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# Technical Sharing Issues Between Broadcast-Satellite and Fixed Services

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# TECHNICAL SHARING ISSUES BETWEEN BROADCAST-SATELLITE AND FIXED SERVICES

H.M. Gates and D.A. Hill*

The Regional Administrative Radio Conference will be convened in 1983 for planning broadcasting-satellite service in the International Telecommunication Union Region 2 to resolve the issue of allocating orbital positions and radio frequencies in the band 12.1-12.7 GHz. In the United States the band 12.2-12.7 GHz has also been allocated to fixed service. This domestic sharing issue must be resolved in part or in total as part of the United States preparations for the 1983 RARC. This research expands on selective conditions for domestic sharing, and concludes that sharing is possible, but only under several restrictive conditions.

Key words: 1983 Region 2 Regional Administrative Radio Conference (RARC); band sharing; Broadcasting-Satellite Service (BSS); Fixed Service (FS); microwave interference

## 1. INTRODUCTION

The 1977 World Administrative Radio Conference (WARC) of the International Telecommunication Union (ITU) performed detailed planning of the Broadcasting-Satellite Service (BSS) in the 12-GHz band. This conference adopted a plan for the allotment of frequencies and orbital positions for the BSS in the 12-GHz band for Regions 1 and 3. It was also resolved that a Region 2 Administrative Radio Conference (RARC) for the BSS be convened in 1983. The 1983 RARC is to divide the band 12.1-12.3 GHz in two sub-bands and allocate the lower sub-band to the Fixed-Satellite Service (FSS) and the upper sub-band to the BSS, Broadcasting Service (BS), mobile (except aeronautical mobile), and Fixed Services (FS). The 1983 RARC is to draw up detailed frequency allotments and an orbital position plan for the BSS for Region 2 in the band 12.3-12.7 GHz and in the upper portion of the band 12.1-12.3 GHz which it will allocate to the BSS.

Under the provisions of Part 94 of the United States Federal Communications Commission (FCC, 1980), Rules and Regulations, the band 12.2-12.7 GHz has been allocated to FS use and is to be potentially shared with both BSS and BS or reassigned to a different band. Part 94 of the FCC Rules and Regulations refers to the FS as a Private Operational Fixed Microwave Service. Therefore, one technical issue

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is the sharing and compatibility of these two services within this frequency band which is the central topic of this report. This research expands on the findings of a key study by Akima (1980) in which sharing is proven feasible under certain conditions. In this study, we expand on several technical issues which deal with inband sharing options for the United States which are based on more recently available (and compiled) U.S. FS-user deployment data (FCC, 1981; SPI, 1980). This domestic related research is necessary in providing further insights for a U.S. international position at the 1983 RARC in the arbitration of orbital positions and frequency allotments.

## 2. CURRENT DEPLOYMENT OF EXISTING FS TERRESTRIAL MICROWAVE

A data base for the FS terrestrial 12.2-12.7 GHz band (SPI, 1980) reveals that there are 1529 microwave transmitters in operation today within the continental United States as shown in Table 1. In addition, there are approximately 680 applications into the FCC for inband frequency assignments, and there are about 188 applications in preparation. New systems are being installed at the rate of 10% to 15% each year. Figure 1 is an interconnection map of these microwave systems (corresponding to 1,241 paths) in the continental United States. This map shows approximately 20 multipoint, long-haul microwave paths (for example between the metropolitan areas of Los Angeles and San Francisco). The remainder of these systems are mostly localized in and around the larger metropolitan areas of the United States where about 71% of the links are less than 10 miles (16 km) long, and approximately 32% of all links are 2 miles (3.2 km) or less. These link-length distributions are shown in Figure 2.

The eight states having the greatest number of FS terrestrial systems in this band are California with 248 operational links, Texas with 153 links, New York with 87 links, Pennsylvania with 66 links, Massachusetts with 60 links, Ohio with 58 links, New Jersey with 57 links, and Illinois with 53 links. The largest user group appears to be state and local governmental institutions. In California more than 70% are in this category.

The largest private users are AT&T and Hahnemann Medical Center, operating on 28 links each. Banks, other medical institutions, aerospace firms, publishing and newspaper companies, computer manufacturers, private universities and colleges, gas and electric utility companies, oil companies, and specialized communication firms form the next echelon user base. Transportation users of this frequency band (operational, applied for, or planned) are relatively small.

Table 1. FS Terrestrial Microwave Systems Within the Continental United States

| | Operational | Applied For | Planned | Total |
|---|---|---|---|---|
| No. of Links (Tower-Tower Paths) | 780 | 362 | 99 | 1241 |
| No. of Microwave Sites | 1560 | 724 | 198 | 2482 |
| No. of Transmitters | 1529* | 680 | 188 | 2397** |

* FCC data base contains 1426 transmitters (FCC, 1981).

** Compucon, Inc. data base contains approximately 2300 emitters (Compucon, 1981).

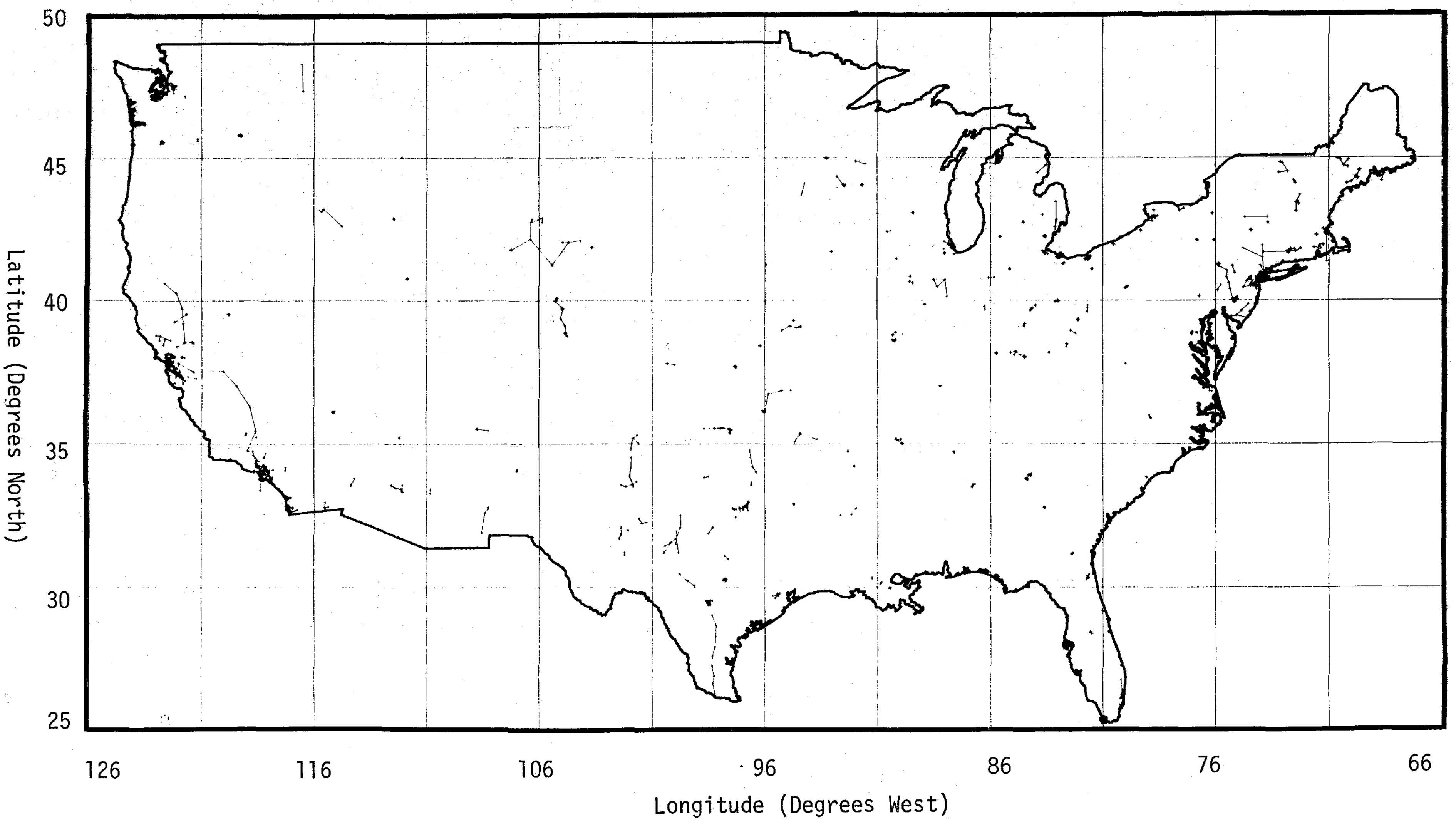



Figure 1. Private operational fixed microwave service in the United States for 12.2-12.7 GHz.

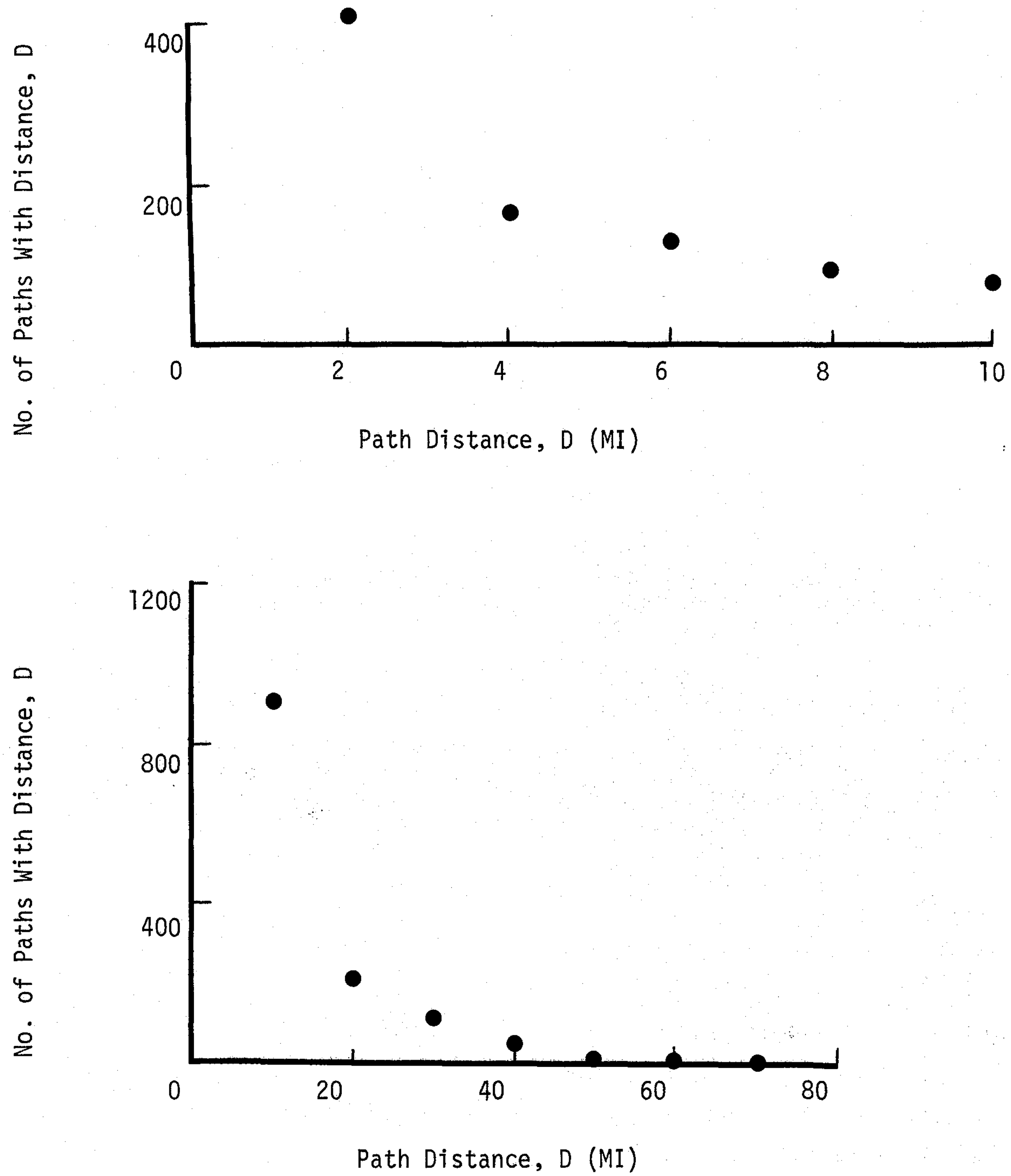



Figure 2. Long and short path distributions for private operational fixed microwave service in the 12.2-12.7 GHz band.

The FS terrestrial users are also located within bands at 6 GHz, 2 GHz, 1 GHz, and 0.9 GHz frequencies. Figures 3, 4, 5, and 6 are the interconnect maps for these bands also provided through the SPI data base (SPI, 1980). The transportation industries do appear as large, long-haul users in these bands.

Of the 1,529 operational transmitters in the continental United States, 763 are reported to support video-type data, 388 are used for analog (assumed voice traffic), and 25 for digital transmission. The remaining 353 are unknown. Table 2 is a detailed summary of this information.

The user data base also shows that 94% of the deployed systems use phase modulation, 5% use amplitude modulated vestigial sideband television, and 1% use amplitude modulation with two independent sidebands. And finally, the average bandwidth specified in the user data base is approximately 20 MHz. This has been summarized in Figure 7.

## 3. THE AVAILABLE SPECTRUM IN SELECTED LARGE METROPOLITAN AREAS

The proliferation of 12.2-12.7 GHz FS terrestrial users in the metropolitan areas appears to be proportional to the population. Two of the most congested metropolitan areas are Los Angeles and New York City, shown in Figures 8 and 9. The top twelve metropolitan areas appear to be Los Angeles with 187 transmitters, New York with 141, San Francisco with 91, Boston with 62, Dallas/Ft. Worth with 47, Detroit with 47, Philadelphia with 42, Seattle with 42, Chicago with 41, Cedar Rapids with 37, and Houston with 27. A comparison of frequency use in these areas is made between the SPI (SPI, 1980) FS terrestrial data base for fully operational systems and the data presented in the Harris Corporation -- Farinon Electric Operations comments (Harris, 1981). The data are presented in Table 3 for Los Angeles and in Table 4 for New York. Correlation between these two sources is high. The correlation coefficient r (Papoulis, 1965, p. 112), where $-1 \le r \le 1$ is 0.96 for Los Angeles and 0.87 for New York.

In every case, where there are no frequency assignments, the adjacent channel bandwidth assignments are 20 MHz. There appears to be little room for added frequency assignments to terrestrial microwave systems in these congested areas. The Rules and Regulations, Part 94.65(H)(1) and (2) state the FCC policies for the stated channel planning and are consistent with these data and findings.

On a national basis 42% of the 12.2-12.7 MHz FS terrestrial microwave transmitters are located in the Eastern time zone, 26% in the Central time zone, 6% in the Mountain time zone, and 26% in the Pacific time zone. Total frequency

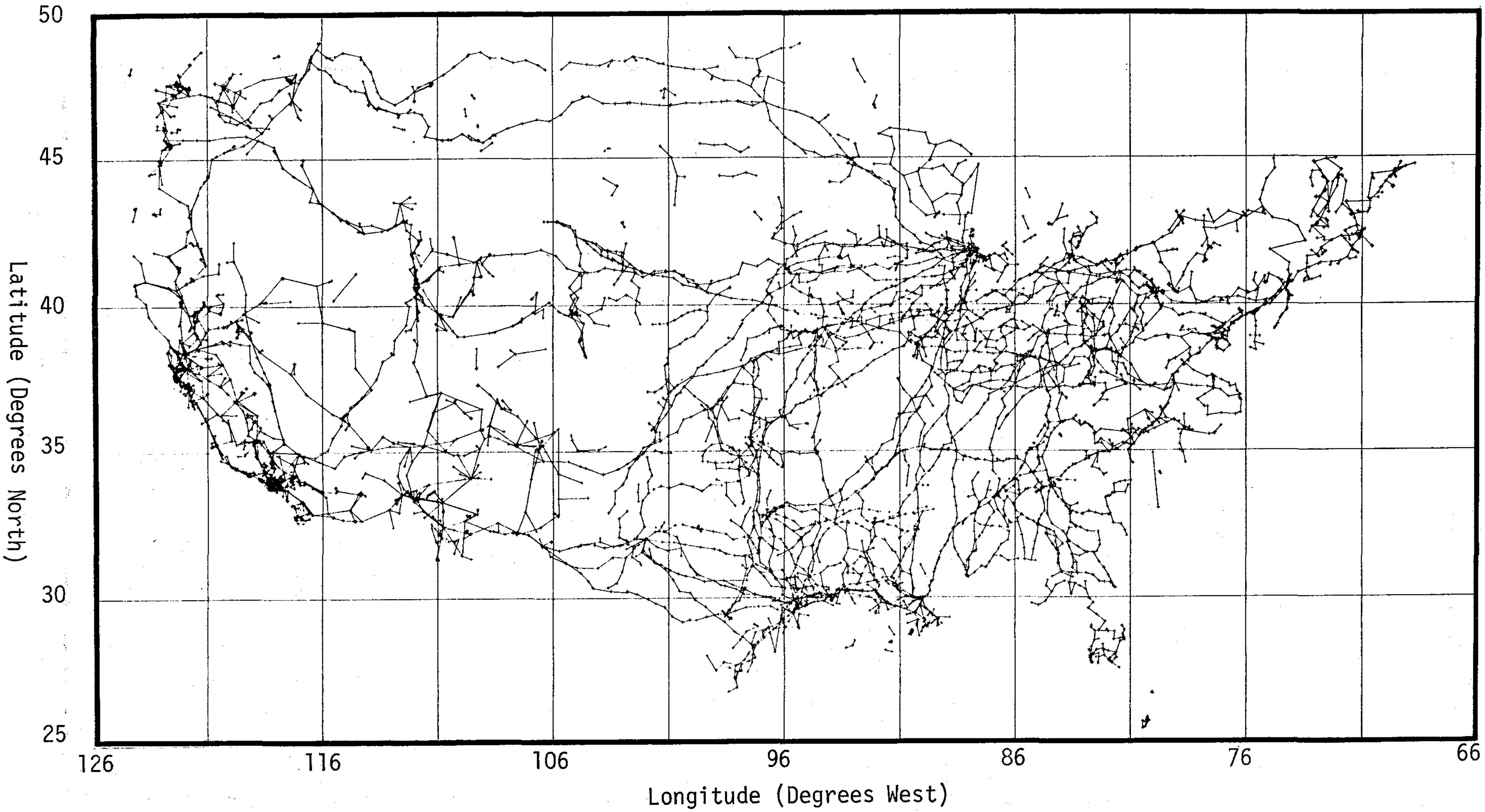



Figure 3. Private operational fixed microwave service in the United States for 6.525-6.875 GHz.

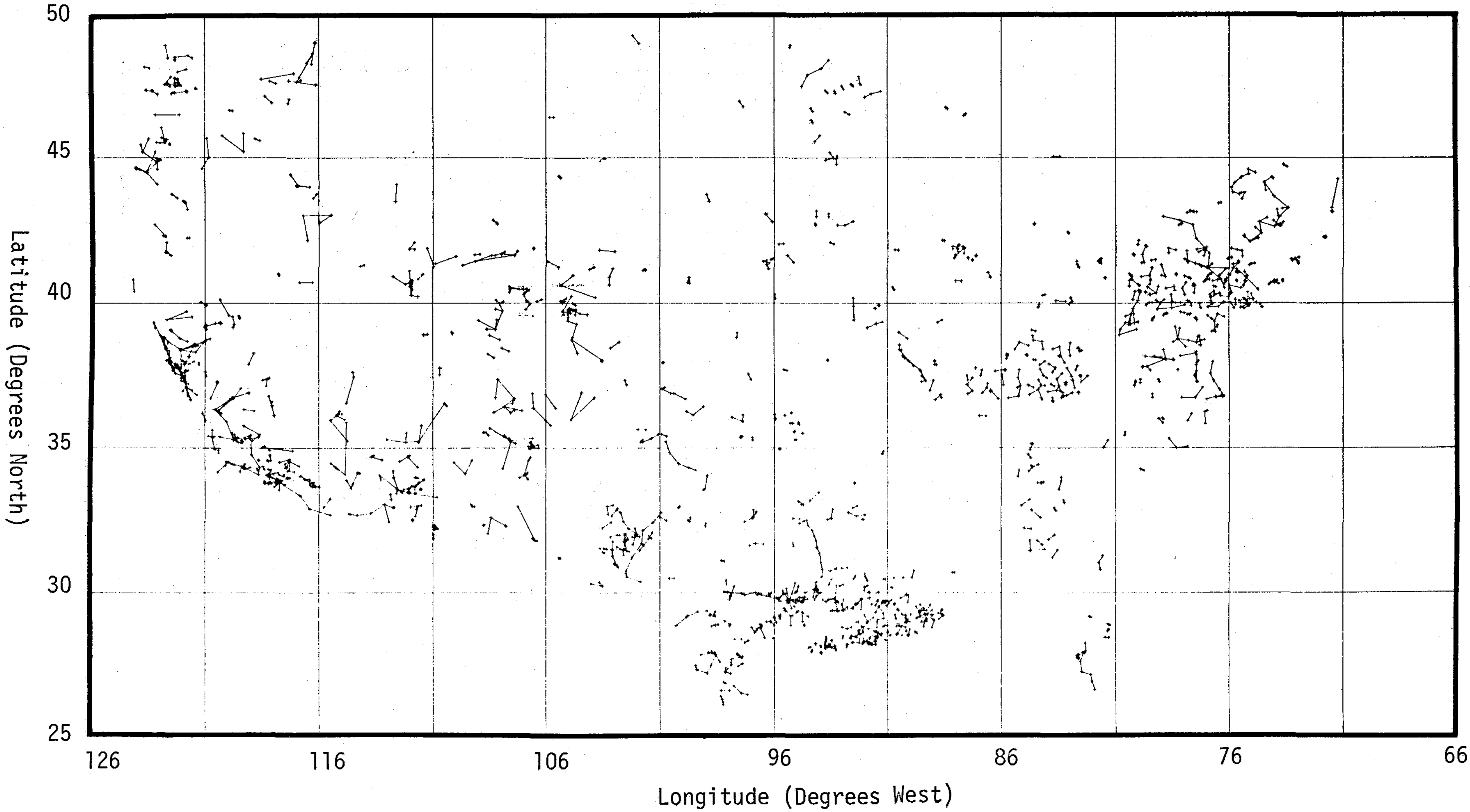



Figure 4. Private operational fixed microwave service in the United States for 2.13-2.15 and 2.18-2.20 GHz.

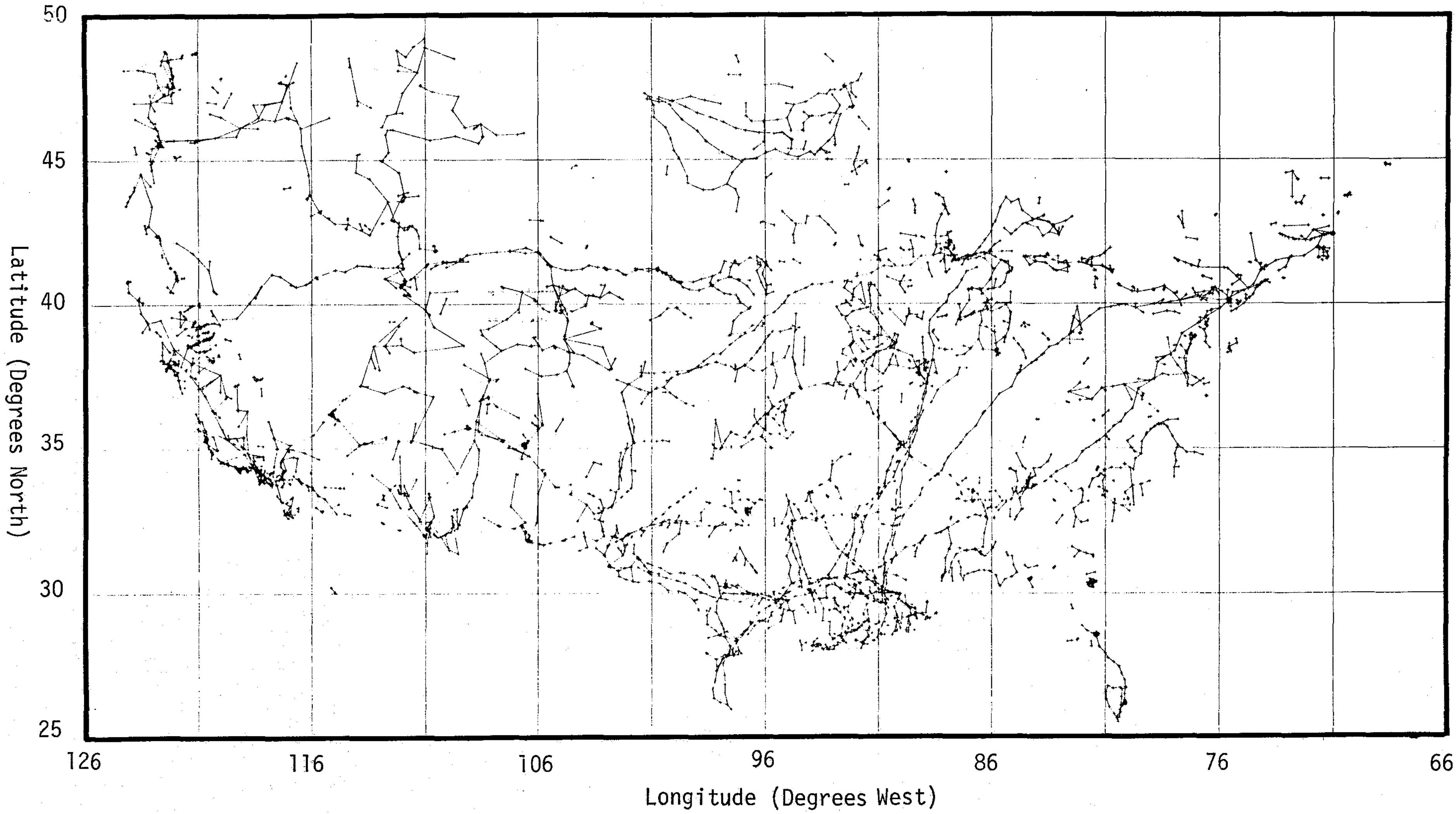



Figure 5. Private operational fixed microwave service in the United States for 1.85-1.99 GHz.

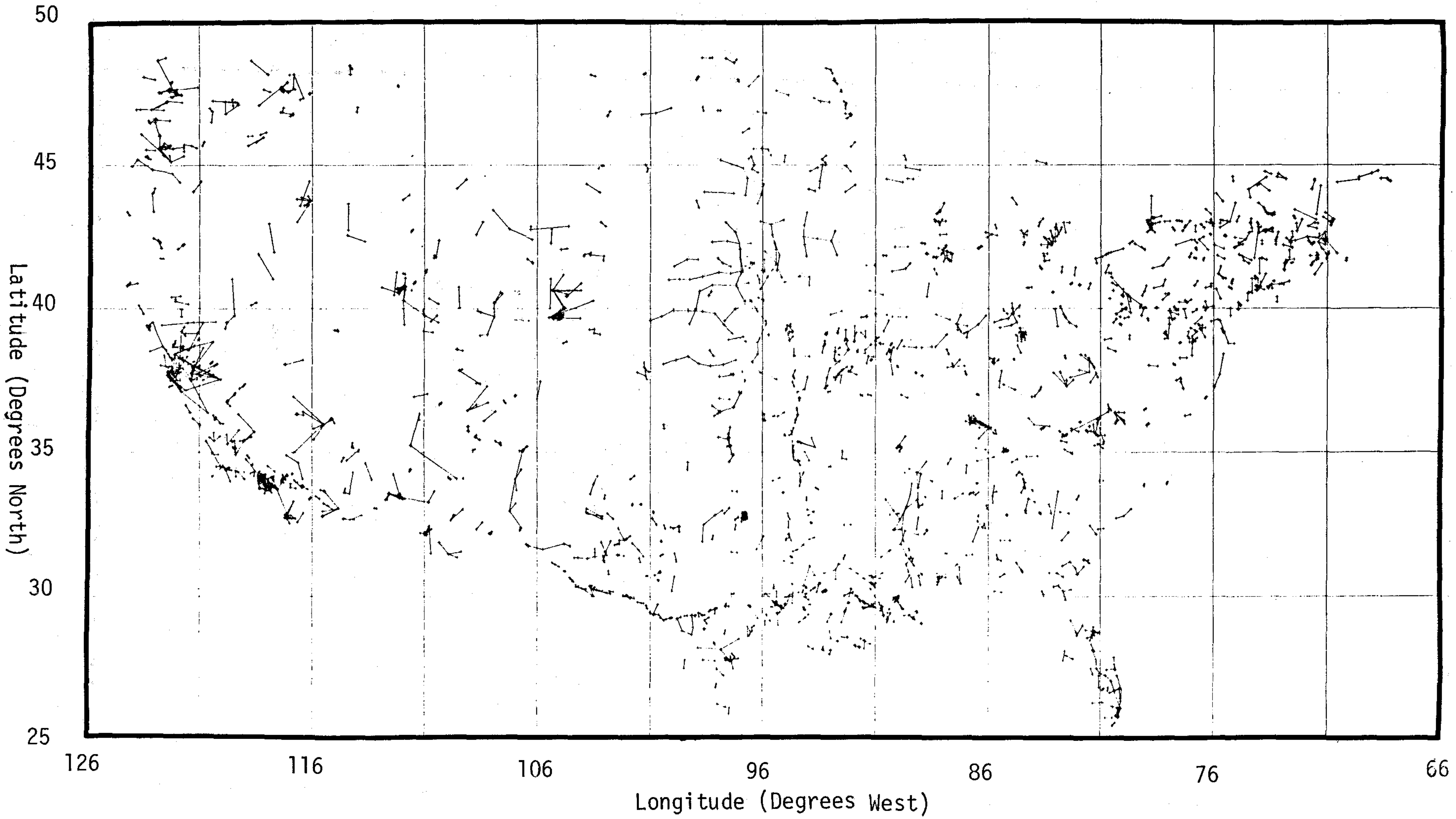
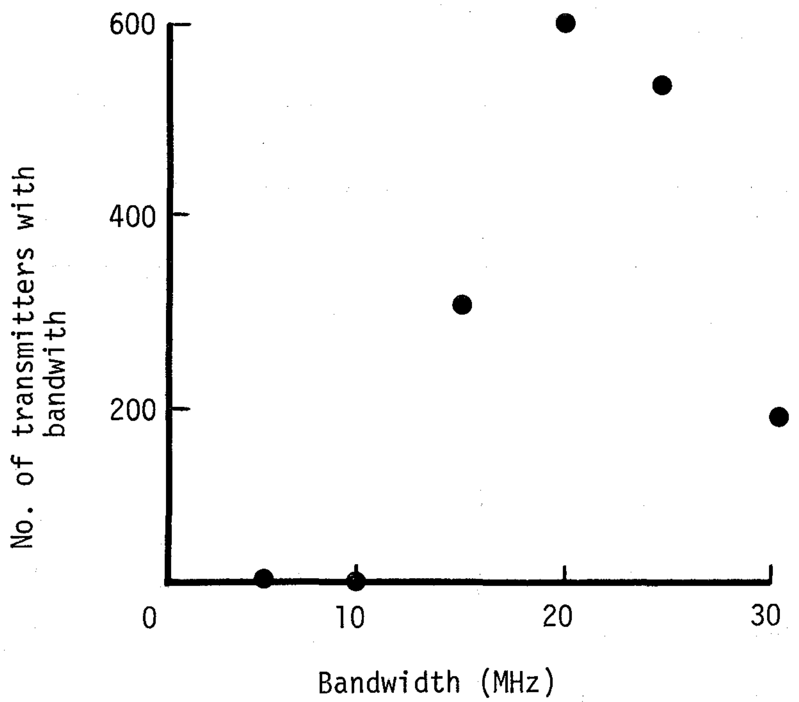



Figure 6. Private operational fixed microwave service in the United States for 0.952-0.960 GHz.

Table 2. Traffic Summary For Operational Systems in the United States

| | Subtotals | Totals |
|---|---|---|
| Analog Video Channels | | 763 |
| Analog Voice Channels | | |
| No. of 6 Channel Systems | 23 | |
| No. of 24 Channel Systems | 2 | |
| No. of 60 Channel Systems | 10 | |
| No. of 120 Channel Systems | 24 | 388 |
| No. of 240 Channel Systems | 29 | |
| No. of 300 Channel Systems | 49 | |
| No. of 420 Channel Systems | 40 | |
| No. of 600 Channel Systems | 54 | |
| No. of 900 Channel Systems | 23 | |
| No. of 1200 Channel Systems | 134 | |
| Digital Channels | | 25 |
| Not Specified | | 353 |




| Bandwidth in MHz (From-to) | No. of Transmitters (Operational, Applied For, and Planned) | No. of Transmitters (Operational Only) |
|---|---|---|
| 2.5-7.5 | 12 | 10 |
| 7.5-12.5 | 5 | 2 |
| 12.5-17.5 | 307 | 218 |
| 17.5-22.5 | 593 | 382 |
| 22.5-27.5 | 519 | 290 |
| 27.5-30.0 | 191 | 168 |
| Sample Size | 1627 | 1070 |

Figure 7. Distribution of transmitter bandwidths.

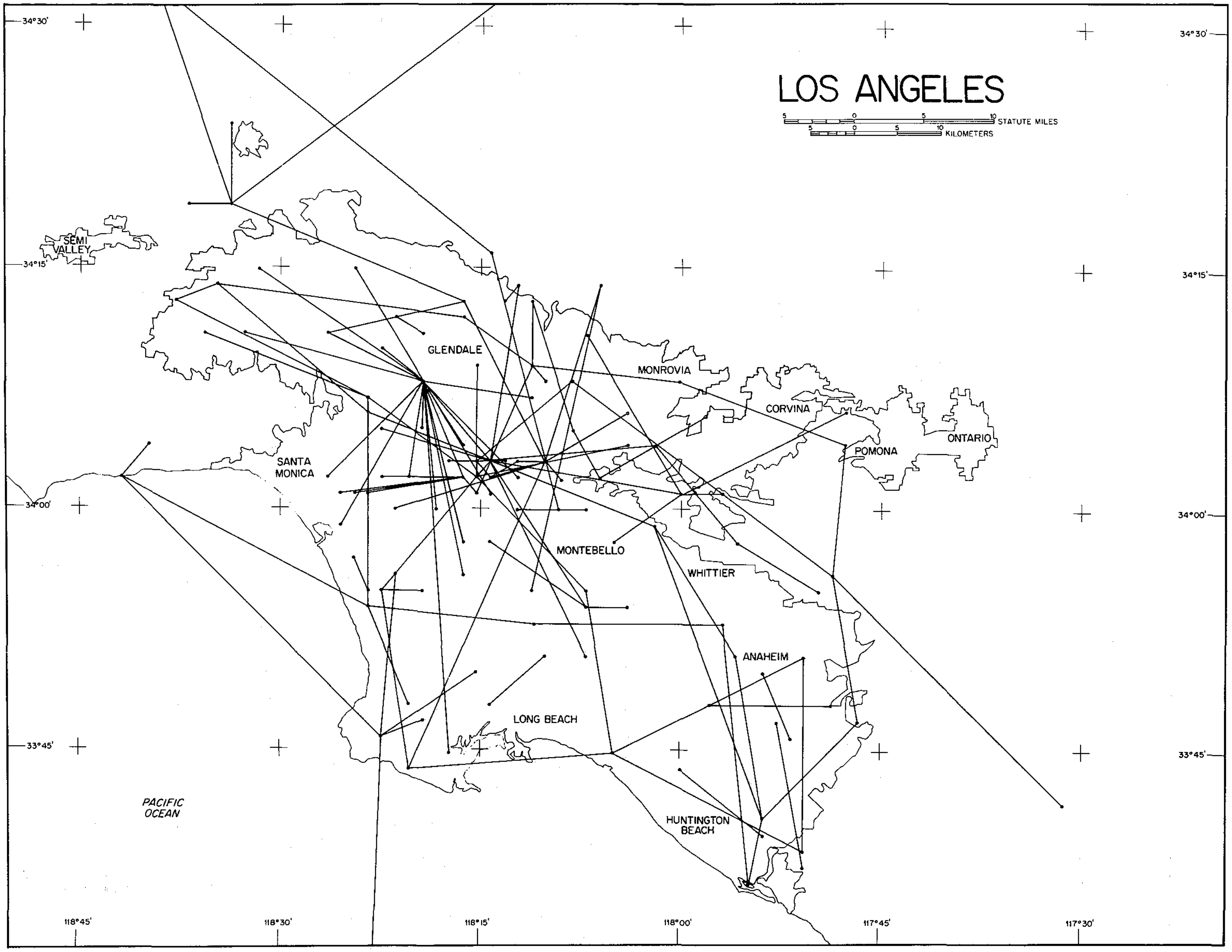



Figure 8. Terrestrial FS user connectivity for the 12.2-12.7 GHz band in the greater Los Angeles Area.

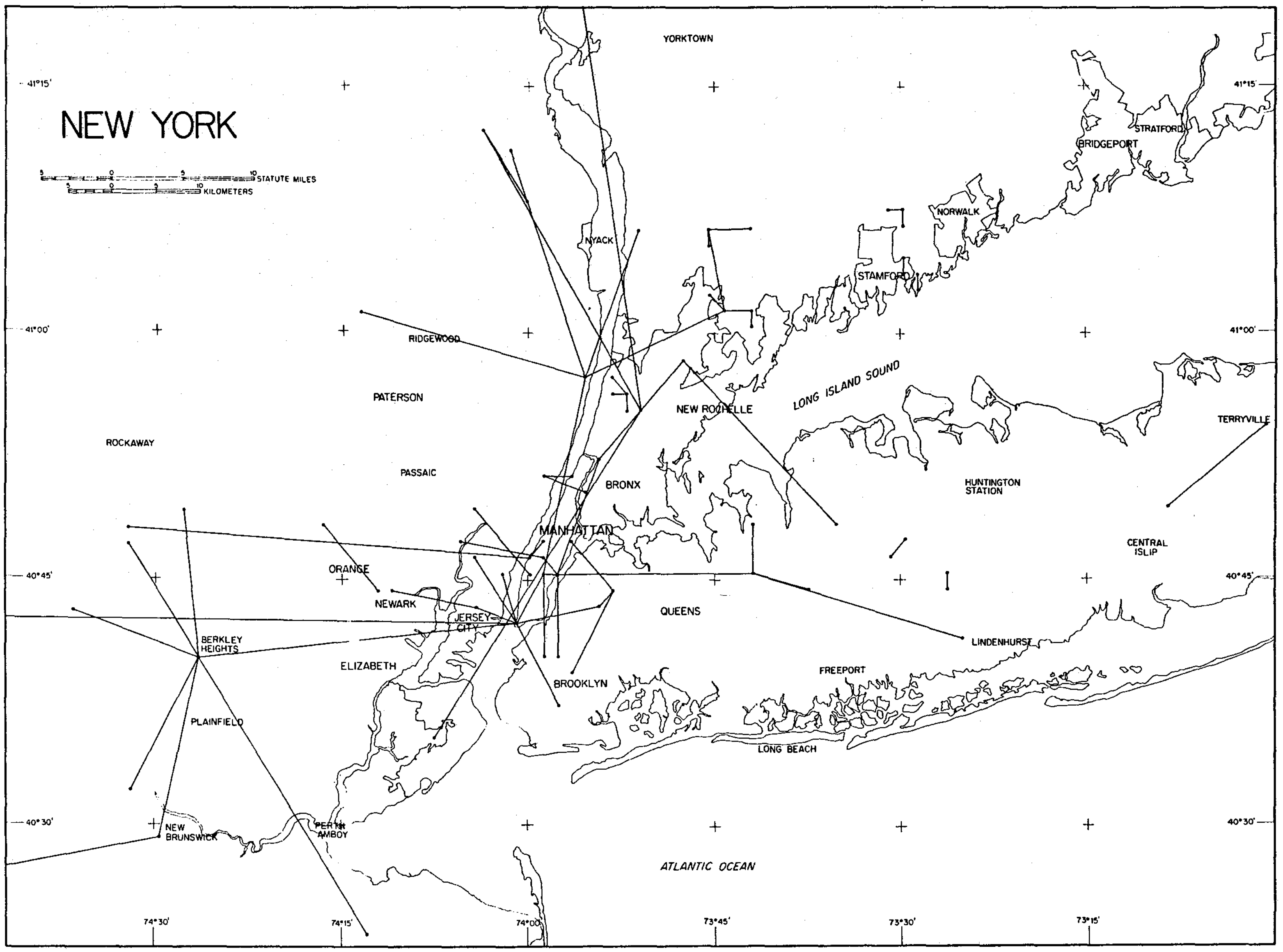



Figure 9. Terrestrial FS user connectivity for the 12.2-12.7 GHz band in the greater New York City area.

Table 3. Frequency Comparisons in the Greater Los Angeles Area

| Frequency | Number of Transmitters SPI[1] (Operational Only) | Number of Transmitters Farinon[2] | Frequency | Number of Transmitters SPI[1] (Operational Only) | Number of Transmitters Farinon[2] |
|---|---|---|---|---|---|
| 12210 | 11 | 13 | 12460 | 2 | 3 |
| 12220 | 3 | 3 | 12470 | 5 | 5 |
| 12230 | 9 | 11 | 12480 | 0 | 0 |
| 12240 | 0 | 0 | 12490 | 3 | 2 |
| 12250 | 9 | 13 | 12500 | 1 | 1 |
| 12260 | 0 | 0 | 12510 | 2 | 5 |
| 12270 | 18 | 23 | 12520 | 0 | 0 |
| 12280 | 0 | 0 | 12530 | 5 | 11 |
| 12290 | 4 | 11 | 12540 | 0 | 1 |
| 12300 | 0 | 0 | 12550 | 3 | 5 |
| 12310 | 14 | 15 | 12560 | 0 | 0 |
| 12320 | 0 | 0 | 12570 | 7 | 8 |
| 12330 | 8 | 12 | 12580 | 1 | 2 |
| 12340 | 3 | 3 | 12590 | 8 | 11 |
| 12350 | 6 | 10 | 12600 | 0 | 0 |
| 12360 | 0 | 0 | 12610 | 7 | 11 |
| 12370 | 3 | 4 | 12620 | 0 | 0 |
| 12380 | 0 | 0 | 12630 | 11 | 13 |
| 12390 | 3 | 8 | 12640 | 0 | 0 |
| 12400 | 0 | 0 | 12650 | 8 | 12 |
| 12410 | 13 | 14 | 12660 | 0 | 0 |
| 12420 | 0 | 0 | 12670 | 7 | 10 |
| 12430 | 2 | 3 | 12680 | 0 | 0 |
| 12440 | 0 | 0 | 12690 | 5 | 9 |
| 12450 | 6 | 6 | | | |

1. Operational data only (SPI, 1980).

2. Comments by Harris Corporation-Farinon Electronics Operations (Harris, 1981).

Table 4. Frequency Comparisons in the Greater New York City Area

| Frequency | Number of Transmitters SPI[1] (Operational Only) | Number of Transmitters Farinon[2] | Frequency | Number of Transmitters SPI[1] (Operational Only) | Number of Transmitters Farinon[2] |
|---|---|---|---|---|---|
| 12210 | 7 | 11 | 12460 | 0 | 0 |
| 12220 | 2 | 3 | 12470 | 7 | 11 |
| 12230 | 5 | 6 | 12480 | 0 | 0 |
| 12240 | 0 | 0 | 12490 | 3 | 4 |
| 12250 | 2 | 5 | 12500 | 3 | 5 |
| 12260 | 0 | 2 | 12510 | 5 | 6 |
| 12270 | 8 | 8 | 12520 | 0 | 0 |
| 12280 | 0 | 0 | 12530 | 4 | 5 |
| 12290 | 4 | 4 | 12540 | 1 | 1 |
| 12300 | 1 | 1 | 12550 | 1 | 2 |
| 12310 | 6 | 9 | 12560 | 0 | 0 |
| 12320 | 0 | 0 | 12570 | 7 | 7 |
| 12330 | 2 | 5 | 12580 | 1 | 1 |
| 12340 | 1 | 1 | 12590 | 5 | 7 |
| 12350 | 4 | 5 | 12600 | 0 | 0 |
| 12360 | 0 | 0 | 12610 | 6 | 8 |
| 12370 | 8 | 8 | 12620 | 0 | 4 |
| 12380 | 0 | 0 | 12630 | 8 | 8 |
| 12390 | 12 | 9 | 12640 | 0 | 2 |
| 12400 | 0 | 0 | 12650 | 5 | 7 |
| 12410 | 0 | 6 | 12660 | 0 | 0 |
| 12420 | 0 | 0 | 12670 | 4 | 8 |
| 12430 | 4 | 4 | 12680 | 0 | 0 |
| 12440 | 0 | 0 | 12690 | 9 | 6 |
| 12450 | 6 | 6 | | | |

1. Operational data only (SPI, 1980).

2. Comments by Harris Corporation-Farinon Electronics Operations (Harris, 1981).

assignments in the United States are given in Table 5. The SPI data base (SPI, 1980) is compared with the Satellite Television Corporation DBS Application (STC, 1980) results which in turn were referenced to an older version of the FCC data file (FCC, 1980). These two data files are not closely correlated, r = 0.67.

## 4. SOME IMPLICATIONS OF THE 1979 WARC

Incorporated in the Final Acts of the 1979 WARC (ITU, 1982, Appendix 30) and the Final Acts of the 1977 WARC-BS (World Administrative Radio Conference for the Planning of the Broadcasting-Satellite Service) (ITU, 1982, Articles 9 and 10) are the methodologies for determining the limiting interferring power flux densities at the edge of a broadcasting-satellite service area and for the power flux density produced there by a terrestrial station at 11.7-12.2 GHz for Region 2, and 11.7-12.5 GHz for Regions 1 and 3.

A report by Akima (1980) delineates the results of the WARC-BS into specific U.S. and Canadian sharing applications. There were many important conclusions reached in this report based on the WARC-BS assumptions. First, Akima (1980, p. 8) states that:

> "The results of the study indicate that interference from the BSS to the FS is, in general, not a serious problem."

A second major conclusion reached (Akima, 1980, p. 20) is that:

> "The results of the study indicate that interference from the FS to BSS is not a negligible problem. For successful sharing between the BSS and the FS, the interference must be controlled by prudent use of both the BSS and FS systems."

He continues:

> "To avoid intolerable interference from the FS system currently in use in the United States, the two services must use two different portions of the band in each BSS service area. In other words, sharing must be done by frequency division in each BSS service area."

This was predicated on a set of two-dimensional contour diagrams (see Figure 10) which define zones of interference for both co-channel and adjacent-channel interference. The BSS receiver antenna diameter is 3.1 feet (0.96 m) and the FS transmitter antenna diameter is 3.1 feet (0.96 m). The FS transmitter power is assumed to be 1 W (or 0 dBW). The outer contour is referred to as worst case in which the angle of elevation of the BSS receiving antenna is 15°, and the azimuths of both the FS transmitter and BSS satellite seen from the BSS receiver coincide with each other. The inner contour is for a more favorable case in

Table 5. Distribution of Assigned Frequencies for the United States Which Occupy the Band 12.2-12.7 GHz

| Frequency | Number of Transmitters SPI[1] (Operational Only) | Number of Transmitters STC[2] | Frequency | Number of Transmitters SPI[1] (Operational Only) | Number of Transmitters STC[2] |
|---|---|---|---|---|---|
| 12200 | 1 | 3 | 12460 | 16 | 33 |
| 12210 | 166 | 101 | 12470 | 63 | 53 |
| 12220 | 19 | 45 | 12480 | 0 | 3 |
| 12225 | 0 | 1 | 12490 | 61 | 41 |
| 12230 | 52 | 58 | 12500 | 10 | 17 |
| 12240 | 0 | 2 | 12510 | 49 | 38 |
| 12250 | 72 | 61 | 12520 | 1 | 0 |
| 12260 | 5 | 18 | 12530 | 65 | 48 |
| 12270 | 70 | 60 | 12540 | 2 | 7 |
| 12280 | 1 | 0 | 12550 | 23 | 34 |
| 12290 | 64 | 51 | 12560 | 0 | 0 |
| 12300 | 8 | 21 | 12570 | 63 | 38 |
| 12310 | 55 | 56 | 12580 | 8 | 12 |
| 12320 | 0 | 0 | 12590 | 33 | 33 |
| 12330 | 74 | 49 | 12600 | 0 | 1 |
| 12332.5 | 0 | 1 | 12610 | 51 | 37 |
| 12340 | 9 | 16 | 12620 | 0 | 0 |
| 12345 | 0 | 2 | 12630 | 46 | 31 |
| 12350 | 39 | 36 | 12640 | 0 | 0 |
| 12360 | 0 | 0 | 12650 | 48 | 39 |
| 12370 | 48 | 32 | 12660 | 0 | 0 |
| 12380 | 0 | 1 | 12670 | 29 | 33 |
| 12390 | 58 | 44 | 12671 | 0 | 1 |
| 12400 | 0 | 0 | 12677 | 0 | 1 |
| 12410 | 32 | 41 | 12680 | 0 | 2 |
| 12420 | 0 | 0 | 12683 | 0 | 1 |
| 12430 | 39 | 26 | 12689 | 0 | 1 |
| 12440 | 0 | 3 | 12690 | 48 | 35 |
| 12450 | 101 | 79 | | | |

1. Operational data only (SPI, 1980).

2. From the STC filing (STC, 1980).

which the elevation angle of the BSS receiving antenna is so large that the antenna gain in the direction of the FS transmitter is equal to the residual gain regardless of the azimuthal relations. Table 6 (from Akima, 1980, p. 15) tabulates the data presented in Figure 10.

These formulations are in complete consort with the WARC 1979 and WARC-BS 1977 Final Acts. They represent an important technical contribution to the sharing issues in the United States. It is the union of Akima's research, the newly obtained materials in the data bases of the FS deployment in the United States, and extended research into the assumptions made by the WARC 1979 and WARC-BS 1977 Final Acts that form the backdrop for the remainder of this report.

## 5. THE FS TRANSMITTER ANTENNAS

Figure 11 is a scatter diagram of FS terrestrial microwave antenna diameters as a function of distance between transmitter and receiver stations within the United States for the 12.2-12.7 GHz band. The top two station distances are highlighted for each antenna diameter. Several observations can be made. Antenna manufacturers fabricate their products in diameter multiples of 2 feet (0.61 m) from 2 to 12 feet (0.61 to 3.66 m). There are very few 12-foot (3.66 m) antennas deployed in the United States. There is a natural trend by the user community to use larger diameter antennas for longer distances.

There were 103 antenna patterns of antenna pattern envelopes collected by this agency for the 10.7-11.7 GHz common-carrier band. These patterns were measured at 11.2 GHz by the various antenna vendors. The data were sorted both by antenna diameter and by antenna pattern characteristics. The antenna patterns were found to vary widely even for antennas of the same diameter. However, some typical antenna patterns for diameters of 2, 6, and 12 feet (0.61, 1.83 and 3.66 m) are displayed in Figure 12.

Included in the diagram of Figure 12 and in the next three figures is a four-part pattern model. This model will be expanded later in the report, and references will be made to these figures and the four-part pattern model.

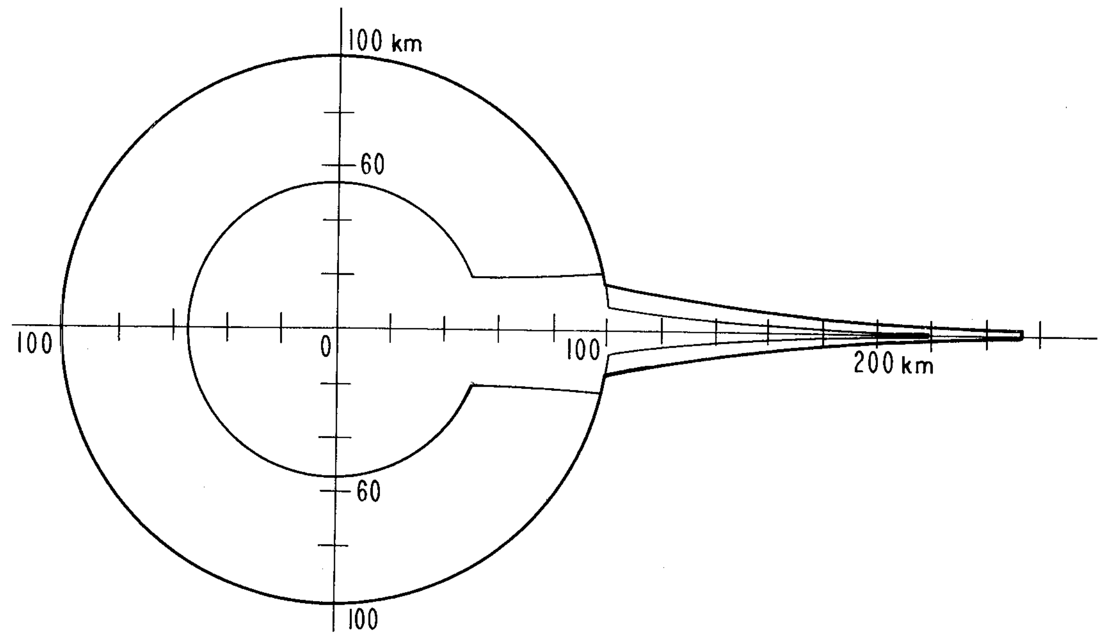
The frequency dependence of antenna sidelobes can be derived using CCIR Report 614-1 (CCIR, 1978, Vol. IX, p. 113) in which

$$G = M - 10 \log \frac{D}{\lambda} - 30 \log \phi, \qquad (1)$$

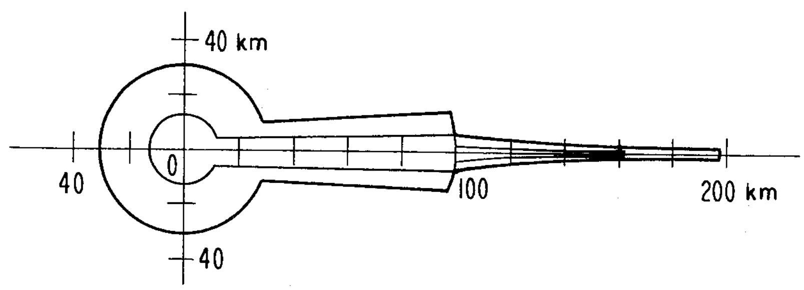
where G is the gain in dB; D and $\lambda$ are the dish diameter and wavelength, respectively, expressed in the same units; $\phi$ is the angle in degrees measured from the

Table 6. Minimum Separation Distance Required for the Co-Channel and Adjacent-Channel Interference From FS to BSS

| Channel Interference Reference | FS System | Antenna Diameter (m) | Transmitter Power (dBW) | Distance (km) | | | |
|---|---|---|---|---|---|---|---|
| | | | | Worst Case | | Most Favorable Case | |
| | | | | On-Axis | Distant | On-Axis | Distant |
| Co-Channel | U.S.<br>Low-Power | 0.6 | Typical -20.0<br>Max. - 3.0 | 126.8<br>200.0 | 13.0<br>92.2 | 100.0<br>166.4 | 5.3<br>37.6 |
| | U.S.<br>High-Power | 1.8 | Typical 0.0<br>Max. 10.0 | 254.0<br>297.0 | 100.0<br>104.1 | 220.4<br>263.4 | 53.1<br>100.0 |
| Adjacent-Channel | U.S.<br>Low-Power | 0.6 | Typical -20.0<br>Max. - 3.0 | 100.0<br>144.5 | 3.0<br>20.9 | 69.8<br>110.9 | 1.2<br>8.5 |
| | U.S.<br>High-Power | 1.8 | Typical 0.0<br>Max. 10.0 | 198.4<br>241.5 | 29.5<br>93.3 | 164.9<br>207.9 | 12.0<br>38.0 |




(A) Co-channel Interference




(B) Adjacent-Channel Interference

Figure 10. Contours on which the receiver interfering FS signal power is equal to its maximum permissible limits for a United States high-power FS system. The outer contour is for the worst case, and the inner contour is for the most favorable case (Akima, 1980, p. 12).

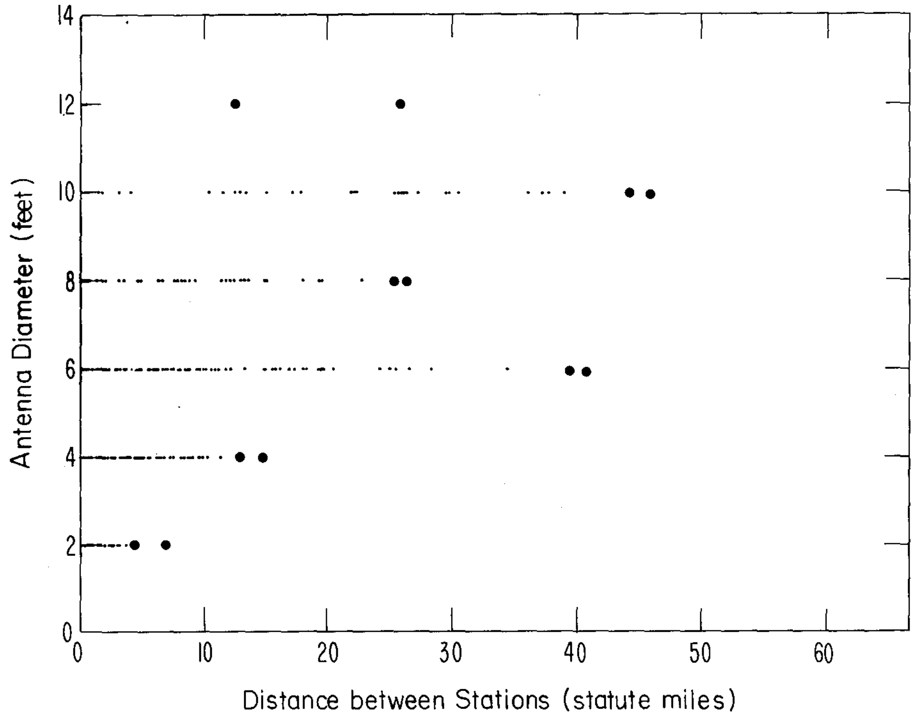



Figure 11. Scatter diagram of United States deployed FS antenna systems as a function of distance between transmitter and receiver versus antenna diameter.

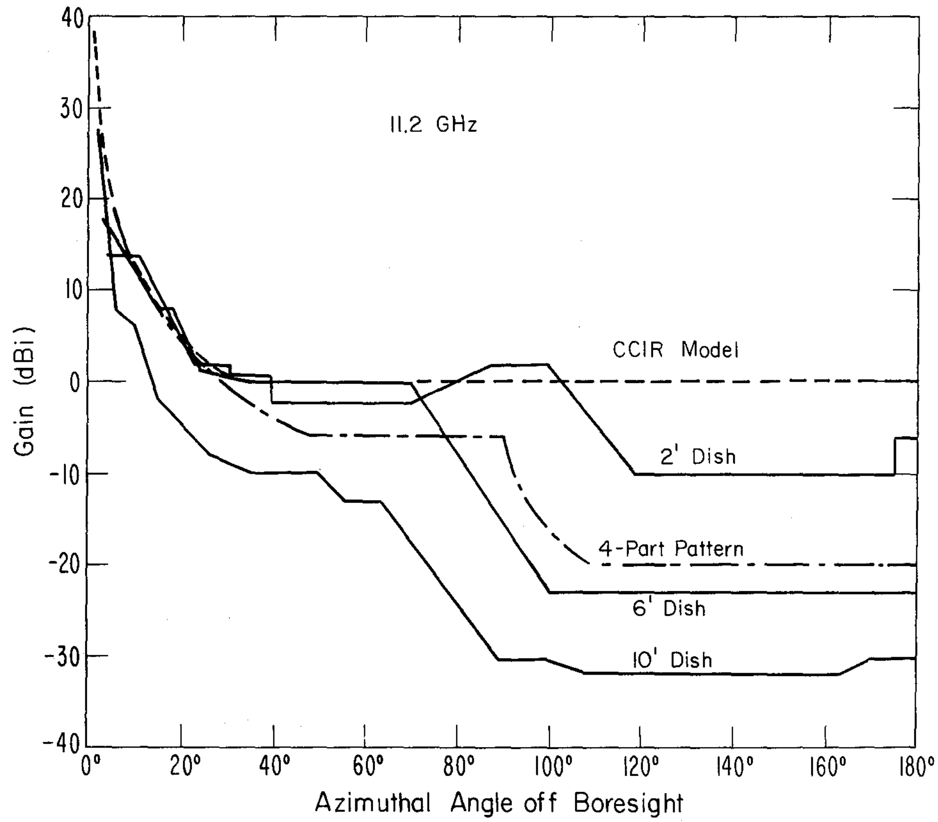



Figure 12. Radiation patterns of typical parabolic dish antenna in the 10.7 to 11.7 GHz range.

main-lobe axis, and M is a constant (independent of $\lambda$) which depends on the illumination function. Hence

$$G = M - 10 \log D + 10 \log \lambda - 30 \log \phi. \quad (2)$$

All of the sidelobe envelope frequency dependence is in the term $10 \log \lambda$. A 10% decrease in $\lambda$ which corresponds to an increase in frequency from 11.2 GHz to 12.45 GHz, will decrease G by 0.46 dB. Therefore, the radiation patterns in Figure 12 for the 12.2-12.7 GHz band should improve slightly.

There are other radiation patterns of typical dish antennas in the 2-through-11-GHz bands. Figure 13 represents 100 different antenna measurements at 4, 6, and 11 GHz made for the CCIR Study Programme 17A/9 in 1972.[1] This diagram displays a set of distributions at various angles off the main-beam axis. Figures 14 and 15 represent similar findings which were reported at the Advisory Group for Aerospace Research and Development (AGARD) in 1973 (Colavito and Masone, 1973). Superimposed on all four radiation pattern figures is the CCIR model (CCIR, 1978, Vol. IX, p. 114).

There are several observations from Figures 12 through 15. First, the CCIR model is a conservative representation of the FS microwave antenna. Second, there appear to be four distinct parts to these patterns which gives rise to the possibility for a four-part pattern model in sharing. From this observation, Colavito and Masone (1973) developed an equation with variable coefficients for a four-part pattern. The coefficients were determined from a best fit with measured patterns, and the resulting four-part pattern for production antennas is shown in Figures 12 and 13. Third, these diagrams are for frequencies between 2.0 and 11.2 GHz. Transposition of these data to the 12.2-12.7 GHz will slightly lower all of the envelopes.

## 6. THE FS TRANSMITTER POWER

The FS terrestrial user group in the United States operates on a wide spectrum of power in the 12.2-12.7 GHz band. Figure 16 is a scatter diagram of transmitter power and transmitter/receiver distance representing 1529 transmitters. The largest power points are highlighted. The scale in Figure 16 is expanded in Figure 17 so that only the distances up to 10 miles (16 km) are plotted. There are 881 transmitters represented in this diagram. The 1-watt transmission

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[1] CCIR, March 21, 1972, Radiation Diagram of Line-of-sight Radio-Relay antennae For Use In Interference Studies With Communications Satellite Earth Stations, Study Programme 17A/19, Doc. 9/38-E, p. 7.

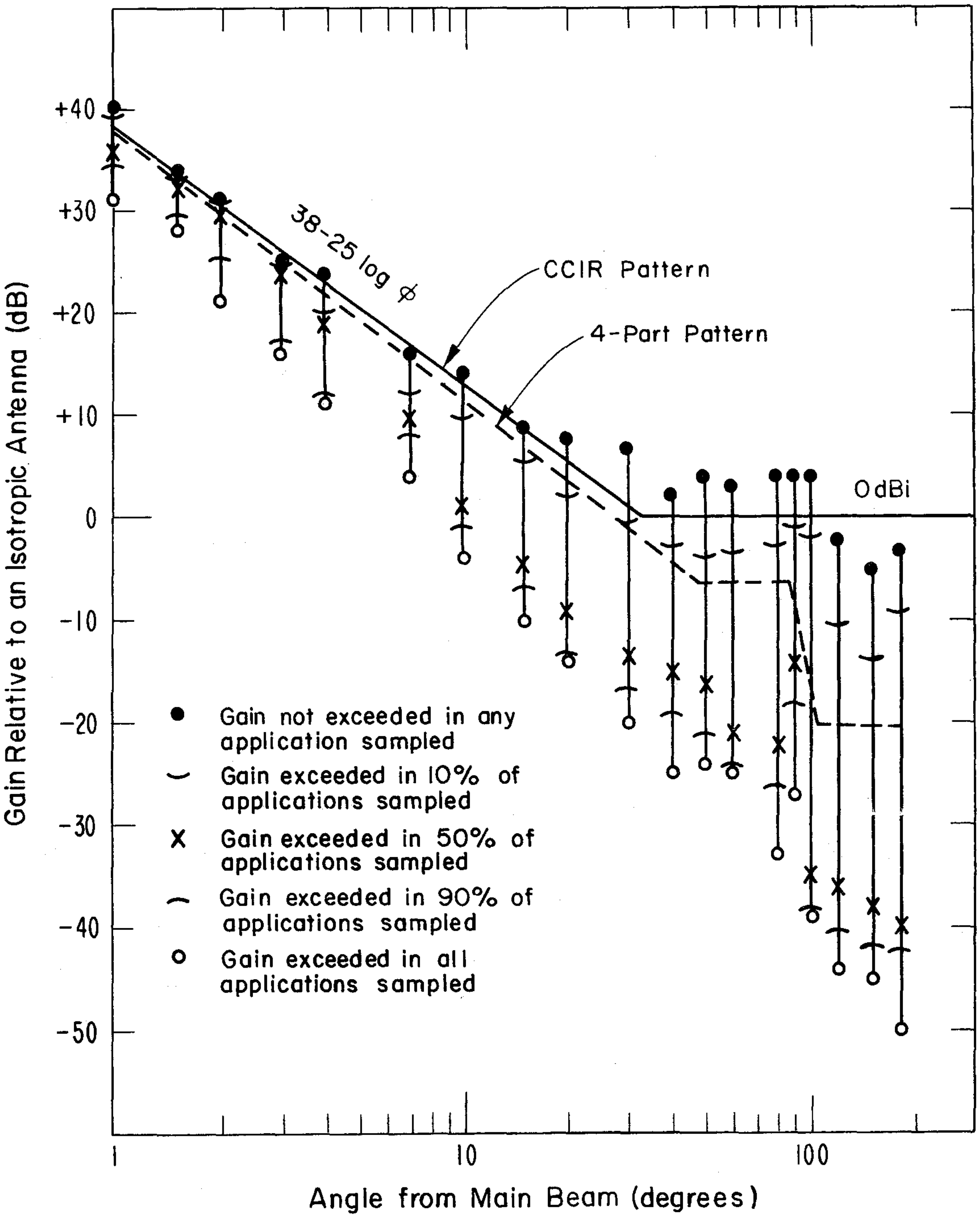


Figure 13. Distribution of horizontal plane gain for line-of-sight radio-relay antenna (CCIR, March 21, 1972, Radiation Diagram of Line-of-sight Radio-Relay antennae For Use In Interference Studies With Communications Satellite Earth Stations, Study Programme 17A/19, Doc. 9/38-E, p. 7).

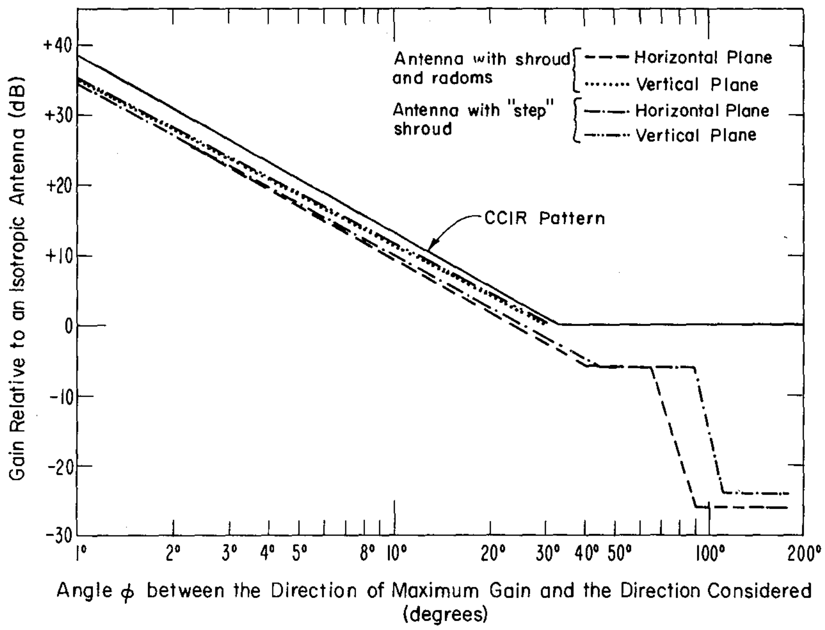


Figure 14. Radiation patterns of two typical parabolic dish antennas in the 7125-7750 MHz frequency range (Colavito and Masone, 1973, p. 11-6).

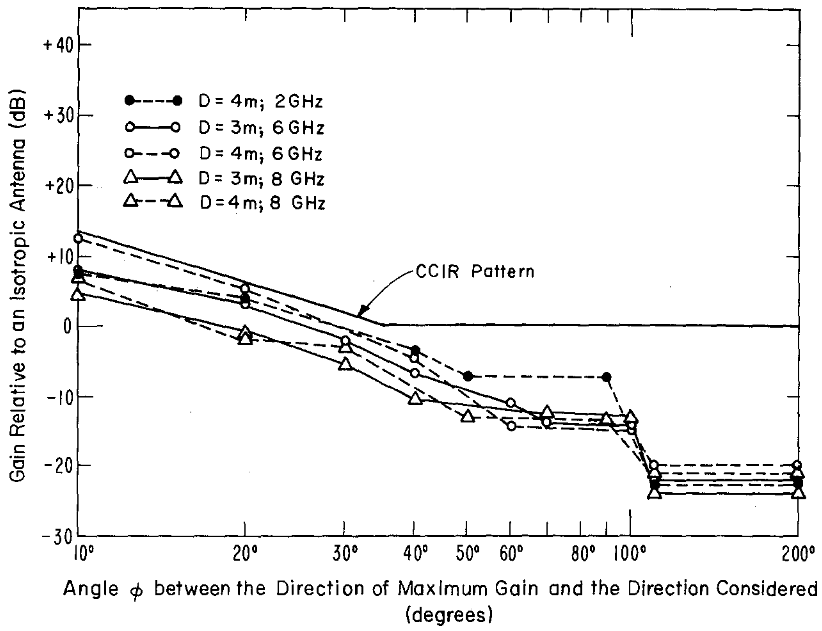


Figure 15. Radiation patterns of some parabolic dish antennas (from 2 GHz to 8 GHz) (Colavito and Masone, 1973, p. 11-6).

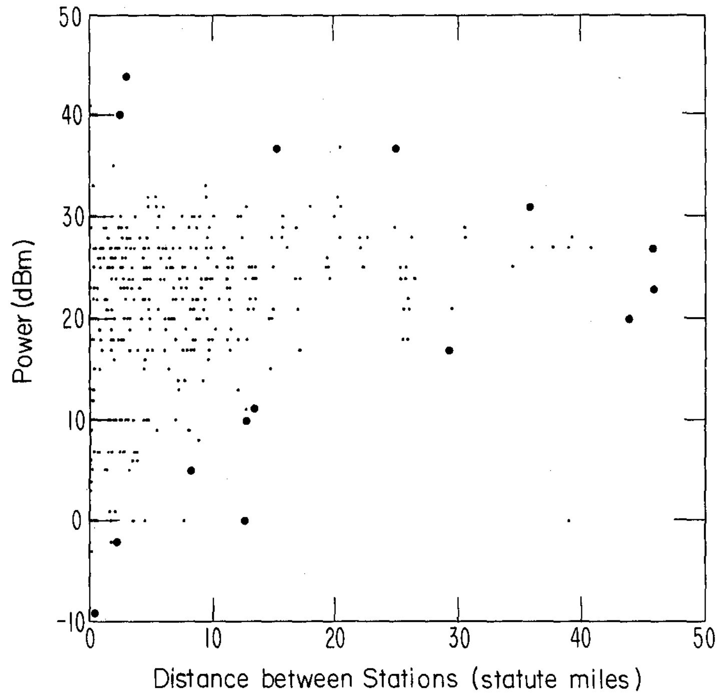


Figure 16. Station distance and transmitter power scatter diagram of 1529 FS transmitters in the United States.

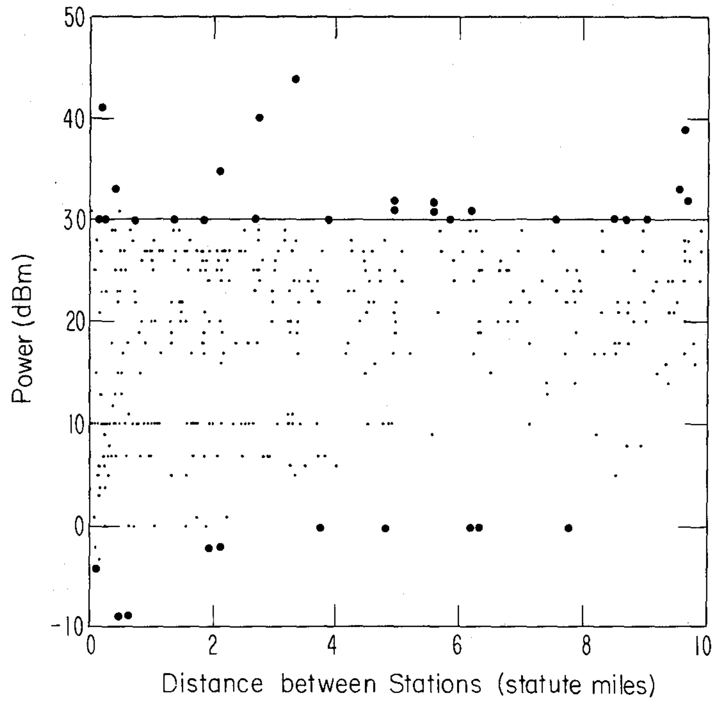


Figure 17. Expanded station distance and transmitter power scatter diagram of 881 FS transmitters in the United States.

reference line is shown. Transmitters with power equal to or greater than 1 watt are highlighted. The lower bound of transmitter power versus distance is also highlighted. Of the 881 transmitters, 12 are operating at 1 watt and 13 are operating at greater than 1 watt.

## 7. FS SYSTEM EIRP (EQUIVALENT ISOTROPICALLY RADIATED POWER) AND BANDWIDTH PERFORMANCE

The FS terrestrial transmitter EIRP values computed from the data base (SPI, 1980) are shown in two basic forms: as a scatter diagram in Figure 18 and as density function in Figure 19. Superimposed on Figure 18 are constant power-flux density (PFD) curves for -50, -70, and -105 dBW/m$^2$ in which

$$PFD = EIRP - 71 - 20 \log d \tag{3}$$

where d (distance between stations in km) is the unknown.

The BSS signal on the surface of the earth measured as PFD to be exceeded for 99% of the worst month at the edge of the service area is defined by the WARC-BS (ITU, 1977, pp. 82 and 103) as -105 dBW/m$^2$ for service areas in Region 2. There are added weather provisions which allow the PFD to vary between -100.5 dBW/m$^2$ and -96.7 dBW/m$^2$ in Region 2 using the materials in the Final Acts of the WARC-BS (ITU, 1977, p. 91) and the Akima report (Akima, 1980, p. 3). Reviewing the results displayed in Figure 18 clearly reveal the differences between the operating zones of both the FS and BSS systems in the 12.2 to 12.7 GHz band.

Figure 18 graphically demonstrates that a BSS signal of -105 dBW/m$^2$ will not interfere with the FS terrestrial reception which is almost exclusively above -70 dBW/m$^2$. However, one can begin to conceptualize graphically the magnitude of the interference potentials of the FS to the BSS particularly for co-channel interference with such operational power margins.

The PFD curves on this figure represent the flux densities at the FS and BSS receiver sites. Therefore, this figure also shows the general lack of FS system link budgeting. If a well-established budget process existed, one would expect to find most of the FS users located between PFD bands. Instead, for example, there are FS users successfully operating between two stations at 10 miles (16 km) at an EIRP of 25 dBW (PFD = -70 dBW/m$^2$) while another is operating at an EIRP of 55 dBW (PFD = -40 dBW/m$^2$). There appears to be little rationale given to these practices unless it is basically a desire for maintaining some form of reliability. The problem is compounded at station distances less than 2 miles (3.2 km).

It is possible to account for FS bandwidth (BW) in the data presented in Figures 18 and 19 by dividing the transmitter power component by the FS operating

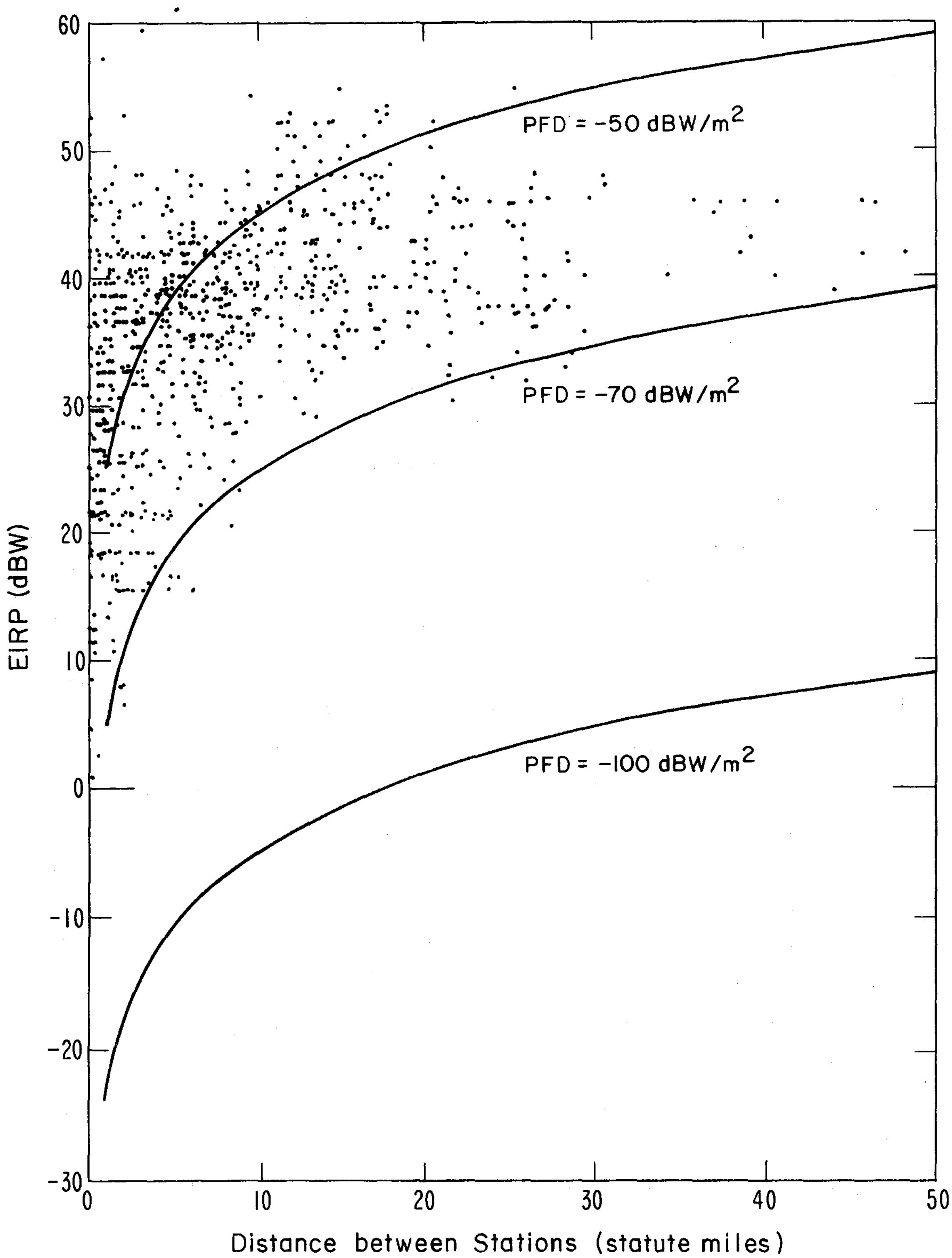


Figure 18. United States FS system operating levels roughly bounded between -50 and -70 dBW/$m^2$ PFD compared with the BSS PFD on the surface of the earth at -100 dBw/$m^2$.

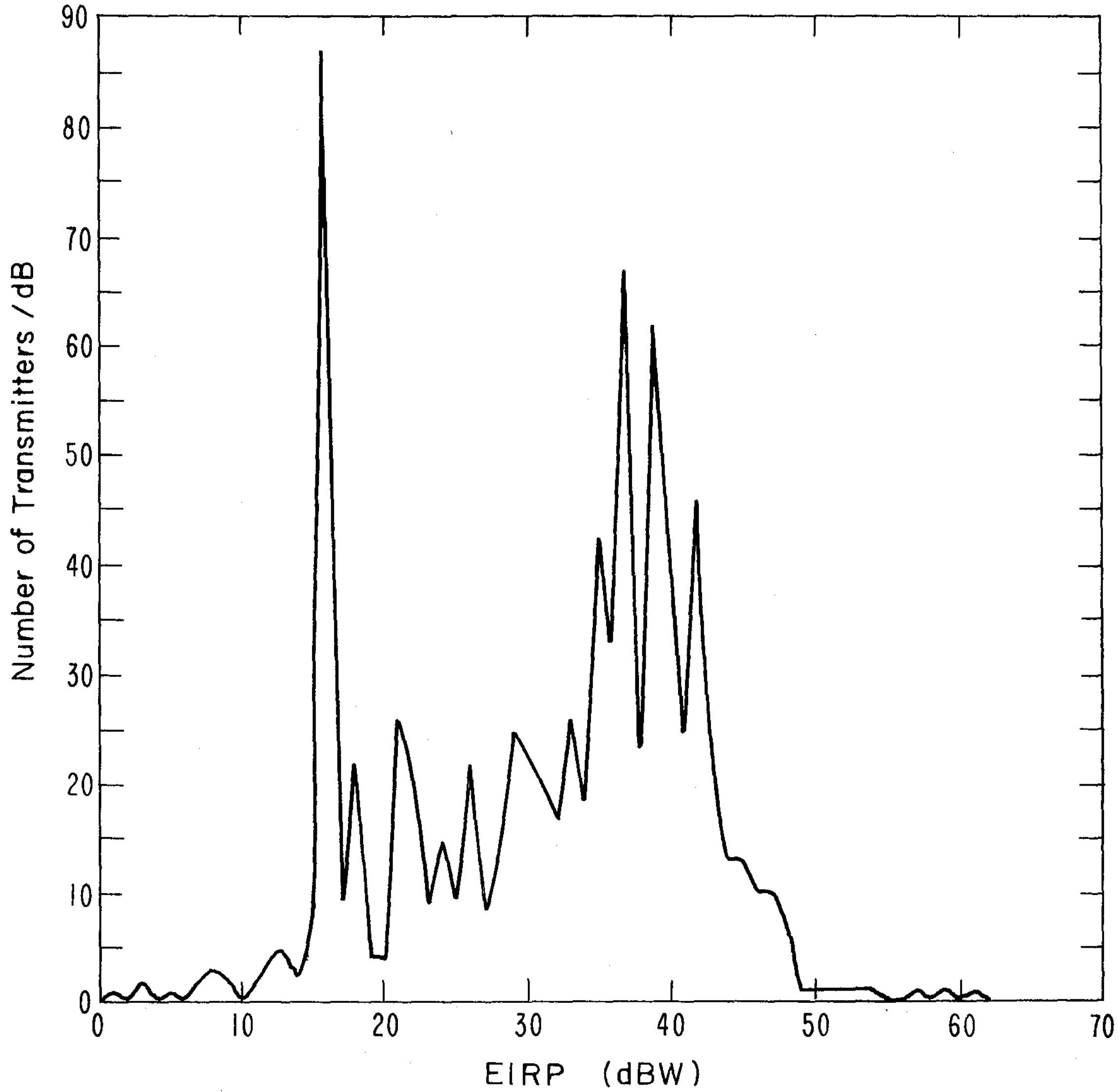


Figure 19. Density function of all operating FS transmitter EIRP's in the United States.

bandwidth. The EIRP's in Figures 18 and 19 are expressed logarithmically (in dBW). The logarithmic representation is therefore

$$PFD/BW = EIRP - 71 - 20 \log d - 10 \log BW \; (dBW/m^2Hz). \quad (4)$$

Predominantly, the FS system bandwidth varies between 10 and 30 MHz. The variation, $\delta$, for the effect of FS bandwidth is therefore

$$\delta = 10(\log BW_2 - \log BW_1) \quad (5)$$

$$\delta = 4.77 \text{ dB}. \quad (6)$$

The worst-case variation in Figure 18 is a downward shift of 4.77 dB with the FS user. It is relatively insignificant.

The data presented in Figures 18 and 19 do not include any final output attenuation or pads. It is unknown to what extent the FS output transmitter power is controlled by this practice.

## 8. PROPAGATION CONSIDERATIONS

The FS transmitter and rf equipment were treated in the previous section of this research. This section concerns itself with the path propagational characteristics between the FS and BSS.

FS Power-flux density (PFD) calculations are reduced in the WARC-BS Final Acts to a simplified form (ITU, 1977, p. 85) in which

$$PFD = E - A + 43. \quad (7)$$

The term E is the equivalent isotropically radiated power in dBW of the FS station in the direction of a point on the edge of the service area, and A is the total path loss in dB. For distances d (in km) between the transmitter and receiver unit less than 100 km.

$$A = 109.5 + 20 \log d. \quad (8)$$

This represents the line-of-sight loss minus 4.5 dB to account for possible ground reflection and focusing for which CCIR Report 569-1 (CCIR, 1978, Vol. V, p. 245) gives a 1% probability of occurrence. For d greater than 100 km

$$A = 137.6 + .2324 d, \quad (9)$$

which is the beyond-horizon propagation (because of smooth-earth diffraction), reflection, and ducting for which CCIR Report 724 (CCIR, 1978, Vol. V, p. 264) gives a 1% probability of occurrence. All FS paths in the United States are assumed to be over land, though provisions are available in the WARC-BS Final Acts to account for over-the-water paths. Figure 20 plots the path loss A using these assumptions as a function of distance. Note the discontinuity at 100 km.

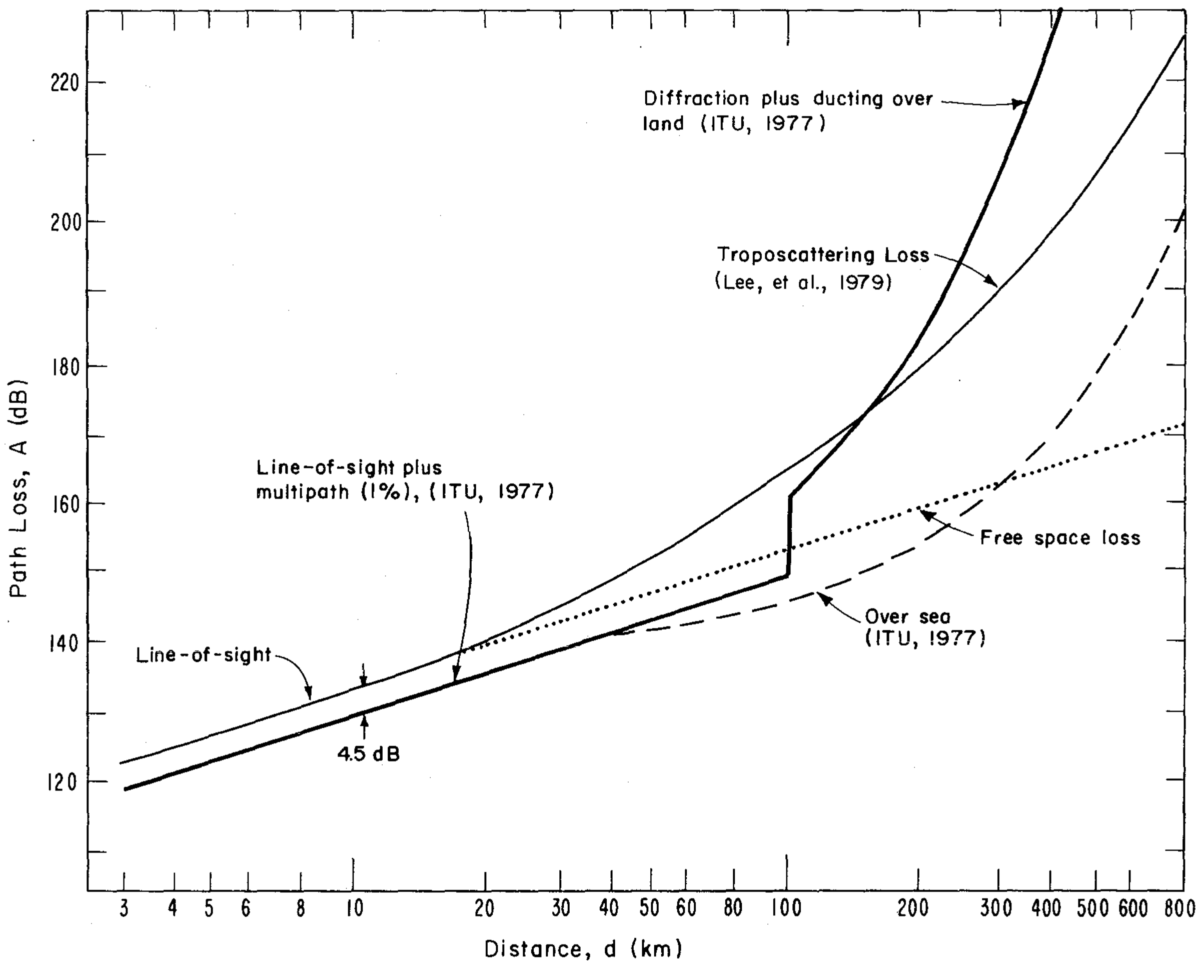


Figure 20. The terrestrial propagation path loss as a function of distance.

## 9. FS SIGNAL POWER RECEIVED BY THE BSS RECEIVER

The interfering FS signal power received by a BSS receiver is a function of the FS transmitting antenna gain in the direction of the BSS receiver, the FS transmitting power, the propagation loss, and the BSS receiving antenna gain in the direction of the FS transmitter.

Akima (1980, p. 10 through 14) computed areas of interference for both co-channel and adjacent-channel operations using the reference radiation patterns for a circular FS antenna pattern given in CCIR Report 614-1 (CCIR, Vol. IX, 1978), for a 1-watt FS transmission, the propagation calculations reported above, and the BSS receiving antenna pattern for Region 2 specified in the Final Acts (ITU, 1977, p. 84). These were the results shown in Figure 10 and tabulated in Table 6.

This process is repeated with two exceptions: (1) the less conservative four-part FS antenna pattern defined in Figures 12 and 13 is used, and (2) there is an added 3-dB polarization discrimination factor allowed by the Final Acts (ITU, 1977, p. 84) in which the interfering terrestrial service uses linear polarization and the broadcasting-satellite service is circularly polarized. Akima's assumption of a 1-watt FS transmitter is very good, based on the data presented in Figures 16 and 17. The results of the recalculations are given in Figure 21. The inside line is the four-part pattern calculation, and the outside line is the original Akima result. Notice at 100 km the pattern discontinuity caused by the discontinuity described in the propagation plot in Figure 20. The 3-dB polarization factor is manifested in the shortened main beam.

These patterns are overlayed on New York City in Figures 22 and 23 for co-channel and adjacent-channel interference contours. A factor which would further reduce the FS signal power received by the BSS receiver is site shielding. The effectiveness of site shielding has not been well studied at SHF, but measurements have shown as much as 30 dB of site shielding at UHF (CCIR, 1978, Vol. V, p. 154). Thus, the 20-dB, site-shielding assumption of Lee, et al., (1979) appears to be easily achievable.

## 10. NETWORK AND PATH SELECTION

Compacting FS users into part of the 12.2-12.7 GHz band requires that added attention be given to the FS network. The most obvious network problem is a star in which many transmitters and receivers are placed at one location with spokes emanating from this centroid in many different directions. These centroids are

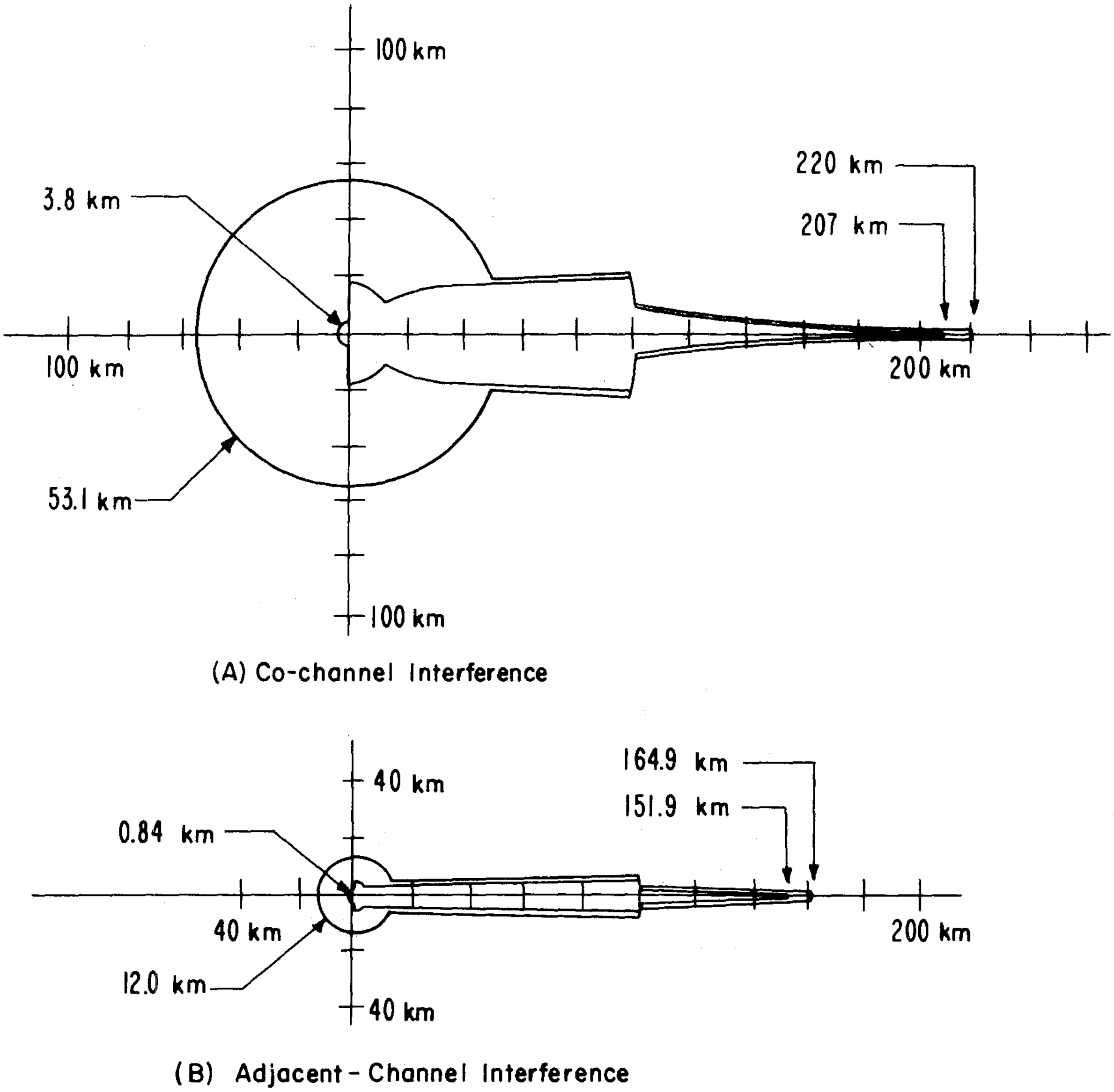


Figure 21. Interference contours based on four-part FS antenna pattern. The inside contours are based on calculations using the four-part pattern, and the outside contours from Akima (1980, p. 12).

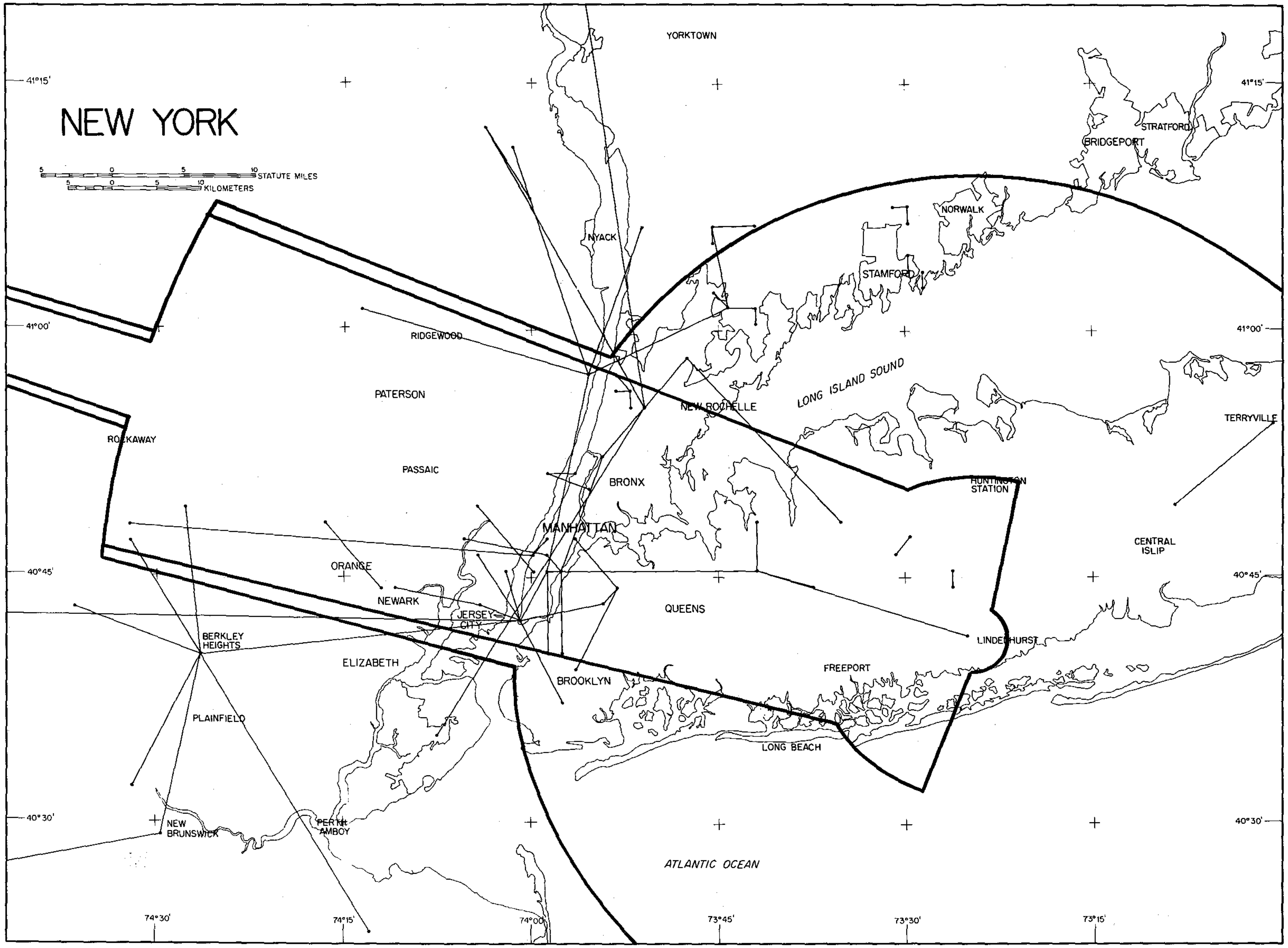


Figure 22. Co-channel interference contours overlayed on New York City. Inside contour derived from four-part pattern, outside contour derived by Akima (1980) using CCIR standards.

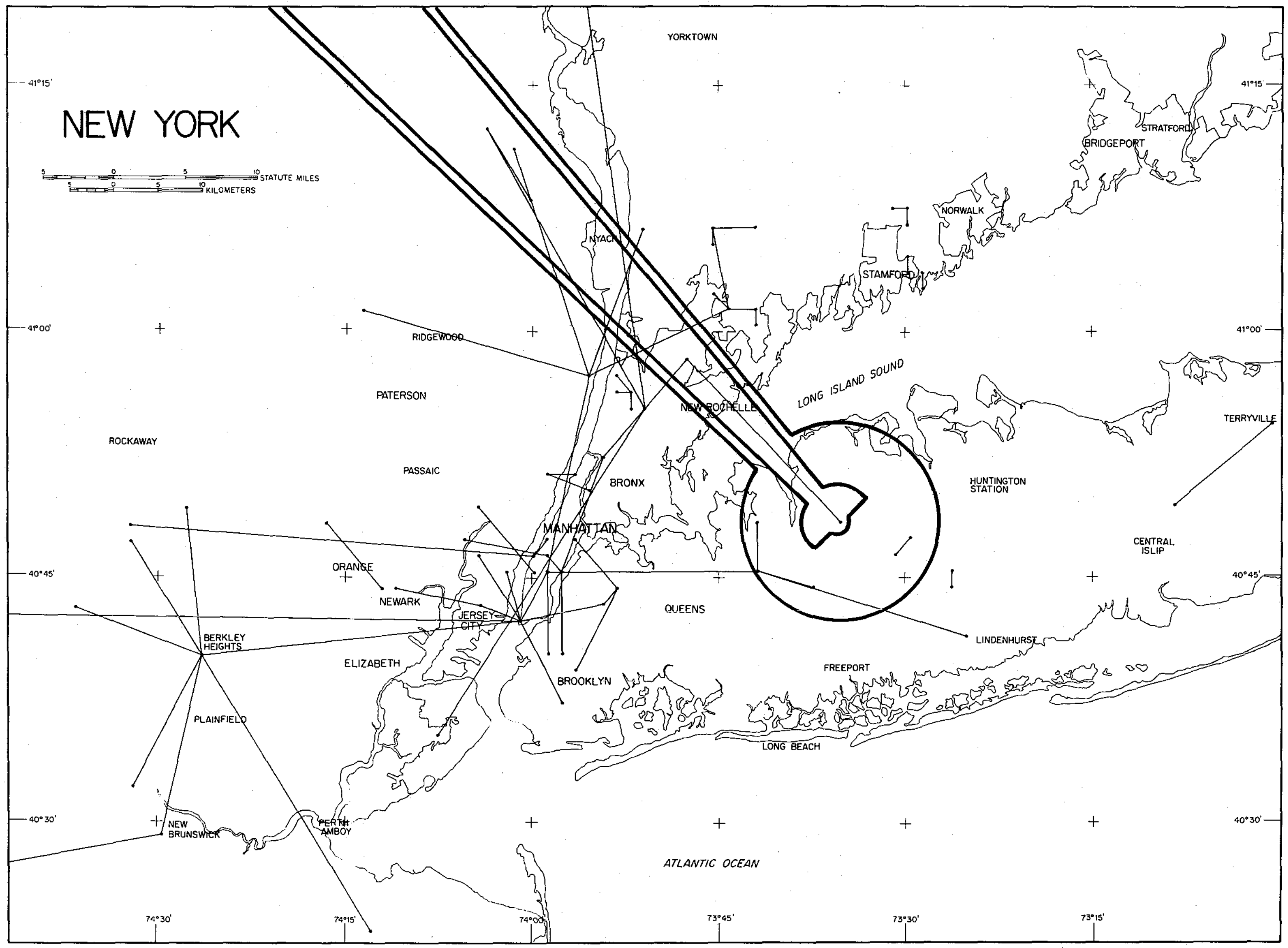


Figure 23. Adjacent-channel interference contours overlayed on New York City. Inside contour derived from four-part pattern, outside contour derived by Akima (1980) using CCIR standards.

generally tall buildings or hill-top sites. An example of such a site may be found south of Glendale in the Los Angeles metroplitan area, Figure 8. There are FS spoke-type paths to and from this location. There is absolutely no opportunity in this locale for frequency reuse. Of all possible network situations in a compact environment, this is perhaps the only condition which may force an FS user to seek either another site or move to an entirely different band outside the 12.2-12.7 GHz band.

In other cases, FS frequency reuse may force a user to a different site out of the projected mainbeam of a distant user. If FS band compaction is adopted by the United States for sharing between FS and BSS, additional analysis must be performed in the area of networking.

## 11. CONCLUSIONS

A detailed study of the FS deployment data base (FCC, 1981; and SPI, 1980), extended research of the WARC 1979 (ITU, 1979) and the WARC-BS 1977 (ITU, 1977) Final Acts, and the research performed by Akima (1980) have given new insights into the issues of sharing FS and BSS in the 12 GHz band.

It is now clear that the 12.2-12.7 GHz FS application primarily supports local network distribution (Figure 1) as opposed to long-haul FS (Figure 3). It is also clear that there are only a few highly conjested metropolitan areas in the United States, specifically in Los Angeles, New York, San Francisco, Boston, Dallas/Fort Worth, Detroit, Philadelphia, Seattle, and Chicago.

It is also apparent that the CCIR FS radiation patterns of a circular parabolic dish antenna (CCIR, 1978, p. 112) are a conservative representation of the FS user community in the United States (Figures 12 through 15). In addition, the ITU path-loss curve (shown in Figure 20) is conservative.

It is unknown to what extent path engineering and power budgeting is performed on the design of the FS in the 12.2-12.7 GHz region, particularly for the paths shorter than 20 mi (32 km). There are large numbers of users who operate well above -50 dBW/$m^2$ at distances less than 5 miles (8 km), in which other users successfully operate at -70 dBW/$m^2$ and below (Figure 18). Analytical adjustments for bandwidth considerations appear not to alter this observation.

There have been several basic assumptions made in this report for sharing 12.2-12.7 GHz between FS and BSS. It is assumed that the BSS receiver antenna, which is circularly polarized, can not exceed 3.3 feet (1.0 meter) in diameter, and that the BSS PFD at the center of the service area in Region 2 falls in a range between -100 $dBW/m^2$ and -97 $dBW/m^2$ (Akima, 1980, p. 3). In addition, all sharing possibilities remain inband, i.e., FS and BSS systems are not allowed to seek other frequencies of operation outside 12.2-12.7 GHz.

Under these assumptions, the worst possible case for sharing is to take no action, and allow FS users to continue to install operating systems under their current design modus-operandi. Interference, which will occur with a high degree of certainty in larger metropolitan areas, will worsen and spread. The BSS receiver, in this environment, must rely heavily on site shielding by placing his receiving antenna in the rf shadows of local FS interferers.

FS and BSS sharing in the United States under a frequency division scheme must be predicated on using a more closely scrutinized system design, frequency assignment, and physical placement process. There are several options.

It is possible to establish sharing criteria based on limiting the FS transmitter power and expanding on the transmitter antenna performance. The FS user can be restricted to a predefined clear-weather PFD. The data derived in this study indicate that -40 or -50 $dBW/m^2$ at the FS receiver site is a practical upper bound and includes the appropriate gain margins for heavy rainfall. It has also been suggested (Lee, et al., 1979) that adaptive gain control be employed as an option so that the FS transmitter power is dynamically increased from a nominal value of operation to compensate for water absorption during heavy storms. It is assumed, therefore, that such a system would operate at a PFD of approximately -80 $dBW/m^2$ signal at the receiver. Power at the transmitter would increase by 25 to 35 dB during heavy storms to maintain the -80 $dBW/m^2$ at the receiver.

The baseline FS transmitter antenna performance specifications can be improved which force selected changes to be made with current FS deployed systems. Interference calculations between FS and BSS are based on a CCIR FS transmitter antenna envelope (CCIR, 1978, p. 112) and a CCIR BSS receiver antenna envelope (ITU, 1977, p. 84). The FS-to-FS interference is not directly addressed by the CCIR. It is possible, however, to perform interference calculations by simply using the CCIR FS transmitter performance specifications for both transmitter and receiver. It is suggested that a less conservative pattern be adopted (see the 4-part pattern, Figures 12 and 13) by the United States for its domestic FS users who are farther than say 62 mi (100 km) from an international border. Within a 62 mi (100 km) zone of an international boundary, the CCIR international sharing criteria would be followed.

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The Regional Administrative Radio Conference will be convened in 1983 for planning broadcasting-satellite service in the International Telecommunication Union Region 2 to resolve the issue of allocating orbital positions and radio frequencies in the band 12.1-12.7 GHz. In the United States the band 12.2-12.7 GHz has also been allocated to fixed service. This domestic sharing issue must be resolved in part or in total as part of the United States preparations for the 1983 RARC. This research expands on selective conditions for domestic sharing, and concludes that sharing is possible, but only under several restrictive conditions.

16. Key Words *(Alphabetical order, separated by semicolons)*

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