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SPECTRUM-CONSERVATION TECHNIQUES FOR FIXED MICROWAVE SYSTEMS

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ABSTRACT

Since the spectrum is a limited natural resource, the spectrum management community has a major interest in identifying spectrum conservation techniques that will provide more efficient spectrum utilization. Advances in new technology for fixed microwave systems in antennas, modulation schemes and signal processing techniques offer increased efficiency in spectrum utilization. This report analyzes the spectrum conserving properties of the various new technologies for fixed microwave systems applying the concepts in CCIR Report 662-2, and was defined as the spectrum conservation factor (SCF). The report concludes that the SCF technique is an effective indicator of the spectrum conserving properties of technologies which can be used to develop new spectrum standards.

KEYWORDS

Spectrum Efficiency
Spectrum Conservation Factor (SCF)
Fixed Microwave System
7125-8500 MHz Band

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INTRODUCTION

BACKGROUND

The National Telecommunications and Information Administration (NTIA) is responsible for managing the Federal Government's use of the radio frequency spectrum. NTIA's responsibilities include establishing policies concerning spectrum assignment, allocation and use, and providing the various departments and agencies with guidance to ensure that their conduct of telecommunications activities is consistent with these policies.[1] In discharging these responsibilities, NTIA assesses spectrum utilization, identifies existing and/or potential compatibility problems among the telecommunications systems that belong to various departments and agencies, provides recommendations for resolving any compatibility conflicts that may exist in the use of the frequency spectrum, and recommends changes to promote spectrum efficiency and improve spectrum management procedures.

The radio spectrum is a limited natural resource that must be carefully managed to ensure its availability to accommodate spectrum requirements for new telecommunication systems. Therefore, NTIA has established a long-range plan for management and use of the radio spectrum.[2] One of NTIA's major policy initiatives outlined in the plan is the establishment of procedures to ensure the efficient and effective use of the spectrum. However, because of the economic burden that can be associated with requirements for spectrum efficient communication techniques, NTIA adopts regulatory controls only where necessary to ensure the continued availability of the spectrum. This encourages effective and economical use of the spectrum, development of new technologies in a less restrictive regulatory environment, and the

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1 NTIA, Manual of Regulations and Procedures for Federal Radio Frequency Management, National Telecommunications and Information Administration, Washington, D.C., Revised May 1988.

2 Long-Range Plan for Management and Use of the Radio Spectrum (U), U.S. Department of Commerce, National Telecommunications and Information Administration, Washington, D.C., May 1988.

application of new spectrum conserving technologies only where necessary. In order to accomplish this policy initiative, NTIA has begun:

1. the development of methods to identify heavily used geographical areas in a band,
2. the evaluation of available radiocommunication technologies with respect to their ability to conserve the spectrum.

These two elements will allow NTIA to identify heavily used geographical areas with sufficient lead-time to allow the identification and/or development of appropriate and economical spectrum conservation techniques so that a spectrum crises does not occur and regulatory and policy options are not limited.

Pursuant to element (1) above, NTIA has developed a method for identifying heavily used geographical areas in a band and indices for degree of band use.[3] With respect to spectrum conservation techniques, the Interdepartment Radio Advisory Committee (IRAC) has endorsed a study to identify spectrum conservation techniques for the Fixed Service.[4] This report specifically investigates those techniques applicable to fixed microwave systems.

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[3] Mayher, R.J.; Haines, R.H.; et al, The Sum Data Base: A New Measure of Spectrum Use, U.S. Department of Commerce, National Telecommunications and Information Administration, TR-88-236, Washington, D.C., August 1988.

[4] MEMORANDUM TO: Deputy Associate Administrator, Office of Spectrum Management; FROM: Executive Secretary IRAC; SUBJECT: Spectrum Resource Assessment of the Federal Government Fixed Service Bands (Above 400 MHz.) NTIA Technical Memorandum 87-127, IRAC Doc. 25498/2.

OBJECTIVE

The objective of this task was to evaluate spectrum conservation techniques for fixed service point-to-point microwave systems to identify system-design considerations that promote more effective and efficient spectrum use.

APPROACH

The following approach was taken to accomplish the above objective.

1. Identify major fixed microwave system design factors that conserve spectrum (e.g., antennas, modulation, signal processing, transmitter output device, and RF filters) and the available technology options within each of the major design factors.

2. Establish a microwave reference system to permit the determination of representative systems parameters.

3. Develop a computer model to evaluate spectrum conservation techniques for the fixed microwave systems by applying the definition of spectrum utilization given in the International Radio Consultative Committee (CCIR) Report 662-2.[5]

4. Apply the computer model to determine which major design factors have the most impact on spectrum conservation and to rank available technology options within each of the major design factors.

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

GENERAL CONCLUSIONS

The following are general conclusions resulting from the study.

1. The spectrum conservation factor (SCF) is a technical concept that can be used to quantitatively assess the spectrum conserving potential of new technologies and to develop new spectrum standards.

2. The spectrum conserving potential of a system is a function of several design factors all of which must be taken into consideration when evaluating the spectrum utilization efficiency of a system. That is one can not say that a system with a particular modulation is more spectrum conserving than a system with another modulation without considering all other design factors such as antennas, signal processing, RF filters, etc.

SPECIFIC CONCLUSIONS

The following are specific conclusions related to spectrum conservation for each of the major system design factors.

1. Antennas

Microwave system antenna characteristics (sidelobe/backlobe levels) have a significant effect on the denial area of a system. For the three types of antennas (dish, shrouded dish and conical horn reflector) considered in the investigation, the following were determined.

a. The relative improvement in spectrum conservation of the shrouded dish and conical horn reflector antennas over the standard dish antenna is a function of the system modulation. The spectrum conservation improvement is approximately 0 to 150 percent for shrouded dish and approximately 150 to 1500 percent for a conical horn reflector. The greatest improvement occurs for 256-QAM modulation.

b. Due to the somewhat higher sidelobe levels close to the mainbeam, less than 20 degrees off-axis, for shrouded dish type antennas, there is no appreciable improvement in spectrum conservation for some modulations. However, the low backlobe level characteristics of shrouded dish antennas enhance the accommodation of systems in crowded cosite conditions.

2. Modulation

The choice of modulation type used in a microwave system has an effect on the spectrum (occupied bandwidth) and spatial area denied to other users. For the nine types of modulations considered in this investigation, the following were determined.

a. Single sideband (FDM/SSB) modulation, from a spectrum conserving point of view, is more efficient than the other modulations considered in the analysis for all antenna types.

b. The higher order digital modulations (modulations with higher transmission efficiency, bits/s/Hz) require higher transmitter output power levels. Therefore, when the CCIR definition of spectrum use and efficiency which takes into consideration denied area is used, modulations which have higher transmission efficiency (bits/s/Hz) may not necessarily be more spectrum conserving. Thus the transmission efficiency (bits/s/Hz) of the digital modulation may not suffice as an indicator of spectrum conservation.

c. For equivalent systems, with identical signal processing techniques, 64-QAM (Quadrature Amplitude Modulation) is more spectrum conserving (i.e., higher SCF value) than 256-QAM for all antenna types considered.

3. Signal Processing

Microwave system signal processing techniques can be used to improve the spectrum conserving properties of a system. For a microwave system using 64-QAM, the following were determined for the digital signal processing techniques considered in the analysis .

a. The improvement in spectrum conservation due to signal processing techniques is a function of the system antenna type. Microwave systems with dish type antennas obtain the greatest improvement in spectrum conservation when signal processing is used, with the improvement decreasing for systems with shrouded dish and conical horn reflector antennas respectively.

b. Because of the trade-off between system bandwidth and required carrier-to-noise ratio in error correction/coding techniques, high-efficiency coding techniques (i.e., coding techniques with high coding rates and coding gain) must be used to obtain an improvement in spectrum conservation.

c. The use of adaptive equalizers can improve the spectrum conservation properties of a system from approximately 25 to 90 percent depending on the type of antenna used.

d. Some microwave systems use both adaptive equalizers and error correction/coding techniques to improve system performance. The use of both signal processing techniques can improve the spectrum conservation properties of a system from approximately 30 to 170 percent depending on the type of antenna used.

4. RF Filters

The use of transmitter and receiver RF filters greatly enhance the spectrum conserving properties of microwave systems. Their application reduces intermodulation, adjacent channel and receiver spurious response interference.

RECOMMENDATIONS

The following are NTIA staff recommendations based on the findings of this report. NTIA management will evaluate these recommendations to determine if they can or should be implemented from a policy, regulatory, or procedural viewpoint. Any action to implement these recommendation will be via separate correspondence modifying established rules, regulations and procedures. The recommendations are as follows.

1. The NTIA in fulfillment of it's long-range planning objective of promoting more effective and efficient use of the spectrum, should initiate follow-on tasks to continue the investigation of spectrum conservation techniques for other services.

2. In geographical areas where bands are heavily used, the SCF concept should be for use in the development of spectrum standards which will promote more efficient use of the spectrum.

SECTION 3

ANALYSIS OF SPECTRUM CONSERVATION TECHNIQUES

INTRODUCTION

This section contains a discussion of the analytical approach used to evaluate spectrum conservation techniques for fixed point-to-point microwave systems. A reference system was used to determine nominal system parameters for the various design factors such as antenna, modulation, signal processing, transmitter output device and RF filters. These nominal system parameters are then used to evaluate the spectrum conservation trade-offs for the various design factors. The relative spectrum utilization efficiency for the various design factors are analyzed as well as the relative spectrum utilization efficiency of the state-of-the-art technologies within each of the major design factors.

The analysis is based on characteristics of microwave systems deployed in the government fixed service band of 7125-8500 MHz. However, the analysis was extended to consider the technology deployed in other point-to-point microwave fixed service bands and current state-of-the-art technology being developed.

ANALYSIS APPROACH

To assess the efficiency of the various design factors and technology options, it is necessary to have a quantitative measure of the relative spectrum conservation enhancement properties of that technology. In the past, analysis of spectrum efficiency has dealt primarily with RF bandwidth, transmission efficiency (Bits/second/Hz) or capacity efficiency (Voice channels/Hz).

To utilize the spectrum efficiently, any radiated energy should be kept to a minimum consistent with ensuring an adequate grade of service. This minimization should be effective in the time, frequency, and spacial domains. CCIR Report 662-2 defines spectrum efficiency as the ratio of communications achieved to the spectrum-space used. Spectrum-space is defined as the product of time, bandwidth, and the spatial volume denied to other users due to potential interference. For this study on analysis of spectrum conservation techniques for the fixed point-to-point systems, the equation in CCIR Report 662-2 was defined as the spectrum conservation factor (SCF) and is given as:

$$SCF = \frac{VC}{T*A*B} \qquad (3\text{-}1)$$

where:

VC = Number of voice channels.
T = Fraction of time a system is used. Defined to be equal to 1 for this analysis.
A = Denial area (km^2)
B = Receiver System Bandwidth (MHz)

The above equation was chosen because it takes into consideration both spectrum and spatial (area) denial in assessing the spectrum conservation enhancement properties of a system. The denial area is the area in which another system can not operate without degradation in system performance below a specified performance criteria. The denial area is a function of the microwave system antenna pattern characteristics, transmitter output power and interference threshold level. APPENDIX A contains a detailed description of the computer program used to evaluate Equation 3-1 and examples of program input and output data.

The relationship between spectrum and spacial (area) denial trade-offs for the various design factors addressed in this section are summarized in TABLE 3-1.

TABLE 3-1

SPECTRUM CONSERVATION DESIGN FACTORS

DESIGN FACTORS	TRADE-OFFS
Antenna	Space
Modulation	Spectrum-space
Signal Processing	Spectrum-space
Transmitter Output Device	Spectrum
RF Filters	Spectrum

The following is a discussion of the application of Equation 3-1 for the design factors listed in TABLE 3-1. Representative system parameters for each of the design factors and technology options within each of the design factors are identified, and the associated spectrum conservation enhancement properties are assessed.

MICROWAVE REFERENCE SYSTEM CHARACTERISTICS

In order to apply Equation 3-1 to point-to-point microwave systems, it is necessary to establish characteristics of a microwave reference system between two microwave sites. TABLE 3-2 shows the system parameters for sites Alpha and Beta used to calculate the required system gain (G_s). The system parameters used in TABLE 3-2 are nominal values considered to be representative of a typical microwave hop. The system gain of 103 dB calculated in TABLE 3-2 is representative of nominal system gains for microwave systems in the 7/8 GHz band. This value of system gain will be used to determine the required transmitter power used to evaluate the spectrum conservation enhancement for the various design factors which follow.

ANTENNAS

The antenna of a microwave system is a key system design factor in addressing spectrum conservation. One of the major radiocommunications system components contributing to denial area is the system antenna. In recent years, significant advances in the antenna-design areas of sidelobe/backlobe reduction and polarization discrimination have provided the capability for enhanced spectrum efficiency in fixed microwave systems. Frequency re-use can be achieved by implementing antenna-design spectrum-conservation techniques. For example, antenna polarization discrimination is an effective and efficient means to double the channel capacity of a fixed point-to-point microwave system.

Antenna Pattern Characteristics

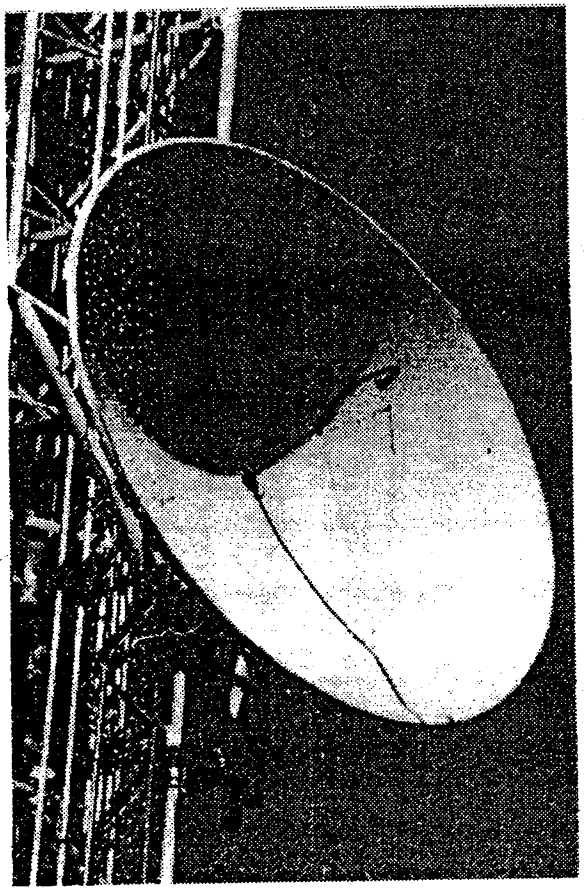
Spatial denial can be minimized if antenna pattern sidelobe/backlobe levels are minimized. The antenna radiation patterns, and therefore sidelobe distributions, vary with antenna type. For this analysis an eight foot antenna, approximately 43 dBi gain, has been used. Three antenna types (see Figure 3-1) commonly used in point-to-point microwave transmission are:

1. Standard Dish (STD)
2. Shrouded Dish, (SHD)
3. Conical Horn Reflector (CHR)

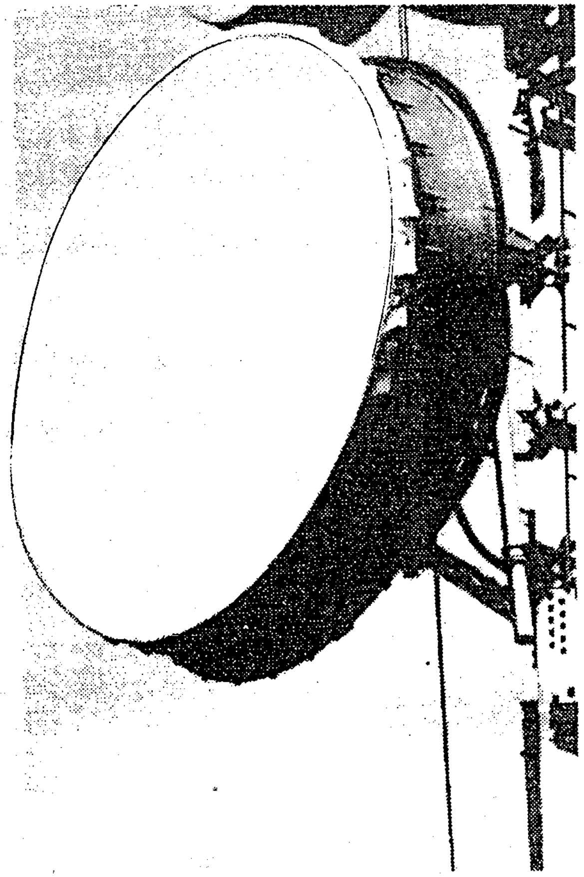
TABLE 3-2

HYPOTHETICAL HOP CHARACTERISTICS

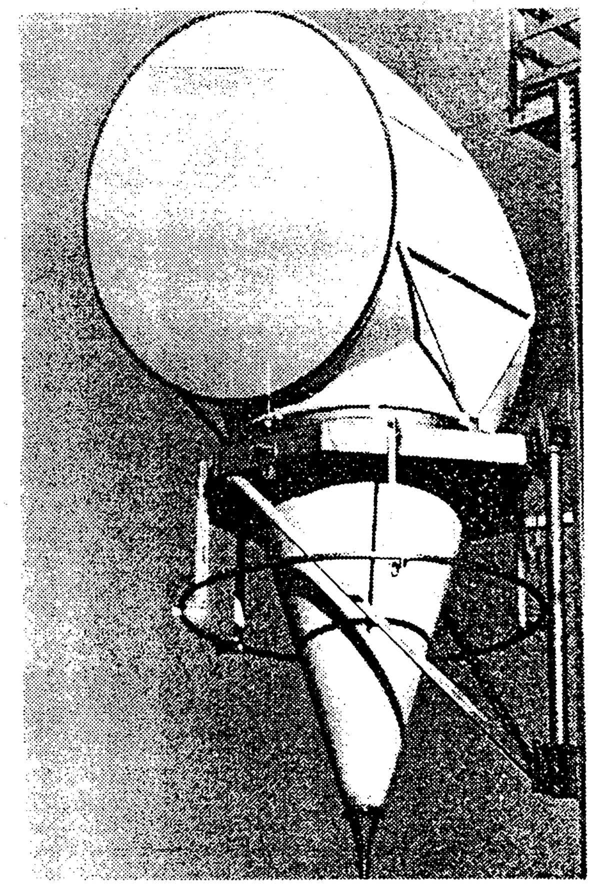
FREQUENCY (MHz)		8000.0	
PATH LENGTH (kMS)		50.0	
SITE	ALPHA		BETA
SITE ELEVATION (METERS)	125.0		250.0
ANTENNA HEIGHT (METERS)	50.0		50.0
PATH ATTENUATION (dB)		142.0	
WAVEGUIDE LOSS (dB)	2.5		2.5
CONNECTOR LOSS (dB)	0.5		0.5
RADOME LOSS (dB)	0.5		0.5
TOTAL FIXED LOSSES (dB)	3.5		3.5
TOTAL LOSSES (dB)		149.0	
ANTENNA GAIN (dB)	43.0		43.0
TOTAL GAIN (dB)		86.0	
NET PATH LOSS (NPL) dB		- 63.0	
RECEIVER NOISE FIGURE (dB)	7.0		7.0
THEORETICAL RF C/N RATIO (dB)		SEE TABLES 3-3 & 3-4	
PRACTICAL THRESHOLD (C[MIN]) (dBm)		SEE TABLES 3-3 & 3-4	
FADE MARGIN (FM) dB		40.0	
SYSTEM GAIN (GS) dB [FM - NPL]		103.0	
TRANSMITTER POWER P(t) dBm		SEE TABLES 3-3 & 3-4	



STANDARD DISH (STD)



SHROUDED DISH (SHD)



CONICAL HORN REFLECTOR (CHR)

Figure 3-1. Fixed microwave system antenna types.

Standard parabolic dish (STD) antennas have unshielded reflectors and have a relatively low front-to-back ratio. Because of this, the radiation pattern characteristics of standard dish antennas produce larger denial areas than those for the two other types of antennas. A typical radiation pattern for a standard dish antenna with a 43 dBi gain is shown in Figure 3-2. Note that the backlobe levels for these antennas are only 55 dB down from the main beam. Despite this shortcoming, in many applications where frequency congestion is not serious and interference is less restrictive, these antennas may be used more economically.

The shrouded dish (SHD) type antennas are similar to the standard parabolic dish type antennas, except that they include a cylindrical built-out shield or shroud which improves the front-to-back ratio and wide angle radiation discrimination. A shrouded antenna typically has a front-to-back ratio of approximately 70 dB. The SHD type antennas are used in areas where frequency plans and operational coordination require the suppression of relatively high levels of side and backlobe radiation. A typical radiation pattern for a shrouded dish antenna with a 43 dBi gain is shown in Figure 3-2. One inherent characteristic of the shrouded dish antenna is the higher sidelobes close in (less than 20^0) from the main lobe (See Figure 3-2).

Conical horn reflector (CHR) antennas offer high quality radiation characteristics. These horn reflector type antennas, are well suited for use in areas where frequency congestion is burdensome. The feed for a CHR antenna includes a metallic conical horn structure. The front-to-back ratio for this type of antenna is approximately 90 dB. A typical pattern for the 43 dBi horn reflector antenna is shown in Figure 3-2.

Spectrum Conservation Factor

A plot of the transmitter output power versus denial area for a receiver interference threshold of -101 dBm is shown in Figure 3-3 for the three types of antennas. Although, the mainbeam gain for all the antennas were the same, the results shown in Figure 3-3 indicate that the CHR antenna has less denial area than the other two types of antennas. Also the difference in denial area for the three types of

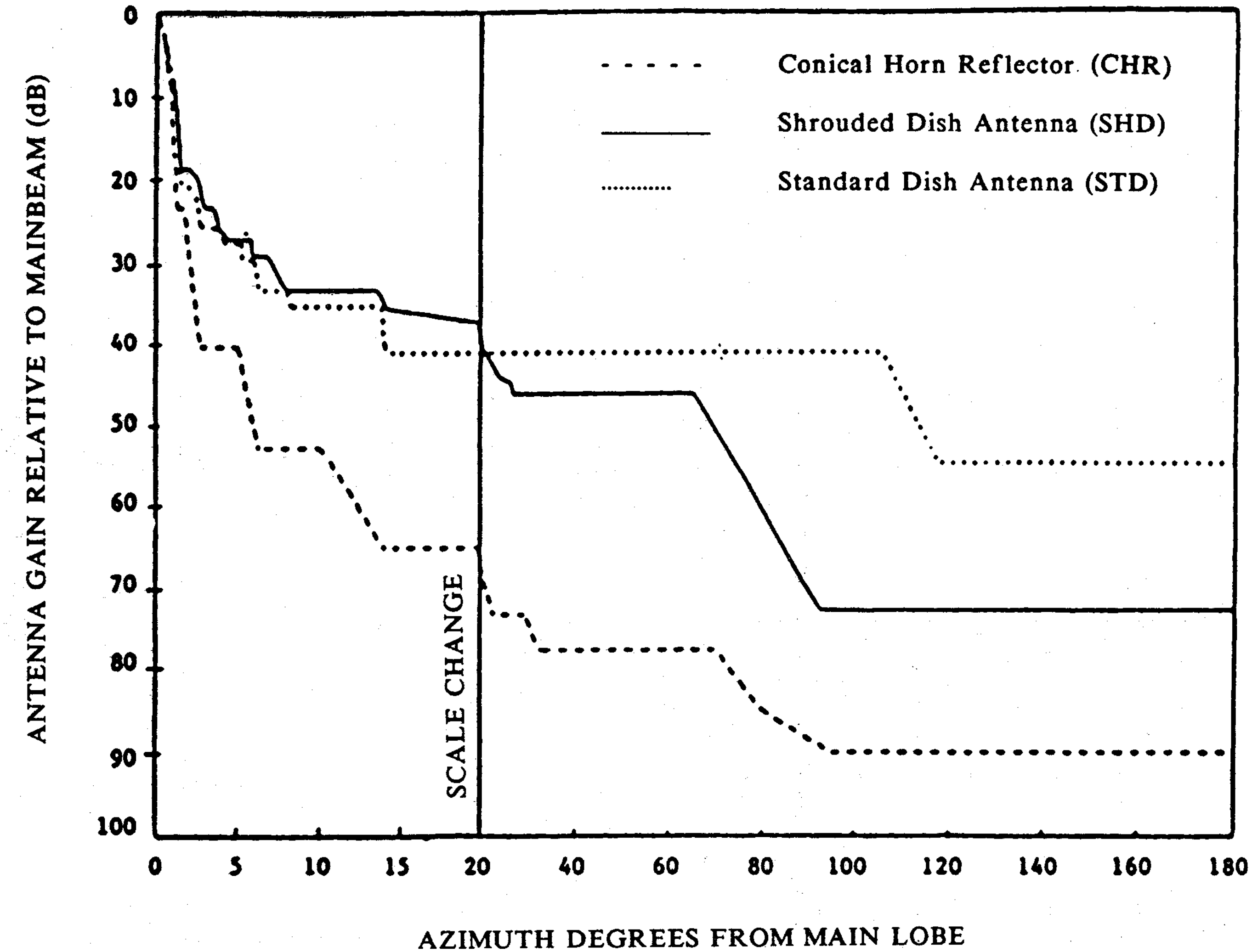


Figure 3-2. Radiation patterns for STD, CHR, SHD antennas.

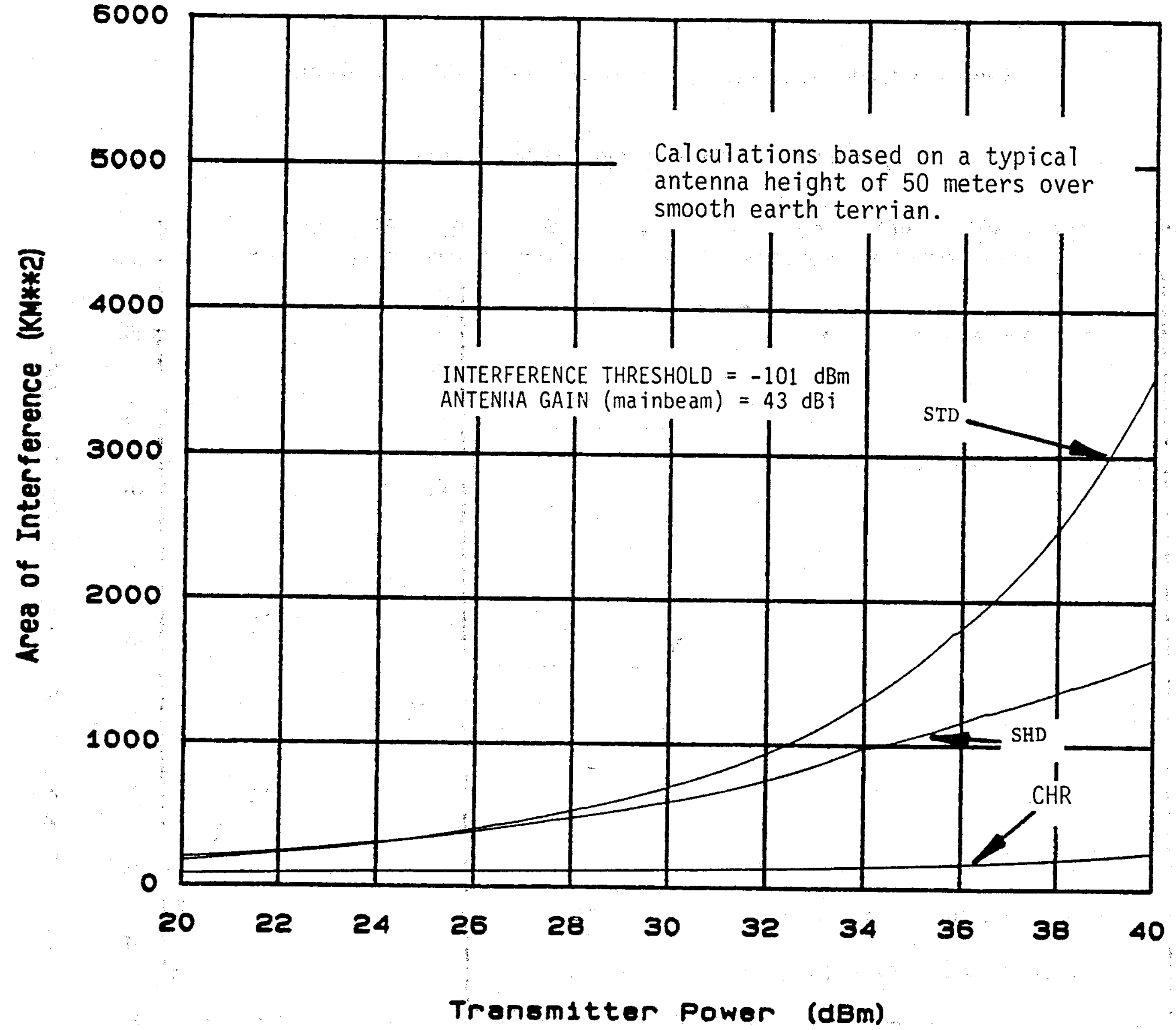


Figure 3-3. Denied area as a function of antenna type and transmitter output power for an interference threshold of -101 dBm.

antennas is small until the transmitter power is greater than 30 dBm. This is understandable because the contribution to the denial area caused by sidelobe/backlobe antenna characteristics is small until the transmitter power is increased beyond 30 dBm. At transmitter output powers greater than 30 dBm, the difference in denial area for the three types of antennas is significant. The denial area is also a function of the receiver interference threshold. Figure 3-4 shows the denial area for an interference threshold of -103 dBm. A comparison of Figures 3-3 and 3-4 shows a significant increase in denial area for only a 2 dB decrease in the interference threshold. Hence a general observation may be made that microwave systems that require higher transmitter power and/or lower interference thresholds generally need to use better antennas (i.e., antennas with lower sidelobe/backlobe characteristics).

Since the denied area for the three types of antennas is a function of the transmitter output power and the maximum permissible interference level, the spectrum conserving properties for the three antenna types must also be related to system modulation type. Thus the spectrum efficiency enhancement properties of the STD, SHD and CHR antennas will be discussed in the modulation section.

Antenna Cost

For the 7/8 GHz band, the cost of a standard parabolic dish antenna is approximately $2,700 for single polarization, and approximately $3,700 for dual polarization. The shrouded dish (SHD) antennas are substantially more bulkier, heavier and more expensive than the standard dish (STD) antenna. However, they are often used on the same antenna tower as the standard dish antenna. The cost of an SHD antenna is approximately three times a STD antenna, and cost approximately $8,000 for single polarization and $9,100 for dual polarization. A conical horn reflector (CHR) antenna is approximately $18,500, and requires a more substantial tower.

The cost of the antenna is approximately 5 to 10 percent of the total cost of a microwave system (building, radio equipment, tower and antenna). The relative percentage is a function of: 1) number of antennas per tower, 2) cost of radio communication equipment and 3) the number of transmitters and receivers using the same antenna. Therefore, the purchase of a more spectrum efficient antenna (SHD and CHR) generally will not have a major impact on the total system cost.

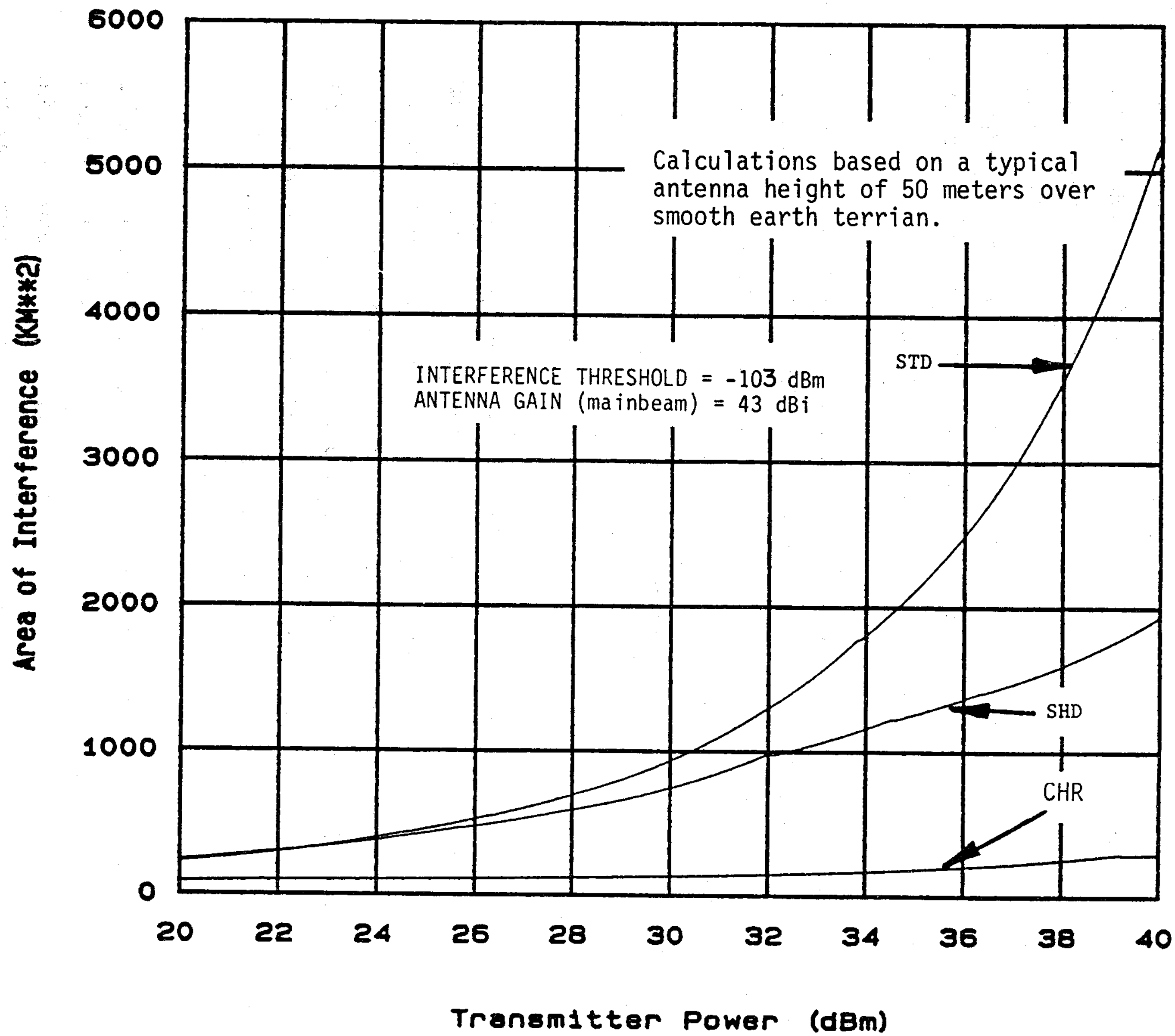


Figure 3-4. Denied area as a function of antenna type and transmitter output power for an interference threshold of -103 dBm.

MODULATION

The evaluation of spectrum conservation properties for different modulation schemes is very complex in that both spectrum and spacial denial are effected by the choice of modulation type used in a system. In general, system parameters such as occupied bandwidth, required receiver input carrier-to-noise ratio, $(C/N)_i$, and maximum permissible interference level are all functions of the modulation type and have a direct bearing on spectrum utilization. For most modulations, all these factors can be exchanged. For example, one can decrease the required occupied bandwidth, B, in a tradeoff for an increase in the required C/N ratio or vice versa. This tradeoff is given by the Shannon-Hartley Law.[6] The occupied bandwidth, B, is directly related to spectrum denial, and the required $(C/N)_i$ is indirectly related to spatial (area) denial since an increase in the required $(C/N)_i$ requires an increase in required transmitter output power.

In this analysis eight different modulation types often used in fixed service point-to-point microwave systems were considered. The analysis utilized theoretical parameters for the different modulation types instead of manufacturer specifications and measured performance information to ensure a just comparison. In order to evaluate the spectrum conservation properties for the different modulation types it was necessary to determine the occupied bandwidth, required transmitter output power level and maximum permissible interference level for each modulation type.

Digital Modulation

The following is a discussion of the determination of occupied bandwidth and required transmitter output power level for the digital modulations analyzed. In order to analyze the spectrum conservation properties of different digital modulation it is necessary to establish reference system characteristics to do the analysis. The reference system characteristics assumed here were:

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6 B. P. Lathi, Communication Systems, John Wiley & Sons, Inc. (1965).