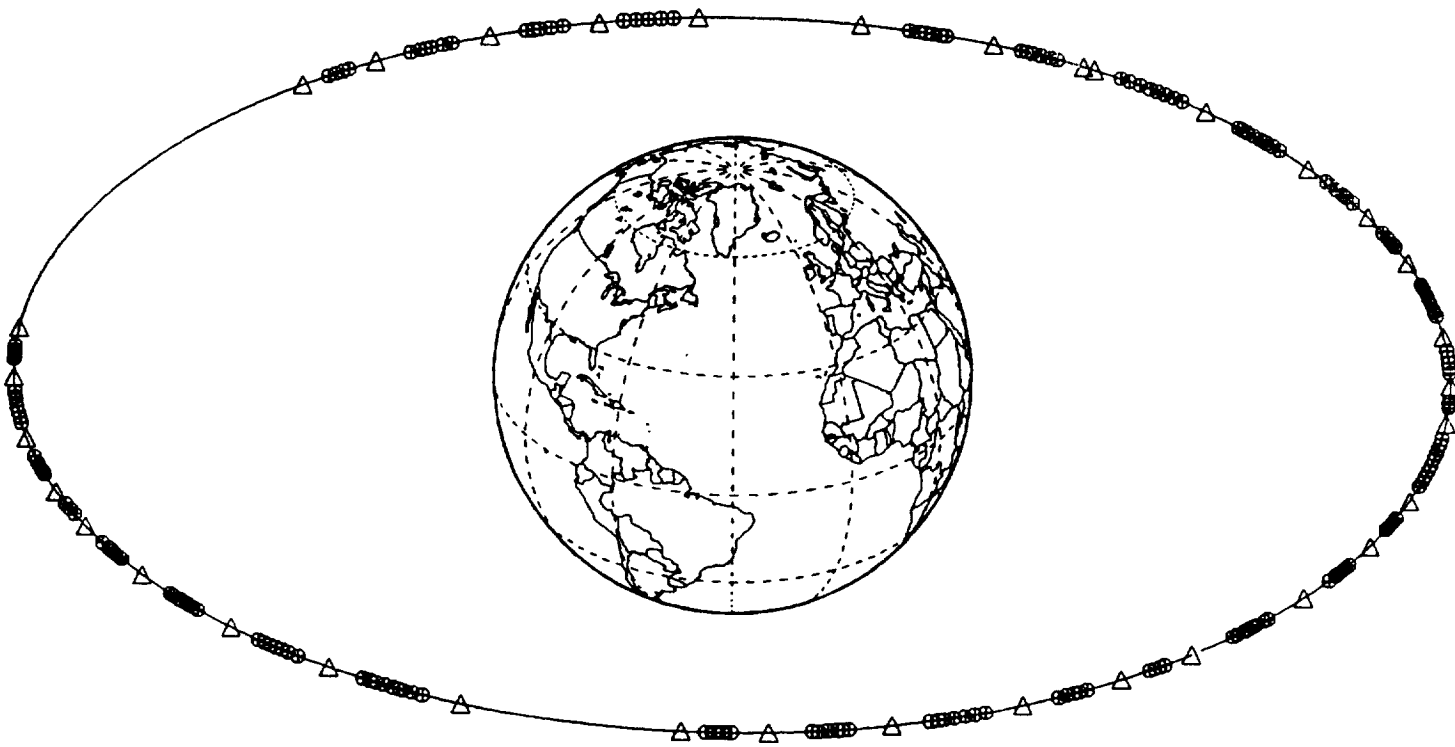


Numerical Arc Segmentation Algorithm for a Radio Conference – NASARC (Version 4.0)

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 6, 1988

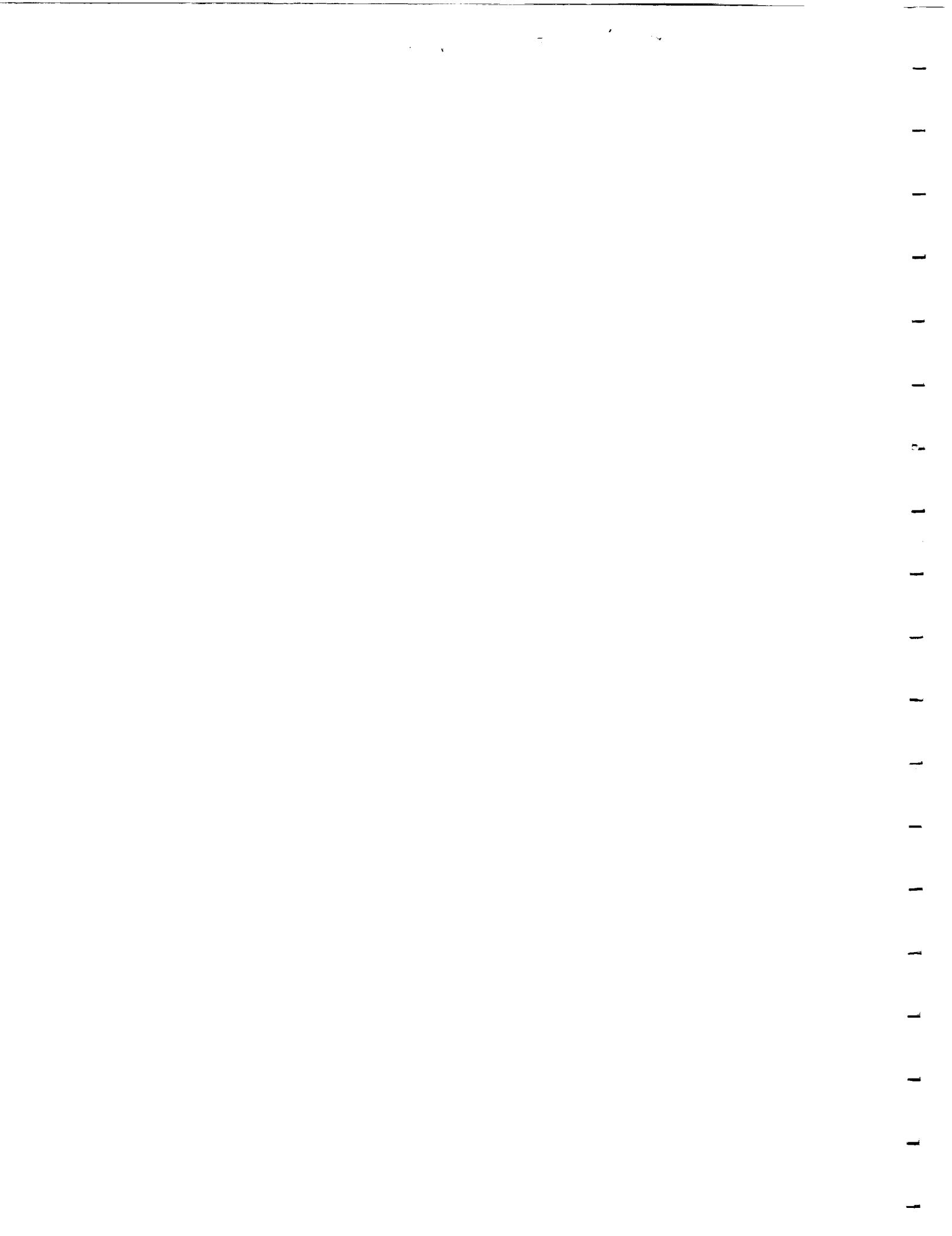
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Cover: The Technical Memorandum number should be 101453 (NOT 100453). (The number is correct on the RDP page at the back of the report.)

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PREFACE

The software package, Numerical Arc Segmentation Algorithm for a Radio Conference (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). Through careful selection of the predetermined arc (PDA) for each administration, flexibility can be increased in terms of choice of system technical characteristics and specific orbit location. The NASARC software determines pairwise compatibility between all possible systems at discrete arc locations. NASARC then exhaustively enumerates groups of administrations whose satellites can be closely located in orbit and finds the arc segment over which each such compatible group exists. From the set of all possible compatible groupings, groups and their associated arc segments are selected using a heuristic procedure such that a PDA is identified for each administration.

The information contained in the *NASARC (Version 4.0) Technical Manual* (NASA TM-101453) and the *NASARC (Version 4.0) User's Manual* (NASA TM-101454) relates to the state of Numerical Arc Segmentation Algorithm for a Radio Conference (NASARC) software development through November 1, 1988. The *Technical Manual* describes the NASARC concept and the algorithms 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 4.0 software over prior versions. These revisions have further enhanced the modeling capabilities of the NASARC procedure and provide improved arrangements of predetermined arcs within the geostationary orbit. Array dimensions within the software have been structured to fit within the currently available 12-megabyte memory capacity of the International Frequency Registration Board (IFRB) computer facility. A piecewise approach to predetermined arc generation in NASARC (Version 4.0) allows worldwide planning problem scenarios to be accommodated within computer run time and memory constraints with enhanced likelihood and ease of solution.

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1.0 INTRODUCTION

1.1 Purpose and Scope

The purpose of the *Numerical Arc Segmentation Algorithm for a Radio Conference (NASARC Version 4.0) 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 for use 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. It was to provide a method of generating predetermined arc (PDA) segments in the development of an allotment plan. The predetermined arcs so generated are in conformity with decisions of WARC-85 and as set forth in its *Report to the Second Session of the Conference*. NASARC (Version 4.0) is the software package that was offered to the International Frequency Registration Board (IFRB) by the United States for use at WARC-88 as a means of PDA generation. NASARC used with a synthesis program can serve as a tool for developing allotment-type plans in which all service areas are treated equitably.

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 4.0 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 (KDD), 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. The approach proposed has the flexibility to accommodate the specification of key technical parameters over a range of values.

Additionally, subregional groupings of administrations can be accommodated in the initial allotment planning process by defining appropriate service areas that include the participating administrations. After plan development, 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. Both uplink and downlink paths are considered, and rain attenuation can be optionally included in the transmitter power calculations. Systems are generally assumed homogeneous, with prescribed space station and earth station antenna characteristics. The capability also exists, however, for individual specification of all system technical characteristics.

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 (i.e., 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 collocation 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.

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.

NASARC (Version 4.0) incorporates a new program module, the PDA interchange program (NASARC4), into the NASARC concept. The NASARC4 module is designed to reduce the required isolation between networks in abutting predetermined arcs by improving the arrangement of PDA's in the orbital arc. PDA's which are determined to be more compatible are placed in adjacent portions of the arc, while less compatible PDA's are moved further apart. Rearrangement of PDA's is accomplished by a heuristic swapping procedure that interchanges arc locations of PDA's.

A fourth program module, the group arc extension program (NASARC3), is used to enhance the operation of the NASARC4 module. NASARC3 is used to extend the group arc boundaries of all groupings selected by NASARC2 to the maximum extent possible. This allows NASARC4 full flexibility in interchanging selected groupings to reduce adjacent grouping interference.

User prompted inputs are passed to the various NASARC program modules by 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. 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 4.0 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 *C/I*'s 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 a full link analysis. Parameters such as the uplink and downlink carrier-to-noise ratio and/or uplink and downlink transmitter power, receiver noise temperatures, antenna characteristics, and rain attenuation are used in the calculations. These parameters are individually specifiable for each service area and are available in the Service Area file input to NASARC1.

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).

NASARC2 performs an additional operation in the selection process for the critical grouping which helps to alleviate adjacent grouping interference. After an orbital slot of sufficient size has been found to accommodate the candidate critical grouping, the required separation between the critical group and its potential east and west neighboring groups is determined using values from a precalculated separation matrix (see section 3.1.2.3) and the arc lengths of the critical group and its potential neighboring PDA's. If the required separation between the critical group and its east and west neighbors is within acceptable limits (i.e., such that satellites of service areas in each group will experience minimal interference from neighboring satellites in the adjacent groupings) then the candidate critical grouping is selected and given the corresponding PDA. If the required separation is not within acceptable limits, the next candidate critical grouping is chosen for examination. Additional details are given in section 3.3.6.

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 Reduction of Adjacent Grouping Interference

Version 4.0 of the NASARC software package contains a new program module, the PDA interchange program (NASARC4), that (along with NASARC2) addresses the interference relationship between adjacent groupings.

The NASARC4 module is designed to improve the arrangement of PDA's in the orbital arc by placing more compatible PDA's in adjacent portions of the arc and moving less compatible PDA's further apart. Rearrangement of PDA's is accomplished by a heuristic swapping procedure that interchanges arc locations of PDA's. This procedure is discussed in more detail in section 3.5.

The NASARC4 module regards the arrangement of PDA's in orbit derived by NASARC2 as an initial arrangement and seeks to improve the arrangement by interchanging PDA segment locations. The object is to improve the compatibility between immediately adjacent PDA's so as to produce an arrangement that provides more flexibility in orbital positioning and ultimately higher aggregate *C/I*'s for individual systems within the PDA.

The quality of a particular arrangement of PDA's is evaluated by assessing the degree of compatibility between each PDA and its immediate neighbors to the west and east. The degree of incompatibility in each direction is assessed by utilizing required orbital separations calculated by the satellite separations program (see section 3.1.2.3). These measures are then summed over both directions to provide an objective value for each PDA. The collection of objective values for an arrangement provides a measure of its quality.

Improving the set of objective values for an arrangement is accomplished by interchanging PDA segment locations in an effort to place more compatible PDA's in adjacent positions and reduce objective values. A matrix of feasible PDA interchanges is generated to provide a complete list of possible interchanges. All such interchanges are explored, and each interchange is compared with the current best arrangement. If an improvement is found, the current best arrangement is replaced. When all possible interchanges are exhausted, the best arrangement is held constant, the interchange matrix is regenerated, and new alternatives are built from the best alternative thus far. When no further improvements are possible, the arrangement of PDA's undergoes a final operation. This operation is designed to provide further orbital separation, when needed, between pairs of both adjacent and nonadjacent PDA's.

2.1.6 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. NASARC (Version 4.0) incorporates 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 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 4.0) 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 2.1.2 to 2.1.5) 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 and then perform the NASARC2 arc determination process on those groupings, NASARC1, NASARC2, NASARC3, and NASARC4 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.

SERVICE ARC DENSITY

WORLD ARCS FILE

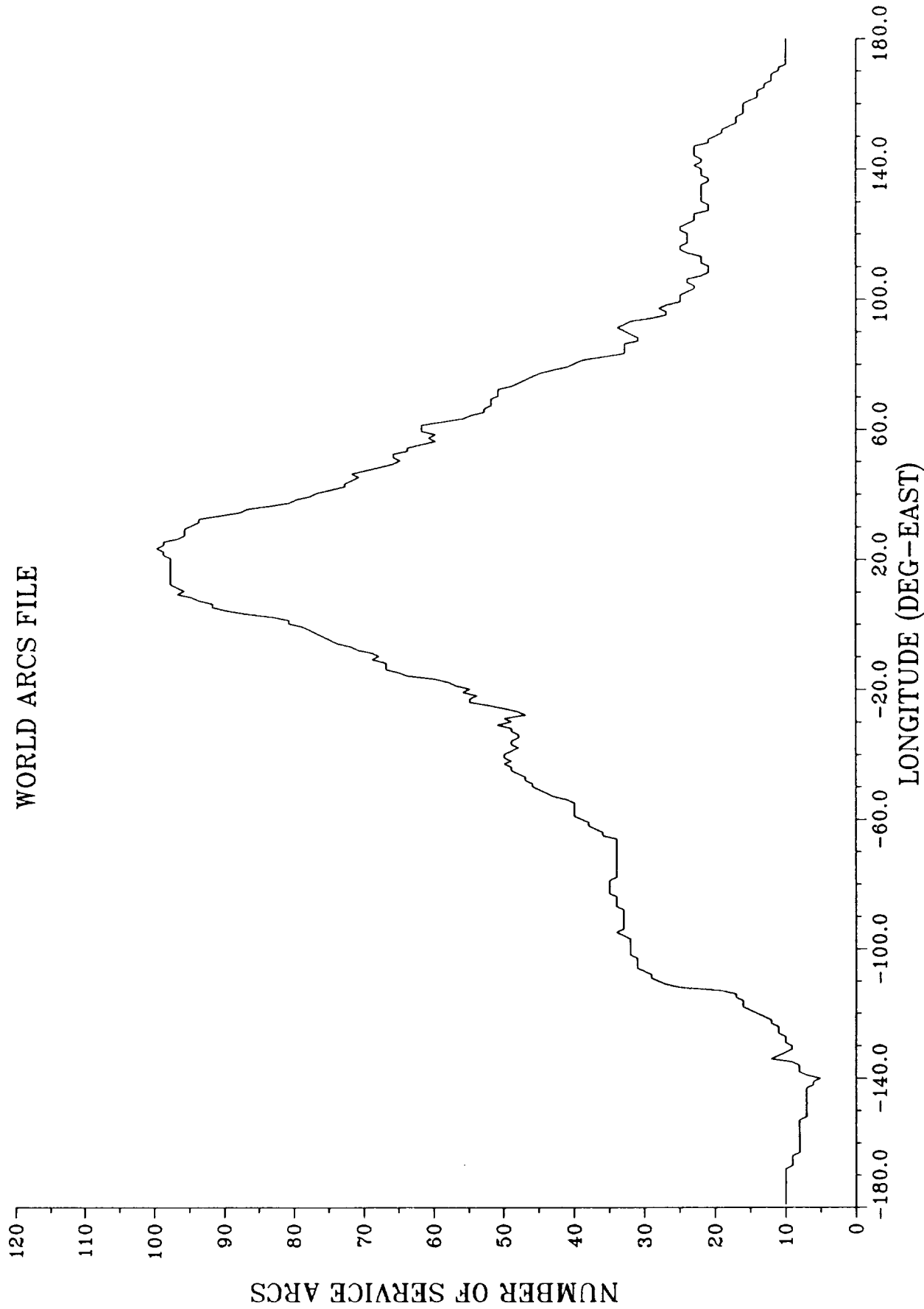


Figure 2.1-1.

Details on the specification of segment boundaries can be found in the *NASARC (Version 4.0) 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. 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.

When processing multiple segments using the piecewise approach, NASARC2 associates a priority level with each service area related to the criticality of being accommodated within the segment being processed. This determination 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 piecewise approach also necessitates special 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.

Following the NASARC2 selection of all groupings in a particular segment, the group arc extension program NASARC3 is used to extend the group arcs of the selected groupings across the boundaries of the cumulative arc. 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.

2.1.7 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 NASARC Software Features

The NASARC (Version 4.0) software package was developed under certain assumptions that were based on general planning principles and decisions of both sessions of the World Administrative Radio Conference on the Use of the Geostationary-Satellite Orbit and the Planning of Space Services Utilizing It held in Geneva, Switzerland, in 1985 and 1988 (WARC-85 and WARC-88). In certain cases, it is desirable or necessary to modify or override such assumptions. Therefore, certain program features were included in the NASARC (Version 4.0) software package to address these cases. Software features included in this version of NASARC are rain attenuation, individual antenna parameters, power calculation options, minimum power values, different required *C/I*'s, variable grouping criterion, and affiliated sets of service areas. Each of these features will be explained in subsequent sections of this manual and specific examples of possible uses of these features will be given. The use of these software features allows certain baseline assumptions to be modified or overridden, some on an individual service area basis. Additionally, these features also provide a way to handle two specific allotment planning problems: existing systems and dispersed territories.

2.2.1 Conference Decisions Affecting NASARC

A major decision of WARC-85 that became a major objective of WARC-88 was 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 included 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 was 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. That plan was to be established in the bands proposed in the *Report to the Second Session* of the WARC and described in Article 8 of the WARC-88 Final Acts:

- 4,500 to 4,800 MHz and 6,725 to 7,025 MHz for a total of 300 MHz in the C-band expansion band
- 10.70 to 10.95 GHz, 11.20 to 11.45 GHz, and 12.75 to 13.25 GHz for a total of 500 MHz in the Ku-band expansion bands

The applicability of the so-called improved procedures was limited by WARC-88 to the currently used FSS bands rather than extending it to additional bands such as the Ka-band frequencies. These procedures, however, have no direct bearing on the NASARC software or its development.

The *Report to the Second Session* indicates that "[t]he allotment plan shall be limited to national systems providing domestic services. The procedures associated with 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 as submitted by the individual administrations to the IFRB prior to and during the 1988 session of the WARC. Administrations wishing to combine their service areas into a subregional coverage area could request a single allotment to provide such coverage. NASARC would handle this type of service area as it would any single service area in that it would utilize a set of longitude/latitude points to define that subregional service area. Although this is technically feasible in the software, WARC-88 decided to handle any subregional coverage separate from the regular allotment plan as part of the procedures of the plan.

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 was to be accomplished in the allotment plan by providing to all administrations "at least one orbital position, within a predetermined arc and predetermined band(s)." The NASARC software was developed specifically to generate predetermined arcs for every service area for a given set of technical parameters. The NASARC concept uses no prejudgment of individual administrations preferences and formulates groupings and their associated allotted arcs solely on technical considerations. All service areas are considered on an equal basis.

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." In general, existing systems are given the specific orbital positions for which they originally filed in a NASARC scenario. NASARC (Version 4.0) contains specific modifications which allow for this possibility. Additionally, existing systems will generally have technical characteristics which differ from those selected for use with the allotment systems contained in a NASARC scenario. Many of the software features contained in NASARC (Version 4.0) provide a way to handle these differences.

2.2.2 Rain Attenuation

The effects of rain attenuation on the propagation of radio waves on both the earth-satellite path (uplink) and the satellite-earth path (downlink) can be utilized in determining pairwise compatibility. Attenuation due to rainfall adversely affects the availability of a satellite circuit. These effects are considered in the pairwise compatibility calculations if the user sets the appropriate flag in the service area file.

The rain attenuation data for each service area at every test point for each discrete arc location within the corresponding service arc are given in the precalculated Ellipse file. The attenuation data are present for both uplink and downlink for the C-band and Ku-band expansion band frequencies. The attenuation values were calculated using the CCIR rain model for the percent outage of 0.01 (or, conversely, a percent availability of 99.99) and are given in decibels. The NASARC software determines the worst-case attenuation value for both the uplink and downlink for a user-specified outage percentage and uses this value in the link calculations. The software can also limit the attenuation value to a user-specified maximum if desired. Both the annual percent outage and the maximum attenuation value are globally applied parameters for which the user is prompted when executing the Input Program.

The exact details of how the software utilizes the rain attenuation values are given in section 3.2.2.1.1 of this manual. In general, NASARC uses rain attenuation to calculate the required power for transmitting from and to each test point in a given service area based on a required carrier-to-noise ratio (C/N). If the actual power is specified in the Service Area file describing the scenario, it is assumed that this power is a faded power level (i.e., this power level is assumed to be based on operating the link with rain attenuation present).

2.2.3 Individual Antenna Parameters

The NASARC (Version 4.0) software contains 14 different antenna patterns. These antenna patterns correspond to the rolloff characteristics of various antennas expressed as an envelope rather than an exact sidelobe pattern. Using this approximation yields a more conservative estimate of antenna discrimination which is appropriate for planning purposes. Of the 14 antenna patterns, 11 are satellite antenna patterns and 3 are earth station antenna patterns. The satellite antenna types include 3 standard rolloff antennas, 2 empirically based antennas, and 6 fast rolloff antennas. The so-called fast rolloff antennas are approximations of the sidelobe effects of shaped beam antennas which effectively give greater discrimination outside the main beam contour. The antenna parameters come from a variety of sources such as CCIR reports, recommendations from the IWP 4/1 and JIWP groups, the 1983 Regional Administrative Radio Conference (RARC-83) and 1977 WARC Final ACTS, and the ORBIT-II synthesis program used at the 1988 WARC. Further details on the antenna types are given in section 3.1.1.2.4 of this manual.

In addition to the antenna patterns themselves and their corresponding parameters, the NASARC software allows for some related parameters to be individually specified. The receiver noise temperatures for both the satellite and earth station receive systems can be specified on a service area by service area basis. NASARC (Version 4.0) also provides for separate earth station transmit and receive antenna types to be specified for each service area. This option is particularly useful with some existing systems that are essentially using these frequency bands for a broadcast service rather than for a normal point-to-point fixed satellite service.

2.2.4 Power Calculation Option

In NASARC (Version 4.0), the power for each service area test point (i.e., earth station location) is determined for the required C/N value specified in the Service Area file. As stated previously, the power can be calculated with or without the inclusion of rain attenuation. The maximum power over all points is then used to calculate the C/I used to determine pairwise compatibility. This is done for both the uplink and downlink. Optionally, individually specified power values can be utilized in the C/I calculations. The uplink and downlink power calculation can be individually specified. Thus, it is possible to specify that the individual power be used on the uplink and the required C/N be used to calculate the power on the downlink and vice versa. There is also an option to determine the compatibility based on the uplink or downlink only rather than on the overall link. This could be utilized for systems that have only the uplink or downlink in the frequency bands being analyzed as is the case with some of the existing systems.

2.2.5 Minimum Power Values

The user can specify a minimum power level for both the earth station high power amplifier (HPA) and the satellite travelling wave tube amplifier (TWTA). This is a global parameter specified in the Service Area file. The specified minimum power values override any individually specified or calculated power level which falls below this minimum. This feature allows the user to minimize any *unrealistic* inhomogeneities in power values due to differences based on minimum beamwidth sizes and differences due to existing systems which operate at powers substantially below those of planned systems.

2.2.6 Different Required C/I s

The required protection ratio (i.e., the required C/I) can be specified on a service area by service area basis. In general, the planned systems will probably all require the same amount of protection. However, some of the existing systems may not require the same C/I needed for the planned systems. It may be possible to use a smaller protection ratio for the existing systems than for the planned systems (which need to be handled in a more conservative manner), depending on the modulation schemes and the type of communications traffic which will be present in the existing systems. Conversely, a larger protection ratio may be necessary for certain existing systems. The ability to use different required C/I 's in NASARC (Version 4.0) allows these differences to be handled on an individual service area basis.

2.2.7 Variable Grouping Criterion

In the NASARC concept, a compatible grouping consists of a group of service areas that are sufficiently separated geographically so that collocation or near collocation of their corresponding satellites results in achieving the proper overall single-entry C/I for any pair of satellites in that group. The grouping criterion, which is the orbital spacing used to assess pairwise compatibility, is explained in more detail in section 3.1.1.5.1 of this manual. This grouping criterion is specified on a segment by segment basis and is found in the Segments file. Although the same criterion can be specified for each segment of the orbital arc to be examined, the flexibility of having different grouping criteria throughout the orbital arc gives the user another tool in attacking the allotment planning problem. For instance, increasing the grouping criterion (i.e., easing the compatibility requirement) in the more dense areas of the orbit can increase the probability of finding solutions on large

scenarios. Additionally, since the grouping criterion used in finding a given compatible grouping is an element of the allotted arc equation, the variable grouping criterion does not effect the relative flexibility of the allotted groupings themselves.

2.2.8 Affiliated Sets of Service Areas

Some administrations may wish to illuminate several affiliated but geographically separated service areas from a single orbital location within that administration's allotted arc. In NASARC (Version 4.0) this is known as an affiliated set of service areas. Thus, this affiliated set of service areas would be defined by a number of nonadjacent service areas to be served from the same satellite. Service areas within an affiliated set are assumed to be compatible with each other. Thus, interference effects between members of the same affiliated set are not examined. As a result, one potential use of the affiliated set option is to synthesize 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 effects between beams are not examined because of their inherent affiliation with each other. In the case of a multiple beam coverage of a single service area, it is not necessary for the coverage areas to be nonadjacent.

The NASARC software treats the members of any affiliated set as separate entities when determining pairwise compatibility, but the software does not determine the compatibility between the set members since this is assumed to exist. The compatibility information is then combined as if the affiliated set were indeed a single service area. Thus, an affiliated set is only considered compatible with another service area if each of its component members is individually compatible with the other service area in question and vice versa.

2.2.9 Planning With Homogeneous Systems

Planning the geostationary orbit/spectrum resource has commonly been performed with a homogeneous set of technical parameters. There are several reasons for this methodology. First, it is difficult to assess specific parameter values to associate with each satellite before the intended purpose of the system has been identified. This is especially true with systems in the fixed satellite service. Additionally, different signal types may require different levels of interference protection. However, it is extremely difficult to know which types of communications traffic will be present in satellites that are not yet being designed for a particular purpose. Without specific knowledge of the systems being planned, results obtained from randomly introduced inhomogeneities could be misleading. Therefore, planning is normally done with homogeneous systems.

In certain cases, it may be necessary to override certain baseline assumptions. This can be done by utilizing the various NASARC software features. These features can also be applied to certain planning problems to better model such things as the so-called existing systems, dispersed territories, and multiple beam systems.

2.2.9.1 Application of Features to Baseline Assumptions

Many of the baseline assumptions inherent in the NASARC software can be overridden by using various software features, some on an individual service area basis. For planning purposes, the assumption was made to perform an analysis based on achieving a constant C/N at the edge of the individual coverage areas. This can be overridden by using the power calculation option to model a constant power assumption. Alternatively, the constant power option can be used to specify actual power levels if they are known. Using the minimum power value feature also can override the constant C/N assumption in certain cases. Another assumption for planning was to use the minimum area ellipse defining the coverage area. This implies using a single beam standard rolloff antenna on the satellite. This assumption can be overridden by using the individual antenna patterns to specify fast rolloff antennas which approximate shaped beam antennas. The assumption of homogeneous antennas and receivers can be overridden by using individually specified antenna parameters for both the satellite and/or earth station. Although planning can be done on the basis of clear sky conditions, rain attenuation can be included in the compatibility calculations through the rain attenuation feature. Although uniform protection ratios can be utilized

for all systems, different required *C/I*'s can be used if desired. Finally, compatibility can be based on a single, uniformly applied grouping criterion. Conversely, the variable grouping criterion feature can be utilized to apply different grouping criteria in different areas of the orbit.

2.2.9.2 Application of Features to Planning Problems

One planning problem to be addressed in the allotment plan is the handling of existing systems. In general, the characteristics of existing systems are different than those of the planned systems. The NASARC software features can be used to more accurately model existing systems for compatibility analysis. The individual antenna parameters are particularly useful in attempting to accurately model the antennas of the existing systems. The satellite antenna pattern of each existing system can be approximated by choosing the pattern which most closely matches the actual falloff characteristics of the system in question. The individual antenna parameters can be used to specify various earth station antenna diameters and receiver noise temperatures. Additionally, individual parameter specification allows for the use of different earth station transmit and receive antenna characteristics required with some existing systems. The power calculation option can be utilized to specify actual powers for existing systems when known. Furthermore, using the minimum power feature can limit extreme power inhomogeneities between the planned and existing systems. Different *C/I*'s can be used for certain existing systems to allow for either more or less protection than is required by the planned systems. Lastly, the affiliated sets feature can be used to simulate a multiple beam system as required by some of the existing systems.

The affiliated sets option can also be used to accommodate a single administration and its dispersed territories. Similarly, the affiliated sets option can be used for the case of nonadjacent administrations wishing to combine their requirements into a subregional grouping.

3.0 DETAILED DESCRIPTION OF NASARC (VERSION 4.0) 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. Six 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 precursor programs which can be utilized in running NASARC. 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 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 uses heuristic approaches in the determination of the predetermined arcs for the selected groups and in the relative placement of these arcs within the confines of the available group arc. The fourth topic is a description of the next module in the NASARC software package, NASARC3, the *group arc extension* program. The function of NASARC3 is to extend the group arcs of the currently selected compatible groups in the piecewise approach used in NASARC (Version 4.0) to maintain flexibility throughout the process. The fifth topic is a discussion of the inner workings of NASARC4, the *arc interchange* program. The functions of NASARC4 are to improve the adjacent PDA interference environment by interchanging select groupings within their group arcs and to output all of the NASARC final results. The sixth and final topic gives a brief overview of the various technical assumptions inherent in the NASARC software.

3.1 Inputs to NASARC Software

The description of the inputs to the NASARC software is divided into three areas: prestored file inputs, precursor programs, and input parameter constraints. Each of these is addressed in the following sections. Additionally, the modules NASARC1, NASARC2, NASARC3, and NASARC4 take inputs from intermediate files created by the various modules of the NASARC software package used in the NASARC piecewise approach as well as the precursor programs which are used to create some of the input files. These files are described briefly in the *User's Manual* for completeness, but they require no input from the user. The precursor programs also create various input files but these are essentially transparent to the user with the notable exception of those files created by the interface program. This caveat is explained further in section 3.1.2.1 of this manual.

3.1.1 Prestored Files

There are five prestored input files used in the NASARC (Version 4.0) software package: the Point Sets file containing polygon/test point information, the Service Area file which contains most of the scenario technical parameters for each service area, the Ellipse file with all possible required ellipse parameters, the Affiliated Sets file containing set information, and the Segments file containing the segment information and associated grouping criteria needed for the NASARC piecewise approach. Typical input values for the various files as well as the organization of some of the prestored data are provided where appropriate.

3.1.1.1 Point Sets File

In NASARC (Version 4.0), the Point Sets file consists of a set of latitude/longitude coordinate pairs for each service area or beam to be included in the scenario which is being examined. The file also includes both the unique three character code used throughout the NASARC software package and the eight character beam codes as designated by the IFRB in preparations for the 1988 Space World Administrative Radio Conference. The eight character codes are necessary in order for NASARC to be compatible with the format of the ellipse file developed by the IFRB. However, the three character codes used in NASARC are an essential element in keeping the storage requirements at a reasonable level. More information about storage considerations is given in section 3.1.3 of this manual.

The latitude/longitude pairs used in forming the Point Sets file can be any combination of polygon and/or test points. There can be as few as one point specified for a service area or as many as ten points. The ten point maximum can be exceeded, but this would require a dimensioning change to the software. See sections 2.3.1.4 and 3.2.3 of the *User's Manual* for more details on the file and software requirements. The format for the point sets is similar to that found in the IFRB Requirements file and is given in the aforementioned sections of the *User's Manual*. All polygon and test 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 measured eastward from the prime meridian while negative longitudes are measured westward from that meridian. The source for the point set data given in the IFRB Requirements file and used by the interface program in forming a NASARC Point Sets file was either the ITU administration to which that service area belongs or the IFRB itself when no point set data were submitted by an administration.

The Point Sets file is read by NASSEP (precursor satellite separations program), NASARC1 (grouping program), and NASARC3 (group arc extension program). The point set data are used by these programs to perform interference calculations to determine satellite separations in the case of NASSEP and to determine compatibility in the case of NASARC1 and NASARC3. Additionally, the Point Sets file is read by NASARC4 to produce the output reports.

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 does not need to be changed on a scenario by scenario basis. The Service Area file contains the basic scenario information required by the NASARC software. The first line of the file contains some important global parameters which apply to the entire scenario. The remaining lines contain all the technical parameters which are specified on an individual service area basis using one record of the file for each service area in the scenario. The remaining global input data are supplied by the user to the input program NASARC0 and are written to the Input Data file for use by all the NASARC major program modules. A further description of NASARC0 is given in section 3.1.2.2 of this manual.

There are nine items of global data in the first line of the Service Area file. The first item is the rain attenuation flag which is simply a one character (Y or N) code to indicate whether or not rain attenuation is to be considered

when performing power calculations in the NASARC software. In other words, the rain attenuation flag indicates whether the power calculated is to be a faded or unfaded value.

The minimum half-power beamwidth (HPBW), which is specified in decimal degrees, is related to the maximum allowable diameter of satellite 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 beamwidth 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 fast rolloff antenna patterns. These patterns are so named because their falloff from maximum gain rolls off as an antenna whose half-power beamwidth is equal to the minimum HPBW.

The next four global data items are the four 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. Another piece of global data is the reference noise bandwidth given in MHz which is used in calculating power values from specified C/N 's. Although any appropriate value can be used, the value utilized at the 1988 Space WARC was 1.00 MHz. The final two data items in the Service Area file global parameter line are the minimum values for the earth station and satellite transmitter powers. These parameters can be utilized to help minimize the effects of large inhomogeneities in power levels when calculating power values from a required C/N .

Each subsequent record of the Service Area file contains all of the technical parameters needed for that service area. Included in each record are the NASARC three character beam code, the service arc boundaries, the numeric affiliated sets code, satellite and earth station antenna information, and information used in the power calculations. The following sections explain the most important of these data items in more detail. Information on the actual format of this file is given in section 2.3.1.3 and 3.2.2 of the *User's Manual*.

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 typically uses service arcs based on a minimum elevation angle of 10° 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 should be chosen to yield an arc span large enough to allow for some grouping to occur. There is, however, nothing in the software itself to prevent the user from specifying a single orbital position as the service arc for any given service area. In fact, such a practice may be necessary when handling the existing systems mentioned in section 2.2.1 of this manual. In general, a single orbital position or very small service arcs should be avoided as they defeat the overall objectives of the NASARC software concept.

While 10° was selected for use as the baseline or typical 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.

In general, 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

- Δ 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.)
- ϵ minimum desirable elevation angle
- R geostationary orbit radius, in earth radii (6.6105)
- β polygon/test point latitude

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

$$\left. \begin{aligned} E &= \alpha + \Delta \\ W &= \alpha - \Delta \end{aligned} \right\} \quad (3.1-2)$$

where

- Δ as previously defined
- α 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 $+15$.

In the case where an IFRB Requirements Data file exists for the scenario in question, the interface program (NASINTRF) uses the service arc data given in the Requirements Data file and converts them to the appropriate format for use in the Service Area file.

3.1.1.2.2 Affiliated Sets

As mentioned previously, 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. 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.

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 2.3.1.3 and 3.2.2 of the *NASARC (Version 4.0) User's Manual*.

Derivation of Resultant Service Arcs

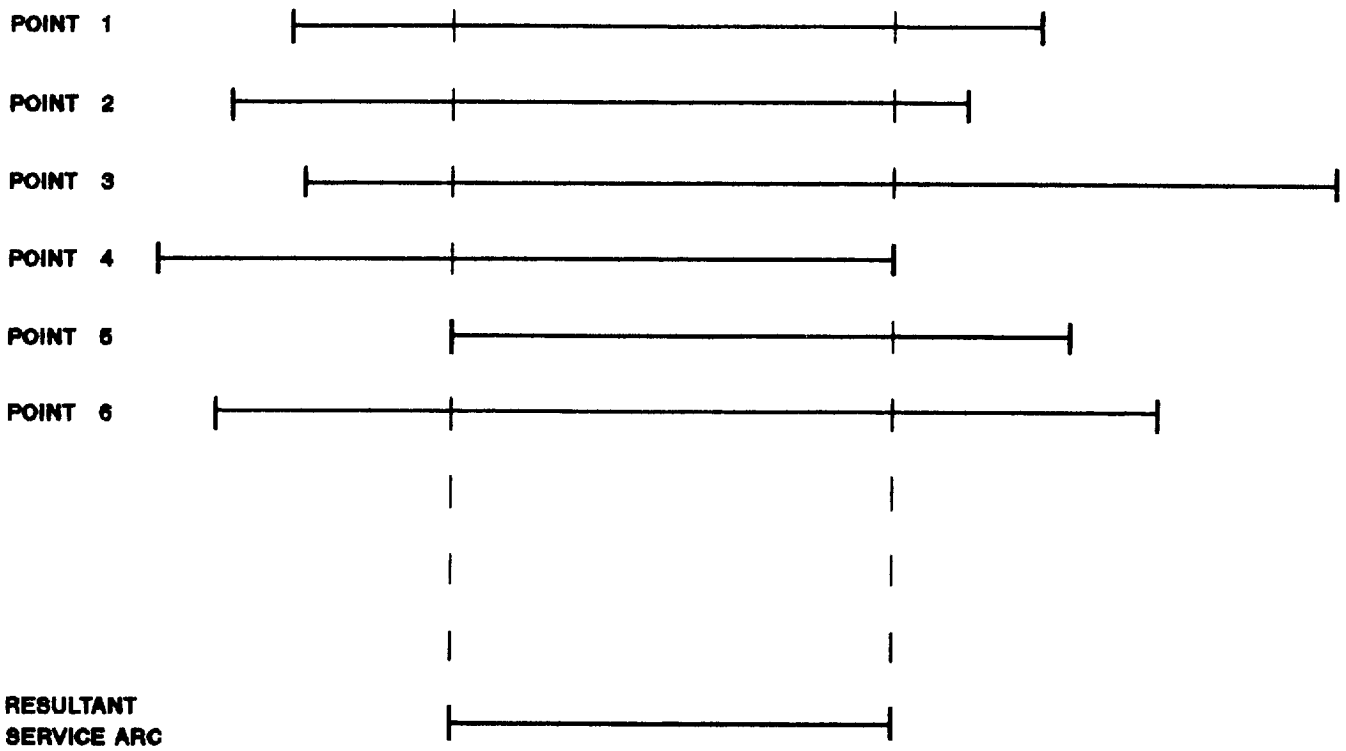


Figure 3.1-1.

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 Power Calculation Parameters

The NASARC Service Area file contains several parameters which are specific to the calculation of the C/I used in determining pairwise compatibility in the NASARC software. Many of these parameters are directly related to calculating the transmitter powers for both the earth stations and the satellites. The simplest case is when the transmitter power is known for the satellite and/or the earth station. In this case, the user can simply specify the TWTA (i.e., the travelling wave tube amplifier for the satellite) and the HPA (i.e., the high power amplifier for the earth station) power levels in dBW. These power values are used in calculating the received carrier and interference powers which in turn are used in determining the pairwise compatibility. If rain attenuation is to be included, these values are assumed to be faded power values.

The other possibility for calculating power values is for the user to specify a desired uplink and/or downlink C/N criterion and have the software calculate the transmitter power levels. There are three *flags* which the user can set to yield the various permutations of these power calculation possibilities. The link calculation flag allows the user to designate if a given system is operating in the uplink frequency band being considered, the downlink frequency band, or both the uplink and downlink bands. In the latter case, the links are treated independently in the sense that each has its own required C/N which must be achieved. There is also an uplink and a downlink power calculation flag which specifies for each link whether power is to be calculated based on a required C/N criterion or is simply read from the Service Area file. The actual calculation of transmitter power is described in some detail in the subsections of section 3.2 of this manual.

The Service Area file also contains the satellite and earth station receiver noise temperatures given in decibels—degrees kelvin (dB-k). These noise temperatures are actually the total receive system noise temperatures which include the background noise which appears in the field of view of the antenna system as well as the internal thermal noise of the receiver itself. In addition to the data directly related to the power calculations, there are two other data items which are more indirectly related. One is the existing system flag which tells the software which systems in the scenario are existing systems and which are planned systems. Although this has no bearing on the actual calculation of power values, it does have an effect on how pairwise compatibility is determined in that existing systems are a special case. More detail on existing systems is given in section 2.2. of this manual.

The other data item not directly related to the power calculations is the aggregate C/I criterion. NASARC uses a target single-entry C/I in determining pairwise compatibility between the particular service area in question and all other service areas in the scenario. Therefore, the aggregate C/I criterion must be converted to a single-entry C/I through an aggregate-to-single-entry C/I . At the May 1987 IFRB ORB Informational Meeting, an aggregate C/I of 26 dB and a single-entry C/I of 32 dB were recommended for planning purposes. Based on these values, an aggregate-to-single-entry C/I of 6 dB was incorporated into the NASARC (Version 4.0) software. This value could be changed, but such a change would require the recompilation of the software. The 6-dB difference between aggregate and single-entry C/I 's should be sufficient to allow the desired aggregate C/I to be met when the NASARC results are analyzed.

3.1.1.2.4 Antenna Parameters

For each service area or beam in the Service Area file, the user must specify antenna codes and parameters for both earth station and satellite antenna patterns. These patterns correspond to various falloff or discrimination characteristics which are used in determining pairwise compatibility in the NASARC (Version 4.0) software. The antenna discrimination, and therefore the antenna pattern, is generally the most important contributor to the

determination of pairwise compatibility. The NASARC software determines the pairwise compatibility of each pair of service areas by examining the total single-entry C/I achieved between the wanted and interfering satellites and their corresponding earth stations. Therefore, the combined effects of the interfering earth station antenna discrimination and the wanted satellite antenna discrimination on the uplink, and the interfering satellite antenna discrimination and the wanted earth station antenna discrimination on the downlink are the primary contributors to the determination of pairwise compatibility based on the total achieved single-entry C/I for the overall link.

The user can choose from 14 antenna patterns in NASARC (Version 4.0), including 3 earth station falloff patterns and 11 satellite falloff patterns. Antenna specification consists of a six-character descriptive code, the overall antenna efficiency given as a decimal, and the antenna parameter associated with the selected pattern. The efficiency is required for every antenna type since it is needed when calculating the on-axis gains of the antennas. The antenna parameter associated with a particular pattern is specified in a simple and straightforward manner and is of a strictly engineering nature (i.e., required parameters are such things as antenna diameter, sidelobe level, etc.). In some cases, no parameter is required. Additionally, with respect to the earth station antenna selection, the user must specify both a transmit and a receive antenna type and a diameter for both transmit and receive earth stations, although only a single efficiency is needed. The reason for this is explained in section 2.2 of this manual, but it should be noted that the transmit and receive antennas may be and in most cases will be identical. The 14 NASARC antenna patterns are as follows:

ETA391	earth station antenna pattern presented in CCIR Report 391-4
ETAIMP	same as Report 391-4 earth station antenna but with improved sidelobe envelope (i.e., $29-25 \log \varphi$)
ETACOM	similar to Report 391-4 earth station antenna but uses a combination of standard and improved sidelobe envelopes
SCA558	standard rolloff satellite antenna pattern presented in CCIR Report 558-3
RARCST	standard rolloff satellite antenna pattern given in RARC-83 Final Acts
RARCFR	fast rolloff satellite antenna pattern given in 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 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 WARC-77 Final Acts
IWP4/1	fast rolloff satellite antenna pattern presented in CCIR Report 558-3 and recommended by IWP 4/1
IWPREV	same as IWP4/1 but with a simple elliptical main beam
JIWPFR	fast rolloff satellite antenna recommended by CCIR in the Report to the Second Session of WARC-ORB(2)
JIWPRV	same as JIWPFR but with a simple elliptical main beam

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. 3.1-2 through 3.1-23).

3.1.1.2.4.1 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 is entered via the input program, the diameter-to-wavelength ratio is calculated. For $D/\lambda \geq 100$, the falloff equations for this antenna are given by

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

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} - G_1 \quad \frac{\varphi_m}{\varphi_o} \leq \frac{\varphi}{\varphi_o} < \frac{\varphi_r}{\varphi_o} \quad (3.1-3b)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} - 32 + 25 \log\left(\frac{\varphi}{\varphi_o}\right) + 25 \log \varphi_o \quad \frac{\varphi_r}{\varphi_o} \leq \frac{\varphi}{\varphi_o} < \frac{48}{\varphi_o} \quad (3.1-3c)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} + 10 \quad \frac{\varphi}{\varphi_o} \geq \frac{48}{\varphi_o} \quad (3.1-3d)$$

where

- $\frac{\varphi}{\varphi_o}$ relative off-axis angle
- φ_o half-power beamwidth, deg
- G_{MAX} antenna on-axis gain, dB

and

$$G_1 = 2 + 15 \log \frac{D}{\lambda} \quad (3.1-3e)$$

$$\varphi_m = \frac{20\lambda}{D} \sqrt{G_{MAX} - G_1} \quad (3.1-3f)$$

$$\varphi_r = 15.848932 \left(\frac{D}{\lambda}\right)^{-0.6} \quad (3.1-3g)$$

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

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

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} - G_1 \quad \frac{\varphi_m}{\varphi_o} \leq \frac{\varphi}{\varphi_o} < \frac{100}{(D/\lambda) \varphi_o} \quad (3.1-3i)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} - 52 + 10 \log \frac{D}{\lambda} + 25 \log \frac{\varphi}{\varphi_0} + 25 \log \varphi_0 \quad \frac{100}{(D/\lambda)\varphi_0} \leq \frac{\varphi}{\varphi_0} < \frac{48}{\varphi_0} \quad (3.1-3j)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} - 10 + 10 \log \frac{D}{\lambda} \quad \frac{\varphi}{\varphi_0} \geq \frac{48}{\varphi_0} \quad (3.1-3k)$$

where

$\frac{\varphi}{\varphi_0}$ relative off-axis angle
 φ_0 half-power beamwidth, deg
 G_{MAX} antenna on-axis gain, dB

and

$$G_1 = 2 + 15 \log \frac{D}{\lambda} \quad (3.1-3l)$$

$$\varphi_m = \frac{20\lambda}{D} \sqrt{G_{MAX} - G_1} \quad (3.1-3m)$$

A plot of this antenna pattern for a 7.0-m antenna at a frequency of 4.500 GHz is given in figure 3.1-2 as gain relative to on-axis gain versus relative off-axis angle.

3.1.1.2.4.2 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 3.1.1.2.4.1 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 the input program, the diameter-to-wavelength ratio is calculated. For $D/\lambda \geq 100$ the falloff equations for this antenna are given by

$$F\left(\frac{\varphi}{\varphi_0}\right) = 2.5 \times 10^{-3} \left(\frac{D}{\lambda} \frac{\varphi}{\varphi_0}\right)^2 \varphi_0^2 \quad 0 \leq \frac{\varphi}{\varphi_0} < \frac{\varphi_m}{\varphi_0} \quad (3.1-4a)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} - G_1 \quad \frac{\varphi_m}{\varphi_0} \leq \frac{\varphi}{\varphi_0} < \frac{\varphi_r}{\varphi_0} \quad (3.1-4b)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} - 29 + 25 \log \frac{\varphi}{\varphi_0} + 25 \log \varphi_0 \quad \frac{\varphi_r}{\varphi_0} \leq \frac{\varphi}{\varphi_0} < \frac{48}{\varphi_0} \quad (3.1-4c)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} + 10 \quad \frac{\varphi}{\varphi_0} \geq \frac{48}{\varphi_0} \quad (3.1-4d)$$

where

$\frac{\varphi}{\varphi_o}$ relative off-axis angle
 φ_o half-power beamwidth, deg
 G_{MAX} antenna on-axis gain, dB

and

$$G_1 = 15 \log \frac{D}{\lambda} - 1 \quad (3.1-4e)$$

$$\varphi_m = \frac{20\lambda}{D} \sqrt{G_{MAX} - G_1} \quad (3.1-4f)$$

$$\varphi_r = 15.848932 \left(\frac{D}{\lambda} \right)^{-0.6} \quad (3.1-4g)$$

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

$$F \left(\frac{\varphi}{\varphi_o} \right) = 2.5 \times 10^{-3} \left(\frac{D}{\lambda} \frac{\varphi}{\varphi_o} \right)^2 \varphi_o^2 \quad 0 \leq \frac{\varphi}{\varphi_o} < \frac{\varphi_m}{\varphi_o} \quad (3.1-4h)$$

$$F \left(\frac{\varphi}{\varphi_o} \right) = G_{MAX} - G_1 \quad \frac{\varphi_m}{\varphi_o} \leq \frac{\varphi}{\varphi_o} < \frac{100}{(D/\lambda) \varphi_o} \quad (3.1-4i)$$

$$F \left(\frac{\varphi}{\varphi_o} \right) = G_{MAX} - 49 + 10 \log \frac{D}{\lambda} + 25 \log \frac{\varphi}{\varphi_o} + 25 \log \varphi_o \quad \frac{100}{(D/\lambda) \varphi_o} \leq \frac{\varphi}{\varphi_o} < \frac{48}{\varphi_o} \quad (3.1-4j)$$

$$F \left(\frac{\varphi}{\varphi_o} \right) = G_{MAX} - 10 + 10 \log \frac{D}{\lambda} \quad \frac{\varphi}{\varphi_o} \geq \frac{48}{\varphi_o} \quad (3.1-4k)$$

where

$\frac{\varphi}{\varphi_o}$ relative off-axis angle
 G_{MAX} antenna on-axis gain, dB
 φ_o half-power beamwidth, deg

$$G_1 = 2 + 15 \log \frac{D}{\lambda} \quad (3.1-4l)$$

$$\varphi_m = \frac{20\lambda}{D} \sqrt{G_{MAX} - G_1} \quad (3.1-4m)$$

Figure 3.1-3 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 3.1-2, the difference in the sidelobe envelopes between the two earth terminal antenna patterns is readily observed.

3.1.1.2.4.3 Earth Terminal Antenna ETACOM

This earth terminal antenna pattern is basically a combination of those given in the previous two sections. It is the pattern given in the CCIR Report to the second session of the Space WARC-ORB(2) and recommended for use by *developed* countries. It was recommended that the *developing* countries use the ETA391 antenna pattern since its envelope is less restrictive than this combined falloff pattern. As with the other earth station patterns, the required parameter is the antenna diameter given in meters. From this parameter and the transmission frequency, the diameter-to-wavelength ratio is calculated.

For $D/\lambda \geq 100$, the falloff equations for this antenna pattern are given by

$$F\left(\frac{\varphi}{\varphi_0}\right) = 2.5 \times 10^{-3} \left(\frac{D}{\lambda} \frac{\varphi}{\varphi_0}\right)^2 \varphi_0^2 \quad 0 \leq \frac{\varphi}{\varphi_0} < \frac{\varphi_m}{\varphi_0} \quad (3.1-5a)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} - G_1 \quad \frac{\varphi_m}{\varphi_0} \leq \frac{\varphi}{\varphi_0} < \frac{\varphi_r}{\varphi_0} \quad (3.1-5b)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} - 29 + 53.3 \log \frac{\varphi}{\varphi_0} + 53.3 \log \varphi_0 \quad \frac{\varphi_r}{\varphi_0} \leq \frac{\varphi}{\varphi_0} < \frac{1}{\varphi_0} \quad (3.1-5c)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} - 29 + 25 \log \frac{\varphi}{\varphi_0} + 25 \log \varphi_0 \quad \frac{1}{\varphi_0} \leq \frac{\varphi}{\varphi_0} < \frac{20}{\varphi_0} \quad (3.1-5d)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} + 3.5 \quad \frac{20}{\varphi_0} \leq \frac{\varphi}{\varphi_0} < \frac{26.3}{\varphi_0} \quad (3.1-5e)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} - 32 + 25 \log \frac{\varphi}{\varphi_0} + 25 \log \varphi_0 \quad \frac{26.3}{\varphi_0} \leq \frac{\varphi}{\varphi_0} < \frac{48}{\varphi_0} \quad (3.1-5f)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} + 10 \quad \frac{\varphi}{\varphi_0} \geq \frac{48}{\varphi_0} \quad (3.1-5g)$$

where

- $\frac{\varphi}{\varphi_0}$ relative off-axis angle
- φ_0 half-power beamwidth, deg
- G_{MAX} antenna on-axis gain, dB
- D/λ diameter-to-wavelength ratio

and

$$G_1 = 2 + 15 \log \frac{D}{\lambda} \quad (3.1-5h)$$

$$\varphi_m = \frac{20 \lambda}{D} \sqrt{G_{MAX} - G_1} \quad (3.1-5i)$$

$$\varphi_r = 15.848932 \left(\frac{D}{\lambda}\right)^{-0.6} \quad (3.1-5j)$$

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

$$F\left(\frac{\varphi}{\varphi_o}\right) = 2.5 \times 10^{-3} \left(\frac{D}{\lambda} \frac{\varphi}{\varphi_o}\right)^2 \varphi_o^2 \quad 0 \leq \frac{\varphi}{\varphi_o} < \frac{\varphi_m}{\varphi_o} \quad (3.1-5k)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} - G_1 \quad \frac{\varphi_m}{\varphi_o} \leq \frac{\varphi}{\varphi_o} < \frac{100}{(D/\lambda) \varphi_o} \quad (3.1-5l)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} - 49 + 10 \log \frac{D}{\lambda} + 25 \log \frac{\varphi}{\varphi_o} + 25 \log \varphi_o \quad \frac{100}{(D/\lambda) \varphi_o} \leq \frac{\varphi}{\varphi_o} < \frac{\varphi_B}{\varphi_o} \quad (3.1-5m)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} - 49 + 10 \log \frac{D}{\lambda} + 25 \log \varphi_B \quad \frac{\varphi_B}{\varphi_o} \leq \frac{\varphi}{\varphi_o} < \frac{\varphi_c}{\varphi_o} \quad (3.1-5n)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} - 52 + 10 \log \frac{D}{\lambda} + 25 \log \frac{\varphi}{\varphi_o} + 25 \log \varphi_o \quad \frac{\varphi_c}{\varphi_o} \leq \frac{\varphi}{\varphi_o} < \frac{48}{\varphi_o} \quad (3.1-5o)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} - 10 + 10 \log \frac{D}{\lambda} \quad (3.1-5p)$$

where

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

φ_o half-power beamwidth, deg

G_{MAX} antenna on-axis gain, dB

and

$$G_1 = 2 + 15 \log \frac{D}{\lambda}$$

$$\varphi_m = \frac{20 \lambda}{D} \sqrt{G_{MAX} - G_1}$$

$$\varphi_B = \frac{D/\lambda}{5}$$

$$\varphi_c = 0.26365 \frac{D}{\lambda}$$

Figure 3.1-4 gives an example plot of this pattern for a 7.0-m-diameter antenna and an operating frequency of 4.500 GHz.

3.1.1.2.4.4 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 parameter used is the 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

$$F\left(\frac{\varphi}{\varphi_o}\right) = 12\left(\frac{\varphi}{\varphi_o}\right)^2 \quad 0 \leq \frac{\varphi}{\varphi_o} < \frac{SLL}{12} \quad (3.1-6a)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = SLL \quad \frac{SLL}{12} \leq \frac{\varphi}{\varphi_o} < 3.154787 \quad (3.1-6b)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = SLL - 20 + 25 \log \frac{2\varphi}{\varphi_o} \quad 3.154787 \leq \frac{\varphi}{\varphi_o} < \varphi_i \quad (3.1-6c)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} + 10 \quad \frac{\varphi}{\varphi_o} \geq \varphi_i \quad (3.1-6d)$$

where

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

G_{MAX} antenna on-axis gain, dB

SLL user input first sidelobe level, dB

and

$$\varphi_i = 0.5 \times 10^{[(G_{MAX} + 30 - SLL)/25]} \quad (3.1-6e)$$

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.

3.1.1.2.4.5 Satellite Antenna RARCST

The two antenna types available in NASARC (Version 4.0) which resulted from the 1983 Regional Administrative Radio Conference (RARC-83) 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:

$$F\left(\frac{\varphi}{\varphi_o}\right) = 12\left(\frac{\varphi}{\varphi_o}\right)^2 \quad 0 \leq \frac{\varphi}{\varphi_o} < 1.449908 \quad (3.1-7a)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 22 + 20 \log \frac{\varphi}{\varphi_o} \quad 1.449908 \leq \frac{\varphi}{\varphi_o} < \varphi_i \quad (3.1-7b)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} \quad \frac{\varphi}{\varphi_o} \geq \varphi_i \quad (3.1-7c)$$

where

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

G_{MAX} antenna on-axis gain, dB

and

$$\varphi_i = 10^{[(G_{MAX} - 22)/20]} \quad (3.1-7d)$$

3.1.1.2.4.6 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 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 found in the Service Area file. The falloff equations are given as

$$F\left(\frac{\varphi}{\varphi_o}\right) = 12\left(\frac{\varphi}{\varphi_o}\right)^2 \quad 0 \leq \frac{\varphi}{\varphi_o} < 0.5 \quad (3.1-8a)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 12\left(\frac{\varphi_o}{b}\right)^2\left(\frac{\varphi}{\varphi_o} - X\right)^2 \quad 0.5 \leq \frac{\varphi}{\varphi_o} < 1.449908 \frac{b}{\varphi_o} + X \quad (3.1-8b)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 25.226811 \quad 1.449908 \frac{b}{\varphi_o} + X \leq \frac{\varphi}{\varphi_o} < 1.449908 \quad (3.1-8c)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 22 + 20 \log \frac{\varphi}{\varphi_o} \quad 1.449908 \leq \frac{\varphi}{\varphi_o} < \varphi_i \quad (3.1-8d)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} + 10 \quad \frac{\varphi}{\varphi_o} \leq \varphi_i \quad (3.1-8e)$$

where

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

G_{MAX} antenna on-axis gain, dB

φ_o half-power beamwidth, deg

b minimum half-power beamwidth, deg

and

$$X = 0.5 \left(1 - \frac{b}{\varphi_o}\right) \quad (3.1-8f)$$

$$\varphi_i = 10^{\lfloor (G_{MAX} - 12) / 20 \rfloor} \quad (3.1-8g)$$

3.1.1.2.4.7 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 found in the global parameter line of the Service Area file. The falloff relationships are given by

$$F\left(\frac{\varphi}{\varphi_o}\right) = 12\left(\frac{\varphi}{\varphi_o}\right)^2 \quad 0 \leq \frac{\varphi}{\varphi_o} < 0.5 \quad (3.1-9a)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 12\left(\frac{\varphi_o}{b}\right)^2 \left(\frac{\varphi}{\varphi_o} - X\right)^2 \quad 0.5 \leq \frac{\varphi}{\varphi_o} < \frac{b}{\varphi_o} \sqrt{2.5} + X \quad (3.1-9b)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 30 - 30 \log\left(\frac{b}{\varphi_o} \sqrt{2.5} + X\right) + 30 \log \frac{\varphi}{\varphi_o} \quad \frac{b}{\varphi_o} \sqrt{2.5} + X \leq \frac{\varphi}{\varphi_o} < \varphi_i \quad (3.1-9c)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} + 10 \quad \frac{\varphi}{\varphi_o} \geq \varphi_i \quad (3.1-9d)$$

where

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

G_{MAX} antenna on-axis gain, dB

φ_o half-power beamwidth, deg

b minimum half-power beamwidth, deg

and

$$X = 0.5 \left(1 - \frac{b}{\varphi_o}\right) \quad (3.1-9e)$$

$$\varphi_i = \left(\frac{b}{\varphi_o} \sqrt{2.5} + X\right) 10^{(G_{MAX}-20)/30} \quad (3.1-9f)$$

3.1.1.2.4.8 Satellite Antenna ORBIT0

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:

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

where

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

α antenna decay constant

3.1.1.2.4.9 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 is utilized 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

$$F\left(\frac{\varphi}{\varphi_o}\right) = 10 \log \left[1 + \left(\frac{2\varphi}{\varphi_o}\right)^\alpha \right] \quad 0 \leq \frac{\varphi}{\varphi_o} < \varphi_i \quad (3.1-11a)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} + 10 \quad \frac{\varphi}{\varphi_o} \geq \varphi_i \quad (3.1-11b)$$

where

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

G_{MAX} antenna on-axis gain, dB

α antenna decay constant

and

$$\varphi_i = 0.5 \left(10^{[(G_{MAX} + 10)/10]} - 1 \right)^{1/2} \quad (3.1-11c)$$

3.1.1.2.4.10 Satellite Antenna WARC77

The satellite antenna pattern given in the WARC-77 Final Acts is also available in NASARC (Version 4.0). 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 $G_{MAX} + 10$. There is no parameter required for this antenna type. This antenna is shown in figure 3.1-15 and the equations defining its characteristics are

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

$$F\left(\frac{\varphi}{\varphi_o}\right) = 30 \quad 1.581139 \leq \frac{\varphi}{\varphi_o} < 3.154787 \quad (3.1-12b)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 10 + 25 \log \left[2 \left(\frac{\varphi}{\varphi_o}\right) \right] \quad 3.154787 \leq \frac{\varphi}{\varphi_o} < \varphi_i \quad (3.1-12c)$$

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

where

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

G_{MAX} antenna on-axis gain, dB

and

$$\varphi_i = 0.5 \times 10^{[(G_{MAX} - 10)/25]} \quad (3.1-12e)$$

3.1.1.2.4.11 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 found in the global parameters of the Service Area file. The falloff for this pattern is defined by the following equations:

$$F\left(\frac{\varphi}{\varphi_0}\right) = 0 \quad 0 \leq \frac{\varphi}{\varphi_0} < 0.5 \quad (3.1-13a)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = 3 - B + B \left(\frac{\varphi_0}{b}\right)^2 \left(\frac{2\varphi}{\varphi_0} + \frac{b}{\varphi_0} - 1\right)^2 \quad 0.5 \leq \frac{\varphi}{\varphi_0} < 0.5 \left(1 + C \frac{b}{\varphi_0}\right) \quad (3.1-13b)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = SLL \quad 0.5 \left(1 + C \frac{b}{\varphi_0}\right) \leq \frac{\varphi}{\varphi_0} < 0.5 \left(1 + E \frac{b}{\varphi_0}\right) \quad (3.1-13c)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = SLL + 20 \log \left(2 \frac{\varphi}{\varphi_0}\right) - 20 \log \left(1 + E \frac{b}{\varphi_0}\right) \quad 0.5 \left(1 + E \frac{b}{\varphi_0}\right) \leq \frac{\varphi}{\varphi_0} < \varphi_i \quad (3.1-13d)$$

$$F\left(\frac{\varphi}{\varphi_0}\right) = G_{MAX} \quad \frac{\varphi}{\varphi_0} \geq \varphi_i \quad (3.1-13e)$$

where

- $\frac{\varphi}{\varphi_0}$ relative off-axis angle
- G_{MAX} antenna on-axis gain, dB
- b minimum half-power beamwidth, deg
- φ_0 half-power beamwidth, deg
- φ_i value of φ/φ_0 where $F(\varphi/\varphi_0) = G_{MAX}$
- SLL user input first sidelobe level, dB

and

$$B = 1.413 + 0.0638 SLL \quad (3.1-13f)$$

$$E = 4.191 - 0.0134 SLL \quad (3.1-13g)$$

$$C = \sqrt{(SLL - 3 - B)/B} - 1 \quad (3.1-13h)$$

3.1.1.2.4.12 Satellite Antenna IWPREV

This satellite antenna pattern is the same as that described in section 3.1.1.2.4.11 except that the main beam is modelled as a simple ellipse. Figure 3.1-18 shows this pattern for various values of the ratio of HPBW to minimum HPBW while Figure 3.1-19 gives the falloff pattern for a single value of the ratio. The required parameters for this antenna are the same as those for the IWP4/1 antenna type. The falloff for this pattern is defined by the following equations:

$$F\left(\frac{\varphi}{\varphi_o}\right) = 12 \left(\frac{\varphi}{\varphi_o}\right)^2 \quad 0 \leq \frac{\varphi}{\varphi_o} < 0.5 \quad (3.1-14a)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 3 - B + B \left(\frac{\varphi_o}{b}\right)^2 \left(\frac{2\varphi}{\varphi_o} + \frac{b}{\varphi_o} - 1\right)^2 \quad 0.5 \leq \frac{\varphi}{\varphi_o} < 0.5 \left(1 + C \frac{b}{\varphi_o}\right) \quad (3.1-14b)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = SLL \quad 0.5 \left(1 + C \frac{b}{\varphi_o}\right) \leq \frac{\varphi}{\varphi_o} < 0.5 \left(1 + E \frac{b}{\varphi_o}\right) \quad (3.1-14c)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = SLL + 20 \log \left(2 \frac{\varphi}{\varphi_o}\right) - 20 \log \left(1 + E \frac{b}{\varphi_o}\right) \quad 0.5 \left(1 + E \frac{b}{\varphi_o}\right) \leq \frac{\varphi}{\varphi_o} < \varphi_i \quad (3.1-14d)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} \quad \frac{\varphi}{\varphi_o} \geq \varphi_i \quad (3.1-14e)$$

where

- $\frac{\varphi}{\varphi_o}$ relative off-axis angle
- G_{MAX} antenna on-axis gain, dB
- b minimum half-power beamwidth, deg
- φ_o half-power beamwidth, deg
- φ_i value of φ/φ_o where $F(\varphi/\varphi_o) = G_{MAX}$
- SLL user input first sidelobe level, dB

and

$$B = 1.413 + 0.0638 SLL \quad (3.1-14f)$$

$$E = 4.191 - 0.0134 SLL \quad (3.1-14g)$$

$$C = \sqrt{(SLL - 3 - B)/B} - 1 \quad (3.1-14h)$$

3.1.1.2.4.13 Satellite Antenna JIWPFR

This fast rolloff antenna pattern was recommended by CCIR in its Report to the Second Session of the Space WARC in 1988. 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 3.1-20 shows this pattern for various values of HPBW to minimum HPBW while figure 3.1-21

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. The CCIR report recommends a focal length-to-diameter ratio in the range of 0.73 to 1.3 be utilized in this pattern. Additionally, the minimum HPBW is utilized in the falloff equations for the antenna pattern:

$$F\left(\frac{\varphi}{\varphi_o}\right) = 3 - B + 4B\left(\frac{\varphi}{\varphi_o}\right)^2 \quad 0 \leq \frac{\varphi}{\varphi_o} < 0.5 \quad (3.1-15a)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 3 + B\left(\frac{\varphi_o}{b}\right)^2 \left(\frac{2\varphi}{\varphi_o} - 1\right)\left(\frac{2b}{\varphi_o} + \frac{2\varphi}{\varphi_o} - 1\right) \quad 0.5 \leq \frac{\varphi}{\varphi_o} < 0.5 \left(1 + C\frac{b}{\varphi_o}\right) \quad (3.1-15b)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 20 \quad 0.5 \left(1 + C\frac{b}{\varphi_o}\right) \leq \frac{\varphi}{\varphi_o} < 0.5 \left[1 + (C + 0.5)\frac{b}{\varphi_o}\right] \quad (3.1-15c)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 20 - 2.5\frac{\varphi_o}{b} \left[(C + 0.5)\frac{b}{\varphi_o} - \frac{2\varphi}{\varphi_o} + 1 \right]$$

$$0.5 \left[1 + (C + 0.5)\frac{b}{\varphi_o}\right] \leq \frac{\varphi}{\varphi_o} < 0.5 \left[1 + (C + 4.5)\frac{b}{\varphi_o}\right] \quad (3.1-15d)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 30 - 20 \log \left[(C + 4.5)\frac{b}{\varphi_o} \right] + 20 \log \frac{2\varphi}{\varphi_o} - 1$$

$$0.5 \left[1 + (C + 4.5)\frac{b}{\varphi_o}\right] \leq \frac{\varphi}{\varphi_o} < 0.5 \left[1 + K(C + 4.5)\frac{b}{\varphi_o}\right] \quad (3.1-15e)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} \quad \frac{\varphi}{\varphi_o} \geq 0.5 \left[1 + K(C + 4.5)\frac{b}{\varphi_o}\right] \quad (3.1-15f)$$

where

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

G_{MAX} antenna on-axis gain, dB

b minimum half-power beamwidth, deg

φ_o half-power beamwidth, deg

F/D focal length-to-diameter ratio of satellite antenna

and

$$K = 10^{[(G_{MAX}-30)/20]} \quad (3.1-15g)$$

$$C = \sqrt{1 + 17/B} - 1 \quad (3.1-15h)$$

$$B = B_o \quad \frac{\varphi_o}{b} < 1.25 \quad (3.1-15i)$$

$$B = B_o - \frac{\varphi_o}{b} - 1.25 \Delta B \quad \frac{\varphi_o}{b} \geq 1.25 \quad (3.1-15j)$$

$$B_o = 2.25 + \frac{F/D - 1.3}{1.5} \quad (3.1-15k)$$

$$\Delta B = 0.28 - \frac{F/D - 1.3}{30} \quad (3.1-15l)$$

3.1.1.2.4.14 Satellite Antenna JIWPRV

This fast rolloff antenna pattern is basically the same as the JIWPFR antenna of section 3.1.1.2.4.13 except that the main beam is modelled as a simple ellipse. Figure 3.1-22 shows this pattern for various values of HPBW to minimum HPBW while figure 3.1-23 gives the falloff pattern for a single value of this ratio. The required parameter for this antenna as with the JIWPFR antenna type is the satellite antenna focal length-to-diameter ratio with the same restrictions applying. Additionally, the minimum HPBW is utilized in the falloff equations for the antenna pattern:

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

$$F\left(\frac{\varphi}{\varphi_o}\right) = 3 + B \left(\frac{\varphi_o}{b}\right)^2 \left(\frac{2\varphi}{\varphi_o} - 1\right) \left(\frac{2b}{\varphi_o} + \frac{2\varphi}{\varphi_o} - 1\right) \quad 0.5 \leq \frac{\varphi}{\varphi_o} < 0.5 \left(1 + C \frac{b}{\varphi_o}\right) \quad (3.1-16b)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 20 \quad 0.5 \left(1 + C \frac{b}{\varphi_o}\right) \leq \frac{\varphi}{\varphi_o} < 0.5 \left[1 + (C + 0.5) \frac{b}{\varphi_o}\right] \quad (3.1-16c)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 20 - 2.5 \frac{\varphi_o}{b} \left[(C + 0.5) \frac{b}{\varphi_o} - \frac{2\varphi}{\varphi_o} + 1 \right]$$

$$0.5 \left[1 + (C + 0.5) \frac{b}{\varphi_o}\right] \leq \frac{\varphi}{\varphi_o} < 0.5 \left[1 + (C + 4.5) \frac{b}{\varphi_o}\right] \quad (3.1-16d)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = 30 - 20 \log \left[(C + 4.5) \frac{b}{\varphi_o} \right] + 20 \log \frac{2\varphi}{\varphi_o} - 1$$

$$0.5 \left[1 + (C + 4.5) \frac{b}{\varphi_o}\right] \leq \frac{\varphi}{\varphi_o} < 0.5 \left[1 + K(C + 4.5) \frac{b}{\varphi_o}\right] \quad (3.1-16e)$$

$$F\left(\frac{\varphi}{\varphi_o}\right) = G_{MAX} \quad \frac{\varphi}{\varphi_o} \geq 0.5 \left[1 + K(C + 4.5) \frac{b}{\varphi_o}\right] \quad (3.1-16f)$$

where

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

and

$$K = 10^{[(G_{MAX}-30)/20]} \quad (3.1-16g)$$

$$C = \sqrt{1 + 17/B} - 1 \quad (3.1-16h)$$

$$B = B_o \quad \frac{\varphi_o}{b} < 1.25 \quad (3.1-16i)$$

$$B = B_o - \frac{\varphi_o}{b} - 1.25 \Delta B \quad \frac{\varphi_o}{b} \geq 1.25 \quad (3.1-16j)$$

$$B_o = 2.25 + \frac{F/D - 1.3}{1.5} \quad (3.1-16k)$$

$$\Delta B = 0.28 - \frac{F/D - 1.3}{30} \quad (3.1-16l)$$

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. The minimum ellipse data can be generated by any existing minimum ellipse program as long as the format described in section 2.3.1.8 of the *User's Manual* is followed. The current master ellipse file was generated using a minimum ellipse generation program written by Dave Netterville of the IFRB which is based on routines developed by G. Chouinard of Canada. The ellipse data used by the NASARC software are comprised of the service area or beam 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). All angles, including longitudinal positions and beamwidths, are required to be in decimal degrees.

Also contained in the Ellipse file is the precalculated rain attenuation data for both C and Ku-band. Attenuation data are present for each service area for each test point at each discrete arc location. This is discussed in more detail in section 2.2.2 of this manual. The use of these data is described in section 3.2.2.1.1 later in this manual.

The ellipse data are used for various purposes in NASSEP, the satellite separations program, 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.

CCIR REP 391-4 STANDARD EARTH STATION ANTENNA PATTERN

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

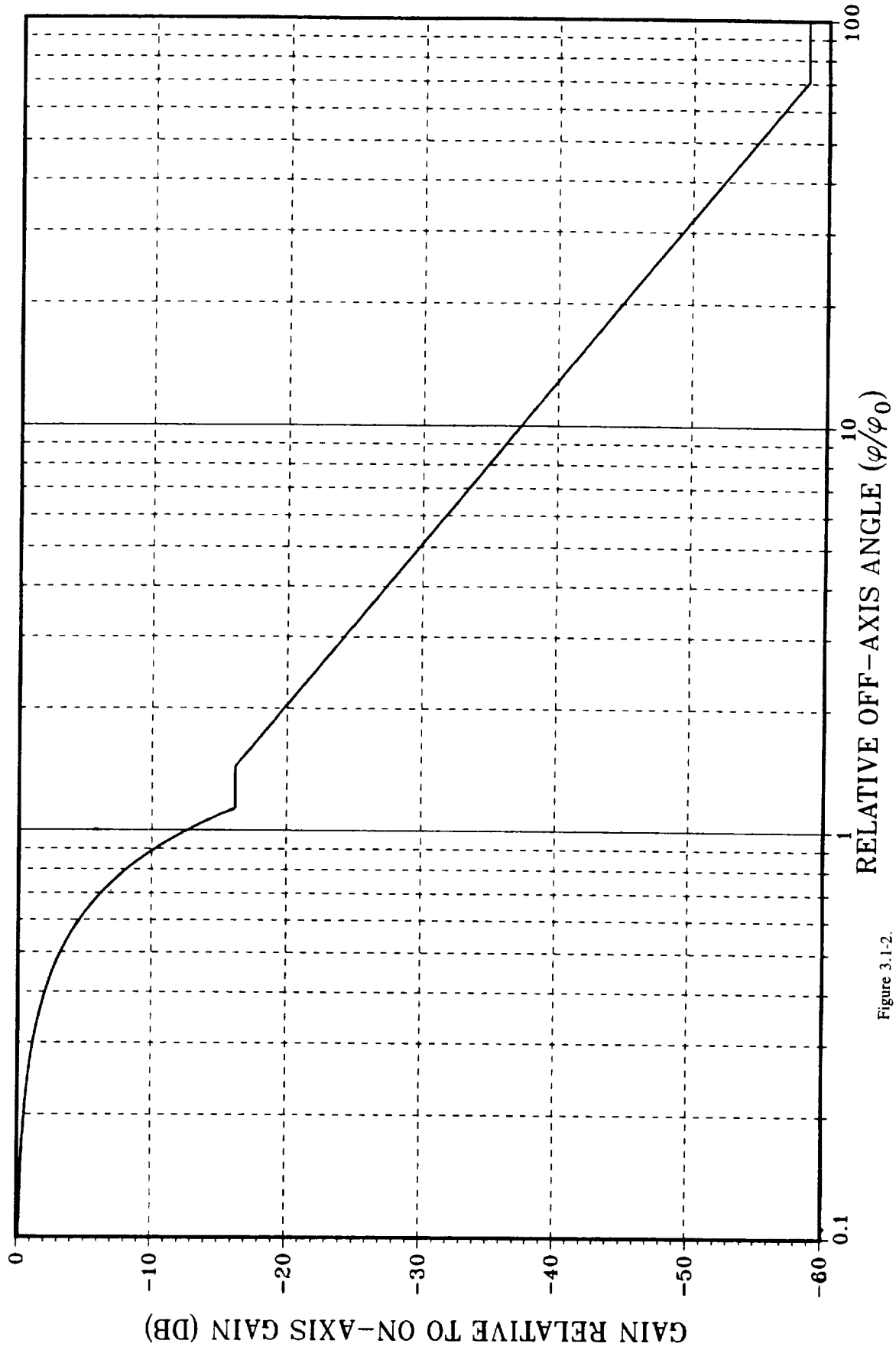


Figure 3.1-2.

EARTH STATION PATTERN USING 29 - 25 LOG(φ) SLL

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

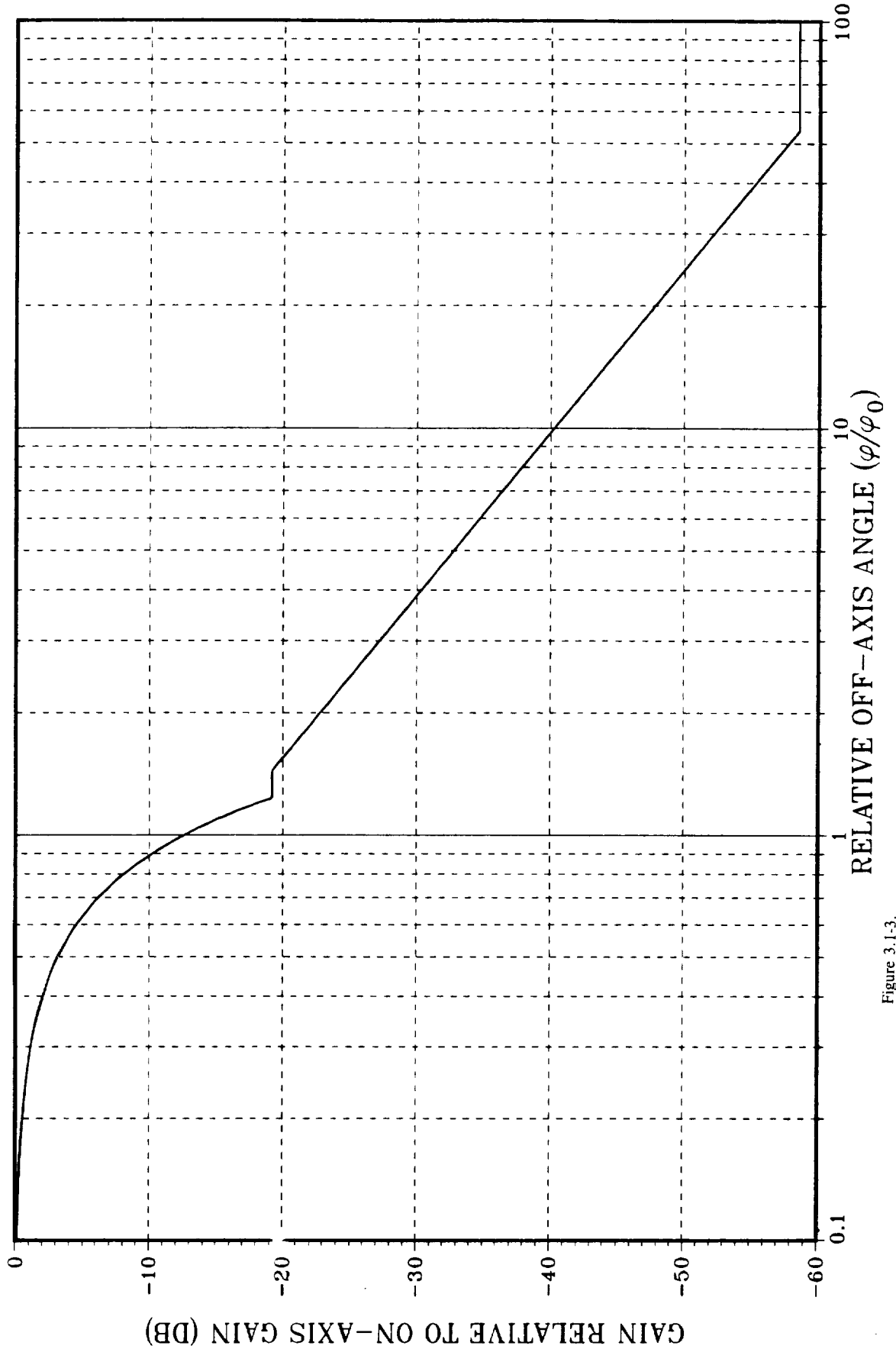


Figure 3.1-3.

EARTH STATION ANTENNA PATTERN FOR DEVELOPED COUNTRIES

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

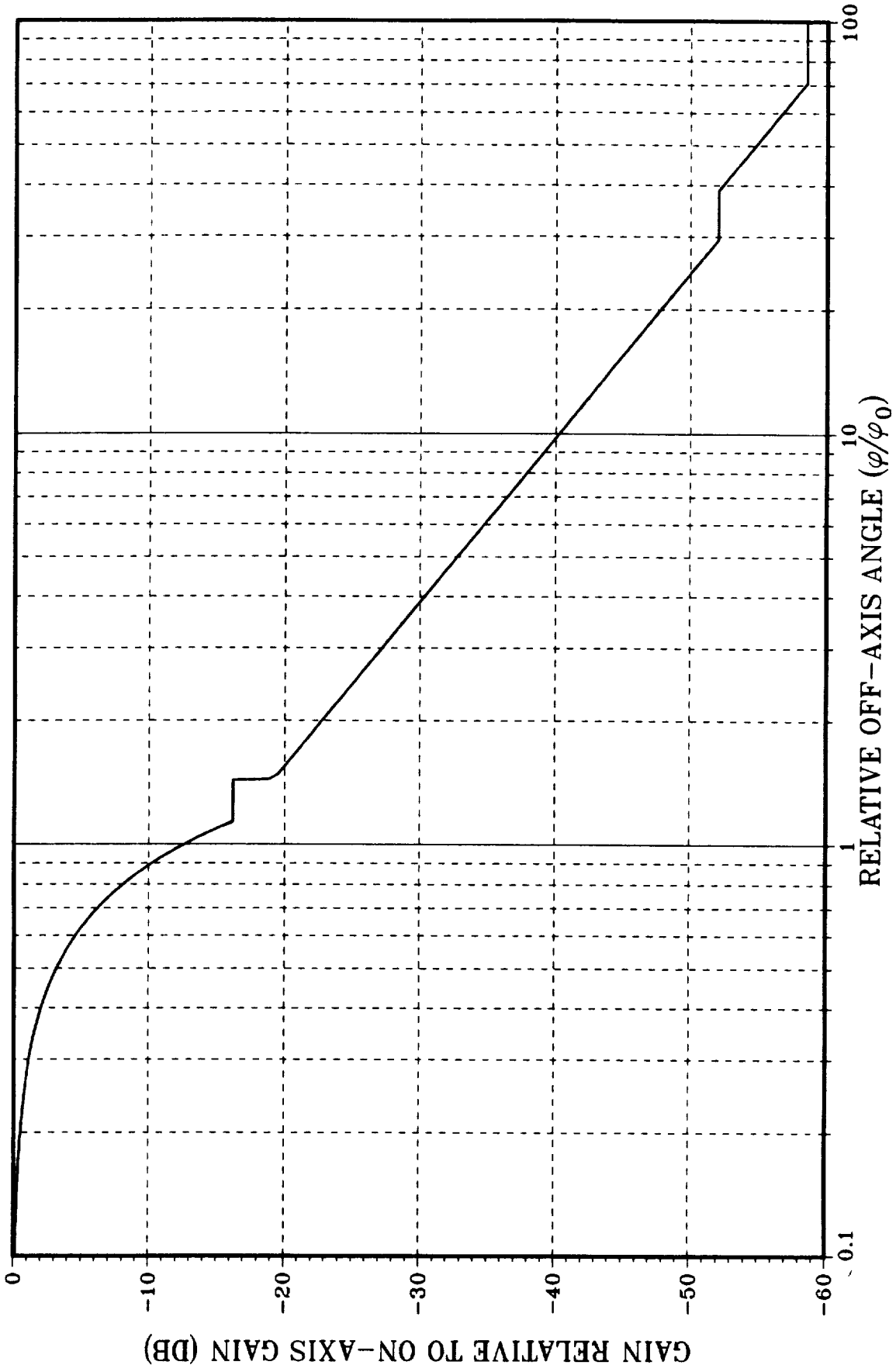


Figure 3.1-4.

CCIR REP 558-3 STANDARD SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB SIDELOBE = 20.0

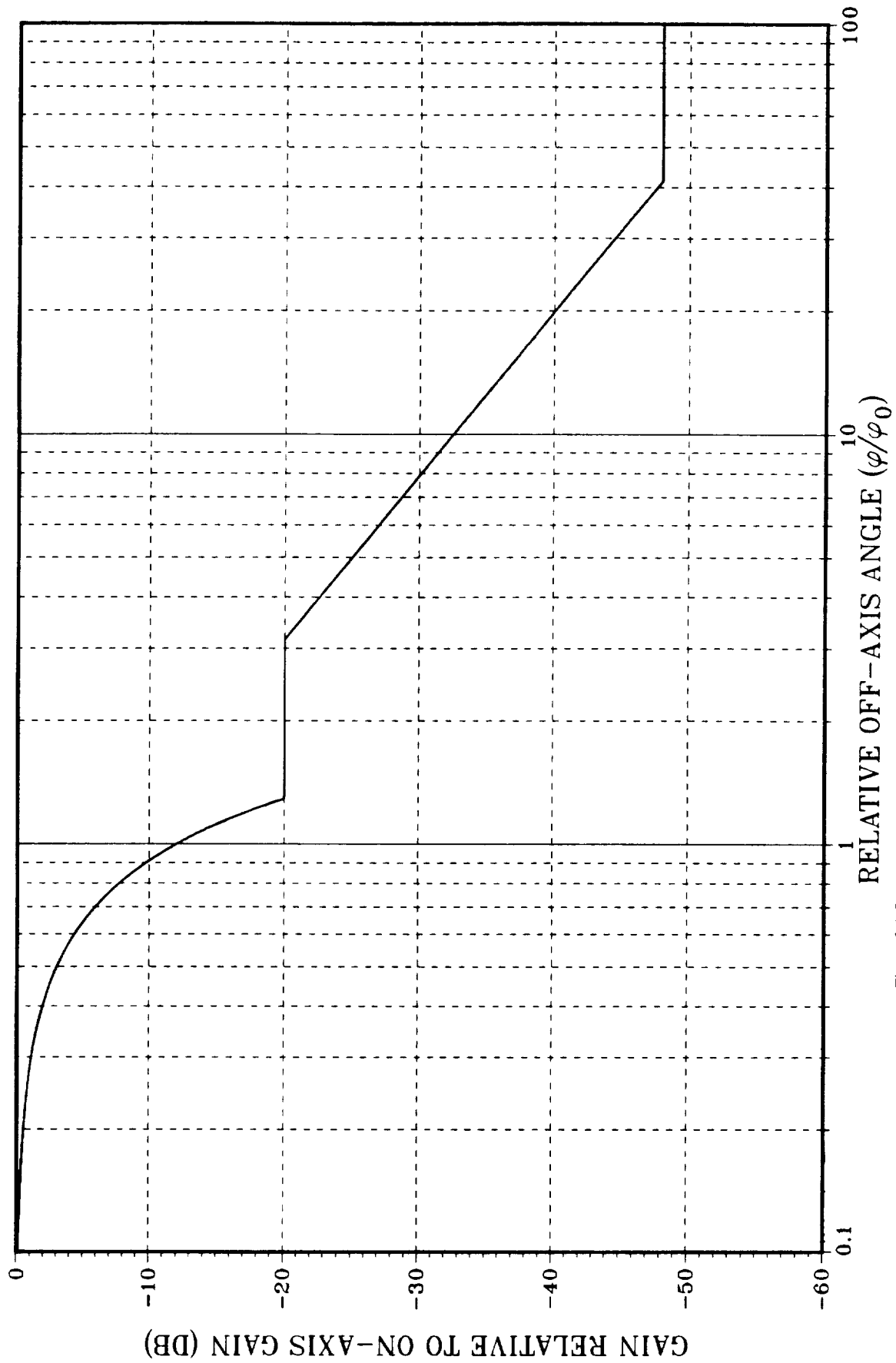


Figure 3.1-5.

CCIR REP 558-3 STANDARD SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB SIDELOBE = 25.0

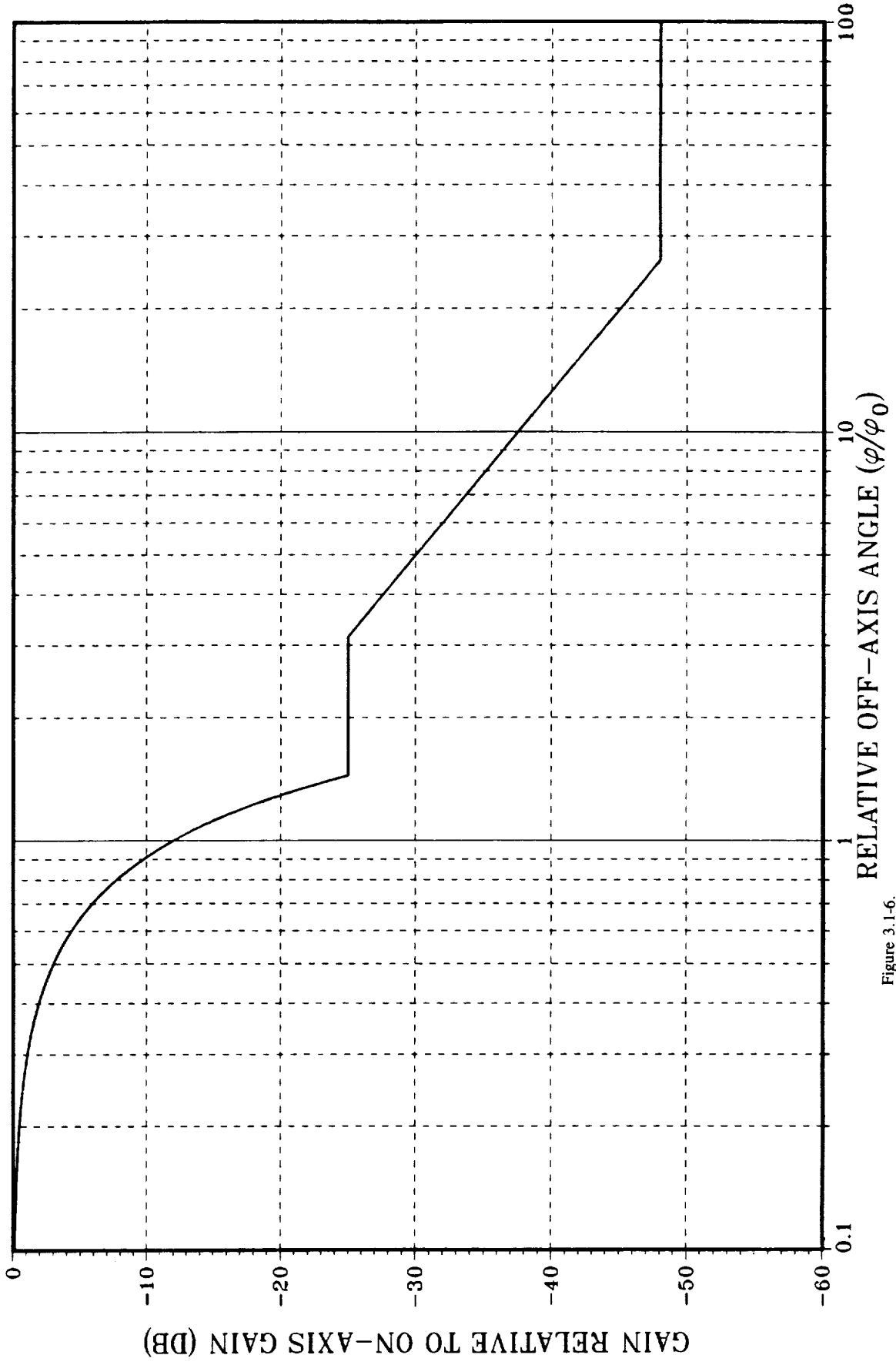


Figure 3.1-6.

CCIR REP 558-3 STANDARD SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB SIDELOBE = 30.0

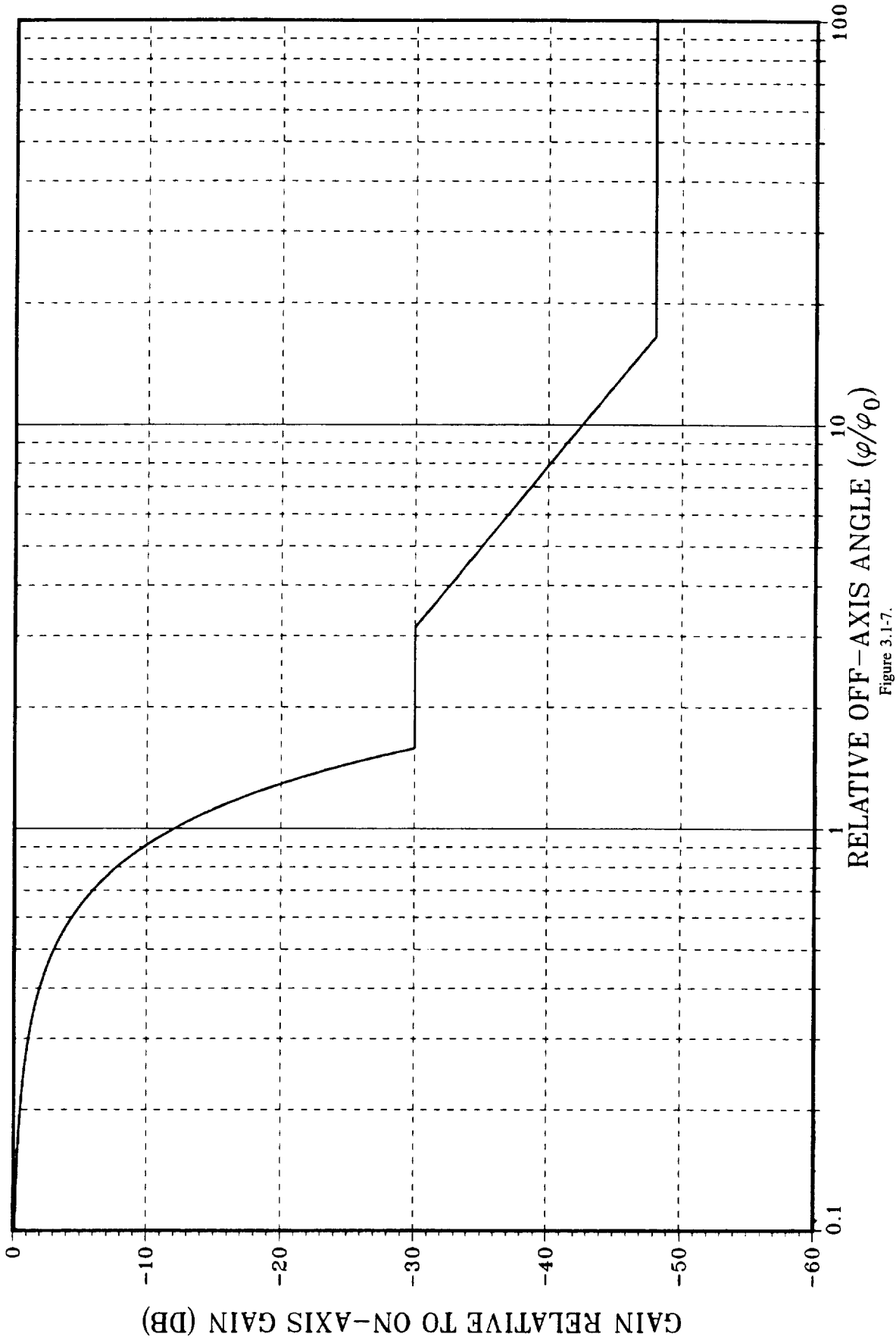


Figure 3.1-7.

RARC 83 STANDARD ROLL-OFF SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB

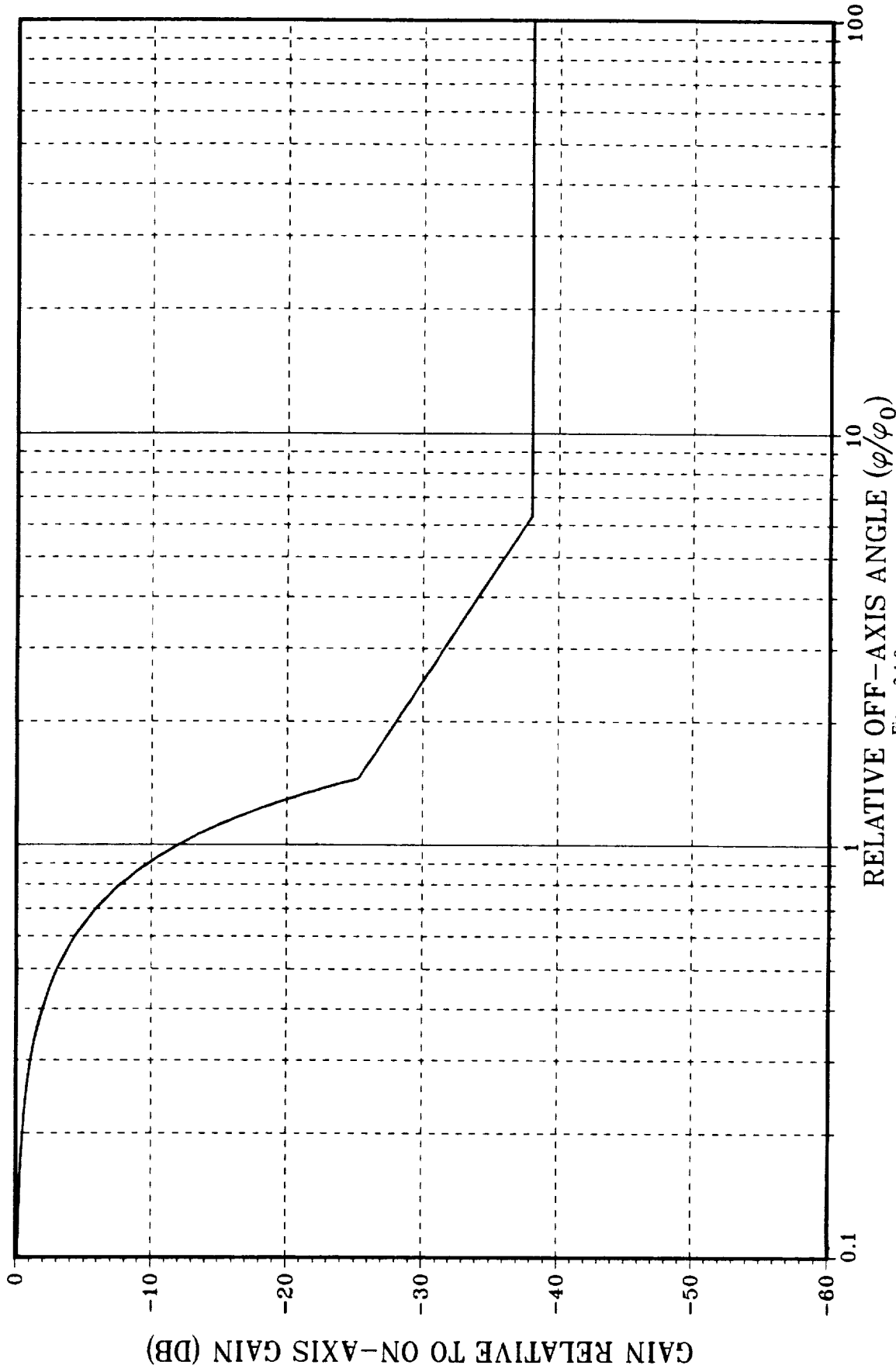


Figure 3.1-8.

RARC 83 FAST ROLL-OFF SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB

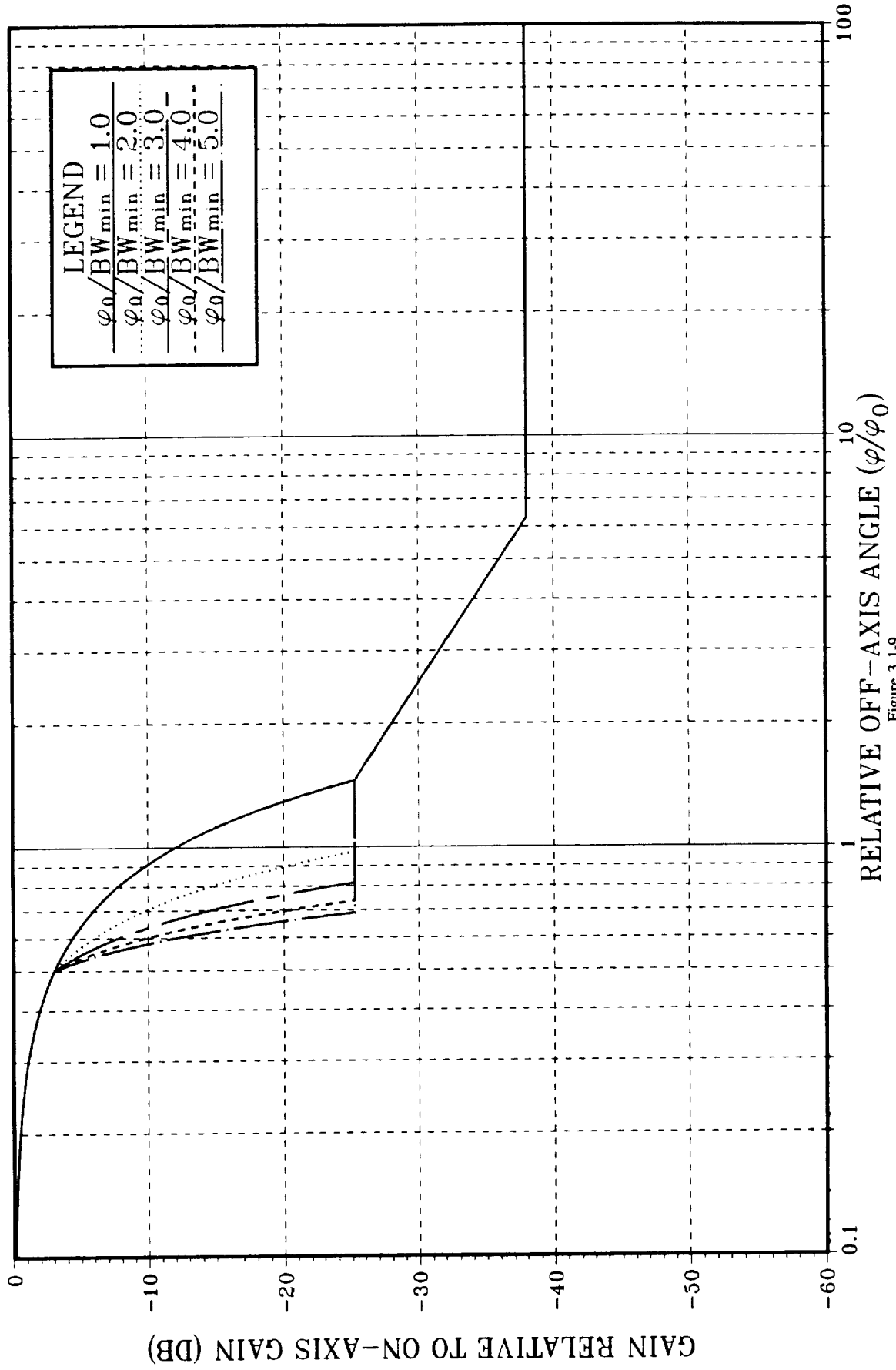
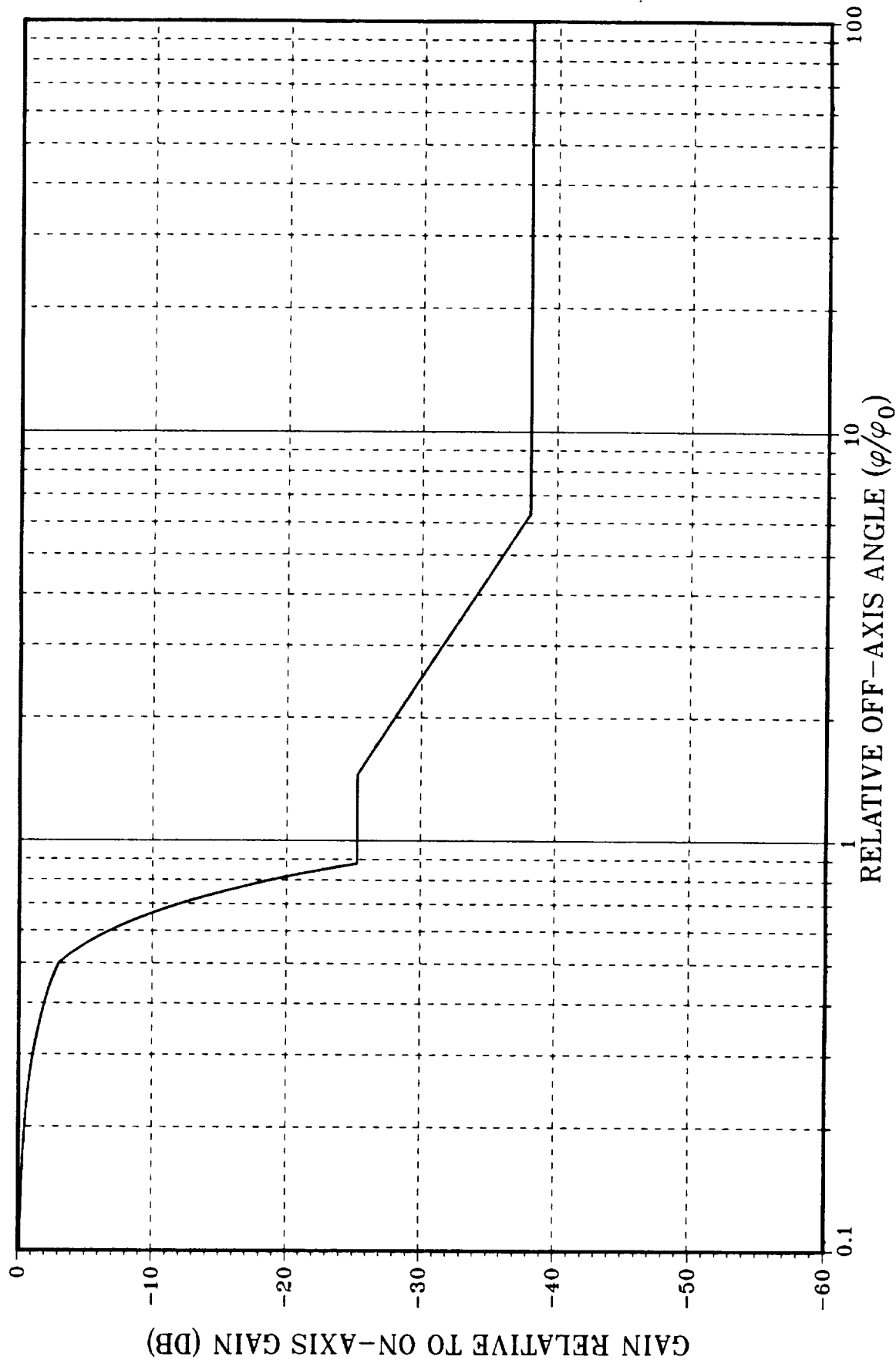


Figure 3.1-9.

RARC 83 FAST ROLL-OFF SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB HPBW/MIN = 2.5



IMPROVED FAST ROLL-OFF SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB

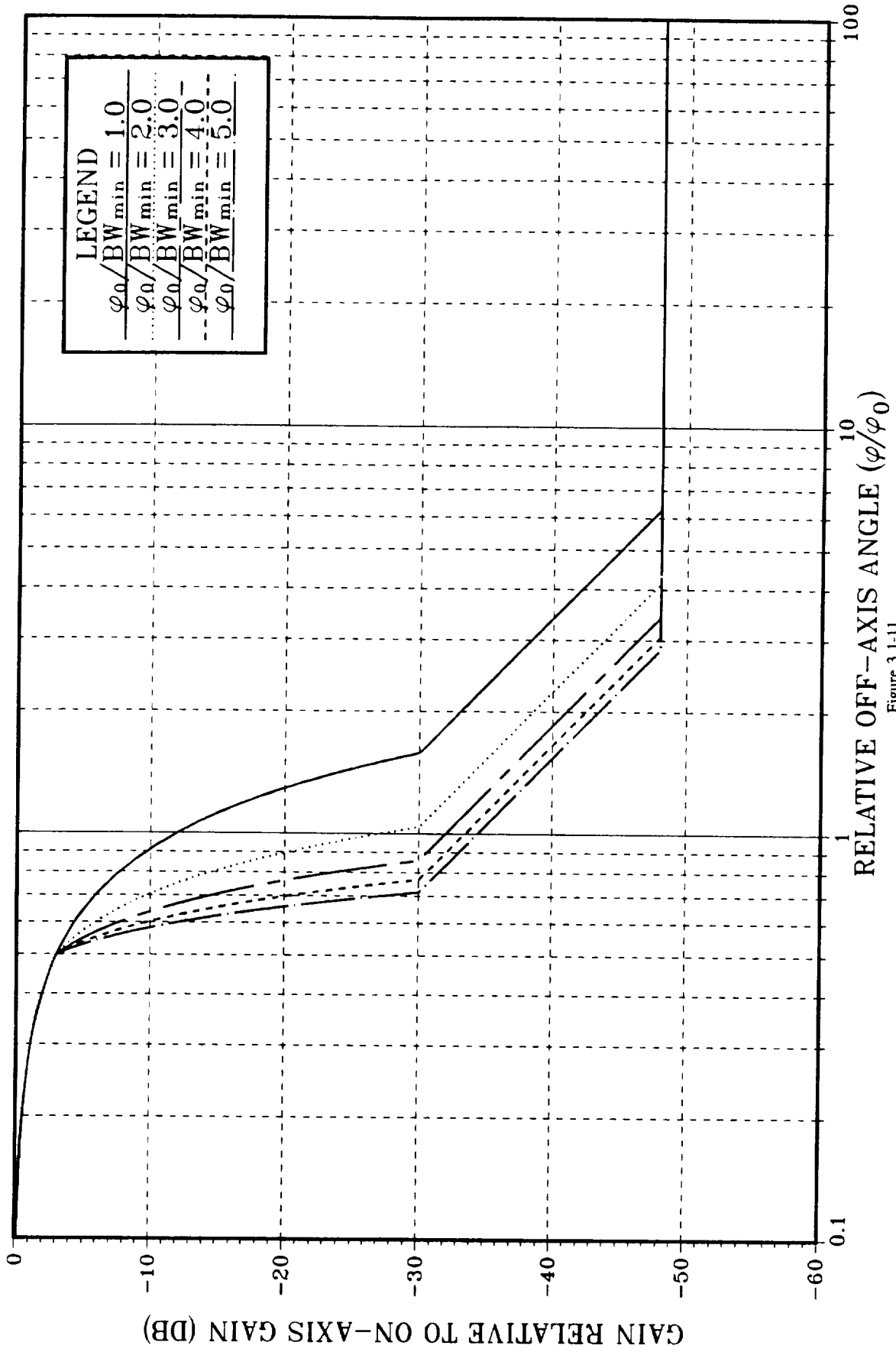


Figure 3.1-11.

IMPROVED FAST ROLL-OFF SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB HPBW/MIN = 2.5

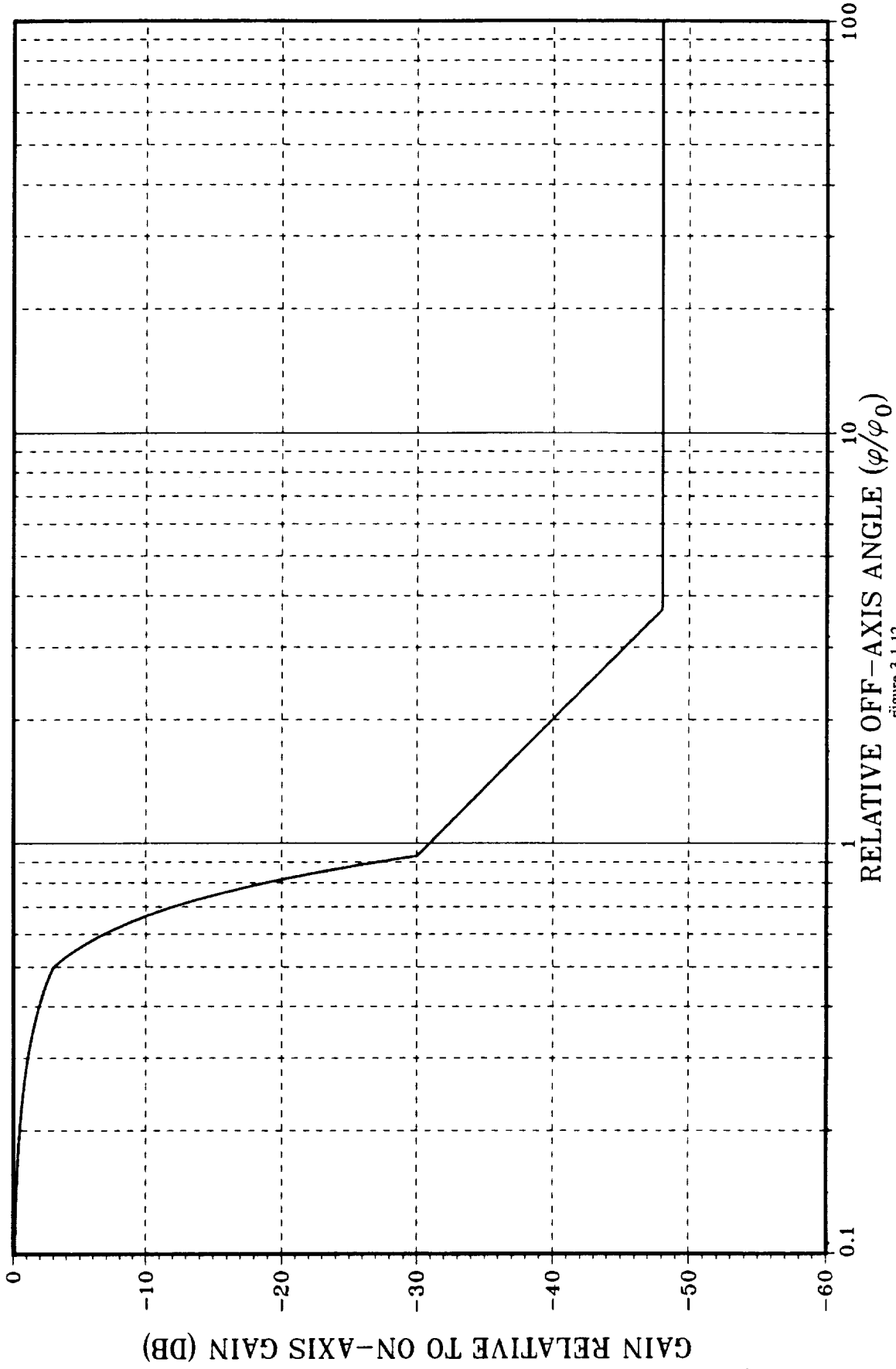


figure 3.1-12.

ORBIT-II STANDARD SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB

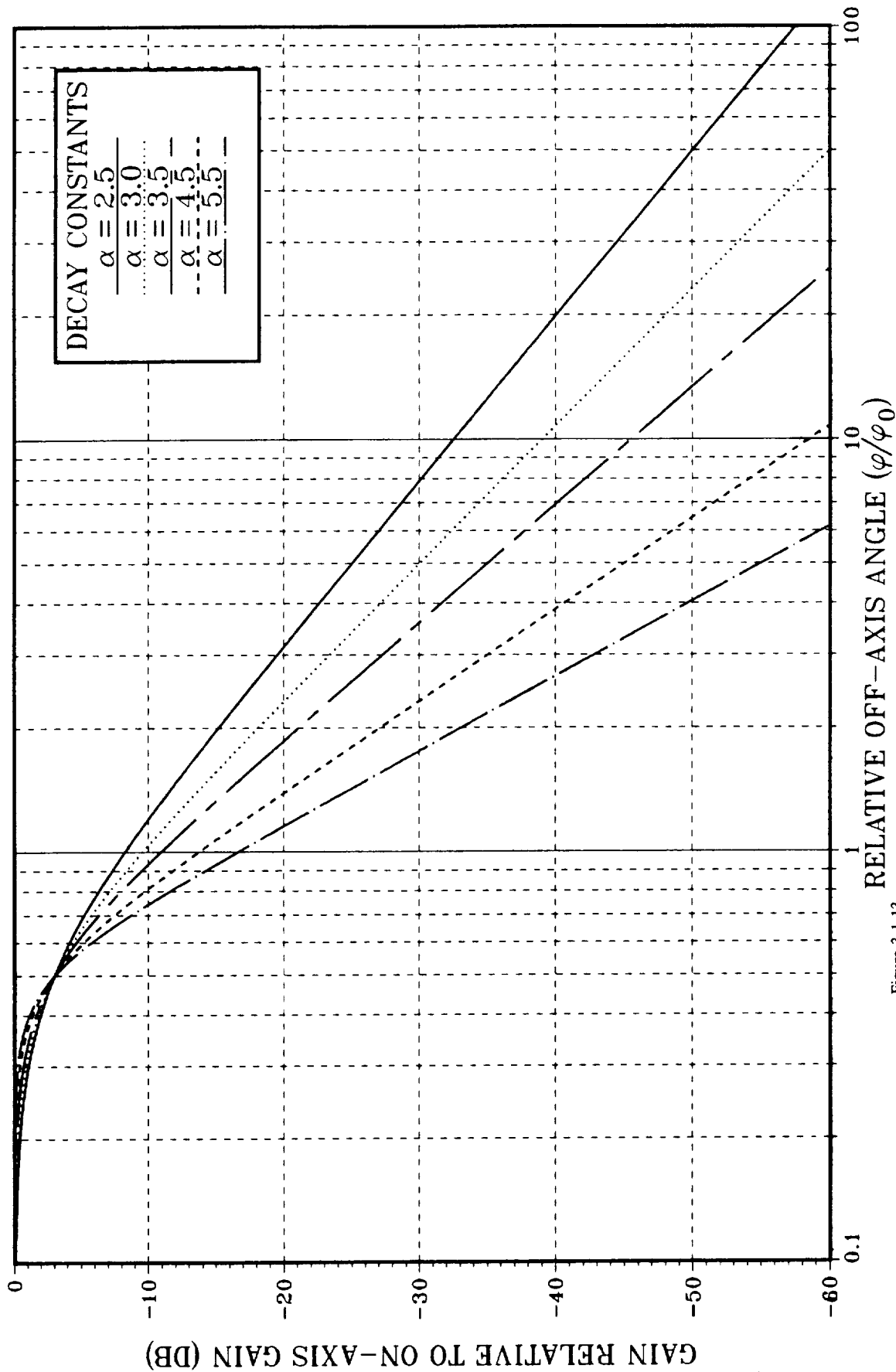


Figure 3.1-13.

ORBIT-II SATELLITE ANTENNA PATTERN WITH FLOOR

GAIN = 38.0 DB $\alpha = 4.0$

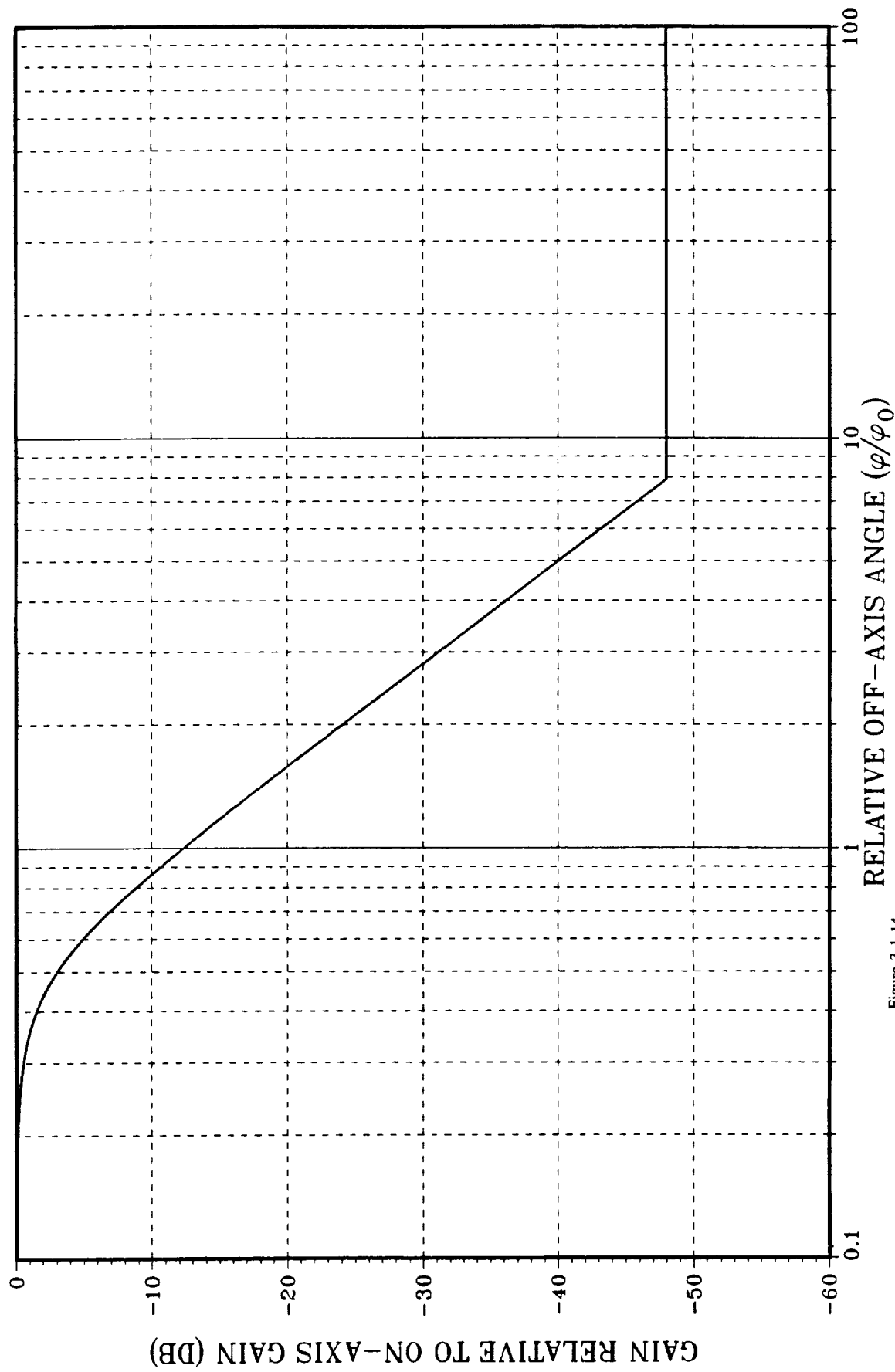


Figure 3.1-14.

WARC 77 STANDARD ROLL-OFF SATELLITE ANTENNA PATTERN

GAIN = 38.0 DB

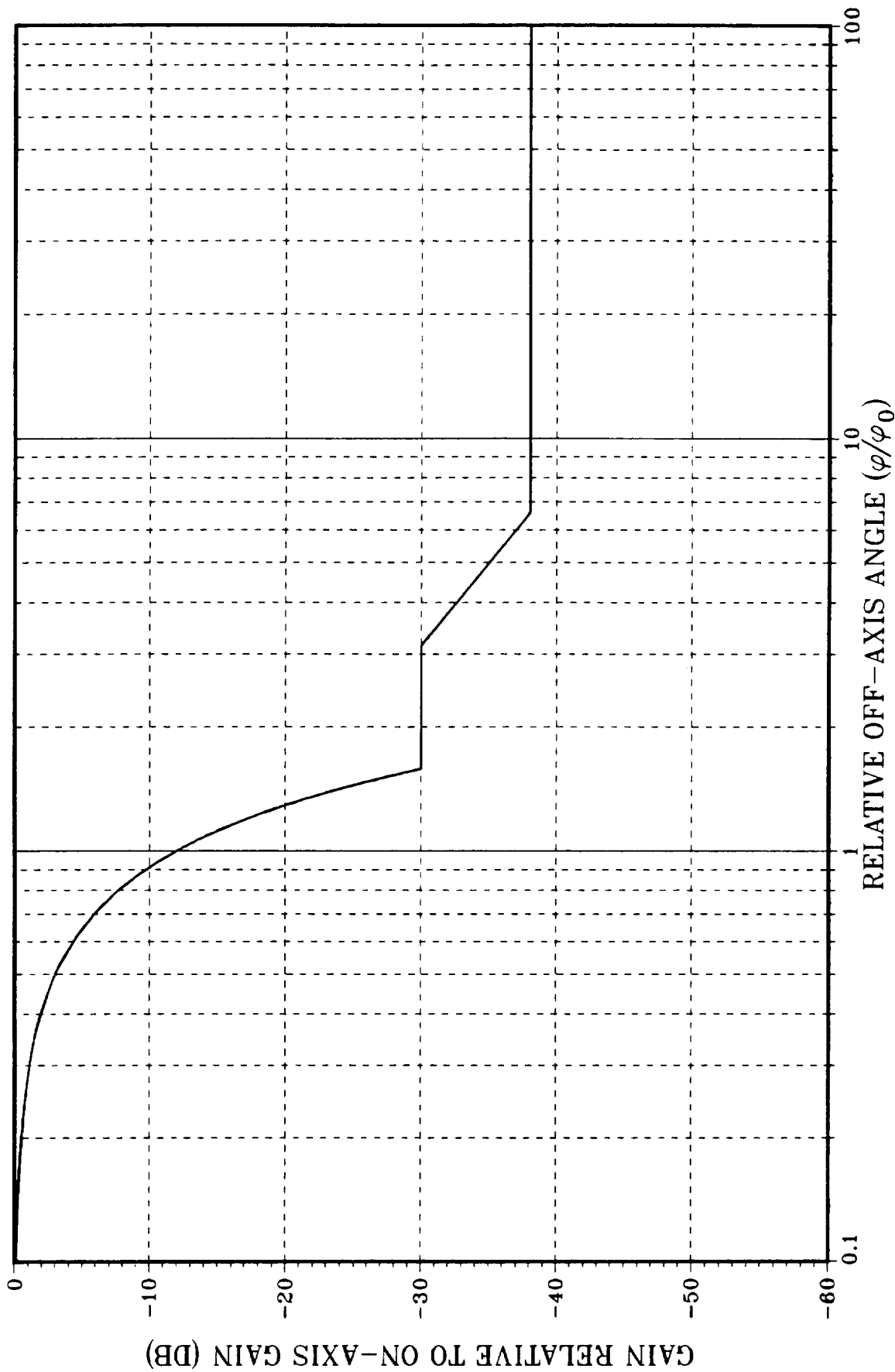


Figure 3.1-15.

FAST ROLL-OFF SATELLITE ANTENNA FROM IWP4/1

GAIN = 38.0 DB SIDELOBE = 25.0

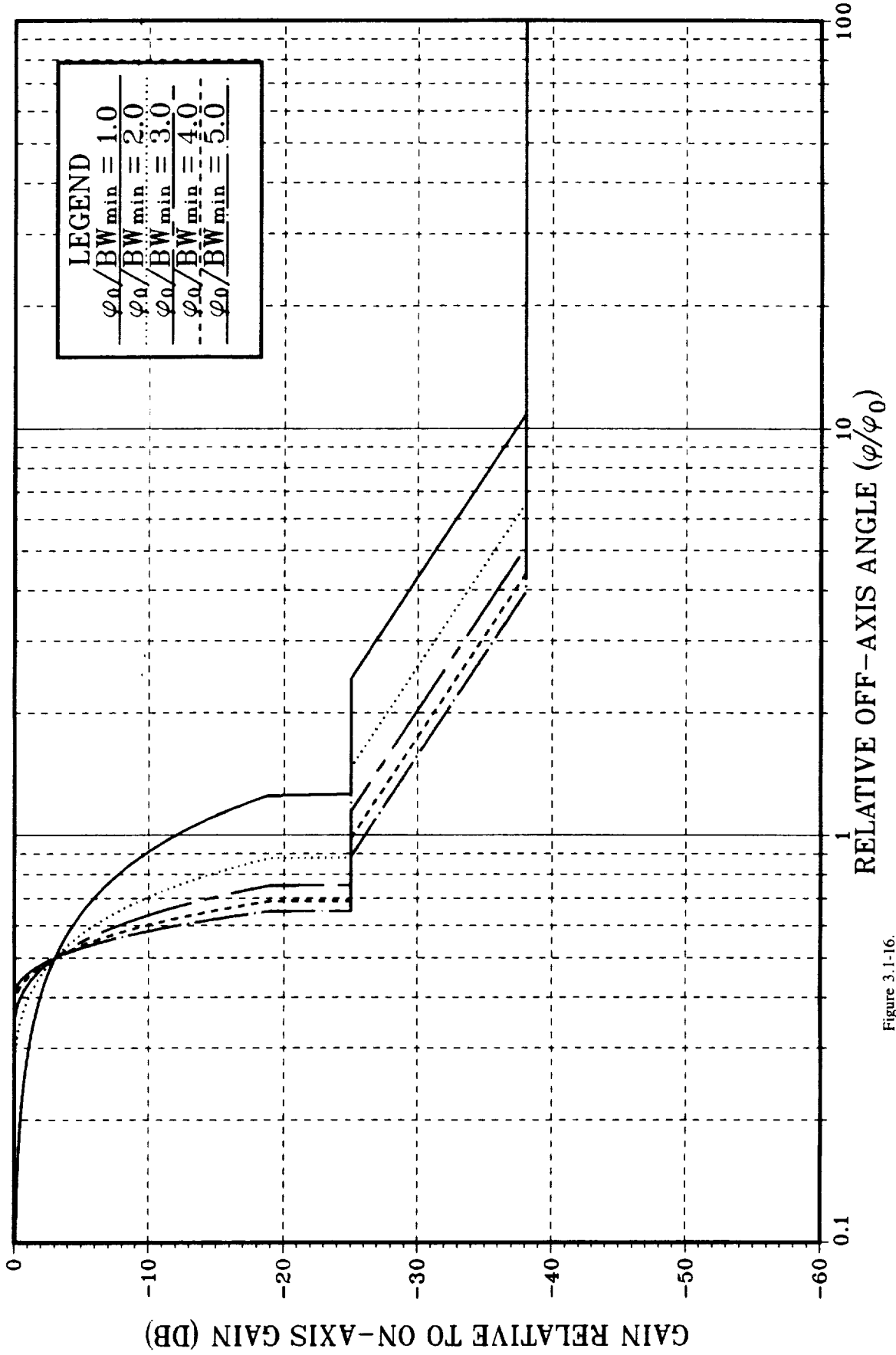


Figure 3.1-16.

FAST ROLL-OFF SATELLITE ANTENNA FROM IWP4/1

GAIN = 38.0 DB HPBW/MIN = 2.5

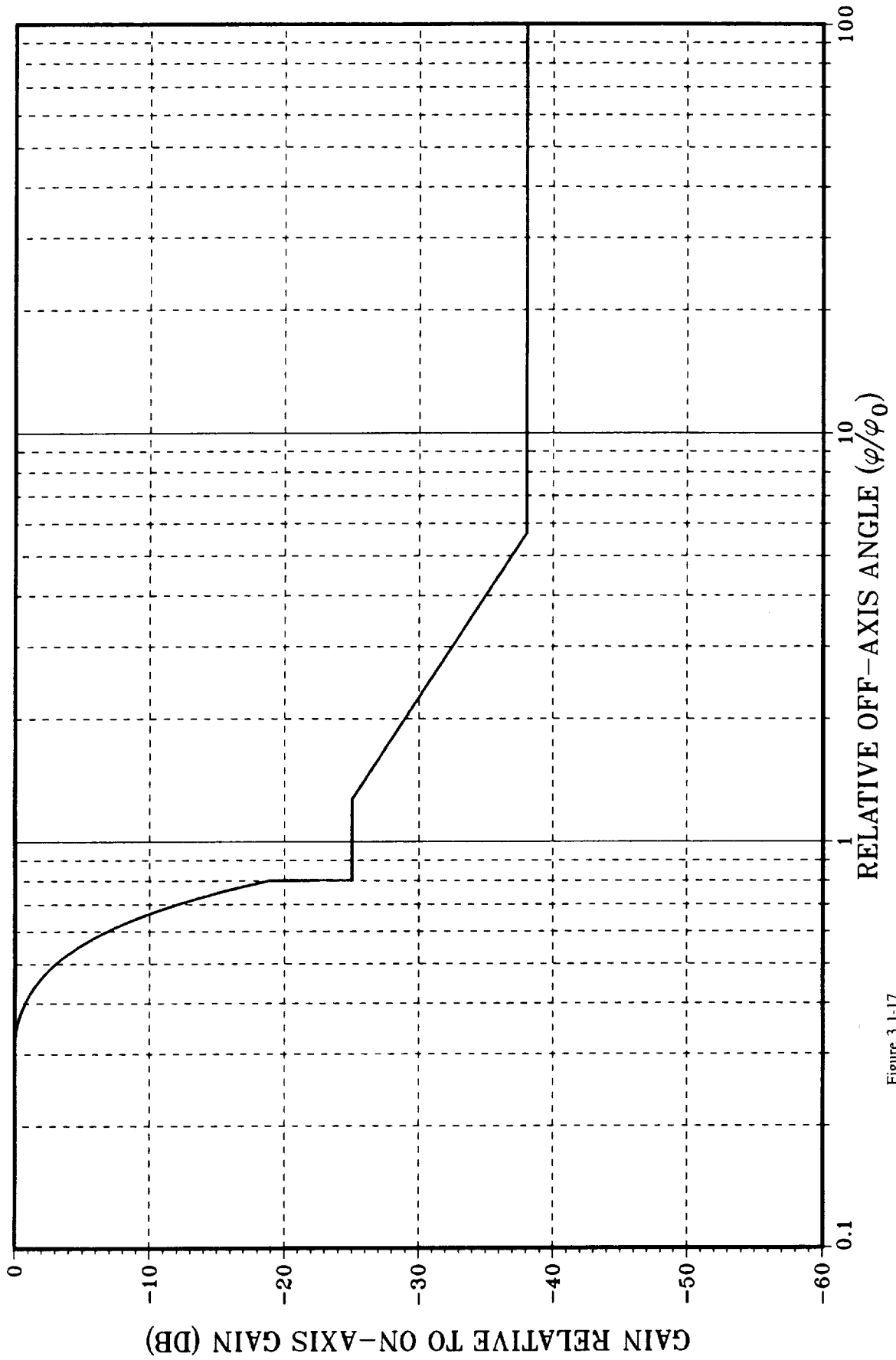


Figure 3.1-17.

IWP4/1 SAT. ANTENNA WITH ELLIPTICAL MAIN BEAM

GAIN = 38.0 DB SIDELOBE = 25.0

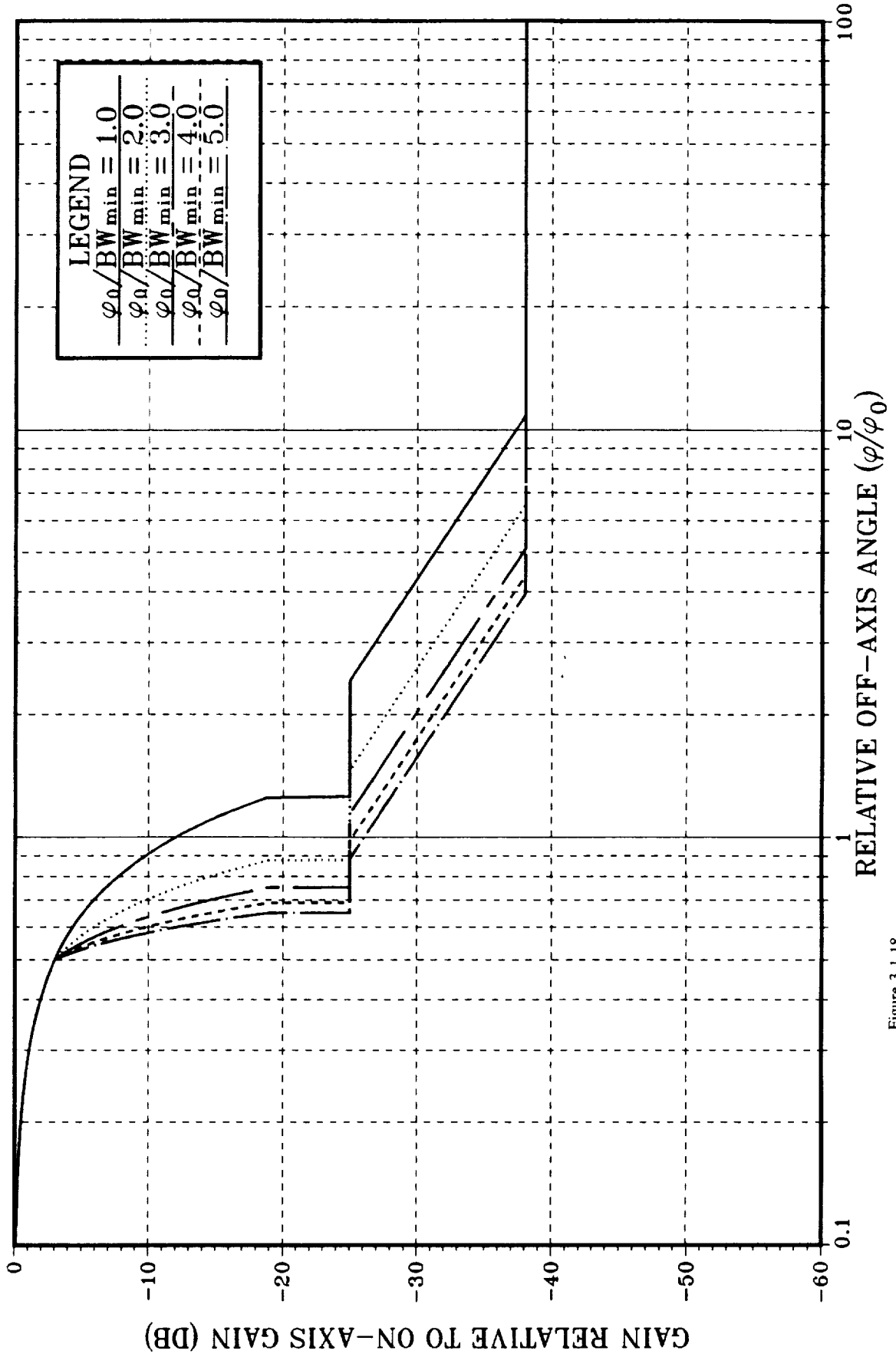


Figure 3.1-18.

IWP4/1 SAT. ANTENNA WITH ELLIPTICAL MAIN BEAM

GAIN = 38.0 DB HPBW/MIN = 2.5

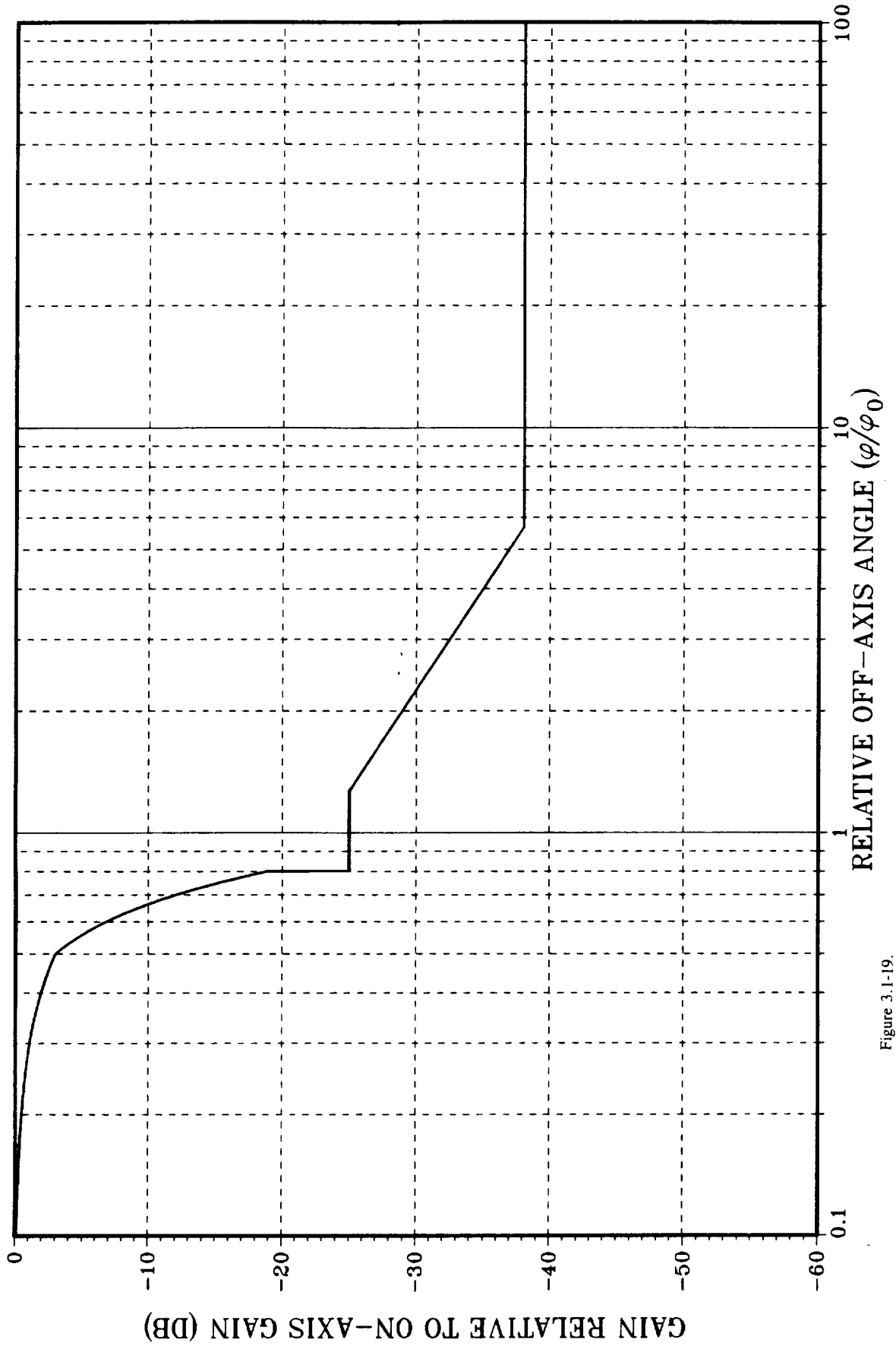


Figure 3.1-19.

CCIR FAST ROLL-OFF SATELLITE ANTENNA --- JIWP

GAIN = 38.0 DB F/d = 1.0

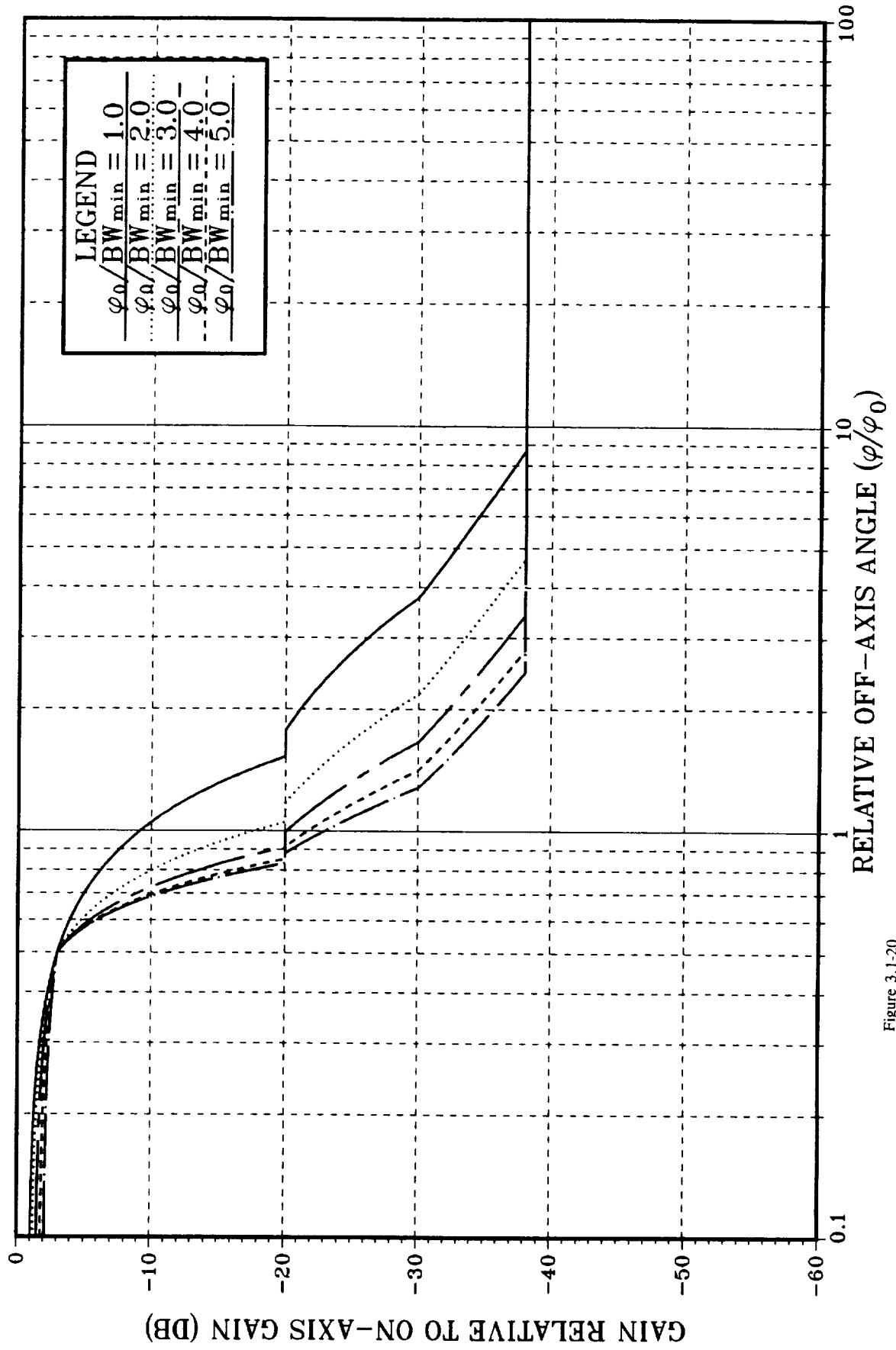


Figure 3.1-20.

CCIR FAST ROLL-OFF SATELLITE ANTENNA -- JIWP

GAIN = 38.0 DB HPBW/MIN = 2.5

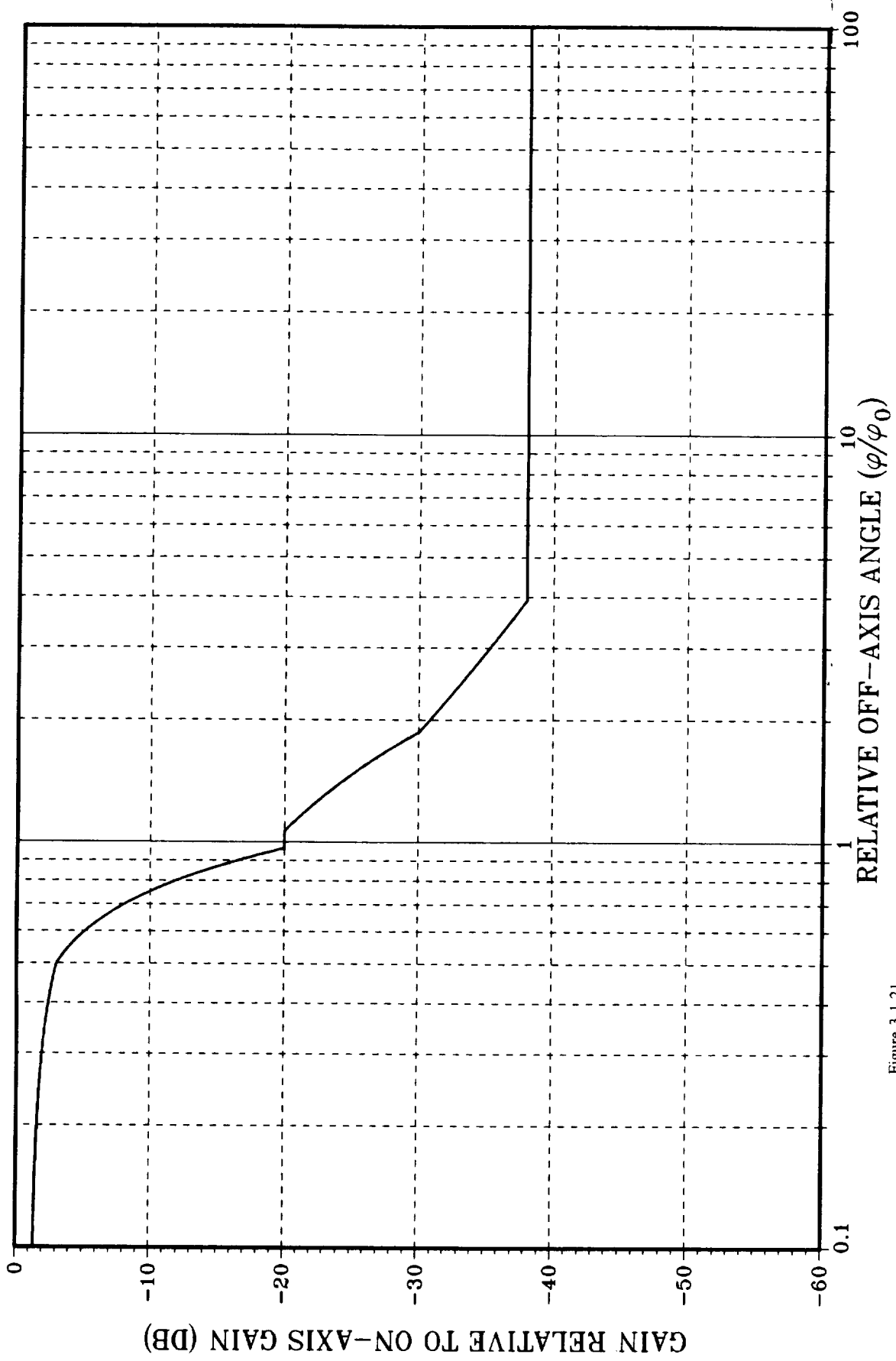


Figure 3.1-21.

JIWP SAT. ANTENNA WITH ELLIPTICAL MAIN BEAM

GAIN = 38.0 DB F/d = 1.0

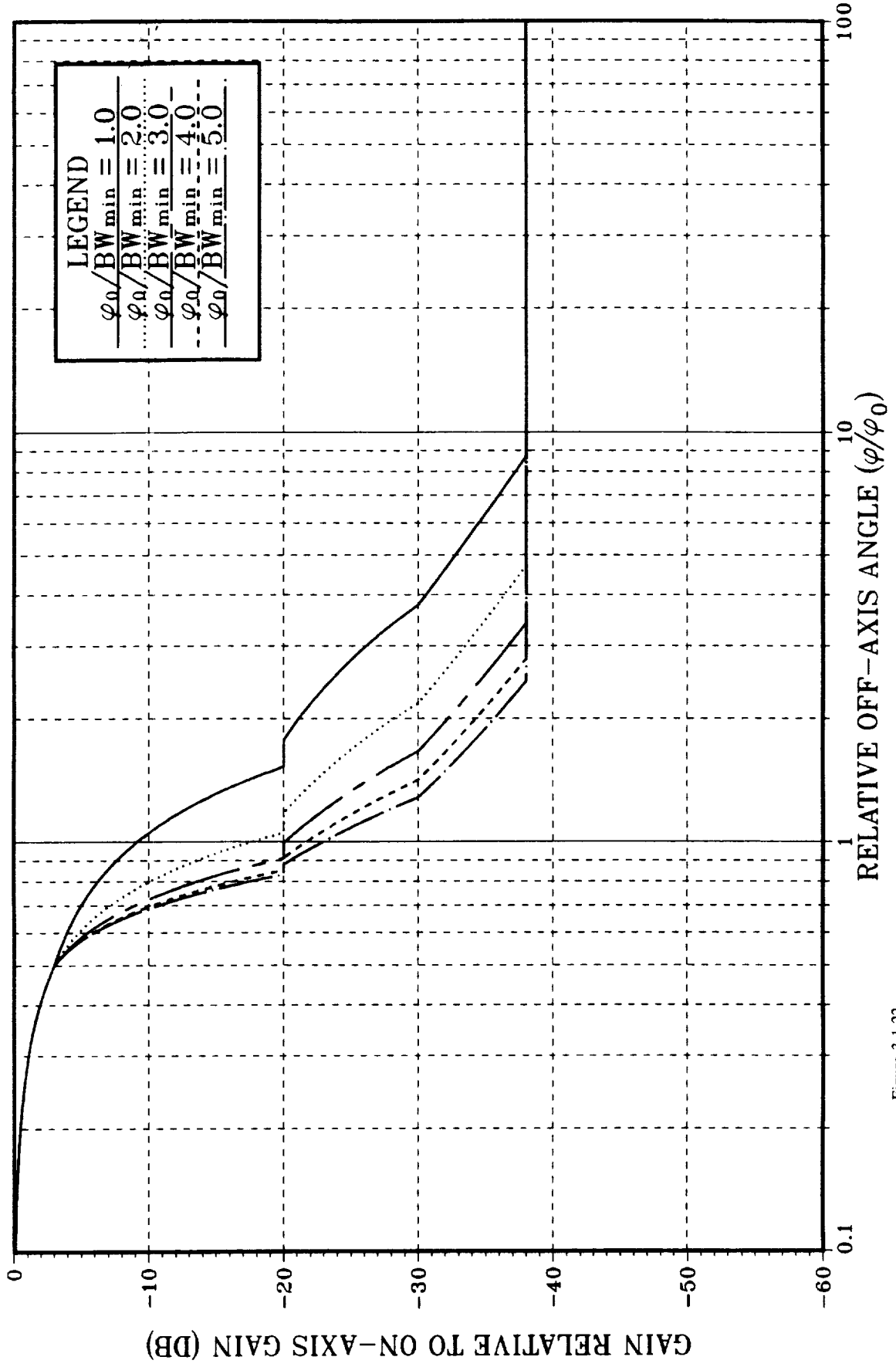


Figure 3.1-22.

JIWP SAT. ANTENNA WITH ELLIPTICAL MAIN BEAM

GAIN = 38.0 DB HPBW/MIN = 2.5

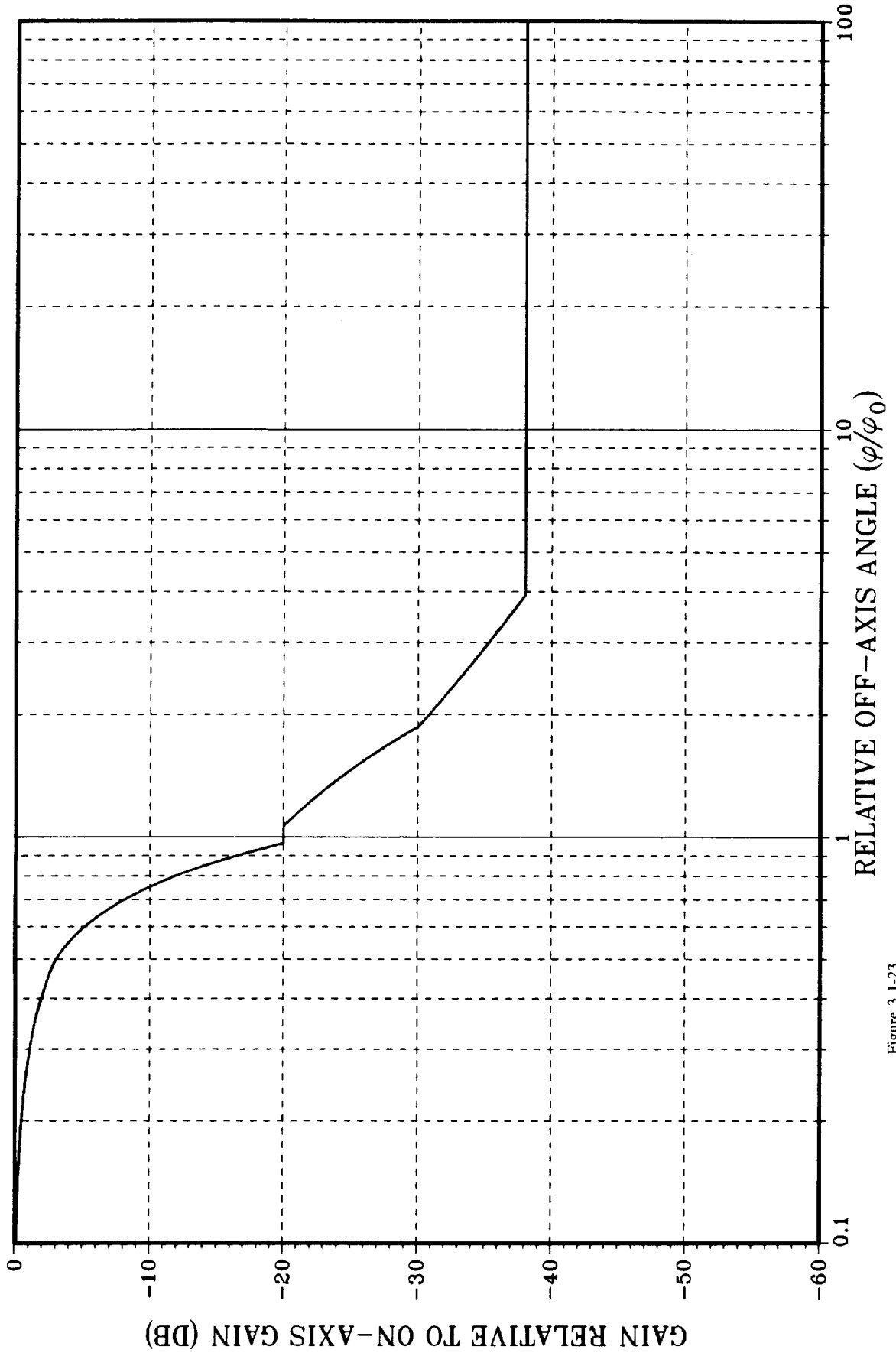


Figure 3.1-23.

When the ellipse major and/or minor axis beamwidths are less than the minimum half-power beamwidth given in the Service Area file, 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 2.3.1.5 and 3.2.4 of the *User's Manual*.

When the affiliated sets option is in effect, NASARC1, NASARC3, and NASARC4 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. Additionally, this file contains a grouping criterion specified individually for each segment to be used in the processing of that segment. A further description of the grouping criterion is given in the next section (section 3.1.1.5.1). 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.

3.1.1.5.1 Segment Information

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 as far as is 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. The NASARC4 module attempts to improve the adjacent PDA interference environment by interchanging selected groupings within the confines of their group arc boundaries. All subsequent segments are processed by NASARC1, NASARC2, NASARC3, and NASARC4 in this manner until all segments from the original Segments file have been exhausted. At this point, the NASARC4 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 4.0) 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.

3.1.1.5.2 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 single-entry *C/I* for any pair of space stations in that group. Compatibility on a pairwise basis is determined by applying the grouping criterion. The grouping criterion is found in the segments file and is specified, in decimal degrees, on a segment by segment basis, although the same grouping criterion can be used for each segment if desired. 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* 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° . Near colocation would be specified by a grouping criterion of 1° or less. Grouping criteria greater than 1° are **not** permitted. 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 determining 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 Precursor Programs

There are three precursor programs in the NASARC (Version 4.0) software package. These programs do not **necessarily** have to be used for each and every execution of the NASARC software. Rather, the precursor programs have specific purposes and are to be used as is appropriate with their stated functions. The first of the precursor programs is the interface program NASINTRF, which serves as an interface between the IFRB Requirements Data file and three of the NASARC prestored data files. This program need only be utilized when a Requirements Data file exists for the desired scenario.

The second precursor program is the input program NASARC0. Its function is to take some key user interactive inputs and scenario identifiers and place them in an Input Data file. The Input Data file is used by all the NASARC main modules as well as the satellite separations precursor program. NASARC0 also performs several checks on the consistency and correctness of other input data found in some of the prestored files. Once an Input Data file exists for a given scenario, it is not absolutely necessary for NASARC0 to be executed when that scenario is run again. The user can simply edit the Input Data file and alter whatever data entries are necessary for the new scenario. However, it is **strongly recommended** that the user execute NASARC0 whenever possible for its very important data checking operations.

The third and final precursor program is NASSEP, the satellite separations program. The function of this program is to form a required satellite separations matrix of all required orbital separations between all possible pairs of service areas in the scenario. The Separation Matrix file is used by NASARC2 and NASARC4 to place and interchange allotted arcs. Prior to the execution of this program, all the NASARC input files including the Input Data file must exist. Once again, it is not necessary to run this program for each scenario as long as none of the technical parameters have changed. For instance, if the user simply wants to execute NASARC with a different set of segments and grouping criteria, it is not necessary to rerun NASSEP since no technical parameters have changed. Each of these programs is explained further in the following sections.

3.1.2.1 NASINTRF: The Interface Program (and Requirements Data File)

In the preparatory work to the 1988 Space World Administrative Radio Conference, the IFRB had the task of gathering data on the allotment requirements of the individual ITU member administrations. When data were not sent to the IFRB by an administration, the IFRB created appropriate data as required to perform the various planning exercises. The sum total of all these data was the basis for the IFRB Requirements Data file. This data file contains all the technical data required to do planning exercises for a worldwide scenario in a format that is compatible with the ORBIT-II synthesis program. The NASARC interface program reads the IFRB Requirements Data file and uses these data to form three of the NASARC prestored data files: the Point Sets file, the Affiliated Sets file, and the Service Area file. There are potentially several versions of the Requirements Data file available, although only two different ones are essential for planning purposes, one for the C-band expansion band frequencies and one for the Ku-band expansion band frequencies.

The function of the interface program is to convert the requirements data from the IFRB Requirements Data file into the aforementioned NASARC input files. The interface program reads several pieces of global data from the requirements file and utilizes them where appropriate in the NASARC input files. The rain attenuation flag, the minimum half-power beamwidth, and the minimum transmitter power values are read directly from the requirements file and written to the global line of the Service Area file. The allotted arc length constants and the reference noise bandwidth are data coded directly into the interface program and are also written to the Service Area file. If the user wishes to change these values, the Service Area file can be edited for that purpose. Other global data such as the antenna efficiencies and default antenna types are used for the individually specified service area data where appropriate.

The remaining data in the requirements file are given on an individual service area basis. The interface program operates on the data and converts them to NASARC data where necessary. The eight-character beam code given in the requirements file is converted to its unique three-character NASARC code. Both the NASARC three-character code and the corresponding eight-character beam code are written to the Point Sets file. The eight-character code is preserved to facilitate reading the ellipse file which only uses this code to designate a given beam. The NASARC code is also written to the Service Area file. The service arc present in the requirements file is read, rounded off to the appropriate integer degree, and written to the Service Area file. The interface program also determines which service areas are to be included in which affiliated sets and forms the appropriate NASARC codes for these affiliations. The interface program creates the Affiliated Sets file which contains the codes cross-reference data used in processing NASARC affiliated set information.

The rest of the service area data pertains to antenna and power specifications. The interface program reads the earth station antenna gains and sidelobe levels and from this information determines the earth station antenna diameters and antenna types. It converts the IFRB satellite antenna specifications to their equivalent NASARC six-character antenna codes and parameters where applicable, and it also converts receiver noise temperatures from degrees kelvin to decibels—degrees kelvin (db-K). Lastly, the interface program converts the power calculation, link calculation, and existing system flags to their equivalent NASARC flags and writes all these data to the Service Area file. NASINTRF also reads the polygon/test point data from the requirements file and writes these data to the Point Sets file for use in NASARC. The flowchart of NASINTRF, the interface program, is given in figure 3.1-24.

3.1.2.2 NASARC0: The Input Program

Through the use of NASARC0, the input program, the user interactively enters several key technical parameters for the desired scenario which are not generated as an output of NASINTRF, the interface program. These additional data are stored in the Input Data file which is used by NASSEP, NASARC1, NASARC2, NASARC3, and NASARC4. If an Input Data file is pre-existing, NASARC0 reads in the data and prints them out to the user's terminal. The user may then choose to retain the pre-existing data or enter new parameter values. The flowchart for NASARC0 is given in figures 3.1-25(a) to (c) for reference.

NASINTRF -- The Interface Program

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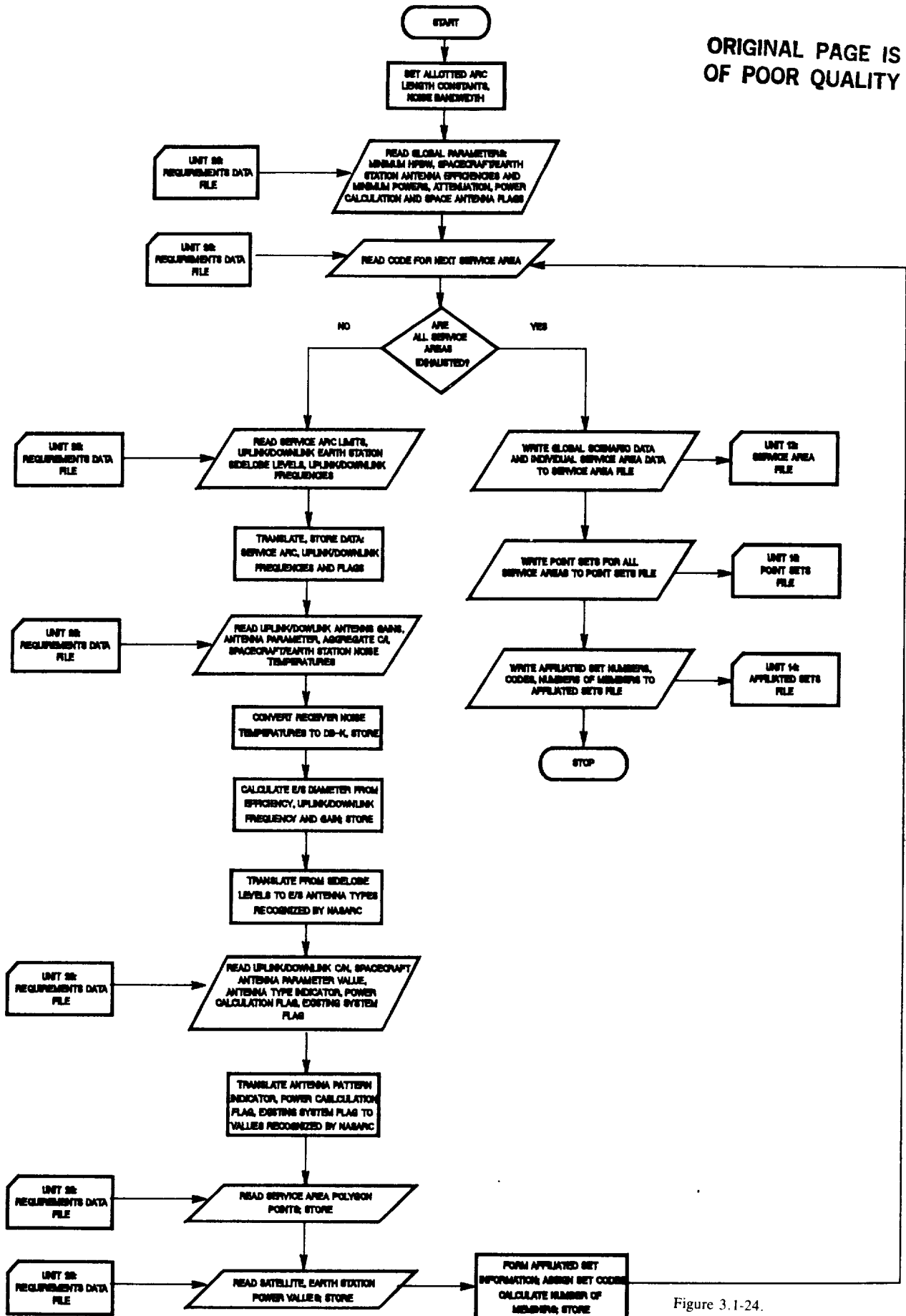


Figure 3.1-24.

By executing the NASARCO module, the user is prompted to enter the uplink and downlink transmission frequencies, and optionally the rain outage percentage of year and maximum rain attenuation limit if rain attenuation is to be included in the scenario. These inputs are described in sections 3.1.2.2.1 and 3.1.2.2.2. Additionally, the user is prompted for the scenario identifier (date and time) and up to two lines of comment information which will appear in the NASARC Report. The remaining entries in the Input Data file are either retrieved or derived from the Service Area file. The arc length constants and the receiver noise bandwidth are simply copied while the Affiliated Sets flag is set based on the presence of (or lack of) affiliated set designations within the Service Area file.

In addition to the primary function of accepting the prompted user inputs and forming the Input Data file, NASARCO also checks various prestored input files for any critical errors which would stop execution of the major NASARC modules. NASARCO checks data in the Service Area file, the Segments file, and the Affiliated Sets file for errors such as numerical data being out of range, illegitimate code specification, and inconsistencies in data from file to file. If any of the data verification procedures find an error, the input program halts the execution and sets an error flag at the top of the Input Data file. This allows the other NASARC modules to ascertain that a critical input error has occurred and to abort execution.

The first file that is checked by NASARCO for critical input errors is the Service Area file. First checked are the allotted arc length constants appearing at the top of the file. NASARCO checks to make sure that at least one nonzero constant exists. If the constants pass this test, they are written to the Input Data file. Next, NASARCO checks the validity of the service arc boundaries. For each service area present in the file, NASARCO calculates the service arc length. If the length does not exceed 162° (corresponding to a 0° elevation angle), the service arc boundaries are considered valid. Also, if affiliated sets are present, service arcs for members of like affiliated sets are checked for common overlap. Lastly checked in the Service Area file are the earth station and satellite antenna specifications: specified antenna codes are checked to verify that legitimate codes were used; the antenna parameters are checked to verify that they are within established limits; and, if affiliated sets are present, like members are checked to ensure that they are all using the same antenna specifications.

The second file that is checked for errors that would severely impact execution of the NASARC modules is the Segments file. NASARCO reads in the segment boundaries and checks that, in the order listed, the user has provided a contiguous cumulative arc. This requirement is vital for proper execution of the piecewise approach for a world scenario.

Lastly, if affiliated sets are to be included in the scenario, NASARCO cross checks the Affiliated Sets file with the Service Area file to verify that the number of members in each affiliated set matches the number of service areas designated as set members. The following two subsections give further details regarding the prompted inputs.

3.1.2.2.1 Transmission Frequencies

The uplink and downlink frequencies are input in gigahertz (GHz) during execution of the NASARCO module. They are then stored in the Input Data file for use in NASARC1, NASARC2, NASARC3, and NASARC4. Though any frequency assigned to satellite communications can be analyzed by the NASARC software, NASARCO is presently configured to accept only frequencies that fall within the following bands (see section 2.2.1):

- 4.5 to 4.8 GHz and 6.425 to 7.075 GHz
- 10.70 to 10.95 GHz, 11.20 to 11.45 GHz, and 12.75 to 13.25 GHz

If the desired frequency falls beyond the range of these bands, the user should manually edit the frequency specifications in the Input Data file created by NASARCO prior to executing the main NASARC modules.

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NASARCO -- The Input Program

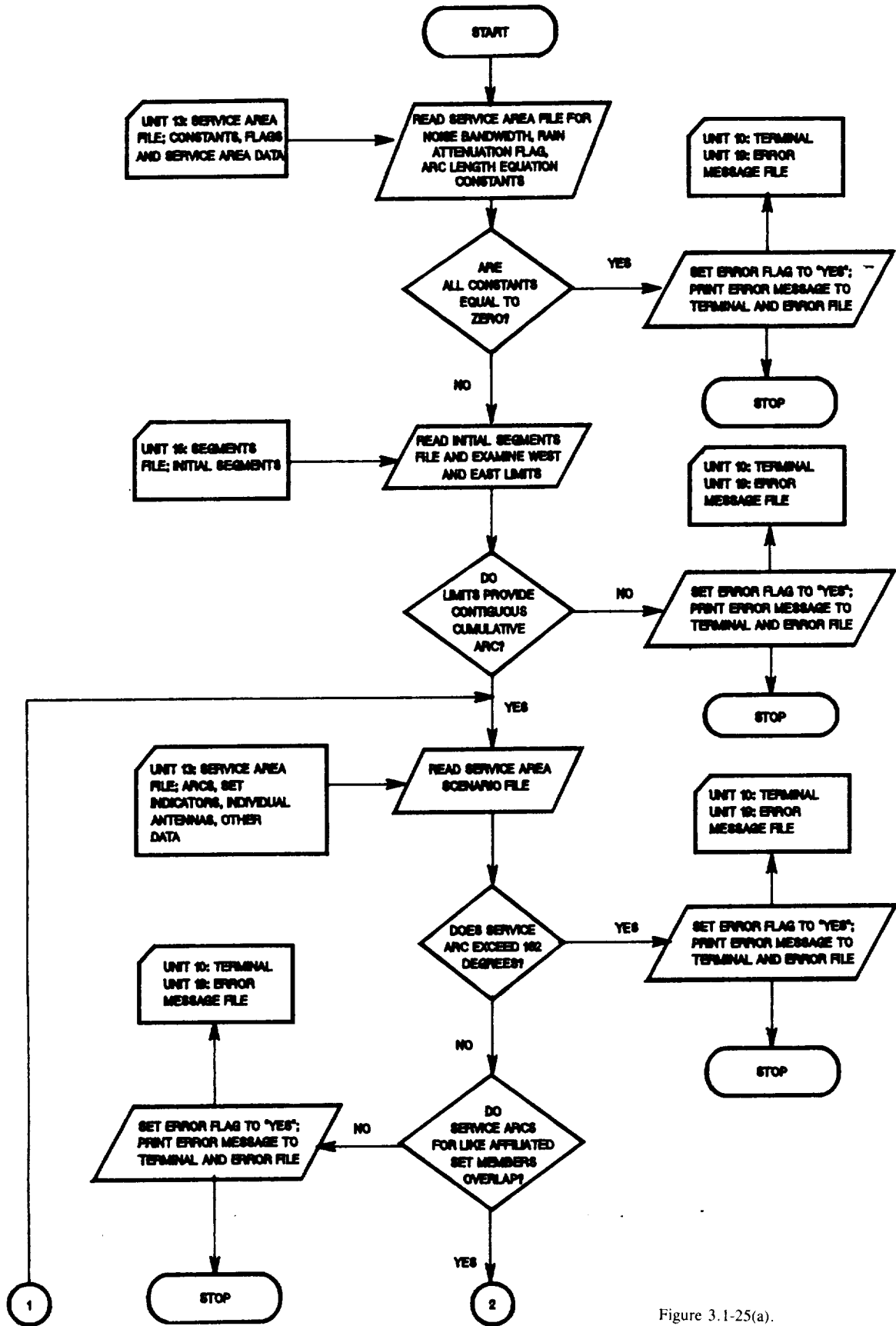


Figure 3.1-25(a).

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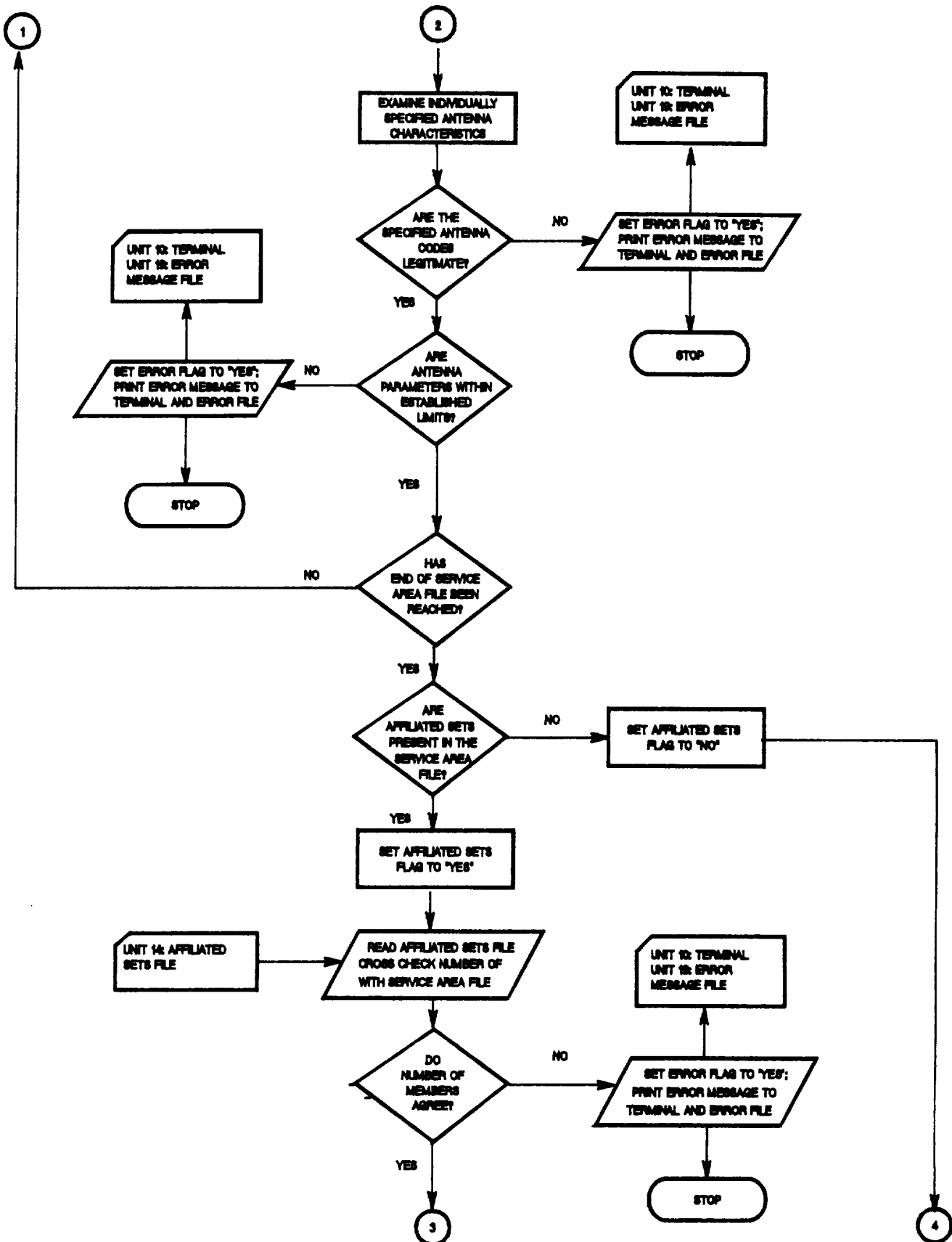


Figure 3.1-25(b).

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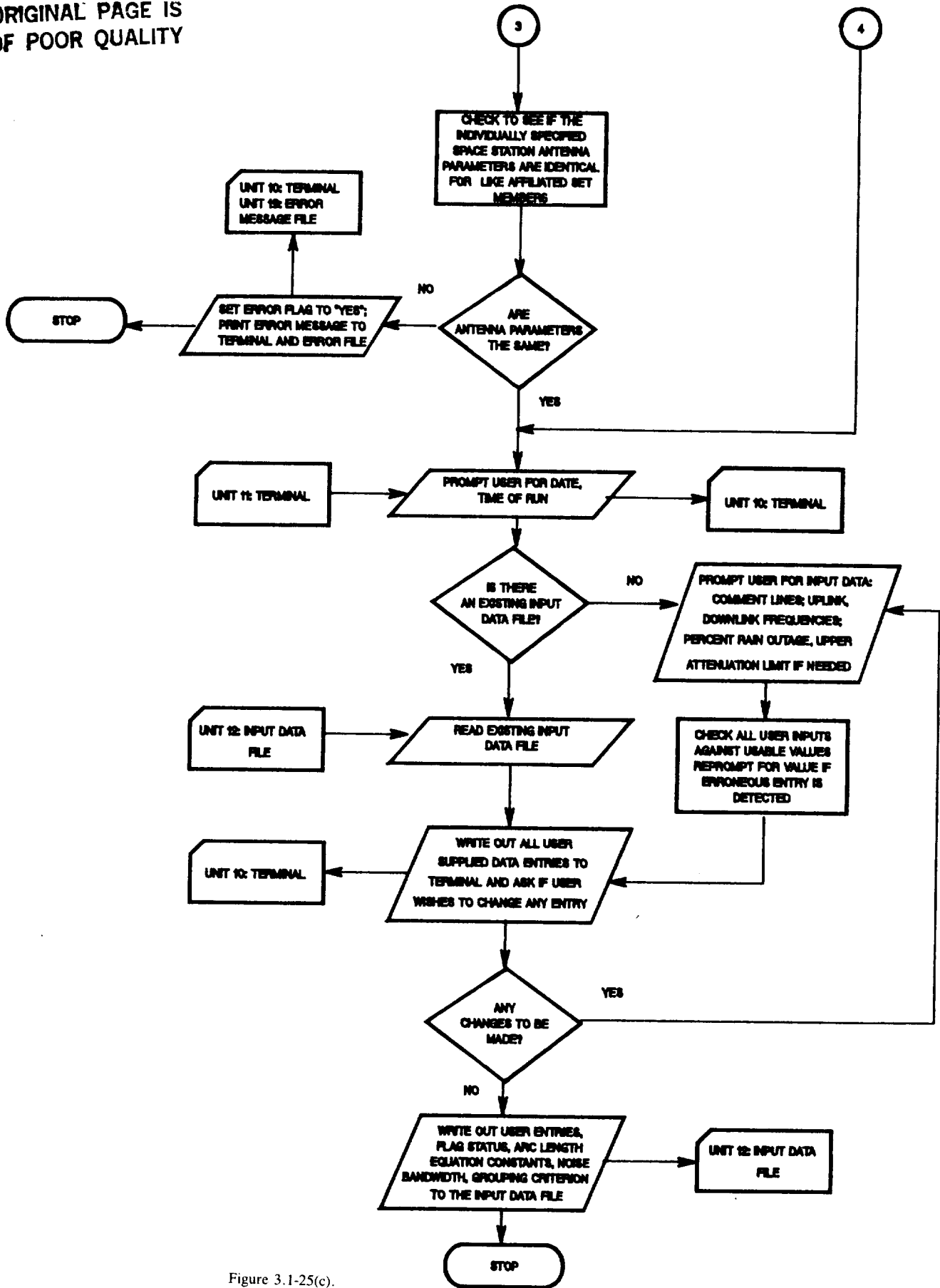


Figure 3.1-25(c).

The uplink and downlink frequencies are used extensively throughout all calculations required to determine pairwise compatibility between systems. 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. Care should be taken in selecting a single frequency from within a band of interest. The lowest frequency within a band will yield lower antenna gains and D/λ ratios (used in falloff equations to determine antenna discrimination) while the highest frequency may require larger rain margins. If rain attenuation is being considered in a given scenario, it is recommended that the user select a frequency from the middle of the band to offset the characteristics of the high and low frequency bounds. If rain attenuation is not being considered, it is recommended that the lowest frequency be used to realize the worst case results.

3.1.2.2.2 Rain Outage Parameters

NASARCO determines if rain attenuation is to be included in a given scenario by reading the corresponding flag at the top of the Service Area file. If it is set to Y to indicate that rain attenuation is to be included in the link analysis, NASARCO prompts the user for two parameters that can be used to modify the rain attenuation data given in the Ellipse file: the rain outage percentage of year, and the maximum rain attenuation limit.

The NASARC software is presently structured to read in rain attenuation data for each test point defining a service area from the Service Area file. To minimize the effort of the user in examining the effect of rain on a given scenario, exact values of rain attenuation for an annual outage of 0.01 percent at the midband of the frequency ranges given in section 3.1.2.2.1 are stored in the Ellipse file. Then, through the use of the two additional parameters, these data can be easily modified without actually editing the file. By having the initial data represent an annual outage of 0.01 percent, less stringent requirements on signal availability can easily be obtained by a simple conversion (see section 3.2.2.1.1) from 0.01 percent to the user specified rain outage percent of year. Similarly, for a given frequency, locations with very high rain rates can produce extremely large rain attenuation values which cannot realistically be offset by additional transmitter power. For this case, the user may wish to cap this amount by setting the maximum rain attenuation limit to a value that is more in line with common practice.

At the WARC-88 Conference, the rain outage percent of year was set to 0.10 percent for Ku-Band and 0.05 percent for C-Band, and the maximum rain attenuation limit was 8 dB for both bands.

3.1.2.3 NASSEP: Satellite Separation Program

The satellite separation program (NASSEP) is executed to generate decision-making data for use in NASARC2 and NASARC4. As was briefly described in sections 2.1.4 and 2.1.5, the NASARC2 and NASARC4 program modules use a matrix of required satellite separations in determining the relative compatibility among members of perspective adjacent groupings. The intent is to improve the arrangement of PDA's in the orbital arc so that more flexibility in orbital positioning and ultimately higher aggregate C/I 's are achieved for individual systems within the PDA's. The separation matrix must be generated prior to execution of the NASARC software using the scenario data sets to be input to NASARC (i.e., Input Data file, Service Area file, Affiliated Sets file, Point Sets file, and Ellipse file). Changes to any of the parameters in these files require regenerating the separation matrix based on the new data.

The satellite separation program fixes the orbital location of the wanted satellite and then iteratively moves the interfering satellite away from the wanted satellite location until the separation is sufficient to meet a specified total C/I (single-entry uplink plus downlink interference). The NASSEP software uses the same C/I calculations that are performed in NASARC1 (and described in detail in section 3.3.2). The calculated C/I value is used in conjunction with a bisecting search technique to collapse on the separation needed to just meet the required C/I . The basic logic flow for the separation program is given in figures 3.1-26(a) to (d).

It has been found that separation requirements between any two satellites covering different service areas are greatest at the edges of the intersection of their service areas. Therefore, to reduce the number of necessary calculations, the required separation between any pair of satellite systems is determined by locating each *wanted* system in turn at each edge of the intersection of their service arcs. The interfering satellite is then moved away from the wanted satellite location until the required C/I is just met.

NASSEP -- The Satellite Separations Program

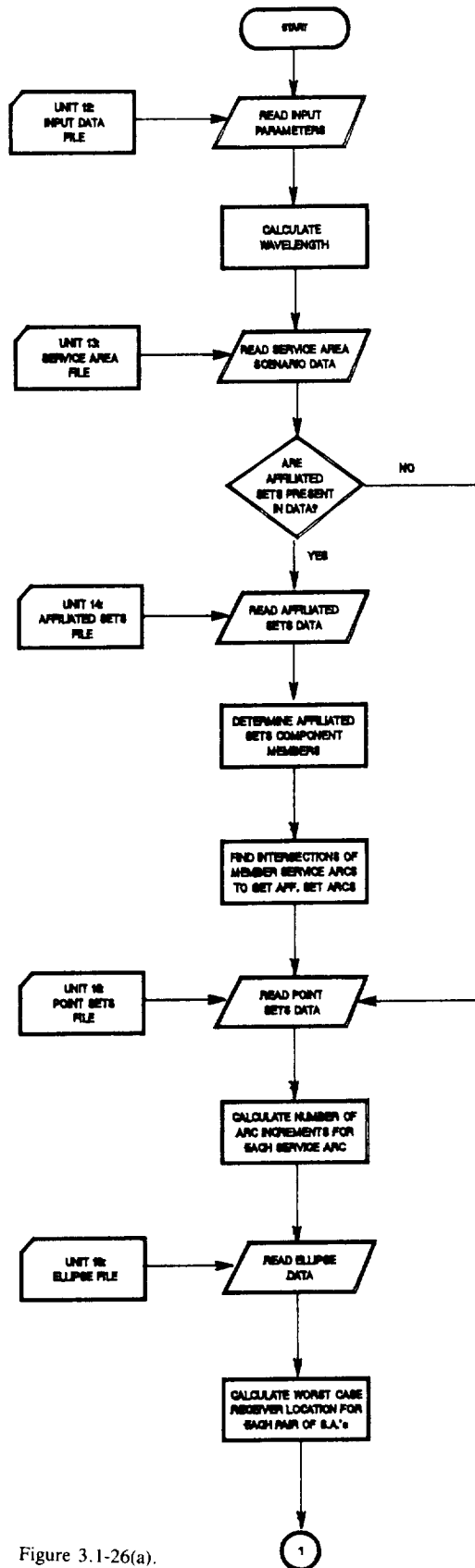


Figure 3.1-26(a).

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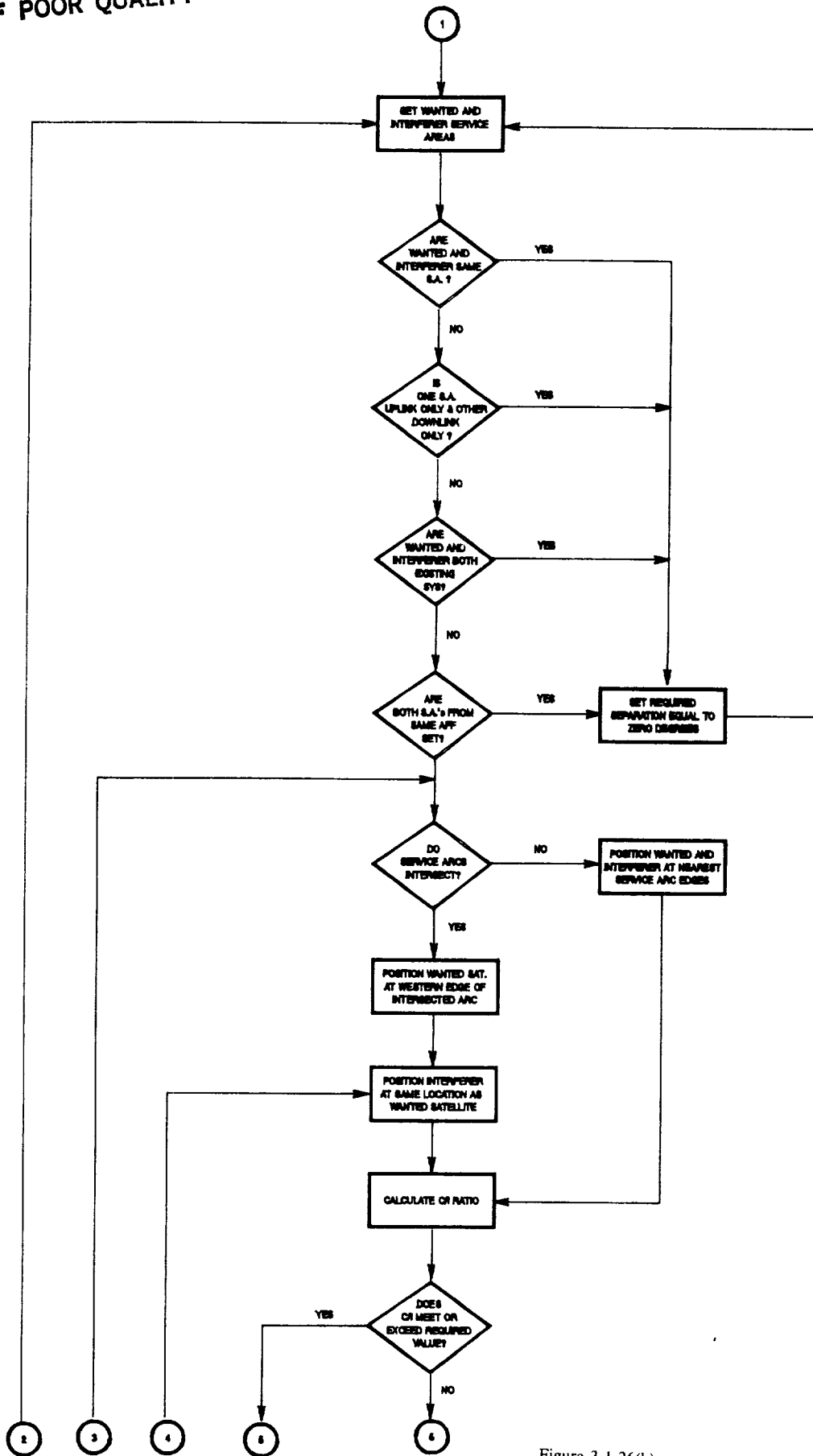


Figure 3.1-26(b).

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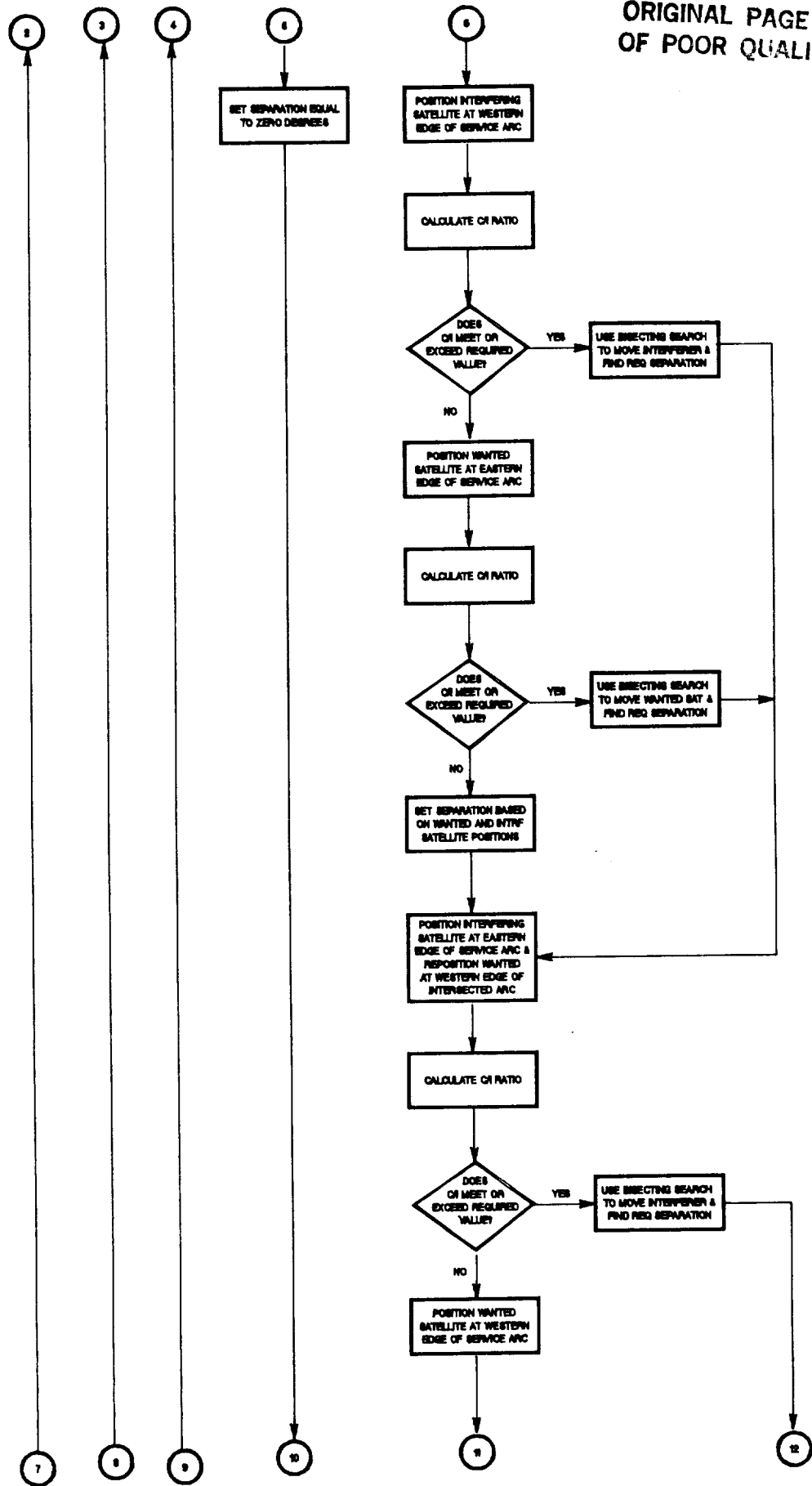


Figure 3.1-26(c).

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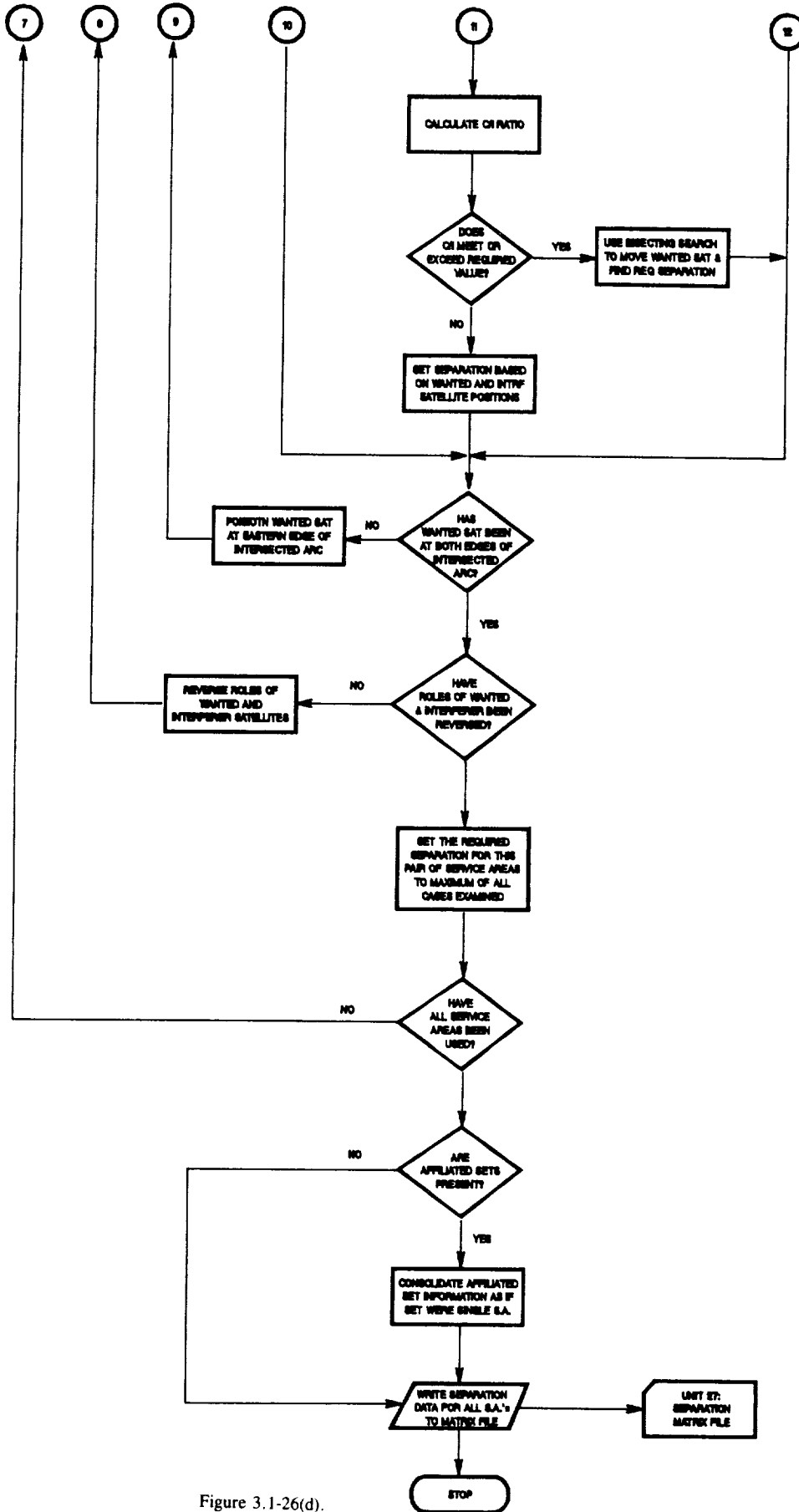


Figure 3.1-26(d).

The actual separation retained for the matrix is then the worst case separation of the four values determined for each pair of satellite systems (i.e., B into A with A at western edge of intersected arc, B into A with A at eastern edge of intersected arc, A into B with B at western edge of intersected arc, and A into B with B at eastern edge of intersected arc). For service areas whose service arcs do not intersect, the satellites are located at the nearest boundary points in the two arcs. If at these locations the available separation is sufficient to meet or exceed the required C/I , the difference between the nearest orbital locations of the two service arcs is provided to the matrix. If additional separation is required, the interfering system is again moved away from the wanted satellite location until the C/I is just met. In those cases where the service arcs do not intersect, only two values of separation are available from which to select the worst value for the matrix (i.e., B into A with A at the edge of its service arc nearest to B's service arc, and A into B with B at the edge of its service arc nearest to A's service arc).

The value of the required C/I for which the separation is determined is obtained by adding 3 dB to the aggregate C/I given for each service area in the Service Area file. The required C/I value was chosen to fall between the single-entry C/I (aggregate $C/I + 6$ dB) and the aggregate C/I because the kinds of interference situations that NASARC4 is intended to improve upon are those in which a dominant interfering system is located in an adjacent PDA. Under such circumstances the dominant interferer would contribute most heavily toward the aggregate C/I . Since it is the aggregate C/I , and not the single-entry C/I , which must ultimately be met in the allotment plan, the dominant interferer can be allowed to contribute a greater portion of the interference to the aggregate interference budget. Therefore, so as not to place an undue restriction on the adjacency of groupings in their predetermined arcs, the required C/I for which the separation is calculated is less than the single-entry C/I used in assessing compatibility in NASARC1.

3.1.3 Input Parameter Constraints

There are some general constraints on the input parameter values which must be considered when using NASARC (Version 4.0). These constraints are not technical in nature. Rather, they result directly from the amount of memory allocated to the NASARC program modules in the NASARC software package. To fit within the available 9-megabyte memory limit of the IFRB computer system (see *User's Manual* for details), the maximum number of service areas that the programs can handle has been set to 300 and the maximum number of total groupings has been set to 90,000. Of these two parameters, the maximum number of total groupings has a much greater effect on the required storage than does the maximum number of service areas. Therefore, it is important to specify input parameters so as not to exceed the 90,000 group maximum. It is not possible to provide exact parameter values which will guarantee that this limit is not exceeded due to the interactive effect of the parameters. However, some general guidelines are provided which should be helpful in the formation of realistic scenarios for NASARC (Version 4.0).

There are six input parameters which have a direct impact on the total number of groupings produced by the NASARC1 program module: service areas, service arcs, piecewise approach arc segment boundaries, grouping criteria, target single-entry C/I , and antenna characteristics. The first three of these parameters are interrelated. The more service areas in a scenario, the more potential *group members* there are available with which to group a given service area. Similarly, a given service area has the potential to group with other service areas whose service arcs intersect the service arc of the given service area. Therefore, large service arcs imply more intersections and more potential grouping opportunities. The combination of the number of service areas and the length of their service arcs results in a density of service areas which can utilize a given orbit longitude (see fig. 2.1-1). As the density increases, the potential for groupings increases. The third parameter, the arc segment boundaries for the NASARC piecewise approach, can be used to reduce the peak density areas of the orbital arc and thereby limit the number of groupings generated in a given segment.

The piecewise approach (see section 2.1.5) limits the number of NASARC1 groupings in two ways—by limiting the orbital arc over which intersections of service arcs are investigated, and by reducing the number of service areas to be processed in future segments. Of the two, the second has the greatest impact on overall reduction of groupings generated. As was explained in section 2.1.5, after service areas have been selected in a grouping and given an allotted arc within the current segment of the piecewise approach, these service areas no longer need to

be considered in future segments. This reduces the number of service area pairs in future segments which must be investigated for potential compatibility. Prudent selection of segment boundaries can greatly reduce the number of groupings generated without significantly impacting the overall NASARC selection procedure.

The remaining three parameters affecting the total number of groupings produced are specified directly or indirectly by user inputs. All three of these parameters are directly involved in the determination of service area compatibility occurring in the grouping program NASARC1 (see sections 2.1.2 and 3.2.2). The grouping criterion can drastically alter the total number of groupings produced (see section 3.1.1.5.1). A 0° grouping criterion translates to a test for colocation while a 1° criterion means that all service areas which can be spaced 1° or less from each other can be considered compatible. The effect of the grouping criterion is directly related to the receive earth station antenna off-axis gain. For grouping criteria greater than zero (colocation), the earth station antenna discrimination becomes a factor in meeting the target *C/I* value. (It should be noted, however, that grouping criteria greater than 1° should not be utilized.) In addition, the larger the diameter of the earth station antenna, the greater the discrimination for a given space station separation. Therefore, a larger grouping criterion will produce many more groupings than would a smaller grouping criterion. It is important to note that a rather small change in the grouping criterion can produce a very large change in the total number of groupings produced by NASARC1. The value selected for the grouping criterion also has an effect on the average number of members of the groupings generated by NASARC1. In general, the larger the grouping criterion, the larger the average size of the groupings and the greater the total number of groupings.

Another significant factor affecting the total number of groupings is the target single-entry *C/I*. The input value, threshold aggregate *C/I*, is modified by the ratio of aggregate to single-entry *C/I* to be a target *C/I* value which is used as the required protection for which pairwise compatibility is assessed. Increasing the target *C/I* reduces the total number of groupings produced. The 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 antenna can have wide ranging impact on the number of groups. The type of earth station antenna and the diameter also have wide ranging impact. All the antenna parameters can be individually specified in the Service Area file.

While the grouping criteria, 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 they are 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 uplink and downlink wavelengths from the transmission frequencies for later use. The Service Area scenario file is then read so that a list of service areas can be assembled. 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.

NASARC1 -- The Grouping Program

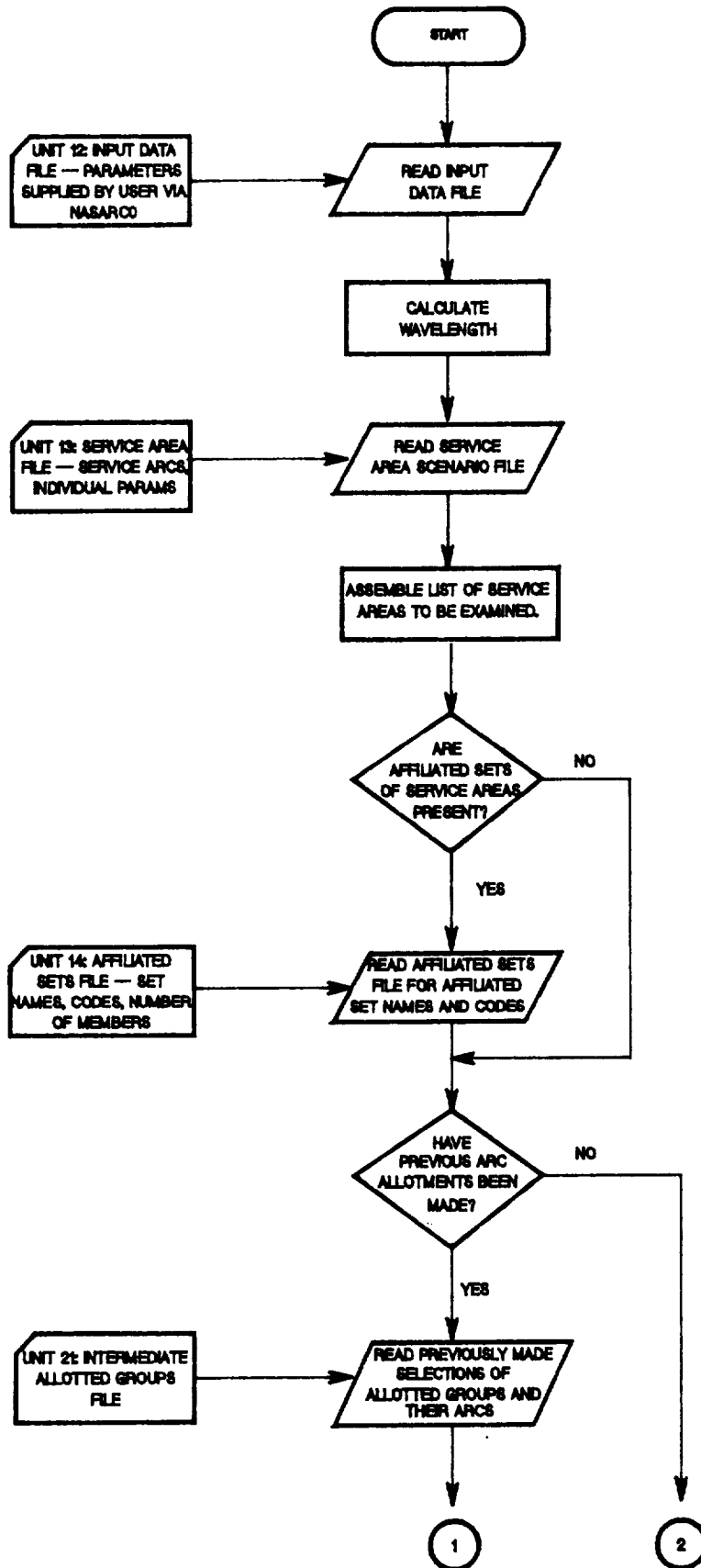


Figure 3.2-1(a).

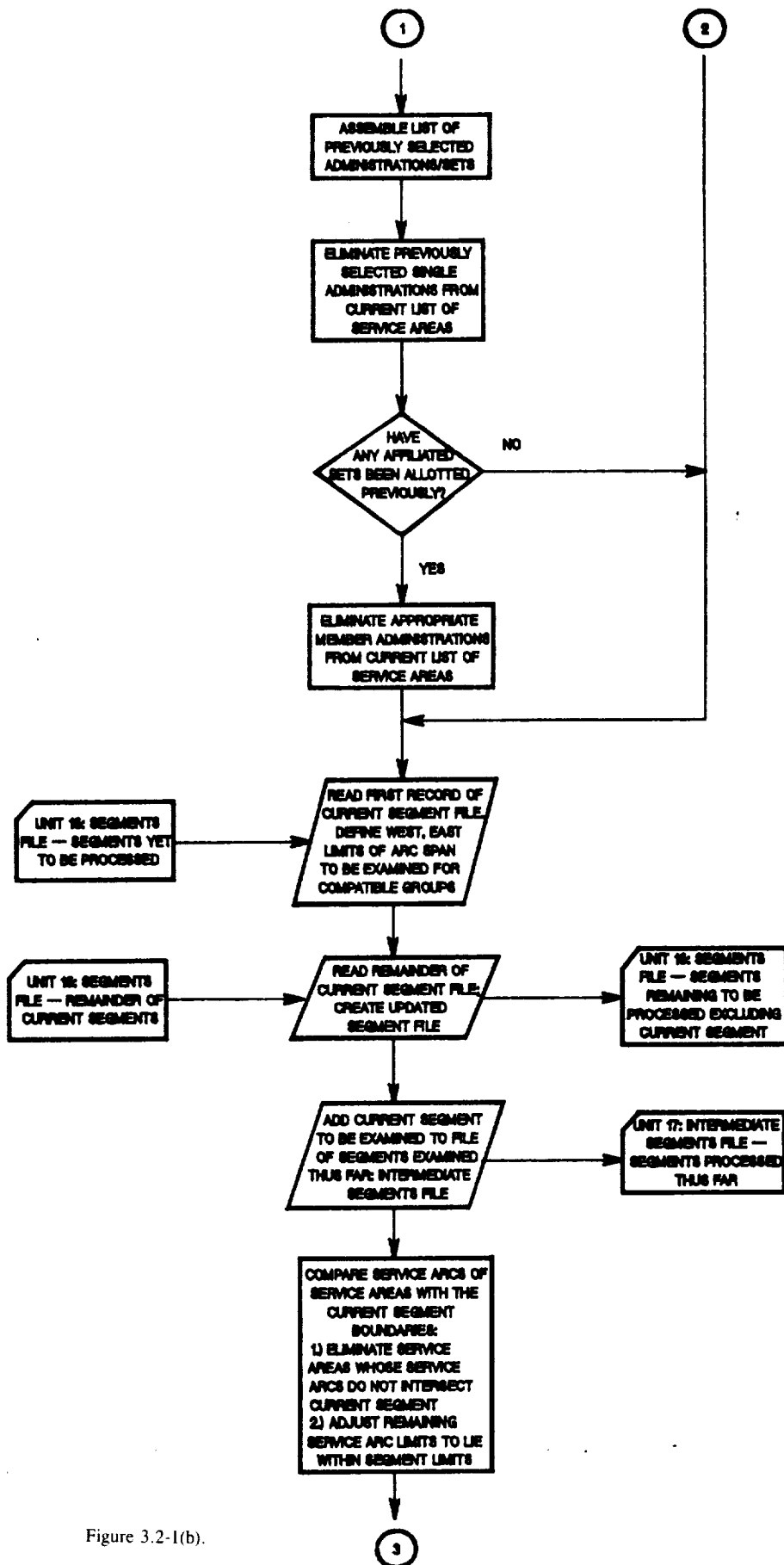


Figure 3.2-1(b).

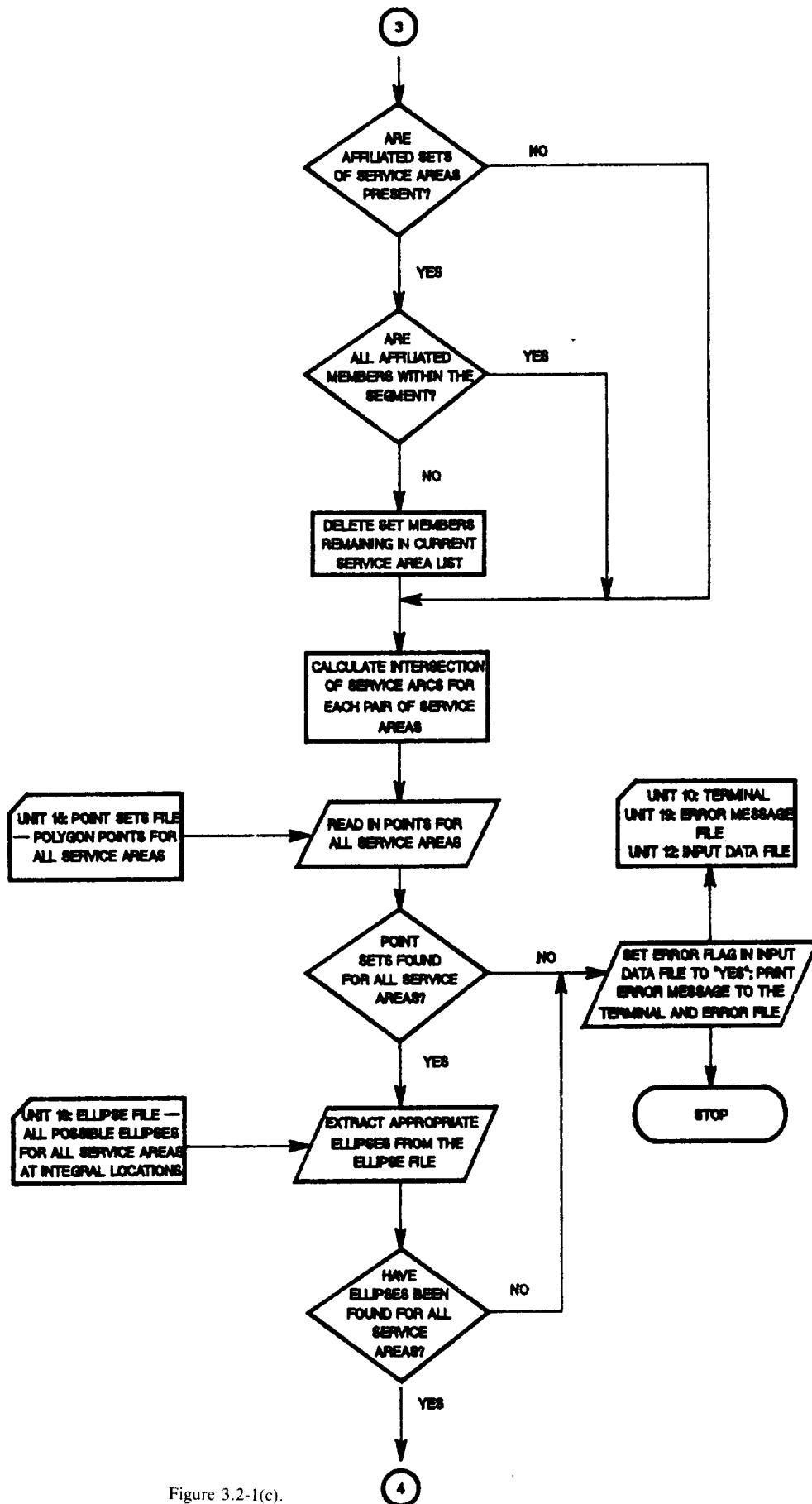


Figure 3.2-1(c).

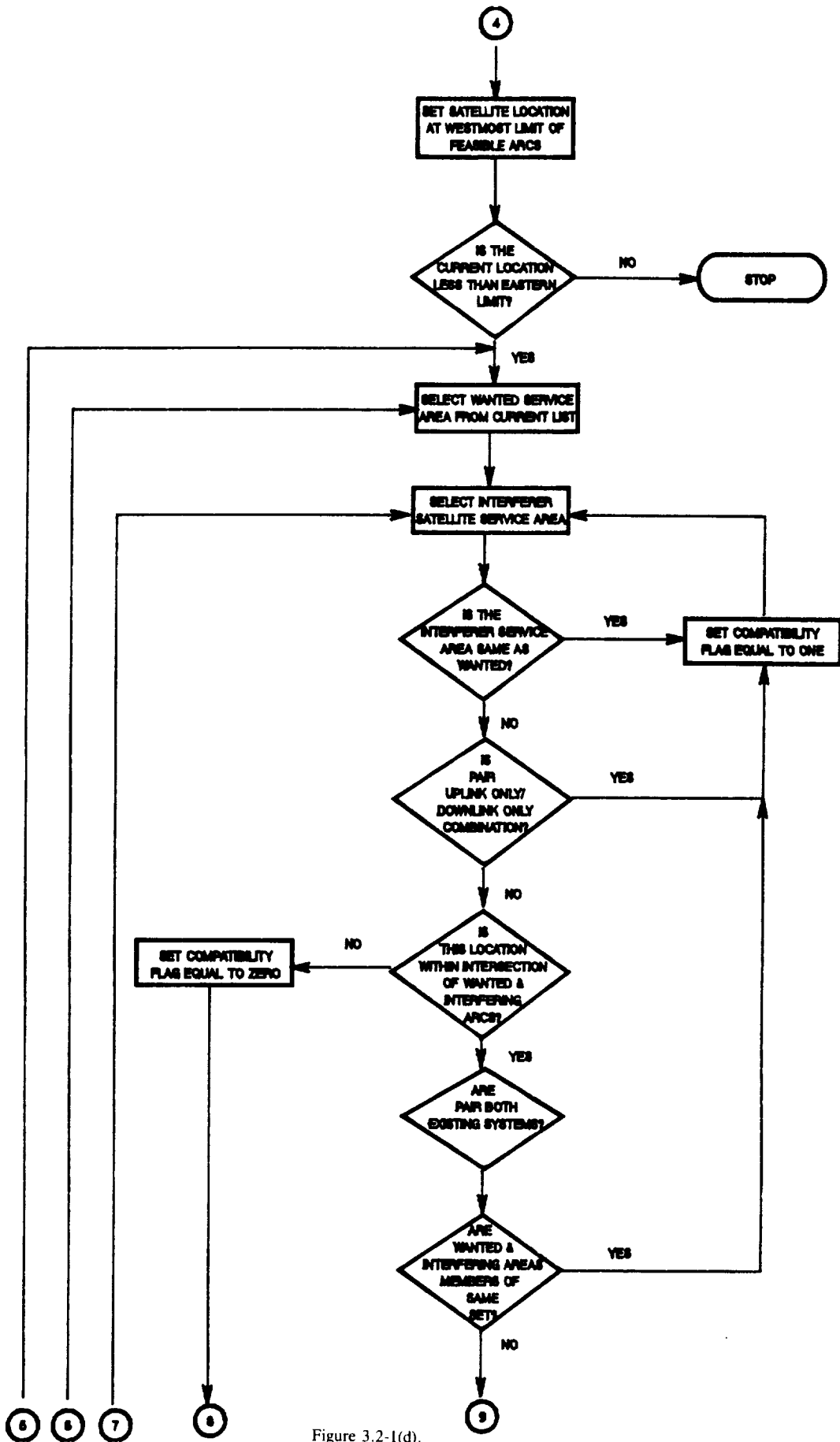


Figure 3.2-1(d).

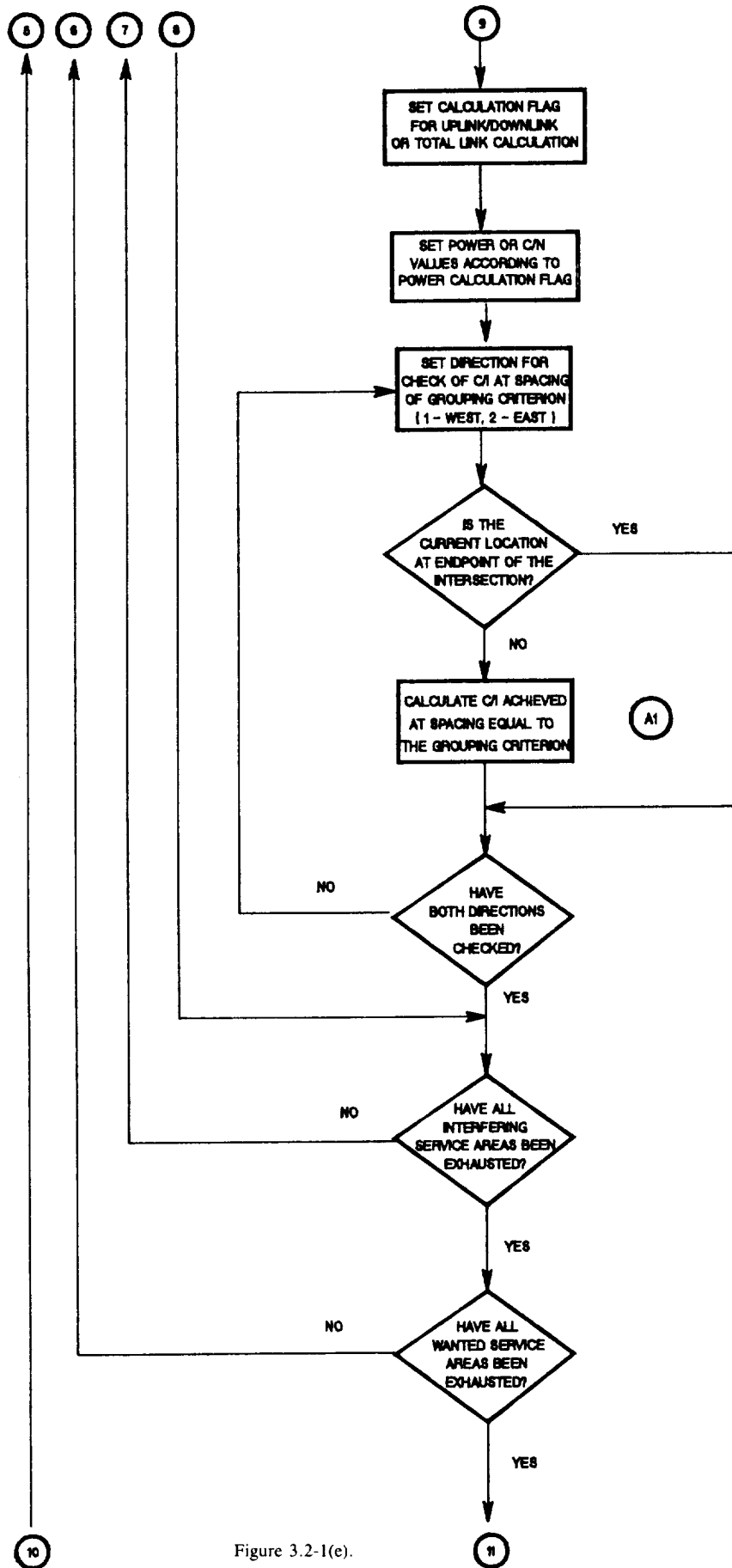


Figure 3.2-1(e).

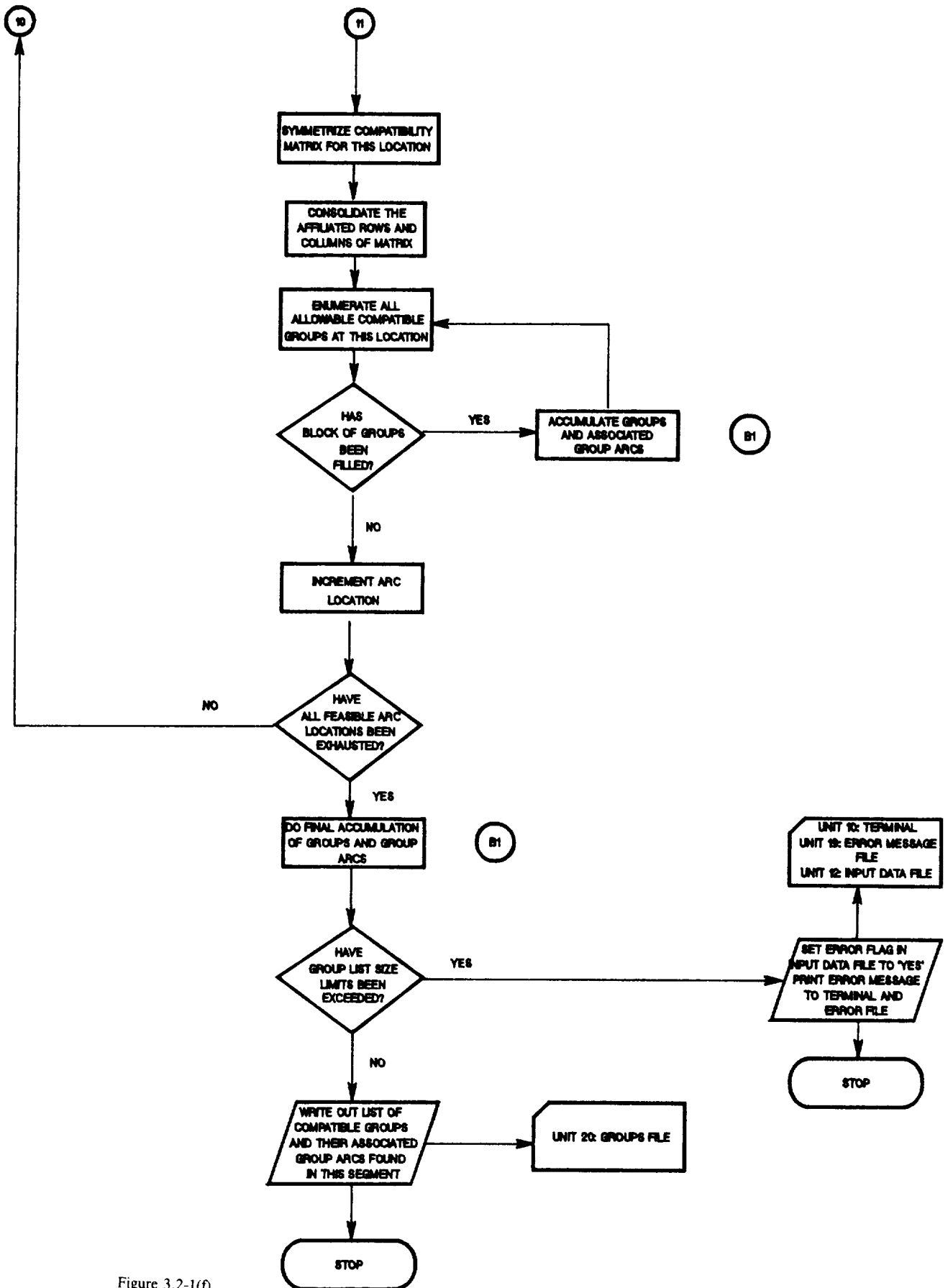


Figure 3.2-1(f).

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 all the service arcs with the current segment boundaries. Any service areas whose service arcs do not intersect the current segment are eliminated from the list of service areas to be considered 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 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.

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 do not share any arc locations within the current segment. Starting with the arc location at the western boundary of the segment, the grouping program performs calculations to determine pairwise compatibility and enumerates groups of compatible service areas. 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 and angular relationships 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 among members of the same affiliated set is not explicitly determined. Rather, affiliated set members are assumed to be compatible with each other. 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 Calculation of Transmit Powers

In NASARC Version 4.0, the user has two ways to specify the earth station HPA power and the satellite TWTA power. The first is to directly specify the actual power delivered to the transmit antenna (i.e., output tube power minus losses). Or secondly, the user can specify the received C/N for a given bandwidth and receiver characteristics and allow NASARC to calculate the transmit power required to achieve the specified C/N . NASARC is capable of using either specification method independently in determining pairwise compatibility (i.e., each system may be individually specified, and the uplink and downlink may be individually specified). When the received C/N is specified for calculating transmit power, the following equation is used for both uplink and downlink transmission:

$$P_T = \frac{C}{N} + L + k + T + B - G_R - G_T + D_S + A \quad (3.2-1)$$

where

- P_T transmit power, dBW
- C/N link carrier-to-noise ratio, dB
- L free-space loss on desired path, dB
- k Boltzmann's constant, -228.6 dB/K-Hz
- T system noise temperature, dBK
- B system noise bandwidth, dBHz
- G_R on-axis gain of receive antenna, dB
- G_T on-axis gain of transmit antenna, dB
- D_S discrimination factor between satellite on-axis gain and satellite off-axis gain in the direction of the earth station, dB
- A link rain attenuation compensation, dB

In this equation, C/N , T , and B are specified by the user. The remaining factors are either derived or calculated by NASARC1. One of the first calculations NASARC1 performs is to determine the uplink and downlink wavelengths:

$$\lambda = \frac{c}{f} \quad (3.2-2)$$

where

- λ transmission wavelength, m
- c speed of light in a vacuum, 2.997925×10^8 m/sec
- f transmission frequency, Hz

After the wavelength is calculated, NASARC1 calculates the range and the free-space loss:

$$R = R_o \left[1 + K^2 - 2K \cos \theta_E \cos (\phi_E - \phi_S) \right]^{1/2} \quad (3.2-3)$$

and

$$L = \left(\frac{4\pi R}{\lambda} \right)^2 \quad (3.2-4)$$

where

- R link range, m
- R_o earth's radius, 6.3782×10^6 m
- K radius of geostationary orbit in earth radii, 6.6105
- θ_E latitude of earth station, deg
- ϕ_E longitude of earth station, deg
- ϕ_S longitude of satellite, deg

The calculations for the on-axis gains of the transmit and receive antennas depend on whether the power is being calculated for the uplink or downlink. If it is an uplink calculation, the transmit antenna is located at the earth station site and the receive antenna is mounted onboard the satellite. If it is a downlink calculation, the reverse is true. The earth station and spacecraft antenna characteristics can be individually specified in the Service Area file. The following equations are utilized in determining the on-axis gains of the earth station and spacecraft antennas:

$$\varphi_{oES} = \frac{223\lambda}{180d} \quad (3.2-5)$$

$$G_{ES} = \eta_{ES} \left(\frac{223\pi}{180\varphi_{oES}} \right)^2 \quad (3.2-6)$$

where

- G_{ES} earth station on-axis gain, numeric
- φ_{oES} earth station HPBW, radians
- d earth station antenna diameter, m
- η_{ES} earth station antenna efficiency, numeric

and

$$G_{SC} = \eta_{SC} \left(\frac{223\pi}{180} \right)^2 \frac{1}{ab} \quad (3.2-7)$$

where

- G_{SC} spacecraft on-axis gain, numeric
- η_{SC} spacecraft antenna efficiency, numeric
- a major axis of coverage ellipse, radians
- b minor axis of coverage ellipse, radians

The discrimination factor in equation (3.2-1) is used to adjust the spacecraft on-axis antenna gain to the actual antenna gain in the direction of the earth station. This factor is obtained by deriving the satellite relative off-axis angle and applying it to the correct satellite antenna pattern (see section 3.1.1.2.4). Detailed information on the calculation of the satellite off-axis angle in the direction of an earth station is presented in section 3.2.2.2.

The link rain attenuation compensation factor in equation (3.2-1) is utilized when the effect of rain fade on the signal is to be analyzed. If clear sky conditions are being analyzed, this factor is not included in equation (3.2-1) (i.e., it has a zero value). Further detailed information on the applied value of the link rain attenuation compensation factor is presented in the next section.

In determining the overall uplink or downlink transmit power, NASARC calculates the individual transmit powers for each test point representing an earth station for a given service area. The maximum uplink and downlink power levels are then used in the C/I calculations (see section 3.2.2.3).

3.2.2.1.1 Rain Attenuation Compensation

NASARC1 utilizes the rain attenuation compensation factor in equation (3.2-1) when the effect of rain attenuation on signal strength is to be analyzed in a given scenario. Data on rain fade values for each test point are stored in the Ellipse file and can be modified by the two input parameters: the rain outage percentage of year and the maximum rain attenuation limit. The rain data in the Ellipse file is precalculated for an annual outage of 0.01 percent at the midband of the frequency ranges given in section 3.1.2.2.1. NASARC1 uses the single maximum value of rain attenuation over all test points for a given frequency when calculating the transmit power. If an annual outage other than 0.01 percent is desired, the user specifies the desired rain outage percentage of year and NASARC modifies the data as follows:

$$A = A_{01} \left(\frac{P}{0.01} \right)^{-0.41} \quad (3.2-8)$$

where

- A rain attenuation compensation factor, dB
- A_{01} maximum rain attenuation factor over all test points for 0.01-percent outage per year, dB
- P rain outage percentage of year, 0.01 percent $< P \leq 0.10$ percent

For additional information on the rain outage parameters and their practical values, refer to section 3.1.2.2.2.

3.2.2.1.2 Minimum HPA and TWTA Limits

In NASARC Version 4.0, the user can specify minimum power limits to create a lower bound on the earth station HPA and spacecraft TWTA transmitter power levels for all systems. These are supplied as global parameters and, as such, affect all systems in a given scenario. Power levels are either calculated based on the C/N criteria, or are taken directly from input values as required. These power levels are then compared against the appropriate minimum power limit (HPA or TWTA). The maximum power of the compared values is then used in the C/I calculations. This feature is provided as a means of reducing power inhomogeneities among systems.

3.2.2.2 Calculation of Antenna Off-Axis Angles

In order for NASARC1 to accurately determine the exact earth station and spacecraft off-axis antenna gains, relative off-axis angles from beam center to the direction of interest must be derived. The relative off-axis angle is defined as the ratio of the actual off-axis angle to the HPBW in the direction of interest. Once the relative off-axis angle is determined, it is applied to the specified antenna pattern and the corresponding falloff equations (see section 3.1.1.2.4) to obtain the antenna discrimination. Then, the actual antenna gain in the direction of interest is simply the on-axis antenna gain minus the antenna discrimination factor. The following two subsections present the derivations and results of the spacecraft and earth station off-axis angles and HPBW in the direction of interest.

3.2.2.2.1 Derivation of Satellite Off-Axis Angle

Within this section is the derivation of the satellite off-axis angle, the orientation angle of an earth point, and the ellipse half-power beamwidth in the direction of an earth station. The derivation employs a matrix approach based on a boresight-point coordinate system that has its origin at the satellite beam boresight on the earth's surface. The result of this derivation is only valid for geostationary satellites, but it could easily be extended to other orbits.

The geocentric coordinate system has its origin at the earth's center and the positive axes specified as follows:

- x-axis in direction of 0° E, 0° N
- y-axis in direction of 90° E, 0° N
- z-axis in direction of 90° N (North Pole)

Let $\{i, j, k\}$ be an orthonormal set of basis vectors along the x , y , and z axes, respectively.

If we let the earth's radius be the basic unit of distance, then the geocentric coordinates of the satellite point, boresight point, and earth station point are given by

$$S = \begin{bmatrix} X_S \\ Y_S \\ Z_S \end{bmatrix} = \begin{bmatrix} R \cos \theta_S \cos \phi_S \\ R \cos \theta_S \sin \phi_S \\ R \sin \theta_S \end{bmatrix} = \begin{bmatrix} R \cos \phi_S \\ R \sin \phi_S \\ 0 \end{bmatrix} \quad (3.2-9)$$

$$B = \begin{bmatrix} X_B \\ Y_B \\ Z_B \end{bmatrix} = \begin{bmatrix} \cos \theta_B \cos \phi_B \\ \cos \theta_B \sin \phi_B \\ \sin \theta_B \end{bmatrix} \quad (3.2-10)$$

$$E = \begin{bmatrix} X_E \\ Y_E \\ Z_E \end{bmatrix} = \begin{bmatrix} \cos \theta_E \cos \phi_E \\ \cos \theta_E \sin \phi_E \\ \sin \theta_E \end{bmatrix} \quad (3.2-11)$$

where

- ϕ_s satellite longitude, deg
- R geostationary radius in earth radii ($R = 6.6105$)
- $\{\theta_B, \phi_B\}$ boresight point latitude and longitude, deg
- $\{\theta_E, \phi_E\}$ earth station point latitude and longitude, deg

Now consider the boresight-point coordinate system shown in figure 3.2-2 that has its origin at the satellite beam boresight on the earth's surface and the positive axes specified as follows:

- x' -axis in direction of satellite
- y' -axis orthogonal to x' -axis and parallel to equator
- z' -axis orthogonal to both x' and y' and on north side of x' - y' plane

Let $\{i', j', k'\}$ be an orthonormal set of basis vectors along the x' , y' , and z' axes, respectively.

If we can find the coordinates of the satellite and earth station point in the boresight-point coordinate system, then the off-axis angle φ_{SC} and the orientation angle β of the earth station point can be easily found as shown in figure 3.2-2. In this coordinate system, the boresight point is at the origin so

$$B' = \begin{bmatrix} X'_B \\ Y'_B \\ Z'_B \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \quad (3.2-12)$$

We need to find the coordinates of the satellite and earth station point:

$$S' = \begin{bmatrix} X'_S \\ Y'_S \\ Z'_S \end{bmatrix} \quad (3.2-13)$$

and

$$E' = \begin{bmatrix} X'_E \\ Y'_E \\ Z'_E \end{bmatrix} \quad (3.2-14)$$

In general, the coordinates of a point in the geocentric system can be transformed to coordinates in the boresight-point system by the matrix equation

$$X' = A[X - B] \quad (3.2-15)$$

where

$$X' = \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix}$$

are the boresight point coordinates of an arbitrary point,

$$X = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

are the geocentric coordinates of the arbitrary point,

$$B = \begin{bmatrix} X_B \\ Y_B \\ Z_B \end{bmatrix}$$

are the geocentric coordinates of the boresight point, and

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

is a 3×3 transition matrix. The columns of A represent the boresight-point coordinates of the geocentric $\{i,j,k\}$ unit vectors.

Conversely, the coordinates of a point in the boresight-point system can be transformed to coordinates in the geocentric system by the matrix equation

$$X = A^{-1}X' + B \quad (3.2-16)$$

Now, since A represents the transition matrix from one orthonormal basis $\{i, j, k\}$ to another orthonormal basis $\{i', j', k'\}$, A is an orthogonal matrix (i.e., $A^{-1} = A^T$) and

$$A^{-1} = A^T = \begin{bmatrix} a_{11} & a_{21} & a_{31} \\ a_{12} & a_{22} & a_{32} \\ a_{13} & a_{23} & a_{33} \end{bmatrix} \quad (3.2-17)$$

The columns of A^T represent the geocentric coordinates of the boresight-point unit vectors $\{i', j', k'\}$:

$$\left. \begin{aligned} i' &= a_{11}i + a_{12}j + a_{13}k \\ j' &= a_{21}i + a_{22}j + a_{23}k \\ k' &= a_{31}i + a_{32}j + a_{33}k \end{aligned} \right\} \quad (3.2-18)$$

The task is to find the elements of A .

To find elements a_{11} , a_{12} , a_{13} , consider the coordinates of the satellite in the geocentric system (eq. (3.2-9))

$$S = \begin{bmatrix} X_S \\ Y_S \\ Z_S \end{bmatrix}$$

and the boresight-point system (eq. (3.2-13))

$$S' = \begin{bmatrix} X'_S \\ Y'_S \\ Z'_S \end{bmatrix} = \begin{bmatrix} X'_S \\ 0 \\ 0 \end{bmatrix}$$

Now X'_S is simply the distance from boresight to the satellite. Hence,

$$X'_S = \sqrt{(X_S - X_B)^2 + (Y_S - Y_B)^2 + (Z_S - Z_B)^2}$$

Substituting S and S' in equation (3.2-16) gives

$$S = A^{-1}S' + B \rightarrow \begin{bmatrix} X_S \\ Y_S \\ Z_S \end{bmatrix} = \begin{bmatrix} a_{11} & a_{21} & a_{31} \\ a_{12} & a_{22} & a_{32} \\ a_{13} & a_{23} & a_{33} \end{bmatrix} \begin{bmatrix} X'_S \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} X_B \\ Y_B \\ Z_B \end{bmatrix}$$

or

$$\begin{bmatrix} X_S \\ Y_S \\ Z_S \end{bmatrix} = \begin{bmatrix} a_{11}X'_S + X_B \\ a_{12}X'_S + Y_B \\ a_{13}X'_S + Z_B \end{bmatrix}$$

which results in

$$a_{11} = \frac{X_S - X_B}{X'_S}$$

$$a_{12} = \frac{Y_S - Y_B}{X'_S}$$

$$a_{13} = \frac{Z_S - Z_B}{X'_S}$$

Thus, a_{11} , a_{12} , and a_{13} are known.

To find elements a_{21} , a_{22} , a_{23} , first observe that since the y' -axis is *parallel* to the equator, points on the y' -axis have coordinates

$$\begin{bmatrix} 0 \\ Y' \\ 0 \end{bmatrix}$$

in the boresight system and coordinates

$$\begin{bmatrix} X \\ Y \\ Z_B \end{bmatrix}$$

in the geocentric system. Substituting these two vectors in equation (3.2-16) we get

$$\begin{bmatrix} X \\ Y \\ Z_B \end{bmatrix} = \begin{bmatrix} a_{11} & a_{21} & a_{31} \\ a_{12} & a_{22} & a_{32} \\ a_{13} & a_{23} & a_{33} \end{bmatrix} \begin{bmatrix} 0 \\ Y' \\ 0 \end{bmatrix} + \begin{bmatrix} X_B \\ Y_B \\ Z_B \end{bmatrix}$$

$$\begin{bmatrix} X \\ Y \\ Z_B \end{bmatrix} = \begin{bmatrix} a_{21}Y' + X_B \\ a_{22}Y' + Y_B \\ a_{23}Y' + Z_B \end{bmatrix} \rightarrow Z_B = a_{23}Y' + Z_B \rightarrow a_{23}Y' = 0 \rightarrow a_{23} = 0$$

To find a_{21} and a_{22} we need two equations in these two unknowns. Since j' is a *unit* vector, its length is 1 and $j' \cdot j' = 1$. Hence, using equation (3.2-18) gives

$$j' \cdot j' = a_{21}^2 + a_{22}^2 + a_{23}^2 = 1 \rightarrow a_{21}^2 + a_{22}^2 = 1 \quad (3.2-19)$$

Also, since i' and j' are orthogonal, $i' \cdot j' = 0$. Hence,

$$i' \cdot j' = a_{11}a_{21} + a_{12}a_{22} + a_{13}a_{23} = 0 \rightarrow a_{11}a_{21} + a_{12}a_{22} = 0 \quad (3.2-20)$$

Solving equations (3.2-19) and (3.2-20) for a_{21} and a_{22} we get

$$a_{21} = \frac{a_{12}}{\sqrt{a_{12}^2 + a_{11}^2}}$$

$$a_{22} = \frac{a_{11}}{\sqrt{a_{12}^2 + a_{11}^2}}$$

To choose the correct sign, we note that since the Z' -axis is on the north side of the X' - Y' -plane the z -component of the k' unit vector (i.e., a_{33}) must be positive. Since $k' = i' \times j'$,

$$k' = i' \times j' = \begin{bmatrix} a_{31} \\ a_{32} \\ a_{33} \end{bmatrix} = \begin{bmatrix} a_{12}a_{23} - a_{13}a_{22} \\ a_{13}a_{21} - a_{11}a_{23} \\ a_{11}a_{22} - a_{12}a_{21} \end{bmatrix} = \begin{bmatrix} -a_{13}a_{22} \\ a_{13}a_{21} \\ a_{11}a_{22} - a_{12}a_{21} \end{bmatrix} \quad (3.2-21)$$

Looking at the third line of equation (3.2-21) and substituting for a_{21} and a_{22} , we get for $a_{21}^{(-)}$ and $a_{22}^{(+)}$

$$a_{33} = a_{11}a_{22} - a_{12}a_{21} = \frac{a_{11}^2}{\sqrt{a_{12}^2 + a_{11}^2}} - \frac{a_{12}^2}{\sqrt{a_{12}^2 + a_{11}^2}} = \sqrt{a_{11}^2 + a_{12}^2}$$

which is always positive. Other sign cases could result in negative a_{33} . Therefore,

$$a_{21} = \frac{-a_{12}}{\sqrt{a_{12}^2 + a_{11}^2}}$$

$$a_{22} = \frac{a_{11}}{\sqrt{a_{12}^2 + a_{11}^2}}$$

and a_{31} , a_{32} , and a_{33} are given in equation (3.2-21).

Thus, the nine elements of the transition matrix A are

$$a_{11} = \frac{X_S - X_B}{X'_S} \quad a_{21} = \frac{-a_{12}}{\sqrt{a_{11}^2 + a_{12}^2}} \quad a_{31} = -a_{13}a_{22}$$

$$a_{12} = \frac{Y_S - Y_B}{X'_S} \quad a_{22} = \frac{a_{11}}{\sqrt{a_{11}^2 + a_{12}^2}} \quad a_{32} = a_{13}a_{21}$$

$$a_{13} = \frac{Z_S - Z_B}{X'_S} \quad a_{23} = 0 \quad a_{33} = a_{11}a_{22} - a_{12}a_{21}$$

Now that we know A , the coordinates of the earth station relative to the boresight-point system are (using eq. (3.2-15))

$$E' = \begin{bmatrix} X'_E \\ Y'_E \\ Z'_E \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} X_E - X_B \\ Y_E - Y_B \\ Z_E - Z_B \end{bmatrix}$$

$$= \begin{bmatrix} a_{11}(X_E - X_B) + a_{12}(Y_E - Y_B) + a_{13}(Z_E - Z_B) \\ a_{21}(X_E - X_B) + a_{22}(Y_E - Y_B) + a_{23}(Z_E - Z_B) \\ a_{31}(X_E - X_B) + a_{32}(Y_E - Y_B) + a_{33}(Z_E - Z_B) \end{bmatrix}$$

Then, the satellite off-axis angle φ_{SC} is

$$\varphi_{SC} = \tan^{-1} \frac{\sqrt{Y'^2_E + Z'^2_E}}{X'_S - X'_E} \quad (3.2-22)$$

and the orientation angle of an earth point β is

$$\beta = \tan^{-1} \frac{Z'_E}{Y'_E} \quad (3.2-23)$$

The relationship between the orientation angle of the earth station and the orientation angle of the satellite elliptical beam is shown in figure 3.2-3. The perspective is along the ellipse boresight axis looking onto the $y'-z'$ -plane of the boresight point coordinate system.

If we let a be the *semimajor* axis beamwidth and b be the *semiminor* axis beamwidth, then the equation of the ellipse in the rotated $x_1 - y_1$ coordinate system is

$$\frac{x_1^2}{a^2} + \frac{y_1^2}{b^2} = 1$$

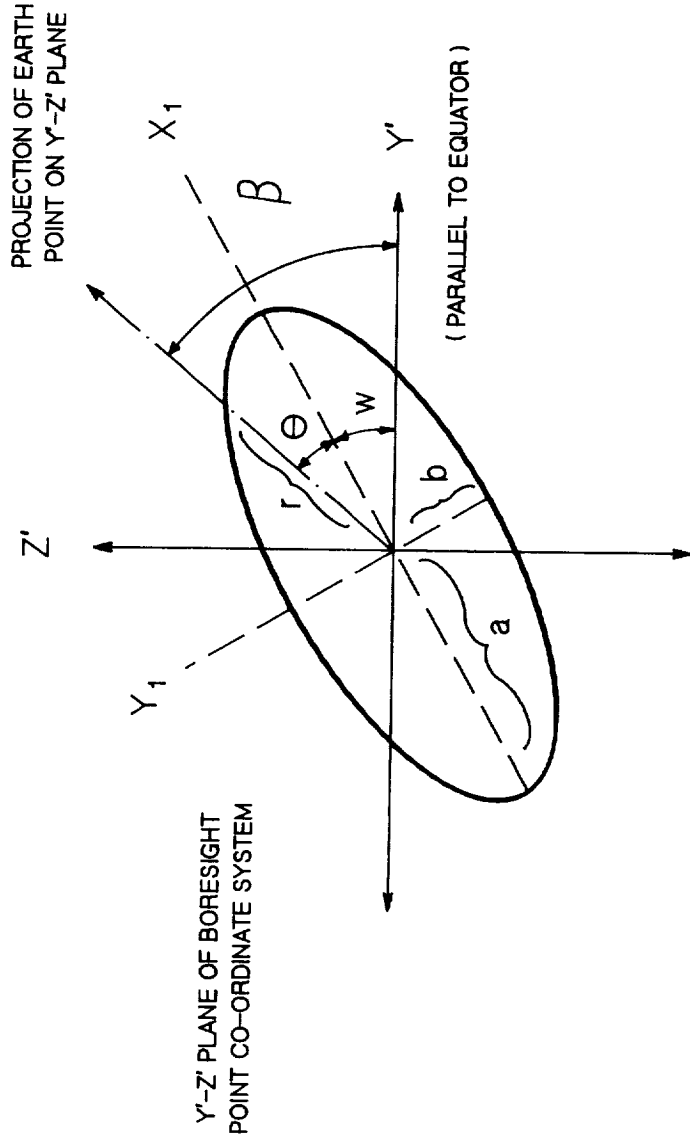
In polar form where r is measured from the **center** of the ellipse and θ is measured **CCW from the X_1 axis**,

$$\frac{(r \cos \theta)^2}{a^2} + \frac{(r \sin \theta)^2}{b^2} = 1 \rightarrow r_2 \left[\left(\frac{\cos \theta}{a} \right)^2 + \left(\frac{\sin \theta}{b} \right)^2 \right] = 1$$

Note that $\theta = \beta - \omega$ is the angle of the earth position projection **relative to the ellipse major axis**. Hence,

$$r^2 = \frac{1}{\left(\frac{\cos \theta}{a} \right)^2 + \left(\frac{\sin \theta}{b} \right)^2} \rightarrow r = \frac{1}{\left\{ \left[\frac{\cos (\beta - \omega)}{a} \right]^2 + \left[\frac{\sin (\beta - \omega)}{b} \right]^2 \right\}^{1/2}} \quad (3.2-24)$$

ELLIPSE GEOMETRY FOR CALCULATING ELLIPTICAL BEAM HPBW IN THE DIRECTION OF A GIVEN EARTH POINT



- a = SEMI-MAJOR AXIS BEAMWIDTH OF ELLIPTICAL BEAM
- b = SEMI-MINOR AXIS BEAMWIDTH OF ELLIPTICAL BEAM
- r = HALF THE HPBW IN THE DIRECTION OF EARTH POINT
- w = ORIENTATION ANGLE OF ELLIPTICAL BEAM
- β = ORIENTATION ANGLE OF EARTH POINT
- θ = ANGLE OF EARTH POINT RELATIVE TO ELLIPSE MAJOR AXIS

Figure 3.2-3.

Finally, for the full HPBW in the direction of the E/S (φ_{oSC}), we want $2r$ or

$$\varphi_{oSC} = \frac{1}{\left\{ \left[\frac{\cos(\beta - \omega)}{a} \right]^2 + \left[\frac{\sin(\beta - \omega)}{b} \right]^2 \right\}^{1/2}} \quad (3.2-25)$$

The relationship between the satellite off-axis angle φ and the satellite HPBW in the direction of interest is shown in figure 3.2-4.

3.2.2.2.2 Derivation of Earth Station Off-Axis Angle

In NASARC Version 4.0 it is assumed that the earth station antennas are pointed directly at their system's wanted satellite. Therefore, in calculating the transmitter powers, the earth station antenna gain is the calculated on-axis gain. There is no discrimination factor for the earth station antenna present in equation (3.2-1). This is not the case when C/I s are calculated. It now becomes necessary to calculate relative earth station off-axis angles to determine the amount of antenna discrimination present, both on the uplink and downlink.

The earth station off-axis angle depends on the location (latitude and longitude) of the earth station, and it also depends on the geocentric angular separation between the wanted and interfering satellites. The NASARC software incorporates a matrix approach, similar to that of section 3.2.2.2.1, to determine earth station off-axis angles. The resulting equations are

$$N = K^2 \cos(\phi_W - \phi_I) - K \cos \theta_E [\cos(\phi_W - \phi_E) + \cos(\phi_I - \phi_E)] + 1 \quad (3.2-26)$$

$$D = [K^2 - 2K \cos \theta_E \cos(\phi_W - \phi_E) + 1]^{1/2} [K^2 - 2K \cos \theta_E \cos(\phi_I - \phi_E) + 1]^{1/2} \quad (3.2-27)$$

$$\varphi_{ES} = \cos^{-1}(N/D) \quad (3.2-28)$$

where

- φ_{ES} earth station off-axis angle, deg
- θ_E earth station latitude, deg
- ϕ_E earth station longitude, deg
- ϕ_W wanted satellite longitude, deg
- ϕ_I interfering satellite longitude, deg
- K radius of geostationary orbit in earth radii, 6.6105

The earth station off-axis angle is then used with the half-power beamwidth to calculate the relative off-axis angle and then the falloff from the selected antenna. The half-power beamwidth required for the earth station is simply the HPBW which was calculated to obtain the earth station on-axis gain (see eq. (3.2-5)).

3.2.2.3 Determination of Pairwise Compatibility

The determination of pairwise compatibility between a pair of 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 spacecraft separation is achieved at an orbital spacing equal to the grouping criterion. Compatibility analysis between a pair of service areas is performed at an earth point location determined to be the so-called worst-case point. The worst-case point is the wanted receiver location closest to the interferer service area. An illustration of the worst-case point is shown in figure 3.2-4 and its derivation is given in section 3.2.2.3.1.

ANGLES OF INTEREST

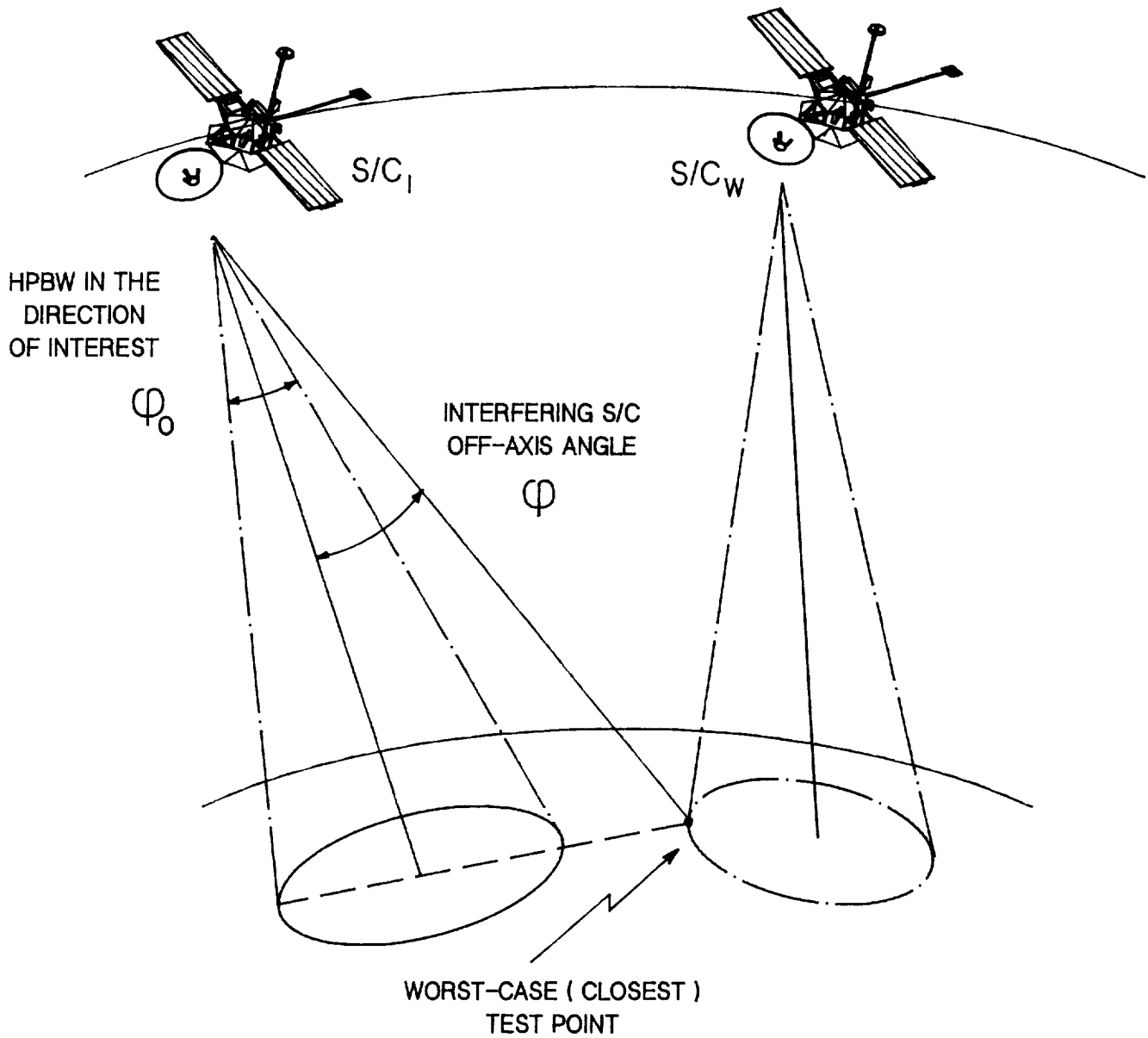


Figure 3.2-4.

The procedure for determining pairwise compatibility begins with the wanted satellite location 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. Next, the single-entry C/I is calculated and compared to the target single-entry C/I . If the calculated C/I meets or exceeds the target value, the pair of wanted and interfering service areas are compatible in this direction. The equations used for calculating the uplink C/I , downlink C/I , and total single-entry C/I are given in section 3.2.2.3.2.

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 the feasible arc. 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 when 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 figures 3.2-5(a) to (d).

3.2.2.3.1 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,

$$M = \frac{E - W}{2} \quad (3.2-30)$$

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

$$C = W + M \quad (3.2-31)$$

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

Verification of Sufficient Space Station Separation at Grouping Criterion

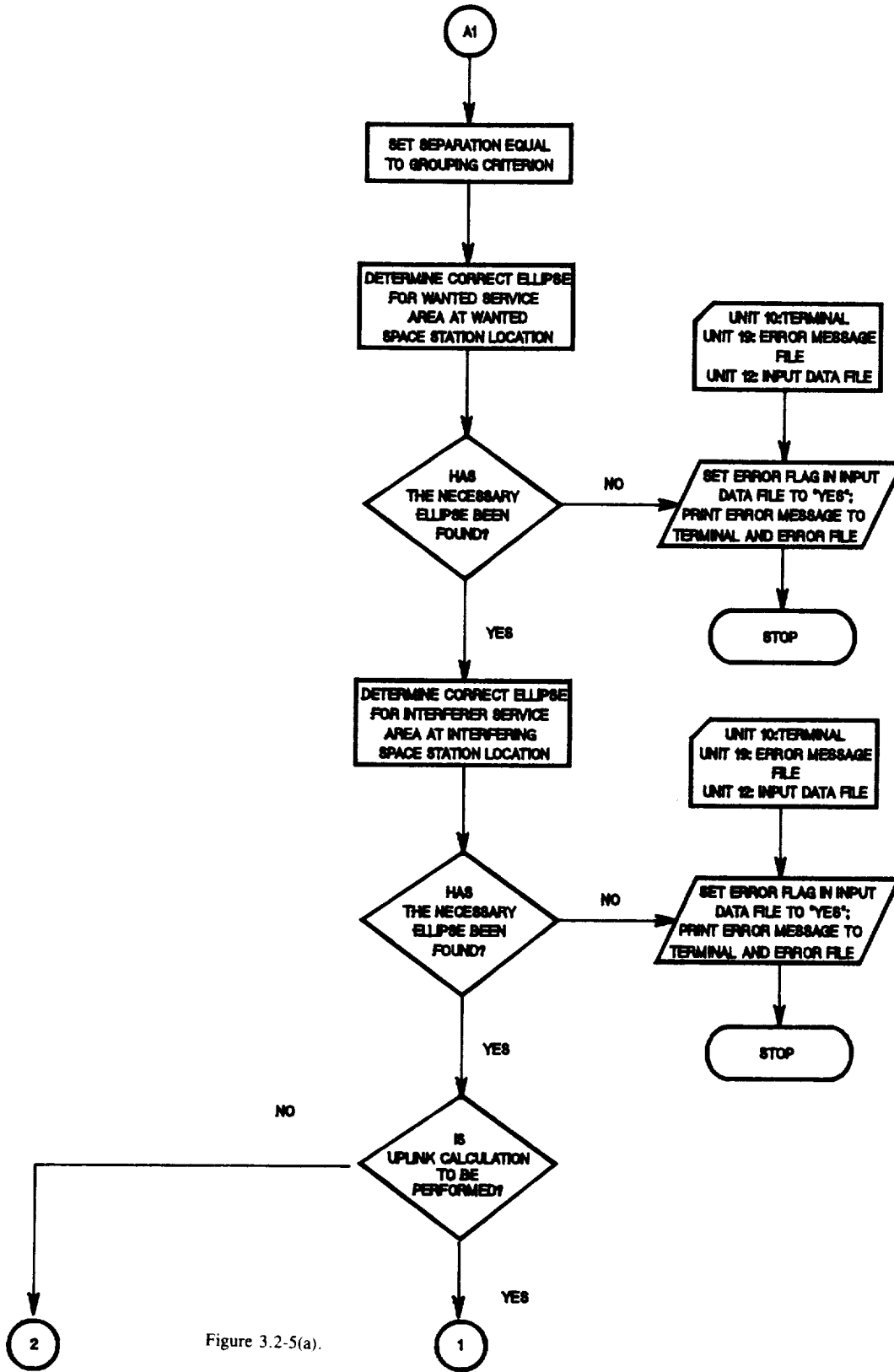


Figure 3.2-5(a).

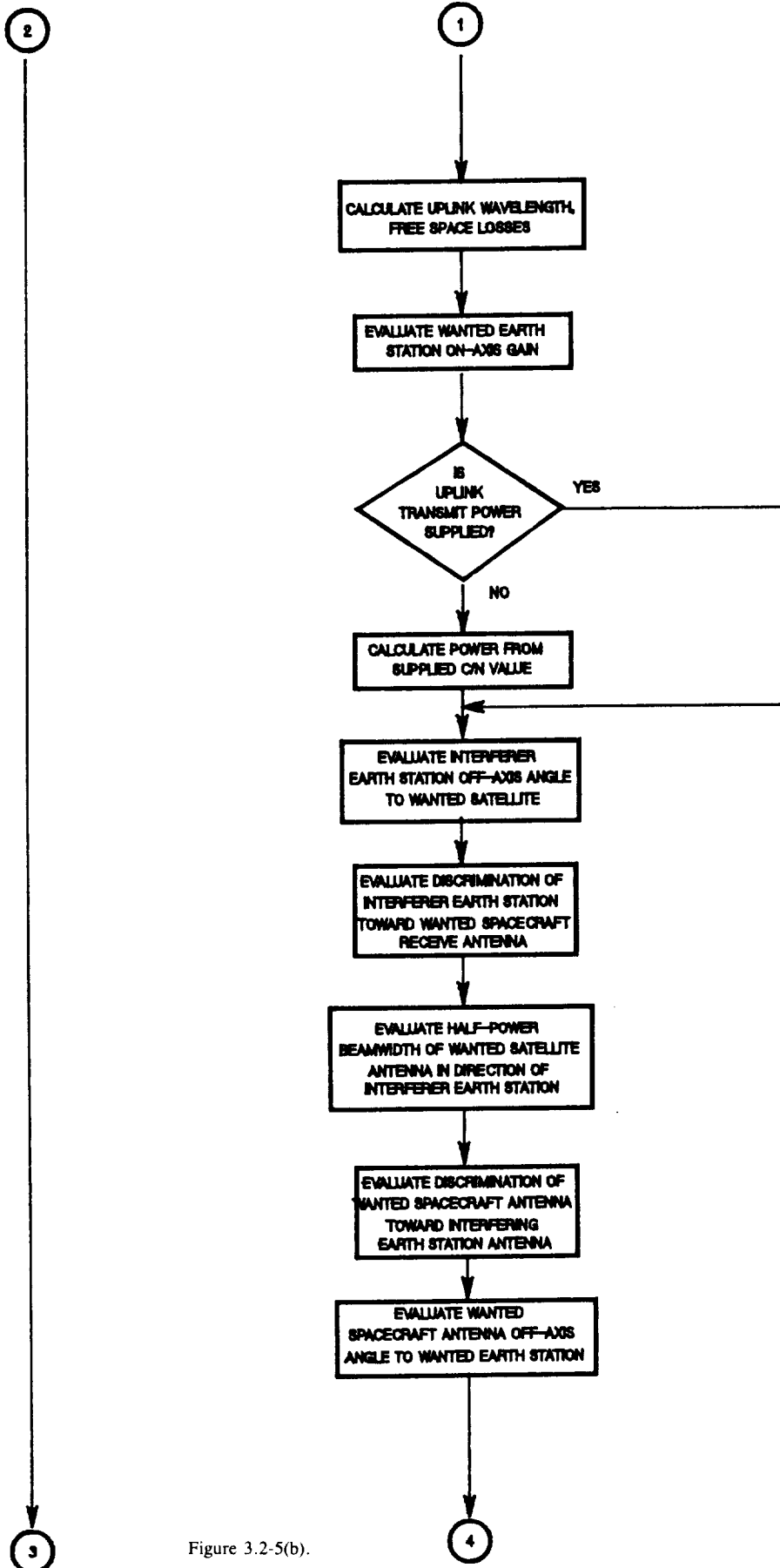


Figure 3.2-5(b).

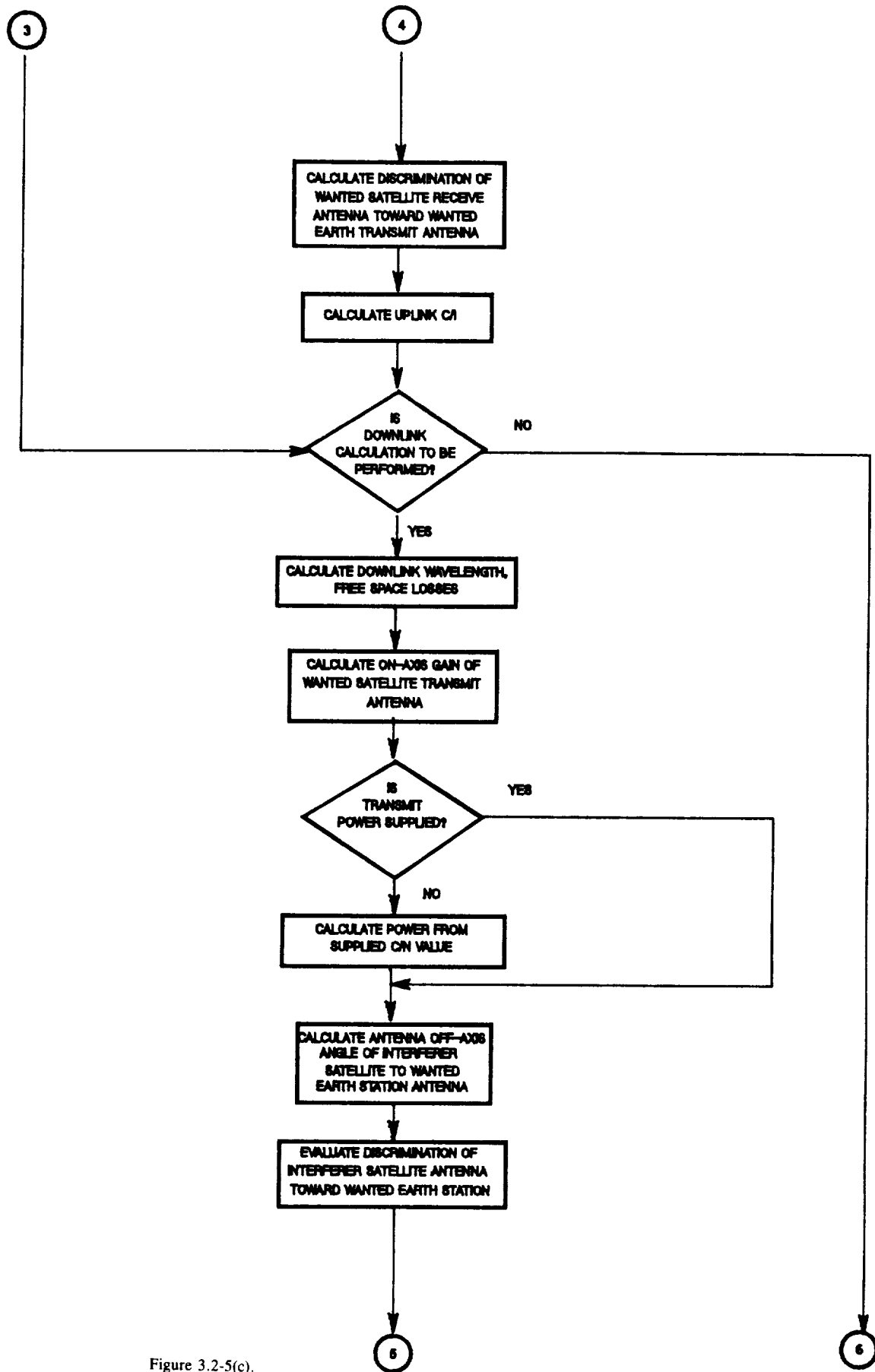


Figure 3.2-5(c).

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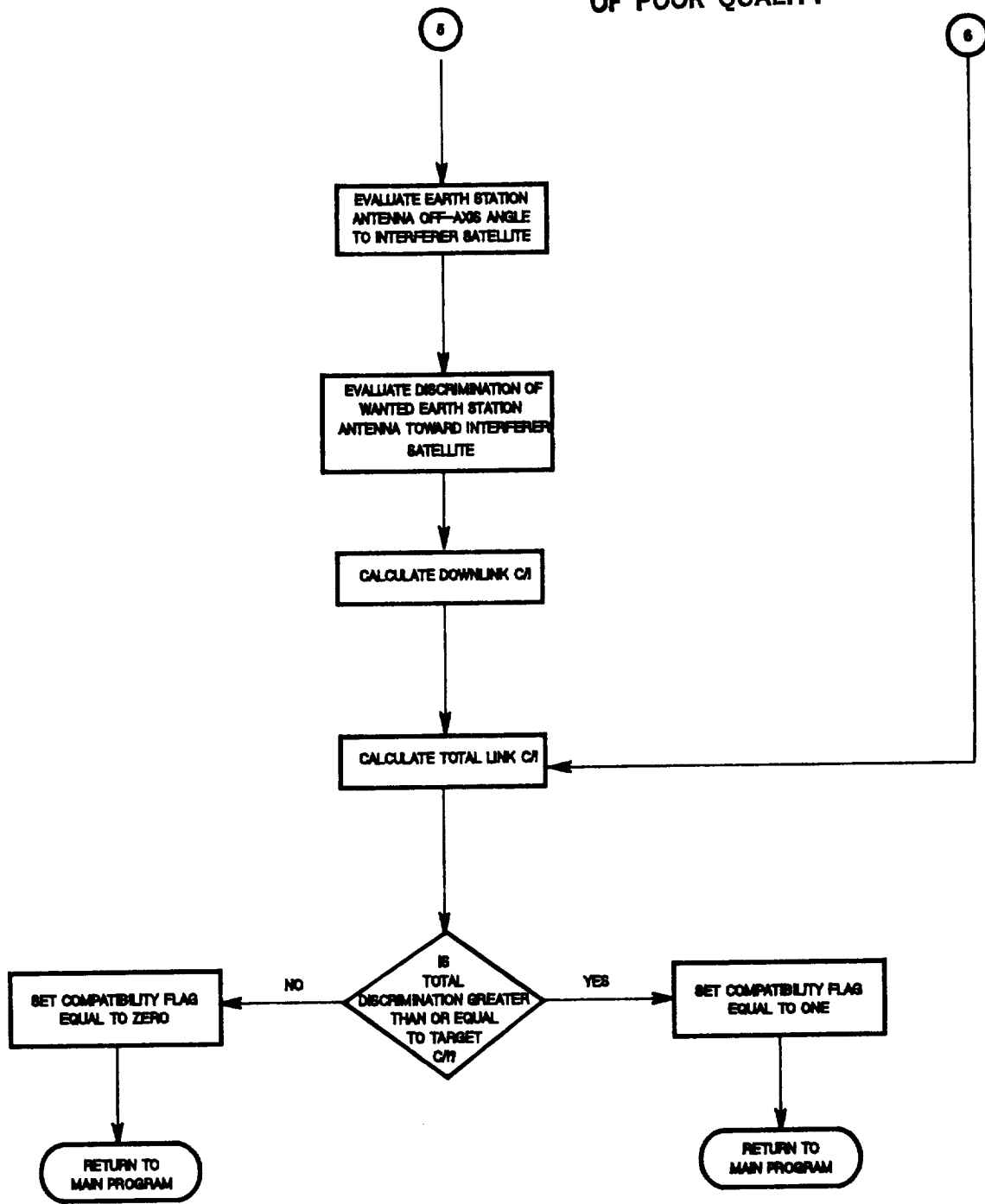


Figure 3.2-5(d).

and the wanted service area point, as seen from a satellite at the central location determined in equation (3.2-31), 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:

$$N = R^2 - R [\cos \theta_w \cos (C - \phi_w) + \cos \theta_c \cos (C - \phi_c)] + \cos \theta_w \cos \theta_c \cos (\phi_w - \phi_c) + \sin \theta_w \sin \theta_c \quad (3.2-32)$$

$$D = [R^2 - 2R \cos \theta_w \cos (C - \phi_w) + 1]^{1/2} \times [R^2 - 2R \cos \theta_c \cos (C - \phi_c) + 1]^{1/2} \quad (3.2-33)$$

$$\gamma_{dist} = \cos^{-1} \frac{N}{D} \quad (3.2-34)$$

where

- R radius of geostationary orbit in terms of earth radii, 6.6105
- C defined by eq. (3.2-2)
- θ_c latitude of interfering service area minimum area ellipse boresight as seen from central location of arc intersection between two service areas, deg
- ϕ_c longitude of interfering service area minimum area ellipse boresight as seen from central location of arc intersection between two service areas, deg
- θ_w latitude of polygon point in wanted service area, deg
- ϕ_w longitude of polygon point in wanted service area, deg
- γ_{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.

3.2.2.3.2 Calculation of C/I 's

In this section, the equations used to calculate C/I 's in NASARC Version 4.0 are presented. These equations are used in determining pairwise compatibility between two service areas. Recall from section 3.2.2.3 that the wanted satellite is placed at integer arc locations across the feasible arc and the interfering satellite is spaced a distance away equal to the grouping criterion in both directions. The wanted earth station is located at the *worst-case* point in the *wanted* service area, and the interfering earth station is located at the *worst-case* point in the *interferer's* service area. To determine the total (or aggregate) single-entry C/I , it is first necessary to compute both the uplink and downlink C/I 's:

Uplink:

$$C_U = P_{WE} + G_{WE} - L_{Wu} + G_{WS} - D_{WS}$$

$$I_U = P_{IE} + G_{IE} - L_{Iu} - D_{IWu} + G_{WS} - D_{WIu}$$

or

$$(C/I)_u = (P_{WE} + G_{WE}) - (P_{IE} + G_{IE}) - (L_{Wu} - L_{Iu}) + (D_{IWu} + D_{WIu}) - D_{WS} \quad (3.2-35)$$

where

- $(C/I)_u$ uplink single-entry C/I , dB
- C_u received wanted power at the wanted satellite, dBW
- I_u received interferer power at the wanted satellite, dBW
- P_{WE} wanted earth station transmit power, dBW
- G_{WE} wanted earth station on-axis antenna gain, dB
- P_{IE} interfering earth station transmit power, dBW
- G_{IE} interfering earth station on-axis antenna gain, dB
- L_{wu} free space loss on wanted uplink path, dB
- L_{Iu} free space loss from interfering E/S to wanted S/C, dB
- D_{Iwu} discrimination of interferer E/S antenna toward wanted S/C, dB
- D_{wIu} discrimination of wanted S/C antenna toward interferer E/S, dB
- G_{WS} on-axis gain of wanted S/C antenna, dB
- D_{WS} discrimination of wanted S/C antenna toward wanted E/S, dB

Downlink:

$$C_d = P_{WS} + G_{WS} - L_{wd} + G_{WE} - D_{WS}$$

$$I_d = P_{IS} + G_{IS} - L_{Id} - D_{Iwd} + G_{WE} - D_{wId}$$

or

$$(C/I)_d = (P_{WS} + G_{WS}) - (P_{IS} + G_{IS}) - (L_{wd} - L_{Id}) + (D_{Iwd} + D_{wId}) - D_{WS} \quad (3.2-36)$$

where

- $(C/I)_d$ downlink single-entry C/I , dB
- C_d received wanted power at the wanted earth station, dBW
- I_d received interferer power at the wanted earth station, dBW
- P_{WS} wanted satellite transmit power, dBW
- G_{WS} wanted satellite on-axis antenna gain, dB
- P_{IS} interfering satellite transmit power, dBW
- G_{IS} interfering satellite on-axis antenna gain, dB
- L_{wd} free space loss on wanted downlink path, dB
- L_{Id} free space loss from interfering S/C to the wanted E/S, dB
- D_{Iwd} discrimination of interferer S/C antenna toward wanted E/S, dB
- D_{wId} discrimination of wanted E/S antenna toward interferer S/C, dB
- G_{WE} on-axis gain of wanted E/S antenna, dB
- D_{WS} discrimination of wanted S/C antenna toward wanted E/S, dB

Figure 3.2-6 shows the relationship of the wanted and interfering signal paths and the off-axis antenna angles that determine the discrimination factors. Once the separate uplink and downlink single-entry C/I 's are determined, the total (or aggregate) single-entry C/I is obtained by the power combination

$$10^{-(C/I)_{TOTAL}/10} = 10^{-(C/I)_u/10} + 10^{-(C/I)_d/10}$$

Then

$$(C/I)_{TOTAL} = -10 \log [10^{-(C/I)_d/10} + 10^{-(C/I)_u/10}] \quad (3.2-37)$$

where $(C/I)_{TOTAL}$ is the total single-entry C/I (dB).

PARAMETER DEFINITIONS

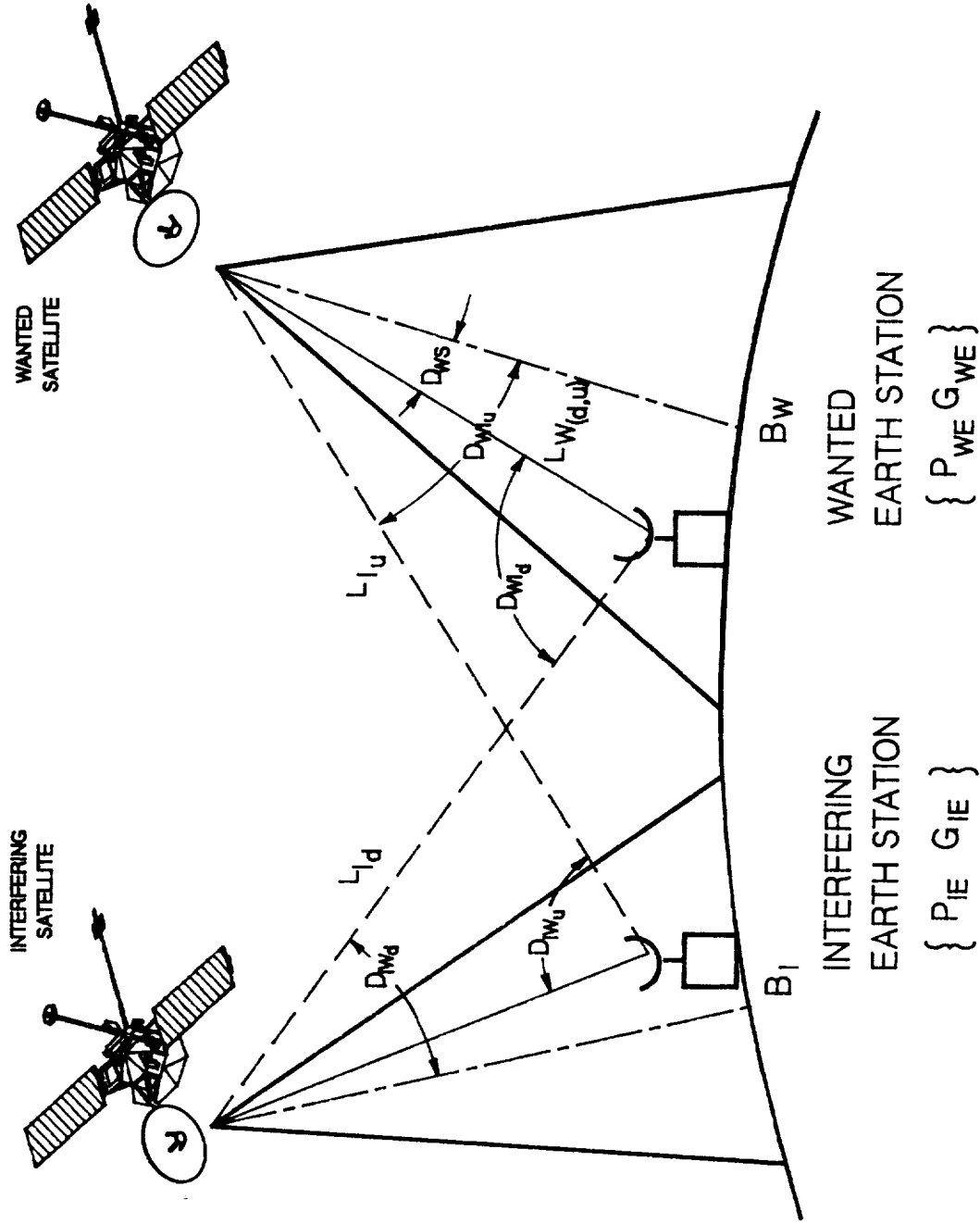


Figure 3.2-6.

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 expresses the compatibility between each service 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 3.2-7 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

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 3.2-7.

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.

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 stored in the Groups file. It 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 3.2-8 for reference.

3.2.5 Calculation of Transitional Arc Lengths

One of the factors utilized by NASARC2 in determining the allotted arc length for each compatible grouping is the transitional arc. (The allotted arc length equation is described in detail in section 3.3.4.2.) The transitional arc can be used as a means of reducing the overall coordination requirements between members of adjacent groupings. Transitional arcs are calculated in NASARC1 for each service area using the individually specified earth station antenna parameters and the interference criterion. These values are passed to NASARC2 along with the list of enumerated groupings in the NASARC1 Groups file. The equations for calculating the transitional arc length are as follows:

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

$$T = 10^{[(C/I-6)-G_{MAX}+32]/25} \quad (3.2-38)$$

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

$$T = 10^{[(C/I-6)-G_{MAX}+29]/25} \quad (3.2-39)$$

For $D/\lambda \leq 100$ and earth station antenna sidelobe envelope of 32-25 log:

$$T = 10^{[(C/I-6)-G_{MAX}+52-10 \log (D/\lambda)]/25} \quad (3.2-40)$$

For $D/\lambda \leq 100$ and earth station antenna sidelobe envelope of 29-25 log:

$$T = 10^{[(C/I-6)-G_{MAX}+49-10 \log (D/\lambda)]/25} \quad (3.2-41)$$

where

- T transitional arc length, deg
- D earth station antenna diameter, m
- λ wavelength corresponding to input frequency, m
- C/I threshold downlink C/I , dB
- G_{MAX} earth station on-axis gain, dB
- 6 single-entry to aggregate C/I , dB (see section 3.1.1.2.3)

A transitional arc length is calculated by NASARC1 for each service area.

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

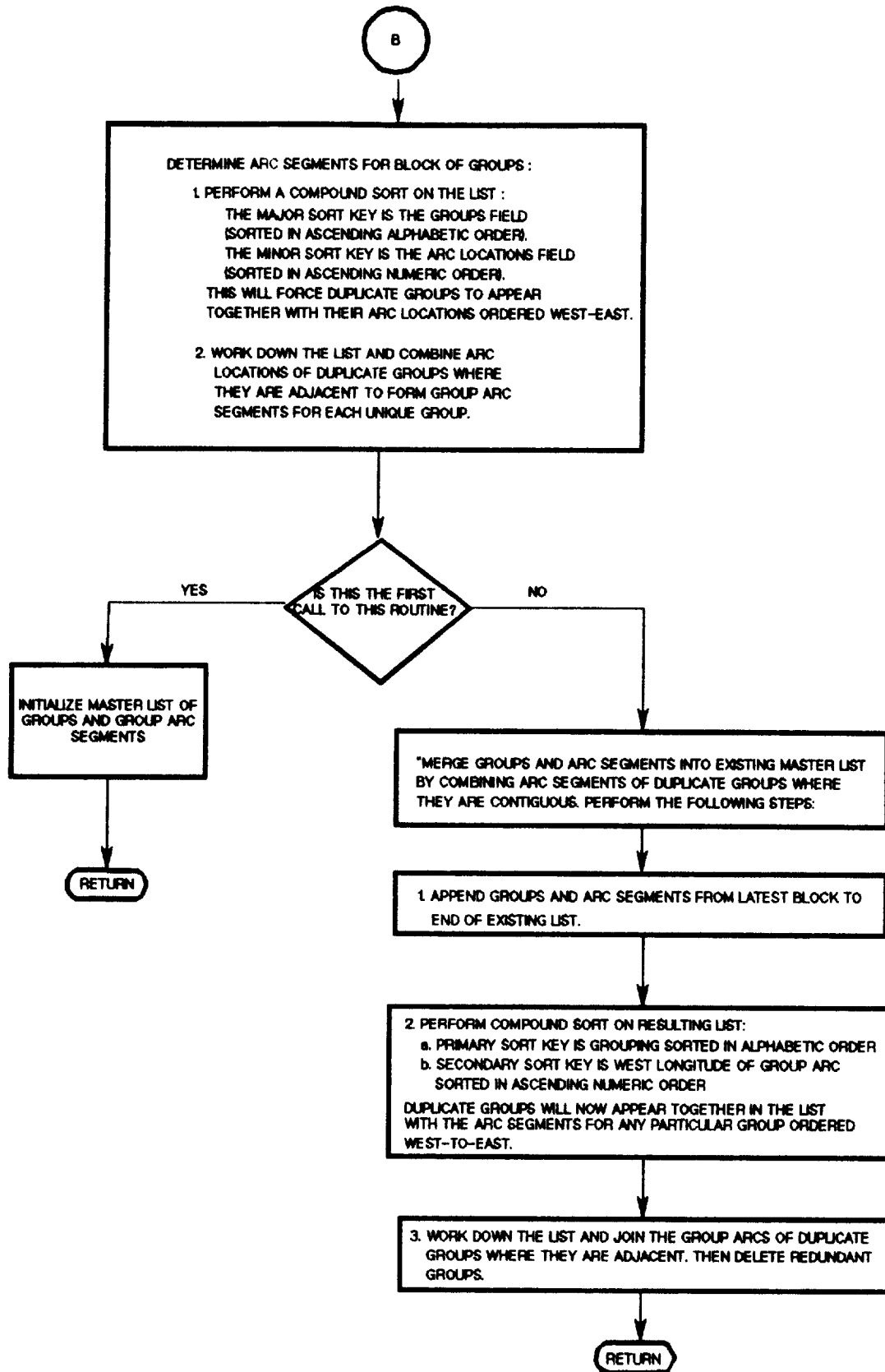


Figure 3.2-8.

3.3 NASARC2: Arc Determination Program

In the NASARC (Version 4.0) software package, NASARC2 is used to select appropriate groupings from among those enumerated in the NASARC1 program module within the current segment boundaries 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 NASARC4 (see section 3.6.6). 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 figures 3.3-1(a) and (b). 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.

3.3.2 Prioritization of Service Areas

As was indicated in section 2.1.6 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 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 the cumulative arc by more than the length of their transitional arc are given a priority P1, meaning that these service areas must be accommodated within the current

NASARC2 – THE ARC DETERMINATION PROGRAM

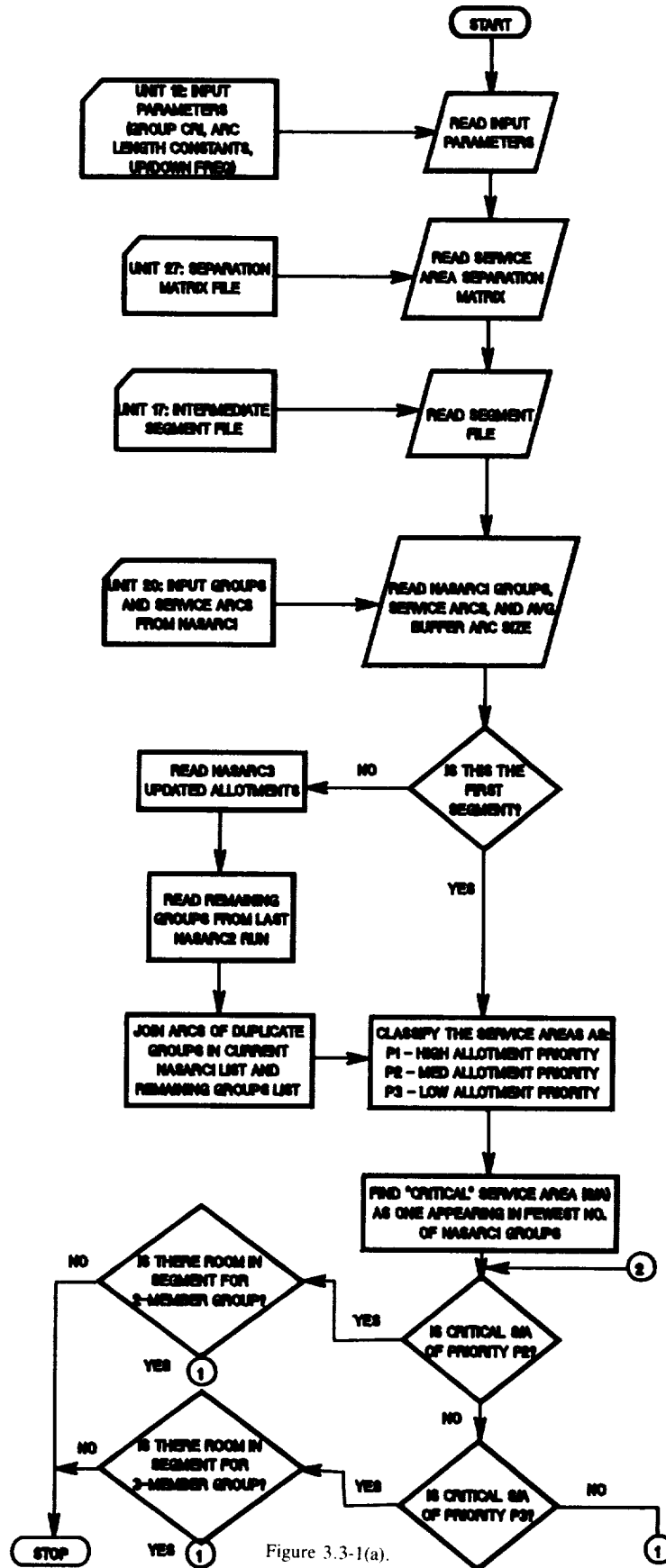


Figure 3.3-1(a).

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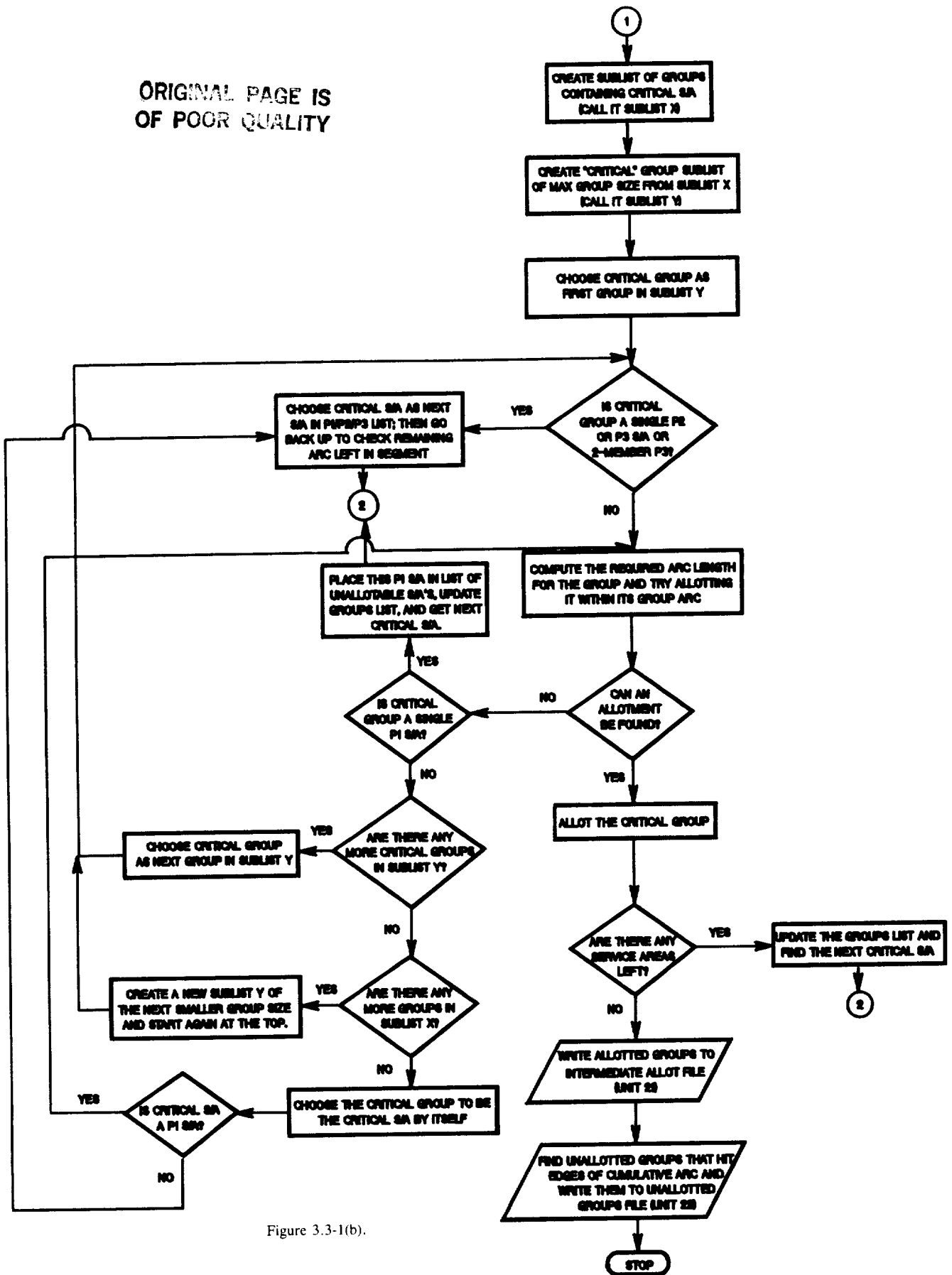


Figure 3.3-1(b).

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 FOM0. 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) and (b), 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) along with service arc information. 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 the current cumulative arc. Service areas with priority level P1 are sorted according to service arc length, from shortest to longest in length. FOM1 is used to sort the service areas within priority levels P2 and P3 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 priority P2 followed by P3, is selected as the critical service area. 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.

Selecting 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 unallottable service areas.

3.3.4 Selection of Critical Grouping

After the critical service area has been selected, the next step in the NASARC2 process is to select a grouping that contains the critical service area (i.e., the critical grouping). Once selected, the software attempts to allot a common PDA to the members of the selected critical grouping.

The first step in the selection process of the critical grouping is to generate a sublist of all groupings from the NASARC1 master groups list which contains the critical service area. From this sublist, groups are examined in descending order of the number of members within a grouping. Initially, all groupings of the maximum size N (i.e., greatest number of members per group) are extracted from the sublist. If an allotted arc can not be found for any of the extracted groupings of size N , the sublist is reexamined to extract groupings of size $N-1$ and so on. Groupings of size $N-1$ and smaller must go through a subset arc extension procedure to determine if any of these groupings are subsets of larger groupings (e.g., size N). This is necessary because 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.

Once groupings of the specified size have been extracted from the sublist and examined for subset arc extension, the group arc length of each grouping is compared against the minimum allotted arc length requirement for the given grouping size. (The allotted arc length equation is discussed in section 3.3.4.2.) Using this figure of merit 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 sufficient length group arcs) are sorted in the manner presented in the next section.

3.3.4.1 Sorting of Groupings Containing the Critical Service Area

Sorting the sublist of equal size groupings is done to increase the likelihood for successful accommodation of PDA's containing all service areas in a given scenario. Since NASARC2 uses a heuristic procedure rather than an optimization procedure, the sorting process helps to maintain a greater flexibility of choice in the selection of future groupings as the NASARC process works to completion.

Groupings of equal size are first sorted in descending order according to their group arc length. In cases of ties (i.e., equal group arc lengths), the groupings are sorted in ascending order of the total frequency of occurrence values (see FOM1 in section 3.3.3) 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 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 until the list is exhausted. If the list of equal size groupings is exhausted, a new sublist of the next smaller size groupings is extracted from the list of groupings which contain the critical service area. These new groupings will go through subset arc extension, sorting and attempt to be allotted, and so on until eventually either one of critical groupings is accommodated or the list of groupings which contain the critical service area itself is exhausted. If the latter happens (i.e., a critical grouping containing the critical service area could not be 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 occur only 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 Allotted 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 exact basis for determining the allotted arc length of each PDA can vary depending on the requirements related to efficiency of orbit utilization. Therefore, the equation which has been implemented in the NASARC (Version 4.0) process allows the user considerable flexibility in determining the arc length to be allotted to a given size grouping (i.e., the allotted arc length). 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:

$$AL = K_1(N-1)GRP + K_2T(i) + K_3N + K_4 \quad (3.3-1)$$

where

AL	allotted arc length, deg
N	number of grouping members
GRP	grouping criterion, deg
$T(i)$	transitional arc length, related to grouping i , deg
K_1, K_2, K_3, K_4	user specified constants

All entries in the allotted arc 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 transitional arc length $T(i)$ is calculated based on user specified earth station parameters (see section 3.1.1.2); and the constants K_1 , K_2 , K_3 , and K_4 are specified by the user in the Service Area file (see section 3.1.1.2). Specification of the four constants allows the user to determine the basis for the allotted arc length.

Constant K_1 affects the emphasis of the grouping criterion on the allotted arc 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_2 affects the emphasis of the transitional arc length related to each grouping on the allotted arc length. The transitional arc is included as a means of reducing the overall coordination requirements between members of adjacent groupings.

Section 3.2.5 gives the equations for determining the transitional arc length which is based on earth station parameters. NASARC1 calculates an individual transitional arc length related to each service area from 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 transitional arc length $T(i)$ related to grouping i , selects the largest individual transitional arc length associated with any of the members of grouping i . The transitional arc 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 transitional arc area and not cause or receive harmful interference. The purpose of specifying the transitional arc 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 transitional arc area might be required to coordinate with administrations from the affected adjacent grouping. The length of the transitional arc 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 an allotted arc 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 for determining the minimum allotted arc length (see section 3.3.4). If a grouping containing the critical service area has a group arc greater than or equal to the necessary allotted arc 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. One of the 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).

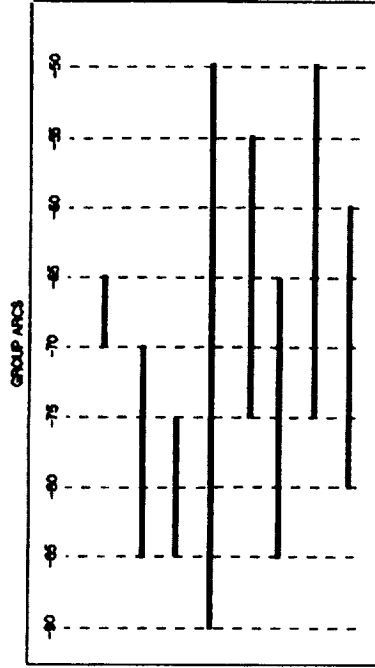
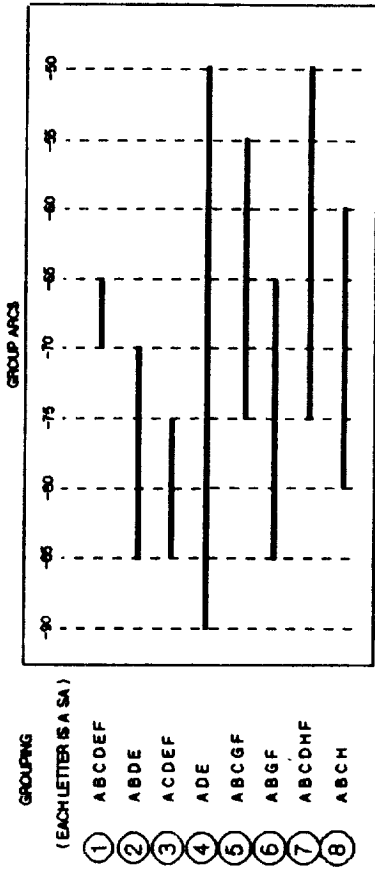
The first step is to delete critical group members from the groups in the list in which they appear. This is shown in step 1 of the example. The critical group which has just been allotted is XCF, where X, C, and F are the critical group members.

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 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.

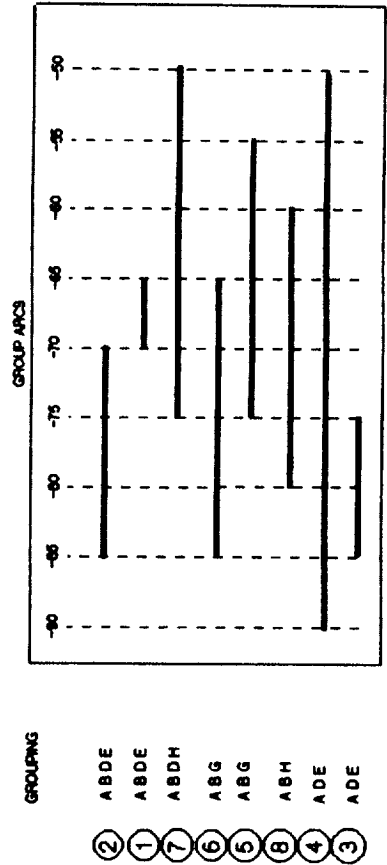
FIGURE 3.3-2 EXAMPLE OF GROUPS LIST UPDATING
XCF IS THE ALLOTTED CRITICAL GROUP

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.

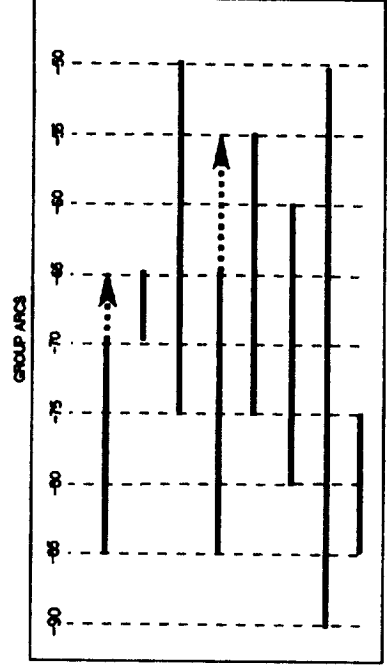


Figure 3.3-2.

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. Only those groups with the same fewest number of members are candidates for subset arc extension.

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. In the example, ABG is 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 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. This is done if and only if the next group has the same number of members as the last key group (i.e., from the sublist of equal size groupings).

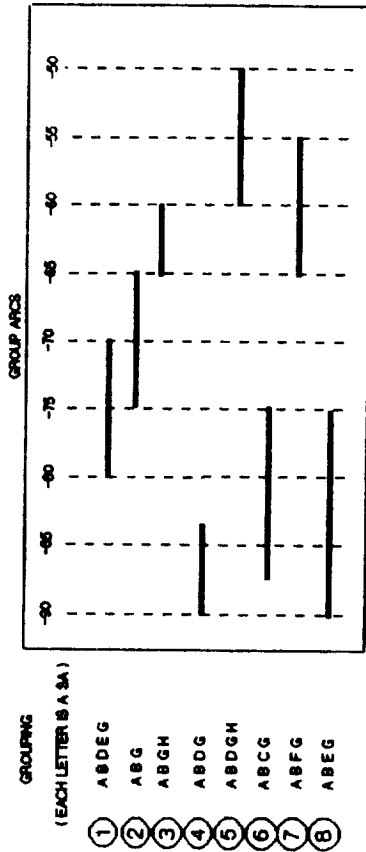
Once the subset arc extension process has been performed on each of the groups in this sublist, determination of the next critical group to be allotted can proceed.

3.3.6 Allotted Arc Determination Procedures

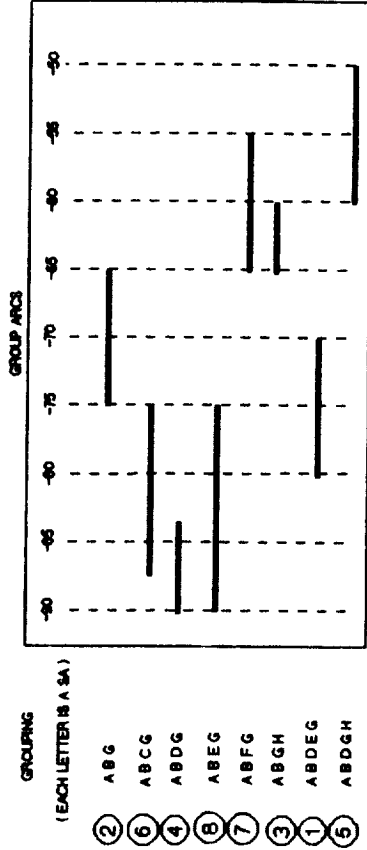
Up to this point, the NASARC2 program has selected a critical service area and a corresponding critical grouping of which it is a member. NASARC2 now checks to see if any priority P1 service areas are missing from the Groups file by examining the service area information list. If so, these are given 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 grouping's 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.

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

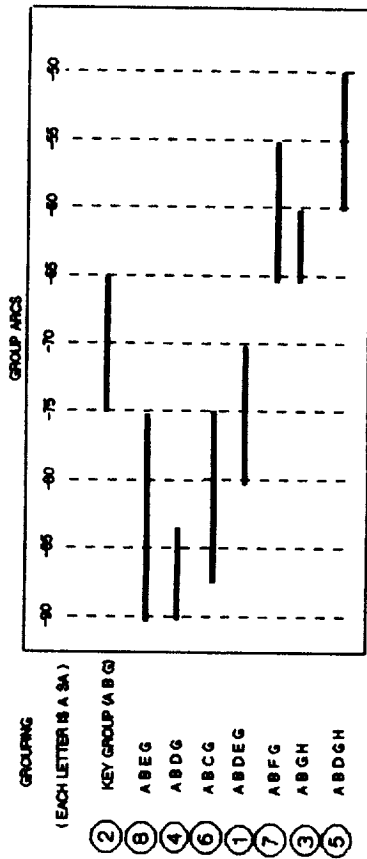
INITIAL SUBLIST OF CRITICAL GROUPS
(B IS THE CRITICAL SERVICE AREA)



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.

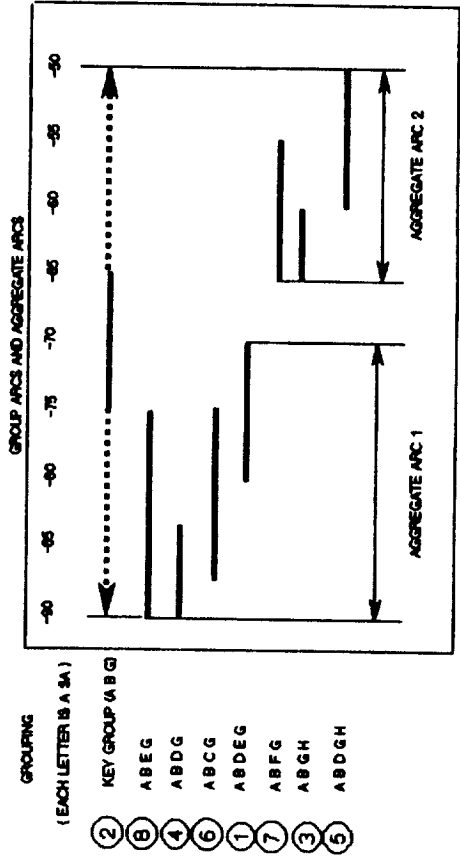


Figure 3.3-3.

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 transitional arc 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. The NASARC2 software takes advantage of the information available in the Satellite Separation Matrix file (see section 3.1.2.3) during the arc determination process. This file contains the worst-case (maximum) satellite orbital separations needed between each pair of service areas in the scenario in order to satisfy a specified *C/I* criterion. These values are used to aid in selecting a critical group and positioning the group in an allotted arc which improves the compatibility between satellites in adjacent PDA's. In the arc determination process, each critical group from the critical groups sublist is stepped along its group arc in 1° increments. At each position, tests are performed to determine if an orbital slot of sufficient width (equal to the critical group's required allotted arc length) exists to possibly accommodate the group or if such a slot can be opened by *pushing* existing allotted groups within their respective group arcs (the relative west-to-east ordering of existing groups remains unchanged during the push process). If a slot can not be created, then the critical group is simply stepped 1° eastward (or westward) in its group arc and the tests are repeated. If a slot exists, then the required separation between the critical group and its potential east and west neighboring groups is determined using the values in the separation matrix and the arc lengths of the critical group and its potential neighbors. Specifically, the required separation between two groups (i.e., between the nearest edges of their allotted arcs) is found by taking the difference of the worst-case (largest) separation required between any pair of service areas in the two groups and the available separation that can be achieved by placing this worst-case pair of service areas near the extreme ends of their respective allotted arcs. Required separation is calculated on the worst-case assumption that the two groups abut one another, although they may, in fact, have several degrees of arc between them. If the required separation between the critical group and its east and west neighbors is negative or zero (i.e., the available separation is greater than or equal to the worst-case separation), then satellites of service areas in the critical group will experience minimal interference from neighboring satellites in the adjacent groupings. Accordingly, for each critical service area, NASARC2 will attempt to select the largest critical group and position it between neighbors where it has minimal separation requirements. Further improvement in the allotted group arrangement is accomplished in the NASARC4 PDA Interchange Program as described in section 3.5.

Figures 3.3-4(a) to (c) present the flowchart of the arc determination process implemented in NASARC2. The following subsections provide additional information on the *push* operation as well as the adjacent grouping compatibility check.

3.3.6.1 Push Allotted Arc Routine

The Push Allotted Arc Routine is used to attempt to clear an opening in the orbital arc so that the PDA of the current critical grouping may be accommodated. The push operation is required only if existing PDA's overlap the orbital slot under examination (see fig. 3.3-5). Overlapping PDA's are pushed eastward and westward to attempt to clear the desired orbital slot. As figure 3.3-5 illustrates, since the relative west-to-east ordering of existing PDA's remained unchanged by the push operation, the push may result in trying to relocate multiple PDA's, including PDA's which do not intersect the orbit slot. If all the overlapping PDA's can be pushed sufficiently far to clear the orbital slot, the candidate critical grouping is then tested for compatibility with the nearest neighboring groupings to the east and west. If the push is not successful, the PDA of the candidate grouping is stepped 1° eastward (or westward depending on the direction of arc buildup), and the allotment

NASARC2
ALLOTTED ARC
SUBROUTINE

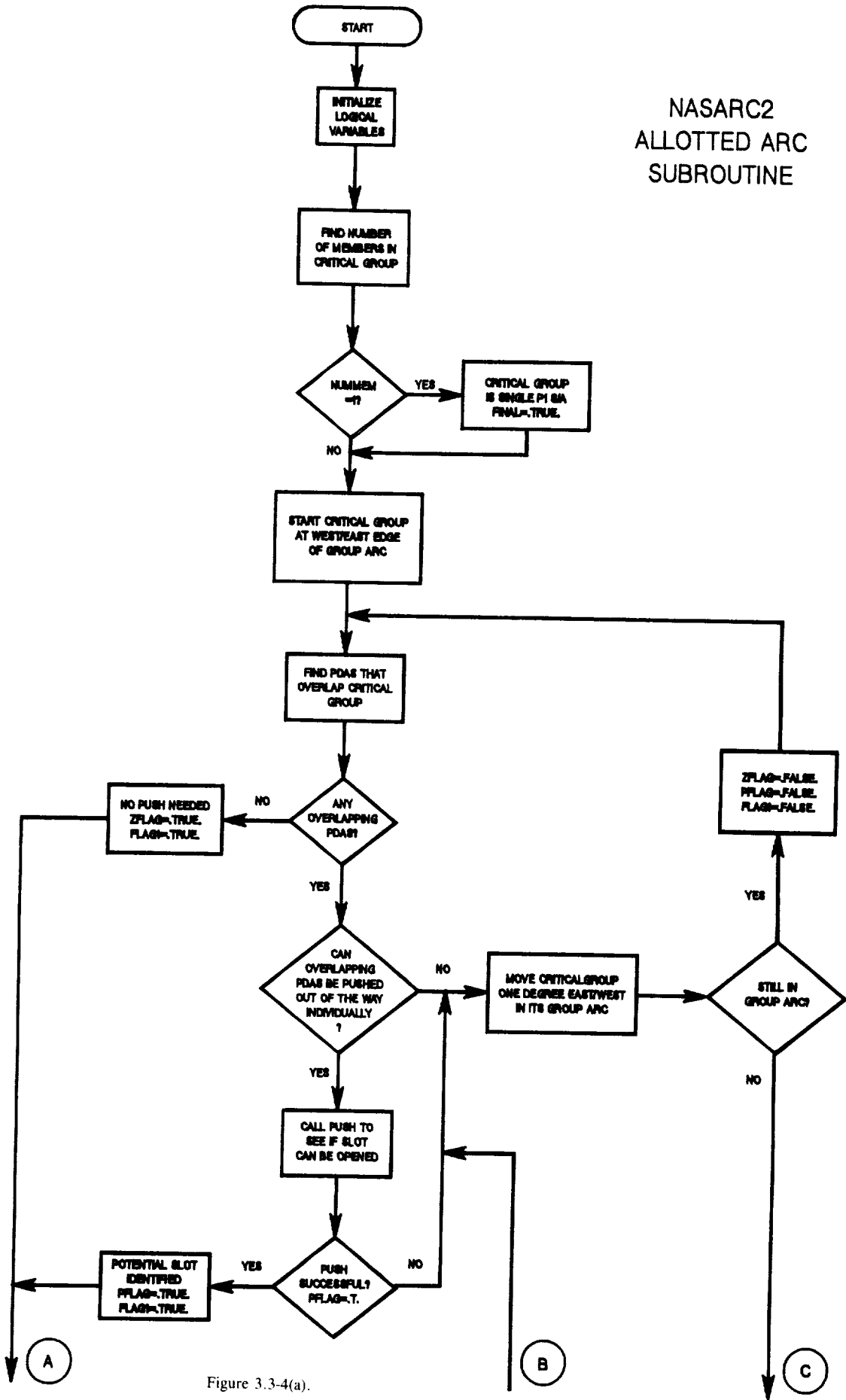
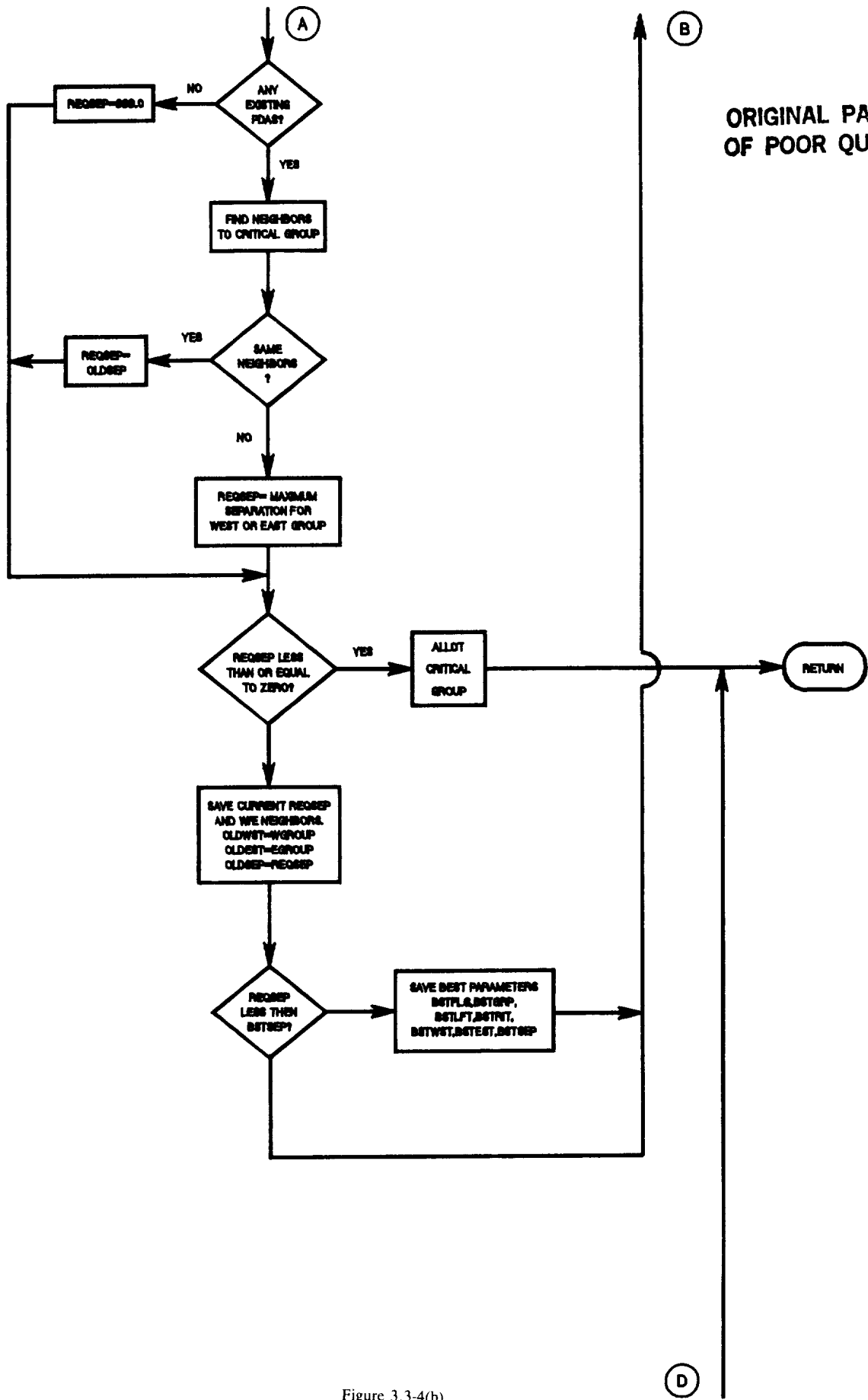


Figure 3.3-4(a).



ORIGINAL PAGE IS OF POOR QUALITY

Figure 3.3-4(b).

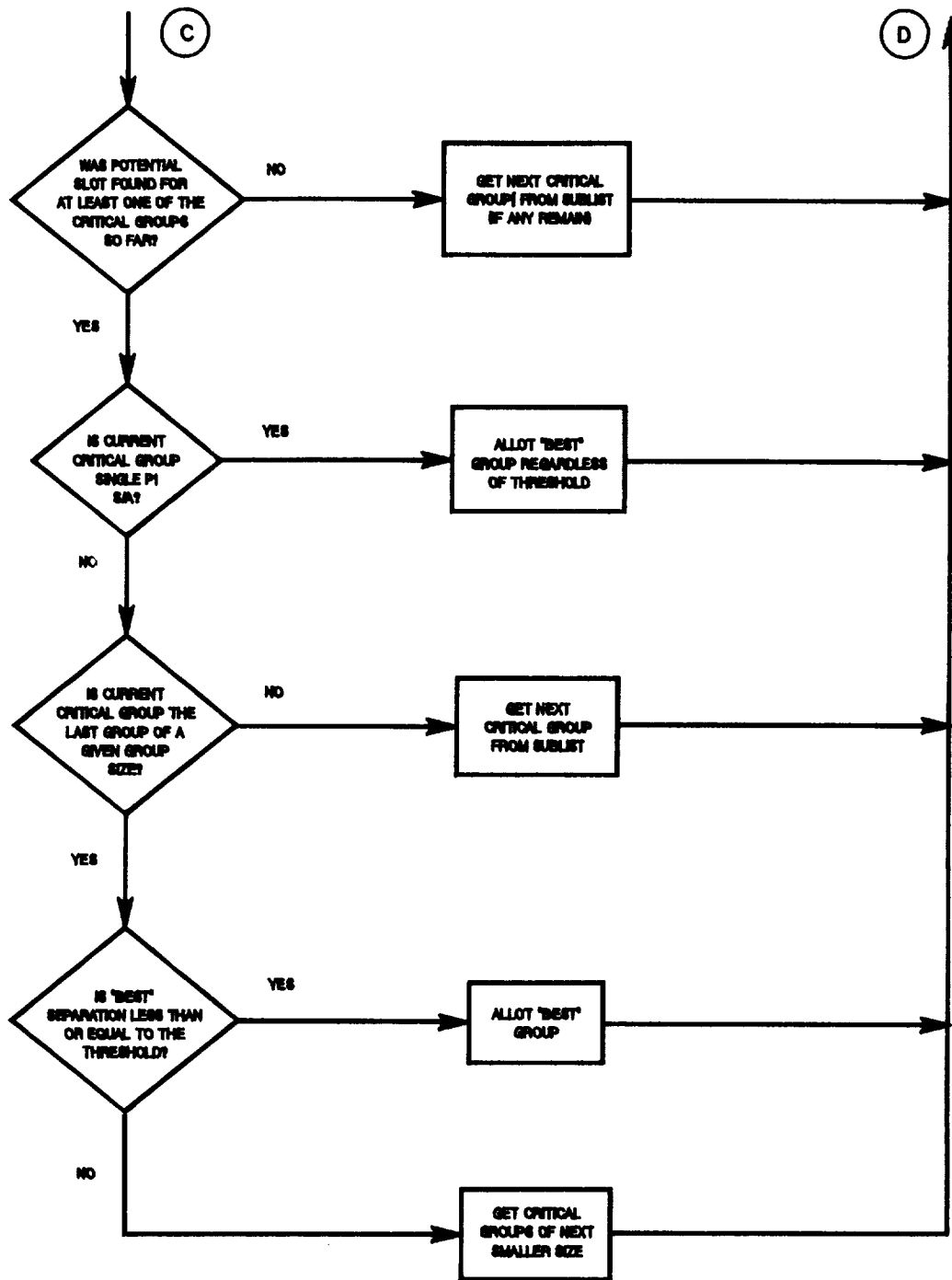


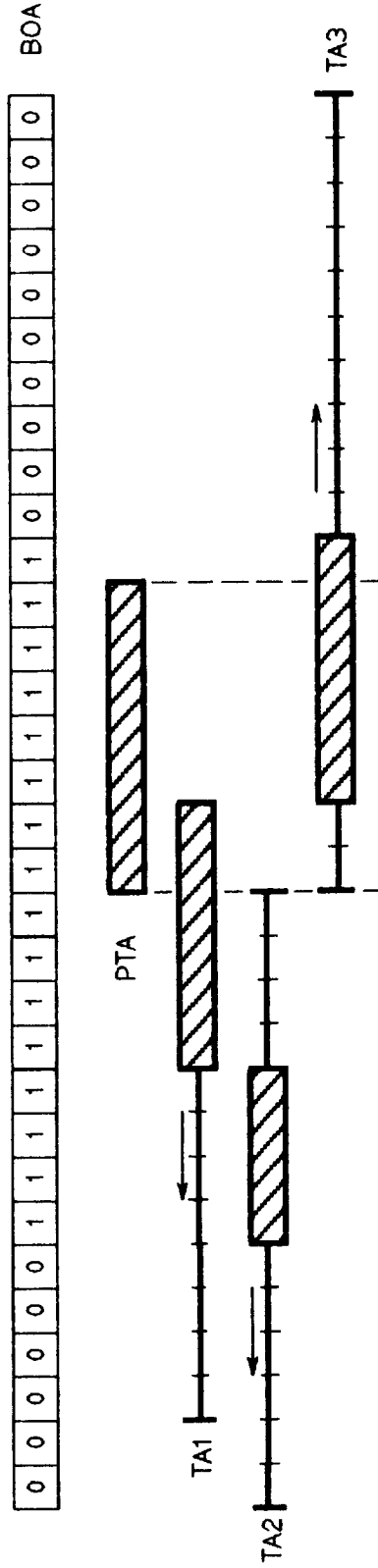
Figure 3.3-4(c).

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:

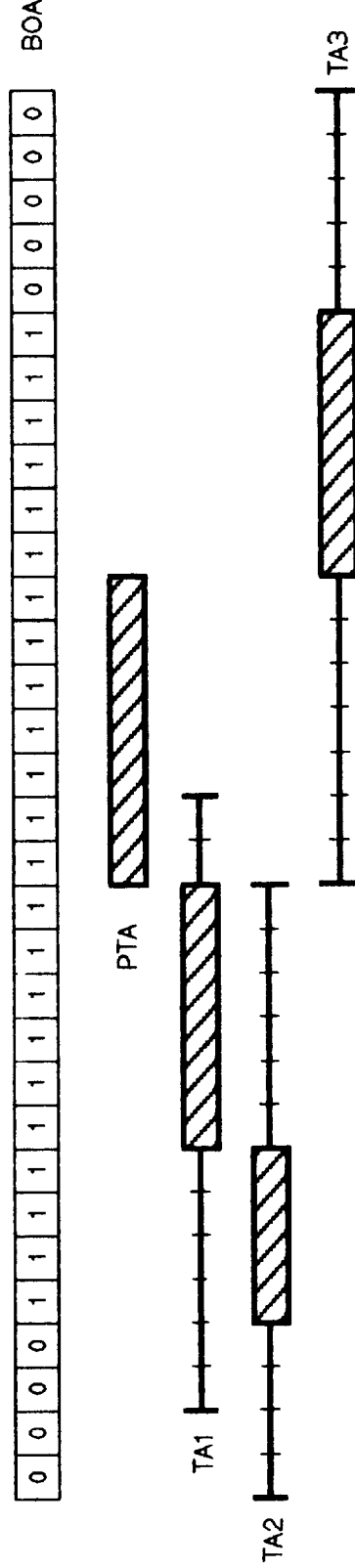


Figure 3.3-5.

process is repeated. The candidate critical grouping will continue to be stepped across its group arc until it can either be accommodated or until its group arc is exhausted, at which time a new candidate critical grouping is sought.

The Push Allotted Arc Routine allows the NASARC2 program to alter past decisions relative to the placement of the PDA's of previously selected groupings. It does not, however, allow previously selected groupings to be eliminated, since the push operation is restricted to maintain all selected groupings within the confines of their respective group arcs. A successful push operation does not guarantee the ultimate acceptance of a candidate critical grouping. It merely identifies an opening in the orbital arc of sufficient size to accommodate the required PDA length. The final test involves an examination of the relative compatibility between the candidate grouping and its immediate neighboring groupings.

3.3.6.2 Adjacent Grouping Compatibility Check

An important enhancement incorporated into Version 4.0 of the NASARC software is the ability to assess compatibility between members of adjacent groupings. This is done in NASARC2 by initially selecting groupings and their corresponding PDA's on the basis of certain compatibility requirements being met between members of adjacent groupings. Adjacent grouping compatibility is also taken into account in NASARC4 where selected groupings are examined for compatibility and then swapped or rearranged in orbit to further reduce harmful interference across PDA boundaries. Details of the NASARC4 program can be found in section 3.5.

In NASARC2, after a critical grouping has been selected and an orbital arc of sufficient size has been determined, a check of adjacent grouping compatibility is performed. This check is made by first determining the worst-case required separation between members of the potential neighboring groupings to the east and west. The required separation data are obtained from the Satellite Separation Matrix file generated by the NASSEP program module (see section 3.1.2.3). This file contains required orbital separation values for each pair of systems in a given scenario. From these values, the largest required separation between any of the paired combinations of systems in adjacent groupings is retained as the required separation between the two groupings. The values of required separation are then compared to the available separation which is calculated on the basis of the PDA lengths of the two adjacent groupings. The available separation is calculated as the sum on the lengths of the PDA's of the critical grouping and the adjacent grouping minus the length of the transitional arc. Required and available separation values are determined relative to both east and west adjacent groupings. A critical groupings is then considered compatible if the available separations meet or exceed the respective required separations for both neighboring groupings. When such compatibility is found, the allotment procedure is completed and the critical grouping and its allotted arc (PDA) are retained along with the previously selected groupings. If sufficient arc remains in the current segment to accommodate additional PDA's, the NASARC2 process is repeated by selecting the next critical service area in the prioritized list and trying to allot an arc to a grouping containing the new critical service area.

If, however, the compatibility check is unsuccessful (i.e., required separation exceeds available separation), a measure of the relative incompatibility is maintained for later use and one of several procedures is then followed:

- (1) If the critical grouping is not at the end of its available group arc, the PDA is stepped 1° eastward (or westward) and the allotment process is repeated.
- (2) If the group arc of the critical grouping has been exhausted, the PDA location which resulted in the least incompatibility is retained and the next critical grouping of the same size is examined for allotment.
- (3) If all critical groupings of a given size (i.e., number of members) have been exhausted, the grouping and PDA location which resulted in the least incompatibility from among all the critical groupings within the current size is reexamined. If the level of incompatibility is less than a specified threshold (the program uses a threshold of 1°), the retained critical grouping is selected for allotment.
- (4) If the level of incompatibility exceeds the threshold, a critical grouping from the next smaller size (i.e., one less member) is examined for allotment.

(5) If the critical groups list is exhausted, a new critical service area is selected and the entire allotment process is repeated.

The allotment process stops when either all the available service areas have been accommodated successfully or the available arc within the current segment becomes insufficient to allow additional PDA's. At such time, NASARC2 updates the Intermediate Allotted Groupings file by including the groupings and PDA's selected for allotment within the current segment of orbital arc.

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 4.0) 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 could change the input parameters to the NASARC software and rerun the scenario, or the user could attempt to identify a grouping within the service arc of the unallotted service area that could provide marginal compatibility. The data available in the Satellite Separation Matrix file can be used to identify separation requirements between the unallotted service area and the members of perspective groupings into which it may be combined.

3.4 NASARC3: Group Arc Extension Program

NASARC3, the group arc extension program, is the fourth major program in the NASARC (Version 4.0) software package. The primary function of this module is to extend the group arcs of the groupings that were previously allotted in NASARC2, the arc determination program, to their fullest extent in both directions regardless of segment boundaries. This function is necessary to the NASARC methodology so as to maintain full flexibility when accessing the allotted arc module (see section 3.3.6) in NASARC2 on future segments, and to facilitate the operation of the NASARC4 module, the arc interchange program.

For NASARC3 to perform the previously stated function, it must obtain data from a variety of files—including all the technical input data 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 to be used subsequently in NASARC4 and in NASARC1 and NASARC2 in future segments of the piecewise approach.

The first operation NASARC3 performs when executing the group arc extension function is to determine which of the allotted groupings are candidates for arc extension. Since NASARC3 extends an allotted grouping's group arc to its fullest extent, once a grouping has been considered, it no longer needs to be considered on subsequent executions of the NASARC3 module. Therefore, once NASARC3 performs the group arc extension function on an allotted grouping, it sets a corresponding flag in the Intermediate Allotted Groupings file to Y to indicate that the grouping has been considered. Then, on future accesses of the NASARC3 module during execution of the piecewise approach, as the program systematically examines all the allotted groupings to check if their group arcs can be extended, it passes over those with their flags set to Y and only examines groupings whose flags are set to N (i.e., the grouping has not yet been considered for extension). Clearly, on the first segment executed, all allotted groupings in the Intermediate Allotted Groupings file will have their flag set to N, and on subsequent segments only newly allotted groupings will require group arc extension.

Once an allotted grouping has been found that is eligible for having its group arc extended, a compatibility 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 minicompatibility 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 can no longer exist in its entirety and the new group arc boundary becomes the last arc location at which complete compatibility existed.

In determining the amount of arc extension, both eastward and westward, for a given allotted grouping, NASARC3 must examine all pairwise compatibilities between group members. This is achieved by the construction of a minicompatibility matrix (similar to the concept described in section 3.2.2). The procedure for developing the compatibility matrix is outlined as follows:

- Step 1: Read in polygon points, ellipses, and service arcs for all service areas within the present grouping being considered for arc extension.
- Step 2: Calculate the feasible arc limit by deriving the interception of all the members' service arcs.
- Step 3: Begin extending the group arc in the eastward direction. Place the current location 1° beyond the eastern group arc boundary.
- Step 4: Select the wanted service area from the current group. Place at current location.
- Step 5: Select the interfering service area from the current group.
- Step 6: Check for any of the following situations: the interfering service area is the same as the wanted; they are both members of the same affiliated set; they are both existing systems; or they are a downlink only/uplink only combination. If any of these situations occur, set the compatibility flag for this pair of service areas in the minicompatibility matrix to 1 and select a new interferer. If not, continue.
- Step 7: Calculate the C/I values by locating the interferer a distance equal to the grouping criterion from the wanted in both the eastward and westward direction.

- Step 8: Compare the calculated C/I values to the target C/I . If the calculated C/I values exceed the target C/I , set the compatibility flag for this pair of service areas in the minicompatibility matrix to 1 and continue. If they do not, set the compatibility flag to 0 and discontinue examining the group in the present direction as complete compatibility does not exist. If the extension is eastward, go to step 13. If the extension is westward, go to step 14.
- Step 9: Repeat steps 5 to 8 for the remaining interfering service areas. (Examine one column in minicompatibility matrix.)
- Step 10: Repeat steps 4 to 9 for the remaining wanted service areas. (Examine remaining entries in minicompatibility matrix.)
- Step 11: Extend group arc to current location. Complete compatibility within the group exists. (Minicompatibility matrix is the identity matrix.)
- Step 12: Increment (or decrement depending on extension direction) the current location. If the current location is within the feasible arc limits, repeat steps 4 to 12 (examine compatibility of group at new location).
- Step 13: Repeat steps 3 to 12 with arc extension taking place in the westward direction.
- Step 14: Retrieve the next grouping to examine and execute steps 1 to 14.

After all the allotted groupings have been examined for arc extension, NASARC3 updates the Intermediate Allotted Groupings file with any extended group arcs it has found, and it sets all the compatibility flags to Y to indicate that they have been considered.

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

3.5 NASARC4: Arc Interchange Program

NASARC4 is the final module in the NASARC (Version 4.0) software package. The primary function of this module is to improve the arrangement of allotted arcs in orbit via a heuristic interchange procedure. Secondary functions of this module are performed when all user-specified segments of the orbital arc are exhausted: restoration of the user's original segments file for future runs of the NASARC software package, and generation of the NASARC Report, Condensed Report, and Predetermined Arc files.

In order to perform the arc interchange function, NASARC4 must first determine which allotted arc segments may be feasibly interchanged. This process is described in section 3.5.1. NASARC4 then attempts to find an improved starting arrangement of allotted arcs in orbit from the original arrangement of arcs found in the last run of NASARC2 and stored in the Intermediate Allotted Groupings file. This process is described in section 3.5.2. Using this improved starting arrangement, NASARC4 then generates new alternative arrangements using a heuristic swapping procedure that interchanges the orbital locations of allotted arc segments. This process is presented in section 3.5.3. NASARC4 will then repeatedly select one of the newest generations of alternatives as a starting point for further improvement by performing paired comparisons among alternative arrangements as they are generated. This procedure is described in section 3.5.4. Finally, if further separation is needed between allotted arc end points, the allotted arcs are modified further. This process is described in section 3.5.5.

When no further improvement of the existing arrangement of allotted arcs is found, and all user-supplied segments of orbit specified within the Segments file are exhausted, NASARC4 will restore the user's initial Segments file and will produce the NASARC Report, Condensed Report, and Predetermined Arc files, which contain the final results of executing the NASARC software on a given scenario. These functions are described in section 3.5.6.

NASARC3 -- The Group Arc Extension Program

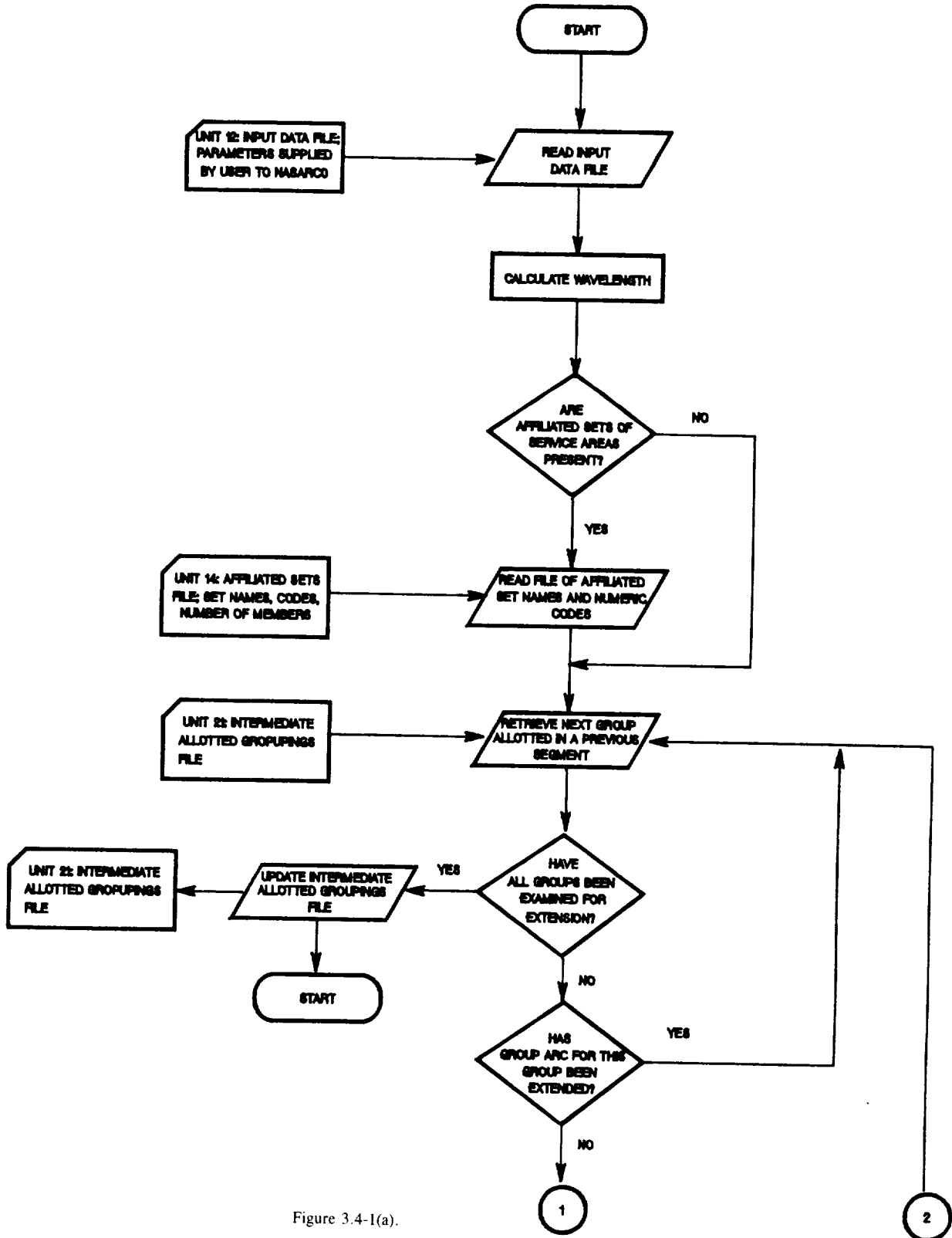


Figure 3.4-1(a).

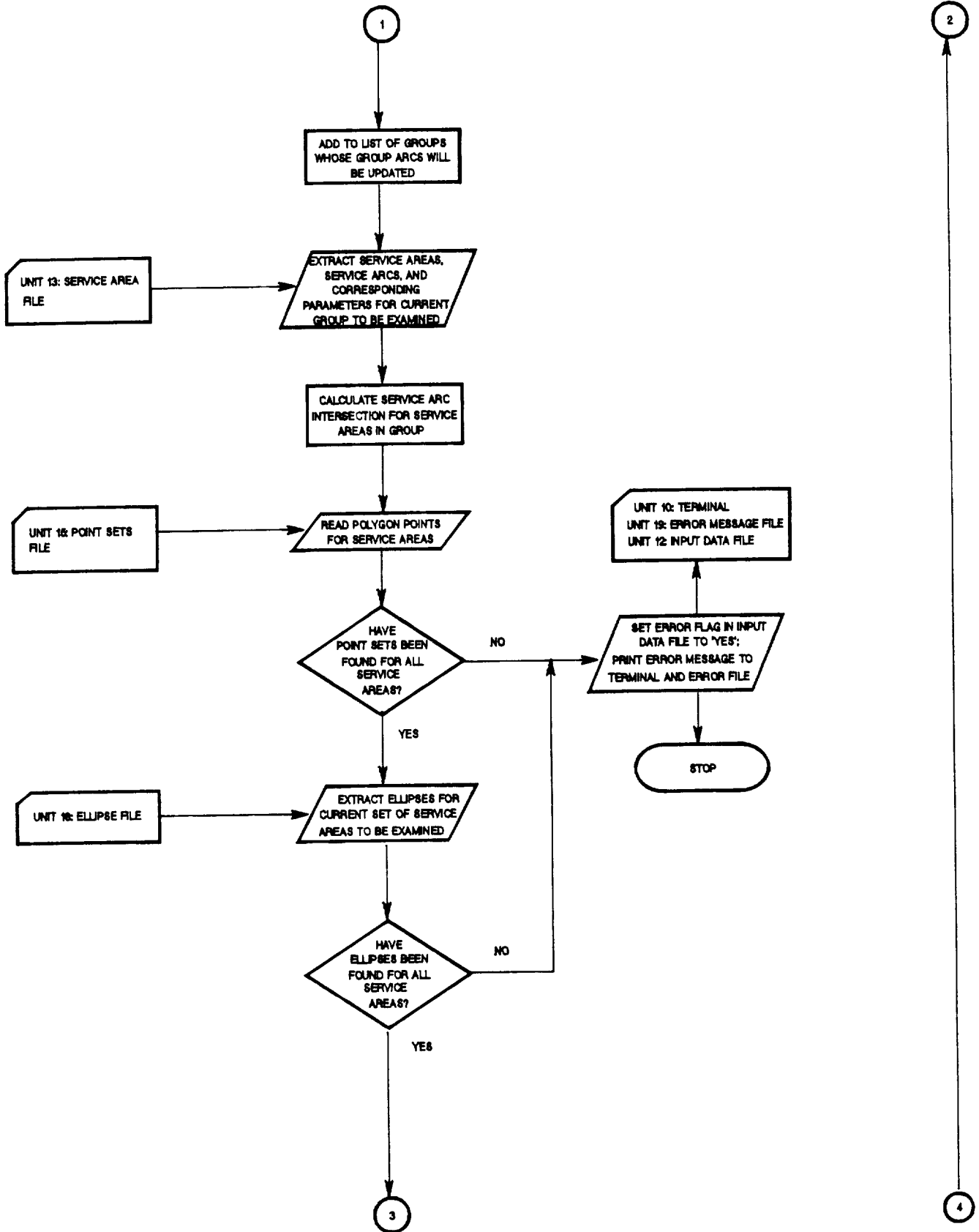


Figure 3.4-1(b).

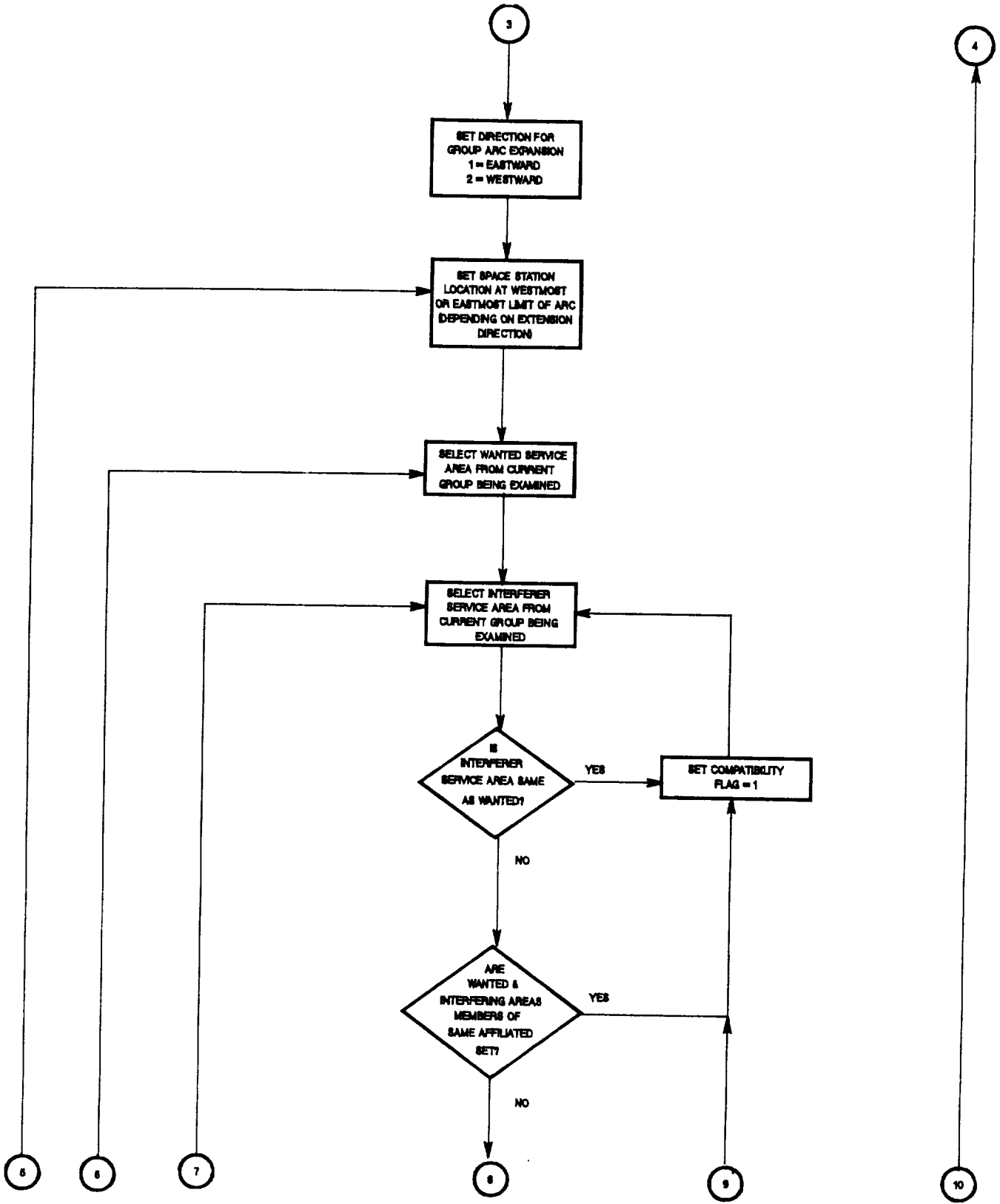


Figure 3.4-1(c).

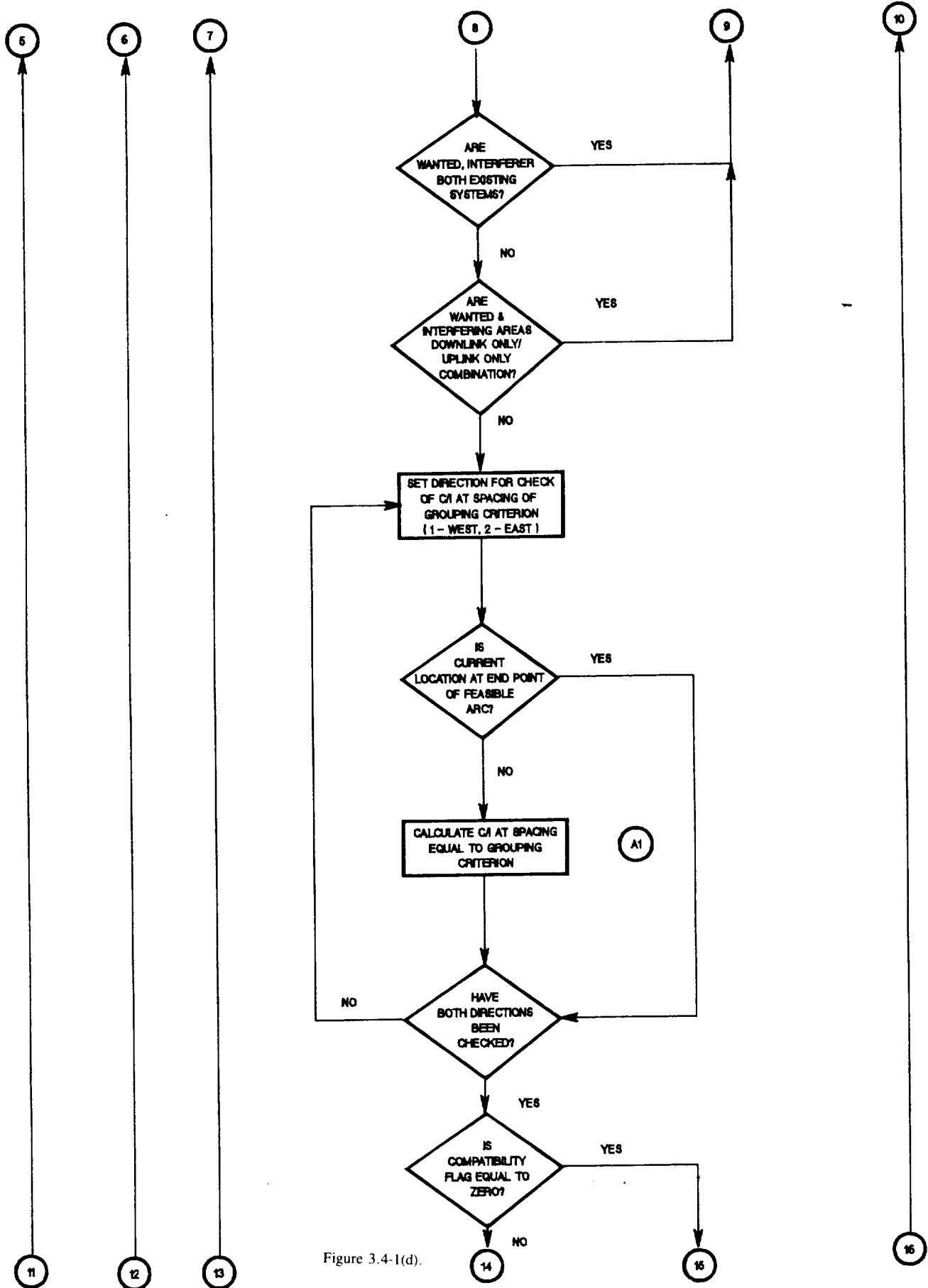


Figure 3.4-1(d).

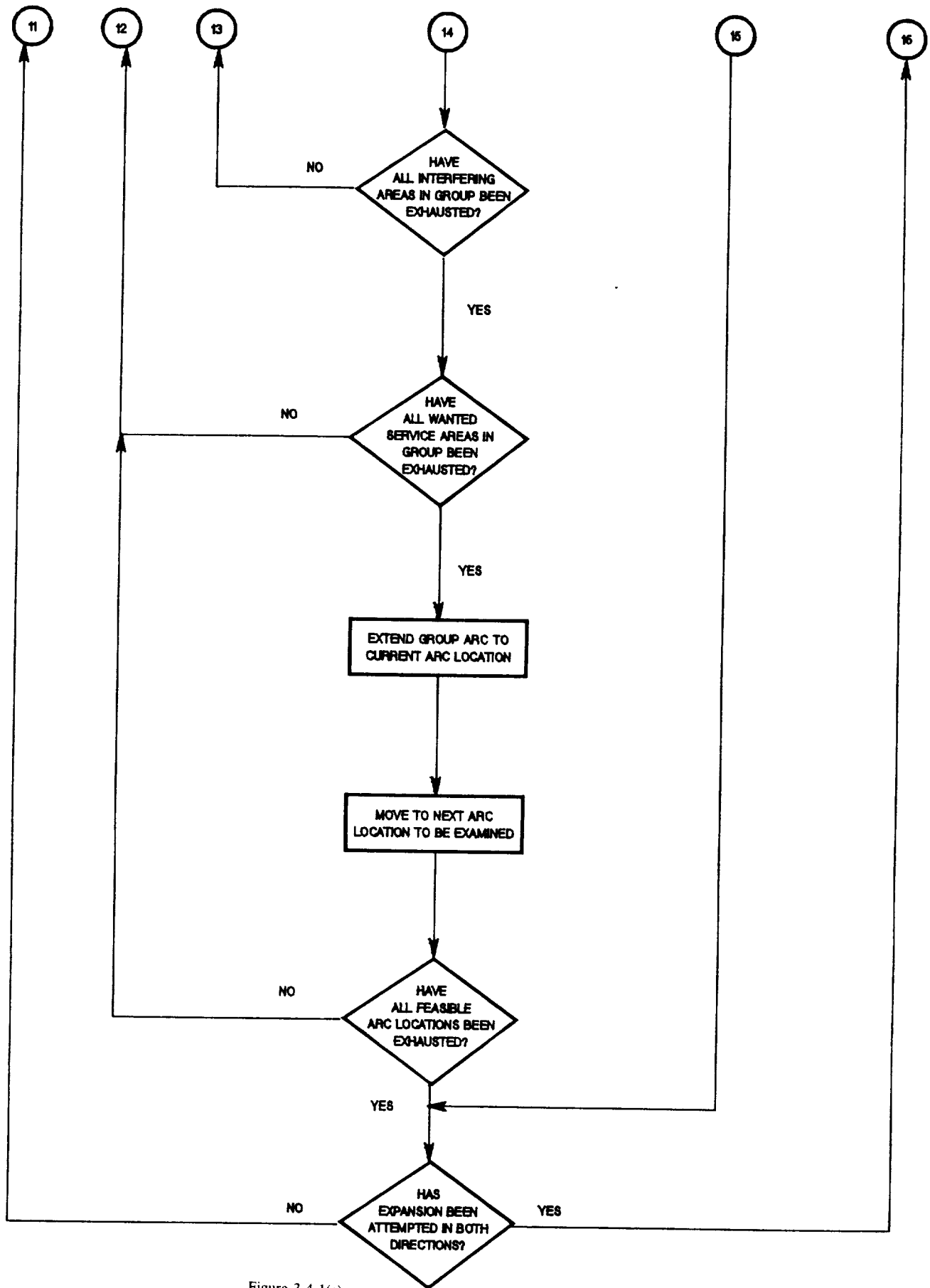


Figure 3.4-1(e).

3.5.1 Generation of Feasible Interchange Matrix

In order for NASARC4 to attempt to improve an existing arrangement of allotted arcs in orbit through interchange of their locations, the program must first be able to determine what arc interchanges are feasible to perform.

Within the Intermediate Allotted Groupings file, allotted arcs appear in a west-to-east ordering. NASARC4 reads and numbers the allotted arcs in the order in which they appear; these indices will be associated with the allotted arcs throughout remaining NASARC4 operations. The allotted arc associated with index 1, for example, will be the westmost allotted arc segment appearing within the Intermediate Allotted Groupings file. If that location is later changed, this will be reflected in the fact that the arc locations associated with the 1 will change; the index itself will not, even if another allotted arc occupies the westmost position after an interchange is performed.

The indexing convention described previously is utilized in the construction of a matrix of feasible arc interchanges. Prior to discussing the structure of the matrix itself, it is necessary to describe which conditions must be met in order for an interchange to be considered feasible. These conditions are illustrated in figure 3.5-1. First, the group arcs associated with each allotted arc must overlap by at least the sum of the required arc length for each allotment. This condition ensures that only meaningful interchanges are considered; if the condition were not met, then the satellites associated with each allotted arc might not be visible from their intended service areas if the allotted arcs were interchanged. Second, the intersection of the group arcs associated with the allotted arcs must encompass both allotted arc locations. This condition ensures that the allotted arcs can in fact be directly interchanged in location, subject to adjustments that may be necessary if the allotted arcs are of slightly different lengths. A pair of allotted arcs that meets these conditions is a feasible interchange.

The feasible interchange matrix will be square but not symmetric. Each column index represents an allotted arc segment, indexed with respect to its original order within the Intermediate Allotted Groupings file. Each column of the matrix contains, in essence, a list of feasible interchanges for that arc segment; the appropriate index for the interchange candidate is placed in the appropriate row. Thus, if element (1,3) contained a 3, this would indicate that allotted arc segment 3 is a feasible interchange candidate for allotted arc segment 1. The structure of the feasible interchange matrix is illustrated in figure 3.5-2.

3.5.2 Generation of an Improved Starting Arrangement

In the process of constructing the matrix of feasible interchanges, it is possible that NASARC4 will find that certain pairs of allotted arcs may only be feasibly interchanged with each other. Such interchanges will be referred to as pair-restricted.

If a given interchange of allotted arc locations is retained, other alternatives that might have resulted had the interchange not taken place may not be examined. For example, if arcs 3 and 5 are both interchangeable with arc 1, and the interchange of 1 and 3 is retained, it is possible that other arrangements reachable from 1 and 5 interchange will not be examined. However, pair-restricted interchanges cannot affect the outcome of generating further alternative arrangements. If such an interchange results in an improved arrangement of the allotted arcs in orbit, a new and better arrangement may be obtained without eliminating any future alternatives. Thus, NASARC4 automatically performs all pair-restricted interchanges; those that produce improvement are automatically retained, and all future alternatives can be generated from a better-quality starting solution. If such pair-restricted interchanges do not exist in the matrix of feasible interchanges, or exist but do not improve the initial arrangement read from the Intermediate Allotted Groupings file, then the starting point will continue to be the initial arrangement read from the file.

3.5.3 Generation of Alternative Arrangements

NASARC4 generates a new alternative arrangement by performing an improving interchange of two allotted arcs in a current basic arrangement. The basic arrangement will be held constant while various interchanges are tried and evaluated. When an interchange is to be retained, the new basic alternative arrangement will be the old basic alternative modified by the selected interchange.

Feasible Interchange Conditions

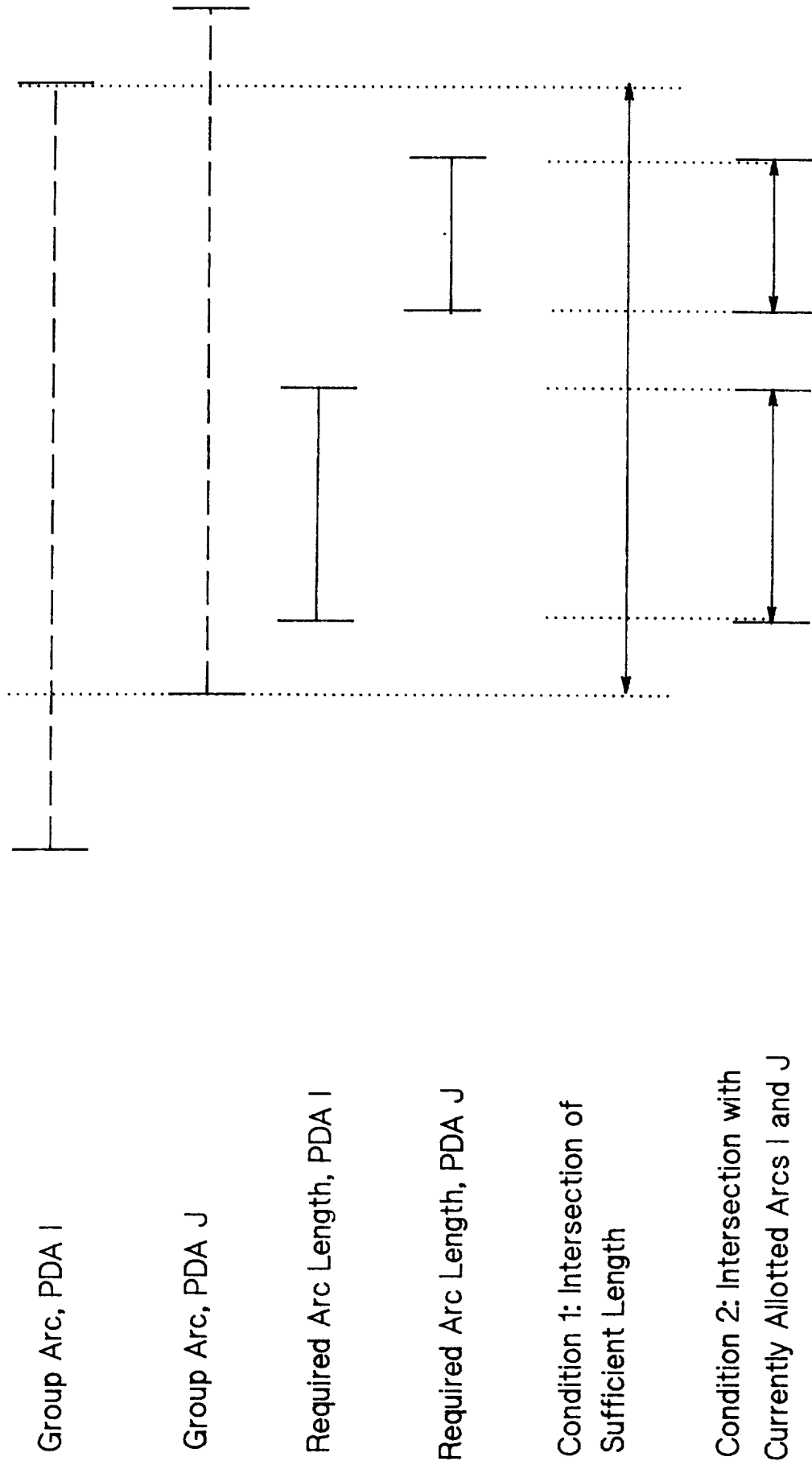


Figure 3.5-1.

Sample Feasible Interchange Matrix

	1	2	3	4	5
1	1			1	1
2		2	2		
3		3	3		
4	4			4	4
5	5			5	5

Figure 3.5-2.

Trial interchanges will not become candidates for selection unless they represent an improvement to the current basic arrangement. To assess whether or not this is the case, a new temporary arrangement must be generated and evaluated with respect to the basic arrangement. This is done via a heuristic swapping procedure carried out by a subroutine of NASARC4. Prior to discussing the swapping procedure, however, it is appropriate to define what constitutes an improved arrangement and what criteria are utilized to determine if an arrangement is in fact an improvement.

3.5.3.1 Definition of Objective Functions

The quality of a particular arrangement of allotted arcs in orbit is evaluated through the use of objective functions. An objective function is associated with each allotted arc segment and is defined as follows:

$$\text{minimize } T_K = E_K + W_K \quad k = 1, \dots, n$$

where

n total number of allotted arc segments

E_K normalized orbital separation required between systems in allotted arc K and allotted arc $K+1$

W_K normalized orbital separation required between systems in allotted arc K and allotted arc $K-1$

The normalized separation between systems in a given allotted arc and those in the allotted arc immediately to the east or west (E_K or W_K) is calculated as follows:

$$E_K \text{ (or } W_K) = \frac{\sum_i \sum_j s_{ij}}{ij}$$

where

i number of systems in allotted arc K

j number of systems in allotted arc $K+1$ (or $K-1$), respectively

s_{ij} orbital separation required between system i and j

It can be seen from this discussion that E_K represents the cost of placing allotted arc K adjacent to its immediate neighboring allotted arc, and W_K represents a similar quantity associated with placement of allotted arc K adjacent to its western neighbor.

The goal of the NASARC4 program is to improve compatibility **across** allotted arc boundaries; thus, an interchange involving allotted arc K , or one of its neighbors, can lower the objective function value associated with several allotted arcs and thus improve the overall arrangement.

3.5.3.2 Improvement Criterion

As may be inferred from the discussion presented in the previous section, improving an arrangement generated through the heuristic swapping procedure is measured via changes in objective function values. However, the definition of an improved arrangement is not solely restricted to those arrangements for which all affected objective function values are strictly decreased.

The user will recall that the goal of rearranging allotted arc segments is to improve the quality of the **overall** arrangement. Thus, a slight increase in an affected objective function value may be more than offset by a more dramatic decrease in another objective function value, which is desirable. It would be inappropriate to discard this type of arrangement because of a slight degradation in one or more objective values.

The swapping subroutine is called several times for a single allotted arc segment in order to exhaust all of the candidate interchanges for that segment. Since we wish to improve the objective function value for this allotted arc segment, the change in this objective function will be computed first. Changes in all other affected objective function values will be computed and compared against the first value. The first value must represent a decrease in objective function value. If any other objective function value is degraded (increased), that degradation must be offset by the improvement gained in the first value.

Arrangements that represent improvement of the basic arrangement are passed back to the main program for a paired comparison with other improved arrangements.

3.5.3.3 Interchange Procedure

As stated previously, the interchange procedure is carried out within a subroutine of NASARC4. Two allotted arcs that are candidates for an interchange are supplied as arguments to the subroutine; potentially, their interchange may affect up to six objective function values, as described in section 3.5.3.2.

First, the new objective value associated with the place in the ordering formerly occupied by the first allotted arc segment is calculated. If the value is improved, the amount of improvement is calculated and the process continues. If the objective is degraded, the interchange is rejected. If the two candidates for interchange are separated by at least two allotments between their locations, there remain five new objective values to calculate. This concept is illustrated in figure 3.5-3. If the two interchange candidates are labeled i and j , we must also calculate new objective values for arc segments $i-1$, $i+1$, $j-1$, and $j+1$. The i th objective has already been calculated, as described previously. As discussed in section 3.5.3.2, a degradation in any objective that is greater than the improvement gained in the i th objective is rejected as unacceptable. Assuming that this has not occurred, the interchange represents an improvement in the basic arrangement passed to the subroutine.

Before the improved arrangement can be fully accepted, however, it must be verified that the arc locations of the two interchange candidates can indeed be changed. If the candidate allotted arcs are the same length, a direct swap may be performed. If, however, the two arcs are of different lengths, other arcs in the arrangement may need to be pushed slightly to the west or east to accommodate a larger allotted arc in a space formerly occupied by a smaller allotted arc. Owing to group arc limitations, some allotted arcs may not be able to be moved, in which case the interchange may not be able to be performed. If this is the case, the interchange is rejected. If sufficient movement can occur, the appropriate allotted arc endpoints are adjusted and the modified arrangement is passed back to the main program for comparison against arrangements generated from other interchanges.

3.5.4 Selection of Preferred Arrangement Through Paired Comparison

As stated previously, it is possible to generate many alternative arrangements from a current, basic arrangement of allotted arcs by performing a variety of feasible interchanges. Clearly, it is desirable to select the best of these to become the new basic arrangement from which future alternatives will be generated. This is accomplished through successively comparing the most recently generated alternative with the current best alternative—a paired comparison. One of the two alternatives will be selected as preferable, and will become the new current best alternative.

Since the goal is to improve the overall arrangement for as many allotted arcs as possible, the magnitudes of the objective function values are not as important as their comparative status—i.e., whether a given objective value in one arrangement is lower or higher than its counterpart in the arrangement it is compared to.

An arrangement is preferred if it has a **greater** number of **lower** objective values than the arrangement it is compared to. In comparing two alternatives, then, the number of objective values in alternative 1 which are lower than their counterparts in alternative 2 is calculated. A similar figure is calculated for alternative 2. The higher of the two numbers corresponds to the preferred alternative. Should a tie result, the preferred alternative is determined on the basis of the lowest average objective value. In the unlikely event that the two arrangements are tied with respect to this figure of merit, the existing best alternative is retained.

Objective Values Affected By PDA Interchange

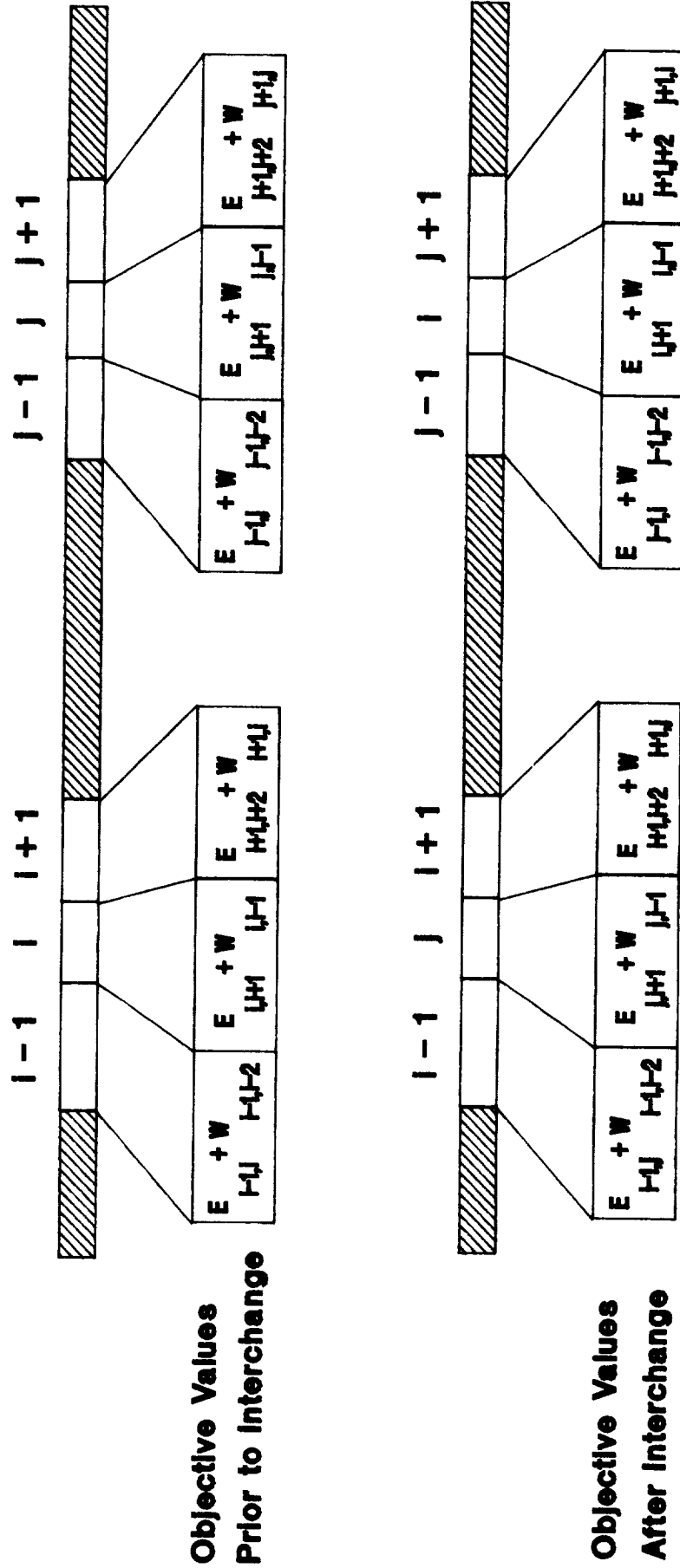


Figure 3.5-3.

3.5.5 Further Modification of Allotted Arcs

While the procedures described in the previous sections are directed toward generating and selecting the best arrangement of allotted arcs in orbit, the resulting arrangement may still require improvement in one respect. The user will recall that the processes in the NASARC4 module are needed to improve compatibility between systems across allotted arc boundaries. Compatibility between systems is assessed on the basis of the orbital separation required between systems; it is possible that the type of allotted arc interchange described in section 3.5.3.3 may not result in full achievement of the separation required between systems in different allotted arcs, even if the arcs are no longer adjacent. Thus, further adjustment of the best arrangement found may be necessary.

Determining the separation required between allotted arc endpoints is described in section 3.5.5.1; the adjustment process to attempt to achieve the required separation values is described in section 3.5.5.2.

3.5.5.1 Required Separation Between Allotted Arcs

While the objectives described in section 3.5.3.1 provide a measure of each allotted arc's compatibility with its immediate neighbors, they do not account for situations where two arcs are not adjacent but may still have insufficient orbital separation. To assess the separation required between a pair of allotted arcs, the worst-case orbital separation between any two systems in the pair of arcs is found as follows:

$$W_{ij} = \max_{i,j} [s_{ij}]$$

where

i index of system in arc I

j index of system in arc J

s_{ij} orbital separation required between systems i and j

Since we wish to evaluate the orbital separation that is desired between the closest endpoints of the pair of allotted arcs, we must first determine the separation that may be achieved between the two most incompatible systems if the arcs are immediately adjacent. The available separation is calculated as follows:

$$A_{ij} = R_i + R_j - t$$

where

A_{ij} available separation between worst-case pair of systems in PDA's i and j

R_i arc length of PDA i

R_j arc length of PDA j

t transitional arc length

The available separation calculated by this procedure corresponds to the separation that would exist between the two most incompatible systems if they were placed as closely as possible to opposite ends of adjacent allotted arcs. If the available separation is greater than or equal to the worst-case separation required, then no additional separation is required between the closest endpoints of the arcs. If, however, the available separation is not sufficient, the difference between the worst-case separation required and the available separation represents the additional separation that will be sought between the endpoints of the allotted arcs. This concept is illustrated in figure 3.5-4.

PDA Interchange Accompanied By
 "Push" Of Adjacent PDA's To West Or East

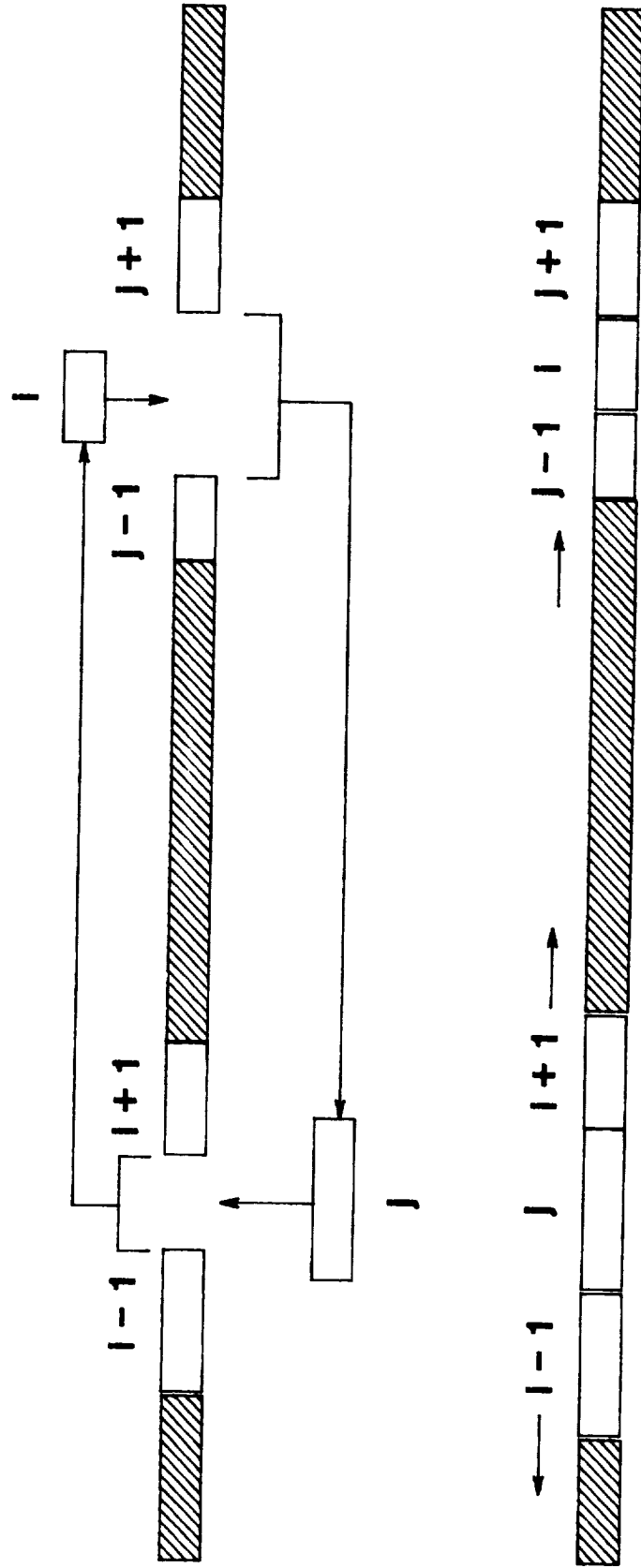


Figure 3.5-4.

3.5.5.2 Obtaining Additional Separation Between Allotted Arcs

The final phase of the arc interchange process attempts to spread the arc segments further apart if needed. In section 3.5.5.1, additional separation requirements for allotted arcs were discussed; these consist of orbital spacings necessary between the nearest endpoints of segments. In the majority of cases, no orbital separation is required between allotted arcs; in other cases, the required distance between PDA's will be acquired through the swapping process. Further required separation between both adjacent and nonadjacent PDA segments is provided by *pushing* allotted arcs in an east-to-west direction. This process is nearly identical to the pushing operation of NASARC2, and it will not be discussed in further detail here. The operations differ in that while NASARC2 attempts to create an unoccupied orbital segment of a single specified length NASARC4 first attempts to obtain the full separation still needed between allotted arcs; if this separation cannot be obtained, successive reductions of the required separation take place until the maximum obtainable separation is achieved.

This phase concludes the improvement process of NASARC4. When this process is completed, locations for the allotted arcs are output to the Intermediate Allotted Groupings file originally produced by NASARC2.

3.5.6 Other NASARC4 Functions

As previously mentioned, NASARC4 performs additional functions if there are no further orbital segments to be examined. After NASARC4 determines that the present segment is the final segment contained in the Segments file, it will execute the improvement process described in previous sections in an attempt to improve the final arrangement of allotted arcs found by NASARC2. When the improvement process is concluded, the improved arrangement will be written to the Intermediate Allotted Groupings file, as described in section 3.5.5.2.

When no new orbital segments remain to be examined, NASARC4 will restore the user's original Segments file. At this point, the Intermediate Segments file contains all of the past and present orbital arc segments examined by the NASARC modules in the order of their execution; NASARC4 copies these data to the original Segments file, which may then be reused for future runs.

NASARC4 also produces the NASARC Report file, Condensed Report file, and Predetermined Arc file. These files present, in various formats, the final results obtained by the NASARC run. The Report files also contain input data information.

For further details on the execution of the NASARC4 program, the reader is referred to the NASARC4 flowchart (figs. 3.5-5(a) to (g), 3.5-6(a) and (b), and 3.5-7(a) to (c)).

3.6 Technical Assumptions Inherent in NASARC Software

3.6.1 Introduction

In response to the decisions of WARC'85 regarding allotment planning for the Fixed Satellite Service and in preparation for use at the 1988 Space World Administrative Radio Conference, the NASARC software package was 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 was necessary to incorporate various technical assumptions into the design of NASARC. During the course of the development of NASARC, efforts were made to ensure that these assumptions were reasonable and that the software would be 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 4.0) 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.

NASARC4 -- The Arc Interchange Program

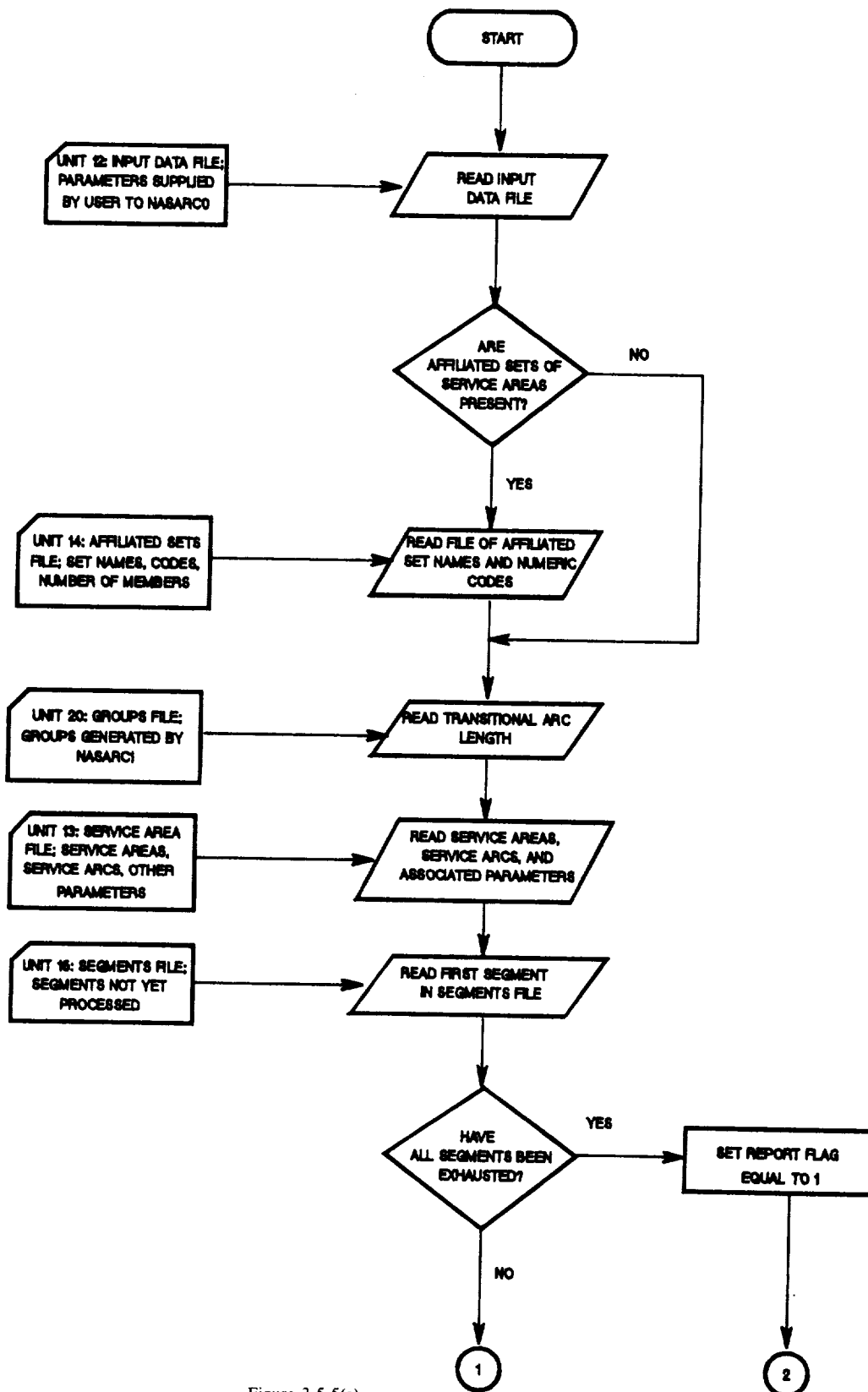


Figure 3.5-5(a).

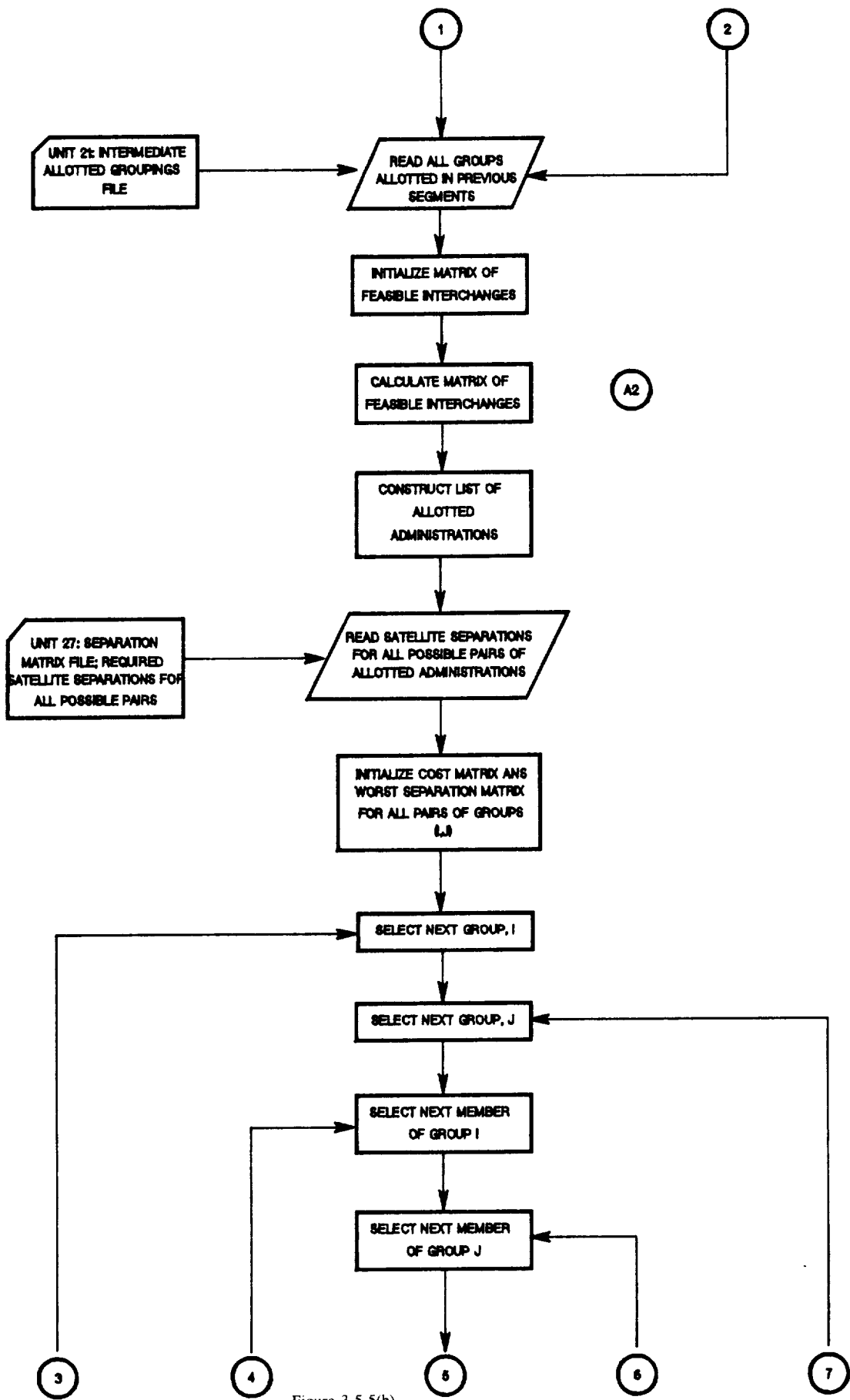


Figure 3.5-5(b).

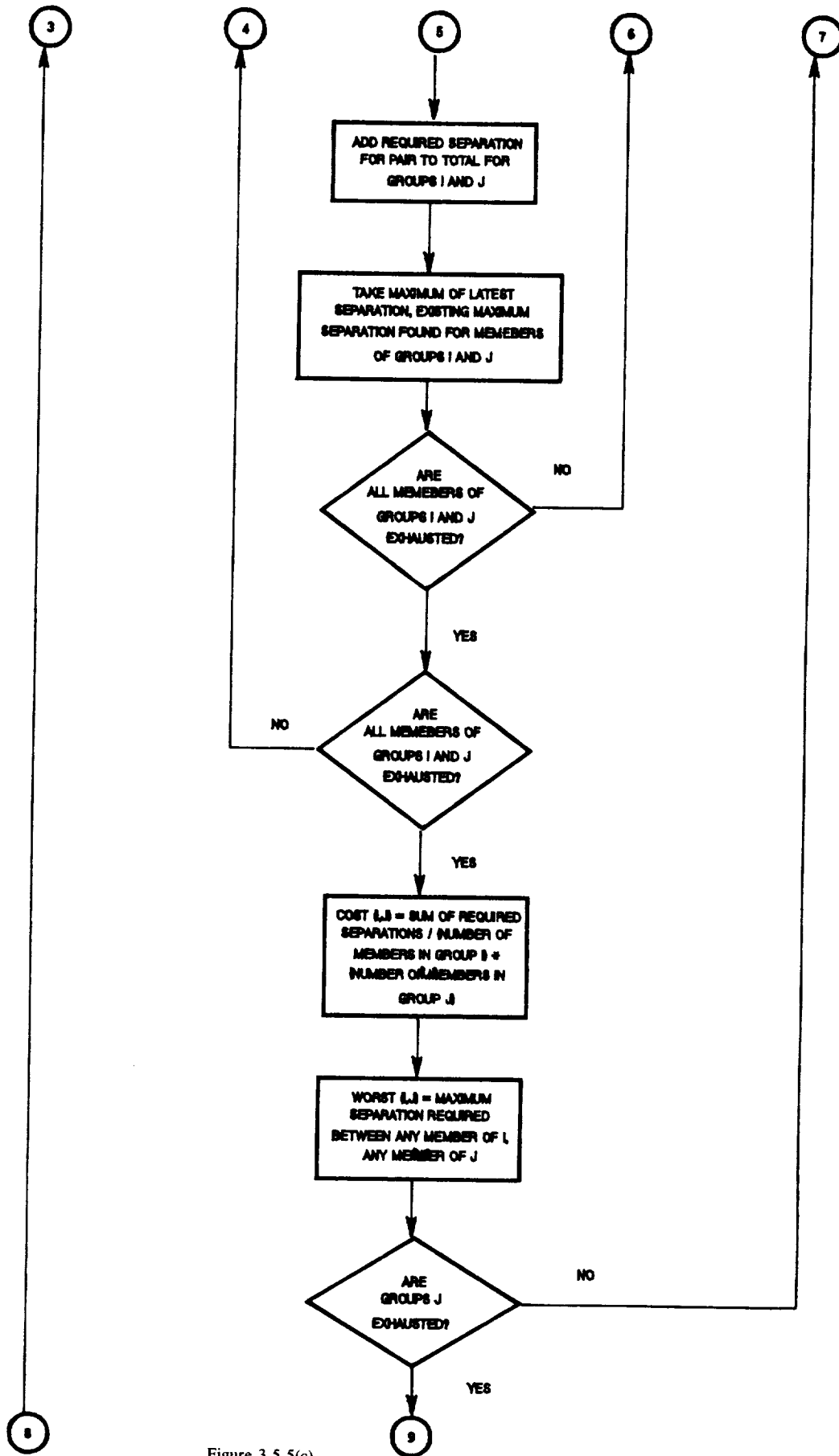


Figure 3.5-5(c).

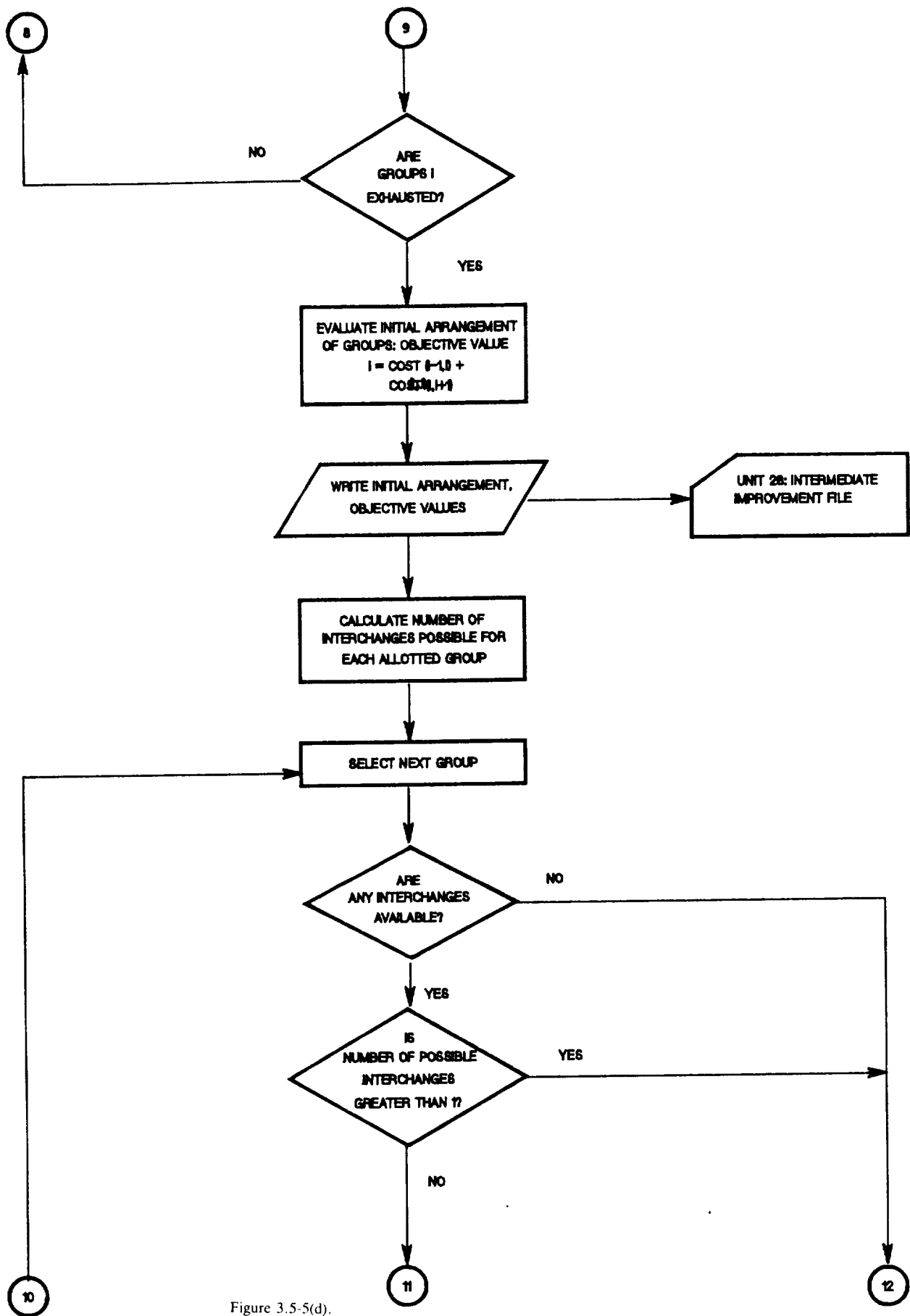


Figure 3.5-5(d).

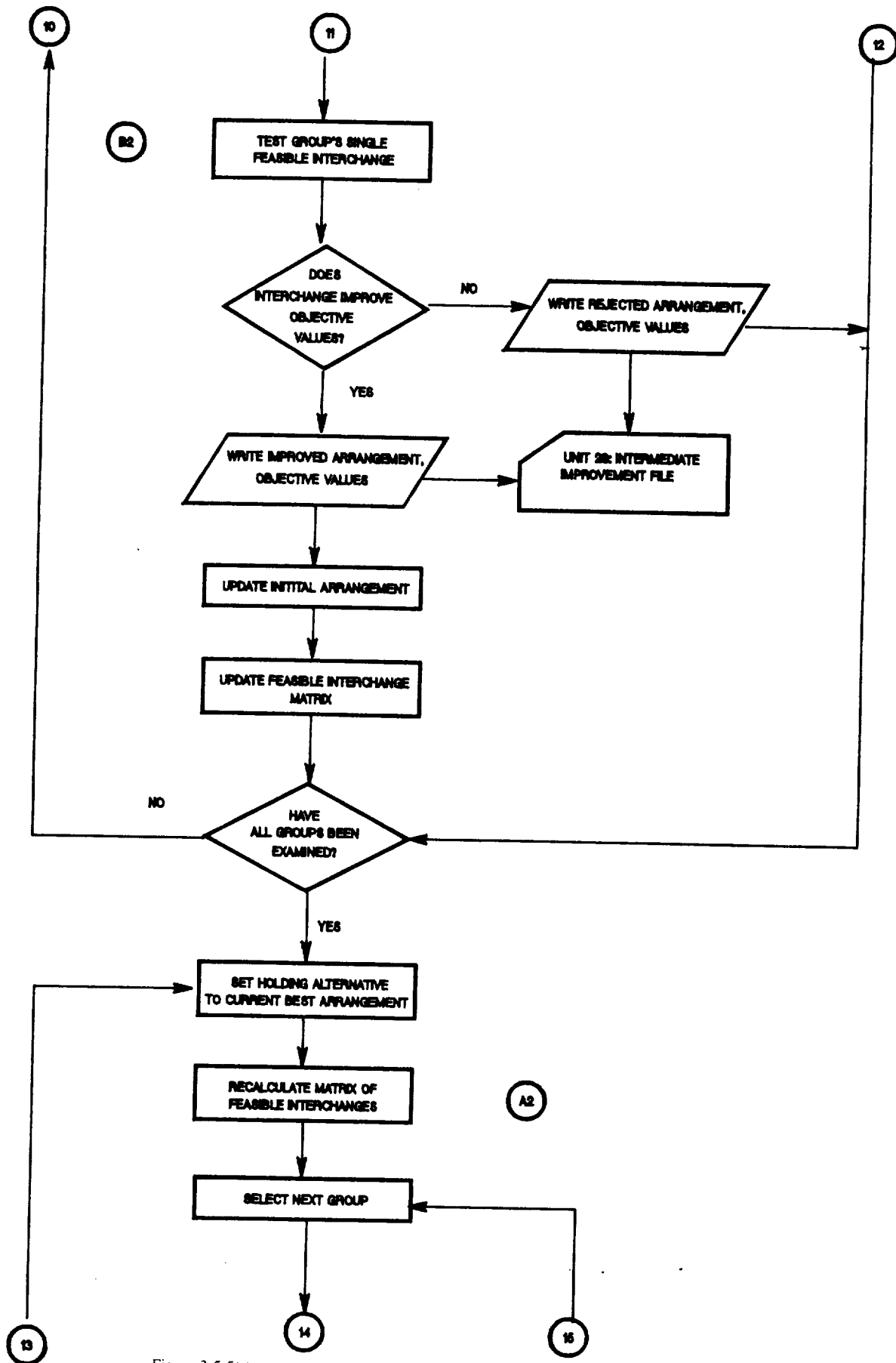


Figure 3.5-5(e).

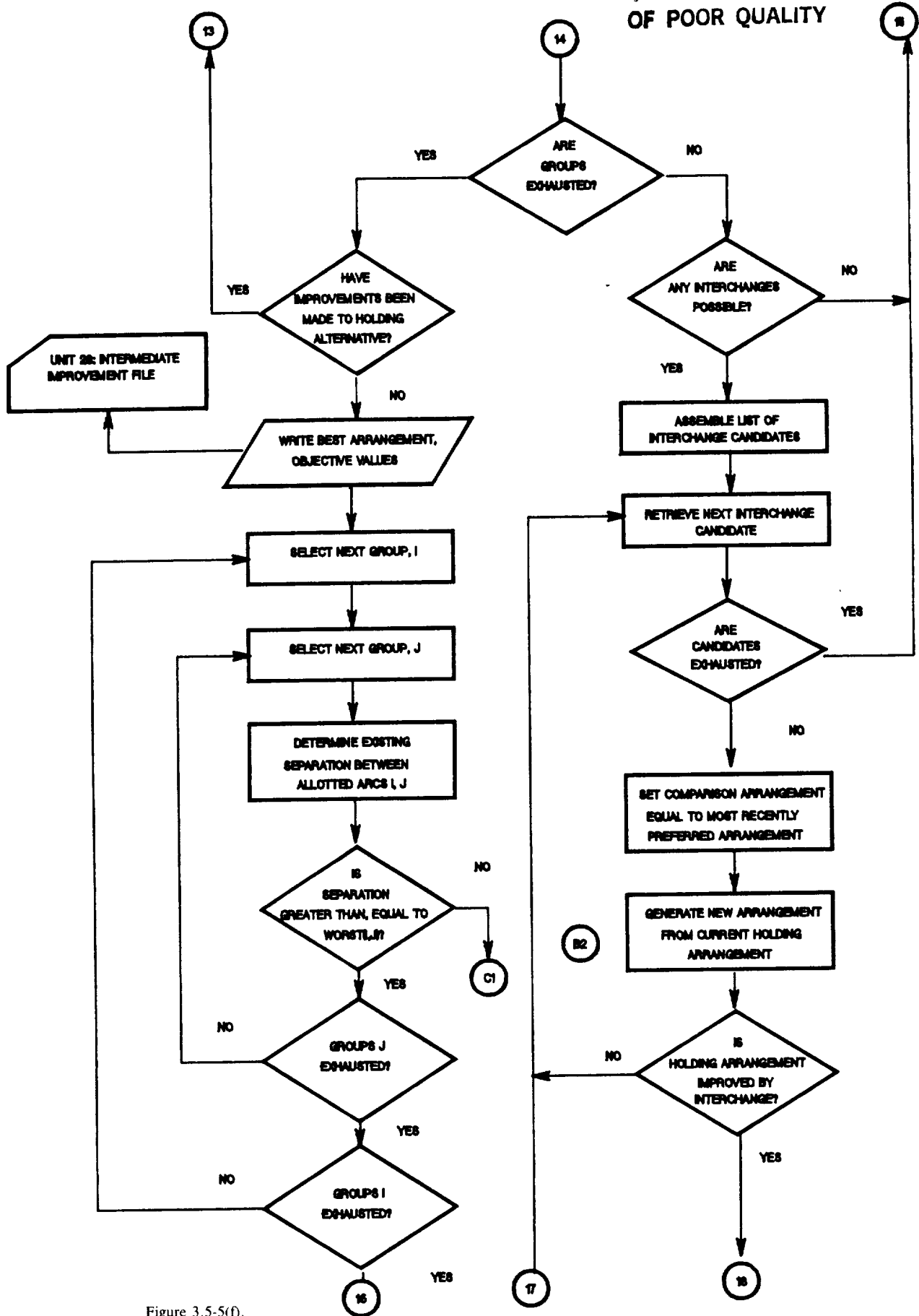


Figure 3.5-5(f).

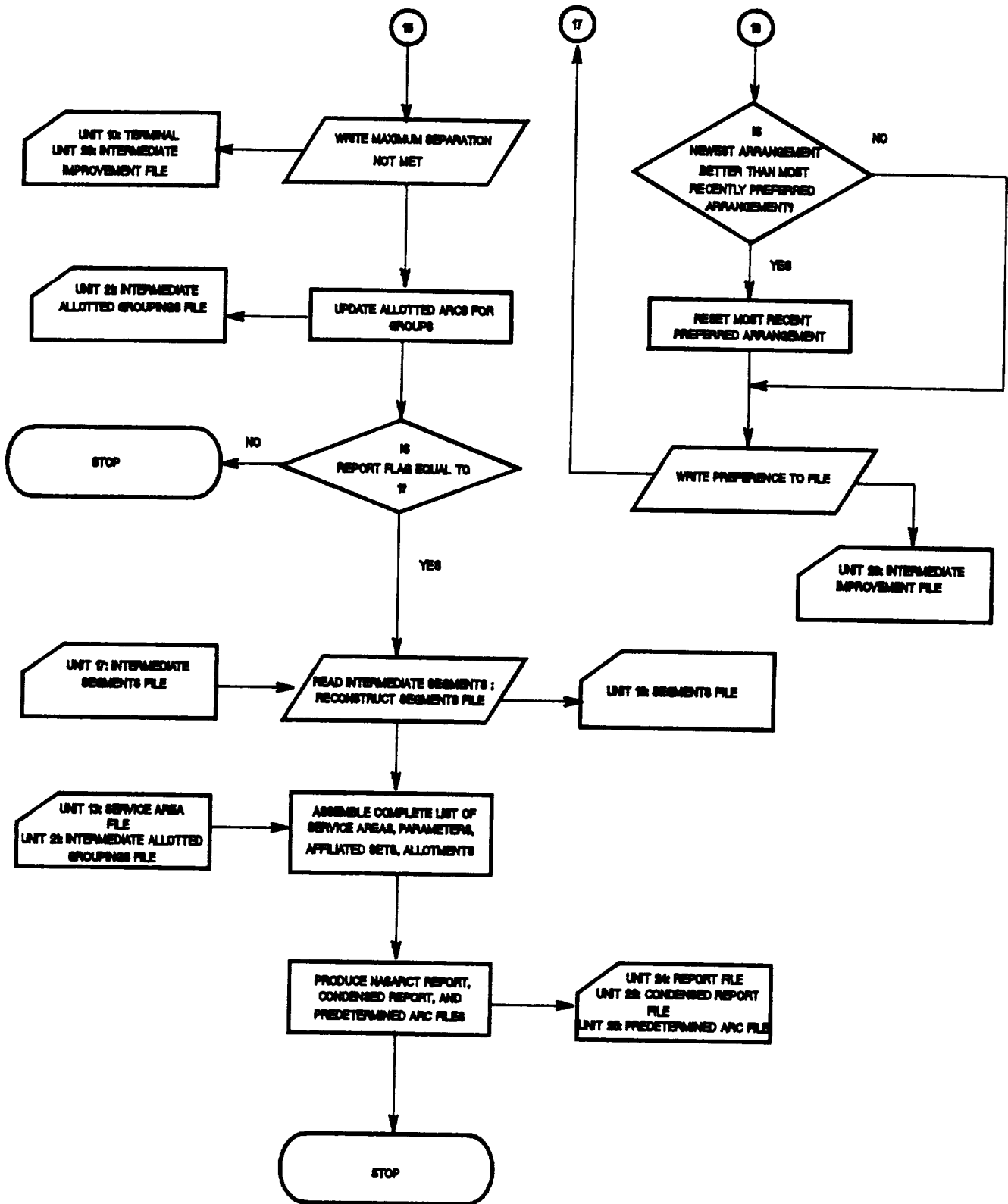


Figure 3.5-5(g).

Calculation of Matrix of Feasible Interchanges

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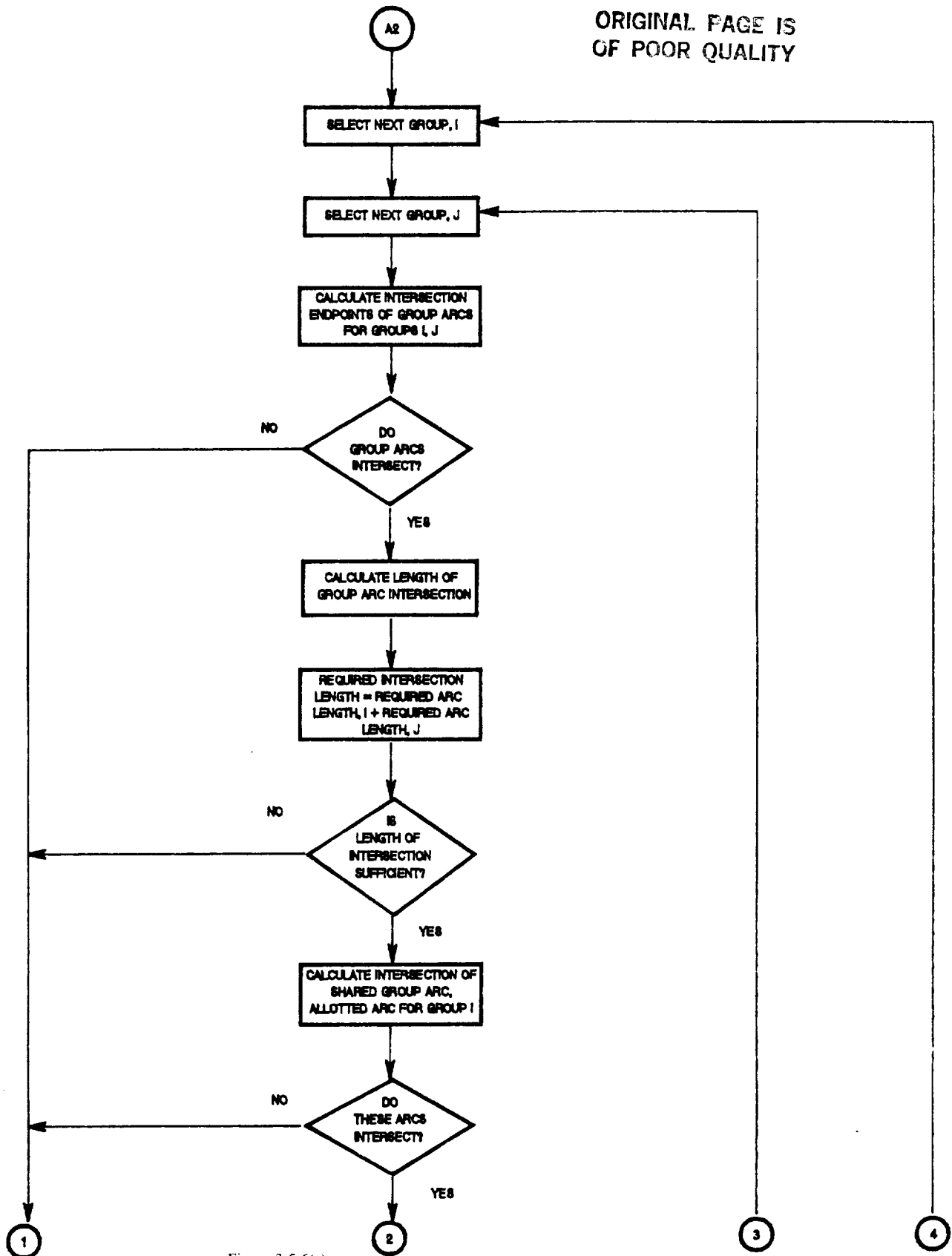


Figure 3.5-6(a).

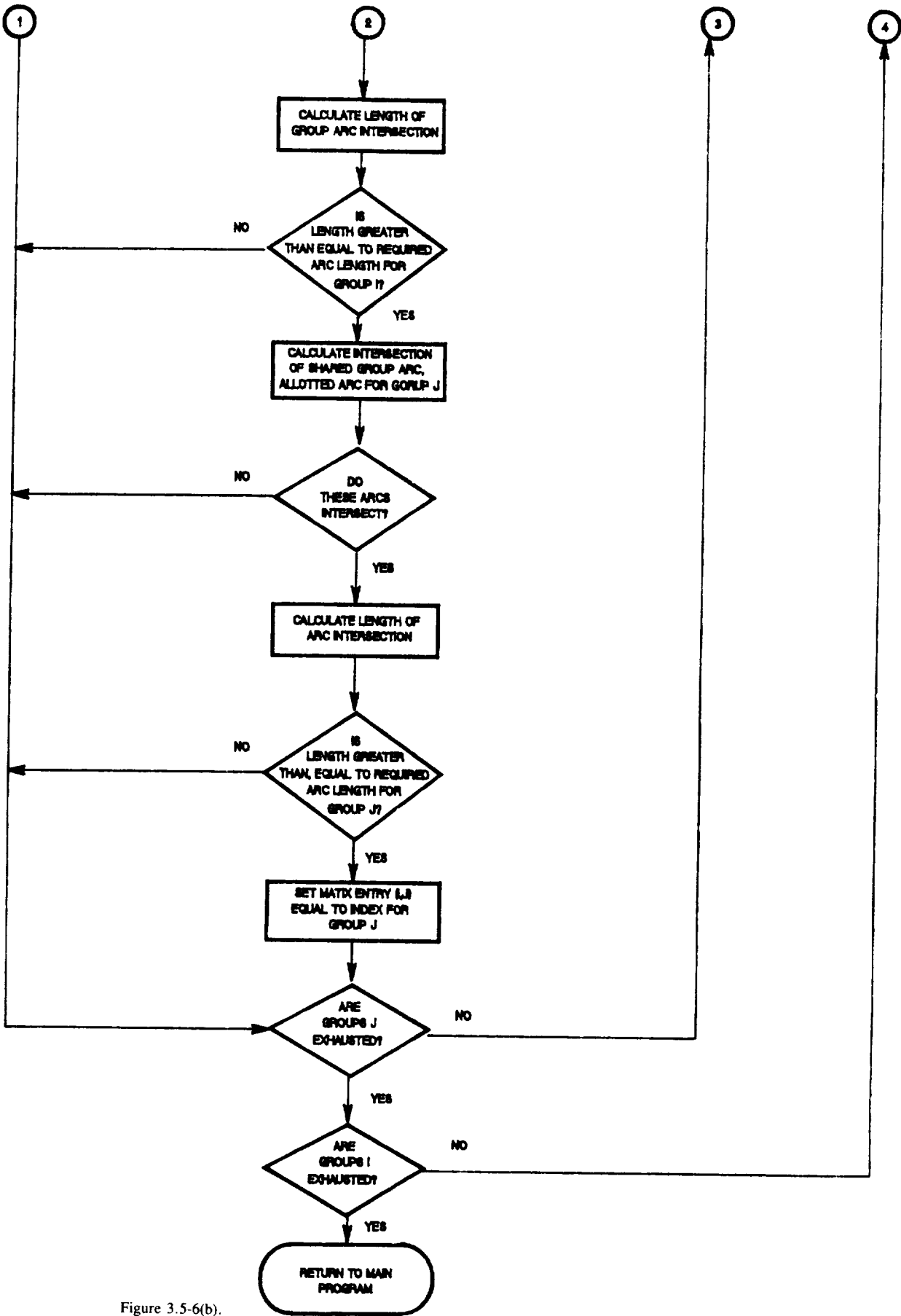


Figure 3.5-6(b).

Generation of New Arc Arrangement Through Allotted Arc Interchange

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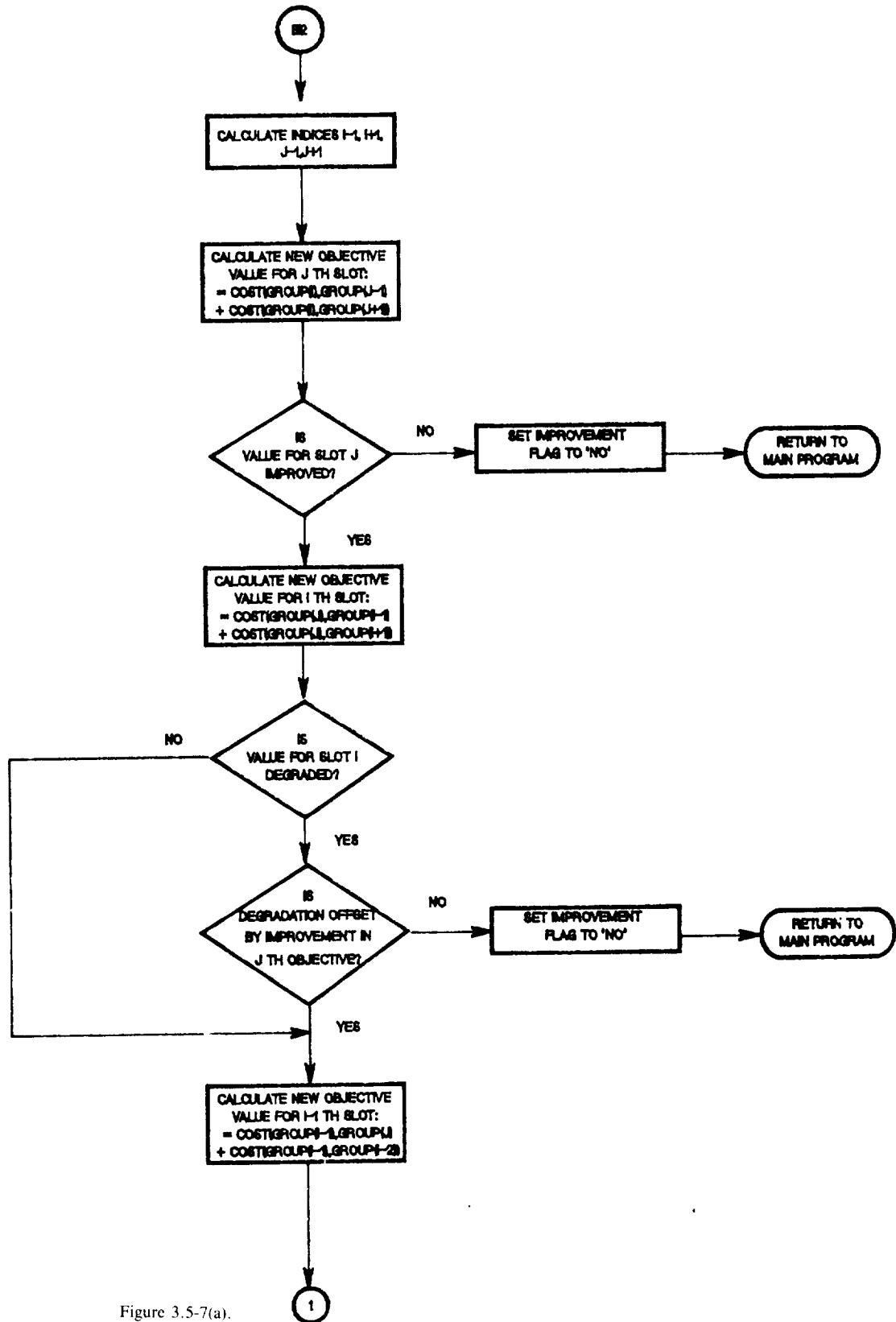


Figure 3.5-7(a).

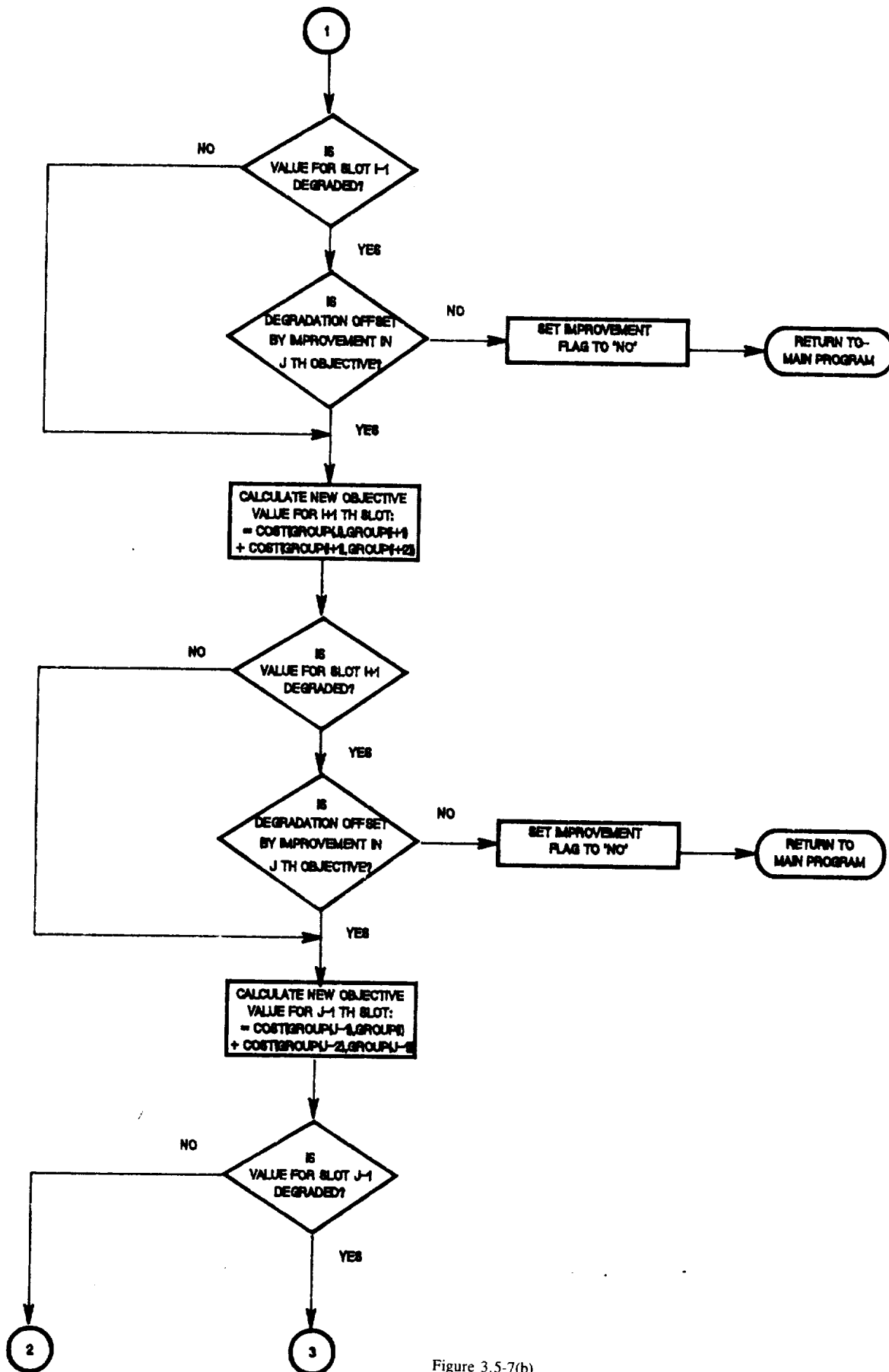


Figure 3.5-7(b).

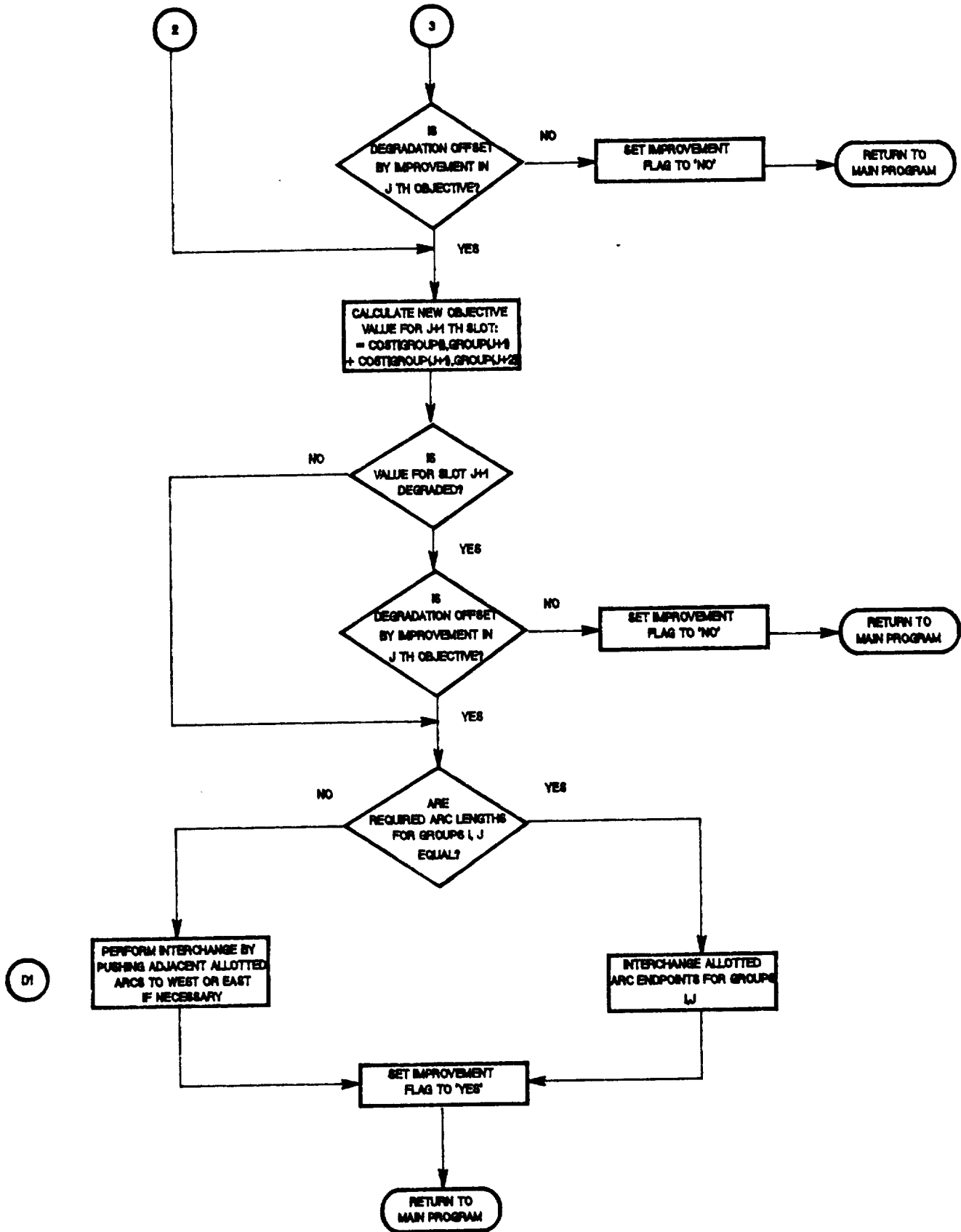


Figure 3.5-7(c).

3.6.2 Assumptions

3.6.2.1 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.

3.6.2.2 Total Link Interference

The compatibility between pairs of service areas is assessed on the basis of a target single-entry C/I to be met, on an overall link basis, at the worst-case test point of the desired service area. Thus, NASARC (Version 4.0) performs calculations on an overall link basis. Total link interference is an inherent assumption in the NASARC concept.

3.6.2.3 Clear-Sky Conditions

The determination of service area compatibility within NASARC (Version 4.0) is performed assuming clear-sky conditions. This assumption can be altered by simply setting a flag in the Service Area file related to the inclusion of rain attenuation in determining pairwise compatibility (see sections 2.2.2 and 3.2.2.1.1).

3.6.2.4 Required Carrier-to-Noise Ratio

The determination of service area compatibility is performed under the assumption of meeting or achieving a required C/N at the edge of the ellipse covering each service area. This assumption can be altered through the use of various power calculation options (see section 2.2.9.1).

3.6.2.5 Use of Minimum Area Ellipses

Coverage of a service area by a space station antenna has been modelled in NASARC (Version 4.0) 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 another input which can be changed by the user for a given scenario.

3.6.2.6 Individual Antenna Patterns

Within NASARC (Version 4.0), individual earth station transmit and receive antenna patterns and individual satellite antenna falloff characteristics can be specified by the user in the Service Area file. The variety of patterns available to the NASARC user for the description of earth station and satellite 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.

3.6.2.7 Uniform Aggregate *C/I* to Single-Entry *C/I* Ratio

The requirements set forth prior to the 1988 World Administrative Radio Conference by the IFRB for planning purposes specify an aggregate *C/I* ratio to be used in the formation of an allotment plan. However, NASARC determines compatibility on a pairwise basis and therefore also requires a single-entry *C/I*. At the May 1987 IFRB ORB Informational Meeting, an aggregate *C/I* ratio of 26 dB and a single-entry *C/I* of 32 dB were recommended. Thus, based on this information, an aggregate *C/I* to single-entry *C/I* ratio of 6 dB was incorporated into the NASARC (Version 4.0) software. This assumption can be altered, but requires recompilation of the software.

3.6.2.8 Single Uplink and Single Downlink Frequency

The determination of service area compatibility is performed based on a single uplink and 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 is utilized.

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16. Abstract The information contained in the <i>NASARC (Version 4.0) Technical Manual</i> (NASA TM-101453) and <i>NASARC (Version 4.0) User's Manual</i> (NASA TM-101454) relates to the state of Numerical Arc Segmentation Algorithm for a Radio Conference (NASARC) software development through November 1, 1988. The <i>Technical Manual</i> describes the NASARC concept and the algorithms 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 4.0 software over prior versions. These revisions have further enhanced the modeling capabilities of the NASARC procedure and provide improved arrangements of predetermined arcs within the geostationary orbit. Array dimensions within the software have been structured to fit within the currently available 12-megabyte memory capacity of the International Frequency Registration Board (IFRB) computer facility. A piecewise approach to predetermined arc generation in NASARC (Version 4.0) allows worldwide planning problem scenarios to be accommodated within computer run time and memory constraints with enhanced likelihood and ease of solution.					
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