4 Individual Antenna Specification

The satellite and earth station antennas are both specified by the user in the NASARCO input sequence and are applied globally to all service areas given in the Service Area file. However, these homogeneous antenna patterns can be overridden on an individual service area basis in the Service Area file as another scenario option available in the NASARC (Version 2.0) software package. The user-specified antenna patterns input via NASARCO (the input program) are applied to each service area that does not have an individual antenna specification, thus becoming the default antennas for the scenario. The user has the choice of specifying either the earth station antenna or the satellite antenna or both antennas for each service area in the Service Area file.

In this version of NASARC, there are two earth terminal antenna types and nine satellite antenna types available. Many of these antennas require some additional parameter such as diameter for the earth terminals or sidelobe level as one possible parameter for the space stations, and all antennas require specification of the aperture efficiency. The available antenna codes and the corresponding parameters are described in detail in sections 3.1.2.3.1 through 3.1.2.3.11. It is very important to understand which parameter is required for each different antenna type specified in the Service Area file and to place an appropriate value in the correct field of this file. Guidance on the format and setup of the Service Area file for the individual antenna specifications can be found in sections 2.3.1.2 and 3.2.2 of the *User's Manual*.

Another caution must be given with respect to specifying individual antenna types. This involves using individual antenna types and the affiliated set option. Although both of these options may be utilized at the same time, if the user wishes to individually specify the space station antenna type for an affiliated set, care must be taken in specifying the same space station antenna type and same space station antenna efficiency and parameter value for every service area that is a member of a given affiliated set. Of course, different affiliated sets may utilize different antennas or parameter values, as long as the individual members of a single given affiliated set have identical space station antenna specifications. The earth station antenna characteristics need not be identical for members of the same affiliated set.

The NASARC software determines the pairwise compatibility of each pair of service areas by examining the total antenna discrimination achieved on the downlink for a given orbital spacing between the wanted and interfering space stations. Therefore, the combined total of interfering satellite antenna discrimination and wanted earth station antenna discrimination is determined. With individual antenna specifications rather than the globally specified antenna specifications, the software simply accesses the specific patterns which correspond to the wanted and interfering service areas to determine these achieved discrimination values.

There are various reasons for using the individual antenna specification option available in the NASARC software. One possible use might be with existing systems. The appropriate satellite antenna pattern and parameter value could be chosen which most closely approximates the antenna pattern of a planned or existing system. Another potential application might be in the examination of nonhomogeneous scenarios. With this option, it would be possible to specify fast rolloff antennas for larger service areas and less stringent antenna patterns for the smaller service areas, if so desired. With this option and the option of using inhomogeneities as described in the previous section, a wide range of technical variations in scenarios can be examined. However, as was mentioned in the previous section on inhomogeneities, the user must be very careful in the application of any inhomogeneities in the planning process. Without the requisite knowledge of the differences between systems being investigated, indiscriminate specification of individual antenna types may yield misleading results.

#### 3.1.1.3 Ellipse File

The NASARC Ellipse file contains data on the minimum area ellipse at every integral orbital location within the visible arc of each service area represented in the Point Sets file. Although the minimum ellipse data could be generated by any existing minimum ellipse program, the current master ellipse file was generated using Akima's minimum ellipse generation program (Akima (1981)). The ellipse data used by the NASARC software is comprised of the service area code and space station orbital location, the beam aimpoint (i.e., the antenna

boresight), the ellipse major and minor axis half-power beamwidths (HPBW), and the orientation angle of the ellipse measured counterclockwise from the horizontal (i.e., counterclockwise from the equator). The format of the ellipse data in this file is given in section 2.3.1.6 of the *User's Manual*. All angles, including longitudinal positions and beamwidths, are required to be in decimal degrees.

The ellipse data are used for various purposes in both NASARC1, the grouping program, and NASARC3, the group arc extension program. The NASARC software accesses this precalculated Ellipse file in the process of determining pairwise compatibility for each pair of service areas in a given scenario. The ellipse major and minor axis half-power beamwidths are used to calculate the space station on-axis gain and the interfering space station's half-power beamwidth in the direction of interest. The ellipse boresight coordinates are used in the latter calculation, in determining the interfering satellite's off-axis angle, and in determining the *worst case* polygon point of the wanted service area with respect to the interfering service area. The ellipse orientation angle is used in the calculation of the HPBW in the direction of interest.

When the ellipse major and/or minor axis beamwidths are less than the user-supplied minimum half-power beamwidth, the NASARC software adjusts the beamwidth in question to be equal to this minimum value. Because of this action, any service area which requires a minimum area ellipse having a major or minor axis beamwidth less than the minimum value will subsequently be covered by a beam which is larger than the precalculated minimum area ellipse. This result will impact the pairwise compatibility calculations in that more orbital separation may be required between the service area in question and other service areas in the scenario than would have been required by using exclusively the precalculated minimum area ellipses.

#### 3.1.1.4 Affiliated Sets File

The Affiliated Sets file is used in conjunction with the affiliated set option in the Service Area file which describes the NASARC scenario. When the affiliated set option is in use, the user must create an Affiliated Sets file containing the affiliated set numeric code (i.e., 1, 2, etc.), a unique three character set name of the user's choice, and the number of members in the set for each affiliated set present in the Service Area file. The format and setup of the Affiliated Sets file is given in sections 2.3.1.4 and 3.2.4 of the *User's Manual*.

When the affiliated sets option is in effect, both NASARC1 and NASARC3 access the Affiliated Sets file to determine how many members are in each set for purposes of combining the affiliated set members into a single compatibility entry, and to get the unique three character set code to be used in the enumeration of compatible groupings. This unique set code is what will be present in compatible groupings, although the affiliated sets and their members will be fully noted in the NASARC final output report produced at the completion of program execution.

#### 3.1.1.5 Segments File

The Segments file serves as the basis of the NASARC piecewise approach. This file is used to define the individual segment boundaries and the order of processing the segments for the NASARC software package. The Segments file may contain one or more records, each record defining the western and eastern boundaries of a segment to be processed. The first segment may be anywhere in the orbital arc, but each successive segment must be adjacent to either the eastern or western boundary of a previous segment. In this manner, a continuous piece of arc is always being processed.

The NASARC1 grouping program reads the first record of the Segments file to determine which portion of the arc will be examined for compatibility determination and enumeration of compatible groupings. The grouping program updates the Segments file by deleting the segment which has been processed. It also writes the processed segment boundaries to the Intermediate Segments file which is used by NASARC2, the arc determination program. The NASARC2 module accesses the Intermediate Segments file to determine the cumulative arc which has been processed up to this point. NASARC2 then operates on the available compatible groupings and

determines the portion of the grouping's group arc in which to place the selected allotted arc. The NASARC3 group arc extension program reads the Segments file which was updated by the NASARC1 module. Thus, the first record in the updated Segments file is the next segment to be processed. The NASARC3 module extends the group arcs of each of the selected groupings into the next segment where possible. This is done so that the temporary allotted arcs can have additional flexibility in being repositioned by the NASARC2 software when processing the next segment. All subsequent segments are processed by NASARC1, NASARC2, and NASARC3 in this manner until all segments from the original Segments file have been exhausted. At this point, the NASARC3 module restores the Segments file to its original state so that these segments can be used again if desired.

If only a single segment is given in the Segments file, the operation of the NASARC (Version 2.0) software package is fundamentally the same as in earlier versions. The format and setup of the Segments file is described in sections 2.3.1.1 and 3.2.1 of the *User's Manual*. As described in section 2.1.5 of this manual on the NASARC piecewise approach, the Segments file and the entire piecewise approach were devised to reduce storage requirements and program execution times by processing the arc piece by piece, thereby eliminating from consideration in a given segment those service areas who have already had an allotted arc determined for them. By judicious choice of segment boundaries, order of processing the segments, and the length of each segment, the user can make efficient use of the available computer resources and time while arriving at a successful outcome.

### 3.1.2 User-Specified Inputs Using NASARC0: The Input Program

Through the use of NASARC0, the input program, the user interactively enters several key technical parameters for the desired scenario. The prompted inputs are the threshold single-entry downlink  $C/I$ , the downlink frequency, the space station and earth station antenna specification codes, antenna efficiencies and required antenna parameters, the grouping criterion, and the minimum half-power beamwidth. These inputs are described in sections 3.1.2.1 through 3.1.2.5, and the flowchart for NASARC0 is given in figures 3.1-2(a) to (d) for reference.

In addition to the primary function of accepting the prompted user inputs and forming an input data file to be used by NASARC1, NASARC2, and NASARC3, the input program also checks various prestored input files for any critical errors which would stop execution of the major NASARC modules. The NASARC0 module reads the allotted arc length equation constants which appear in the Point Sets file and checks to make sure at least one nonzero constant exists. If the constants check out, they are written to the input data file. Next, the initial Segments file is read to determine if the segment boundaries in the order listed provide a contiguous cumulative arc for the software to examine. The Service Area file is read by NASARC0 and several items are checked. First the service arcs are checked to make sure the western and eastern limits of the given arc have not been inadvertently switched. Also, service arcs of members of like affiliated sets are checked to verify all of the arcs overlap. That is, the input program checks to verify the affiliated set is valid by making sure the individual service arcs of the members intersect. If the arcs do not intersect at a minimum of one arc location, they cannot possibly be served by the same orbital position as is the intent of the affiliated set option. The individually specified antennas are checked for several items. First, the specific antenna codes are checked to verify legitimate codes were used. Second, the antenna parameters are checked to verify that they are within established limits. Lastly, if individual antenna types have been specified, a flag is set in the input data file to indicate this to the NASARC1 and NASARC3 modules. If affiliated sets are present in the Service Area file, a flag is set in the input data file to indicate this. The Affiliated Sets file is read to verify if the number of members in each affiliated set matches the number of service areas listed as members of each set in the Service Area file. NASARC0 also checks to see if the individually specified space station antennas and parameters are identical for members of like affiliated sets. If any of these verification procedures finds an error, the input program halts execution and sets an error flag in the input data file. This allows the other NASARC modules to ascertain that a critical input error has occurred and execution is aborted.

The input program also uses the user-specified default earth station antenna pattern and the interference criterion to calculate the default buffer length. The buffer length is one factor which may be utilized in determining the allotted arc length for each compatible grouping in NASARC2. The allotted arc length equation is described in detail in section 3.3.4.2. The equations for calculating the buffer length are as follows:

# NASARCO -- The Input Program

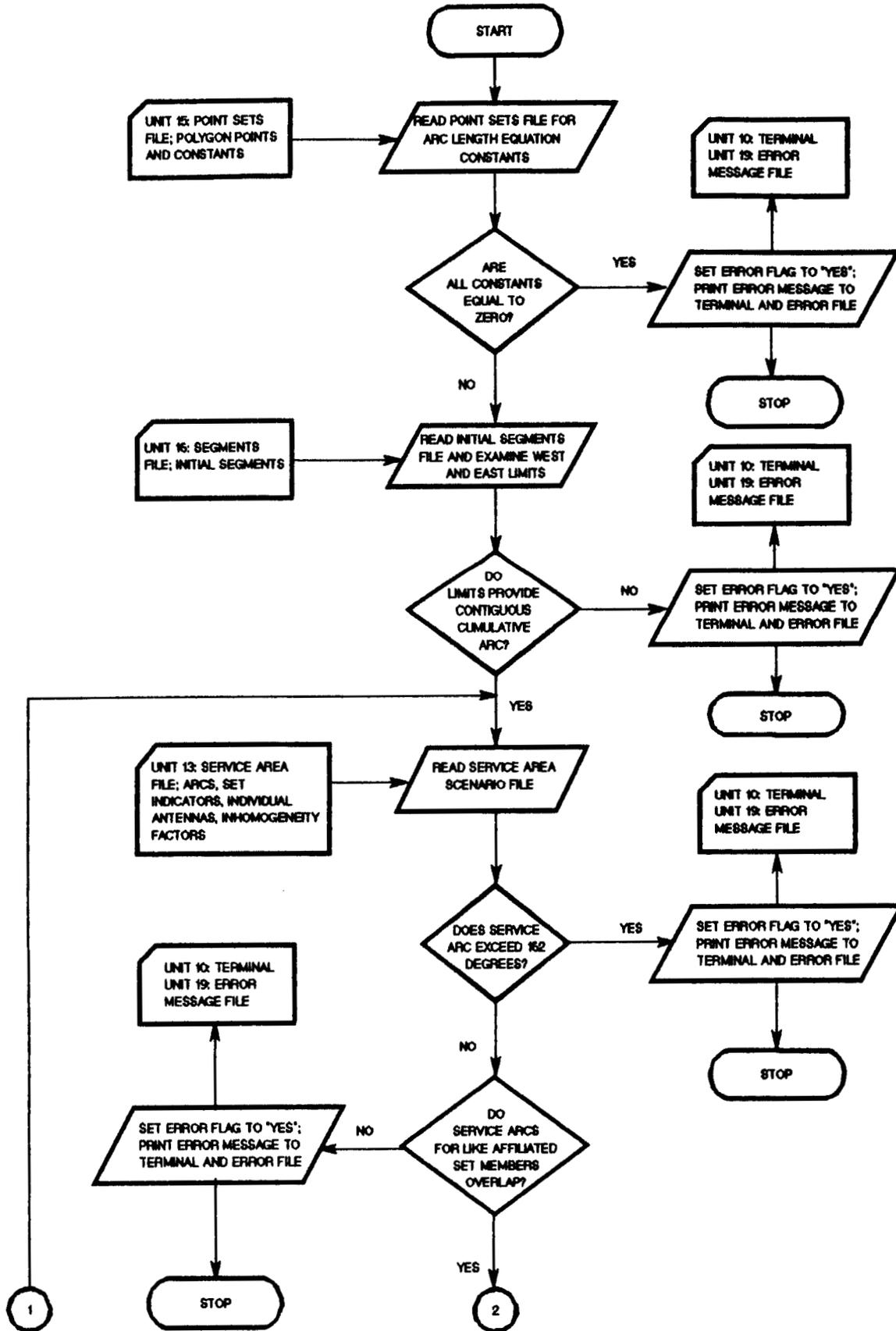


Figure 3.1-2(a).

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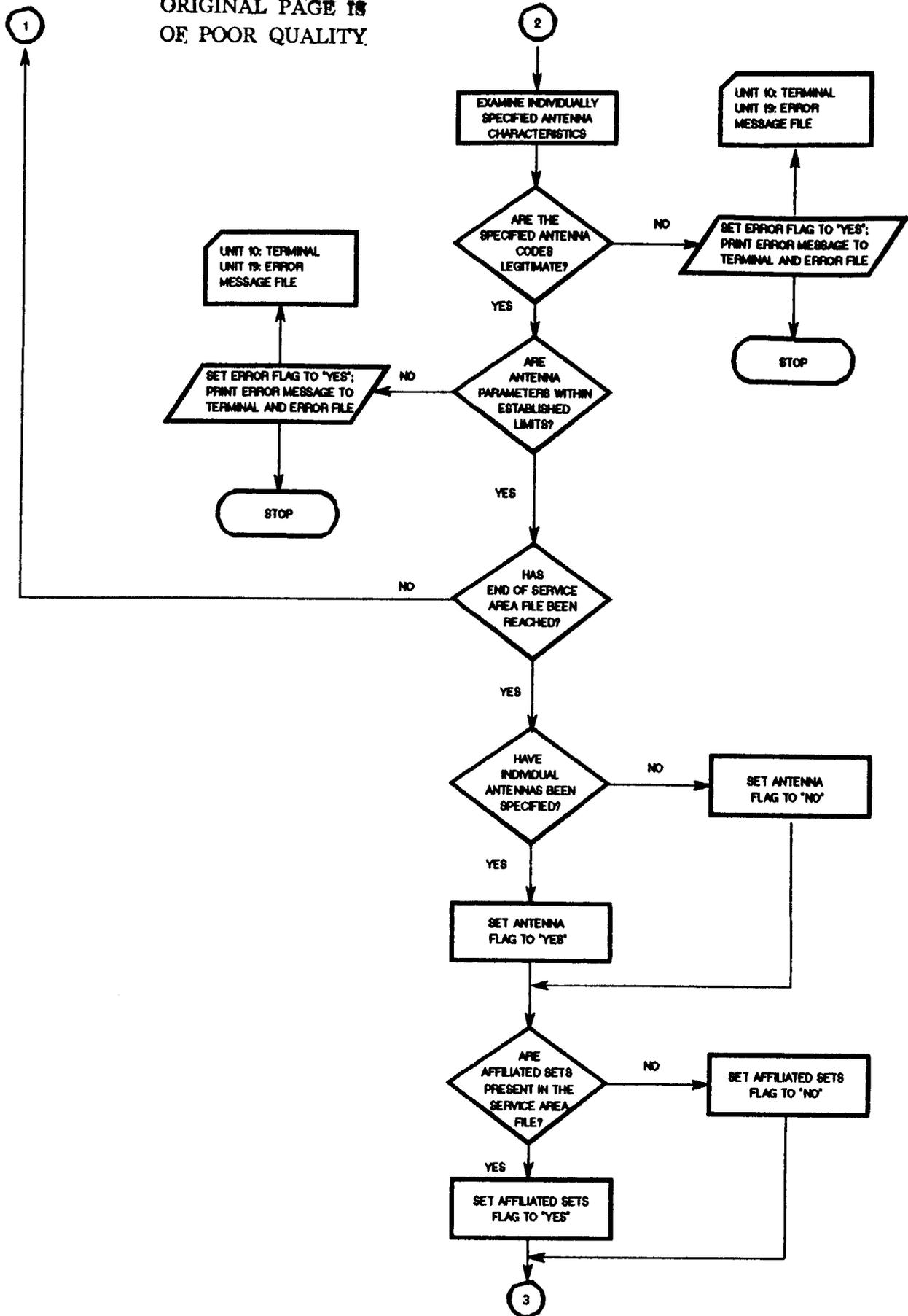


Figure 3.1-2(b).

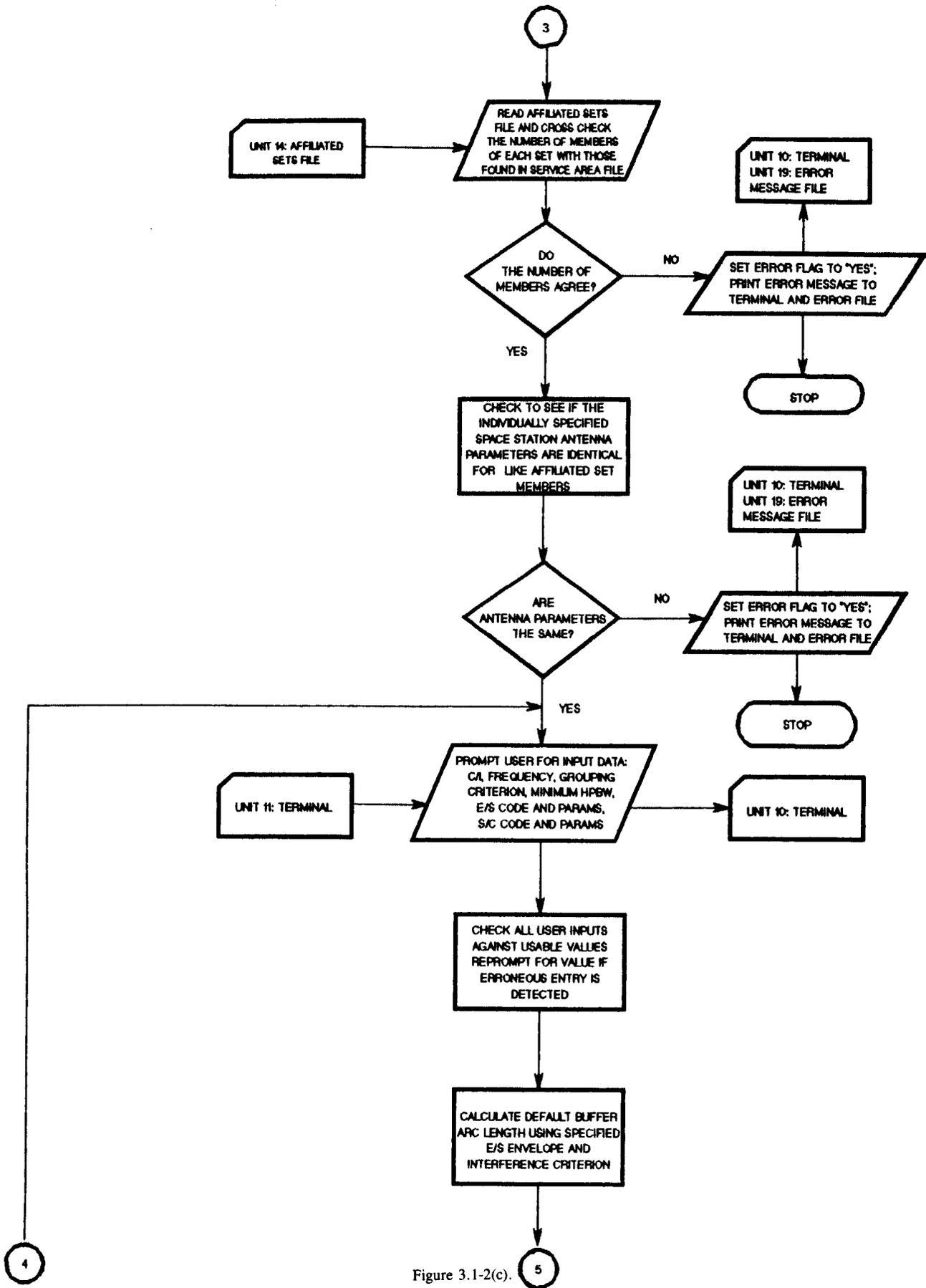


Figure 3.1-2(c). 5

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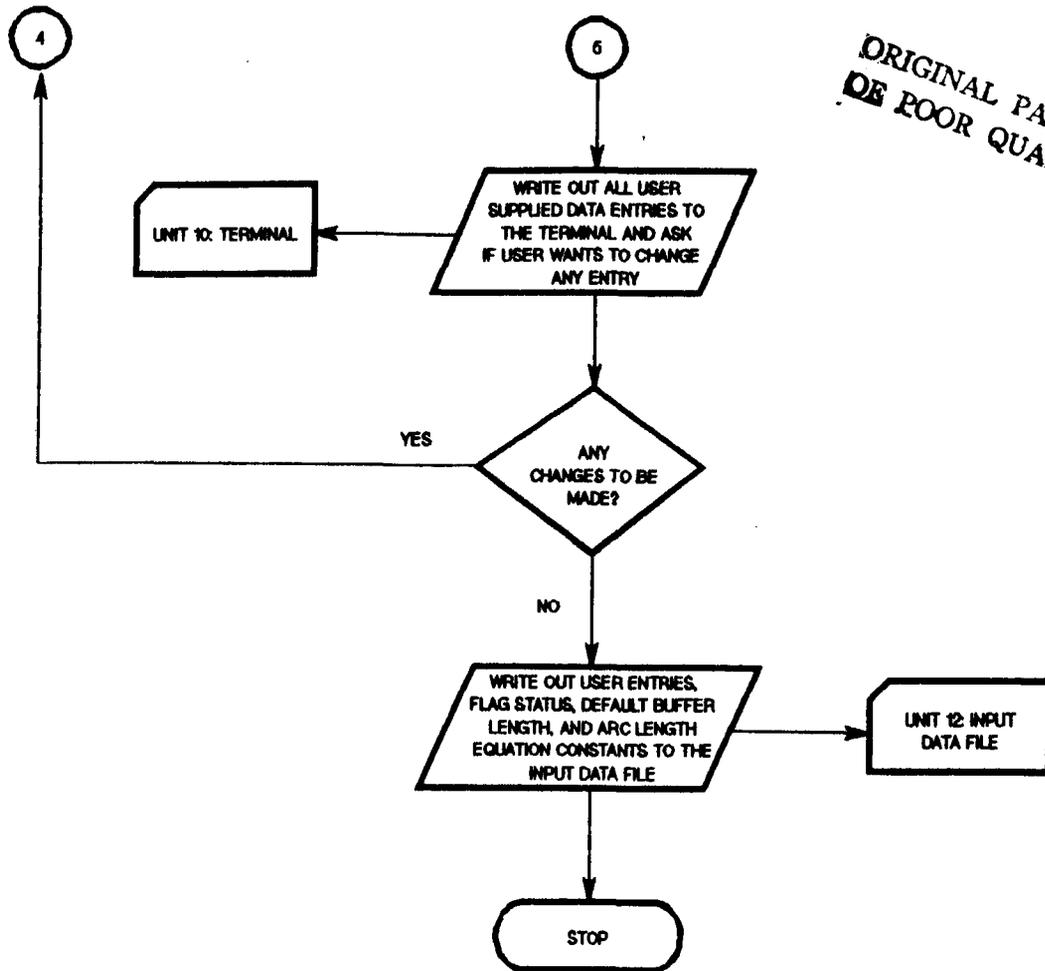


Figure 3.1-2(d).

For  $D/\lambda \geq 100$  and antenna sidelobe envelope of  $32-25 \log \varphi$ :

$$B = 10^{[(C/I-6)-G_{MAX}+32]/25} \quad (3.1-8)$$

For  $D/\lambda \geq 100$  and antenna sidelobe envelope of  $29-25 \log \varphi$ :

$$B = 10^{[(C/I-6)-G_{MAX}+29]/25} \quad (3.1-9)$$

For  $D/\lambda < 100$  and antenna sidelobe envelope of  $32-25 \log \varphi$ :

$$B = 10^{[(C/I-6)-G_{MAX}+52-10 \log (D/\lambda)]/25} \quad (3.1-10)$$

For  $D/\lambda < 100$  and antenna sidelobe envelope of  $29-25 \log \varphi$ :

$$B = 10^{[(C/I-6)-G_{MAX}+49-10 \log (D/\lambda)]/25} \quad (3.1-11)$$

where

- $B$  buffer length, deg
- $D$  earth station antenna diameter, m
- $\lambda$  wavelength corresponding to input frequency, m
- $C/I$  threshold downlink carrier-to-interference ratio, dB
- $G_{MAX}$  earth station on-axis gain, dB
- 6 single-entry to aggregate  $C/I$  ratio, dB (see section 3.1.2.1)

The buffer length is adjusted (i.e., recalculated) by NASARC1 for each service area which has an individually specified earth station antenna with a different type and/or different parameters from the user-specified default values.

### 3.1.2.1 Threshold Single-Entry Downlink $C/I$

A user-specified threshold single-entry downlink  $C/I$  is utilized by both NASARC1 and NASARC3 in the determination of pairwise compatibility between each pair of service areas. This threshold  $C/I$  value is specified by the user during the prompted input sequence of NASARC0, the input program. The NASARC software determines the pairwise compatibility of each pair of service areas in a given scenario by evaluating the total achieved antenna discrimination on the downlink at an orbital spacing equal to the grouping criterion and by comparing the total discrimination with a target  $C/I$ . The target  $C/I$  value is calculated using the threshold  $C/I$  value and the inhomogeneities given in the Service Area file as shown in equation (3.1-2). If both inhomogeneities of the service areas in question are identical or if inhomogeneities are not being utilized, the target  $C/I$  value is simply equal to the threshold value entered by the user. The use of inhomogeneities is described in section 3.1.1.2.3 while compatibility determination is explained in detail in section 3.2.2.5.

Although NASARC determines compatibility on a pairwise basis, thus requiring a single-entry  $C/I$  value for analysis, the software does incorporate an aggregate  $C/I$  in the buffer calculations described in the previous section. NASARC (Version 2.0) utilizes an aggregate-to-single-entry  $C/I$  ratio of 6 dB which is used in conjunction with the user-supplied threshold single-entry  $C/I$  in the buffer equations. At the May 1987 IFRB Informational Meeting, an aggregate  $C/I$  value of 26 dB and a single-entry  $C/I$  value of 32 dB were recommended for planning purposes. Based on these values, an aggregate-to-single-entry  $C/I$  ratio of 6 dB was incorporated into the NASARC (Version 2.0) software. This value could be changed if desired, but such a change would require the recompilation of the software. This 6-dB difference between aggregate and single-entry  $C/I$  values should be sufficient to allow the desired aggregate  $C/I$  value to meet when the NASARC results are analyzed. When entering the threshold single-entry  $C/I$  value, it is recommended that a value be input which is 6 dB greater than the intended desired aggregate  $C/I$  value.

### 3.1.2.2 Downlink Frequency

The NASARC software determines compatibility based on achieving the target single-entry  $C/I$  ratio on the downlink for a given pair of service areas. Thus, the downlink frequency is a required user-supplied input in the NASARC0 prompted input sequence. The uplink is not explicitly considered in the software since the downlink is generally the more constraining of the two links. This assumption can be verified by analysis of the NASARC results on an aggregate interference basis.

The downlink frequency is input in gigahertz (GHz) and is the frequency at which all calculations are performed. Performing the calculations at a single frequency is consistent with the requirement of full bandwidth for each allotment (i.e., 300 MHz in C-band and 500 MHz in Ku-band) allowing for planning on a co-channel basis. Although any frequency within a frequency band of interest can be used as input to NASARC, it is recommended that the lowest frequency in the desired band be utilized to realize the worst case results. The lowest frequency yields the lowest antenna gains and  $D/\lambda$  ratios; the former affects both the space station and earth station antennas while the latter affects the falloff equations of the earth station antennas which are used in determining antenna discrimination and, ultimately, pairwise compatibility between service areas.

### 3.1.2.3 Antenna Specification Code

The antenna specification consists of a six-character descriptive code which is either given as an interactive input in NASARC0 for specifying antennas in the global sense or as an individual antenna type specified in the Service Area file as described in section 3.1.1.2.4. In addition to the antenna specification code, the user must also supply the appropriate antenna parameters for those antennas which require them. These parameters are specified in a simple and straightforward manner and are of a strictly engineering nature (i.e., required parameters are such things as diameter, sidelobe level, etc.). Besides these parameters, the antenna efficiency is required for every antenna type since it is needed in the calculation of the on-axis gains of the antennas. In NASARC (Version 2.0), there are eleven antenna types available:

ETA391	earth station antenna pattern presented CCIR Report 391-4
ETAIMP	same as Report 391-4 antenna but with an improved sidelobe envelope (i.e., $29-25 \log \phi$ )
SCA558	satellite antenna pattern presented in CCIR Report 558-3
RARCST	standard rolloff satellite antenna pattern given in the RARC-83 Final Acts
RARCFR	fast rolloff satellite antenna pattern given in the RARC-83 Final Acts
FASTRO	improved fast rolloff satellite antenna pattern presented in Document No. AH-178-296 of the IRAC
ORBITO	satellite antenna pattern utilized in the ORBIT-II synthesis program by KDD Japan
ORBITF	ORBIT-II satellite antenna pattern with a 10-dB floor added for use in NASARC
WARC77	satellite antenna pattern given in the WARC-77 Final Acts
IWP4/1	fast rolloff satellite antenna pattern presented in CCIR Report 558-3 and recommended by IWP4/1
IWPIMP	fast rolloff satellite antenna recommended by IWP4/1 in May 1987

These antenna types are described further in the following sections. Additionally, the various required antenna parameters are discussed and plots of each antenna pattern for typical parameter values are given (figs. 3.1-3 through 3.1-19).

### 3.1.2.3.1 Earth Terminal Antenna ETA391

In Annex I of CCIR Report 391-4, a reference earth terminal radiation pattern is given which gives a good approximation of actual earth terminal antenna patterns. The required parameter for this antenna is the antenna diameter given in meters. From this parameter and the transmission frequency (given in GHz), which was entered previously, the diameter-to-wavelength ratio is calculated. For  $D/\lambda \geq 100$ , the falloff equations for this antenna are given by

$$F\left(\frac{\varphi}{\varphi_o}\right) = 2.5 \times 10^{-3} \left(\frac{D}{\lambda} \frac{\varphi}{\varphi_o}\right)^2 \varphi_o^2 \quad 0 \leq \frac{\varphi}{\varphi_o} < \frac{\varphi_m}{\varphi_o} \quad (3.1-12a)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} - G_1 \quad \frac{\varphi_m}{\varphi_o} \leq \frac{\varphi}{\varphi_o} < \frac{\varphi_r}{\varphi_o} \quad (3.1-12b)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} - 32 + 25 \log\left(\frac{\varphi}{\varphi_o}\right) + 25 \log(\varphi_o) \quad \frac{\varphi_r}{\varphi_o} \leq \frac{\varphi}{\varphi_o} < \frac{48}{\varphi_o} \quad (3.1-12c)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} + 10 \quad \frac{\varphi}{\varphi_o} \geq \frac{48}{\varphi_o} \quad (3.1-12d)$$

where

$\frac{\varphi}{\varphi_o}$  relative off-axis angle

$\varphi_o$  half-power beamwidth, deg

$G_{MAX}$  antenna on-axis gain, dB

and

$$G_1 = 2 + 15 \log\left(\frac{D}{\lambda}\right) \quad (3.1-12e)$$

$$\varphi_m = \frac{20\lambda}{D} \sqrt{G_{MAX} - G_1} \quad (3.1-12f)$$

$$\varphi_r = 15.848932 \left(\frac{D}{\lambda}\right)^{-0.6} \quad (3.1-12g)$$

For  $D/\lambda < 100$ , the falloff equations are given by

$$F\left(\frac{\varphi}{\varphi_o}\right) = 2.5 \times 10^{-3} \left(\frac{D}{\lambda} \frac{\varphi}{\varphi_o}\right)^2 \varphi_o^2 \quad 0 \leq \frac{\varphi}{\varphi_o} < \frac{\varphi_m}{\varphi_o} \quad (3.1-12h)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} - G_1 \quad \frac{\varphi_m}{\varphi_o} \leq \frac{\varphi}{\varphi_o} < \frac{100}{D/\lambda \varphi_o} \quad (3.1-12i)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} - 52 + 10 \log\left(\frac{D}{\lambda}\right) + 25 \log\left(\frac{\varphi}{\varphi_0}\right) + 25 \log \varphi_0 \quad \frac{100}{D/\lambda \varphi_0} \leq \frac{\varphi}{\varphi_0} < \frac{48}{\varphi_0} \quad (3.1-12j)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} - 10 + 10 \log\left(\frac{D}{\lambda}\right) \quad \frac{\varphi}{\varphi_0} \geq \frac{48}{\varphi_0} \quad (3.1-12k)$$

where

$\frac{\varphi}{\varphi_0}$  relative off-axis angle

$\varphi_0$  half-power beamwidth, deg

$G_{MAX}$  antenna on-axis gain, dB

and

$$G_1 = 2 + 15 \log\left(\frac{D}{\lambda}\right) \quad (3.1-12l)$$

$$\varphi_m = \frac{20\lambda}{D} \sqrt{G_{MAX} - G_1} \quad (3.1-12m)$$

A plot of this antenna pattern for a 7.0-m antenna at a frequency of 4.650 GHz is given in figure 3.1-3 as gain relative to on-axis gain versus relative off-axis angle.

### 3.1.2.3.2 Earth Terminal Antenna ETAIMP

This earth terminal antenna pattern is basically the same as that which is given in Annex I of CCIR Report 391-4 but with an improved sidelobe envelope. The pattern given in section 3.1.2.3.1 has a sidelobe envelope of  $32-25 \log \varphi$  whereas this pattern has an improved sidelobe envelope of  $29-25 \log \varphi$ . The required parameter for this antenna is the antenna diameter in meters. As in ETA391, from the diameter and the transmission frequency input via NASARCO, the diameter-to-wavelength ratio is calculated. For  $D/\lambda \geq 100$  the falloff equations for this antenna are given by

$$F\left(\frac{\varphi}{\varphi_0}\right) = 2.5 \times 10^{-3} \left(\frac{D}{\lambda} \frac{\varphi}{\varphi_0}\right)^2 \varphi_0^2 \quad 0 \leq \frac{\varphi}{\varphi_0} < \frac{\varphi_m}{\varphi_0} \quad (3.1-13a)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} - G_1 \quad \frac{\varphi_m}{\varphi_0} \leq \frac{\varphi}{\varphi_0} < \frac{\varphi_r}{\varphi_0} \quad (3.1-13b)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} - 29 + 25 \log\left(\frac{\varphi}{\varphi_0}\right) + 25 \log(\varphi_0) \quad \frac{\varphi_r}{\varphi_0} \leq \frac{\varphi}{\varphi_0} < \frac{48}{\varphi_0} \quad (3.1-13c)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} + 10 \quad \frac{\varphi}{\varphi_0} \geq \frac{48}{\varphi_0} \quad (3.1-13d)$$

where

$\frac{\varphi}{\varphi_0}$  relative off-axis angle

$\varphi_0$  half-power beamwidth, deg

$G_{MAX}$  antenna on-axis gain, dB

and

$$G_1 = 15 \log \left( \frac{D}{\lambda} \right) - 1 \quad (3.1-13e)$$

$$\varphi_m = \frac{20\lambda}{D} \sqrt{G_{MAX} - G_1} \quad (3.1-13f)$$

$$\varphi_r = 15.848932 \left( \frac{D}{\lambda} \right)^{-0.6} \quad (3.1-13g)$$

For  $D/\lambda < 100$ , the falloff equations are given by

$$F \left( \frac{\varphi}{\varphi_0} \right) = 2.5 \times 10^{-3} \left( \frac{D}{\lambda} \frac{\varphi}{\varphi_0} \right)^2 \varphi_0^2 \quad 0 \leq \frac{\varphi}{\varphi_0} < \frac{\varphi_m}{\varphi_0} \quad (3.1-13h)$$

$$F \left( \frac{\varphi}{\varphi_0} \right) = G_{MAX} - G_1 \quad \frac{\varphi_m}{\varphi_0} \leq \frac{\varphi}{\varphi_0} < \frac{100}{D/\lambda \varphi_0} \quad (3.1-13i)$$

$$F \left( \frac{\varphi}{\varphi_0} \right) = G_{MAX} - 49 + 10 \log \left( \frac{D}{\lambda} \right) + 25 \log \left( \frac{\varphi}{\varphi_0} \right) + 25 \log \varphi_0 \quad \frac{100}{D/\lambda \varphi_0} \leq \frac{\varphi}{\varphi_0} < \frac{48}{\varphi_0} \quad (3.1-13j)$$

$$F \left( \frac{\varphi}{\varphi_0} \right) = G_{MAX} - 10 + 10 \log \left( \frac{D}{\lambda} \right) \quad \frac{\varphi}{\varphi_0} \geq \frac{48}{\varphi_0} \quad (3.1-13k)$$

where

$\frac{\varphi}{\varphi_0}$  relative off-axis angle

$G_{MAX}$  antenna on-axis gain, dB

$\varphi_0$  half-power beamwidth, deg

$$G_1 = 2 + 15 \log \left( \frac{D}{\lambda} \right) \quad (3.1-13l)$$

$$\varphi_m = \frac{20\lambda}{D} \sqrt{G_{MAX} - G_1} \quad (3.1-13m)$$

Figure 3.1-4 gives an example plot of this pattern for a 7.0-m antenna and an operating frequency of 4.500 GHz. If one compares this plot with the plot given in figure 3.1-3, the difference in the sidelobe envelopes between the two earth terminal antenna patterns is readily observed.

### 3.1.2.3.3 Satellite Antenna SCA558

In CCIR Report 558-3 entitled *Satellite Antenna Patterns in The Fixed Satellite Service* several satellite antenna patterns are discussed. One is a standard rolloff (as opposed to a fast rolloff) antenna pattern. An allowance is made for this pattern to have various sidelobe levels which are represented by a plateau in the reference pattern. Therefore, the user is asked to enter a falloff to first sidelobe value for this antenna (i.e., 20.0, 25.0, 30.0 dB, etc.). The falloff equations for this spacecraft antenna are

$$F\left(\frac{\varphi}{\varphi_0}\right) = 12\left(\frac{\varphi}{\varphi_0}\right)^2 \quad 0 \leq \frac{\varphi}{\varphi_0} < \frac{SLL}{12} \quad (3.1-14a)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = SLL \quad \frac{SLL}{12} \leq \frac{\varphi}{\varphi_0} < 3.154787 \quad (3.1-14b)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = SLL - 20 + 25 \log\left(\frac{2\varphi}{\varphi_0}\right) \quad 3.154787 \leq \frac{\varphi}{\varphi_0} < \varphi_i \quad (3.1-14c)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} + 10 \quad \frac{\varphi}{\varphi_0} \geq \varphi_i \quad (3.1-14d)$$

where

$\frac{\varphi}{\varphi_0}$  relative off-axis angle

$G_{MAX}$  antenna on-axis gain, dB

$SLL$  user input first sidelobe level, dB

and

$$\varphi_i = 0.5 \times 10^{[(G_{MAX} + 30 - SLL)/25]} \quad (3.1-14e)$$

Figures 3.1-5 through 3.1-7 are plots of this antenna pattern for falloff to first sidelobe levels of 20, 25, and 30 dB, respectively.

### 3.1.2.3.4 Satellite Antenna RARCST

There are two antenna types now available in NASARC (Version 2.0) which resulted from the 1983 Regional Administrative Radio Conference (RARC-83) and are found in the RARC-83 Final Acts. One of these patterns is a standard rolloff satellite antenna pattern. The distinguishing feature of this antenna pattern is that the second segment of the pattern is not a plateau as in the *standard* fixed satellite service reference pattern; rather, the falloff in this region of the pattern is logarithmic in nature, as seen in figure 3.1-8. The falloff equations for this antenna are as follows:

$$F\left(\frac{\varphi}{\varphi_0}\right) = 12\left(\frac{\varphi}{\varphi_0}\right)^2 \quad 0 \leq \frac{\varphi}{\varphi_0} < 1.449908 \quad (3.1-15a)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = 22 + 20 \log\left(\frac{\varphi}{\varphi_0}\right) \quad 1.449908 \leq \frac{\varphi}{\varphi_0} < \varphi_i \quad (3.1-15b)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} \quad \frac{\varphi}{\varphi_0} \geq \varphi_i \quad (3.1-15c)$$

where

$\frac{\varphi}{\varphi_0}$  relative off-axis angle

$G_{MAX}$  antenna on-axis gain, dB

and

$$\varphi_i = 10^{[(G_{MAX} - 22)/20]} \quad (3.1-15d)$$

### 3.1.2.3.5 Satellite Antenna RARCFR

The second antenna type which resulted from the 1983 RARC and is given in the 1983 RARC Final Acts is a satellite fast rolloff antenna pattern. This pattern is the same as the standard rolloff RARC-83 pattern of the previous section if the satellite HPBW is the same as the minimum half-power beamwidth.

However, if the satellite HPBW is greater than the minimum HPBW, then the rolloff outside of the coverage area is the same as that of a minimum beamwidth antenna. This type of characteristic is typical of *fast* rolloff antenna patterns. Figure 3.1-9 illustrates this concept with plots of this pattern for various ratios of the actual HPBW to the minimum HPBW. Additionally, in figure 3.1-10 the pattern is shown for a HPBW/minimum HPBW ratio of 2.5 for clarity. The only parameter used in this pattern is the minimum HPBW which is entered elsewhere in the user input sequence. The falloff equations are given as

$$F\left(\frac{\varphi}{\varphi_0}\right) = 12\left(\frac{\varphi}{\varphi_0}\right)^2 \quad 0 \leq \frac{\varphi}{\varphi_0} < 0.5 \quad (3.1-16a)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = 12\left(\frac{\varphi_0}{b}\right)^2\left(\frac{\varphi}{\varphi_0} - X\right)^2 \quad 0.5 \leq \left(\frac{\varphi}{\varphi_0}\right) < 1.449908 \frac{b}{\varphi_0} + X \quad (3.1-16b)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = 25.226811 \quad 1.449908 \frac{b}{\varphi_0} + X \leq \frac{\varphi}{\varphi_0} < 1.449908 \quad (3.1-16c)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = 22 + 20 \log\left(\frac{\varphi}{\varphi_0}\right) \quad 1.449908 \leq \frac{\varphi}{\varphi_0} < \varphi_i \quad (3.1-16d)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} + 10 \quad \frac{\varphi}{\varphi_0} \leq \varphi_i \quad (3.1-16e)$$

where

$\frac{\varphi}{\varphi_0}$  relative off-axis angle

$G_{MAX}$  antenna on-axis gain, dB

$\varphi_0$  half-power beamwidth, deg

$b$  minimum half-power beamwidth, deg

and

$$X = 0.5 \left(1 - \frac{b}{\varphi_0}\right) \quad (3.1-16f)$$

$$\varphi_i = 10^{[(G_{MAX} - 12)/20]} \quad (3.1-16g)$$

### 3.1.2.3.6 Satellite Antenna FASTRO

In Document AH-178-296 of the Ad Hoc Committee 178 of the IRAC, another fast rolloff antenna was presented that was slightly different from that of RARC-83. This satellite antenna pattern is an improvement over the RARC-83 fast rolloff antenna in that there is no plateau for antennas with a HPBW greater than the minimum HPBW. This is illustrated in figure 3.1-11 for various values of the HPBW/minimum HPBW ratio. Figure 3.1-12 gives the pattern for a HPBW/minimum HPBW ratio of 2.5 as a representative example of a typical satellite. As in the RARC-83 fast rolloff antenna, the only parameter needed is the minimum HPBW which is entered in another section of the user input sequence. The falloff relationships are given by

$$F\left(\frac{\varphi}{\varphi_o}\right) = 12\left(\frac{\varphi}{\varphi_o}\right)^2 \quad 0 \leq \frac{\varphi}{\varphi_o} < 0.5 \quad (3.1-17a)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 12\left(\frac{\varphi_o}{b}\right)^2 \left(\frac{\varphi}{\varphi_o} - X\right)^2 \quad 0.5 \leq \frac{\varphi}{\varphi_o} < \frac{b}{\varphi_o}\sqrt{2.5} + X \quad (3.1-17b)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 30 - 30 \log\left(\frac{b}{\varphi_o}\sqrt{2.5} + X\right) + 30 \log\left(\frac{\varphi}{\varphi_o}\right) \quad \frac{b}{\varphi_o}\sqrt{2.5} + X \leq \frac{\varphi}{\varphi_o} < \varphi_i \quad (3.1-17c)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} + 10 \quad \frac{\varphi}{\varphi_o} \geq \varphi_i \quad (3.1-17d)$$

where

$\frac{\varphi}{\varphi_o}$  relative off-axis angle

$G_{MAX}$  antenna on-axis gain, dB

$\varphi_o$  half-power beamwidth, deg

$b$  minimum half-power beamwidth, deg

and

$$X = 0.5 \left(1 - \frac{b}{\varphi_o}\right) \quad (3.1-17e)$$

$$\varphi_i = \left(\frac{b}{\varphi_o}\sqrt{2.5} + X\right) 10^{(G_{MAX}-20)/30} \quad (3.1-17f)$$

### 3.1.2.3.7 Satellite Antenna ORBITO

Another antenna pattern available in NASARC to be used as a general satellite antenna pattern is the ORBIT-II standard spacecraft antenna pattern. This antenna is the satellite antenna pattern used in the ORBIT-II synthesis program by KDD of Japan. The key parameter in this pattern is the decay constant which defines how rapid the rolloff is for this antenna pattern. Anything from a standard rolloff antenna to a fast rolloff antenna can be approximated to some degree by choosing various values of this constant. Figure 3.1-13 illustrates the shape of this pattern for several values of the decay constant. The following is the falloff equation for this pattern:

$$F\left(\frac{\varphi}{\varphi_o}\right) = 10 \log \left[ 1 + \left(\frac{2\varphi}{\varphi_o}\right)^\alpha \right] \quad \frac{\varphi}{\varphi_o} \geq 0 \quad (3.1-18)$$

where

$\frac{\varphi}{\varphi_o}$  relative off-axis angle  
 $\alpha$  antenna decay constant

### 3.1.2.3.8 Satellite Antenna ORBITF

The antenna pattern type designated ORBITF is exactly the same as the standard ORBIT-II satellite antenna pattern except that a  $-10$  dB floor was added to the pattern. Once again, the only parameter that the user is prompted for is the antenna decay constant. Figure 3.1-14 shows this pattern for a decay constant of 4.0 for illustrative purposes. The falloff equations are

$$F\left(\frac{\varphi}{\varphi_o}\right) = 10 \log \left[ 1 + \left(\frac{2\varphi}{\varphi_o}\right)^\alpha \right] \quad 0 \leq \frac{\varphi}{\varphi_o} < \varphi_i \quad (3.1-19a)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} + 10 \quad \frac{\varphi}{\varphi_o} \geq \varphi_i \quad (3.1-19b)$$

where

$\frac{\varphi}{\varphi_o}$  relative off-axis angle  
 $G_{MAX}$  antenna on-axis gain, dB  
 $\alpha$  antenna decay constant

and

$$\varphi_i = 0.5 \times (10^{[(G_{MAX} + 10)/10]} - 1)^{1/2} \quad (3.1-19c)$$

### 3.1.2.3.9 Satellite Antenna WARC77

The satellite antenna pattern given in the WARC-77 Final Acts is also available in NASARC (Version 2.0). It is similar to the CCIR standard satellite antenna for the fixed satellite service with a falloff to the first sidelobe level of 30 dB except that the maximum falloff is  $G_{MAX}$  rather than  $G_{MAX} + 10$ . This antenna is shown in figure 3.1-15 and the equations defining its characteristics are

$$F\left(\frac{\varphi}{\varphi_o}\right) = 12 \left(\frac{\varphi}{\varphi_o}\right)^2 \quad 0 \leq \frac{\varphi}{\varphi_o} < 1.581139 \quad (3.1-20a)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 30 \quad 1.581139 \leq \frac{\varphi}{\varphi_o} < 3.154787 \quad (3.1-20b)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 10 + 25 \log \left[ 2 \left(\frac{\varphi}{\varphi_o}\right) \right] \quad 3.154787 \leq \frac{\varphi}{\varphi_o} < \varphi_i \quad (3.1-20c)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} \quad \frac{\varphi}{\varphi_o} \geq \varphi_i \quad (3.1-20d)$$

where

$\frac{\varphi}{\varphi_0}$  relative off-axis angle

$G_{MAX}$  antenna on-axis gain, dB

and

$$\varphi_i = 0.5 \times 10^{[(G_{MAX} - 10)/25]} \quad (3.1-20e)$$

### 3.1.2.3.10 Satellite Antenna IWP4/1

This satellite antenna pattern is given in the previously mentioned CCIR Report 558-3 and is another fast rolloff antenna type. Its general shape is similar to the RARC-83 fast rolloff antenna in that the second segment is a plateau and it is also similar to the improved fast rolloff antenna in that its logarithmic section also is dependent on the ratio of HPBW to minimum HPBW. Figure 3.1-16 shows this pattern for various values of this ratio while Figure 3.1-17 gives the falloff pattern for a single value of the ratio. The required parameters for this antenna are the falloff to the first sidelobe level and the minimum HPBW which is entered elsewhere in the user input sequence. The falloff for this pattern is defined by the following equations:

$$F\left(\frac{\varphi}{\varphi_0}\right) = 12 \left(\frac{\varphi}{\varphi_0}\right)^2 \quad 0 \leq \frac{\varphi}{\varphi_0} < 0.5 \quad (3.1-21a)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = 3 - B + B \left(\frac{\varphi_0}{b}\right)^2 \left(\frac{2\varphi}{\varphi_0} + \frac{b}{\varphi_0} - 1\right)^2 \quad 0.5 \leq \frac{\varphi}{\varphi_0} < 0.5 \left(1 + C \frac{b}{\varphi_0}\right) \quad (3.1-21b)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = SLL \quad 0.5 \left(1 + C \frac{b}{\varphi_0}\right) \leq \frac{\varphi}{\varphi_0} < 0.5 \left(1 + E \frac{b}{\varphi_0}\right) \quad (3.1-21c)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = SLL + 20 \log \left(2 \frac{\varphi}{\varphi_0}\right) - 20 \log \left(1 + E \frac{b}{\varphi_0}\right) \quad 0.5 \left(1 + E \frac{b}{\varphi_0}\right) \leq \frac{\varphi}{\varphi_0} < \varphi_i \quad (3.1-21d)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} \quad \frac{\varphi}{\varphi_0} \geq \varphi_i \quad (3.1-11e)$$

where

$\frac{\varphi}{\varphi_0}$  relative off-axis angle

$G_{MAX}$  antenna on-axis gain, dB

$b$  minimum half-power beamwidth, deg

$\varphi_0$  half-power beamwidth, deg

$\varphi_i$  value of  $\varphi/\varphi_0$  where  $F(\varphi/\varphi_0) = G_{MAX}$

and

$$B = 1.413 + 0.0638 SLL \quad (3.1-21f)$$

$$E = 4.191 = 0.0134 SLL \quad (3.1-21g)$$

$$C = \sqrt{(SLL + 3 - B)/B} - 1 \quad (3.1-21h)$$

### 3.1.2.3.11 Satellite Antenna IWPIMP

This fast rolloff antenna pattern was recommended by IWP4/1 in May of 1987. It was offered as an improvement to the fast rolloff antenna pattern given in CCIR Report 558-3 and is quite similar to that pattern in many respects. It is also similar to the other fast rolloff satellite antenna patterns. Figure 3.1-18 shows this pattern for various values of HPBW to minimum HPBW while figure 3.1-19 gives the falloff pattern for a single value of this ratio. The required parameter for this antenna is the satellite antenna focal length-to-diameter ratio. In the global antenna specification case, this parameter is not supplied by the user. Rather, it is set to a value of 2.0 which is considered a representative value for the homogeneous antenna case. In the individual antenna specification option, this parameter does have to be specified by the user. Additionally, the minimum HPBW is utilized in the falloff equations for the antenna pattern:

$$F\left(\frac{\varphi}{\varphi_0}\right) = 12 \left(\frac{\varphi}{\varphi_0}\right)^2 \quad 0 \leq \frac{\varphi}{\varphi_0} < 0.5 \quad (3.1-22a)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = 3 + B \left(\frac{\varphi_0}{b}\right)^2 \left(\frac{2\varphi}{\varphi_0} - 1\right) \left(\frac{2b}{\varphi_0} + \frac{2\varphi}{\varphi_0} - 1\right) \quad 0.5 \leq \frac{\varphi}{\varphi_0} < 0.5 \left(1 + C \frac{b}{\varphi_0}\right) \quad (3.1-22b)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = 20 \quad 0.5 \left(1 + C \frac{b}{\varphi_0}\right) \leq \frac{\varphi}{\varphi_0} < 5 \left[1 + (C + 0.5) \frac{b}{\varphi_0}\right] \quad (3.1-22c)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = 20 - 2.5 \left(\frac{\varphi_0}{b}\right) \left[ (C + 0.5) \frac{b}{\varphi_0} - \frac{2\varphi}{\varphi_0} + 1 \right] \quad 0.5 \left[1 + (C + 0.5) \frac{b}{\varphi_0}\right] \leq \frac{\varphi}{\varphi_0} < 0.5 \left[1 + (C + 4.5) \frac{b}{\varphi_0}\right] \quad (3.1-22d)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = 30 - 20 \log \left[ (C + 4.5) \frac{b}{\varphi_0} \right] + 20 \log \left(\frac{2\varphi}{\varphi_0}\right) - 1 \quad 0.5 \left[1 + (C + 4.5) \frac{b}{\varphi_0}\right] \leq \frac{\varphi}{\varphi_0} < 0.5 \left[1 + K(C + 4.5) \frac{b}{\varphi_0}\right] \quad (3.1-22e)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} \quad \frac{\varphi}{\varphi_0} \geq 0.5 \left[1 + K(C + 4.5) \frac{b}{\varphi_0}\right] \quad (3.1-22f)$$

where

- $\frac{\varphi}{\varphi_0}$  relative off-axis angle
- $G_{MAX}$  antenna on-axis gain, dB
- $b$  minimum half-power beamwidth, deg
- $\varphi_0$  half-power beamwidth, deg
- $F/D$  focal length-to-diameter ratio of satellite antenna

and

$$K = 10^{[(G_{MAX} - 30)/20]} \quad (3.1-22g)$$

$$C = \sqrt{1 + 17/B} - 1 \quad (3.1-22h)$$

$$B = B_o \quad \frac{\varphi_o}{b} < 1.25 \quad (3.1-22i)$$

$$B = B_o - \frac{\varphi_o}{b} - 1.25 \Delta B \quad \frac{\varphi_o}{b} \geq 1.25 \quad (3.1-22j)$$

$$B_o = 2.25 + \frac{F/D - 1.3}{1.5} \quad (3.1-22k)$$

$$\Delta B = 0.28 - \frac{F/D - 1.3}{30} \quad (3.1-22l)$$

#### 3.1.2.4 Grouping Criterion

As previously mentioned, a compatible grouping consists of a group of service areas that are sufficiently separated geographically so that colocation or near colocation of their corresponding space stations results in achieving the proper downlink single-entry  $C/I$  ratio for any pair of space stations in that group. Compatibility on a pairwise basis is determined by application of the user-supplied grouping criterion. The grouping criterion is entered by the user during the NASARC0 input sequence in decimal degrees. The grouping criterion is a *threshold* required spacing for a compatible group. That is, if the minimum orbital spacing required between a pair of space stations based on a target single-entry  $C/I$  ratio is less than or equal to the grouping criterion, then the pair of space stations are compatible. For a group to be compatible, each space station within the group must be compatible with all other space stations in that group. Colocation would be specified by a grouping criterion of  $0^\circ$ . Near colocation would be specified by a grouping criterion of the order of  $1^\circ$  or less. Colocation requires all the antenna discrimination to come from the satellite antenna while a nonzero grouping criterion allows some earth station antenna discrimination to be utilized to meet the target single-entry  $C/I$  value.

The grouping criterion is also utilized in the determination of the allotted arc length for each compatible group selected in the NASARC2 module. The extent of the effect of the grouping criterion on the allotted arc length is controlled by the constants used in the allotted arc length equation as described later in section 3.3.4.2.

#### 3.1.2.5 Minimum Half-Power Beamwidth

The minimum HPBW is a user-supplied value entered during the NASARC0 input sequence. Entered in degrees, the minimum HPBW is related to the maximum allowable diameter of space station transmit antenna and the user-specified downlink frequency. There are two ways in which the minimum HPBW is used in the NASARC software. First, if the major or minor axis half-power beamwidths of any coverage ellipse falls below the minimum HPBW, the beamwidth for that axis is set equal to the minimum value. For very small service areas, this has the effect of over-illuminating the desired coverage area with a beam which is larger than the minimum area ellipse.

The minimum HPBW is also used in the falloff equations of the so-called fast rolloff antenna patterns. A fast rolloff satellite antenna is one in which the falloff from maximum gain rolls off as an antenna whose half-power beamwidth is equal to the minimum HPBW. Thus, when fast rolloff satellite antenna patterns are utilized, the minimum HPBW affects the interfering satellite antenna discrimination in the direction of the wanted service area.

# CCIR REP 391-4 STANDARD EARTH STATION ANTENNA PATTERN

GAIN = 48.5 DB  $D/\lambda = 105.07$

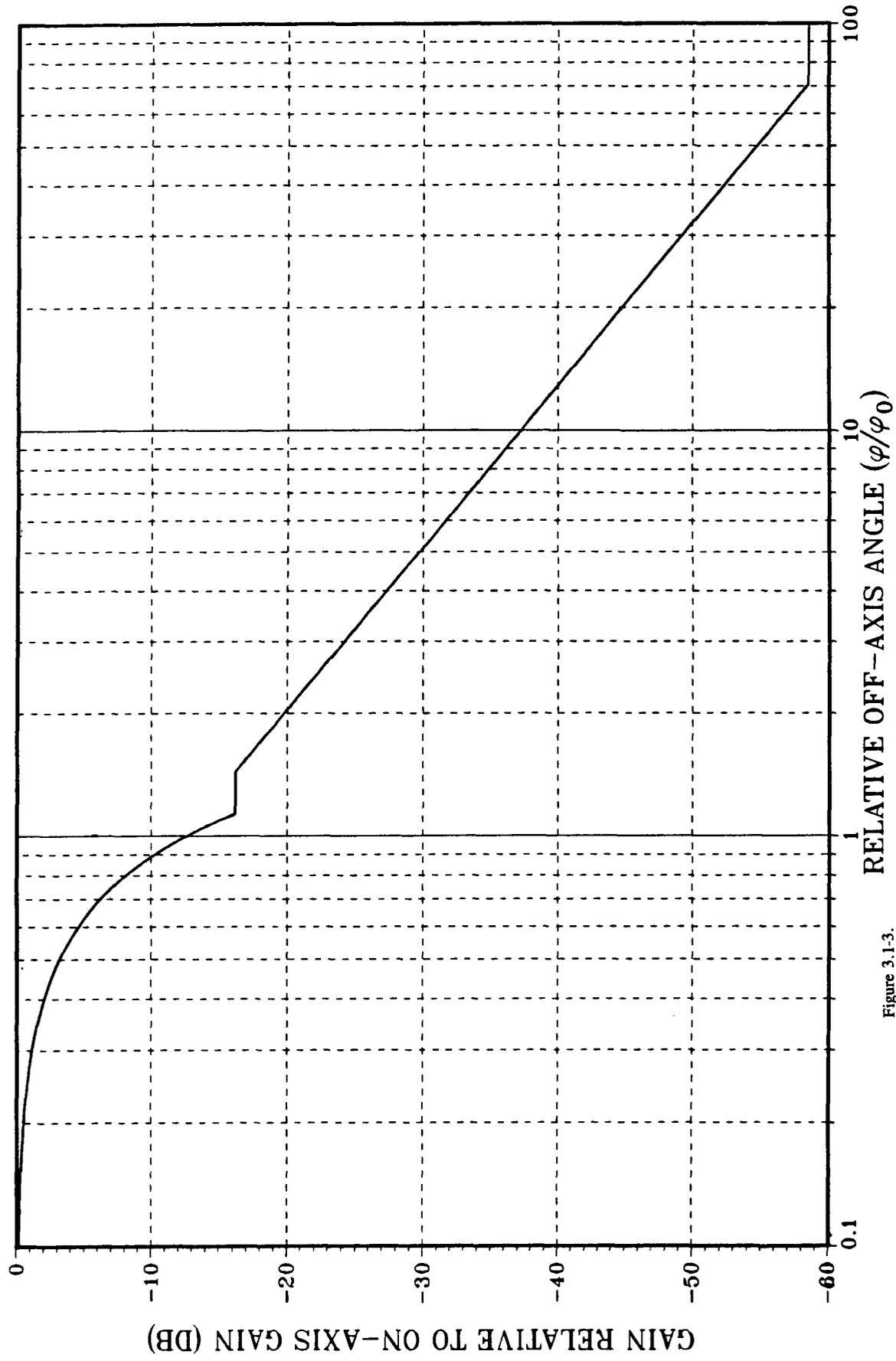


Figure 3.1-3.

# EARTH STATION PATTERN USING 29 - 25 LOG( $\varphi$ ) SLL

GAIN = 48.5 DB  $D/\lambda = 105.07$

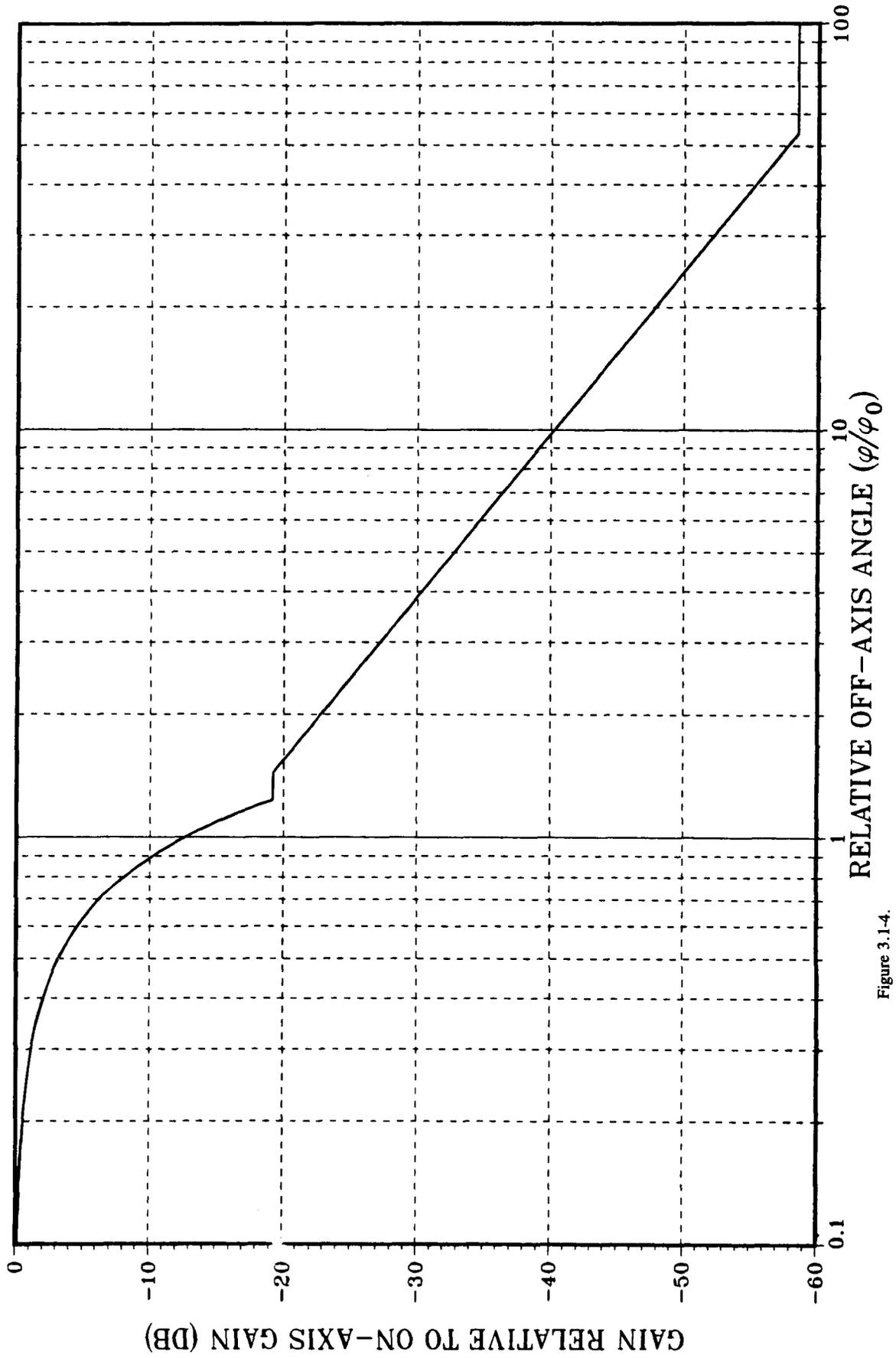


Figure 3.1-4.

# CCIR REP 558-3 STANDARD SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB SIDELOBE = 20.0

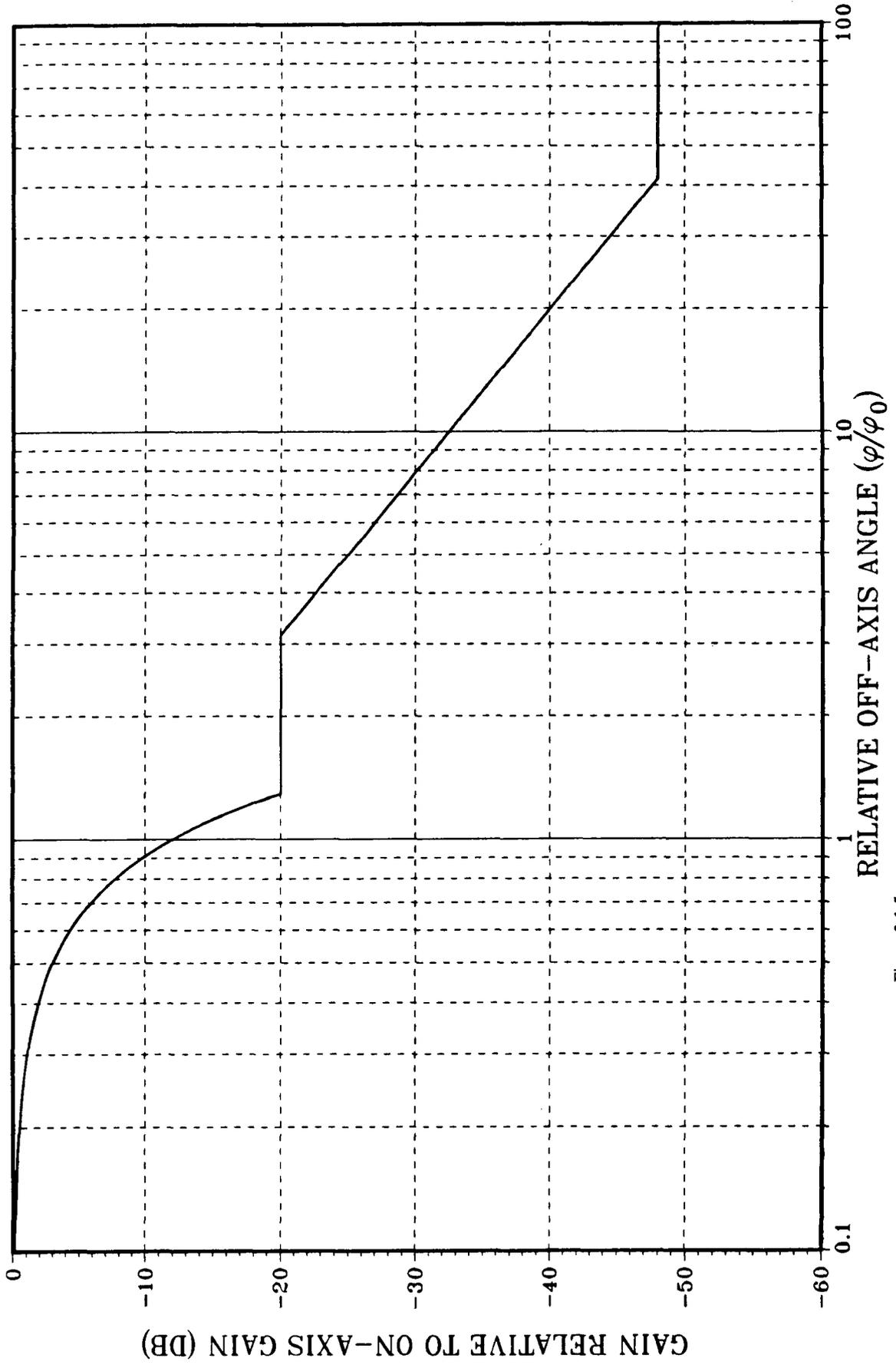


Figure 3.11-5.

# CCIR REP 558-3 STANDARD SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB SIDELOBE = 25.0

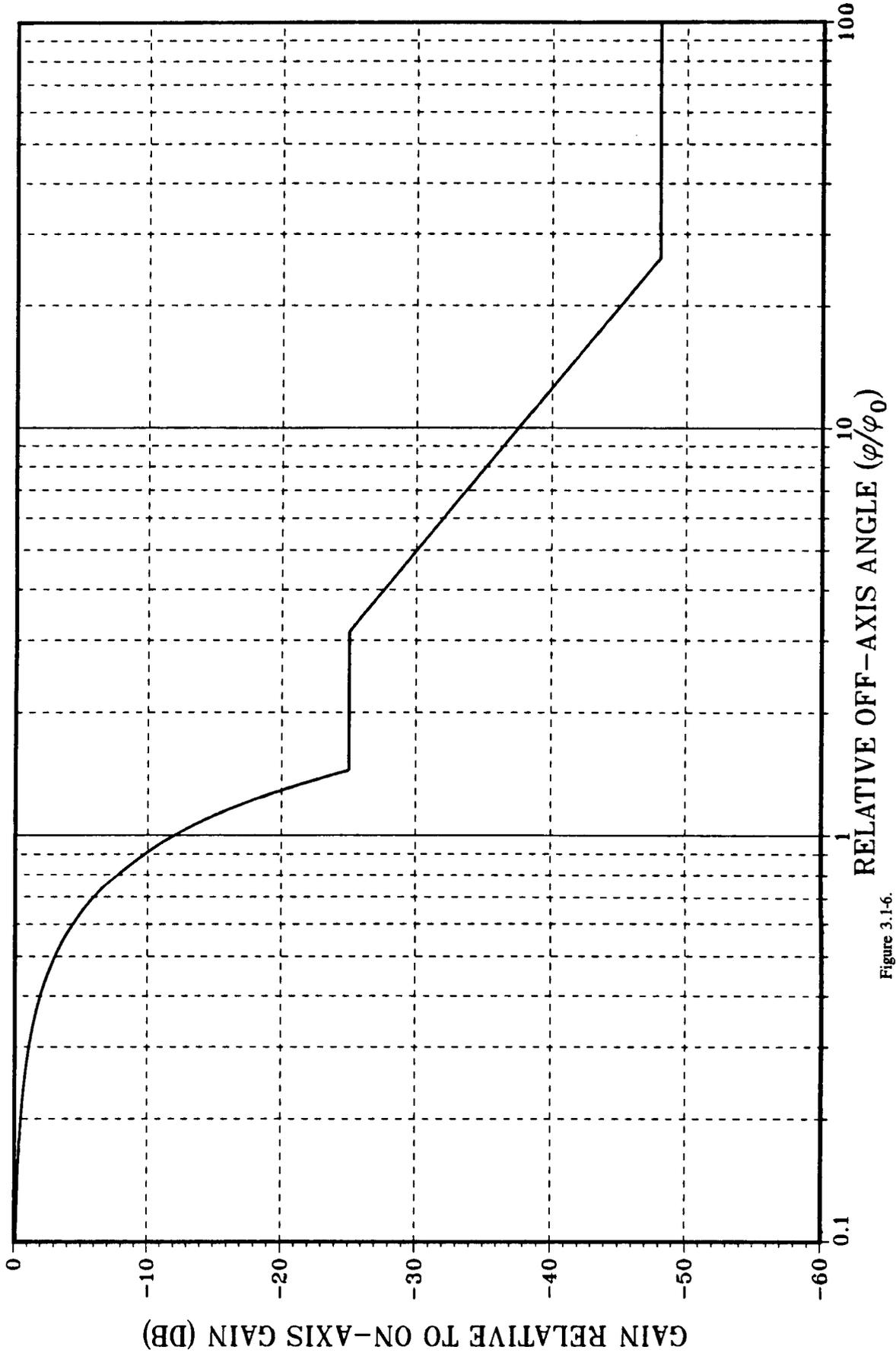


Figure 3.1-6.

# CCIR REP 558-3 STANDARD SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB SIDELOBE = 30.0

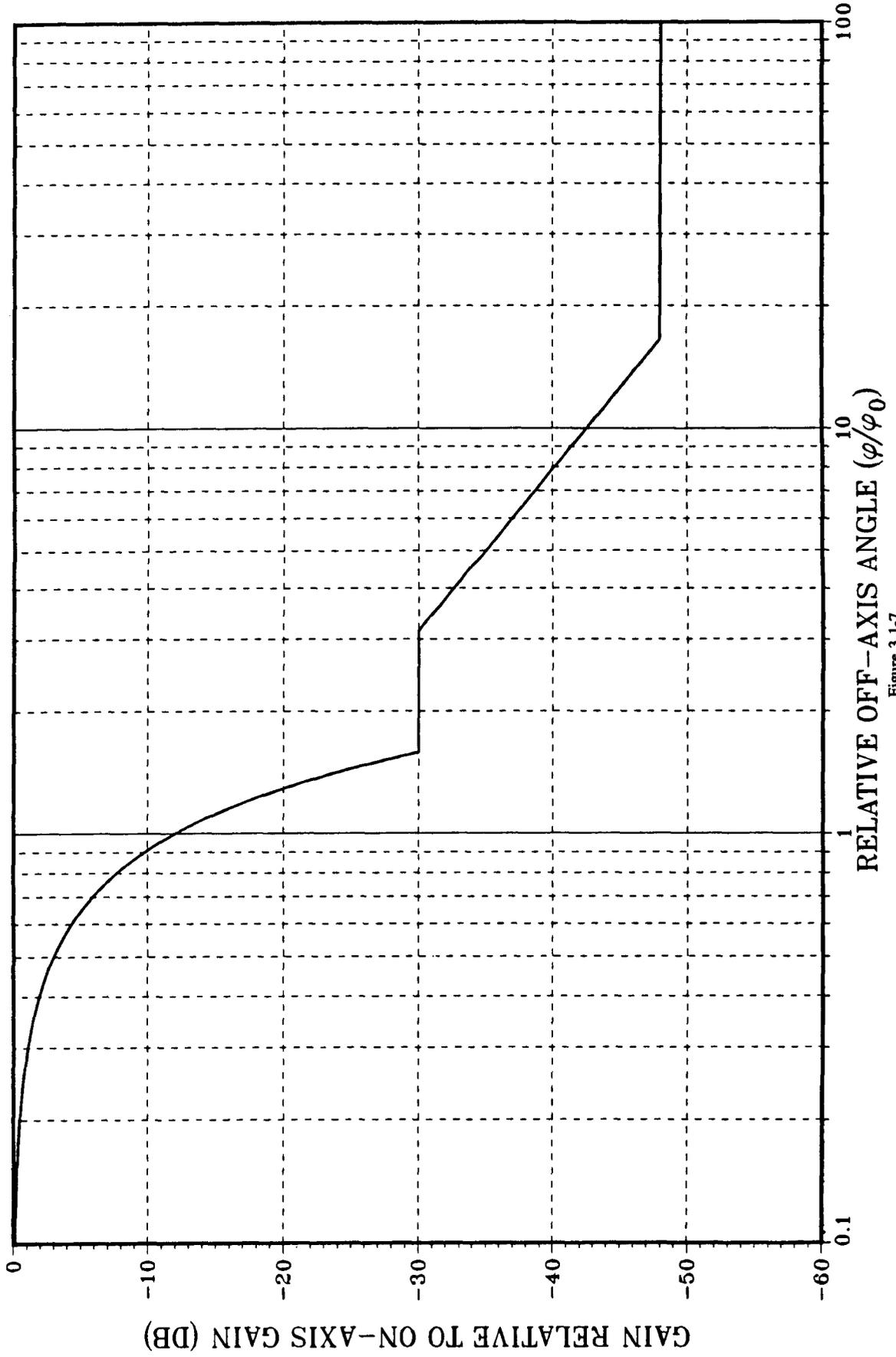


Figure 3.1-7.

# RARC 83 STANDARD ROLL-OFF SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB

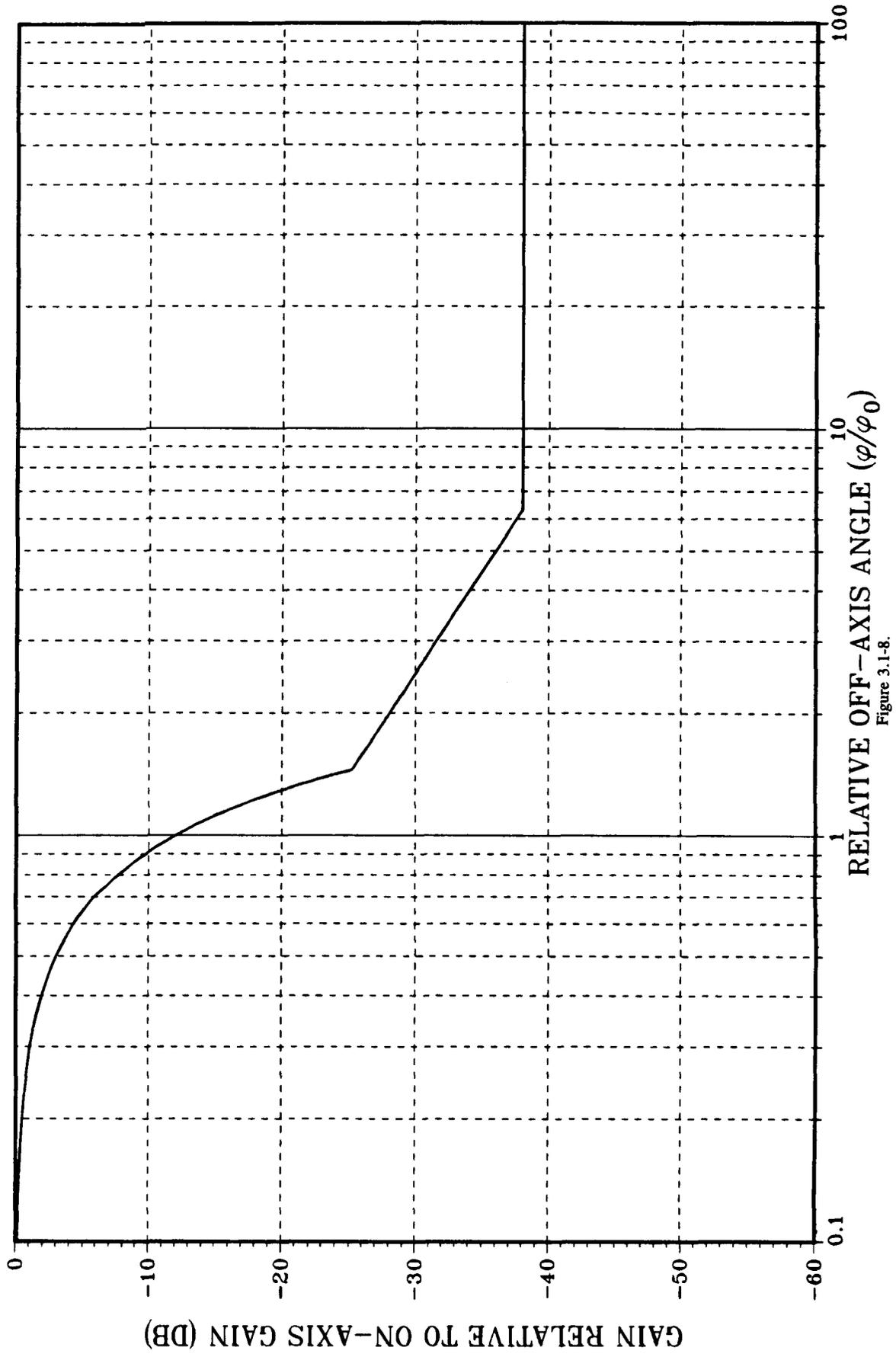


Figure 3.1-8.

# RARC 83 FAST ROLL-OFF SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB

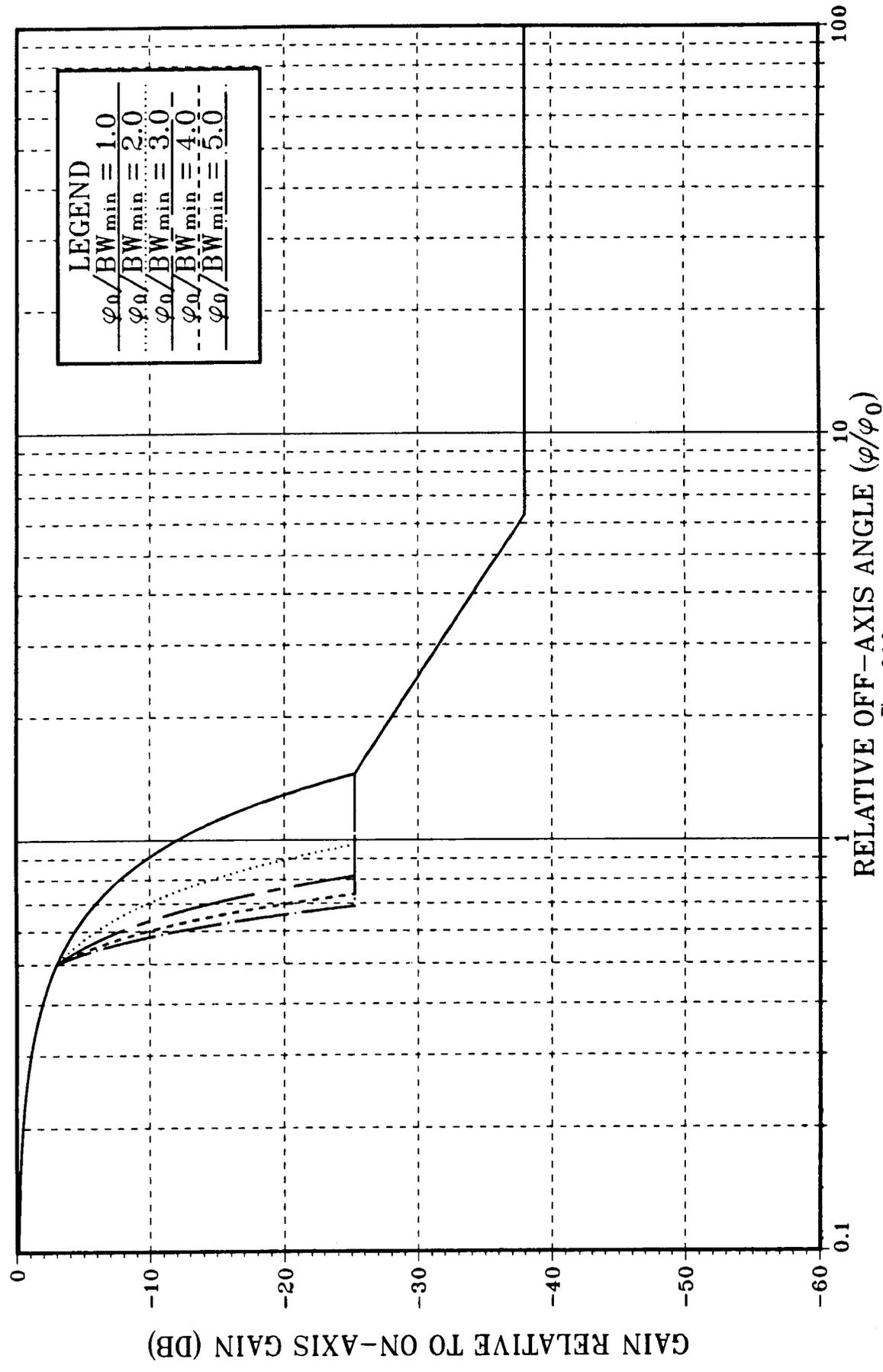


Figure 3.1-9.

# RARC 83 FAST ROLL-OFF SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB HPBW/MIN = 2.5

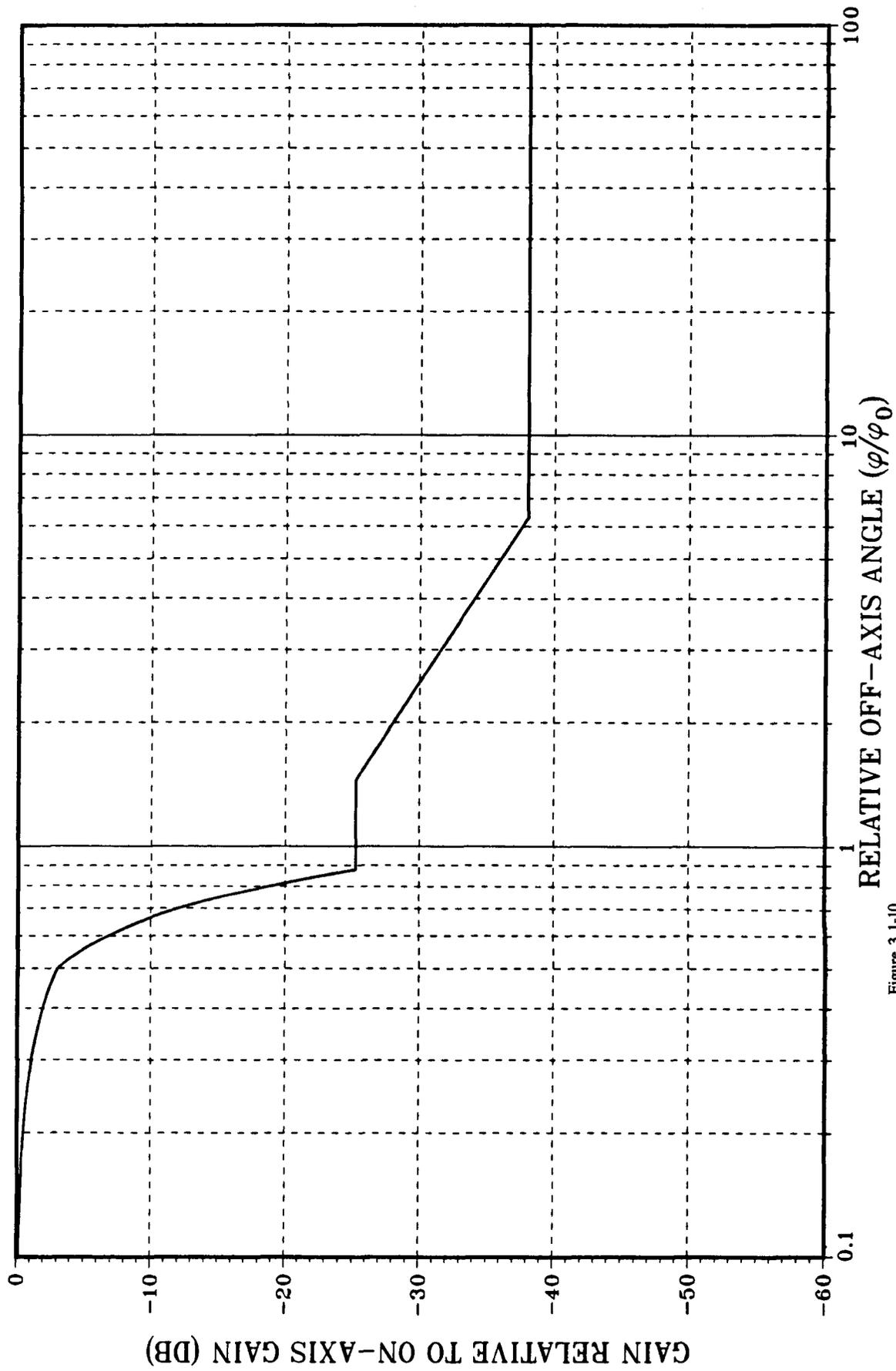


Figure 3.1-10.

# IMPROVED FAST ROLL-OFF SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB

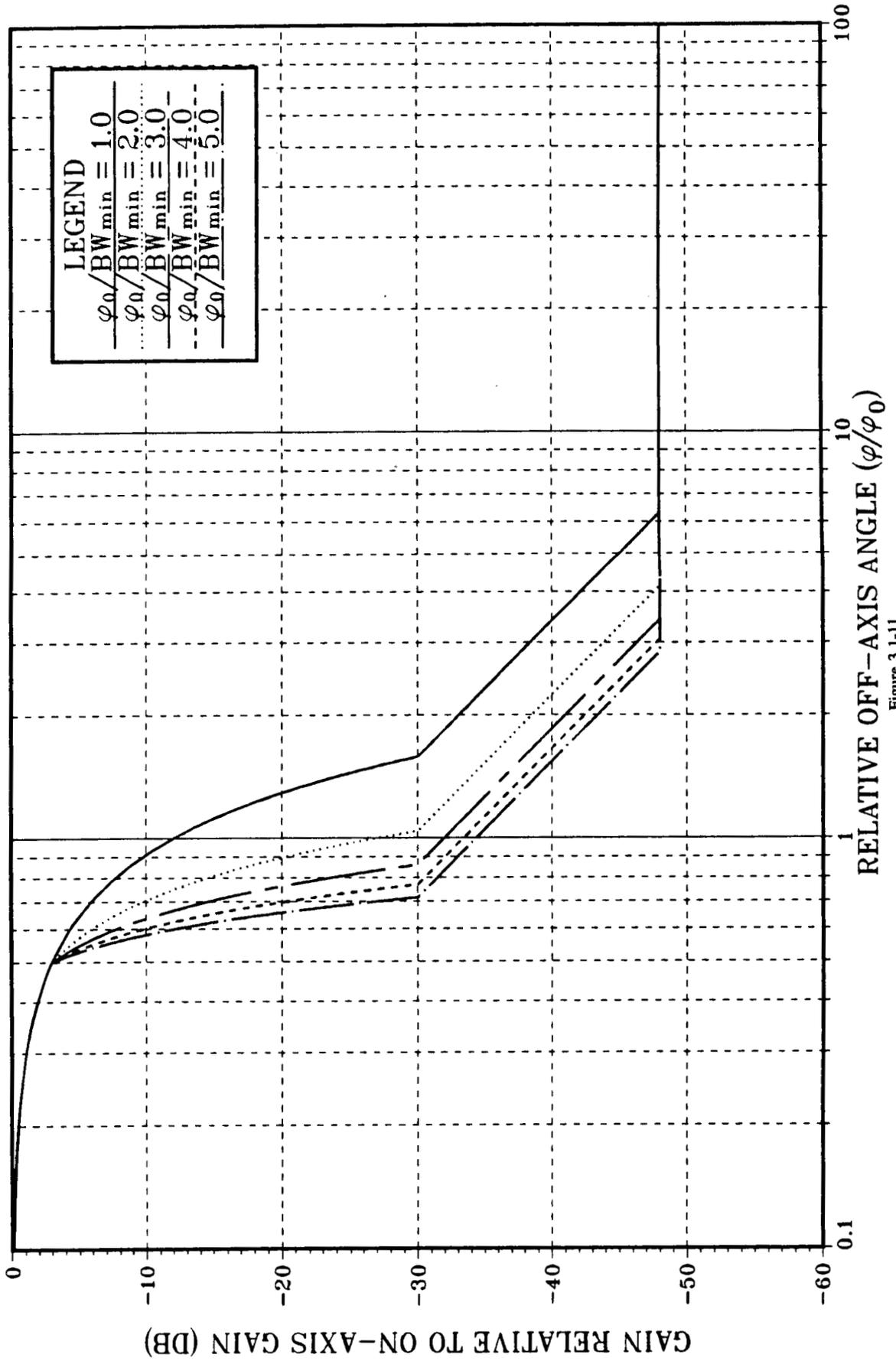


Figure 3.1-11.

# IMPROVED FAST ROLL-OFF SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB HPBW/MIN = 2.5

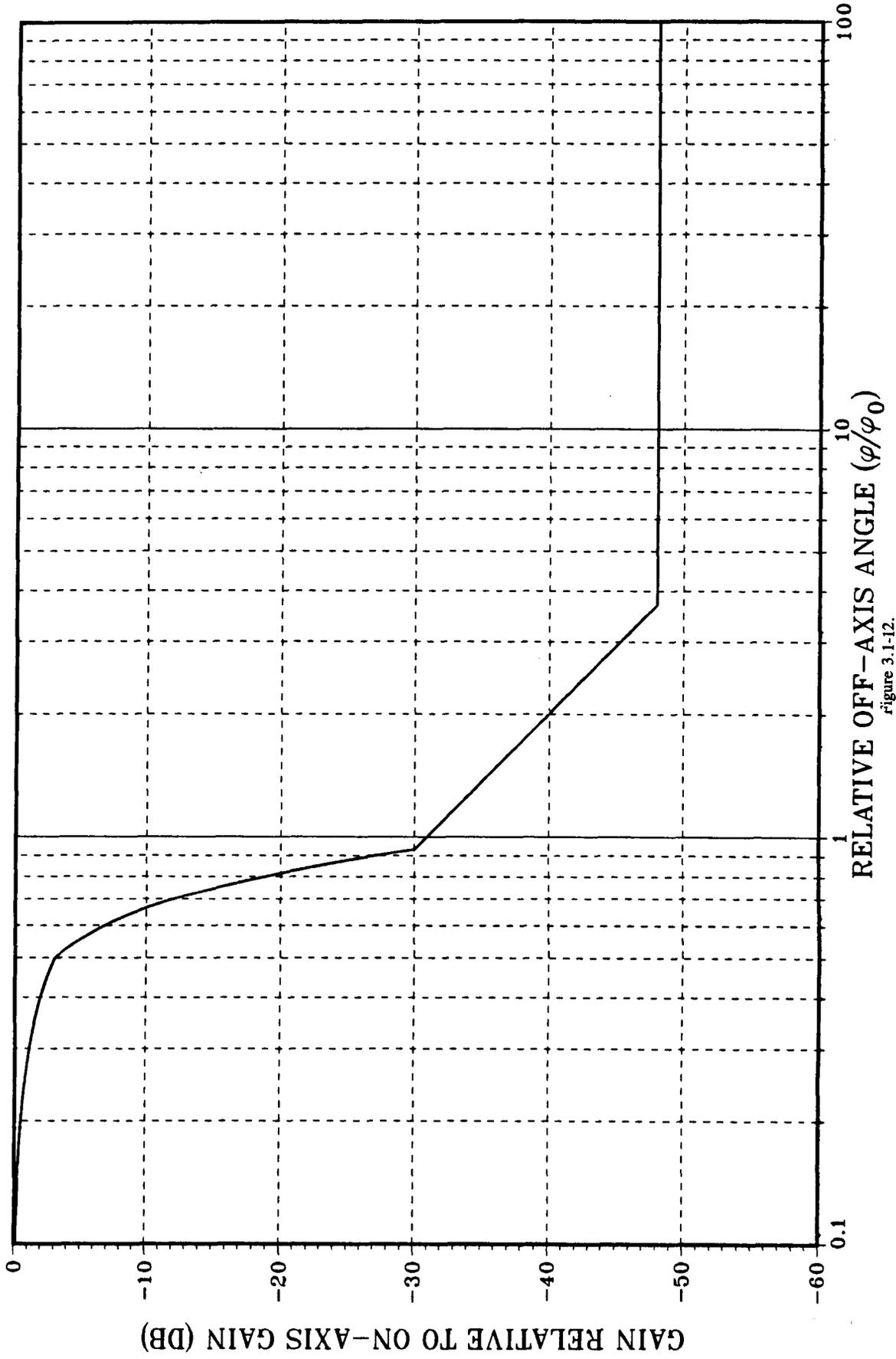


figure 3.1-12.

# ORBIT-II STANDARD SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB

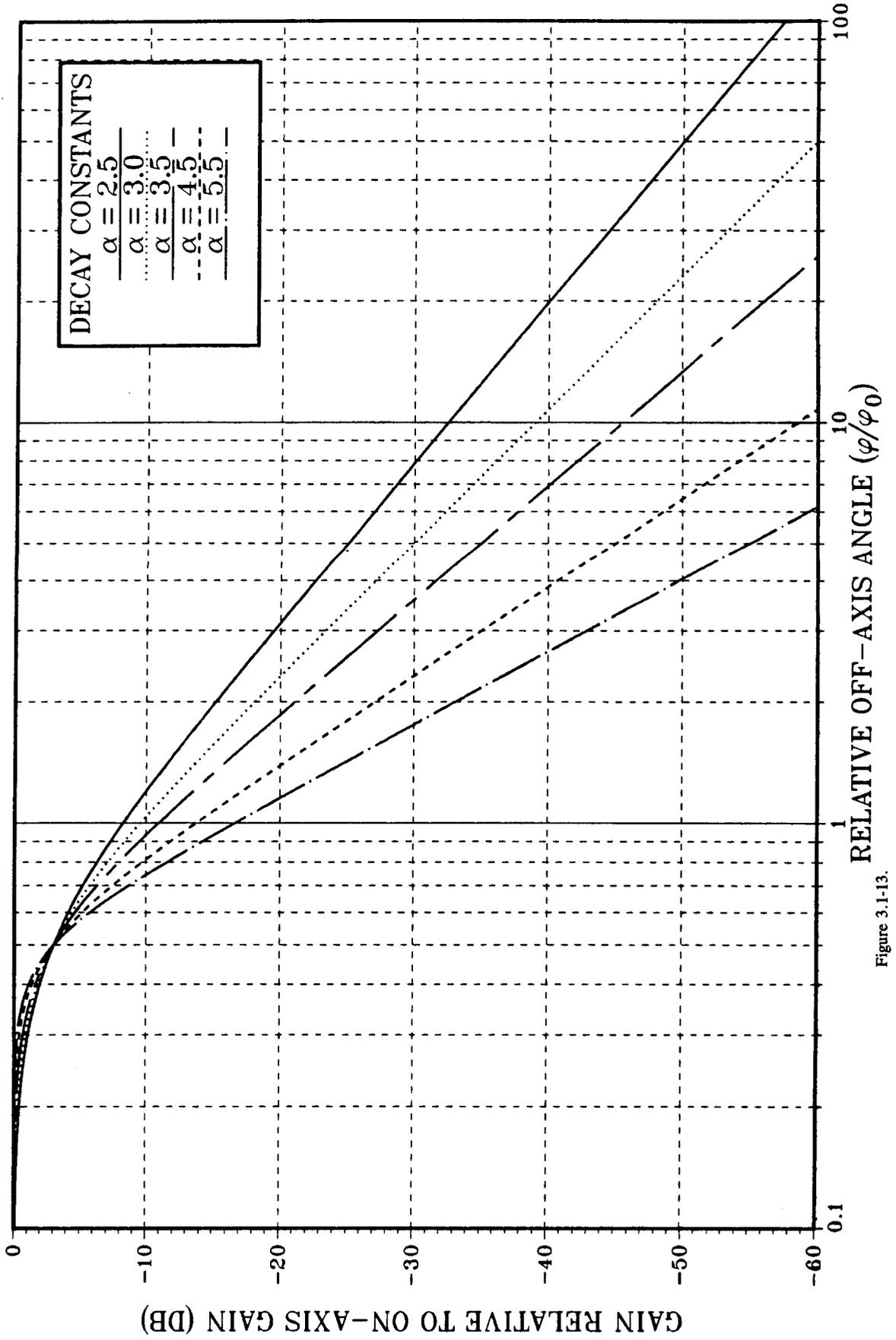


Figure 3.1-13.

# ORBIT-II SATELLITE ANTENNA PATTERN WITH FLOOR

GAIN = 38.0 DB     $\alpha = 4.0$

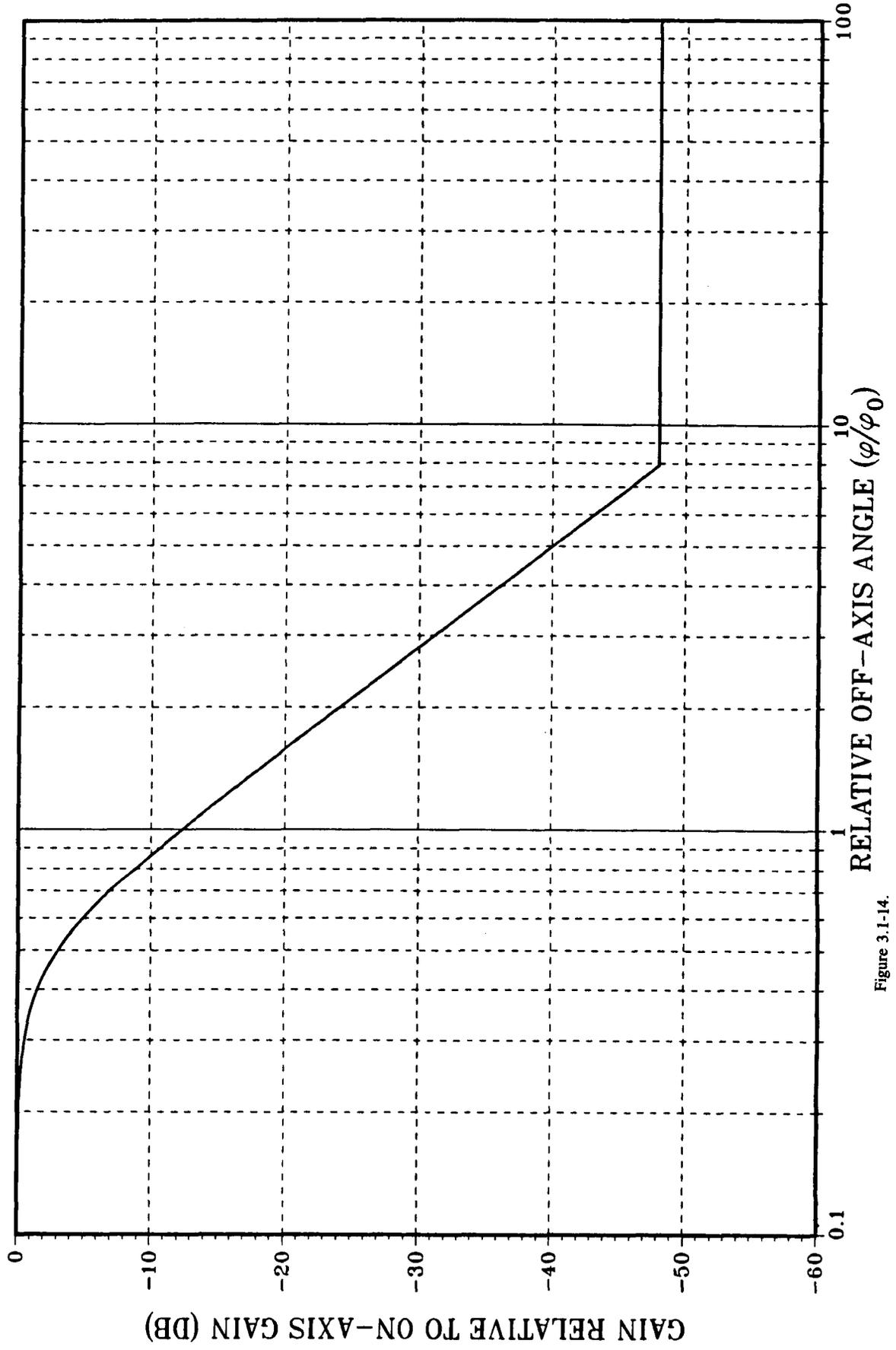


Figure 3.1-14.

# WARC 77 STANDARD ROLL-OFF SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB

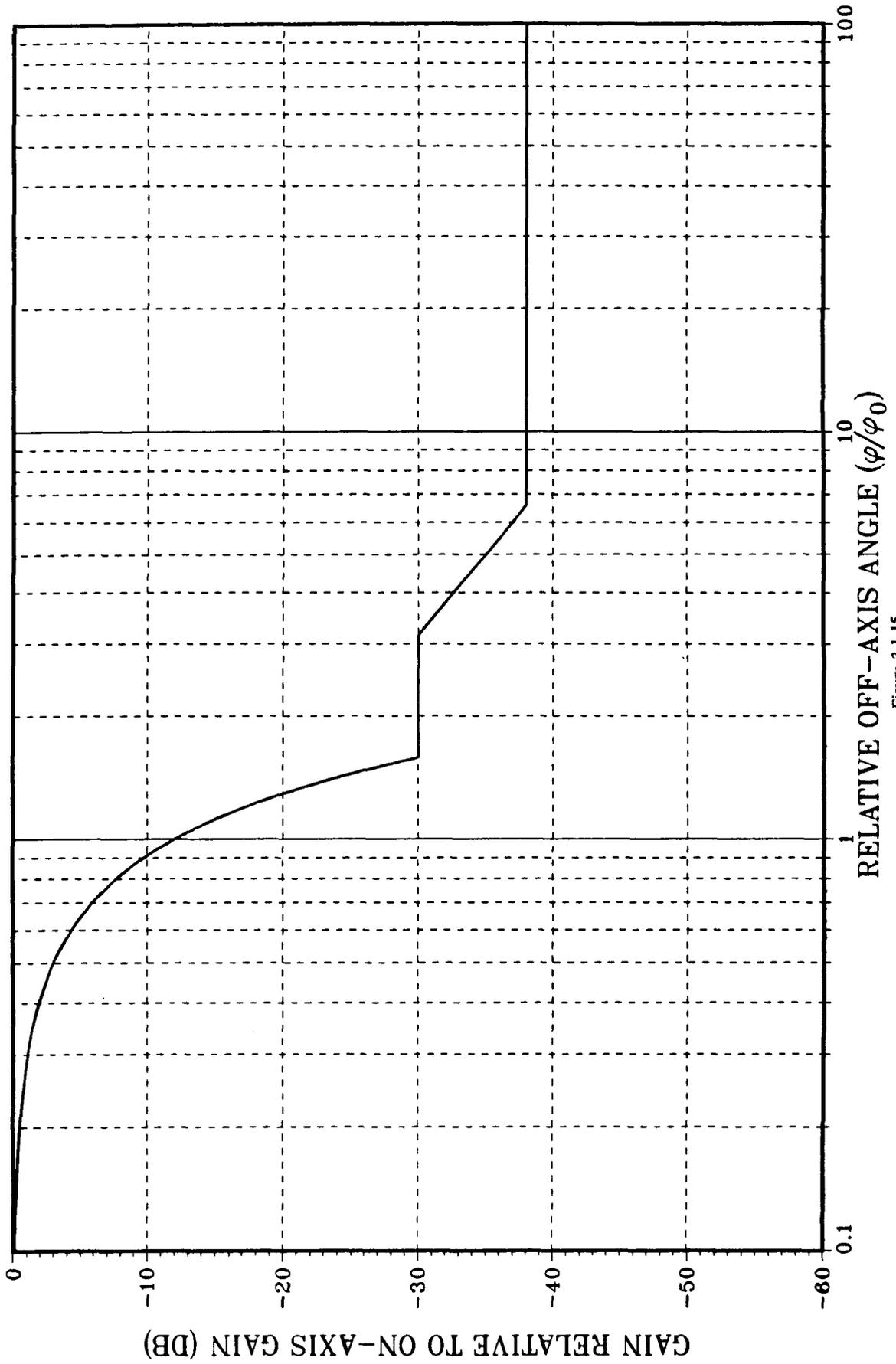


Figure 3.1-15.

# FAST ROLL-OFF SATELLITE ANTENNA FROM IWP4/1

GAIN = 38.0 DB SIDELOBE = 25.0

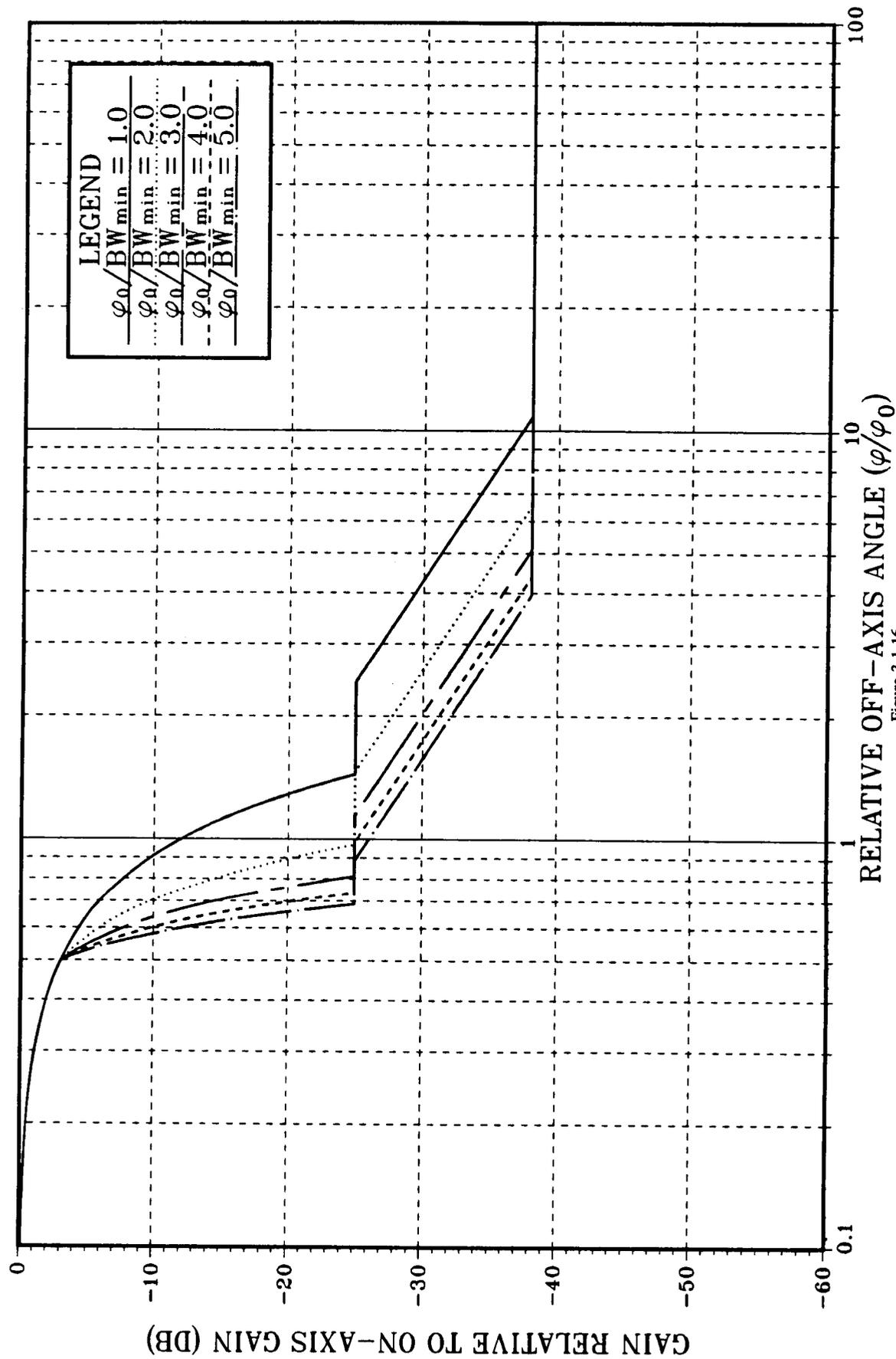


Figure 3.1-16.

# FAST ROLL-OFF SATELLITE ANTENNA FROM IWP4/1

GAIN = 38.0 DB HPBW/MIN = 2.5

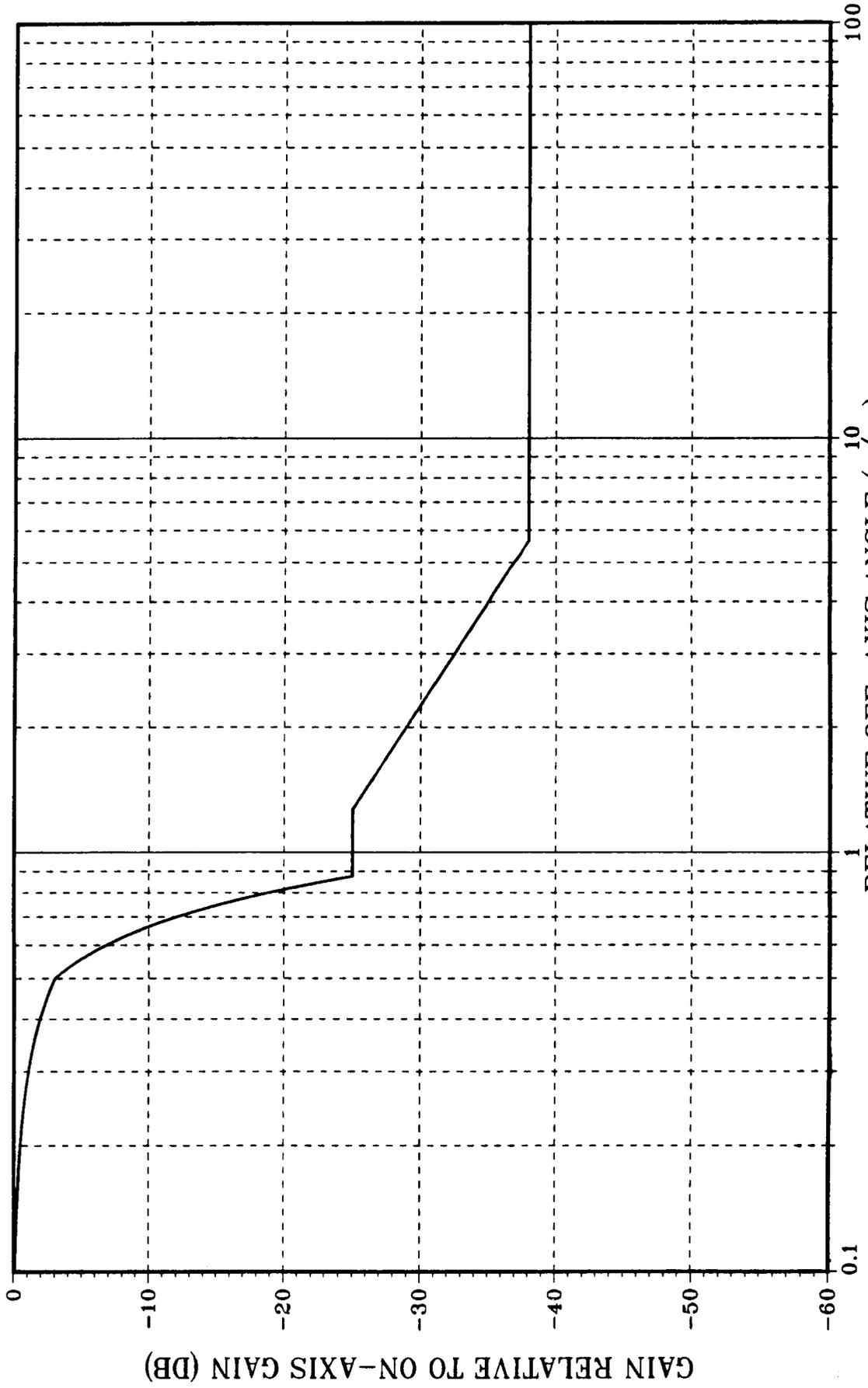


Figure 3.1-17.

# IMPROVED FAST ROLL-OFF SATELLITE ANTENNA FROM IWP4/1

GAIN = 38.0 DB F/d = 2.0

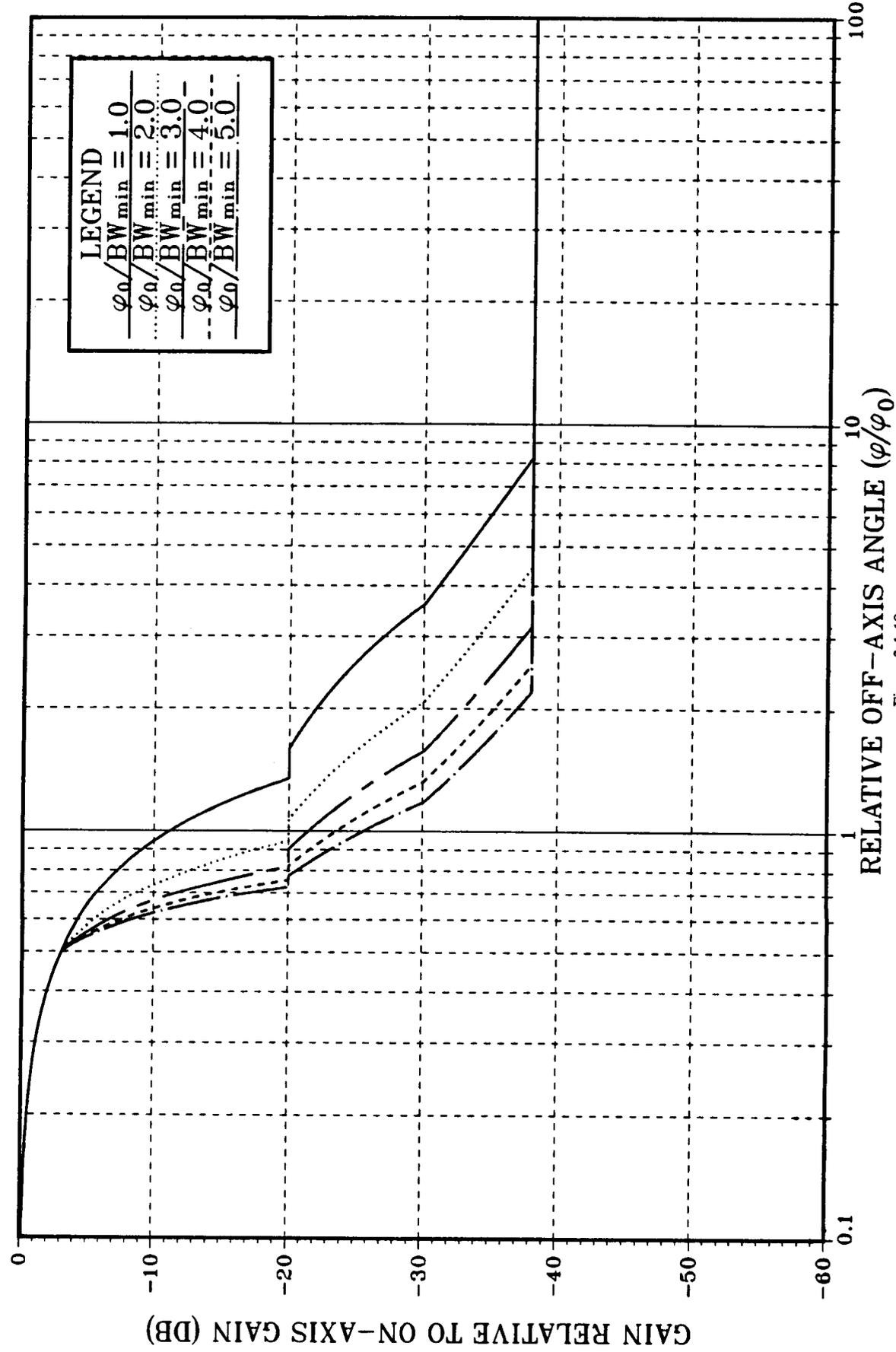


Figure 3.1-18.

# IMPROVED FAST ROLL-OFF SATELLITE ANTENNA FROM IWP4/1

GAIN = 38.0 DB HPBW/MIN = 2.5

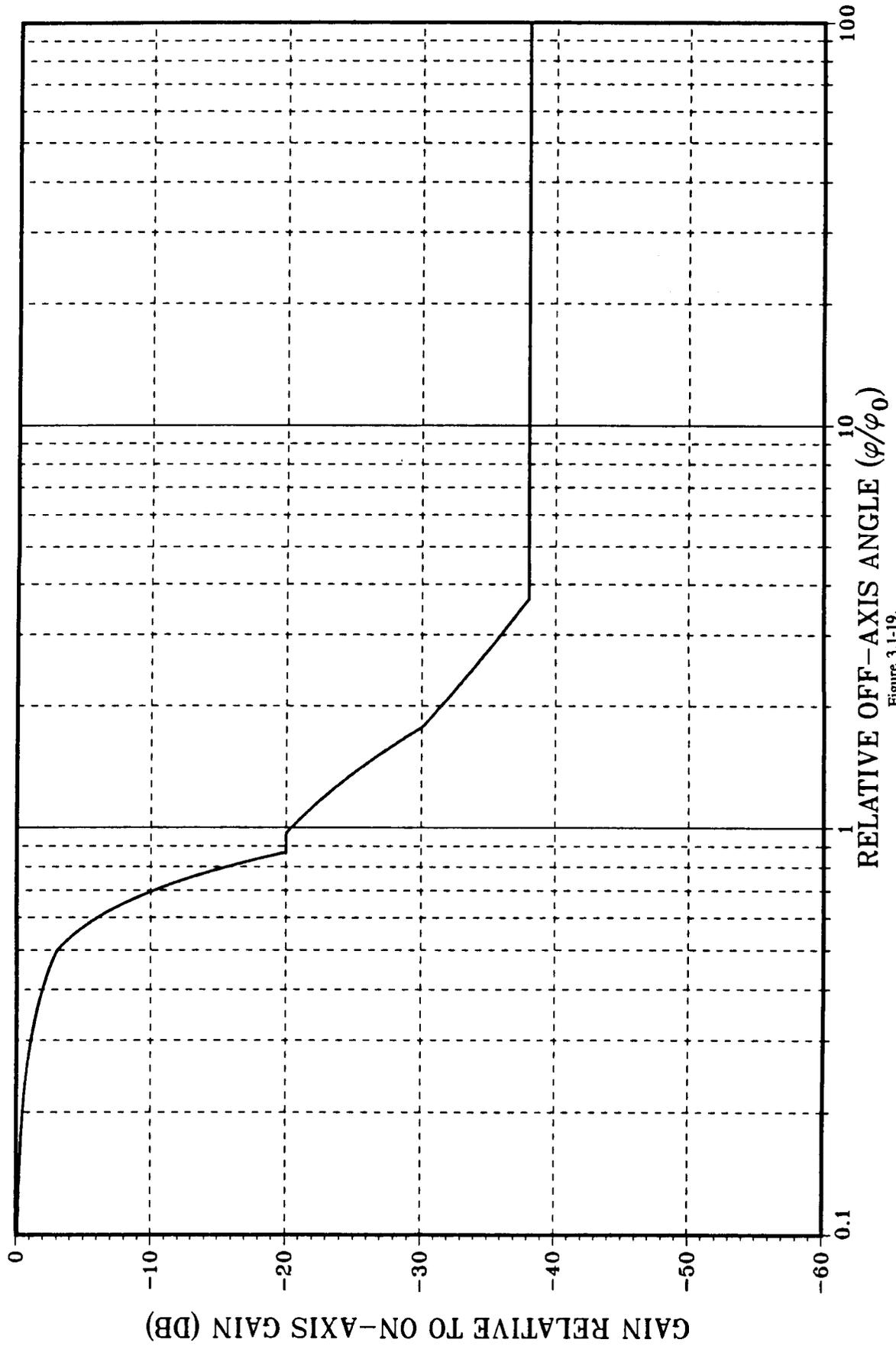


Figure 3.1-19.

last parameters having a significant effect on the total number of groupings are the antenna characteristics. Different antenna types and minimum half-power beamwidths of the space station transmit antenna can have wide ranging impact on the number of groups. The type of earth station receive antenna and the diameter also have wide ranging impact. All the antenna parameters can either be uniformly specified for all service areas through prompted inputs or can be individually specified in the Service Area file.

While the grouping criterion, target  $C/I$ , and antenna characteristics can significantly impact the number of groupings produced by NASARC1, it is not desirable to restrict these important parameters as a means of limiting the total number of groupings. It is far more preferable to utilize the piecewise approach as a means of limiting the total number of groupings to stay within computer memory limitations. The process of group arc extension employed in the NASARC piecewise approach assures continuity across segment boundaries and minimizes the impact on performance of the PDA generation process.

### 3.2 NASARC1: Grouping Program

The NASARC1 module determines all unique compatible groupings and their associated group arcs within each segment in the NASARC piecewise approach. There are four basic functions performed by NASARC1 and described in detail in the subsections which follow. First, service arcs and segment boundaries are intersected to determine feasible arc limits. Second, at each possible arc location, pairwise compatibility is determined for each pair of service areas within the current segment. Third, at each arc location, all unique compatible groups are enumerated using the pairwise compatibility information. Finally, after each arc location within the current arc segment has been processed, group arcs are determined within the current segment boundaries. The NASARC1 flowchart is given in figures 3.2-1(a) to (f) for completeness.

Before performing the basic functions stated in the previous paragraph, several preliminary operations are performed when each new segment is processed. NASARC1 retrieves the Input Data file created by NASARC0 and calculates the wavelength from the downlink frequency for later use. The Service Area scenario file is then read so that a list of service areas can be assembled. Individual antenna parameters are set to the globally specified default values from the Input Data file if not otherwise specified. If any affiliated sets of service areas are present, their codes are determined from the Affiliated Sets file. Next, if any groups have been allotted in previous segments, the individual service areas in these groups are eliminated from the list of service areas to be considered in the current segment. If any of the individual service areas of an allotted group are affiliated sets, then the appropriate member service areas are also eliminated from consideration in the current segment being examined. All these operations are to reduce the number of service areas which need to be processed at one time by NASARC1; this is one of the major goals of the piecewise approach. In this manner, software execution times and storage requirements can be kept to a reasonable level.

#### 3.2.1 Intersection of Arcs

Before any calculations to determine compatibility are performed, it is necessary to determine exactly where in the current arc segment any given pair of service areas has the potential to be compatible. This is done by first intersecting the service arcs with the current segment boundaries. The service arc boundaries are then adjusted to lie within the segment limits for processing in this segment. Any service areas whose service arcs do not intersect the current segment are eliminated from the list of service areas for consideration in this segment. Similarly, affiliated set members of like affiliated sets are examined to determine if all of the members' individual service arcs intersect the current segment. If any of the members' individual arcs do not intersect the segment, all the member service areas are eliminated from consideration in this segment. If all of the members' individual service arcs do intersect the segment for a given affiliated set, the total intersection of these individual service arcs within the segment is found and all the members' service arc boundaries are adjusted to these total intersection boundaries. This is done so that the individual members can be treated as a set in the compatibility determination procedure.

# NASARC1 -- The Grouping Program

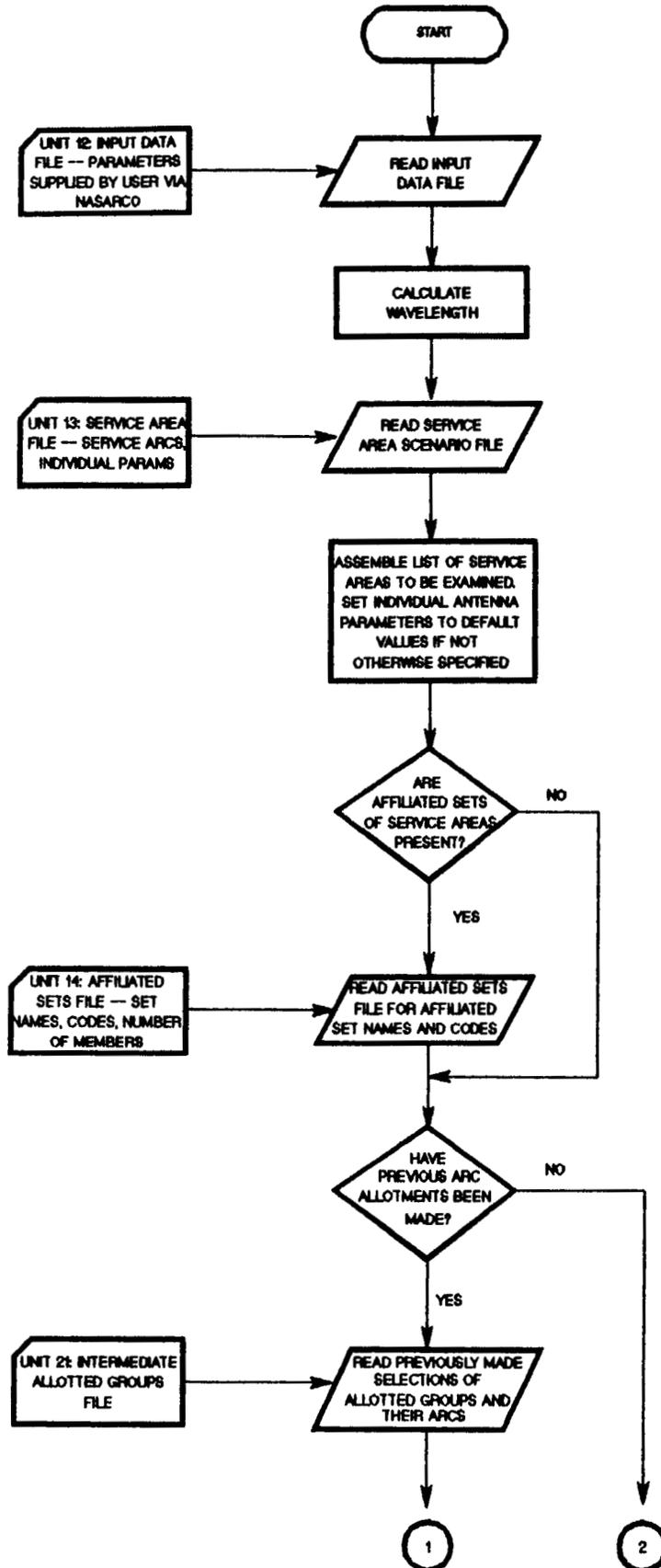


Figure 3.2-1(a).

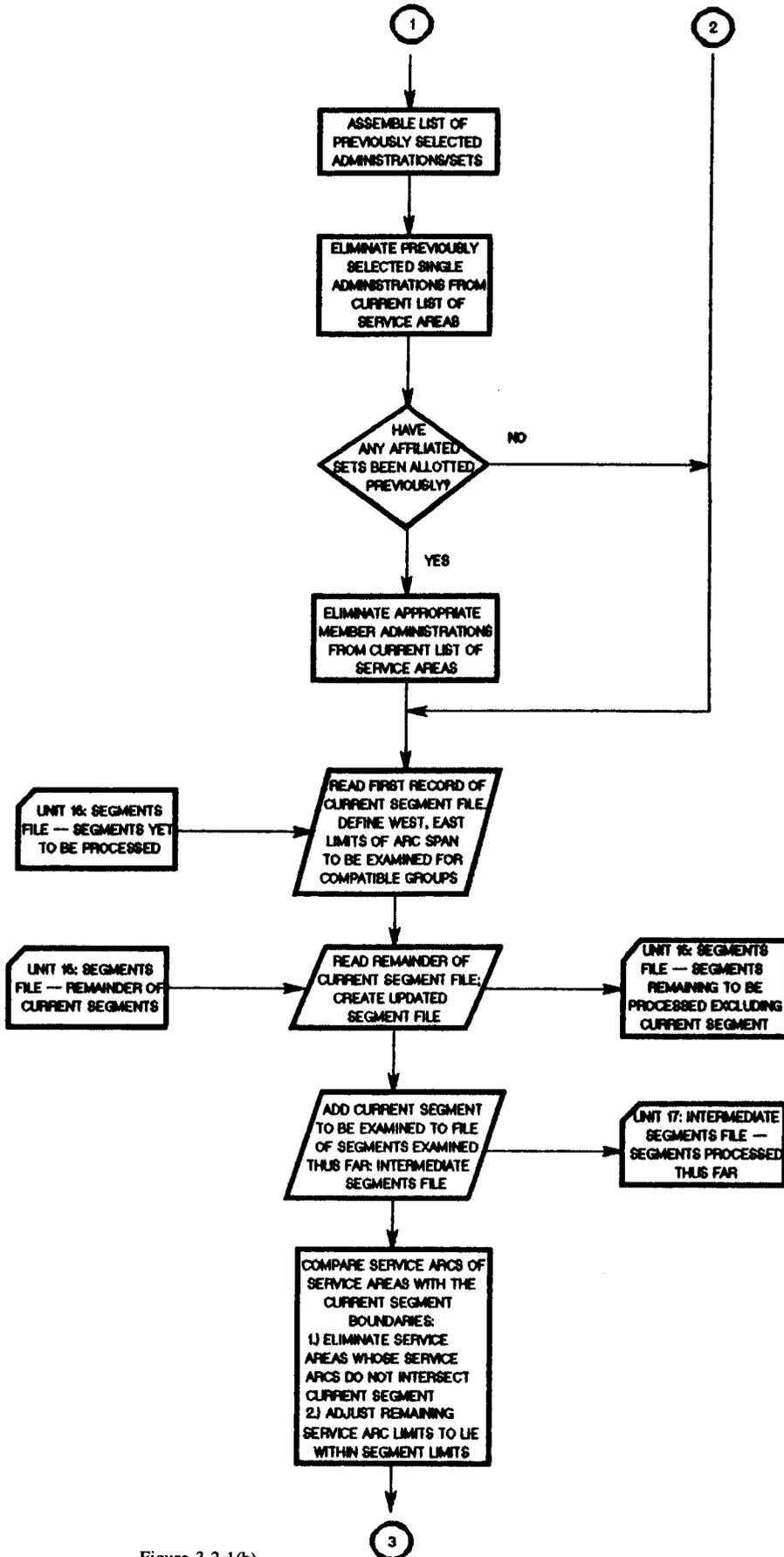


Figure 3.2-1(b).

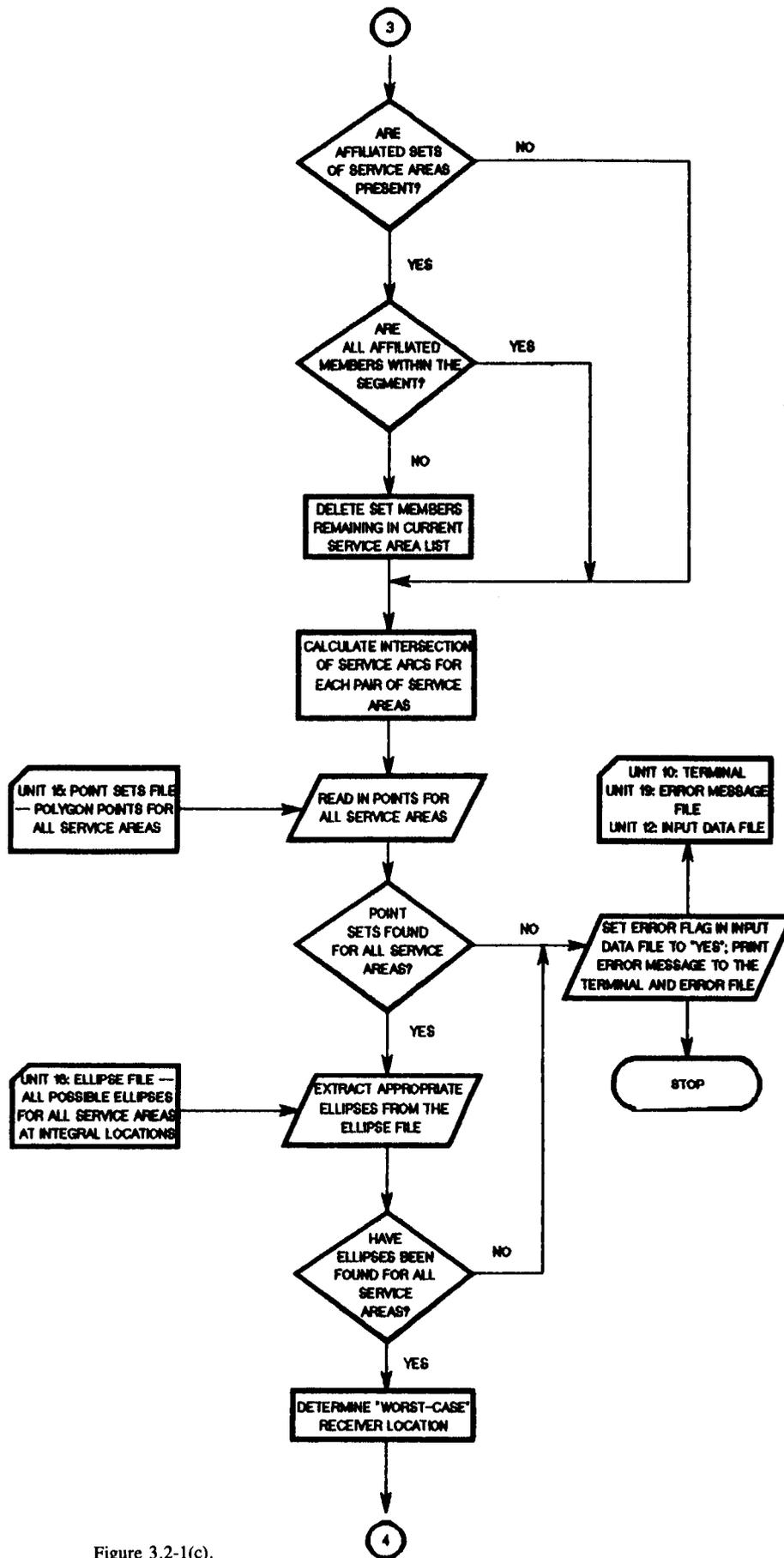


Figure 3.2-1(c).

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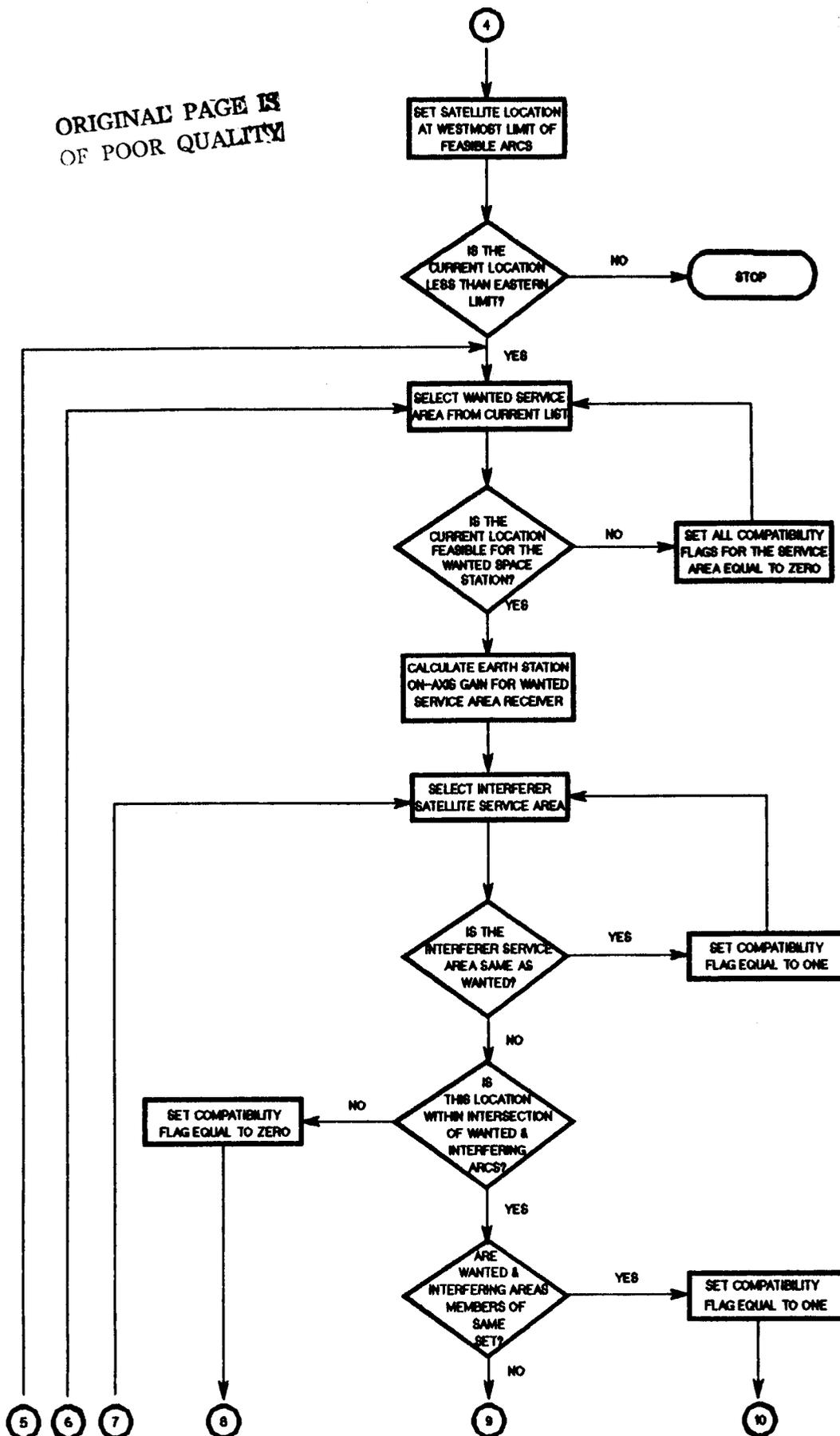


Figure 3.2-1(d).

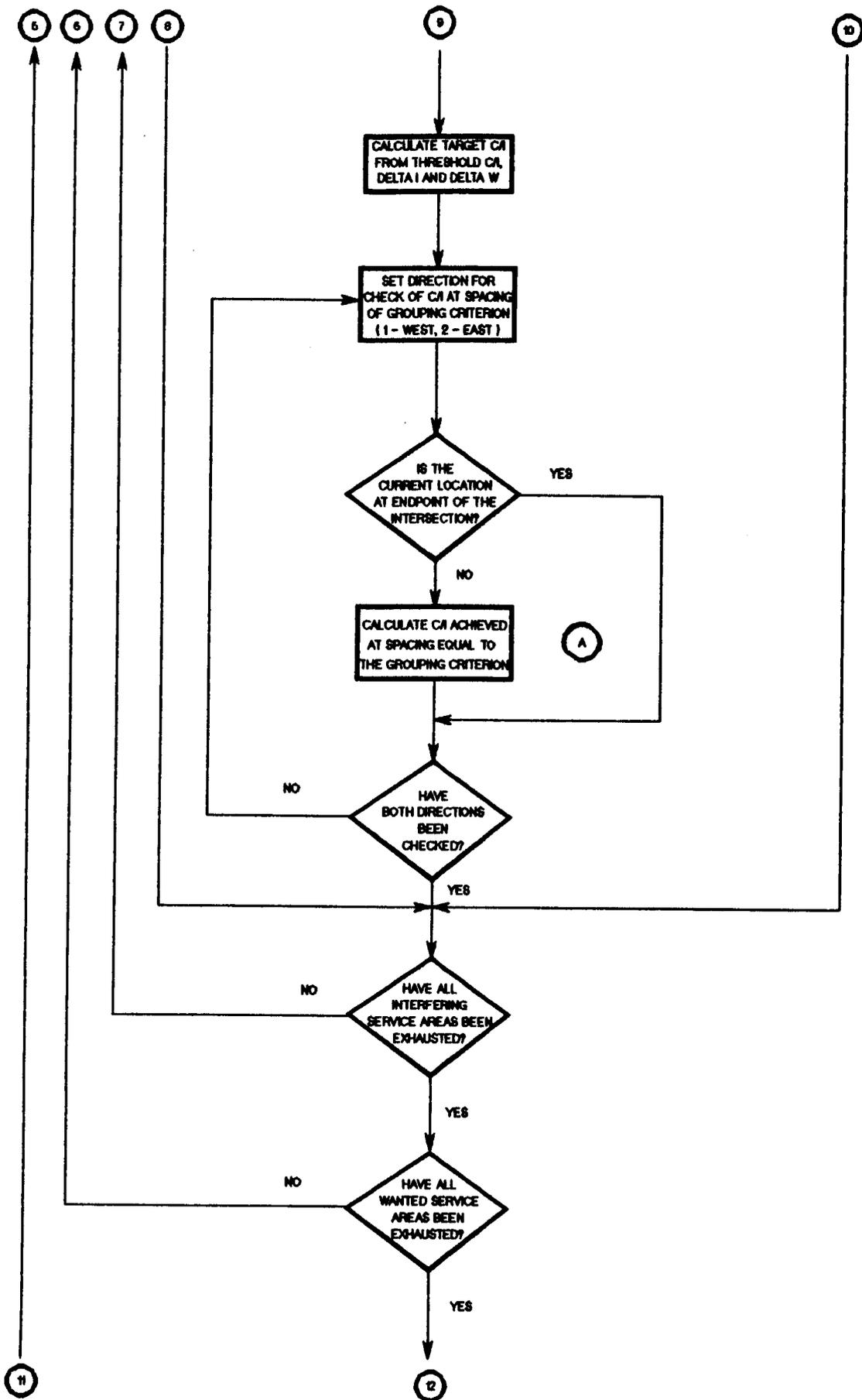


Figure 3.2-1(e).

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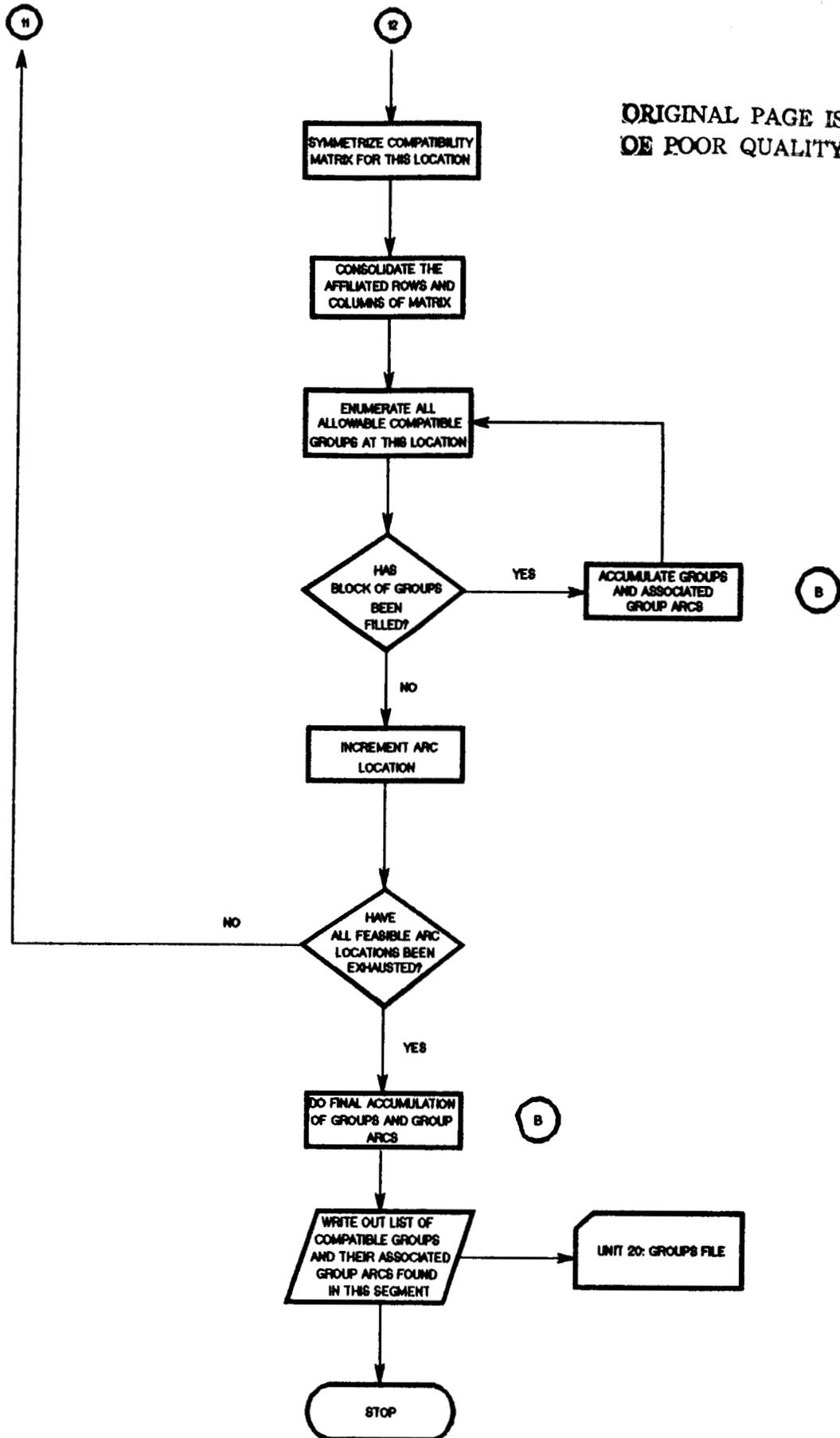


Figure 3.2-1(f).

The next step is to find the intersections of the adjusted service arcs for each pair of service areas being considered in the current segment. If the two arcs in question do not intersect within the segment, their pairwise compatibility will not be examined since they cannot be compatible at any arc locations within the current segment. Starting with the western boundary of the segment, the grouping program performs calculations to determine pairwise compatibility and enumerates groups of compatible service areas at this arc location. The arc location is then incremented and the process is repeated until all possible arc locations within the current segment limits have been exhausted. A detailed description of calculations taking place at each arc location for each pair of wanted and interfering service areas is given in subsequent subsections. If the arc location being examined does not fall within the arc intersection of a given pair of service areas, that pair is considered to be incompatible at that arc location and no calculations are necessary.

### 3.2.2 Pairwise Compatibility Matrix

A pairwise compatibility matrix is determined at each discrete arc location starting with the western boundary of the current segment. Each entry represents the compatibility between two satellites serving a pair of service areas where the satellite regarded as the wanted satellite is represented by the row index and the satellite regarded by the interferer satellite is represented by the column index. Due to differences in the geographical extent of the service areas corresponding to the satellites, the beam coverage sizes will be different in general and in some cases they will be vastly different. This means that the required orbital separation between a pair of satellites when one is seen as the wanted and the other is regarded as the interferer probably will not be the same as the separation required when the roles of the two satellites are reversed. In terms of pairwise compatibility, this means that a satellite corresponding to the wanted service area may be compatible with the satellite corresponding to the interferer service area; but, when the roles are reversed, they might not be compatible. Therefore, in many cases the pairwise compatibility matrix will be nonsymmetric.

This nonsymmetric matrix must be symmetrized for the enumeration of compatible groupings. Each entry of the pairwise compatibility matrix corresponding to a (row, column) index is compared to its corresponding entry, that is, that with the row and column indices transposed. The pairwise compatibility matrix is a matrix of 1's and 0's, with 1 representing compatibility and 0 noncompatibility. If either of the corresponding entries is 0, then the two service areas in question are not mutually compatible and 0's are placed in both of these corresponding positions. This process is applied to the entire matrix, the result being a symmetric compatibility matrix at each arc location within the current segment.

If any affiliated sets are present in the current segment, the compatibility between members of like groups is not explicitly determined. Rather, group members are assumed to be compatible with each other within the group. Because of this assumption, corresponding entries between members will be equal to 1. After the matrix has been symmetrized, the rows and columns corresponding to each affiliated set are consolidated into a single row and column in the compatibility matrix associated with the affiliated set code for each set. Thus, in enumerating groupings at each arc location, each affiliated set is treated as a single service area. That is, when examining compatibility with other service areas outside of the affiliated set, the individual service areas making up the affiliated set must each be compatible with the other nonaffiliated service areas for the affiliated set as a whole to be compatible with those service areas.

#### 3.2.2.1 Determination of *Worst-Case* Polygon Point

Before determining the pairwise compatibility for each pair of service areas at a given arc location, it is necessary to determine the *wanted* receiver location closest to the *interferer* service area. This location is the so-called *worst-case* point. The procedure is done for all available polygon points which define the service areas in question, as found in the Point Sets file. To avoid finding this point every time the wanted or interfering location in the orbital arc changes, the point selection process is done only once for each pair of service areas.

The following is a description of the algorithm which selects the closest polygon point (of the wanted service area) to the center of the interfering service area. First, the midpoint of the arc intersection interval between the two service areas must be found. This is accomplished in two simple steps. First,

$$M = \frac{E - W}{2} \quad (3.2-1)$$

where

- $M$  relative adjustment factor to find the midpoint, deg longitude
- $W$  western boundary of arc intersection, deg longitude
- $E$  eastern boundary of arc intersection, deg longitude

If the intersection of the two service arcs and the current segment boundaries crosses the 180° longitude, the eastern boundary of the arc intersection is adjusted to be numerically greater than the western boundary.

Next, the central location of the arc intersection is found from

$$C = W + M \quad (3.2-2)$$

where  $C$  is the central location of the arc intersection between the two service areas (deg longitude).

To determine the point in the wanted service area which is closest to the *center* of the interfering service area, thereby being the point which receives the greatest amount of interference, the angular distance between the center and the wanted service area point, as seen from a satellite at the central location determined in equation (3.2-2), is found over all wanted service area polygon points. The point which produces the shortest such distance is judged to be the *closest* or *worst-case* polygon point for the service area in question. For any polygon point in the wanted service area we have the following:

$$N = R^2 - R[\cos \theta_w \cos (C - \varphi_w) + \cos \theta_c \cos (C - \varphi_c)] + \cos \theta_w \cos \theta_c \cos (\varphi_w - \varphi_c) + \sin \theta_w \sin \theta_c \quad (3.2-3)$$

$$D = [R^2 - 2R \cos \theta_w \cos (C - \varphi_w) + 1]^{1/2} \times [R^2 - 2R \cos \theta_c \cos (C - \varphi_c) + 1]^{1/2} \quad (3.2-4)$$

$$\gamma_{\text{dist}} = \cos^{-1} (N/D) \quad (3.2-5)$$

where

- $R$  radius of geostationary orbit in terms of earth radii, 6.6105
- $C$  defined by eq. (3.2-2)
- $\theta_c$  latitude of interfering service area minimum area ellipse boresight as seen from central location of arc intersection between two service areas, deg
- $\varphi_c$  longitude of interfering service area minimum area ellipse boresight as seen from central location of arc intersection between two service areas, deg
- $\theta_w$  latitude of polygon point in wanted service area, deg
- $\varphi_w$  longitude of polygon point in wanted service area, deg
- $\gamma_{\text{dist}}$  angular distance between polygon point being considered and center of interfering service area, deg

The point which produces the minimal angular distance is considered the worst-case polygon point.

### 3.2.2.2 Calculation of Antenna On-Axis Gain

The earth station and spacecraft antenna characteristics can be individually specified in the Service Area file. For this reason, the following calculations are performed for the parameters related to each service area. The antenna characteristics are expressed in terms of falloff from the on-axis gain of each antenna. It is due to this fact that we need to calculate the earth station and spacecraft antenna on-axis gains. The on-axis gain is utilized to determine the falloff *floor* of the antenna characteristics and it is also used in some of the falloff equations themselves for certain antenna types. Since the wavelength is not read in directly, it is calculated in the Grouping Program from the frequency, which is input by the user. Thus, the wavelength is given by

$$\lambda = c/f \quad (3.2-6)$$

where

- $\lambda$  wavelength of transmission, m
- $c$  speed of light in a vacuum,  $2.997925 \times 10^8$  m/sec
- $f$  transmission frequency, Hz

After the wavelength is calculated, HPBW is computed for the earth station as

$$\varphi_{oES} = \frac{223\lambda}{180d} \quad (3.2-7)$$

where

- $\varphi_{oES}$  earth station HPBW, radians
- $d$  earth station antenna diameter, m

Then, the earth station on-axis gain can be calculated:

$$GOA_{ES} = \eta_{ES} \left( \frac{223\pi}{180\varphi_{oES}} \right)^2 \quad (3.2-8)$$

where

- $GOA_{ES}$  earth station on-axis gain (numeric)
- $\eta_{ES}$  earth station antenna efficiency

The spacecraft on-axis gain depends partially on the ellipse parameters which will vary with satellite location. Thus, the gain is calculated whenever the satellite location changes using the ellipse parameters which are contained in the ellipse input file. Satellite antenna on-axis gain is computed from

$$GOA_{SC} = \eta_{SC} \left( \frac{223\pi}{180a} \right)^2 \frac{a}{b} \quad (3.2-9)$$

where

- $GOA_{SC}$  spacecraft on-axis gain (numeric)
- $\eta_{SC}$  spacecraft antenna efficiency
- $a$  major axis of coverage ellipse, radians
- $b$  minor axis of coverage ellipse, radians

### 3.2.2.3 Calculation of Antenna Off-Axis Angles

To determine the discrimination achieved by either the receiving earth station or the interfering satellite antennas, we first need to calculate the actual off-axis angles which are needed in the falloff equations. The interfering satellite antenna off-axis angle depends primarily on the angular separation between the interfering satellite's service area and the receiving earth station in question, as well as the location of the interfering satellite. The following equations give the interfering satellite off-axis angle using a three-dimensional earth-centered coordinate system:

$$N = R^2 - R [\cos \theta_R \cos (\varphi_I - \varphi_R) + \cos \theta_B \cos (\varphi_I - \varphi_B)] + \cos \theta_R \cos \theta_B \cos (\varphi_R - \varphi_B) + \sin \theta_R \sin \theta_B \quad (3.2-10)$$

$$D = [R^2 - 2R \cos \theta_R \cos (\varphi_I - \varphi_R) + 1]^{1/2} \times [R^2 - 2R \cos \theta_B \cos (\varphi_I - \varphi_B) + 1]^{1/2} \quad (3.2-11)$$

$$\varphi_{SC} = \cos^{-1} (N/D) \quad (3.2-12)$$

where

- $\theta_R$  receiving earth station polygon point latitude, deg
- $\varphi_R$  receiving earth station polygon point longitude, deg
- $\theta_B$  interfering satellite boresight latitude, deg
- $\varphi_B$  interfering satellite boresight longitude, deg
- $R$  radius of geostationary orbit in earth radii, 6.6105
- $\varphi_I$  interfering satellite longitude, deg
- $\varphi_{SC}$  interfering satellite off-axis angle, deg

The earth station antenna off-axis angle depends on the latitude and longitude of the receiving earth station in question and it also depends on the geocentric angular separation between the wanted and interfering satellites. Similar to the off-axis calculation for the spacecraft antenna, the equations for the earth station off-axis angle are

$$N = R^2 \cos (\varphi_W - \varphi_I) - R \cos \theta_R [\cos (\varphi_W - \varphi_R) + \cos (\varphi_I - \varphi_R)] + 1 \quad (3.2-13)$$

$$D = [R^2 - 2R \cos \theta_R \cos (\varphi_I - \varphi_R) + 1]^{1/2} \times [R^2 - 2R \cos \theta_R \cos (\varphi_I - \varphi_R) + 1]^{1/2} \quad (3.2-14)$$

$$\varphi_{ES} = \cos^{-1} (N/D) \quad (3.2-15)$$

where

- $\varphi_W$  wanted satellite longitude, deg
- $\varphi_{ES}$  earth station off-axis angle, deg

The off-axis angles are then used with the half-power beamwidths to calculate the relative off-axis angles and then the falloff from the given antenna. The beamwidth required for the earth station is simply the HPBW which was calculated to obtain the earth station on-axis gain. For the satellite, we need to calculate the beamwidth in the direction of interest as seen from the interfering satellite.

### 3.2.2.4 Half-Power Beamwidth in Direction of Interest

The half-power beamwidth in the direction of interest as seen from the interfering satellite is required in determining the spacecraft relative off-axis angle. These angles are shown in figure 3.2-2. This quantity is, in turn, needed to find the amount of discrimination achieved at the receiving earth station in the wanted service area from the interfering satellite antenna. The beamwidth in question depends on the ellipse parameters which will vary from satellite location to location.

Therefore, this calculation will take place many times for changing satellite locations. In the following equations, several intermediate angles are calculated. Unless otherwise stated,  $B$  will denote the interfering satellite boresight,  $I$  the interfering satellite itself, and  $R$  the wanted receiver. Intermediate angles are calculated as follows:

$$\alpha_B = \tan^{-1} \left[ \frac{\sqrt{1 - \cos^2 \theta_B \cos^2 (\varphi_B - \varphi_I)}}{R - \cos \theta_B \cos (\varphi_B - \varphi_I)} \right] \quad (3.2-16)$$

$$\beta_B = \tan^{-1} \left[ \frac{\sin \theta_B}{\cos \theta_B \sin (\varphi_B - \varphi_I)} \right] \quad (3.2-17)$$

$$\alpha_R = \tan^{-1} \left[ \frac{\sqrt{1 - \cos^2 \theta_R \cos^2 (\varphi_R - \varphi_I)}}{R - \cos \theta_R \cos (\varphi_R - \varphi_I)} \right] \quad (3.2-18)$$

$$\beta_R = \tan^{-1} \left[ \frac{\sin \theta_R}{\cos \theta_R \sin (\varphi_R - \varphi_I)} \right] \quad (3.2-19)$$

where  $R$ ,  $\theta_B$ ,  $\varphi_B$ ,  $\theta_R$ ,  $\varphi_R$ ,  $\varphi_I$  are as defined in section 3.2.2.3 while  $\alpha$  and  $\beta$  with the appropriate subscripts are various intermediate angles.

Next, it is necessary to find the intermediate angles associated with the interfering satellites. These angles are obtained as follows:

$$\alpha_I^2 = \alpha_B^2 + \alpha_R^2 - 2\alpha_B\alpha_R \cos (\beta_B - \beta_R) \quad (3.2-20)$$

If  $(\beta_R - \beta_B) \geq 0$ , then

$$\beta_I = \beta_R + \cos^{-1} \left( \frac{\alpha_I^2 + \alpha_R^2 - \alpha_B^2}{2\alpha_I\alpha_R} \right) \quad (3.2-21)$$

If  $(\beta_R - \beta_B) < 0$ , then

$$\beta_I = \beta_R - \cos^{-1} \left( \frac{\alpha_I^2 + \alpha_R^2 - \alpha_B^2}{2\alpha_I\alpha_R} \right) \quad (3.2-22)$$

Finally, we can calculate the half-power beamwidth of the interfering satellite antenna in the direction of interest (i.e., the half-power beamwidth in the direction from the boresight of the service area corresponding to the satellite at the current interfering location to the wanted receiver). This is given by

$$\varphi_o = 0.25 \left[ \frac{\cos^2 (\beta_I - \omega)}{a^2} + \frac{\sin^2 (\beta_I - \omega)}{b^2} \right]^{-1} \quad (3.2-23)$$

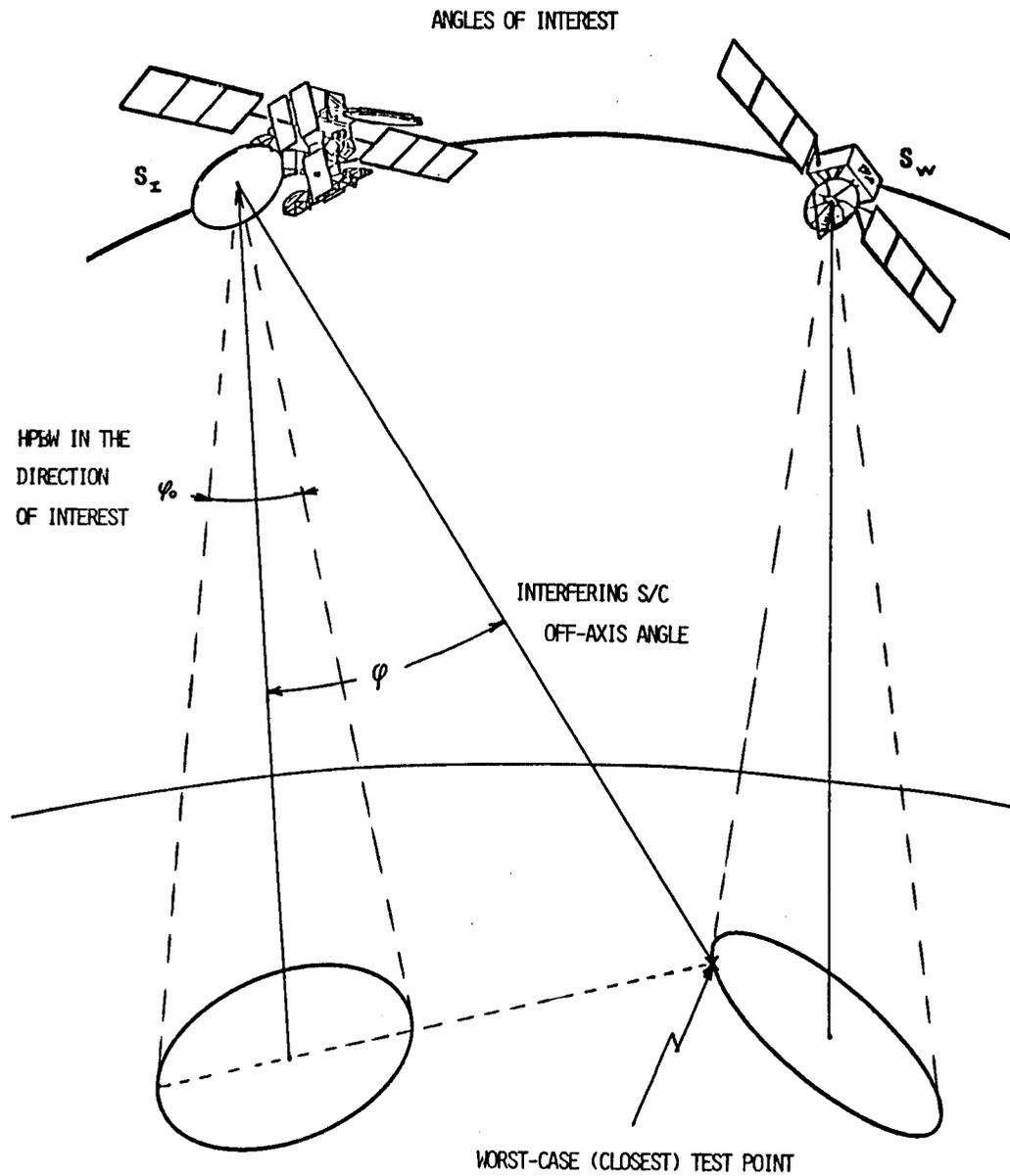


Figure 3.2-2.

where

- $\varphi_o$  beamwidth in direction of interest
- $\omega$  orientation angle of *interfering* coverage ellipse defined from *horizontal* (i.e., counterclockwise from equator)
- $a$  ellipse major axis
- $b$  ellipse minor axis

### 3.2.2.5 Determination of Pairwise Compatibility

The determination of pairwise compatibility between a pair service areas is done at each arc location within the current segment where the two service arcs intersect. This compatibility is determined for each feasible pair of wanted and interfering service areas by verifying that sufficient space station separation is achieved at an orbital spacing equal to the grouping criterion. First, the wanted satellite location is set equal to the current feasible arc location under consideration. The interfering satellite is placed at a spacing equal to the grouping criterion to the west of the wanted satellite location. The interfering satellite antenna on-axis gain is calculated for use in the antenna falloff equations as described earlier in section 3.2.2.2. Next, the interfering space station off-axis angle to the nearest polygon point of the wanted service area is determined as given in section 3.2.2.3. The interfering satellite's half-power beamwidth in the direction of the nearest polygon point of the wanted service area is evaluated as described in section 3.2.2.4. With the ratio of the satellite off-axis angle to HPBW in the direction of interest (i.e., the relative off-axis angle) and the satellite on-axis gain, the interfering satellite antenna discrimination is determined utilizing the appropriate falloff equations for the satellite antenna in question. After the earth station antenna off-axis angle is found as describes in section 3.2.2.3, the ratio of the off-axis angle to the earth station HPBW is calculated. The wanted earth station antenna discrimination is found by using this relative off-axis angle and the proper earth station antenna falloff equations.

The total discrimination on the downlink is the sum of the interfering satellite antenna discrimination and the wanted earth station antenna discrimination. This total discrimination is actually the single-entry *C/I* ratio achieved on the downlink at an orbital spacing equal to the grouping criterion for the two satellites/service areas in question, given the assumption of equal power flux density at edge of minimum area coverage ellipse. Any inhomogeneities are taken into account in the target *C/I* value for this pair of service areas as described in section 3.1.1.2.3. Therefore, to determine compatibility for the case in question, the total discrimination achieved on the downlink is compared with the calculated target single-entry *C/I* ratio. If the total achieved downlink discrimination meets or exceeds this target value, the pair of wanted and interfering service areas are compatible in this direction. Recall that the target single-entry *C/I* ratio may be different for each pair of wanted and interfering service areas based on the inhomogeneities used in the scenario.

After this procedure is done for the case of the interfering satellite location to the west of the wanted satellite, the procedure is repeated with the interfering satellite placed to the east of the wanted satellite. The exceptions to this are when the current location for the wanted satellite is either the western or eastern endpoint of the feasible arc intersection. In these cases, the interfering satellite is not placed to the west of the western endpoint or to the east of the eastern endpoint as either would be outside of the feasible arc intersection. Thus, compatibility is only verified in one direction for these cases, while the other direction is considered compatible for comparison purposes only. If the given pair of wanted and interfering satellites/service areas are found to be compatible in both directions, a 1 is placed in the appropriate location in the pairwise compatibility matrix. Full compatibility between the pair of service areas is achieved when they are found to be compatible if either service area is the wanted and the other is the interferer as explained in section 3.2.2 on the pairwise compatibility matrix. The flowchart for this procedure is given in figure 3.2-3(a-b).

### 3.2.3 Enumeration of Compatible Groups

The compatibility matrix, as stated previously, will be a symmetric matrix. As such, it may be regarded as a collection of rows (or columns), one for each service area, which express the compatibility between each service

# Verification of Sufficient Space Station Separation at Grouping Criterion

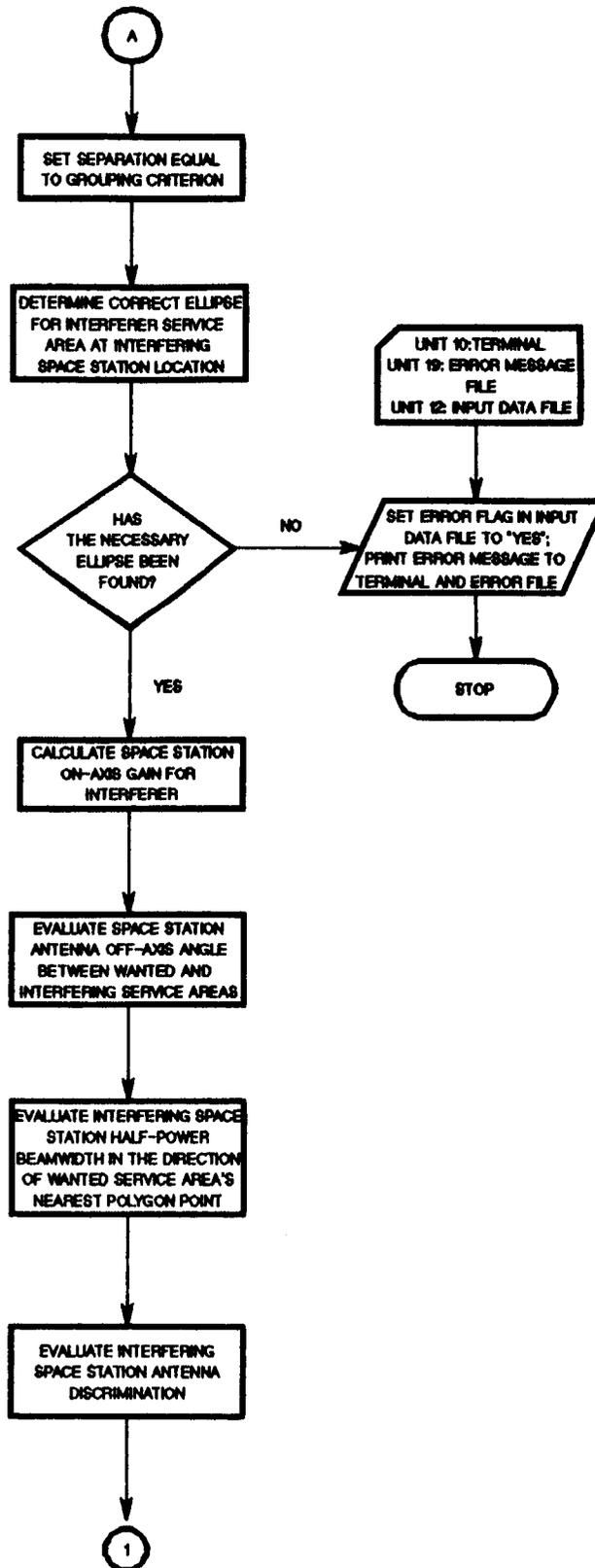


Figure 3.2-3(a).

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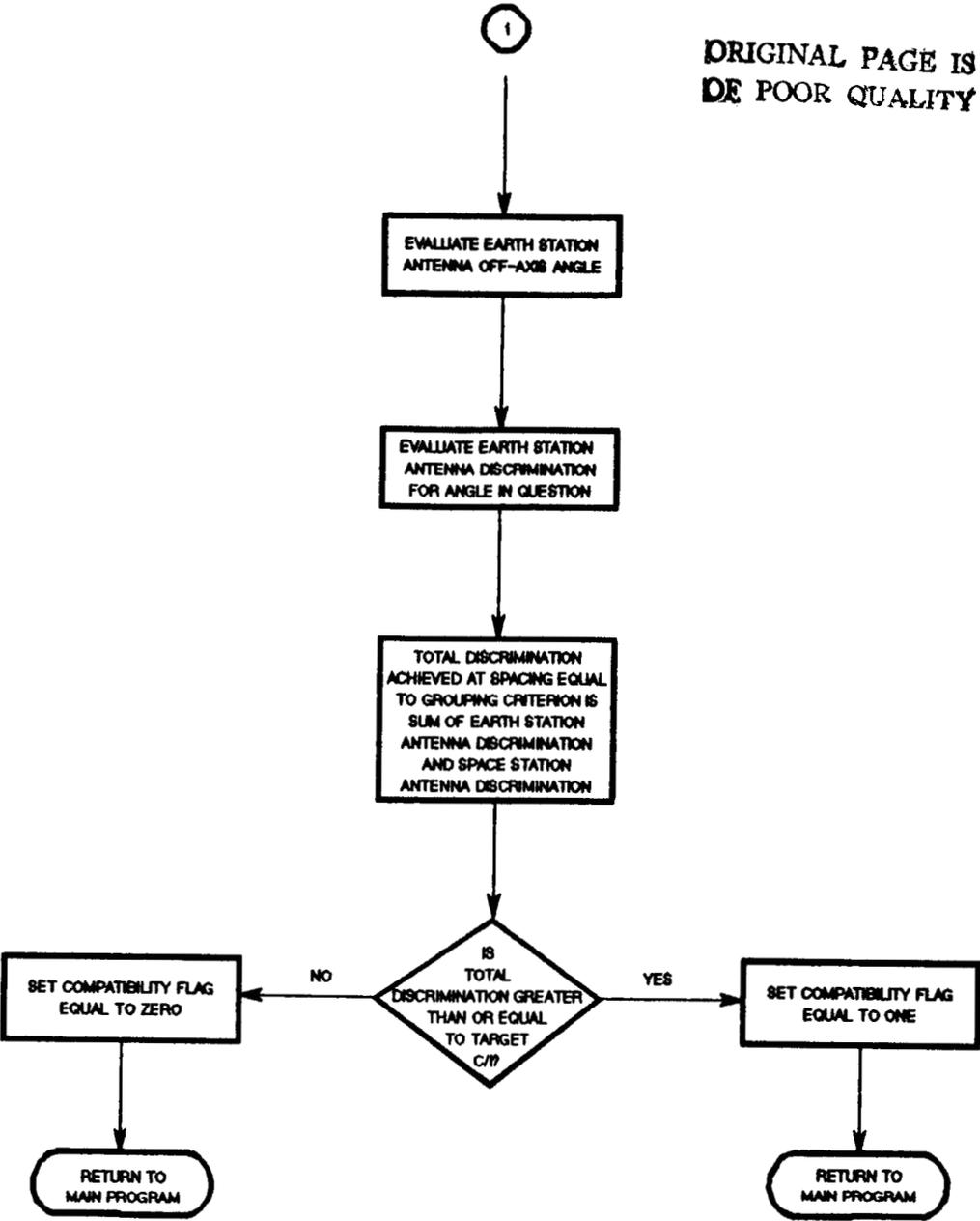


Figure 3.2-3(b).

area and all others. Each row (or column) will have a 1 in the element corresponding to its own service area index, and additional 1's and 0's indicating compatibility or noncompatibility with all other service areas on a one-to-one basis. A *compatible group* will consist of a set of service areas whose members are each compatible with all other members in the group.

The enumeration of groups is a procedure which finds all unique compatible groups at a given arc location. The groups are unique in that no subset groups are generated. Each compatible group has the attribute of complete compatibility within the group. That is every member of a compatible group is *compatible* with every other member of the group. The enumeration process uses the compatibility matrix to generate the set of unique compatible groups at each discrete arc location. In figure 3.2-4 these are two example compatibility matrices and the resultant groups from the enumeration process. In the first example it is very simple to see the compatible groups as the group members are neighbors in the matrix and the 1's are clustered together. In the second example the process becomes slightly more complex due to service areas A, C, and D appearing in more than one compatible group. The final result of the enumeration process is the generation of all compatible groups of size greater than or equal to 2.

#### 3.2.4 Determination of Group Arcs

In NASARC1, the grouping program, three basic procedures are performed. Two of these procedures take place at each discrete arc location within the current segment. First, there is the determination of the pairwise compatibility of each service area with every other service area at each arc location. The second procedure is the enumeration of unique compatible groups at each arc location, described in the previous section. In this section, the third procedure is discussed. This procedure results in the desired output of all potential unique compatible groups with two or more members and their corresponding group arcs. The group arc is the arc span over which a compatible group could potentially exist. This arc might be considered the largest possible shared predetermined arc for the given group. Thus, this third procedure in the grouping program is called the determination of group arcs.

The software for determining the group arcs accumulates the groups enumerated at each arc location and determines the span of arc locations over which each unique compatible group exists. If a group appears in two or more distinct, nonadjacent arc segments, each unique arc segment is identified for that group. Thus, execution of NASARC1 results in the identification of all unique groups and their associated group arcs for the current arc segment being examined.

Unlike the procedures which determine the compatible groups, the group arc determination procedure does not occur at each arc location. Rather, this procedure is exercised whenever a set number of single groups (i.e., unique compatible groups at individual arc locations) have been enumerated. There are two basic functions which are performed by the group arc determination software. First, a list of single groups at individual locations is processed into a block of groups and their associated arc segments. This is accomplished by accumulating the unique groups as they occur at each location in the list. Second, this block of groups is used to update the unique groups master list and the group arcs of the entries already present in that list. In this procedure, duplicate groups (i.e., groups with identical members) are found and their arc spans adjoined if the arcs are adjacent.

The first function might be thought of as the block accumulation function and the second function as the update function. The block function is a fairly straightforward process. When the list of single groups is sent to the group arc determination routine, it first enters the block accumulation procedure. In this procedure, the list of groups is sorted so that duplicate groups appear together. Then, for a given group, arc locations are combined where they are adjacent to form group arcs. It is possible that a group may exist at more than one nonadjacent arc span. If this is the case, each arc span is found for the group in question and the group with each of its separate arc spans become entries in the compiled block of unique groups and group arcs. (It is important to note that a unique group, at this point, is comprised of the group members AND the corresponding group arc. This is the reason why two groups with the exact same members but different arc spans are termed unique groups.) This procedure is performed until all unique groups have been processed into a block of groups and their arc spans. This block is returned to the arc accumulation procedure and is merged with the current master list. In the event that this is the first block of groups processed in the routine, there is no existing master list and this block becomes the first master list. If this is the case, no merging is required.

## Enumeration of Groups using the Compatibility Matrix

	A	B	C	D	E	F	G	H
A	1	1	1	1	0	0	0	0
B	1	1	1	1	0	0	0	0
C	1	1	1	1	0	0	0	0
D	1	1	1	1	0	0	0	0
E	0	0	0	0	1	1	1	0
F	0	0	0	0	1	1	1	0
G	0	0	0	0	1	1	1	1
H	0	0	0	0	0	0	1	1

Resultant Compatible Groups:

A - B - C - D  
 E - F - G  
 G - H

### Example - 1

	A	B	C	D	E	F	G	H
A	1	0	1	1	1	1	1	0
B	0	1	0	0	0	0	1	1
C	1	0	1	1	1	1	1	0
D	1	0	1	1	1	1	1	0
E	1	0	1	1	1	0	0	0
F	1	0	1	1	0	1	1	0
G	1	1	1	1	0	1	1	1
H	0	1	0	0	0	0	1	1

Resultant Compatible Groups

A - C - D - E  
 A - C - D - F - G  
 B - G - H

### Example - 2

Figure 3.2-4.

## FORMATION OF GROUP ARC SEGMENTS AND CREATION / UPDATING OF MASTER GROUPS LIST

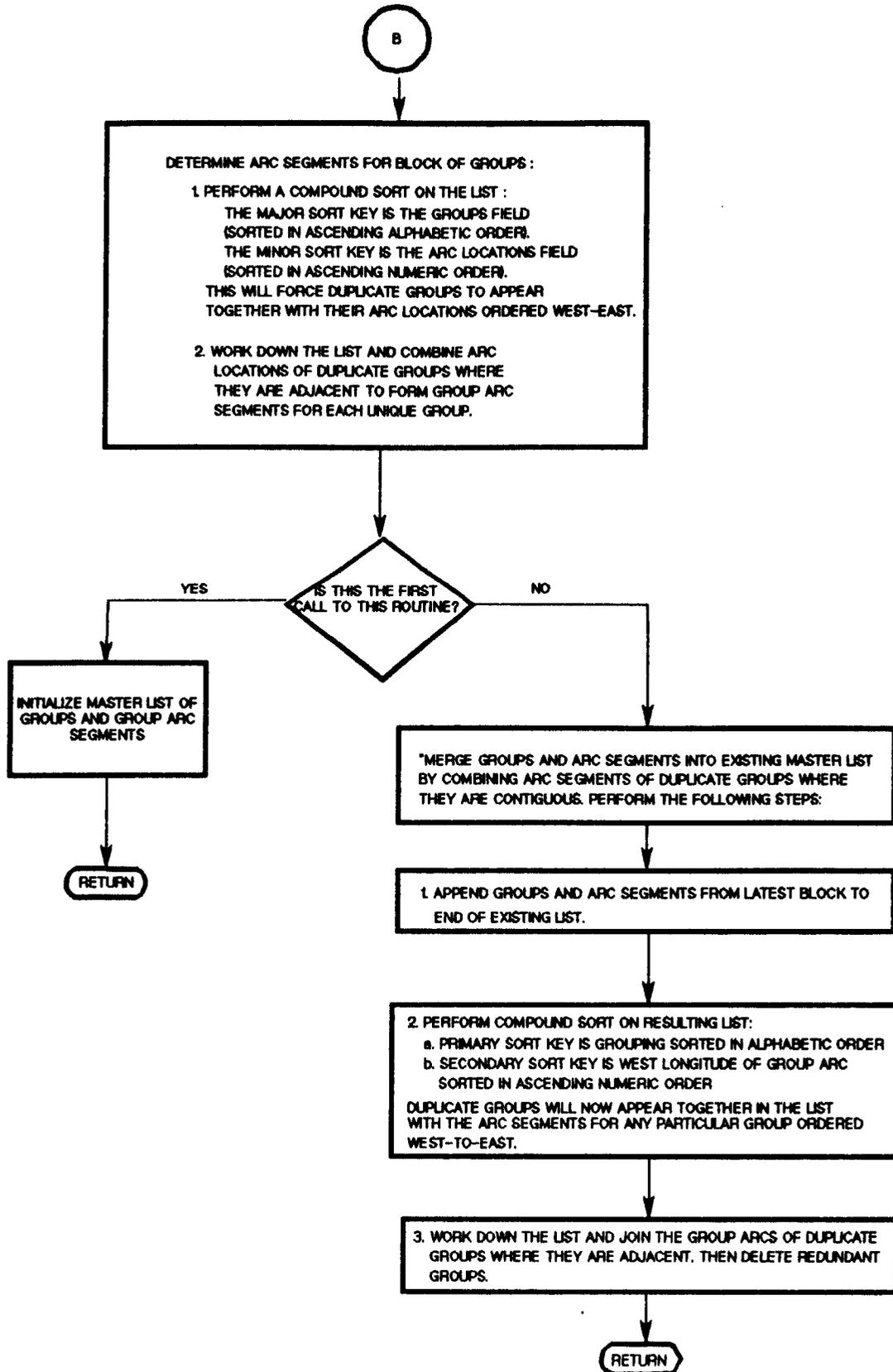


Figure 3.2-5.

After the list has been processed into a block of groups, each unique group (and its associated arc boundaries) must be combined into the current master list. The master list, with the latest processed block of accumulated groups appended to it, is sorted so that the duplicate groups appear together. For each unique group, arc spans of duplicate groups are combined if their arc spans are adjacent. This procedure is done each time a new block is processed.

When all the arc locations within the current segment have been accounted for and all processed blocks have been combined into the unique group master list, the final list of unique groups and their group arcs is completed for the current segment being processed. This list of groups is then processed by the NASARC2 software to determine the allotted arcs for appropriate groups. This entire process is shown by the flowchart in figure 3.2-5 for reference.

### 3.3 NASARC2: Arc Determination Program

In the NASARC (Version 2.0) software package, NASARC2 is used to select appropriate groupings from among those enumerated in the NASARC1 program module within the current segment boundaries from the Segments file and to generate predetermined arc segments associated with the groupings selected. The details of the selection process and the PDA generation procedure are contained in this section. There are seven major subtopics covered in this section which deal with the selection of a critical service area and a grouping containing it, the specific procedures for generating PDA's used in the software, generation of information related to each service area, and the handling of special case service areas.

The output of NASARC2 is found in the Intermediate Allotted Groups file which contains a listing of selected groupings and their predetermined arc segment boundaries for the orbital arc encompassed by the cumulative arc. After all segments in the Segments file have been examined using the NASARC piecewise approach (see section 2.1.5), the Intermediate Allotted Groups file forms the basis of results for the NASARC Report file which is generated in NASARC3 (see section 3.4.4.2). Each service area represented in the output will have been allotted to a group within a common predetermined arc which is shared by the members of the group. The guarantee of existence of an orbital position within the PDA's for each service area would be provided through runs of a synthesis program (ORBIT-II) demonstrating example placements of space stations within the PDA's.

#### 3.3.1 Generation of Service Area Information

One of the first functions performed by the NASARC2 software is the generation of service area information from the groupings output of NASARC1. This function can be seen in the NASARC2 flowchart in figure 3.3-1(a). The service area information is used in the arc determination program to generate figures of merit (FOM's) related to each service area in the scenario. The FOM's are the basis for determining which service area (or grouping containing that service area) is to be allotted first. The service area information consists of a compilation of the number of groups containing each service area and the service arc for each service area represented in the current segment. The list of service areas and their service arcs are obtained by NASARC2 from the NASARC1 Groups File. The number of groupings containing each service area is the total number of groupings from the NASARC1 groupings output for the current segment that have the service area as a member. This is determined by sequentially examining each grouping in the file and counting those in which the service area appears. *Service arc* refers to the length of the service area's original service arc. The parameters compiled in the service area information list are fairly simple in concept but, as mentioned previously, they are used in areas of critical decision making such as the determination of which service area is to be accommodated first and which of its groupings is to be selected. The process of updating the service area information must be carried out each time a group is allotted a PDA. For these subsequent compilations of data, the groups file that is searched is an updated version of the original file (output Groups file of NASARC1). This updating process is discussed further in section 3.3.5.

# NASARC2 -- The Arc Determination Program

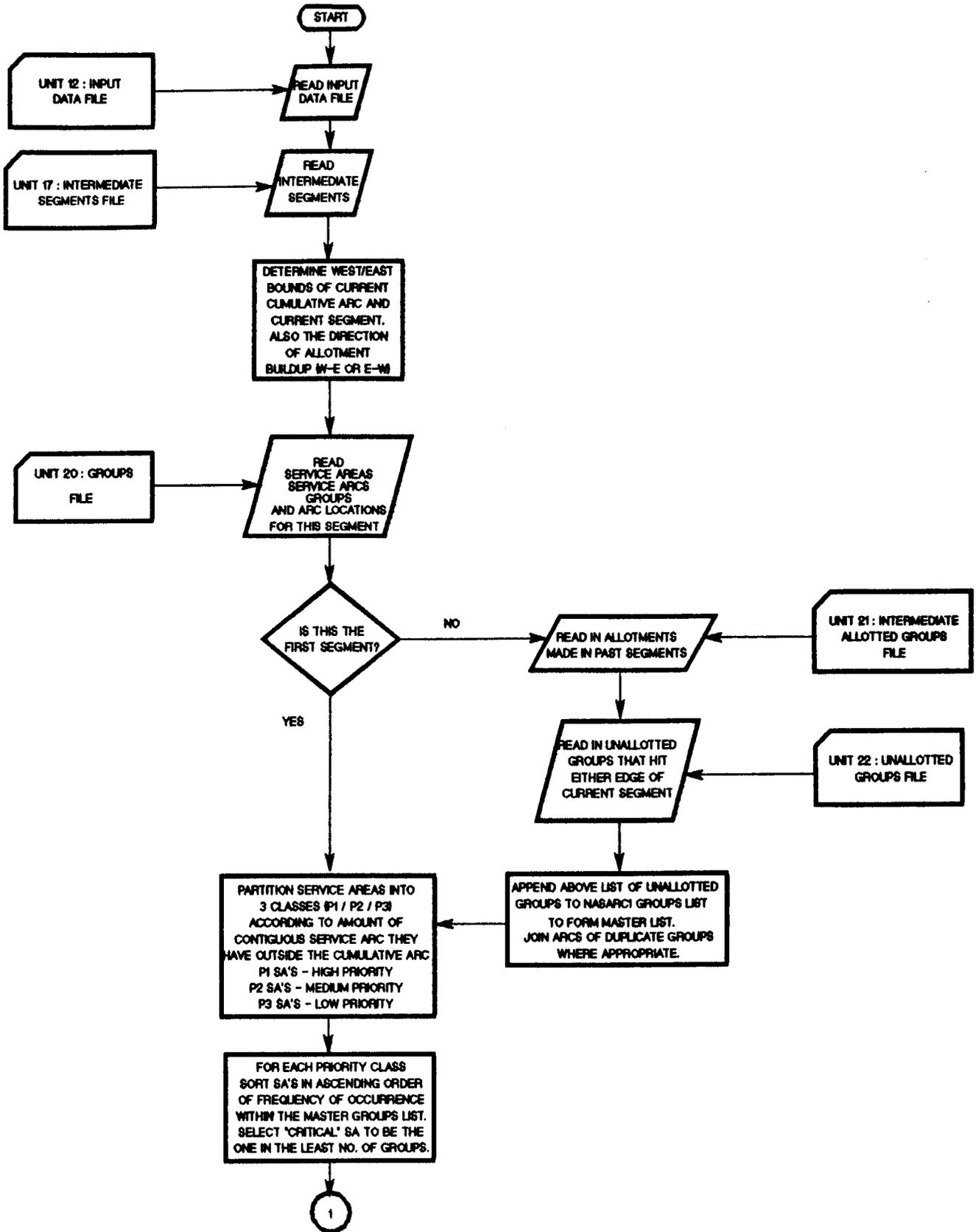


Figure 3.3-1(a).

NASARC2 (CONTINUED)

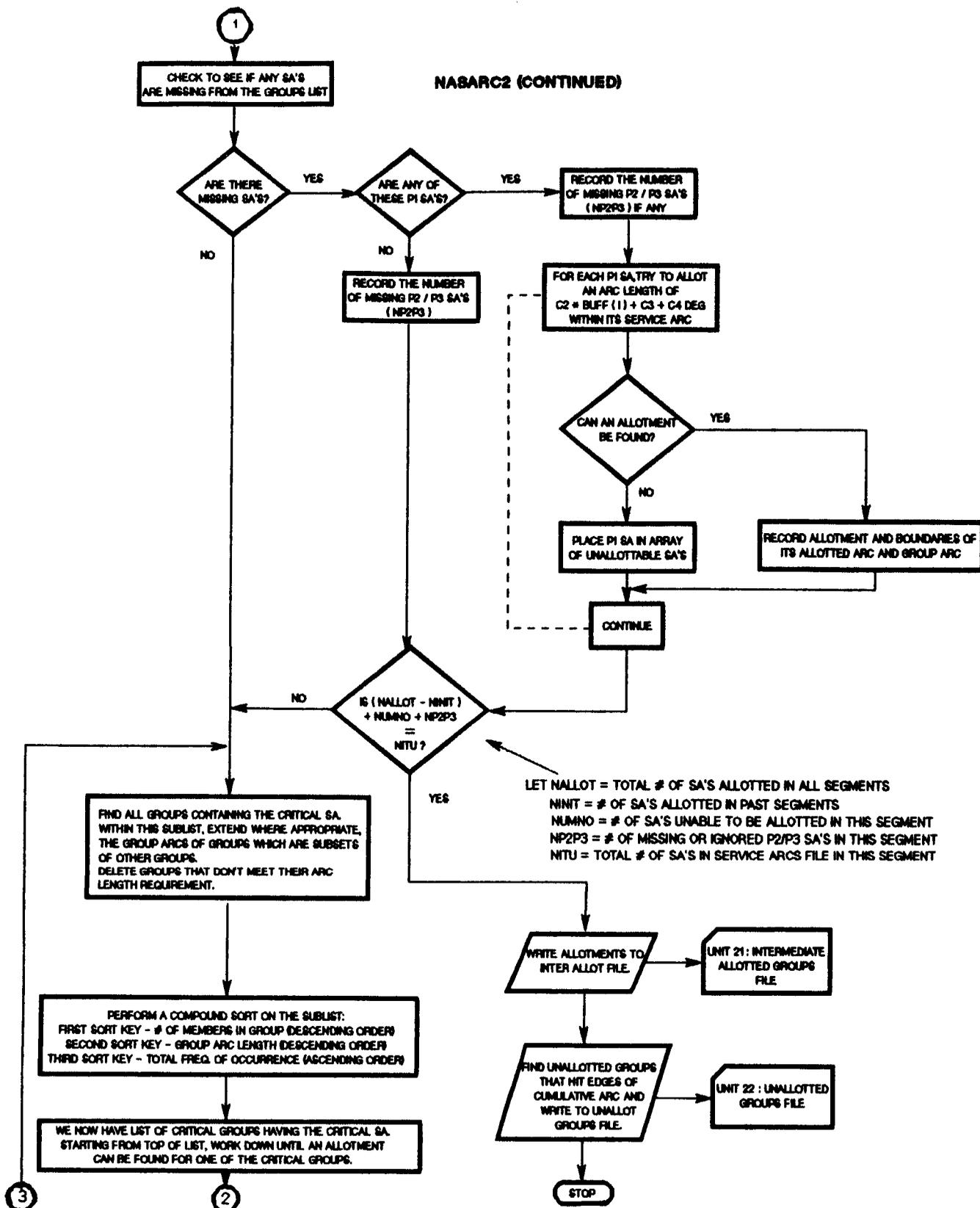


Figure 3.3-1(b).

NASARC2 (CONTINUED)

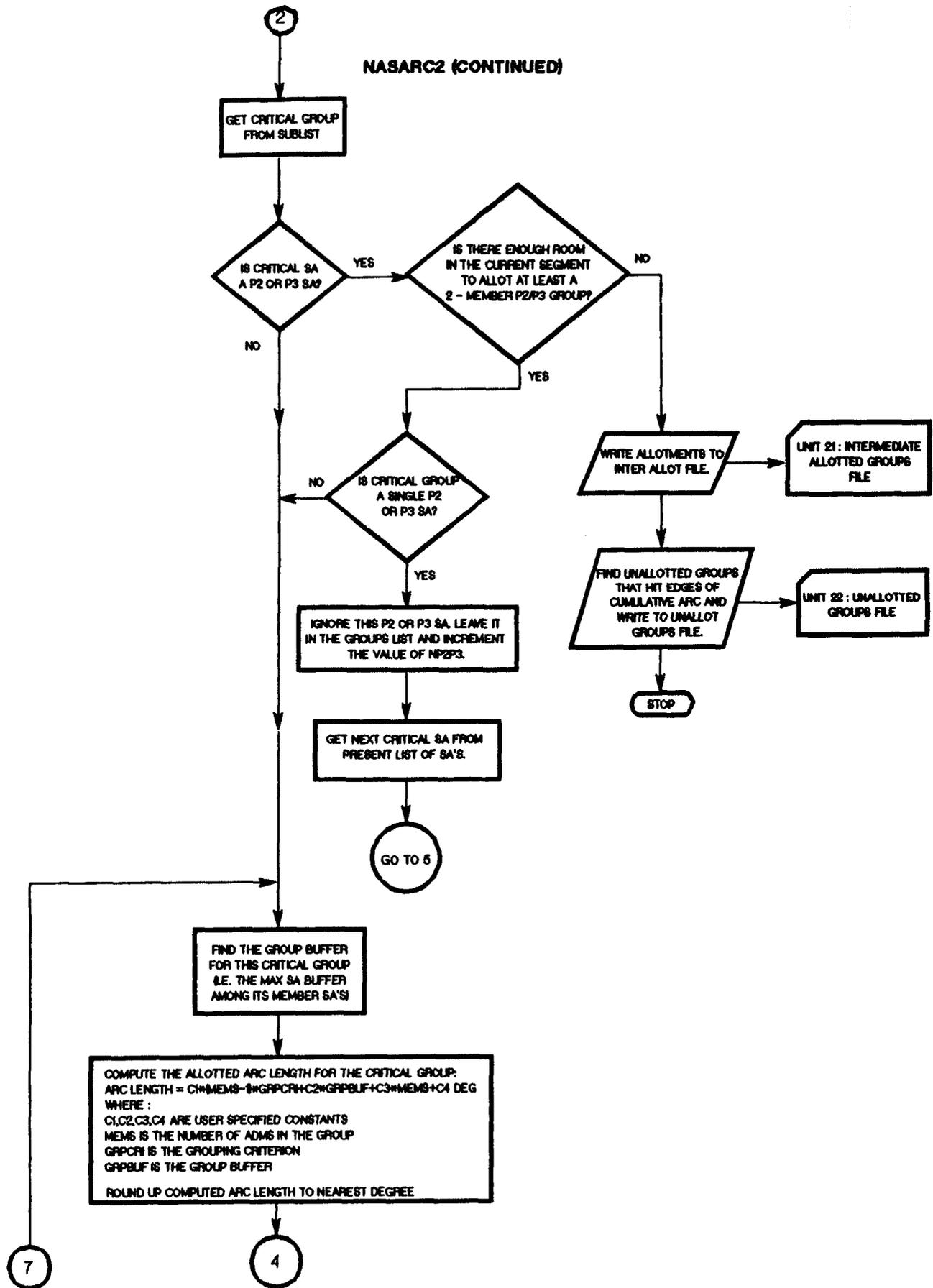


Figure 3.3-1(c).

ORIGINAL PAGE IS  
OF POOR QUALITY

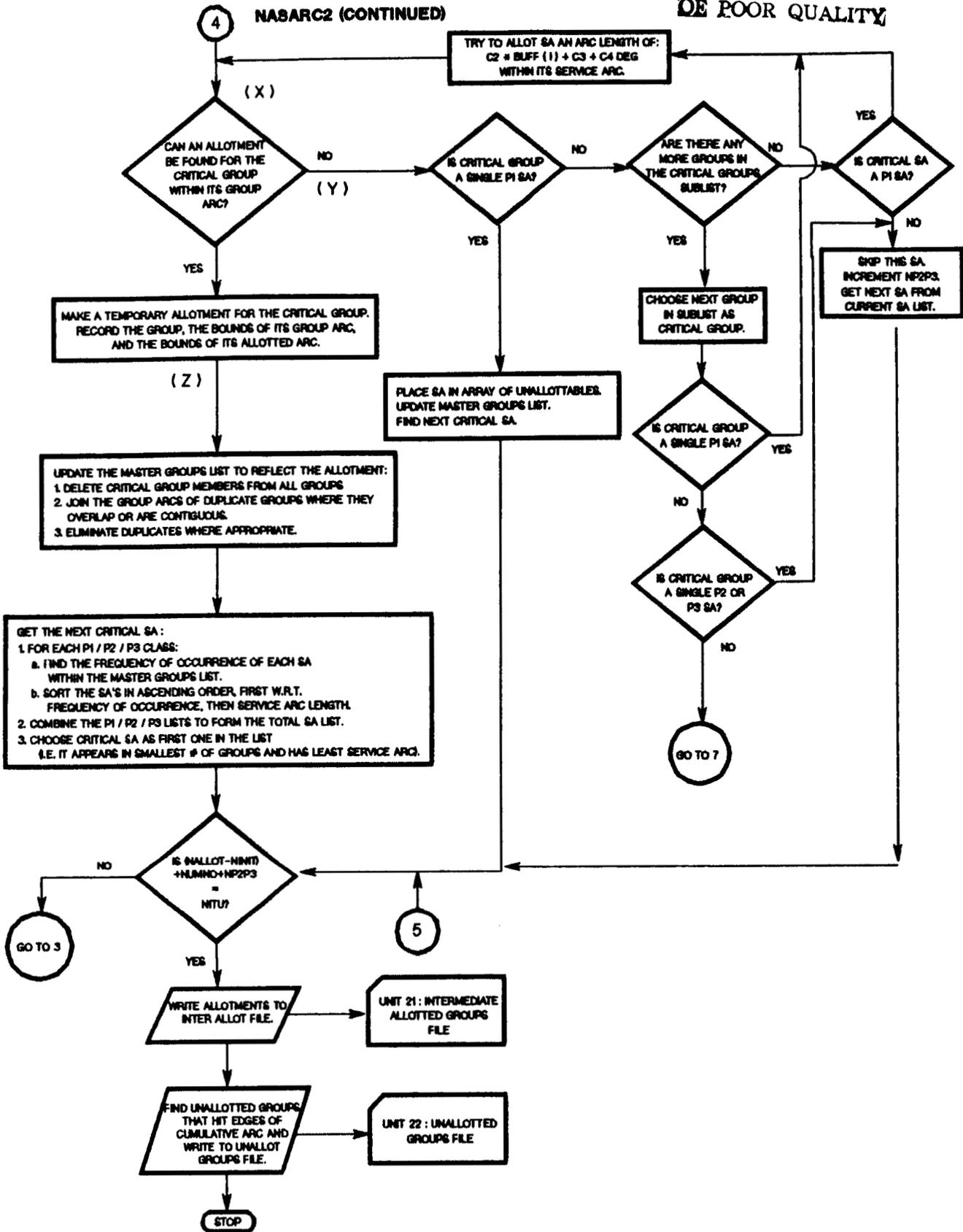


Figure 3.3-1(d).

### 3.3.2 Prioritization of Service Areas

As was indicated in section 2.1.5 relating to the NASARC piecewise approach, it becomes necessary to prioritize service areas for accommodation within each segment according to the remaining service arc outside of the current cumulative arc. The cumulative arc encompasses the current segment being processed and all prior segments in which groups have been allotted PDA's. The cumulative arc will always be continuous (i.e., the current segment must adjoin either the western or eastern boundary of the prior cumulative arc). The NASARC1 Groups file passes to NASARC2, along with the enumerated groupings, only the service areas and service arcs of those service areas whose service arc intersects at least some portion of the current segment. It is from this list of service areas that NASARC2 determines the priority of each service area represented in the current segment. (A service area may consist of an individual administration, an affiliated set of territories, a subregional grouping of administrations or the territories covered by an *existing system*.)

Service areas whose service arcs do not extend outside cumulative arc by more than their buffer size are given a priority P1, meaning that these service areas must be accommodated within the current segment. A priority P2 is given to service areas whose remaining service arc, outside of the cumulative arc, is 20° or less. Finally, a priority P3 is given to service areas whose remaining service arc exceeds 20°.

In the selection of the critical service area, which is discussed further in section 3.3.3, the service area priority is the first level figure of merit for that determination. All P1 service areas must be accommodated in the current segment in some form—either as a member of a multimember group, as a single service area group, or identified as unable to be allotted. The first of these (multimember group) is the standard and most desirable method of accommodation. However, if technical constraints are such that the P1 service area can not be allotted within a multimember group, the software will then attempt to provide an individual PDA for that service area within the bounds of the cumulative arc. (Single P2 or P3 service areas are not allotted individual PDA's since future segments may provide orbital arc in which they could be included with multimember groups.) Unallottable P1 service areas are flagged as such and identified in the NASARC output report. Section 3.3.7 discusses the handling of unallotted service areas. These arise from input technical parameters which do not allow a complete solution to be achieved.

After all P1 service areas have been accommodated within the current segment, if sufficient orbital arc remains in the segment, NASARC2 attempts to allot a PDA for a grouping which contains the most critical P2 service area, and so on for P3 service areas as long as there remains sufficient orbital arc in the segment.

### 3.3.3 Selection of Critical Service Area

Once the service area information has been generated, NASARC2 is ready to begin the selection of groups and the generation of PDA's. The basic approach of the NASARC2 methodology, as seen in the flowcharts in figures 3.3-1(a) to (d), is (briefly) as follows:

- (1) Select a service area (critical service area) to accommodate first.
- (2) Select a grouping (critical grouping) to allot that contains the critical service area (see section 3.3.4).
- (3) Determine the required arc length to allot the critical grouping (see section 3.3.4).
- (4) Determine where in the geostationary orbit to place the PDA (see section 3.3.6).
- (5) If the critical grouping can be accommodated, update the listing of remaining groupings (see section 3.3.5) and repeat steps 1 to 5 until all service areas have been allotted PDA's or until the orbital arc is exhausted for the current segment. If the critical grouping can not be accommodated, try to accommodate the next most critical grouping.

The first step in this approach is to select a critical service area from the list of unaccommodated service areas. The decision as to which service area to select is made based on two figure-of-merit factors (FOM0 and FOM1). FOM0 was described previously in section 3.3.2 and relates to the priority of each service area based on the remaining service arc outside of the current cumulative arc. FOM1 is used to sort the service areas within each of

the priority levels resulting from FOM0. FOM1 is equal to the number of groupings in which each service area appears in the NASARC1 Groups file. This is obtained from the service area information list. Based on FOM1, the service area appearing in the fewest number of groupings, from among those service areas with the highest priority (i.e., P1 followed by P2 followed by P3), is selected as the critical service area.

Selection of the critical service area in this manner preserves the maximum likelihood for remaining service areas to be accommodated in multimember groups, since the critical service area effects the fewest number of remaining groups. However, more importantly, it addresses the most difficult service areas to allot a PDA first, thereby reducing the possibility for unallotable service areas.

In the event FOM1 results in a tie, a secondary FOM1 has been included in the NASARC software to break the tie. The secondary FOM1 selects the critical service area from the tied service areas as the one having the least amount of service arc. If this also produces a tie, the final tie breaker is to simply take the first one appearing alphabetically in the list as the critical service area.

### 3.3.4 Selection of Critical Grouping

After the critical service area is selected, the next step in the NASARC2 process is the selection of a grouping that contains the critical service area (i.e., the critical grouping). Once selected, the software will attempt to allot a common PDA to the members of the selected critical grouping. The grouping selection process employs two figure-of-merit factors (FOM2 and FOM3) simultaneously. FOM2 is a measure of the number of members in each grouping containing the critical service area. FOM3 is a measure of the minimum group arc that must be available for a given grouping in order that a PDA can be allotted to the grouping. NASARC2 uses FOM2 along with the length of the group arcs and FOM1 (number of groupings in which each service area appears) to sort the list of groupings containing the critical service area in order of the most desirable groupings to allot.

Before the sorting process takes place, however, the groupings which contain the critical service area are compared to determine if any of the groupings are subsets of one another. As was discussed in sections 3.2.3 and 3.2.4, only unique groupings are enumerated in the NASARC1 process. Therefore, groupings which are subsets of other groupings, are only present in the NASARC1 Groups file if they appear uniquely in a portion of the orbit over which the larger group, for which it is a subset, does not exist. It becomes necessary at this time to extend the group arcs of the subsets over the entire arc in which they may exist (i.e., to include the group arc of the larger grouping as part of the subset grouping's group arc). This process of subset arc extension is discussed in more detail in section 3.3.5.2.

After the subset arc extension process is completed, the group arc of each grouping containing the critical service area is compared against FOM3 (measure of the minimum necessary group arc). The determination of FOM3 is discussed in section 3.3.4.2, but FOM3 is basically the length of the PDA for a given grouping size. Therefore, using FOM3, those groupings whose group arcs are not sufficient in length to be able to allot the required length PDA for that grouping are eliminated from consideration as the critical grouping. The remaining groupings which contain the critical service area (i.e., those having group arcs which exceed their respective values of FOM3) are sorted in the following manner.

#### 3.3.4.1 Sorting of Groupings Containing Critical Service Area

The groupings are sorted according to descending group size (number of members). Within groupings having the same number of members the groupings are sorted according to descending group arc length. Finally, for equal size groupings that also have equal group arc lengths, the groupings are sorted according to ascending total frequency of occurrence of the grouping's members. This final sort uses frequency of occurrence values from FOM1 to determine the total number of groupings in which all members of a given grouping appear in the Groups file. The result of the sorting process is that the largest grouping with the largest group arc whose members appear in the fewest total number of groupings will be selected as the critical grouping. NASARC2 will then attempt to find an open area in the orbital arc in which to place the PDA for this grouping (see section 3.3.6). If

an area can be located and the grouping accommodated, the groups list will be updated to reflect the allotted grouping and a new critical service area will be determined from the updated groups list. If no open area is available within the group arc of the critical grouping, the next grouping, in the sorted list of groupings containing the critical service area, will be chosen for accommodation. This process continues until one of the critical groupings has been accommodated or when the list has been exhausted. If the list is exhausted and a critical grouping containing the critical service area has not been accommodated, NASARC2 will attempt to allot a PDA to the critical service area as a single member grouping using its entire service arc as its available group arc. This final step (single service area PDA) will only occur if the critical service area is a priority P1 service area. Otherwise, for P2 or P3 service areas, NASARC2 will wait and attempt to allot the service area in a multimember grouping in a later segment.

### 3.3.4.2 Determination of Predetermined Arc Length

The size of each PDA is determined by the number of members within the grouping and by certain technical characteristics. Different PDA's may have different numbers of space stations grouped within them. The technical characteristics which affect the number of administrations that can be grouped include the space station antenna rolloff characteristics, the earth station antenna diameter, the required single-entry *C/I*, and the grouping criterion (i.e., the specified orbital separation requirement for near colocation). The specification of an appropriate set of technical characteristics will be decided on at WARC-88 with the guidance of activities to be carried out during the intersessional period by the IFRB.

The exact basis for determining the size of each PDA can vary depending on the desires of the conference related to efficiency of orbit utilization. Therefore, the equation which has been implemented in the NASARC (Version 2.0) process allows the user considerable flexibility in determining the arc length to be allotted to a given size grouping (i.e., the PDA length). It is essential to remember, however, that the requirement of one allotment per ITU member be met. With this in mind a conservative PDA length would allow for an increased likelihood of generating PDA's for a successful allotment plan. The following formula is implemented in NASARC2 for determining the predetermined arc length:

$$AL = K_1(N-1)GRP + K_2B(i) + K_3N + K_4 \quad (3.3-1)$$

where

<i>AL</i>	PDA length, deg
<i>N</i>	number of grouping members
<i>GRP</i>	grouping criterion, deg
<i>B(i)</i>	buffer length, related to grouping <i>i</i> , deg
<i>K<sub>1</sub>, K<sub>2</sub>, K<sub>3</sub>, K<sub>4</sub></i>	user specified constants

All entries in the PDA length equation are dependent on user specified inputs with the exception of *N*, the number of members of a given grouping. The grouping criterion *GRP* is a user specified parameter; the buffer length *B(i)* is calculated based on user specified earth station parameters (see section 3.1.2); and the constants *K<sub>1</sub>*, *K<sub>2</sub>*, *K<sub>3</sub>*, and *K<sub>4</sub>* are specified by the user in the Point Sets file (see section 3.1.1.1). Specification of the four constants allows the user to determine the basis for the PDA length.

Constant *K<sub>1</sub>* affects the emphasis of the grouping criterion on the PDA length. Allowance can be made for each member of the group to be separated from its nearest neighbors in orbit by the amount of the *GRP*. In practice, some space stations may be collocated with others or may be separated from others by distances less than *GRP*. This results in less of each PDA being required to meet the service areas requirements, and results in more available flexibility.

Constant *K<sub>2</sub>* affects the emphasis of the buffer length related to each grouping on the PDA length. The buffer is included as a means of reducing the overall coordination requirements between members of adjacent groupings.

Section 3.1.2 gives the equations for determining the buffer length which is based on earth station parameters. Since earth station parameters can be specified individually for each service area in the Service Area file, a different buffer length can be calculated for each set of earth station parameters. A default buffer length is calculated in NASARC0 for those service areas using the user prompted earth station parameter responses. NASARC1 calculates an individual buffer length related to those service areas with individual earth station parameter specifications in the Service Area file and passes these value to NASARC2 through entries in the Groups file. NASARC2, in determining the buffer length  $B(i)$  related to grouping  $i$ , selects the largest individual buffer length associated with any of the members of grouping  $i$ . The buffer is not a guard zone where no space stations may be located. Some of the members within a grouping may be compatible with all members of an adjacent grouping and could therefore choose to locate within the buffer area and not cause or receive harmful interference. The purpose of specifying the buffer is to reduce the required coordination any administration would need to be involved in when implementing a system. Any administration wishing to locate a space station within the buffer area might be required to coordinate with administrations from the affected adjacent grouping. The length of the buffer is sufficient to isolate space stations serving neighboring territories based on an aggregate interference criterion.

Constant  $K_3$  gives the user the option of specifying a PDA length based solely on the number of members in each grouping. Constant  $K_4$  can be used to uniformly increase or decrease the size of all PDA's independent of the number of members in each grouping.

Equation (3.3-1) is used as the basis of FOM3. If a grouping containing the critical service area has a group arc greater than or equal to the necessary PDA length determined using equation (3.3-1), it is retained for consideration as the critical grouping. If not, it is removed from consideration and not included in the sort procedure outlined in section 3.3.4.1.

### 3.3.5 Updating and Arc Adjustment of Groups and Group Arcs

The primary selection criterion for the critical service area is its frequency of occurrence within the master groups list. In other words, the service area appearing in the fewest number of groups will be chosen as the critical service area. (If two service areas have the same frequency of occurrence, the one having the smaller service arc is chosen.) In order to maintain the accuracy of this selection criterion, NASARC2 must prevent redundant groups from appearing in the master groups list and remove from the list service areas which are already in allotted groups. This updating of the master groups list occurs after a critical group has been allotted but before the next critical service area is selected. It is more fully described in section 3.3.5.1.

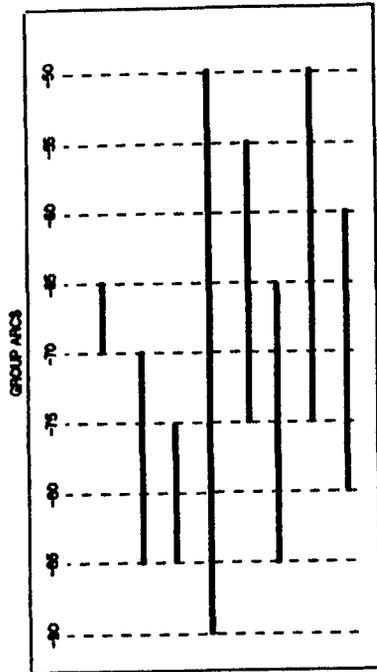
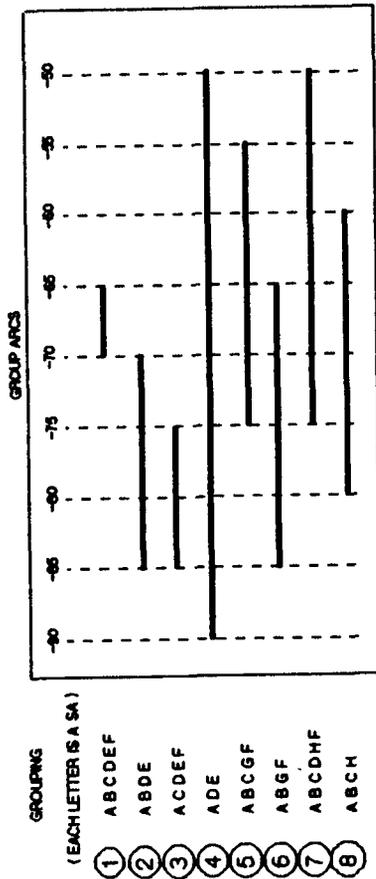
A similar situation exists in selecting the critical group. The secondary selection criteria is the group's group arc length. For groups with the same number of members, choosing the one with the largest group arc will allow greater flexibility in placing the group's allotted arc somewhere within the group arc. Therefore it is important that a group's full, complete group arc (or as much as is available within the current cumulative arc) is utilized. This includes groups in a critical groups sublist which may, in fact, be subsets of other groups in the sublist. It must be pointed out that the updating of the master groups list mentioned previously only performs arc readjustment on groups which are duplicates of other groups, not subsets. Hence, before selecting a critical group with the criteria described in section 3.3.4, the group arcs of subset groups in the sublist must be extended where possible. This subset arc extension process is performed after collecting all groups containing a critical service area but before ordering the sublist groups according to the selection criteria. This process is more fully described in section 3.3.5.2.

#### 3.3.5.1 Updating and Arc Adjustment of the Master Groups List

The best way to understand the update procedure after a critical group has been allotted is by means of an example. Refer to figure 3.3-2. The upper left of the figure shows a small portion of the master groups list before updating begins. Changes will be made to both the group itself (i.e., the character string representing the group) as well as to its associated group arc (group arcs are represented by the heavy lines on the longitude scale).

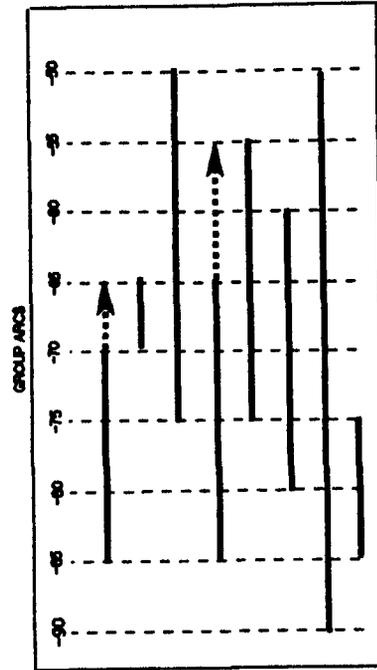
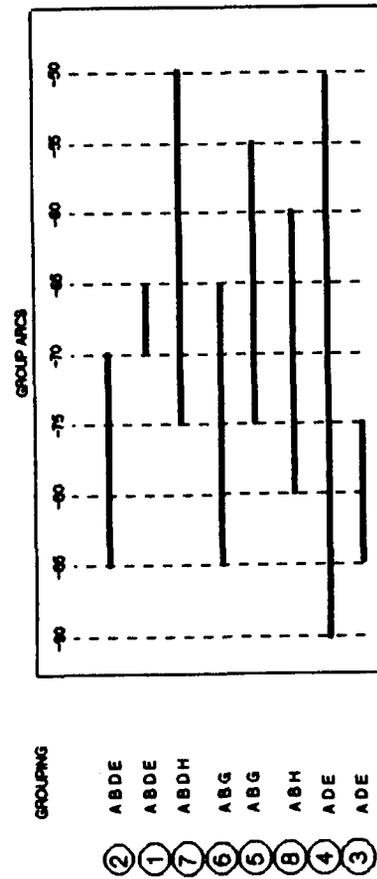
FIGURE 3.3-2 EXAMPLE OF GROUPS LIST UPDATING  
(XCF IS THE ALLOTTED CRITICAL GROUP)

INITIAL GROUPS AND GROUP ARCS



STEP 1: DELETE CRITICAL GROUP MEMBERS FROM GROUPS  
(EXAMPLE CRITICAL GROUP IS 'X C F')

STEP 2: SORT GROUPS ALPHABETICALLY. FOR DUPLICATE  
GROUPS, SORT GROUP ARCS WEST-TO-EAST.



STEP 3: EXTEND GROUP ARCS OF DUPLICATE GROUPS IF THEY  
OVERLAP OR ARE CONTIGUOUS. THEN DELETE DUPLICATE GROUPS.

Figure 3.3-2.

The first step is to delete critical group members from the groups in the list in which they appear. This is shown in step 1 of the example. The critical group which has just been allotted is XCF, where X, C, and F are the critical group members.

The second step is to perform a compound sort on the groups list. This is shown in step 2 of the example. First the groups are sorted alphabetically. This forces all duplicate groups to appear together in the list. Second, for duplicate groups, group arcs are sorted in west-to-east order. Third, for duplicate groups whose group arcs happen to start at the same western longitude, sorting is done so that the group whose group arc extends furthest east appears first in the list. The purpose of the sorting is to arrange the groups and their group arcs into a list which can easily be scanned to detect whether the group arcs of duplicate groups are contiguous, overlapping, or nonadjacent.

The third step is to perform the group arc adjusting among the duplicate groups, where appropriate, and afterwards to delete redundant groups. This is shown in step 3 of the example. Here, group arc 1 is contiguous to group arc 2; extend group arc 2 and delete group 1. Similarly, group arc 5 overlaps group arc 6; extend group arc 6 and delete group 5. Lastly, group arc 3 is completely encompassed by group arc 4; group arc 4 stays the same but eliminate the redundant group 3.

Note that in updating the master groups list, group arc adjusting only occurs to groups that are duplicates of other groups, not subsets. Hence, it is still possible that even after list updating, a group's group arc may still not appear as its full, complete group arc since it may be, for example, encompassed by another group's group arc of which it is a subset. However, at this stage in the program, it is not important to have the total group arcs since it is not part of the critical service area selection criteria. What is important at this stage is that allotted service areas have been eliminated from the groups list and redundant groups, resulting from those eliminations, have also been deleted. This will result in correctly finding the frequency of occurrence of the remaining service areas in the list upon which the next critical service area is chosen.

### 3.3.5.2 Subset Arc Extension in the Critical Groups Sublist

To help understand how the subset arc extension process is performed, refer to figure 3.3-3. This example shows how one particular subset's group arc is extended. All groups which may be subsets of other groups are treated in exactly the same manner. The upper left of the figure shows an example of a critical group's sublist in which all groups contain the critical service area B. Along with each group is shown their associated group arc.

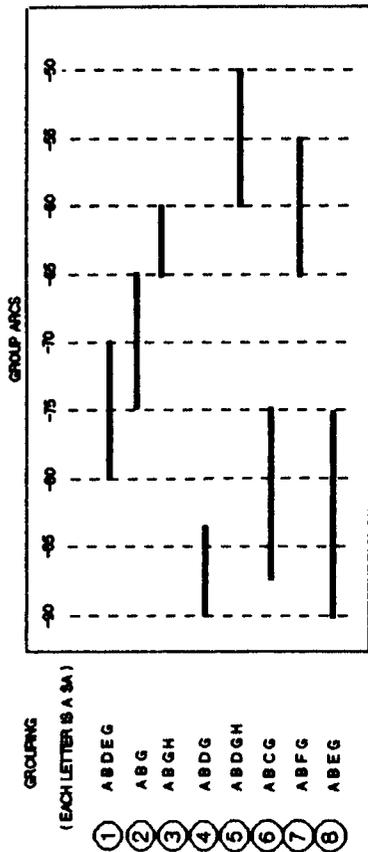
The first step in the process is to perform a compound sort on the sublist groups. They are first sorted according to the number of members in the group, and then for groups with the same number of members, the groups are sorted alphabetically. This is shown in step 1 of the example. The list is sorted in this manner to identify the groups that are subsets of other groups.

The second step is to identify a *key* group from the list in step 1. The key group is the group whose group arc will be extended by looking at the group arcs of those groups for which the key is either a duplicate or a subset. For reference purposes these groups will be called test groups. The ordering of the groups in step 1 provides the order in which to choose the key group. In other words, the first group in step 1 is designated the key group; its group arc is compared against the group arcs of its test groups, and its group arc is appropriately extended. Then the second group in step 1 is designated the key group and the process repeated. Then the third group, and so on. Note that the ordering of the groups in the first step makes it unnecessary to search for test groups above the key group; only those entries beneath the key are searched. In the example, ABG is initially the key group, and its test groups are listed below it in step 2 of the figure. (In the execution of the program, only the group arcs of the test groups are stored.) Note also that the test group arcs are sorted in west-to-east order. This allows easier scanning of the list of test group arcs to identify aggregate arcs formed by arc overlapping.

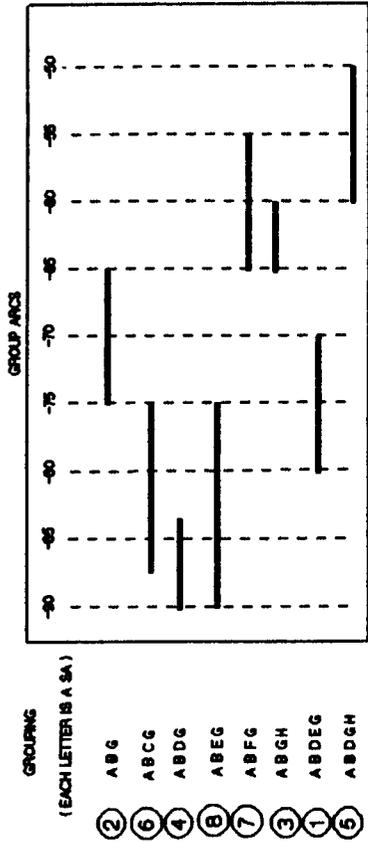
The last step in the arc extension of the key group is to form the aggregate arcs from the test group arcs and compare them with the key group arc. This is shown in step 3 of the example. Here, the key group arc actually bridges the two aggregate arcs. Hence, its group arc (the group arc of ABG) is extended to the outermost bounds

FIGURE 3.3-3 EXAMPLE OF SUBSET ARC EXTENSION IN CRITICAL GROUPS SUBLIST  
( B IS THE CRITICAL SERVICE AREA )

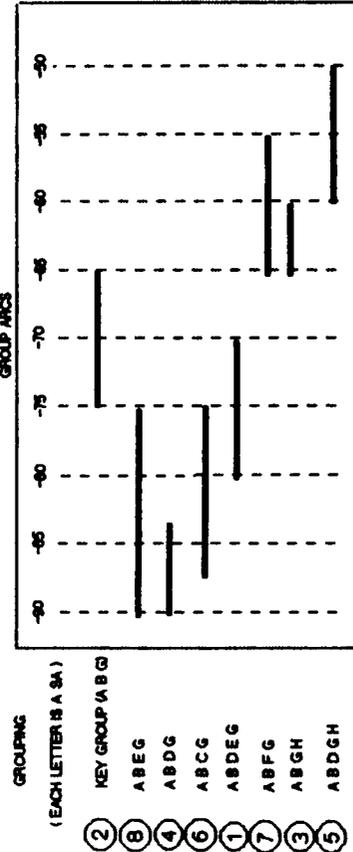
INITIAL SUBLIST OF CRITICAL GROUPS  
( B IS THE CRITICAL SERVICE AREA )



STEP 1: SORT LIST FIRST ACCORDING TO NUMBER OF MEMBERS  
THEN ALPHABETICALLY.



STEP 2: CHOOSE 1ST GROUP AS KEY (A B G) AND FIND GROUP  
ARCS OF THOSE GROUPS FOR WHICH KEY IS A DUPLICATE OR  
SUBSET. SORT THESE GROUP ARCS WEST-TO-EAST.



STEP 3: FIND AGGREGATE ARCS FROM GROUP ARCS. COMPARE KEY  
GROUP ARC WITH AGGREGATES AND EXTEND WHERE POSSIBLE.  
CHOOSE NEXT KEY FROM LIST IN STEP 1 AND REPEAT.

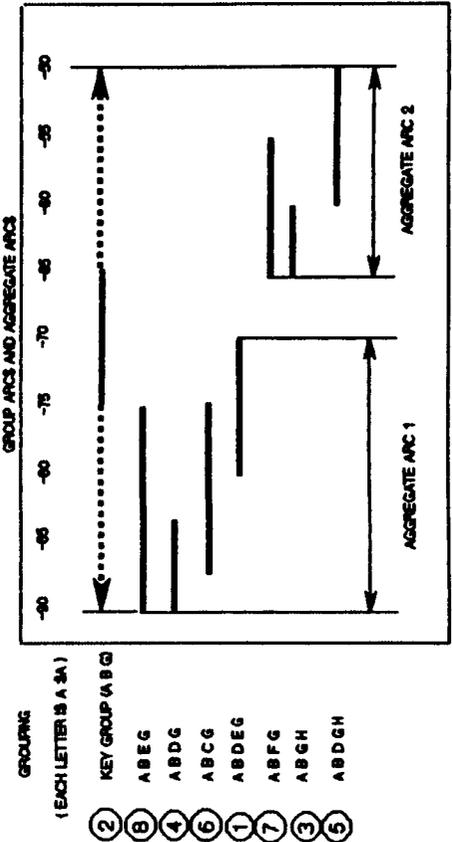


Figure 3.3-3.

of the aggregate arc. At this point, one subset group from the original critical groups list has been extended. To continue, the next group in the ordered list from step 1 is chosen as the key group and steps 2 and 3 are repeated.

Once the subset arc extension process has been performed on each of the groups in the critical group's sublist, determination of the next critical group to be allotted can proceed.

### 3.3.6 Allotted Arc Determination Procedures

Up to this point, the NASARC2 program has selected a critical service area and a corresponding critical grouping of which it is a member. NASARC2 now checks to see if any priority P1 service areas are missing from the Groups file by examining the service area information list. If so, these are given individual allotted arcs within their service arcs. If not, the next major task is to determine where in the geostationary orbit within the group arc constraint, the groupings' temporary allotted arc should be located. This task is performed by a heuristic approach. Temporary has been used because locations of past allotted arcs are subject to change as additional groupings are selected to receive allotted arcs.

Since the allotted arc determination procedure is based on a heuristic approach, the NASARC2 methodology has been constructed so that it will not allow any new critical grouping to exclude any previously allotted grouping. This is achieved by allowing the new critical grouping to be given an allotted arc if and only if all prior allotted groupings can successfully maintain temporary allotted arcs within their respective group arc constraints. If this is not possible, the critical grouping is discarded and a new grouping containing the critical service area is sought. The limit is reached when the complete list of groupings containing the critical service area has been exhausted; NASARC2 then attempts to allot the critical service area to an individual predetermined arc equal to its buffer length within its service arc. A single service area is allotted an individual PDA only if it is a P1 service area; otherwise the next critical service area is selected and the P2 or P3 service area that could not be allotted to a multimember grouping is retained for accommodation in a future segment.

Formally stated, the objective of the allotted arc procedure is to determine a temporary allotted arc for the critical grouping of a length determined by using equation (3.3-1) (see section 3.3.4.2) within its group arc, while maintaining temporary allotted arcs for all previous selected groupings. Three different heuristic approaches of varying complexity are attempted in trying to achieving the objective. The first approach is referred to as the Zero Density Allotted Arc Routine and is the simplest in concept; find a vacancy in the geostationary orbit that can accommodate the grouping's required PDA length within its group arc constraint.

The second and third approaches are referred to as the Push and Shuffle Allotted Arc Routines and involve a greater degree of complexity in determining temporary allotted arcs than the Zero Density Allotted Arc Routine. Both routines involve clearing an orbital arc width of the required length for the critical grouping by relocating existing temporary allotted arcs; exactly how and where this is done depends on the routine. These two routines are accessed if and only if the Zero Density Allotted Arc Routine is unsuccessful in finding a temporary allotted arc for the critical grouping. Throughout these procedures, a check routine (formally referred to as the Pairwise Check Routine) is employed to circumvent the possibility of excluding an existing grouping by allotting a new temporary allotted arc in an occupied area of the orbit.

In order to fully detail the allotted arc determination procedure, it is necessary at this point to define a few auxiliary concepts. The first is the BOA or binary orbital arc. This is a one-dimensional, 360-element array indicating where in the geostationary orbit temporary allotted arcs are located. A 1 indicates that the orbit location has been allotted while a 0 indicates a vacancy. This is a fundamental tool for the Zero Density Allotted Arc Routine and is also used throughout the other procedures.

The second concept is referred to as the PTA, potential temporary allotted arc. For a given critical grouping there is an associated group arc and required arc length (PDA length). Any placement of the required arc length within the group arc is considered a PTA. Because the NASARC groupings are enumerated over integer degrees in the geostationary orbit, there is a discrete, limited number of PTA's within a groupings group arc. NASARC2

makes successive attempts to find a solution for each given PTA. The first PTA that is found which will allow all prior allotted groupings to maintain temporary allotted arc within their group arc constraints becomes the temporary allotted arcs for the critical grouping. If all PTA's have been tried unsuccessfully, a new grouping containing the critical service area is sought. The following subsections explain in greater detail the Zero Density Allotted Arc Routine, the Pairwise Check Routine, the Push Allotted Arc Routine, and the Shuffle Allotted Arc Routine.

The following subsections detail each approach used in the allotted arc determination procedure. In the NASARC (Version 2.0) piecewise approach to predetermined arc generation, PDA's are formulated in a manner consistent with the segment boundaries being processed. That is, the direction of PDA buildup is dependent on the location of the current segment relative to the prior cumulative arc. For the first segment, the PDA buildup proceeds in a west to east fashion. If the second segment adjoins the eastern boundary of the cumulative arc (in this case, the eastern boundary of the first segment), then the PDA buildup for the second segment will proceed in a west to east fashion. However, if the second segment adjoins the western boundary of the cumulative arc (i.e., the western boundary of the first segment), then the PDA buildup will proceed in an east to west fashion. This reversal of the direction of buildup is done so as to effectively utilize the orbital arc across segment boundaries. Groupings which can exist across segment boundaries are then able to about groupings allotted in prior segments.

In the subsections that follow, the allotted arc procedures are given for a west to east buildup of the PDA's within the boundaries of a given segment. An east to west buildup is executed in a manner consistent with the procedures described for the west to east buildup of PDA's.

#### 3.3.6.1 Zero Density Allotted Arc Routine

The Zero Density Allotted Arc Routine is the most straightforward approach that can be taken to identify a predetermined arc segment. The routine is used to search a portion of the geostationary orbit, pertaining to the critical groupings' group arc, from west to east to find a vacancy that can accommodate an orbital arc equal to the length of the critical groupings' required PDA. This approach is performed by the top third of Allotted Arc Module Flowchart (fig. 3.3-4).

The PTA is placed at the western edge of the group arc (see the top of the flowchart, fig. 3.3-4). Next, the density of the PTA across BOA is calculated (summation of 1's) and stored. If the density is zero, the temporary allotted arc (TA) for the critical grouping has been found and the Allotted Arc Module is exited. If the density is nonzero, PTA is moved eastward  $1^\circ$  and the process is repeated again (see fig. 3.3-5). This continues until a zero density PTA is found or all PTA's within the group arc have been tried unsuccessfully. If a zero density is found, the corresponding PTA becomes the critical grouping's temporary allotted arc and the module is exited with the solution. If all PTA's are exhausted without success, they are ordered from lowest to highest density, and the Push and Shuffle Allotted Arc Routines are called on to attempt to find a solution.

The Zero Density approach is the first solution method tried by the Allotted Arc Module because of its simplistic nature. The one major hindrance to this approach is that it can not alter past decisions. As the PDA's are generated, grouping by grouping, the orbital arc may become congested to the point that a vacancy of the required PDA length does not exist within the new critical grouping's group arc. However, with proper adjustment of existing TA's within their group arcs a solution could be obtained. For this reason, the Push and Shuffle Allotted Arc routines have been implemented in the NASARC software in the NASARC2 program module.

#### 3.3.6.2 Pairwise Check Routine

The Pairwise Check Routine is called in the Allotted Arc Module to examine the PTA's available for the critical grouping's TA to see if any of the PTA's would exclude any of the prior allotted grouping's TA's. If so, the PTA which would cause such an exclusion is eliminated from consideration for the critical grouping. This function is performed by determining if there is sufficient, continuous, remaining group arc (RGPARC) left for

# ALLOTTED ARC MODULE

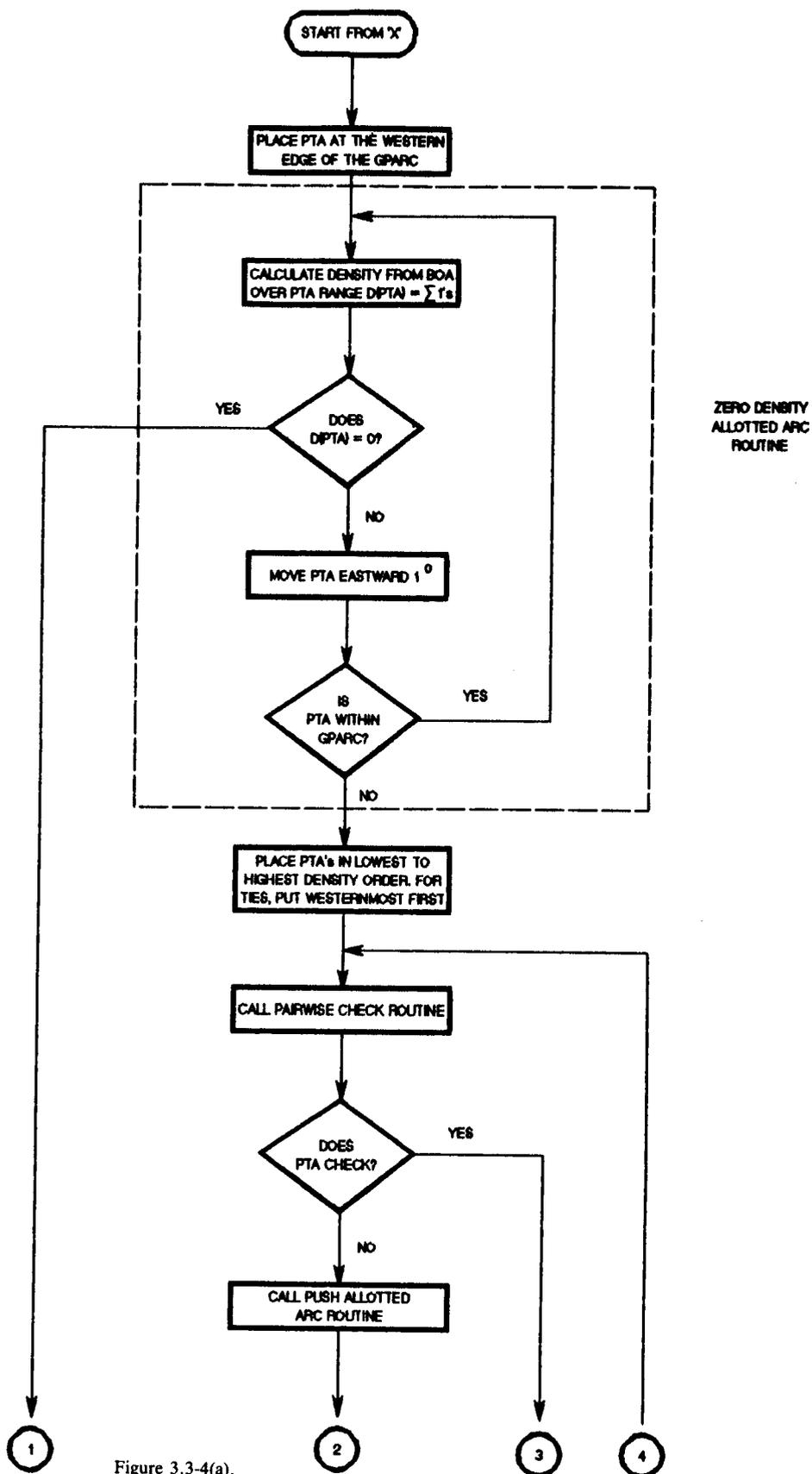


Figure 3.3-4(a).

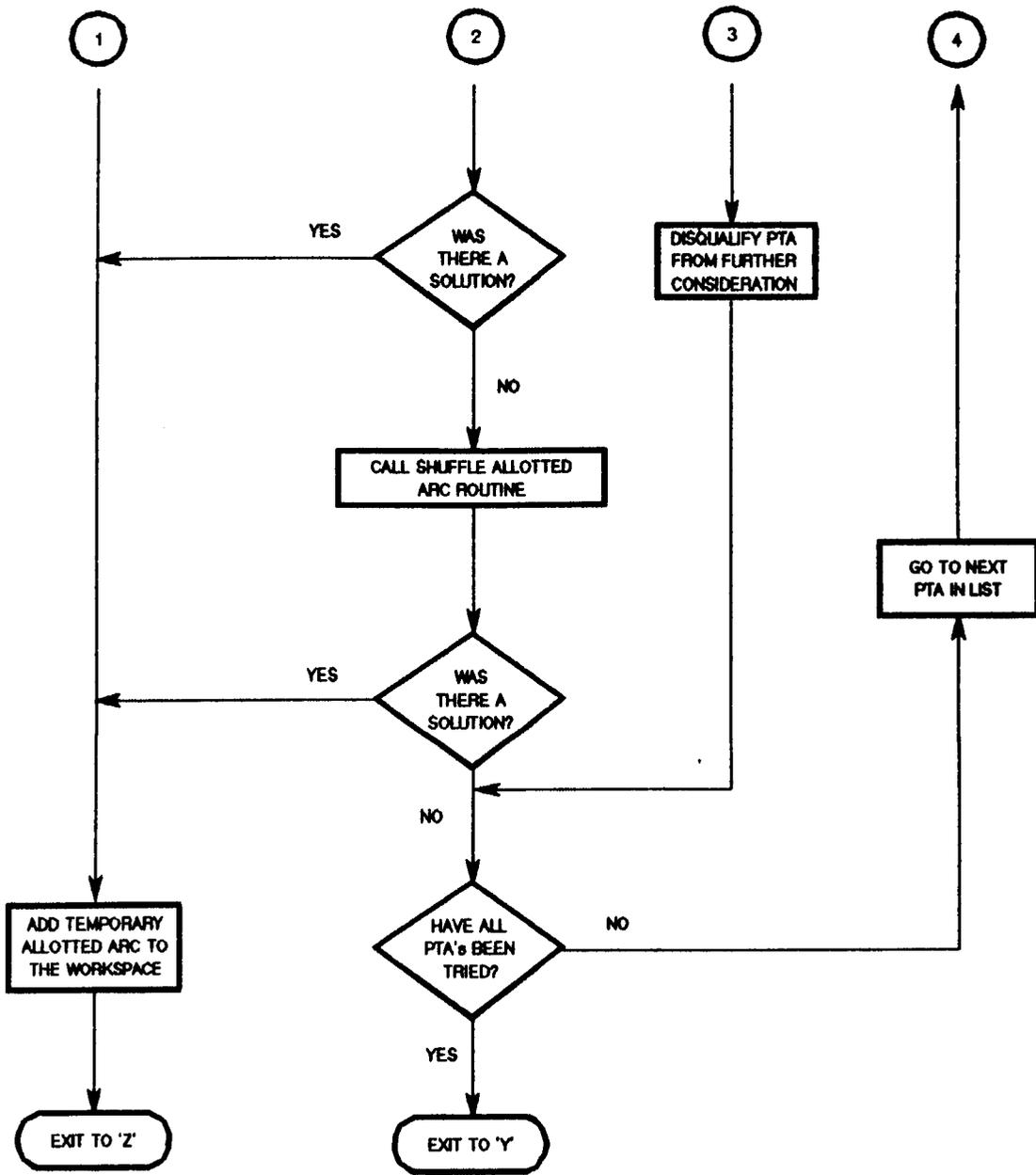


Figure 3.3-4(b).



each TA that intersects the given PTA in which to be relocated. The given PTA is classified as good if each intersecting TA checks, or it is disqualified if any of the prior allotted TA's would be excluded as a result of implementation of the given PTA. The flowchart for the Pairwise Check Routine is given in figure 3.3-6. This check routine is used solely to eliminate trying PTA's in the Push and Shuffle Allotted Arc routines that could not produce a solution.

Example 1 in figure 3.3-7 shows a PTA that checks, since each intersecting TA (TA1 and TA2) has sufficient RGPARC greater than or equal to their respective required arc lengths to allot. Example 2 in figure 3.3-7 shows a PTA that is disqualified because the second intersecting TA (TA2) has a RGPARC less than its required arc length to allot. It is important to note that the result of this routine does not guarantee that if a PTA checks a solution exists. It does determine which PTA's could never produce a solution so as not to access the Push and Shuffle Allotted Arc routines unnecessarily.

### 3.3.6.3 Push Allotted Arc Routine

The Push Allotted Arc Routine is one of two alternate routines incorporated into the software of NASARC2 that are accessed when (and only if) the Zero Density Allotted Arc Routine fails to find a temporary allotted arc for the critical grouping (see fig. 3.3-4). The objective of this routine is to clear the arc space required by a given PTA (i.e., the arc length required for the critical grouping's predetermined arc) by pushing intersecting TA's out and beyond the PTA boundaries. Since the Push Allotted Arc Routine is accessed on a PTA by PTA basis, before any attempts are made the critical groupings PTA's are sorted from lowest to highest density order. This sorting is performed because, in general, the lower density PTA will have a greater success rate in achieving a solution than a higher density PTA since it has a greater amount of vacant arc. When a solution is found in either of these routines (Push or Shuffle) the Allotted Arc Module is exited immediately.

The approach employed in the Push Allotted Arc routine is outlined as follows. Initially, the PTA is searched from west to east to locate the first eastern boundary of an intersecting TA. At this point, the program attempts to push the TA westward out of the arc encompassed by the PTA regardless of the presence of any other TA's. Since NASARC2 does not allow more than one TA to occupy any given arc location, other existing TA's may be affected by the attempted push. More precisely, when a TA is pushed, if it then overlaps another TA, the overlapped TA must also be pushed; this produces a chain reaction until no overlapment exists. If a TA being pushed overlaps more than one TA, the overlapped TA's are ordered from least to most remaining group arc in the pushing direction. These ordered TA's are then successively pushed within the constraints of their group arc boundaries.

A push attempt is considered successful if the pushed TA (one intersecting the PTA) and all TA's it affects can be moved in the direction of the push within the constraints of their respective group arcs. When a successful push occurs, a check is done to see if the PTA is clear. If it is, the routine is exited; if it is not clear, the search continues eastward for the next eastern boundary of an intersecting TA. When this is found, another westward push is tried as described previously. This process continues until either the PTA is cleared or a push was unsuccessful.

An unsuccessful push is one in which an affected TA (one requiring moving) becomes abutted against its group arc boundary and can not be pushed any further. At this point, the program maintains all (if any) successful pushes in the workspace and begins to try alternatively pushing TA's remaining in the PTA outward in the eastward direction. If it is able to clear the PTA in this direction, the Allotted Arc Module is exited with a new solution containing temporary allotted arcs for the critical grouping and all previously selected groupings. If it was unable to clear the PTA in this direction, the routine is exited without solution and the Shuffle Allotted Arc Routine is accessed. The flowchart of the Push Allotted Arc Routine is given in figure 3.3-8.

An example of the Push Allotted Arc Routine successfully clearing a PTA is given in figure 3.3-9. In this example, TA1 and TA3 intersect the PTA and require pushing. The program begins at the PTA's western edge and begins searching east for the first eastern boundary of an intersecting TA. For this case, it finds TA1's eastern

# PAIRWISE CHECK ROUTINE

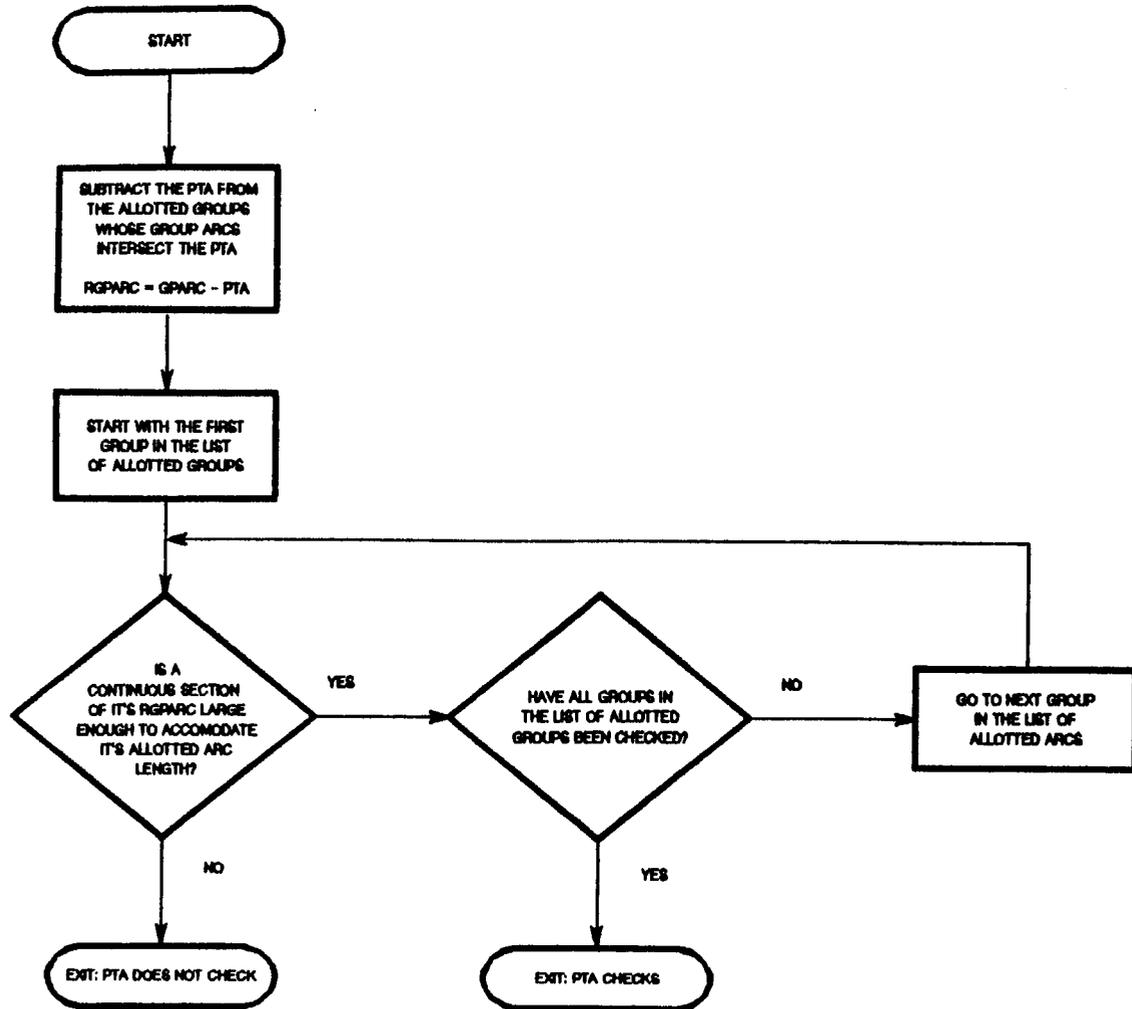
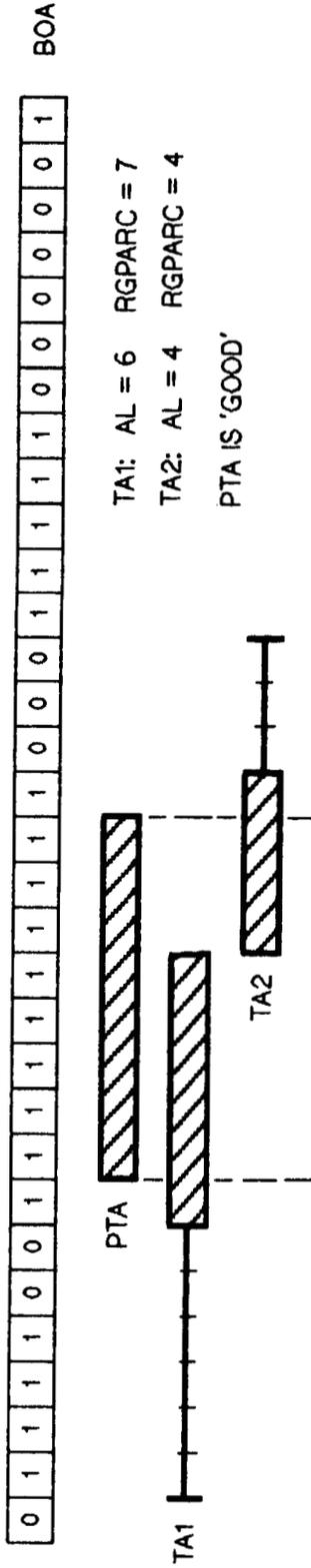


Figure 3.3-6.

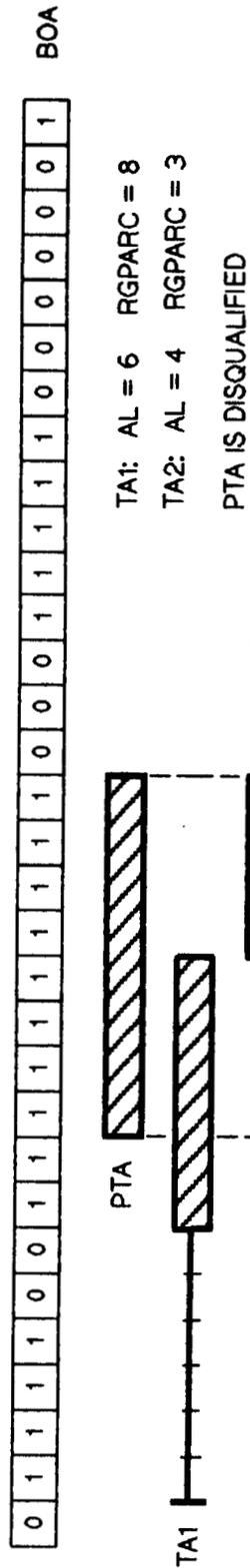
# PAIRWISE CHECK ROUTINE

**OBJECTIVE: DETERMINE IF EACH TA THAT INTERSECTS THE PTA HAS SUFFICIENT REMAINING GPARC FOR IT TO BE POSITIONED IN. PTA IS CLASSIFIED AS 'GOOD' OR DISQUALIFIED**

## EXAMPLE 1:



## EXAMPLE 2:



- \* AL = ALLOTTED ARC LENGTH
- \* RGPARC = REMAINING GROUP ARC

Figure 3.3-7.

# PUSH ALLOTTED ARC ROUTINE

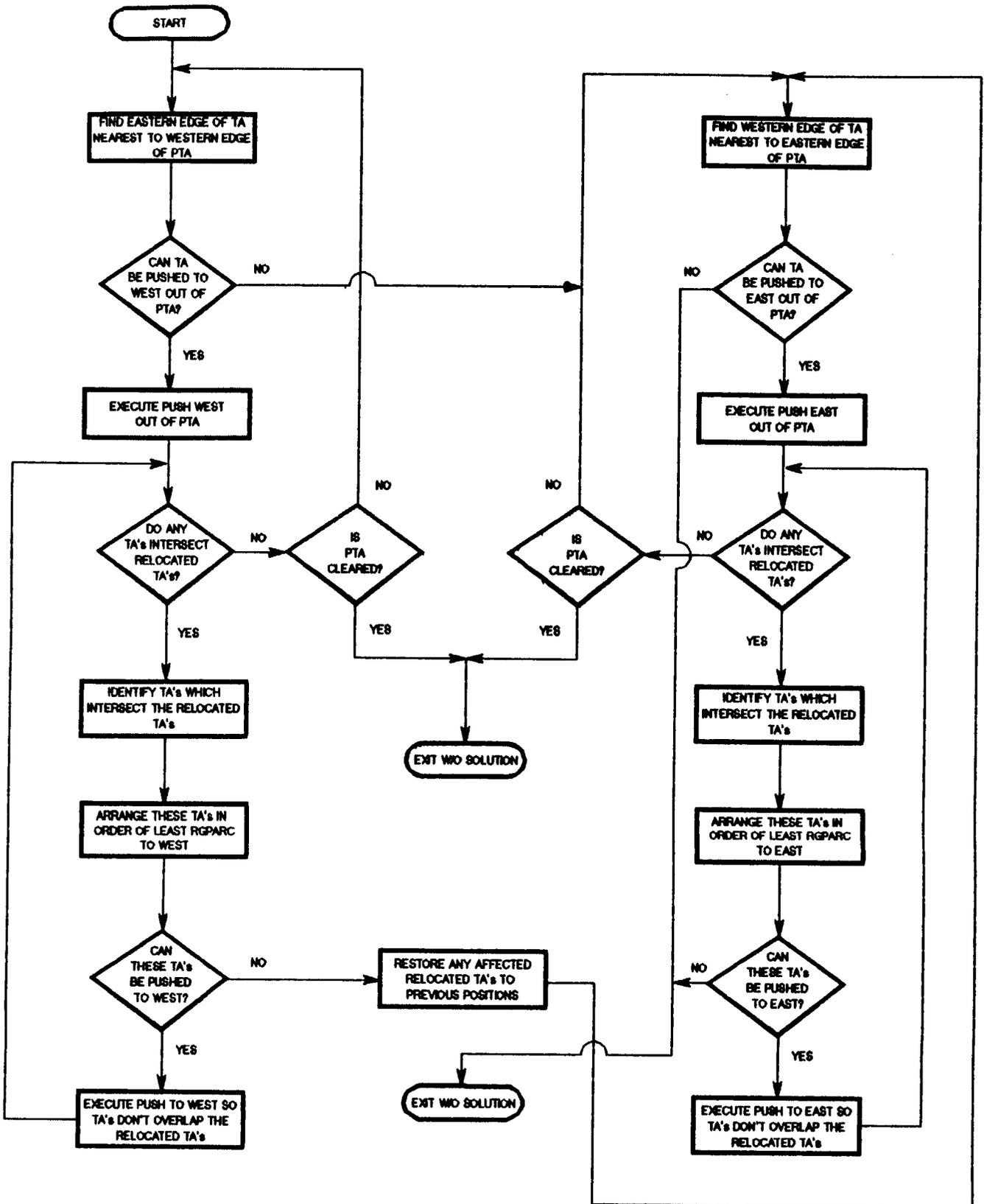


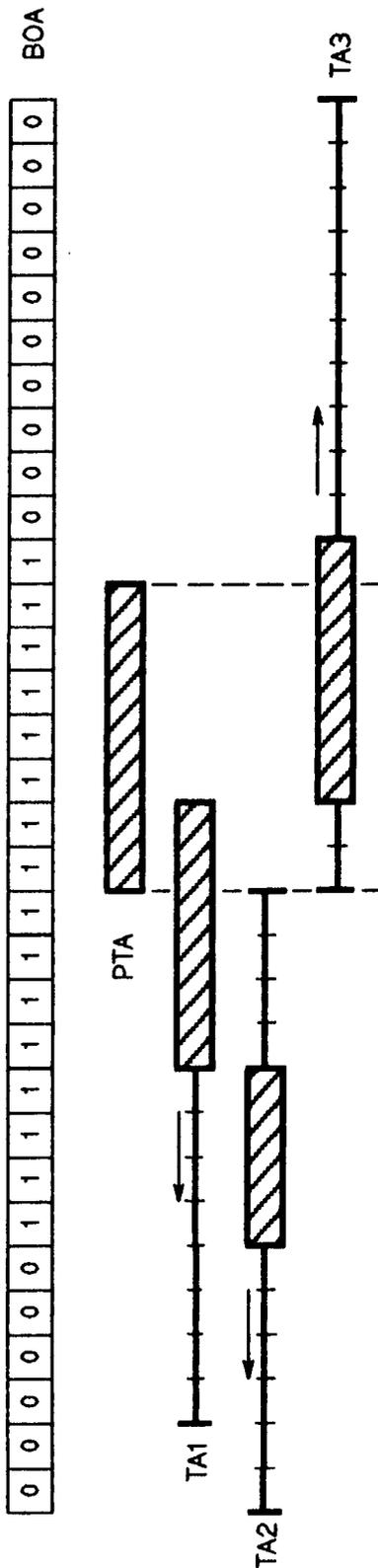
Figure 3.3-8.

# PUSH ALLOTTED ARC ROUTINE

**OBJECTIVE: CLEAR THE PTA FOR THE CRITICAL GROUPING BY 'PUSHING' EXISTING**

**TA'S OUT OF THE ARC SPACE REQUIRED BY THE PTA**

**EXAMPLE:**



**SOLUTION:**

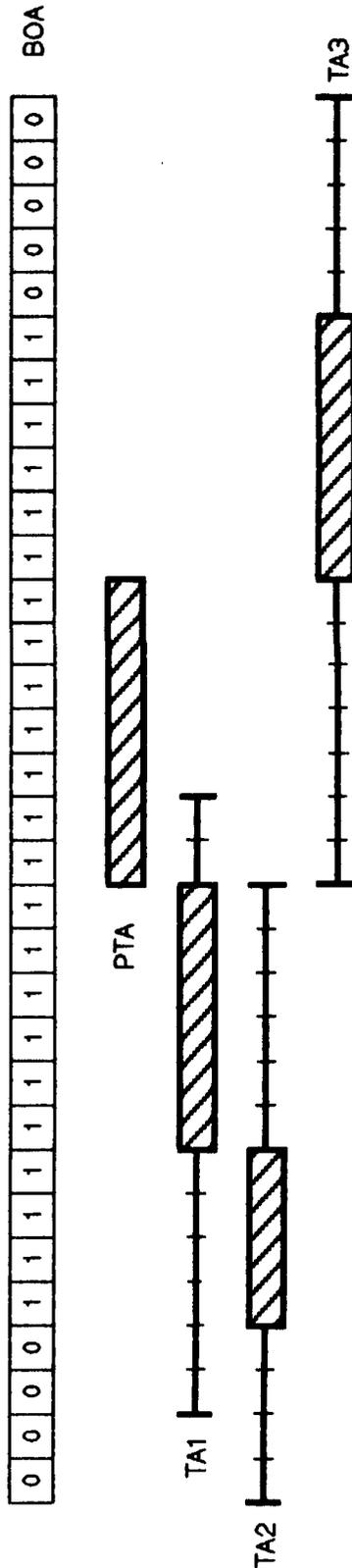


Figure 3.3-9.

edge and pushes it westward until it is beyond the PTA boundaries. At this point, it checks if TA1 is within its group arc. Since it is, the program proceeds. Next, it checks if TA1's new location overlaps any other TA's. It does, therefore TA2 must also be pushed west. When this is done, the program performs the group arc check on TA2 and the overlap check determining that no overlap remains and therefore the push was complete and successful.

The program is now at the point where it has successfully moved TA1 out of the PTA and a check is done to see if the entire PTA is clear. Since it is not, it continues searching east for the next eastern group arc boundary. When it locates TA3's eastern boundary, it attempts a second western push. This is unsuccessful because TA3 is presently abutted against its western arc edge. The program search now flips to the PTA's eastern arc edge and begins searching in the opposite direction (west) for the first western boundary of an intersecting TA. When TA3's western arc edge is located, the first eastern push is attempted. This will be successful because TA3 has sufficient group arc and its new location does not overlap any other TA's. When the PTA is checked to see if it is clear, and it is, a new solution (temporary allotted arcs for the critical grouping and all previous selected groupings) is obtained by the Push Allotted Arc Routine and the Allotted Arc Module is exited.

It is important to keep in mind the following fundamental concepts of the Push Allotted Arc Routine:

- (1) Westward pushes are attempted first.
- (2) If the PTA can not be cleared by pushing west, eastward pushes are attempted.
- (3) If the PTA can not be cleared by pushing east, the program exits the routine without a solution.
- (4) A western push is executed by searching east across the PTA for a TA's eastern group arc boundary.
- (5) An eastern push is executed by searching west across the PTA for a TA's western group arc boundary.
- (6) If all pushes (both west and east as required) are successful, the PTA is cleared and the program exits the routine with a solution.

The Push Allotted Arc Routine will have a fairly good success rate since it has the ability to alter past decisions made by the program. However, this routine is just one heuristic method of moving previously placed TA's to accommodate a PTA and does not guarantee a solution even though solutions may exist. For this reason, an alternate approach to obtain a solution has been included in the NASARC2 software, the Shuffle Allotted Arc Routine.

#### 3.3.6.4 Shuffle Allotted Arc Routine

The basic objective of the Shuffle Allotted Arc Routine is principally the same as the Push Allotted Arc Routine—clear the arc space required for a given PTA by relocating any existing TA's that intersect the PTA boundaries. The approach taken differs, however. In the Shuffle Allotted Arc Routine, TA's that intersect the PTA are relocated to zero-density regions outside the PTA but within their respective group arc constraints. In view of the fact that only TA's that intersect the PTA are moved (the rest remaining fixed), this approach is less complicated than the Push Allotted Arc Routine; but, because less group arc constraints are involved, it can handle cases where the Push routine would fail to find a solution.

When the Shuffle Allotted Arc Routine is accessed, the program identifies the TA's that intersect the PTA. Next, the TA's that intersect the arc locations required by the PTA are removed from the BOA. The method employed in the Zero-Density Allotted Arc Routine is now applied to find new temporary allotted arcs for the TA's that had intersected the PTA and are now removed from the BOA.

If new temporary allotted arcs can not be found for the TA's intersecting the PTA, the program exists without a solution. If all are successfully relocated, the program exits the Shuffle Allotted Arc Routine with the new temporary allotted arcs. Figure 3.3-10 presents a flowchart of the Shuffle Allotted Arc Routine.

An example of the Shuffle Allotted Arc Routine, successfully producing a new solution containing the critical grouping and all previously selected groupings, is given in figure 3.3-11. Based on the discussion in section 3.3.6.3,

# SHUFFLE ALLOTTED ARC ROUTINE

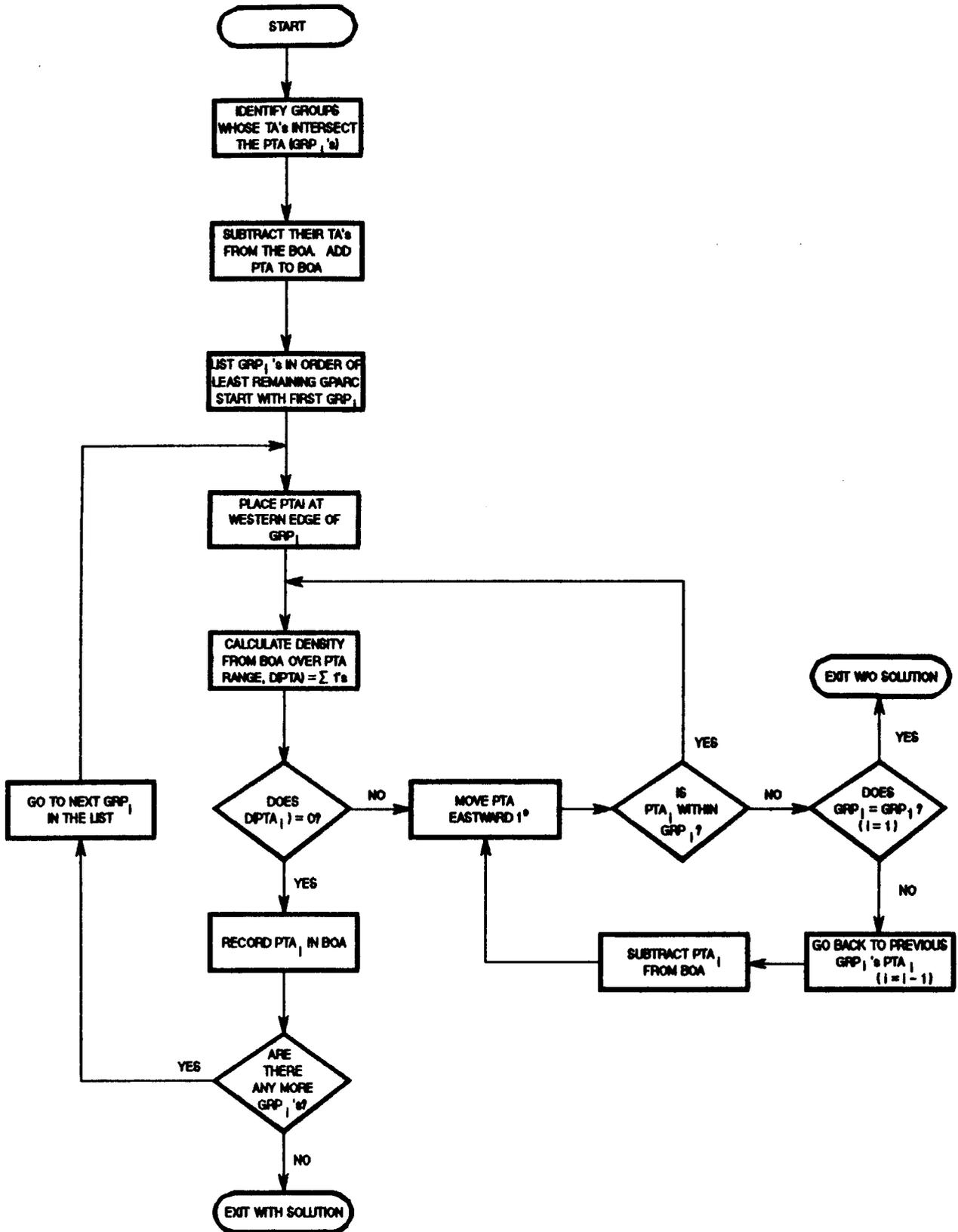


Figure 3.3-10.



it can be seen that the Push routine would have been unsuccessful for the case represented in the example in figure 3.3-11. In the example, one TA (TA1) intersects the PTA. After removing TA1 from the BOA and registering the PTA into the BOA, a search from west to east across TA1's group arc is performed to find a zero-density region of the required arc length corresponding to TA1. In the example, the search identified a new location for TA1, and the resulting solution is given at the bottom of the figure.

Accessing the Push and Shuffle Allotted Arc routines is done consecutively on an individual PTA basis (see fig. 3.3-4). If either routine achieves a solution, the loop is exited and the Allotted Arc Module returns the updated temporary allotted arcs to the main program. If both routines exhaust the list of PTA's for the critical grouping without finding a solution, the Allotted Arc Module is exited and a new grouping containing the critical service area is sought. If the critical grouping had been a single priority P1 service area, it is flagged for special handling (see section 3.3.7) and a new critical service area is selected.

With the overall objective of the Allotted Arc Module [Given a critical grouping with its corresponding group arc, find a temporary allotted arc for it that maintains temporary allotted arcs for all previously selected groupings.], the combination of the three heuristic approaches (Zero Density, Push, and Shuffle) operating on multiple PTA's offers a high probability of successfully formulating predetermined arcs for all service areas given a suitable set of technical parameters.

### 3.3.7 Special Handling of Unallottable Service Areas

Given some sets of technical parameters as input to NASARC, solutions providing all ITU members with a predetermined arc in which they are included will be possible. However, certain combinations of technical parameters are likely not to produce a solution which allows the fulfillment of the requirements of the allotment plan. Parametric analyses will need to be performed during the intersessional period to identify ranges of parameters and tradeoffs in parameter values that will allow the requirements of an allotment plan to be satisfied. The planning software must be capable of accepting a range of input parameter values even if an acceptable solution can not be found for a particular combination of parameters.

For certain scenarios, it may not be possible to allocate a predetermined arc segment to every service area due to the choice of input technical parameters (e.g., spacecraft antenna rolloff not sufficient to allow proper grouping or downlink C/I value specified too high for the grouping criterion to be met). Under situations such as these, the NASARC programs may not be able to accommodate all service areas into predetermined arcs. Some service areas will be unallottable as a result of the parameter values chosen for the scenario. The NASARC (Version 2.0) software flags service areas for which a predetermined arc could not be found within their service arc constraints. These unallotted service areas are identified in the NASARC Report file for special handling external to the programs. That is, the unallotted service areas would need to be handled manually.

The likelihood of accommodating unallotted service areas manually is dependent on the number involved. If the number of these service areas is large, it is an indication that the scenario input parameters need to be adjusted to obtain a workable solution. However, if the number of unallotted service areas is small it may be possible to fit the service areas into holes in the orbital arc where other PDA's were not allotted by the NASARC software. One possible approach to this would be to expand the service arc limits of the unallotted service areas beyond the service arcs originally supplied to the NASARC programs. If holes in the orbital arc were then available within the new service arc limits, the previously unallotted service areas could be allotted individual predetermined arcs equal to their buffer size. Expansion of the service arc limits should not cause appreciable degradation in performance for the few service areas which might be affected.

Expanding the service arcs of unallotted service areas still may not provide a workable solution in some cases (e.g., original NASARC output used all of the orbital arc leaving no holes). In this case, the user would need to change the input parameters to the NASARC software and rerun the scenario.

### 3.4 NASARC3: Group Arc Extension Program

NASARC3, the fourth program in the NASARC (Version 2.0) software package, performs three different functions in the overall NASARC concept. The first and primary function of this module is to extend the group arcs of the groupings that were previously allotted in the NASARC2 module into the next segment to be executed in the piecewise approach. This function is performed to maintain full flexibility when accessing the Allotted Arc Module (see section 3.3.6) in NASARC2 for future segments. If there are no future segments remaining in the Segments file, NASARC3 performs two secondary functions before NASARC successfully terminates the run: restoration of the original Segments file for future runs of the NASARC software package and printing the NASARC output report.

For NASARC3 to perform the previously stated functions, it must access and create a variety of files. In order to determine which function to perform, NASARC3 must first determine from the original Segments file if there are any remaining segments to execute. If there are, it must access all the technical input parameters and the most recent NASARC2 results residing in the Intermediate Allotted Groupings file. After performing any necessary arc extensions for the allotted groups, NASARC3 produces an updated Intermediate Allotted Groupings file for use in future segments of the piecewise approach.

If there are no future segments to execute, NASARC3 restores the original Segments file that has been exhausted by NASARC1 (see section 3.2.1) by transferring back the information contained in the Intermediate Segments file, which at this point contains all of the segments in the original order. Finally, NASARC3 is responsible for printing the NASARC output report containing all of the technical input data and the final results consisting of the final list of allotted groupings and their corresponding PDA boundaries, and a listing of any unallotted service areas.

There are two major subtopics covered in this section which discuss the concepts necessary to perform the group arc extension function (i.e., determination of the extension direction, determination of feasible arc limits, and the minicompatibility matrix). Also covered are the other NASARC3 functions (restoration of the Segments file and output of the final results).

#### 3.4.1 Determination of Candidate Groupings, Extension Direction, and Feasible Arc Limits

The first operation that NASARC3 performs when executing the group arc extension function is to determine which of the allotted groupings are feasible candidates and in which direction their group arcs should be considered for arc extension. This is done by a simple comparison of each allotted groupings' group arc boundaries with the corresponding boundaries of the next segment to be executed in the piecewise approach. If either of the group arc boundaries adjoin one of the segment's boundaries, the grouping is a candidate for arc extension and is placed in an update list for further consideration. If neither boundaries adjoin, the grouping is no longer considered.

The direction of arc extension for each candidate grouping is easily determined by noting which of the group arc boundaries adjoin which of the segment boundaries. When the eastern boundary of the group arc adjoins the western segment boundary, an eastward search is indicated. Similarly, if the western boundary of the group arc adjoins the eastern segment boundary, a westward search is indicated. Once a grouping has been found that is a candidate for group arc extension, the range over which the inner compatibility among the group members must be examined is calculated. This is accomplished by performing an intersection operation on the group members service arcs with the segment arc. The resultant feasible arc could extend completely across the segment or it may not exist at all. The latter case results when a group members service arc boundary coincides with the adjoining segment boundary. If this occurs, the grouping is no longer considered.

The result of this procedure is a determination of a group's candidacy for arc extension, a determination of the extension direction, and a calculation of its feasible arc limits. Following this is a calculation of the group's compatibility over its feasible arc range resulting in an updating of the Interim Allotted Groupings file.

### 3.4.2 Extending Group Arc for Allotted Groups

Once an allotted grouping has been found that is eligible for having its group arc extended into the next segment and its feasible arc limits have been established, a compatability analysis of all service areas within the allotted group must be performed to determine the actual amount to extend the group arc. To accomplish this NASARC3 performs many of the same calculations as in NASARC1, but on a much smaller scale. NASARC1 must analyze all service areas within the scenario that intersect a given arc location on a pairwise basis, while NASARC3 need only analyze the service areas present within the allotted grouping. On this smaller scale, the process reduces to the construction of a mini-compatability matrix at each given arc location, incremented (or decremented depending on the extension direction) across the feasible arc range. When an incompatibility is found between any pair of service areas, the grouping no longer exists and the new group arc boundary becomes the last arc location at which complete compatability existed.

In determining the amount of arc extension for a given allotted grouping, NASARC3 must examine all pairwise compatabilities between group members across the feasible arc range. This is achieved by the construction of a mini-compatability matrix (similar to the concept described in section 3.2.2). The procedure for developing the compatability matrix is outlined as follows:

- Step 1 Read in polygon points and ellipses for all service areas within the grouping being considered.
- Step 2 Begin with space station location at the edge of the feasible arc that adjoins the group arc.
- Step 3 Select the wanted service area from the current group.
- Step 4 Select the interfering service area from the current group.
- Step 5 Check if the interfering service area is the same as the wanted or if they are both members of the same affiliated set. If they are, set the compatability flag for this pair of service areas in the mini-compatability matrix to 1 and select a new interferer. If they are not, continue.
- Step 6 Calculate the target  $C/I$  from the threshold  $C/I$ ,  $\Delta_i$ , and  $\Delta_w$ .
- Step 7 Calculate the  $C/I$  in both directions (unless the location is at the limit of the feasible arc, then only in the direction within the arc range) at a spacing equal to the grouping criterion.
- Step 8 Compare the calculated  $C/I$  value(s) to the target  $C/I$ . If the calculated  $C/I$  values exceed the target  $C/I$ , set the compatability flag for this pair of service areas in the mini-compatability matrix to 1 and continue. If they do not, set compatability flag to 0 and discontinue examining group, as complete compatability does not exist. Retrieve the next grouping to examine and repeat steps 1 to 12.
- Step 9 Repeat steps 4 to 8 for all remaining interfering service areas.
- Step 10 Repeat steps 3 to 9 for all remaining wanted service areas.
- Step 11 Extend group arc to current location.
- Step 12 Increment (or decrement depending on the extension direction) the space station location. If space station location is within the feasible arc limit, repeat steps 3 to 11. If it is not, retrieve the next grouping to examine and execute steps 1 to 12.

After all allotted groups whose group arcs adjoining the new segment have been examined for arc extension, NASARC3 updates the Intermediate Allotted Groupings file with any extended group arcs it has found and the program halts execution.

### 3.4.3 Other NASARC3 Functions

As previously mentioned, NASARC3 performs two secondary functions if there are no future segments to execute. The first action the program takes after it determines the present segment is the final one in the scenario, is the restoration of the original Segments file. Since at this point, the Intermediate Segments file contains all of the past and present segments in the order of their execution, NASARC3 copies the data in the Intermediate Segments file to the original Segments file. This maintains the ability to reuse the same Segments file for future runs.

Secondly, NASARC3 is responsible for producing the NASARC final results output report (NASARC Report file). This document contains all input parameters including service arcs, affiliated sets, inhomogeneity factors, individualized antenna parameters, segment data, downlink *C/I*, downlink frequency, grouping criterion, minimum ellipse beamwidth, and buffer length information. Included in the presentation of the final results is a listing of the allotted groups and their associated PDA boundaries, information on any unallotted service areas, and a pictorial line chart representation of each PDA's location in the orbital arc.

For further details on the execution of the NASARC3 program, the reader is referred to the NASARC3 flowchart (fig. 3.4-1.)

## 3.5 Technical Assumptions Inherent in NASARC Software

### 3.5.1 Introduction

In response to the decisions of WARC'85 regarding allotment planning for the Fixed Satellite Service, the NASARC software package has been developed to identify and select predetermined arcs for use by each service area in an allotment plan. As it is neither possible, nor desirable, to include contingencies within the software for all possible decisions on allotment planning issues, it has been necessary to incorporate various technical assumptions into the design of NASARC. During the course of the development of NASARC, efforts have been made to ensure that these assumptions are reasonable, and that the software is sufficiently flexible to accommodate a variety of technical parameter specifications.

This section identifies technical assumptions which were made in the development of the NASARC (Version 2.0) software. These assumptions fall into two categories: (1) those that are inherent in the NASARC concept, and (2) those that establish a baseline but may be altered through individual parameter specification for each service area. The distinction will be made in the details to be given. The assumptions are summarized in table 3.5-1.

### 3.5.2 Assumptions

#### 3.5.2.1 Shared Predetermined Arcs

The NASARC software has been developed to correspond to a specific interpretation of the predetermined arc. Each predetermined arc is shared by a group of compatible service areas. NASARC first finds all such groups of service areas and the arc span over which each group may exist. Each compatible group consists of service areas that are sufficiently separated geographically so that colocation or near colocation of their corresponding satellites will result in achieving a specified single-entry *C/I*. When a complete list of all such groups, and their associated arcs, has been assembled within a given arc segment by NASARC, selection of groups and arcs to be allotted is made on the basis of a variety of figures of merit. As a final result, a service area is allotted a portion of the geostationary orbital arc which it will share with other service areas. Due to the grouping of service areas whose satellites may be located closely together in orbit, flexibility of satellite positioning is maintained within the allotted arc segment. Shared predetermined arcs is an assumption which is inherent in the NASARC concept.

# NASARC3 -- The Group Arc Extension Program

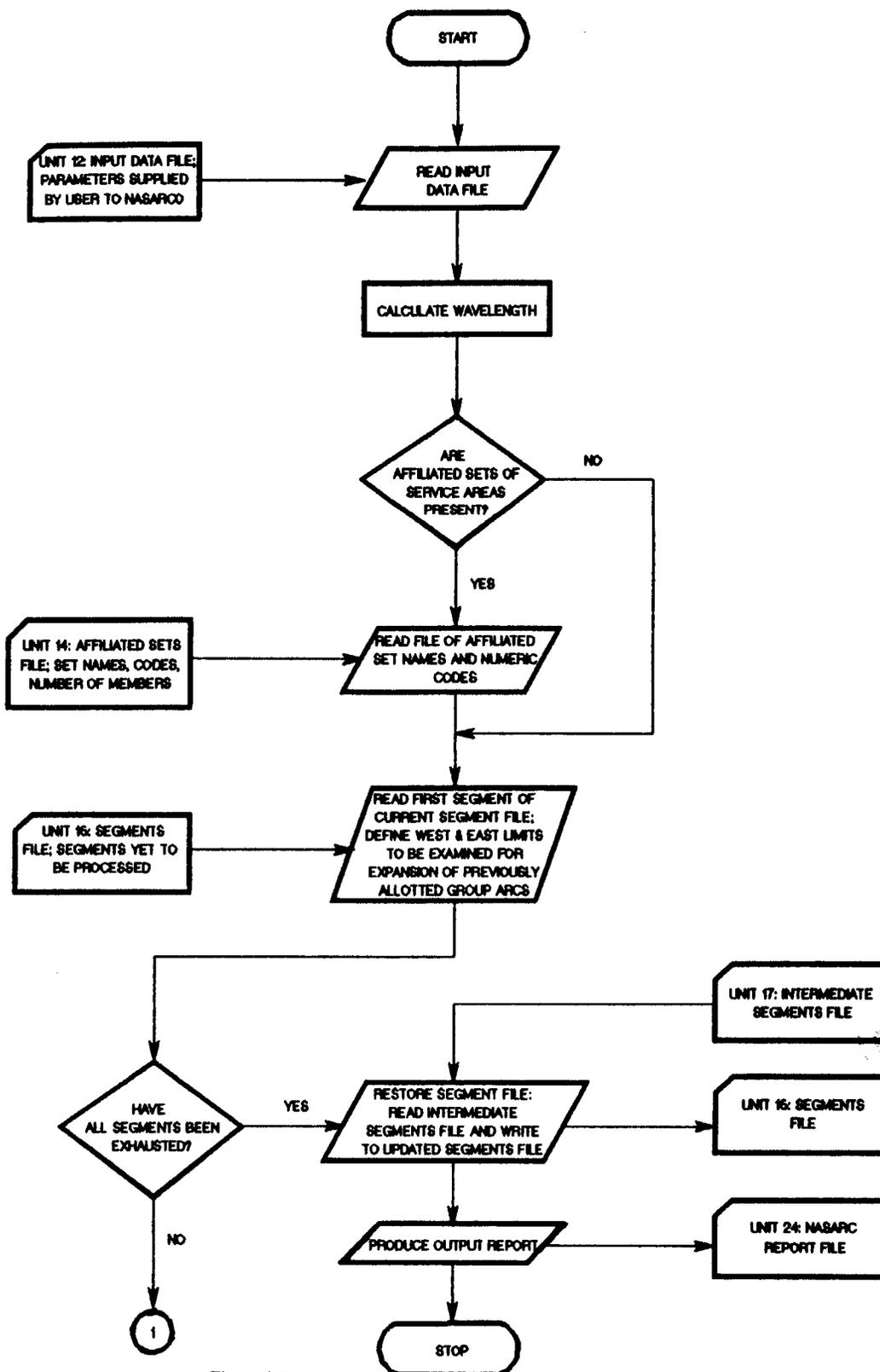


Figure 3.4-1(a).

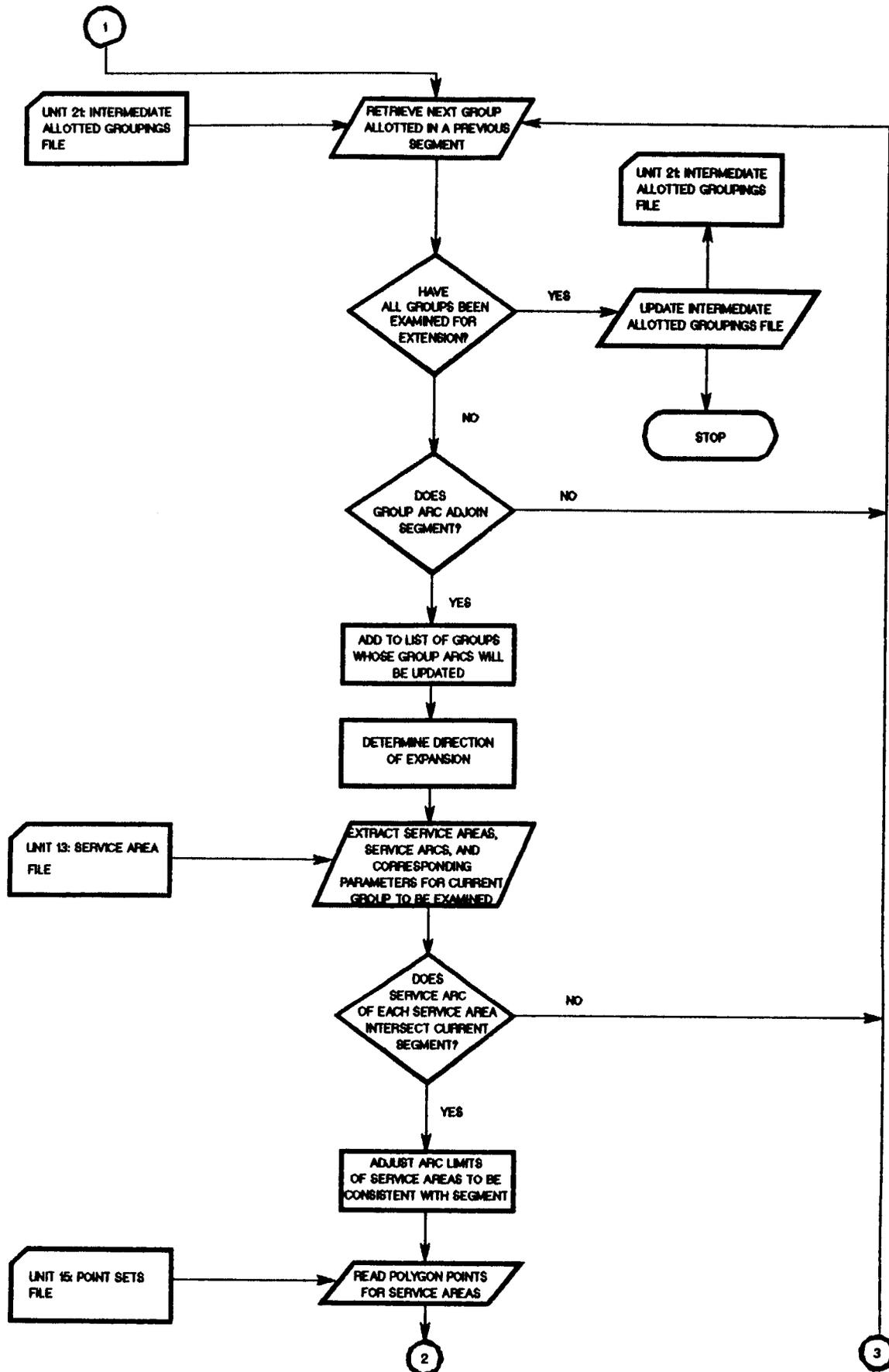


Figure 3.4-1(b).

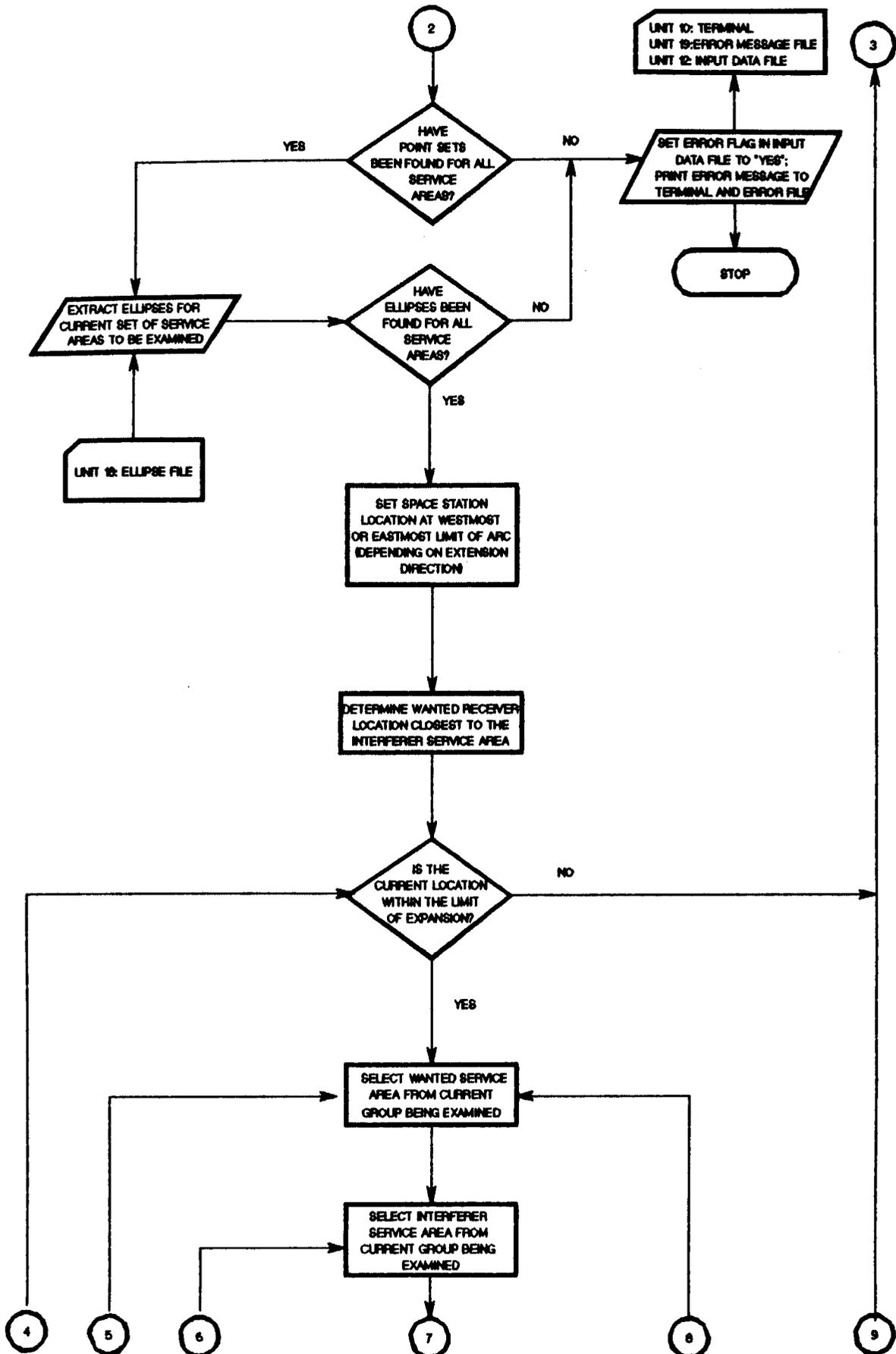


Figure 3.4-1(c).

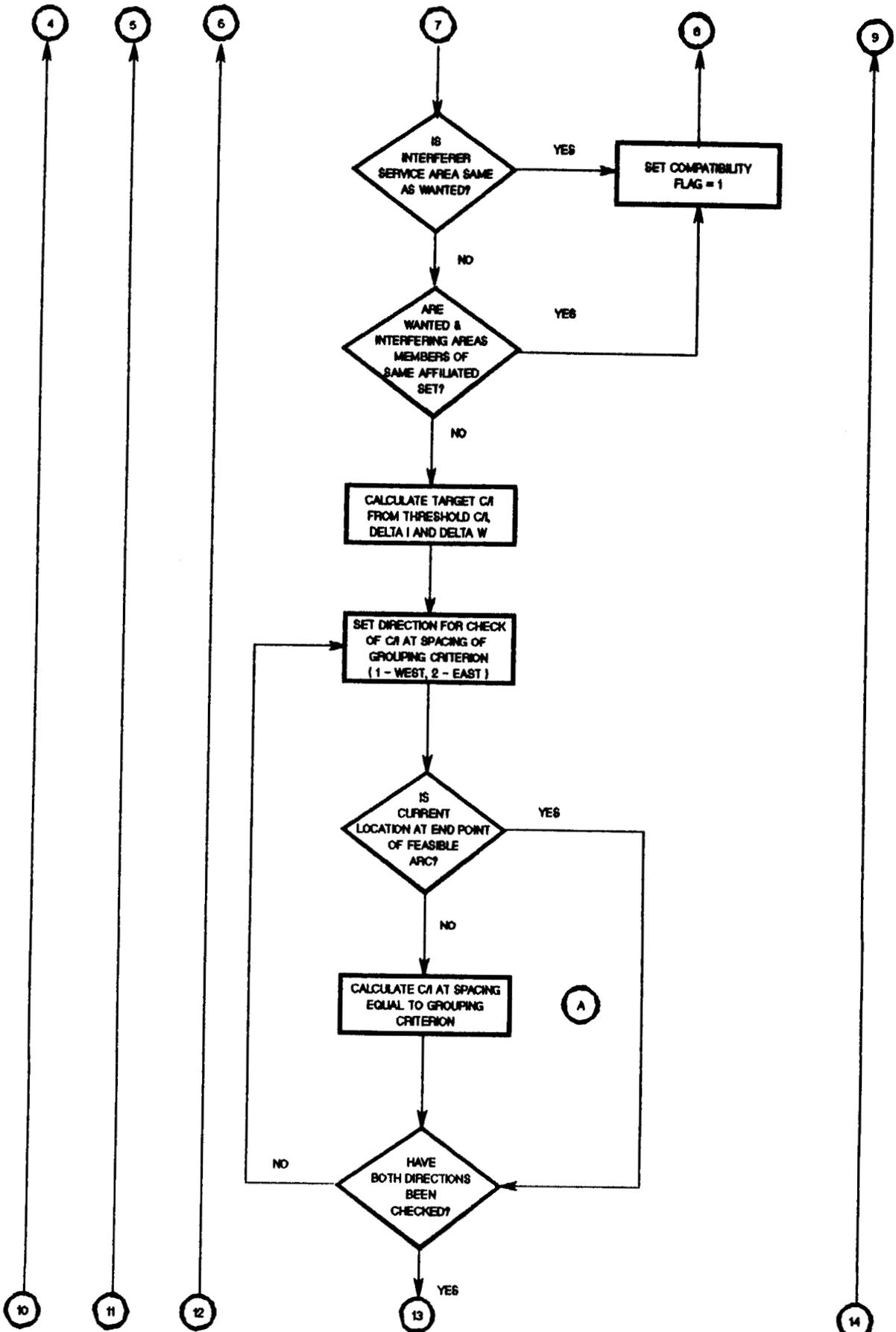


Figure 3.4-1(d).

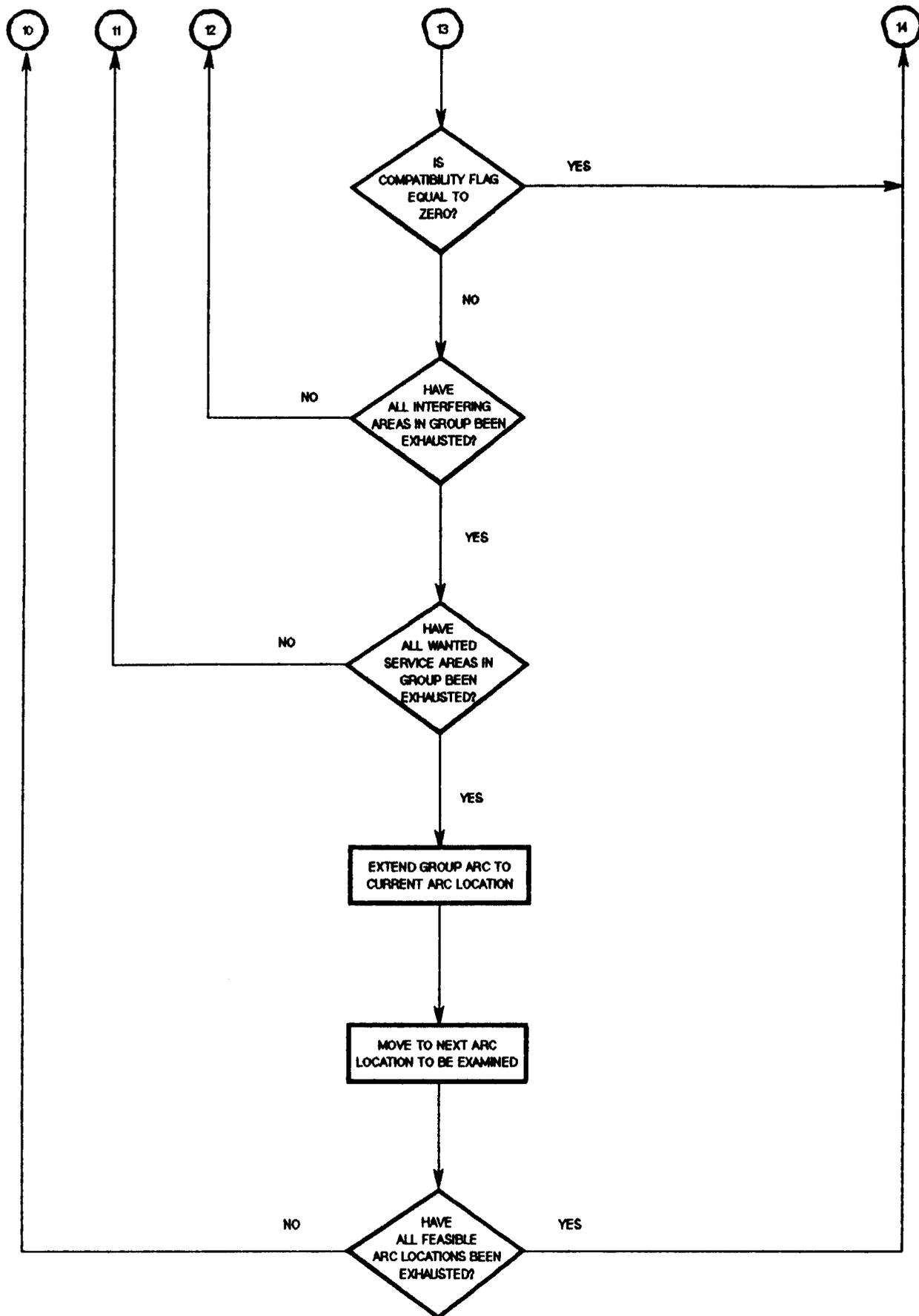


Figure 3.4-1(e).

### 3.5.2.2 Downlink Interference

The compatibility between pairs of service areas is assessed on the basis of a target single-entry  $C/I$  to be met, on a downlink-only basis, at the worst-case test point of the desired service area. Thus, NASARC (Version 2.0) performs calculations on a downlink-only basis. Downlink-only interference is an inherent assumption in the NASARC concept.

### 3.5.2.3 Clear-Sky Conditions

The determination of service area compatibility within NASARC (Version 2.0) is performed assuming clear-sky conditions. This assumption can be altered by user specified inputs in the Service Area file related to the inhomogeneity factor (see section 3.1.1.2.3).

### 3.5.2.4 Constant Power Flux Density

The determination of service area compatibility is performed under the assumption of constant power flux density at the edge of the ellipse covering the downlink service area. This assumption can be altered by user specified inputs in the Service Area file related to the inhomogeneity factor (see section 3.1.1.2.3).

### 3.5.2.5 Use of Minimum Area Ellipses

Coverage of a service area by a space station antenna has been modelled in NASARC (Version 2.0) using the minimum area ellipse for the service area. However, the capability to model more sophisticated technologies is not eliminated. For example, shaped beams may be approximated by the use of a fast rolloff space station antenna pattern, in which gain from the edge of the minimum area ellipse declines at the same rate as that of a minimum half-power beamwidth antenna. The minimum half-power beamwidth for the space station antenna is a user-supplied input.

### 3.5.2.6 Homogeneous Antenna Patterns

Within NASARC (Version 2.0), uniform earth station receive and uniform satellite transmit antenna falloff characteristics specified by the user will be applied to all service areas unless individual antenna parameters are specified in the Service Area file. The variety of patterns available to the NASARC user for the description of earth station receive and satellite transmit antennas offers a large degree of flexibility (e.g., the ability to use a fast rolloff satellite antenna pattern as a simplified method of approximating shaped-beam rolloff). Section 3.1.1.2.4 provides information on the specification options available to the user for individual earth station and satellite antenna characteristics.

### 3.5.2.7 Uniform Single-Entry Downlink Carrier-to-Interference Ratio

The threshold downlink  $C/I$ , set by the user, is used as a uniform single-entry requirement for all possible pairs of service areas when the inhomogeneity factor optional input is not used in the Service Area file. Otherwise, a target downlink  $C/I$  is used which is the threshold  $C/I$  value as modified by the inhomogeneity factors associated with each service area (see section 3.1.1.2.3).

### 3.5.2.8 Single Downlink Frequency

The determination of service area compatibility is performed based on a single downlink frequency to be input by the NASARC user. Thus, interference is examined on a cochannel basis only. This is consistent with full bandwidth allotments as no frequency discrimination will be available.

### 3.5.3 Summary of Assumptions

The assumptions made in developing the NASARC (Version 2.0) software are consistent with the allotment planning policy guidelines set forth by WARC-85. In areas where such guidelines have not been given, the NASARC software has been designed to incorporate assumptions that are reasonable and that allow for allotment planning success.

The assumption for shared predetermined arcs is fundamental to NASARC, as is the concept of compatibility between service areas. Service areas are regarded as compatible if they possess sufficient geographic separation to allow near colocation of their satellites, based on a single-entry  $C/I$  criterion.

NASARC (Version 2.0) assumes that the downlink is dominant for the purpose of planning, and that effective planning may take place under the assumption of clear-sky conditions. The NASARC (Version 2.0) software performs its determination of service area compatibility for downlink-only interference on the basis of constant power flux density, with service area coverages modelled by minimum-area elliptical beams. The user has the option of specifying homogeneous inputs for the satellite antenna falloff characteristic, earth station antenna, and threshold downlink carrier-to-interference ratio to be applied to all service areas. All such parameters are user-specified. In addition, the user has the option of overriding some of the baseline assumptions in the software through specification of individual parameter values for each service area related to the earth station and satellite antenna characteristics. Finally, the inhomogeneity factor option may be used to alter the clear-sky assumption, constant power flux density assumption, or constant  $C/I$  assumption.

TABLE 3.5-1—SUMMARY OF TECHNICAL ASSUMPTIONS INHERENT IN NASARC SOFTWARE

Assumption	Comments
1. Shared predetermined arcs	Fundamental to NASARC grouping concept.
2. Calculations performed on downlink-only basis	
3. Calculations performed under clear-sky conditions	May be altered through use of inhomogeneity factor.
4. Calculations based on constant pfd	May be altered through use of inhomogeneity factor.
5. Use of minimum-area elliptical beams	Sufficiently flexible to approximate shaped-beam rolloff. User-input minimum half-power beamwidth. Requires input file of appropriate ellipses.
6. Same satellite transmit falloff characteristics and earth station receive antenna used by all service areas	Sufficiently flexible to accommodate variety of antenna technologies including rapid rolloff beams.  User-input patterns used. May be overridden through individual antenna specification.
7. Calculations based on uniform single-entry downlink threshold $C/I$	User-input value.  May be altered through use of inhomogeneity factor.
8. Calculation based on single downlink frequency	User-input value.

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16. Abstract <p>The information contained in the <i>NASARC (Version 2.0) Technical Manual</i> (NASA TM-100160) and <i>NASARC (Version 2.0) User's Manual</i> (NASA TM-100161) relates to the state of NASARC software development through October 16, 1987. The <i>Technical Manual</i> describes the Numerical Arc Segmentation Algorithm for a Radio Conference (NASARC) concept and the algorithms which are used to implement the concept. The <i>User's Manual</i> provides information on computer system considerations, installation instructions, description of input files, and program operation instructions. Significant revisions have been incorporated in the Version 2.0 software over prior versions. These revisions have enhanced the modeling capabilities of the NASARC procedure while greatly reducing the computer run time and memory requirements. Array dimensions within the software have been structured to fit within the currently available 6-megabyte memory capacity of the International Frequency Registration Board (IFRB) computer facility. A piecewise approach to predetermined arc generation in NASARC (Version 2.0) allows worldwide scenarios to be accommodated within these memory constraints while at the same time effecting an overall reduction in computer run time.</p>					
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