Appendix A

Development of Possible HDFS/FSS Gateway Earth Station Sharing Criteria

1.0 Summary

This Appendix describes ana possible approach to developing V-band Fixed Satellite Service (FSS) service rules that would significantly reduce interference to the high density Fixed Service (HDFS) in the 37.5-40.0 GHz band, while permitting FSS to operate gateway earth stations in the band.

The 37.5-40.0 GHz band is shared between Fixed Service systems (FS) and downlinks of the FSS. FS uses this band for HDFS[4] while the FSS uses it for gateway operations.[5] Normally, co-primary FS and FSS systems must go through a coordination process to ensure that newly introduced stations of either service will not cause or receive interference. Implementation of HDFS, on the other hand, on a co-primary basis with FSS implies deployment without coordinating with FSS and without receiving harmful interference.

The Commission has designated the 40.0-42.0 GHz frequency band for high density FSS (HDFSS) operations to customer premises. In the 37.5-40.0 GHz band, current Commission regulations permit FSS to operate continuously with 'clear-air' Power Flux Density (PFD)[6] levels and allow increases in PFD levels up to 12 dB above the clear-air level to compensate for rain-fades. In the 40.0-42.0 GHz band FSS may operate continuously at the higher PFD level.

Severe rain fades that occur in the V-band affect the way both FS and FSS systems are designed and operated.[7] The intense rainstorms responsible for creating the most severe rain-fades are generally only a few kilometers wide. The use of diversity earth stations within the FSS system can alleviate, but will not eliminate, the need for PFD levels above the clear-air level. Some operations above clear-air PFD levels will be necessary for FSS to meet system availability requirements.

If HDFS terminals are implemented without consideration of FSS systems, FSS clear-air PFD levels will cause some interference to some FS sites. Both International Telecommunication Union (ITU) and Commission staff studies agree that higher FSS PFD levels affect more FS

---

[4] The designation of a frequency band as a "high density" band means that the designated service should be able to deploy a large number of terminals (i.e., ubiquitous deployment), within a given area, without undergoing the expense and delay of having to coordinate with the other co-primary service.s.

[5] Gateway operations do not originate or terminate traffic, but interconnect user terminals with the satellite. Gateway operations are not for the exclusive use of a single customer. As a result, we expect FSS gateway operations to employ relatively few receiving sites, and those sites will not be ubiquitously deployed on customer premises.

[6] Power Flux Density is a measure of the satellite transmitted power, in a reference bandwidth, incident on the surface of the Earth. "Clear-air" PFD is the level of PFD that is 12 dB below the internationally authorized PFD levels for the V-band contained in ITU-R International Radio Rules, Art. 21, Table 4.

[7] Rain fade is the phenomenon by which radio signals are scattered and absorbed by water droplets in the air, thus reducing signal reliability. Rain fade varies with frequency, and is quite severe in the 37.0-43.0 GHz band.

links. The HDFS applications used in the V-band differ from fixed operations in many other bands because a relatively high number of FS station antennas are pointed at higher elevation angles, and are therefore more likely to be sensitive to receiving interference from FSS systems.

FS operators seek to limit FSS use of PFD above the clear-air level in order to minimize the number of HDFS sites that may receive interference when FSS operates at higher PFD. FSS operators, on the other hand, seek to provide service at a specified availability level to gateway earth stations that required operating some period of time above the clear-air PFD levels. The Commission seeks to find a way to meet the operational needs of FSS without causing unreasonable interference to HDFS.

Because of high rain fade losses over much of the country, FSS systems must use several different techniques, in addition to raising PFD levels, to meet system availability requirements. Rain fade in the United States ranges from a high of 51 dB in Miami, FL, to 9 dB in Los Angeles, CA.[8] The rain fade for New York City (NYC), for the conditions under discussion, is approximately 25 dB.[9] Rain fades in most parts of the United States are considerably greater than the maximum allowable increase in PFD of 12 dB. In many cases, alternate rain fade compensation techniques, referred to here as "non-power ameliorative measures," will be required in addition to increased PFD levels. Use of these non-power ameliorative measures should have no negative effect on the HDFS. If FSS uses non-power ameliorative measures prior to increasing PFD levels, the percentage of time that PFD is raised above 'clear-air' levels can be limited. At the same time, the percentage of time that FS stations are exposed to the highest levels of PFD can be significantly reduced.

Implementing non-power ameliorative measures, however, affects FSS by reducing the amount of user traffic that can be transmitted over a given bandwidth. This means a loss of channel capacity for the FSS systems while non-power ameliorative measures are in use. Conversely, increasing PFD to overcome rain fade does not directly result in reduced channel capacity. A schedule that defines how much rain fade compensation to employ, prior to increasing PFD levels, can be developed based on the average rain rate at the earth station location. Such a rain fade compensation schedule could form the basis for rules regarding FSS rain fade compensation. FSS systems could be required to apply non-power ameliorative measures to compensate for certain amounts of rain fade prior to increasing PFD levels. The deployment of such a schedule can account for the use of diversity earth stations. This approach involves a trade-off that limits the percentage of time FS sites are exposed to PFD levels above those of clear-air operations, at the cost of reduced channel capacity for FSS operations during rain fades. Developing service rules based on such a rain fade compensation schedule ~~will~~would permit HDFS to operate in a

[8] These figures assume 99.9% satellite signal availability~~ and~~, a satellite link elevation angle of 30~~º.~~° and a mid-band frequency of 38.75 GHz. The assumed availability figure comes from the ITU JWP4-6S Chairman's Report 3 July 2002. Attachment 4. Annex 2. page 2. Additionally. because rain-fade losses increase significantly as the elevation angle of the Earth station decreases. we expect that most GSO FSS systems will operate with elevation angles of 30 degrees or higher.

[9] This means that rain fade conditions near NYC cause the signal reliability of FSS systems to degrade ~~by 25 dB~~ from clear-air levels~~.~~ by 25 dB or more. for 0.1 percent of the time. In order to maintain acceptable system reliability for a gateway earth station near NYC, the FSS operator must increase its system reliability by 25 dB during severe rain fade events.

known, relatively benign interference environment while permitting FSS to operate with the desired reliability.

2.0 Introduction

The World Radiocommunication Conference of 2000 (WRC-2000) considered allocations in the 37.5-43.0 GHz range to both FS and FSS.[10] The decision of WRC-2000, supported by the United States, was to allocate the entire 37.5-42.0 MHz band to both FSS and FS on a co-primary basis, but to permit the HDFS operations in 37.5-40.0 GHz band and HDFSS downlinks in the 40.0-42.0 GHz band. This approach, know as "soft segmentation," was accomplished by "designating" FS operations below 40 GHz for HDFS operations and FSS operations above 40 GHz for HDFSS operations.[11] The Commission stated that it would implement this designation by structuring the service rules to provide for the high-density, non-coordinated operations of the designated service in each sub-band, while permitting limited operations of the non-designated service.[12] The *V-Band Second Report and Order*, released on Dec. 5, 2003, modified the U.S. Table of Frequency Allocations to reflect the International Table of Allocations in the 35.7-42.0 GHz band with respect to FS and FSS services and designations. This Appendix addresses the development of proposed service rules for FSS in the 37.5-40.0 GHz band that would allow FSS to operate to gateway earth stations while sharing on a co-frequency basis with the HDFS operations.

FS, FSS, and the Mobile Service share co-primary allocations in the 37.5-42.0 GHz band.[13] In the HDFS band at 37.5-40.0 GHz, the Commission established a PFD limit envelope for FSS. This PFD envelope defined the PFD limit for FSS systems for clear-air operations, and a higher PFD limit FSS systems may use to compensate for rain fade conditions. The *V-Band Second Report and Order* did not address the conditions under which the FSS system could use the higher PFD limits, nor how long the FSS system could remain above the lower clear-air limits. The higher PFD limits are based on the ITU Radio Regulations, Article 21, Table 4. The lower, clear-air PFD limits are 12 dB below these limits.

Additionally, the *V-Band Second Report and Order* limited the type of FSS earth stations that will be permitted in the HDFS portion of the band to gateway Earth stations,[14] in order to reduce

---

[10] WRC 2000 produced a compromise on the allocations in the V-band, designating spectrum below 40 GHz for primary use by high density FS, and spectrum above 40 GHz for primary use by high density FSS. The decision called for ensuring spectrum sharing between FS and FSS via service rules, rather than assigning discrete spectrum blocks to each service. The intent of this compromise is to favor FS to operate in 37.5-40 GHz, while permitting GSO FSS to operate downlink to gateway stations at PFDs 12 dB below Table 4 of ITU Appendix 21 (Table 21-4). GSO FSS may also have limited use of PFDs higher than 12 dB below Table 21-4 to Earth station gateways; however, the maximum FSS PFDs may not be raised over the limit set by Table 21-4. In the V-band Report and Order, the Commission adopted the lower PFD limit by Table 21-4 minus 12 dB for "clear-air" operation and the upper PFD limit by Table 21-4. PFDs above Table 21-4 minus 12 dB may only be justified on case-by-case basis.

[11] *See V-band Second Report and Order* at 25,434, ¶ 14.
[12] *See id.* at 25,438, ¶ 23.
[13] See 47 C.F.R. § 2.106.
[14] 25.202(a)(1) footnote 16.

the coordination impact of FSS earth stations on the deployment of HDFS stations without specifying a numerical limit on the number of FSS Earth stations in the HDFS band.

This Appendix presents a technical discussion of possible rules that could permit the deployment of HDFS systems with a minimum of system constraints, while permitting FSS systems to operate to gateway earth stations.

3.0 Background

3.1 FS Characteristics

FS operations in the United States in the 37.5-40.0 GHz band are described in ITU-R documents dealing with Joint Working Party 4-9S and in the *V-band Report and Order.*[15] In general, this band is used to supply "last mile" connections to fiber backbone systems in, among other places, large cities. The fixed links that make up these systems go from building to building and, because of the high cost of roof-top real estate, some of the links may go from the side of one building to the top, or side, of another building.

Most FS applications are designed to transport information from one point on the Earth's surface to another across fairly long distances. Because the installation of the transmit/receive equipment, including supporting towers, is expensive, FS operators typically locate their antennas as far apart as is technically practical. This means that most FS antennas point toward the horizon and, therefore, have low elevation angles. By contrast, interconnecting facilities in large cities mean that a substantial portion of the V-band fixed FS links go from one building to another where the receiving antenna on one building may be many floors above or below the transmitting antenna on another building. Having short FS links separated by large vertical distances means that many of the V-band FS antennas do not point at the horizon but, rather, point at higher elevation angles. Approximately 48 percent of the FS links in the V-band have receive antenna elevation angles above 10 degrees, with 7 percent of the FS links in the V-band having elevation angles above 45 degrees.[16] The use of high elevation angles for FS ~~links~~link receive antennas means that V-band FS systems are more susceptible to interference from FSS transmissions than other types of FS systems.

3.2 Fixed Satellite Service Operations

FSS systems operating in the 37-50 GHz band will have available a number of frequency bands for different uses. For communications to and from the high density FSS user community, the 40.0-42.0 GHz downlink is paired with the 48.2-50.2 GHz uplink band. For operations to gateway Earth stations, the 37.5-40.0 GHz downlink band is paired with the 47.2-48.2 GHz uplink band. This latter band pairing includes a larger bandwidth in the downlink direction than in the uplink direction. The Commission authorized the greater downlink bandwidth for FSS in the V-band because it recognized that FSS gateway operation in this high-density FS band would necessitate the use of lower FSS downlink PFDs than in other FSS bands. Therefore, FSS

---

[15] *See, e.g.*, Appendix 3 to Attachment 4 of the 2003 ITU Chairman's Report for JWP4-9S and from ex parte comments from Winstar in 95-95 see March 4, 2004.
[16] JWP 4-9S Chairman's report Attachment 4, annex 3 at 1.

operators would have to use robust, relatively low-data rates, simpler modulations and channel codings to maintain signal availability with lower PFD.[17] Because these robust modulations and channel codings lower the data rate per hertz of bandwidth, the Commission authorized greater bandwidth in the 37.5-40.0 GHz band so FSS operators could improve their data throughput by using wider bandwidths in the FSS downlink spectrum at 37.5–40.0 GHz than in the 47.2-48.2 GHz uplink band.[18]

Rain fade of FSS operations results from water droplets in the air reflecting, or scattering, radio waves.[19] This is analogous to driving in a fog, where the scattering effects of the very small water droplets that make up the fog scatter the light from the automobile headlights, thereby making it difficult to see objects ahead of the car.[20]

_Similarly, the intensity of the rain and the size of the rain drops may significantly attenuate the amount of a V-band radio signal that reaches the receiver. For example, when communicating with an Earth station near New York City, a geostationary orbit (GSO) FSS satellite located at 110 degrees west longitude can experience over 25 dB of attenuation for relatively small periods of time during intense rain storms.[21] One method to compensate for this attenuation is to increase the transmit power level at the satellite. This method would increase the PFD on the surface of the Earth and increase the possibility of interference into some HDFS receivers in the same band.[22] Additionally, as mentioned above, the Commission has limited the maximum

[17] The use of lower-data rates (which reduces the E_b/N_o for the same BER), lower order modulations (for example QPSK, in lieu of 8PSK), and channel coding could be used to maintain signal availability with a lower PFDs, at the cost of a lower information data rate transmitted in a given bandwidth. We note that part of the extra downlink bandwidth could be used to add Forward Error Correction (FEC) coding, which could be used to reduce the E_b/N_o requirements for the same BER. The use of FEC coding would also increase the link margin by up to 5 dB, which would be a significant benefit. The remainder of the any extra bandwidth could be used to increase data throughput. We observe, however, that if the FSS operator were to use Trellis Coded Modulation (TCM), then all of the extra downlink bandwidth would be available for increased data throughput since TCM does not require the extra bandwidth.

[18] *See V-band Second Report and Order and Further Notice of Proposed Rulemaking* at 25,458, ¶ 67.

[19] This physical scattering effect is strongest when the wavelength of the radio wave is comparable to the size of the rain drops. The wavelength of a 40 GHz radio wave is 0.75 cm or approximately 1/3rd of an inch. Because the wavelength is close to the rain drop size, the scattering is very pronounced in this frequency range. Therefore, when a rain storm passes between a transmitter and a receiver, the radio signal at the receive site is reduced by the scattering effect of the rain drops. Additionally, water vapor, which tends to be in higher concentration when it is raining, absorbs radio waves. However, the peak water peak absorption frequency is at 22.235 GHz, so the principal transmission impairment at 40 GHz is caused by hydrometeor, or rain drop, scattering. See ITU-R Rec. P676-6, Table 2; ITU-R Rec. P.840.3; ITU-R Rec. P.618-8.

[20] There are two effects caused by fog – first, a high percentage of the scattered light is scattered back towards the viewer masking any objects behind the fog, and second, the scattering significantly reduces the light that actually illuminates the subject. The second of these effects is analogous to the reduction in RF receiver power.

[21] The attenuation value was obtained from ITU-R Rec. 618-7 based on a location of 40.753°N/73.994°W. The percentage of time of 0.1% was used because FSS operating in this band generally are interested in link availabilities on the order of 99.9% (=100%-0.1%). *See* ITU JWP4-6S Chairman's Report 3 July 2002, Attachment 4, Annex 2, page 2.

[22] An increase in PFD at a particular geographic location does not automatically result in interference to an FS receiver. Whether or not actual interference will occur, i.e., a loss of data within the FS system, depends on a number of additional factors such as the presence of an FS receiver at that location, the specific geometry of the FS receiver antenna and the FSS satellite, the actual signal level within the FS system and the rain fade ~~with~~within the FS system and between the FS and FSS systems that exists when the PFD is raised.

allowable PFD in the V-band to only 12 dB higher than the ~~lowest~~ clear-air PFD. Therefore, the FSS system would have to use additional techniques to compensate for the remaining 13 dB of the 25 dB attenuation caused by rain fade in this example.

Because the rain statistics vary across the United States, the amount of rain attenuation experienced by the FSS system will vary with location of the gateway earth station served by the satellite. As an example, an earth station in the Miami-Ft. Lauderdale area of Florida would experience a maximum rain fade attenuation of almost 51 dB, while an earth station in Los Angeles, CA would experience less than 9 dB of attenuation.[23] The large rain fade in Miami would make it difficult for an FSS system to communicate with the Miami earth station, having to make up 39 dB (51 dB total compensation minus 12 dB PFD increase) of attenuation via non-power ameliorative measures. As a result, an FSS operator serving Miami area gateway earth stations may have to reduce the percentage of time it provides service to those Earth stations. On the other hand, in Los Angeles, an FSS operator would have to overcome a total of 9 dB of attenuation, and could therefore increase power to compensate for rain fade in Los Angeles and still remain within the PFD envelope described in the *V-Band Second Report and Order*.

Attachment 4 to the 2003 Chairman's report for ITU Joint Working Party (JWP) 4-9S describes the possible differences in the faded and non-faded operations of a FSS system: "in the normal [clear-air] operation, the [FSS] system operates with higher order modulations (8PSK), light coding and high transmit data rate to achieve the desired capacity. During fading conditions, the system will operate with conventional QPSK modulation, heavy coding and reduced transmit data rate to achieve the desired link availability."[24] For most of the United States, some of these techniques will be required in addition to the use of higher PFD levels to meet the availability requirements of FSS systems.

One alternative open to FSS system operators to increase system availability in the face of high rain fades is to deploy "diversity" earth stations. A diversity earth station is a second earth station, interconnected with the first, located some distance from the first earth station. This configuration of multiple earth stations increases FSS signal availability because rain storms with the heaviest rain, causing the highest rain fades, tend to be relatively small in size. The diameter of these "rain cells" is typically significantly less than 100 km. Therefore, the use of a second earth station located more than a "rain-cell distance" from the first earth station means that a single rain cell is unlikely to affect both earth stations at the same time, and increases the probability that FSS operators will be able to maintain the FSS link. Having a diversity earth station effectively reduces rain-fade attenuation by a factor known as the "diversity gain."[25] The diversity gain depends on the distance between the diversity earth stations, the relative location of the two stations with respect to the satellite, and the rain rate in the area of the earth stations. For the Miami area, the diversity gain could be as high as 20 dB and for the New York City area~~,~~

[23] These values are for the satellite-to-Earth station slant path attenuation for 0.1% of the time for the locations sighted. This analysis assumes a 30 degree elevation angle. We used ITU-R Rec. P.618-7 to calculate the attenuation versus percent of time relationship.

[24] ITU JWP4-6S Chairman's Report 3 July 2002, Attachment 4, Annex 2, page 2.

[25] *See* ITU-R P.618-7 Section 2.2.4 for a discussion of diversity gain.

9 dB.[26] Near Los Angeles, the diversity gain would be approximately 3 dB. The drawback of this approach for FSS operators is the added cost of the second earth station.

In New York City, for example, rain fade producing a 25 dB or more of attenuation is expected to occur 0.1 percent of the time.[27] FSS operators that wish to operate in the V-band require a system availability of 99.9 percent and, therefore, must design their systems to overcome any losses expected to occur for all but 0.1 percent of the time. Rainfall, however, in the New York City area occurs for more than 0.1 percent of the time. Table 3.1 shows the percents of time that FSS links serving New York City will experience certain levels of rain fade. For example, an FSS link serving New York may experience a rain fade loss of more than 6 dB for 1.32 percent of an average year. This percentage represents four days, 20 hours spread out throughout the year.[28] The last column of Table 3.1 shows the loss (~~0.25 dB~~1/4th in this example) expressed as a ~~real~~fractional value. This is the portion of clear-air FSS signal level that is received at the Earth station during a ~~six~~6 dB rain-fade. A 30 dB rain fade means that only 0.001 (1/1000th) of the clear-air signal is being received. This condition, or worse, can be expected to occur 0.07 percent of the time, or approximately six hours a year for the New York City example.

Table 3.1 Rain-Fade Statistics for New York City at V-Band[29]

Slant-Path Rain Fade Exceeded (dB)	Percent of Average Year Fade Exceeded	Days	Hours	Proportion of Signal Received
3	3.72%	13	14	½
6	1.32%	4	20	1/4th
9	0.69%	2	12	1/8th
12	0.42%	1	12	1/16th
15	0.28%	1	0	1/31nd
18	0.20%	0	17	1/63th
21	0.15%	0	12	1/126th
24	0.11%	0	9	1/251th
27	0.09%	0	7	1/501th
30	0.07%	0	6	1/1000th

As the intensity of rainfall increases, rain fade loss increases in magnitude, and the percentage of time that that specific value of loss is exceeded decreases. For example, an FSS link serving an earth station near New York will experience a rain fade 12 dB higher than the initial example of 6 dB (i.e., 6+12 = 18 dB) for 0.20 percent of the time, approximately 1/6 the time of the 6 dB

[26] These diversity gain values were calculated to a 10 km Earth station separation, a path elevation of 30 degrees and an angle between the propagation path and Earth station base line of 90 degrees.

[27] To provide an idea of just what 0.1% for the time actually means, 0.1% of a year represents a total of 8 hours and 45 minutes spread throughout the year. The slant-path rain fade attenuation calculations are based on ITU-R Recommendation P.618-7.

[28] Actually most locations have "rainy seasons" in which it is more likely to rain than other times of the year so these high rain-fades would occur more often in these wet seasons.

[29] The equations used to calculate the percentage of time that a given rain-fade affects an area were developed to measure small amounts of time and are therefore not valid for time values greater than 5%. Also, note that durations have been simplified for the purpose of this example.

fade. Similarly, a rain-fade of 24 dB or greater will occur for 0.11 percent of the time or about 1/4 the duration of a 12 dB, or greater, fade. Because the Commission limits FSS systems to a maximum change in PFD level of 12 dB, the FSS operator must resort to a combination of increased PFDs and non-power ameliorative measures to meet the stated availability requirements. The Commission could require FSS operators to use non-power ameliorative measures to overcome several dB of rain fade prior to increasing the satellite PFD. For example, if the FSS system were to compensate for the first 12 dB of rain fade by raising PFD, it would operate 3 dB above the clear-air PFD level 3.72 percent of the time, and 9 dB above the clear-air level 0.69 percent of the time. If non-power ameliorative measures were used to compensate for the first 6 dB of rain fade and PFD increases were used to compensate for the rain fades from 6 to 18 dB, the FSS system would operate at 3 dB above the clear-air level 0.69 percent of the time. This would reduce the time FS stations were exposed to an increased PFD 3 dB above the clear-air level from 3.72 percent to 0.69 percent of the time, and would reduce the sharing burden on the HDFS systems.

There is a cost to the FSS operator of using these non-power ameliorative measures to compensate for rain fade. All of the non-power ameliorative measures listed require either that additional information be transmitted along with the users' data, or that less data be transmitted at the same power levels. In either case, non-power ameliorative measures make the data stream more robust and reduce the effect of rain fade. These measures, however, reduce the total amount of user data being transmitted in a given bandwidth. Thus, all of the non-power ameliorative measures result in a reduced channel capacity for the FSS. This reduced channel capacity results in a reduced ability to serve the same number of customers, compared to clear-air operations, during the time of the rain fade.

Current Commission regulations permit FSS to operate continuously with clear-air PFD levels, and allow increases in PFD levels up to 12 dB above the clear-air level, on a case-by-case basis, to compensate for rain fade. FSS operators will occasionally need to operate at levels above clear-air PFD levels in order to meet system availability requirements even if diversity Earth stations are deployed. By requiring FSS operators to use non-power ameliorative measures prior to increasing PFD, the Commission could structure FSS service rules to reduce significantly the interference potential to HDFS, at a cost of reducing the channel capacity of FSS during rain fade conditions.

3.3 Worst-Case Distance from an FSS Earth Station

For faded operations, where the satellites are transmitting at the maximum permitted PFD, the percentage of FS receivers experiencing interference depends on the distance between FS receivers and the target earth station that is receiving the satellite transmission. Two factors, however, minimize the interference to FS receivers: 1) the FSS satellites will be using large antennas to concentrate the satellite power into very small beams, keeping the PFD constrained to areas near the target earth station; and 2) the same rain storm that blocks the signal between the satellite and the earth station also blocks, or partially blocks, the satellite signal received as interference at the FS receiver. On the surface of the earth, these satellite beams would typically constrain the power from a single FSS to areas approximately a few hundreds of kilometers in diameter. That is, FS receivers more than a few hundreds of kilometers away from the FSS earth station would receive significantly reduced levels of PFD because of the satellite antenna pattern. FS receivers far enough away from the earth station would never receive PFD levels above the clear-air PFD levels even if the satellite transmitted at the maximum permitted PFD level because the FSS antenna would provide more than 12 dB of discrimination toward the FS receiver. With regard to the second point, because FSS operators would only increase the satellite PFD in order to compensate for rain in the vicinity of the earth station, for FS receivers close to the earth station the same rain event would block some of the satellite PFD. This blockage means that the rain itself provides some level of interference protection to FS receivers sufficiently close to the earth station. In this case, the size and severity of the rain storm determines how much interference protection is provided. Therefore, the mixture of rain blockage and satellite antenna patterns limits the areas in which FS receivers can be affected by satellite transmissions, and the potentially negative impact on the FS receivers will vary as the distance between the FS receiver location and the earth station changes.

This combination of rain fade and FSS satellite antenna roll-off creates a "worst-case" distance for the probability of interference to an FS receiver. Rain fade reduces the probability of interference near the satellite earth station, while the FSS satellite antenna roll-off reduces the probability of interference some distance away from the satellite Earth station. Rules limiting the probability of interference at this worst case distance will ensure that the probability of interference will be lower at all other distances from the Earth station.

3.4 Sharing Issues

Interference studies:

ITU ANALYSIS:

The ITU has addressed the problems of co-frequency sharing in the V-band between FS and FSS. The ITU analysis included in the JWP4-9S Chairman's report[30] indicates that under clear-air conditions, with a fully occupied FSS orbit where every satellite is transmitting at the clear-air PFD limits directly illuminating an FS system, approximately 1.25 percent of the FS receivers would be operating with an interference level that was one-tenth or more of the FS system internal noise level.[31]

The ITU study makes a number of conservative assumptions in addressing possible interference to FS in the V-band. First, it assumes that the GSO is packed full of FSS satellites spaced every four degrees along the entire GSO orbit, and makes assumptions about the total radio energy emitted by satellites on that basis. We do not anticipate that the GSO will become fully packed with satellites.[32] Second, the ITU study makes assumptions of satellite power based on the

[30] JPW 49-S Chairman's Report, Attachment 4, Annex 3, Section 3.11.1 at page 5 date: .

[31] The accepted internationals interference criteria for the V-band FS is an N/I = -10 dB **see [...]**

[32] The entire visible GSO orbit as seen from the United States covers the GSO longitudes from approximately 20°W to approximately 175°W. As of June 2004, the Commission has only four applications for V-band FSS satellite networks.

total power from the entire GSO arc. We do not expect that satellites serving the United States will use the portions of the GSO arc that require operations at low elevation angles because the rain fade losses increase significantly as the elevation to the satellite decreases.[33] Third, the ITU study assumes that all FSS satellites that are visible to the FS receiver are illuminating every FS site with interference power, where in fact most FS sites will not be illuminated simultaneously by all of the visible FSS satellites.[34] Fourth, the ITU study ignores the shielding effect of structures, which we believe to be significant.[35] Finally, the ITU study fails to account for a number of technical factors, such as polarization isolation and power control within the FS system. Collectively, these assumptions produce results that overstate the risk of interference to FS links from FSS. However, we consider this overstatement to provide a desirable safety margin for FS.

COMMISSION STAFF ANALYSIS:

In order to evaluate ~~fully~~ the ITU study, Commission staff performed a different type of analysis. In performing its study, Commission staff used all of ~~these~~ the assumptions discussed above except the assumption of an entirely full GSO orbit. The result of the Commission's analysis indicates that the percentage of FS receivers that could receive inference, with the FSS operating with the clear-air PFD level, is approximately 0.7 percent, as opposed to the roughly 1.25 percent obtained by using a full GSO orbit. With FSS operating at the maximum level of 12 dB above the clear-air PFD level, the number of fixed receivers receiving interference is approximately 4 percent, as opposed to the ITU-R value of greater than 10 percent.

Commission staff used a Monte Carlo approach to analyze this data. A Monte Carlo approach is a computational technique that uses random samples drawn from representative statistical distributions and other statistical methods to find solutions to mathematical or physical problems. The Commission staff's analysis was based upon the following assumptions provided in Table 3.2, below. These assumptions represent values the staff considers most likely to prevail in actual FS and FSS operations.[36]

The results of the Commission study generally agreed with the ITU's results, but also indicated that most interference occurred with FS receivers pointing upwards at elevation angles between approximately 35° and 50°. For clear-air operations, FS receivers with elevation angles below 10° were unlikely to receive interference, while approximately 20 percent of receivers with elevation angles between 35° and 50° could expect to receive interference, using the relatively conservative assumptions and definition of interference. According to the ITU reports,

---

[33] Rain-fade attenuation and the need for higher PFD increases as the elevation angle to the satellite decreases. For this reason, it would be more reasonable to assume that FSS will only use orbit positions in the major orbital arc that serves the United States, i.e., from 80°W to 120°W, and not the entire arc visible from the Unites States (20°W to 175°W), because this range of GSO longitudes provides the highest, and therefore the best, elevation angles to the continental United States.

[34] Technical limitations on available satellite power combined with high path losses associated with V-band operations make it necessary for FSS satellites to use antennas with narrow beam widths. The narrow beam widths of FSS antennas will limit the geographic areas that any FSS satellite can serve at any one time. Path loss is a loss in signal strength associated with the distance between the transmitter and the receiver. Path loss is a function of the separation distance and the frequency of the satellite signal.

[35] If an FS receiver is mounted on the side of a building, in many cases, the building itself will shield the receiver from the satellite PFD.

[36] For example, the assumption of FS antenna elevation is based on data provided by Winstar of actual FS antennas. Further, the analysis assumes FSS satellites only in those parts of the GSO arc likely to be used by FSS, and excludes portions of the arc that present very low elevation angles and are unlikely to be used.

approximately 3.5 percent of all FS receivers have elevation angles between 35° and 50°. This use of high elevation angles, and their resulting sensitivity to the FSS transmissions, distinguishes V-band HDFS applications from many other FS applications.

Table 3.2 - Monte Carlo Study Assumptions

- One million iterations with PFD range from clear-air level to ITU Table 21-4 level
- Fixed Service parameters randomly selected from populations:
  - FS Antenna Azimuth (0 to 360 degrees)
  - FS Antenna Elevation (Winstar supplied distribution – from Record)
  - FS Site Latitude & Longitude selected by population from the 32 cities used in the MVDDS Item
- Fixed Service parameters
  - Gain = 44.2 dBi
  - FS System Noise 740 K
  - Antenna pattern ITU-R Rec. F.1245-1
  - Interference Criteria I/N => -10 dB
- Fixed Satellite Service parameters
  - 4 degree spacing in GSO arc from 80° to 120° W longitude
  - All FSS have maximum allowable PFD aimed at all FS sites

To further examine the interactions between FS and FSS, the combined effects of both rain-fade and the FSS antenna roll-off have to be examined in detail.

The first factor in the Commission staff's analysis is the spatial relationship between the FSS satellite earth station and FS receivers. As discussed above, rain fade requires the FSS satellite to raise its PFD toward the target earth station in order to maintain system availability. The FSS satellite raises its PFD within the entire footprint of the antenna beam that is focused on the target earth station. Because the satellite antenna footprint will be several hundred kilometers across, all FS receivers within a large area will be exposed to increased PFD. As the PFD level increases, a higher percentage of FS receivers will experience interference. However, the rain fade that causes the need for higher PFD will also attenuate the interfering signal to FS receivers near the earth station, and will therefore provide some protection to FS receivers near the FSS earth station.[37]

[37] The ITU has addressed the role of rain fade in providing protection to the HDFS from increased FSS PFDs. *See* Liaison Statement to Working Party 4-9S concerning The percentage of time during which fixed-satellite service nominal clear-sky power flux-density levels may be exceeded to overcome fading conditions, while protecting the fixed service, and permitting operation of FSS earth stations in the bands 37.5-40 GHz and 42-42.5 GHz, ITU-R Document 4-9S/299, dated Jun. 4, 2002.

The ITU provided a method of calculating the effect of rain on unwanted FSS signals received by an FS receiver located at a given distance from the FSS earth station, when the satellite increases the PFD at the earth station compensate for the rain fade.[38] Commission staff has calculated the upper bound on the probability of an FS receiver experiencing increased PFDs at a specific distance "d" from the FSS earth station by combining slant path rain statistic equations and diversity Earth station equations.[39] The inputs to the resulting equation are two values of PFD increase (p1 and p2) and a distance (d). The resulting equation permits the calculation of the upper bound probability of having a PFD increase in the range p1 to p2 at a distance "d" from the earth station. In this case, the phrase "upper bound" means that the equation does not predict the exact percentage of time that a specific value of increased PFD will occur, and instead predicts the maximum possible percentage of time that any increase within the range of increased PFD's are likely occur at a given distance from the earth station. For example, the Commission staff's approach calculates the upper bound on the percent of time that an increase in PFD from 2 to 5 dB will occur 100 km from an earth station. Evaluation of this effect indicates that rain fade in the region around the earth station will provide some limited protection to FS receivers. These FS receivers near the target earth station will experience the higher PFD values approximately 20 to 30 percent less of time than FS receivers a few hundred kilometers from the earth station. FS receivers more than a few hundred kilometers from the earth station will, however, receive an insignificant amount of rain fade protection from rainstorms at the earth station because the chance of both the earth station and the FS receiver experiencing rain fade simultaneously is very low. This approach does not take into account the natural roll-off of PFD caused by the FSS antenna.

The second factor of the Commission staff's analysis is the antenna pattern used on the FSS satellite. Because of technical power generation limitations and the fact that space-to-earth transmission losses are frequency-dependent, V-band FSS systems will be forced to use narrow spot beam antennas. The ITU lists typical characteristics of some V-Band GSO satellites.[40] The largest V-band antenna beam has a beam width of only approximately 0.5 degrees. This beam width represents the greatest likelihood for interference to FS links, because it will spread the satellite transmit power over a larger area of the Earth's surface compared to other V-band satellite antennas with narrower beams. If the FSS signal is incident at the target earth station with an elevation of 30°,[41] the PFD will decrease, as shown in Table 4.2, at greater distances from the earth station.[42] There are two causes for this decrease. First, because the FSS satellite antenna is pointed at the earth station, the gain of the FSS antenna decreases in all directions away from the earth station. Second, as the distance from the earth station increases, in a direction also away from the satellite, the range between the satellite and the ground point

[38] *Id.*

[39] *See* ITU-R P.618-7 for technical discussions of both of these topics.

[40] *See, e.g.,* Frequency Sharing Between The Fixed-Satellite Service And The Fixed Service In The Band 37.5-42.5 GHz , ITU-R Doc- 4-9s/179, dated Mar. 23, 2000.

[41] Because rain fade losses increase as the elevation angle of the Earth station decreases, we expect that most GSO FSS systems will operate above 30 degrees. Therefore, using a 30 degree elevation angle enlarges the area affected by the PFD leading to a conservative analysis.

[42] Table 4.1 assumes that the movement is away from the Earth station on the complement of the azimuth that connects Earth station with the satellite.

increases. This increased range accounts for a small decrease in PFD levels compared with the antenna roll-off.

TABLE 4.1 CALCULATED DECREASE IN PFD WITH DISTANCE FROM THE EARTH STATION[43]

Distance from Earth Station (km)	Reduction in PFD (dB)
0	0.0
100	0.3
200	1.0
300	2.2
400	3.8
500	5.7
600	7.9
700	10.4
800	13.0

By combining localized rain fade protection near the earth station and FSS antenna roll-off, it is possible to determine the maximum percent of time that an increase in PFD would be experienced by an FS receiver for a given range in FSS PFD levels. Additionally, if FSS operators use non-power ameliorative measures to compensate for rain fade prior to increasing PFD levels, the combination of these two factors[44] can determine the amount of FSS rain fade compensation required to limit the maximum percentage of time that an FS system is exposed to any PFD increase. We can calculate the percent of time that an FS receiver at the "worst-case" distance from an FSS earth station will receive an increase in PFD by adjusting the input parameters to the ITU WP-3M equation modified to take into account the change in PFD with distance from the earth station.[45]

Evaluating the non-power ameliorative measures required to limit the percentage of time that PFD increases occur for multiple locations within the United States yields a curve of the non-power ameliorative measures required versus the average rain rate at the target earth station.

[43] Antenna beamwidth 0.5 degrees, elevation angle 30 degrees, moving from Earth station away from satellite on azimuth connecting satellite and Earth station.

[44] *I.e.*, the partial correlation of rain-fade with distance from the earth station and the FSS antenna roll-off with distance from the earth station.

[45] As stated previously, the equation has three input parameters: two values defining the range of PFDs of interest (say, p1 and p2) and a distance (d) from the Earth station. The value of p2, the top of the PFD range is always 12 dB higher than the value of p1 – thus the probability will be the upper bound percentage of time that the FS receivers will experience any PFD increase within the permitted range. At the Earth station (i.e., distance=0) the lower PFD of the range (p1) starts at the value of the alternate rain-fade technique used by the FSS system. The value of p1 is increased by the FSS antenna roll-off value at the distance from the Earth station where the calculation is made. This increase compensates for the reduced PFD as the distance from the Earth station increases, because the probability of interest is the probability that the clear-air PFD is exceeded. The calculation is performed iteratively, varying the distance and the value of the alternate rain-fade technique until the wanted upper bound percentage occurs at the distance that yields the highest percentage.

Furthermore, by incorporating diversity gain into the rain-statistics and repeating the analyses, it is possible to develop two curves of non-power ameliorative measures versus the rain-rate at the target earth station; one curve for FSS systems that use diversity earth stations and one for systems that do not.

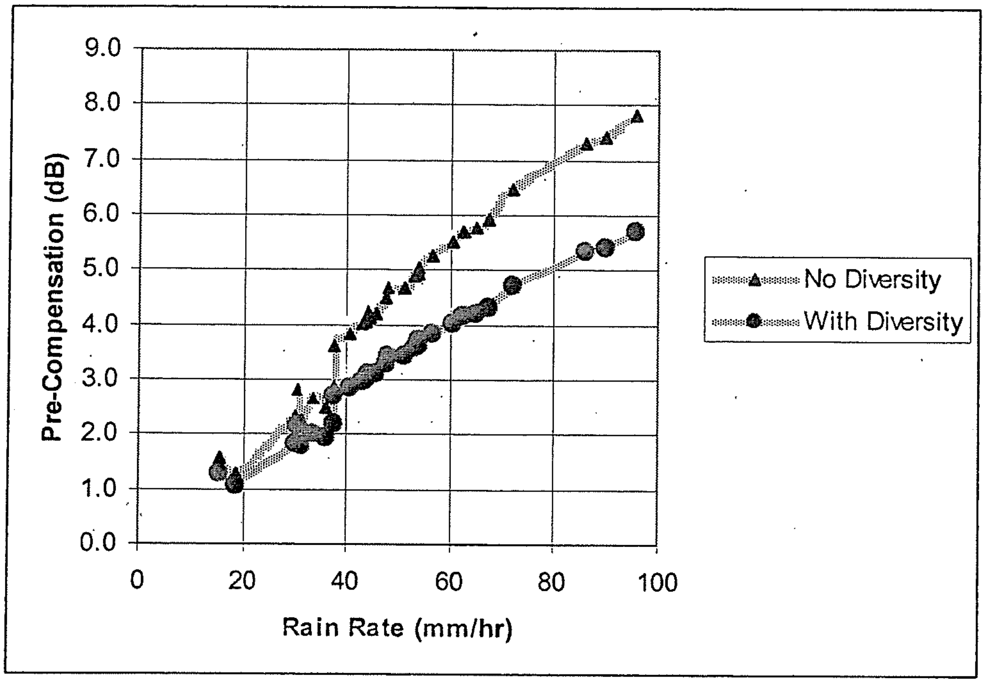
4.2 Development of possible FSS V-Band Service Rules

Figure 4.1 shows the result of performing the calculations described above for 32 cities[46] with and without diversity earth stations. The upper set of points shows the values of non-power ameliorative measures required to limit the total increase in PFD to 1.5 percent of the time at the worst case distance from the earth station. The "x-axis" is the average rain rate[47] at the location of the city. The "y-axis" parameter is the level of pre-compensation – in other words, the value, in dB, of non-power ameliorative measures that the FSS system would be required to implement prior to any increase in PFD above the clear-air value.

Figure 4.1 Results of Alternate Rain-Fade Techniques for 32 Cities

[46] The 32 cities selected here are the same as those used in *Amendment of Parts 2 and 25 of the Commission's Rules to Permit Operation of NGSO FSS Systems Co-Frequency with GSO and Terrestrial Systems in the Ku-Band Frequency Range; Amendment of the Commission's Rules to Authorize Subsidiary Terrestrial Use of the 12.2-12.7 GHz Band by Direct Broadcast Satellite Licensees and Their Affiliates; and Applications of Broadwave USA, PDC Broadband Corporation, and Satellite Receivers, Ltd. to Provide A Fixed Service in the 12.2-12.7 GHz Band,* ET Docket No. 98-206, Memorandum Opinion and Order and Second Report and Order, FCC 02-116, FCC Rcd 9614 (2002). In that item, the Commission used cities representing the top 32 television markets to analyze the potential interference from terrestrial transmitters to GSO satellite receivers. Approximately 55% of the nation's population lives in these 32 cities. In performing this study, the Commission assumed that the Earth station is located at the latitude and longitude of the nominal center of each city, despite the fact that the rain statistics change gradually with distance. In reality, one would be expected that the Earth station to be located several miles from the city center.

[47] In other words, the rain-rate that occur for 0.1% of the average year in mm/hour at the location of the city.



The lower series of points represents the value of non-power ameliorative measures if the FSS system also used a diversity earth station in addition to the primary earth station.[48]

Connecting the points of Figure 4.1, smoothing the lines and converting them to a schedule results in Table 4.2. This figure could form the basis of service rules that require FSS operators to implement the scheduled amount of non-power ameliorative measures prior to increasing PFD, where the value of non-power ameliorative measures, in dB, is dependent on the average rain rate at the target earth station.[49] Note that there is an apparent discontinuity in the curves in Figure 4.1 at a rain-rate value of 38 mm/hr. In producing Table 4.2, we divided the line into two separate linear portions: the first going from a rain-rate of 0 to 38 mm/hr and the second from a rain-rate of greater than 38 mm/hr to 100 mm/hr.

Table 4.2 - Possible Pre-PFD Rain-Fade Compensation Schedule[50]

Average Rain Rate at Earth Station	FSS Non-Power Ameliorative Measures (dB)	
Rain Rate mm/hr @ 0.1%	Without Diversity	With Diversity
0	0.0	0.0
10	0.5	0.6
20	1.4	1.1
30	2.3	1.8

[48] The diversity Earth station is assumed to be located 10 kilometers from the primary station with the azimuth towards the satellite forming a 90-degree angle with the chord that connects the two Earth stations.
[49] Average rain-rate as calculated by techniques provided in ITU-R P.618-7, § 2.2.1.
[50] For values of rain-rate between the rows of the table, use linear interpolation to obtain rain-fade compensation.

38	3.1	2.2
38.1	3.6	2.5
40	3.8	2.9
50	4.7	3.4
60	5.5	4.0
70	6.3	4.5
80	7.1	5.0
90	7.4	5.4
100	8.2	5.9

Table 4.2 shows that, for locations approximately 750 km (470 mi) from the earth station, the reduction in FSS PFD will be greater than 12 dB. Therefore, even if FSS raised the PFD to the maximum value specified in the *V-band R&O* (i.e., clear-air PFD plus 12 dB), FS receivers at this distance will never experience PFDs higher than the clear-air value. As noted above, there is a certain distance from an earth station, which varies from case to case, where there is a maximum probability of an FS receiver being exposed to increased PFD from an FSS satellite. If the FS receiver is closer to the FSS earth station than this "worst-case" distance, the rain fade at the FS receiver provides some, albeit limited, protection from increased PFD. If the FS receiver is farther away from the earth station than this "worst-case" distance, the FSS antenna roll-off results in lower PFDs and, therefore, fewer FS receivers experience interference.

4.3 Cost to FSS Operations

Implementing non-power ameliorative measures will cause the FSS system to lose channel capacity during a rain fade. The amount of channel capacity lost depends on the amount of non-power ameliorative measures required. During peak rain fades, the FSS system will inevitably lose some amount of channel capacity or suffer reduced signal availability because, assuming the FSS systems desire 99.9 percent availability, rain fades in much of the United States are greater than the 12 dB available increase in PFD values. Implementing part of the total non-power ameliorative measures required prior to increasing the PFD means that the FSS system will lose channel capacity more often than it would if it could raise PFD whenever any rain fade occurred. In addition, over much of the country, the loss of channel capacity will be significant when it does occur. For example, the average rain rate[51] in Miami is approximately 96 mm/hr, which occurs for 0.1 percent of the time in an average year. According to Table 4.1, an FSS system transmitting to an earth station near Miami would have to compensate for the first 7.9 dB of rain fade using non-power ameliorative measures prior to raising PFD assuming a diversity earth station is not used, and 5.7 dB assuming the existence of a diversity earth station. If these techniques are implemented, the loss of channel capacity would be approximately 84 percent without the diversity Earth station and approximately 73 percent with diversity. Assuming diversity, this loss would occur for approximately 2.3 percent of the time or approximately 7 days 20 hours per year. If FSS operators raise PFD levels prior to using non-power ameliorative measures, the same channel capacity loss would occur but for only 0.3 percent of the time, or one

[51] i.e.. the rain rate occurring for 0.01 % of the average year

day and three hours per year. Providing this level of protection to HDFS will negatively affect the operation of FSS.

The schedule presented in Table 4.2 is a balance between protecting the HDFS deployment in V-band and permitting the FSS to operate to gateway earth stations. The schedule also depends upon certain operating assumptions, and the values in the schedule will change if the underlying assumptions change. For example, ~~if~~Table 4.2 is based upon limiting the time the worse case FS station is exposed to PFDs higher than clear-air PFDs to 1.5 percent of the time. If the upper bound on the percentage of time that FS receivers are exposed to PFD levels in excess of the clear-air values is reduced from 1.5 percent to 0.1 percent, an FSS system serving New York would have to use 19.6 dB of rain-fade compensation prior to raising PFD levels, instead of the 5.4 dB required by Table 4.2.[52] This compensation requirement would decrease FSS channel capacity by over 99 percent during moderate rain fades, effectively forcing the FSS to cease operation. Even in Los Angeles, ~~the~~ a city with a very low average rain rate, an FSS would have to compensate for 7.9 dB of rain fade prior to raising PFDs, compared with the 1.3 dB[53] of non-power ameliorative measures in Table 4.2. This means that, even in cities with low rain rates, FSS operators would be giving up nearly 84 percent of system capacity for a relatively large percent of the time, if PFD in excess of the clear-air values are permitted for only 0.1 percent of the time.

4.4 Trade-off between the Costs to FS operations and the Costs to FSS operations

The previous discussions have shown that it is possible to use mathematical models based upon work developed in the ITU to calculate the worst-case percentage of time that a FS receiver would experience any increase in PFDs as a function of the non-power ameliorative measures used by the FSS operators to compensate for rain fade prior to increasing PFD levels. Additionally, it has been pointed out that for each dB of non-power ameliorative measures used by the FSS operator the channel capacity of the FSS link will be reduced by about 1 dB. The relationship between the worst-case percentage of time that a FS receiver would experience any increase in PFDs and the reduction in FSS channel capacity will vary with the rain-rate at the location of the FSS earth station.[54] For example, Figure 4.2 examines the tradeoff between these two factors for three cities: Los Angeles, CA; Philadelphia, PA and Miami FL. These three cities were chosen because they represent the range of rain-rates experienced by urban areas of the US. The rain-rate for Los Angeles is approximately 18 mm/hour~~.~~, which occurs 0.1 percent of the time in an average year. For the Miami/Ft, Lauderdale area the rain-rate is approximately 96 mm/hour and for Philadelphia the rain-rate is approximately 48 mm/hour, or approximately half-way between that of Miami and Los Angeles.

---

[52] The average rain-rate for New York City (latitude = 40.8°N, longitude =74.0°W) is 44.0 mm/hour 0.1% of an average year.

[53] The average rain-rate for Los Angeles (latitude = 34.1°N, longitude =118.2°W) is 18.5 mm/hour 0.1% of an average year.

[54] While not the only variable, the rain-rate occurring 0.1 percent of the time in an average year at a given location, is the major parameter in determining the relation between the worst-case percent of time that a FS receiver would experience any increase in PFDs as a function of the non-power ameliorative measures used by the FSS operators to compensate for rain fade prior to increasing PFD levels.

Figure 4.2 - Worst-case Exposure to of FS to Increased PFD versus Worst-case Reduction in FSS Channel Capacity for Some Example City Locations

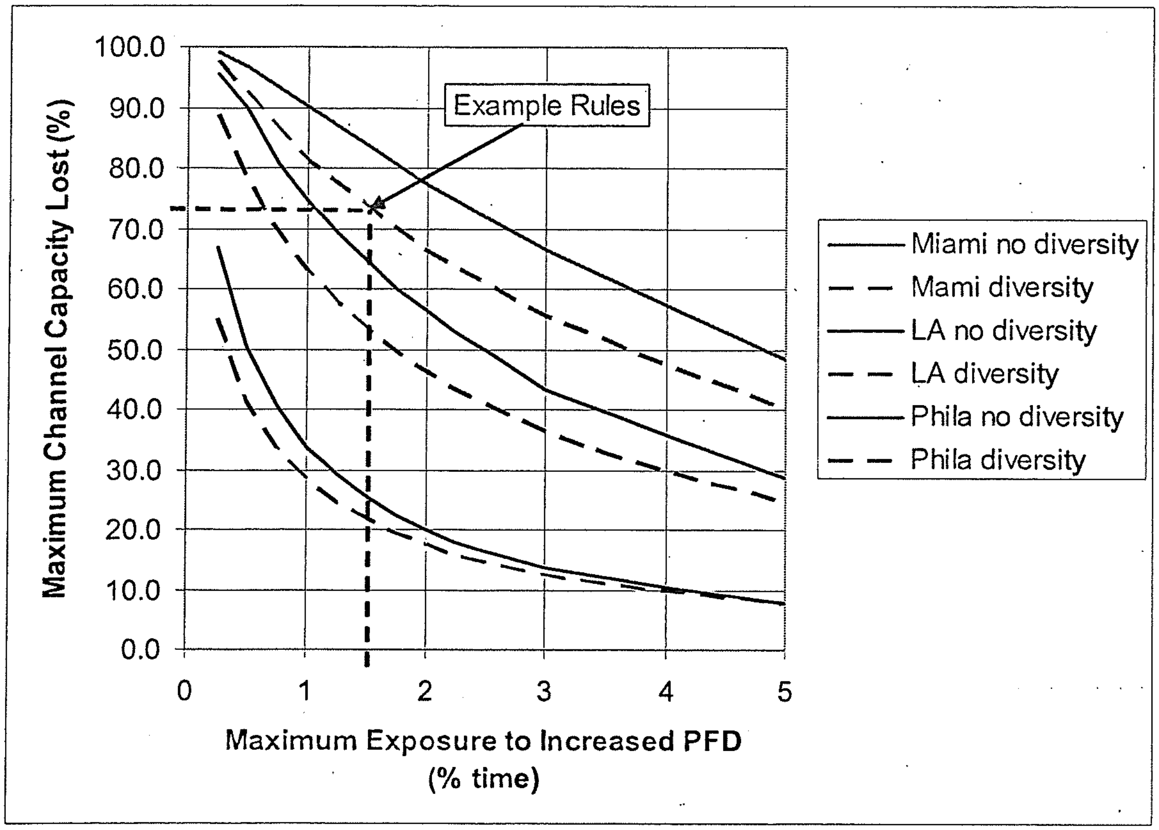


Figure 4.2 contains two curves for each of these three cities. The upper, solid curve shows the relation between the worst-case loss of FSS channel capacity and the exposure to increased PFD for the worst-case location of a FS receiver if the FSS system does not employ a diversity earth station. The lower, dashed curve assumes that the FSS system includes a diversity earth station. As can be seen in the Figure, reducing the percent of time FS are exposed to any increase in PFDs (i.e., looking at the left-hand side of Figure 4.2) increases the loss of channel-capacity for the FSS operator. In general, the channel-capacity loss also increases with rain-rate at the earth station location, so, the channel-capacity loss in the Miami area would be significantly worse than in the Los Angeles area.

Soft-segmentation allows the FSS systems to operate to gateway earth station while favoring the deployment of ubiquitous HDFS systems. This implies crafting service rules for the FSS that result in exposing FS receivers to increased PFD for relatively low percentages of time.