ITS STAFF STUDY

A Preliminary Look at Spectrum Requirements for the Fixed Services

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Disclaimer

This preliminary report was prepared by the Institute for Telecommunication Sciences at the request of the National Telecommunications and Information Administration (NTIA). It summarizes the recent history of the use of the Fixed bands, as well as the market and technology factors which will affect the use of these bands. The document was written to help resolve the questions posed by the Spectrum Requirements Notice of Inquiry (NOI)[1], and it should be considered along with other Comments to the NOI. The opinions expressed herein are the opinions of the authors. This document has not been reviewed by NTIA for policy, and it should not be construed to reflect the official or unofficial policies or planning of NTIA.

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[1]Current and Future Requirements for the Use of Radio Frequencies in the United States. NTIA. Docket No. 920532 - 2132.

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***The above set of figures describing each band are the "Standard Figures" for a band.**

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LIST OF ABBREVIATIONS

ATC	Air traffic control
AMSC	American Mobile Satellite Corporation
AUXBC	Auxiliary broadcasting - used by TV broadcasters to move TV signals to transmitter

BETRS	Basic exchange telecommunications radio service
CARS	Cable relay system - a radio service used to bring TV signals to cable systems
CATV	Cable TV or (same thing) Community Antenna TV - public distribution of TV via cable
DBS	Direct broadcast satellite - high power satellite TV broadcasting
DCTN	Defense Commercial Telecommunications Network
DECCO	Defense Commercial Communications Office (part of DISA)
DEMS	Digital electronic message service
DISA	Defense Information Systems Administration
DoD	Department of Defense
DoE	Department of Energy
EMC	Electromagnetic compatibility
ENG	Electronic news gathering - temporary AUXBC TV link used for remote news coverage
FCC	Federal Communications Commission
FTS 2000	Umbrella contract for Government procurement of commercial telecom services
GaAs	Gallium Arsenide - substrate material used for microwave electronics
GMF	Government Master File - database containing Government radio assignments
GPS	Global Positioning System - satellite system providing accurate position information
HDTV	High-definition Television
ICR	Inter-city relay - AUXBC link carrying TV between and within cities
ISDN	Integrated services digital network- telephone system with all services carried digitally
ISM	Industrial, scientific, medical - a non-communication service that requires no license
ITFS	Instructional TV fixed service - TV used to provide classroom instruction
IXC	Inter-exchance carrier - long distance telephone company
LEC	Local exchange carrier - the local telephone company
LMDS	Local multipoint distribution system - (28 GHz cellular cable)
LMR	Land mobile radio
MAS	Mutiple address system - a point-to-multipoint system
MDS	Multipoint distribution system - an earlier 4-channel version of wireless cable
MMDS	Multichannel multipoint distribution system - new 30-channel wireless cable
MMIC	Monolithic microwave integrated circuit
MSO	Multiple system operator - a company that operates many cable systems
NG	non-government assignment or license - administered by the FCC
NOI	Notice of Inquiry
NPRM	Notice of proposed rulemaking
NTSC	National Television Standards Committee - the technical standards used for regular TV
PCS	Personal communication services - a family of proposed short-range communications
PSN	Public switched network - the network encompassing the whole telephone system

QAM	Quadrature amplitude modulation - amplitude and phase modulation for digital systems
RBOC	Regional Bell operating company - any of the 8 regional telephone holding companies
RDTE	Research, development, testing, and evalutation
SCADA	Supervision control and data acquisition - monitor/control of pipelines, railroads, etc.
SHL	Studio to headend link - CARS link carrying programs from central hub to cable headends
SMA	Small master antenna - like CATV, but serving only one complex (e.g., hotel or condo)
SMR	Specialized mobile radio - a commercial (trunked) mobile radio service
SNG	Satellite news gathering - relay of local news coverage from remote site via satellite
SONET	Synchronous optical network - telecommunications standard for optical fiber systems
STL	Studio-to-transmitter link - a link carrying program material to the transmitter
TDRSS	Tracking data relay satellite system
TIA	Telecommunications Industry Association
TSL	Transmitter-to-studio link - a link carrying program and/or status to the studio
TVRO	TV receive-only. Satellite terminals, whose only function is to receive TV signals
VSAT	Very small aperature terminal - a 2-way satellite system using small antennas at terminal
VTS	Vessel Traffic Service - Coast Guard control system for ships in harbor areas
WLAN	Wireless local area network

This report was prepared by the Institute for Telecommunication Sciences at the request of the National Telecommunications and Information Administration (NTIA). It is intended to summarize recent history of the use of the fixed bands, as well as the market and technology factors which will affect the future use os these bands. The document was written to help resolve the questions posed by the Spectrum Requirements Notice of Inquiry (NOI)[2], and it should be considered along with other Comments to the NOI. The opinions expressed herein are the opinions of the authors. This document has not been reviewed by NTIA for policy, and it should not be construed to reflect the official or unofficial policies or planning of the NTIA.

Executive Summary

Microwave history and background. The class of radio systems called "fixed services" include those services whose function is to provide communications between a fixed transmitting location and a fixed receiving location. In point-to-point systems, there is only a single transmitting location and a single receiving location; in point-to-multipoint systems, there are multiple receiving or transmitting locations. Those point-to-point systems located in the range of frequencies above 1 GHz have historically been called the "point-to-point microwave services", or simply "microwave" services. Typically, microwave systems are built with a highly-directional transmitting antenna aimed at the receiving location and a highly-directional receiving antenna aimed at the transmitting location. Thus, microwave systems can efficiently transmit signals over a line-of-sight path between a transmitter and a receiver, and excellent frequency re-use is obtainable simply by employing the directional qualities of the antennas.

Point-to-multipoint systems often use a base (or master) station with an omnidirectional antenna, along with several response (or slave) stations with directional antennas aimed at the master station. Point-to-multipoint systems are a more recent development than point-to-point stations, but they have become suddently more popular and may play a much wider role in the future.

The fixed or microwave bands have played a very important role in the use of the radio spectrum, because it was believed that they would carry most of the long-range telecommunications traffic in the U.S. (and they actually did for several decades). About half of the radio frequency spectrum above 1 GHz is allocated on a primary basis for fixed microwave communications. These bands were used most heavily by the telephone companies, who used extensive networks of microwave stations to provide nation-wide, coast-to-coast communications for long-distance telephone and video.

Optical fiber. In the last decade, the development of optical fiber has provided a very successful alternative to microwave systems. Optical fiber carries information on a light beam traveling through the fiber. The rate at which the light beam can be turned on and off determines the maximum rate at which data can be transmitted over the fiber. Current optical fiber technology can transmit up to 2400 million bits of information per second (2400 Mbits/s) on a single fiber for a distance of up to 65 kilometers (40 miles). (This compares to a typical maximum microwave data rate of 135 Mbits/s per carrier.) Optical amplifiers or electronic regenerators can be used to re-amplify the signal as needed to cover the required distance. Optical fiber technology is continuing to develop at a rapid rate, providing improved performance at lower cost.

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[2]Current and Future Requirements for the Use of Radio Frequencies in the United States. NTIA. Docket No. 920532 - 2132.

The technical success of optical fiber has been followed by rapid commercial success in the U. S. By 1991, more than 10 million fiber kilometers (6 million fiber miles) had been installed. The fiber communication systems installed each year could carry in excess of 20 times more communications than the microwave radio systems manufactured each year. The worldwide market for fiber optics equipment has been growing at a compounded rate of about 20% a year. Several of the regional Bell operating companies (RBOC)s have nearly abandoned earlier microwave systems, and there is a very noticeable decrease in the number of frequency assignments in the 3 microwave bands that were heavily used by the telephone companies. For example, the number of frequency assignments in the 6 GHz band has dropped to about 2/3 of the 1987 peak value and is still dropping.

It is clear that fixed microwave is no longer the medium of choice for comodity telecommunications; that role has been won by optical fiber. Every trend indicates that fiber will continue to expand and more fully dominate the communications point-to-point marketplace.

Present microwave markets. Although microwaves no longer dominate the mass communications marketplace, it is equally clear that there are several active "niche" markets where microwave offers advantages over fiber. These advantages are based on the fundamental differences between the geometry of the microwave and fiber paths. Fiber has the major disadvantage that a continuous cable must be run between the transmitting location and the receiving location. This requires the time and expense of implementing a continuous path where right-of-way can be obtained and cable can be buried. Since most of the cost of a fiber cable is in the burial process, a large number of fibers are usually included in a cable (typically 50 fibers in a cable) to allow for any conceivable future need. After installation, any part of the pathway continues to hold the potential for total destruction of the communications link. So-called "backhoe fading"--the accidental digging up and severing of optical cables--is a major problem. An industry rule-of-thumb is a fiber cut per year for every 500 km of fiber. On the other hand, microwave links require only available radio spectrum and a line-of-sight path between transmitter and receiver.

The following factors are important in establishing several niche markets where microwave is often used:

1. Fast response - less time needed to install two sites than to bury a continuous cable.

2. Low capacity - microwave is often cheaper for less traffic than about 500 Mbits/s.

3. High reliability - microwave is not subject to accidental cable cuts.

4. Remote locations - alternatives not available, microwave frequency availability is not a problem.

5. Point-to-multipoint - efficient at simultaneous serving multiple sites.

The markets where these factors tend to favor microwave include:

1. **Cellular** telephone. Many cellular providers have built a complete microwave network, bypassing the local exchange carrier (LEC) and avoiding delays in getting fiber to cellular sites.

2. **SCADA** applications. Supervisory control and data acquisition (SCADA) is used to control and monitor powerlines, railroads, pipelines, etc. Often low data rates, but high

reliability is required. SCADA is often needed at remote locations, where telephone is not available or reliable.

3. Remote location. Government uses microwave backbone networks to support mobile radio communication sites in national forests, for state highway patrol, for military test ranges, etc.

4. By-pass of LEC for commercial operations. Government or commerce may save money by connecting multiple sites with microwave, rather than using local phone company to provide inter-site communications.

5. Rural communications. Communications to many small towns and rural areas will continue to be provided more economically by microwave. The low traffic volume and the long distances are deciding factors. Microwave is doubly attractive if terrain is mountainous or difficult in other ways (crosses wilderness areas, lakes, rocky ground, etc.)

Factors affecting future microwave usage. The net result of the decrease of the major telephone and data markets, along with an increase in the niche markets is at present a slight increase in the overall microwave market (measured by frequency assignments) or a slight decrease in the microwave market (measured by funds spent annually on microwave equipment). The present "neutral" market is a transition state between a strong growth market of 10 years ago and a future slowly shrinking market. Some of the major factors for the future of microwave include:

1. An estimated 70% of recent microwave growth has been installed to support cellular telephone systems. Most cellular systems are completing their microwave networks in the next few years, and this growth will be expected to taper off.

2. Fiber is continuing to be installed at a high rate. This includes independent urban fiber companies, LECs, inter-exchange carriers (IXC)s, and cable TV companies. The recent FCC decision to allow LECs to provide video services will surely accelerate the installation of fiber-to-the-curb. All of this fiber should be considered a competitor for microwave. Wherever fiber is already installed, it substantially decreases the economic viability of microwave at that location. In addition, plentiful fiber for alternative paths and fiber ring architecture gives substantially enhanced reliability. Thus, microwave will be competitive at continually fewer locations in the future. Microwave usage is declining especially in the 4 GHz, 6 GHz, and 11 GHz common-carrier bands.

3. The use of microwave for SCADA applications will face increasing competition from satellite VSAT technology and multiple address systems (MAS), as well as generally greater availability of telephone in remote locations.

4. In the past, Federal Government agencies have implemented many special-purpose microwave systems to support specific agency missions. The growth in the capabilities of commercial telecommunications in the last decade is making it increasingly advantageous to replace some of the old agency-specific systems with commercially-supplied telecommunications. The FTS 2000 procurement of commercial

telecommunication services makes it easier for agencies to replace older agency-specific systems with more modern public services.

5. Much of the growth in microwave systems (as well as the largest percentage growth) is in the higher frequency microwave bands (particularly 18 GHz and 23 GHz). These bands have only recently become practical to use because of advances in electronic components that operate at higher frequencies. Although they are useful mostly for short paths (5 miles or less), they are easy to use because of the small antennas that are possible at higher frequencies. Thus, even if the overall use of microwaves is not decreasing, most of the growth will be in the higher frequency bands that are not currently extensively used. The lower frequency bands (below 6 GHz) will be emptying slowly--partly due to migration from the proposed 2 GHz Emerging Technology bands[3].

6. In the majority of markets, the choice between fiber and microwave is made on economic grounds. Fiber is enjoying rapid technological breakthroughs, while microwave is developing less rapidly. The fiber developments are expected to push the future balance even further in the direction of preference for fiber. The general rate of improvement in fiber technology is a major basis for our prediction of further market penetration of fiber.

Summary.

1. It is likely that many of the microwave bands below 6 GHz, as well as the 6 Ghz and 11 GHz common-carrier bands, will experience a decrease in the amount of usage. Most of this traffic will move to commercially-supplied fiber systems or to higher-frequency microwave bands. It is practical to consider re-allocating or sharing portions of those de-populating microwave bands for new services.

2. The 18 GHz and 23 GHz bands will continue to grow for the next 10 years.

3. Many microwave bands are tailored to particular uses because of channelization bandwidths, allowable antenna types, customers, and type of service. Because of these very specific constraints on the use of a particular band, some bands are crowded and growing, while adjacent bands are sparse and shrinking. (Details for existing microwave bands are contained in Section 2.) Since it is difficult to accurately predict what mix of microwave functions will be needed in the future, it would be desirable to allocate future bands as flexibly as possible. Since the propagation and equipment characteristics change over a range of frequencies, it will similarly be desirable to maintain microwave bands distributed over a wide range of frequencies.

Future uncertainties. There are two large areas of uncertainty in the future of microwave usage. These two factors will substantially affect the validity of the predictions which we have made. In both cases, we have assumed the outcome of less microwave usage.

We have assumed that optical fiber connections will be widely available and economically priced in all urban areas. This means that pro-competitive policies will be adopted regarding fiber availability, right-

[3]Redevelopment of Spectrum to Encourage Innovation in the Use of New Telecommunications Technologies. ET docket No. 92-9. NPRM, 7 FCC Rcd 1542, FCC 92-20, February 7, 1992.

of-way for fiber, ability of independent urban fiber providers to gain access to markets and right-of-ways, tax depreciation rules that encourage new technology, etc. In general, these assumptions seem to be in line with current policies. The use of fiber is highly-dependent on a well-developed, user-friendly, flexible infrastructure (legal and political, as well as physical and technical) that makes it easy to get access to existing fiber and to install new fiber where it is needed.

Microwave, on the other hand, can operate much more independently of the infrastructure (though it does depend on frequency management and local zoning regulations). Microwave is often used because the fiber infrastructure is not sufficiently accessible and user-friendly. The use of microwave to support cellular telephone systems is a ready example. The local fiber infrastructure is owned by the LECs, who consider their installed fiber and right-of-ways as major assets which have not been completely scrutinized by the regulatory process. Many LECs have refused to lease unused ("dark") fiber to competitors (e.g. cellular providers) at reasonable rates. The appearance of independent urban fiber providers will help to put competition into the fiber market. Thus, the amount of microwave used in urban environments will be partly a measure of how well regulators are able to effect easy and competitive access to the local fiber market.

The second factor is the development of PCS. If PCS is developed by the LECs as an extension of the local loop, it will be developed almost completely with fiber-to-the curb. If PCS is developed without the heavy involvement of the LECs, it will probably follow the cellular telephone example and make extensive use of microwave networks to by-pass the LEC fiber infrastructure. Regulations encouraging LEC sharing of fiber, conduits, and right-of-ways would substantially affect the amount of microwave used for PCS in urban environments.

(This analysis was developed for the U.S. market and should not be construed to apply to general markets. Many developing countries, for example, will continue to rely much more on microwave and satellite systems, because of difficulties in installation and maintenance of fiber, and lower traffic densities. Even within the U.S. one should expect to see regional differences, based on population density, terrain, and traffic. These differences are readily apparent by observing the different microwave strategies followed by the various RBOCs.)

A Preliminary Look
at
Spectrum Requirements for the Fixed Services

Robert J. Matheson and F. Kenneth Steele*

This study includes a description of the services provided in about 30 of the Government and non-Government frequency bands where Fixed services are accorded Primary status. These frequency bands between 406 MHz and 30 GHz include the services generally known as point-to-point terrestrial microwave. Each of the 30 frequency bands is described in terms of the general services provided in the band, a history of recent frequency assignment trends, a map showing the geographical distribution of current assignments in 1-degree x 1-degree blocks, and a statistical distribution of assignment densities. In addition, technical, regulatory, and economic factors affecting each band are described, as well as a prediction of the rate of future growth (or decrease) for each band.

Technical, regulatory, and market factors affecting the use of Fixed services are described. These topics include the widespread conversion to optical fiber, the prospects for advanced optical components and improved microwave technologies, digital techniques, data compression, frequency band crowding, the effect of new services like cellular telephone and personal communication services (PCS), Government procurement of telecommunication services, and others. Finally, the individual band results are examined in terms of the overall prospects for particular market segments, in terms of Government, private, common carrier, auxiliary broadcasting, and Cable TV relay services.

This staff study was developed by the Institute for Telecommunications Sciences as part of the NTIA program to examine future needs for radio frequency bands and is intended for submission as a comment to the NTIA Notice of Inquiry on Future Spectrum Requirements. The opinions expressed within this document are solely those of the authors and do not necessarily reflect official or unofficial NTIA policy or planning.

Keywords:
fiber optics, fixed radio services, frequency allocation, frequency assignment, future spectrum requirements, microwave radio, spectrum crowding, spectrum management, telecommunications

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1. INTRODUCTION

The development of inexpensive and efficient optical fiber has made possible major changes in the use of the Fixed microwave bands, by providing an efficient non-radio wide-band alternative communications medium. The use of Fixed microwave has also been strongly influenced by changing market patterns, cellular radio, the technical capability to use higher radio frequencies, the development of telecommunication satellites, and the breakup of the telephone companies. These factors have made it technically possible for the telecommunications industry to shift most of its traffic from long chains of microwave links to optical fiber. Important questions remain, however, including: How much traffic has actually shifted from microwaves to fiber? How much traffic will shift in the near future? What factors will affect the rate of shifting? Does this shift imply that some frequencies now allocated to point-to-point microwave should be allocated for other purposes? This report has been written to help answer these questions.

The context in which these questions are being asked is a general review of spectrum requirements, pushed by the need to find spectrum for many new proposed services, including personal communications services (PCS), wireless local area networks (WLAN), digital audio broadcasting (DAB), smart highways, Mobile-Satellite services, and many others. The objective of this study is to examine the likely future spectrum requirements for the fixed services, with an eventual goal of recommending adjustments to future spectrum allocations to correspond to the projected requirements.

In the remainder of Section 1 we discuss some of the historical, economic, and assignment information that will help to form a basis for planning the future use of the microwave spectrum.

In Section 2 we examine the recent historical usage trends in the Fixed microwave bands. Because of the difficulty in actually measuring whether a frequency was being used, we will assume that usage is accurately stated by frequency authorizations and licenses. Therefore, usage information will be taken from the existing frequency management data bases. This part of the study attempts to describe the present level of usage in each of about 30 Fixed frequency bands, as well as recent trends concerning the change in the level of usage.

In Section 3, we review the recent technology and market situations which would be expected to affect the ways that the Fixed bands are used. This includes such factors as the development of fiber optics, the recent availability of higher-frequency electronics, the effects of very complex computer-driven technology, and other factors. In Section 4 we combine the historical evidence and the technology/market factors to attempt to estimate changes in future spectrum requirements for several categories of Fixed users.

Table 1.0-1. shows the bands that we are considering in this report.

Table 1.0-1. Fixed Service Bands (Primary Allocation) in the U. S. Between 406.1 MHz and 30 GHz

Frequency Band	Bandwidth (MHz)	Name	Type of Use
406.1-420 MHz	13.9		Government
928-929 MHz	1		public, private
932-935 MHz	3		public, Govt, private
941-944 MHz	3		public, Govt, private
944-960 MHz	16		public, AUXBC, privt, intrnt
1350-1400 MHz	50		Government
1427-1435 MHz	8		Government
1700-1850 MHz	150		Government
1850-1990 MHz	140	"2 GHz"	private
1990-2110 MHz	120	"2 GHz"	AUXBC, CARS
2110-2130 MHz	40		public
2160-2180 MHz	40		public
2130-2150 MHz	40		private
2180-2200 MHz	40		private
2150-2160 MHz	10	MDS band	public (MDS)
2200-2300 MHz	100		Government
2450-2483 MHz	33	ISM band	AUXBC, private
2500-2690 MHz	190	MMDS band	AUXBC, private, public
3700-4200 MHz	500	"4 GHz"	public, fixed-satellite downlink
4400-4990 MHz	590		Government
5925-6425 MHz	500	"6 GHz"	public, fixed-satellite uplink
6525-6875 MHz	350	"6.5 GHz"	private
6875-7125 MHz	250	"7 GHz"	AUXBC, CARS, public
7125-8500 MHz*	1200	"7-8 GHz"	Government
10.55-10.68 GHz	130	"10.5 GHz"	public, private
10.70-11.70 GHz	1000	"11 GHz"	public
12.20-12.70 GHz	500	DBS band	private & international
12.7-13.25 GHz	550	CARS band	CARS, public, AUXBC, private
14.5-14.7145 GHz	214.5		Government
15.1365-15.35 GHz	213.5		Government
17.70-19.70 GHz	2000	"18 GHz"	public, AUXBC, CARS, private
21.20-23.60 GHz	2400	"23 GHz"	public, Govt, private
25.25-27.50-GHz	2250		Government
27.50-29.50-GHz	2000	"28 GHz"	public

* 175 MHz of this band is allocated to Fixed on a secondary basis.

As seen from the table above, frequency bands that have primary allocations to the Fixed services constitute an appreciable portion of the entire allocated spectrum. For this study, we are not considering the Fixed bands below 406 MHz, since our interest is primarily in those bands which have historically been called the microwave bands. The various types of users indicated in the right-hand column include only the users in the Fixed services. In many cases, there are primary allocations to additional services as well, so it would not be correct to say that "X percent of the spectrum is exclusively (or even mainly) allocated to the Fixed services." However, in fact, in a majority of these bands, microwave Fixed services are the major users. Cumulatively, the microwave Fixed services account for a large portion of the allocated spectrum. Table 1.0-2. shows the percentage of frequencies in various frequency ranges where there are primary allocations to the Fixed services.

Table 1.0-2. Percentage of Frequencies Allocated to the Fixed Services

Frequency Range	Fixed Bandwidth	Percentage Fixed(of allocated spectrum)
0.4-30 GHz	15565.9 MHz	53%
0.4-1.0 GHz	36.9 MHz	6%
1.0-3.0 GHz	881 MHz	44%
3.0-10.0 GHz	3390 MHz	48%
10.0-30.0 GHz	11083 MHz	55%

Note: These totals include frequencies that are shared with other services.

1.1 Historical Background

The old telecommunications paradigm from four decades ago was that long-distance, broad-band communications would be carried across the United States via a network of microwave relay stations. This network was a practical solution successfully implemented in spite of considerable technological limitations. These stations required high-gain receiving and transmitting antennas aimed directly at each other. This not only allowed the system to work at reasonable distances, but provided excellent isolation from undesired signals and multipath and permitted excellent frequency re-use and spectrum efficiency. Because of the need for a line-of-sight path between receiving and transmitting antennas, the geographical bulge of the Earth meant that stations could typically be no more than 30- to 60-km apart. This distance could be stretched by locating the stations on mountaintops or on high towers.

Chains of microwave links were built across the United States, starting in 1951 when AT&T built their analog TD-2 microwave networks across the continent. The 4 GHz band was filled (and later the 6 GHz band) with long-distance telephone calls and occasional coast-to-coast live TV coverage. The FAA built an extensive nationwide 7-8 GHz radar microwave link (RML) network to connect long-range air traffic control radar sites with regional air traffic controllers. The military connected tracking/telemetry stations to control centers on test ranges with microwave networks.

Communication satellites were developed, offering initially a new way to set one relay station at a very high point, dramatically increasing the single-hop range. With the new range advantage, a single pair of hops could span a continent or an ocean, and the cost and capacity of long-range communications improved. Since geostationary communications satellite ground stations and terrestrial microwave relay stations use narrow beamwidth antennas which were aimed in a different set of directions (microwave = horizontal, satellite = upward), it was found that they could very effectively share the same frequency bands. Today, many microwave bands are shared with satellite services. For a while, it seemed that satellites would replace most of the long-range telecommunications infrastructure, and there was a rapid push to move telephone and television channels from microwave to satellite links. Unfortunately, the half-second delay inherent in geosynchronous satellites proved to be greatly annoying to telephone customers, and most domestic telephone traffic was soon removed from satellites.

As the amount of telecommunications traffic increased, the lower-frequency microwave bands became more crowded. Higher-frequency bands were allocated and began to be used, though the equipment was more expensive and the higher frequencies were more adversely affected by weather.

Massive amounts of radio spectrum were allocated to support the anticipated heavy demand for wideband communications traveling via terrestrial microwave relays. About 35 percent of the spectrum between 0.4 and 3 GHz is now allocated to point-to-point microwave on a primary basis, as well as 53 percent of the bandwidth between 0.4 and 30 GHz. This massive commitment of spectrum was realistic and correct, because no practical alternatives to microwave existed before the mid-1970s.

Researchers had looked for non-radio replacements for microwaves for many years. Coaxial cable was a possible solution, but high losses and the need for many difficult-to-build broadband amplifiers made this solution expensive and impractical for long distances (more than 100-km). The recent success of the cable TV industry has been built largely upon relatively short cable runs and the availability of inexpensive high-performance amplifiers. Bell Laboratories developed an experimental 60-GHz helical waveguide which overcame the high losses and bandwidth limitations of coaxial cable, but it was very expensive and required technically demanding, geometrically precise installation. This development was finally abandoned after decades of work to concentrate on a radical new technology using optical fiber.

The first low-loss optical fiber was announced by Corning in 1970. Though this first optical fiber was still quite lossy (20 dB/km), very expensive, and difficult to produce in useful lengths, technology improved rapidly. By 1974, Bell Labs had the loss down to 4 dB/km. Today, fiber costs about $0.05/foot, has a loss of 0.3 dB/km, and can be modulated at 2.4 Gbits/s. At these cost/performance levels, fiber is an almost ideal transmission medium for many telecommunication applications.

The success of fiber in filling many of the market niches previously expected to be filled by microwave systems leads to questions about the amount of spectrum needed for point-to-point microwave communications. Since the old assumptions about the pre-eminent need for microwave spectrum have possibly been made obsolete by the widespread use of fiber optics, it is reasonable to ask whether the 53 percent of the spectrum reserved for fixed microwave applications could now be considered excessive.

1.2 Recent Market Trends

One way to examine the growth of the microwave industry would be to look at the sales of U.S. microwave manufacturers. The Census Bureau provides annual data in their Current Industrial Reports series, MA36P[1]. The following table shows U.S. manufacturers' sales for the 1986-1990 period, separated into frequency bands. These numbers are not adjusted for inflation. Note that these numbers are partly 'growth' numbers (equipment installed to provide new capacity) and partly 'maintenance' (installed to replace old equipment). As such, it is difficult to project whether these numbers indicate a microwave population which is still going up (but at a slower rate in 1990 than in 1986), or whether $500 M in sales is below the zero growth maintenance level for the microwave bands. (Section 1.3 contains data on trends for the number of microwave assignments, which is another way to look at the data.)

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[1] *Current Industrial Reports. Communication Equipment, and Other Electronic Systems and Equipment.* U. S. Dept of Commerce, Bureau of Census. MA36P(year)-1, for years 1987, 1988, 1989, 1990. The most recent revised figures were used.

Table 1.2-1. U.S. Production of Microwave Equipment ($ millions)

Freq band,GHz	1986	1987	1988	1989	1990
.89 - 1.84	38	91	111	88	54
1.85 - 3.69	31	28	35	35	29
3.7 - 6.42	180	138	175	167	179
6.43 - 7.89	60	27	20	22	8
7.9 - 12.2	233	230	52	61	54
13.25 - 19.5	85	76	112	170	200
19.6 - 56.0	62	52	45	58	43
Total $ M	627	590	505	543	524

The dollar amounts above indicate U.S. point-to-point microwave industry manufacturing totals, in millions of dollars. Since some amount of this U.S. equipment was exported, and since additional foreign-manufactured equipment was imported for use in the U.S., it is possible that the slowly declining figure reflect only a decline of U.S. microwave manufacturing. The figures are consistent with a slowly declining microwave market in the U.S., especially when compared to the figures for related industries. (Several microwave manufacturers who were shown the data in Table 1.2-1 were skeptical of the band-by-band numbers, but there was reasonable agreement about the overall market being in the range of $500 million and decreasing slowly. Census has been unable to provide details which would confirm this data, but assumes that some manufacturers may have inadvertently placed data in the wrong frequency bands.)

In the same period, the larger category of 'communication systems and equipment' increased from $11,216 M in 1986 to $15,010 M in 1990--an increase of about 34 percent. Mobile radio of various types increased by 200 - 300 percent over this same period.

Comparable annual sales figures from the same Census bulletin for fiber optics communication equipment are shown in the following table. These figures show a substantial growth trend, with 1990 sales almost twice as large as that of the combined microwave equipment.

Table 1.2-2. Yearly Fiber Optic Equipment Sales

Year	1986	1987	1988	1989	1990
Fiber optic sales ($millions)	637	726	717	772	1006

The 1991 annual report by the FCC on fiber deployment[2] shows fiber deployment at the end of 1991 for three major types of telecommunication suppliers. Table 1.2-3. summarizes the last five years of data. It should be noted that the table shows fiber miles. The table also shows the average cross-section

[2]Jonathan M. Kraushaar. *Fiber Deployment Update. End of year 1991.* Industrial Analysis Division, Common Carrier Bureau, FCC. March 1992.

(number of fibers per cable) and the percentage of the fibers 'lit' or actually in use at the end of 1991. The 'un-lit' fiber is fiber that has been installed in anticipation of future needs, but which is not actually being used at present.

Table 1.2-3. Fiber Miles[3] (in thousands) Deployed by Various Types of Suppliers

Type of service	1987	1988	1989	1990	1991	Cross-section	Percent Lit
IXCs	1293	1725	1901	2131	2385	25.1	49.2
LECs	1192	1588	2037	2767	3811	26.9	40.3
Urban fiber	7	12	34	57	102	45.5	58.0

The lower growth rate for the inter-exchange carriers (IXC) reflects the almost complete 'fiberization' of the IXC networks. The major fiber growth is presently occurring in the local operating companies, where fiber is being installed for inter-office links (between central offices), feeder links (from central offices to major buildings or neighborhood interfaces), and ties to the IXC companies. Independent urban fiber suppliers are beginning to provide competition to the local exchange carriers (LECs). Though these urban fiber companies are growing very rapidly now, they still represent a very small percentage of the business, and it remains to be seen whether they will continue to flourish in the future. Nevertheless, they will tend to keep competitive pressure on the LECs.

Even for the fiber that is used (lit), much of the fiber is used at lower bit rates than the current maximum of 2.4 Gbits/s. For example, a DS-3 feeder link to a remote interface point supporting 672 phone circuits would use 45 Mbits/s. The FCC estimated that the current fiber is being used at a rate equivalent to about 300 Mbits/s/fiber, averaged across all fibers installed by IXCs.

The ratio between new capacity added with fiber and new capacity added with microwave can be estimated. FCC data on the IXC's indicated that they added about 1,100,000 DS-3-miles in 1991 with 254,000 additional fiber miles--an average capacity of 4.33 DS-3 channels per new fiber. Since a DS-3 channel is equivalent to 45 Mbits/s, this says that new fiber is being loaded at an average capacity of 195 Mbits/s per fiber--about 2/3 of the loading for older fiber. From table 1.2-3. we see that the total fiber added in 1991 by IXCs, LECs, and "urbans" was 1,343,000 miles. Assuming the same (4.33 DS-3/fiber) ratio for the local operating companies and the urban fiber providers, this would result in 5,800,000 DS-3 miles added in fiber in 1991. The microwave market was about $500 M in 1991. Assuming that a bi-directional DS-3 receiver and transmitter pair cost about $50,000, this would indicate that about 10,000 new microwave links were established in 1991. Assuming that each link provided one DS-3 channel with a 25-mile route, this would mean that new microwave systems provided 250,000 DS-3 miles in 1991. This analysis shows that in 1991, about 23 times more capacity was added to fiber systems compared to microwave systems.

The above analysis has considerable latitude for 'adjustments', based on details which are not known. Many microwave links carry more than a single DS-3, but many carry less. Many of the microwave

[3]These quantities are reported in miles (instead of km), following the original tables. The calculations using this data in the immediately following paragraphs will also be done using miles.

radios sold today are replacing older radios and do not represent an increase in capacity. It is difficult to know how much of the fiber capacity is used for backup capability. The LEC fiber feeder market (the major part of the new market) uses lower capacity than the long-haul markets where the DS-3 data was obtained.

If the above analysis is correct, new microwave capacity is carrying only 4 to 5 percent of the total new communications capacity. Eventually, the inventory of microwave and fiber capacity would be expected to match the ratio of new capacity being added. Thus, microwave systems would eventually be serving only 4 to 5 percent of its intended market. Could one conclude that microwave systems should then be expected to operate on only 4 to 5 percent of the previously allocated spectrum? Probably not. A more reasonable interpretation would be to say that fiber has made it possible to carry much more communications than would have ever been possible with microwave alone.

It should also be noted that the ratio in new microwave and fiber capacities may understate the importance of microwave radio, since many microwave systems are designed to serve low-capacity links, while fiber serves more high-capacity links. A comparison of route-miles instead of equivalent DS-3 capacity, for example, would probably show microwave with a considerably enhanced percentage.

1.3. Frequency Assignment Trends

The number of microwave channels assigned to users may provide another indication of the growth of microwave spectrum use. This section uses frequency assignment data obtained from Comsearch[4] to examine growth of non-Government use of the microwave bands. (The Government uses the term "assignment" to indicate that a certain radio station has been authorized to operate at a certain frequency. The FCC uses the term "license" for the same purpose. Throughout this study, we will use the term "assignment" to indicate a Government assignment or a non-Government license.)

In the following analysis, we have included all of the Fixed service frequency bands, except the Government bands, the bands below 1 GHz, and the 13-GHz CARS band. The Government bands were left out of this analysis because many of the Government bands contain large numbers of assignments belonging to non-Fixed services, and our historical data did not allow easy separation of the services. The non-Government bands below 1 GHz included thousands of assignments, which cumulatively contained less bandwidth than a single 25-MHz-wide microwave channel; it did not seem equitable to count such disparate bandwidths equally. Finally, the CARS band allows microwave to relay blocks containing 40 to 80 TV channels to each of many cable headend sites, which can result in more than 1,000 licenses at a single site. The 100,000+ assignments in the CARS band would single-handedly mask changes in any other bands. At the same time, the CARS service is a very specialized service which is undergoing rapid changes, so the trends in the CARS bands do not necessarily provide insight to the trends in other services.

Figure 1.3-1. shows the total number of Fixed service frequency assignments, as described in the previous paragraph. The number of assignments seems to be still growing in 1987, hitting a peak in the 1988-90 period, and possibly starting down in 1991. It is too soon to know whether the downward trend (if one year counts as a 'trend') will continue. Whether actually downward or not, it is clear that--as a whole--the number of microwave assignments is not rapidly increasing.

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[4]Contract # 40 RANT2T4674, April 22, 1992 from DoC to Comsearch.

Individual frequency bands and services show a different set of trends, including some that are growing rapidly (2 GHz common carrier, 13 GHz CARS, etc.), some that are remaining about the same (6.5 GHz private), and some that are decreasing rapidly (6 GHz common carrier). Additional information on individual bands is shown in Section 2, including trends in the number of assignments. Additional information on each service is shown in Section 4, including frequency assignment trends in each service. Each of these bands and services has its own reasons for growth or contraction, and that story may be quite different from the story of the microwave industry as a whole.

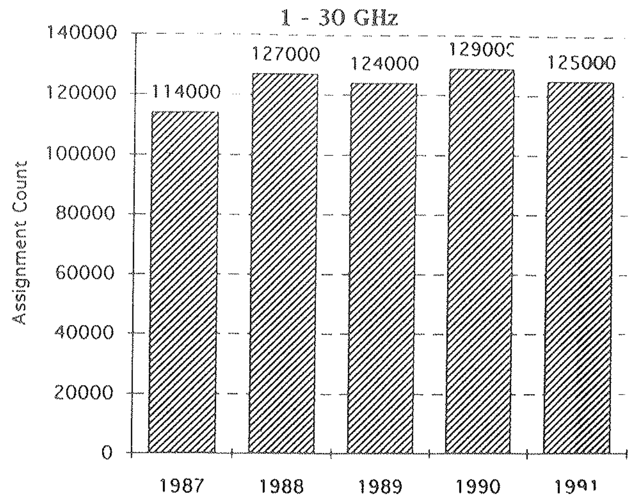

Figure 1.3-1. 5-year trend for non-Government microwave assignments in 1-30 GHz bands.

There are several risks in using assignment data to infer actual use of the spectrum. One risk is the theoretical suitability of assignment data. The permission to use a frequency for a function does not necessarily imply that the frequency is actually used. Frequency assignments have sometimes been used to reserve channels for future use. It has also been widespread practice to be less than diligent in immediately reporting when a frequency is no longer in service. Some assignments are used only on an intermittent basis. Therefore, bands may appear to be crowded on paper when they are, in fact, not as crowded. This can be particularly true when a band is no longer being fully used for its original purpose and there is some uncertainty about its future use.

Another risk is that the assignment data are not up-to-date and accurate, and that they do not accurately reflect what the users have reported concerning their use of the spectrum.

Finally, there is always the problem of interpretation. When counting frequencies, does a wideband channel count for more than a narrowband one? A long link more than a short one? A high-reliability air traffic control link more than an inventory update function? In the totals shown in the previous bar chart, we counted all assignments as equal, except for the 13 GHz CARS band, frequency bands below 1 GHz, and Government bands. We believe that the inclusion of these bands in our calculations would tend to mask some of the basic microwave band trends.

1.4 Description of Non-Government Microwave Services and Users

Non-Government user rights to the Fixed radio bands from 406.1 MHz to 30 GHz, with pertinent regulations, are codified in the Code of Federal Regulations (CFR), Title 47 (Telecommunications) Part 2. Non-Government users have exclusive rights in 17 bands and share with Government users in 3 bands. These bands provide nearly 11,000 MHz of spectrum divided over a wide and growing variety of authorized services. Primary allocations in the bands are to Fixed, Mobile, Radio Navigation, Radio Astronomy, Space Research, and various other satellite services. Total individual assignments in the bands have grown from 207,000 in 1987 to 271,000 in 1991.

Fixed service assignments in the 900 MHz bands include Multiple Address Systems (MAS), Paging, Aural Auxiliary Broadcast, and point-to-point Public, Private Operational, and Government services. The bands from 1427 Mhz to 7125 MHz are used by Common Carrier and Private Operational Fixed services, Auxiliary Broadcast services, Cable Television Relay Stations (CARS), Multipoint Distribution Systems (MDS), Multichannel Multipoint Distribution Service (MMDS), and on a secondary basis for Fixed (Telemetering). Within the bands from 10550 MHz to 19700 MHz allocations are to Common Carrier and Private uses, to Auxiliary Broadcast, to CARS, as well as some newer assigned categories of Digital Termination Systems (DTS) and Digital Electronic Message Service (DEMS). Finally, the bands from 21200 MHz to 29500 MHz are allocated to Domestic Public Fixed, Private Operational Fixed, Auxiliary Broadcasting, and Government Fixed.

For the convenience of the reader, some of the more common specialized Fixed services are described here in the terminology of 47 CFR, with the appropriate section identified for reference.

Auxiliary Broadcasting Services support broadcast services by facilitating the distribution of program material in situations that may be temporary or, in some cases, unusual. Rules pertaining to Auxiliary Broadcast Services are given in subparts of 47 CFR Part 74. Some of these Auxiliary Broadcast Services or stations are briefly described here.

> A **TV pickup** station is a land mobile station used for the transmission of TV program material and related communications from scenes of events occurring at points removed from TV broadcast studios to TV broadcast or low-power TV stations. These are commonly called electronic news gathering (ENG) stations.
>
> A **Studio-to-transmitter link (STL)** relays program material from the studio to its transmitter or to a low-power station.
>
> An **Intercity Relay (ICR)** station relays program material between broadcast stations or between various ENG intermediate relay points and a broadcasting station. International broadcasting, however, is not included in this category. STL and ICR links are used in both aural and television broadcasting.
>
> Although ENG, STL, and ICR are all intended to carry 6-MHz-wide NTSC-format TV signals, the NTSC signal is frequency-modulated on a carrier, using a total bandwidth of 17- to 25-MHz (depending on the channelization of the particular frequency band).

The **Cable TV Relay Service (CARS)** supports cable TV systems in a manner analogous to the Auxiliary Broadcasting support of broadcasting. These services are described in 47 CFR 78.

> **CARS Pickup stations** provide temporary pickup from the scene of events distant from the CARS studio. These are commonly called electronic news gathering (ENG) stations.
>
> **CARS Relay stations** provide for relay of TV program material from a TV broadcast station to a cable headend point.
>
> **CARS Local Distribution Service (LDS)** provides for distribution of a block of TV signals to one or more cable headend sites. One implementation of LDS carries a large number of TV

signals (as many as 42) in NTSC format at 6 MHz spacing. These are commonly called studio to headend links (SHLs)

Digital Termination Service (DTS) is a private point-to-multipoint radio system for providing two-way exchange of digital data as described in 47 CFR Part 94.

The **Digital Electronic Message Service (DEMS)** provides two-way and end-to-end public fixed radio service which incorporates the Digital Termination Systems; it is described in 47 CFR 21.

A **Multiple Address System (MAS)** provides point-to-multipoint communications service either one-way or two-way, to at least four remote stations. Video service is excluded. Pertinent rules to MAS are given in 47 CFR 94.

Multipoint Distribution Service (MDS) is a one-way domestic public radio service which transmits microwave frequencies from a fixed station to multiple fixed receivers. This service is popularly known as 'wireless cable'. The original purpose of MDS was to provide subscribers with digital information. Recently, most MDS has been used for broadcast-quality TV in situations where cable TV is not practical. MDS service is described in 47 CFR 21.

Multichannel Multipoint Distribution Service (MMDS). A recently-expanded version of MDS which allows a single station to broadcast up to 33 channels of TV.

Paging service provides one-way communications from a base station to either fixed or mobile receivers, signaling by tone, voice, or other means. These receivers are commonly called 'beepers'. Rules for the paging service are covered in 47 CFR 90.

The Rural Radio Service is a fixed public radio service which provides **Basic Exchange Telecommunications Radio Service (BETRS)** between subscribers and a central office in rural areas at frequencies below 1000 MHz. Rules given in 47 CFR 22 describe and codify the service.

In addition to the previously described specific services, the following are general categories or descriptions of services often provided by microwave systems.

Public service, sometimes called **common carrier** service, refers to a service provided by one company for the use of other parties. Telephones, cellular phones, and paging are the most common examples of public services. The nature of the traffic carried by the service is not particularly a factor; the important factor is whether the provider of the service intends these services chiefly for himself or for the public-at-large.

Private or private operational services are owned privately for the exclusive use of the company owning the service. There are three major uses of private service:

Supervisory Control and Data Acquisition (SCADA) describes a broad category of functions used by private companies to monitor and control pipelines, railroads, and electrical power lines; dams, irrigation, and navigation canals; and similar functions. These functions are often relatively narrowband (possibly monitoring the status of a few dozen points and controlling a few dozen valves, pumps, and switches) and spread out over a large geographical area. The Federal

Government uses SCADA for the control of electrical power grids, flood control, and hydropower dams, etc.

Support of **thin-route mobile radio** backbone is often required by local, state, and Federal governments. State governments often use microwave systems to link together the large number of land mobile radio sites (often at remote sites) required for communications needed by state police, highway workers, and others. Similar functions are needed by the Federal Government for communications in national forests and parks, test ranges, etc.

Common-carrier bypass, or just 'bypass', is used by private companies, local governments, and cellular telephone companies to directly interconnect multiple sites without paying the local exchange carriers (LECs - local telephone companies) for services.

Technical or regulatory aspects regarding the use of the radio frequency spectrum are discussed in the 200 or so active portions of 47 CFR. Uses, assignments, and trends of the individual bands will be discussed band-by-band in Section 3 of this report.

1.5 Description of Government Microwave Services

Government user rights to the fixed radio bands from 406.1 MHz to 30 GHz, with appropriate regulations, are codified in the 'NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management', which is updated semi-annually. As described in this manual, the Government's primary allocations in these bands include the Fixed, Mobile, Radio Astronomy, and Radiodetermination services, and various space services, including Space Operation, Space Research, Meteorological-Satellite, Earth Exploration-Satellite, Fixed-Satellite, and Inter-satellite Services. The Government has exclusive rights in nine of these fixed bands and shares allocations with non-Government users in three bands. The twelve bands together afford about 5,000 MHz of spectrum to the Government. Its total assignments (including Fixed and non-Fixed services) in these bands grew from about 35,000 in 1987 to approximately 43,000 in 1992. The growth was not uniform in all the bands and services or with time.

Federal Government uses of the microwave spectrum parallel the private and municipal use of microwave communications. SCADA and support of thin-route mobile radio are used throughout many Federal departments. In addition, the military uses microwave to support special activities at test and training ranges. The military also maintains many transportable microwave systems to rapidly set up tactical and strategic communications nets at any location on the globe. Finally, some Federal microwave bands contain systems that are classified because of their function.

In general, Government Fixed-service bands are less homogeneous than corresponding non-Government bands. The bands identified here as Fixed often are shared with sizable numbers of various special-purpose, non-Fixed systems, which modifies the use of the Fixed services in two ways. First, the non-Fixed systems require a considerable amount of spectrum space, which may prevent the assignment of Fixed services. Second, the wide variety of non-Fixed services makes it more difficult to develop an organized channelization plan and sharing strategy. Many Government Fixed bands do not have a channelization plan. Even when a channelization plan is present, it is often followed less strictly than a non-Government band channelization plan.

Many Government Fixed frequency assignments tend to be "hidden," either because they are not extensively used in peacetime, because multiple copies of many transportable systems are not individually assigned, or because they are classified. With the prospect of partially opening Government assignment lists for public access, it is important that Government listings reflect the numbers of users and equipments in a way that is more comparable to FCC practices. Therefore, some agencies are beginning to add individual frequency assignments for multiple copies of transportable microwave terminals and other systems.

The Federal use of radio frequencies is guided by the NTIA Manual[5], and interdepartment frequency management decisions are made in consultation with members of the Interdepartment Radio Advisory Committee (IRAC), following a standardized set of system review procedures. The IRAC includes representatives from all major Federal users of radio system, as well as liaison with the FCC.

The 406.1-420 MHz band is used extensively for Fixed and Mobile services. Mobile services include mostly Land Mobile, as well as applications in telecommand and air mobile. Fixed services often provide the point-to-point backbones in support of Land Mobile voice networks. Hydrological and Meteorological Fixed services include significant uses of the band in such activities as monitoring river depths and velocities or relaying weather information. It is also used for control applications, like controlling airport runway lights, and for monitoring navigational aids, like the Instrument Landing System.

The Government bands between 1350 MHz and 1850 MHz are allocated on primary bases to the Fixed, Mobile, Radiolocation, Space Operation and Meteorological-Satellite services. Specific uses tend to be in Radiolocation; Radionavigation; Mobile Telemetry; and tracking, telemetry and command (TT&C) for military satellites.

The 2200-2300 MHz and 4400-4990 MHz Government bands have primary allocation to Fixed, Mobile, and Space Research services. Earth Exploration-Satellite and Space Operations services are added by footnote. Uses for the 2200-2300 MHz band include TT&C with the NASA Tracking Data Relay Satellite System (TDRSS) and the DoD Space Ground Link Subsystem (SGLS). Uses include terrestrial telemetry, including airborne flight testing telemetry. In the 4400-4990 MHz band, specific uses include transportable, line-of-sight, and troposcatter tactical voice communications, radio drone control, and the Television Ordinance Scoring System (TOSS). Additional uses include tethered balloons in drug interdiction efforts.

The 7125-8500 MHz band is allocated to the Fixed, Space Research, Fixed- and Mobile-Satellite, Meteorological-Satellite, and Earth Exploration-Satellite services, all on a primary basis. The heaviest use is for Fixed microwave communications systems. The FAA has the most assignments in this category; it employs the band to relay radar data to air traffic control centers. DoE has many assignments in the band which utilize SCADA nets in its hydroelectric projects over much of the western United States. After the Fixed service use, military satellite systems are the heaviest users of this band. The largest number of satellite assignments are used in providing strategic communications for the DoD.

[5]*Manual of Regulations and Procedures for Federal Radio Frequency Management.* available from Superintendent of Documents, U.S.Government Printing Office, Washington, Dc., 20402

The Government bands between 14.5 GHz and 27.5 GHz include allocations to Fixed and Mobile Services on primary bases. One of the largest uses is remoting of data from civilian and military air traffic radars. Additional uses are for the transmission of data between remote sites and central facilities (Army), and dockside check of electronic systems (Navy). There is also telemetering use by the military services in association with space and aircraft.

The individual bands will be discussed in more detail in Section 3.0. Table 2.5-1 summarizes several statistics for assignments in the Government fixed bands. Where the bands contain mixed services, these numbers include only data from the fixed assignments. This data is from the January 1992 Government Master File.

Table 1.5-1. Summary of Government Fixed Band User Characteristics

Frequency band	No. of assignments total, transportable	Bandwidth ave, median	Ave power (watts)	Modulation %digit %analog	ave antenna gain (dB)
406-420 MHz	7460 433	20.1, 16.0 kHz	45	0.1 99.9	8
932-935 MHz	3 0	79.0, 25.0 kHz	17	0.0 100	24
941-944 MHz	2 0	12.5, 40 kHz	6	0.0 100	13
1350-1400 MHz	271 271	1.4, 1.2 MHz	20	0.0 100	18
1427-1435 MHz	22 21	1.5, 1.2 MHz	20	0.0 100	14
1700-1850 MHz	5187 275	3.8, 1.9 MHz	4	6.0 94	28
2200-2300 MHz	278 44	3.8, 1.6 MHz	3	0.0 100	27
4400-4990 MHz	896 670	8.0, 3.5 MHz	1200	48.0 52	36
7125-8500 MHz	8384 358	20, 20 MHz	2	8.0 92	41
14.5-14.7 GHz	217 106	22, 23 MHz	1.8	31.0 69	40
15.1-15.3 GHz	92 17	14, 15 MHz	1.1	15.0 85	43
21.2-23.6 GHz	5743 321	27, 25 MHz	0.2	1.0 99	41

2. CURRENT USAGE AND RECENT HISTORY

This section summarizes the usage in about 30 frequency bands having a primary allocation to the Government or non-Government Fixed services. The bands are arranged in ascending frequency order, and each section follows the same general pattern of presentation. Information on the allocations for each band and a description of the significant uses for the band are presented. Numerical information is developed for each band, including the geographical distribution of assignments and a recent history of the number of assignments. General information is presented concerning the technological, regulatory, and market factors that affect the use of the band. Finally, a prediction is made for the future growth (or decrease) in the number of assignments in the band in the next five years.

This study is chiefly a report on the Fixed services, and less a report on the individual frequency bands which are described in the remainder of this section. Therefore, it should be noted that we have spent relatively little effort in exhaustively cataloging all of the non-Fixed services in an individual frequency band, but have concentrated only on the Fixed services in those bands. This usually causes no problems in understanding the non-Government bands, where each band is used according to a channelization plan and contains systems which are highly homogeneous in their characteristics. There are some non-Government bands (e.g. the 4 GHz common carrier band) where extensive sharing with dissimilar systems (e.g., satellite downlinks) limits the use of Fixed systems; we have specifically mentioned the problem in these cases.

The problem of sharing with non-Fixed systems is often more complicated in the Government bands. Government bands are often less homogeneous and follow channelization schemes to a smaller degree. The 1700-1850 MHz band, for example, contains not only a wide variety of terrestrial point-to-point links, but also mobile radio, aeronautical mobile links (including wideband video and telemetry), satellite links, and some classified systems. In the case of the 1700-1850 band, the additional services represent a minority of the total number of assignments, but they substantially constrain use of the band for Fixed systems. Because of the wide variation of system characteristics, the constraints may not be easy to describe, except on an individual basis for each type of system. This level of detail is beyond what was intended for this document.

Therefore, the reader should be aware that the following sections describing individual frequency bands may contain some substantial omissions concerning non-Fixed systems in those bands. These omissions are probably more significant for Government bands than for non-Government bands.

2.1 Methodology and Approach

The number of assignments was obtained from either of two sources, depending on whether the frequency band was a Government band or an non-Government (NG) band. The Government Master File (GMF) was processed to obtain the Government data. Data files from Comsearch were used to get the non-Government data. For the 21.2-23.6 GHz shared band, we used GMF data for the Government use and Comsearch data for the non-Government use.

Data for each band includes three basic sets of numerical information:

1. The current geographical distribution of Fixed assignments
2. A statistical distribution of Fixed assignment geographical densities
3. A historical trend summary of the total number of assignments over the last several years, including Fixed and non-Fixed assignments in Government bands.

For most services, only the transmitters were counted. In some bands with TV receive-only terminals, we counted the receivers because their presence greatly affects the use of the bands.

Geographical and statistical data. The geographical and the statistical presentations were obtained from the same data. Current Government band assignment information was developed from the June 1992 GMF, selecting only Fixed assignments. For the purposes of this study, Government station classes of FX, FXD, FXE, and FXH were considered as Fixed services. Although many Government bands also contain significant numbers of non-Fixed assignments, this study is intended to focus on the Fixed Services. Current non-Government assignment data was developed from the December 31, 1991 Comsearch files. When possible and significant, we attempted to divide the assignments into separate user categories, since this makes trend information easier to understand. Geographical and statistical data are not necessarily commensurate and comparable between different bands and services. The nature of some services makes them difficult to compare with other services. Nevertheless, all bands were treated in as similar a manner as possible. The Government assignment count usually includes classified assignments, but generally does not include information on the number of copies of equipment in the military inventory. For example, the entire inventory of the (fictitious) AN/ABC-123 transportable microwave terminal will often be represented by a few assignments, e.g., one assignment for each facility using that equipment. An exception would be the case where an AN/ABC-123 terminal is permanently installed at a location. In this case, each location would have an assignment. Many of the details of exactly how assignments were treated were not recoverable from the archival file summaries that we used to get the Government historical information.

Geographical maps. An example of a geographical map is shown in figure 2.1-1. This figure shows that much of the use of the 928-929 MHz and 952-953 MHz bands seems to be concentrated in the Gulf of Mexico and large metropolitan areas. The Rocky Mountain area shows very little usage. Other geographical patterns might show up in other bands. For example, the 5925-6425 MHz band shows a much more uniform coverage across the nation. The 2450-2483 MHz band shows most of its usage in the Gulf of Mexico. These maps show usage patterns that help to understand how the bands are used, as well as possibly suggesting services that might be particularly amenable to sharing on a geographic basis. Note that these maps show only the Fixed services; the absence of Fixed assignments should not be construed to indicate an absence of other types of assignments.

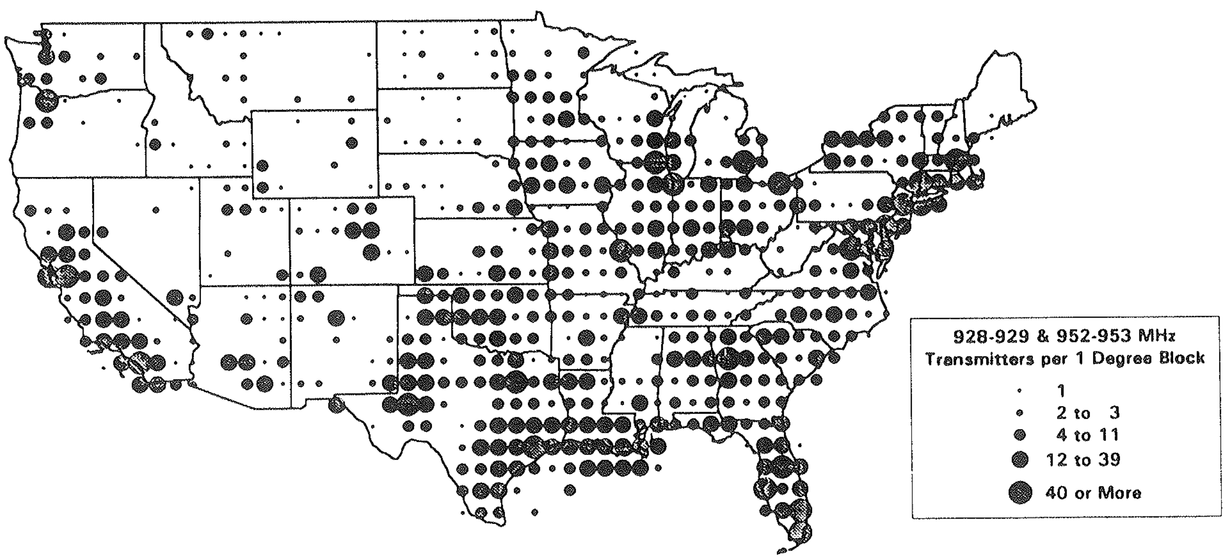

Figure 2.1-1. Example of Geographical assignment density map. (928-929 MHz and 952-953 MHz Bands)

The geographical area of the United States was covered by a grid with 1-degree resolution in latitude and longitude, forming about 1000 1-degree by 1-degree blocks. Circles of various sizes were placed at the center of each of these blocks; the size of the circle indicates the total number of transmitters in that block. The absence of any circle shows that no transmitters were present in that block.

This geographical mapping is intended to show relative usage between various geographical areas in the United States, rather than the difference in crowding between the various frequency bands. Therefore, the values representing the number of transmitters in each block have been scaled according the number of transmitters in the band. This means that the map of a lightly-used band might have the same appearance as the map of a heavily-used band. The scales on these maps should be checked before using these maps to compare the usage in separate frequency bands.

Statistical tables. The statistical tables for each band contain a summary of some of the more important statistical information for the band.

1. Total U.S. assignments (1991). This is the total number of U.S. assignments in that band, as enumerated in the December 1991 Comsearch database or the January 1992 GMF database. In the case of the 406-420 MHz band, the data is for Fixed assignments only.

2. Peak assignments/1-degree block. This is the highest number of assignments found in any 1-degree x 1-degree block in the United States. This number was obtained from the data used to plot the geographical map for each band.

3. Effective # of channels. This number represents the number of channels used to normalize the channel re-use numbers. In the case of a band that is simply divided into a set of (equal or unequal) non-overlapping channels, this number is the total number of channels in the band. When the channels are overlapping, or customarily assigned by combining a number of narrowband channels to obtain the required bandwidth for a system, this field contains a range of numbers representing the largest and smallest numbers of channels into which the band would normally be divided. In the case of most Government bands, the effective number of channels was found by dividing the total bandwidth by the average bandwidth shown in Table 1.5-1.

4. Average U.S. channel re-use. This field shows, on the average, how many times a typical channel was re-used over the entire United States. It is obtained by dividing the total number of U.S. assignments (item #1) by the effective number of channels in a band (item #3). In most Government bands, the effective number of channels in a band was found by dividing total bandwidth by the average bandwidth of a channel (as found in Table 1.5-1). Since the effective number of channels is sometimes a range of numbers, the average U.S. channel re-use may also be a range of numbers.

5. Peak re-use/1-degree block. This field shows the number of times that an average channel was re-used within the 1-degree geographical block with the highest number of assignments. This shows how often a given channel was re-used within the most heavily crowded conditions. It is obtained by dividing the peak number of assignments in a 1-degree block (item #2) by the effective number of channels (item #3).

6. Annual growth rate (last 4 years). This field was calculated to give the (compounded) annual growth rate which would be needed to change the number of 1987 assignments to the number of assignments in 1991 for Comsearch data (or 1988 and 1992, respectively, for GMF data). This is described more fully in a following paragraph describing the historical trend data.

7. Estimated annual growth (next 5 years). This is the annual percentage change for (compounded) growth that would be required to convert present assignment numbers to the expected assignment numbers five years from now. It is described more fully later.

Assignment density distribution graph. The assignment density distribution graph (see Figure 2.1.2) uses the same information found in the geographical map, but organizes it as a statistical distribution showing what percentage of the 1-degree blocks contain at least the particular total number of assignments. The example graph uses data from the 928-929 MHz and 952-953 MHz bands.

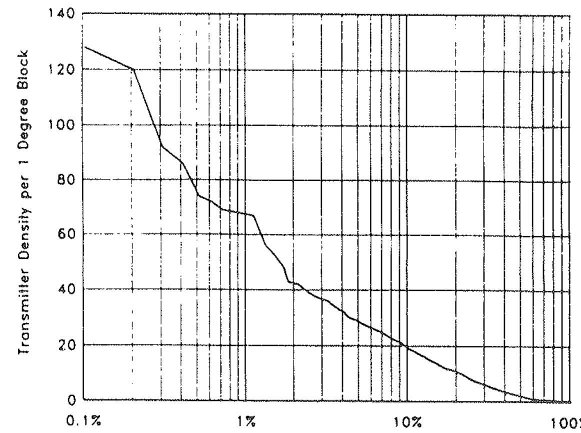

Figure 2.1-2. Example of assignment density distribution graph. (928-929 MHz and 952-953 MHz bands)

The graph shows to what degree the transmitters are uniformly distributed on a geographical basis. If all 1-degree blocks had the same density of transmitters, the graph would mostly show a horizontal line at the level of the density. The example graph shows that the highest density of transmitters was about 128 assignments in a 1-degree block, and that about 1 percent of the blocks have at least 68 assignments.

Typical users. This section describes the current set of typical applications found in a band, along with other information that may help the reader understand the way that a band is being used. In some cases, we have given independent assignment counts for different types of users. This information came from various sources--often from different sources than were used for the geographical/statistical data or the trend data. We note that totals often do not match exactly between the sources, but we believe that this information is still useful to give an approximate indication of the number of different types of users. Most of the information on the number of agency assignments in Government and shared bands came from the July 1992 GMF.

Recent growth in number of assignments. Historical trend information for Government bands was developed for the last 13 years of data in the GMF, using the archived records closest to January 1 of each of the respective years. The archived Government data could not be easily sorted for the assigned service, however, and it was necessary to use the total number of assignments in a band, including all types of users. In most cases, we were able to obtain 13 years of data. The average growth rate (last 4 years) was obtained from only the 1988 and 1992 data. The calculated growth rate is the compounded annual rate (constant) which predicts the net growth from 1988 to 1992. In some cases, where obvious changes of slope had occurred more recently than four years ago, we adjusted the calculations to use a different starting year. The non-Government bands were developed from the archives at Comsearch. In this case, we obtained five years of data, based on December 31 archived data. The growth rates from the Comsearch data were calculated using the first and the last year of data, in a manner identical to the GMF data. It should be noted, however, that the dates on the Government graphs are displaced one year from the dates on the non-Government graphs: 1992 (January) on the Government graphs corresponds to 1991 (December) on the non-Government graphs. For both sets of graphs, the most recent year corresponds to the time period close to the end of 1991 and the beginning of 1992.

In a few shared bands, Comsearch and the GMF files can be directly compared. In the 21.2-23.6 GHz band, we compared the databases to get some understanding of how closely these files matched. We did not get Government data from Comsearch in this band. On the other hand, Comsearch provided independent data on the Public and Private services, which the GMF lumped together as 'non-Government' (NG). Therefore, the only numbers which could be compared directly were the total number of NG assignments. The results are shown below:

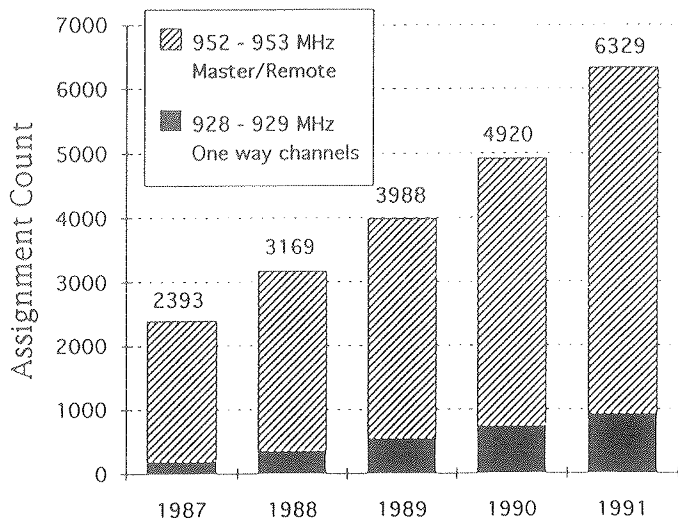

Figure 2.1-3. Example of graph showing recent growth in number of assignments. (928-929 MHz and 952-953 MHz bands)

Table 2.1-1. Comparison of GMF and Comsearch NG Assignment for 23 GHz Band

Comsearch date	No. of assignments	GMF date	No. of assignments	difference
12/31/87	2943	09/87	2456	487
12/31/88	4745	12/88	3364	1381
12/31/89	5037	01/90	3940	1097
12/31/90	6447	------	-----	-----
12/31/91	7158	06/92	7058	100

The significant differences between Comsearch and GMF numbers can be partly explained by different dates. More significant, however, is that the GMF NG data came from the FCC via a process involving considerable delays. It is somewhat encouraging that the most recent information is more closely matched than the earlier information. It is also important to note that the same general growth rates would have been predicted by either set of data. The difference is easily explainable without casting doubt on either the Comsearch NG data or the GMF Government data.

The historical data is useful to show which bands are becoming more or less crowded. This information is based completely on frequency assignment data, however, and does not necessarily show whether the indicated assignments are actually being used. In many bands, there is no mechanism for ensuring that users turn in their frequency assignments when they are finished using them. Therefore, in a frequency band that has been emptying out, the assignment database information may lag a year or more behind the actual usage. The database manager may learn of the disappearance of the equipment only when the frequency user fails to renew an assignment when it becomes due several years later. Data from Comsearch clients may be more accurate in this respect, since users are charged annual fees for monitoring FCC filing activities to protect the assignment from encroachment, and it is financially advantageous to stop paying the fee when the assignment is no longer needed.

Comments. This section contains any additional information that may be helpful in understanding the current or future use in this band, or which may illustrate general trends or technology factors having significance over a number of bands.

Estimated future growth rate. This section indicates the predicted annual percentage growth, averaged over the next five years. The growth rate derived in this section is also included in the table of statistics for the band, Table 2.X-1. In some bands, we expect that the growth rate will change substantially over the next five years, so that the present growth rate will be considerably different from the predicted average growth rate. This rate was calculated by estimating the number of assignments at the end of 1996 and calculating the average compounded growth rate needed to achieve that number. If the number of assignments is expected to decrease, the growth rate will be expressed as a negative number. A narrative description of the factors that were included in that prediction are found in each band description in the paragraph on 'estimated future growth rate'.

It should be noted that the estimated growth rate for each band is based on a large number of factors, each of which is subject to uncertainty and possible error. The reader is reminded that these estimates are solely the authors' opinions and have not been subjected to other review.

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2.2 Usage in the 406.1-420 MHz Band
Government Service

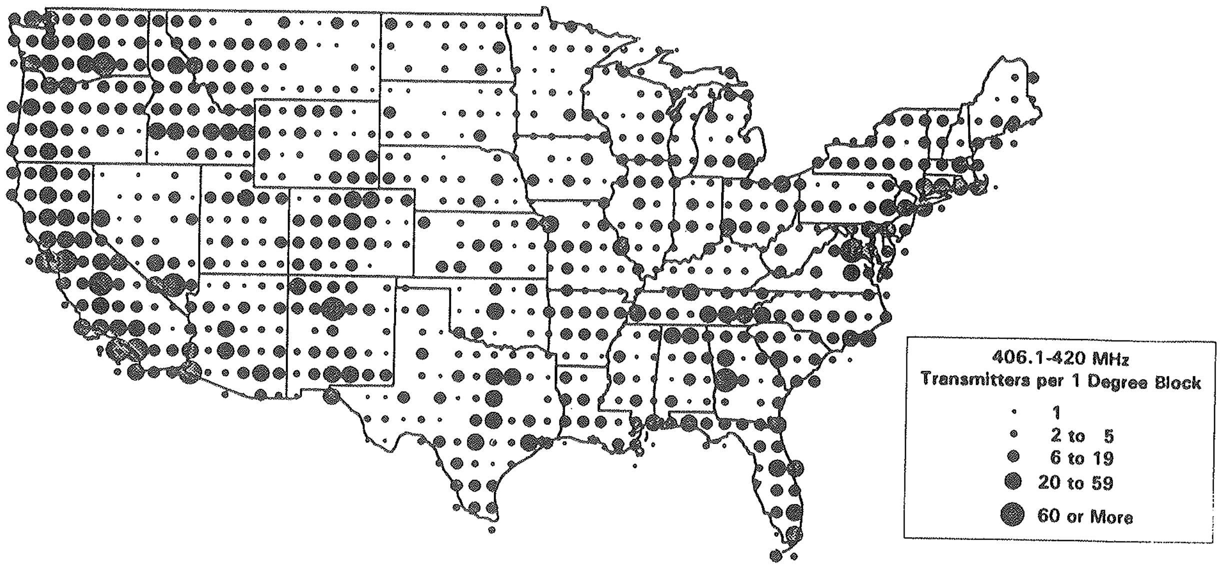

Figure 2.2-1. Density of Fixed assignments per square degree in the 406.1-420 MHz band.

Table 2.2-1. Statistics for the Fixed assignments only in the 406.1-420 MHz band

total US assignments (1991)	7460
peak assgnmts/1-degree block	105
effective # of channels	NA
average US channel re-use	NA
peak re-use/1-degree block	NA
annual growth rate (last 6 yr)	-0.6%
est. annual growth (next 5 yr)	-3%

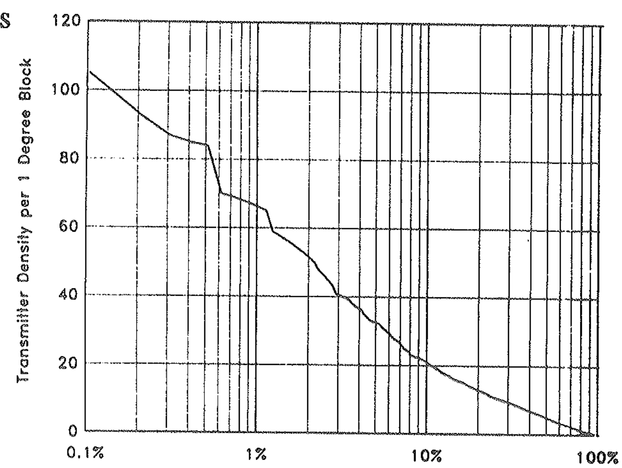

Figure 2.2-2. Percentage of blocks exceeding indicated transmitter densities.

Typical users. The 406.1-410 MHz band is shared by Government and non-Government users. Primary allocations for the Government are the Fixed, Mobile, and Radio Astronomy services, while non-Government has only Radio Astronomy allocations. The 410-420 MHz part is exclusive to the Government and the allocations are to Fixed and Mobile services.

This band is shared between LMR and fixed services, typically using 25-kHz channelization of FM voice circuits. The band is primarily allocated for non-military users, though military agencies can use it for administrative traffic. This band is the Government general-purpose UHF LMR band, and mobile users represent about 62 percent of the band assignments in 1992. Of the 12,000 mobile assignments, approximately 9,000 are for civilian agencies. Typical fixed uses include links to connect nodes of LMR networks (more than 5,000 fixed assignments belonging mostly to Agriculture, Energy, Interior, Justice, VA, and TVA), as well as links for narrowband weather, hydrology, or seismic sensors.

Civilian Government agencies have over 70 percent of the assignments in the band, and the Departments of Agriculture, Energy, Interior and Justice, as a group, have more than 60 percent of the Government assignments. Justice has about 3,900 assignments; Agriculture has nearly 1,600 assignments. Energy has 1,760 assignments used for telecommand, law enforcement, administrative purposes, trunking and seismic telemetry. Commerce, FAA, Treasury and Interior have, respectively, about 1,300, 1,250, 1,100, and 1,200 assignments used for law enforcement and protection of Government personnel, trunking, flood and wind-shear warning, administration, and for SCADA with electric power transmission nets. Air Force, Army, and Navy respectively, have about 1,880, 1,780, and 760 assignments. These assignments are used for administration, maintenance, trunking, paging and range control, disaster preparedness, training, shipboard operations, and security.

Recent trends in number of assignments. Growth in this band over the past 13 years is shown in Figure 3.2-3. The consistent growth reflects the increasing use of land mobile radio (LMR) to meet the needs of providing Government services. A 1986 study showed there were about 12,500 assignments in the 406.1-420 MHz band, of which 7,736 or about 62 percent were to the Fixed services. In 1992, there were 19,741 assignments in the band, of which 7,460 or about 38 percent were to the Fixed services. Although the total assignments in the band increased over this period by about 49 percent, the number of Fixed assignments decreased about 3.6 percent, thus indicating a compounded growth rate of 15 percent a year for mobile services and a decrease of 0.6 percent a year for fixed services.

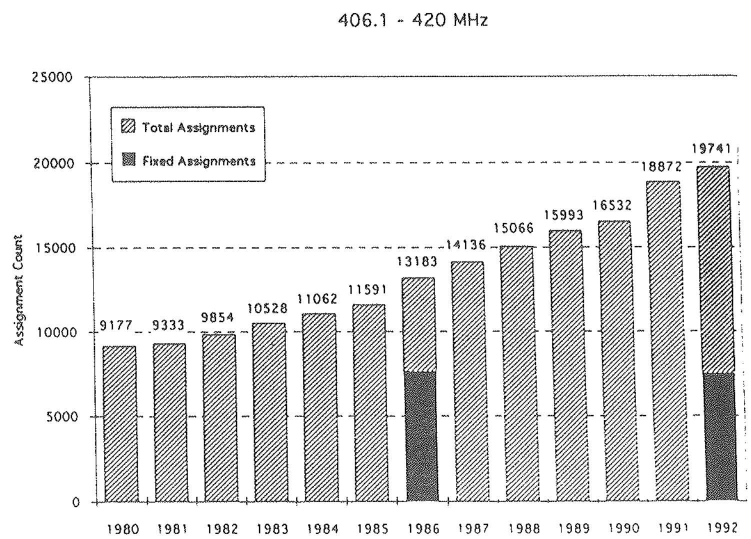

Figure 2.2-3. Number of assignments in the 406.1-420 MHz Band (1980-1992).

Comments. This band is changing from a predominately fixed to a predominately mobile band. The recent allocation of the 932-935 MHz and 941-944 MHz bands was intended as a migration destination for many of the Fixed service assignments still remaining in the 406-420 MHz band. Strong encouragement for the development of multi-agency Government LMR trunking systems is expected to result in more efficient spectrum utilization in this band in the future. This will result in fewer single-channel, single-user assignments. In addition, this band is in the process of being re-channelized to provide 12.5-kHz channels.

Estimated future growth rate. The Fixed service assignments in this band are expected to diminish at a rate of 3 percent a years. The number of mobile assignments will continue to grow.

2.3 Usage in the 928-929 MHz and 952-953 MHz Bands MAS Private Operational, Public Services

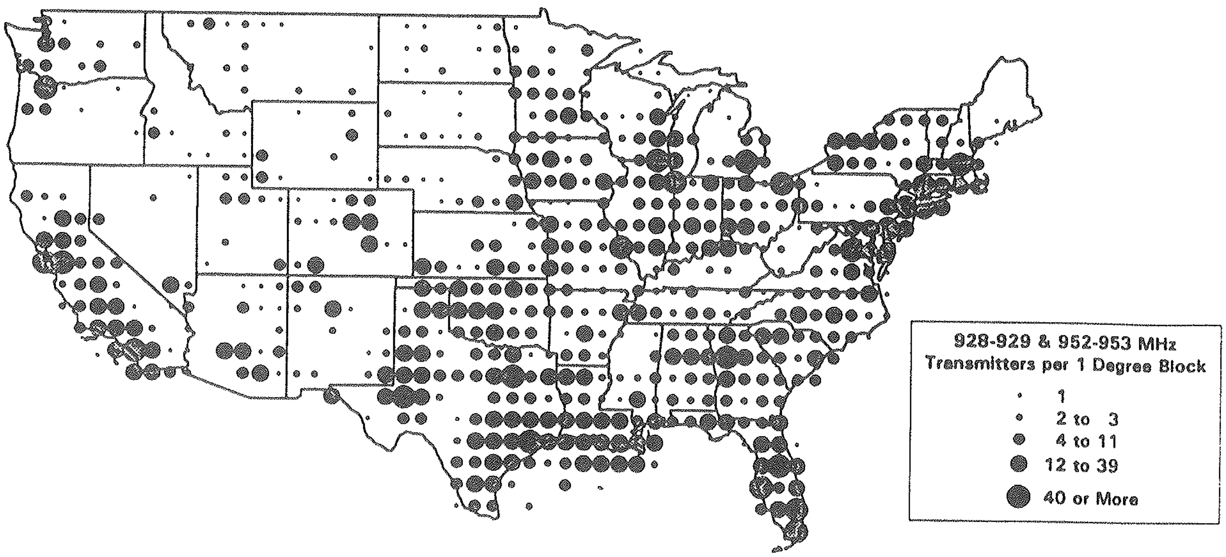

Figure 2.3-1. Density of assignments per square degree (928-929 MHz & 952-953 MHz bands)

Table 2.3-1. Statistics for 928-929 MHz and 952-953 MHz Bands

total US assignments (1991)	6329
peak assgnmts/1-degree block	128
effective # of channels	80-160
average US channel re-use	40-80
peak re-use/1-degree block	0.8-1.6
annual growth rate (last 4 yr)	27.5%
est. annual growth (next 5 yr)	20%

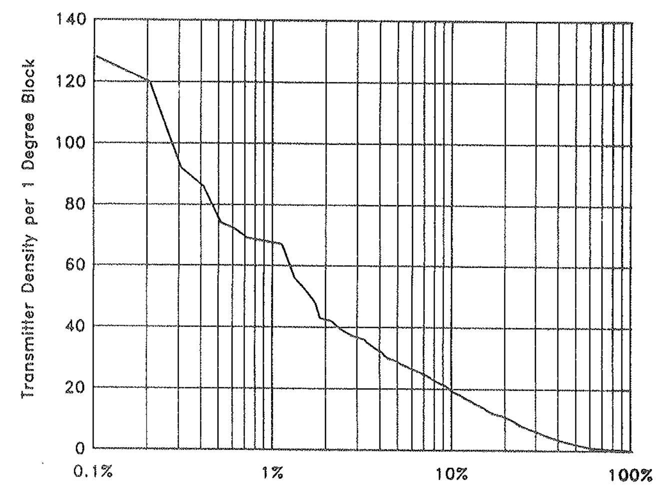

Figure 2.3-2. Percentage of blocks exceeding indicated transmitter densities.

Typical users. This pair of bands is allocated for Multiple Address Service (MAS), using 80 pairs of 12.5-kHz channels, which can also be used as 40 pairs of 25-kHz channels. Various parts of the band are allocated to general users (28 pairs of 12.5-kHz channels), electrical utility users (40 pairs of 12.5-kHz channels, opened up recently to other users), and public mobile users (12 pairs of 12.5-kHz channels). These stations are used in a master-interrogator/remote-reply mode of operation, with the 928-929 MHz band used for the remote stations and the 952-953 MHz band used for the master station. At least four remote stations must be used with each master to qualify for this type of service. The MAS service is a relatively new service, with innovative uses being developed each year. Representative uses include system control and data acquisition (SCADA) for typical utility customers, alarm systems (fire, burglar, intrusions), and point-of-sale applications (credit card and checking account verifications).

These bands are also allocated via footnote to Government offshore radiolocation systems, which can operate on a not-to-interfere basis.

Recent growth in number of assignments. Growth in this band over the past five years is shown in Figure 2.3-3. This data shows the number of assignments in the 952-953 MHz master-interrogator band. The shaded area shows the number of MAS systems, which are assigned on the basis of the master station assignment (which also includes the assignment for the remote stations in paired channels in the 928-929 MHz band.) The black shows the number of one-way (simplex) stations licensed in the 928-929 MHz band.

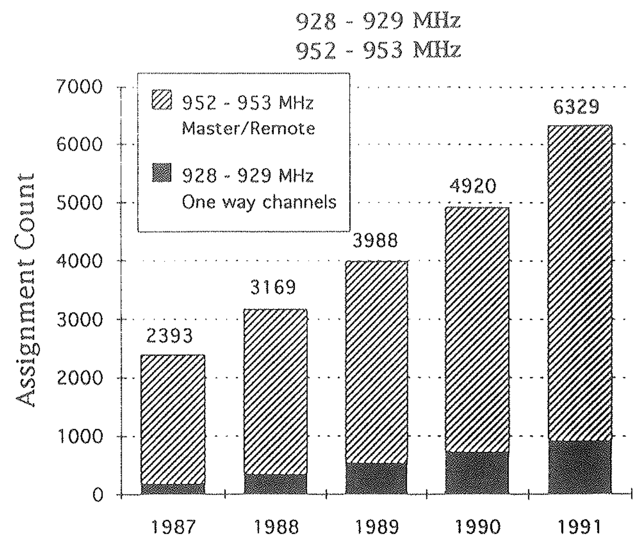

Figure 2.3-3. Number of assignments in the 928-929-MHz band and 952- 953 MHz band (1987-1991).

Comments. The MAS service takes advantage of the economy of time-sharing equipment between remote sites, giving considerable economy where the system permits the required configuration. The rules permit remote stations only with directional antenna and base stations with omnidirectional antennas.

Estimated future growth rate. The present 27 percent annual growth rate indicates a high level of interest in these services. We have assumed that part of the growth rate is an initial surge which will taper off after the first few years and continue at a 20 percent growth rate, until crowding in this band encourages the movement of new systems to other less-crowded bands. A large number of additional MAS assignments should soon be available in the 932/941 MHz band, which may take the pressure off this band. This is a relatively new service, and the amount of market for this service is not fully known at this time.

2.4 Usage in the 932-935 MHz and 941-944 MHz Bands
Government, Private Operational, Public Services

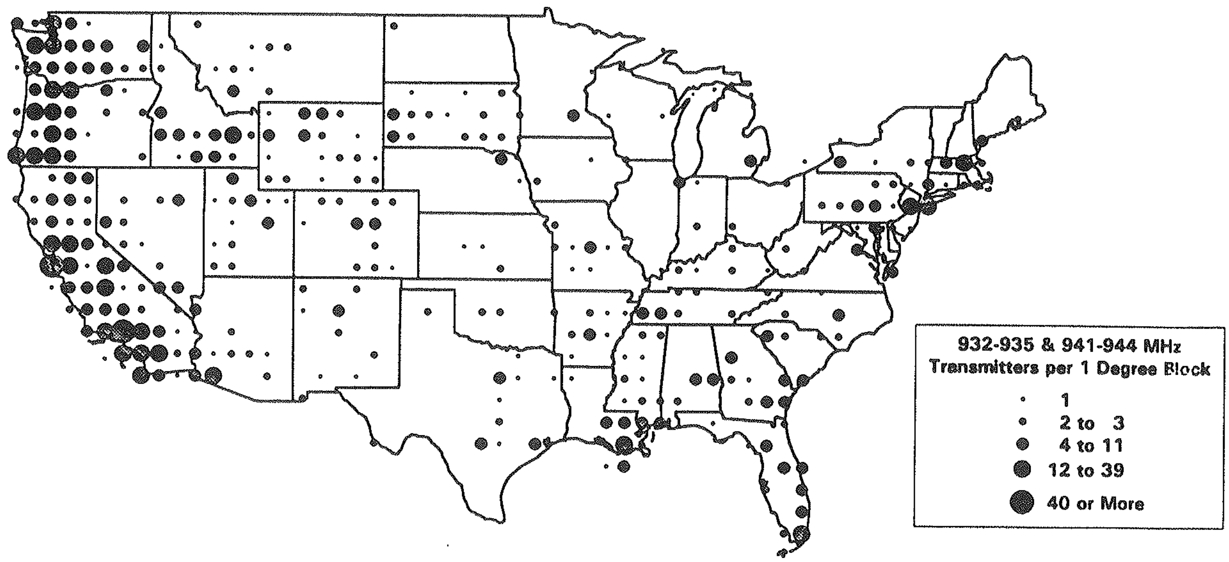

Figure 2.4-1. Density of assignments per square degree (932-935 MHz & 941-944 MHz bands.)

Table 2.4-1. Statistics for the 932-935 MHz and 941-944 MHz bands

total assignments (1991)	NA
peak assgnmnts/1-degree block	59
annual growth rate	high
estimated assignments in 1996	8,000

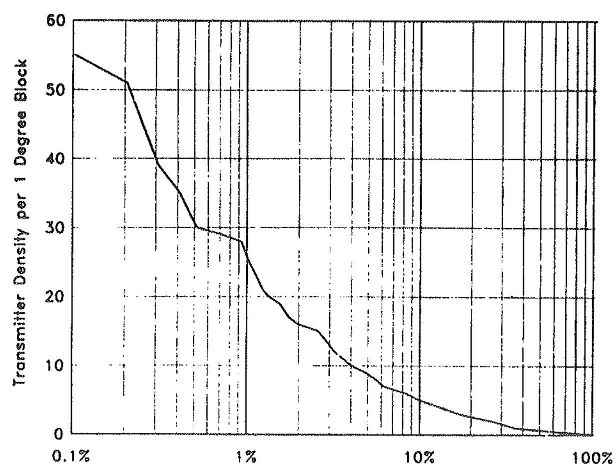

Figure 2.4-2. Percentage of blocks exceeding indicated transmitter densities.

Typical users. This is a shared band, allowing private, public, and Government users. MAS operations are allowed in the 932-932.5 MHz and 941-941.5 MHz parts of the band.

Typical MAS users are expected to include numerous system control and data acquisition (SCADA) uses, point-of-sale applications (check and credit card verifications), security alarms, airport runway lighting control, and many miscellaneous applications. This band is channelized in paired 12.5-kHz segments. This is a new band and no MAS licenses have been granted yet, pending a lottery to decide between approximately about 50,000 non-Government and 1,700 Government applications. Point-to-point applications are permitted in the 932.5-935 MHz and 941.5-944 MHz bands. These bands provide for pair channels with bandwidths of 25 kHz, 50 kHz, 100 kHz, and 200 kHz. GMF data, July 1992, shows 1,159 Government assignments and 453 non-Government assignments. Most of the 453 non-Government assignments support paging systems. Of the total of 1,159 Government assignments, Agriculture has 294 assignments (mostly for LMR backbone), FAA has 600 assignments (voice and data), DOE has 107 assignments (SCADA, telemetry, data), and Interior has 73 assignments (backbone, law enforcement, fire suppression, etc.).

Recent growth in number of assignments. Growth in this band over the past five years is shown in Fig 2.4-3. When the band was opened for applications in 1990, more than 50,000 applications were received for commercial MAS, as well as 1,700 for government applications. Although many of the non-Government applications may be "speculative", the mass of applications has exceeded the number of assignments that can be issued, and the selection (including Government requests) will have to be settled by a lottery--which has not yet been performed. Fewer applications were received for the point-to-point frequencies, and the assignment of those frequencies is shown in the figure.

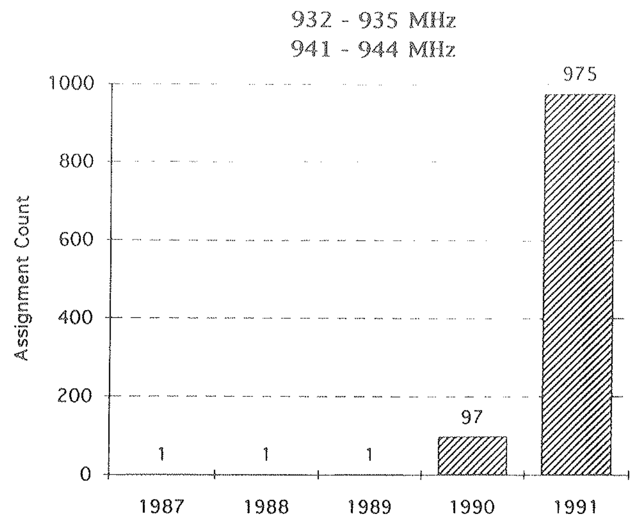

Figure 2.4-3. Number of assignments in the 932-935 MHz and 941-944 MHz bands (1987-1991).

Comments. The initial intent of creating this band was to provide a point-to-point band for government point-to-point operations, especially those now in the 406 MHz band. Later modifications to the policy included sharing the band between Government, private, and public services, as well as allocating the lower 0.5 MHz of each band for multiple address service (MAS).

Expected future growth rate. The large number of frequency applications suggests that the growth in this band will be very rapid. More realistically, however, the MAS services are new and the market demand for them is not yet known. Much of the current application backlog is believed to be speculative. The point-to-point part of the band should grow by 10% a year for the next five years--partly reflecting the movement of point-to-point systems from other bands (406-420 MHz, for example).

2.5 Usage in the 944-952 MHz Band
Auxiliary Broadcast

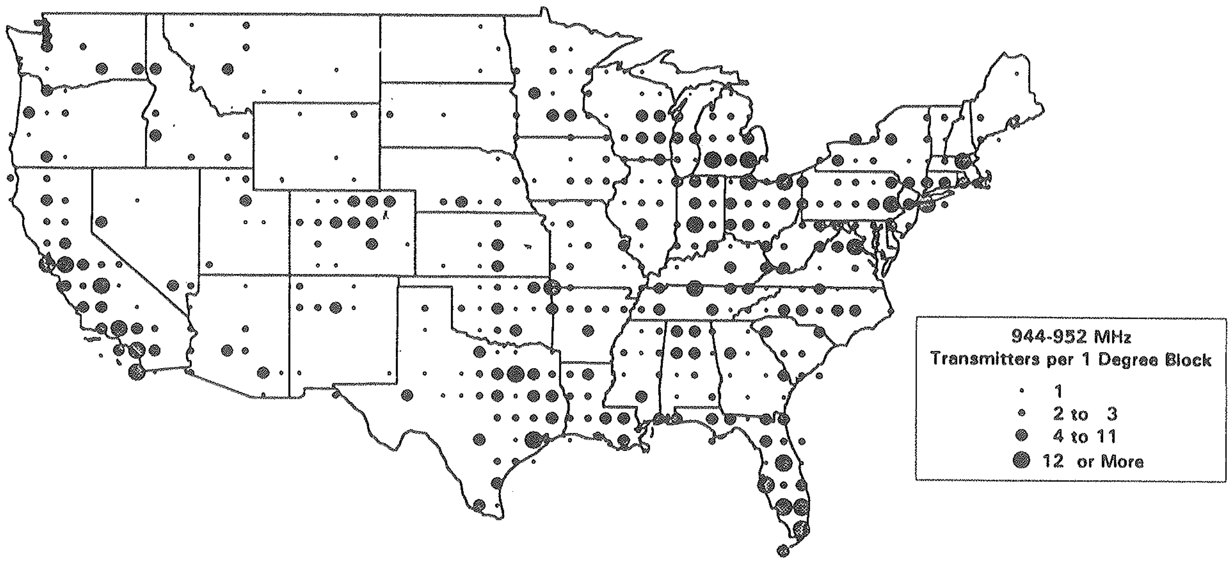

Figure 2.5-1. Density of assignments per square degree in the 944-952 MHz band

Table 2.5-1. Statistics for 944-952 MHz.

total US assignments (1991)	1790
peak assgnmts/1-degree block	37
effective # of channels	16-320
average US channel re-use	6-112
peak re-use/1-degree block	0.1-2.3
annual growth rate (last 4 yr)	19.4%
est. annual growth (next 5 yr)	20%

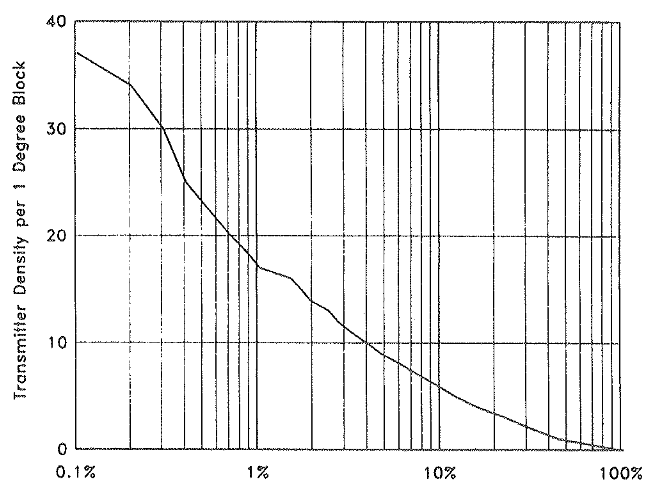

Figure 2.5-2. Percentage of blocks exceeding indicated transmitter densities.

Typical users. This band is used by FM broadcasters for aural studio-to-transmitter (STL) and inter-city relay (ICR) links. The 25 kHz bandwidth channels can be stacked to give bandwidths up to 300 kHz, and a single broadcasting station can use up to a total of 500 kHz. Some of this bandwidth can be leased for other broadcasting or non-broadcasting purposes.

Recent growth in number of assignments. Growth in this band over the past five years is shown in Fig 2.5-3. The approximately 20 percent growth rate is due mostly to AM and FM broadcasters switching to radio links as a way of bypassing the traditional equalized telephone lines, which have recently become very expensive and not easy to obtain. In addition, each broadcaster can apply for up to 500-kHz of spectrum, some of which can be used to send non-broadcast-related information to other customers.

Comments. Most of the growth is from FM broadcasters switching from existing dedicated equalized telephone lines used as STLs. Many telephone companies have become reluctant to supply the specially dedicated and carefully "tweaked" telephone lines needed to carry high-fidelity stereo signals from the studio to the transmitter site. The breakup of the telephone system has apparently produced LECs which are less willing to bother with the special equalized lines. Costs have become high and reliability has suffered, particularly when the link passes through multiple telephone companies.

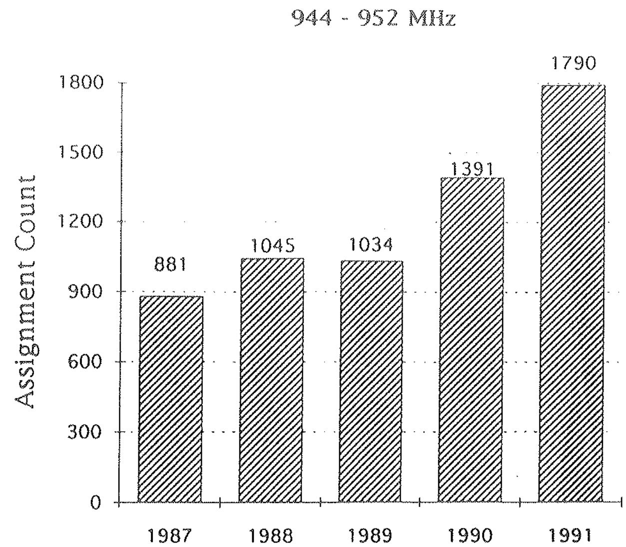

Figure 2.5-3. Number of assignments in the 944-952 MHz band (1987-1991).

Most STL equipment in the band requires 200-500 kHz bandwidth to carry two audio signals (for stereo) and some transmitter control signals. Although most STLs are FM, some manufacturers are beginning to introduce digital STLs. Some manufacturers recommend single integrated links carrying a stereo signal; others use two independent monaural transmitters, so that one can serve as a backup (albeit monaural only) if the other transmitter chain fails.

It is possible that future systems will utilize digital telephone connections (possibly narrowband ISDN) and move back on the telephone systems.

Estimated future growth rate. We are estimating a 20 percent growth rate for this band into the next few years, after which these radio systems will experience a decrease in growth, and possibly even a decrease in the number of systems.

2.6 Usage in the 952-960 MHz Band
Private Operational, Public, International Services

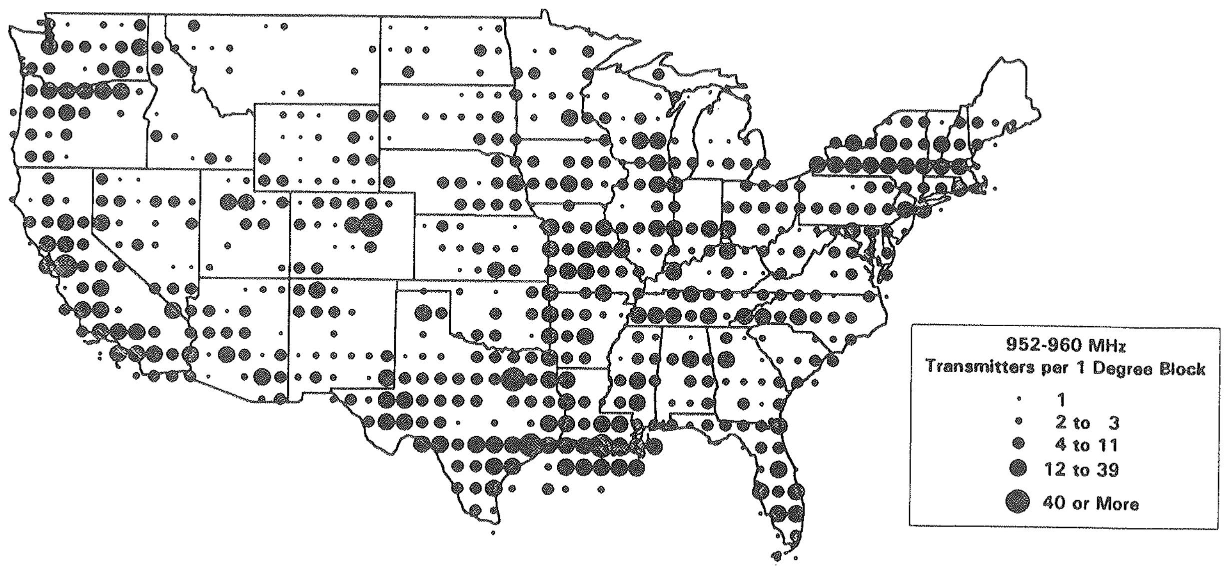

Figure 2.6-1. Density of assignments per square degree in the 952-960 MHz band

Table 2.6-1. Statistics for 952-960 MHz.

total US assignments (1991)	5653
peak assgnmts/1-degree block	50
effective # of channels	64-140
average US channel re-use	40-88
peak re-use/1-degree block	0.4-0.8
annual growth rate (last 4 yr)	5.3%
est. annual growth (next 5 yr)	20%

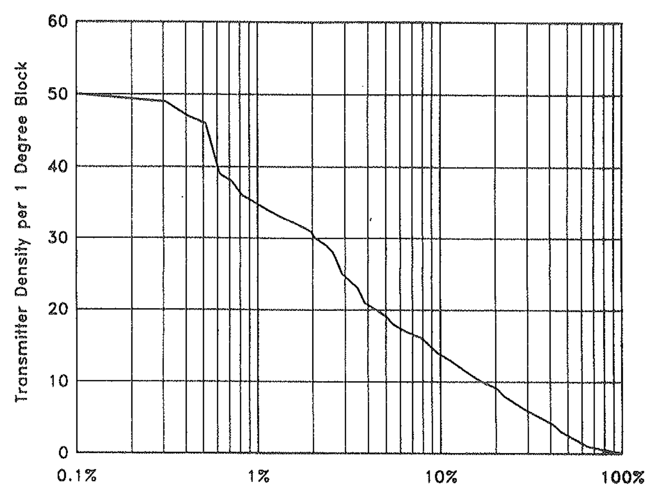

Figure 2.6-2. Percentage of blocks exceeding indicated transmitter densities.

Typical users. This band contains two major types of users, including MAS assignments near 956 MHz and near 959 MHz (a total of twenty-eight 12.5-kHz bandwidth channels or fourteen 25-kHz channels) and private operational point-to-point channels over the remainder of the band, having bandwidths of 12.5 kHz, 25 kHz, 50 kHz, 100 kHz, and 200 kHz. The point-to-point stations must use directional antennas; the MAS remote stations must use directional antennas, though the master stations can use omnidirectional antennas. Typical users of this band include general SCADA applications to public safety; local water, gas, and electric utility companies; petroleum, utilities, and railroads, as well as data applications for manufacturing, banking, and service providers.

Recent growth in number of assignments. Growth in this band over the past five years is shown in Fig 2.6-3. The graphs show the MAS assignments in solid black, with the point-to-point assignments shown in cross-hatching. The 5 percent overall growth rate in this band is due to the point-to-point growth.

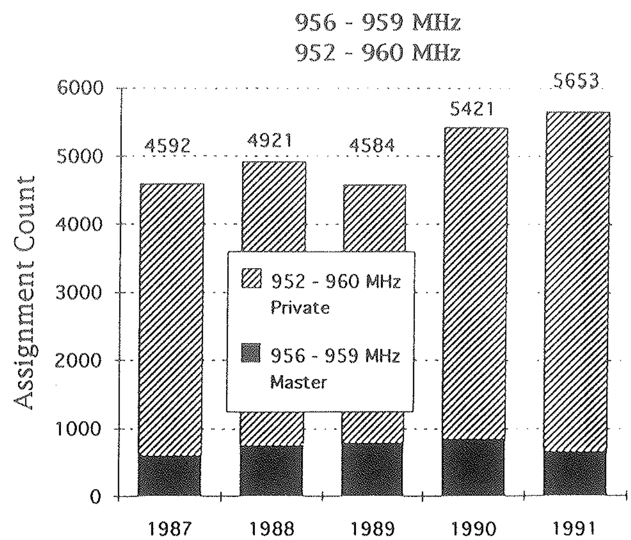

Figure 2.6-3. Number of assignments in the 953-960 MHz band (1987-1991).

Comments. The number of MAS assignments shows a slight decrease, which is surprising because of the interest in MAS in other bands. This is apparently because the MAS band has long been saturated (especially in the most desirable urban areas) and people have begun looking in more promising new MAS bands.

Estimated future growth rate. We are estimating a 5 percent growth rate for this band in the future, including the MAS and point-to-point assignments.

2.7 Usage in the 1350-1400 MHz Band
Government Service

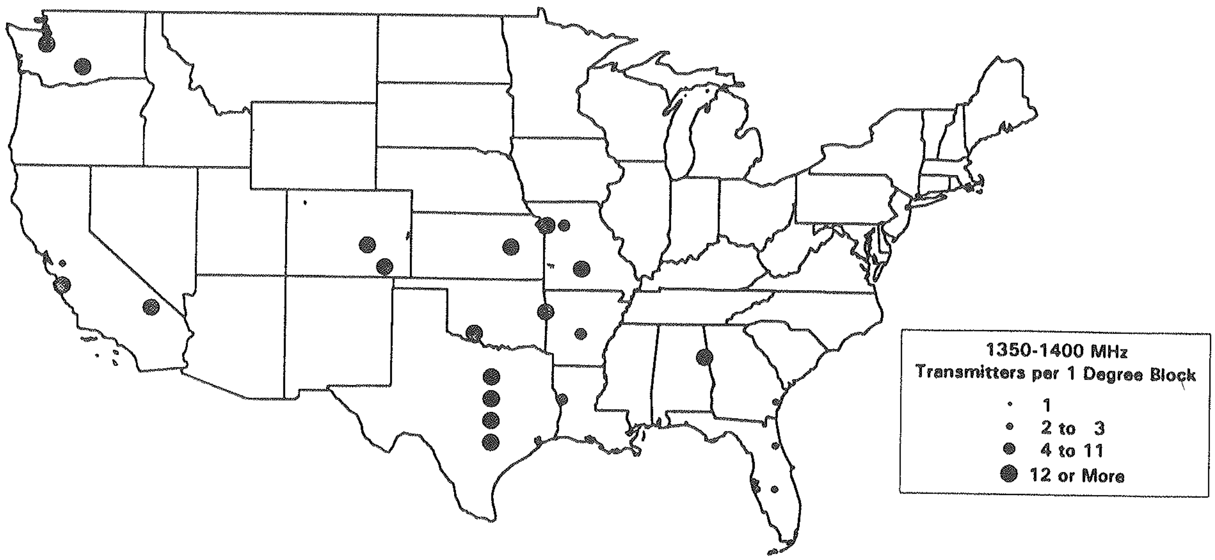

Figure 2.7-1. Density of Fixed assignments per square degree in the 1350-1400 MHz band.

Table 2.7-1. Statistics for 1350-1400 MHz

total US assignments (1991)	582
peak assgnmts/1-degree block	30
effective # of channels	36
average US channel re-use	16
peak re-use/1-degree block	0.83
annual growth rate (last 2 yr)	1.1%
est. annual growth (next 5 yr)	1%

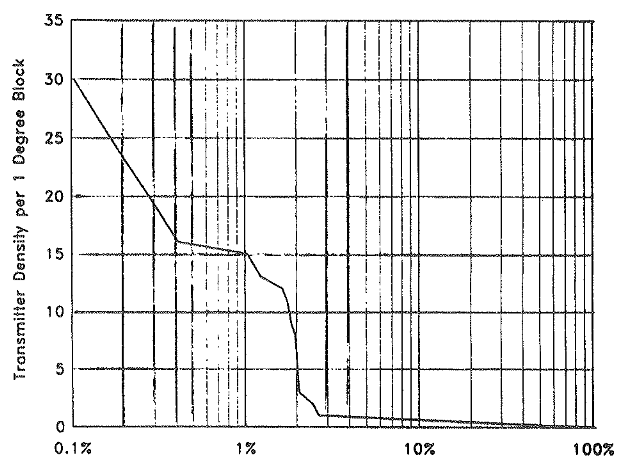

Figure 2.7-2. Percentage of blocks exceeding indicated transmitter densities.

Typical users. The 1350-1400 MHz band is allocated exclusively to the Government for Fixed, Mobile, and Radiolocation services on a primary basis. Footnotes restrict Government Radiolocation, Fixed, and Mobile services to military use. Other footnotes allocate 20-MHz to Aeronautical Radionavigation on a primary basis, and on a secondary basis 30 MHz is allocated to passive Space Research and to Earth Exploration Satellite service.

The Air Force has the largest number of assignments with 335 assignments. Assignment descriptions in the GMF reveal various use categories like data link testing, global positioning system (GPS) testing, maintenance, and miscellaneous RDTE. A particularly heavy Air Force use is for the "Core Automated Maintenance System(CAMS). CAMS uses a large number of hand-held data terminals, communicating with a central base site with 9600-baud data links. The system is used for inventory control and maintenance operations on most Air Force bases.

The Army currently has 112 assignments generally fitting in the use categories of communications training, radio relay, and RDTE support. The Navy's 32 assignments are largely used with the testing and evaluation of electronic systems. The few remaining assignments are for air traffic control, antenna testing, and for ionospheric research. The 271 fixed systems have an average bandwidth of 1.4-MHz, and average power of 20 watts, and are all transportable. The frequency 1381.05 MHz is used as a downlink channel for a nuclear detection satellite.

This band includes a few active air surveillance L-band radars.

Recent trends in number of assignments. Growth in this band over the past 13 years is shown in Figure 2.7-3. The band was reallocated in the late 1980s to add fixed and mobile services to the existing radiolocation service on a primary basis. The military took advantage of the new allocation and moved a variety of systems into the band. Overall assignments in the band have grown by nearly 200 percent from totals of 196 in 1987 to 582 in 1992. Fixed assignments have grown from 9 to 271 in this period. Since the initial set of frequency assignments, however, the number of assignments in the band has remained relatively constant.

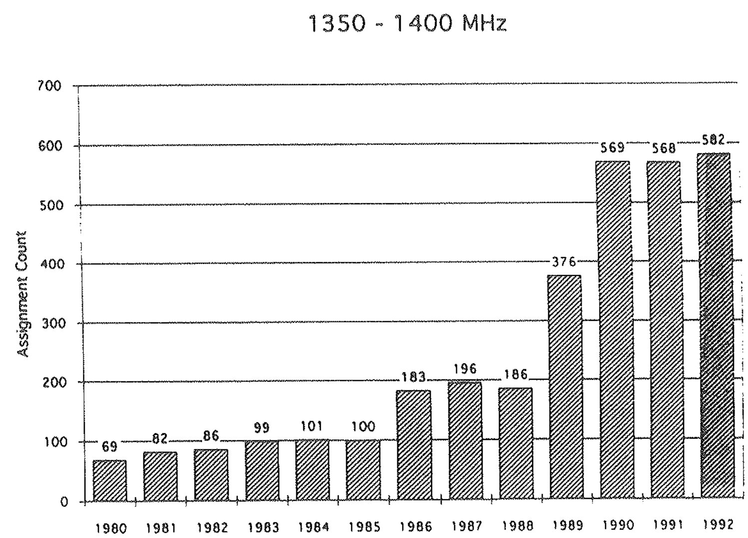

Figure 2.7-3. Number of assignments in the 1350-1400 MHz band (1980-1992).

Comments: This is a military-only Government band, containing a wide variety of systems.

Estimate of future growth: The current use of the band is low, and the band is expected to grow at its current 1% rate.

2.8 Usage in the 1427-1435 MHz Band
Government Service

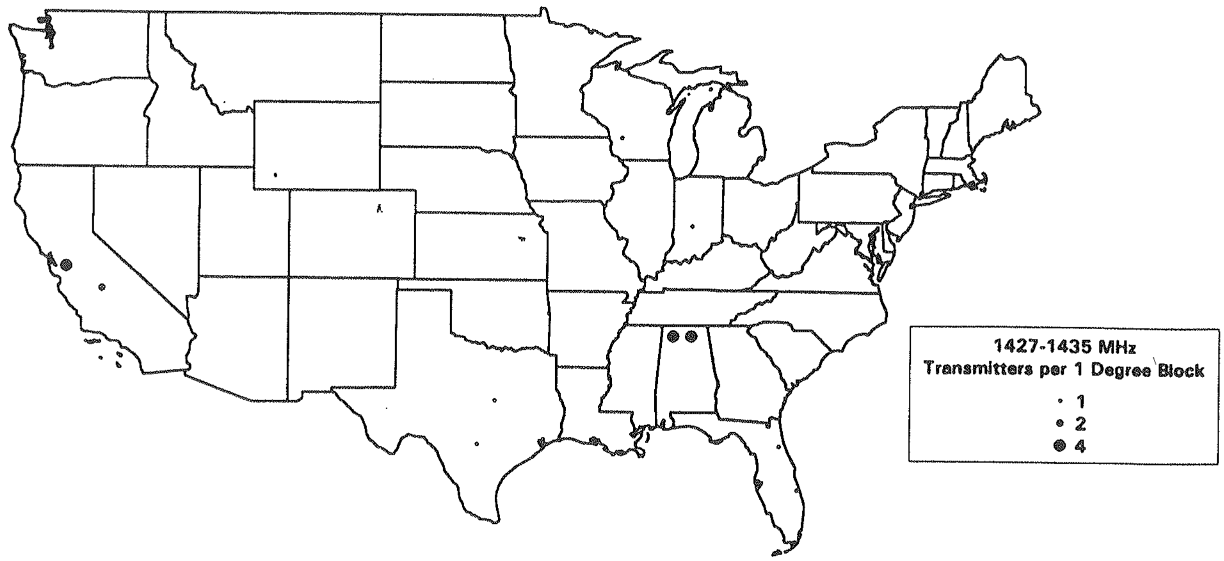

Figure 2.8-1. Density of Fixed assignments per square degree in the 1427-1435 MHz band.

Table 2.8-1. Statistics for 1427-1435 MHz.

total US assignments (1991)	218
peak assgnmts/1-degree block	4
effective # of channels	5.3
average US channel re-use	41
peak re-use/1-degree block	0.75
annual growth rate (last year)	0%
est. annual growth (next 5 yr)	0%

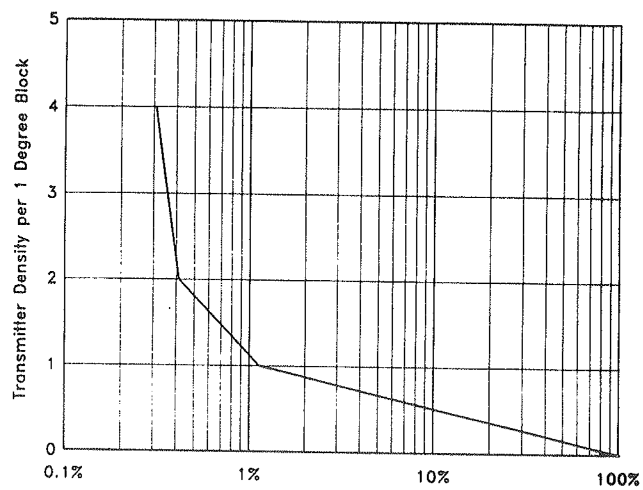

Figure 2.8-2. Percentage of blocks exceeding indicated transmitter densities.

Typical users. The 1427-1429 MHz band is shared by Government and non-Government users. Primary Government allocations are to Fixed, Mobile, and Space Operation. Non-Government primary allocation is to Space Operations, and secondary allocations are to Land Mobile (Telemetering and Telecommand) and to Fixed (Telemetering). The 1429-1435 MHz band is allocated to the Government for Fixed and Mobile on a primary basis, and non-Government allocation is to Land Mobile on a secondary basis. In both bands, footnote G30 limits Fixed and Mobile services to the military forces, and footnote 722 alerts users to the existence of passive research programs investigating radio signals of possible extra-terrestrial origin.

The 1429-1435 MHz band is channelized (de facto) in 500-kHz increments, beginning at 1429 MHz, though Fixed systems have an average bandwidth of 1.5 MHz. The main uses of the band are for aeronautical telecommand of missiles, experimental testing, tactical and training, and light route radio relay. The Air Force has 91 assignments for such uses as radar cross-section measurement, telecommand, and data link testing. The Navy has 25 assignments. Some of these assignments are for the testing of shipboard electronics, control of remotely piloted vehicles, and for research and testing. The Army has 25 assignments which are for such uses as tactical and training, and miscellaneous telemetry. Other agencies and non-Government uses are in administration, antenna testing, and with Voice of America. The automobile industry has a couple dozen assignments as part of an automation and manufacturing development effort. Almost half of these non-Government assignments are for use in all parts of the United States.

Recent trends in number of assignments. Growth in this band over the past 13 years is shown in Fig 2.8-3. Total assignments in the 1427-1435 MHz band have grown from 73 in 1987 to 218 in 1992, but there was no growth in the last year. Currently there are 22 Fixed assignments.

Comments. The band is only 8 MHz wide and therefore should be expected to support a limited number of assignments.

Estimated future growth rate. We estimate that there will be little growth in this band. (0%).

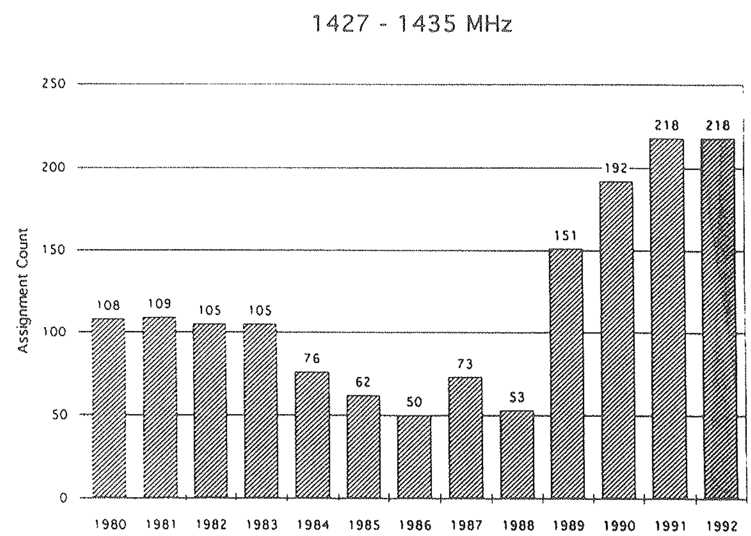

Figure 2.8-3. Number of assignments in the 1427-1435 MHz band (1980-1992).

2.9 Usage in the 1700-1850 MHz Band
Government Service

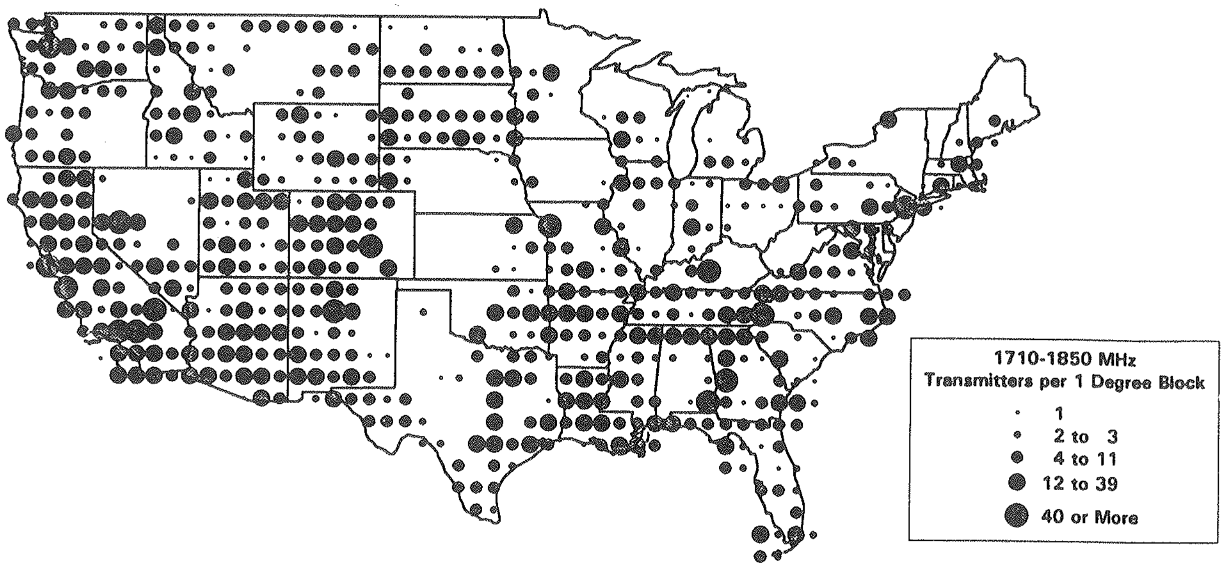

Figure 2.9-1. Density of Fixed assignments per square degree in the 1710-1850 MHz band.

Table 2.9-1. Statistics for 1700-1850 MHz.

total US assignments (1991)	6114
peak assgnmts/1-degree block	69
effective # of channels	39.5
average US channel re-use	150
peak re-use/1-degree block	1.7
annual growth rate (last 4 yr)	3.5%
est. annual growth (next 5 yr)	2%

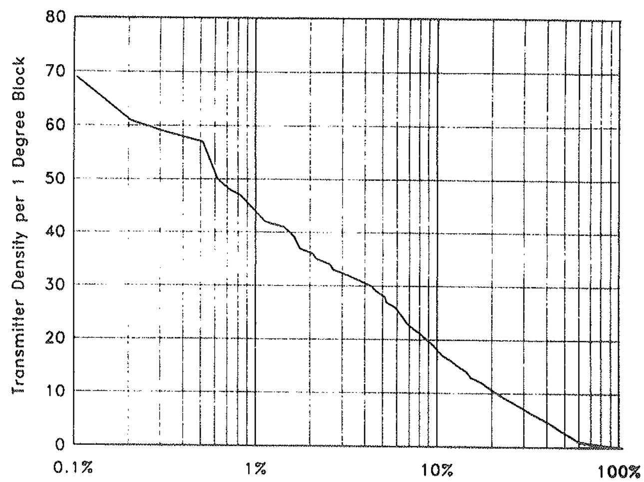

Figure 2.9-2. Percentage of blocks exceeding indicated transmitter densities.

Typical users. The 1700-1710 MHz band is shared by Government and non-Government allocations to Fixed and Meteorological Satellite on a primary basis (except that non-Government Fixed is secondary), including many TIROS-N assignments. The 1710- to 1850-MHz band is Government exclusive. Footnotes limit Government fixed operations and provide for space operations on an equal basis with Fixed and Mobile, and allow the Earth Exploration-Satellite Service on a non-interference basis.

The 1710-1850 MHz band is used for long-range, low density paths, used to service a remote location with a small number of voice channels or digital control/monitoring channels. Bandwidths vary from 0.5 MHz to 10 MHz, with the average Fixed user bandwidth equal to 3.8 MHz. Typical uses include utilities control and sensing (Tennessee Valley Authority (TVA), Bonneville Power Administration, Army Corps of Engineers (locks and dams)), military test ranges (Edwards AFB, White Sands Missile Range, etc.), National Forests and Parks (backbone for communications in remote areas), transportable microwave communication terminals (military services), and many miscellaneous uses. This band is also used for airborne telemetry and satellite applications.

The Army has the greatest number of assignments of a single agency at 1,634. These assignments are divided among backbone voice and data, administrative, tactical and training, hydrologic, and weather uses. The Air Force has 877 assignments used in backbone communications, system testing, the Satellite Ground Link System (SGLS), and video data links. The Navy has 478 assignments for such uses as line-of-sight diversity links, telemetry, tactical training, video links for missile evaluation, and testing of shipboard electronics.

Agriculture has 1,624 assignments used mainly in backbone networks or National Forest management. Justice has 801 assignments mainly for LMR backbone. Energy has 741 assignments connected with SCADA, law enforcement or communications with nuclear sites. The Federal Aviation Administration and Interior each have 272 assignments. These are used in law enforcement, resource management, SCADA, and fire suppression. The 101 TVA assignments are used heavily in SCADA for electrical power networks. The remaining 140 assignments are used for experimental testing, research, backbone, law enforcement, emergency communications, and data links.

Recent trends in number of assignments. Growth in this band over the past 13 years is shown in Fig 2.9-3. Assignments in the 1700-1850 MHz band have grown from 5,128 in 1987 to 6,114 in December 1991. Fixed assignments currently total 5187. The consistent growth reflects the continued growth of agency-specific communications throughout the whole of Government. More than 800 assignments (not shown in the bar chart) have been added since December 1991, mainly due to a change in policy, which added individual assignments for transportable military microwave terminals.

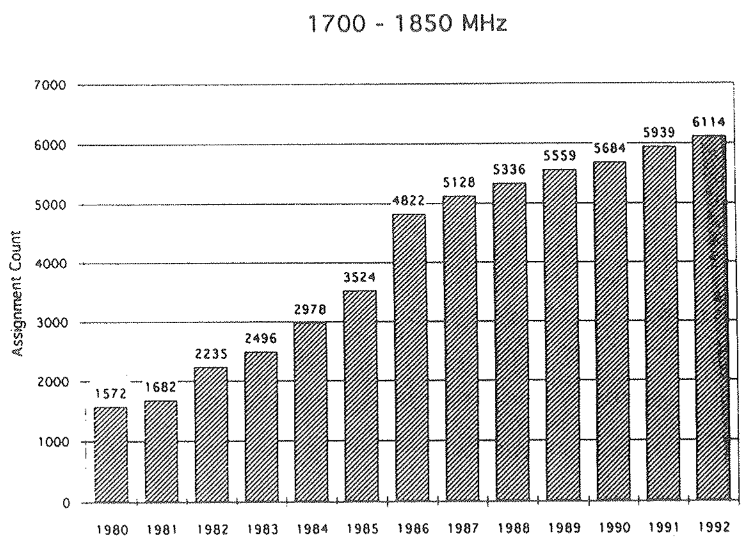

Figure 2.9-3. Number of assignments in the 1700-1850 MHz Band (1980-1992)

Comments. Government's need to provide increased services to many remote locations for environmental or other concerns suggests that this band may continue growing. In many National Parks and Forests, concerns about damage to the environment by burying fiber or cable, as well as the cost, seems to make microwave an attractive alternative. Traditional users of this band are beginning to install fiber, and this will eventually reduce the amount of microwave in use.

Estimated future growth rate. This band will continue a 2 percent rate of real growth (not counting the change in reporting policy that has recently added 800 additional transportable tactical radios). FAA is adding 300 assignments for Low Data Radio Communication Links, with up to 4 DS-1 channels each.

2.10 Usage in the 1850-1990 MHz Band
Private Operational Service

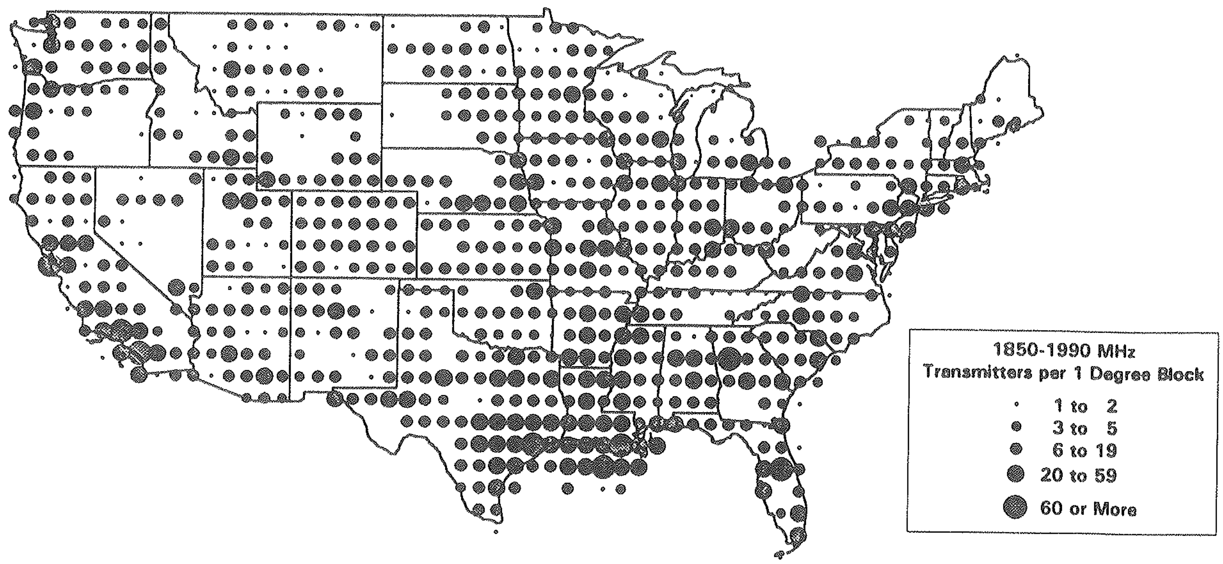

Figure 2.10-1. Density of assignments per square degree in the 1850-1990 MHz band

Table 2.10-1. Statistics for 1850-1990 MHz.

total US assignments (1991)	9358
peak assgnmts/1-degree block	85
effective # of channels	24
average US channel re-use	386
peak re-use/1-degree block	3.5
annual growth rate (last 4 yr)	3.9%
est. annual growth (next 5 yr)	-4%

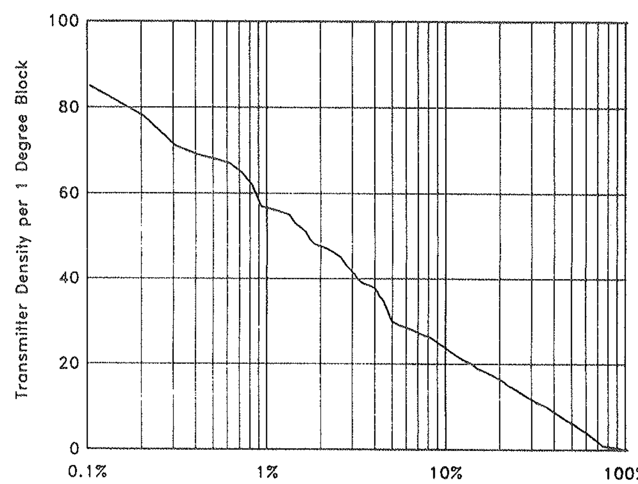

Figure 2.10-2. Percentage of blocks exceeding indicated transmitter densities.

Typical users. The 1850-1990 MHz band is allocated to the private operational services. Typical users of this band include public safety and local government (2,011), petroleum (2,487), railroads (895), electrical utilities (3,197), and others (668)[6]. This band is channelized with 5-MHz and 10-MHz channels. Typical uses include a wide range of system control and monitoring applications (typically used for railroads, petroleum pipelines, and electrical utilities), as

[6] Marrangoni, et al. *Creating new technology bands for emerging telecommunications technology.* FCC, Office of Engineering and Technology, OET/TS 92-1. Table 1, p8.

well as more general data and voice communications for local and state government (especially to support far-flung mobile communication systems, including public safety), and private business.

Recent growth in number of assignments. Growth in this band over the past five years is shown in Fig 2.10-3. This data shows the number of active microwave assignments. In addition to the increased numbers of assignments shown here, there has been considerable activity from users who are upgrading older analog equipment with newer digital equipment. Therefore, in addition to the increased number of channels, many users have upgraded older analog equipment to multilevel digital modulation.

Comments. This band is part of the proposed "emerging technologies" bands recently earmarked by the FCC for future PCS systems. Growth in this band has come to an abrupt slowdown in the past months (not shown by the graph), and users are looking to alternative frequency bands. The Utilities Telecommunications Council has petitioned the FCC for new channelization rules in the 6 GHz band that would permit Private low capacity systems at 6 GHz.

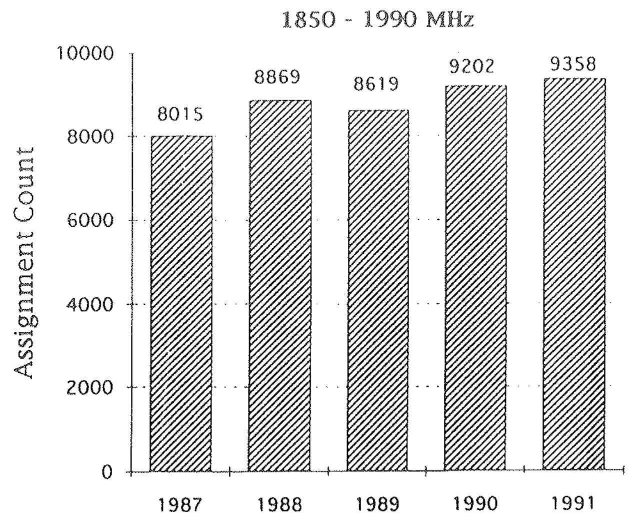

Figure 2.10-3. Number of assignments in the 1850-1990 MHz band (1987-1991).

Typically the existing microwave link works well and can economically provide limited bandwidth communications service, particularly in the case where full-time monitoring of a narrowband circuit is needed. High reliability is a major requirement for many users of this band, in support of time-critical utilities operations as well as safety-of-life operations in the public safety field. For many of these users, fiber optics is not a reasonable alternative, unless redundant fiber circuits can be employed to guarantee operation even when the fiber is accidently cut. Fiber is not normally price-competitive for the narrow bandwidths that are often used here, and the need for redundancy makes it even more expensive.

Many of these sites were originally built in the 1960's and 1970's with the very narrow purpose to support operations of a particular pipeline, railroad, or electrical power grid. Since some of these users had access to right-of-way over great distances, these systems became the routes (or remain potential routes) for some independent fiber communications suppliers.

Estimated future growth rate: This band is part of the proposed Emerging Technologies band, which means that many of the present microwave links may be moved out in 10 to 15 years, and future growth will be moved to other bands. Therefore, we predict a growth rate of -4% a year for the next five years. This considers only the point-to-point microwave, and it ignores the PCS systems which may be moving into the band. We assume that many of the existing rural links may be left in the band longer, since there will be less demand for rural PCS. For the next two years, the number of assignments will be about constant, because of uncertainty about general policies. Systems will not begin actively moving out of the band until PCS begins to be installed, and PCS operators begin to nudge (and possible reimburse) point-to-point operators.

2.11 Usage in the 1990-2110 MHz Band
Auxiliary Broadcast Service, CARS (ENG-only)

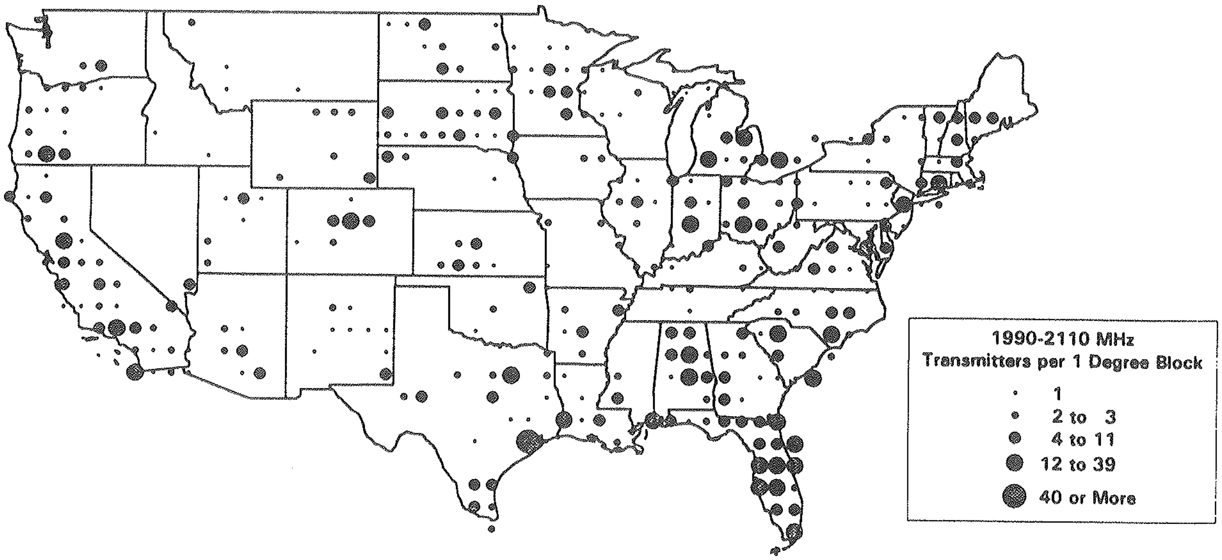

Figure 2.11-1. Density of assignments per square degree in the 1990-2110 MHz band.

Table 3.11-1. Statistics for 1990-2110 MHz

total US assignments (1991)	1536
peak assgnmts/1-degree block	95
effective # of channels	7
average US channel re-use	219
peak re-use/1-degree block	13.6
annual growth rate (last 4 yr)	14.6%
est. annual growth (next 5 yr)	15%

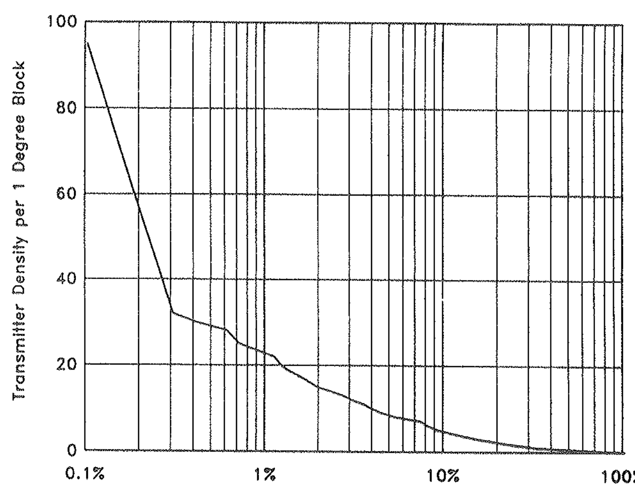

Figure 2.11-2. Percentage of blocks exceeding indicated transmitter densities.

Typical users. Typical users of this band include local TV broadcasters and the national network TV broadcasters. This band is used for electronic news gathering (ENG), studio-to-transmitter links (STL), intercity relay (ICR), and transmitter-to-studio links (TSL). In all cases, the 6-MHz-wide NTSC signal is frequency modulated on a 17-MHz-wide channel. In major TV markets, the band is crowded and ENG is coordinated on an hour-by-hour basis between TV channels, particularly during major scheduled or unscheduled events. Although alternative higher frequency bands exist for these functions, the 2 GHz band is particularly preferred for ENG.

Recent growth in number of assignments. Growth in this band over the past five years is shown in Figure 2.11-3. This growth is due to a continuing increase in the popularity of 'live' coverage of local events (ENG) by TV broadcasters.

Comments. This band is conspicuously absent from inclusion in the 'emerging technologies' bands recently earmarked by the FCC for future PCS and other similar systems. Broadcasters claim that the band is already very crowded, and that higher frequency bands do not permit the same degree of flexible use needed for ENG purposes. The prospect of needing additional auxiliary broadcast signals to support HDTV is a potentially serious problem, particularly if the HDTV signals are transmitted before they are digitally compressed. On the other hand, it is likely that increased availability of fiber will result in some STL and ICR links moving to fiber sometime in the future, which could free some spectrum for ENG. When crowding in this band becomes sufficiently acute, it may be possible to go to half-width channels with analog FM or digitally compressed signal formats.

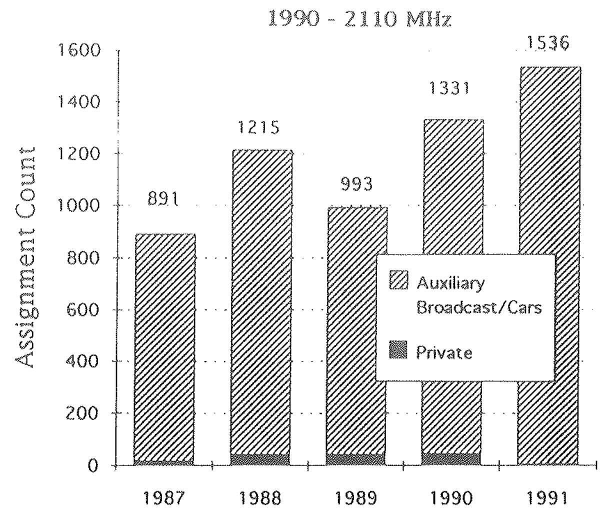

Figure 2.11-3. Number of assignments in the 1990-2110 MHz band (1987-1991).

Expected future growth rate. This band is already crowded in many major markets. Since it is the band most preferred for ENG, it is likely that continuing growth of ENG will take place, but some of the ICR and STL will be shifted to higher frequency bands or to fiber. In addition, broadcasters will continue to develop facilities to relay short ENG paths, which will generally provide more intensive re-use in this band. Finally, HDTV will eventually increase the numbers of equipments in this band. In summary, we would expect to see approximately the same growth rate (15 percent) continue for the next five years.

2.12 Usage in the 2110-2130 MHz and 2160-2180 MHz Bands
Public Service

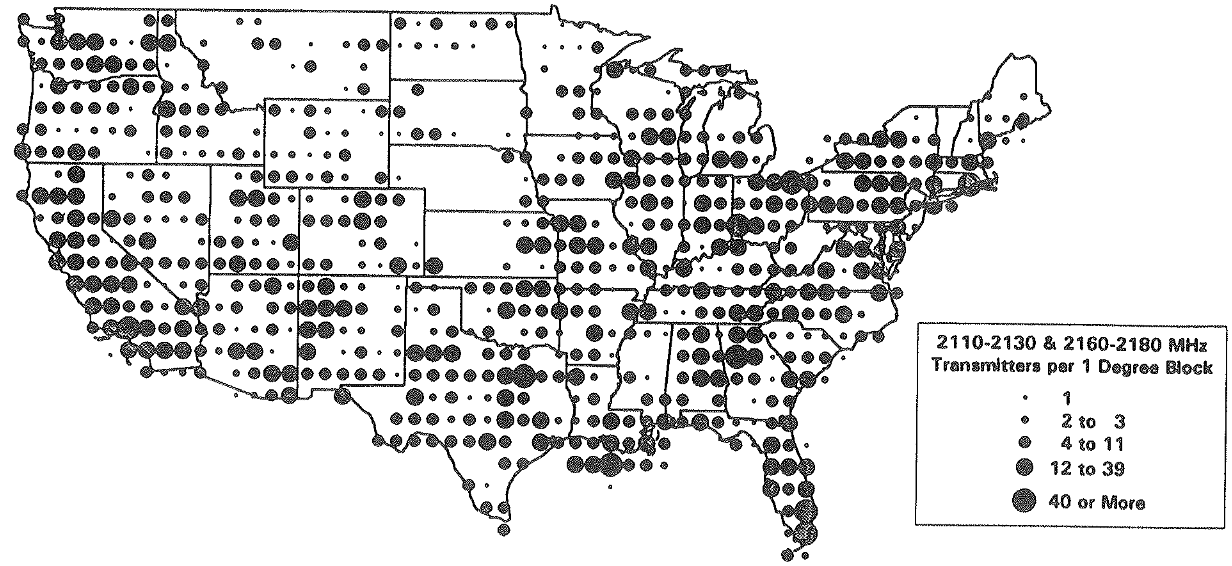

Figure 2.12-1. Density of assignments per degree (2110-2130 MHz & 2160-2180 MHz bands.)

Table 2.12-1. Statistics for the 2110-2130 MHz and 2160-2180 MHz bands

total US assignments (1991)	6329
peak assgnmts/1-degree block	66
effective # of channels	10-12
average US channel re-use	527-633
peak re-use/1-degree block	5.5-6.6
annual growth rate (last 4 yr)	28.0%
est. annual growth (next 5 yr)	5%

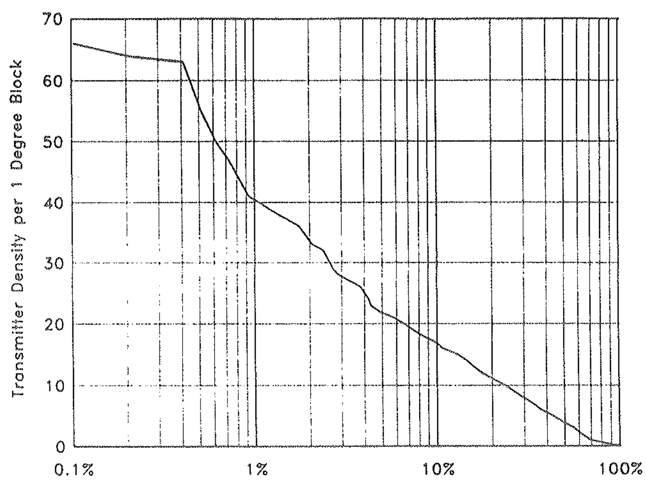

Figure 2.12-2. Percentage of blocks exceeding indicated transmitter densities.

Typical users. Typical users of these bands include low density telephone links, including trunks and feeders between cellular sites and connections to the local exchange carrier. This allocation includes a pair of frequency bands, each having six 3.2-MHz channels or five 3.6-MHz channels. Modern 256-QAM equipment permits up to 12 DS-1 signals on each channel.

Recent growth in number of assignments. Growth in this band over the past five years is shown in Figure 2.12-3. This band has been used for many years as a low-capacity feeder for telephone service. Recently, it has experienced almost explosive growth in support of cellular networks. Many cellular providers have chosen to build a complete and independent network for their cellular system, providing complete by-pass of the LEC. The low cost and low density of the 2 GHz band is ideally suited to many of the low bandwidth connections needed between cellular sites. When more capacity is needed, the cellular operator can select the 6 GHz or 11 GHz bands.

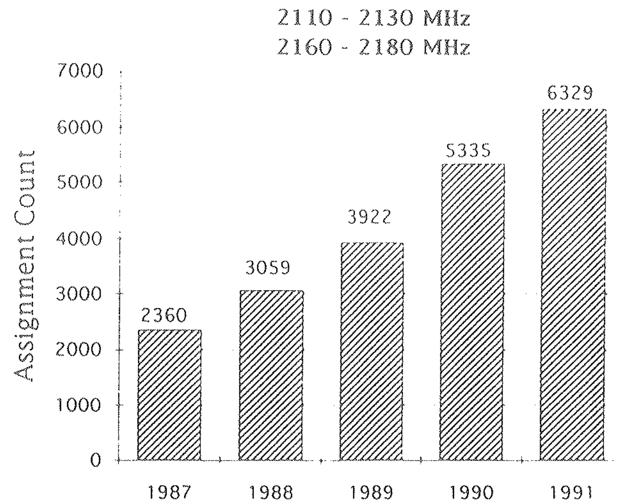

Figure 2.12-3. Number of assignments in the 2110-2130 MHz & 2160-2180 MHz bands.

Comments. This band is part of the 'emerging technologies' bands recently proposed by the FCC for future PCS and other similar systems, and users are looking to alternative frequency bands. Because of the rapid payback in today's cellular business environment, cellular companies will continue to install 2 GHz links, assuming that the equipment will be paid off long before PCS makes them move from the band. As soon as other bands become available, the growth will move to the new bands. The FCC has indicated that the 4 GHz, 6 GHz, and 11 GHz bands will be used as migration destinations from the 2 GHz bands.

Because of the continuing reduction in cell size, microwave links between cellular sites are continually getting shorter and many will not require the long-range capabilities of 2 GHz. Thus, 18 GHz, 23 GHz, or even 38 GHz may be suitable frequencies for many future feeder links to individual cells.

Estimate of future growth. Growth in this band will continue, but at a slower rate. Most of the major construction of the cellular microwave backbone has been completed around the major US cities. Additional construction to the cellular network will include adding smaller cells, where the long-distance characteristics of 2 GHz are not needed. Therefore, additional links will be easily made using the higher frequency migration bands identified by the FCC. When replacement is needed, cheap 38 GHz radios designed to serve PCS cells may be available. An average growth rate of 5 percent predicted for the next five years. The 2 GHz band will continue to be used in remote locations, where long range is desirable and where PCS will not be rapidly deployed. The use of 2 GHz will decline more rapidly in urban areas, due to pressure from PCS and the requirement for shorter paths.

2.13 Usage in the 2130-2150 MHz and 2180-2200 MHz Bands
Private Operational Services

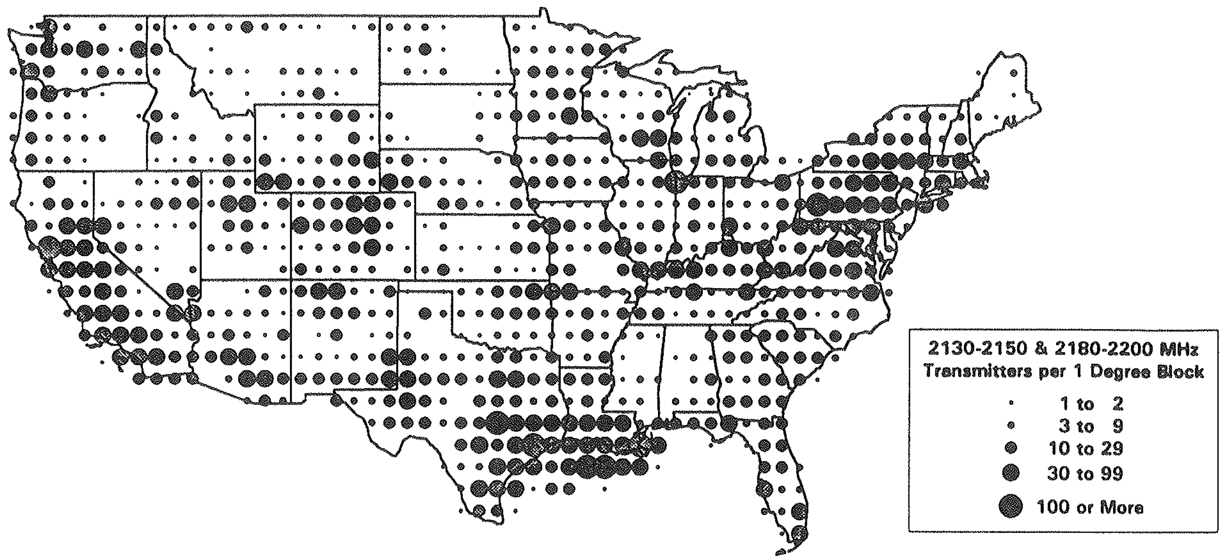

Figure 2.13-1. Density of assignments per degree (2130-2150 MHz & 2180-2200 MHz bands)

Table 2.13-1. Statistics for the 2130-2150 MHz and 2180-2200 MHz bands

total US assignments (1991)	13,455
peak assgnmts/1-degree block	151
effective # of channels	24-48
average US channel re-use	280-561
peak re-use/1-degree block	3.1-6.3
annual growth rate (last 4 yr)	6.7%
est. annual growth (next 5 yr)	-4%

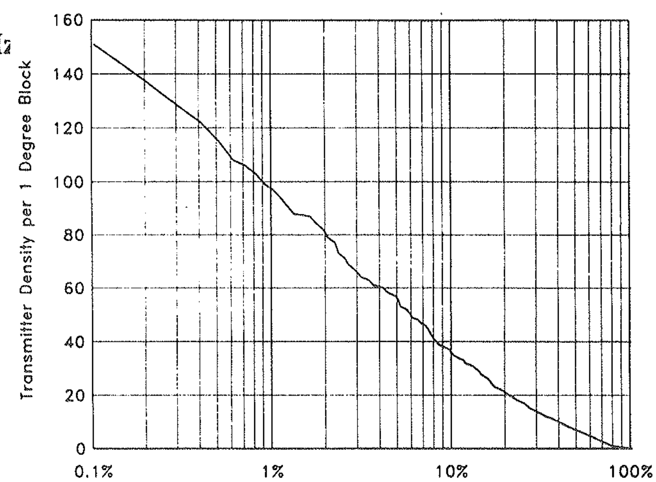

Figure 2.13-2. Percentage of blocks exceeding indicated assignment densities.

Typical users. This private operational microwave band has paired sub-bands, each with 24 channels of 800-kHz (or 1.6-MHz using adjacent channels) maximum bandwidth and a maximum transmitted power of 20 watts. Typical users of these bands include local government and public safety (4,052), petroleum (2,933), railroads (991), utilities (3,521), and others (1,538) including, but not limited to, manufacturing, banking, and service providers.[7]

[7] Marrangoni. Table 1, page 8.

Recent growth in number of assignments. Growth in this band over the past five years is shown in Figure 2.13-3. This data shows the number of active microwave assignments. In addition to the increased numbers of assignments shown here, there has been considerable activity from users who are upgrading older analog equipment for newer digital equipment. Therefore, in addition to the increased number of channels, many users have upgraded receiving equipment to multilevel digital modulation, so that each channel can transport more data than previously.

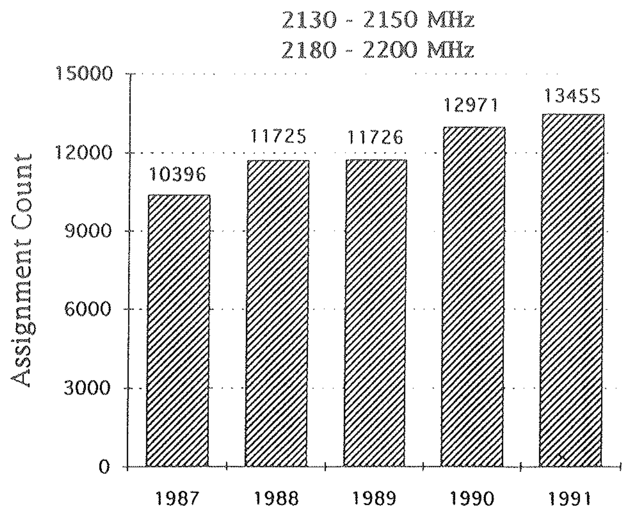

Figure 2.13-3. Number of assignments in the 2130-2150 MHz and 2180-2200 MHz bands.

Comments. This band is part of the 'emerging technologies' bands recently proposed by the FCC for future PCS and other similar systems. Growth in this band has come to an abrupt halt, and users are looking to alternative frequency bands. The Utilities Telecommunications Council has petitioned the FCC for new channelization rules in the 6 GHz band that would permit the typical 2 GHz low-capacity private operational system to be licensed at 6 GHz. The FCC has indicated that the 4 GHz, 6 GHz, and 11 GHz bands will be used as migration bands for systems displaced from 2 GHz.

Estimated future growth rate. The use of this band for point-to-point microwave will begin to decrease, mainly because of the FCC action on emerging technologies. Many of the systems displaced from the 2 GHz band will end up at 6 GHz or even higher frequency bands. Some of these microwave links will be replaced with fiber or VSAT links.

2.14 Usage in the 2150-2160 MHz Band
Public (Multipoint Data Service), Private

Typical users. This band is allocated for multipoint data service (MDS), originally intended as a common carrier means to distribute digital data to a large number of customers. The intended use of the band for digital data never developed, but the band was used to distribute television programming. Two 6-MHz channels of 'wireless cable' TV channels are available by extending the band to 2162-MHz. (The band can be extended to 2162-MHz only near major metropolitan areas, and only when it will not cause interference to existing public point-to-point stations in the 2160- to 2162-MHz range.) These stations will generally use omnidirectional transmitting antennas with total power less than 10 watts.

The creation of the multichannel multipoint distribution system (MMDS) in the 2500- to 2690-MHz band has incorporated the 2150-2160 (or 2162) MHz band channels as part of the 33-channel package available to an MMDS operator. It is expected that the MMDS service will be much more attractive to operators than the older MDS rules. There are currently about 24,000 applications for MMDS licenses, many of which will ask for the use of the two channels in this band also.

Private operators are also allowed to use this band, using omnidirectional antennas only.

Recent growth in number of assignments. We do not have numerical assignment information in this band, which has been lightly used in the past The allocation rules have recently been changed to encourage this band to be used as part of the MMDS 'wireless cable' service, along with frequencies in the 2500-2690 MHz band. A large number of applications (24,000) have been received for MMDS, but only about 75 have been granted at this time.

Comments. This band is not part of the 'emerging technologies' bands recently earmarked by the FCC for future PCS and other similar systems. One of the FCC's purposes in setting up MDS/MMDS is to provide a wireless alternative to cable TV, thus introducing additional competition into the cable market.

Estimated future growth rate. We estimate that the growth rate will be rapid over the next five years, mainly tied to new MMDS systems. See further information in Section 2.17.

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2.15 Usage in the 2200-2300 MHz Band
Government Service

Figure 2.15-1. Density of Fixed assignments per square degree in the 2200-2300 MHz band.

Table 2.15-1. Statistics for 2200-2300 MHz

total US assignments (1991)	2258
peak assgnmts/1-degree block	19
effective # of channels	26
average US channel re-use	87
peak re-use/1-degree block	0.73
annual growth rate (last 4 yr)	1.4%
est. annual growth (next 5 yr)	1%

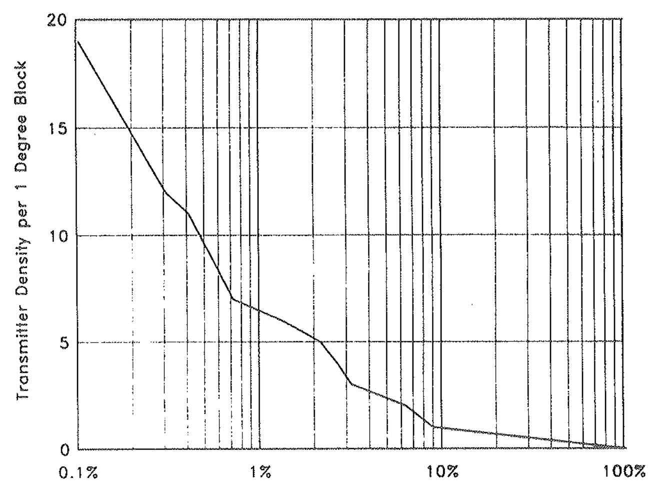

Figure 2.15-2. Percentage of blocks exceeding indicated assignment densities.

Typical users. The 2200-2290 MHz band is Government exclusive and is allocated, on a primary basis to Fixed, Mobile and Space Research. Footnotes give non-Government Space Research rights to transmit to the TDRSS satellite on a non-interference basis and give space operations co-equal status with the other primary allocations. The 2290-2300 MHz band is shared by Government and non-Government. Government has primary allocations to Space Research, Fixed and Mobile Services and non-Government allocations are to Space Research on a primary basis. This band was stated to be unavailable for reallocation to non-Government functions because of national defense priorities. Publicly announced users include point-to-point microwave, airborne, mobile, and satellite applications.

The 2200-2300 MHz band is heavily used by the Government in space, deep space, and terrestrial telemetry, telecommand and control. NASA uses the band with the TDRSS satellite, and Air Force uses the band with the Space Ground Link Subsystem (SGLS). It is the primary down link band for Government Satellite Systems operating on the 1710-1850 MHz and 2025-2110 MHz uplink bands.

The total assignment count in June 1992 was 2,266, of which Fixed assignments totalled 278. The Fixed assignments are mainly used for microwave service in conjunction with land mobile systems for voice and data in remote areas. The Fixed assignments have an average bandwidth of 3.8 MHz.

The Air Force has 894 assignments for uses such as telemetry, missile testing, miscellaneous space activities, and electronic warfare testing. Navy has 413 assignments for missile telemetry, inter-ship data relay, range operations, and atmospheric research telemetry. Army has 349 assignments for backbone, testing, Global Positioning System, and RDTE support. Energy has 257 assignments for flight telemetry, data links, and other program telemetry. NASA's 171 assignments are for sounding rocket telemetry, command and tracking for Voyager 2, and for communication with the TDRSS satellite. The remaining 141 assignments are held by 9 agencies and are used for law enforcement, resource management, spacecraft monitoring communications.

Recent trends in number of assignments. Growth in this band over the past 13 years is shown in Figure 2.15-3. Assignments in the 2200-2300 MHz band have grown from 1,979 in 1987 to 2,258 in December 1991.

Comments. Band growth has been stable at about 1.4 percent annual.

Estimated future growth rate. The growth is likely to be constant at its present 1 percent annual rate.

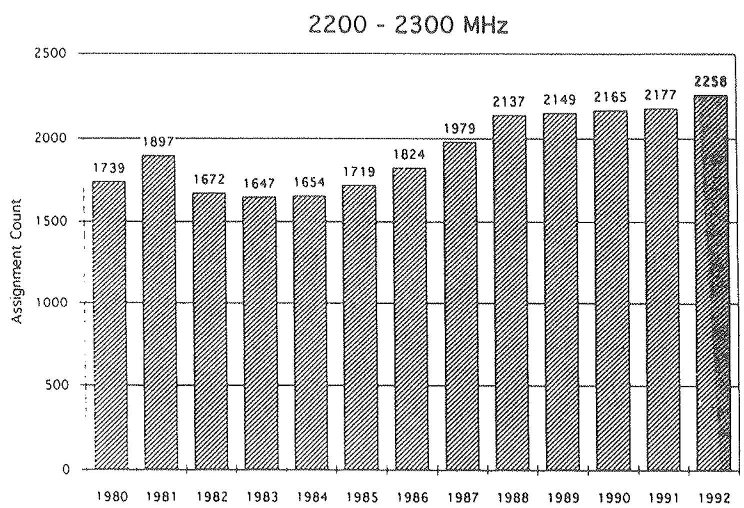

Figure 2.15-3 Number of assignments in the 2200-2300 MHz band (1980-1992).

2.16 Usage in the 2450-2483.5 MHz Band
ISM, Government, Auxiliary Broadcast, Private Services

Figure 2.16-1. Density of assignments per degree in the 2450-2483 MHz band

Table 2.16-1. Statistics for 2450-2483.5 MHz

total US assignments (1991)	441
peak assgnmts/1-degree block	6, 32
effective # of channels	2, 60
average US channel re-use	41, 6
peak re-use/1-degree block	3, 0.5
annual growth rate (last 4 yr)	10.1%
est. annual growth (next 5 yr)	5%

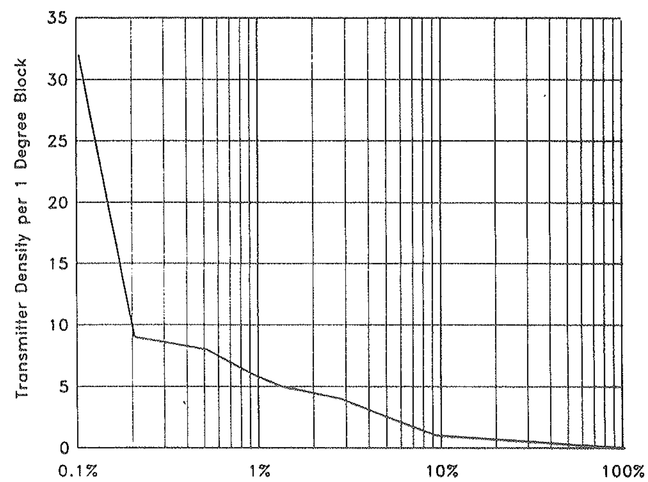

Figure 3.16-2. Percentage of blocks exceeding indicated transmitter densities.

Typical users. This ISM band has a wide variety of Government and non-Government functions. Since this band is assigned on a primary basis to the industrial, scientific, and medical (ISM) service, no other service has any protection from interference from ISM devices. The FCC has recently allowed spread spectrum communications in this band with up to one watt of power (without licensing or protection), and many experiments are under way for wireless LANs, PCS, and other spread-spectrum systems. Private operations has 30 pair of channels with 800 kHz bandwidth over the 2450-2500 MHz band. AUXBC has two 17-MHz channels over the 2450-2483.5 MHz band. The band is also allocated on a secondary basis for non-Government radiolocation, on a primary basis for Mobile, and on a non-interfering basis (via a footnote) for Government radiolocation.

The most notable ISM use is for 80 million microwave ovens, operating at a nominal 2450 MHz. The two sets of numbers for number of channels and channel re-use are for AUXBC and Private Operational, respectively.

Recent growth in number of assignments. Growth in this band over the past five years is shown in Fig 2.16-3. This data shows the number of licensed microwave assignments. In 1991, there were 82 AUXBC assignments and 359 private operational assignments. It should be noted, however, that the overwhelming majority of transmitters in this band are nonlicensed ISM devices which greatly limits the opportunity for fixed stations in this band.

Comments. This band was originally allocated up to 2500 MHz. In 1985, a non-Government radiolocation satellite service was allocated to the 2483.5-2500 MHz portion of the band, but existing AUXBC and private operational stations were "grandfathered". A recent change in FCC rules allows this band to be used by nonlicensed spread-spectrum communication systems with up to 1 watt of power. This band is currently the band of choice for much development work in wireless LANs. The opportunity to use an ISM band for communications may be the driving force behind recent international efforts to put radiated power restrictions on ISM bands.

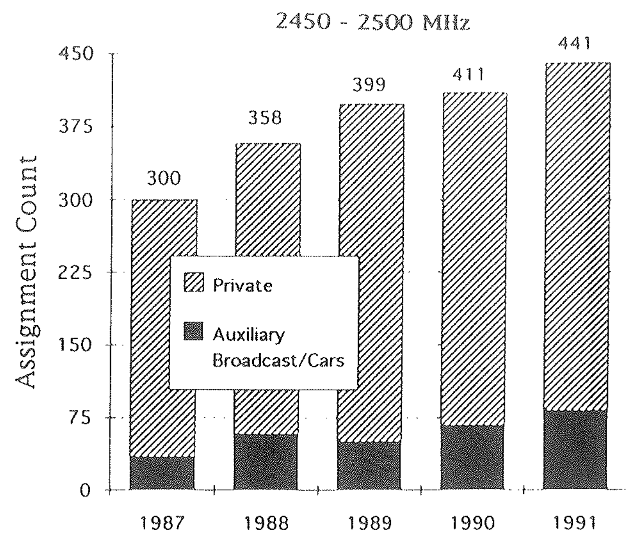

Figure 2.16-3. Number of assignments in the 2450-2483.5 MHz band (1987-1991).

The geographical location of licensed Fixed stations--mainly in the Gulf of Mexico--shows the wariness of users concerning the possibility of interference from microwave ovens. Apparently, users feel that interference from microwave ovens can be controlled there to a much greater degree than on land.

Estimated future growth rate. Since most of the transmitters in the band are nonlicensed, it may be pointless to imply that the small percentage of licensed transmitters is significantly related to the use of the band. The number of microwave ovens will continue to grow slowly, having already penetrated most US households. The number of nonlicensed wireless LANs using spread-spectrum technology will grow rapidly (30 percent a year), until additional bands are allocated for low power wireless devices. Licensed private and AUXBC systems will continue to grow slowly at the rate of 5 percent a year. Interference problems will discourage the use of this band for point-to-point microwave in many urban environments, especially for systems for which reliable operation is important.

2.17 Usage in the 2500-2690 MHz Band
Auxiliary Broadcast, Private Operational Services

Typical users. Typical users of this band include 'wireless cable' TV broadcasting throughout the whole band. Recent changes in FCC rules in this band allow a single organization to license multiple channels, facilitating the development of systems that broadcast many TV channels from a single site. These TV services are usually broadcast with omnidirectional antennas and received with directional antennas. Additional uses include private operational uses in three 6-MHz channels and three 1-MHz channels in the 2650-2690 MHz range.

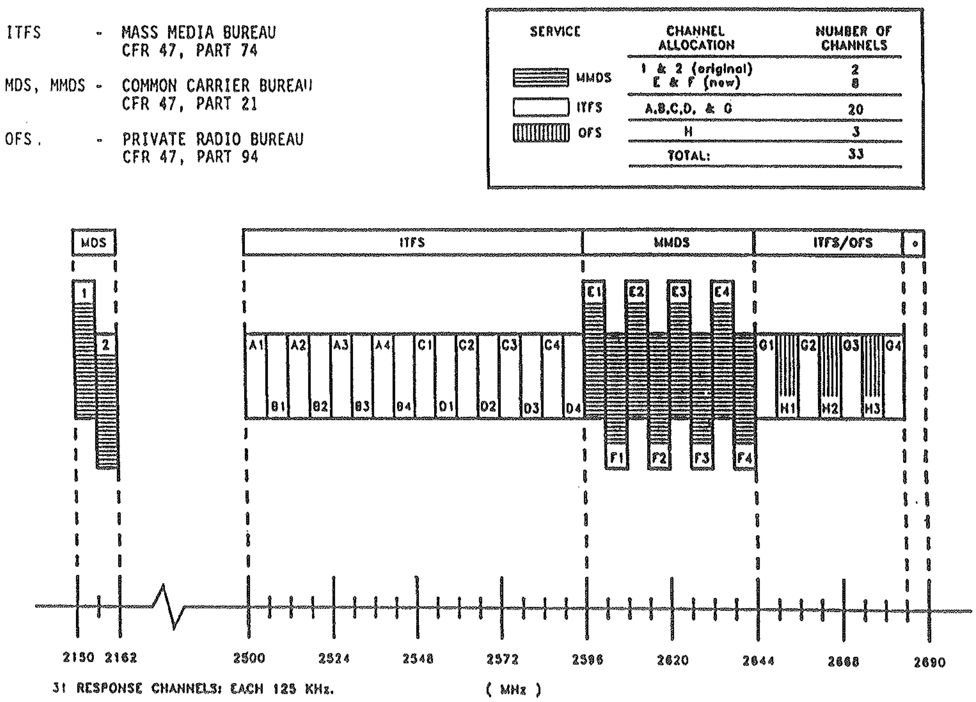

Figure 2.17. Channelization in the 2500-2690 MHz band.

Recent growth in number of assignments. Due to a recent change in the rules for this service, this band is undergoing rapid changes, which prevent the historical data on the band from being useful. There is currently a backlog of 24,000 applications for licenses in this band, although only 75 systems are currently operational (probably another 20 by the end of 1992). The recent growth (in license applications, at least) is due to a 1990 change in rules, which increased the number of channels that could be broadcast by the same owner. The FCC said in their December 1992 LMDS NPRM that they had granted more than 900 MMDS applications for licenses.

Comments. This band was set up in 1983 to provide a wireless alternative to cable TV. It also has particular application to some semi-rural areas, where the population density is not sufficient to support the initial capital investment needed for a cable system. The regulations were changed again in 1990 to permit more channels so that MMDS could compete more effectively with cable. The band contains several services, shown in the preceding figure and described in the following paragraphs.

Instructional TV Fixed Service (ITFS), Part 74, AUXBC. ITFS uses 5 groups of four 6-MHz stations (with 6-MHz spaces between stations). Groups A&B: 2500-2548 MHz, Groups C&D: 2548-2596 MHz, Groups E&F: 2596-2644 MHz, Group G: 2644-2686 MHz. Group G was eliminated in 1970. Groups E&F were converted to MDS in 1983, though existing ITFS channels were grandfathered. One owner could have only one group of 4 stations. Directional transmit and receive antennas are used. These channels are intended for TV classroom instruction, and are typically used when a local university brings in-house classroom instruction to the employees of a manufacturing corporation.

Multipoint Distribution Service (MDS), Part 21, Public. MDS operates at 2150-2162 MHz and 2596-2644 MHz. A single owner can have up to four 6-MHz channels. It is expected that TV will be the signal, but it doesn't have to be. Each channel transmits 10 watts (up to 100 watts with permission). MDS service is secondary to ITFS. MDS uses directional receive antennas, and omnidirectional transmit antennas.

Multichannel, multipoint Distribution Service (MMDS), Part 21, Public. Although MMDS has only ten channels (eight channels in 2596-2644 MHz, two MDS channels in 2150-2162 MHz) up to 33 channels are available by adding 20 ITFS channels and three private operational channels. These 33 channels can be broadcast from omnidirectional antennas with up to 100 watts per channel. The directional receiving antennas and decoder box are typically rented to the customer, who pays rental fees as part of the general service fee.

The usual arrangement for borrowing ITFS channels is for the MMDS operator to furnish transmitter facilities to the ITFS operator during the workday, with the ITFS channels being available to the MMDS operator after 5 pm.

Response channels, 2684-2690 MHz, Part 21, Public. These 31 channels are used to provide an audio response path from student to instructor in the ITFS service.

Private Operational channels, Part 94, Private. These channels occupy the 6-MHz slots between the 4 Group G ITFS channels.

Estimated future growth rate. This band supports a new service, which has not yet proved itself in the commercial world. It remains to be seen whether MMDS is a successful alternative to cable (with 80 channels and optical fiber), the telephone company (recently given permission to carry video), direct broadcast satellite, regular satellite, 28 GHz LMDS (cellular cable), etc. From a telecommunications standpoint, we should consider this band to be dominated by MMDS for the next 10 years, with minimal effect on activities in the other point-to-point microwave bands. We estimate that the band will grow to 1000 operational systems in the next 5 years, with about half of them in rural areas.

The recent entry of many competitors into the video distribution business means that several years will be needed to determine which markets (if any) are best served by wireless cable.

2.18 Usage in the 3700-4200 MHz Band
Public Service

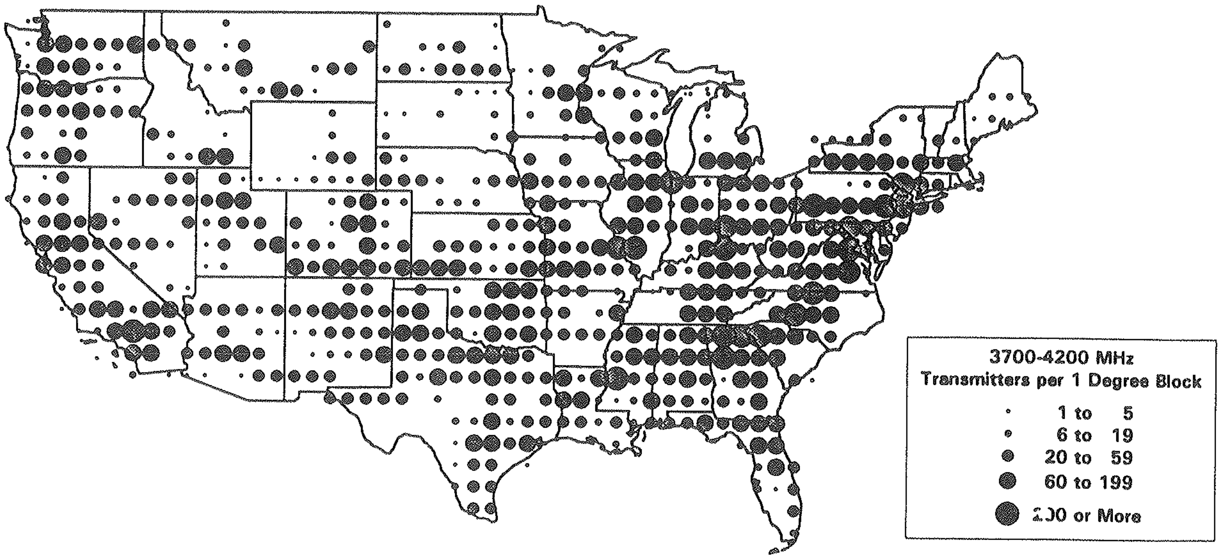

Figure 2.18-1. Density of assignments per square degree in the 3700-4200 MHz band

Table 2.18-1. Statistics for 3700-4200 MHz.

total US assignments (1991)	33174
peak assgnmts/1-degree block	342
effective # of channels	25
average US channel re-use	1327
peak re-use/1-degree block	13.7
annual growth rate (last 3 yr)	-5.2%
est. annual growth (next 5 yr)	-15%

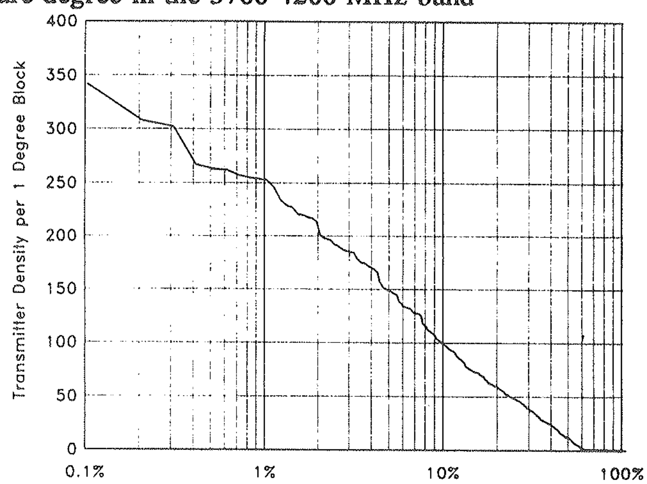

Figure 2.18-2. Percentage of blocks exceeding indicated assignment densities.

Typical users. This band was the original long-haul microwave band, built to provide the first analog transcontinental network to transport television and analog long-distance telephone circuits. As this band filled up, the overflow went into the 6 GHz band. Typical users of this band include the telephone companies--local, long distance, and alternative carriers. This band is channelized at 20-MHz spacing. The divestiture left AT&T with 90 percent of the 4-GHz network. The early analog equipment has mostly been upgraded with digital equipment or replaced with fiber optics. The band is also shared with large numbers of licensed and nonlicensed fixed-satellite downlinks, which are used in TV and digital services.

Recent trend in number of assignments. Since reaching a peak in 1988, the number of assignments has slowly declined, as shown in Fig 2.18-3. These numbers do not fully reflect how precipitous the decrease in the use of this band has been, since many of the licensed channels are relatively inactive. AT&T had begun selling off its microwave tower sites, but later decided that the sites might be useful in PCS or other future systems. Although much equipment to support cellular networks has been installed at 6 GHz, the 4 GHz band has not been used because of the difficulty in coordinating around the downlink sites.

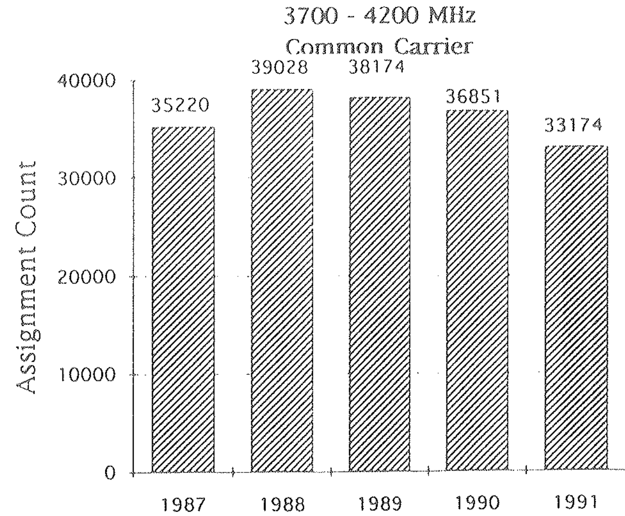

Figure 2.18-3. Number of assignments in the 3700-4200 MHz band (1987-1991).

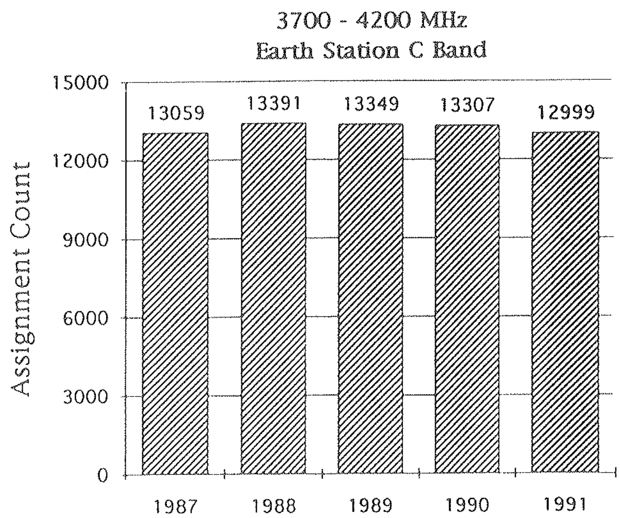

Figure 2.18-4. Number of downlink assignments in the 3700-4200 MHz band.

This band is shared with fixed-satellite downlinks, carrying television (mostly) and data. The downlinks include VSAT terminals (licensed at their uplink frequency), 12,000 CATV (cable TV), 7,000 SMA (small master antenna), and 3 million unlicensed 'backyard' TVRO (TV receive-only) terminals. Unlicensed receive-only downlinks are legal, but they are not protected from interference.

Licensed downlinks (including about 75 percent of the CATV and SMA installations), shown in figure 2.18-4, are protected against interference from terrestrial microwave, blocking new microwave links from most urban locations. Downlinks have very little link margin, making them susceptible to even low levels of interference. Since a typical downlink site utilizes the entire 3700-4200 MHz band and all points of the synchronous orbit, it is difficult to operate fixed transmitters near downlink sites at any frequency in the band. Although a new downlink site must tolerate any interference it receives from existing transmitters, it does not have to accept any interference from new transmitters. Thus, new fixed links have been kept out of this band in many urban locations.

Comments. There is wide variation between the RBOCs in how this band is used. In some areas, it is completely full; in others it is empty. Some areas are all digital; others still have much analog.

Estimated future growth trends. This band is proposed as an Emerging Technologies migration band and will be rechannelized at 0.4-, 0.8-, 1.6-, 5-, 10- and 20-MHz bandwidths for private and public services. Because of the numerous downlink sites in urban areas, it is unlikely that departing common carrier stations can be easily replaced by systems migrating from the proposed Emerging Technologies bands. We expect band usage (point-to-point) to decline 15 percent per year over the next five years.

2.19 Usage in the 4400-4990 MHz Band
Government Services

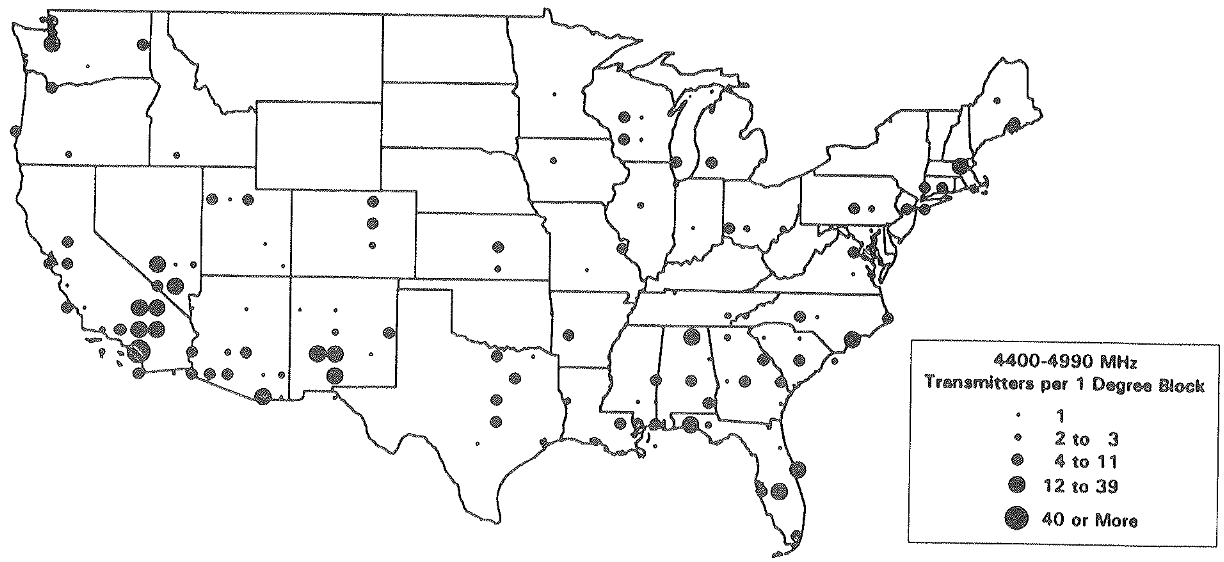

Figure 2.19-1. Density of Fixed assignments per square degree in the 4400-4990 MHz band.

Table 2.19-1. Statistics for 4400-4990 MHz

total US assignments (1991)	1582
peak assgnmts/1-degree block	50
effective # of channels	74
average US channel re-use	21
peak re-use/1-degree block	0.68
annual growth rate (last 4 yr)	1.0%
est. annual growth (next 5 yr)	1%

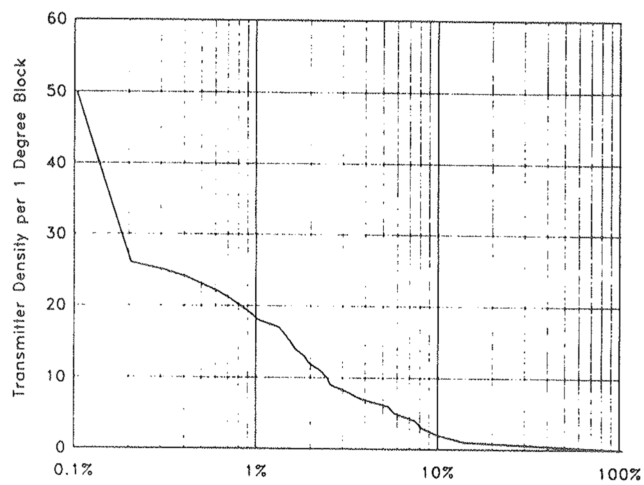

Figure 2.19-2. Percentage of blocks exceeding indicated assignment densities.

Typical users. The 4400-4500 MHz band is Government exclusive and is allocated to Fixed and Mobile on a primary basis. The 4500-4800 MHz band is shared with non-Government users. The Government has primary allocations to Fixed and Mobile, and non-Government users have primary allocations to Fixed-Satellite. A footnote limits the Fixed-Satellite use to intercontinental systems. The 4800-4990 MHz band is Government exclusive. Footnotes afford protection to Radio Astronomy, and allocate space research and earth exploration satellite services on a secondary basis.

Military agencies are the primary users of the band. Uses include dual-purpose line-of-sight/troposcatter links for tactical communications. These systems are transportable point-to-point systems, with sufficient power (greater than 1 KW) to allow tropospheric scatter communications for beyond-line-of-sight links. In addition, the band is used in drone control, target scoring, and balloon-to-ground data links for tethered balloon surveillance. The average bandwidth for Fixed systems is 8 MHz.

Air Force has 886 assignments for training, remoting of tactical radar, and for miscellaneous activities associated with electronic warfare. Army has 437 assignments for training, mobile data links, and for use on test ranges. Navy has 298 assignments for tactical training, links to remotely piloted vehicles, and for quality control test evaluation. The remaining assignments, held by civilian agencies and by non-Government entities, are for law enforcement, antenna testing, data links for balloon surveillance, or aircraft data down links.

Recent trends in number of assignments. Growth in this band over the past 13 years is shown in Figure 2.19-3. Assignments in the 4400-4990 MHz band have grown from 1,518 in 1988 to 1,582 in January 1992, for an average growth rate of 1 percent per year. In June 1992, the GMF indicated there were 1,738 assignments in the band, of which 896 were Fixed. Table 1.5-1 shows that almost 75% of the listed Fixed terminals were transportable terminals.

Comments. For the last four years band growth has been fairly stable at about 1 percent annually. There has been a growth of about 10 percent for the first six months of 1992, with the addition of more individual assignments for existing transportable terminals. This recent growth is not shown in the bar chart.

Estimated future grow rate. We expect real growth in the band to remain around one percent a year, not counting the additional assignments from already-existing transportable terminals.

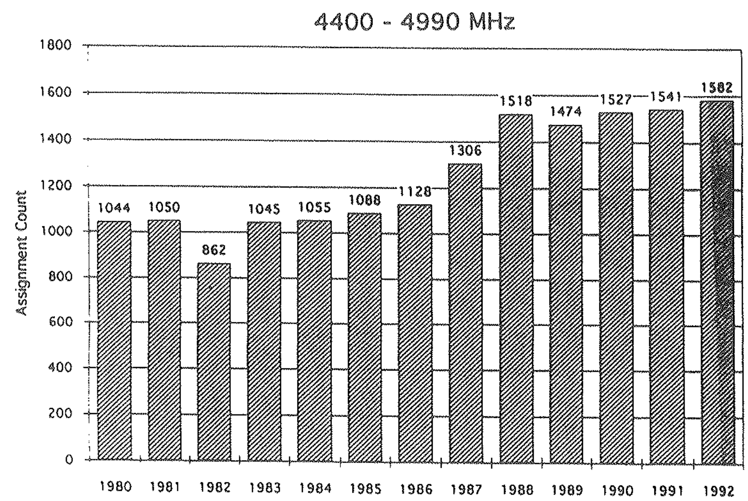

Figure 2.19-3. Number of assignments in the 4400-4990 MHz band (1980-1992).

2.20 Usage in the 5925-6425 MHz Band
Public Service

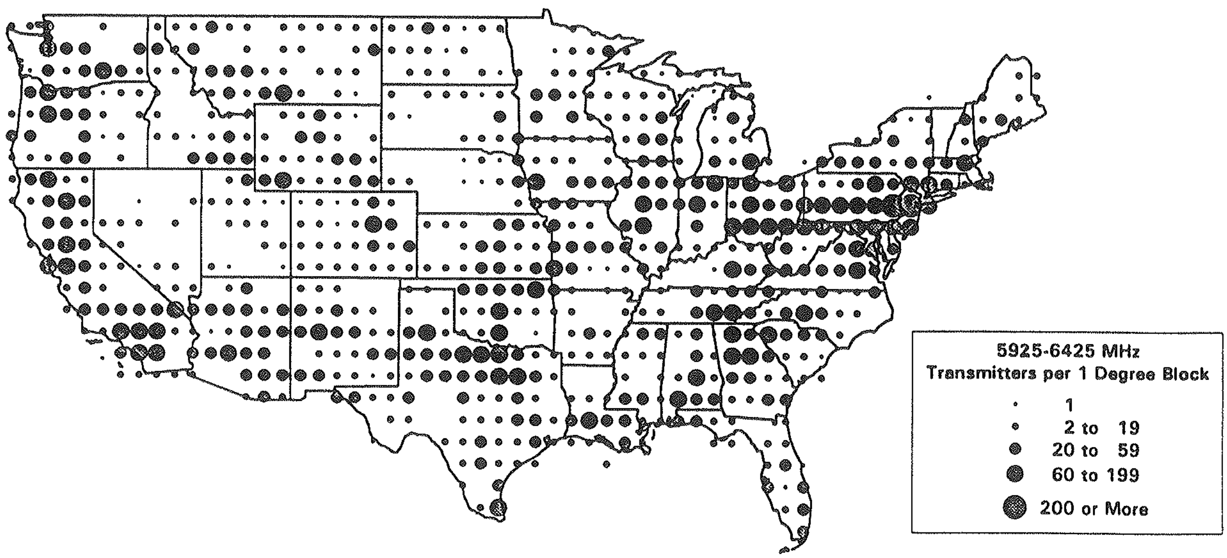

Figure 2.20-1. Density of assignments per square degree in the 5925-6425 MHz band.

Table 2.20-1. Statistics for 5925-6425 MHz

total US assignments (1991)	18,679
peak assgnmts/1-degree block	366
effective # of channels	16-20
average US channel re-use	934-1167
peak re-use/1-degree block	18.3-22.8
annual growth rate (last 4 yr)	-9.3%
est. annual growth (next 5 yr)	-6%

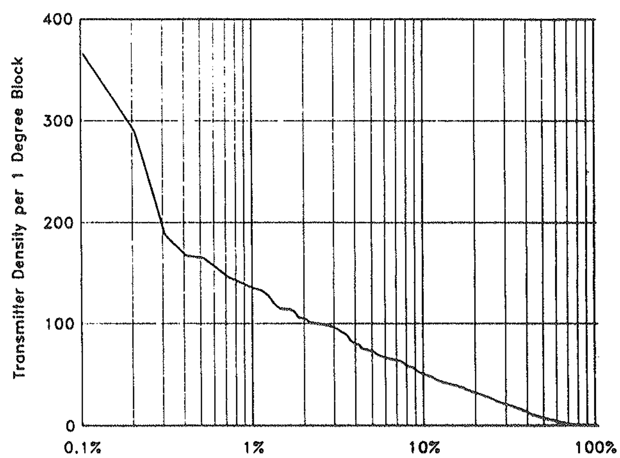

Figure 2.20-2. Percentage of blocks exceeding indicated assignment densities.

Typical users. This band is used by the IXCs, the LECs, alternative providers, and the cellular companies This band provides 30-MHz channelization and is used for the long-haul backbone routes, connections between central offices, and between central offices and customer interface locations. It is also used as backbone by cellular providers, who have built independent networks which by-pass the LEC. This band is shared with large numbers of satellite uplinks, used extensively for TV and data applications.

Recent trends in number of assignments. Population changes in this band over the past five years are shown in Fig 2.20-3. The band has exhibited an average decline over the past four years of 9.3 percent The decline in 1991 was 22 percent.

Comments. Many of the IXC cross-continent networks and the LEC interoffice links and feeders are being replaced by fiber. Many microwave links have been abandoned, and many microwave links that remain in service are being used only as backup links. AT&T had begun to sell their microwave sites. The policy was reversed when AT&T decided that the sites might be useful for PCS or other future services.

A large amount of new growth is occurring as cellular telephone companies use 6 GHz to build the supporting network backbones which bypass the LEC. Much of the cellular growth is now completed and growth will slow down in the future. The FCC has indicated that this band is a migration destination for those displaced from the proposed 2-GHz Emerging Technologies bands and has been proposed for rechannelization into 0.4-, 0.8-, 1.6-, 5-, 10-, and 30-MHz channels.

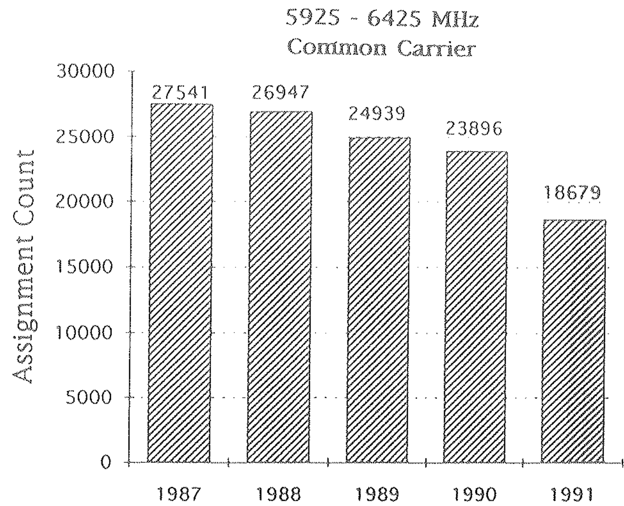

Figure 2.20-3. Number of Fixed assignments in the 5925-6425 MHz band (1987-1991).

This band is shared with a growing number of satellite uplinks (Fig 2.20-4). These uplinks include a large number of VSAT systems (probably 90 percent of the total count), uplinks to TV networks, uplinks intended for cable distribution, and many miscellaneous types of data and services. Since the uplinks are not bothered by the terrestrial transmitters and the terrestrial receivers have enough link margin to tolerate substantial interference, this band has not suffered from the sharing problems that have occurred at the 4 GHz band.

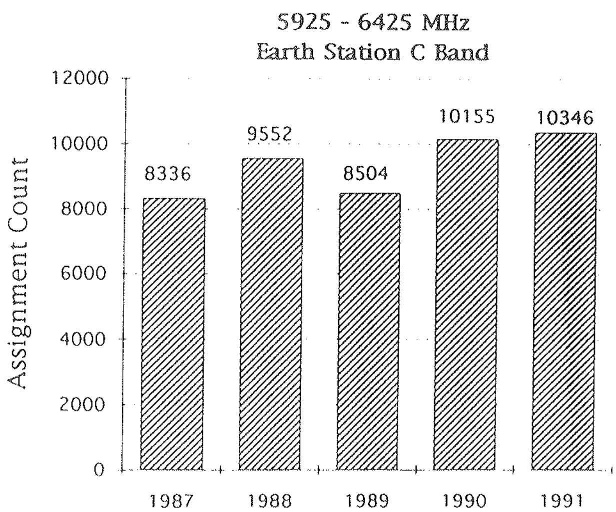

Figure 2.20-4. Number of satellite uplink assignments in the 5925-6425 MHz band

The use of this band varies widely among the phone companies. In some areas, the 6 GHz bands are quite full; in other areas the bands are empty. Many bands contain only digital modulations; others still contain some analog.

Estimated future growth trends. This band will continue to shrink at the overall rate of 6 percent a year. Older microwave links will continue to be replaced with fiber. Much of the growth associated with cellular has already been accomplished, leaving less growth in the future. There will be considerable growth caused by migration from 2 GHz, but not enough to balance the loss of common carrier traffic. The future deployment of PCS could cause future additional use of this band.

2.21 Usage in the 6525-6875 MHz Band
Private Operational Service

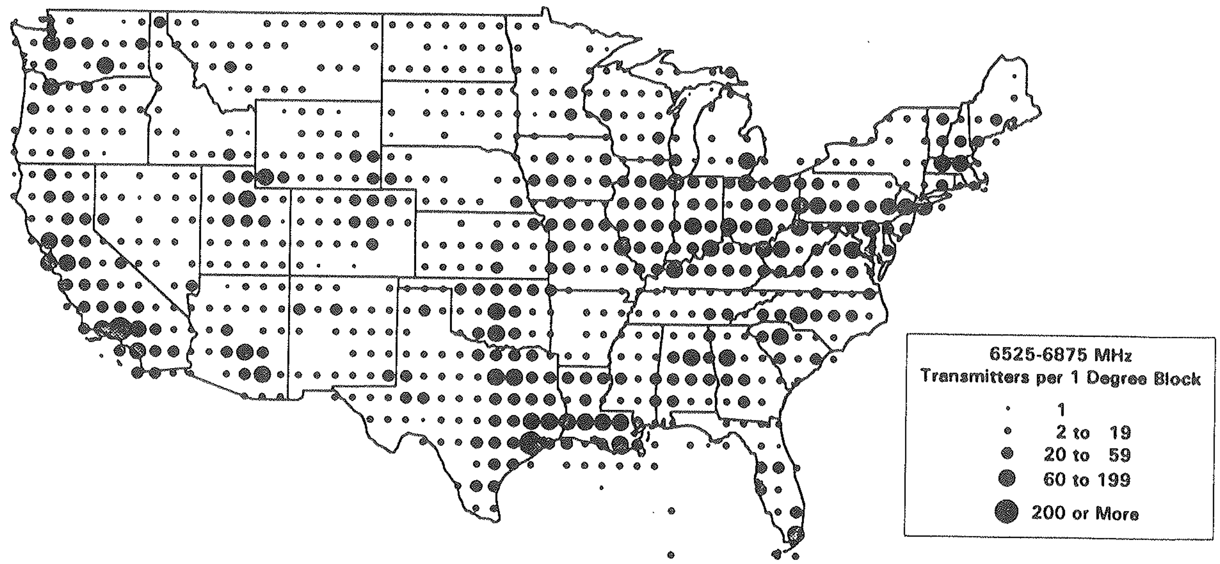

Figure 2.21-1. Density of assignments per square degree in the 6525-6875 MHz band.

Table 2.21-1. Statistics for 6525-6875 MHz.

total US assignments (1991)	16,557
peak assgnmts/1-degree block	282
effective # of channels	40-76
average US channel re-use	218-414
peak re-use/1-degree block	3.7-7.0
annual growth rate (last 4 yr)	2.5%
est. annual growth (next 5 yr)	3%

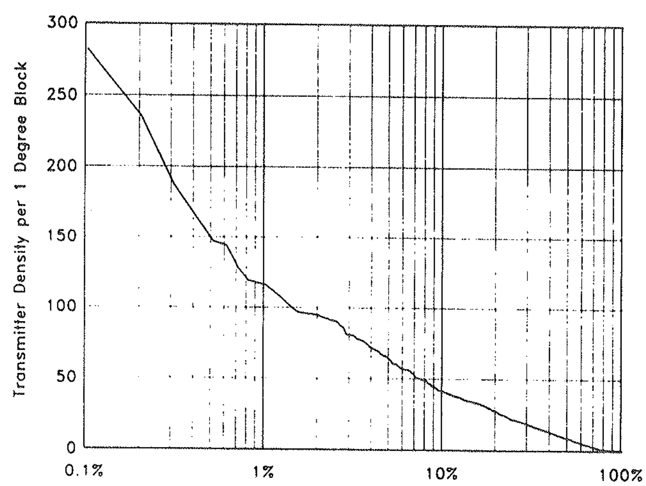

Figure 2.21-2. Percentage of blocks exceeding indicated assignment densities.

Typical users. Typical users of this band include public safety, petroleum, railroads, utilities, and others including, but not limited to manufacturing, banking, and service providers. This band has paired channels, including bandwidths of 800 kHz, 1.6 MHz, 5 MHz, and 10 MHz.

Recent growth in number of assignments. Growth in the 6.5 GHz band over the past five years has averaged about 2.5 percent and is shown in Fig 2.21-3. In addition, Comsearch records show 375 Auxiliary Broadcasting assignments and 40 common carrier assignments. This band is used by numerous manufacturers and businesses to by-pass the LEC.

Comments. The FCC is proposing that this band be one of the 'migration' bands allocated to accept systems leaving the proposed 2 GHz Emerging Technologies bands. Although new channelization rules are being proposed to permit narrower bandwidth systems in most of the migration bands, the 6.5 GHz band already is channelized with appropriate bandwidths. Therefore, the major change proposed for this band is that the common carriers will be co-primary with private operational services.

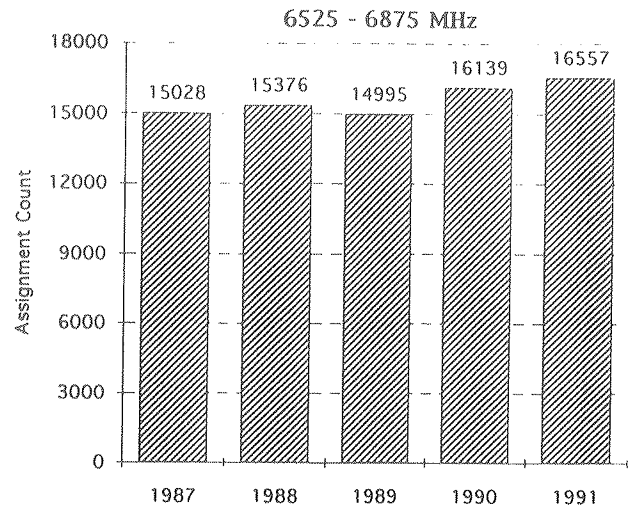

Figure 2.21-3. Number of assignments in the 6525-6875 MHz band (1987-1991).

Estimated future growth rate. Some growth would be expected from licensees displaced from the 2 GHz Emerging Technologies' reallocation. Although the additional systems from the 2 GHz bands will probably be divided among all of the migration bands, the 6.5 GHz band will be the only migration band operating under the Private Operational rules and protection ratios. In addition, this band is less crowded than some of the other migration bands and coordination procedures and rules are already in place and working and equipment is already available. Thus, this band may get a larger share of the initial migration from 2 GHz. We estimate 3 percent growth averaged over the next five years.

2.22 Usage in the 6875-7125 MHz Band
Auxiliary Broadcast, Public, CARS(ENG-only)

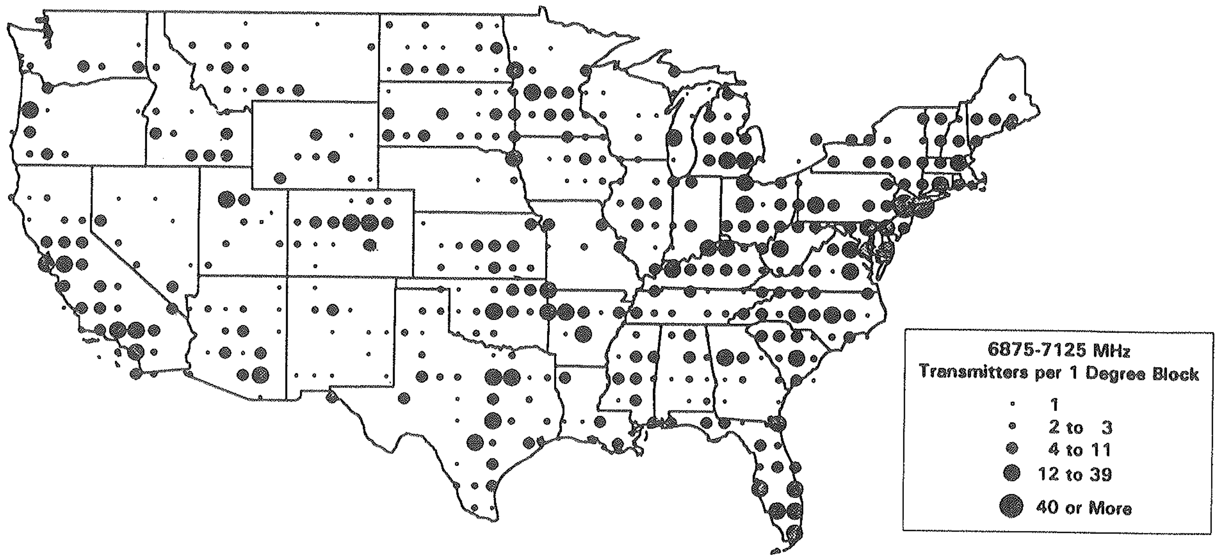

Figure 2.22-1. Density of assignments per square degree in the 6875-7125 MHz band.

Table 2.22-1. Statistics for 6875-7125 MHz.

total US assignments (1991)	2607
peak assgnmts/1-degree block	74
effective # of channels	10
average US channel re-use	261
peak re-use/1-degree block	7.4
annual growth rate (last 4 yr)	9.5%
est. annual growth (next 5 yr)	5%

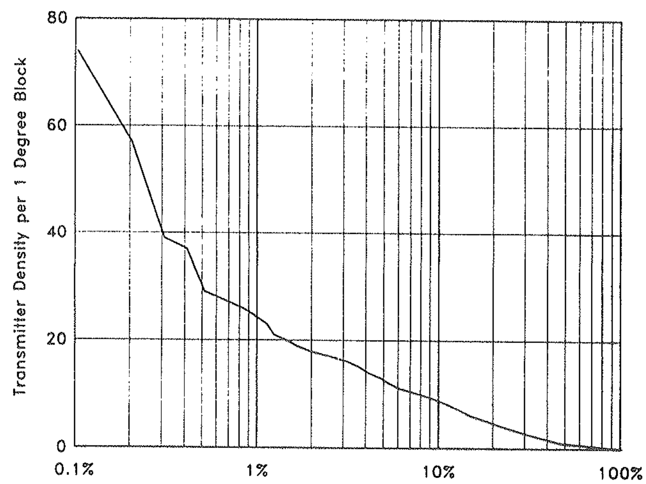

Figure 2.22-2. Percentage of blocks exceeding indicated assignment densities.

Typical users. This band is allocated to auxiliary broadcasting, using NTSC frequency-modulated on 25-MHz bandwidth channels. CARS is limited to mobile Cable TV pickup stations (similar to ENG). The "7 GHz" band is channelized into 10 channels with 25-MHz bandwidth. This band is the most heavily-used band for studio-to-transmitter links (STL), intercity relays (ICR), and electronic news gathering relay (ENG relays). The band is also used for electronic news gathering (ENG), and for Cable TV pick up stations. TV translator relay stations are also permitted on a secondary basis.

Recent growth in number of assignments. Growth in this band over the past five years for auxiliary broadcasting and cable TV relay is shown in Fig 2.22-3. Comsearch records also show one common carrier assignment. The rapid growth (9.5 percent per year) is mainly due to the increased comprehensiveness of support for ENG and coverage of local events.

Comments. This band may require some adjustments to accommodate the anticipated arrival of HDTV services, since many stations will need to simultaneously support HDTV and NTSC formats with STLs, ICRs, and ENGs. This subject is treated more completely in Section 3.8

Some major metropolitan areas (Washington DC, New York and Los Angeles) have already begun to move a large number of ICRs and STLs onto fiber.

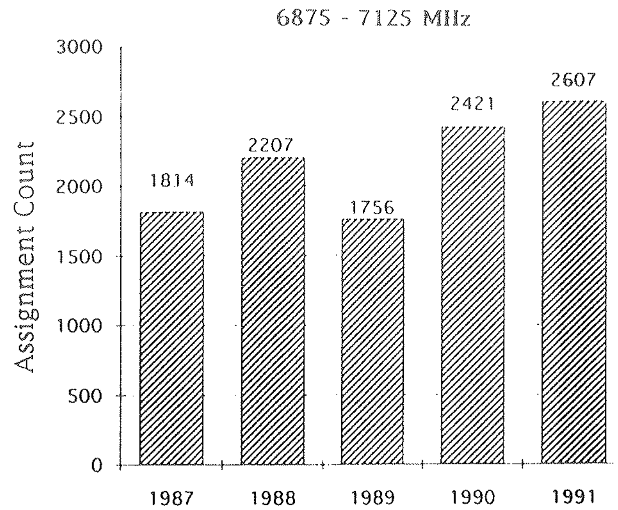

Figure 2.22-3. Number of assignments in the 6875-7125 MHz band (1987-1991).

Estimated future grow rate. The requirements on this band will continue to grow, especially with the implementation of HDTV broadcasting. Since STL, ICR, and ENG relay are all fixed services, there is the potential to implement them with fiber. It is difficult to predict exactly when the economics of fiber vs. microwave will tip strongly in the direction of fiber, but the need to increase the number of STLs and ICRs for HDTV broadcasting might be a major factor, along with the optical fiber experience gained recently by cable companies. We estimate an overall growth rate of 5 percent for the next five years, with the number of assignments actually decreasing at the end of that period.

2.23 Usage in the 7125-8500 MHz Band
Government Service

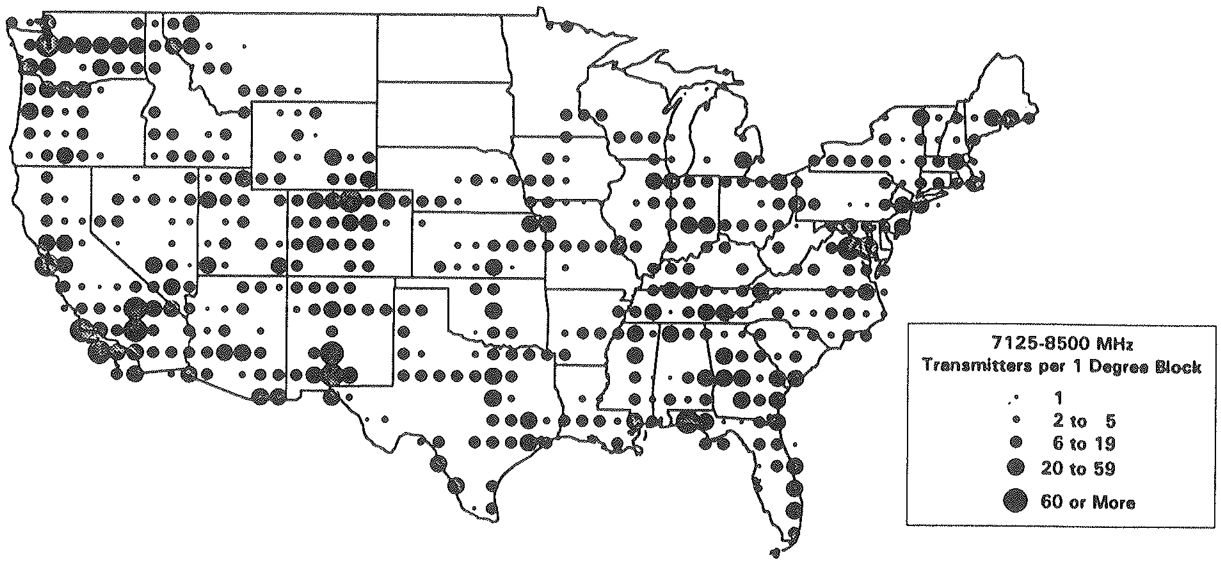

Figure 2.23-1. Density of Fixed assignments per square degree in the 7125-8500 MHz band.

Table 2.23-1. Statistics for 7125-8500 MHz

total US assignments (1991)	10,034
peak assgnmts/1-degree block	122
effective # of channels	68
average US channel re-use	148
peak re-use/1-degree block	1.8
annual growth rate (last 4 yr)	-0.4%
est. annual growth (next 5 yr)	-2%

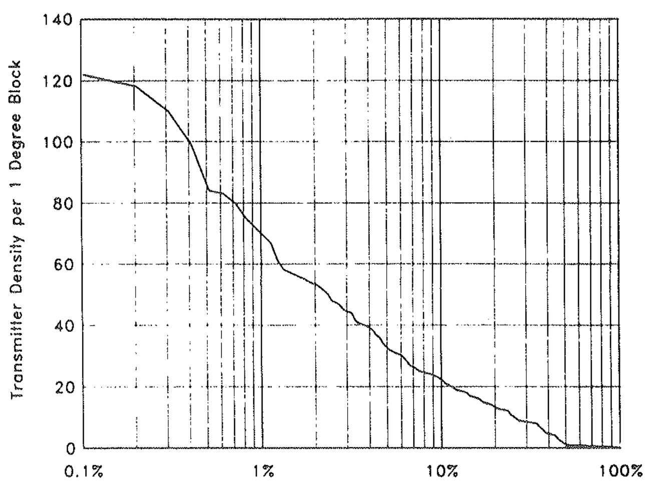

Figure 2.23-2. Percentage of blocks exceeding indicated assignment densities.

Typical users. The band is allocated exclusively to the Government from 7125-8450 MHz; from 8450-8500 MHz, it is shared with a non-Government primary allocation to Space Research. The Government primary allocations are to Fixed, Space Research, Fixed-Satellite, Mobile-Satellite, Meteorological Satellite, and Earth Exploration Satellite in various portions of the band. Government Fixed allocations are primary, except for secondary status at 7250-7300 MHz and 7900-8025 MHz. Footnotes allocate Space Research service to a limited geographical area, Earth Exploration Satellite service to non-Government users on a case-by-case basis, and earth-to-space transmission in the Space Operations service on a limited basis. Additional footnotes give

Military Satellite service precedence by restricting Fixed Satellite and Mobile Satellite service to military use.

The FAA has 3,968 assignments, including the radio communications link (RCL) system, used mainly for relay of air traffic control communications and radar data from remote radar sites. The Air Force has 2,171 assignments, used mainly for electronic warfare training and remote bomb scoring. Navy has 1,098 assignments, used mainly in voice and data links, Defense Satellite Communications Systems (DSCS) and LEASAT satellite links, miscellaneous space links, point-to-point microwave training, ground forces communication, and in land-line back up. The Army has 660 assignments, used for video scoring, closed circuit TV (security), point-to-point communications training, and for administrative traffic.

DOE has 1,087 assignments used for system control and data acquisition (SCADA) for electric power distribution networks, perimeter security surveillance, laboratory telecommunication systems and closed circuit television for a test site. Justice has 304 assignments which are mostly for fixed backbone nets used in law enforcement communications. TVA has 224 assignments which are used almost entirely for SCADA for electric power distribution systems. Nine other civilian agencies have a total of 455 assignments used in space research (space shuttle link), tracking and command of Voyager 1, emergency and administrative communications, and for DSCS backbone. Non-Government users have 11 assignments for antenna testing, checkout of equipment for foreign export or for demonstration purposes.

Recent trends in number of assignments. Growth in this band over the past 13 years is shown in Fig 2.23-3. Assignments in the band from 7125-8500 MHz have grown from 9,224 in 1987 to 10,034 in December 1991. In June 1992, the total assignment count was 10,110, of which more than 8,300 were Fixed assignments.

The number of assignments in this band has remained stable over the past five years. Some military test ranges have modernized their communications by installing fiber optics over much of the range. The FAA has recently modernized much of their RCL microwave system with new microwave radios.

Comments. This is the traditional Government point-to-point microwave band. Much of the equipment is old analog equipment, which is becoming expensive to maintain and is a candidate to be replaced with fiber, VSAT, or public telecommunication services.

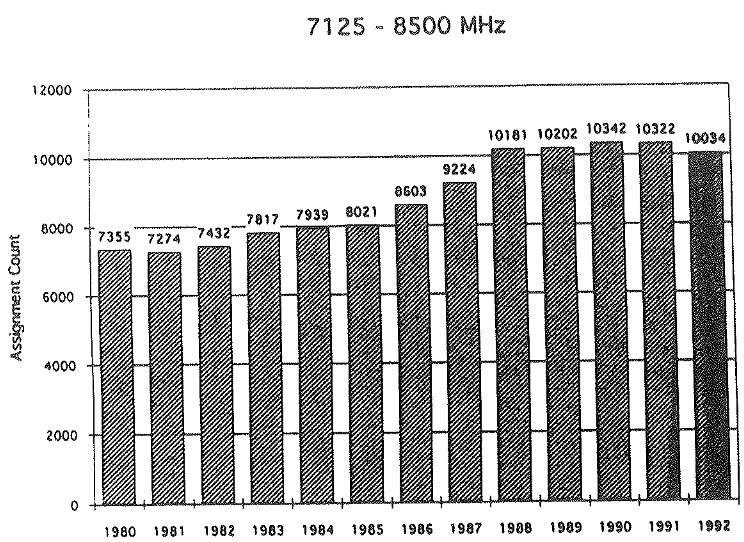

Figure 2.23-3. Number of assignments in the 7125-8500 MHz band (1980-1992).

Estimated Future growth rate. The Federal government is under pressure to operate more efficiently, and some agency-specific microwave systems will be replaced with commercial alternatives. Although this will not happen on a wholesale basis, there will be a continuing decrease of these links. We estimate that the usage in this band will decrease at an average rate of two percent per year over the next five years.

2.24 Usage in the 10.55-10.68 GHz Band
Public Service, Private Operational

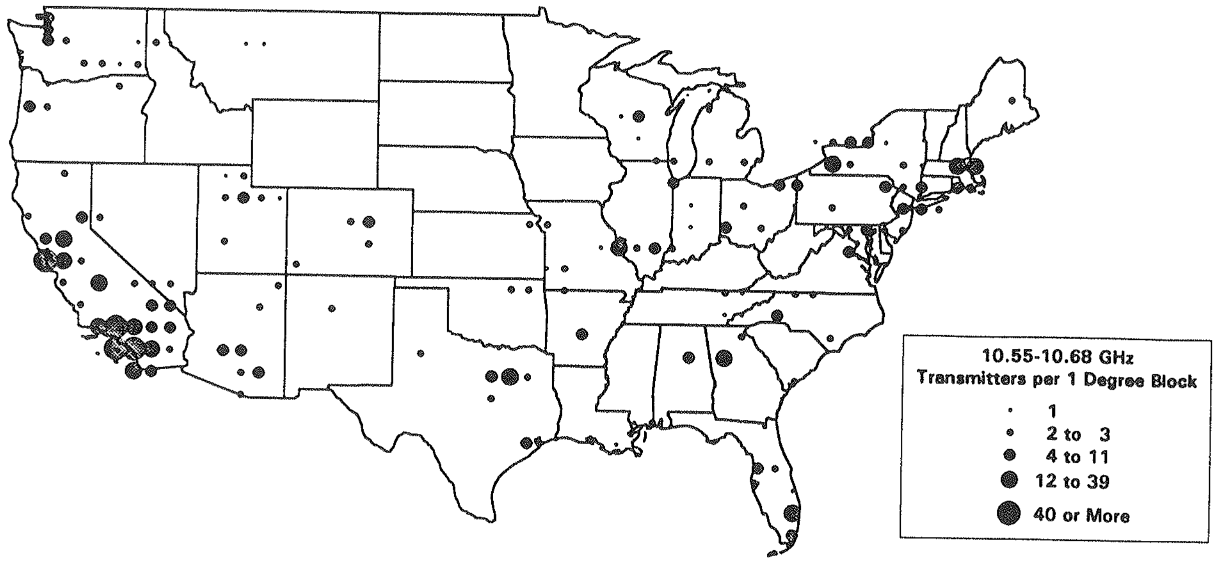

Figure 2.24-1. Density of assignments per square degree in the 10.55-10.68 GHz band

Table 2.24-1. Statistics for the 10.55-10.68 GHz band.

total US assignments (1991)	893
peak assgnmts/1-degree block	75
effective # of channels	8-16
average US channel re-use	56-111
peak re-use/1-degree block	4.7-9.4
annual growth rate (last 4 yr)	70%
est. annual growth (next 5 yr)	15%

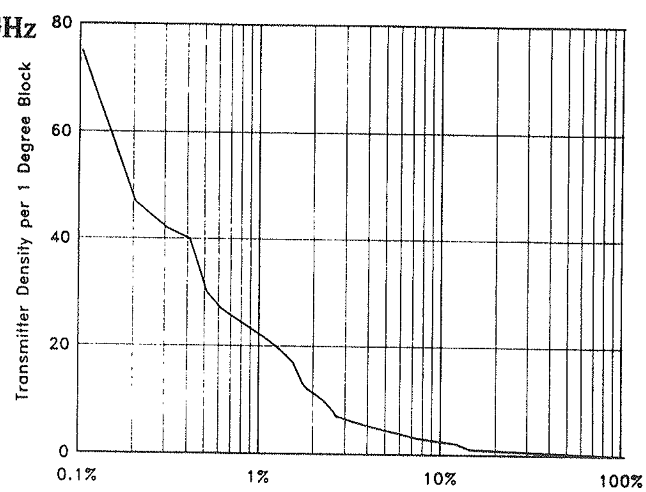

Figure 2.24-2. Percentage of blocks exceeding indicated assignment densities.

Typical users. This band was originally intended for Digital Electronic Message Service (DEMS), using paired channels with 2.5-MHz and 5-MHz bandwidths. DEMS systems are intended to transmit digital information between an omnidirectional nodal station and multiple user stations with directional antennas. The band also contains channels for use as point-to-point links between nodal stations. Several large corporations had intended to construct a large network of DEMS stations (which were never built), and the band remained unused. This band has a few frequencies for point-to-point microwave stations with 1.25-MHz or 2.5-MHz bandwidth.

Recent trend in number of assignments. Growth in this band over the past five years is shown in Figure 2.24-3. These assignments are all associated with the non-DEMS point-to-point channels. There have been a very limited number of applications for DEMS. The 10.5-GHz band has been growing rapidly with short-range links deployed in support of cellular sites with narrowband channelization.

Comments. This band is shared with radio astronomy, which causes the transmitter power levels to be limited to lower values.

Estimated future growth rate. There appears to be little interest in the DEMS allocation of this band. Cellular operators have recently 'discovered' this band, which is ideal for short, narrowband cellular links. The FCC has proposed that this band be rechannelized as a migration band for the 2 GHz Emerging Technologies bands. The proposed re-channelization will fill the band with 0.4-, 0.8-, 1.25-, 1.6-, 2.5-, 3.75-, and 5-MHz channels.

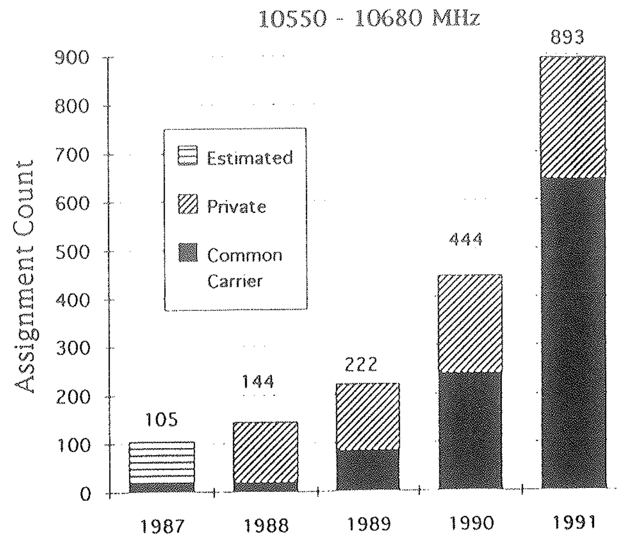

Figure 2.24-3. Number of assignments in the 10.55-10.68 GHz band (1987-1991).

The present allocation for the 10.55-10.68 GHz band breaks down as follows (Oct 1989):

Public DEMS/DTS
Pt-Pt used with DTS: 10.55-10.565 GHz - Channels A11-A18, 2.5-MHz BW. Paired with B11-B18.
DTS Nodal stations: 10.565-10.585 GHz - Channels A1-A4, 5-MHz BW. Paired with B1-B4.
Reserved DTS Nodal: 10.585-10.600 GHz - Channels A19-A24, 2.5-MHz BW. Paired with B19-B24.
DTS Nodal stations: 10.600-10.615 GHz - Channels A5-A10, 2.5-MHz BW. Paired with B5-B10.

Pt-Pt used with DTS: 10.615-10.630 GHz - Channels B11-B18, 2.5-MHz BW. Paired with A11-A18.
DTS User stations: 10.630-10.650 GHz - Channels B1-B4, 5-MHz BW. Paired with A1-A4.
Reserved DTS Nodal: 10.650-10.665 GHz - Channels B19-B24, 2.5-MHz BW. Paired with A19-A24.
DTS User stations: 10.665-10.680 GHz - Channels B5-B10, 2.5-MHz BW. Paired with A5-A10.

Private or Public pt-pt stations not associated with DTS:
Pt-Pt: 10.550-10.560 GHz - 4 channels of 2.5-MHz BW, paired with 10.615-10.625 GHz
Pt-Pt: 10.560-10.565 GHz - 4 channels of 1.25-MHz BW, paired with 10.625-10.630 GHz

Pt-Pt: 10.615-10.625 GHz - 4 channels of 2.5-MHz BW, paired with 10.550-10.560 GHz
Pt-Pt: 10.625-10.630 GHz - 4 channels of 1.25-MHz BW, paired with 10.560-10.565 GHz

More recently (1991), the 15-MHz of spectrum can be used as four 3.75-MHz or six 2.5-MHz channels.

2.25 Usage in the 10.7-11.7 GHz Band
Public Service

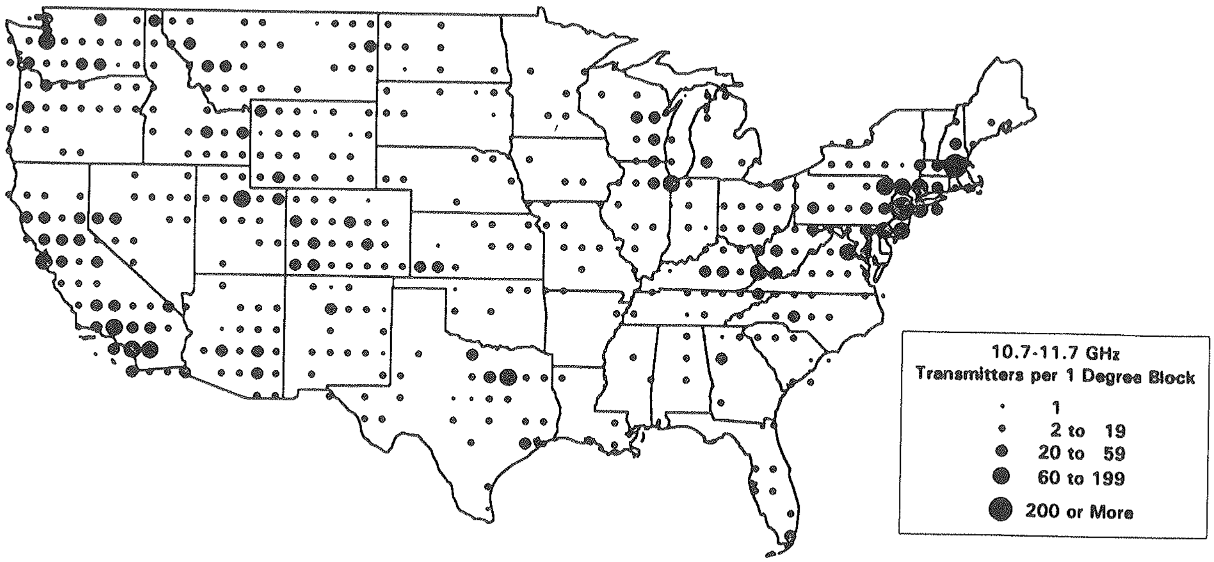

Figure 2.25-1. Density of assignments per square degree in the 10.7-11.7 GHz band.

Table 2.25-1. Statistics for 10.7-11.7 GHz

total US assignments (1991)	7609
peak assgnmts/1-degree block	413
effective # of channels	24-48
average US channel re-use	158-317
peak re-use/1-degree block	8.6-17.2
annual growth rate (last 3 yr)	-5.7%
est. annual growth (next 5 yr)	-7%

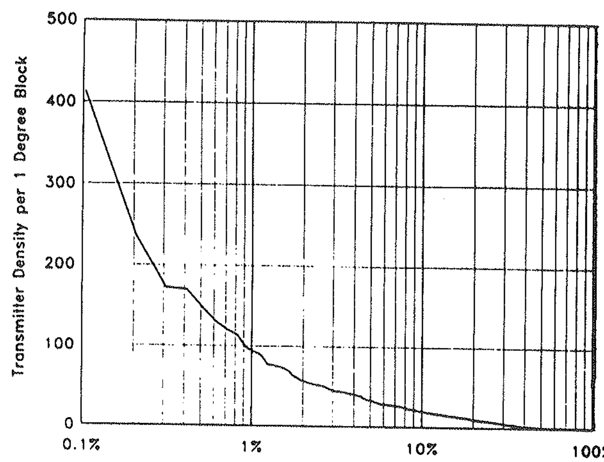

Figure 2.25-2. Percentage of blocks exceeding indicated assignment densities.

Typical users. This band is allocated to point-to-point service by common carriers. The channelization includes 48 channels with 20-MHz spacing, or the use of adjacent channels to give 24 channels with 40 MHz bandwidth. The band is also used by common carriers providing relay of analog TV studio-to-transmitter links. International fixed-satellite downlinks share the 10.95-11.2 GHz and 11.45-11.7 GHz portions of the band.

Recent trend in number of assignments. Growth in this band over the past five years is shown in Figure 2.25-3. Since reaching a peak in 1988, the use of the band had diminished by about 6 percent a year. This band has been heavily used by the telephone companies to provide wideband links (up to three DS-3) over shorter distances and was used heavily for early analog and digital telephone and analog video. These wideband links are mostly found in urban areas and are routinely being replaced with fiber.

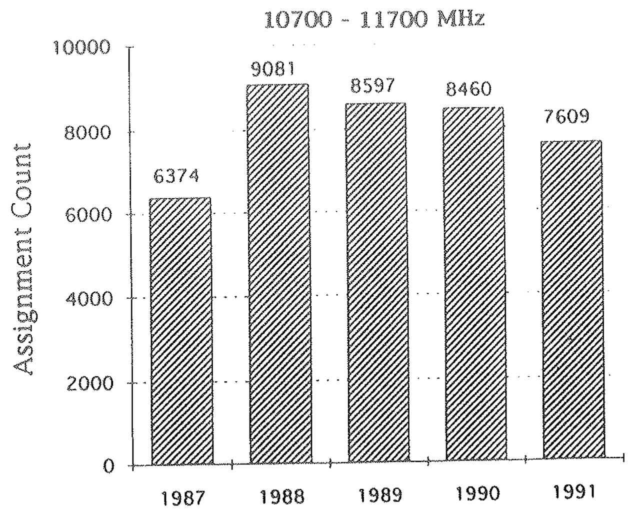

Figure 2.25-3. Number of assignments in the 10.7-11.7 GHz band (1987-1991).

Comments. This band was one of the bands used heavily by AT&T. It was used especially in urban situations where the 4 GHz and 6 GHz bands were already crowded, and the higher rain fading at 11 GHz could be tolerated because of a short path length. The common carriers are replacing many of these microwave links with fiber. The FCC has indicated that the 11 GHz band will be one of the migration bands for systems displaced from the proposed 2 GHz Emerging Technologies bands. This band will be re-channelized to permit common carriers and private users to use 10-MHz or 30-MHz channels.

Estimated future growth rate. The use of this band will continue to diminish fairly rapidly (7 percent decrease per year) as existing common carrier microwave links are replaced with fiber. Some additional systems will migrate into this band from the 2 GHz bands, but not enough to replace the common carrier links lost to fiber.

2.26 Usage in the 12.2-12.7 GHz Band
Private Operational, International Services, DBS

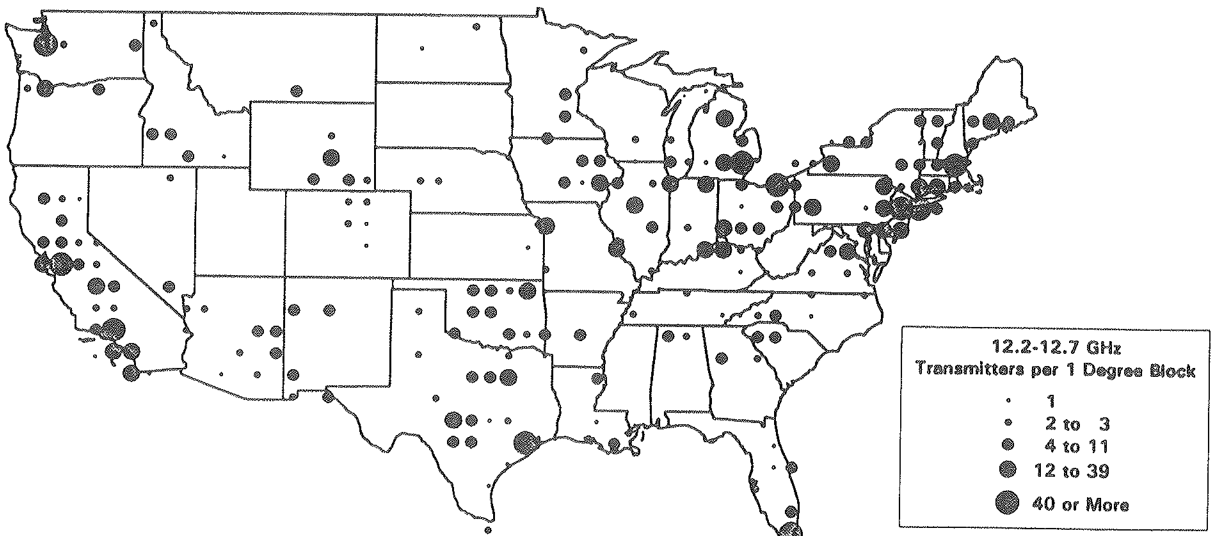

Figure 2.26-1. Density of assignments per square degree in the 12.2-12.7 GHz band.

Table 2.26-1. Statistics for 12.2-12.7 GHz

total US assignments (1991)	1906
peak assgnmts/1-degree block	101
effective # of channels	25
average US channel re-use	76
peak re-use/1-degree block	4.0
annual growth rate (last 4 yr)	-2.8%
est. annual growth (next 5 yr)	-3%

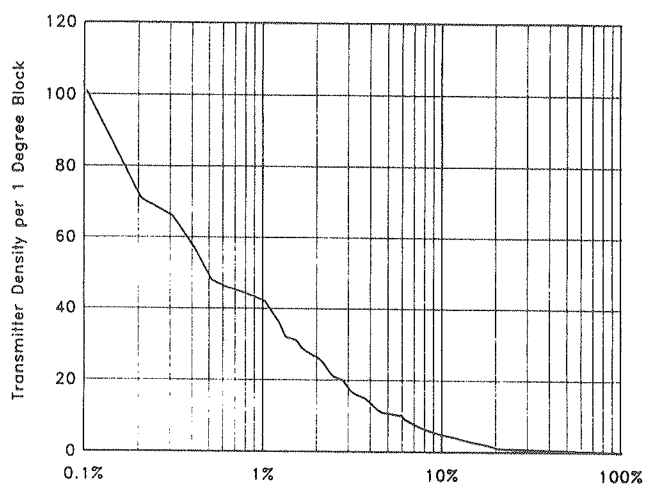

Figure 2.26-2. Percentage of blocks exceeding indicated assignment densities.

Typical users. Typical point-to-point users of this band include a variety of private users with 20-MHz bandwidth. This band is allocated on a primary basis to direct broadcast satellite (DBS) services, and existing microwave users have had only a secondary status since 1988.

Recent trends in number of assignments. Growth in this band over the past five years is shown in Figure 2.26-3. This data shows the number of active microwave assignments. This band has been allocated to broadcasting satellite service (BSS), and point-to-point assignments are allowed only on a non-interfering basis. No BSS assignments have been implemented yet in the US, and the band remains relatively unused.

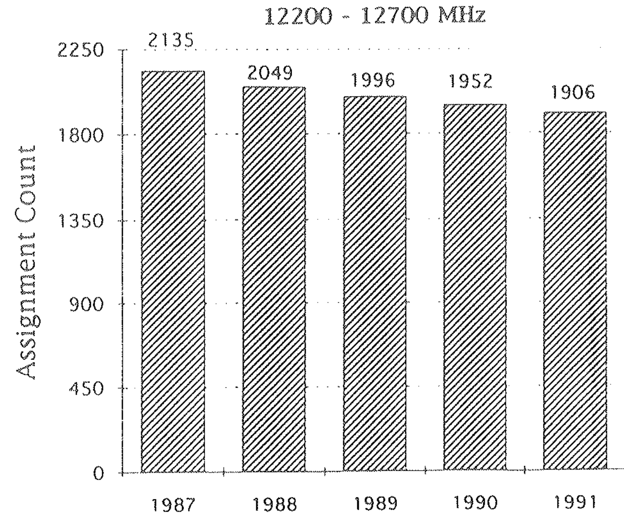

Figure 2.26-3. Number of assignments in the 12.2-12.7 GHz band (1987-1991).

Comments. This band was converted to BSS in 1983, but existing microwave users were 'grandfathered' until 1988, when they became secondary in status. Since there has been no U.S. use of this band for BBS so far, many existing microwave users have been inclined to stay, but not encouraged to upgrade equipment or add new assignments. This situation left many microwave users quite bitter, because many users went to a lot of trouble and expense to move out of the band (and the ones who stayed have been reduced to secondary status), but no BBS operators appeared and wanted to use the vacated spectrum. The history of this band has been recounted often during discussions of the current 2-GHz proposed Emerging Technologies migration.

Considerable recent worldwide interest in broadcast satellites, including HDTV in Japan and digital audio in Europe, may finally cause the BSS services to be offered in this band in the US. Hughes is planning to launch a DBS satellite and expects to begin nationwide DBS service in 1994.

Estimated future growth rate. The number of fixed assignments in this band will continue to decline slowly (3 percent decrease a year) as old equipment is eventually retired. The rate of decline may accelerate rapidly if DBS services are offered in this band, resulting in potential interference situations.

2.27 Usage in the 12.7-13.25 GHz Band
CARS, Auxiliary Broadcasting, Private Operational, Public Services

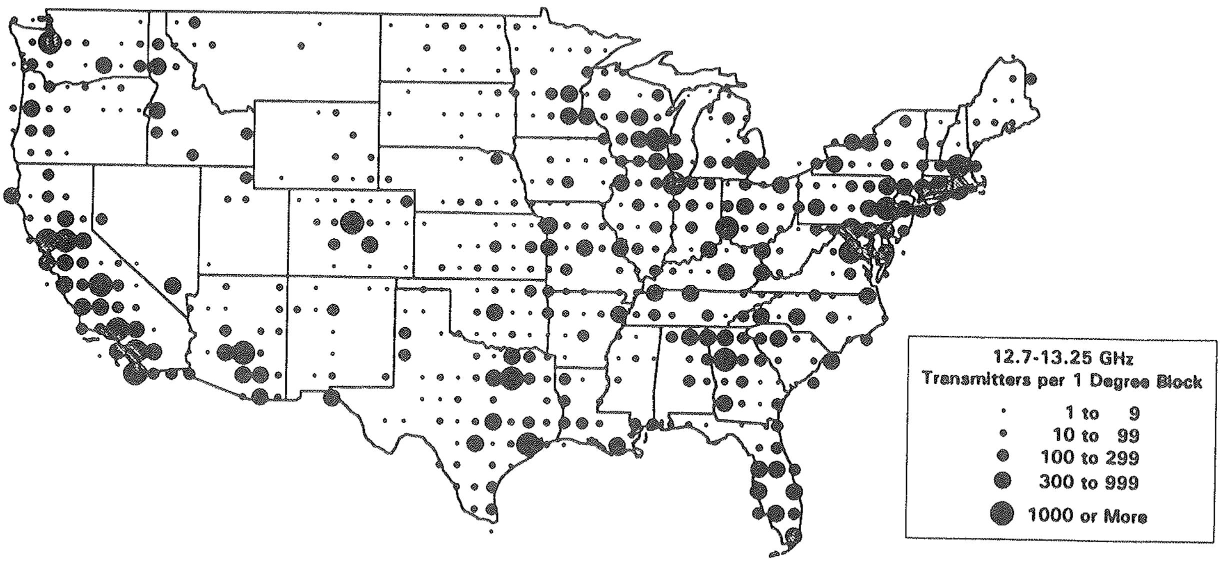

Figure 2.27-1. Density of assignments per square degree in the 12.7-13.25 GHz band.

Table 2.27-1. Statistics for 12.7-13.25 GHz

total US assignments (1991)	107,402
peak assgnmts/1-degree block	3306
effective # of channels	44-90
average US channel re-use	1193-2441
peak re-use/1-degree block	37-75
annual growth rate (last 4 yr)	15.7%
est. annual growth (next 5 yr)	-5.0%

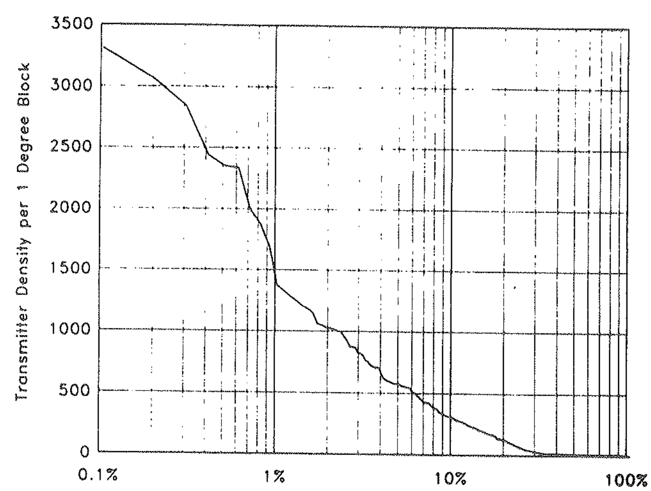

Figure 2.27-2. Percentage of blocks exceeding indicated assignment densities.

Typical users. This band is allocated to Cable Relay Systems (CARS) with four large blocks of 6-MHz-wide channels (32 to 42 channels, depending on the block), some 12.5-MHz channels, and to TV auxiliary broadcasting with 25-MHz channels allocated in two groups offset from each other by 12.5 MHz. Typical users include Cable TV system operators, along with a few TV broadcasters and networks. The major functions include block transmission of NTSC-format TV channels from a central distribution point to a cable head-end site (studio-to-headend link, SHL), studio-to-transmitter links (STL), electronic news gathering (ENG), intercity relay (ICR), and comparable functions by cable and public operators. Public point-to-point stations are allowed in the top 50 MHz of the band.

Recent trend in number of assignments. Growth in this band over the past five years is shown in Figure 2.27-3. The very large number of assignments results partly from the counting of each 6 MHz channel as a separate assignment, even though as many as 80 channels can be transmitted as a single block of frequencies. The whole frequency block could be transmitted from a single distribution point to as many as 15 cable head ends, using a separate SHL point-to-point link for each destination. Thus, as many as 1,200 assignments could be used at a single site. Nevertheless, this band is not only notable for the very large number of assignment, but also because it is growing fairly rapidly.

In addition to the 107,000 CARS and AUXBC assignments, the Comsearch data base showed 38 public and 218 private assignments in the band at the end of 1991. Some of the private operational users migrated to this band when the 12.2- to 12.7-GHz DBS band was cleared out.

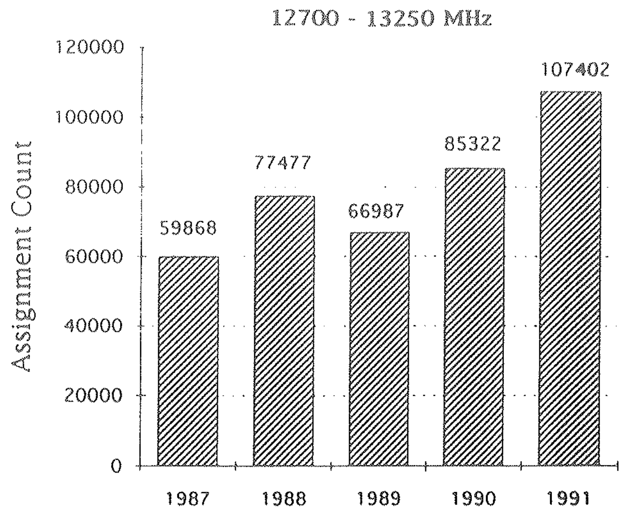

Figure 2.27-3. Number of assignments in the 12.7-13.25 GHz band (1987-1991).

Comments. The CARS assignments are used to transport a block of NTSC TV channels in a format ready for direct downconversion to the cable frequencies (see discussion in Section 3.7). This distribution architecture can use a very large number of assignments in a one-degree block, because every channel in the block counts as an assignment for each direction it is transmitted, permitting hundreds of assignments at a single distribution hub. This constitutes a high degree of frequency re-use, but is actually more like broadcasting the same signal simultaneously in multiple directions, using highly-directional transmitting antennas aimed at multiple cable headend sites.

Optical fiber is beginning to find extensive use in cable network trunks and feeders, and it is reasonable to expect that fiber will be extended towards the hub and begin to replace SHLs, also. An 80-channel link would carry the equivalent to 4,000 Mbits/s, which is far larger than the 500 Mbits/s rule-of-thumb where fiber becomes cheaper than microwave. In addition, the present one-way microwave SHL architecture will not easily support the more advanced two-way digital/video/voice cable systems that are being vigorously developed and tested, greatly limiting the future use of microwave SHL in its present form.

This band allocation was revised in 1988 to include the feeder uplinks for the new AMSC mobile satellite service. The uplink allocation includes the 13.0-13.15 GHz and 13.2-13.25 GHz bands. No satellites have been launched yet using these frequencies. The satellite mobile links will be in L-band.

Estimated future grow rates. Although the growth rate over the last several years has been about 16 percent, this growth will reverse in the next five years, giving a net decline for the five years of 5 percent a year. Optical fiber technology is now being used extensively in cable trunks and feeders and will soon begin replacing some of the microwave headend distribution links. Future cable systems carrying digital information and 2-way services will be incompatible with the current CARS microwave SHL architecture.

2.28 Usage in the 14.5-14.7145 GHz Band
Government Service

Figure 2.28-1. Density of Fixed assignments per square degree in the 14.5-14.7145 GHz band.

Table 2.28-1. Statistics for 14.5-14.7145 GHz

total US assignments (1991)	418
peak assgnmts/1-degree block	8
effective # of channels	9.8
average US channel re-use	43
peak re-use/1-degree block	0.82
annual growth rate (last 4 yr)	3.0%
est. annual growth (next 5 yr)	3%

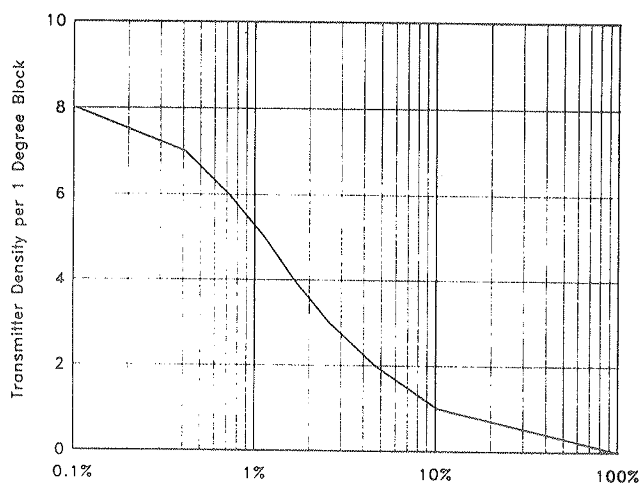

Figure 2.28-2. Percentage of blocks exceeding indicated assignment densities.

Typical users. The 14.5-14.7145 GHz band is allocated exclusively to the Government. The Fixed service is primary, while Mobile, and Space Research allocations are secondary. The band is divided into 84 channels, each of which is 2.5 MHz wide. Adjacent channels can be combined to obtain the required bandwidth. Table 1.5-1 shows the average bandwidth for Fixed users is 22 MHz.

The Air Force has 211 assignments for training, electronic warfare activities, radar microwave links, and radar cross section measurement. Army has 67 assignments for communications between remote sites and central facilities, training, experimental research and test range support. Navy has 25 assignments typically for evaluating shipboard electronics, microwave date links, and in threat simulation. FAA has 91 assignments, which are used mainly in microwave links connected with air traffic control, closed circuit television on runways, and for remote operation of Britescopes. The remaining few assignments, held by civilian agencies, are used for transfer of administrative data, closed circuit television at the DOE Nevada test site, satellite links or supervision and control of an electric power distribution system.

Recent trends in number of assignments. Growth in this band over the past 13 years is shown in Figure 2.28-3. Assignments in the GMF increased from 280 in 1987 to 418 in January 1992. By June of 1992, there were 424, of which 217 were fixed.

Comments. The apparent decrease in assignments between 1981 and 1982 is due to a change in the frequency band limits. At that time, the 14.5- to 15.35-GHz band was split into three subbands. All of the assignments in the earlier large band were put into the lowest frequency subband, resulting in too many assignments in the lowest subband and no assignments in the highest subband (see Section 2.29).

Estimated future growth rate. The present growth rate of three percent is likely to continue into the foreseeable future.

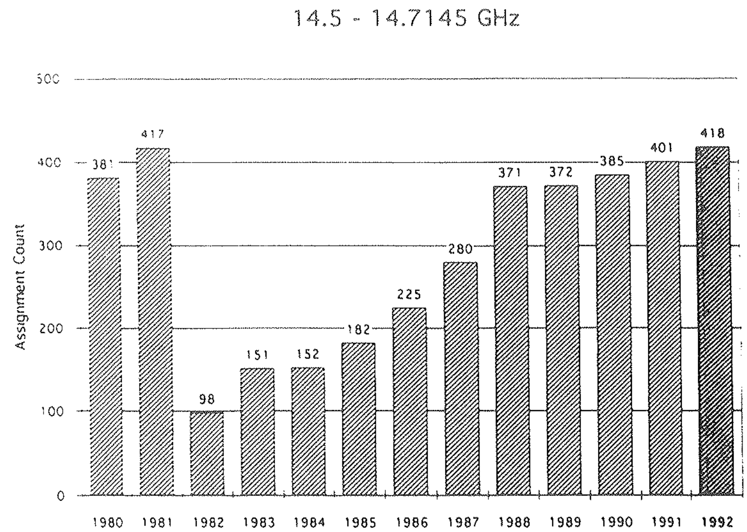

Figure 2.28-3. Number of assignments in the 14.5-14.7145 GHz band (1980-1992).

2.29 Usage in the 15.1365-15.35 GHz Band
Government Service

Figure 2.29-1. Density of Fixed assignments per square degree in the 15.1365-15.35 GHz band.

Table 2.29-1. Statistics for 15.1365-15.35 GHz

total US assignments (1991)	228
peak assgnmts/1-degree block	4
effective # of channels	15
average US channel re-use	15
peak re-use/1-degree block	0.27
annual growth rate (last 4 yr)	3.7%
est. annual growth (next 5 yr)	3%

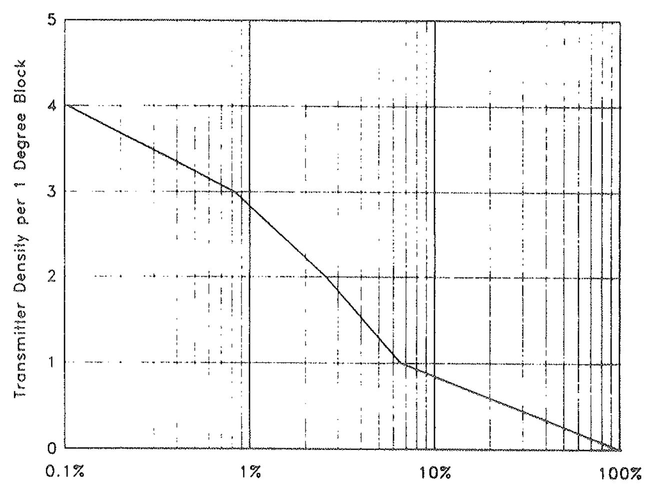

Figure 2.29-2. Percentage of blocks exceeding indicated assignment densities.

Typical users. The 15.1365-15.35 GHz band is allocated exclusively to the Government for primary Fixed Service and secondary Mobile and Space Research. Footnotes protect Radio Astronomy in the band and provide secondary allocations to Passive Earth Exploration Satellite service. The band is divided into 84 channels that are 2.5 MHz wide. Adjacent channels can be combined to obtain the required bandwidth. Table 1.5-1 shows the average bandwidth to be 14 MHz. This band is used for video data links in air traffic control, electronic warfare activities, experimental research, and to transport administrative data.

Air Force has 133 assignments, used mainly for microwave data links and electronic warfare activities. FAA has 69 assignments which are used mostly in Britescope links. NASA has 12 assignments used mainly for satellite uplinks or propagation studies. The remaining assignments are held by five agencies and are used in backbone nets, administration, experimental research, or supervision, control and protection of electric power distribution systems.

Recent trends in number of assignments. Growth in this band over the past 13 years is shown in Figure 2.29-3. Assignments have grown from 125 in 1987 to 228 in January 1992. In June of 1992 the total number of assignments was 242, of which 92 were Fixed.

Comments. The absence in assignments between 1981 and 1982 is due to a change in the frequency band limits. At that time, the 14.5-15.35 GHz band was split into three subbands. All of the assignments in the earlier large band were put into the lowest frequency subband, resulting in too many assignments in the lowest subband (see Section 2.28) and no assignments in this subband.

Estimated future growth rate. We estimate a continued growth of three percent.

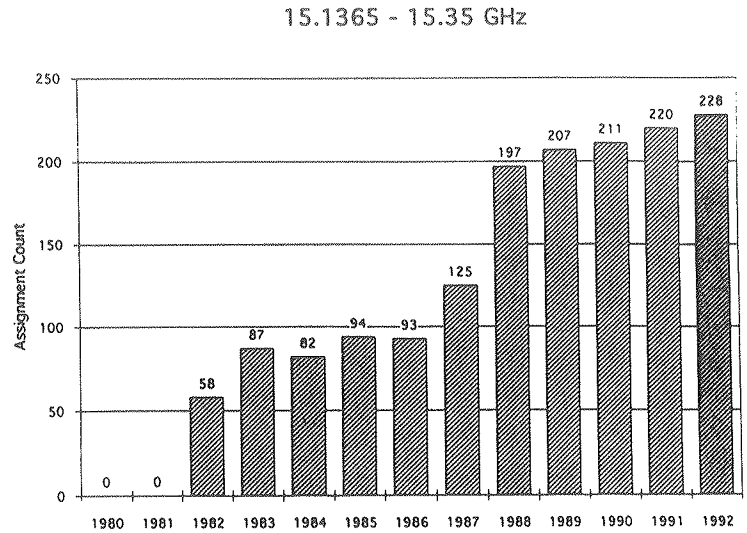

Figure 2.29-3. Number of assignments in the 15.1365-15.35 GHz band (1980-1992).

2.30 Usage in the 17.7-19.7 GHz Band
Auxiliary Broadcasting, CARS, Private Operational, Public Services

Figure 2.30-1. Density of assignments per square degree in the 17.7-19.7 GHz band.

Table 2.30-1. Statistics for 17.7-19.7 GHz

total US assignments (1991)	3833
peak assgnmts/1-degree block	277
effective # of channels	100-200
average US channel re-use	19-39
peak re-use/1-degree block	1.4-2.8
annual growth rate (last 2 yr)	45%
est. annual growth (next 5 yr)	20%

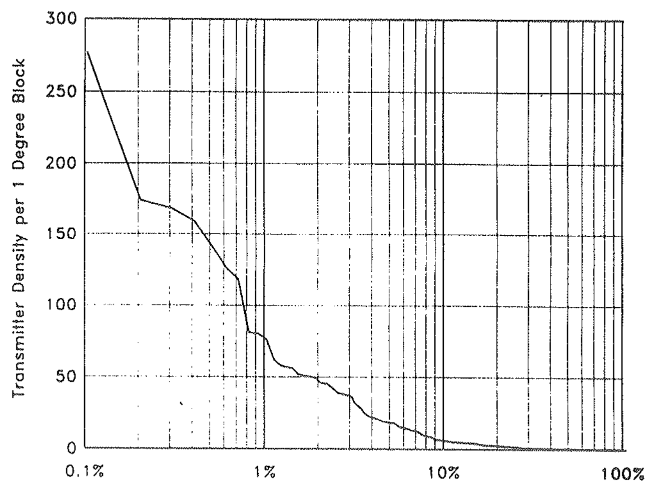

Figure 2.30-2. Percentage of blocks exceeding indicated assignment densities.

Typical users. The "18-GHz" band is a general-purpose point-to-point microwave band, allocated for many types of users sharing the band on a co-equal basis. Bandwidths of 2 MHz, 5 MHz, 6 MHz, 10 MHz, 12.5 MHz, 20 MHz, 40 MHz, 80 MHz, and 220 MHz are available with various channelization plans and various services. Representative numbers of assignments in these services include STL, private, common carrier, CARS, and others. Digital Electronic Message Service (DEMS) and Digital termination service (DTS) are also allowed on several pair of frequencies in the band. The 220-MHz channelization was made for a very wideband microwave system, which was apparently made obsolete by fiber and never deployed in the United States. Other bandwidths allow for CARS transport of blocks of adjacent TV channels, as do the blocks of 6-MHz channelization.

Recent trend in number of assignments. Growth in this band over the past five years is shown in Figure 2.30-3. This band has begun to be used recently, with very rapid growth taking place in both public and private uses. In addition to the 3,833 private and common carrier assignments shown in the bar graph, auxiliary broadcasting has 148 assignments.

Comments. This lightly-used band is recently being exploited, due partly to the recent availability of equipment for this frequency range. In a recent action, Centel asked for four sets of DTS channels to implement wireless local loop connections in 17 US cities.

Direct broadcast satellite (DBS) shares the 17.3- to 17.8-GHz part of this band for uplink functions.

Estimated future growth rate. This band will continue growing at an average rate of 20 percent a year for the next five years. Because of its sensitivity to rain fading, the band will be used mostly for shorter links (less than 20- km).

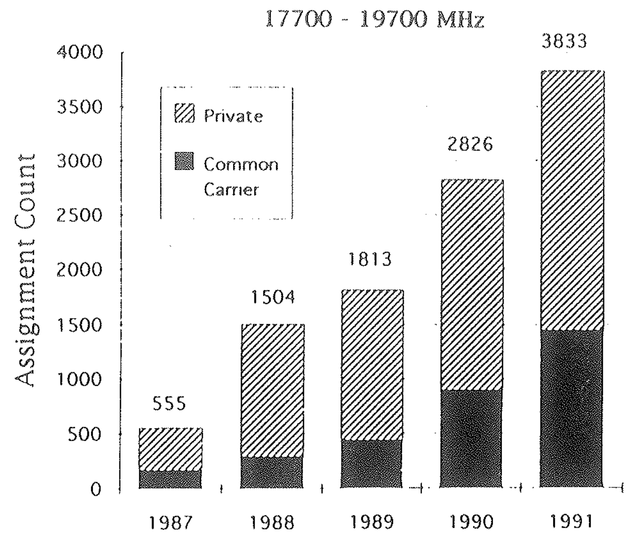

Figure 2.30-3. Number of assignments in the 17.7-19.7 GHz band (1987-1991).

2.31 Usage in the 21.2-23.6 GHz Band
Government, Private Operational, Public Services

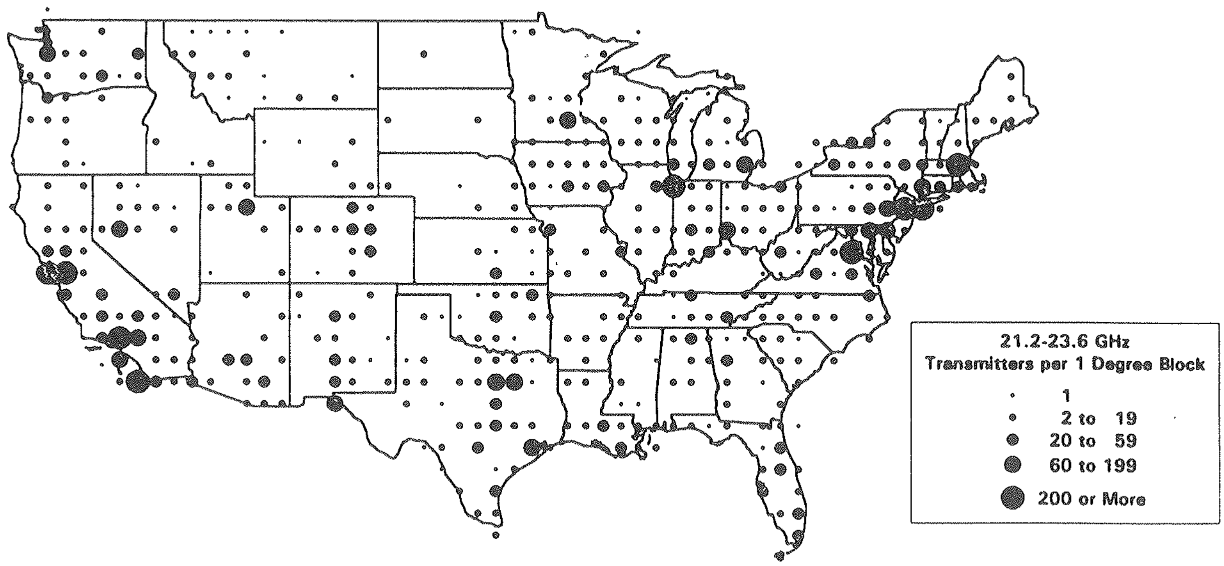

Figure 2.31-1. Density of assignments per square degree in the 21.2-23.6 GHz band.

Table 2.31-1. Statistics for 21.2-23.6 GHz.

total US assignments (1991)	8438[8]
peak assgnmts/1-degree block	390
effective # of channels	24-48
average US channel re-use	176-352
peak re-use/1-degree block	8-16
annual growth rate (last 4 yr)	22.5
est. annual growth (next 5 yr)	9%

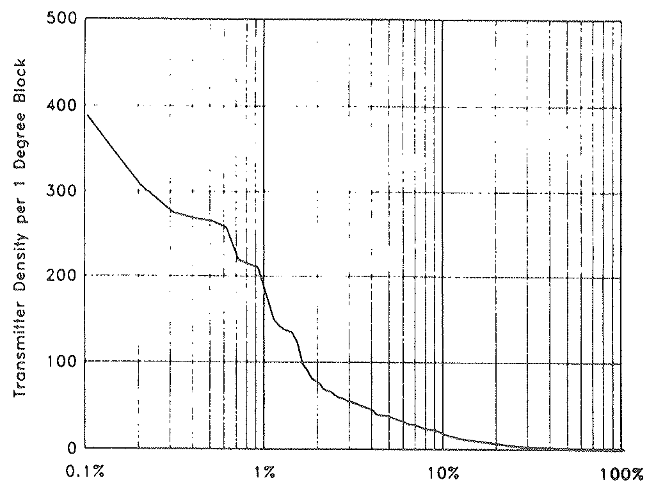

Figure 2.31-2. Percentage of blocks exceeding indicated transmitter densities.

Typical users. The "23 GHz" band is a general-purpose point-to-point band shared by private, public, and Government users. The band is channelized at 50 MHz, with a maximum bandwidth of 100 MHz. Alternate 600-MHz portions are set aside for common carrier and private operational users, with Government use across the entire 2.4 GHz. Typical users of this band include common carrier (492 assignments), private operational (6,666), and

[8]This total comes from the January 1992 GMF database for Government assignments and from the Comsearch database for non-Government assignments.

Government (1,280). The numbers for common carrier and private come from the Dec 31, 1991, Comsearch databases; the Government count comes from the June 1992 GMF.

The major government users include the Navy (317), Army (263), Agriculture (211), and Air Force (200). Government uses include video links for security and safety monitoring, video weather maps and data, and general voice and data applications.

Recent trend in number of assignments. Growth in this band over the past five years is shown in Figure 2.31-3. The rapid 22 percent growth rate of the past four years seems to be following a linear growth pattern (adding 1,000-1,500 assignments per year), and we expect this pattern to continue, giving a slightly lower percentage growth rate in the future.

Comments: This band is one of the newer bands in terms of the availability of popular equipment. At one time this band was hailed as the band that would make possible bypass of the LECs, and huge growth was forecast. This huge growth did not occur, but the band is experiencing healthy growth now. A wide variety of equipment is available, including some fairly inexpensive equipment where the transmitter or receiver is integrated with the antenna. Much of the equipment uses only simple frequency modulation, depending on the wide frequency bandwidth to obtain high data rates, instead of multiple bits per sample. The resulting package is much smaller than many systems operating at lower frequencies, often allowing operation from an office window and eliminating rooftop antenna rent.

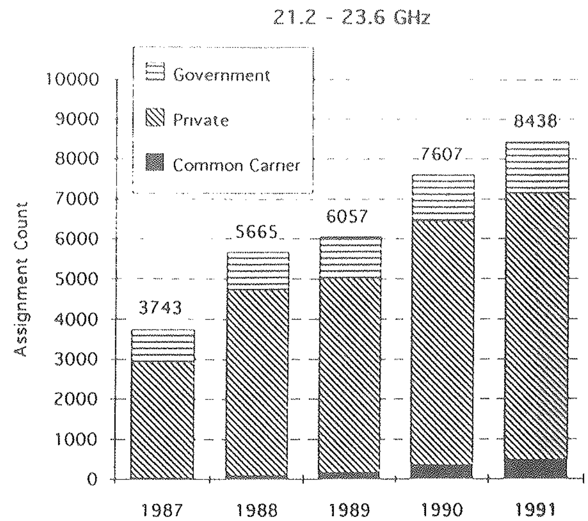

Figure 2.31-3. Number of assignments in the 21.2-23.6 GHz bands (1987-1991).

Estimated future growth rate. Although the huge growth once forecast for this band has not materialized, an average of a 9 percent compounded growth rate is expected for the next five years. This will be widely distributed over a number of short-range services including LEC bypass, ENG and ENG relay, and others.

2.32 Usage in the 25.525-27.5 GHz Band Government Service

Typical users. This Federal Government band is virtually unused, having recently a total of 11 developmental and experimental assignments. The Navy is the major user, testing shipboard electronic systems.

Comments. This band is currently above the threshold of commercial viability, and no commercial systems have been installed in the band.

Estimate of Future Growth. This band will probably grow substantially in the future. However, it is not clear to what services this band will be allocated by the time that growth occurs.

2.33 Usage in the 27.5-29.5 GHz Band Public Service

Typical users. This band is allocated to public (common carrier) microwave service, using bandwidths up to 220 MHz. Out of a total of 53 assignments, 42 are for NASA. The NASA assignments are associated with tests and development of the 28-GHz antennas and systems for the Advanced Communicating Technology Satellite (ACTS).

Recent trend in number of assignments. This band is essentially unused.

Comments. This band was--until recently--higher in frequency than the present state of the art for commercial equipment, and no systems have been moved into this band yet. A recent NPRM[9] proposes using this band for Local Multipoint Distribution Service (LMDS--sometimes called 'cellular cable'}. The NPRM proposes dividing the band into two blocks of 1000 MHz. Each block would allow 50 channels of 20 MHz each, for TV distribution to subscribers who use directional antennas. The NPRM also permits two-way video, data, and voice.

Estimate of future growth. This band will probably be used extensively in the future, as a cellular cable band and possibly as a satellite band.

2.34 Other bands of interest

38 GHz. The 38-GHz band is being mentioned often as a band that will furnish the microwave backbone for future PCS systems. Several manufacturers are already delivering 38-GHz microwave systems in substantial numbers to British companies, who are installing prototype PCS systems linked together using the 38 GHz band. This market has not yet materialized in the US, except for a small number of ENG relays.

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[9]Rulemaking to Amend Part 1 and Part 21 of the Commissions's Rules to Redisignate the 27.5-29.5 GHz Frequency Band and to Establish Rules and Policies for Local Multipoint Distribution Service. CC Docket No. 92-297.

The 38.6-40 GHz band is channelized in 14 pairs of 50-MHz blocks. Permission is granted to use a given pair of 50-MHz blocks over a stated geographical area. It is expected that a user will subdivide the 50-MHz pairs into much smaller channels, suitable for a specific microcell frequency re-use architecture. Users will be responsible for their own internal frequency coordination in the 50-MHz blocks.

We expect extensive use of the 38 GHz band within the next ten years for numerous short-range applications, including PCS.

55 GHz and 58 GHz. This pair of frequency bands has been allocated in the U.K. to serve future PCS and other short-range systems. The 58 GHz band will suffer 15-20 dB/km attenuation, due to oxygen in the air. The 55 GHz band is not affected by oxygen absorption, and the range of signals in this band will be considerably greater. In the U.K., this means that the same equipment can be used in both bands. The 58 GHz band will operate unlicensed, and the 55 GHz band will operate licensed. No such allocation has been made yet in the United States, but the U.K. allocation suggests a constructive way to use some of the peculiar propagation characteristics of the millimeter-wave bands. There is no commercial use of these bands yet.

3. TECHNOLOGY AND MARKET FACTORS

3.1 Introduction

The relative cost and desirability of fixed microwave systems depends on certain technological developments--those relating to the state of the art of microwave systems, as well as those affecting the vigor of its competitors. In the early days of microwave development, a major impediment to the use of microwave systems was the high cost of electronics equipment, especially for the higher frequency bands. More recently, the development of fiber optics has resulted in some applications moving from the microwave bands to fiber optics.

In addition, microwave systems are a part of the infrastructure that must meet the telecommunications needs of a changing society. Technology and other factors are continually modifying the society's telecommunications needs, and fixed microwave systems may find themselves with a larger or smaller set of functions to perform. For example, the rapid deployment of cellular telephone systems is currently causing rapid expansion of microwave systems used to by-pass the local carriers. At the same time, the expansion of the services offered by the wired network has caused many LEC microwave trunk systems to be displaced by higher-capacity fiber systems.

This section describes some of the current technology factors, as well as the changing telecommunications needs. It also speculates on how those factors may change in the near future.

3.2 Optical Fiber

The development of fiber optic technology has provided an almost ideal answer to the need for a non-radio wideband point-to-point transmission media. The bandwidth of the fiber is very great; the current state-of-the-art commercial practice puts up to 2.4 Gbits/s over a fiber. The 2.4 Gbits/s limitation is in the opto-electronics, however, rather than in the fiber. The infra-red carrier frequency used in optical fiber is around 10^{14} Hz. Assuming a usable bandwidth of 10 percent of center frequency and a 2-GHz signal bandwidth, this would provide enough bandwidth for 5,000 such signals on each fiber. Commercial systems using optical band-splitting techniques have combined three separate signals in a fiber. Experimental techniques using optical heterodyning have the potential to put dozens or hundreds of signals on a single fiber.

In the meantime, developments are proceeding vigorously to increase the bandwidth of opto-electronic components. The historical trend of 15 percent per year improvement in modulation rate is expected to continue. Since the improved modulators can be incorporated without replacing the existing optical fiber, such increases in performance can be applied to many systems which are already in place.

Losses in single-mode commercial quartz fiber are currently about 0.3 dB/km. Compared to more traditional coaxial cable technologies, fiber has several orders of magnitude of advantages. Loss for a coaxial cable used in cable TV, for example, is in the range of 50 dB/km for a signal at 800 MHz. This means that coaxial cable has 150 (expressed in dB) times greater losses than fiber, even at the much lower information bandwidth of 800 MHz. This means that for any given amount of loss, one could span a distance 150 times as far with optical fiber as with coaxial cable. There will be some minor additional improvement in the loss and dispersion characteristics of single-mode quartz fibers. Experimental halide-based media can theoretically provide much lower loss than quartz, but these materials have proved difficult to fabricate into useful fiber.

Although we do not expect great improvement in the fiber characteristics in the next five years, there will be major changes in the components used with the fiber. These include wider-bandwidth modulator technology, optical switching technology, optical amplifiers, and the use of soliton modulation.

The recent development of optical amplifiers will allow significant improvements in the way that fiber is used. Amplifiers can replace the very elaborate opto-electronic regenerators that are now needed every few tens of kilometers along a long-distance fiber path. The regeneration involves conversion of a weak optical signal into a weak electrical signal, which is amplified and processed to modulate a laser, which injects a strong copy of the original signal into the next section of fiber. The next generation of long distance fibers will use optical amplifiers that amplify the signal directly, without conversion to electrical signal.

Optical amplifiers will do more than merely provide a much cheaper substitute for regeneration. A regenerator is dependent on the bit rate and other modulation characteristics of the signal. Going to a higher bit rate on a transcontinental line would require changing all of the regenerators along that line. Since optical amplifiers do not depend on the modulation characteristics of the signal, an amplified fiber cable could handle future improvements, e.g., higher bit rate, without modification. Optical amplifiers will permit more flexible and elaborate network topologies, using amplifiers to overcome losses from power splitters and combiners and optical switches. Optical amplifiers can also be used to boost a very low level signal to a level where it can be successfully detected, thus allowing an increase in the maximum passive fiber span.

The use of 'soliton' techniques employs special optical pulse shapes that hang together without changing shape (dispersion). Thus, dispersion of the pulse does not occur, and wider bandwidths can be achieved over longer distances. Soliton modulation will be particularly important when amplifiers replace regenerators, since signal dispersion will gradually accumulate over successive fiber/amplifier stages, even though amplifiers maintain adequate signal amplitude. Soliton research is still in the laboratory phase, but Bell Labs has demonstrated soliton/amplifier combinations with 10-Gbit/s data rates over 11,000 km of fiber.[10] One application where such technology will be particularly useful is in under-sea cables. In this case, optical amplifiers and soliton modulation will allow undersea cables to be built without regenerators, which will simultaneously decrease the cost, increase the capacity, and improve the reliability of such cables.

In most fiber applications, however, the existing fiber transmission qualities already are sufficient to meet the needs of the market. Improvements to fiber technology, welcome as they are, will cause only incremental improvements in the general use of fiber. The 70- to 100-km range with existing fiber is generally sufficient for any application in a metropolitan area.

Technological improvements are greatly needed, however, in the fields of switching, routing, and signal-processing on optical fiber. Switching optical signals from one path to another, for example, like signal regeneration, is currently done by converting the optical signal to an electrical signal, switching the electrical signal, then converting it back to an optical signal. The ability to directly switch optical signals would provide much simpler signal control and processing. Opto-electronics components that can function as multi-position switches or even cross-bar relays, frequency-selective tuners and bandpass filters, amplifiers, and wider-bandwidth modulator/demodulators will be needed to decrease the cost of optical switching and processing in the central office.

When such technical developments are available, the cost of providing wideband communications (or even switched dark fiber connections) over the switched network will be greatly reduced. When the cost drops drastically, there should be a widespread increase in the amount of broadband fiber throughout metropolitan areas, which could replace many fixed microwave applications. Temporary or intermittent wideband requirements, such as TV coverage of a football game, a full-bandwidth video conference, or intermittent connections between large computers could be accomplished much more cheaply and routinely. Possibly most important of all, improved switching technologies could lead to very robust optical networks, fully utilizing extensive route diversity and network fault sensing. This would make fiber networks more acceptable as high-reliability replacements for microwave systems.

As impressive as the present and future technical fiber capabilities are, however, some very simple non-technical problems prevent much greater use of fiber. The major single impediment to the use of fiber is the cost of installing it--including right-of-way permission and the work involved in burial. Since a single bare fiber costs around $125 per km ($200 per mile), the rule-of-thumb costs of $25,000 per km ($40,000 per mile) for a buried fiber cable shows where the real problem lies. Probably the second-greatest disadvantage of fiber is the ease with which it is accidently broken. The dreaded phenomenon of "backhoe fading" causes fiber to be seen as an inherently less reliable path compared to microwave. Redundant path topologies are considered mandatory for many fiber applications. Until these problems are solved, there will be market resistance to using fiber for greatly expanded uses.

There are partial cures for these problems. In Los Angeles, for example, the cellular companies have become members of the Joint Pole Commission. This allows them to place fiber on 'telephone' poles, a much cheaper and faster way of installing fiber. As fiber becomes much more universal, the vulnerability to being broken may be partially overcome by redundancy using many heavily-parallelled paths. However, the mere existence of many alternative fiber paths is not particularly useful without

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[10] Photonics, March 1992, page 42.

efficient means of switching between fiber paths and diverting appropriate parts of the signal on a fiber to an alternative path.

Overall, the future seems very promising for increased use of optical fiber, even if systems were limited by today's technology. Improvements in fiber and optical processing technology will only increase the rate of fiber utilization and the relative shift from microwave systems to fiber. Nevertheless, microwave systems will remain the best answer for many present and future communication needs.

3.3 Optical Fiber vs. Microwaves

Optical fiber and microwave are two greatly different technologies, each of which can be used to carry signals from one location to another for telecommunications purposes. They perform this function in such different ways, however, that they should be considered to be genuinely complementary solutions to the telecommunications problem. There are some situations which can only be solved using optical fiber; other situations can only be solved with microwaves. There are a significant number of situations, however, where either technology can efficiently provide service. In this 'overlap area' there is the possibility of migration from one technology to the other, depending on various current relative economic, technical, and policy factors. Before we can hope to pin down the details of the 'migration', we need to look at some of the differences between fiber and microwave, since these differences will define the areas where their services do <u>not</u> overlap.

Pathway/media considerations. Microwave is a radio-based medium. It travels through the air, without benefit of or need for the real estate between the transmitter and receiver. In fact, the intervening terrain can assume only a negative factor in the design of a microwave system; microwave systems are designed so that 'free space' propagation conditions are achieved in a microwave path. Although highly-directive antennas are usually employed on both ends of the microwave path for important practical reasons, this does not mean that the terrain under the microwave path is important (except to stay out of the way). The path is defined only by the end points.

The implications of a communications path being defined only by the end points include

1. The path can be changed merely by moving one of the end points - allowing mobile systems or temporary systems.
2. The path can span obstacles, such as canyons, rivers, uncooperative landowners, right-of-way agreements, etc.
3. Only two small parcels of real estate need to be controlled (receiver and transmitter sites)
4. The cost of a link is independent of length of path, for paths that can be met with one hop.

The implications of a communications path being a radio path include

1. The airwaves are shared. Privacy is not ensured, and interference is possible.
2. Weather conditions (particularly rainstorms) may block the signal.
3. A license is needed to operate. Frequencies may not be available.
4. A license limits user to particular signal parameters, bandwidth, user applications.
5. Usually limited to line-of-sight outdoor paths, using large antennas.
6. The cost of the link is somewhat proportional to bandwidth.

Optical fibers do not depend on radio waves, but they require a real, continuous path between the transmitting point and the receiving point. An optical fiber path is defined by every point between the ends. A coaxial cable or other hardwired path will have similar qualities. Implications of a hardwired communications path include

1. The path is defined by every point on the path.
2. A single point of disruption anywhere on path (e.g., a backhoe) can destroy the link.
3. Right-of-way agreements are crucial. A single landowner can stop the link.
4. Burial is very expensive. Cost of a link is proportional to length.
5. Large construction time and expense are needed before path becomes operational.
6. Location of path is fixed.

Since the optical fiber path is not a radio link:

1. No frequency permits are needed.
2. There are few limitations on bandwidth, multiple fibers, or type of communications
3. The cost of path is independent of bandwidth.
4. Privacy is ensured; there is no interference.
5. Small cross-section path can be underground, inside a building, etc.

As can be seen from the above lists, there are major differences in the services that can be provided by fiber optical and microwave. The present use of microwave and fiber reflects many of those differences.

Deployment. Microwave terminals can be moved, installed, and operated quite rapidly. Electronic news gathering (ENG), for example, uses transportable microwave terminals that can be driven to a location of interest and operated to relay TV coverage back to the local studio. Satellite news gathering (SNG) is similar, but relays the video via a satellite, providing network coverage. These mobile and temporary functions depend on the ability to change position to provide coverage in temporary and changing locations. On the other hand, some of this role could be replaced by fiber, since there are many locations that are served repeatedly and predictably by ENG and SNG. These locations (such as sports stadiums, selected Government buildings, airports, etc.) could be permanently wired with fiber for coverage of the expected events.

The military uses microwave (and satellite) links with transportable terminals in many operational modes. These involve being able to rapidly move entire communications networks to unimproved foreign sites and setting up complex operational networks within a few days. These portable links may be moved often, as the tactical or strategic situation changes. A large portion of the military inventory of microwave equipment is specifically intended for this purpose, with a great emphasis on speed of establishing a new communications network.

Many microwave links have recently been installed to service cellular telephone sites. The choice of microwave is dictated by the pressure to have sites rapidly become operational, to by-pass the LEC for revenue and operational reasons, and because the cellular networks typically require far fewer telephone circuits than a central office.

Local exchange carriers, on the other hand, not only have a relatively permanent plant configuration, but also have historically been left holding a large number of old underground conduits, telephone poles, and right-of-way authorities. Thus, the placement of fiber optic cable has been far more practical for the LECs, and they have been very active in the use of fiber instead of microwave.

Capacity. Connections between telephone central offices, which carry tens-of-thousands of telephone calls, have been largely converted to fiber. The required frequencies and bandwidths would simply not have been available in the heart of a city. Whereas a single 20- to 30-MHz bandwidth high-capacity microwave link might carry as many as three DS-3 channels (135 Mbits/s total), a single fiber can be modulated to carry more than 50 DS-3 links (2400 Mbits/s). As many as 144 individual fibers are buried in a fiber cable, providing capacities which are--practically speaking--infinite.

In addition, some large cities provide the opportunity for alternative carriers to share conduit space, which decreases the large initial cost of installing the first fiber. Alternative fiber suppliers are currently quite small, but they are growing rapidly (almost doubling in route miles each year), and they are expected to place substantial competitive pressure on the LECs to supply installed fiber on an inexpensive basis. Most IXCs (inter-exchange carriers, or long distance phone companies) have switched to fiber, because of the need for high-capacity digital circuits for telephone and other applications.

Technological improvements will continue to raise the capacity of an individual fiber; increases of another factor of ten are quite foreseeable. Microwave links can increase capacity by increasing the number of links in use, but the ability to increase the capacity of a single link by increasing the number of bits per sample (incorporating modulations higher than the current 512-QAM, for example) seem to be reaching the limit of feasible technology and will probably not improve much more.

Reliability. Microwave links suffer from occasional outages due to multipath fading, heavy rainstorms (only for frequencies above 10-GHz), and equipment malfunction. These events seem to be statistically predictable, and they can be compensated for in the design of the link. Fiber optics suffers from cable breaks--due mostly to backhoes, but with some assistance from gophers and earthquakes. A rule-of-thumb is that a break occurs once a year for every 500 km of fiber.

Most fiber users must obtain a redundant link to protect against loss of service due to fiber cuts. A ring structure is quite efficient at providing the needed redundancy, and many fiber suppliers are beginning to provide ring architectures to customers. Needless to say, if getting one fiber route to a customer is difficult and expensive, getting two independent fiber routes to the same customer is even harder. However, as more fiber (and more independent fiber suppliers) becomes available in metropolitan areas, the difficulty in finding fiber backup capabilities should become easier and less costly. The development of techniques for easy optical switching should also make it much easier to exploit the presence of alternative fiber suppliers and pathways.

Many customers are currently using microwaves to back up a portion of their traffic. Although it may be too expensive to back up all of the capability available in fiber, microwave redundancy can be used to back up the part of the traffic that really needs to get through. The solution for fiber reliability will probably include several overlapping fiber coverages by various suppliers, and possibly some assistance from microwave and satellite. This is a national problem whose solutions have not yet been fully explored.

Cost. Based on many of the previously stated factors, there are strong patterns to the relative cost of providing microwave and fiber communications. Figure 3.3-1 and Table 3.3-1 show the relative cost of an 80-mile circuit requiring three microwave hops or one fiber repeater site. The table extends the data from the original figure to include a larger number of DS-3 links, based on the same cost information as the figure. The fiber system was based on buried fiber cost of $8 per foot. Though the cost was estimated for an actual 80-mile system in the north-western US, the numbers are representative of many locations in the US. Note that a single DS-3 link is equivalent to one TV channel or 762 voice circuits. A single optical fiber can currently carry up to 48 DS-3 circuits.

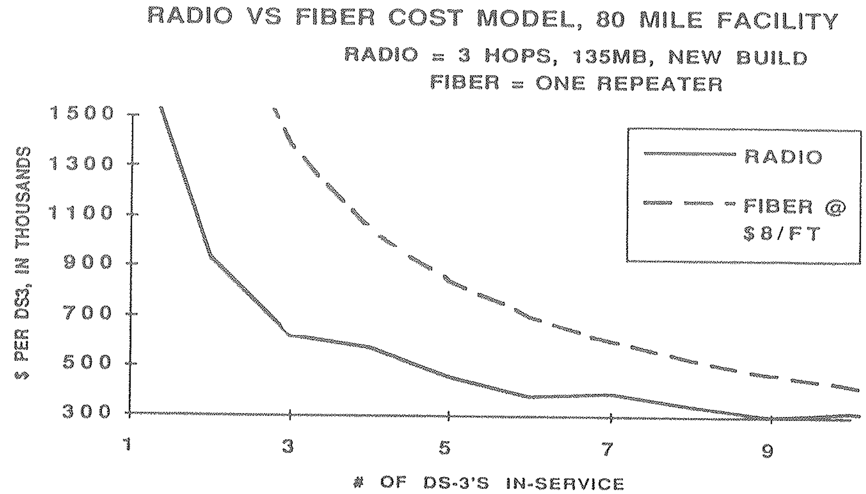

Figure 3.3-1. Comparison of microwave vs fiber cost for 80-mile circuit.

The relative costs show why microwave is often chosen for routes with less dense traffic and fiber is selected for denser routes[11].

Table 3.3-1. Construction Cost per DS-3 Link, 80 miles, Oregon. (in $1000's)

# of DS-3 links	1	2	3	6	12	24	36	60	96
microwave	1890	945	630	450	260	203	183	168	160
fiber optics	4410	2205	1470	735	367	195	138	88	67

The cost of optical components tends to be very high, with individual optical amplifiers, laser modulators, optical switches, etc. often costing $25,000 to $50,000 apiece. This cost could decrease rapidly (by a factor of 10) with economies of scale and improved technology. As the cost of these items decreases, the cost of placing fiber in the ground will become increasingly important, and this cost is not likely to change dramatically. Similarly, the rental cost of rooftop space for a microwave antenna is said to be as much as $1500/month in New York City. Thus, major portions of the cost of both systems are due to non-technology factors which are not subject to improvement by technological advances.

Summary. Various industry rules-of-thumb which have been suggested to decide between the use of fiber or microwave include

1. "If fiber is already available on site, use it."

2. "When fiber is not already available, use fiber for applications greater than 800-Mbits/s; use microwave for applications less than 500-Mbits/s."

[11] Wand, David. "Proactively surviving fiber fever". US West Communications. National Wireless/radio engineers conference. June 1992.

3. "Put in fiber if the cost is not greater than 150 percent the cost of microwave (because of the ease of expansion into future requirements with fiber)."

4. "Always use widely separated redundant paths (possibly a ring structure) for fiber; use redundant paths (at least a hot back-up channel) for microwave. Plan on one fiber cut/year/500 km of fiber."

These rules-of-thumb are only a rough starting point, which could be greatly influenced by particular circumstances. Factors such as limited frequency availability, difficult terrain or landowner, existing fiber nearby, etc., could be more important in many situations than the rules-of thumb. Although a single factor may be of overwhelming importance, usually decisions are made on a basis of total costs from a large number of factors.

3.4 Microwave Band Crowding

Although we have obtained much information on the number of assignments, including trends over many years and the density of assignments in 1-degree blocks, we have very little "hard" information on which (if any) bands are crowded. One frequency coordinator said that "a band is crowded when you can't figure how to get the next new link to fit into the band, but that a good frequency coordinator can always figure an angle, somehow." On the other hand, all of the bands seem to be crowded if you ask which bands might give up a little spectrum to some other service. Nevertheless, understanding whether a band is crowded is much more than a matter of designing the right survey question, since it is at the heart of deciding how much spectrum is needed for various services. We will consider a band to be crowded if the existing radio systems (either similar to or different from the system in question) make it substantially more expensive or more difficult to place a new system in the band.

Channel re-use. One place to start on the crowding question is to consider a heavily used band (e.g. the 3700-4200 MHz band), employing that band as an example of how many signals can reasonably be assigned. The 3700-4200 MHz band is channelized in 20-MHz segments, giving a total of 25 channels. The number of assignments reached a peak of about 39,000 in 1988, implying that each channel was re-used an average of 1,560 times. The channel re-use factor for this band may be close to the maximum, since this band was extensively used to move signals between cities, as well as inside cities, which geographically spreads out the links and makes them less likely to interfere with each other. In addition, these links were mostly planned in a coordinated, long-term manner by the pre-divestiture telephone system, using antennas and transmitters with excellent technical characteristics.

We can examine other bands to see how many times a channel was re-used. In many cases, this is not easy to calculate, since the bands contain mixed channelization bandwidths, and we did not obtain information on the bandwidth of the assignments. Nevertheless, in some cases, it is still meaningful to calculate some bounds on the channel re-use. Table 3.4-1 contains information on selected bands where we have sufficient information to make a useful estimation of channel re-use.

Table 3.4-1. Channel Re-use Factors for Various Bands

Frequency band (MHz) (G=GHz)	Channel bandwidth (MHz)	# of channels	# of assigns	U.S. re-use factor	Peak re-use per sq. degree	Comments
928-953	.012, .025	80-160	6329	40-79	0.8-1.6	MAS
1700-1850	Av 3.8	39.5	6114	150	1.7	Govt
1850-1990	5, 10	24	9358	386	3.5	private opn
1990-2110	17	7	1536	219	13.6	Auxbc video
2110-2180	3.2, 3.6	10-12	6329	527-633	5.5-6.6	public
2130-2200	0.8, 1.6	24-48	13,455	280-561	3.1-6.3	private opn
3700-4200	20	25	39,028	1561	13.7	AT&T
4400-4990	8	74	1582	21	0.68	transportable
5925-6425	30	16-20	27,541	1377-1721	18-23	RBOCs
6525-6875	0.8,1.6,5,10	40-76	16,577	218-414	3.7-7.0	private opn
6875-7125	25	10	2607	261	7.4	Auxbc video
7125-8500	Av 20	68	10,034	148	1.8	Govt
10.5-10.7 G	1.25,2.5,3.75	8-16	893	56-111	4.7-9.4	public, priv.
10.7-11.7 G	20, 40	24-48	9081	189-378	8.6-17.2	RBOCs
12.7-13.2 G	6, 12.5, 25	44-90	107402	1193-2441	37-75	CARS video
14.5-14.7 G	2.5 x n	9.8	418	43	0.82	Govt
15.1-15.3 G	2.5 x n	15	228	15	0.27	Govt
17.7-19.7 G	5-220 MHz	100-200	3833	20-40	1.4-2.8	priv,pub,auxbc
21.2-23.6 G	50, 100	24-48	8438	176-352	8-16	Mixed

As shown in the table above, channel re-use factors in the range of 1500-2000 have been achieved in several bands. Since this is five to ten times greater than the re-use factors in many of the bands, it would seem to suggest that many bands are using only 10 to 20 percent of the capacity in the band and have much room left for future growth.

Peak re-use in a 1-degree x 1-degree block. The above argument greatly oversimplifies the problem of band crowding. One crucial factor is the geographical distribution of systems. If the systems are used only in urban areas, for example, the total number of assignments may be limited by severe crowding in urban areas, while vast areas of the rural countryside remain mostly empty. Because various bands have different patterns of geographical use, the maximum density of assignments in a given geographical area may be a better measure of band crowding. Since the maximum number of assignments possible in a given area will be proportional to the number of assignable channels, the peak assignment density has been divided by the number of channels, to give a number representing the maximum number of times that a typical channel was re-used in a 1-degree x 1-degree block. The sixth column of Table 3.4-1 shows the peak re-use (the greatest number of times that an average channel was re-used in any 1-degree x 1-degree block) for each of the bands. Again, since there is sometimes uncertainty about how to count the number of channels in a band (leading to a range of values for the number of channels), there will be a range of values in the computed maximum 1-degree re-use factor.

The highest peak re-use per block is 37 to 75 in the 12.7-13.25 GHz CARS band, where large blocks of TV channels are transmitted to multiple cable headends. The RBOCs and AT&T show peak re-use per block in the 10 to 23 range in the 4 GHz, 6 GHz and 11 GHz bands. Since the use of these bands has fallen recently, we have used the higher numbers from the recent past. These bands have the advantage of being mostly planned by a single entity, using excellent equipment and planning techniques. In the remainder of non-Government bands, the typical peak re-use per block is 5-7.

The Government bands seem to have a much lower peak re-use per block, which should be viewed in light of some important differences between Government and commercial services. In general, Government Fixed-service bands are much less homogeneous than corresponding non-Government bands. The bands identified here as Fixed often are shared with sizable numbers of various special-purpose, non-Fixed, high-priority systems. The wide variety of these non-Fixed systems not only require a substantial amount of spectrum, but they also make it more difficult to develop an efficient channelization and sharing strategy for the Fixed systems. In addition, many Government Fixed frequency assignments tend to be "hidden"--either because they are not extensively used in peacetime, because multiple copies of most transportable systems are not individually assigned, or because they are classified. Finally, the need to rapidly and successfully deploy large numbers of transportable microwave links requires considerable "slack" in the frequency-sharing process, since assignments may be made under considerable haste, with incomplete and changing data, and the need to meet contingencies (such as attrition and continuous re-configuration). Battlefield conditions may add many constraints not present with commercial systems, in addition to making it extremely important that the system perform its intended function.

When an estimate of band crowding is based on peak re-use, it can be seen that the maximum re-use in the most highly re-used bands (not counting the 12.7-13.25 GHz band) are about 12-23, which is 2 to 4 times the peak re-use in many of the remaining bands. This suggests that more of the microwave bands are closer to their maximum achievable density (in urban areas) than in the country at large. It may show that users have filled the most-preferred bands to a comfortable density, and then changed bands and continued filling the less-desired bands. It is not known whether the different peak re-use achieved by the RBOCs and AT&T is the result of more demand or better frequency management and system design. In any case, it suggests that most of the microwave bands have considerable capacity remaining, even in the most crowded areas.

If all microwave bands were filled to capacity, one would expect greater channel re-use factors in the higher frequency bands, where smaller antenna beamwidths are practical and where operational distances are less. The relative lack of assignments in the higher bands must, presumably, show the effect of other factors like more expensive equipment, less desirable operating characteristics, less desirable frequency allocation factors, or less historical equipment availability. Equipment availability is surely a major factor for bands above 23 GHz, where essentially no assignments have been made.

Urban communications density threshold. Since fiber is more economical than microwave when a large amount of communications is required (see Table 4.3-1, above), very high concentrations of microwave are not likely to occur. Whenever a certain 'communications density threshold' is exceeded, it will become cheaper to use fiber than microwave. The fiber entrepreneurs will be attracted to the region, construct a fiber network, and start moving communications on to fiber. When the threshold is applied to a single new link, a rule-of-thumb is to choose fiber when the required capacity is more than 500-800 Mbits/s. Usually, the threshold criterion will not be applied to a single link, however, because the fiber will eventually serve much more than that link. The threshold being discussed here is a cumulative geographical concentration of perceived present and future communications requirements (possibly 10 Gbits/sec in a 5-km-diameter circle); it would be more visible to an investor than an engineer. (This is a fuzzy threshold, and local circumstances may grossly distort its application, but the concept is still useful).

This scenario also suggests how microwave systems will be distributed geographically. Although the greatest density of communications is near the center of urban areas, these high concentrations of population and commerce will also be most completely served by optical fiber. The suburban areas will have less need for communications, but will be less completely served by fiber. The rural locations may have little need for communications, but almost no fiber.

From a spectrum management viewpoint, it is not necessary to provide more microwave spectrum (or perhaps several times more, just to be on the safe side) than is needed to support the microwave concentration corresponding to the 'communications density threshold'. This concept describes a fortuitous set of circumstances, since it says that economic considerations will cause communication systems to be implemented in fiber in exactly those circumstances where severe crowding would otherwise demand additional microwave spectrum.

There are two independent factors that affect the division between microwave and fiber. One is the amount of geographical area already served by fiber (where we believe that microwave will often not be economical). The area served by fiber is continually increasing; thus, microwave is being continually excluded from a larger geographical area. The second factor is the actual value of the 'communications density threshold' discussed in preceding paragraphs. Since this threshold is determined chiefly by the ratio of fiber and microwave costs--both of which are decreasing--it is difficult to determine whether the threshold is increasing or decreasing. This is particularly uncertain because, although fiber technology is rapidly decreasing in cost, the major cost of fiber currently seems to be the cost of burial or other installation. The installation cost does not seem as likely to be greatly influenced by advancing technology as by policy and legal matters. On the other hand, the general level of telecommunications used in U.S. society seems to be increasing rapidly, so more geographical areas seem likely to exceed the threshold.

Protection criteria. Most bands have well-defined rules for deciding whether a new system can be placed in the band without causing interference to or receiving interference from the systems already in the band. These rules involve parameters describing frequency separation, spatial separation, antenna patterns and gain, transmitter power, emission bandwidth, shielding from buildings and terrain, etc. The rules describe calculations using these technical parameters to determine theoretically whether interference will result. Because some aspects of nature are neither constant nor easy to describe precisely, it is necessary to add some "margin of error" (often called "link margin" or "fade margin") to these calculations. This margin is designed to allow the system to operate even under the worst weather conditions, the worst multipath situation, the worst equipment degradation, and the worst amount of interference. Cumulatively, these factors are called "protection criteria" and they often total 40 to 60 dB beyond what the typical operating circumstances of the equipment require.

A new assignment must meet all of the conditions implied by the rules, including the 40 to 60 dB of protection criteria. If the protection criteria are very large, they force a very conservative assignment strategy and limit the number of assignments that can be made in a band. Therefore, the values designated for these protection criteria can be a factor in preventing additional assignments in bands that do not appear to be crowded. Protection criteria are needed to meet real changes in propagation conditions and variation in equipment operating characteristics; if the values are set too low, systems will experience unreliable operation. Therefore, the question is whether these criteria are set at values that best balance the goals of efficient band utilization and reliable system operation.

The arguments for setting lower values include a general advancement in our knowledge of how to design robust systems. Frequency management databases and propagation and electromagnetic compatibility models are getting better. This provides considerably less uncertainty in the results of performance prediction models, thus requiring a smaller part of the fade margin to allow for errors in the prediction process. In addition, receiver manufacturers have learned more about the use of adaptive equalizers and diversity antennas to handle multipath. Digital systems can use error-correction techniques to achieve very reliable operation without the brute-force signal-to-interference ratios needed by analog systems. Improved antennas provide better rejection of interference through the sidelobes or backlobes of the antenna. Altogether, these advancements may provide the opportunity to re-evaluate the required fade margins, and possibly set them at lower values, allowing more systems to be assigned in a given band.

Future studies. The microwave industry has few tools to decide objectively and quantitatively whether a given band is crowded or not, i.e., whether a shortage of spectrum in that band has substantially increased the cost of adding new assignments. It would be very useful to determine specific measures of band crowding and to determine the relative cost of implementing a system in bands with various levels of crowding. Ideally, proper studies would allow the cost of band crowding to be quantified, so that economic judgements could be undertaken in deciding which services needed more or less spectrum. For example, it would be important to know whether decreasing the amount of microwave spectrum by 20 - percent would result in substantially higher costs for microwave service, or whether it would only make a small increase in engineering costs and initial equipment costs. Similarly, it would be important to know whether a change in protection criteria would result in lower costs and more spectrum availability, or higher long term costs caused by degraded system performance and interference.

3.5 Microwave Technology

Advances in microwave technology will make point-to-point microwave a more flexible and more economical means of supplying communication, at the same time that improvements in fiber technology make fiber more competitive. In the next few years, continued changes in microwave technology will include:

1. Improved higher frequency gallium arsenide (GaAs) RF transistors, monolithic microwave integrated circuits (MMIC)s, and other components, leading to cheaper and better receivers, especially at the higher frequency bands (18 GHz, 23 GHz, and 38 GHz).

2. Innovative packaging and electronic architecture, which will decrease the size and complexity of microwave systems.

3. Improved digital control and monitoring of microwave systems. This includes many self-calibrating and self-monitoring features, flexible and convenient compatibility with common-carrier digital standards, and smaller, cheaper, and more reliable equipment.

4. Improved multi-level digital modulation, which packs higher digital bit rates into a given channel bandwidth. This is discussed in Section 3.6.

5. Data compression techniques, which allow voice and video signals to be transmitted in fewer bits than were contained in the original bit stream. This is discussed in Section 3.7.

Without intending to summarize the entire technology of designing and building a point-to-point microwave system, it will be useful to make a few points regarding some design and performance trade-offs which will affect the economics and utility of microwave systems.

Lower-frequency microwave bands (2 GHz, for example) require larger dish antennas to achieve a given antenna beamwidth or gain. On the other hand, the clear air path loss is less at the lower frequencies, and signals at the lower frequencies are not attenuated as much by rain and other precipitation. Therefore, the lower frequencies are more suitable for very long paths (up to 150 km) where line-of-sight paths can be obtained. Higher frequencies (11 GHz and above) can suffer more outages due to local thunderstorms.

Lower-frequency systems (2.5 GHz and below) are historically less expensive because the electronic components are cheaper, cheaper grid antennas can be used (though sidelobes not suppressed as well), coaxial cable can be used instead of expensive waveguide to carry signals to and from the antenna, and less-rigid towers can be used (since the wider beamwidth of 2 GHz systems tolerates more antenna movement).

Though the laws of physics do not change, technology and market factors will cause major changes in the way microwaves are used.

Higher frequencies. The development of higher-frequency gallium-arsenide (GaAs) transistors and microwave monolithic integrated circuits (MMICs) has made practical the exploitation of the higher-frequency microwave bands. Recently, a transistor was demonstrated operating at 300 GHz and MMIC wideband 18 GHz amplifiers are economically available from numerous commercial sources. These new technologies have provided a continuously improving set of components useful in the design and construction of microwave systems at higher frequencies. As a consequence, 18 GHz and 23 GHz systems are now common, and 38 GHz systems are being commercially produced in moderate numbers (though 38 GHz is mainly for use in the U.K.).

Although these higher-frequency bands have been allocated for many years, the availability of commercial equipment at affordable prices means that these bands have become available as practical alternatives to the lower frequency microwave bands. The higher frequency bands are used much less than the lower ones. The 18 GHz and 23 GHz bands are beginning to be used; the 26 GHz Government band and the 28 GHz non-Government band are still completely empty. The near future should see the continuation of a shift to the higher-frequency bands, as some systems are pushed out of the lower bands and other systems move to exploit the advantages of the higher bands.

Compact packaging. The use of higher frequencies makes transmission lines between the antenna and the receiver more expensive and less efficient, but it allows smaller antennas. These factors combine to make it practical to integrate the antennas with all or part of the receiving/transmitting electronics. The result is a compact antenna package which suffers fewer transmission line problems and can be mounted on buildings much more easily. This package can be mounted inconspicuously in an office window, instead of using a rooftop location. Thus, much smaller antennas and lower logistics and installation costs can compensate for the disadvantages of shorter allowable path length at the higher frequencies.

The use of integrated antenna/electronics packages is also made practical by complex MMICs that produce a cheaper, smaller, and more reliable electronics package. Mass-production cost reduction has not yet hit the microwave industry in the same overwhelming way that it has affected consumer electronics, because the microwave receiver industry is too small and fragmented to fully utilize the benefits of custom complex MMICs. Nevertheless, MMICs provide a substantial reduction in size and complexity and improved reliability, and the potential is there for substantial cost reduction if standardization can allow better mass-production economies.

Complex digital electronics. The incorporation of microprocessors to control and monitor the internal workings of microwave receivers has permitted the economical addition of many useful features to modern microwave systems. This includes a complex mix of self-calibration and diagnostic features, easy interfacing with complex industry standards for telecommunications systems, and features that provide great flexibility of operation and adaptability to a wide variety of communications traffic. Since many functions which were hard-wired or performed with specific hardware components are now performed with inexpensive microprocessors and software routines, the increased utility and reliability of modern microwave systems can be provided at a lower cost than with earlier units. It is interesting to note that microwave power amplifiers and many microwave hardware components have not noticeably decreased in price; modern digital computer techniques have been responsible for much of the improved value of modern microwave equipment.

3.6 Digital Modulation Techniques

The use of digital modulations has greatly affected the entire telecommunications industry. Since digital techniques allow regeneration of 1's and 0's virtually without error, signals can travel through hundreds of circuits without accumulating gradually increasing levels of noise and distortions. Thus, digital techniques permit long-distance telephone circuits that sound as good from halfway around the globe as from next door. Small amounts of error correction will ensure that any errors that are introduced somewhere will be soon eliminated. The use of digital modulations provides great flexibility in the types of traffic carried, since a wide range of digital and analog signals can be converted to a series of bits which can be carried efficiently in a digital system. Finally, advanced digital modulation technologies have given greatly expanded information capacities to microwave systems, through the use of higher-order modulations (512-QAM is the highest, to date), allowing more information to be carried over a constant bandwidth. In the case of 512-QAM, each sample of signal can carry 9 bits of information. This makes it possible to greatly increase the amount of data carried in a given bandwidth, opening up even the narrower microwave channel allocations to substantial wideband service. For example, a 10-MHz BW channel at 2 GHz can be used to carry a full DS-3 (45 MBits/s) using 256- QAM. Three DS-3s (135 Mbits/s) can be carried in a 20-MHz channel, using a 64-QAM modulation.

This increases the potential of a given microwave channel by allowing it to provide a service which previously could not fit within the allocation. Since one of the major reasons that fiber is selected over microwave is that microwave bands do not have enough capacity to meet a particular requirement, the availability of higher-order digital modulations may increase the number of situations where microwaves can be used to fill a need--thereby increasing the use of microwaves in the fixed service. On the other hand, the ability to get by with less spectrum in providing a service may mean that fewer channels are used for a given baud-rate requirement--thus decreasing the use of microwaves.

There are disadvantages in the use of the higher-order modulations like 64- or 256-QAM. The first disadvantage is considerably higher cost, due to the need for more complex and precise receiving equipment. An adaptive equalizer will be needed to eliminate even small amounts of multipath interference. The receiver and transmitter will need excellent phase and amplitude linearity, a requirement for reliably distinguishing between signals whose difference is only 1/16 in phase or amplitude. In addition to high equipment complexity and cost, these modulations require higher signal-to-noise ratios and higher signal-to-interference ratios.

Part of the spectrum efficiency advantage obtained by putting more data over a fixed bandwidth channel is canceled by the decreased tolerance for other signals sharing the band. Spectrum efficiency studies have shown that the spectrum efficiency seems to be a maximum for modulation levels around 16-QAM or 32-QAM, when one also considers the maximum numbers of users that can be put in a band[12]. For example, interference from radars in adjacent bands has become a more common occurrence since microwave links have switched to digital modulation. Thus, higher-order modulations may actually be less efficient when the entire radio spectrum is considered.

Digital modulation techniques have replaced much of the older analog modulation used by earlier microwave equipment. Most of the original analog telephone equipment in the 4 GHz and 6 GHz common carrier bands has been retired or replaced with digital equipment. The switch to digital modulations in the common carrier bands was required for compatibility with the new digital telephone standards (like DS-1, DS-3, and SONET). A small amount of analog equipment remains in the common carrier band, mostly to connect to some old analog TV video relay or similar special equipment.

In the private bands, the equipment is mixed between analog and digital. Many of the earlier analog voice circuits are being replaced with digital, but many of the circuits used for Supervisory Control and Data Acquisition (SCADA) remain analog, because of faster response time with simpler circuits.

The TV broadcasters have largely remained with analog video formats for all of their ENG, STL, TSL, and ICR links. In these cases, the standard NTSC modulation format is used; often it is modulated on to a 15- to 25-MHz-wide FM channel. The FM provides excellent performance at a lower cost than a digital channel. The spectrum efficiency of the FM systems is excellent, and going to digital systems would give little advantage in this regard, unless extensive digital signal compression were used.

The largest microwave network operated by the Federal Government, the FAA radar communications link (RCL) network, is a wideband analog system used to carry narrowband digital information about aircraft to air traffic control centers from dozens of radars, both long-range enroute and at airports.

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[12] Robert L. Hinkle and Andrew A Farrar. "Spectrum Conservation Techniques for Fixed Microwave Systems" NTIA Report TR-89-243. May 1989.

3.7 Data Compression and Error Correction Techniques

Digital systems can be designed to incorporate some very helpful types of signal processing, including data compression and error correction. Data compression reduces the number of bits that need to be sent. Error correction adds a small number of additional bits to detect and correct a limited number of errors, usually giving error-free transmission. The small amount of additional power needed to transmit the error-correction bits is usually much less than the amount of extra power needed to achieve a signal-to-noise ratio which would give equivalent error-free performance.

Data compression decreases the amount of data which must actually be transmitted by eliminating inherent redundancies in the transmitted information. When there is little redundancy in bit-streams, data compression is not particularly useful. There is often a great deal of redundant information in a TV picture. For example, a background color may remain the same for many successive pixels. Therefore, instead of individually sending pixel information '$pink_1$, $pink_2$, $pink_3$, ... , $pink_{100}$', Huffman coding simply sends a collective '100 pinks'--thus greatly reducing the amount of data that needs to be transmitted.

Other types of data compression take advantage of other types of redundancies in the data. Motion estimation coding takes advantage of the situation where most of the TV picture in one TV frame is quite similar to the picture in the next frame--possibly with the exception of being slightly translated or rotated. In the case of translation, a small band of new picture is added to one edge of the old picture, while a similar-sized band of old picture is discarded from the opposite edge.

Digital data can sometimes be compressed, but only when there is a redundancy that can be exploited. For example, some text information can be compressed because some partial lines full of spaces can be removed when sentences end short of the right margin, between paragraphs, etc. Sometimes partially-filled standard-length files are filled up with blanks, whenever the text information does not completely fill the file. Since words are often repeated in a message, it may be profitable to devise a code for words that are repeated often. If the code is shorter than the word it represents, less data can be used to transmit the message. In general, however, a string of binary bits may have few redundancies that can be recognized and exploited, and the resulting coded message may not be shorter than the original.

There are two basic types of data compression that may be used: exact and lossy. The Huffman coding described above is an exact compression, since the '100 pinks' corresponds exactly to the '$pink_1$, $pink_2$, $pink_3$, ... , $pink_{100}$' sequence. The conversion can be performed backwards and forwards as many times as desired, and the bits will still be exactly the same. Many types of data compression produce results which are only approximately the same, however, and result in the loss of some picture quality (hence, the term 'lossy'). The compression of video information in HDTV using motion estimation techniques results in compressed data that only approximately matches the original picture. If the match is very close, no one will notice, since the eye comprehends only a small part of the data that enters it. Each application of the compression and expansion algorithms may add cumulative distortion to the original picture, however.

The cumulative effect of successive processing in a future HDTV studio may produce a picture that is noticeably degraded. Therefore, HDTV studios may be reluctant to use multiple stages of compression and re-expansion during the production process (ENG links, recording, editing and mixing, and finally broadcasting), even though compression will be used during the broadcasting process.

The net result of extensive recent advances in data compression is that several types of signals can be sent using a much lower data rate or a much lower bandwidth than would otherwise have been possible. For example, NTSC television can be compressed to provide four to ten channels in the same bandwidth as a single uncompressed NTSC channel. An HDTV channel can be sent using the bandwidth of a standard NTSC channels. Video conferencing signals can be compressed more than 100:1 and carried on telephone lines. As many as three to six compressed digital cellular voice channels can be fit into the same 30-kHz bandwidth as a single standard analog cellular signal. The technique is not without its cost, however; a recent chip-set for video conferencing was described as a "6,000 MIPs[13], highly pipelined hardware implementation."

An interesting example of data compression concerns FAA radar information. Data from distant long - range radars is sent to air traffic controllers via a nationwide network of broadband analog microwave links--called radio communication links (RCLs). When this system was built in the 1950's, it was necessary to transmit several channels of wideband analog radar and beacon returns, a total bandwidth of about 10 MHz. Today, CD-2 digital processors at each radar site produce a 9,600- to 56,000-baud digital data stream identifying and locating all aircraft seen by the radar. The final processed digital data is equivalent to a normal telephone voice channel, representing a 1,000:1 reduction in the amount of data transferred. The microwave network has been maintained by FAA because of the higher reliability of microwave links compared with the alternative telephone circuits.

When compressed signals are carried over microwave links, they allow the links to carry more signals than would have been possible otherwise. For example, if HDTV electronic news gathering (ENG) is carried in a digitally compressed form, it will fit within the standard 20-MHz-wide ENG channel. Otherwise, it would require a much larger bandwidth (possibly 50 MHz), causing serious crowding problems in the bands allocated to ENG.

Although such compression can greatly reduce the spectrum needed to carry a fixed amount of information, it will also allow some signals to be carried by narrower bandwidth microwave which could not previously have been carried at all. This may make it practical to use microwave for some applications which would have been limited otherwise to wider bandwidth optical fiber. Thus, the availability of efficient digital compression techniques will not necessarily reduce the demand for microwave systems, since microwave is often more competitive when carrying narrowband signals.

3.8 Video Distribution Technology

Video programming (television) is a singular type of traffic which has greatly influenced the allocation of microwave band and the development of microwave equipment. In terms of bandwidth of information delivered to a total number of customers, video exceeds all other forms of telecommunications by several orders of magnitude. For example, a telephone circuit can be encoded with 64 kbits/s of data. A single TV channel can be encoded on a DS-3 circuit using 45 Mbits/s of data. A 60-channel cable TV system would provide as much as 2700 Mbits/s to a typical household. (CATV is analog, of course, but it would be equivalent to a 2700 Mbit/s circuit). Thus, a cable TV circuit provides about 40,000 times as much data as a standard telephone circuit, for approximately the same monthly cost. It should not be surprising that a large investment has been made in specialized systems to transport video programming efficiently and economically.

[13]MIPS: millions of instructions per second

The remainder of this section describes some of the uses of microwave to support video communications. AUXBC and CARS use microwave systems to support non-microwave distribution of video signals; the distribution medium is VHF/UHF spectrum or coaxial cable. On the other hand, some of the newer distribution systems like MDS, MMDS (wireless cable), and proposed LMDS (cellular cable) rely on microwave spectrum for the medium of distribution. Presumably, systems using microwave media for distribution will require additional supporting (microwave or non-microwave) systems to transport the video signals to the transmitter locations.

The system used to bring video signals to a distribution site is completely independent of the medium used by the distribution site. The choice of both of these systems are affected by almost independent sets of criteria. Thus, it would not necessarily be inconsistent to see extensive use of microwave to transport video from a studio to a cable head-end site at the same time that optical fiber is used to transport video to an 28 GHz cellular cable transmitter site. Some of the microwave services which have been allocated to move or broadcast video material are described in the following paragraphs:

Public Service (common carrier). Though not specifically dedicated to the transport of video signals, the common carriers are allowed to carry TV programming on microwave frequencies reserved for common carriers. The critical specification is that more than half of the traffic must belong to organizations other than the microwave operator. Thus, for example, there are a substantial number of ENG and ENG relay in the 23 GHz band, even though this band is not allocated to AUXBC or CARS.

Auxiliary Broadcasting. The auxiliary broadcasting (AUXBC) service has been allocated in seven microwave bands to provide TV broadcasters the means of moving TV signals from one place to another, as needed in support of broadcasting. Studio-to-transmitter links (STL) are fixed links that move TV signals from the studio to the transmitter site. Inter-city relays (ICR) are fixed links used to move video signals between various points within and between cities. Electronic news gathering (ENG) provides live coverage of an event at a remote location. ENG sites are typically moved several times a day, and they are often used for only 10 to 15 minutes at each site. ENG relays are fixed sites used as relay points to extend the distance that ENG operations can travel from the studio. All of these AUXBC functions frequency-modulate the TV signal on a 15- to 25-MHz bandwidth--depending on the frequency band.

A typical metropolitan TV station might use these AUXBC services in the following ways. The TV studio is located in a tall building near the center of the city. Three STLs are used to carry program material to the mountaintop transmitter eight miles away--one carrying the program, one a 'hot back-up', and one carrying transmitter control signals and other communications. The program channel and the back-up are in different frequency bands, in the hope that a bad rainstorm would affect the bands differently and they would not drop out at the same time. The mountaintop transmitter site is a receiving location for several ENG relays. These relays have steerable high-gain antennas so they can be directed to the location of the ENG operation. When not being actively used for ENG relay, a camera attached to each ENG relay can be used to show weather and traffic conditions. Two ICRs are permanently aimed to receive TV signals originating at the local sports complex and the state capitol building. One ICR is aimed to receive signals relayed from a tall building in a busy suburb 15 miles away. This building rooftop has a steerable ENG relay and camera. Finally, the transmitter site has a transmitter-to-studio link (TSL) to carry signals received from the various ICR and ENG relays back to the studio.

On the top of the studio building, a fixed ICR site connects the studio with a satellite feed site in a quiet location outside the city. A steerable ENG receiving antenna (and camera) overlooks much of the city. Finally, two ICRs provide a high-quality signal to the local cable TV system and a low-power fill-in transmitter that provides coverage in a mountain valley. Counting the six ENG systems, the TV station has a total of 15 AUXBC transmitters. Four other stations in the city have a similar complement of equipment. Many of the smaller TV stations have much less equipment and would provide less local coverage.

Cable TV relay service (CARS). The cable TV relay service has been allocated four bands (some shared with AUXBC) to move TV signals into cable systems. In some cases (e.g.,ENG), the uses of these bands are very similar to corresponding uses in the AUXBC bands. Studio-to-headend-links (SHL) are unique to CARS. SHLs transmit a block of TV channels from a studio to the headend point, where the cable originates. In some cases, a single mountaintop location will transmit blocks of up to 80 TV signals to as many as 15 separate cable headends. These signals are kept in 6-MHz NTSC format, so that simple down-conversion is all that is needed at the cable headend to generate the signal for the cable. Each SHL will use a separate point-to-point directional link, although identical frequencies will be used on each link. Since each of 80 channels would be licensed for all 15 SHLs, as many as 1,200 frequency assignments could appear at a single location. This is responsible for the 100,000+ assignments in the 12.75-13.25 GHz band, which is specifically channelized for this use.

Cable system architecture is recently converting the trunks and feeder cables from coaxial cable to fiber optic cable. The much lower loss and wider bandwidth of the fiber allows the system bandwidth to be extended to 1 GHz, with better signal quality and more reliability. The neighborhood distribution system, with drops to individual houses, remains in coaxial cable. A typical cable system in the near future might be organized as follows:

0-50 MHz: Local area networks and viewer response channels.
50-550 MHz: 80 channels of NTSC and HDTV.
550-1000 MHz: Digital compressed NTSC (10:1 compression) and HDTV.

This is the cable industry's version of "fiber-to-the-curb", and there is intense development activity to enable cable to expand the services it now offers. Fiber for cable TV is the most rapidly-expanding fiber market segment, using an estimated 10 to 20 percent of the total new fiber. Some cable companies are rewiring their systems with cable having many individual fibers, apparently in anticipation of pursuing a more general telecommunications market in the future.

Multichannel multipoint distribution service (MMDS). Multichannel multipoint distribution service (MMDS) is a new service which has been allocated in the 2500-2690 MHz band to provide "wireless cable" distribution of TV programming. This service uses omnidirectional transmitting antennas to transmit up to 33 TV channels to subscribers using directional antennas and appropriate decoder boxes. MMDS uses the 6 MHz NTSC format. MMDS replaces the earlier multipoint distribution service (MDS), which was technically similar, but which was prohibited from broadcasting more than four TV channels. MMDS is intended to provide cable-like service in rural areas where sparse population will not support the installation of a cable system. In urban areas, MMDS is intended to provide competition to cable TV systems.

Local multipoint distribution service (LMDS) The FCC is considering a reallocation of the 27.5-29.5 GHz band to permit video and other services to be distributed by LMDS, also called "cellular cable". Cellular cable would be similar in concept to MDS/MMDS, except that higher path losses at 28 GHz would require multiple short-range transmitter sites. An experimental license has been granted.

Effect of video distribution on microwave. The technology of video distribution is in a particularly dynamic and uncertain state. TV broadcasting faces the challenge of broadcasting HDTV, as well as intense and successful competition from cable and satellite. Cable TV is replacing its trunk and feeder links with fiber optics, while trying to position itself to provide a greater range of telecommunication services. Cable's future has suddenly become less predictable, because of the possibility of direct competition from the LECs (along with competition from MMDS, satellites, improved broadcast TV and HDTV, and cellular cable). We do not know how these contests will turn out, except to realize that not all of the offered new and old services will be widely adopted by the marketplace. The outcome will have very large effects on the use of the microwave bands. The MDS service--for example--was available, but largely unused for many years, prompting the recent change in rules which created MMDS.

HDTV and digital compression. The crowding in AUXBC bands may get worse before it gets better, because the arrival of HDTV will (at first glance) more than double the bandwidth requirements for STL and ENG. If each currently assigned NTSC channel exercises its option for a matching HDTV channel, separate NTSC and HDTV STLs will be required for each station. (This will be especially true if HDTV programming is allowed to be different from NTSC.) Presumably, the HDTV program material will be in compressed digital format in the STL, complete with error correction and a well-engineered path, so only a 6-MHz channel will be needed. This is less bandwidth than the present 20-MHz analog FM signal used in current NTSC STLs and ENGs. Still, a separate link would be needed for the NTSC and the HDTV signals.

The situation is either better or worse in the case of ENG services, depending on whether the video is transmitted in a compressed or un-compressed form. Since the ENG services will probably be the last HDTV capability to be added by the local stations (possibly several years after the initial availability of HDTV network feeds), we have less confidence in our prediction of how ENG will commonly be performed in the HDTV era. If the ENG signal is digitally compressed with a 6 MHz bandwidth, it will probably be transmitted in digital form and may require only 1/3 of the 20 MHz bandwidth used for the present NTSC ENG signals. On the other hand, it might be transmitted in some uncompressed analog form--which would probably require four to five times as much bandwidth as the present NTSC signals.

The reluctance to perform digital compression in the ENG is due to size and complexity constraints in the portable equipment, as well as the desire to maintain original picture quality as much as possible, since some scenes will be somewhat distorted by the compression process. Uncompressed analog HDTV ENG operations will require more than three times as much spectrum for an HDTV channel. Since the HDTV equipment should be well-developed by the time that most studios add HDTV ENG capabilities, it is reasonable to guess that most HDTV ENG systems will broadcast compressed digital signals.

It is unlikely that a single ENG system will simultaneously transmit NTSC and HDTV signals, or that a single event will be covered by pairs of NTSC and HDTV cameras. Instead, it is likely that the broadcast NTSC signal will be derived from the broadcast HDTV signal. This would mean that the introduction of HDTV ENG equipment could actually decrease the bandwidth requirements, compared with NTSC. It is also possible that conventional NTSC ENG will be transmitted in a compressed digital format, which could increase the number of available ENG channels by factors of as much as ten. This analysis is heavily dependent on the completely successful operation of digital signal compression techniques which would allow the acceptance of this technology for studio-quality processing. It should be noted that there is already very high interest in developing HDTV VCRs and compressed NTSC decoders for widespread consumer use, which bodes well for the active pursuit of digital compression technologies.

Optical fiber. Replacing fixed links (STL, ICR, and ENG relays) with fiber will become increasingly attractive. The cost of fiber components will continue to decrease, and fiber will continue to become more widespread throughout metropolitan areas, making redundant fiber structures more available. Since studios will have twice as many program channels to transport to the transmitter, the economic factors will be tilted toward the economies of scale that fiber provides. The digital format of HDTV will be particularly compatible with digital fiber technologies. The alternative cost of purchasing new digital microwave STL systems for HDTV will offset some of the cost of fiber. Finally, the industry may feel pressure to free up spectrum so that it can be used with ENG operations. We believe that many fixed transmitters will be replaced by fiber as part of the process of adding HDTV to existing NTSC stations, with additional fiber replacement occurring more gradually afterwards.

ENG links can also be partially replaced with fiber, to the extent that microwave links back to the studio could be replaced with fiber at several popular locations like stadiums, state legislatures, airports, etc. This would permit greater frequency re-use or even no frequency use. Since more buildings will have fiber connections to the switched network in the future, it may be quite practical to make temporary fiber connections via an existing optical fiber network. Since ENG is a fairly intermittent operation, it may be practical to send it over the switched telephone network on a demand basis. The more widespread availability of ISDN might provide this capability at many commercial and public locations. Although the rates would presumably be much higher than normal telephone, only a relatively short period would be needed.

The availability of fiber or ISDN connections for ENG should continually increase, especially in urban areas. Many newer buildings will be 'wired' with fiber and ISDN. The increasing presence of urban fiber providers like Metropolitan Fiber and special-purpose video service providers like Vyvx should provide many more situations where optical fiber can help relieve what would otherwise be a continuing growth in demand for microwave spectrum.

The rapidly expanding use of fiber in cable TV systems will surely speed the development of inexpensive video fiber hardware. The increased bandwidth of cable systems, as well as the development of two-way date/video/voice cable systems, could increase the bandwidth requirements of SHLs to the point where optical fiber would be the only medium with sufficient bandwidth--and the only medium with sufficient bandwidth in both directions. It is likely that many fiber cable TV trunks and feeders will be extended all the way to the distribution hub, eliminating many SHLs. The SHLs that remain, however, might require more bandwidth.

Video takes several forms of modulation, depending on the medium of transport and the purpose of the transport:

1. **NTSC** format is used for VHF/UHF broadcasting. This format uses only a 6-MHz-wide channel, but requires a 30-40 dB signal-to-noise (s/n) ratio for good picture quality. This is the format that is required by a normal TV receiver.

2. **FM** format is used for ENG, SHL, and ICR. This format frequency-modulates an NTSC format on a channel which is 15-25 MHz wide. This format requires less S/N ratio for an acceptable picture than does NTSC.

3. **Wideband FM** format is used for satellite transmission of TV. It is similar to the FM format, except that bandwidths near 50-MHz are used, decreasing the required s/n ratio. This is important because of the very small signal available from a satellite.

4. **DS-3 digital** format is used when video is carried over the public switched network. It requires 45-Mbits/s for high-quality TV.

5. **Compressed digital** formats are being developed, which will decrease the required bandwidth by a factors of up to 10 or more. Several formats have been proposed for use in satellite and cable delivery.

6. **HDTV** (high-definition TV) will use a compressed digital format, which will allow the HDTV signal to be transmitted in a 6-MHz bandwidth. Several formats are under very active consideration.

7. **Optical fiber** for cable TV uses amplitude modulation of NTSC signals. However, advanced forms of cable TV services are planning to used digital modulation for compressed NTSC video and for switched voice and data services.

3.9 Cellular Communications and PCS

The rapid growth of the cellular services is affecting the patterns of growth in the fixed/microwave bands in two very different ways. First, the rapid expansion of cellular radio has been the major cause for recent growth in the microwave bands. Similar effects may be expected from projected growth in PCS services. Second, the need for spectrum for future Emerging Technologies (PCS and other related services) has caused the FCC to propose that several microwave services move out of a 220 MHz region in the 1850-2200 MHz range and move elsewhere.

At the present time, FCC action on the proposed Emerging Technologies band has not been finalized. Therefore, the information contained here may be subject to revisions. Under the proposed Emerging Technologies plans, the following bands will be vacated or shared with new services:

1850-1990 MHz	Private operational services
2110-2130 MHz	Public (common carrier)
2130-2150 MHz	Private operational services
2160-2180 MHz	Public (common carrier)
2180-2200 MHz	Private operational services.

The microwave systems which are already in these bands will have several years to migrate from their bands to new bands. The timing of the moves, financial compensation, and status in the old or new bands are still being discussed. The 'migration bands' being developed to receive the systems moving from the 2 GHz Emerging Technology bands include several higher-frequency microwave bands. At present, these migration bands are channelized for wider channels and are already partly filled by existing microwave systems. All of the migration bands will be allocated co-primary for private operational and common carrier.

The migration bands, their current allocations, and their proposed bandwidths[14] include:

3700-4200 MHz	Public (common carrier)	0.4, 0.8, 1.6, 5, 10, 20 MHz
5925-6425 MHz	Public (common carrier)	0.4, 0.8, 1.6, 5, 10, 30 MHz
6525-6875 MHz	Private operational	0.4, 0.8, 1.6, 5, 10 MHz
10.55-10.68 GHz	DTS and DEMS	0.4, 0.8, 1.25, 1.6, 2.5, 3.75, 5 MHz
10.7-11.7 GHz	Public (common carrier)	10, 30 MHz.

Assuming that the Emerging Technologies proposals are implemented by the FCC, any growth intended for the 2 GHz bands should begin to show up in the migration bands, and the 2 GHz bands should begin to diminish. The estimates for the future band growth assumes that the FCC proposals will be implemented similarly to the present FCC proposals.

The FCC action proposes to use the future demand for PCS spectrum to move microwave users from the 2 GHz range. However, the most intensive growth in any of the microwave bands is in the 2110-2130 MHz and 2160-2180 MHz common carrier bands, caused by the rapid growth of cellular radio. Comsearch has stated that 70 percent of new microwave assignments in 1991 were used to support cellular radio, and that most of those assignments were in the 2 GHz bands. Other industry sources claim that the 2 GHz common carrier band is the most intensely used microwave band in existence. Another independent estimate by a microwave equipment manufacturer stated that 70 percent of cellular sites were being supported by microwave. Whether these numbers are completely indicative of the entire situation, they are useful in suggesting the importance of cellular telephone in the current growth of microwave band usage. The irony is that today's fast-growing cellular service may be the service most seriously affected by the need to reserve spectrum for tomorrow's PCS. The cellular carrier has many reasons to by-pass the LEC, the chief reason being to control their own network to the maximum extent possible, rather than relying on the LEC (who is actually a competitor of sorts). In addition, there is the matter of the cost involved in transporting cellular signals on the LEC, which can be minimized by carrying the signals for the maximum distance on the cellular system.

Typically, a string of cellular sites are connected together, with at least one point being connected to the LEC. The connections between cellular sites can be provided by wires, or fiber optics, or microwave. Wires and fiber have equal disadvantages with respect to right-of-way delays, burial costs, and accidental cable cuts. In many cases, microwave is selected over fiber or wire because of the expense or delay associated with the alternatives. Typically, 2 GHz microwave will be used on the thinner parts of the network, with 6 GHz or 11 GHz used when larger capacity is needed. Fiber has substantial bandwidth and future expansion advantages over microwave, but a few dozen voice channels are typically needed by a cellular site, and the required cellular capacity is far below the 10 to 20 DS-3 links which is considered the rule-of-thumb lower limit for fiber optic installation. Even if many cellular sites are strung together with a chain of microwave links, the total traffic requirements will usually be well below the fiber economic break-even point. Continued growth in cellular capacity, including the tripling of capacity with the new digital or analog systems and the downsizing of cells may eventually produce cellular networks needing fiber capacities on the trunks.

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[14]FCC NPRM and tentative decision. General Docket No. 90-314, ET Docket No. 92-100, and No.92-333. August 19, 1992.

The cost and inconvenience of fiber is aggravated because of the need to provide a "backhoe-proof" redundant route architecture for fiber. In addition, cellular systems often need to add new sites and mini-sites to meet demands for extra capacity. These new sites create the need for constant changes to the cellular network configuration, which incurs still more delay and expense with fiber. Microwave equipment, on the other hand can be easily moved or re-aimed to allow the addition of another site.

There are promising alternatives to the use of microwaves to connect cellular sites. For example, PacTel is using more fiber in Los Angeles since it has obtained permission to string fiber on existing telephone and utility poles. This practice may spread to other cities, along with the critical need for numerous additional smaller cellular sites. In another scenario, fiber could become widespread and inexpensively available in most urban locations. Thus, most cellular sites would be within a convenient and economical distance from existing fiber cable--which might be leased dark or tied into the LEC or alternative provider.

Some new technology has been developed which could allow an inexpensive cellular mini-site installation. This technology uses fiber to carry RF directly to and from the cellular antenna site, with a minimum of additional equipment. This allows a very small package at the site, with the complex electronics and telephone switching gear for multiple sites safely located in a building somewhere. The cost savings at the antenna sites will be considerable, and it will help to pay for the higher cost of the fiber connection.

Finally, the possible difficulty in obtaining future frequencies in the 2 GHz band may result in greater use of fiber to connect cellular sites. It must be noted that 2 GHz may not be the best frequency band to support cellular anyway, when the technical factors are considered. The 2 GHz band was selected because equipment is cheap and the 2 GHz band was already channelized to support low bandwidth service. The long-range characteristics of the 2 GHz band are rarely needed for cellular. Since cellular sites are being downsized in many areas, the 'distance-mismatch' between cellular site requirements and the long-range potential of the 2 GHz band will become even more pronounced.

Since the number of new cellular sites continues to grow, we would expect an increase in the number of associated microwave links which will need to be supported in some frequency band. The FCC has indicated that the 4 GHz, 6 GHz, 10.5 GHz and 11 GHz common carrier bands will be re-channelized and used as destination bands for systems migrating out of the 2 GHz bands. The numerous TV receive-only (TVRO) terminals in the 4 GHz band will limit the usefulness of the 4 GHz band for new links. Probably most of the cellular systems will migrate to the 6 GHz and 11 GHz bands, but equipment may be more expensive and the allowable path lengths are slightly shorter. The continual process of downsizing cellular radii (creating additional cells) to get better capacity and better frequency re-use may make it more practical in the future to use frequencies as high as 18 GHz, 23 GHz, or 38 GHz to connect cellular sites. However, fiber will also become more economical, as the distance between sites decreases.

Many of the proposed PCS systems also plan to use microwaves to link the PCS microcell sites. Because of the very short PCS cell spacing and the use of advanced technology, microwave links would be planned mostly in the 18 GHz, 23 GHz, and 38 GHz bands. Some advanced European plans even include links in the 55 GHz or 58 GHz range. Other PCS systems propose mainly fiber links to microcell, with RF signals being carrier over fiber to each microcell antenna location.

It is not possible to predict at this time whether the future PCS system will use microwave extensively or not, but the very large numbers of PCS microcellular sites makes the PCS decision very important for estimating future microwave spectrum requirements. If PCS is provided under the auspices of the LECs or by CATV companies (who have good access to the existing fiber infrastructures), it would probably use much less microwave than if it is provided by cellular or LEC alternative carriers

3.10 Satellite Systems

Satellite systems represent still another alternative technique in moving data from one place to another. This technique has changed substantially since its earliest days, including the development of much larger satellite antennas, more powerful satellite transmitters, and much cheaper earth terminals. Satellites often share the same frequency bands as point-to-point microwave, since they tend to be inherently compatible in many applications.

When geosynchronous communication satellites were first developed, they were recognized as a major competitor for point-to-point microwave systems. In particular, satellites could transfer television and long-distance telephone calls from coast to coast much more efficiently and inexpensively than the 150-hop microwave system, and much traffic moved from the transcontinental backbone microwave systems to satellites. The development of commercial fiber optic communications tended to eclipse both microwave and satellite, having advantages of very high capacity, no half-second delay, immunity from interference, weather, and orbital crowding, etc.

Geosynchronous satellite systems remain a vigorous competitor for fiber and microwave, serving particular niche markets better than either of them. It is useful to go back to basics to identify the applications where satellite does best. (Our only interest here is in satellites as a competitor to point-to-point microwave. We will not consider low-orbit satellites, which are surely important, but mainly important as components of mobile communication systems. In this section, "satellite" is to be understood as a "geosynchronous satellite"). Geosynchronous satellites are simultaneously line-of-sight to almost anywhere in the U.S. This means that radio signals can travel between the earth and the satellite with only free-space losses, requiring only a single hop uplink and a single hop downlink. As a first approximation, all points in the U.S. are approximately the same distance to the satellite, with a single well-known path loss and time delay.

Although a satellite is a very expensive piece of equipment, one can lease a small part of its capacity for a small prorated monthly cost. When this small monthly cost can be spread out among many users who time-share the link, the cost per user can be more economical than any other alternative. A typical bi-directional system using very-small-aperture terminals (VSATs) operating with a data rate of several kbits/s can be purchased for as little as $15,000 per terminal with a user fee of $150 per month per terminal (including satellite fees). A central "hub" services VSAT responses from many users, and separates out the communications belonging to each user system. The service can be made quite reliable (claims are better than the telephone system), with severe weather being the major unpredictable culprit.

The cost of a VSAT is generally less than a single-hop microwave link, but the satellite can span any distance within the continental US at no increase in cost. VSATs have limitations, however, including the half-second delay that is unavoidable in a synchronous satellite system, the need for a moderate-sized antenna in a quiet location with a view of the satellite, and reliability that is okay (but possibly not good enough for all applications). The favorable applications match many of those currently being performed with private operational SCADA microwave, particularly remote and rural applications for monitoring pipelines, waterways, railroads, etc., where the data rate is quite low and reliable service is needed 24 hours per day. The half-second communications delay time may rule out some applications which require faster response.

Other applications of shared-access satellite links are growing in the business world, where wider-bandwidth communication system are used to by-pass the telephone companies. Dozens of large corporations like insurance companies, travel agencies, large retailers, new car sales, etc. use thousands of VSAT links to maintain a daily update of sales and inventory reports, financial data, advertising data, and general information from and to the corporation headquarters.

Future satellite development, such as the Advanced Communications Technology Satellite (ACTS), will continue to advance satellite capabilities, including the ability to service VSATs with 20 GHz (downlink) and 30 GHz (uplink) frequencies, very small satellite antenna beamwidths (0.3 degrees), and on-board channel switching technologies. Continued advances in VSAT ground station technology would be expected to expand the use of VSATs into some areas now served by terrestrial microwaves.

Wideband applications of satellites for broadcast applications with TV and audio application could decrease the need for wireless cable or fiber, especially in rural areas.

3.11 Voice, Data, and Video distribution

The modern digital public switched network (PSN) can be considered a 'common carrier' in the most basic sense of the words, since all data to be transferred is reduced to a common form (raw digits) before it is transported across the system. At the output end of the system, the network re-assembles the signal from its component bits and presents a 'good as new' signal to the recipient.

Anywhere inside the network, a DS-3 circuit represents 45 Mbit/s. These bits could represent a TV channel, or they could be 28 DS-1 circuits, or they could be 672 voice circuits. Each DS-1 circuit, of course, could contain some computer data, some voice circuits, some 384 kbits/s video conferencing, etc., as long as the total adds up to less than 1.54 Mb/s. The point is that the network can carry almost any signal presented to it, and that the internal parts of the network are not concerned with what the bits originally represented. Voice, data, and video are all the same to the PSN.

Depending on where the customer interfaces with the PSN, the customer may see the PSN as a stream of digits and own the equipment that changes their voice (for example) into the digits that the network needs (this is part of the ISDN concept), or the network may do the conversion and accept the customer's voice as an input. Microwave systems provide capacities up to three DS-3s; a single optical fiber can provide up to 48 DS-3 links on a single fiber. Table 3.11 provides a basis for comparison of the relative capacities of various communication modules. The bits/s column is only approximate, since these numbers often contain some overhead bits. SONET protocols should add about ten percent to the bits/s column.

Table 3.11. Equivalent Communication Capacities

SONET	DS2/DS3	DS1	voice circuits	bits/s
------	------	1 DS-0	1 voice	56 or 64 kbits/s
------	------	1 DS-1	24 voice	1.54 Mbits/s
------	1 DS-2	4 DS-1	96 voice	6.2 Mbits/s

Table 3.11. con't.

SONET	DS2/DS3	DS1	voice circuits	bits/s
OC-1	1 DS-3	28 DS-1	672 voice	45 Mbits/s
OC-3	3 DS-3	84 DS-1	2016 voice	135 Mbits/s
OC-12	12 DS-3	336 DS-1	8064 voice	540 Mbits/s
OC-24	24 DS-3	672 DS-1	16128 voice	1.08 Gbits/s
OC-36	36 DS-3	1098 DS-1	24192 voice	1.7 Gbits/s
OC-48	48 DS-3	1344 DS-1	32256 voice	2.3 Gbits.s

This approach has some advantages and some disadvantages. The main advantage is that the PSN is very flexible, which allows huge economies of scale to be applied to the gross job of transporting a wide variety of data from millions of places to millions of other places--especially when the sources, the messages, and the destinations are all changing rapidly. A major disadvantage is that it costs a lot more per bit transferred, if the job doesn't require the flexibility that the PSN provides. A DS-3 link (equal to a single TV channel) running across a typical city costs at least $2500/month[15]. A special-purpose system to do this job could cost a lot less. For example, a Cable TV subscription costing $20/month provides 50 channels. This is a cost ratio of 6250:1 per TV channel. The use of microwaves or fiber to bypass the LEC is often a matter of not needing the flexibility that the PSN provides (e.g., because my other office building is the only location that those circuits need to reach), and being able to more cheaply fill the need with a dedicated system.

Microwave systems relate to this ubiquitous PSN in many ways, which can change the character of the microwave system in important ways. First, the microwave system is often used as an extension of the PSN, or even as an internal link within the PSN. Many microwave systems use a digital format compatible with the PSN. These microwave systems are often described in terms of the number of DS-1 links or DS-3 links which they can carry. When a microwave system is used to provide telephone service to a small community, for example, the use of a digital microwave system with digital format identical to the PSN is an obvious choice. Since much microwave is used with the PSN, the popularity of digital microwave is understandable.

Even when a microwave system has been set up to perform a very particular function--a SCADA application to monitor the voltages at certain points on a electrical power grid, for example--there may be practical advantages in using digital technology. Most digital microwave systems incorporate error detection and correction, and many sensors/actuators are already designed for digital interfaces. The use of standardized digital formats makes it easier to interface with the PSN--moving onto the PSN where it is available, and back on to microwave where the PSN is not available.

Since digital formats make it easier to use a channel to carry many different types of signals, the digital microwave systems also furnish a convenient method to consolidate multiple communications requirements for one or more users into a single package that can be transported with a minimum of specialized interfaces. SONET formats--which have been duplicated on digital microwave systems--make it easier to separate out particular channels for use at a given site along the length of the microwave

[15]Denver, CO., 5-year lease, 8 miles between central offices. DS-3 cost varies widely and may be as much as 2-3 times as much in the more expensive areas.

backbone circuits. This makes it more practical to lease out some extra capacity on the link to another customer, who could also have an arbitrary mix of voice, digital, or video information.

Thus, many new microwave systems are being implemented with digital microwave, and many older analog microwave systems are being replaced with digital systems. However, it should be noted that many microwave systems are used exclusively to carry TV signals. These special-purpose systems still are normally implemented with analog techniques--using unmodified NTSC or frequency-modulating a carrier with the NTSC signals. The FAA RCL system carrying radar data is still an analog system, even though it is carrying digital data, to retain the capability of carrying wideband analog radar information.

The transition from analog to digital techniques will continue. Many microwave manufacturers have reduced or discontinued their analog product lines. Even microwave relay of TV signals may change to digital techniques--especially when inexpensive digital data-compression technology makes it possible to substantially reduce the bandwidth of the signal without compromising the quality of the signal.

3.12 Point-to-point vs. Point-to-multipoint Services

Fiber and terrestrial microwave are services that inherently provide communications between two locations. They provide connections between multiple points only by accident or by linking many 2-ended links together. Point-to-multipoint services, however, are designed to connect many points to a single point. If this connection is intended to be only in the direction from a common point to the multiple points, the service is like a broadcasting service. It differs from a true broadcasting service, however, since a given message is intended for a known set of locations. With a full point-to-multipoint service, the connection is bi-directional. In this case, the service is usually provided with some type of time-shared, multiple-addressed system configuration; in fact, this type of service is often called a multiple address service (MAS). Usually, the common port will address the multiple ports in turn (or randomly), leaving a fixed amount of time when the addressed port can transmit a message to the common port.

MAS systems are particularly appropriate when a large number of separated locations need to be in communication with a common point on a relatively infrequent basis. This allows a lower capital investment than building independent radio links to each of the multiple point, since the common point receiver and transmitter can be shared between all of the multiple locations. The amount of time between contacts of the multiple points can range from milliseconds (some wireless data systems), to minutes (some credit card and check verification systems), to weeks (for systems that automatically read residential electric meters). Because of the relatively complicated address recognition and time-shared aspects and the need for many radio links, MAS systems have become economically practicable only in the relatively recent past, with the development of cheap microprocessor-controlled radio systems.

MAS systems provide an alternative to conventional narrowband point-to-point microwave radio service. Since the range of MAS systems can be as much as 30-40 km, they could replace a 30-40 km microwave system. Although an omnidirectional MAS system would not be as spectrally efficient as a narrowbeam microwave system serving a single location, the MAS system could service many independent functions in many directions from the base station. Overall, the MAS system might be much more efficient than the directional microwave system. Thus the MAS system would be seen as a legitimate competitor for some of the narrowband, short-range sensing and control functions which have been a traditional client of the private operational service.

A shared (Government/NG) MAS service was recently allocated in the bottom 0.5 MHz of the paired 932-935 MHz and 941-944 MHz bands. Approximately 50,000 requests for assignments were received from private organizations, suggesting that the time may be here for widespread commercial use of MAS systems.

It should be noted that MAS systems can be implemented via satellites, usually utilizing very small aperture terminals (VSATs). This has many of the same characteristics as the fixed MAS discussed previously, but it allows the multiple points to be located anywhere within the service area of the satellite, e.g., anywhere in the U.S. This type of system is used by many large companies to maintain continuous communications between a central headquarters and many branch locations throughout the U.S.

3.13 FTS 2000 Services

The Federal Government has adopted a policy of procuring its telecommunication services from commercial service providers, whenever it is possible to do so. This policy has been implemented recently with the Federal Telecommunications Services 2000 Act, which directs Federal Agencies to procure voice and data services from an umbrella contract of telecommunications services provided by AT&T and US Sprint, the successful bidders for the current contract. Military command and control communications are exempted from this order by the Warner Amendment, though administrative traffic must be procured from FTS 2000 via DECCO (DISA)[16]. The Defense Commercial Telecommunications Network (DCTN) provides an umbrella contract for procurement of military command and control services. Other military and civilian functions can be excluded with the approval of the GSA. The present FTS 2000 contract includes no radio services (LMR or cellular) and no wideband services (like DS-3). It does provide videoconferencing services and T1 service. Recent events suggest that DS-3 and highly reliable services will be offered under FTS 2000 in the near future. In 1992, the Government will purchase about $500 million in services under FTS 2000, about 80 percent of which will be voice services.[17]

In the past, many separate Government telecommunication systems were designed and implemented when there was no alternative commercial service, or when the commercial service would be much more expensive or suffer from operational limitations. For example, the National Forest Service built its own land mobile radio (LMR) nets, since most of the extensive national forests had no other means to talk to its rangers when they were out in the field. The FAA built a network of radar microwave links (RMLs) to bring radar tracking information from the distant radar sites to the Air Traffic Control Centers. Other specialized Government links required survivability under nuclear attack, performance at 300 meters deep in the ocean, cryptological security, etc. These were often very expensive links, but their importance made it justifiable to obtain the required performance with less regard for expense.

Some new situations have reduced the need for specialized Government communications systems, including the general improvement in the capability of the commercial telecommunications infrastructure and a policy decision for competitive procurement of commercial services whenever possible.

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[16]The Defense Commercial Communications Office (DECCO) is a branch of the Defense Information Systems Agency (DISA).

[17]Government Computer News, June 22, 1992, page 6. From a report on a talk by Donald Scott, FTS2000 administrator.

Government agencies will be encouraged to use commercial services to replace specialized agency systems that have been built up in the past. It remains to be seen whether this results in a successful pooling of fragmented agency and public services into more efficient general-purpose public telecommunication systems. Some Government agencies have already replaced or supplemented LMR nets with cellular telephone and efficient shared trunking systems. Nevertheless, the FTS 2000 umbrella will help to provide the impetus to integrate individual Government systems into more efficient large public systems. It may require many years before all of the needed adjustments in Government and common carrier infrastructures can be made, and the promised savings can be fully realized.

It should be noted that some Government users are skeptical about the ability of FTS 2000 to meet all of their communication needs. It is difficult to believe, for example, that AT&T can provide narrowband communications into the remote reaches of a National Park any more efficiently than the Government can, especially if there is no other customer to help provide economies of scale. FTS 2000 has limited ability to provide simultaneous communications to a widely-dispersed group of users (similar to LMR dispatch systems). It has limited ability to economically provide continuous narrowband monitoring of a remote function (SCADA). The FAA has successfully resisted using FTS 2000 for replacing its massive microwave network to transport radar signals (RCL) by claiming that the public switched network was not sufficiently reliable. Besides its continued use and improvement of the RCL, FAA has recently purchased communication services from MCI, claiming that the level of reliability offered by FTS 2000 was not adequate for their needs. The FTS 2000 administrator has indicated that high-reliability circuits--backed up by diverse paths--are a service that FTS will consider adding to their contract. DCTN already provides the option of highly reliable services with diverse routing.

Many state and municipal governments maintain very extensive private telecommunication networks. States have generally not adopted policies which encourage switching to public suppliers, even when public suppliers are available. The state networks often make heavy use of narrowband microwave backbone to provide LMR communications coverage statewide to the state highway police, forest and parks employees, etc. These private facilities usually offer cost advantages over the use of public facilities, as well as functional advantages such as state-wide dispatch services. On the other hand, many states and municipal governments are actively consolidating communication networks between various departments and functions, for purposes of reducing costs, ensuring coordination and interoperability, and improving the variety of available services.

The net result of FTS 2000 will be a decreased use of agency-specific communication networks, resulting a relative decrease in the number of microwave frequencies used in the future. This change will be accomplished over the next 1-2 decades, as agency-specific systems are discontinued and replaced by services from FTS 2000.

3.14 Spectrum Sharing

Spectrum sharing is possible when two sets of services can be accommodated in the same band, without interfering with each other. These services can be very similar (like private operational and public services) or very different (like PCS and terrestrial microwave). The full range of sharing is likely to occur in the fixed service bands, and more should be expected in the future. In some respects, fixed service offers almost ideal characteristics to share with other services Since fixed links are stationary and have well-defined characteristics, it allows fairly tight frequency coordination to be performed. On the other hand, many fixed links require very high reliability, and sharing criteria must be met that will not permit unacceptable levels of interference. Spectrum sharing in the fixed bands has had some successes and some failures.

Sharing with the fixed satellite service. The most obvious circumstance of spectrum sharing in the entire RF spectrum is the sharing between the fixed service and the fixed satellite service. Both services are stationary in location and pointing angle, using highly directional antennas, with generally similar low levels of received power. What makes them compatible is that the two services use different antenna pointing angles, with the fixed service using antennas aimed generally toward the horizon and fixed satellites aimed upward toward a position in the geosynchronous orbit. The Fixed and Fixed-Satellite services represent a particularly successful combination of shared services in most of the Fixed bands.

A notable exception to the successful sharing between fixed and fixed satellite services has occurred in the 3.7-4.2 GHz band. Although this band was originally allocated to the Fixed service for common carriers, and once was the most important of the Fixed service bands, it is now difficult to add any new Fixed assignments. The culprit is the large number of TV receive-only (TVRO) satellite downlink receiving stations. About 13,000 TVROs have been licensed, from a total of 12,000 CATV (Cable TV) and 7,000 SMA (small master antenna) systems. A license entitles TVROs to protection from any interference from new microwave links. Since most TVROs are licensed for any channel on any satellite and can tolerate almost no interfering signal, a single TVRO typically denies the use of many times the amount of spectrum than a typical point-to-point microwave does. Even when a microwave link can be designed which protects the existing licensed TVROs, there is the substantial possibility of interference to some of the three million nonlicensed 'backyard' TVROs. Although there is no legal requirement to protect the unlicensed TVRO, there is still a possible problem with bad publicity. The net result is that the old 4 GHz microwave links are gradually being abandoned and not replaced with any other microwave service. Many industry coordinators consider the 4-GHz common carrier band to be lost to any new fixed microwave use, especially in urban areas where there are many TVROs.

Sharing with PCS. A future circumstance of sharing may involve the sharing between the fixed service and possible PCS services. Whether this application will ever be successfully deployed depends on many of the specific characteristics of the proposed PCS systems. Simple sharing strategies depend on the relatively sparse occupancy of the frequency band by both fixed and PCS services, as well as the very low power used by the PCS systems. Some studies suggest that PCS/fixed sharing would be possible in most locations. A major challenge for successful sharing strategies is that people eventually seem to get everywhere, even close-by in the mainbeam of a microwave link. Thus, an acceptable sharing strategy must positively control even such extreme instances without causing interference to the microwave link.

Sharing between various fixed services. The FCC has suggested that more sharing will be allowed between various fixed services in the remaining microwave bands to accommodate microwave users displaced in the migration from the 1850-2200 MHz microwave bands. This would allow more efficient use of the fixed microwave spectrum, particularly in locations where a single user type (e.g. cellular) was much more crowded than other users. It is more important that users with similar technical needs (bandwidths/data rates, path lengths, required reliabilities, etc.) be placed in the same band rather than users serving similar industries (which may require a wide range of link characteristics). If this strategy is followed, it is important that shared bands are channelized with appropriate bandwidths and other characteristics to meet the needs of the targeted uses. Allowing newly displaced microwave users into an established microwave band may be the most efficient and least disruptive way of reducing the number of microwave bands--particularly if a long period of time is available for migration.

3.15. Rural vs. Urban Locations

The use of fixed microwave links changes considerably in moving from a rural area to an urban area. The most important difference is that the traffic requirements are much less in a rural area and the customers are farther apart. This makes it less economical to provide the high capacity of a fiber system. Also, there is usually no shortage of microwave frequencies in rural areas. This means that microwave will often be the best option for delivering a variety of services to a rural area, even for the common carriers. Moreover, it is likely that microwave will remain the medium of choice in many rural areas for many years.

On the other hand, many relatively rural areas of the country are attempting to entice service industries to locate in their towns. One of the enticements offered is the availability of high-quality, high-capacity telecommunications utilities. Thus, Omaha, Nebraska, is the telemarketing capital of the United States. In addition, there has been talk about national policies to make rural areas more attractive to industry, and the ability of telecommunications to overcome the distance between the cities/factories and the rural areas has been noted often.

Multichannel multipoint distribution service (MMDS) or "wireless cable" was created by adding more channels to the earlier MDS, making it a more attractive alternative to cable TV. MMDS can now provide more than 30 channels of TV, using the 2500-2690 MHz band. This makes MMDS particularly suitable to provide TV in rural areas, where the low population density does not allow the large infrastructure investment needed to run cable to most homes. In these cases, a single transmitter tower could economically provide more than 30 different TV channels, using home dish antennas considerably smaller and cheaper than those needed for satellite TV reception. In urban settings, MMDS is intended as a competitor to cable TV, breaking the virtual monopoly that cable TV companies have in many cities. Whether MMDS will be viable in an urban setting with strong competition from improved fiber optic cable (which can offer many more TV channels and other services) remains to be seen.

Telephone service in some rural areas is being provided by radio. The basic exchange telecommunications radio service (BETRS) is a digital radio telephone service being offered on several channels around 454 MHz and 459 MHz in locations where the terrain and the low density of users make radio an alternative to telephone lines. Although this service uses some of the same frequencies earlier used for the improved mobile telephone service (IMTS), BETRS is intended only for fixed operation in carefully coordinated locations at ranges up to 30 mi. Though the band of operation (450-470 MHz) is mainly a mobile band, BETRS is a relatively new fixed service which may grow in importance.

In urban areas, on the other hand, experimental radio replacement of the local loop is occurring in the 1.8 GHz and 18 GHz microwave bands. These systems are limited to very short range (150 m) and are intended to overcome some of the obstructions which prevent ready access to many urban locations. In some forms, they might easily grow into a PCS-type of service.

In urban areas, microwave systems will continue to be squeezed out of the urban core and replaced by fiber systems. This will result from vigorous competition from various fiber providers, including the LECs, IXCs, alternative urban fiber providers, Cable TV companies, and from individual businesses and entrepreneurs. The urban fiber network will continue to grow inexorably, and the percentage of communications carried by fiber will continue to grow. This will happen even if there is no radical change in policies, e.g., a national policy decision to "wire" all businesses and homes with fiber.

Rural fiber will also continue to grow, but at a slower rate than urban fiber. Eventually, as fiber is installed, it will replace some of the existing microwave links. Eventually, 15-20 years from now, one might expect fiber systems containing TV, voice, and digital communications to become a part of the normal rural setting.

A recent request for proposals (RFP) by US West[18] for several typical telephone situations resulted in the conclusion that a rural optical fiber system would be about half the cost of a conventional copper-based system. Extensive use of passive optical techniques were a key factor. Though this particular RFP is not the basis for a massive rewiring of rural areas, it does suggest that widespread fiber in rural areas may be more practical than has been commonly assumed. Still, it seems likely that there will be relatively more microwave and less fiber in the rural areas.

Even though microwaves will play a larger relative role in rural areas than in urban areas, the concentration of microwave systems in urban areas will be greater than in rural areas. It is a case of microwaves taking a larger share of a much smaller rural market. When frequency congestion occurs in the microwave bands, it will occur in urban areas first.

4. ESTIMATED SPECTRUM REQUIREMENTS FOR THE FIXED SERVICES

4.1 Introduction

Based on the data and trends considered in the preceding sections of this report, we are in a position to make some estimates of how much spectrum will be adequate to support the fixed service bands in the near future (five years from the end of 1992: 1997) and the distant future (ten years from the end of 1992: 2002). We will express the estimated spectrum required in terms of percentage of the present use of the spectrum, i.e., as a percentage change from the use in 1992. We will summarize the spectrum requirements for the categories of Government, Private operations, public (common carrier), auxiliary broadcasting, and cable TV relay systems (CARS). For each of these services, we will summarize the overall change in spectrum use that we expect to see in the next five years.

The fast pace of technology and world events makes predictions beyond five years a more speculative exercise, but we will mention factors which we believe will be pertinent into the future. Even the near future predictions can be easily distorted by unforeseen legislation or court decisions, or unexpected technological breakthroughs.

With the preceding in mind, the predictive process will be based mostly on broad technological capabilities, current policy considerations, and trends that are already evident. Some of the major trends which have been described in earlier sections include:

1. Development of optical fiber technologies, which have moved much common carrier (and many other) communications from microwave links to fiber. Fiber will continue to improve and spread.

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[18]RFP RPTNR44126, used by TIA and its counsel under protective agreement with US West Business Resources, Inc.

2. Development of electronic components which operate at much higher frequencies, allowing operation of microwave circuits at frequencies above 30 GHz.

3. A trend to use large numbers of short-range radio links for personal convenience, including cordless telephone, cellular phone, wireless LAN, and PCS systems.

4. A rapid growth in the types and numbers of communications services which are made available in an entrepreneurial business environment.

The following sections show how these trends are changing the present and future use of the various fixed service types.

4.2 Government Service Bands

Government Services include a large number of widely-varied services, located in a wide range of frequency bands, which are listed in the table below.

Table 4.2-1. Federal Government Service Bands

Frequency Band	Designation	Comments
406-420 MHz		25 kHz bandwidth, mostly mobile
932-935 MHz		shared with public, private
941-944 MHz		shared with public, private
1350-1400 MHz		
1427-1435 MHz		
1700-1850 MHz	"2 GHz"	major pt-to-pt band
2200-2300 MHz		
4400-4990 MHz		many transportable systems
7125-8500 MHz	"7-8 GHz"	major pt-to-pt band
14.5-14.7145 GHz		
15.1365-15.35 GHz		
21.20-23.60 GHz	"23 GHz"	shared with public, private
25.25-27.50 GHz		minor use, mostly experimental

In general, Government Fixed-service bands are less homogeneous than corresponding non-Government bands. The bands identified here as "Fixed" often are shared with sizable numbers of various special-purpose, non-Fixed systems. The wide variety of these non-Fixed systems not only require substantial amounts of spectrum, but they make it more difficult to develop an organized channelization and sharing strategy. In addition, many Government Fixed frequency assignments tend to be 'hidden'--either because they are not extensively used in peacetime, because multiple copies of many transportable systems are not given individual assignments, or because they are classified.

Government applications include many narrowband fixed applications servicing various sensors and actuators (e.g., stream water-level sensors, seismic activity sensors), which will continue to increase in number as continually larger areas of the U.S. are protected from unexpected severe weather and other environmental concerns. These narrowband sensors are mainly at lower frequencies (e.g., 406-420 MHz and around 900 MHz) using very narrow bandwidths . Changes in band allocations in the 406-420 MHz band provided a number of 6.25-kHz channel assignments for narrowband functions. The 932/941 MHz bands were specifically intended as a destination for fixed links moved from the 406-420 MHz band; the new band includes allocations for MAS systems. It is expected that the number of these narrowband links will continue to increase, because of the increasing interest in monitoring more types of environmental phenomena at more locations. Note, however, that these links can be relatively spectrum-efficient and a large number of links may not represent a large amount of spectrum consumption.

There will be a sizable increase in the number of narrowband point-to-point and MAS channels in the 932 MHz band, but the number of narrowband fixed assignments in the 406 MHz band will decrease (partly a result of the move to the 932 MHz band). Because the channels in 406 MHz and 932/941 MHz bands channels are so much narrower than traditional microwave band channels, we did not include them in the count of Government microwave assignments.

Several Government agencies have their own long-haul point-to-point microwave networks. These include some of the agencies in Table 4.2.2.

Table 4.2-2. Major Government Microwave Networks

Agency	Major Band	Function
FAA	7-8 GHz	radar to ATC centers
Bonneville Pwr Adm	7-8 GHz	electrical power distribution (SCADA)
Southwest Pwr Adm	2, 7-8 GHz	electrical power distribution (SCADA)
Western Pwr Adm		electrical power distribution (SCADA)
TVA	2, 7-8 GHz	electrical power distribution (SCADA)
Army	-----	test/training ranges
Air Force	1710-1850	test/training ranges
DOE	1710-1850	test ranges and SCADA
Agriculture	1710-1850	LMR and data in national forest
Interior	1710-1850	LMR and data in national parks
Justice	1710-1850	LMR

Large point-to-point microwave networks are in place on most military test ranges, designed to monitor the performance and results of the testing, and to give assurance of the test environment and safety concerns. These networks have been supplemented by fiber on many test ranges. Most of the old microwave still remains, however, and continues to be used for backup, for narrower-bandwidth channels, and for parts of the range where fiber is not yet available. The major reason for switching to fiber was the need to handle increased data rates. The data now includes radar tracking data, high-resolution video data, wideband telemetry, spectrum surveillance information, video safety and security monitoring, voice and data command and control circuits, and many other functions. These functions will continue to grow in complexity as test and training simulators add realism and weapon systems become more complex.

The process of switching from microwave to fiber on test ranges is going slowly, held up partly by the expense of the conversion. In some new test ranges, the cost of fiber installation has resulted in microwaves being installed instead. In at least one instance, the cost of right-of-ways across private land and railroads was a major factor in the selection of microwaves over fiber. Nevertheless, we believe that the conversion process will continue, pushed by the need for more bandwidth, the high cost of maintaining old microwave equipment, and the improving price/performance value of fiber systems.

Many Government agencies have extensive microwave networks to support supervisory control and data acquisition (SCADA) applications. These include agencies with electrical power generation and distribution facilities like the Bonneville Power Administration, TVA, the Southwestern Power Administration, and the Western Power Administration. It includes agencies with major navigation and irrigation projects, like TVA and Army Corps of Engineers, which need to monitor water flow and to control locks and dams.

The FAA installed a transcontinental network of microwave links to bring radar data from remote radar sites to the regional Air Traffic Control Centers. This network comprises some 1400 fixed microwave assignments in the 7.9-8.4 GHz band. The majority of this network was completed in the 1960's, but a recent modernization of the network has installed new radios and digital data compression at the radar sites. The actual transmitted bandwidth has dropped by a factor of 100-1000, though the number of channels used has remained about the same.

The Coast Guard maintains microwave networks in major port areas to relay radar and communications traffic in support of Vessel Traffic Service (VTS) systems. Existing networks are being upgraded, and VTS is being planned for up to 40 more ports, as mandated by the Oil Pollution Act of 1990. This expansion will rely primarily on microwave networks, although some fiber may be used where it is feasible and cost-effective.

TVA has allowed several IXCs to install fiber optic circuits on the right-of-way on some of its power lines. In exchange, TVA got a portion of the fiber communications bandwidth to perform power line net SCADA functions without the typical microwave SCADA links.

Other Federal agency networks include many systems in remote areas like the National Forests to provide two-way radio and other telecommunication services used in the management of these areas. Some of these networks may be partially replaced with commercial services, possibly by a supplier who would bring additional commercial services (like paging, cellular phone, or SMR) into these areas. Although FTS 2000 encourages the use of commercial suppliers, most commercial radio services do not currently meet all of the functional requirements for Government mobile radio; these unfilled requirements include scrambling, pre-emption for priority calls, and group-call capabilities.

Many of these remote areas will continue to remain without commercial service because there is not sufficient traffic to make commercial service profitable for the supplier. Since many of the commercial carriers would use microwave backbone (in non-Government bands) to supply the services, a change to commercial services would not necessarily decrease the total number of microwave systems in use, but it would shift the use from Government bands to non-Government bands. There may be major advantages, however, to actively encouraging the sharing of Government and non-Government microwave backbone, where feasible, since many of these links are lightly loaded.

The U.S. military uses many transportable microwave links to rapidly bring communications to many regions throughout the world. Since communications will be increasingly important as a military force multiplier in future conflicts, it is likely that these transportable links will remain highly important to the U.S. Armed Forces. However, in the United States, they will be used only occasionally outside training ranges.

Many agency-specific microwave systems will continue in operation for the same reason that the systems were originally built: because they provide needed services which would not be available otherwise. Many of these systems are still implemented best with microwave, because of low traffic density, remote locations, difficult terrain, the need for high reliability, rapid deployment, etc. For some other systems, however, technology and other factors have changed since the systems were built. In particular, Government networks that have parallel networks provided by commercial suppliers may be affected by the present Government policy (including FTS 2000) which strongly encourages the use of commercial systems. We believe that the net result is that some agency-specific systems will eventually be replaced by commercial systems. This will tend to result in a commercial supplier serving a consolidation of Federal, state, and private telecommunication needs. These consolidated needs may be large enough to be served with fiber, but could also be met with microwave, satellite VSAT, or other appropriate technologies.

Table 4.2-3 summarizes the change in use for the Federal Government fixed services in the near future. This shows that we expect the Government use of fixed point-to-point microwave services to be stable in the near future (up 0.3 percent/yr for the next five years). The period ending in 1996 will be essentially a zero-growth period ending many years of continual increase; the next five years will be a period of actual decrease. We expect the Federal Government use to slowly decrease in the future: down five percent/yr for the period of 5 to 10 years from now. This decrease will be driven by the combination of: 1) increased availability of fiber, VSAT, and MAS, 2) declining defense funding at test and training ranges, and 3) increasing pressure to use commercial telecommunication suppliers.

Table 4.2-3. Summary of 5-Year Growth Trends for Government Microwave Bands

Frequency range	# of assn	% change	1996 assn	Comments
406-420 MHz*	7460 fxd	-3.0%	6,400	LMR backbone support
932-944 MHz*	1159 fxd	25%	3,500	Pt-pt, MAS
1350-1400 MHz	582	1%	610	Miscellaneous systems

Table 4.2-3. (Continued)

Frequency range	# of assn	% change	1996 assn	Comments
1427-1435 MHz	218	0%	220	Miscellaneous systems
1700-1850 MHz	6,114	2%	6,750	SCADA, LMR backbone,Pt-pt
2200-2300 MHz	2,258	1%	2,400	Telemetry, vital defense sys
4400-4990 MHz	1,582	1%	1,700	Transportable pt-pt
7125-8500 MHz	10,034	-2%	9,100	SCADA, test ranges, RCL
14.5-14.7145 GHz	418	3%	500	SCADA, data, video
15.1365-15.35 GHz	228	3%	260	Video, data
21.2-23.6 GHz	1,398	5%	1,800	General purpose data, voice
25.25-27.5 GHz	--------	--------	negligible	No current use
Totals	22,832		23,300	Net increase: 0.3% per year

* not included in the totals

4.3 Private Operations Service Bands

Private Operations services include services shown in Table 4.3-1. These services have been growing slowly. In addition, many older analog radios have been replaced with digital radios having greater reliability and capacity. The traditional mainstay of the Private Operational services near 2 GHz faces great uncertainty now, with the FCC proposal to reallocate these bands for PCS-related services. This will surely result in private growth moving to other bands, but many older systems may not be replaced.

Table 4.3-1. Private Operations Service Bands

Frequency band	Designation	Comments
928-929/952-953 MHz		MAS, shared with public
932-935/941-944 MHz		MAS, shared with public, Govt
953-960 MHz		Shared with public, international
1850-1990 MHz	"2 GHz"	being reallocated to Emerging Tech.
2130-2150, 2180-2200		being reallocated to Emerging Tech.
2450-2483 MHz		shared with AUXBC
2500-2690		mainly AUXBC
6525-6875 MHz		

Table 4.3-1. (continued)

Frequency band	Designation	Comments
12.20-12.70 GHz		shared with international
12.75-13.25 GHz	"13 GHz"	mainly CARS, shared with public, auxbc
17.70-19.70 GHz	"18 GHz"	shared with public, AUXBC, CARS
21.20-23.60 GHz	"23 GHz"	shared with public, Govt

Private operations service has traditionally been concentrated in three large areas:

1. System control and data acquisition (SCADA)
2. State and local governments
3. LEC bypass for office and industry.

SCADA operations include the monitoring and control of pipelines, electrical power lines, railroads, dams and canals, etc. SCADA operations have traditionally been limited to narrow bandwidths, slower data rates, long distances, and high-reliability requirements. Because of these requirements, SCADA has not faced such strong competition from fiber, which is normally competitive only at much higher data rates. At the present time, for example, several major telephone companies have a rule-of-thumb which suggests using microwave systems for applications requiring less than 500 Mbits/s. Since this is at least ten times the maximum rate obtainable with the Private Operations service in the 2 GHz band, it is likely that fiber will not be competitive in this environment. Narrowband SONET provides easier data drops than many other protocols, and may become more widely used in situations where a few functions have to be monitored every few miles.

In addition, fiber has a failure rate, mainly from cable cuts, which may exceed the failure rate that the SCADA application can tolerate. The use of fiber or wire would require a redundant backup system, increasing the cost still more. Thus, fiber is not a reasonable substitute for microwave for many SCADA applications.

On the other hand, it appears that many SCADA applications could be performed more cheaply with VSAT technology. A VSAT station is often much less expensive than a microwave station, and any location in the U.S. is within one hop of the VSAT hub. Therefore, a single VSAT station could replace multiple microwave links in some applications. In addition, the switched network and other private fiber networks are reaching more locations in the U.S., and many sites that in the past only had access by microwave will have more convenient and reliable access in the future.

State and local governments also use Private Operational services for regular administrative traffic and for law enforcement and public safety traffic. In Colorado, for example, the state government uses a statewide microwave network to provide LMR communications to State Highway Patrol officers and other state employees. The concentration of traffic within downtown areas may make this type of traffic a good candidate for bypassing the LEC, saving funds for the taxpayer. Law enforcement and public safety activities often require extensive radio nets, supported in remote areas of the state with regional or statewide microwave systems. In addition, such functions often use microwave to provide a highly reliable backup network in urban areas. These systems are usually too narrowband to make fiber a viable choice, so they will continue to grow, using microwave networks.

As with Federal Government LMR systems, some of the administrative traffic carried by private LMR systems in the past will be (or has been) switched to cellular telephone. However, the state and local governments must still maintain (and sometimes expand) their own microwave-supported LMR systems for law enforcement and public safety, etc., to provide expanded services over all of the geographical area for which they are responsible. Since most state governments have no policy comparable to FTS 2000, they are not as strongly encouraged to use commercial communication systems whenever possible.

By-passing the telephone company is another major use of Private Operational microwave. This is usually an economic decision, which can be decided by comparing the cost of communicating between two company locations via commercial telephone or via private microwave. Ten years ago, it was predicted that 23 GHz microwave would provide widespread LEC by-pass. However, the large market predicted for the 23 GHz band never occurred. Today, independent urban fiber providers are planning to provide another means to bypass the LECs.

Private Operational radio is also used to back up communications to some high-priority business and government applications, like stock exchanges and fire departments. In these cases, a private microwave link may be used to provide access to an adjacent central office or an IXC. Thus, some high-priority communications can be maintained, even if communications through the local central office are disabled.

IXCs, LECs, alternative suppliers, and cable TV companies are all installing large amounts of optical fiber and will continue to do so. Fiber will continue to become more available and more affordable, and will continue to compete more aggressively with Private Operations microwave.

In addition, many of the traditional users of Private Operations services --pipelines, electrical utilities, and railroads--already have ownership of long distance right-of-ways. They would find it particularly easy to parallel many of their existing microwave nets with optical fiber, which would greatly increase the traffic capacity of their networks. In the past, many fiber optic systems have been laid alongside railways or pipelines, or even inside pipelines. Recently, some electric utilities have incorporated optical fiber in the hollow core of the 'ground wire' that is strung along with the high voltage power lines. Even if microwave equipment is already in place and paid for, it may have a hard time being competitive with a modern fiber system which completely parallels its path.

We believe that the use of traditional Private Operational SCADA microwave service for utilities, pipelines, and railroads will decrease slowly. Some existing microwave networks will not be upgraded when the present equipment becomes obsolete and will cease operation when maintenance becomes too expensive. Some of the Emerging Technologies migration comments hint at this situation, when the commentors ask for reimbursement, even if the old microwave system is not migrated to another microwave band. On the other hand, there will continue to be numerous opportunities for private microwave to service low-capacity routes and routes across difficult terrain, where fiber paths will have problems. Many of the private links in urban areas will be shorter links using frequencies above 18 GHz. We believe that Private Operations SCADA service will decrease five percent in the near future (five years) and will decrease by another 20 percent in the next ten years.

On the other hand, we believe that microwave requirements for the state and local governments will increase ten percent in the next five years, and will increase by another ten percent in the following five years.

Table 4.3-2 summarizes the expected five-year use of the Private Operational microwave bands. We have omitted the 900 MHz bands from the totals, because they are substantially different in use and bandwidth. We expect considerable growth in the 900 MHz MAS and point-to-multipoint services.

Table 4.3-2. Summary of 5-Year Growth Trends for Private Operations Bands.

Frequency range	# of assgn	% change	1996 assgn	Comments
1850-1990 MHz	9,358	-4%	7,600	Emerging Tech band
2130-2150 MHz 2180-2200 MHz	6,114	-4%	5,000	Emerging Tech band
2450-2483 MHz	359	5%	460	ISM band, interference
5925-6425 MHz	-------	------	1,500	Migration from E.T. bands
6525-6875 MHz	16,577	3%	19,000	Some E.T. migration
12.2-12.7 GHz	1,906	-3%	1,600	DBS band allocation
17.7-19.7 GHz	2,384	20%	5,900	35% public, 65% private
21.2-23.6 GHz	6,041	5%	8,700	7% public, 93% private
Totals	42,739		50,000	Net increase: 3.2% per yr

The table above shows that for the next five years we expect a net increase in private microwave usage of 3.2 percent per year, with much of the growth occurring in the 18 GHz and 23 GHz bands. This analysis has assumed that no great shifts in technology or markets will occur. However, we recognize that the SCADA market is susceptible to competition from VSAT technology and the "by-pass" market is susceptible to competition from the growing local fiber market.

The trends for the next ten years are harder to predict. We assume that fiber will be much more available from many vendors in the urban areas, which will hit the bypass market. Better communications throughout the nation will continue to provide competition for SCADA and the state/local government markets, but better communication services will be needed in more remote locations. We estimate a continued growth for the five to ten year future block of about three percent, most of it in the higher frequency bands, including some use of 28 GHz, 31 GHz, and 38 GHz.

4.4 Public Service Bands

The Public Service bands are used by telecommunication common carriers, such as the telephone companies, cellular phone companies, and paging companies. These bands have historically been the most heavily-used bands and have developed much of the technology used in other services. The recent patterns of use in these bands is varied and striking.

Table 4.4-1. Fixed Public Service Bands

Frequency band	Designation	Comments
928-929/952-953 MHz		MAS, shared private
932-935/941-944 MHz		MAS, shared Government, private
953-960 MHz		shared private, international
2100-2130 MHz	"2 GHz"	cellular support, reallocated PCS
2160-2180 MHz	"2 GHz"	cellular support, reallocated PCS
3700-4200 MHz	"4 GHz"	shared fixed-satellite downlink
5925-6425 MHz	"6 GHz"	shared fixed-satellite uplink
6875-7125 MHz		mainly AUXBC, shared CARS
10.55-10.68 GHz	"10.5 GHz"	mainly DTS
10.70-11.70 GHz	"11 GHz"	
12.75-13.25 GHz	"12 GHz"	mainly CARS, shared AUXBC,private
17.70-19.70 GHz	"18 GHz"	shared AUXBC, CARS, private
21.10-23.60 GHz	"23 GHz"	shared Government, private
27.50-29.50 GHz	"28 GHz"	recently allocated to LMDS

The 2 GHz common carrier band is used for low capacity telephone links, especially in rural areas where the higher capacity of the 4 GHz or 6 GHz channels is not needed. The number of links in this use is remaining about constant. Some new rural areas are being served; some old links are being replaced with fiber.

The 2 GHz common carrier band is also used by cellular carriers to link cellular sites with each other and bypassing the local switched network whenever possible. Comsearch stated that 70 percent of all of their new microwave assignment coordinations in 1991 were being made in support of cellular telephone, and that the majority of these assignments were in the 2 GHz band. The resulting large growth rate for microwave common carrier bands will continue for the next two to three years--at which time, most of the cellular networks will have been largely completed.

Because the cellular companies are continuing to squeeze sites closer together to increase capacity by greater frequency re-use, the distance between sites is continually decreasing, which makes practical the use of higher frequency bands, such as 10 GHz, 11 GHz, 18 GHz, 23 GHz, and possibly even 38 GHz. This movement to higher frequencies will surely be hastened by the FCC's Emerging Technologies spectrum re-allocation. Depending on the time-scale for the implementation of the process, cellular carriers may continue to build new 2 GHz links, assuming that the links could be replaced with cheap fiber or cheap microwave technology five years from now. More likely, however, is that cellular will continue to build in 2 GHz until migration bands (probably the 6 GHz and 11 GHz bands) are rechannelized to include narrowband channels. When the migration band is available, new construction will quickly shift to the new bands.

The 4 GHz and 6 GHz bands were developed as the major telephone company long-haul and feeder bands. The 11 GHz band was used as a short-range overflow band. The 4 GHz and 6 GHz bands are being vacated as the common carriers switch to fiber. The switch to fiber optics is accelerated since older analog microwave equipment is being made obsolete by the switch to digital technology. In addition, the telephone companies need the high capacity made possible by fiber, which is not available with microwave. Finally, the telephone companies have adequate capital to pay for the change to fiber.

The conversion to fiber in the long-haul service is already a historical fact, with only a small amount of microwave remaining in that service. The conversion of feeder routes between central offices is already more than half complete. The major current work is the conversion to fiber communications from the central office to customer interface points. The 11 GHz band is showing the beginnings of what will be a substantial (50 percent) decline in use in the next ten years.

The 4 GHz band is also allocated on a co-primary basis to Fixed-Satellite service, which includes the downlink portion of the C-band TV relay satellites. The presence of about 18,000 licensed TV receive-only (TVRO) ground stations has created overlapping protection contours in many urban areas, which make it difficult to find locations where 4 GHz common-carrier microwave links can be assigned. In addition to the licensed TVROs which are legally entitled to interference protection, there are about three million nonlicensed private "back-yard" TVROs, which are not entitled to legal protection, but which can exert considerable unfavorable publicity from complaints. Thus, the 4 GHz band will be essentially unusable for new point-to-point microwave in most urban areas, even when the earlier common carrier microwave assignments have mostly been vacated. We believe that some 4 GHz band assignments have been retained by the common carriers in the knowledge that it will be impossible to ever re-use those assignments if they are relinquished; the existing TVROs will immediately claim the protection that they have been operating without (since they were assigned later than the microwave links), and no new microwave links will be possible.

The 6 GHz band is allocated on a co-primary basis for the uplink portion of the C-band TV relay satellites. Since the uplink sites do not need the same degree of protection and separation as the downlink sites, the 6 GHz band will still remain very usable after it is vacated by the majority of the common carrier microwave links. AT&T has historically held the great majority of the microwave links in the 6 GHz band; their proposal to use this band for PCS suggests that AT&T also believes that the band is ripe for major changes. Equally important, however, is the probable re-channelization of the 6 GHz band to provide some narrowband channels for private and common carrier systems migrating from 2 GHz.

The common carrier bands above 4 GHz will continue to see increased use for cellular, and possibly PCS applications. Initially, the 6 GHz, 10 GHz and 11 GHz bands will be used in place of the 2 GHz band. It seems certain that the future cellular and PCS systems will utilize relatively small cells, which could be efficiently connected with frequencies in bands at 18 GHz and above. Whether future PCS and cellular systems will be more extensively connected with fiber or microwave technologies will be determined by policy and technological factors that have not yet been determined. It seems reasonable, based on historical precedent, to predict that the LECs and cable TV companies will plan to use much less microwave in their PCS systems (since they already have an extensive fiber infrastructure) than any competitors will plan to use.

The LECs have been considering replacement of some conventional local loops with short range radio links. This would be done to reduce the cost of stringing wire in some very difficult (and often dangerous) urban neighborhoods. At least one LEC is planning to use DTS channels at 18 GHz to provide wireless local loop, and others have obtained experimental licenses in the 2 GHz band for the same service. In addition, fixed radio systems like BETRS at 450 MHz may be more extensively used to provide telephone service to some rural neighborhoods, where radio is less expensive than installation of wires. (BETRS is a long-range system for sparsely-populated rural areas where there should be less competition for radio spectrum.) The other local loop radio services are very short range (several hundred meters) and should offer very efficient frequency re-use.

Microcell technology using fiber to carry RF signals between a central point and a very simple remote PCS or cellular antenna site is an example of innovative technology that could make a significant difference in the relative economic desirability of using microwave or fiber to connect PCS and cellular sites.

We predict continued emptying of the 4 GHz and 6 GHz bands by the common carriers, to the point where only 30 percent of the LEC and IXC channels will still be used in five years. The 6 GHz band, however, will be rechannelized and will gain a large number of cellular and private operational customers, resulting in a two percent net yearly loss for the next five years. The LEC use of the 11 GHz band will decrease substantially in five years, but will also be partly balanced by added cellular and private use, giving a net decrease of seven percent a year. (Note, however, that each RBOC has chosen considerably different strategies in their use of the microwave bands.)

The 18 GHz and 23 GHz bands have only moderate use now, but their use is expanding rapidly. The 28 GHz band remains unused at this time, but it has been recently proposed for re-allocated to LMDS.

Table 4.4-2 summarizes the expected use of the public bands in the next five years. (The 900-MHz bands and the MMDS bands have not been included here, because of the substantially different nature of those bands.)

Table 4.4-2. Summary of 5-Year Growth Trends for Public Microwave Bands.

Frequency range	# of assn	% change	1996 assn	Comments
2110-2130-MHz 2160-2180-MHz	6329	5%	8,100	Cellular expansion
3700-4200-MHz	33,174	-15%	14,700	Move to fiber
5925-6425-MHz	18,679	- 4%	15,200	cellular, to fiber
10.55-10.68-GHz	893	25%	2,700	DEMS band
10.7-11.7-GHz	7,609	- 7%	5,300	Move to fiber
17.7-19.7-GHz	1,499	20%	3,700	.35 public, .65 priv
21.1-23.6-GHz	492	9%	760	.07 public, .93 priv
27.5-29.5-GHz	-- 0 --	----	----	Negligible use to date
totals	68,675		50,500	net decrease: -6.0% per yr

The use of these bands ten years into the future is expected to be influenced by many of the same factors. Fiber replacement of microwaves will be even more extensive, with additional help from the cable and private urban fiber companies, as well as from extensive fiber-to-the-curb programs by the LECs. The greatest uncertainty is how PCS will be implemented, and who will do it. If it is provided by the LECs, very little additional microwave will be used. A non-LEC or non-cable supplier will use much more microwave, with many of the PCS microwave links at 38 GHz.

4.5 Auxiliary Broadcasting Service Bands

The Auxiliary Broadcasting service consists of two completely different types of services: 1). fixed links use for studio-to-transmitter links (STL), inter-city-relays (ICR), transmitter-to-studio links (TSL), and ENG relays, and 2). electronic news gathering (ENG) services. The fixed STL/TSL/ICR are carefully engineered and are typically used on a 24-hour-per-day basis. The ENG services represent a much more dynamic operation, typically moving to multiple locations each day, often alternating between being totally unused or being saturated and in need of tight time sharing of the few available frequencies.

Table 4.5-1. Auxiliary Broadcasting Service Bands

Frequency band	Designation	Comments
944-952 MHz		aural STL, ICR
1990-2110 MHz	"2 GHz"	ENG, STL
2150-2160 MHz		MDS
2450-2483 MHz		shared with private
2500-2690 MHz	"2.5 GHz"	mainly MMDS, also private, broadcasting (ITFS)
6875-7125 MHz	"7 GHz"	shared with public, cars
12.7-13.25 GHz	"13 GHz"	mainly CARS, shared with public, private
17.70-19.70 GHz	"18 GHz"	shared with public, CARS, private

A 1989 survey of television stations in the 50 major markets by NAB on current and planned usage in these frequency bands[19] elicited 350 usable replies (76.6% response rate). The current use of various frequency bands and alternative services for STL, ICR, and ENG are summarized in Table 4.5-2 below.

[19]Cohen, E., *Television Auxiliary Frequencies Usage Surveys*, NAB Research and Planning, June 1989.

Table 4.5-2. TV Auxiliary Broadcasting Use by Frequency Band

freq band/ medium	Stations w/STL	Ave # of STLs	Stations w/ICR	Ave # of ICRs	ENG relays	Stations with ENG	Ave # of ENGs
2 GHz	66	1.23	55	1.98	16	191	4.78
2.5 GHz	4	1.00	-	-	52	25	2.12
7 GHz	238	1.40	157	2.58	98	39	2.49
13 GHz	13	1.47	120	2.67	91	132	2.58
18 GHz	3	1.0	9	1.89	5	-	-
23 GHz	-	-	-	-	24	11	1.91
40 GHz	-	-	-	-	-	3	1.00
DS-3	32	*	30	*	*	*	*
Fiber	20	*	28	*	*	*	*
Coax	18	*	13	*	*	*	*

The same survey indicated broadcaster plans to substantially increase their use of ENG (mostly at 2 GHz), with some additional use of STLs and ICRs. An asterisk (*) in the preceding table indicate no information; a dash (-) indicates no use of the indicated function. "Stations with STL" indicates the number of stations (out of 350 responding) that have at least one STL in the indicated frequency band. The "Av # of STLs" indicates the average number of STLs used by each station. Similar meanings are attached to the columns dealing with ICRs and ENGs. ENG relays are used to relay signals from ENGs to the station or to other relays. "ENG relays" indicates the total number of stations that used at least one ENG relay; the report did not indicate how many ENG relays the stations used.

The heavy use of the spectrum in the 1990-2110 MHz band (2 GHz band) and the apparent lack of alternatives has resulted in this band being excluded from the list of bands that the FCC designated for Emerging Technologies.

Predicted band use. The AUXBC bands are mostly allocated for the same services, i.e. STL, ICR, ENG, and ENG relay. Therefore, the use of one particular AUXBC band over another is often a somewhat arbitrary choice, based on relative availability of frequencies, compatibility with existing equipment, and a general consideration of required path length and equipment size, etc. Therefore, the discussion of future band use will proceed in a topical manner--with the assumption that a given topic applies to many bands, followed by a specific discussion of particular bands.

HDTV and digital compression. The arrival of HDTV will cause considerable upset in the AUXBC bands, which will cause some initial crowding as stations make room for additional STL/ICR and ENG. However, it is not likely to suddenly result in a doubling of the number of AUXBC links required (one for NTSC, one for HDTV). ENG coverage will usually be provided by a station in either format (not both) and converted to the other format at the studio.

Independent NTSC and HDTV STLs will be required for many stations. It is expected that somewhat different programming and commercials will be used for HDTV and NTSC, and the two transmitters may be located at different sites. Presumably, the HDTV program material will be in compressed digital format in the HDTV STL, complete with error correction and a well-engineered path, so only a 6 MHz channel will be needed. This is less bandwidth than the present 15-25 MHz analog FM signal used in current NTSC STLs and ENGs. It is unlikely that existing STL/ICR/ENG relay equipment will handle the digital formats of the HDTV signals, so investment in new equipment will be necessary. Since many stations share transmitting sites, the cumulative need to upgrade transmission facilities for HDTV could trigger installation of fiber at many sites.

STL, ICR, and ENG relay. TV broadcasters and cable companies will continue to develop more elaborate networks to produce programming and to relay that programming to their viewers. At the present time, most of those networks are implemented with microwaves. Optical fiber will continue to become cheaper and more widespread, however, and a larger proportion of the fixed video links will be carried via fiber. In particular, the experience that cable companies and others gain with installing and maintaining fiber video systems, as well as the presence of alternative fiber companies, will make fiber a much more available and attractive medium. By 1996, we estimate that the number of microwave video links will have risen 30 percent, leveled off, and begun decreasing at a five percent a year rate.

ENG. We believe that ENG will continue to increase in popularity, as the mobile and portable TV equipment gets cheaper and better, and as viewers expect improved live coverage of events. This phenomena--rather than HDTV--will put additional pressure on the spectrum in this service. One reaction to crowding in the 2 GHz band (the most popular band for ENG) will be to move to the higher frequency bands. This not only has the advantage of providing more bandwidth, but the antennas are much more directional and can support more frequency re-use. The 13 GHz band is already the second-most popular band for ENG, and it will have additional advantages when used over shorter paths.

ENG is a mobile service that cannot be served as easily with fiber or other parts of the permanently-anchored infrastructure. On the other hand, fiber and other wideband digital links will be getting continually more available, more buildings will be wired with fiber, and there will be more opportunity to tap into a copper or fiber circuit back to the studio (replacing ENG and ENG relay), particularly at popular ENG locations like stadiums, state legislatures, airports, etc. Since ENG is a very intermittent operation, it would also be possible to send it over the switched telephone network, using switched DS-3 on a demand basis. In a future fiber-to-the-curb or ISDN environment, this capability might be available at many commercial and public locations. Although the billing rates would presumably be high, only a few minutes would be needed at a location. At present, DS-3 is not widely available on a demand basis through the LECs.

Optical fiber. Replacing fixed links (STL, ICR, and ENG relays) with fiber will become increasingly attractive. The cost of fiber components will continue to decrease, and fiber will continue to become more widespread throughout metropolitan areas, making redundant fiber structures more available. Since studios will have twice as many program channels to transport to the transmitter, the economic factors will be tilted toward the economies of scale that fiber provides. The digital format of HDTV will be particularly compatible with digital fiber technologies. The alternative cost of purchasing new digital microwave STL systems for HDTV will offset some of the cost of fiber. Finally, sheer number of links required will exceed the amount of available spectrum in some locations, and the switch to fiber may be the only viable alternative. Industry may choose to free up STL and ICR spectrum so that it can be used with ENG operations. We believe that many fixed transmitters will be replaced by fiber as part of the process of adding HDTV to existing NTSC stations, with additional fiber replacement occurring more gradually afterwards. The switch to fiber has already begun in several major metropolitan area (e.g. Washington DC, New York, and Los Angeles).

The expected use of the auxiliary broadcasting bands are summarized in Table 4.5-3. The three bands in the table with "N. A." are bands where other services are dominant and the dominant services are expected to increase substantially. The 2150-2160 MHz and 2500-2690 MHz bands have recently been allocated to MMDS (wireless cable), which is expected to expand rapidly. Although we were unable to get current assignment information about these two bands, we believe that AUXBC use is relatively low (table 4.5-2 shows 56 AUXBC assignments in the 2.5 GHz band) and will go down if MMDS is greatly successful. In the 12.75-13.25 GHz band, the major numerical growth is in the CARS assignments, though the AUXBC use of the band is also active and growing.

Table 4.5-3. Summary of 5-year Growth Trends for Auxiliary Broadcasting.

Frequency range	# of assgn	% change	1996 assgn	Comments
944-953 MHz*	1,790	20%	4,500	Aural STL and ICR
1990-2110 MHz	1,536	15%	3,100	ENG, STL, and ICR
2150-2160 MHz*	N. A.	decrease#	N. A.	MDS, newly part of MMDS
2450-2483 MHz	82	10%	130	ISM band. STL, ICR, ENG
2500-2690 MHz*	N. A.	decrease#	N. A.	New MMDS band, ITFS, MDS
6875-7125 MHz	2,607	5%	3,300	ENG, STL, ICR, ENG relay
12.7-13.25 GHz*	N. A.	increase#	N. A.	ENG, STL, ICR, ENG relay Mostly CARS head-end relay
17.9-19.7 GHz	148	25%	450	
Totals	4,373		7,000	net increase: 10% a year

* not included in totals. #includes only the AUXBC portion of assignments.

Although we estimate that the number of assignments will almost double over the next five years, it is not clear that the AUXBC bands will be more crowded than they are now. It would be technically possible to decrease the bandwidth of the NTSC FM microwave channels to half of their present 16-50 MHz bandwidth. In addition, the HDTV signal can probably be transmitted in a 6-MHz bandwidth (less than half of their current bandwidth of 16-25 MHz. We note in section 3.8 that the current state of video distribution is undergoing great change and it is not yet clear what technologies or services will gain the greatest acceptance.

4.6 Cable Television Relay Systems

Cable TV relay systems (CARS) use fixed links in many of the same ways that auxiliary broadcasting (AUXBC) does, and electronic news-gathering (ENG) for cable is permitted in most of the AUXBC bands. ENGs are used extensively by multiple system operators (MSOs) such as ESPN, CNN, and some local cable organizations. Studio-to-headend links (SHLs) are used to bring signals from individual TV channels to the cable origination point (headend). These links may also take the form of a single wideband signal carrying a block of up to 42 channels in NTSC format from an outlying satellite teleport to multiple cable headend sites in a metropolitan area.

We have also included multipoint distribution service (MDS), and multichannel, multipoint distribution service (MMDS) in this section. Although these services are actually allocated to the Public service, they are used today as an alternative to cable or broadcast TV. The term 'wireless cable' is usually applied to MMDS.

Table 4.6-1. CARS Service Bands

Frequency Band	Designation	Comments
2150-2160 MHz		shared with public (MDS)
6875-7125 MHz	" 7 GHz"	shared with public, AUXBC
12.7-13.25 GHz	"13 GHz"	mainly CARS; public, AUXBC,private
17.70-19.70 GHz	"18 GHz"	shared with public, AUXBC, private

Table 4.6-2. MDS/MMDS Service Bands

Frequency Band	Designation	Comments
2150-2162 MHz		shared with CARS
2500-2690 MHz	"2.5 GHz"	shared with public, AUXBC, CARS

Table 4.6-3 Summary of 5-Year Growth for CARS and MMDS Bands.

Frequency range	# of asgn	% change	1996 asgn	Comments
2150-2162 MHz	100	82%	2,000	Combined with 2500-2690
2500-2690 MHz	100	82%	2,000	recent allocation for MMDS
6875-7125 MHz	2,607	5.0%	3,300	shared with AUXBC
12.75-13.25 GHz	107,402	-5.0%	83,000	CARS band
17.9-19.0 GHz	148	25%	450	General-purpose band
Totals:	110,357		90,000	net decrease: -4% a year

The totals are not particularly useful since the bands are not used for the same purposes, but the individual band numbers are useful. MMDS, though just beginning, will grow rapidly. The 13 GHz band will grow in the near future but will decrease rapidly later, as it begins to be replaced with fiber.

The 7 GHz and 18 GHz bands will grow. However, none of these bands should be considered to be heavily used now, except for the 12.75-13.25 GHz band.

CARS seems to have adequate spectrum, as long as the basic nature of the service doesn't change drastically. However, one should note that cable systems seem to be poised for significant changes in any of several possible directions. These possible changes include:

1. Cable may attempt to compete with the LECs, developing their own versions of fiber-to-the-curb, PCS, interactive video, video dial tone, LANs, etc.

2. Cable may add digital compressed NTSC and/or HDTV. The first would greatly increase the number of channels available; the second would dramatically increase the quality of the presentation.

3. Cable may experience competition from the LECs, who will provide "video dial tone" in conjunction with their fiber-to-the-curb systems.

4. Cable may experience competition from MDS and MMDS "wireless cable" systems, LMDS 'cellular cable', and new direct broadcast satellite (DBS) systems.

5. The recent regulation of cable by the Government to control consumer costs may inhibit the rate at which cable can make changes to the services that they offer.

In all of these areas of possible change, it would seem reasonable to expect that the cable systems would implement their new services over the existing coaxial cable and fiber systems which cable companies have become expert at setting in place. In any expansion of service, of course, there may be occasional needs for microwave links to tie parts of the system together or to tie to LECs or IXCs.

Many CARS SHLs will be replaced with fiber links to cable head ends. This is partly an economic question, with the increased bandwidth of cable pushing many CARS links into the area of traffic volume where fiber is more economical than microwave. The future cable configurations will utilize fiber trunks and feeders; the extension of fiber to the distribution hub will often be accomplished at the expense of microwave SHLs. In addition, the ability of cable to add extra services--especially 2-way services--will be dependent on having a continuous fiber network, without the restrictions of the one-way microwave SHL architecture.

The amount of fiber available in rural areas will be one major factor in determining how much microwave is used in rural areas. The expansion of fiber-based TV distribution into rural areas (possibly combined with telephone and other telecommunication services) might provide strong competition to microwave used for MMDS.

Although the 1996 numbers show an increase over the 1991 numbers, we believe that microwave use in the CARS bands will have reached a peak by 1993 and begin decreasing by 5 percent a year. The MMDS bands will be reaching a maximum around 1996, with the most promising markets already built up. Growth may continue in the MMDS bands, depending on how successful they are in meeting the competition from VHF and UHF broadcasting, cable, satellite, satellite DBS, and telephone fiber-to-the-curb services.

5. CONCLUSIONS

This study has examined more than 30 of the frequency bands above 406 MHz with primary allocations to the Fixed services, including Government, non-Government, and shared bands. Although there were a wide range of circumstances and services represented by the bands included in the study, a single common trend affecting almost all bands and services is that optical fiber technology is rapidly taking a continually greater share of all Fixed telecommunications traffic.

The trend is strongest in the common carrier bands used by the LECs and IXCs, where the high traffic density has made fiber particularly advantageous. A similar strong trend is expected to develop in the next few years in the CARS and AUXBC services, where fiber will replace many SHLs, STLs, and ICRs. The replacement of SHLs, STLs, and ICRs will free up spectrum needed for projected growth in ENGs. It is likely that the CATV companies, now consuming much microwave spectrum for SHLs, will build extensive general-purpose fiber networks and perhaps even become "net exporters of microwave spectrum." (They will not only free up most of their present microwave spectrum, but will provide extensive fiber services to other current microwave users, freeing up more microwave spectrum in other services than they use themselves.)

Although optical fiber technology is rapidly capturing the central core of the traditional point-to-point microwave Fixed services, it is leaving a number of niche markets to be served by microwave. These niche markets will be much more resistant to replacement by fiber, and some may even show considerable growth over the next 5 or 10 years. These niche markets are defined by one or more of the following factors:

1. Temporary or transportable operations. This includes military and emergency restoral operations, as well as electronic news gathering (ENG) and TV coverage of special events (sports, entertainment, etc.)

2. Communications over difficult terrain. This includes rivers, lakes, mountains, wilderness areas, etc. This also includes operations over any type of terrain where it is physically or administratively difficult to install or maintain optical cable systems. Right-of-way difficulties, political boundaries, vandalism, etc. might be additional factors here.

3. Low traffic density routes. Microwave will probably remain less expensive for low traffic requirements for many years, because of the high initial cost to install fiber.

4. High reliability. Because optical fiber cable can be accidently cut, microwave may provide better reliability and faster repair. However, the development of fiber rings may remove many of the reliability problems with fiber. Microwave will be used to back up fiber for a limited number of highly critical operations.

5. Rapid implementation. This factor covers a range of applications, where the time available for deployment may be weeks to months, but still considerably shorter than the time needed to implement optical fiber cable.

6. By-pass of the LEC. Some special-purpose applications can be provided more cheaply with the installation of a special-purpose microwave system designed to carry data directly between two locations, without involving the public switched network.

Applications which typically benefit from one or more of these factors include:

1. SCADA - Factors include difficult terrain, low traffic, high reliability
2. Military - Factors include transportable, difficult terrain, high reliability, rapid implementation.
3. Rural communications - Factors include low traffic, possibly difficult terrain.
4. Cellular telephone and (possibly) PCS - rapid implementation, low traffic, high reliability, LEC bypass, sometimes difficult terrain.
5. Emergency/safety-of-life municipal services - Factors include high reliability, low traffic.
6. Electronic news gathering (ENG) - Factors include transportable operations and rapid implementation, sometimes difficult terrain.

Microwave systems will often have advantages over fiber for the above applications, and microwave will continue to dominate these niche markets. In addition, microwave may be more widely used by business for LEC by-pass, based on a simple cost comparison of the various alternatives. This is a more difficult prediction, because it is based on a comparison of two costs--each of which is decreasing rapidly.

Many new telecommunication services will surely be developed; some of these services may be delivered best by Fixed microwave radio. Because of the substantial uncertainty concerning what these services will be and when (or if) they might become widely used, we cannot include these services in the predictions. Such systems might include PCS applications, LDMS, or a wide range of future tetherless fixed systems like wireless LANs.

The following list summarizes predictions for the next five years for the 5 major market divisions examined. The significance of the projected percentage change can be estimated somewhat by considering the number of existing Fixed assignments as of December 1991 (non-Government) and January 1992 (Government).

Market division	# of assignments	Predicted annual growth rate for next 5 years
Federal Government	22,800	0.3%
Private Operations.	47,700	3.2%
Public service.	68,700	-6.0%
Auxiliary Broadcasting	4,400	10% (mainly ENG growth)
Cable TV	110,400	-4.0%

These predictions indicate that the general use of Fixed microwave systems will decrease over the next 5 years, but that certain niche markets will grow. Much of the expected growth will be in frequency bands above 10 GHz.

These predictions are strictly the opinion of the authors and have received no NTIA approval or sanction.

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