THE SUM DATA BASE:

A NEW MEASURE OF SPECTRUM USE

Robert J. Mayher

Robin H. Haines

Steven E. Litts

Leslie A. Berry

Gerald F. Hurt

Carl A. Winkler

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FOREWORD

This report presents a new and innovative approach to analyzing use of the radio spectrum. The report sets out a framework for a Spectrum Use Measure (SUM) data base which, for the first time, joins the technical properties of the radio spectrum to the geographical dimension in a manner that allows for the quantification, measurement and graphic display of how the nation's spectrum resource is utilized. Further expansion and development of the SUM data base is expected to lay the foundation for new approaches to spectrum management and promote more efficient and effective use of the radio spectrum.

The radio spectrum is one of this country's most important national and natural resources. It has been less than one hundred years that we have been aware of its usefulness, yet the radio spectrum has been the source of numerous innovations and new industries, all based on the exploitation of that resource's potential. Broadcasting, land mobile and satellite communications are but a few of the services that have been made possible.

Spectrum is an invisible resource; it exists unseen around us. Additionally, while technically finite, the spectrum resource has been expanded by the important work of many whose efforts have added to our knowledge of the spectrum's fundamental nature and provided new ways to increase the intensity of spectrum use.

While the physical properties of this invisible resource are well understood by radio engineers, they are substantially less well appreciated by others. Yet it is important that the management of this critical resource be carried on in such a way as to render understandable and visible the nature of spectrum use. Costs must be assessed, benefits understood and objective decisions made. An accurate measurement of what is available and the geographic costs of a proposed use will better equip us to make the balanced decisions.
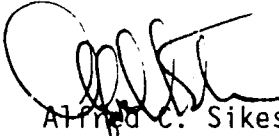
It is this challenge which NTIA's scientists and engineers have sought to address in creating the SUM data base. The essence of the SUM approach is to tie technical measurements of spectrum use to geography by way of the computerized Government Master File (GMF) of radio frequency assignments. The result is a tool capable of quantifying spectrum usage in a geographically specific manner. The approach creates a three dimensional information field within a computer, from which we can plot the nation's fixed spectrum resources against its fixed geographical boundaries. Using the "denied area" concept, it allows for objective quantification and measurement of spectrum use in the following ways:

o **Preclusive Use.** The SUM data base can measure the amount of "spectrum acreage" used preclusively (i.e., no other use is possible) within a given band and geographic location.

o **Nonpreclusive Use.** The data base can display areas where spectrum is being used but where other uses may be possible.

o **Nonuse.** By definition, the amount utilized, either preclusively or nonpreclusively, subtracted from the total resource available, provides the amount of the resource not in use and isolates its location.

o **Intensity of Use.** By utilizing generally accepted propagation and signal strength prediction techniques, the intensity of use of the spectrum resource in a given location can be calculated.
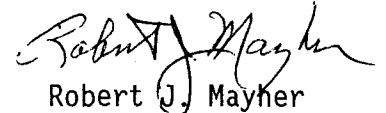
Additionally, the SUM data base allows the spectrum manager to perform new types of both static and dynamic spectrum use analysis. Usage for any given location can be analyzed for a given time or over periods of time; increases and decreases can be identified and monitored. The SUM data base is also able to generate maps which graphically render the information developed in readily identifiable form. These should prove helpful to both the spectrum manager and the communications system designer.

Overall, the report represents an important beginning. With all the important issues to be faced in the dynamic field of communications, it is easy to defer needed attention to the hinges which do not squeak loudest. This is particularly true where the resource that must "squeak" is an invisible one. The issues which involve the efficient and effective use and management of the radio spectrum are among the most important in communications and we will continue to work toward realizing the full potential of this important resource. It is our intention to extend the SUM approach to additional parts of the Federally managed spectrum and ultimately to include all parts that merit such treatment. Further, we intend to work with the Federal Communications Commission and other interested members of the user community to determine what additional ways the SUM approach might prove useful.

Alfred C. Sikes
Assistant Secretary for
Communications and Information

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PREFACE

This project could not have been completed without the special efforts of a number of individual NTIA staff members. Particularly noteworthy are the efforts of: Charles Schott in providing the initial policy guidance, for the project; Leslie A. Berry, in defining and developing spectrm use measurement concepts; Robin H. Haines in fully defining and developing a practical implementation of the engineering model and verifying its accuracy; Gerald F. Hurt in elucidating uses of the model in future planning efforts; Carl A. Winkler in providing initial software planning guidance; and Steven E. Litts in developing and integrating new software with existing commercial software to provide a working model. Also, the editorial and publishing expertise of Georgia (Gigi) C. Chinault and the critical technical review of Paul C. Roosa, Jr. have greatly enhanced this report.

Robert J. Mayher
Director, Spectrum Plans and Policy
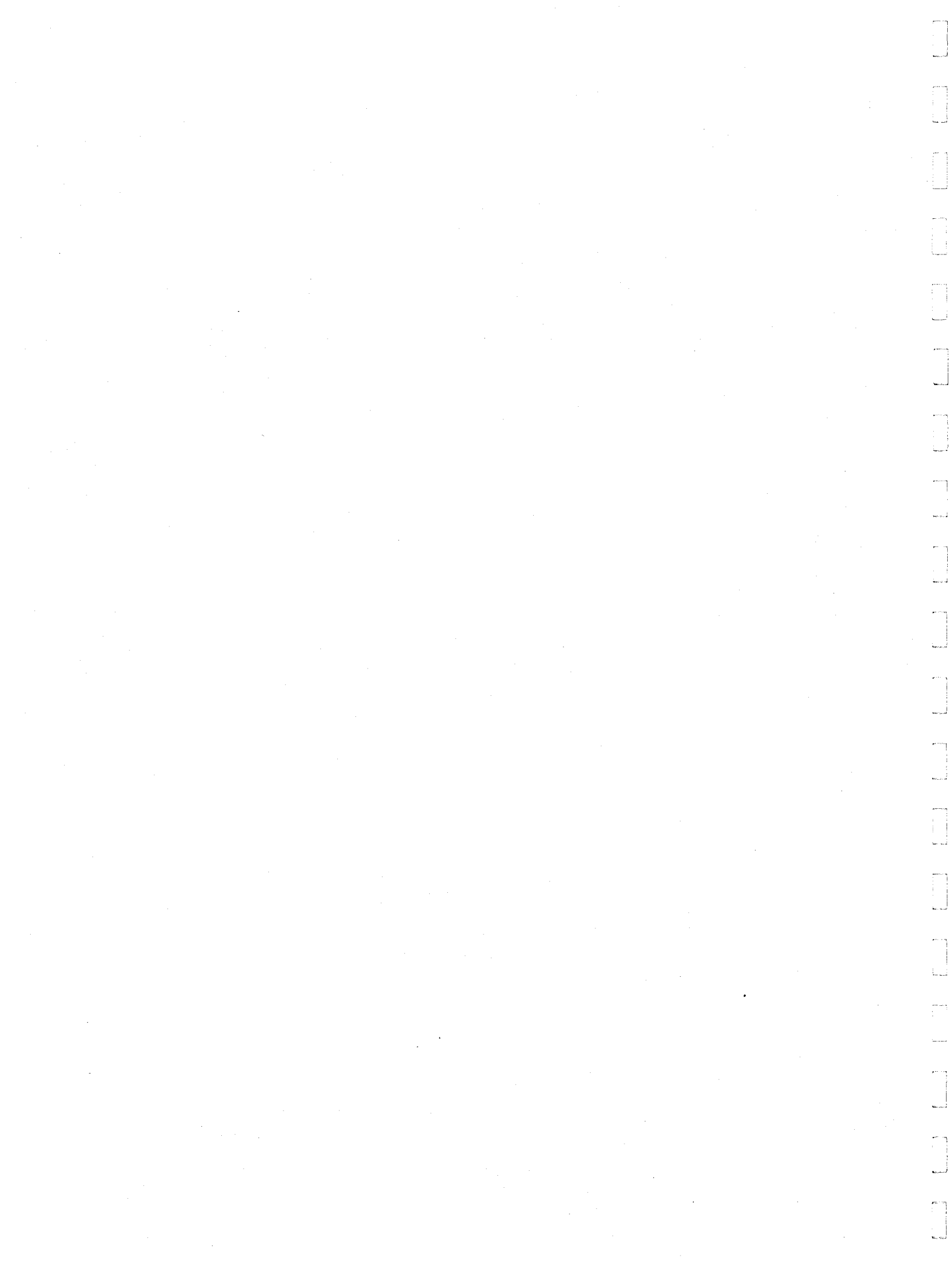
EXECUTIVE SUMMARY

This report describes the Spectrum Use Measure (SUM) data base and model, a new technique for calculating the extent that the radio frequency spectrum is used by systems in a frequency band. The SUM model performs interference calculations using data on existing systems from a frequency assignment file and produces a data base of spectrum use values for geographic points throughout the region being studied. The SUM data base is then used to prepare maps, histograms and indices describing the extent to which the frequency band is used. The results can be used to show the overall use of a frequency band in a geographic area, to chart the growth in the use of a frequency band over time and to identify uncrowded areas which may be available for new assignments.

Previously, a standard technique for representing spectrum use was to plot maps showing the locations and connectivity of terrestrial transmitters and receivers. This technique, however, did not quantitatively indicate the effects of the frequency assignments on the spectrum-space used.

The SUM model determines the spectrum use of existing systems based on potential interference to or from a reference system chosen by the user. The model treats separately the spectrum use of existing transmitters and receivers. When all assignments have been analyzed, the cumulative effect can be determined for each test point.

The SUM model can compute either of two measures of spectrum use. The spectrum use bandwidth (SUB) measures the amount of spectrum made unavailable to the reference system by existing systems. The spectrum use factor (SUF) measures the probability that a location is unavailable to the reference system because of existing systems. Indices may be also derived from either of these measures to show the extent of spectrum use over the entire region being examined.

ABSTRACT

This report describes a new technique for calculating the spectrum space used by existing frequency assignments. The Spectrum Use Measure (SUM) model determines the amount of spectrum used at a given location or the probability that a given location is unavailable for a new assignment. These quantities, stored in a SUM data base, can be used to produce maps, histograms and indices of spectrum use. The SUM technique has been effectively applied to the 1710-1850 MHz and the 7750-7900 MHz bands. The report concludes that the SUM technique is an effective indicator of spectrum use and reccomends that it should be used when evaluating service bands.

KEYWORDS

GLOSSARY

Assigned Station — A transmitter or receiver that is part of an assigned system. The site of the station is the location of the antenna.

Assigned System — A system (transmitter and one or more associated receivers) with a frequency assignment in the band being studied that is used in creating a SUM data base.

Reference Station — A transmitter or receiver that is part of a reference system. The site of the station is the location of the antenna.

Reference System — The hypothetical system (transmitter and receiver) used with the assigned systems for the computation of interference. The characteristics of the reference system represent the typical fixed service system in the frequency band being studied.

Spectrum-Area Use Index (SAUI) — The spectrum-area use product, expressed as a percentage of the product of the total spectrum and the total area.

Spectrum-Area Use Product (SAUP) — A value, in MHz - km^2, representing the product of the bandwidth and area used by assigned systems in a given frequency band. The SAUP is derived from a SUM data base having SUB values.

Spectrum Use Bandwidth (SUB)	-	The total bandwidth, in MHz, used at a test point by assigned systems.
Spectrum Use Factor (SUF)	-	A value at a test point between 0 and 1 representing the probability that the reference system, if located at that test point, would occupy a frequency/azimuth combination used by assigned systems.
Spectrum Use Index (SUI)	-	A value between 0 and 1 representing the probability that the reference system, if located at a randomly selected test point within the study region, would occupy a frequency/azimuth combination used by assigned systems. The SUI is derived from a SUM data base having SUF values. It can be expressed as a percentage
Spectrum Use Measure (SUM)	-	A measure of the extent of use of the frequency spectrum in a given frequency band.
SUM Data Base	-	A set of files containing either SUB or SUF values in a given frequency band for all test points within the contiguous United States.
Test Point	-	Any of the points in the vicinity of the assigned station at which the reference station is assumed to be located and at which SUB and SUF calculations are performed.

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INTRODUCTION

BACKGROUND

The National Telecommunications and Information Administration (NTIA), the Executive Branch agency principally responsible for the development of both domestic and international telecommunications policy, is also responsible for managing the Federal Government's use of the radio frequency spectrum. NTIA establishes policies concerning spectrum assignment, allocation and use, and provides the various federal departments and agencies with guidance to ensure that their conduct of telecommunications activities is consistent with these policies.[1] In support of these requirements, NTIA has completed a number of spectrum resource assessments (SRAs). The objectives of these assessments are to evaluate spectrum use, identify existing or potential compatibility problems, provide recommendations to promote efficient use of the radio frequency spectrum, and improve spectrum management procedures. This assessment documents the development of a new spectrum use measure (SUM) that will be used to provide a technical indication and quantification of the spectrum used in a given frequency band.

NTIA has used various methods of measuring and graphically presenting how the spectrum is used by, or denied to, another system or systems. The basic methods involve presenting Government Master File (GMF) data in such forms as transmitter/receiver location diagrams and GMF data statistics. The GMF data can then be used with a manual or automated frequency-assignment procedure to select a new transmitter frequency, to plan for near- and far-term spectrum

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[1] NTIA, *Manual of Regulations and Procedures for Federal Radio Frequency Management*, National Telecommunications and Information Administration, Washington, DC, Revised May 1988.

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use and to aid in the resolution of interference problems. In addition, NTIA has used a denied-area concept to develop restricted frequency-area maps to assign frequencies to mobile platforms. These maps, referred to as ATTIC[2] maps (An Automatic Technique for Calculating Interference from Airborne Transmitter to Terrestrial Receivers), were used as aids in establishing the effective sharing of frequencies and geographical areas in selected bands in the mobile and fixed services.

NTIA has also investigated various methods of calculating spectrum use and efficiency. These methods include investigations by L. A. Berry and others in the area of "spectrum metrics," which led to the general form of the spectrum-efficiency (SE) measure described in CCIR Study Group 1 Report 662-2.[3] This measure is the ratio of communication achieved to the spectrum space used, where the spectrum space used is the product of bandwidth used, spatial volume denied to other users because of interference and time used. The concept of considering denial to other users was proposed in the *Joint Tactical Advisory Committee (JTAC) Report*.[4] It is the ratio of the product of volume, bandwidth, and time required by an "ideal" system for accomplishing the required mission to the same product for the system under consideration. Note that both the CCIR and JTAC definitions take into account the denial of service to other users.

The SE work of the Technical Subcommittee (TSC) of the Interdepartment Radio Advisory Committee (IRAC) is based on the JTAC definition (Reference 4), since government systems, in many cases, involve a mix of radio services in various bands. They have, however, chosen to use a reference system representing a "procurable state-of-the-art" system rather than an "ideal"

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[2]   Wheeler. J.K. and Haakinson, E.J., *An Automated Technique for Calculating Interference from Airborne Transmitters to Terrestrial Receivers*, U.S. Department of Commerce, Office of Telecommunications, OT Report 77-110, Washington, DC.

[3]   CCIR, *Definition of Spectrum Use and Efficiency*, Report 662-2, Vol.1, XVIth Plenary Assembly, Dubrovnik, Yugoslavia, 1986.

[4]   IEEE and EIA, *Joint Tactical Advisory Committee (JTAC) Report*, New York, NY, March 1968.

system. The TSC initially investigated fixed and mobile systems and only considered the denial of the placement of receivers due to transmitters. The TSC defines their measure as the Technical Spectrum Efficiency Factor (TSEF).[5] This is to emphasize that other factors, such as cost, operational conditions, etc., also enter into system design and influence efficiency; however, these are not included in the TSEF calculation.

While the results of past applications of SE are useful, there are additional factors that need to be included before more complete information concerning the efficient use of the spectrum can be provided. The first is that of receivers being the cause for denying the placement of transmitters. This is similar to the ATTIC concept previously mentioned (Reference 2). A second factor is the extension of the concept of the spectrum efficiency of systems to the spectrum efficiency of radio-service bands. This extension requires careful handling of overlapping frequency-area segments, as detailed by S.I. Cohn.[6]

The following describes the extension of the previously described techniques for general evaluation of technical spectrum use. The technique developed is intended to be used with other technical and economic indices to evaluate spectrum usage.

OBJECTIVES

The overall objective was to develop a technical procedure to assess, both in the spatial and frequency domain, how a radio frequency band is used. The specific objectives were to:

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[5]   Berry, L.A. et al., *Application of the Technical Spectrum Efficiency Factor (TSEF) to the Fixed Service in Three Frequency Bands*, NTIA TM 86-115, National Telecommunications and Information Administration, Washington DC, September 1986.

[6]   Cohn, S.I., *Final Report Methodology for Determining Spectrum Efficiency*, Sachs/Freeman Associates, Landover, MD, under National Telecommunications and Information Administration contract 43SANT503717, 1986.

1. develop a computer program to calculate the spectrum used by existing systems in a given frequency band and to describe graphically the geographical areas used by existing system

2. develop indices of the spectrum-geographical area used

3. apply and evaluate these techniques in two frequency bands

4. evaluate the effectiveness of the concept as an indicator of spectrum use.

APPROACH

To accomplish these objectives, a team of experts from the Institute of Telecommunications Sciences (ITS) and the Office of Spectrum Management (OSM) was assigned to develop the rationale and software used to determine the Spectrum Use Measure (SUM). The basic planning concepts were developed by ITS, the engineering analysis was done by the Spectrum Engineering and Analysis Division (SEAD) of OSM, and the automated data base and related computer programs were developed by the Computer Services Division (CSD) of OSM.

To achieve the objectives, the following tasks were undertaken:

1. development of an overall spectrum-area use concept

2. development of indices of spectrum-area use

3. development of computer software for the spectrum-area use diagrams and indices

4. application of the SUM approach to the evaluation of the 7750-7900 MHz fixed service band

5. application of the SUM approach to the evaluation of the 1710-1850 MHz fixed and mobile service bands

6. evaluation of SUM concept and development of a plan for future improvements and applications.

REPORT CONTENT

Section 2 describes the background and the engineering calculations required for the SUM data base and analysis model. Sections 3 and 4 describe applications of the SUM to the 7750-7900 and 1710-1850 MHz bands. These sections include descriptions of the fixed and fixed and mobile equipment usage, respectively. Section 5 describes general plans for future application and development of the SUM concept. Section 6 summarizes the results of the SUM investigation.
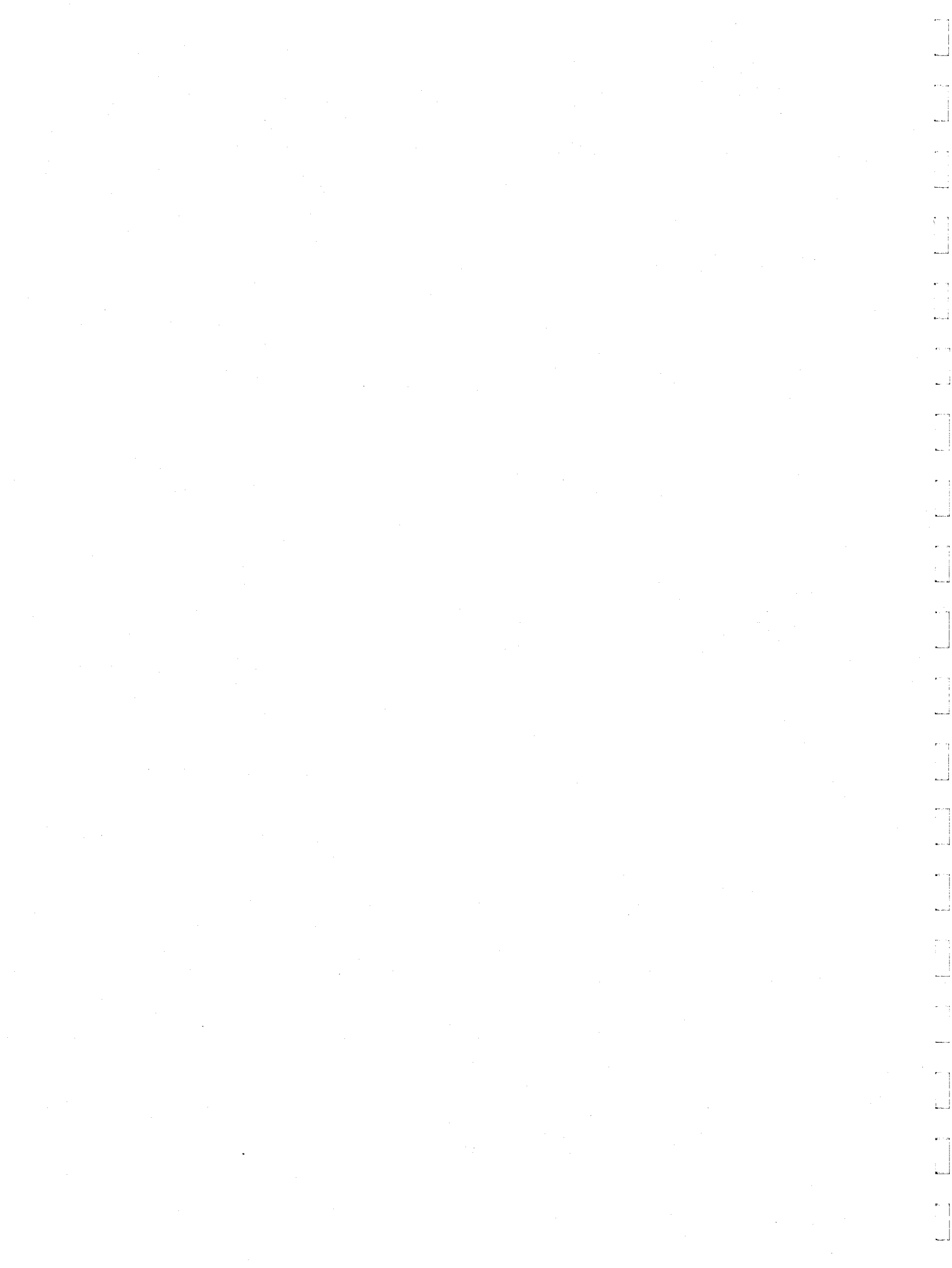
SECTION 2

SUM DATA BASE AND MODEL

INTRODUCTION

The Spectrum Use Measure (SUM) data base is a set of files containing data used to describe the extent to which a frequency band is used. The data files contain spectrum use values for selected points spaced at even intervals of latitude and longitude throughout the geographic region of interest. The basic input data on existing systems is derived from frequency assignment data contained in an automated data base. Automated calculations are performed for the selected points in the vicinity of each existing transmitter and receiver, using the SUM model. The resulting SUM data base can then be used to develop maps, bar graphs and indices describing the extent to which the frequency band is used.

Concepts and Terminology

This subsection describes concepts and terminology unique to this project. The terms in boldface type are defined in the GLOSSARY.

Figure 2-1 shows a transmitter and receiver (an **assigned system**) and several nearby **test points**, at which the extent of spectrum use is to be determined. If, hypothetically, a new receiver is installed at test point "P", interference along path "a" might occur, depending on the characteristics of the assigned transmitter and the new receiver. Under certain conditions, the possibility of interference from the assigned transmitter could preclude the use of a range of frequencies by the new receiver at that test point. Part of the radio frequency spectrum would then be "used" by the assigned transmitter at test point "P".

2-1
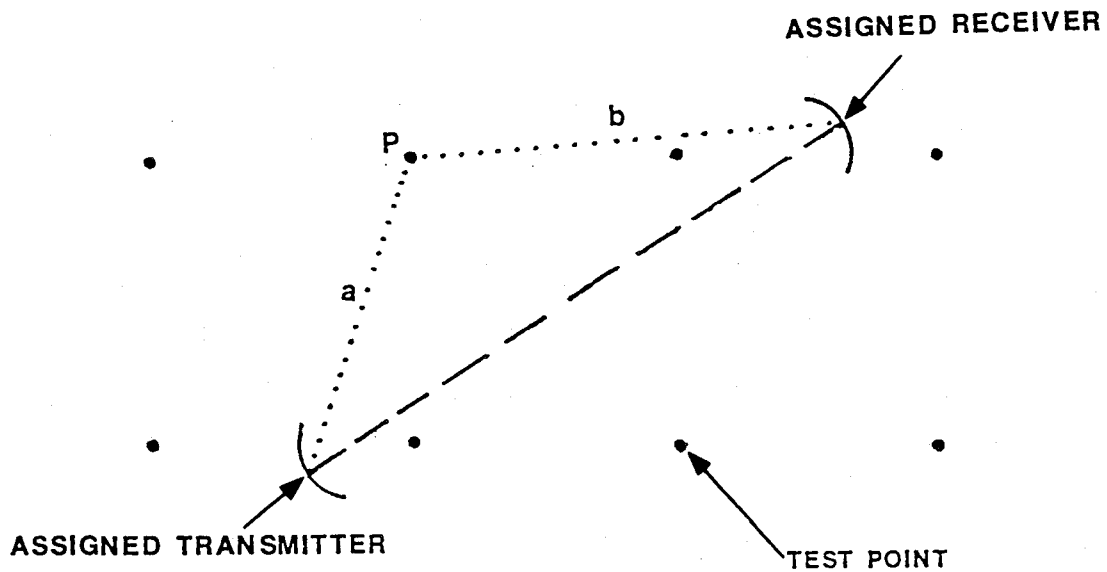
Figure 2-1.   Assigned transmitter and receiver and several nearby test points.

In the same way, the assigned receiver could preclude the use of a range of frequencies by a new transmitter at test point "P" because of the possibility of interference to the assigned receiver along path "b". In this

case, part of the spectrum would be "used" by the assigned receiver at test point "P".

As evidenced from the preceding description, the range of frequencies used by the assigned system depends heavily on the characteristics of the hypothetical new transmitter and receiver (the **reference system**). The characteristics of the reference system can be hypothetical or those of an actual system of interest to the user.

The total spectrum, in MHz, used by assigned systems at a test point is called the **Spectrum Use Bandwidth (SUB)**, one of two measures of spectrum use employed by the SUM model. The product of the SUB for a test point and the area represented by the test point is the total frequency and area resources used at that point. The sum of these products over the entire study region the **spectrum-area use product (SAUP)**, measured in MHz-km^2. The **spectrum-area use index (SAUI)** is the SAUP expressed as a percentage of the total spectrum-area resources (the product of the total bandwidth and the total area).

The second measure of spectrum use estimates the probability that a reference station at the test point would either receive or cause interference. Just as interference is limited to a range of reference station frequencies, it is also generally limited to a range of antenna mainbeam azimuths for a fixed system (e.g. a reference receiver that experiences interference if its antenna mainbeam is directed toward an assigned transmitter may not experience interference if its mainbeam is directed away from the transmitter). The product of the fraction of the total azimuths used and the fraction of the total frequencies used is called the **spectrum use factor (SUF)**. The SUF for a test point represents the probability that a randomly chosen combination of frequency and azimuth for the reference station, when located at that point, would result in interference. The **spectrum use index (SUI)** is the sum of the products of the SUF and the associated area for each test point, divided by the total area. The SUI represents the probability that a reference station in the study region with a random location, frequency and antenna mainbeam azimuth either cause or experience interference. Both the SUF and the SUI are dimensionless.

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Procedure

In this report, government radio systems in two frequency bands are analyzed using data from the Government Master File (GMF). The assumed technical parameters of the reference system (power, bandwidth, antenna gain, etc.) are the median values of those parameters for fixed service systems in the appropriate frequency band (the user may also choose other values for the reference system). All systems considered in these examples are within the conterminous United States (CONUS).

Calculations are performed separately for each transmitter and receiver identified in the data base. The SUM model locates all test points in the vicinity of the assigned station and computes either the SUB or the SUF, as chosen by the user, for each test point. The value is stored in the location for that test point in either the transmitter array or the receiver array, as appropriate. The transmitter and receiver arrays containing the aggregate values for all assigned systems form the SUM data base for that frequency band.

Presentation of Data

The transmitter and receiver arrays can be combined into a single array with the greater of the transmitter and receiver values at each location. Using the combined array, the SUB or SUF data can be presented on a contour map of the study region. The contour maps show areas having certain values of SUB or SUF. The distribution of SUB or SUF values over the study region can also be shown using bar graphs. Each bar represents a range of SUB or SUF values with a height proportional to the area having a value within that range. The spectrum area used and SUI indices represent the extent of spectrum use in a frequency band for a region as a single value.

The following subsections provide a detailed description of the computations and assumptions used in the SUM model for the production of a SUM data base.

CALCULATION OF SPECTRUM USE BANDWIDTH AND SPECTRUM USE FACTOR

A location is "used" by the assigned systems in a certain frequency band if, hypothetically, the reference station at that location would either cause unacceptable interference to one or more assigned systems or experience unacceptable interference from one or more assigned systems. The criterion for unacceptable interference is the ratio of received carrier power to interference power (C/I, in dB): if the C/I ratio at the receiver is less than the threshold or protection ratio value (C/I_{th}), an unacceptable interference condition is assumed.

Computations

This subsection shows the computations used to determine the spectrum use bandwidth (SUB) and the spectrum use factor (SUF). Later subsections describe the models and assumptions used and other details of the computations.

The carrier power at a receiver from the associated transmitter is:

$$C = P_D + G_D(0) + G_R(0) - L_P(d_D) \qquad (1)$$

where:

C	$=$	Desired carrier power at the receiver, in dBW
P_D	$=$	Power of the desired transmitter, in dBW
$G_D(0)$	$=$	Mainbeam gain of the desired transmitter antenna, in dBi

$G_R(0)$ =   Mainbeam gain of the receiver antenna, in dBi

d_D =   Distance between the desired transmitter and the receiver, in km

$L_P(d_D)$ =   Propagation path loss associated with the distance d_D, in dB

The transmitter power and the antenna gains are obtained from the GMF records. The distance between the transmitter and the receiver can also be determined from GMF data. In this way, the desired carrier power can be determined for a link.

The power at the receiver from an interfering transmitter is:

$$I = P_I + G_I(\theta_I) + G_R(\theta_R) - L_P(d_I) - OTR \qquad (2)$$

where:

I   =   Interference power at the receiver, in dBW

P_I =   Power of the interfering transmitter, in dBW

θ_I =   Angle at the interfering transmitter between the direction to the receiver and the mainbeam direction, in degrees

$G_I(\theta_I)$ =   Gain of the interfering transmitter antenna $\theta_I°$ off the mainbeam, in dBi

θ_R =   Angle at the receiver between the direction to the interfering transmitter and the mainbeam direction, in degrees

$G_R(\theta_R)$ =   Gain of the receiver antenna $\theta_R°$ off the mainbeam, in dBi

d_I = Distance between the interfering transmitter and the receiver, in km

$L_P(d_I)$ = Propagation path loss associated with the distance d_I, in dB

OTR = On-tune rejection of the interfering signal by the receiver IF filter, in dB

Path loss and antenna gain terms are often combined into a single term, called the transmission loss. For the interfering signal path:

$$L_I = L_P(d_I) - G_I(\theta_I) - G_R(\theta_R) \tag{3}$$

where:

L_I = Transmission loss between the interfering transmitter and the receiver, in dB

Using Equation 3, Equation 2 can be simplified as follows:

$$I = P_I - L_I - OTR \tag{4}$$

The carrier-to-interference ratio then becomes:

$$C/I = C - P_I + L_I + OTR \tag{5a}$$

By rearranging the terms, a transmissions loss threshold can be expressed in terms of the C/I threshold:

$$L_{Ith} = P_I - OTR - C + C/I_{th} \tag{5b}$$

Using Equation 5b, the transmission loss threshold can be determined from known and assumed parameters of the desired and interfering systems. This

calculation is independent of the relative positions and orientations of the interfering transmitter and desired receiver antennas. Both cochannel and adjacent-signal interference are considered in the SUM model. Either a cochannel (C) or an adjacent-signal (A) subscript follows the C/I and L_I thresholds in Equation 5b to indicate the type of interference.

As described earlier, values for the SUM data base are determined by calculating the spectrum use bandwidth or spectrum use factor at points in the vicinity of the assigned station. Once the transmission loss threshold is determined, the spectrum use bandwidth or spectrum use factor is calculated based on the location of the test point.

To permit the use of the same equation for both assigned transmitters and assigned receivers, Equation 3 can be generalized:

$$L_I = L_p(d_I) - G_1(\theta_1) - G_2(\theta_2) \tag{6}$$

where:

θ_1 =   Angle at the assigned station between the direction to the test point and the mainbeam direction, in degrees

$G_1(\theta_1)$ =   Gain of the assigned station antenna $\theta_1°$ off the mainbeam, in dBi

θ_2 =   Angle at the test point between the direction to the assigned station and the mainbeam direction, in degrees

$G_2(\theta_2)$ =   Gain of the reference station antenna $\theta_2°$ off the mainbeam, in dBi

Figure 2-2 shows θ_1, θ_2 and d_I for a typical station in the fixed service. The assigned station and a test point are also shown along with the antenna mainbeam directions. Test points within the inner pattern have SUB and SUF values greater than zero. The rectangle encloses test points

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Area Containing Test Points at Which Calculations Are Performed

Area Affected by Assigned Station

θ_1

θ_2

d_1

Assigned Station
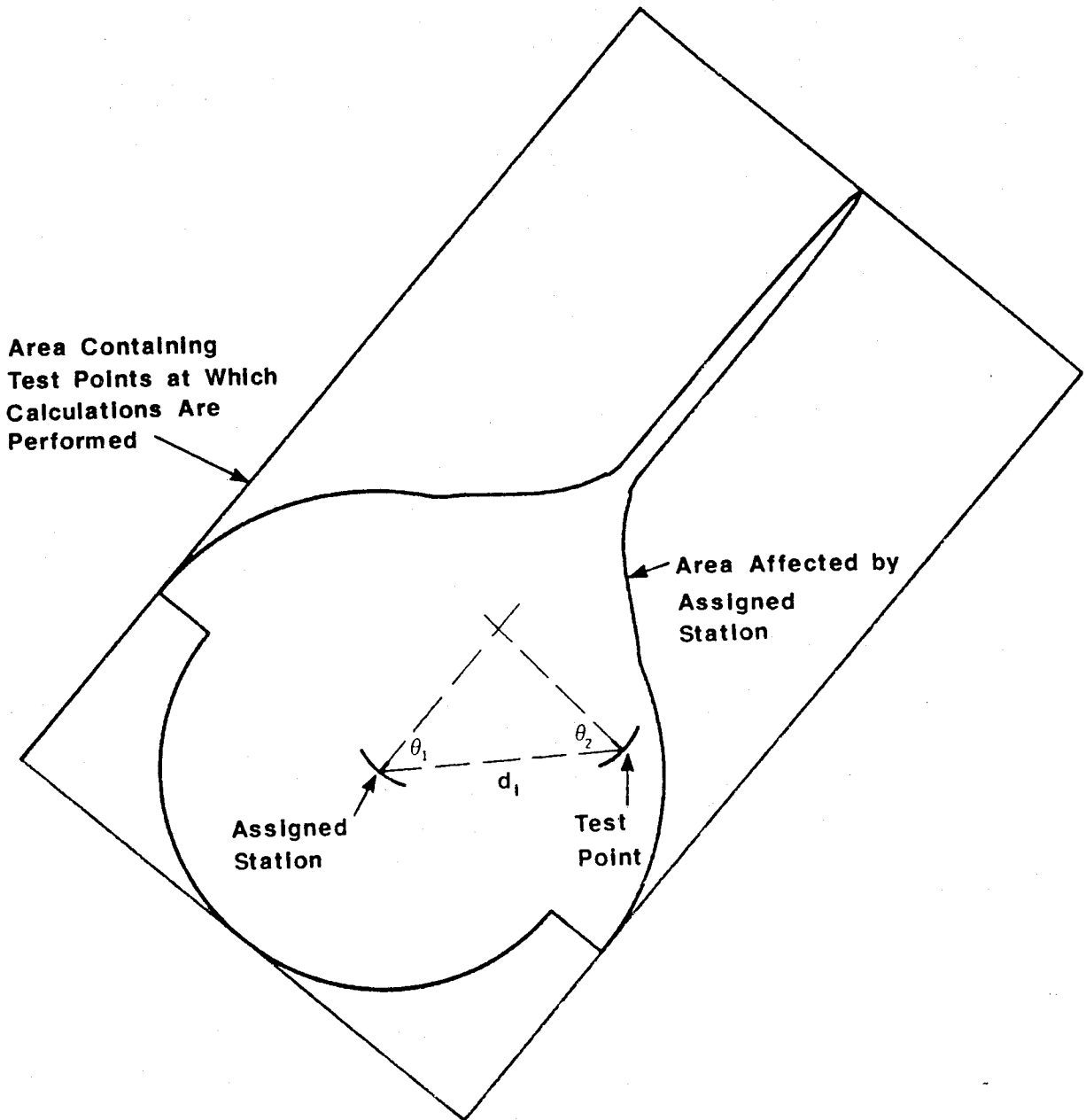
Test Point

Figure 2-2.   Typical geometry for calculations at a test point in the vicinity of a fixed service station.

considered to be in the vicinity of the assigned station for calculation purposes.

Spectrum Use Bandwidth. The spectrum use bandwidth (SUB) at a test point, the total bandwidth used at that test point by assigned systems, is determined using Equation 7:

$$
\begin{aligned}
SUB &= BW_A & \text{if } L_I \leq L_{IthA} &\quad (7)\\
&= BW_C & \text{if } L_{IthA} < L_I \leq L_{IthC}\\
&= 0 & \text{if } L_I > L_{IthC}
\end{aligned}
$$

where:

SUB = Spectrum use bandwidth at the test point, in MHz

BW_C = Bandwidth over which cochannel interference will occur, in MHz

BW_A = Bandwidth over which cochannel or adjacent-signal interference will occur, in MHz

BW_C and BW_A are discussed in the protection ratios subsection below.

Equation 6 gives the transmission loss L_I in terms of the path loss and antenna gains. While θ_1 and d_I can be calculated based on the location and orientation of the assigned station antenna and the location of the test point, θ_2 is unknown. The most conservative assumption is that the reference station antenna mainbeam is directed toward the assigned station ($\theta_2 = 0°$: where other values for θ_2 can also be chosen), in which case Equation 6 becomes:

$$
L_I = L_P(d_I) - G_1(\theta_1) - G_2(0) \qquad (8)
$$

where:

$G_2(0)$ =   Mainbeam gain of the reference antenna, in dBi

If L_I from Equation 8 is less than the transmission loss threshold, the bandwidth BW_{int} is used by the assigned system at that test point.

Equation 7 is used to compute the SUB based on a single assigned station. To compute the aggregate SUB for all assigned stations, the SUM model establishes a set of frequency "bins" for each test point. As the model analyzes each assigned system, the memory bit representing a bin at a test point is set to "one" if any frequency in that bin is used by the assigned system. The aggregate SUB is the number of "ones" times the bin width, in MHz.

Spectrum-Area Use Product (SAUP)

The spectrum-area use product (SAUP) is the total spectrum-area used in a frequency band, based on SUB data. The SAUP is calculated using Equation 9:

$$SAUP = \Sigma(SUB_i \times A_i) \tag{9}$$

where:

$SAUP$ =   Spectrum-area use product, in MHz-km^2

SUB_i =   Spectrum use bandwidth at test point i, in MHz

A_i =   Area represented by test point i, in km^2

Spectrum-Area Use Index (SAUI)

The SAUP can also be expressed as a percentage of the product of the total spectrum and the total area. This spectrum-area use index (SAUI) is calculated using Equation 10:

$$SAUI = \frac{\Sigma(SUB_i \times A_i)}{BW_{tot} \times \Sigma A_i} \times 100\% \tag{10}$$

where:

SAUI   =   Spectrum-area use index, dimensionless

BW_{tot} =   Total width of the band being studied, in MHz

SPECTRUM USE FACTOR (SUF)

The use of the SUF eliminates the need to assume a value for θ_2. Instead of calculating the transmission loss and comparing it to the threshold value, the transmission loss threshold L_{Ith} is converted to the threshold off-mainbeam angle θ_{2th}. The relationship between θ_{2th} and L_{Ith} is shown in Equation 11:

$$G_2(\theta_{2th}) = L_P(d_I) - L_{Ith} - G_1(\theta_1) \tag{11}$$

Given L_{Ith} and the location of the test point, $G_2(\theta_{2th})$ can be calculated using Equation 11. θ_{2th} can then be determined based on the radiation pattern of the reference station antenna. The SUF at the test point will then be:

$$SUF = \theta_{2th}/180 \times BW_{int}/BW_{tot} \tag{12}$$

where:

      SUF   =   Spectrum use factor at the test point, dimensionless

Since the SUF is not simply a bandwidth, the one-bit frequency bins used in computing the aggregate SUB can not be used to calculate the aggregate SUF. Instead, the aggregate SUF at a test point is the sum of the SUF values for individual assigned systems. While this leads to incorrectly large values if two assigned systems use the same azimuths in the same frequency range, the effect is expected to be negligible for narrow beam fixed systems.

SPECTRUM USE INDEX (SUI)

The spectrum use index (SUI) for a frequency band is the probability that the reference system, if located at a randomly selected test point in the study region, would occupy a frequency/azimuth combination used by assigned systems. The SUI is calculated using Equation 13:

$$SUI = \frac{\Sigma(SUF_i \times A_i)}{\Sigma A_i} \qquad (13)$$

SUI   =   Spectrum-area use index, dimensionless

SUF_i =   Spectrum use factor at test point i, dimensionless

Models and Assumptions

In this subsection, the models and assumptions used to compute the SUB and SUF are discussed. Some of the equations are also discussed further.

Modeling of Systems. The data required to make a very basic model of the assigned system is available from the GMF. This data generally includes

2-13

transmitter and receiver locations and elevations, transmitter power and bandwidth and transmitter and receiver antenna gains and antenna heights. The desired carrier power can then be computed at each receiver (there may be more than one receiver associated with a transmitter) using Equation 1 above.

Fixed service systems employing passive repeaters (reflectors)[7] were modeled by considering each path (between the transmitter and a passive repeater, between passive repeaters and between the receiver and a passive repeater) greater than a certain length[8] as a separate transmitter/receiver pair. The transmitter powers, desired carrier powers and antenna gains were determined by assuming that the desired carrier power at the last receiver would be the same whether the signal travels via the passive repeaters or directly from the transmitter to the receiver.

Reference System

For the reference system, the transmitter power and bandwidth, the antenna gains, the effective antenna heights (described below in the propagation loss subsection) and the desired carrier power at the receiver were set to the median values for the fixed service assignments in the band being analyzed. The user may choose other values for the reference system.

Given the basic data for the assigned and reference systems, the transmission loss threshold is calculated using Equation 5b, given earlier:

$$L_{Ith} = P_I - OTR - C + C/I_{th}$$

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[7] Microflect Co., Inc., *Passive Repeater Engineering*, Manual No. 161A, 1984 Edition, Salem, OR, 1984.

[8] The minimum distance for a far-field path between two passive repeaters is $10A_{eff}/\lambda$ (Reference 1, p. 38), where A_{eff} is the smaller of the effective areas of the two passive repeaters and λ is the wavelength of the carrier. Between a passive repeater and the transmitter or the receiver, the minimum farfield distance is $10A_{eff}/\pi\lambda$ (Reference 1, p. 40). Paths smaller than these minimum lengths are not considered in the analysis. The assumed typical effective area for a passive repeater is 47.6 m^2 (512 ft^2).

If the SUB or SUF for receivers is being determined, P_I for the assigned system and C for the reference system are used. If the SUB or SUF for transmitters is being determined, P_I for the reference system and C for the assigned system are used.

The OTR term in Equation 5b is calculated using Equation 15:

$$OTR = 10\log(BW_I/BW_R) \quad \text{if } BW_I > BW_R \qquad\qquad (14)$$
$$= 0 \qquad\qquad\qquad \text{otherwise}$$

where:

BW_I =   Bandwidth of the interfering signal, in MHz

BW_R =   Bandwidth of the desired receiver, in MHz

The necessary bandwidths listed in the GMF are used for the assigned systems and for determining the median value for the reference system.

Protection Ratios. The protection ratio, in this case the C/I threshold of Equation 5b, should ideally be based on several factors, including the signal characteristics of both the assigned and reference systems. Based on EIA criteria, two values for C/I_{th} were assumed: 60 dB for cochannel interference and 0 dB for adjacent-channel interference (corresponding to 60 dB off-frequency rejection for adjacent signals).

The bandwidths over which cochannel and adjacent-signal interference occur are calculated using Equations 15a and 15b:

$$BW_C' = BW_I + BW_R \qquad (15a)$$

$$BW_A' = 3 \times (BW_I + BW_R) \qquad (15b)$$

BW_C and BW_A are the parts of these bands that fall within the limits of the band being studied.

Distance and Bearing. Distance and bearing calculations are necessary for determining directional antenna gain and propagation loss. The calculations used are based on a spherical earth. The distance between the assigned station and the test point is calculated using Equation 16:

$$d_i = \cos^{-1}[\sin(L_1)\sin(L_2) + \cos(L_1)\cos(L_2)\cos(\delta)] \times C \qquad (16)$$

where:

L_1 =   Latitude of the assigned station, in degrees

L_2 =   Latitude of the test point, in degrees

δ =   Difference between longitude of the test point and the longitude of the assigned station, in degrees

C   =   Distance corresponding to one degree of latitude on the Earth's surface, in km

At 30° North, one degree of latitude corresponds to 69.048 miles or about 11.122 km. This value is used for the entire CONUS.

The bearing from the assigned station to the test point is calculated using Equation 17:

$$B_{12} = \cos^{-1}\left[\frac{\sin(L_2)-\cos(d_1/C)\sin(L_1)}{\sin(d_1/C)\cos(L_1)}\right] \qquad (17)$$

where:

B_{12} = Bearing from the assigned station to the test point, in degrees east of north

If the test point is west of the assigned station ($\delta<0$), B_{12} must be subtracted from $360°$ to give the bearing in degrees east of north.

Propagation Loss. The propagation loss between a transmitter and a receiver is a function of the distance between them. For determination of the desired carrier power, the propagation loss is based on the distance between the transmitter and the receiver of the assigned system.

Figure 2-3 shows how distances are calculated for assignments consisting of a mobile station and a base station. In general, d_D is the maximum length of the desired path, while d_I is the minimum length of the interference path. In the case shown, d_D is the authorized radius of the mobile station. For the base station, d_I is the distance between the test point and the base station. For the mobile station however, d_I is the distance between the test point and the nominal location of the mobile station (the center of its operating area) less the authorized radius of the mobile station.

For determination of the desired carrier power, free space propagation loss is used. This is appropriate, except for transhorizon systems. Using free space propagation loss, the desired carrier power calculated at the receiver of a transhorizon system will be unreasonably large, resulting in excessively small use areas for transmitters. The free space loss is calculated using Equation 18:
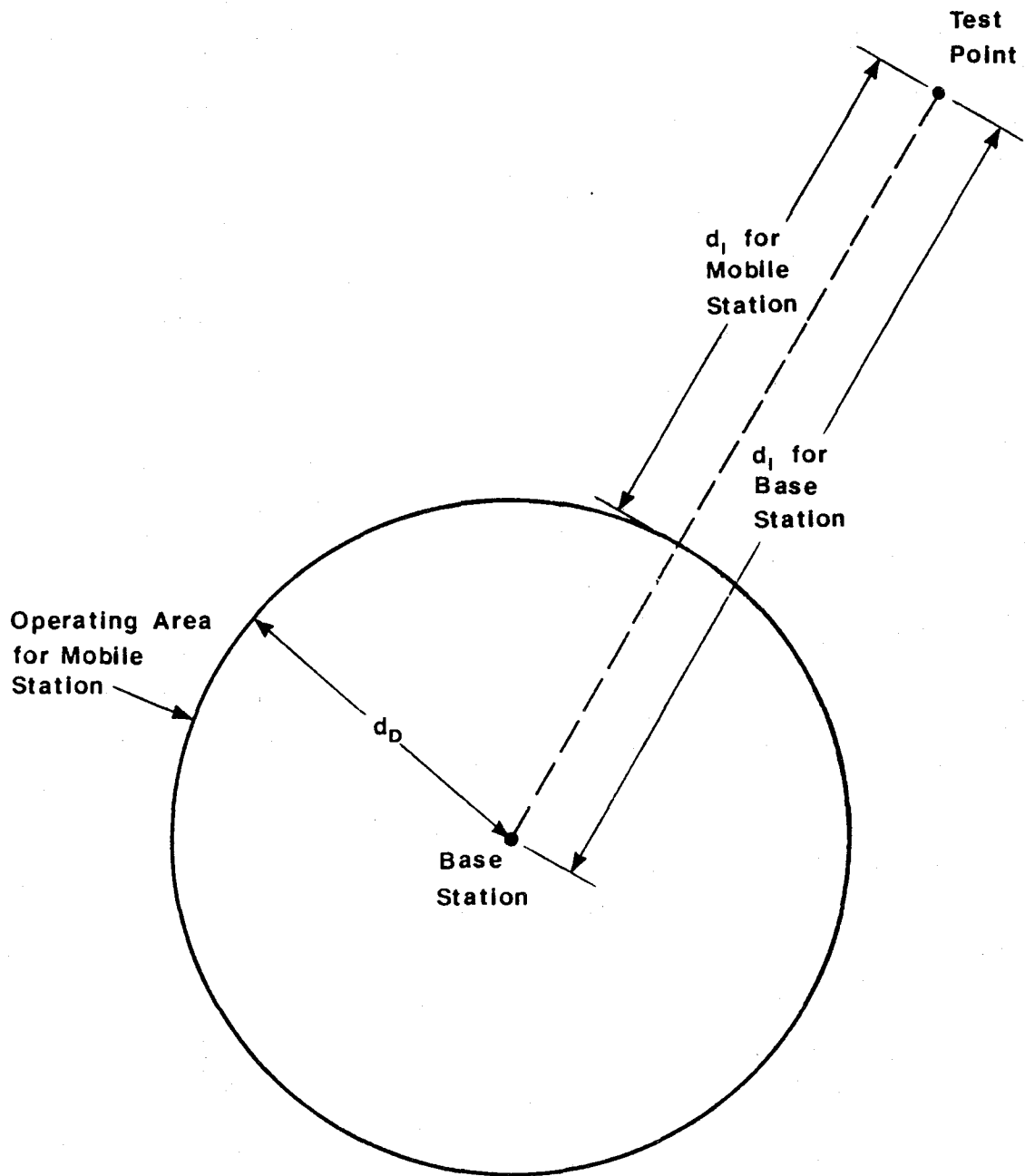
Figure 2-3.   Method for calculating distances between stations in the mobile service.

$$L_p(d_D) = 20\log(4\pi f d_D/c) \qquad (18)$$

where:

f =   Frequency of the desired receiver

c =   Speed of light

For simplicity, f is assumed to be the midband frequency of the band being analyzed. In Equation 18, f, d_D and c must have corresponding units.

The Integrated Propagation System (IPS) model was used to determine the propagation loss for interference paths. This model includes diffraction and transhorizon modes as well as the free space mode. The model chooses the appropriate mode based on the path length and the antenna heights.

When using a smooth-earth model like the IPS, an effective antenna height should be used for the transmitter and receiver stations. The effective antenna height is the difference between the height of the antenna above mean sea level (the sum of the site elevation and the height of the antenna above the ground) and the average elevation of several points in the direction of propagation. Since the use of detailed elevation data is not practical when large areas are being analyzed, a simpler method of determining the average elevation in the vicinity of a site was needed. An ITS file containing average elevation values for points every fifteen minutes of latitude and longitude was used. The average elevation values were calculated by averaging 30" data within a 25 km radius of the center point. To determine the effective antenna height for an assigned station, the antenna height was added to the difference between the elevation given in the GMF and the average elevation (but not less than zero). (Additional describing decreasing the average terrain elevation value are contained in APPENDIX D.) For the reference station, the median antenna height alone was used since the test point site was assumed to be at the average elevation.

For the airborne and assigned stations, the user enters an assumed nominal altitude above mean sea level. The default value is 9144 m (30000 ft). The average terrain elevation is subtracted from the nominal altitude to obtain the effective antenna height.

Antenna Radiation Patterns. CCIR Report 614-2[9] provides reference antenna patterns for radio-relay systems. The basic envelope pattern for antenna sidelobes is:

$$G(\theta) = 52 - 10\log(D/\lambda) - 25\log(\theta) \tag{19}$$

$$\text{for } G(\theta) < G_1$$

where:

$G(\theta)$ = Gain of the antenna θ degrees off the mainbeam, in dBi

D = Diameter of the parabolic reflector

λ = Wavelength of the carrier

G_1 = Gain of the first sidelobe, in dBi

D and λ must be in the same units. When the reflector diameter is not known, CCIR Report 391-5, Annex I[10] suggests the following estimate be used:

$$20\log(D/\lambda) \approx G_{max} - 7.7 \tag{20}$$

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[9]   CCIR, *Reference Radiation Patterns for Radio-Relay System Antennas*, Report 614-2, Volume IX - Part I, International Telecommunication Union, Geneva, Switzerland, 1986, pp 270-274.

[10] CCIR, *Radiation Diagrams of Antennas for Earth Stations in the Fixed-Satellite Service for Use in Interference Studies and for the Determination of a Design Objective*, Report 391-5, Volume IV - Part I, International Telecommunication Union, Geneva, Switzerland, 1986, pp 138-156.

where:

$$G_{max} = \text{Mainbeam gain of the antenna, in dBi}$$

Reference 10 gives the following equation for the gain of the first sidelobe:

$$G_1 = 2 + 15\log(D/\lambda) \tag{21}$$

The mainbeam pattern from Reference 10 is:

$$G(\theta) = G_{max} - .0025[(D/\lambda)\theta]^2 \tag{22}$$

$$\text{for } G(\theta) > G_1$$

For frequency re-use problems assuming parallel polarization, CCIR Report 614-2 recommends 0 dBi residual gain up to 90° and -15 dBi residual gain between 90° and 180°.

Since information on antenna types is not readily extracted from the GMF, this model is used for all antennas having a mainbeam gain greater than 10 dBi. For antennas having a smaller mainbeam gain, the gain is assumed to be constant in all directions.

In calculating the spectrum use factor (SUF) at a test point, it is necessary to determine an angle θ given $G(\theta)$. For values of $G(\theta)$ greater than, or equal to, G_{max}, setting θ equal to 0° will correctly result in SUF = 0 when Equation 12 is used. Equations 23 and 24, derived from Equations 19 and 22, are used to calculate θ when $G(\theta)$ is between 0° and G_{max}:

$$\theta = \frac{20[G_{max} - G(\theta)]^{\frac{1}{2}}}{D/\lambda} \tag{23}$$

$$\text{for } G_1 < G(\theta) < G_{max}$$

In the sidelobe region:

$$\theta = 10^{.04[52 - 10\log(D/\lambda) - G(\theta)]} \tag{24}$$

for $0 < G(\theta) \leq G_1$

Based on the residual gain assumptions described above, $\theta = 90°$ when $G(\theta)$ is greater than -15 dBi and less than or equal to 0 dBi, and $\theta = -180°$ when $G(\theta)$ is -15 dBi or less.

SECTION 3

ANALYSIS OF THE 7750-7900 MHz BAND

The first frequency band chosen for inclusion in the SUM data base was the 7750-7900 MHz band, allocated exclusively to the government fixed service in the United States. This band was chosen because it is one of the few bands allocated to a single service and because it has few assignments compared to other government bands. This band therefore represents a relatively simple and straightforward case. (Please note that for printing purposes, Figures 3-2 through 3-3 appear at the end of this section.)

FREQUENCY ALLOCATIONS

The 7750-7900 MHz band is part of the 7125-8500 MHz band, which is allocated to the fixed service in both the national and international tables of frequency allocations. Portions of the larger band are also allocated to various space services in both tables and to the mobile service in the international table. In the national table, the 7125-8500 MHz band is allocated exclusively for government use, except for nongovernment allocations to the earth-exploration satellite service (space-to-earth) in the 8025-8400 MHz band and to the space research service (space-to-earth) in the 8450-8500 MHz band.

The 7750-7900 MHz band is unique within the larger band in that it is allocated exclusively to the government fixed service in the national table (see TABLE 3-1). Internationally, the 7750-7900 MHz band is allocated to the fixed and mobile (except aeronautical mobile) services on a primary basis.

3-1

TABLE 3-1

7750-7900 MHz ALLOCATIONS

INTERNATIONAL			UNITED STATES				
Region 1 MHz	Region 2 MHz	Region 3 MHz	Band MHz 1	National Provisions 2	Government Allocation 3	Non-Government Allocation 4	Remarks 5
7750-7900	FIXED MOBILE except aeronautical mobile		7750-7900		FIXED		

USE OF THE BAND

Major Users

TABLE 3-2 shows the distribution of GMF frequency assignments in the 7750-7900 MHz band by agency and service. The column marked "other" represents experimental stations or assignments with no station class. Since some assignments have more than one station class, the sum of the numbers in the "fixed service" and "other" columns may be greater than the "total assignments." For computation of the "percent of fixed assignments," the smaller of the "fixed service" and "total assignments" numbers was used to represent the number of fixed service assignments for each agency. The data in this table was current as of April 21, 1988.

The use of the 7125-8500 MHz band is described in a 1984 NTIA Spectrum Resource Assessment (SRA).[11] The U.S. Government uses the 7125-8500 MHz band primarily for high-capacity microwave links. Portions of the band (not including 7750-7900 MHz) are also used in the fixed- and mobile-satellite services.

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[11] Crandall, G., *Spectrum Resource Assessment of the 7125-8500 MHz Band*, NTIA Report 84-159, September 1984.

TABLE 3-2

DISTRIBUTION OF ASSIGNMENTS BY AGENCY
AND SERVICE IN THE 7750-7900 MHz BAND

AGENCY	FIXED SERVICE	OTHER	TOTAL ASSIGN- MENTS	% OF ASSIGN- MENTS	% OF FIXED ASSIGN- MENTS
AF	78	99	170	18.1	9.3
AR	77	2	79	8.4	9.2
C	7	0	7	0.7	0.8
CG	17	0	17	1.8	2.0
DOE	141	0	141	15.0	16.9
FAA	311	0	311	33.2	37.2
GSA	10	0	10	1.1	1.2
I	4	0	4	0.4	0.5
J	28	0	28	3.0	3.4
N	89	4	93	9.9	10.7
NASA	22	0	8	0.9	1.0
NG	0	2	2	0.2	0.0
NSF	2	0	2	0.2	0.2
SI	2	0	2	0.2	0.2
TVA	40	0	40	4.3	4.8
USIA	2	0	2	0.2	0.2
VA	15	0	15	1.6	1.8
OTHER	4	2	6	0.6	0.5
TOTAL	849	109	937		
% BY SERVICE	88.6	11.4			

The Federal Aviation Administration (FAA) accounts for over 37% of the fixed service assignments in the 7750-7900 MHz band. The FAA operates Radar Microwave Links throughout the U.S. to relay air traffic information from radar sites to central locations. Department of Defense systems account for an additional 29% of the fixed service assignments. The military agencies use these systems to relay radar, video and voice data in the vicinity of military bases and test ranges. The DoE Bonneville Power Administration (BPA) and the Tennessee Valley Authority (TVA) are responsible for power transmission in the Pacific Northwest and the southeastern United States, respectively. Both these groups use fixed service systems in this band for monitoring and control

of their power transmission systems. Together, BPA and TVA account for about 22% of the fixed service assignments in this band. Figure 3-1 shows the geographic distribution of frequency assignments in the 7750-7900 MHz band.

Types of Systems

Since experimental stations are on a secondary basis to stations of all other services (Reference 1, p. 6-23), they are not included in the SUM data base. While a fixed service assignment most often implies a direct link between a stationary transmitter/receiver pair, transportable equipment and passive repeaters are also used in the fixed service.

REFERENCE SYSTEM CHARACTERISTICS

The characteristics of the reference system for the 7750-7900 MHz band are shown in TABLE 3-3. These characteristics are the median values of the fixed service assignments in this band.

IMPLICATIONS OF OUTPUT

Spectrum Use Bandwidth

Figure 3-2 shows 25 MHz, 75 MHz and 125 MHz contours of the SUB for the 7750-7900 MHz band. Areas of heavy use (125 MHz or more) include much of the West and the Southeast, and smaller areas such as Omaha, Washington, Baltimore and New York City. For much of the midwest, especially the north central states, little or none of the spectrum in the band is used.

Comparison of Figures 3-1 and 3-2 shows the effects of the individual fixed service assignments on the spectrum use bandwidth. Assignments shown in Figure 3-1 that do not affect Figure 3-2 are either unprotected experimental systems or systems denying less than 25 MHz bandwidth, even in areas where use

3-4

X = Transmitter
0 = Receiver
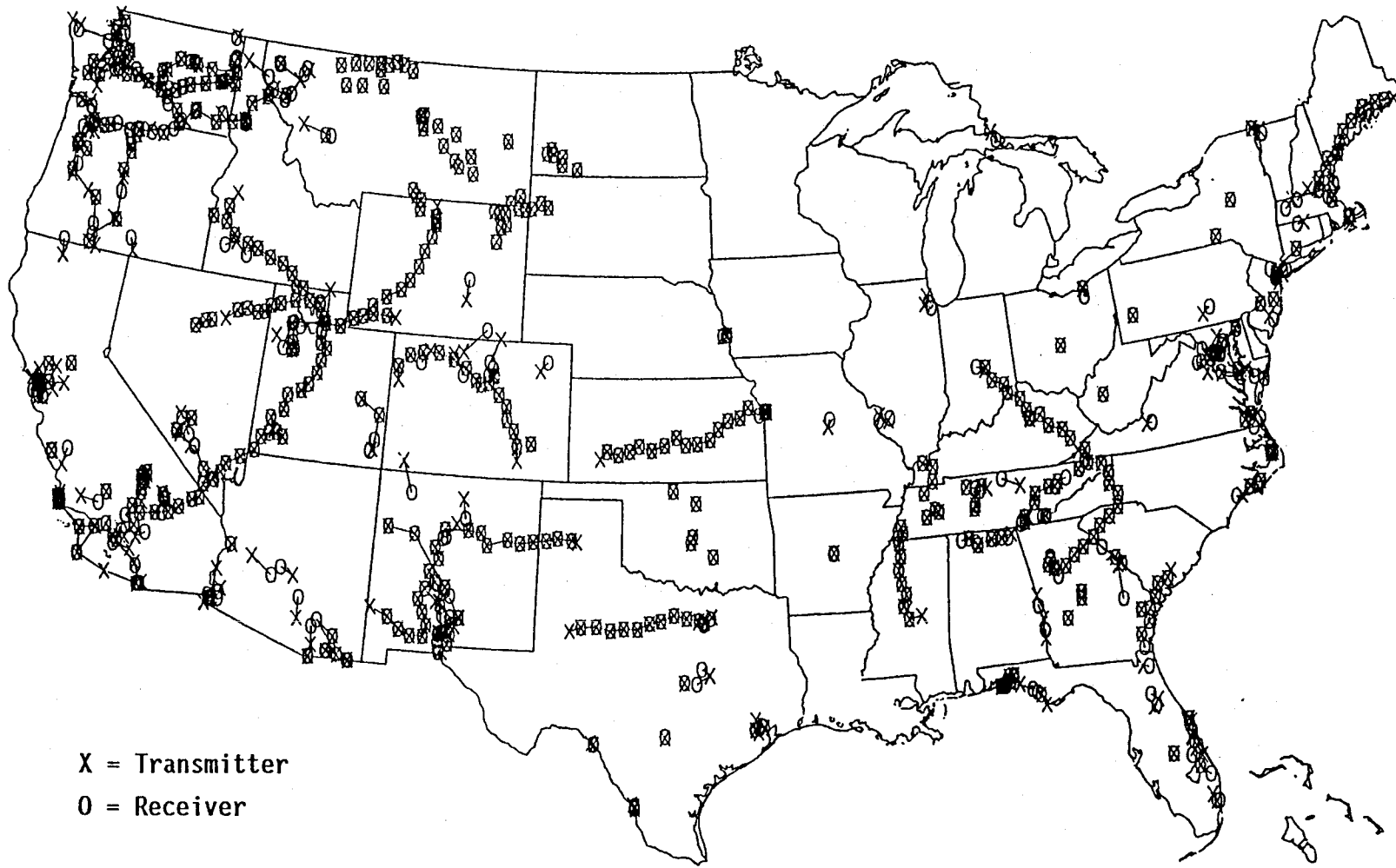
Figure 3-1.   Geographical distribution of frequency assignments in the 7750-7900 MHz band.

TABLE 3-3

REFERENCE SYSTEM CHARACTERISTICS
FOR THE 7750-7900 MHz BAND

Transmitter Power	1.0	W
Bandwidth	20.0	MHz
Antenna Gain	40.0	dBi
Effective Antenna Height	88.4	m
(290.0 ft.)		
Received Carrier Power	-57.1	dBW

areas overlap. Circular patterns on Figure 3-2 (e.g. at the western end of the Florida panhandle), generally indicate transportable systems used at military installations.

Figure 3-3 shows the total area and the percent of area of the contiguous United States having each value of SUB. The histogram shows that for 60% of the area of the contiguous United States, less than 10% of the spectrum in the 7750-7900 MHz band is used. For 10% of the CONUS area, all 150 MHz of the band is used.

The spectrum-area use product (SAUP) for the 7750-7900 MHz band is 4.0×10^8 MHz-km^2, which translates into a spectrum-area use index (SAUI) of 26%.

Spectrum Use Factor

Contours of the SUF for the 7750-7900 MHz band are shown in Figure 3-4. These contours correspond to a probability of use of 0.1, 0.5 and 0.9. While the SUB calculations assume that the reference system antenna mainbeam is directed at the assigned system, the SUF calculations assume that all azimuths are equally likely for the reference system antenna. This generally results in smaller contours.

Figure 3-5 shows the total area and the percent of area of the contiguous United States having each value of SUF. The histogram shows that little or none of the spectrum in this band is used with less than a 10% probability for nearly 90% of the CONUS. Nearly 10% of the CONUS area has a SUF value of 0.1 or 0.2 while only 1.5% of the area is totally used.

The spectrum use index for the 7750-7900 MHz band is 5% (.05) based on SUF values in the data base.

The examples shown in Figure 3-4 evaluated spectrum usage for the entire CONUS. It is also possible to use the SUM technique to display the results over a much smaller geographic area such as a state, city or smaller area. Based on the SUM model as currently configured, Figure 3-6 illustrates the spectrum use factor for the 7750-7900 MHz band in the Baltimore, MD and Washington, D.C. area. By focusing on a small area such as this, much more detail is possible than in a U.S.-wide display. From this example, it is seen that this band is more intensely used in the Washington area and less so in the Baltimore area. At this level of detail, it will be possible to examine the effects on spectrum use by individual transmitters and receivers. This type of detailed results will also be useful in graphically showing effective and ineffective spectrum management procedures and regulations.

The preceding example has shown that the SUM technique can be used to examine a particular area in detail. Additional magnification of an area could also be made. However, as with any analytical procedure, the accuracy of the output depends upon the input data, the assumptions and the method used. The factors affecting the accuracy of the SUM model can be broken into four major groups:

1. The propagation loss along both the desired and interference paths is calculated using a model that does not consider topography, except for the height of the transmitter site above the surrounding terrain.

2. The radiation patterns of the antennas are based on envelope patterns that do not consider the nulls between the pattern lobes.

3. The signal bandwidth, off-tuning and protection-ratio assumptions also effect the interference calculations.

4. The locations of the assigned stations are, at best, specified to the nearest second of latitude and longitude.

Currently the spacing between test points is limited by the software to one minute. There is theoretically, however, no limit to the spacing that could be shown on a plot. However, the factors described above limit the use of small spacings. The present use of one minute spacing appears to be sufficiently accurate unless a more detailed propagation loss methods is chosen. The SUM maps are therefore limited to details of approximately one minute (approximately one mile).

SUMMARY

The 7750-7900 MHz band is allocated for and used exclusively by the Federal Government. There are currently 937 assignments to stations in this band used predominantly for conventional fixed microwave transmission by the DOD, DOE, and FAA. Functional uses include support for air traffic control, electrical power transmission control, and military base and test range communications. The assignments are geographically dispersed throughout much of the U.S. The majority of assignments are located in the western states, along the East Coast and in the Tennessee Valley Authority (TVA) area. Few assignments are found in the midwest and north central states.

The spectrum use bandwidth data base generated for this band confirmed this geographic distribution of spectrum usage in the band. Particular areas of relatively heavy spectrum use are found in portions of the western states along the East Coast and the TVA area. The results show that in approximately 60% of the area of the contiguous U.S., less than 10% of the spectrum is used.

On the other hand, in 10% of the area of the contiguous U.S., all 150 available MHz is used. The spectrum area used by existing systems in the 7750-7900 MHz band is approximately 400 million MHz-km^2 which is 26% of the total spectrum area available in this band in the contiguous U.S.

The results of the spectrum use factor data base shows similar geographic distribution trends. However, the technical assumptions used in calculating the spectrum use factor are less conservative, i.e., less worst case, than in calculating the spectrum use bandwidth. These results show that approximately 90% of the area of the contiguous U.S. is lightly used in this band and only 1.5% of the area is totally used. An overall index of the spectrum use factor data base is 5% which represents the extent of use of the band.
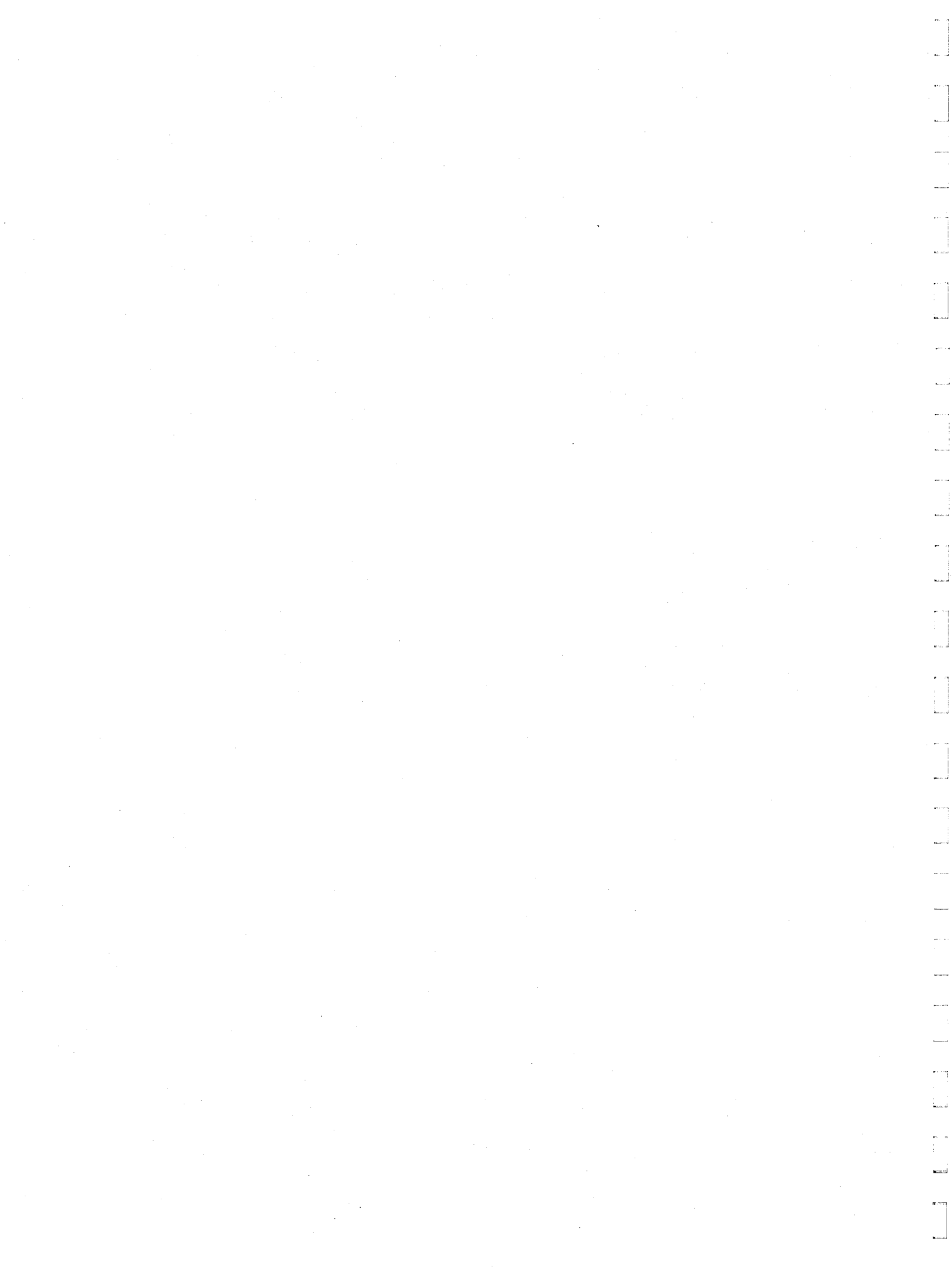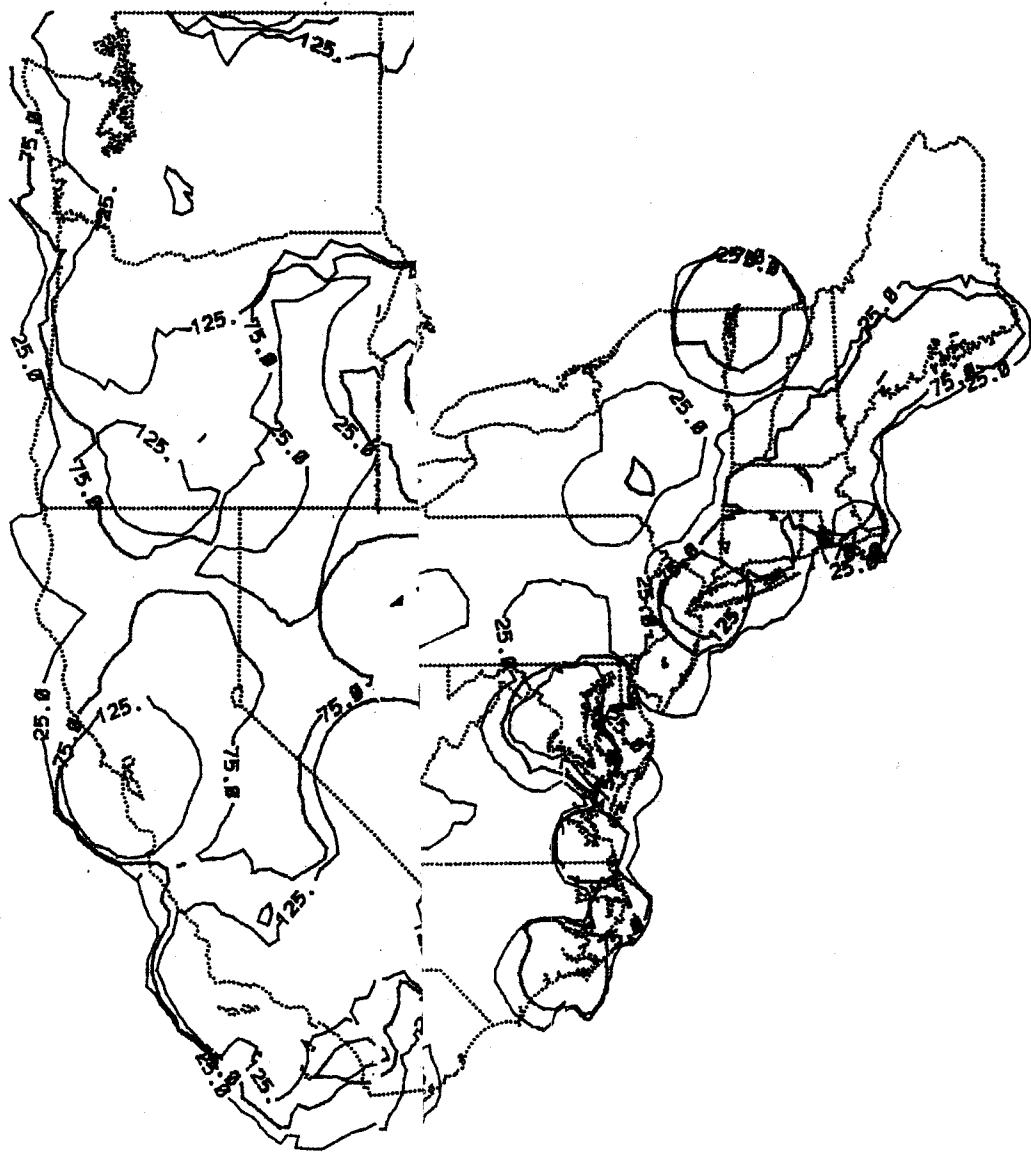
Figure 3-2.   Contours f(
            MHz, 75 MH
            MHz Band.
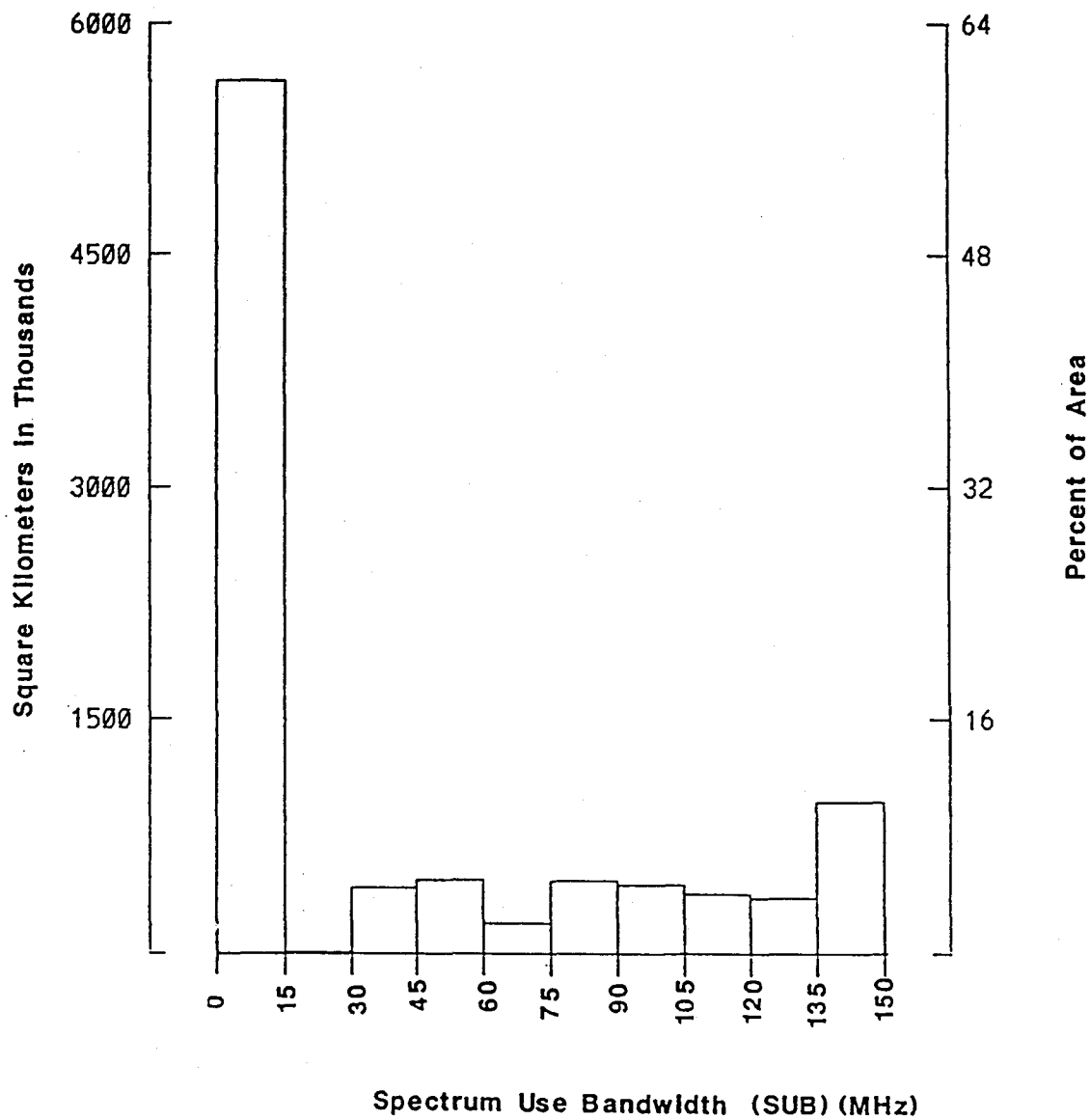
Figure 3-3.   Area and Percent of Area for Various Values of Spectrum Use Bandwidth (SUB) in the 7750-7900 MHz Band.

Figure 3-4.   Contours f
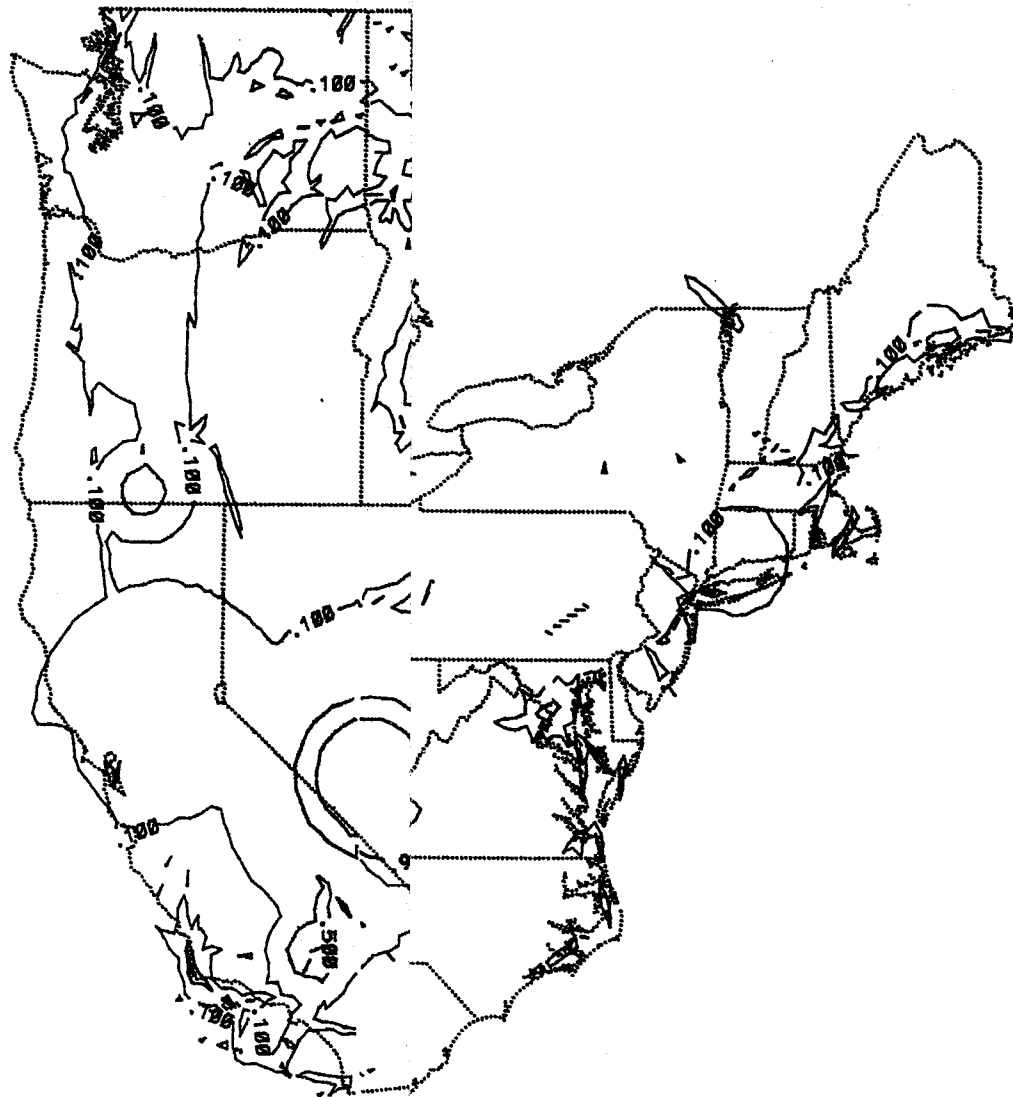   0.1 (10%),
               7750-7900
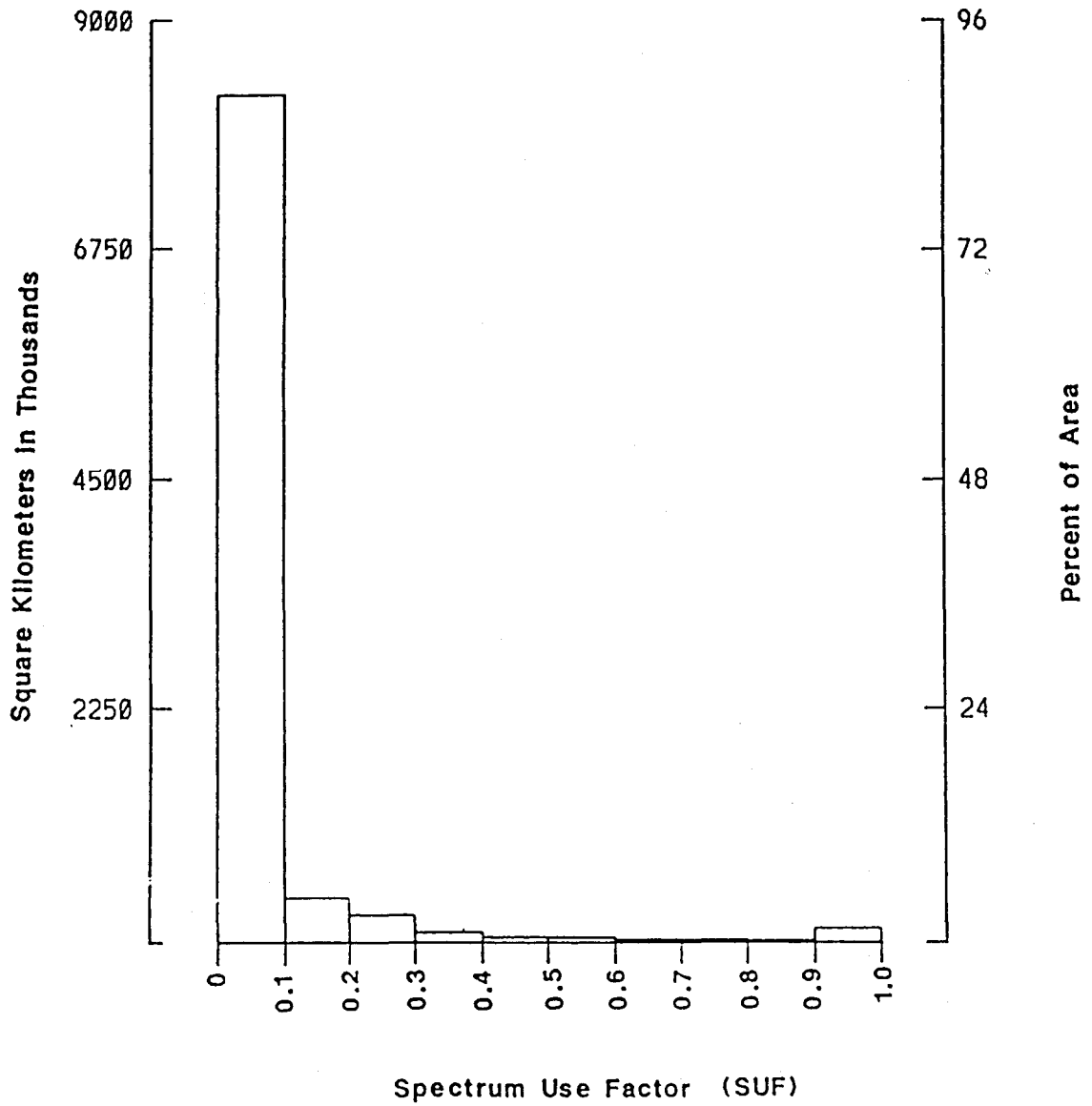
Figure 3-5.   Area and percent of area for various values of the spectrum use factor (SUF) in the 7750-7900 MHz band.
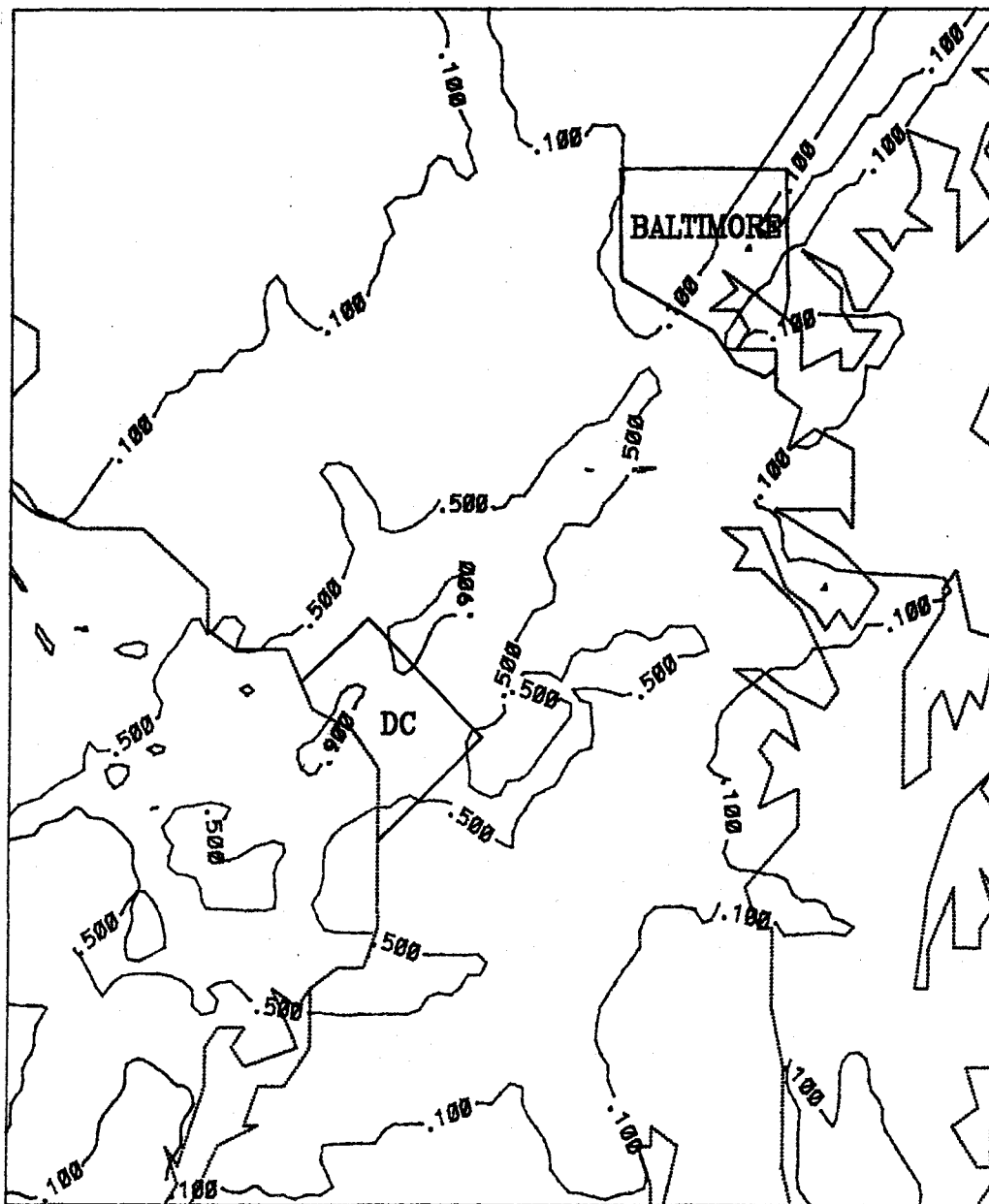
Figure 3-6   Spectrum Use Factor (SUF) for the Washington, DC-
              Baltimore, MD area in the 7750-7900 MHz band.

SECTION 4

ANALYSIS OF THE 1710-1850 MHz BAND

The 1710-1850 MHz band was the second frequency band chosen for inclusion in the SUM data base. This government band includes fixed, mobile and space services, and has far more assignments than the 7750-7900 MHz band. Therefore, it provides a more general case for analysis. (Please note that for printing purposes, Figures 4-2 through 4-9 appear at the end of the section.)

FREQUENCY ALLOCATIONS

The 1710-1850 MHz band is part of the 1710-2290 MHz band, which is allocated to the fixed and mobile services (see TABLE 4-1). Portions of the larger band are allocated, mostly by footnotes, to various space services. In the national table, the 1710-1850 MHz and 2200-2290 MHz bands are allocated almost exclusively for government use. The 1850-2200 MHz band is allocated for nongovernment use with government space services allocated by several footnotes.

Within the U.S., the 1710-1850 MHz band is allocated to the government fixed and mobile services on a primary basis. In the 1761-1842 MHz band, footnote G42 provides for space command, control, range, and range rate system uplinks on a co-equal basis with the fixed and mobile services. Such allocations are subject to Article 14 agreement under international footnote 745. Footnotes 722 and US256 provide for passive operations below 1727 MHz and specifically in the 1718.8-1722.2 MHz band. These operations are not protected.

TABLE 4-1

1710-2290 MHz ALLOCATIONS

INTERNATIONAL			UNITED STATES				
Region 1 MHz	Region 2 MHz	Region 3 MHz	Band MHz *1*	National Provisions *2*	Government Allocation *3*	Non-Government Allocation *4*	Remarks *5*
1710-2290 FIXED Mobile	1710-2290 FIXED MOBILE		1710-1850	US256 722	FIXED MOBILE G42		
			1850-1990			FIXED	
			1990-2110	US90 US111 US219 US222		FIXED MOBILE NG23 NG118	
722 744 746 747 748 750	722 744 745 746 747 748 749 750		2110-2200	US111 US252		FIXED NG23	
			2200-2290	US303	FIXED (LOS*only) MOBILE (LOS only including aeronautical telemetering, but excluding flight testing of manned aircraft) SPACE RESEARCH (Space-to-Earth) (Space-to-space) G101		*Line of sight

The following footnotes apply to the 1710-1850 MHz band:

722—In the bands 1 400–1 727 MHz, 101–120 GHz and 197–220 GHz, passive research is being conducted by some countries in a programme for the search for intentional emissions of extra-terrestrial origin.

744—The band 1 718.8–1 722.2 MHz is also allocated to the radio astronomy service on a secondary basis for spectral line observations. In making assignments to stations of other services to which the band is allocated, administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from space or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 343 and 344 and Article 36).

745—Subject to agreement obtained under the procedure set forth in Article 14 and having particular regard to tropospheric scatter systems, the band 1 750–1 850 MHz may also be used for space operation (Earth-to-space) and space research (Earth-to-space) services in Region 2, in Afghanistan, Australia, India, Indonesia, Japan and Thailand.

746—Additional allocation: in Bulgaria, Cuba, Hungary, Mali, Mongolia, Poland, the German Democratic Republic, Roumania, Czechoslovakia and the U.S.S.R., the band 1 770–1 790 MHz is also allocated to the meteorological-satellite service on a primary basis, subject to agreement obtained under the procedure set forth in Article 14.

US256—Radio astronomy observations may be made in the band 1718.8–1722.2 MHz on an unprotected basis. Agencies providing other services in this band in the geographic areas listed below should bear in mind that their operations may affect those observations, and those agencies are encouraged to minimize potential interference to the observations insofar as it is practicable.

National Astronomy and Ionosphere Center Arecibo, Puerto Rico	Rectangle between latitudes 17°30'N and 19°00'N and between longitudes 65°10'W and 68°00' W.
Haystack Radio Observatory Tyngsboro, Massachusetts	Rectangle between latitudes 41°00'N and 43°00'N and between longitudes 71°00'W and 73°00'W.
National Radio Astronomy Observatory Green Bank, West Virginia	Rectangle between latitudes 37°00'N and 39°15'N and between longitudes 78°30'W and 80°30'W.
National Radio Astronomy Observatory Socorro, New Mexico	Rectangle between latitudes 32°30'N and 35°30'N and between longitudes 106°00'W and 109°00'W.
Owens Valley Radio Observatory Big Pine, California	Two contiguous rectangles, one between latitudes 36°00'N and 37°00'N and between longitudes 117°40'W and 118°30'W and the second between latitutdes 37°00'N and 38°00'N and longitudes 118°00'W and 118°50'W.
Hat Creek Observatory Hat Creek, California	Rectangle between latitudes 40°00'N and 42°00'N and between longitudes 120°15' W and 122°15'W.

G42—Space command, control, range and range rate systems for earth station transmisssion only (including installations on certain Navy ships) may be accommodated on a co-equal basis with the fixed and mobile services in the band 1761–1842 MHz. Specific frequencies required to be used at any location will be satisfied on a coordinated case-by-case basis.

Internationally, the space operation and space research uplinks provided under footnote 745 cover the 1750-1850 MHz band. Also, several administrations have an additional primary allocation for the meteorological-satellite service in the 1770-1790 MHz band under footnote 746.

USE OF THE BAND

Major Users

TABLE 4-2 shows the distribution of GMF frequency assignments in the 1710-1850 MHz band by agency and service. The column marked "earth-to-space links" represents tracking and telecommand uplinks. The column marked "other" represents experimental stations, a space-to-space assignment in the space research service and a mobile radiolocation assignment. Since some assignments have more than one station class, the "total of assignments" may be less than the sum of the numbers in the six columns to the left. For computation of the "percent of fixed assignments," the smaller of the "fixed service" and "total assignments" numbers was used to represent the number of fixed service assignments for each agency. The data in this table was current as of April 14, 1988.

TABLE 4-2

DISTRIBUTION OF ASSIGNEMENTS BY AGENCY
AND SERVICE IN THE 1710-1850 MHz BAND

AGENCY	FIXED SERVICE	MOBILE SERVICE	AERO-NAUTICAL MOBILE SERVICE	LAND MOBILE SERVICE	EARTH-TO-SPACE LINKS	OTHER	TOTAL ASSIGN-MENTS	% OF ASSIGN-MENTS	% OF FIXED ASSIGN-MENTS
A	1270	0	0	0	0	0	1268	24.2	28.4
AF	153	33	62	0	350	195	599	11.4	3.4
AR	626	23	4	24	0	41	711	13.6	14.0
C	11	0	0	0	0	0	11	0.2	0.2
CG	141	0	0	0	0	0	141	2.7	3.2
DOE	616	1	2	3	0	0	622	11.9	13.8
FAA	216	0	0	1	0	1	218	4.2	4.8
FEMA	26	0	0	0	0	0	26	0.5	0.6
I	285	0	0	0	0	0	285	5.4	6.4
J	579	0	0	0	0	0	579	11.1	13.0
N	347	181	19	0	0	14	559	10.7	7.8
NASA	10	8	1	0	0	4	23	0.4	0.2
NG	0	0	0	0	0	9	8	0.2	0.0
NSF	2	0	0	0	0	0	2	0.0	0.0
SI	4	0	0	0	0	0	4	0.1	0.1
T	35	0	2	0	0	0	37	0.7	0.8
TRAN	63	2	0	0	0	0	33	0.6	0.7
TVA	97	0	0	0	0	0	97	1.9	2.2
USPS	3	0	0	0	0	0	3	0.1	0.1
OTHER	8	0	0	0	0	0	8	0.2	0.2
TOTAL	4492	248	90	28	350	264	5234		
% BY SERVICE	82.1	4.5	1.6	0.5	6.4	4.8			

The use of the 1710-1850 MHz band is described in four SRAs published by NTIA.[12,13,14,15]   Figure 4-1 shows the geographic distribution of frequency assignments in the 1710-1850 MHz band.

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[12]   Hurt, G. and Crandall, G., *Spectrum Resource Assessment in the 1710-1850 MHz Band, Phase I - Background and Study Definition*, NTIA-TM-79-26, November 1979.

[13]   Hurt, G. and Crandall, G., *Spectrum Resource Assessment in the 1710-1850 MHz Band*, NTIA Report 80-47, September 1980.

[14]   Grant, W. and Chilton, C., *Spectrum Resource Assessment of the Fixed and Mobile Services in the 947-17,700 MHz Band*, NTIA Report 84-161, September 1984.

[15]   Matos, F., *Spectrum Resource Assessment of the Aeronautical Mobile Service between 400 MHz and 17.7 GHz*, NTIA Report 84-162, September 1984.
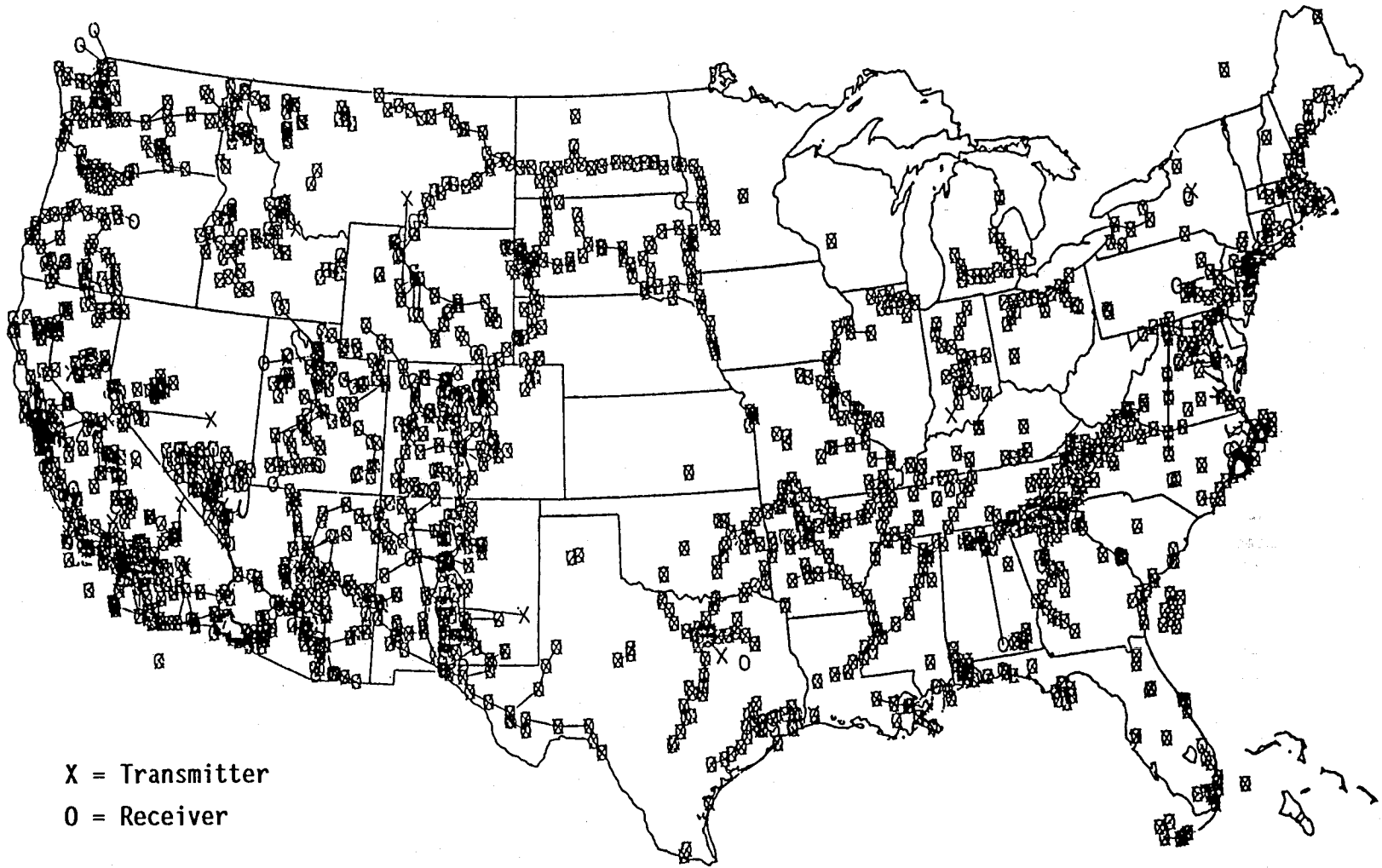
X = Transmitter

O = Receiver

Figure 4-1.   Geographical distribution of frequency assignments in the 1710-1850 MHz band.

Fixed Service. The 1710-1850 MHz band is the major government band for accommodating medium capacity line-of-sight microwave links. Fixed service assignments account for 82% of the assignments in the 1710-1850 MHz band and 99% of the non-military assignments. The primary applications include law enforcement networks, backbone trunking systems and control links for power, land and water management systems. The largest users include the Department of Agriculture (28%), the Army (14%), the Department of Energy (14%) and the Department of Justice (13%).

Mobile Service. Various assignments in the mobile services, including the mobile service, the aeronautical mobile service and the land mobile service, account for 7% of the 1710-1850 MHz assignments. Ninety-five percent of these assignments are to the military agencies. The primary land mobile system is the Defense Advanced Research Projects Agency (DARPA) Packet Radio system for transmission of digital data using spread spectrum multiple access techniques. Using the Packet Radio system, multiple mobile terminals can access a central station. Military aeronautical activities include air combat telemetry, scoring systems, air-to-ground video links and tactical weapons systems.

Space Systems. The Air Force Space Ground Link Subsystem (SGLS) accounts for an additional 6% of the assignments in the 1710-1850 MHz band. SGLS provides tracking, telemetry and command (TT&C) uplinks for both geostationary and non-geostationary DoD satellites via earth stations in Guam, Hawaii, New Hampshire and California. The SGLS system consists of twenty channels separated by 4 MHz over the 1761-1842 MHz band. A NASA frequency assignment provides a low-power TT&C link from the Space Shuttle to DoD payloads after release from the Shuttle.

Types of Systems

While fixed service systems with assignments in the 1710-1850 MHz band are generally of the point-to-point line-of-sight variety, several other types are represented in the GMF. As in the 7750-7900 MHz band, fixed service links

occasionally employ passive repeaters. U.S. Army assignments for tactical and training purposes often employ transportable stations. Military test ranges make use of timing distribution systems in the fixed service. These systems consist of a central transmitter with an omnidirectional antenna and numerous remote receivers with directional antennas. Finally, transhorizon systems, linking stations not within line-of-sight, are not excluded from this band as they are from the 2200-2300 MHz band. Though not numerous, these systems are significant in that they employ high power transmitters and large antennas.

Land mobile systems in this band generally consist of a land station and numerous mobile stations authorized to operate within a given area. Aeronautical mobile systems consist of line-of-sight air-to-ground, air-to-air or ground-to-air links.

Experimental classes of stations are again not included in the measure of spectrum use. Likewise, the radiolocation assignment, not in conformance with the allocations table, and the space research (space-to-space) assignment are not included.

REFERENCE SYSTEM CHARACTERISTICS

The characteristics of the reference system for the 1710-1850 MHz band are shown in TABLE 4-3. These characteristics are the median values of the fixed service assignments in this band.

TABLE 4-3

REFERENCE SYSTEM CHARACTERISTICS
FOR THE 1710-1850 MHz BAND

Transmitter Power	1.0	W
Bandwidth	1.6	MHz
Antenna Gain	28.0	dBi
Effective Antenna Height (350.0 ft.)	106.7	m
Received Carrier Power	-67.3	dBW

IMPLICATIONS OF OUTPUT

Spectrum Use Bandwidth

Figure 4-2 shows 20 MHz, 70 MHz and 120 MHz contours of the SUB for the 1710-1850 MHz band. Areas of heavy use (120 MHz or more) include most of the Southwest and the Southeast, the Atlantic coast to southern Maine, the Pacific coast and smaller areas throughout much of the United States. Only a few areas along the northern border have less than 20 MHz used.

Since mobile systems (especially aeronautical mobile systems) can affect large areas and obscure the effects of fixed service systems, another data base was generated using fixed service systems only. The contours for this data base are shown in Figure 4-3. This map shows areas of heavy use corresponding to the fixed service systems shown in Figure 4-1. For several areas, including northern New York and New England, the northern Great Lakes states and an area running from central Nebraska through south central Texas, little or none of the spectrum in this band is used. Circular patterns on Figure 4-3 (e.g. northern North Dakota), generally indicate transportable systems used at military installations.

Comparison of Figures 4-2 and 4-3 indicates that much of the congestion in the Southwest, the Southeast and the northern states from Maine to Minnesota is a result of mobile systems. Assignments shown in Figure 4-1 that do not affect Figures 4-2 and 4-3 are either systems not considered in the analysis or systems denying less than 20 MHz bandwidth, even in areas where use areas overlap.

Figure 4-4 shows the total area and the percent of area of the contiguous United States having each value of SUB. Figure 4-5 is similar, except that only fixed service systems are included.

The histogram for fixed service systems only is somewhat similar in appearance to the histogram for the 7750-7900 MHz band, but with only half as much area having very light use of the spectrum (34% vs. 60%). However, when

mobile and space systems are included, 30% of the area has the entire 140 MHz used.

The spectrum area used by existing systems in the 1710-1850 MHz band is 8.93×10^8 MHz-km^2 (61%) or 6.5×10^8 MHz-km^2 (45%) if only fixed service systems are included.

Another future use of the SUM data base will be to identify increases or decreases in spectrum use as a function of time. For example, the spectrum area used product for the 1710-1850 MHz band was 893 million MHz - km^2 for the April 1988 time period. A similar calculation for April 1987 shows the spectrum area used product to be 764 million MHz - km^2. This indicates that approximately a 17% increase in spectrum use occurred over a period of one year. The SUM data base is, therefore, also a valuable indicator of overall changes in spectrum use and is an effective tool to indicate changes and trends in spectrum forecasting.

Spectrum Use Factor

Contours of the SUF for the 1710-1850 MHz band are shown in Figure 4-6. These contours correspond to a probability of use of 0.1, 0.5 and 0.9. While the SUB calculations assume that the reference system antenna mainbeam is directed at the assigned system, the SUF calculations assume that all azimuths are equally likely for the reference system antenna. This generally results in smaller contours. In this figure, circular use areas around Air Force earth stations in southern California and southern New Hampshire can be identified.

Figure 4-7 shows the SUF contours for the 1710-1850 MHz band based only on fixed service assignments. On this map, the areas in the northeastern and south central United States having little or none of the spectrum used are more pronounced.

Figure 4-8 shows the total area and the percent of area of the contiguous United States having each value of SUF. Figure 4-9 is similar, except that only fixed service systems are included.

Again, the histogram for fixed service systems only is somewhat similar in appearance to the histogram for the 7750-7900 MHz band, but with much less area having none of the spectrum used (56% vs. 86%). When mobile and space systems are included, the area having the entire 140 MHz used increases dramatically (from 3% to 18%).

The spectrum use index for the 1710-1850 MHz band is 42% considering systems of all services and 17% for fixed service systems only.


SUMMARY

The 1710-1850 MHz band is allocated for and used exclusively by the Federal Government. There are currently 5,234 assignments to stations in this band used predominantly for fixed microwave transmissions, various airborne mobile functions, and certain earth-to-space transmissions. Functional uses include electrical power transmission control, resource management, law enforcement, and military base and test range communications. Assignments are geographically dispersed throughout much of the U.S. A significant number of assignments are found in most states with only a few central states showing a limited number of assignments.

The spectrum use bandwidth data base generated for this band confirmed the wide geographic distribution of spectrum usage and indicated a relatively heavy usage over large areas of the country. Much of this spectrum congestion is a result of airborne mobile systems located in the southwest, southeast, and northeast.

The results show that approximately 12% of the area of the contiguous U.S. is unused in this band. On the other hand, in 30% of the area of the contiguous U.S., all 140 available MHz is used. The spectrum-area used by

existing systems in the 1710-1850 MHz band is approximately 900 million MHz-km^2 which is 61% of the total spectrum-area available in this band in CONUS.

The results of the spectrum use factor data base shows similar geographical distribution trends. However, the technical assumptions used in calculating the spectrum use factor are less conservative, i.e., less worst case, than in calculating the spectrum use bandwidth. These results show that approximately 30% of the area of the contiguous U.S. is unused in this band, whereas 19% of the area is totally used. The spectrum use index is 17% which represents relatively heavy use of the spectrum.
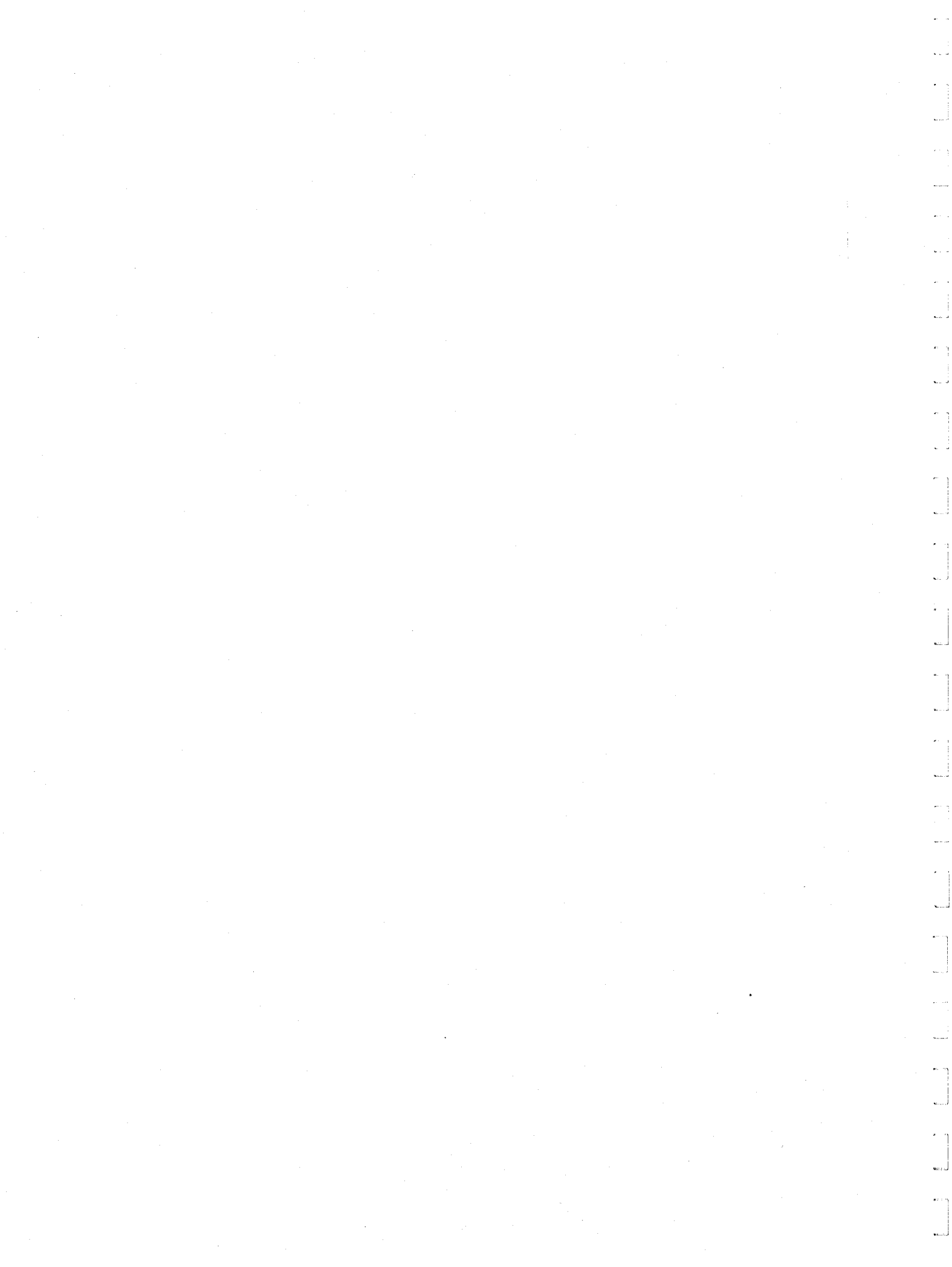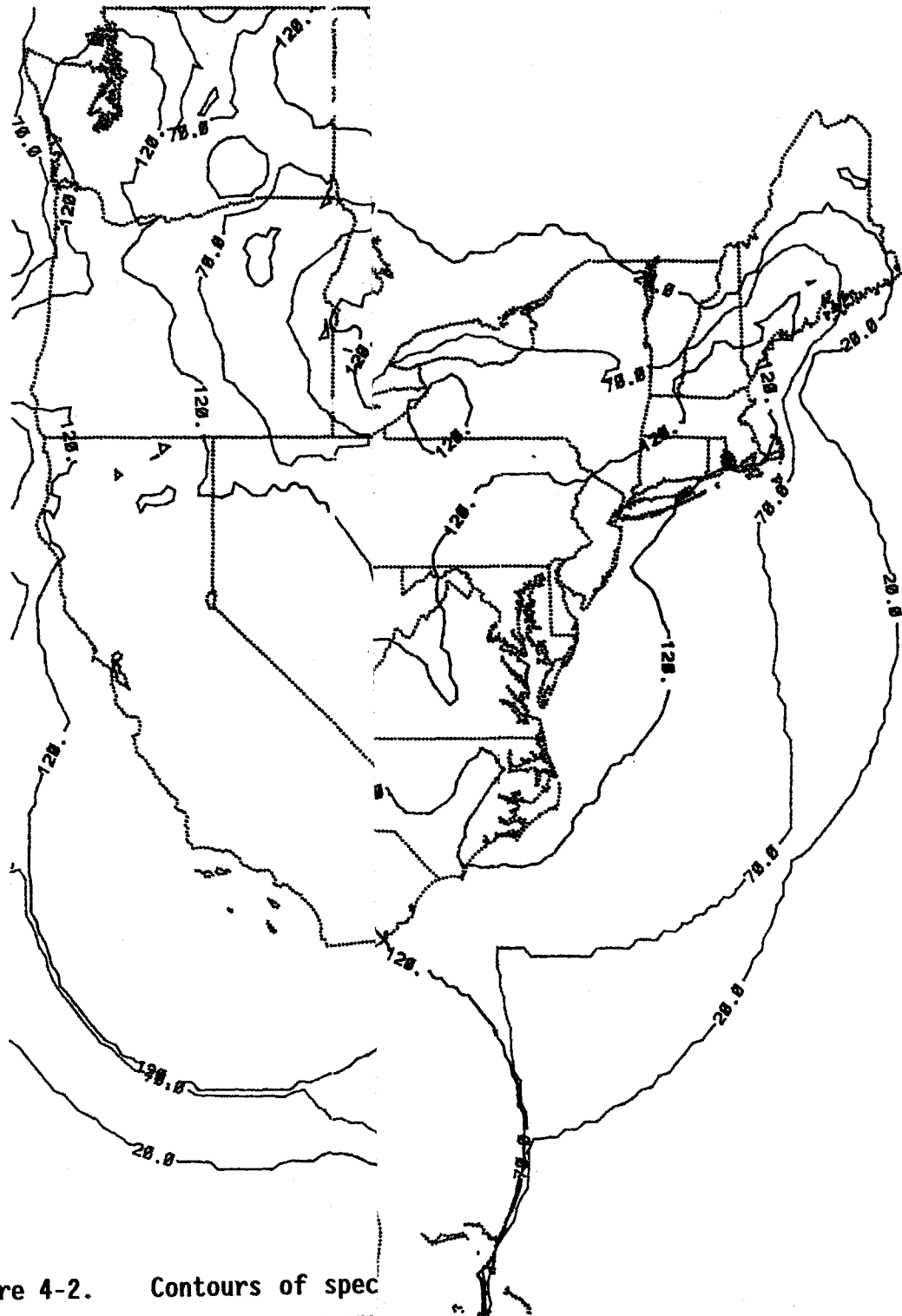
Figure 4-2.   Contours of spec
of 20 MHz, 70 MH;
1850 MHz band.
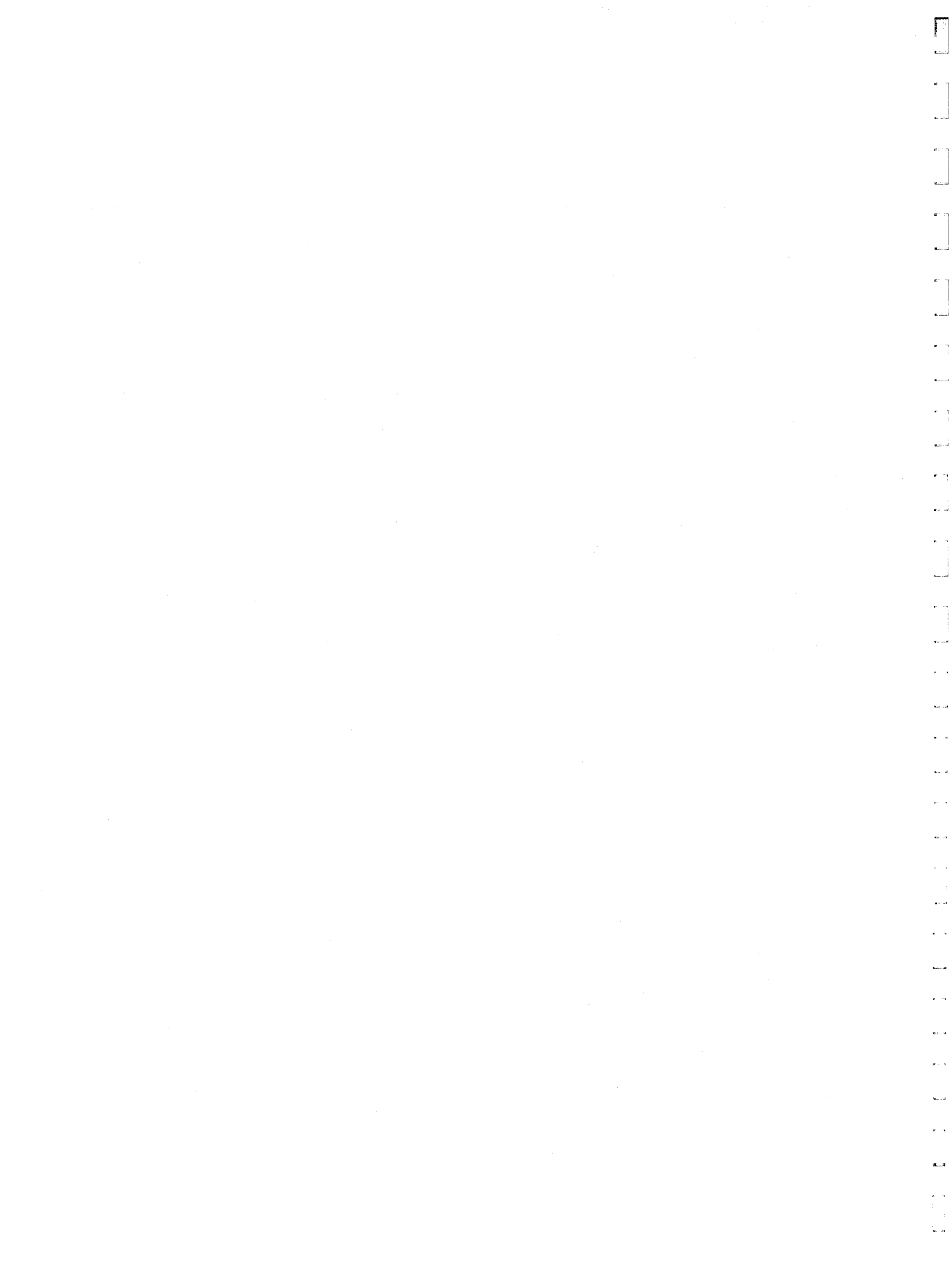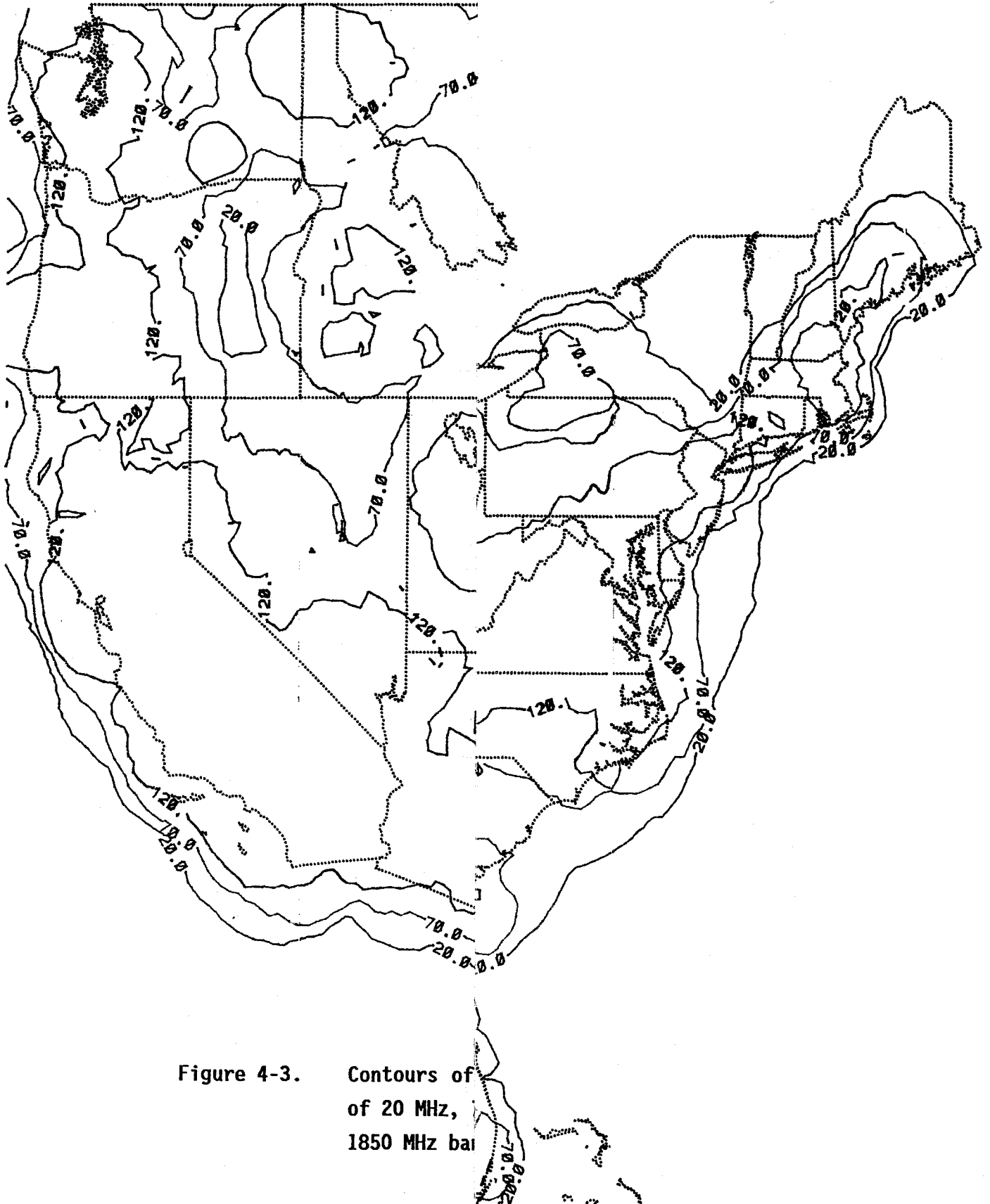
Figure 4-3.   Contours of
of 20 MHz,
1850 MHz bar
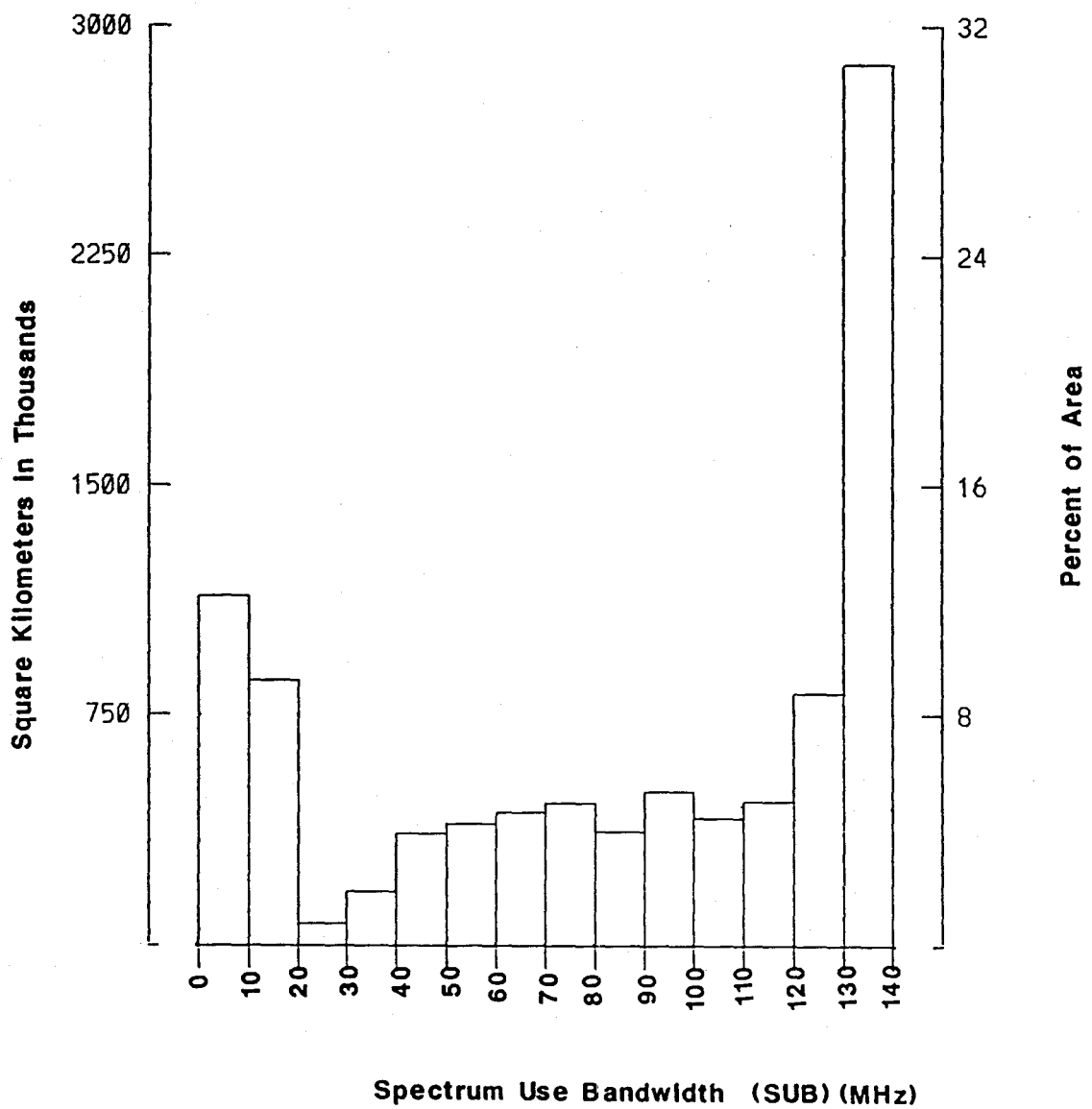
Figure 4-4.   Area and percent of area for various values of spectrum use bandwidth (SUB) in the 1710-1850 MHz band.
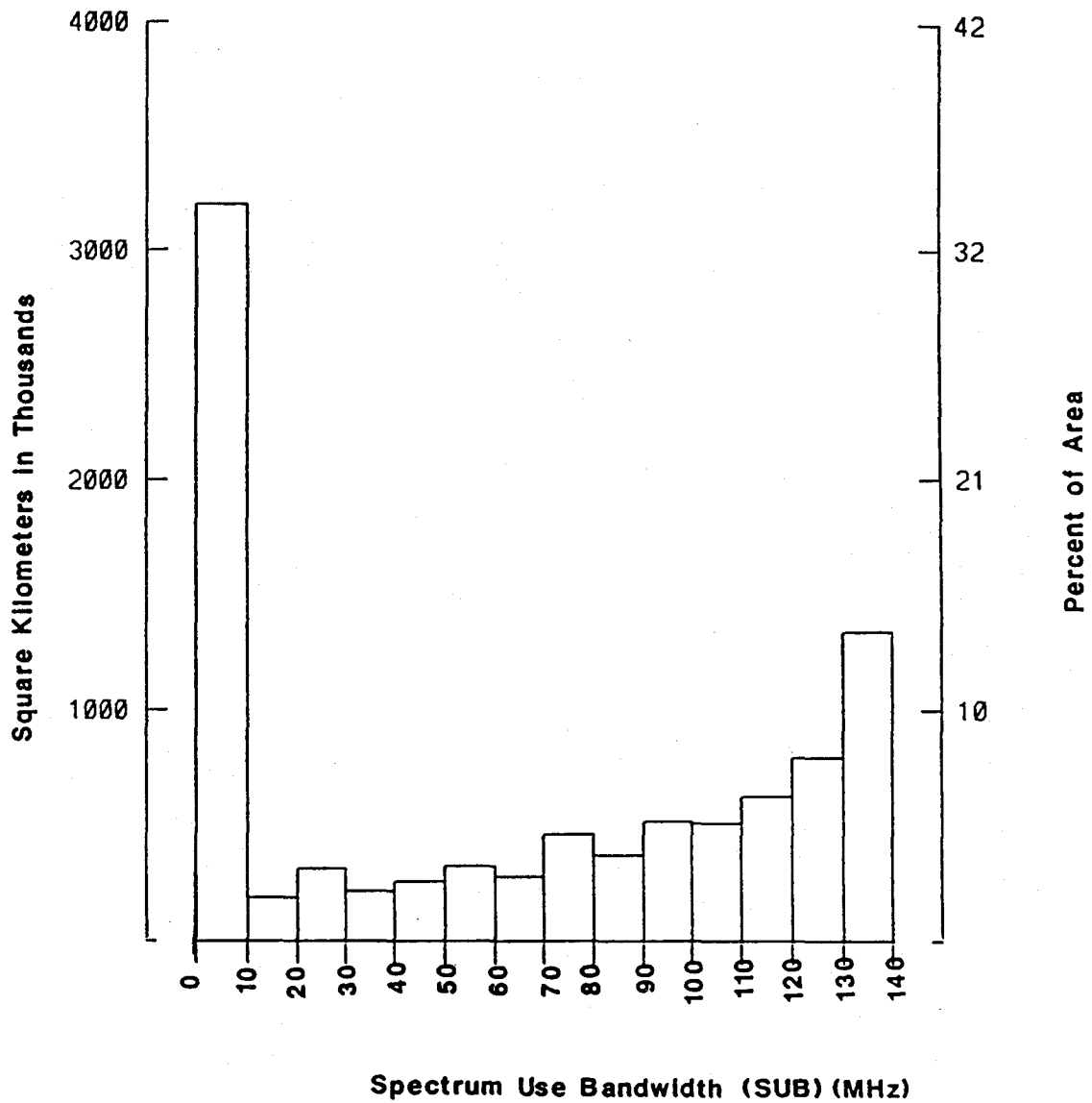
Figure 4-5. Area and percent of area for various values of spectrum use bandwidth (SUB) in the 1710-1850 MHz band (fixed service only).

Figure 4-6.   Contours for
               0.1 (10%),
               1710-1850 MH

Figure 4-7.   Contours for
               0.1 (10%), (...)
               1710-1850 MH
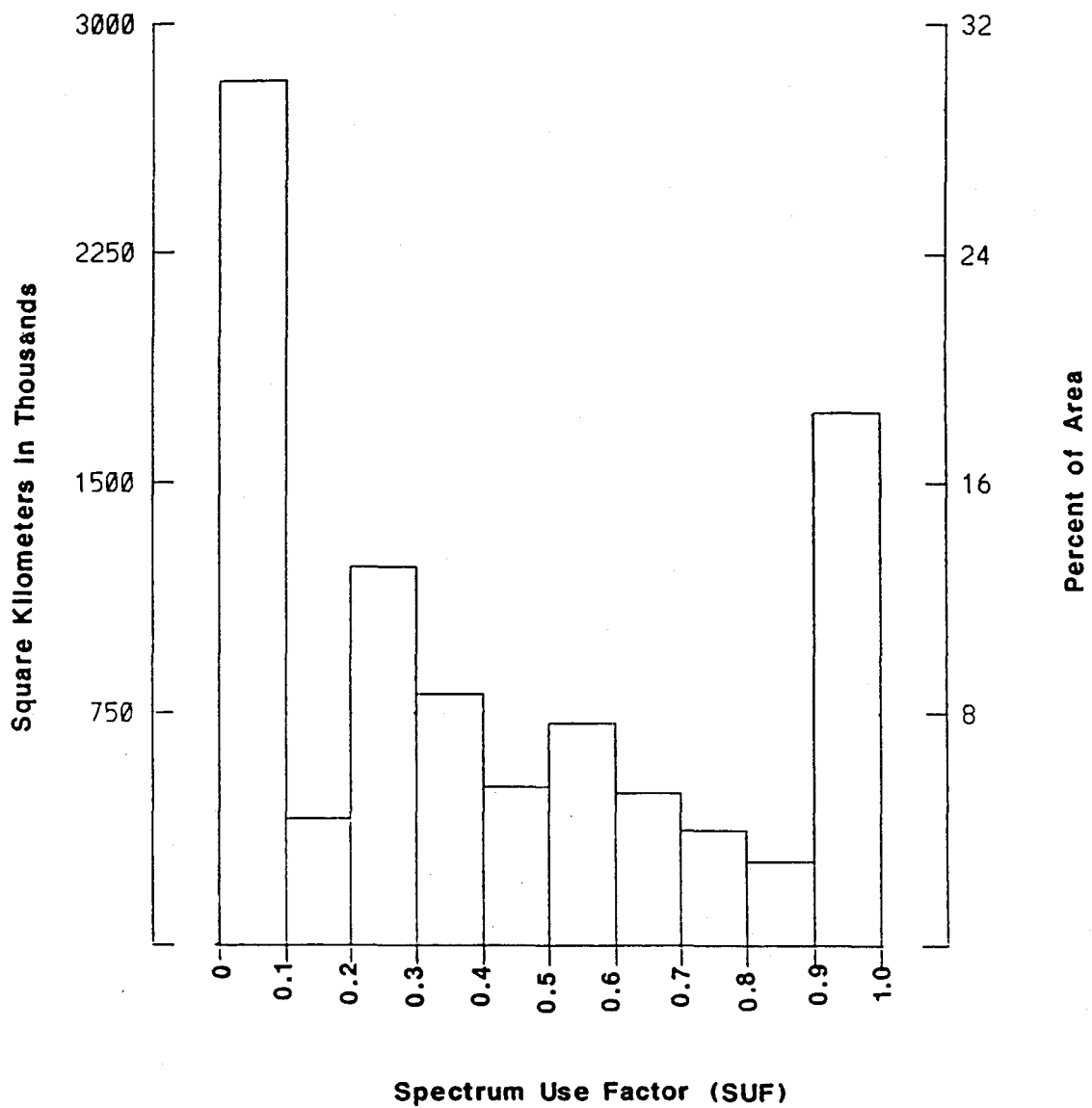
Figure 4-8. Area and percent of area for various values of the spectrum use factor (SUF) in the 1710-1850 band.
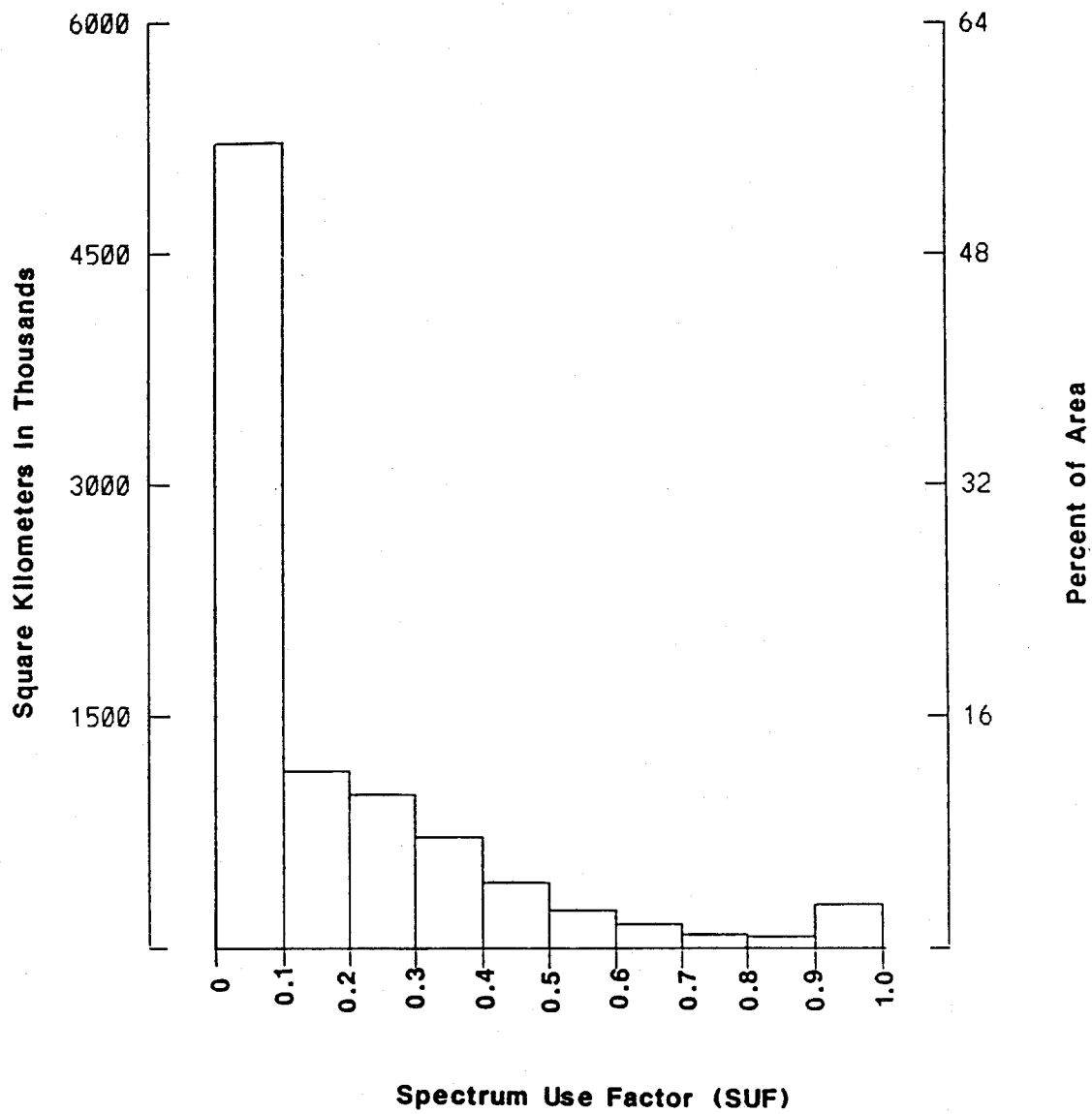
Figure 4-9.   Area and percent of area for various values of the spectrum use factor (SUF) in the 1710-1850 band.

SECTION 5
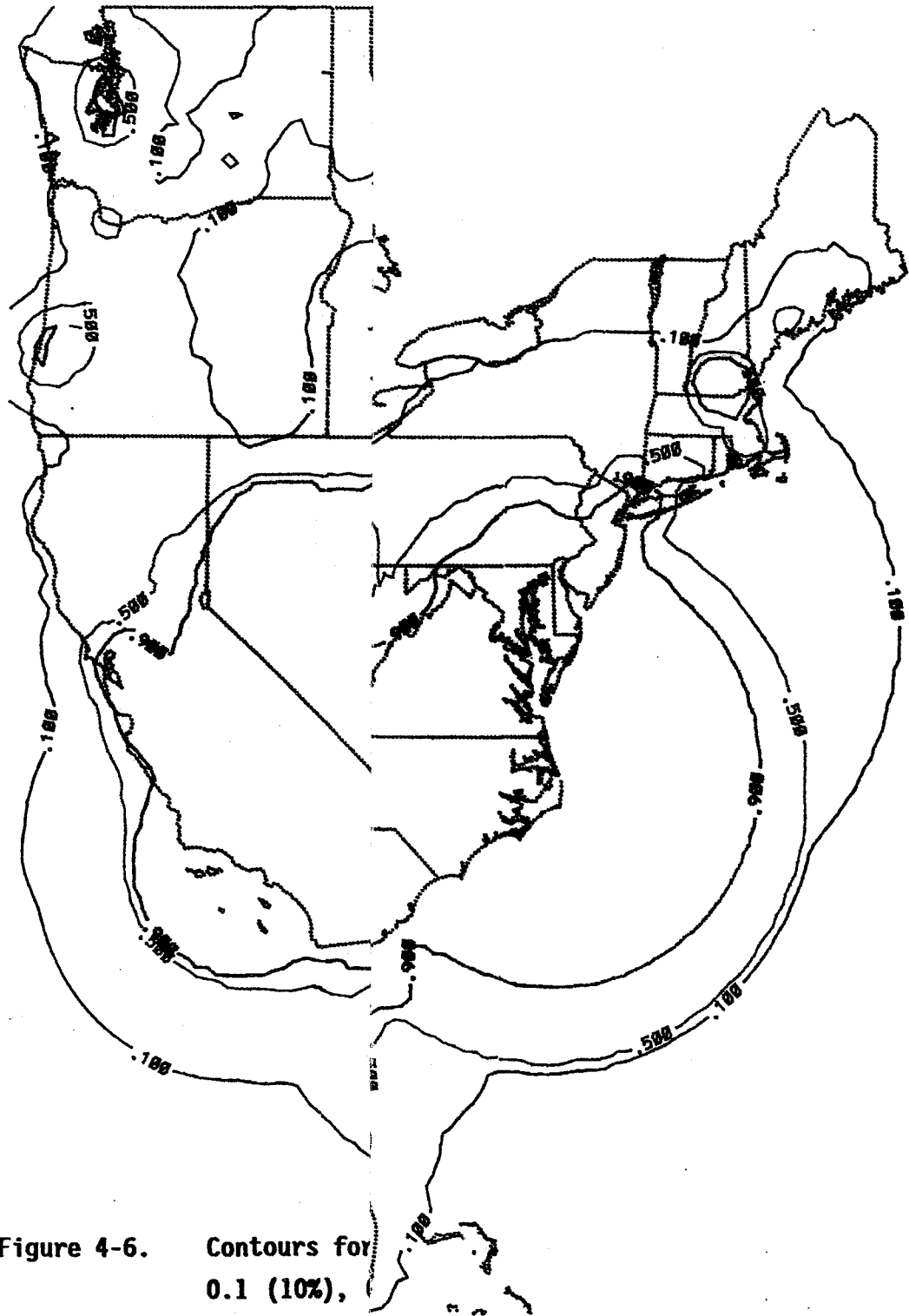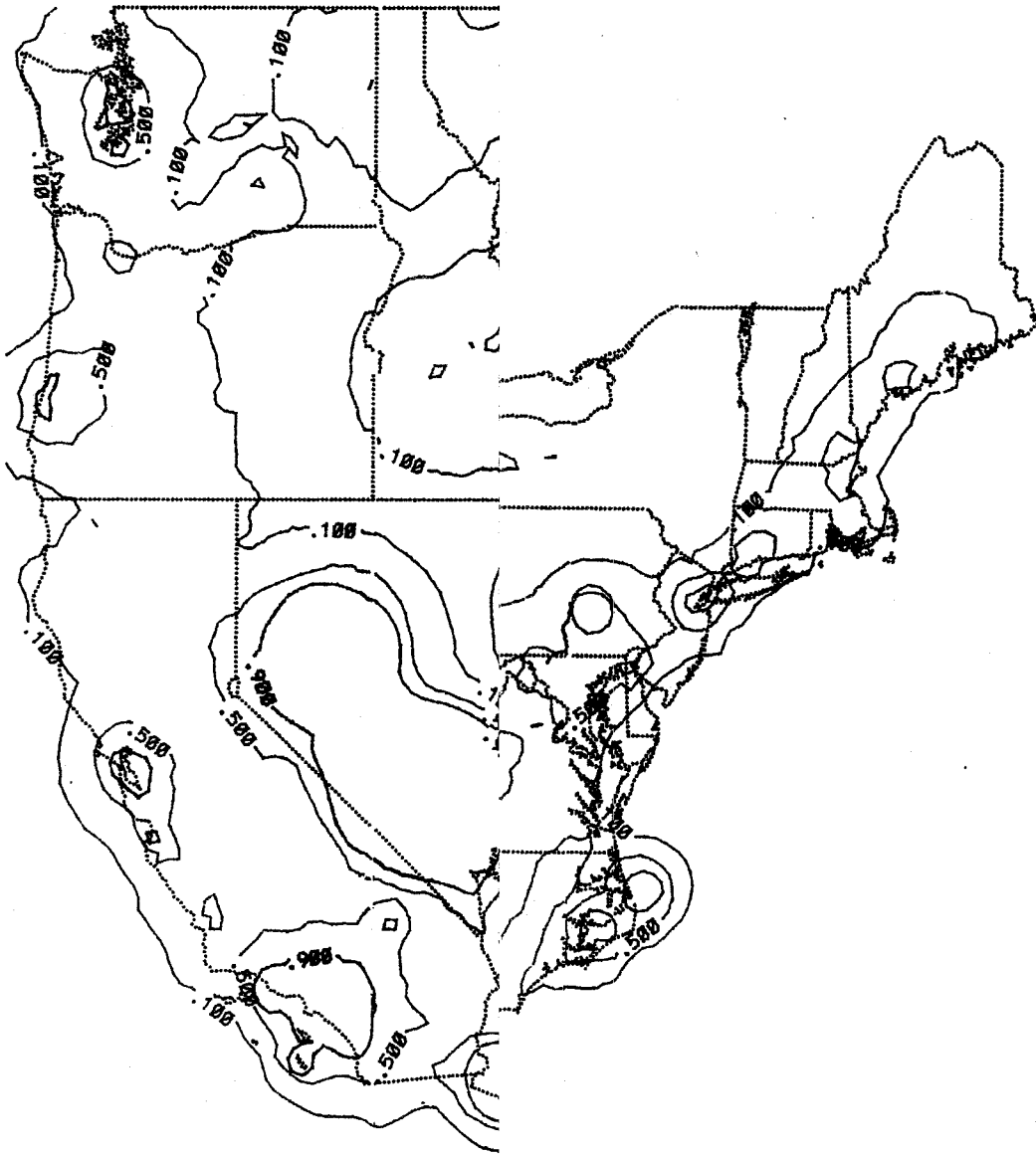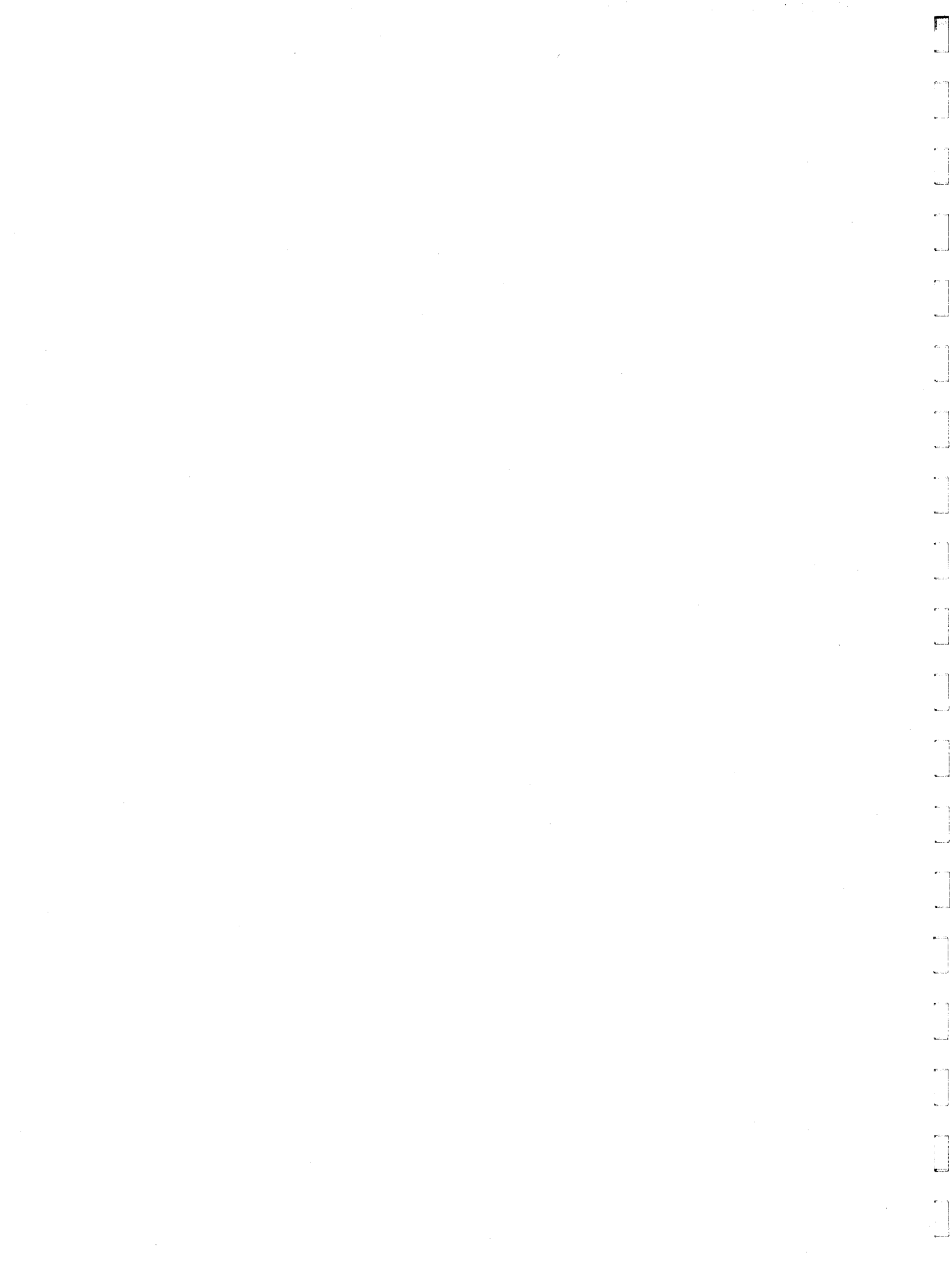
PLANS FOR FUTURE SUM ACTIVITIES

GENERAL

The SUM Data Base is being developed as a method to quantify spectrum usage. The output from this data base will serve as a key technical tool to assure that the spectrum is effectively managed and efficiently used. The development of the data base is proceeding based on planning for present and future activities. The principal goals achieved during this period include achieving a fully functional computer model and data base for two important government frequency bands. The future activity will include continuing development and refinement of the existing capability and application of the data base to additional frequency bands and radio services.

In the following paragraphs, the continuing development efforts are described in detail and an outline provided for future efforts. The development efforts can be categorized into: a) refinement, b) validation, c) expansion of scope, and d) applications. These elements are described below.

REFINEMENT

The SUM data base that has been previously described is fully functional for use in the NTIA spectrum management process. However, a number of engineering and automation improvements and refinements need to be made to enhance the effectiveness of the data base and the cases with which the results can be used. Planned automation and engineering enhancements are discussed below.

- **Radio propagation calculations.** The calculation of spectrum used is currently based on the characteristics of radio propagation over a smooth spherical earth. Specific terrain features are not considered. The

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effective antenna heights are computed based on stored values of average terrain elevation. These values will be updated to provide values using a smaller grid spacing to improve the accuracy of the results (see Appendix D for a detailed discussion of this problem). Improvements will also be made to permit calculation of radio propagation loss over specific terrain, using the NTIA terrain data base. This option will be practical only for detailed investigations of relatively small geographic areas because of expected long computer run times.

- **Output presentation.** The current data base provides outputs in two forms: 1) contours of MHz used for a given band over the U.S., and 2) contours of the probability of spectrum used in the U.S. These two results are expected to serve as basic visual aids in the analysis of most spectrum management issues. Future effort will be devoted to improving the "user friendliness" of the outputs.

- **Ease of data base use.** The current automated program requires use of 8 separate computer runs to develop a full CONUS presentation of results. Future improvements in the contour program are required to plot the U.S. in a single graph.

- **Processing of the Government Master File.** The current data base requires access to the Government Master File to determine key technical parameters for existing frequency assignments. Improvements will be made to the processing routines to extract additional technical parameters from the GMF to further refine the technical results.

- **Computer processing time.** The current automated data base requires up to 8 hours of computer run time to complete a typical frequency band in the U.S. (based on 3000 assignments per band and a grid spacing of 5 minutes). Future effort will identify time intensive elements of the data base process and to investigate methods to reduce the required computer run time. A reduction in run time is desirable to permit use of the data base on a production basis for bands with larger number of assignments.

- **Frequency dependent rejection.** Future efforts will aim towards improving the method used to calculate the frequency dependent rejection of receivers to off-tuned interfering signals. Currently, a single value is used for all cases. This will be replaced by a variable depending on specific modulation types.

- **Antenna gain.** Improvements will be made to the computer routines that calculate off-axis antenna gains. Currently, any gain greater than 10 dB is assumed to be a parabolic dish reflector antenna while those less than this value are assumed to be omnidirectional. Improvements will include an improved transition region from 6 dB to 20 dB that depends on frequency and other technical factors.

- **Interference criteria.** Currently the calculation of spectrum used is based on a single interference criterion representative of a typical fixed microwave system used at frequencies of 1800 and 8000 MHz. As additional frequency bands and radio services are added to the capability, the single interference criterion will be replaced by a variable criterion that depends upon the specific radio service and modulation type. This change will further improve accuracy of the data base results.

- **Reference system.** Modifications will be made to the current data base capability to permit use of reference systems other than the fixed service.

VALIDATION

The SUM data base capability described herein has been validated for technical correctness (see Appendix C). That is, given the stated assumptions, the values of spectrum used computed in the data base accurately portray the radio environment. As the previously described automation and engineering improvements are incorporated into the data base, additional, more

complex validation steps must be undertaken to assure validity of the results. The need also exists to validate the results of the data base from an operational standpoint. NTIA has for a number of years performed measurements of radio spectrum usage at various locations in the U.S. using the NTIA Radio Spectrum Measurement System (RSMS) Van. The results of these measurements have been compiled, analyzed, and used in support of the various spectrum management issues. These measurement results could be compared with the output of the SUM data base. This effort would further validate the results of the SUM data base and identify any additional "realism" that needs to be included in the technical approach.

EXPANSION OF SCOPE

The SUM data base is being developed in an evolutionary manner. Timely first results from the data base were required to demonstrate the viability of the concept. This also permitted early application of the concept. The initial phase of the effort, by necessity, was limited in scope. The results described in this report demonstrate that these initial goals have been achieved. However, the development of a comprehensive capability that addresses all radio services and all frequency bands is very complex. Across the entire radio spectrum, hundreds of different functional radio types are used. Each frequency band and each radio service has associated technical features peculiar to that band and/or service. In the paragraphs below, the scope of present and future phases of the SUM data base development effort is summarized.

As stated, the present phase described in this report was limited in scope. It focused on two important government frequency bands, 7750-7900 MHz and 1710-1850 MHz. Within these bands, three types of radio services are accommodated, namely, fixed, mobile and space operations. Study of these three service types permitted completion of the initial data base and validation of the concept. However, the NTIA authorizes 17 different services across the radio spectrum. These will be addressed in future phases.

Future efforts will continue to focus on the important or critical frequency bands and radio services used by the Federal Government. For example, several types of radio stations will require a modification of the basic concept to illustrate spectrum usage. Space stations are examples. Spectrum usage for space stations cannot be illustrated geographically over the country, but rather must be represented three dimensionally considering the geostationary satellite orbit. Spectrum usage for frequencies below about 30 MHz cannot be addressed using the current concept because of the long range interference effects of ionospheric radio propagation. Similarly, radio astronomy, military tactical and certain radiodetermination functions will need to be addressed in an alternative manner.

The principal areas of focus for future phases will be the bands used for fixed, mobile, and radiodetermination services. The development of trends such as this will prove useful in many aspects of spectrum management.

APPLICATION

The SUM data base will be applied within the NTIA spectrum management process in a number of ways. Several of these are listed below.

Technical standards. The results of the SUM data base will assist in the development of cost effective government spectrum standards. The SUM outputs will define geographic areas of the country where spectrum congestion is present such that restrictive standards are needed to assure efficient use of the spectrum. Similarly, areas of the country where the spectrum is less intensively used, less expensive relaxed standards are possible. This approach can help assure that NTIA spectrum standards are most effectively applied.

Spectrum Planning. The results from the SUM data base will be a major input in planning for future Federal agency radio communication systems to assure that spectrum will be available when the system is deployed. The graphical outputs will more clearly identify if, or under what restrictions,

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spectrum will be available for the new systems. NTIA certification can thus be better applied to minimize costly after-the-fact retrofits to assure compatible operation.

Frequency assignment. NTIA is currently developing a detailed computer model to analyze potential interference between new fixed (above 500 MHz) stations and existing stations. The model will assist NTIA and the federal agencies to select frequencies in bands that are spectrally congested. The SUM data base will serve as a very useful graphical supplement to that model.

Spectrum Resource Assessments (SRAs). Each year NTIA undertakes a number of technical studies to assess spectrum utilization, identify existing or potential compatibility problems, and recommend changes in spectrum management policies to promote efficient use of the radio spectrum. The use of the SUM data base in future SRAs will provide access to data not previously available. For example, the spectrum use bandwidth and spectrum use factors given in Section 3 and 4 are displayed geographically over the entire continental U.S.

It is also possible to display the results over a much smaller geographic area such as a state, city, or smaller area. Based on the SUM model as currently configured, Figure 3-6 illustrates a typical spectrum use factor for the 7750-7900 MHz band associated with the Baltimore, MD and Washington, D.C. area. By focusing on a small area such as this, much more detail is possible than in a U.S.-wide display. At this level of detail, it will be possible to examine the effects on spectrum use by individual transmitters and receivers. This type of detailed results will also be useful in efficient siting of new communication stations. The results may be useful in graphically showing effective and ineffective spectrum management procedures and regulations.

Another future use of the SUM data base in the SRA process·will be to identify increases or decreases in spectrum use as a function of time. For example, the spectrum-area used product for the 1710-1850 MHz band indicates that an approximate 17% increase in spectrum use occurred over a period of one

year.   These types of change can also be used to indicate changes and trends in spectrum forecasting.

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

GENERAL

A Spectrum Use Measure (SUM) data base and several associated models were developed to address the subject of spectrum usage in a radio frequency band. The data base output is intended for use with other technical and economic data to give an overall evaluation of frequency use and availability. Information from a frequency assignment data base provides the basic input data for the SUM analysis procedure. The SUM has been applied to the 7750-7900 MHz and 1710-1850 MHz bands to demonstrate the procedure and provide a basis for further evaluation of the technique. The initial evaluation indicates that it is feasible to measure spectrum usage, both graphically and with numerical indices, in a given radio frequency band, over large geographic areas, containing thousands of transmitting and receiving equipments. The following are conclusions and recommendations relevant to the SUM data base, procedures and applications.

CONCLUSIONS

1. It is generally feasible to perform the technical calculations necessary to measure spectrum usage in a frequency band over a large geographic area. The resulting SUM data base, can be used to develop a map that effectively indicates the overall use of radio frequency band, taking into account the technical characteristics of the transmitting and receiving systems.

2. A numerical index of the spectrum-geographical area used throughout a given study area can be calculated and used, with the SUM maps, as an

effective indicator of the overall spectrum-geographical area used. Changes of this index over time will indicate changes in the use of the frequency band under study.

3.   The SUM map overlays and indices are useful in several ways:

   a.   As a macro-level indicator of spectrum use in a study area in a portion of the spectrum.

   b.   As an indicator of the rate of change of the use and type of use of a portion of the spectrum in a study area.

   c.   As an aid in designing a radio communication network and in determining potential locations for transmitting and receiving stations.

4.   The SUM maps of the 7750-7900 MHz band indicate the band is used moderately throughout CONUS, with the central northern states having very light to no usage. The major congested areas are in the Western and the Southeastern states. This band was selected for the initial development and evaluation of the SUM data base procedure because previous Spectrum Resource Assessment (SRA) efforts indicated that only fixed service systems operate in the band and it is not heavily used. This band, therefore, provided a first test of the procedures and the results substantiated the earlier SRA analyses.

5.   The SUM maps of the 1710-1850 MHz band indicate the band is used heavily throughout CONUS, with the West and East Coast areas being the most crowded. The shared use between radiocommunication systems operating in the fixed and aeronautical-mobile services contributes to the congestion in the band. This band was selected for evaluation because previous SRA efforts had indicated that the band is heavily used by fixed service systems and is shared with a number of aeronautical mobile systems. This provided a test of multiservice calculation procedures for a heavily used band and the results substantiated the earlier SRA analysis.

6. The study indicates that examination of other services and bands using the SUM techniques is warranted.

7. Refinements to enhance the usefulness and the effectiveness of the SUM data base are desired. These include improvements to the engineering calculation procedures, user friendliness, ease of data base use, and computer processing time.

RECOMMENDATIONS

1. The SUM technique should be used to support the evaluation of other fixed service bands, both government and nongovernment.

2. The SUM techniques should be extended for use in the evaluation of other radio services.

3. The SUM technique should be refined to enhance its usefulness and effectiveness.

4. The enhanced SUM techniques should be:

   a. used to investigate the RF spectrum and determine (1) where congestion is likely to occur and (2) what standards and procedures can be used to alleviate problems identified.

   b. used to plan for future radiocommunication operations throughout the spectrum and as an aid in the planning of radio networks.

   c. made available to government agencies and spectrum users in the private sector.

APPENDIX A

SUM DATA BASE CREATION PROGRAMS

OVERVIEW

Flowchart

The SUM data base creation process consists of several steps as shown in Figure A-1. The starting point is the Government Master File (GMF) containing current Government frequency assignments. Records from the frequency band of interest are selected from the GMF and used as inputs to program PREUSAGE. PREUSAGE reformats the GMF data and performs preliminary calculations. The output of PREUSAGE is used as the input to program USAGE. USAGE calculates the geographic spectrum usage for an 8 degree wide by 24 degree long section of the US. It takes eight runs of program USAGE to completely cover the 48 contiguous states. The eight data sets together form the SUM data base of the US for the frequency band of interest. The data can be contoured using program SUMPLOT, or a tabulation of spectrum usage in square kilometers can be obtained from program HISTO.

Hardware/Software

The GMF data base is maintained on the NTIA Unisys 1100 computer. Programs PREUSAGE, USAGE, SUMPLOT, and HISTO reside on the NTIA MicroVAX II computer. All programs on the MicroVAX II were written in FORTRAN 77. Plots were created using GRAFkit graphics software and an HP 7550 8-pen plotter.
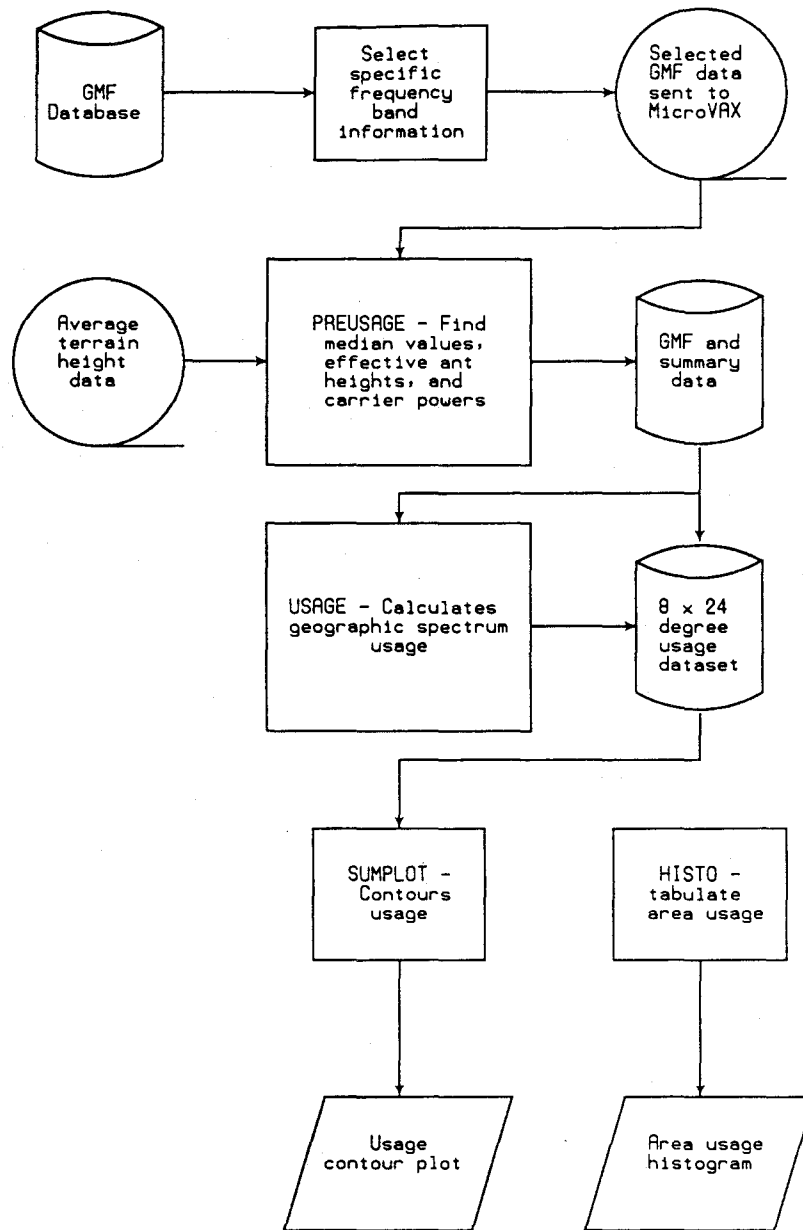
Figure A-1. Flow chart of SUM Database creation.

A-2

PREUSAGE PROGRAM

Purpose

Program PREUSAGE preprocesses the selected GMF records in several ways:

- effective antenna heights are calculated,
- bearings and distance between transmitter and receiver(s) are calculated,
- carrier powers are computed,
- records containing errors are skipped,
- radius of operation is computed when applicable,
- reflector paths are calculated,
- median values are calculated for use as a typical fixed system.

Inputs

Program PREUSAGE inputs include GMF records for the frequency band of interest, and the average US terrain elevation file. The average terrain file contains elevations, in meters, for a 15 second grid covering the contiguous 48 states. The terrain data has been averaged over a 50 kilometer radius circle centered on each grid point.

Calculations

Effective antenna heights are calculated for each transmitter and receiver location. Ground based fixed service antennas are defined to be the base height above mean sea level minus the average terrain elevation plus the tower height. If this calculation is less than zero, an effective height of zero is assigned. Airborne antennas are defined to be 30,000 feet minus the average terrain elevation. Ground based mobile systems are defined to be the

tower height, since their radius of operations will on average be equal to the average terrain height of the area.

The bearing and distance between each transmitter and its receiver(s) and the return bearing(s) are calculated for each GMF input record. The calculations assume a spherical earth.

GMF records containing a radius remarks field are assigned a circular location with the given radius. GMF records containing a rectangular area of operation are also assigned a circular location with a radius from the center of the area to one of the corners.

GMF records containing reflector or passive links are broken into separate records with each reflector or passive assuming the role of receiver at the end of a link and then becoming the transmitter at the start of the next link. Further discussion on this topic can be found in Section 2.

The following median values are calculated for all of the input GMF fixed station records: transmitter power, transmitter bandwidth, antenna gain, effective antenna height, and received carrier power. These median values represent the defaults for the typical system used in geographic spectrum usage computations.

A detailed discussion on the engineering theory of this program can be found in Section 2.

Outputs

PREUSAGE outputs a file containing median data in record one, and two lines of data for each transmitter/receiver pair. The first line contains the transmitter and receiver locations, frequency identification, transmitter power, bandwidth, antenna gains, effective antenna heights, and number of mainbeams. The second line contains the received carrier power, authorized

radius, effective reflector width (not used), near-field indicator (not used), bearing, and return bearing(s).

USAGE PROGRAM

Purpose

Program USAGE creates a geographic data file of spectrum usage covering an 8 degree wide by 24 degree long area of the US. The data can be spectrum use bandwidth or spectrum use factor. A discussion of these two spectrum use measures is covered in Sections 2, 3, and 4. It takes eight runs of program USAGE to completely cover the 48 contiguous states (this is caused by limitations in the commercial software presently used and is not a basic limitation). The resulting eight output files together form a SUM data base for a selected frequency band, and a selected spectrum use measure.

Inputs

The output file of program PREUSAGE is used as input file for program USAGE. In addition, the user must supply the following information: lower and upper frequency of band, northern and western limits of map coverage, choose spectrum use bandwidth or spectrum use factor, C/I_{th}, and the option to change default values for the typical fixed system.

Calculations

Path loss calculations are made using the Integrated Propagation System model (IPS). This model uses a smooth-earth approach. A more detailed discussion of this model and other calculations made by program USAGE can be found in Section 2.

Program USAGE loops twice for each input record, once for the transmitter, and once for its associated receiver. Transmitters with more than one associated receiver will have no data for the transmitter field for the additional receiver records. For each loop, a geographic box or circle is calculated which completely encloses the transmitter or receiver antenna pattern. Nondirectional antennas, antennas with gains less than 10 dBi, mobile systems, and airborne systems are enclosed by a circle. All other antennas are enclosed by a box or rectangle. The program steps thru the box or circle at 5 minute data spacings, calculating the spectrum use at each test point. For spectrum use bandwidth calculations, the band is split into 30 equal bins, with each bin occupied by the system bandwidth set to ones. After all records have been processed, the bins set for each 5 minute data point are added and multiplied by the run bandwidth divided by 30. This result represents the total amount of bandwidth used at each point. For spectrum use factor calculations, the computed spectrum use factor is added to any previous values calculated at that point, with 1.0 being the maximum value allowed. All transmitter spectrum usage values are outputted for each geographic data point, followed by the receiver spectrum usage values.

Outputs

Program USAGE creates a data file of geographic sprectrum usage in units of spectrum use bandwidth (SUB) or spectrum use factor (SUF). The file covers an area of 8 degrees in longitude and 24 degrees in latitude. The data points are spaced 5 minutes apart in both latitude and longitude. The first line of the file contains the map limits in latitude and longitude. The second line contains information common to the file: the spectrum use measure (spectrum use bandwidth or spectrum use factor), the frequency band limits, the data point spacing in minutes, the bin width in MHz for spectrum use bandwidth, the typical system parameters (transmitter power, bandwidth, antenna gain, effective antenna height), and the C/I_{th} used. This is followed by the computed spectrum use measure values, 7 values to a line, 14 lines to cover one row west to east, 4046 lines to cover a complete 8 degree by 24 degree

area of transmitter usage, 8092 lines to cover both transmitter and receiver usage.

SUM DATABASE

The SUM data base is comprised of eight 8 degree by 24 degree files as described in the Outputs section of program USAGE of Appendix A. Each data base covers one selected frequency band, using one spectrum use measure (either SUB or SUF). For this project, the data base covers from 49 degrees North to 25 degrees North, and 125 degrees West to 61 degrees West. A C/I_{th} value of 60 dB was used for all runs. The total size of any one data base (8 data files) is approximately 65,000 lines of 80 characters each, or approximately 5 Mbytes of data for machines which store 1 ASCII character per byte.

OUTPUTS GENERATED FROM SUM DATA BASE

Contour plot program

Program SUMPLOT produces contour maps of any 8 degree by 24 degree SUM data file. The contours are plotted over the appropriate map of US state boundaries. The user can interactively select the lowest and highest contour levels, and the contour interval. Refer to figures 3-2, 3-4, 3-6, 4-2, 4-3, 4-6, and 4-7 for example contour plots generated by program SUMPLOT.

Spectrum usage area table

Program HISTO produces two types of output. A histogram is generated showing total area for varying levels of spectrum usage. A table of these values is also generated including either the spectrum area used in MHz-km^2 for a spectrum use bandwidth data base, or the spectrum use index (SUI) for a

spectrum use factor data base. Refer to figures 3-3, 3-5, 4-4, and 4-8 for example tables generated by program HISTO.

APPENDIX B

SUM DATA BASE CREATION USER'S GUIDE

PREUSE PROGRAM SAMPLE RUN

```
$ @PREUSAGE

                    *** Program PREUSAGE ***

Enter the GMF input filename: GMF1.DAT

Enter the lower frequency band limit (MHz) : 7750

Enter the upper frequency band limit (MHz) : 7900

Enter the elevation in feet to be used for all
airborne transmitters and receivers (default = 30,000 ft) :

FORTRAN STOP

$
```

USAGE PROGRAM SAMPLE RUN

```
$ RUN USAGE
```

*** U.S. Spectrum Usage Database Program ***

This program reads an input file prepared by program PREUSAGE of GMF transmitter/receiver data. It outputs a database file of spectrum usage for a 8 by 24 degree area. This database can then be plotted using the program NCARPL.

Enter the input data filename: **PREUSE.DAT**

Enter the output plot filename: **US1.SUM**

Enter the lower frequency of band (MHz): **7750**

Enter the upper frequency of band (MHz): **7900**

Enter the northern-most latitude in degrees N: **49**

Enter the western-most longitude in degrees E: **-125**
Select the output usage parameter:

    0 = Spectrum use factor
    1 = Spectrum use bandwidth

0

Enter C/I_{th} in dB: **60**

Typical values to be used for test-points: Range

1.Transmitter power	00.0 dBw	(-41.9 to 13.0)
2.Transmitter bandwidth	20.0 MHz	(1.0 to 45.0)
3.Antenna gain	40.0 dBi	(0.0 to 64.0)
4.Eff. antenna height	290.0 ft	(10.0 to 6018.0)
5.Received carrier power	-57.1 dBW	(-137.9 to 25.6)

Do you wish to change any of these typical values (Y or N) ? **N**

FORTRAN STOP
$

SUMPLOT PLOT PROGRAM SAMPLE RUN

$ @SUMPLOT

Enter the input plot filename: **US1.SUM**

Plot default parameters:
1. State/country boundaries
   (0=continuous lines, 1=dotted)   1
2. Lat/lon grid line interval in degrees
   (0=no grid, <0 =no perimeter)   -1000
3. Lowest contour level   .10
4. Highest contour level   1.00
5. Contour interval   .40

Do you wish to change any of these (Y or N) ? **N**

CGM Generator
Copyright @ 1986 ICEX Inc.

Metafile Started
Record Number:
     8
Metafile Finished
Block Size:
    23
FORTRAN STOP
$

HISTO PROGRAM SAMPLE RUN

    $ @HISTO

                         *** Program HISTO ***

    Please enter the file name of the first data base file: USA1.SUM
    Opening file USA1.SUM
    Opening file USA2.SUM
    Opening file USA3.SUM
    Opening file USA4.SUM
    Opening file USA5.SUM
    Opening file USA6.SUM
    Opening file USA7.SUM
    Opening file USA8.SUM

    $

APPENDIX C

MODEL VERIFICATION

INTRODUCTION

This appendix provides a verification of the calculations for the spectrum use bandwidth (SUB) and the spectrum use factor (SUF) performed by the SUM model. The calculations were verified by comparing SUM model results for a hypothetical assigned transmitter and three test points with results obtained using the equations from Section 2 and a computer spreadsheet program.

ASSIGNED AND REFERENCE STATIONS

The technical characteristics of the assigned transmitter and the reference receiver are shown in TABLE C-1. Both the assigned transmitter and the reference receiver are fixed service stations. The hypothetical assigned station is located at 30° North latitude, 75° West longitude. The assigned station antenna mainbeam azimuth is 090°.

CALCULATIONS

This subsection shows the intermediate and final results of the calculations described in Section 2 for the assigned and reference systems described above.

C-1

TABLE C-1

ASSIGNED STATION AND
REFERENCE STATION CHARACTERISTICS

	Assigned Station	Reference Station
Frequency (MHz)	7825.0	---
Transmitter Power (dBW)	0.0	---
Bandwidth (MHz)	40.0	20.0
Antenna Gain (dBi)	40.0	40.0
Effective Antenna Height (m)	30.5	30.5
Received Carrier Power (dBW)	---	-60.0

Transmission Loss Thresholds

The on-tune rejection of the interfering signal is calculated using Equation 14 from Section 2. Since the bandwidth of the interfering transmitter is greater than the bandwidth of the desired receiver:

$$OTR = 10\log(BW_I/BW_R)$$

The transmission loss thresholds for cochannel and adjacent-signal interference are then determined using Equation 5b:

$$L_{Ith} = P_I - OTR - C + C/I_{th}$$

The calculated OTR, C/I thresholds and L_I thresholds are shown in TABLE C-2.

TABLE C-2

CALCULATION OF TRANSMISSION LOSS THRESHOLDS
AND INTERFERENCE BANDWIDTHS

OTR	3.0 dB
C/I_{thC}	60.0 dB
L_{IthC}	117.0 dB
C/I_{thA}	0.0 dB
L_{IthA}	57.0 dB
BW_C	60.0 MHz
BW_A	150.0 MHz

The bandwidths over which interference could occur (see Equations 15a and 15b) are also shown in TABLE C-2. The portions of BW_A that fall outside the 7750-7900 MHz band are truncated, leaving BW_A = 150 MHz.

The results of most of the remaining calculations in this appendix are displayed with eight decimal places. While this level of accuracy is not appropriate for actual calculations, it is helpful in verifying the calculations performed by the SUM model.

Propagation Loss and Antenna Gain

Propagation loss and antenna gain for the interference path are dependent upon the distance and bearing from the assigned station to the test point. The distance d_I between these points is calculated using Equation 15 from Section 2:

$$d_I = \cos^{-1}[\sin(L_1)\sin(L_2) + \cos(L_1)\cos(L_2)\cos(\delta)] \times C$$

The bearing B_{12} from the assigned station to the test point is calculated using Equation 16:

C-3

$$B_{12} = \cos^{-1}\left[\frac{\sin(L_2)-\cos(d_1/C)\sin(L_1)}{\sin(d_i/C)\cos(L_1)}\right]$$

where:

B_{12} =   Bearing from the assigned station to the test point, in degrees east of north

The results of these calculations for the assigned station at 30°N, 75°W and the three sample test points are shown in TABLE C-3.

TABLE C-3

CALCULATION OF PROPAGATION LOSS AND ANTENNA GAIN

	Test Point #1	Test Point #2	Test Point #3
Location	30°19'N 75°05'W	30°02'N 74°51'W	30°00'N 74°55'W
Latitude (°N)	30.31666667	30.03333333	30.00000000
Longitude (°E)	-75.08333333	-74.85000000	-74.91666667
d_I (km)	36.08804083	14.90047559	8.01953828
$L_P(d_I)$ (dB)	141.96166992	128.32661438	122.76496887
B12 (degrees)	347.20225499	75.56857022	89.97916666
θ_1 (degrees)	102.79774501	14.43142978	0.02083334
$G_1(\theta_1)$ (dBi)	-15.00000000	6.86726598	39.99815729

The propagation loss $L_P(d_I)$ is determined using the IPS model described in Section 2 and Appendix D.

The angle θ_1 is the difference between the assigned station mainbeam direction (090°) and B_{12}. The assigned station antenna gain $G_1(\theta_1)$ in the direction of the test point is then calculated using the antenna gain equations in Section 2.

Spectrum Use Bandwidth

As described in Section 2, the spectrum use bandwidth at a test point based on the effects of a single assigned station is determined by comparing the calculated value of transmission loss with the threshold value. Equation 8 is used to calculate the transmission loss between the assigned and reference stations (assuming that $\theta_2 = 0°$):

$$L_I = L_p(d_I) - G_1(\theta_1) - G_2(0)$$

The calculated values of L_I for each of the test points are shown in TABLE C-4.

TABLE C-4

CALCULATION OF SPECTRUM USE BANDWIDTH

	Test Point #1	Test Point #2	Test Point #3
L_I ($\theta_2=0°$) (dB)	116.96166992	81.45934840	42.76681158
SUB (MHz)	60.0	60.0	150.0
SUB (SUM model, MHz)	65.0	65.0	150.0

The spectrum use bandwidth is then calculated using these values, the threshold transmission loss values from TABLE C-2 and Equation 7:

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$$SUB = BW_A \quad \text{if } L_I \le L_{IthA}$$
$$= BW_C \quad \text{if } L_{IthA} < L_I \le L_{IthC}$$
$$= 0 \quad\quad \text{if } L_I > L_{IthC}$$

The values for the SUB calculated using this equation and using the SUM model are shown in TABLE C-4. The SUM model uses thirty 5-MHz bins to keep track of the spectrum used. The frequencies over which interference could occur) overlap 13 of the bins,13H accounting fo&k13theOHMHz e s t Poi #1 and #2

Figure C-1 shows 65 MHz and 150 MHz spectrum use bandwidth contours for this example. Test Points #1 and #2 lie within the 65 MHz contour. Test Point #3 lies within the very narrow 150 MHz contour, which extends to the east from the assigned station.

Spectrum Use Factor

The cochannel and adjacent-signal antenna gain thresholds, used in determining the spectrum use factor, are calculated using Equation 9:

$$G_2(\theta_{2th}) = L_P(d_I) - L_{Ith} - G_1(\theta_1)$$

The values for θ_{2thC} and θ_{2thA} are then calculated using Equations 22 and 23. The results of these calculations are shown in TABLE C-5.
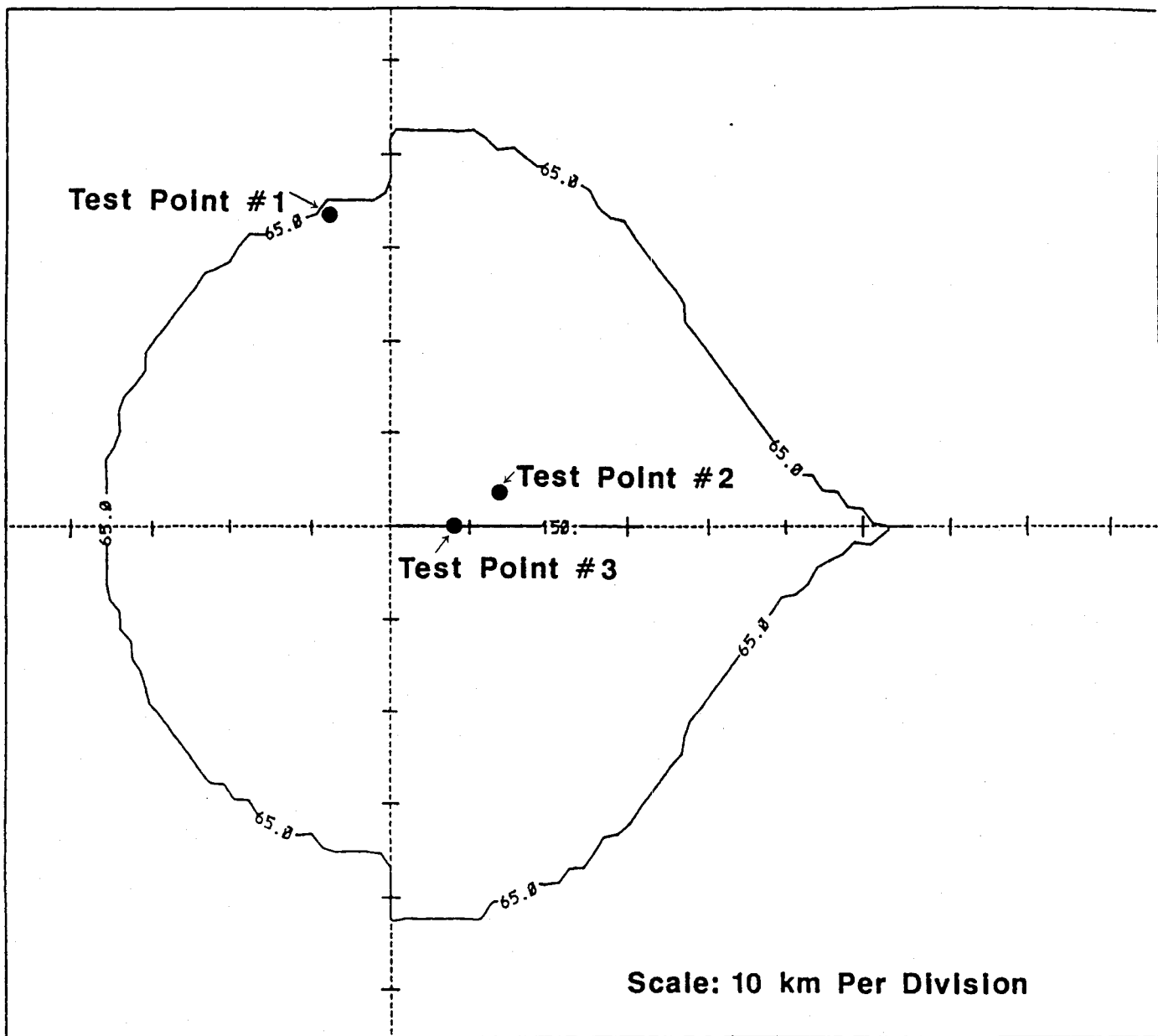
C-6

Figure C-1.   Contours for Spectrum Use Bandwidths of 65 MHz and 150 MHz for
the Verification Example.

TABLE C-5

CALCULATION OF SPECTRUM USE FACTOR

	Test Point #1	Test Point #2	Test Point #3
$G_2(\theta_{2thC})$ (dBi)	39.97196988	4.46964835	-34.22288846
θ_{2thC} (degrees)	0.08125358	17.99757806	180.00000000
$G_2(\theta_{2thA})$ (dBi)	99.97196988	64.46964835	25.77711154
θ_{2thA} (degrees)	0.00000000	0.00000000	2.52880615
SUF	0.00018056	0.03999462	0.40842935
SUF (SUM model)	0.000180	0.039995	0.408429

The spectrum use factor is then calculated using Equation 10:

$$ SUF = \frac{\theta_{2thC}}{180} \times \frac{BW_C}{BW_{tot}} + \frac{\theta_{2thA}}{180} \times \frac{BW_A - BW_C}{BW_{tot}} $$

The SUF values calculated using this equation and those calculated using the SUM model are both shown in TABLE C-5.

Figure C-2 shows 0.00, 0.02 and 0.04 spectrum use factor contours for this example. Test Points #1 and #2 correctly lie very near the 0.00 and 0.04 contours respectively. At Test Point #3, all the azimuths are used in the cochannel frequencies and a small fraction in the adjacent-signal frequencies, resulting in a SUF just over 0.4 (the ratio of BW_C to BW_{tot}).

SUMMARY

The spectrum use bandwidth and spectrum use factor values calculated in this appendix closely match those calculated using the SUM model. The spectrum-area use product, spectrum-area use index and spectrum use index are

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calculated using large numbers of SUB or SUF values and a relatively simple technique. A similar verification is not necessary or practical for these values.
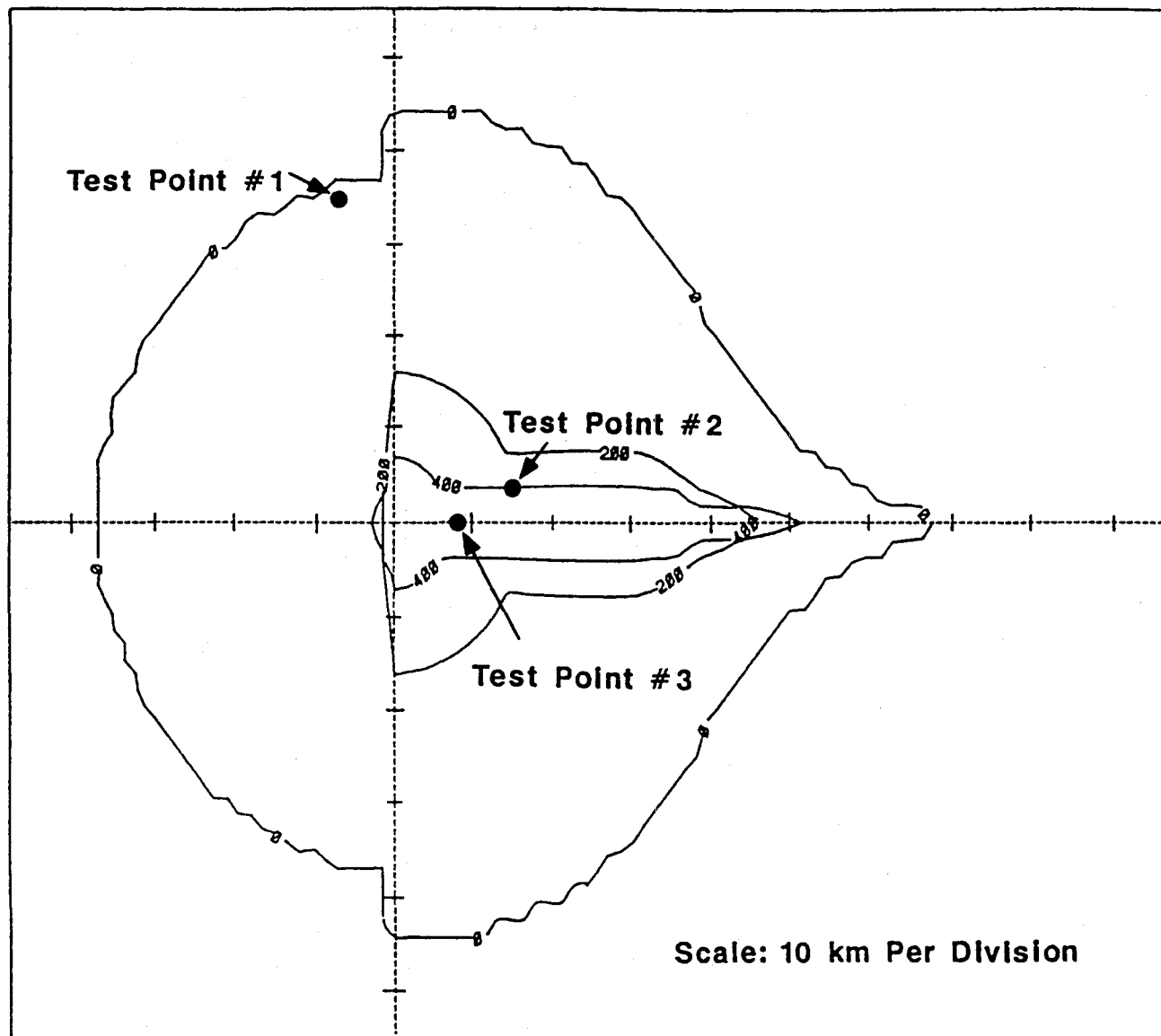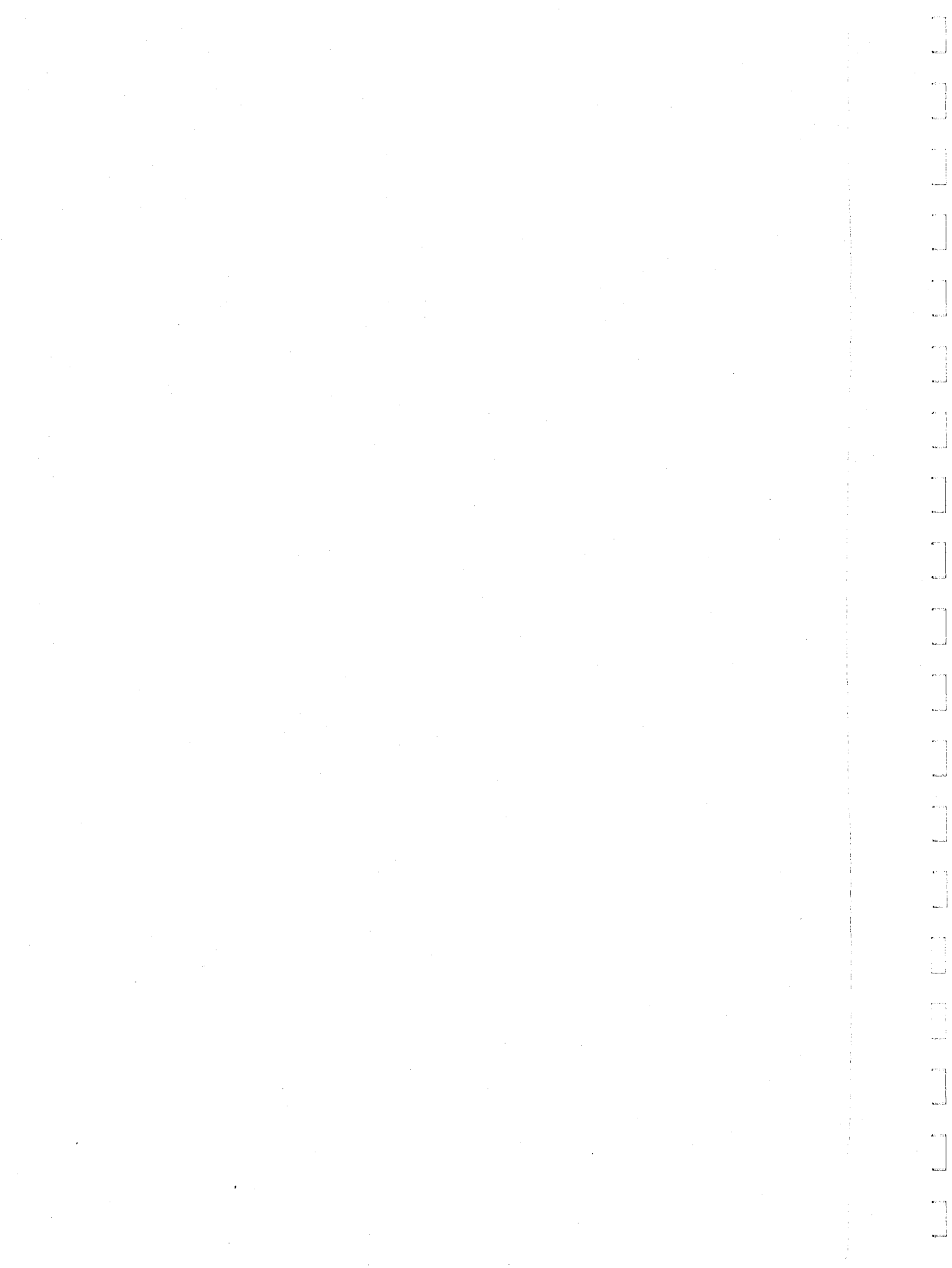

Figure C-2.   Contours for Spectrum Use Factors of 0.00, 0.02 and 0.04 for the Verification Example.

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APPENDIX D

TERRAIN DATA BASE AND EFFECTIVE ANTENNA HEIGHT

INTRODUCTION

This appendix explains the interaction between propagation models and terrain data bases, and their affect on the tradeoff between computation accuracy and computation time. Some of the options available are described, and the choices made in the current implementation of the SUM data base creation program are justified.

EFFECT OF TERRAIN AND ANTENNA HEIGHT

As explained in Section 2, values in the SUM data base depend on the propagation loss, $Lp(d_I)$, where d_I is the distance between the transmitter and the receiver. Lp also depends on the radio frequency, the heights of the two antennas, and the characteristics of the path. For frequencies above 100 MHZ, such as are used in this report, the antenna heights relative to the terrain between the two antennas are most important.

If a transmitter and receiver both have directional antennas that are located high enough so that their conical main beams clear all terrain obstacles between them, the propagation loss is the same as it would be in free space. If the antennas are lower, so that terrain (for example, a hill) partially or completely blocks the view of one to the other, the propagation loss is much greater. On a smooth earth, blockage of the signal occurs when the low antennas are far enough apart that the line-of-sight between them intersects the curvature of the earth.
To reap the benefits of line-of-sight propagation, radio system designers site their antennas on high points in the local terrain.

Accurate calculation of the propagation loss requires the elevation of the antenna sites, the heights of the antennas above their sites, the terrain profile between the two sites, and a propagation model capable of using all this information. In principle, such information and models are available, but they require large amounts of computer storage and calculation time. Some of the alternative propagation loss models and terrain data bases will now be discussed, and the options chosen for the SUM data base creation program will be explained.

Three options were considered:

1. Use the antenna heights from the GMF and a simple smooth-earth propagation loss model. This is the simplest model and requires the least calculation time. Recall that the propagation loss must be computed from each assigned system to many different test points. For calculations such as those in this report, there may be millions of such paths. However, if the earth is assumed to be smooth, all the paths from one assigned system to its test points are the same except for the length. This simplifies propagation loss calculation. Also, this method does not require a terrain data base.

The weakness of this method is its inaccuracy. As mentioned above, system designers often choose the highest local terrain as sites for their antennas. This puts the height of the antenna above the average terrain along the path considerably greater than the height of the antenna above its site. Thus, the antenna can "see" further than would be expected from the antenna height alone, and will cause interference at a greater distance than would be calculated using the antenna height alone. Spectrum use bandwidths and spectrum use factors computed with this method would probably be consistently smaller than they should be.

2. At the other extreme, there are available digital terrain elevation data bases, and propagation loss models that use them. Terrain elevations have been digitized on a threesecond grid. To use this

approach, a detailed terrain profile would have to be retrived from the data base for each path from an assigned system to a test point. There could be hundreds of such points for each assigned system. The propagation models that use detailed terrain profiles are usually more complex than smooth earth models, and therefore take more computer time. The total computation time used by this method might be hundreds of times longer than that required by the first method.

3. The method chosen for the SUM data base creation program is a compromise between methods 1 and 2. The method uses an "effective" antenna height and a smooth earth propagation model.

Because of the smooth earth model, all paths from an assigned system are alike except for the length. This simplifies calculation of the propagation loss. The "effective" antenna height captures the most significant effect of the local terrain.

A data base containing the average terrain elevation for all points in the United States is available. In most cases, the "effective" antenna height is defined to be the elevation of the antenna site minus the average terrain elevation plus the height of the antenna above its site. If the antenna is sited on a hill, then (very roughly) the "effective" height of the antenna is the height of the hill plus the tower height. Intuitively, this yields the correct distance from the antenna to the horizon, which is the important distance for interference calculations.

In some cases, the definition in the preceding paragraph would yield a negative "effective" height. For example, consider an antenna in Boulder, Colorado. Boulder is on the border between the plains and the Rocky Mountains. Thus, a circle centered on Boulder would include many points much higher than Boulder, and the computed average terrain height might be several hundred yards higher than Boulder itself. Then the "effective" antenna height defined above would be negative, even though the antenna itself could see for many miles in any easterly directon.

D-3

To handle these exceptional cases, the "effective" antenna height is defined to be the largest of the antenna height above its site and the definition given above. This definition will of course produce errors in the propagation loss for some situations. However, it is believed that these errors will not be consistently biased in either direction, and will "average out" in the calculation of the spectrum use bandwidth and spectrum use factor.
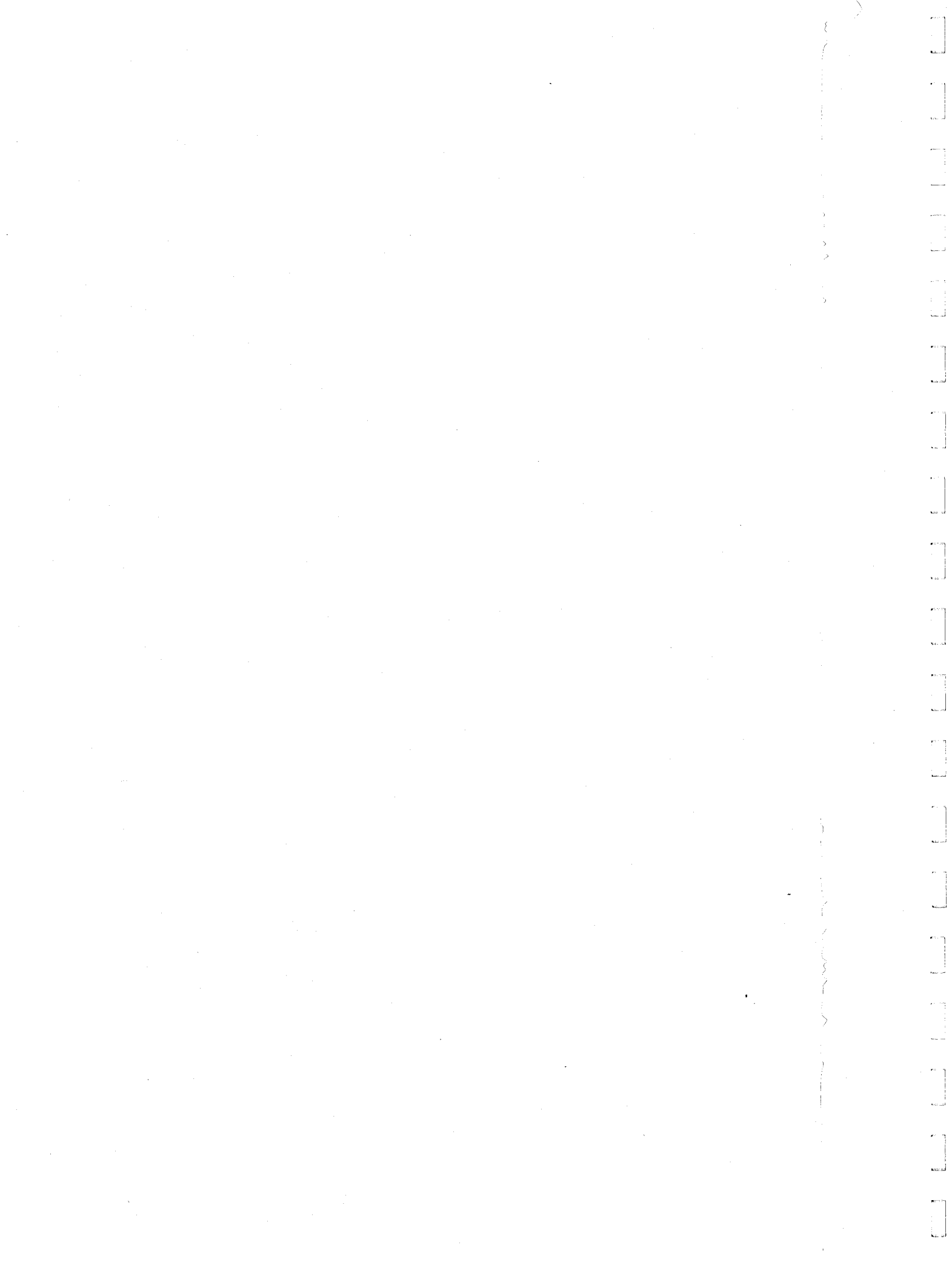
POSSIBLE REFINEMENTS OR MODIFICATIONS IN THE SUM CREATION PROGRAM

The SUM creation program is modular, so that it is possible to change the terrain and propagation decisions made in its development. Two possible changes will be discussed.

If greater accuracy in the calculation is deemed to be worth much greater computer time, then the detailed terrain data base and complex propagation loss models described in the previous section can be installed in the creation program. This is not a trivial modification. It would only be worth doing if highly-accurate calculations were desired for a small geographic area.

A much easier refinement would be to change the size of the area averaged to get the average terrain used in method 3, or to compute the average terrain on a smaller grid. The data base now used has average terrain elevations every 15' in latitude and longitude. The average is computed for a circle with radius 25 km (16 mi) centered on the point. The FCC sometimes uses an effective antenna height based on terrain from 3 to 16 km (2 to 10 mi) from the transmitter along a path. It has been suggested that the average terrain height be computed for 16 km (10 mi) around the grid point rather than 25 km (16 mi) to conform to this definition. It is unknown how much this would change the SUM calculations. It should be noted that "16 km (10 mi) from the grid point" is not the same as "16 km (10 mi) from the transmitter" because it is unlikely that assigned transmitters will be located on evenly spaced grid points.

Another possible refinement in the current method would be to use a smaller grid spacing for the average terrain elevation data base. This would increase the computer storage required, but would not affect the time. How much this would affect the accuracy of the SUM calculation needs to be determined.

BIBLIOGRAPHIC DATA SHEET

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14. SUPPLEMENTARY NOTES

15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report describes a new technique for calculating the spectrum space used by existing frequency assignments. The Spectrum Use Measure (SUM) model determines the amount of spectrum used at a given location or the probability that a given location is unavailable for a new assignment. These quantities, stored in a SUM data base, can be used to produce maps, histograms and indices of spectrum use. The SUM technique has been effectively applied to the 1710-1850 MHz and the 7750-7900 MHz bands. The report concludes that the SUM technique is an effective indicator of spectrum use and recommends that it should be used when evaluating service bands.

16. Key Words *(Alphabetical order, separated by semicolons)*
Interference; Radio-Frequency Spectrum; Spectrum Use; Spectrum Use Measure (SUM); Spectrum Use Bandwidth (SUB); Spectrum-Area Use Product (SAUP); Spectrum-Area Use Index (SAUI); Spectrum Use Factor (SUF); Spectrum Use Index (SUI); Frequency Assignment; Spectrum Efficiency; Technical Spectrum Efficiency Factor (TSEF)

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