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21 Private Frequency Coordination In The Common Carrier Point-To-Point Microwave Service

September 1986

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PRIVATE FREQUENCY COORDINATION
IN THE COMMON CARRIER POINT-TO-POINT MICROWAVE SERVICE

(A Review of Procedures and an Empirical Assessment of Its
Effectiveness in Promoting Economically Efficient Use of the Spectrum)

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I. INTRODUCTION

Applicants in the Common Carrier Point-to-Point Microwave Radio Service (hereinafter CCPMRS) must coordinate their proposed frequency usage with existing applicants and licensees with whom they may interfere prior to filing their applications with the Commission. This coordination requirement protects existing systems from interference from subsequently authorized systems and forces new applicants to internalize the interference-related costs of their proposed systems in much the same way as other costs. In the CCPMRS, coordination is coupled with an unusual degree of technical flexibility which provides applicants a wider range of options in solving particular interference problems. The incentives created by this regime are believed to motivate applicants to find solutions that reflect the economic value of the spectrum.¹

¹ For an analysis of the economics of private frequency coordination see Agnew, et al, 1979, pp V-1 through V-38. The author characterizes coordination as a system of limited, transferable property rights which protects users from interference and creates incentives that encourage economically efficient use of the spectrum. A spectrum management technique is economically efficient if it encourages spectrum to be employed in those uses which yield the highest economic output to society. This in turn implies the existence of incentives to conserve spectrum according to its economic value, ie., to design and use radio systems which consume only as much spectrum as will produce the desired product at the lowest overall cost to society.

Because of its theoretical efficiencies, the CCPMRS regime is of interest as a potential model in the development of future spectrum management policies. The service is also of interest in understanding how (and how well) the private sector responds to increased spectrum management responsibilities, particularly such common interest functions as database management and standardization which require consensus building among all or a large number of users. Because the CCPMRS has been in existence for many years it is a particularly attractive subject for empirical study into the viability of increased reliance on the private sector in the management of the radio spectrum.

From outward appearances, the regulatory approach seems to be working quite well, with continued growth in services, development and implementation of new technologies, and few conflicts or other problems requiring the Commission's attention. However most of the day-to-day spectrum management activities associated with the service take place within the private sector and are therefore not generally visible to the Commission. Also, while theoretical analysis suggests this type of regime will lead to economically efficient use of the spectrum, there would be greater confidence in this conclusion if it could be substantiated by factual evidence.

This report is divided into two parts. The first part reviews the Commission's rules and policies governing frequency coordination and other

aspects of spectrum management in the CCPMRS. It also traces the development of industry practices and standards that have grown out of these rules. Part 2 is an empirical study making a comparison, based on FCC assignment data, of transmitting equipment authorized in a generally congested area (New York City) with that in a generally non-congested area (the state of North Carolina). The hypothesis is that transmitters in the congested area should be generally more spectrum efficient² in response to higher spectrum value. This would be an expected outcome of a regulatory regime that encourages economically efficient use of the spectrum. A positive finding would provide empirical evidence of the efficiency of the CCPMRS regime.

The transmitter characteristics examined in Part 2 are frequency tolerance, modulation efficiency, antenna size and antenna type (horns vs. parabolics). The relationships between these parameters and spectrum efficiency are discussed, and, where possible, predictions are made regarding the kinds of differences that can be expected between the two areas based on an analysis of licensee motivations under an economically efficient regime. The predicted outcome in each case is compared with the empirical study and conclusions discussed.

² The terms "spectrum efficiency" and "technical efficiency" are used interchangeably in this report to refer to the quantity of information transferred by a radio system per unit of spectrum consumed.

II. PART 1: REGULATION AND INDUSTRY PRACTICES

A. Introduction

Applicants in the CCPMRS are required to select the individual frequencies and locations for their proposed transmitting facilities. They are also required to engineer their proposed systems to avoid interference to or from previously authorized or planned usage and to coordinate with anyone who could potentially experience interference from the proposed operation before filing applications with the Commission. These policies ensure that interference conflicts are resolved through private negotiations before applications are filed, thereby minimizing the need for arbitration through cumbersome and time consuming administrative processes. Another important consequence of these policies is to allocate interference avoidance costs to applicants, thus encouraging system designs and frequency selections that minimize interference and ensuring that each new use ultimately implemented has a value at least as great as the cost of the interference it causes.

Because of the apparent efficiency advantages of this form of prior coordination, there is interest, from a spectrum policy perspective, in

studying the technique and in possibly applying it more widely in other frequency bands and services. However, many of the detailed standards and day-to-day procedures used in prior coordination in the common carrier microwave bands have been developed informally within the private sector and are not well documented. The purpose of this part of the study is therefore to present a more comprehensive documentation of the prior coordination process, including industry practices and standards. A review of relevant regulations and a brief history of the development of the service are also included.

B. Historical Perspective.

1. Common Carrier Point-to-point Microwave Radio Service.

Microwave radio communications evolved from radar technology developed during World War II. Following that war, developmental efforts shifted toward commercial applications. By avoiding the costly rights-of-way required for wire and cable, microwave technology was seen as an economically attractive alternative for point-to-point communications services such as long distance transmission of telephone traffic and networking of broadcast stations.

Development moved rapidly from the laboratory to field tests following the Commission's decision in 1945 establishing specific frequency

allocations in various bands above 1 GHz for microwave relay services.³ Included in those allocations were the current 4, 6 and 11 GHz common carrier bands, designated initially for general non-government fixed and mobile service and limited to experimental/developmental use. In 1946, the bands 3700-4200, 5850-6350 and 10500-11500 MHz were allocated exclusively for common carrier use.⁴ The two higher bands were later adjusted to 5925-6425 and 10700-11700 MHz, which are the current limits in Part 21.

The first commercial microwave inter-city relay system, operating in the 4 GHz band, was constructed in 1945 by Western Union between New York City and Philadelphia. This system was later extended to Washington, Pittsburgh, Cincinnati and Chicago. In 1948, AT&T installed its first commercial system, also in the 4 GHz band, linking New York and Boston. Over the next 10 years the AT&T system expanded nationwide covering some 27,000 route miles, and by 1968 it had grown to 48,000 miles. Western Union's system also expanded, although less dramatically, and some of the independent telephone companies constructed limited systems of their own.

³ Report of the Federal Communications Commission "In the Matter of Allocation of Frequencies to the Various Classes of Non-Governmental Services in the Radio Spectrum from 10 Kilocycles to 30,000,000 Kilocycles", Docket No. 6651, May 25, 1945, 39 F.C.C. 68.

⁴ Public Notice, July 19, 1946, 39 F.C.C. 242

During the first 20 years of its existence, the CCPMRS was a de facto monopoly of the wireline based carriers, dominated by AT&T. However, in 1969 the Commission authorized a non-wireline company, MCI, to construct a 6 GHz system between St. Louis and Chicago and to provide specialized common carrier private line data and telephone transmission services.⁵ Within a few months following the MCI grant, the Commission received a large number of applications for similar facilities from MCI and other companies seeking to enter the long-distance common carrier business. In 1970, the Commission initiated an inquiry proceeding to formulate regulatory policies concerning these new specialized common carrier services (see discussion of Docket 18920, below). The proceeding culminated in 1971 with the adoption of licensing rules, including the requirement for prior coordination.

2. Domestic Satellite Services.

On September 21, 1965, the American Broadcasting Companies, Inc. filed the first application with the Commission for a domestic communications satellite system. The proposed system was to be used for one-way distribution of network television programming from earth station

⁵ FCC Decision, Adopted August 13, 1969, "Microwave Communications, Inc.", 18 F.C.C. 2d 953.

transmitters in New York and Los Angeles to receive only stations at network affiliates throughout the U.S. The application proposed use of the 4 and 6 GHz common carrier bands, which had been allocated internationally for satellite use at the 1963 World Administrative Radio Conference for Space Telecommunications.

On March 2, 1966, the Commission returned the ABC application and issued a Notice of Inquiry⁶ to develop its policies regarding domestic use of communication satellites. Included in the inquiry were questions about potential interference between domestic satellite systems and the extensive terrestrial microwave operations in the 4 GHz band. In addition to responding to the questions in the inquiry, parties were invited to submit concrete proposals for domestic satellite systems.

System proposals were received from ABC, AT&T, Comsat and the Ford Foundation. After evaluating these proposals and the responses to the inquiry, the Commission, on March 20, 1970, issued a decision setting forth its tentative licensing policies and inviting applications for construction

⁶ Docket 16495, Notice of Inquiry, 31 FR 3507; Supplemental Notice of Inquiry, October 20, 1966, 31 FR 13763, 5 F.C.C. 2d 354.

permits.⁷ Included in the appendix to the decision was a "Technical Annex" outlining the procedures to be used in calculating earth station "coordination contours" within which more detailed studies of potential interference to or from terrestrial stations were required. These interference calculations were to be submitted to the Commission along with the domestic satellite system applications.

The domestic satellite decision contained no explicit requirement for direct coordination between satellite system applicants and terrestrial licensees, although any such coordination that had taken place was to be reported in the application. Applicants were also instructed to "endeavor to find suitable locations for earth stations that present the least amount of potential interference problems." Rules requiring prior coordination of earth stations were later included in Part 25 following the decision in Docket 18920 (see below) to require coordination of terrestrial system.

3. Docket 18920.

Following the initial MCI grant in 1969, the Commission received a large number of applications for common carrier terrestrial microwave

7 Report and Order, Docket No. 16495, 22 F.C.C. 2d 86

systems. Most of these applications requested frequencies in the 6 GHz band and were filed without prior frequency coordination with existing carriers or other applicants. The result was that many of the proposals were mutually incompatible or posed potential interference conflicts with existing or planned frequency usage of the established wireline carriers. In July 1970, in response to these applications, the Commission initiated proceedings in Docket 18920 to develop policies towards the licensing of specialized common carrier services.⁸

In its initial decision in the proceeding,⁹ the Commission decided that it would not resort to comparative hearings to choose among the conflicting applications. Instead it expressed the opinion that all or most of the proposals could be accommodated without interference or undue costs if applicants would engineer their systems to minimize interference and coordinate their frequency usage. Based on this finding the Commission adopted rules making prior frequency coordination mandatory and applied the policy retroactively to the group of applications then on hand. Pending applications in conflict with existing stations were returned for coordination whereas conflicts between pending applications were resolved by

8 24 F.C.C. 2d 318

9 First Report and Order, Adopted May 25, 1971, 29 F.C.C. 2d 870.

assigning responsibility for corrective action to the applicant having the most recent application. The policy of mandatory prior coordination of terrestrial common carrier microwave facilities was incorporated into the Commission's Rules as new paragraph 21.100 (d).

C. General Regulatory Framework.

1. The Basic Regime.

The most fundamental aspect of the CCPMRS regime is the service definition itself. Contained in Section 21.2, the definition reads as follows:

Point-to-point microwave radio service. A domestic public radio service rendered on microwave frequencies by fixed stations between points which lie within the United States or between points to its possessions or to points in Canada or Mexico.

The definition limits the service both in terms of permissible system design, i.e., must be "rendered on microwave frequencies by fixed stations between points," and in terms of licensee eligibility, i.e., the service must be "domestic public". The definition thus excludes common carrier

currently being marketed must meet the frequency tolerance standard, older transmitters not meeting the standard may continue to be used as long as they are not involved in interference conflicts which would not exist if the standard were met. In case of such a conflict, the non-compliant transmitter may have to be replaced or brought into compliance at the licensee's expense even though it may be the earlier authorized system. The same reversal of protection applies to existing and new antennas not meeting the Commission's standard "A" specification. Hop lengths shorter than the minimums specified in the rules may be authorized if applicants can show compliance would result in excessive costs, and transmitters may be pointed within 2 degrees of the geostationary orbit where "there is no reasonable alternative" and subject to a prescribed decrease in power.

Perhaps the most interesting aspect of the CCPMRS technical regulations is what they do not contain. Except for the antenna pointing rule (and of course the general allocation constraint) there are no a priori restrictions on the selection, location or orientation of specific frequency assignments. There are no prior allotments of channels to markets, as in the broadcast services; no pre-channelization of the band, as in the private microwave and most other services; and no minimum mileage separations as in the private land mobile services. Perhaps most notable of all is the absence of even a working definition of harmful interference. Individual licensees are allowed to set their own protection ratios. While this could theoretically lead to abuses or confusion, that apparently has not happened. Whether

re-engineer a proposal in cases involving conflicts." A unique feature of this service is the extension of protection not only to existing and applied for assignments but also to planned usage. Section 21.100 (d) states that "Applicants should make every effort to avoid blocking the growth of systems that are likely to need additional capacity in the foreseeable future."

As discussed at greater length elsewhere in this report, exclusivity in the context of the CCPMRS means that once the coordination process has been initiated for a proposed frequency usage, that proposed usage has priority, enforced by the Commission, over any subsequently proposed use which may result in an interference conflict. The only exception to this general policy occurs where the otherwise protected facilities do not meet certain minimum performance standards, in which case the existing licensee may be required to upgrade to the standard if that will eliminate the interference conflict (see more on this in the following section).

2. Technical Rules

Licensees in the CCPMRS are subject to a number of technical regulations, the most important of which are summarized in Table 1. These rules effect a variety of regulatory controls: the limits on frequency tolerance, transmitter power, antenna directivity, authorized bandwidth and emission rolloff define the maximum bandwidth and geographical extent of

During the initial years of microwave implementation, interference avoidance was mostly an intra system concern as AT&T planned and implemented its nationwide microwave system in the 4 GHz band. When other companies began entering the business in the early 1970s, however, interference avoidance and coordination increasingly required consultations between different licensees and the need for industry consensus on standard criteria and procedures became clear. In response to that need, engineers representing the various licensees and technical consulting firms involved in frequency coordination found it useful to meet informally every year or so to discuss and resolve technical and procedural matters of common interest. What started as a small group of 10 or so has now evolved into a national industry association with approximately 100 members. This group, known as the National Spectrum Managers Association (NSMA), was organized in Rockville, Maryland in August 1984 and has held annual conferences in San Diego, California (April 1985) and Orlando, Florida (April-May 1986).¹²

The basic technical work of the NSMA is carried out through a working group structure formed to focus on specific coordination issues. The titles

¹² Account based on conversations with NSMA principals and articles in the NSMA newsletter.

each frequency assignment; the antenna pointing rule prevents terrestrial transmitters from interfering with space station receivers in the geostationary orbit; the path length rule encourages the use of the higher frequency bands for short hops;¹⁰ the digital modulation efficiency rule ensures at least some minimum technical efficiency in the use of the assigned bandwidth by systems employing digital modulation; and the minimum loading standard discourages stockpiling of unused assignments.¹¹

Several of these technical regulations have escape clauses that allow a degree of variation under certain circumstances and usually at some increased risk to the licensee. For example, while all transmitters

10 This rule and others like it are based on the assumption that it is economically efficient to place systems requiring short hops in the higher frequency bands where propagation is limited, thus reserving the lower bands, with their longer range capability, for systems requiring longer hops. It also assumes that the efficient matching of systems to frequency bands would not occur in the absence of regulation. While it is not the purpose of this paper to analyze the CCPMRS technical rules, both of these underlying assumptions are open to question if one accepts the reasoning presented elsewhere in this paper that licensees in this service experience the full opportunity cost of their use of the spectrum.

11 Loading standards and other diligence rules are imposed as a barrier to speculative applications and spectrum warehousing. Such rules are based on both equity and efficiency concerns. The equity argument is that it is unfair to allow certain licensees to warehouse unused spectrum while denying spectrum to others who have immediate uses for it. The efficiency concern hinges on the assumption that it is economically inefficient for spectrum to be sitting idle while there are valuable uses to which it could be put. While the equity argument can only be addressed in subjective terms, the efficiency concern may not be valid if, as appears to be the case in this service, the opportunity costs of warehousing have been internalized to the licensees.

of these working groups are listed in Table 2 and are descriptive of the kinds of issues being studied by the association. One of the NSMA working groups is looking specifically at coordination procedures and may eventually document the many informal procedures and practices that have evolved over the years and which generally govern the day-to-day conduct of frequency coordination within the industry. At the time of this writing, however, no comprehensive documentation exists. The following description of the system design and coordination process has been pieced together from a number of informal sources, including conversations with several industry engineers directly involved in coordination activities.

2. System Design and Interference Analysis.

The earth station coordination flowchart in Figure 1 is generally illustrative of the kinds of interference analyses performed prior to initiation of formal coordination. Every effort is made to avoid interference conflicts that could require costly changes later or delay licensing. This is not only good engineering practice, but it is required under Section 21.100 (d) Commission's Rules which states that new applicants must "select sites, transmitters, antennas and frequencies that will avoid harmful interference to other users." Formal coordination thus serves to verify that each proposed frequency use complies with the non-interference policy to the satisfaction of existing applicants and licensees.

because of the threat of appeal to the Commission or possible retaliation against one's own future applications, or perhaps just an unwritten code of ethics, there appear to be few cases in which licensees have been unreasonably protective of their facilities. In fact, while the Commission has not required it, a consensus appears to have emerged for adherence to a single, uniform set of interference criteria as a voluntary industry standard in order to facilitate the general coordination process. These voluntary standards are discussed further in the next section.

D. Industry Practice and Procedures.

1. Standardization.

The Commission's Rules in Part 21 outline the basic framework for coordination within the CCPMRS but leave many of the detailed standards and procedures to be worked out by the licensees. For example, in coordinating terrestrial transmitters and receivers, the rules call for coordination with all existing and applied for terrestrial systems in the area with which there may be an interference conflict, but do not specify how large an area must be examined nor what the acceptable limits of interference are. For the process to function satisfactorily, a certain degree of standardization of these details is necessary.

Interference analysis requires access to various data bases, including one containing the technical details of existing and proposed systems, and computer and engineering resources necessary to make the required interference calculations. Some of the larger carriers, notably AT&T, Western Union and the BOCs (through Bellcore), maintain their own internal resources for this purpose. Others rely on outside consulting firms, such as Compucon, Comsearch and Spectrum Planning, which maintain extensive proprietary data bases and specialize in providing frequency coordination and system engineering services.

Because spectrum allocations place satellite transmitters in the 4 GHz band and earth station transmitters in the 6 GHz band, potential interference exposures that must be considered in coordination also vary from band to band. In the 4 GHz band, interference is possible from terrestrial station transmitters to terrestrial and earth station receivers. In the 6 GHz band, interference is possible from terrestrial and earth station transmitters to terrestrial station receivers. Interference to or

TABLE 2

NSMA WORKING GROUPS

- Working Group 1 - Standardized PCN Formats and Electronic Mail.
- Working Group 2 - "OH-Loss" Program.
- Working Group 3 - Coordination Procedures.
- Working Group 4 - Standardized RFI Test Methods.
- Working Group 5 - C/I Objectives.
- Working Group 6 - Earth Station Site Shielding.
- Working Group 7 - DTS Coordination.
- Working Group 8 - Reflection Prediction Model.
- Working Group 9 - Short-Term C/I Objectives.
- Working Group 10 - Narrowband Frequency Offset Advantage.
- Working Group 11 - Adjacent Satellite Interference.
- Working Group 12 - Transborder Coordination.
- Working Group 14 - Mixed High-Low Plans and Reflection RFI.
- Working Group 16 - Antenna Patterns
- Working Group 17 - Short-Fuse Coordination.
- Working Group 18 - Automatic Power Control.

From the NSMA Newsletter, 1986 - Issue 2

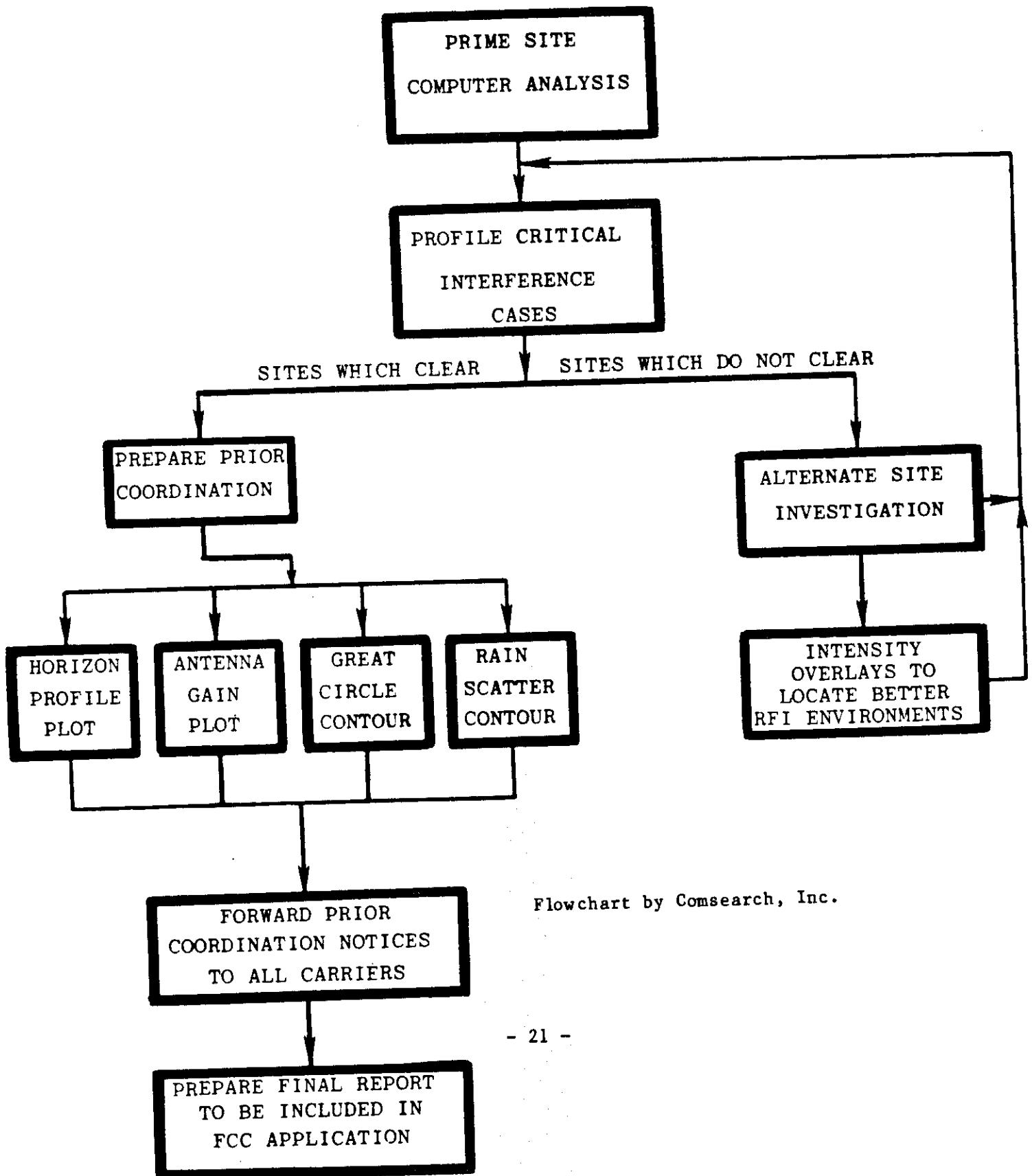
To account for these variables, industry has developed tables setting forth the minimum acceptable C/I ratio for each combination of interfering and interfered with system. These minimum C/I ratios, or interference objectives, are based on overall system performance objectives. While each licensee is entitled to specify its own interference objectives, it appears that a majority have adopted AT&T's. Table 3 shows AT&T's interference objectives for the 6 GHz co-channel case. It is noted that the NSMA has a C/I working group and may therefore assume greater standards making responsibility in this area in the future.

In contrast to the voluntary standards of interference between terrestrial stations, the maximum permissible levels of interference between transmitting earth stations and terrestrial station receivers, including the methods of calculation, are specified in the Commission's Rules.¹⁴ Those rules also specify the method of calculating interference from a terrestrial transmitter to a receiving earth station, although the acceptable interference level in that case is specified by each earth station licensee and included in the coordination notification for that station.

¹⁴ See FCC Rules, Sections 25.251-25.256.

FIGURE 1

EARTH STATION FREQUENCY ANALYSIS AND COORDINATION FLOW CHART



Flowchart by Comsearch, Inc.

The rules contain no prescribed method of calculating interference between terrestrial systems. However standard procedures and models have evolved in the industry and have been incorporated in the various proprietary computer programs utilized by the companies who perform such calculations. The need for a greater degree of standardization in these computational programs is one of the issues being studied by the NSMA.

3. Notification.

Once a proposed frequency usage has been designed to satisfy the Commission's non-interference requirement and, of course, to meet the requirements of the prospective applicant, formal coordination can begin. Rule 21.100 (d) requires coordination with other usage "in the area" that could receive interference from or cause interference to the proposed usage. The standard industry practice is to coordinate with all existing and planned terrestrial usage in the same band within 125 miles of the proposed usage, whether or not calculations show such systems could be affected.

The rules for coordination of terrestrial stations with earth stations (21.706 (c) and (d)) are more specific, requiring coordination with all licensed or applied for earth stations whose calculated coordination

from the satellite station is controlled through technical regulations¹³ and is therefore not considered in coordination.

The level of interference from a particular undesired signal is a function of the ratio of the power in the carrier of the desired signal to that of the interfering signal (the C/I ratio) at the input terminals of the protected receiver. However, a given C/I ratio may produce different interference effects depending on the characteristics of the receiver and of the desired and undesired signals, including method of modulation (e.g., analog or digital), type of information being transmitted (e.g., voice, data or video), and the quantity of information packed within the rf channel (e.g., the number of voice channels per rf channel).

13 Rule 25.208 (a) limits the power density (watts/Hz/m²) that a satellite may deliver to the surface of the earth at different angles of arrival. Rule 21.108 (e) prohibits, except by waiver and with reduced power, the pointing of terrestrial station antennas within 2° of the geostationary orbit. These rules together with the terrestrial station antenna minimum directivity standard in 21.108 (c) and maximum transmitter output power limit in 21.107 (b) effectively preclude interference interactions between terrestrial stations and stations on board the satellite. Interference between satellite systems is precluded by a required minimum angular separation between co-channel satellites (see Report and Order, FCC 83-184, adopted April 27, 1983, for the current separation standards) and minimum directivity and polarization standards for earth station transmitting antennas. (Rules 25.209 (a) and (b)). There are no mandatory performance standards for earth station receiving antennas. However, the protection afforded a licensed receive-only (R/O) earth station from interference from a satellite in an adjacent orbit position assumes that it (the receiving earth station) is employing an antenna meeting the standards for transmitting earth stations. (see Rule 25.209 (c)) Unlicensed R/O earth stations are, of course, not protected from interference at all.

included in PCNs. One of the NSMA working groups is developing recommendations for industry standards regarding such additional information, and the possibility of a standard PCN format is also being considered.

4. Conflict resolution.

The rules provide a 30 day period for responding to terrestrial station PCNs and up to 45 days for earth stations.¹⁷ Any interference conflicts raised in responses are to be resolved before the application is filed with the Commission. The burden of eliminating interference conflicts is assigned to the coordinating party with the exception that an existing terrestrial station licensee who is using a Standard B antenna¹⁸ may be required to upgrade to Standard A at his own expense, if that will resolve the problem.

Any changes in either the proposed or existing systems which are made to remove an interference conflict, but which could affect the potential of

¹⁷ Rules 21.100 (c)(5) and 25.203 (c)(3), respectively.

¹⁸ Rule 21.108 (c) defines two antenna standards for terrestrial stations: Standard A, which is the accepted and preferred standard; and Standard B which is for a less directional antenna having greater sidelobe radiation.

TABLE 3
6-GHZ INTERFERENCE OBJECTIVES
CO-CHANNEL

INTERFERING SYSTEMS	INTERFERED WITH SYSTEMS																			
	TH1-600 .02	TH1-900 .02	TH1-1200 .02	TH1-1200 .002	TH1-1200 .005	TH1-1800 .002	TH1-1800 .005	TH1-1860 .002	TH1-2100 .002	TH1-2400 .002	TH1-1800 .002, DUW	TH1-2400 .002, DUW	VIDEO .02	VIDEO .02	DIC-90 .002	DIC-45/78 .002	DIC-20 .002	SSB .0002	DR6-10 .002	NEC-16QAM .002
TH1-600 .02	75/57	80/60	83/64	76/72	77/73	78/75	79/75	80/74	79/75	78/73	86	84	68	68	65	65	65	90/67	65	65
TH1-900 .02	76/55	80/59	83/63	76/71	77/72	79/74	79/73	80/73	79/74	78/72	86	84	68	68	65	65	65	90/65	65	65
TH1-1200 .02	76/56	80/60	83/63	76/71	77/71	79/73	79/72	80/72	80/73	78/71	86	84	67	68	65	65	65	59	65	65
TH2-1200 .002	74/56	77/59	79/61	66	67	67	68	68	69	66	67	66	68	67	65	65	65	60	65	65
NU-1200 .005	75/56	78/60	80/61	67	70/68	68	72/69	70/68	69	67	73	67	68	67	65	65	65	55	65	65
TH1-1800 .002	75/55	78/58	80/59	64	65	66	66	66	65	64	67	64	68	67	65	65	65	57	65	65
NU-1800 .005	75/55	78/58	80/60	66	70/67	67	72/68	70/66	68	66	73	67	68	67	65	65	65	55	65	65
TH1-1860 .002	75/53	78/55	80/56	62	62	64	63	67	64	63	68	63	68	67	65	65	65	54	65	65
TH1-2100 .002	75/54	78/57	80/58	63	65	64	66	65	65	64	67	63	68	67	65	65	65	56	65	65
TH1-2400 .002	73/56	76/58	77/60	65	66	67	67	67	68	65	68	65	68	67	65	65	65	55	65	65
TH1-1800 .002, DUW 68	71	71	73	65	72	67	72	75	66	64	67	64	68	67	65	65	65	56	65	65
TH1-2400 .002, DUW 68	71	71	73	66	72	68	72	75	67	65	68	65	68	67	65	65	65	55	65	65
VIDEO .02	76/69	80/72	83/74	78	81	82	83	84	83	80	82	80	80	69	65	65	65	90/77	65	65
VIDEO .002	75/67	78/69	80/69	73	74	77	77	78	77	73	77	73	73	69	65	65	65	63	65	65
DIC-90 .002	54	60	63	73	73	79	78	80	81	78	79	78	84	64	65	65	65	64	65	65
DIC-45/78 .002	54	59	62	72	72	79	78	80	81	79	79	79	64	64	65	65	65	70	65	65
DIC-20 .002	59	63	65	74	74	78	77	81	80	76	78	76	68	68	65	65	65	64	65	65
SSB .0002	54	59	62	72	72	79	78	81	81	79	79	79	63	63	65	65	65	64	65	65
DR6-30 .002	54	60	63	73	73	79	78	81	82	79	79	79	64	64	65	65	65	64	65	65
NEC-16QAM .002	54	60	64	74	74	80	79	81	83	80	78	77	64	64	65	65	65	64	65	65

* 14 dBmco objectives -- all others are 4 dBmco for continuous or sideband interference and 17 dBmco for carrier-beat (carrier-beat assumes 10 dB burble)

When two objectives appear as AA/BB, AA is the carrier-beat objective and BB is the continuous objective.

If there is no response to a PCN within the prescribed period, the coordinating party may file his application with a written explanation to that effect. A party who fails to respond to a PCN does not lose his right to protest, however, and may raise interference objections during the 30 day public notice period which begins after an application is accepted for filing. If such an objection is raised, acceptance of the application is withdrawn until the conflict is resolved. There is some sentiment in the industry that this policy is unfair to applicants who diligently follow the prior coordination procedure only to be delayed because of a protest from a party who failed to comply with the 30 day response period.

When all of the conflicts raised in prior coordination have been resolved, the application may be filed with the Commission, where it is then placed on public notice for 30 days. Usually, if the coordination was done properly, there will be no objections to the application and a construction permit will be routinely issued following the public notice period. If a protest is filed, acceptance of the application is withdrawn until the conflict is resolved.

contours encompass the proposed terrestrial station.¹⁵ Similarly, where the proposed station is an earth station, Rules 25.203 (c) and (e) require coordination with all terrestrial stations within the coordination contours of the proposed earth station.¹⁶

The rules require that each of the parties identified through the above-described procedure be notified by the coordinating party. The minimum technical data that must be included in such notifications (referred to in the industry as Prior Coordination Notifications or PCNs) are listed in Rule 21.100 (d)(2) where the station being coordinated is a terrestrial station and in 25.203 (b)(2) for proposed earth stations. Under 25.203 (c)(2), prospective earth station applicants must also furnish interference calculations to the parties with whom coordination is being sought. While this is not required of terrestrial station applicants, it is considered good industry practice to do so. Other information relevant to the coordination process but not required by the Commission is often

15 Coordination contour calculations for earth stations are carried out in accordance with the technical procedures and equations in Sections 25.253 and 25.254. These rules were included in the "Technical Annex" to the Commission's Report and Order in Docket 16495. See note 7, supra.

16 In 1979 the Commission adopted a policy of voluntary licensing of receive only (R/O) earth stations. If the applicant elects to apply for an FCC license for an R/O earth station, and thereby be protected from future interference, prior coordination is required; otherwise coordination is not required. See First Report and Order in CC Docket No. 78-374, adopted October 18, 1979, 74 FCC 2d 205.

5. Protection of Growth Channels

To receive an authorization for the initial radio frequency channel on a microwave route in this service, an applicant must show by traffic studies that there will be a need for at least 900 voice channels or 10 Mb/s data rate along that route within a 5 year period.²⁰ To add channels to an existing route, applicants must show that the traffic load will "shortly exhaust the capacity of existing equipment." While these rules limit the amount of reserve or growth capacity that may be officially authorized to a licensee at a given point in time, the prior coordination rules provide for the reservation and protection of additional capacity through the coordination process.²¹ Exactly how much reserve capacity may be protected in this way is not specified in the rules. However, according to industry sources, it is generally accepted practice to protect planned frequency usage for a period of 10 years. In other words, planned usage may be

²⁰ See Section 21.710 (c). The minimum loading requirement for an initial channel is reduced to 240 voice channels or 5 Mb/s in the 11 GHz band if a channel less than 20 MHz wide is requested.

²¹ The protection of future use channels flows from language in 21.100 (d) requiring that proposed frequency usage be coordinated with existing licensees and applicants whose "ultimate system capacity" could be affected. The rule also states that "Applicants should make every reasonable effort to avoid blocking the growth of systems that are likely to need additional capacity in the foreseeable future," and advises licensees to supply coordinating parties with "data and information concerning existing or proposed facilities and future growth plans."

interference to others must also be coordinated. The cost of changing an existing system therefore involves not only the cost of the facilities modification itself but also the cost of re-coordinating the modified system, which could lead to other conflicts and the possible disruption of services while modifications are being made. In most cases it is less costly to change a proposal than to modify an existing system. Since the coordinating party must pay in either case, the incentive is to take the least costly approach.

In coordinating proposed earth stations, especially in congested areas, actual on-the-air tests using transportable earth stations are frequently used to provide definitive answers to potential interference conflicts. Calculations are intentionally conservative, ie., overly protective, because of the many uncertainties involved in even the most sophisticated interference prediction models. Also, the models may not be designed to account for special shielding and other extraordinary measures that may be taken in some cases to reduce interference potential. On site measurements can therefore result in the successful coordination of an earth station that would otherwise be blocked on the basis of calculations alone. It is generally not feasible to make measurements in the case of a proposed terrestrial station, because of the cost of erecting a tower. Even in the case of earth stations, the costs limit the use of measurements to installations of unusually high value. One of the NSMA working groups is developing standard test procedures to be used in making such measurements.

construction permit is to be filed, it is considered good practice to advise other licensees and coordinators 6 months ahead of time, even though the frequency has been previously cleared. Advisories are also expected if a protected channel is dropped from a licensee's growth plan.

6. Exchange of Coordination Data.

Microwave frequency coordination is a data intensive activity. Interference studies done in preparing a new frequency usage proposal require access to detailed technical information about previously coordinated, and therefore protected, systems. The Commission collects and stores a considerable amount of technical data as a byproduct of its licensing system, and this data can be purchased on magnetic tapes from the NTIS. However, the NTIS tapes do not include the most recent authorizations (i.e., those made since the last periodic update) and contain no information on either previously coordinated growth channels for which applications have not yet been filed or proposed frequency usage that is currently in the process of coordination. Since both of these latter categories of proposed usage are protected under industry procedures, they must be included in data bases used for interference studies.

The principal means of updating frequency usage data is through the coordination notices. However, Commission rules require that notices be sent only to licensees operating in the same general area whose existing or

Based on a review of currently pending protest cases,¹⁹ various causes of the protests appear to be involved, including discrepancies between the data filed in the application and that contained in the PCN, interference conflicts raised during coordination that were unresolved prior to filing the application, systems overlooked in prior coordination, and late filed oppositions by parties not responding to PCNs. According to information in the case folders and as confirmed by the Commission's licensing staff, most of these protests are eventually resolved informally through private negotiations between the parties and involve only minimal intervention by the Commission. The Commission gets involved only if one of the parties requests it, and then functions more as a mediator than a judge. However, since the Commission has the ultimate power to mandate a solution, a solution recommended by a member of the licensing staff no doubt carries considerable weight with licensees.

¹⁹ At the time of the review, there were approximately 100 active cases in the Commission's files, which according to the Commission personnel involved in the processing of these cases is a fairly constant number. It is also a relatively small number considering that approximately 15,000 coordination notices were distributed in the industry during 1985, according to the NSMA newsletter (Issue 1 - 1986).

An understanding of the long term results of this type of spectrum regime should thus provide useful insights as the Commission considers proposals that would give licensees in other services greater flexibility and control over their use of the spectrum.

How common carrier microwave users have organized themselves to meet the challenge of increased spectrum management responsibility was the focus of Part 1 of this report. Part 2 provides an empirical assessment of the economic efficiency of the regime based on an examination of the current deployment of transmitter technology in three of the principal microwave bands available to the service. If, as many believe, this type of regime creates incentives for economically efficient use of the spectrum, there should be evidence of such efficiency in the selection of transmitter equipment. Just as economically efficient management of land results in the construction of taller buildings in urban areas in response to high land values, economically efficient use of spectrum should result in the use of transmitters which are capable of generally more intense use of spectrum (i.e., which are more spectrum efficient) in congested (high spectrum value)

coordinated, and thus protected, as much as 10 years in advance of its intended implementation. This protection is afforded to what industry refers to as "natural growth", i.e., addition of frequencies in the same band to existing routes, as well as to planned construction of new routes and so-called "underbuilds" and "overbuilds" which add frequencies in other microwave bands to existing routes.²²

The rules in 21.100(d) also require licensees wishing continued protection for planned frequency usage to send notices to that effect every 6 months to other licensees.²³ However, the general practice among industry coordinators is not to require 6 month renewal notices for natural growth channels but to require them in all other cases. Where notices are required, the 6 month period is considered to begin 1 month after the date of the PCN. A one month grace period is also normally allowed before the protected channel is deleted from a coordinator's data base. When a protected growth channel is to be activated, i.e., an application for a

²² Generally, frequencies from a lower band can be added to an existing route simply by installing the necessary transmitting and receiving equipment at existing stations. Adding higher frequencies, however, may require the construction of intervening stations because of greater atmospheric absorption of the transmitted signal.

²³ If such notice has not been received, Rule 21.100 (d)(11) states that "carriers may assume...that such frequency use is no longer desired."

differ markedly from systems currently in use.²⁵ Therefore, the amount of spectrum denied future systems by an existing system, and hence its overall spectrum efficiency, cannot be determined.

As a substitute for a comprehensive spectrum efficiency value, comparisons can be made on the basis of certain equipment parameters which have well defined relationships to spectrum efficiency. A tightening of the frequency tolerance of a transmitter, for example, which reduces the interference potential of a transmitter without reducing its information capacity will always produce an increase in spectrum efficiency. Similarly, an increase in antenna directivity, which allows a corresponding reduction in transmitter output power, will nearly always cause a resultant increase in the potential number of systems that can be operated within a given geographical area. A cross-area comparison of these and other efficiency related equipment parameters should provide an indication of the relative overall spectrum efficiencies of systems in the study areas.

²⁵ This would not be the case if technical characteristics were more narrowly defined by regulation, as is the case in many other services.

planned usage could be affected. Industry interprets this to include all usage within 125 miles and in the same band as the usage being coordinated. Each coordinator's database would thus contain only a fraction of the total protected frequency usage throughout the country. This could potentially cause a problem for a licensee planning a new system outside its normal area of operation where there may be protected usage not reflected in its database. Industry's solution to the problem is routinely to send copies of coordination notices to all parties who are known to be involved in frequency coordination. This voluntary sharing of information helps prevent inadvertent omissions in interference studies and generally facilitates the coordination process. To further improve the flow of coordination data, the NSMA is exploring the possibility of creating a comprehensive central data base resource as well as electronic means of disseminating coordination notices and responses.

III. PART 2: EMPIRICAL STUDY

A. Introduction.

The CCPMRS, perhaps more than any other service, relies on the active participation of the private sector in the detailed management of the radio spectrum. Also, because the service has been in existence for a relatively long period of time, it provides a unique opportunity for empirical study.

The relative geographical density of transmitters in the two areas is believed to be a reasonable, although admittedly imperfect, representation of relative spectrum scarcity. Because congestion is very much a localized condition in this service, there are likely to be hot (or cold) spots within both areas where congestion is higher (or lower) than the average. However, as long as most of the NC transmitters are in relatively non-congested situations and most of the NY transmitters are in relatively congested situations, which appears to be the case, the cross-area comparison should provide an accurate test of the effects of congestion on transmitter choice.

The analytical database used in this study was compiled principally from the Commission's Cross-bureau Frequency System (the "XFS" database) resident on the Commission's Honeywell computer. To this was added certain technical data extracted manually from Commission lists of transmitters and antennas authorized for use under Part 21.²⁷ Information on transmitter baseband loading needed to calculate modulation efficiency was obtained from

²⁷ Transmitter data were taken from "Part 21 Microwave Transmitter List", Domestic Facilities Division, Common Carrier Bureau, June 12, 1985. Antenna data were extracted from a similar but untitled and undated listing also provided by the Domestic Facilities Division.

areas than in a non-congested (low spectrum value) areas.²⁴ An examination of the Commission's licensing data should indicate whether this has in fact been the result.

Generally defined, the spectrum efficiency of a microwave radio system is the quantity of information transferred (e.g., bits per second or standard voice channels) divided by the quantity of spectrum used. The information transfer capability of microwave equipment can be readily determined and quantified, but defining the quantity of "spectrum used" is more difficult. In a strict sense, the definition must include dimensions of time and space as well as frequency: i.e., bandwidth denied other uses (because of interference) over some period of time and range of locations. However, calculating the spectrum that a particular system denies other uses requires knowledge of the technical characteristics and interference thresholds of all potentially conflicting systems, existing and future. Under the CCPMRS regime, however, the interference characteristics of future systems may

24 This analysis is limited, however, by minimum spectrum efficiency standards in the Commission's rules which would tend to cause the average spectrum efficiency of transmitters in non-congested areas to be higher than would be the justified by spectrum value alone. Also, economies of scale in the equipment manufacturing, distribution and servicing industries will cause equipment to be standardized around the requirements of the largest segment of the market and discourage the production of separate models tailored to the specialized conditions of either the most or least congested areas.

means the outcome could not be predicted on a theoretical basis for reasons that are explained in the text below. An "NA" in any of the columns indicates an indeterminate value. To further investigate the statistical relationships between congestion and spectrum efficiency, a multiple linear regression analysis was used to formulate equations defining two of the the efficiency parameters, tolerance and modulation efficiency, as functions of area, licensee group and band. The results of these analyses and the basis for the expected results are discussed in the following section.

C. Results.

1. Frequency Tolerance.

Frequency tolerance refers to the ability of a transmitter (or receiver) to maintain a constant operating frequency and is usually expressed as a percentage of operating frequency. Thus, for example, a 6 GHz transmitter having a tolerance of .005% is capable of maintaining its operating frequency within +/-300 kHz of its designated frequency. Inaccuracy in operating frequency effectively widens a transmitter's occupied bandwidth increasing its potential to interfere with other systems on adjacent or offset channels with no increase in information throughput. Tolerance related shifts in a transmitter's operating frequency can also cause a severe form of co-channel interference called carrier beat interference. The severity of carrier beat interference is directly

B. Methodology.

For practical reasons, the current study considers only transmitters and antennas and not receivers. The Commission's databases, which are byproducts of licensing and the equipment authorization program, contain reasonably complete data on the transmitter portion of microwave systems but very little on receivers. Although it is recognized that receiver design contributes in a significant way to a system's spectrum efficiency, including receivers in this study would have entailed prohibitively high data gathering costs.

The four equipment parameters studied are:

- frequency tolerance
- modulation efficiency (maximum number of voice channels or bits per second transmitted within the emission bandwidth);
- antenna diameter (parabolics only); and
- antenna type (horns vs. parabolics)

Except for modulation efficiency, the data required for the study were included in the Commission's existing databases. The calculation of

This conclusion is generally confirmed by the database analysis. The results of the analysis for frequency tolerance are presented in Tables 5, 6 and 7. Note in Table 7 that the averages are lower in NY than in NC (the expected outcome) in three of the five cases for which a comparison is possible. Because there were no transmitters in the OCC/4 category in NC, a cross-area comparison is not applicable in that case. In the TELCO/4 case the average frequency tolerance was the same in both study areas, and in the TELCO/11 case the average was higher in NY than NC, which is the opposite of what was expected. This result suggests that the TELCO licensee group is less influenced by congestion in selection of transmitter tolerance than is the OCC group. Clustering of data at particular tolerance values, which could indicate a tendency towards standardization, is noted in both licensee categories, but is more pronounced in the TELCO group. A high degree of equipment uniformity is not surprising in this group considering that approximately 93 % of the transmitters in the TELCO data samples in both areas are licensed to a single licensee, namely AT&T.

manufacturers and included in the analytical database.²⁸

The database analysis was performed using the Informix Relational Database Management System running on a Zilog Model 21 computer. The data were sorted first by area, then by licensee group²⁹ and frequency band. Counts were then made of the number of transmitters associated with a particular value or range of values for each of the specified equipment parameters and the count totals arranged in tables allowing direct comparisons to be made between the two areas. Three tables are presented for each equipment parameter: a separate table for each of the two licensee groups, providing a cross-area comparison of the distribution of transmitters across the range of parameter values; and a summary table of comparing the NY and NC averages for each of the six cases represented by the different combinations of band and licensee group.

In the summary tables, entries in the "SIGN" column indicate whether the data agree or disagree with the expected outcome, with a "+" indicating agreement and a "-" disagreement. A "?" in this column

28 The price data included at several points in the report were also obtained from the manufacturers.

29 The TELCO group includes the local operating companies and AT&T. All other licensees are grouped under the OCC category. These two licensee groups were analyzed separately because of differences in their general regulatory environments and other factors which could affect the results.

TABLE 7

NY/NC COMPARISON OF AVERAGE FREQUENCY TOLERANCE (ppm)

<u>CASE</u>	<u>NY</u>	<u>NC</u>	<u>SIGN</u>
OCC/4	39.7	NA	NA
OCC/6	24.3	38.3	+
OCC/11	23.1	50.0	+
TELCO/4	50.0	50.0	
TELCO/6	22.0	46.6	+
TELCO/11	34.4	20.6	-

2. Modulation Efficiency.

Modulation efficiency, as used here, refers to the maximum quantity (rate) of baseband information a particular microwave transmitter is capable of transmitting per unit of emission bandwidth. In analog systems, a voice-grade telephone channel with a maximum baseband frequency of 3000 Hz is typically used as the basic unit of information quantity. The number

proportional to the interfering transmitter's frequency tolerance.³⁰

An indication of the magnitude of interference effects attributable to frequency tolerance is reflected in the co-channel C/I objectives in Table 3. For example, comparing the TM1-1200 and TM2-1200 transmitters (frequency tolerances of .02% and .002%, respectively), we see that the C/I ratios run consistently lower for the transmitter having the lower (tighter) frequency tolerance. Lower C/I ratios mean that more transmitters can be operated within a given area at a defined level of interference.

It can therefore be concluded that low tolerance transmitters are more spectrum efficient (ie., consume less spectrum per unit of information transmitted) than identical transmitters with higher tolerances. Therefore, if the spectrum is being used in an economically efficient manner, one would expect to find generally lower frequency tolerances in congested areas. This would be true as long as the incremental value of spectrum in the congested area is sufficiently great relative to that in the non-congested area to justify the increased cost associated with at least some reduction in frequency tolerance. This is a safe assumption in this case because of the large difference in congestion levels between the two study areas.

30 For a more detailed discussion of interference mechanisms affecting microwave systems see reference 2, beginning at page 191 and reference 3, Volume I, Part B, Sections 2 and 3.

potential geographical density.³²

This inverse relationship between modulation efficiency and geographical density is reflected in the AT&T co-channel C/I objectives in Table 3, above. For example, comparing the TH-1860 (66 voice channels per MHz) with the TH-2400 (80 channels per MHz)³³ as potential interfering sources, we see that 8 of the 20 "interfered with systems" in the table require greater (1 - 4 dB) C/I protection for the system with the higher modulation efficiency; 9 require equal protection; and only 3 require less protection. Thus, even though the 2400 channel model can transmit 21% more voice channels per unit of emission spectrum along a given path, its geographical separation (angular or mileage) from other co-channel systems must, on average, be greater.

Because of this tradeoff, it cannot be said categorically that transmitters with higher modulation efficiencies are more spectrally

32 The inverse of what we are calling modulation efficiency is sometimes referred to as the bandwidth expansion factor. For a more complete discussion of the relationship between this factor and the maximum geographical density of systems in an interference limited environment, see reference 3, Volume I, Part B, Section 2, beginning at page 2-17.

33 The number of voice channels per MHz is obtained by dividing the maximum number of standard voice channels each transmitter is capable of carrying (1860 and 2400 respectively) by its FCC-defined emission bandwidth in MHz (28 and 30, respectively).

TABLE 5

NY/NC AREA COMPARISON
TRANSMITTER COUNT BY FREQUENCY TOLERANCE
OCCs ONLY

TOLERANCE (ppm)	TRANSMITTER COUNT					
	4 GHZ		6 GHZ		11 GHZ	
	NY	NC	NY	NC	NY	NC
500					1	
200			17			
50	23		97	97	73	4
20			42	5	32	
15	4					
10			2	37		
5	4		118		103	
Count:	31.0	0.0	259.0	139.0	208.0	4.0
Av. tol:	39.7	NA	24.3	38.3	23.1	50.0
St. dev:	17.7	NA	20.5	17.9	20.4	0.0

TABLE 6

NY/NC AREA COMPARISON
TRANSMITTER COUNT BY FREQUENCY TOLERANCE
TELCOs ONLY

TOLERANCE (ppm)	TRANSMITTER COUNT					
	4 GHZ		6 GHZ		11 GHZ	
	NY	NC	NY	NC	NY	NC
500					41	11
250						8
200			7	27	1	
100	81	32		40		
50	377	788	19	315	194	4
25					30	
20			199	15	59	14
5			8	16	65	7
Count:	377.0	788.0	226.0	346.0	348.0	25.0
Av. tol:	50.0	50.0	22.0	46.6	34.4	20.6
St. dev.	0.0	0.0	8.9	11.1	18.4	14.4

Note 1: % freq tolerance = ppm / 10,000 (eg., 5 ppm = .0005%)

Note 2: only entries below dashed line (current FCC standard) counted in totals and statistical calculations.

TABLE 8

NY/NC AREA COMPARISON
TRANSMITTER COUNT BY MODULATION EFFICIENCY
OCCs ONLY

EFFICIENCY (voice ch/ MHZ)	TRANSMITTER COUNT					
	4 GHZ		6 GHZ		11 GHZ	
	NY	NC	NY	NC	NY	NC
30.0				26		2
33.6					9	
34.3					4	
36.0			11		55	
38.8			5			
40.8				4		
42.9			1			2
44.8			2		1	
48.0					10	
60.0			73	5	23	
61.0			5			
61.2					1	
66.7			7		16	
69.2			6	12		
75.0	31					
80.0			118	92	76	
90.0			30			
135.0					12	
Count:	31.0	0.0	258.0	139.0	207.0	4.0
Av. eff:	75.0	NA	71.4	67.9	63.5	35.4
St. dev:	0.0	NA	14.0	19.7	25.9	4.5
% digital:	0.0	NA	2.7	0.0	6.3	0.0

of standard voice channels that can be transmitted per MHz of emission bandwidth is therefore a convenient unit for specifying the modulation efficiency of analog transmitters. In digital systems, for which information quantity is specified in bits per second, modulation efficiency is usually expressed in bits per second per Hertz. To allow the comparison to include both types of equipment, the maximum data rate of digital equipment was converted to equivalent voice channels per MHz using manufacturers' baseband specifications.³¹

It is obvious that modulation efficiency is an important contributor to a transmitter's overall spectrum efficiency. The two terms would in fact be equivalent if efficient use of the rf bandwidth were the only objective. However, the potential geographical density of systems in an interference limited environment is also an important dimension of spectrum efficiency, and as a general rule systems with higher modulation efficiency have a greater potential to receive and cause interference and therefore a lower

31 For example, if a 90 Mb/s transmitter is rated for 1344 voice channels and has an FCC emission designator of 30,000 F9Y, its modulation efficiency would be 1344 divided by 30 equals 44.8 voice channels per MHz.

TABLE 10

NY/NC COMPARISON OF AVERAGE MODULATION EFFICIENCY
(voice channels/MHz)

<u>CASE</u>	<u>NY</u>	<u>NC</u>	<u>SIGN</u>
OCC/4	75.0	NA	NA
OCC/6	71.4	67.9	?
OCC/11	63.5	35.4	?
TELCO/4	90.0	90.0	?
TELCO/6	63.3	60.1	?
TELCO/11	48.5	43.9	?

3. Antenna Size (parabolic antennas only).

Systems in this service are, by definition, point-to-point in design. Each transmitted signal originates from a fixed location and is received by a single receiver at a fixed location. Therefore, any energy radiated by a transmitting antenna that is not collected by the desired receiving antenna provides no benefit, represents a waste of transmitted power and becomes a potential source of interference to other systems. Reducing extraneous radiation not only saves transmitter power but increases spectrum efficiency

efficient overall. Similarly, even though it seems intuitively so, one cannot conclude that higher congestion would motivate generally higher modulation efficiencies. Although congestion would certainly create an economic incentive to pack more information within an authorized channel, the marginal cost of the corresponding increase in interference potential would also be higher in congested areas.

The empirical comparison of average modulation efficiency between the two study areas is given in Tables 8, 9 and 10. It is noted that in all five cases, average modulation efficiency in the NY area is equal to or greater than that in the NC area. The data thus suggest a positive correlation between congestion and modulation efficiency, despite the interference tradeoff noted above. More will be said about the statistical significance of this relationship in the discussion of the regression analysis, below.

Therefore, if interference reduction were the only benefit, one could expect antennas to be larger, on average, in congested areas than in non-congested areas. However, increased gain can also provide a strong motivation where maximum hop length is desired, as in crossing open expanses of country or adverse terrain. Since the interference advantage favors congested areas and the gain advantage probably favors rural areas, there is no clear basis for predicting which area will have the larger average antenna size.

TABLE 11 35

Directivity of a 6 GHz Parabolic Antenna as a Function of Diameter

Diameter (ft.)	2	4	6	8	10	12
Gain (dBi)	29.1	35.0	38.6	41.1	43.6	44.6
Beamwidth (°)	5.75	2.93	1.94	1.46	1.17	0.97

The data (Tables 12, 13 and 14) indicate generally smaller antennas in the congested area. This was the finding in three of the five cases where comparisons were possible. In one case there was a tie, and in one (the TELCO/4 case) the opposite result occurred. The margins in all cases were

35 Collins, 1976, p.152.

TABLE 9

NY/NC AREA COMPARISON
TRANSMITTER COUNT BY MODULATION EFFICIENCY
TELCOs ONLY

EFFICIENCY (voice ch/ MHZ)	TRANSMITTER COUNT					
	4 GHZ		6 GHZ		11 GHZ	
	NY	NC	NY	NC	NY	NC
8.0			5			
15.0					15	
20.7				6		
21.4					32	
24.0			1			
25.9				10		
33.6					86	7
36.0				76	2	1
40.0			4			
40.4				52		
40.8				18		
42.9			5	1	9	11
44.8			12	11		
47.2				10		
47.4					2	
48.0				1	2	
50.4					7	
60.0			2		102	1
64.3					4	
66.4			177			
66.7			3			
67.2				2		
72.7						1
75.0	1					
80.0			11	206		
90.0	457	820			36	1
Count:	458.0	820.0	220.0	393.0	297.0	22.0
Average:	90.0	90.0	63.3	60.1	48.5	43.9
St. dev:	0.7	0.0	11.4	21.3	21.4	13.5
% dig.:	0.0	0.0	7.3	47.6	84.5	90.9

TABLE 14

NY/NC COMPARISON OF AVERAGE ANTENNA DIAMETER (ft.)

<u>CASE</u>	<u>NY</u>	<u>NC</u>	<u>SIGN</u>
OCC/4	10.0	NA	NA
OCC/6	10.2	10.2	?
OCC/11	7.7	8.0	?
TELCO/4	10.0	8.5	?
TELCO/6	7.2	9.1	?
TELCO/11	8.9	10.3	?

small. Nevertheless, the overall result suggests that increased power gain is a more important factor in the selection of antenna size than is reduction of interference potential. Again, as in the case of modulation efficiency, the empirical results cannot be viewed as either supportive or non-supportive of the economic efficiency hypothesis, since a predicted outcome was not possible.

4. Use of Horn Antennas.

The economics of horn vs parabolic antennas as a function of congestion is more predictable. A horn antenna has about the same gain as a

by reducing potential interference to other systems.

"Directivity" is a qualitative term often used to describe an antenna's ability to concentrate its radiated power in the desired direction. There is no equivalent quantitative term, but for parabolic antennas of the type commonly used in this service, the diameter of the antenna provides a reasonably accurate representation.³⁴ Table 11 illustrates the relationship between the diameter of a 6 GHz parabolic antenna and its gain and beamwidth, which are two of the characteristics which collectively define an antenna's overall directivity.

Increasing the diameter of an antenna provides two principal benefits: (1) it reduces the required transmitter output power; and (2) it reduces both intra and inter system interference potential. Because the cost of interference is greater in a congested (i.e., high spectrum value) area, licensees in such areas would be more strongly motivated by potential reductions in interference than would licensees in non-congested areas.

³⁴ Antenna gain, beamwidth, or front-to-back ratio could also be used although they are individually less descriptive of the overall directivity of a parabolic antenna than is diameter. It should be noted, however, that the type of materials used, manufacturing tolerances and special add-on devices such as radiation shrouds can give parabolic antennas of the same size different directivity characteristics. Still, for this analysis, a general correlation between the diameter of a parabolic antenna and its overall directivity is assumed.

than in the NC area.

The data on horn antennas are combined with the antenna size data in Tables 12 and 13 and are separately summarized in Table 15. As indicated in the summary table, the expected result of the cross area comparison occurs in four of the five cases in which a comparison is possible. The only disagreement is in the TELCO-11 case in which the horn antenna percentage is greater in NC (86%) than in NY (52%). While this could indicate an economically inefficient choice of antennas, it can also be explained by the economics of 11 GHz implementation.

The least expensive way to implement 11 GHz is to overbuild the frequencies onto existing 4 and 6 GHz systems which currently use horn antennas. The wide bandwidth capability of horn antennas allows them to be used in all three bands, thus avoiding the need for costly antenna modifications or separate antennas when implementing 11 GHz frequencies along existing paths. As the data in Table 12 indicate, most of the 4 and 6 GHz TELCO systems in both areas use horn antennas (97% in NY and 79% in NC).

Low cost implementation of 11 GHz as an overbuild of existing 4 and 6 GHz systems is thus an option that is generally available to this group of

TABLE 12

NY/NC AREA COMPARISON
TRANSMITTER COUNT BY ANTENNA SIZE AND TYPE
OCCs ONLY

SIZE DIAMETER (ft.)	TRANSMITTER COUNT					
	4 GHZ		6 GHZ		11 GHZ	
	NY	NC	NY	NC	NY	NC
HR	6		19		24	
6.0			4	14	95	
8.0	2		91	19	166	6
10.0	41		86	61	27	
12.0	2		71	50	12	
15.0			20	6		
Count:	51.0	0.0	291.0	150.0	324.0	6.0
Av. Dia.:	10.0	NA	10.2	10.2	7.7	8.0
St. dev:	0.6	NA	2.1	2.1	1.5	0.0
% HR:	11.8	NA	6.5	0.0	7.4	0.0
St. dev	0.07	NA	0.03	0.04	0.03	0.2

TABLE 13

NY/NC AREA COMPARISON
TRANSMITTER COUNT BY ANTENNA SIZE AND TYPE
TELCOs ONLY

SIZE DIAMETER (ft.)	TRANSMITTER COUNT					
	4 GHZ		6 GHZ		11 GHZ	
	NY	NC	NY	NC	NY	NC
HR	454	723	288	280	237	39
2.0			1			
4.0			1	4	5	2
5.0					15	
6.0			3	22	35	1
8.0		71	1	23	26	
10.0	4	26	4	121	108	
12.0				2	30	
16.0						3
Count:	454.0	820.0	298.0	452.0	456.0	45.0
Average:	10.0	8.5	7.2	9.1	8.9	10.3
St. dev	0.0	0.9	2.7	1.6	2.2	5.7
% HR:	99.1	88.2	96.6	61.9	52.0	86.7
St. dev	0.02	0.02	0.03	0.02	0.02	0.08

Note 1: "HR" designates horn type antenna. All others are parabolics.
 Note 2: First standard deviation refers to antenna size, second to %HR.

Thus the apparent TELCO standardization in the use of horn antennas in the 4 and 6 GHz bands and the economics of 11 GHz implementation could explain why the data show a higher percentage of 11 GHz horn antennas in the less congested area even though a narrow analysis of the economics of horn antennas suggests the opposite result. By comparison, the 11 GHz OCC data, which reflect no similar early bias toward horn antennas, are consistent with the expected result. The statistical "t" test numbers in Table 15 indicate that the differences between the two areas are statistically significant at a greater than 95 % level of confidence in three of the five cases and at better than 90 % in the OCC/6 case.³⁷

5. Regression Analysis.

The preceding analysis compares the average values of the efficiency parameters in the two areas for each of the six combinations of band (4, 6 and 11 GHz) and licensee group (OCC and TELCO). For the horn antenna cases, the statistical significance of the comparisons was tested using simplified "t" calculations, appropriate where the value of the parameter being studied is binary, in this case either horn or not. However, in the

³⁷ The "t" numbers in Table 15 were calculated from data in tables 12 and 13, using the equation $t = |x_1 - x_2| / (SD_1^2 + SD_2^2)^{1/2}$ where x_1 and x_2 are the decimal equivalents of the %HR values and SD = standard deviation.

10 foot parabolic antenna. However, since the horn is significantly more expensive,³⁶ it would not be the economically efficient choice if high antenna gain were the only or primary objective. Therefore, when a horn antenna is selected it is because of other advantages, which include an inherently wide bandwidth (horns can operate simultaneously in all three bands whereas parabolics are generally limited to a single band or two bands if specially modified) and tighter radiation pattern (a front-to-back ratio typically 10 - 20 dB better than a high quality 10 - 12 foot parabolic antenna).

The multiband feature allows a single horn antenna to replace several parabolic antennas in high traffic installations where full implementation of frequencies in all bands and polarizations is required. Such installations are more likely to be found in congested areas than in non-congested areas. Also, in a congested area even a limited system may have to use frequencies in more than one band and polarization in order to avoid interference conflicts. The horn antenna's tighter radiation pattern also reduces interference potential, which is again of greater benefit in congested areas. Since the principal advantages of horn antennas are all related to congestion, one would expect to find more of them in the NY area

³⁶ For example, one manufacturer lists the price of a horn antenna as \$17,000 vs. \$3,030 for a standard 10 foot parabolic.

relative importance in explaining variations in the dependent variable, and their signs indicate the direction of the effect. The regression program also calculates the t ratio for each coefficient, which indicates the statistical significance of the effect.

To run the regression program, a compressed data record was created for each transmitter record in the original database. Each compressed record contained the actual values of the two dependent variables and dummy values (1 or 0) for the independent variables. The names of the independent variables and the meaning of their assigned dummy values are given in the following table:

TABLE 16

DEFINITION OF INDEPENDENT VARIABLES USED IN THE REGRESSION ANALYSIS

<u>VARIABLE NAME</u>	<u>ASSIGNED DUMMY VALUES</u>
AREA	1 IF NY, 0 IF NC
OCC	1 IF OCC, 0 IF TELCO
6GHZ	1 IF 6 GHZ BAND, else 0
11GHZ	1 IF 11 GHZ BAND, else 0 ⁴⁰

⁴⁰ If variables 6GHz and 11GHz both = 0, then band = 4 GHz.

TABLE 15

NY/NC COMPARISON OF NUMBER OF HORN ANTENNAS (% of total)

<u>CASE</u>	<u>NY</u>	<u>NC</u>	<u>SIGN</u>	<u>"t"</u>
OCC/4	11.0	NA	NA	NA
OCC/6	6.5	0	+	1.33
OCC/11	7.4	0	+	0.21
TELCO/4	99.1	88.2	+	3.81
TELCO/6	96.6	61.9	+	10.24
TELCO/11	52.0	86.7	-	4.42

licensees in both of the study areas. In the relatively un-congested NC area, this lower cost method of implementation has apparently been sufficient in most cases to satisfy the demand for additional circuit capacity, which explains the high percentage of 11 GHz transmitters in that area which use horn antennas. In the more heavily congested NY area, however, there are apparently more situations where the demand for additional circuit capacity could not be met by this method and where the value of such capacity is sufficient to justify the higher cost implementation using dedicated (parabolic) 11 GHz antennas.

TABLE 17

REGRESSION EQUATIONS FOR TOLERANCE AND MODULATION EFFICIENCY

DEPEN. VAR.	# OBSERV.	R ²	INTERCEPT		INDEPENDENT VARIABLES		
			Coefficient/ t-ratio	OCC	(Coefficient / t-ratio)		
					GHZ6	GHZ11	AREA
TOL	3298	0.0522	59.392	-29.819	3.770	24.276	-11.416
			29.655	-10.334	1.367	7.524	-4.417
MODEFF	3114	0.4868	887.40	75.116	-282.120	-377.750	10.045
			182.77	10.461	-41.576	-45.562	1.572

according to the formal definition of that term, does indicate significance at the 90 % confidence level. The strong significance of the area coefficient in the TOL equation and the fact that the area coefficient in the MODEFF equation has the expected sign and a reasonably high t statistic provide support for the basic efficiency-congestion hypothesis.

percent level when its t statistic is equal to or greater than two in absolute value. The cutoff for significance at the 90 percent level is roughly 1.6.

other cases, where the efficiency parameter may assume a range of values, more accurate statistical tests can be made using regression analyses.

Because factors other than congestion may influence transmitter efficiency, it is worth trying to hold some of them constant while examining the congestion-efficiency relationship. This may be done with multiple regression analysis.³⁸ Regression analysis allows estimation of the coefficients of a linear equation in which the left hand side or "dependent variable" is explained by a series of "independent variables" on the right hand side of the equation.

In this study, two separate equations are estimated in which each of two of the efficiency parameters, tolerance and modulation efficiency,³⁹ are treated as dependent variables to be explained by independent variables representing area, licensee group and band. The magnitudes of the coefficients of the independent variables in these equations indicate their

38 See Kmenta, Jan. Elements of Econometrics (New York: The Macmillan Company, 1971), pp. 347-430. See esp. pp. 409-418 for discussion of regression equations in which all of the independent variables are dummy variables.

39 Antenna size is not included in this analysis because neither the theoretical considerations nor the empirical comparisons of averages discussed in the preceding sections suggest a correlation with congestion. Modulation efficiency is included because the data suggest a correlation even though such an outcome could not be predicted on purely theoretical grounds.

factors, such as the tendency towards standardization within the TELCO licensee group. Only in the TELCO/11 frequency tolerance case is there no obvious explanation for the unpredicted outcome.

The modulation efficiency and antenna size comparisons were included in the study because it was believed, initially, that they could be theoretically correlated with congestion under an economically efficient regime. However, closer analysis of licensee incentives with regard to these parameters led to ambiguous expectations. In the case of modulation efficiency, the ambiguity is due to the increased interference potential that inevitably accompanies more intense packing of information within the emission bandwidth. To predict the net effect of congestion on modulation efficiency would have required calculation of the relative value of an incremental increase in bandwidth efficiency vs the cost of an incremental increase in interference potential at different levels of congestion. Such detailed economic information was not available for this study and therefore the prediction could not be made. Similarly detailed and unavailable information is required to predict whether larger antennas could be expected in congested areas because of their reduced interference potential or in rural areas because of their increased power gain.

Although these two comparisons could not be predicted theoretically and therefore cannot be used to test the hypothesis, there is value in having them in the study. For example, the general correlation between

The coefficients and t ratios for each of the two regression equations are presented in Table 17.⁴¹ For the purpose of this study, the relevant entries in the table are those under the AREA column, as they define the effect of congestion on tolerance and modulation efficiency.⁴² A positive AREA coefficient in the modulation efficiency equation indicates a positive correlation between modulation efficiency and congestion, which is the expected result based on the comparisons of average values presented in the preceding section. In the tolerance equation, a negative AREA coefficient is expected, as this would indicate a correlation between increased congestion and lower tolerance (i.e., increased efficiency), which is consistent with the basic hypothesis of this paper.

These expectations are largely borne out in Table 17. The AREA coefficient in both equations has the expected sign and is statistically significant in the tolerance equation. In the modulation efficiency equation, the AREA t ratio, while not indicating statistical significance⁴³

41 The equations were estimated using the ordinary least squares (OLS) technique. See Kmenta, chapter 10, pp. 347-408.

42 The other columns in the table, while not directly relevant to the efficiency-congestion hypothesis are included for completeness and do provide some additional insights on the effects of other factors on transmitter efficiency.

43 For the purpose of this analysis, "statistically significant" means significant at the 95 percent level using a two-tailed t test. See Kmenta, pp. 136-144, 225-227. The t statistics for each coefficient are presented in the table. Roughly speaking, a coefficient is significant at the 95

results of the empirical study suggest that licensees under a regime of technical flexibility and prior coordination will voluntarily implement spectrum saving technology in congested areas where spectrum value is greater. This appears to be true even though there is no explicit pricing system for spectrum and licensees are not charged directly for their use of the spectrum. What this study cannot show, however, is whether the investment in spectrum efficient technology is economically optimal.

The apparent effectiveness of the industry in developing voluntary standards and procedures to facilitate the coordination process should dispel concerns that greater reliance on the private sector in spectrum management might lead to a breakdown in essential standards making functions. That has certainly proven not to be the case in this service. In fact, a whole new industry has emerged with spectrum management as its principal business activity and has formed a national association to resolve issues of common interest. This voluntary process has dealt competently with such contentious matters as interference criteria and channeling plans which are specified by regulation in most other services. The robustness of the coordination industry is evident in its accommodation of changes in regulatory policies which have restructured the common carrier industry and introduced technically dissimilar uses within the allocated bands.

The incentive structure created under this regime work to ensure that procedural and technical problems are resolved expeditiously and

It is also interesting to note the statistical significance of the other coefficients in the regression equations. In addition to suggesting other hypotheses, the statistical significance of these other coefficients underlines the importance of analyzing the basic hypothesis in a multivariate setting. Nevertheless, the statistical robustness of these two regression equations should not be overemphasized. The variables included in the analysis, while believed to be among the most important, are not claimed to be exhaustive. Inclusion of other variables such as equipment age could either strengthen or weaken the congestion-efficiency relationship.

D. Conclusions.

As indicated in the preceding discussion, there is general agreement between the original hypothesis and the data. The cross-area comparison of transmitters and antennas shows the kinds of differences in equipment performance that would be expected where licensees experience the opportunity cost of their use of the spectrum. The incentive structure under such a regime would encourage generally tighter frequency tolerances and greater use of horn antennas in congested areas, and the findings were consistent with that expectation in seven of the ten cases for which the data allowed comparisons to be made. In two of the cases where disagreement between theory and data occurred, the reversal can be explained by other

the process to needless procedural delays.

Despite the apparent success and potential usefulness of the CCPMRS regime as a model for efficient cooperative management of the spectrum, there is also potential for improvement. The positive economic incentives which are evident in this study could be strengthened by elimination of certain technical regulations to give licensees greater freedom to design their systems according to local conditions of spectrum scarcity. Elimination of minimum spectrum efficiency standards has been mentioned. Included in this category are rules on frequency tolerance, antenna directivity (the "A" and "B" standards) and modulation efficiency (e.g., minimum bits per second per Hertz). This study indicates that licensees in this service are motivated to respond on their own initiative to spectrum value in the selection of equipment. Minimum efficiency standards which are designed to compensate for an absence of such responsiveness are out of place in such a regime and could be counterproductive by forcing licensees to be overly conservative of spectrum in areas of low spectrum value.

Although certain to be unpopular with existing users, permitting additional categories of users and uses in these bands (and allowing the current occupants of these bands access to other bands) would cause all users to internalize more accurately the opportunity costs of their use of the spectrum. Absent a spectrum price structure, the internalization of opportunity cost of spectrum use in these bands occurs largely as a result

higher modulation efficiency and congestion suggests that as congestion increases the marginal value of an increase in modulation efficiency will generally exceed the the marginal cost of the resulting increase interference potential. Also, the antenna size analysis which shows generally larger antennas in the less congested area, suggests that power gain is more important factor than interference avoidance in motivating the use of larger antennas.

The statistical tests indicate that the results of the data analysis are statistically significant in the majority of the cases studied. In the horn antenna comparisons, the results were statistically significant in three out of five cases and the computed regression equations for tolerance and modulation efficiency confirm the positive relationship between each of those efficiency ractors and congestion. The area (congestion) coefficient was statistically significant in the regression equation for tolerance and significant at a 90 % level in the modulation efficiency equation.

IV. POLICY IMPLICATIONS.

This study generally confirms the viability of the CCPMRS spectrum regime where the basic approach is cooperative management of the spectrum resource. Not only is the regime effective in the control of interference between licensees, but it appears to create incentives which encourage licensees to use the spectrum in an economically efficient manner. The

expected because increased spectrum demand would increase the cost of future frequency usage by existing eligibles. That it would also increase the value of present assignments would be discounted because licensees generally do not consider their assignments to be marketable assets, a view founded on past Commission policies which have regarded the spectrum assignment as a right awarded only to those who would utilize it for their own communications systems, be they private or common carrier. Also, because existing assignments are tailored in size and location to the licensee's specific system design and service objectives, their potential to accommodate services of a different nature may be quite limited. Thus while opening these bands to other uses would lead to more economically efficient use of the spectrum, the present regime creates incentives to oppose it.

A fundamentally different assignment scheme which would encourage rather than discourage service innovation is being considered in other bands and could possibly be adapted here as well. The principal ingredient in this new approach is the nationwide assignment of spectrum in large blocks with few if any preconditions on service type or system design except as required to control interference between licensees.⁴⁴ Assignments could

⁴⁴ This is the basic concept embodied in the Commission's "Alternative Regulatory Approach" proposed in the 800 MHz mobile reserve bands. See Notice of Proposed Rulemaking, Gen. Docket No. 84-1231, adopted November 21, 1984, pp 31-46.

efficiently. Because inefficiencies in the management of the spectrum could increase the cost of doing business, licensees have a strong incentive to cooperate where necessary and to invest the resources necessary to develop efficient solutions. This is apparent in the industry's active participation in its national association. It is also evident in the large and growing number of technical professionals involved in frequency coordination within licensee firms as well as technical consulting firms who provide engineering and computer resources to licensees on a shared basis. It is difficult to imagine the Commission being able to concentrate this amount of resource on the micro management of spectrum used by a single industry, even though it may be, and apparently is, economically efficient to do so.

As daily participants in the coordination process, licensees and their technical consultants are in a far better position than the Commission or its staff to understand problems with the process and to develop efficient solutions. Many of the complex technical and procedural problems being studied by the NSMA would be difficult to address through the regulatory process. Consider, for example, the industry's extensive C/I tables, which must be updated constantly as new systems are introduced and to reflect refinements in interference calculation models or new channeling conventions enacted by the industry to make more intensive use of allocated spectrum. To attempt to deal with these issues in the adversarial environment of rulemaking would not be conducive to consensus building and would subject

ensue would quickly establish a price structure which would be more effective and accurate in motivating economically efficient use of the spectrum than is the implicit pricing that occurs under the present regime.

These ideas obviously need further refinement before they can be implemented in the context of this service. Control of interference is a paramount concern in any loosening of regulation of the spectrum. In this case, care should also be taken to maximize the utilization of existing industry spectrum management capabilities that have been organized around the present structure. The presence of those resources should, in fact, facilitate the transition to a less regulated, market based regime in which an even greater responsibility for management of the spectrum would be assumed by the private sector.

of negotiations between licensees and applicants during the coordination process. Present allocation restrictions may be (and probably are) causing an inaccurate valuation of spectrum by artificially limiting both spectrum supply and demand. Elimination of these barriers would result in a more accurate reflection of spectrum value in system design and a corresponding increase in overall economic output from the resource. It would also minimize the need for constant administrative adjustments in allocations as changes occur in technology (e.g., the replacement of microwave links with optical fiber) which alter the relative demand for spectrum among the various uses.

To allow the present coordination system to adjust to these changes, the barriers could be lowered gradually, allowing initially only those additional uses that are technically similar and which have similar interference effects, e.g., private point-to-point services. Later, the door could be opened to technically dissimilar uses, such as mobile or omnidirectional systems. Coordinating these latter uses into the existing point-to-point environment would no doubt complicate interference calculations. However, if the cost of coordination is too great, these other uses would simply look elsewhere for lower cost spectrum.

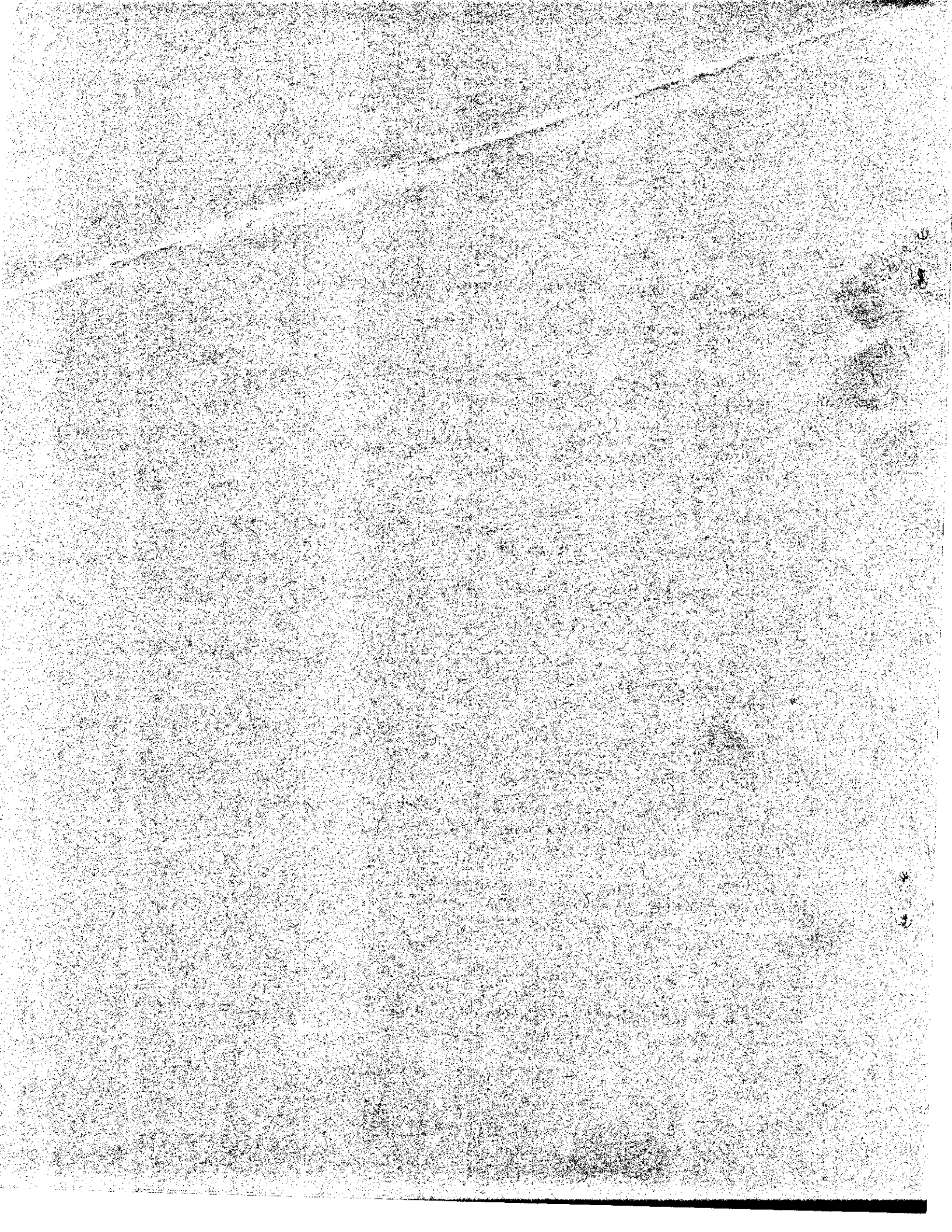
That present users would likely oppose the lifting of restrictions on eligibility or types of service in these bands is itself a sign of a basic flaw in the cooperative spectrum management approach. Opposition is to be

subsequently be traded and combined in whatever dimensions best met the demands of the marketplace. Licensees under such a regime would have powerful incentives to seek out the most highly valued uses whether innovative or traditional and to invest in the management of the spectrum assignment according to its economic value.

The feasibility of applying this concept to the common carrier microwave bands needs further study. But conceivably each band could be divided into several large blocks⁴⁵ for assignment nationwide to individual licensees. Block licensees would then be selected and a cutoff date set for the cessation of licensing and coordination under the current system. Block licensees would be required to protect any licensed or coordinated usage recorded prior to the cutoff date. Other than that and whatever emission limits apply at the edges of their blocks, there would be no restrictions on how licensees use their assignments.

Assignments would be combinable and transferable and the licensees would be free to construct and operate radio systems themselves of whatever type and for whatever service they wish or to allow others to build and operate systems within their spectrum blocks. The transactions that would

⁴⁵ Since larger spectrum blocks would be more efficient than smaller ones, some multiple of the current maximum channel width would be appropriate.



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