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To: Magalie Roman Salas, Secretary

Date: December 6, 1999

From: Jennifer M. Gilsenan

Re: Written *Ex Parte* Communication in ET Docket No. 98-206, RM-9147, and RM-9245

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CHAPTER 3

Non-GSO FSS issues

(WRC-2000 agenda item 1.13 (1.13.1, 1.13.2))

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Non-GSO FSS issues

Agenda item 1.13

"on the basis of the results of the studies in accordance with Resolutions **130 (WRC-97)**, **131 (WRC-97)** and **538 (WRC-97)**"

3.1.1 Agenda item 1.13.1

"to review and, if appropriate, revise the power limits appearing in Articles **S21** and **S22** in relation to the sharing conditions among non-GSO FSS, GSO FSS, GSO broadcasting-satellite service (BSS), space sciences and terrestrial services, to ensure the feasibility of these power limits and that these limits do not impose undue constraints on the development of these systems and services"

3.1.1 Sharing among non-GSO FSS systems

3.1.1.1 Results of studies relating to sharing between non-GSO FSS systems

Several studies contributed to ITU-R addressed the determination of the number of non-GSO FSS systems that can share co-frequency in the 14/11 and 30/20 GHz bands included in Resolution **130 (WRC-97)**. These studies have shown the following:

- that there are several mitigation techniques that should be considered for use to achieve satisfactory sharing between co-frequency, codirectional non-GSO FSS satellite networks in Resolution **130 (WRC-97)** frequency bands as shown in draft new Recommendation ITU-R S.[Doc. 4/65];
- that non-GSO FSS systems that operate with homogeneity in power flux-density levels at the Earth's surface are able to coexist with much smaller inter-system interference levels in the downlink direction for a given avoidance angle than systems with disparate power flux-densities. Thus, these systems should be able to coexist with a smaller avoidance angle to satisfy downlink requirements;
- that an important factor to be taken into account in the determination of the number of non-GSO FSS systems that can share with each other is potentially acceptable levels of interference along with the corresponding avoidance angles necessary to achieve the required interference objectives (draft revision to Recommendation ITU-R S.1323 [Doc. 4/69] gives guidance for determining interference criteria for non-GSO FSS systems);
- that sharing appears to be difficult for non-GSO FSS systems if they are required to operate with large avoidance angles (around 10° to 15°) in order to share with other non-GSO FSS systems due to the reduction in capacity and the potential increase in outages or coverage degradation;
- that some non-GSO FSS systems may be able to use smaller avoidance angles (about 3° to 7°) to share with other non-GSO FSS systems, thus resulting in an increase in the number of systems that can share a given frequency band.

a) Sharing between homogeneous constellations

The possibility of sharing between non-GSO FSS networks employing homogeneous orbital planes, (i.e., where the altitude and inclination angles of the orbital planes of two or more constellations are almost identical) was studied, and three methods identified to allow such sharing:

- plane interleaving or constellation shift, where a non-GSO constellation has its satellite orbital planes placed in between those of the other constellations;

- satellite interleaving within planes; and
- a combination of the above.

Studies have suggested that, in principle, a rather larger number of homogeneous non-GSO FSS systems may be able to share frequencies with each other than with inhomogeneous constellations, since, if all such systems employed the same orbit height and inclination, and either their respective orbit planes were interleaved or the true anomalies of their respective satellites were interleaved within the same orbit planes, no "in-line" transitions would occur between them. However, considerable cooperation between the various operators would be needed throughout the lifetime of the systems, and simulations have confirmed that even very minor differences between the heights or inclinations of the systems would create the need for some satellite diversity. It is concluded that filings by different operators for non-GSO FSS systems with this degree of similarity are extremely unlikely to occur.

b) Sharing between inhomogeneous constellations

The issue of sharing in the bands 10-15 GHz and 20/30 GHz between non-GSO FSS systems using dissimilar constellation parameters (inhomogeneous systems) was also studied in detail. Simulations have shown that sharing between two inhomogeneous non-GSO FSS systems is feasible if one or both of the systems employs mitigation techniques, including satellite diversity to avoid main beam-to-main beam coupling of interference to and from the other system during "in-line" transitions.

These studies showed that when avoidance angles are required to be impracticably large, other mitigation techniques might be required to allow multiple inhomogeneous non-GSO FSS systems to share the same frequency band. It was also demonstrated that as the number of systems sharing the same frequency band increases, the complexity of satellite avoidance implementation increases. Studies showed that the shortest-term interference into a non-GSO FSS system from multiple non-GSO FSS systems is dominated by a single system and so is not additive in either time and power.

Coordination under No. **S9.12** effectively places the obligation for implementing mitigation techniques, such as diversity on the later of the two systems to be filed with the BR. A subsequently filed third non-GSO FSS system would be faced with implementing mitigation techniques with respect to the earlier two systems, and a fourth with respect to the first three, and so on. Each earth station in a system operating with satellite diversity must be able to "see" an alternative satellite in its constellation whenever an "in-line" transition involving it approaches, and that alternative satellite must have a beam and transponder capacity "free" at the appropriate time, otherwise the link will suffer an outage. Unless such outages can be tolerated by the service being provided, it follows that systems operating diversity require either more satellites, or higher capacity satellites, or both, than systems either not operating diversity or operating diversity with respect to fewer prior systems. In certain situations, depending on the particular characteristics of the systems concerned, the simulations have shown that the requirement for space-sector hardware increased rapidly as a consequence of this factor for non-GSO FSS systems having to exercise diversity with respect to more than two or three other systems.

c) Sharing between high-altitude non-GSO (quasi-GSO) and non-GSO systems

No conclusions were reached regarding sharing between high-altitude non-GSOs (i.e. quasi-GSOs) and lower-altitude non-GSOs, such as LEOs and MEOs. It has been noted that the large difference

in orbital characteristics may impose constraints, which need to be assessed through future study by the ITU-R.

d) Maximum effective number of non-GSO FSS system able to share the same frequency band

It was therefore concluded, on the basis of studies performed, that only a small number of constellations using homogeneous orbits and homogeneous transmission parameters could share the same frequency band, but that this sharing could likely be accomplished without the use of interference mitigation techniques, except possibly for earth stations at a certain latitude. It was also concluded that sharing between non-GSO systems employing different orbital characteristics would necessitate some form of interference mitigation to reduce the interference levels and that in this case, the difficulty in mitigating interference increases as the number of systems sharing the band increases.

Studies were also performed to determine the manner in which interference from multiple non-GSO FSS systems aggregates into a GSO FSS earth station. These studies resulted in a method to convert any equivalent power flux-density, $EPFD_{down}$ versus %-of-time curve required to protect GSO downlinks from the aggregate interference from multiple non-GSO FSS systems to the corresponding $EPFD_{down}$ versus %-of-time curve for interference from a single non-GSO FSS system.

These studies also showed that the aggregate interference into a GSO network from "N" non-GSO FSS systems sharing a frequency band will likely be different from the interference into a GSO network caused by one non-GSO FSS system multiplied by a factor of "N" (in either power level or time percentage) since the impact of each non-GSO FSS system will not be identical.

It was agreed that an equivalent number "$N_{effective}$" of systems should be considered for the purposes of studying the impact of aggregate interference from multiple non-GSO FSS systems, under the assumption that each system operates at the single entry EPFD limits.

For the reasons explained above, the use of inhomogeneous parameters was assumed.

The implementation of interference mitigation techniques between the different non-GSO FSS systems in order to provide adequate protection to all other non-GSO systems was considered simultaneously with those mitigation techniques required to meet the single-entry EPFD levels in order to assess the cumulative interference effect from multiple non-GSO FSS systems.

Several studies were reviewed dealing with the determination of the number of simultaneous entries to be considered for determining EPFD levels used in bands covered by Resolution **130 (WRC-97)**, and with sharing among non-GSO FSS systems.

3.1.1.2 Summary

Taking account of the studies leading to assessments of the maximum number of non-GSO FSS systems which are likely to be able to share frequencies, a value of 3.5 for $N_{effective}$ was agreed to be used in the ITU-R studies to determine the final values of single-entry $EPFD_{down}$ versus percentage of time to be applied in bands currently covered under Resolution **130 (WRC-97)**. This value was to be used solely for the purpose of deriving single-entry EPFD masks from aggregate EPFD masks and is not a representation of the actual number of non-GSO FSS systems that can share a given frequency band.

3.1.1.3 Regulatory and procedural considerations

3.1.1.3.1 Coordination between non-GSO FSS systems

It would be beneficial, in order to facilitate sharing between non-GSO FSS systems in the frequency bands covered by Resolutions **130 (WRC-97)** and **538 (WRC-97)**, that the ITU-R should develop a methodology to be used in applying the relevant coordination procedure (No. **S9.12**). Revision of Recommendation ITU-R S.1323 contains several methodologies to derive the permissible level of interference into a wanted non-GSO FSS system, whether the interference is caused by a GSO or by a non-GSO system (See also § 3.1.2.2.2). This permissible level however, relates to the aggregate interference caused by all non-GSO FSS and GSO FSS systems. It is therefore necessary to apportion this aggregate interference into single entry permissible levels to be met by non-GSO FSS systems, taking into account the mechanisms by which all the interference sources cumulate. The ITU-R is continuing its studies to develop such a method.

The Radiocommunication Bureau should not be asked to use the method described in the above paragraph to determine the need for coordination. However, such a method would be very desirable to carry out coordination under No. **S9.12** in a satisfactory way. With the addition of such a method, the coordination process under No. **S9.12** would be facilitated since it would be based on a generally agreed and sufficiently specific method and would therefore facilitate agreement and the timely notification and bringing into service of the non-GSO system for which coordination is sought.

3.1.1.3.2 Example resolution concerning the aggregate EPFD limit from multiple non-GSO systems being exceeded

There is a need to provide a regulatory mechanism that would ensure protection of GSO FSS and GSO BSS networks from the maximum aggregate equivalent power flux-density produced by multiple non-GSO FSS systems in frequency bands where equivalent power flux-density (EPFD) limits have been adopted. One possible mechanism for meeting this objective is a WRC-2000 Resolution that would take the form of the example draft Resolution (Example Resolution WWW) that is included in Annex 2.

3.1.2 Sharing between non-GSO FSS and GSO FSS systems in the bands 10.7-11.7 GHz, 11.7-12.2 GHz (Region 2), 12.2-12.5 GHz (Region 3), 12.5-12.7 GHz (Regions 1 and 3), 12.7-12.75 GHz, 12.75-13.25 GHz, 13.75-14.5 GHz, 17.8-18.6 GHz, 19.7-20.2 GHz, 27.5-28.6 GHz and 29.5-30.0 GHz

3.1.2.1 Protection of the GSO FSS systems

Resolution **130 (WRC-97)** introduced provisional $EPFD_{down}$ and aggregate power flux-density, APFD (which is re-defined as $EPFD_{up}$) limits for non-GSO FSS systems in certain bands intended to protect GSO FSS systems operating co-frequency and requested ITU-R to conduct the appropriate technical, operational and regulatory studies to review the regulatory conditions relating to the coexistence of non-GSO and GSO systems in the FSS.

In order to adequately protect GSO FSS networks, an aggregate interference level from all non-GSO FSS systems, which individually meet the Table **S22-1** limits, needs to be defined. This issue is discussed in § 3.1.1.3.2 and Resolution WWW.

ITU-R has agreed that several mitigation techniques are available to reduce potential interference from non-GSO systems into GSO FSS systems. These techniques may be considered by non-GSO systems in order to operate within the EPFD masks.

3.1.2.1.1 Characteristics of the GSO FSS

Circular Letters CR/92 and CR/116 invited administrations to supply data on existing and planned GSO FSS links in certain frequency bands. The parameters for over 600 14/11 GHz and approximately 200 30/20 GHz carriers were collected in a database. Descriptions of GSO FSS systems are contained in Recommendation ITU-R S.1328. In addition to traditional 14/11 GHz and 30/20 GHz fixed margin FSS systems, i.e. systems that use power to compensate for rain fade, the database and Recommendation ITU-R S.1328 includes a 30/20 GHz GSO FSS system employing adaptive coding to compensate for rain fade.

For fixed margin systems, the more sensitive links include those operating with larger earth station antennas, low link noise temperature, in low rain regions (which could include some links in rain zones A to E), and/or at high altitudes with little or no excess margin. Excess margin is margin above what a link needs to meet its short-term performance objective due to rain.

It was agreed that it is not possible to determine the proportion of sensitive links in the environments based on the information contained in the CR92/CR116 database. However, it is reasonable to suppose that a large number of the links operated or planned to be operated would be less sensitive to short-term interference than the links in the database.

In the revision to Recommendation ITU-R S.1323 [Doc. 4/69], it was agreed that the system designer and operator should have control over the overall performance of a network and have the capability to provide the required quality of service. An additional link margin above that necessary to compensate for fading, e.g. to compensate for equipment ageing, should not be used for the protection from interference by other networks.

The 30/20 GHz GSO FSS system employing adaptive coding provides link robustness to rain fades on a per link basis. The excess margin concept does not apply to adaptive coding systems. Adaptive coding systems set aside a per cent of each beam's channel capacity in reserve as "spare capacity" (similar to rain margin in fixed margin systems) that is used to transmit additional bits/s for links requiring "heavy coding" to compensate for rain. This capacity is sized to cope with the expected rain statistics for a specified availability on a per beam basis which allows constant user data throughput on a link-by-link basis, depending on the link conditions at each user terminal.

For the characteristics of the GSO earth station reference antenna pattern for calculating $EPFD_{down}$ limits, and for conducting interference assessments to GSO networks from non-GSO FSS systems, ITU-R agreed to adopt reference patterns specified in Recommendation ITU-R S.[Doc. 4/57]. These reference antenna patterns are defined in two dimensions only, but it was decided that they would be considered as applicable throughout all rotational planes. Reference patterns were defined to cover both co- and cross-polar signals. These reference patterns differ from those currently referenced in the definitions of $EPFD_{down}$ in Article **S22**, which are based upon worst-case peak envelope patterns. The new agreed reference patterns take into account a more accurate, though conservative, description of the shape of the pattern so that it can be used more realistically in interference calculations involving non-GSO FSS systems, and lead to lower levels of $EPFD_{down}$ than those calculated using the patterns currently referenced in Article **S22**.

Circular Letter CR/115 requested Administrations to provide information on the number, locations and principal characteristics of their current and planned earth station antennas having a receive gain greater than 60 dBi, in order to assess the scope and specifics of a coordination procedure. Several administrations and sector members responded to CR/115, providing data at varying levels of detail on approximately 400 large antennas. Most of the large GSO earth station antennas

identified in response to CR/115 are in the 14/11 GHz band. There were few large antennas identified in

response to CR/115 in the 30/20 GHz band. Some carriers operating in the band 12.2-12.75 GHz use 18 m antennas with a gain of 65 dBi and other carriers operating in the 17.8-21.2 GHz use 20 m antennas with a gain of 70 dBi.

It was concluded that an additional regulatory procedure would be necessary to protect very large GSO FSS antennas from downlink interference from non-GSO networks. The detailed requirements for this proposed new procedure are given in § 3.1.2.4.

3.1.2.1.2 Protection criteria

a) Description of $EPFD_{up}$, $EPFD_{down}$, $EPFD_{is}$

For the protection of GSO uplinks WRC-97 set provisional limits on non-GSO FSS interference in the form of single validation power limits to be met for 100% of the time. It is recommended that this principle should be retained, but that the limits should be redefined to take into account the discrimination of the receive antenna pattern of the GSO satellite, and termed $EPFD_{up}$ limits.

Recognizing that in certain bands covered by Resolution **130 (WRC-97)** there are allocations to FSS space-to-Earth links and also to either BSS or FSS Earth-to-space links, it is recommended that additional power limits be applied to emissions from non-GSO FSS constellations in those bands in order to protect the receivers of satellites operating in the GSO. These additional limits may be termed $EPFD_{is}$ limits.

For the protection of GSO downlinks it is recommended that the individual limits provisionally adopted by WRC-97 to be met for various percentages of time should be replaced by curves prescribing the power levels not to be exceeded for percentages of time from 0% to 100%, and termed $EPFD_{down}$ masks.

In order to simplify the RR and facilitate the understanding of the provision of Article **S22**, it is recommended that the same generic mathematical definition should be used for the $EPFD_{down}$, the $EPFD_{up}$ and the $EPFD_{is}$. The reference GSO FSS space station antenna patterns in the calculation of $EPFD_{up}$ and $EPFD_{is}$ values should be the single-feed patterns defined in Recommendation ITU-R S.672; for this purpose, in the 11/14 GHz bands a peak gain of 32.4 dBi, a beamwidth of 4° and a first side lobe level of -20 dB should be assumed; in the 20/30 GHz bands a peak gain of 40.7 dBi, a beamwidth of 1.55° and a first side lobe level of -10 dB should be assumed. Annex 1 contains regulatory text that is considered to reflect the agreed changes.

The purpose of the limits contained in Section II of Article **S22** is to give an upper bound to the interference that GSO networks may receive from non-GSO FSS networks in some frequency bands. By analogy with the relevant existing ITU-R S-series Recommendations, a 40 kHz reference bandwidth for the 10-15 GHz bands and reference bandwidths of 40 kHz and 1 MHz for the 17-30 GHz bands should be used when expressing the power limits to be included in Section II of Article **S22**.

b) Time allowances for non-GSO FSS interference

With the exception of links using adaptive coding, the principal criterion used as the basis for the derivation of the validation power limits is that the aggregate interference from all non-GSO FSS systems sharing frequencies with a GSO link should not be responsible for more than 10% of the proportion of time for which the link C/(N+I) ratio is permitted to fall below the shortest-term performance threshold defined for the considered link. This criterion is defined in Recommendation ITU-R S.1323 [Doc. 4/69].

c) Criteria for defining loss of synchronization

An additional criterion identified in Recommendation ITU-R S.1323 [Doc. 4/69] refers to the protection of GSO FSS links from loss of synchronization (sync-loss). Specifically, *recommends* 3.2 stipulates that interference from non-GSO FSS systems shall not lead to sync-loss in the GSO FSS network more than once per "x" days ("x" has not been defined in Recommendation ITU-R S.1323). Sync-loss is related to the level of interference, earth station hardware performance, satellite link margin and rainy events, and sun outages in some cases. Based on measurements for sync-loss thresholds for systems with data rates less than 34 Mbits/s, the ITU-R agreed that the following sync-loss thresholds need to be considered when determining EPFD levels that should not be exceeded:

Modulation and coding	C/(N+I) (dB)
QPSK rate 7/8	6.0
QPSK rate 3/4	5.3
QPSK rate 1/2	3.5
8-PSK	8.1
16-QAM	11.0

In all other cases, and in particular when performance objectives are specified with values lower than those assumed above, the ITU-R agreed to assume a 1 dB degradation from the lowest performance objective to the synchronization loss level.

GSO FSS operators design their links so that sync-loss is a rare event. Rain attenuation is the main cause of unpredictable sync-loss events, and thus earth stations in dry climates can be less prone to sync-loss due to precipitation than most earth stations. However, carriers received by earth stations in dry climates may operate with small threshold margins and hence be more prone than others to sync-loss caused by non-GSO interference. For a typical link a mean-time-between-sync-losses due to non-GSO interference of less than about eight weeks would not be acceptable to most GSO FSS operators. The time required to verify compliance with a target of this order makes it impracticable for mean-time-between-sync-losses to be imposed as a regulatory requirement; however the sync-loss interval may be used in the determination of "operational" limits and in the development of a methodology for checking whether they are met. In making use of a sync-loss interval the effect of orbit perturbations and imperfect station keeping should be taken into account.

The degree of protection against sync-loss due to non-GSO interference peaks is related to rain rate. For the same sync-loss threshold C/(N+I) the $EPFD_{down}$ corresponding to the interfering signal (I) can be much lower in the driest areas than in the wettest areas for the same link availability.

d) Criteria for systems using adaptive coding

Recommendation ITU-R S.1323 [Doc. 4/69] also addresses the protection criteria for GSO FSS systems employing adaptive coding. Adaptive coding systems are planned in the 30/20 GHz band but not in the 14/11 GHz band. This criterion defines the impact from all non-GSO FSS systems on a per beam basis versus a per link basis for fixed link margin systems. It allows the aggregate interference from non-GSO systems to be responsible for a 10% decrease in the amount of spare capacity available to adaptive coding links that require heavy coding.

At the 14/11 GHz band frequencies, it was agreed that no additional protection measures should be considered for the protection of GSO systems employing adaptive coding, over and above the protection measures required for other GSO systems.

e) Protection of GSO links having very large earth station antennas

Some links with very large earth station antennas may not be adequately protected by the $EPFD_{down}$ limits proposed in Annex 1. The following points were agreed regarding GSO FSS networks having earth stations with very large antennas:

- Transmissions to earth stations with very large antennas need to be protected, and thus it may be desirable that they be treated separately. A coordination procedure would be one possible mechanism to ensure this protection.
- Downlink transmissions to very large GSO earth station antennas are most sensitive to interference. This sensitivity is more related to the availability degradation than to the potential for synchronization loss (i.e. the 100% $EPFD_{down}$ value).
- For very large GSO earth station antennas, the following factors would facilitate achieving mutually satisfactory coordination:
  - Non-GSO interference $EPFD_{down}$ levels at or near the maximum are likely to occur over only a small proportion of the Earth's surface.
  - The locations of interference $EPFD_{down}$ levels at or near the maximum are likely to differ from one non-GSO system to another.
- Coordination would be triggered for GSO FSS networks having very large earth station antennas meeting all of the following conditions:
  - Earth station antenna maximum isotropic gain (APS4/C.10 *c)* 2)) of 64 dBi or higher for the band 10.7-12.75 GHz and 68 dBi or higher for the bands 17.8-18.6 GHz and 19.7-20.2 GHz, which corresponds to approximately 18 metres.
  - G/T_l of 44 dB/K or higher, where G is earth station antenna maximum isotropic gain and T_l (APS4/C.10 *c)* 5)) is the lowest total system receiving noise temperature which includes the earth station noise temperature, retransmitted uplink noise, cross-polarization noise, inter-modulation noise, and any other internal link noise sources. The link noise temperature as defined herein excludes external noise sources.
  - Space station emission bandwidth (APS4/C.7 *a)*) of 250 MHz or higher for the band 10.7-12.75 GHz and 800 MHz or higher for the bands 17.8-18.6 GHz and 19.7-20.2 GHz.
- In addition to the conditions indicated in the preceding point, the coordination trigger should contain the condition of the $EPFD_{down}$ level radiated by the non-GSO FSS system into the earth station employing the very large antenna considered when this earth station is pointed to the wanted GSO satellite. Two $EPFD_{down}$ values in each band would be needed and exceeding either $EPFD_{down}$ would trigger coordination. Coordination would be triggered if the $EPFD_{down}$ exceeds:
  - either –174.5 dB(W/(m^2.40 kHz)) for any percentage of time or [x] dB(W/(m^2.40 kHz)) for [y]% of the time in the frequency band 10.7-12.75 GHz;
  - either –151 dB(W/(m^2.MHz)) for any percentage of time or [x'] dB(W/(m^2.MHz)) for [y']% of the time in the frequency bands 17.8-18.6 GHz and 19.7-20.2 GHz.

  These $EPFD_{down}$ threshold criteria would be sufficiently conservative to trigger coordination. A reference to these $EPFD_{down}$ thresholds is needed in Appendix S5.

- Based on the responses to CR/115, setting the threshold size of very large GSO earth station antennas at 64 dBi in the band 10.7-12.75 GHz and 68 dBi for the bands 17.8-18.6 GHz and 19.7-20.2 GHz clearly indicates that there would be few cases requiring coordination.
- Additional regulatory and procedural conditions (e.g. due diligence provisions) may be needed to reduce the number of cases requiring coordination.
- The conditions required to initiate coordination would be that the notifying administration provide the specific earth station location (APS4/C.10 *b)*) and satellite location (APS4/C.10 *a)*) and that the BR check that all conditions required to initiate coordination are met.

Implementation of this coordination procedure may include additions or modifications to Articles **S9** and **S22** and Appendixes **S4** and **S5**. Annex 3 contains example regulatory and procedural text for coordination between non-GSO FSS transmitting space stations and GSO receive earth stations with very large antennas. Since there is no mandatory requirement to provide specific earth station information associated with GSO FSS networks, specific provisions would be needed to grandfather existing or planned earth stations having very large antennas. Additional guidance would need to be added to the *Instructions for Filling Out the Form of Notice APS4/II and APS4/III Relating to Space Radiocommunication Stations* distributed via CR/65.

3.1.2.1.3 Methodologies used to assess the adequacy of the limits to protect GSO FSS

a) Methodologies and treatment of the CR/116 links

The ITU-R agreed that in deriving candidate EPFD limits, different methodologies can be used (e.g. Recommendation ITU-R S.1323 [Doc. 4/63]), and then using procedure D included in Annex 2 of Recommendation ITU-R S.1323 [Doc. 4/63] to verify compliance with the requirement that the interference from all non-GSO systems should not account for more than 10% of the short-term time allowance and refine the candidate masks. These methodologies do not apply to 20/30 GHz GSO FSS systems employing adaptive coding.

In order to apply the 10% criterion to carriers in the CR/116 database, it was agreed that the following treatment should be given to links where the time percentage of unavailability without non-GSO interference (T_f) is not equal to 90% of the time percentage T_t corresponding to the unavailability target (fading plus interference): the total allowable unavailability time percentage (with non-GSO interference) should be ($T_f + T_t/10$). Note that when T_f is less than 90% of unavailability target, the link has excess margin; when T_f is more than 90% of unavailability target, the link has insufficient margin.

b) Methodologies to derive the single-entry $EPFD_{down}$ mask from the aggregate $EPFD_{down}$ mask

The 10% of unavailability time allowance criterion leads to the derivation of aggregate EPFD limits. A method was needed to derive a single-entry mask from each aggregate mask.

It was agreed that the following method be employed to convert any $EPFD_{down}$ versus %-of-time curve required to protect GSO downlinks, having earth station antennas of approximately 10 m and larger in the 10.7-12.75 GHz band and 5 m and larger in the 17.8-18.6 GHz and 19.7-20.2 GHz bands, from the aggregate interference from $N_{effective}$ (equal to 3.5: see § 3.1.1.1 c)) non-GSO FSS systems, to the corresponding curve for interference from a single non-GSO FSS system:

The aggregate mask is drawn using a linear abscissa scale for the EPFD in decibel units increasing to the right, and a logarithmic scale for percentage of time increasing upwards. A second line is then

drawn, 10 log($N_{effective}$) dB to the left of the first line, thus representing power division. A third line is then drawn, dividing the first line by a factor of $N_{effective}$, thus representing time division. The single-entry mask is then formed by taking the second line from 100%-of-time to the point where it crosses the third line, the third line between that point and the point where the third line reaches 0.01%-of-time, and the first (i.e. aggregate) line for percentages of time below 0.001%. The single-entry mask is completed by drawing a straight line between the 0.01%-of-time EPFD and the 0.001%-of-time EPFD.

For smaller earth station antennas the third line is taken for all percentages of time less than the point where it crosses the second line.

In those cases where the time-shifted and the power-shifted curves do not intersect, the following procedure is applied:

1) a point P greater than or equal to the 1% of time on the aggregate curve is selected;
2) the corresponding point P on the time-shifted and the corresponding point P on the power-shifted are connected;
3) the single entry curve consists of the power-shifted portion for time between 100% and P%, the segment created in 2) for the time between P% and (P/ $N_{effective}$)% and the time-shifted segment for times less than (P/ $N_{effective}$)%;
4) using the derived single entry mask, the reverse procedure is applied to derive a new aggregate mask. The new aggregate mask is then verified to ensure that it is not greater than the original aggregate mask. If this condition is not met, a new point P is chosen and steps 2) and 3) are repeated.

c) Development of continuous EPFD curves

Once the final limits have been determined by WRC-2000, a new Recommendation if practicable will be developed by ITU-R to provide continuous curves of equivalent power flux-densities versus percentage time for a range of antenna diameters of the GSO FSS earth station to be protected, in order for designers of satellite networks to know that the protection will be adequate in the case of antennas of sizes other than those at which the Radiocommunication Bureau will check compliance.

3.1.2.1.4 Results of studies relating to the review/revision of the provisional power limits appearing in Section II of Article S22

a) $EPFD_{up}$ and $EPFD_{is}$

ITU-R agreed on single-entry $EPFD_{up}$ and $EPFD_{is}$ limits in the 14/11 GHz and 30/20 GHz bands with associated reference antenna beamwidth and radiation pattern: see Annex 1.

It was also concluded that there would be a need to include $EPFD_{up}$ limits in Article **S22** to protect GSO BSS feeder links in the band 18.1-18.4 GHz, if WRC-2000 decides that this band may be used by non-GSO FSS Earth-to-space other than BSS feeder links. The level considered appropriate for these limits to protect GSO BSS feeder links is that proposed in Annex 1 for the $EPFD_{up}$ limits in the adjacent band (17.8-18.1 GHz) and for $EPFD_{is}$ limits in the 18.1-18.4 GHz band. Other sharing considerations in this band are given in § 3.2.

b) $EPFD_{down}$

ITU-R agreed on single-entry $EPFD_{down}$ limits specified in tabular form. The limit consists of the curve on a plot which is linear in decibels for the EPFD levels and logarithmic for the time percentages and defined linear segments joining the data points.

c) $EPFD_{down}$ for 10.7-12.75 GHz band

Although the 10% criterion of Recommendation ITU-R S.1323 was not met in all cases for the validation limits given in Annexes 1 and 2, an agreement by CPM-99 on $EPFD_{down}$ limits in the band 10.7-12.75 GHz was reached. This agreement was based on the following compromise, involving i) "validation" $EPFD_{down}$ masks for reference GSO earth station antenna diameters of 60 cm, 1.2 m, 3 m and 10 m; ii) "operational" $EPFD_{down}$ limits for all antenna diameters between 3 m and 18 m; iii) "additional operational" $EPFD_{down}$ limits for antenna diameters of 3 m and 10 m; and iv) EPFD validation limits for antenna diameters exceeding 60 cm located at high latitudes.

Compliance with the validation masks will be checked by BR under **S11.31**, using software conforming to the specification described in § 3.1.5.1. The administrations represented at CPM-99 agreed to support the adoption and approval of an ITU-R Recommendation which contains that specification. The CPM agreed on single-entry validation masks that, in conjunction with operational EPFD limits, adequately protect GSO FSS systems using 60 cm, 1.2 m, 3 m and 10 m antenna diameters. These masks are given in Table **S22-1** of Annex 1.

Additionally, during operation the non-GSO system shall be subject to the provisions of § 3.1.2.4.7 in order to ensure protection of GSO earth stations using antennas of diameter ≥3 m against loss of demodulator synchronization. The operational limits defined in § 3.1.2.4.7 are given in Table **S22-4** of Annex 1 for certain antenna diameters. For antenna diameters between the tabulated values, the limits are given by linear interpolation using a linear scale for $EPFD_{down}$ in decibels and a logarithmic scale for antenna diameter in metres.

Also, the administration proposing the non-GSO system shall commit that, when in service, the interference from that system into any operational antenna of diameter of 3 m will meet the additional operational limits given in Table **S22-4A1** of Annex 1, and that the interference into any operational antenna of diameter of 10 m will meet the additional operational limits given in Table **S22-4A2** of Annex 1. To assist administrations in making such commitments, ITU-R proposes that WRC-2000 should adopt a Resolution requesting ITU-R to develop, as a matter of urgency, a new or revised Recommendation containing a methodology to determine the cumulative time distribution of the actual $EPFD_{down}$ levels radiated by a non-GSO FSS system into a GSO FSS earth station antenna. The methodology should include means of evaluating the interference into intermediate antenna diameters. For illustration purposes, Figure 3-1 shows the "validation" $EPFD_{down}$ mask and the "operational" $EPFD_{down}$ limits for antenna diameters of 3 m. Similarly, Figure 3-2 provides a graphical representation for the 10 m antenna.

Figure 3-1
Single Entry Limits for 3m antenna

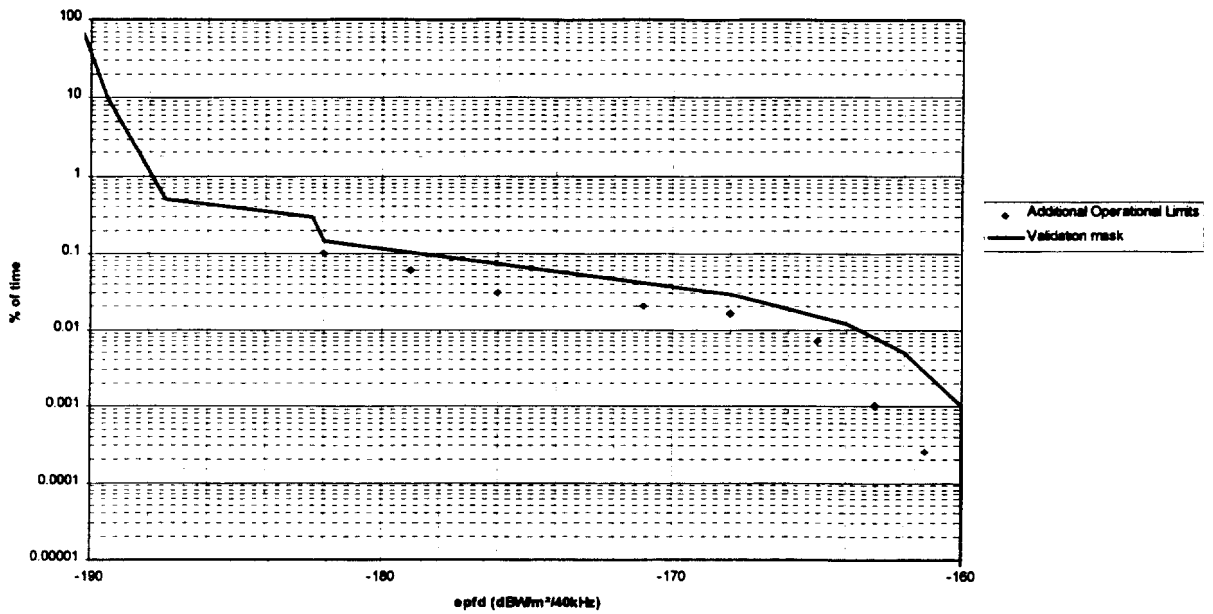
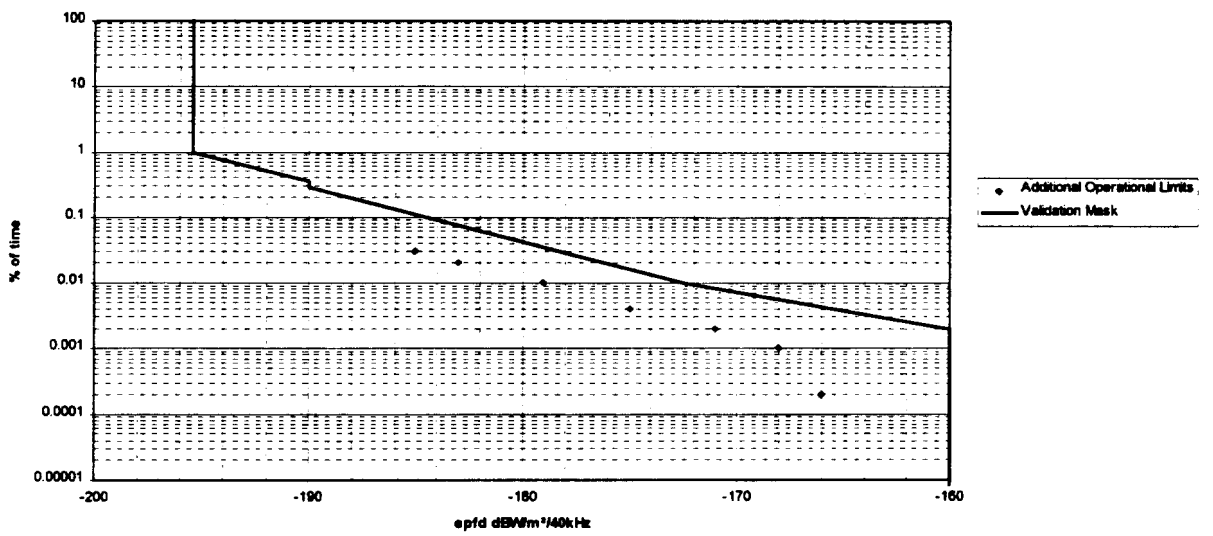


Figure 3-2
Single Entry Limits for 10m antenna



d) $EPFD_{down}$ for 17.8-18.6 GHz

ITU-R agreed on single-entry $EPFD_{down}$ validation limits in conjunction with operational limits that adequately protect GSO FSS systems operating in the 17.8-18.6 GHz band using 1 m, 2 m, and 5 m antenna diameters. These limits are given in Annex 1.

e) $EPFD_{down}$ for 19.7-20.2 GHz

ITU-R agreed on single-entry $EPFD_{down}$ validation limits in conjunction with operational limits that adequately protect GSO FSS systems operating in the 19.7-20.2 GHz band using 70 cm, 90 cm, 2.5 m and 5 m antenna diameters. These limits are given in Annex 1.

3.1.2.2 Protection of non-GSO FSS systems

3.1.2.2.1 Characteristics of the non-GSO FSS

In Circular Letter CR/102 (30 July 1999), administrations were invited to supply data on their planned non-GSO FSS links under a format enabling the assessment of the impact of interference to and from non-GSO systems. The technical characteristics of a number of proposed non-GSO FSS systems have been received and compiled in Recommendation ITU-R S.1328. These parameters have been used and will be available in the sharing studies among GSO and non-GSO systems.

3.1.2.2.2 Protection criteria

The protection criteria included in the draft revision of Recommendation ITU-R S.1323 [Doc. 4/69] apply to the protection of both GSO and non-GSO systems from interference caused by either GSO or non-GSO FSS systems. The same criteria as indicated in § 3.1.2.1.2 for the protection of GSO FSS systems from interference caused by non-GSO FSS systems have therefore been considered in the reverse direction, i.e. for the protection of non-GSO FSS systems.

In-line interference leading to synchronization loss in a non-GSO FSS system can only occur under very specific geometric situations related to the characteristics of both the wanted non-GSO FSS system and interfering GSO networks.

3.1.2.2.3 Methodologies used to assess the adequacy of the limits to protect non-GSO FSS

For geostationary networks, the link to be protected is defined between a given GSO earth station and a given GSO space station. Both of them being fixed, the slant range, elevation and rain attenuation distribution model are static. For the protection of non-GSO systems, the situation is different since the link to be protected is between one given non-GSO earth station and the selected satellite in the non-GSO constellation. This means that the physical link path is constantly moving. The elevation, the slant range and the rain attenuation distribution are not constant anymore. The path attenuation parameters vary with time.

In order to take this dynamic nature into account, a methodology has been developed and is included in § 5 of Annex 1 and Annex 3 of Recommendation ITU-R S.1323 [Doc. 4/69], and has been used to assess the impact of GSO FSS or GSO BSS interference on both regenerative and transparent non-GSO FSS satellite systems, with respect to the two protection criteria in Recommendation ITU-R S.1323 [Doc. 4/69], as reported in § 3.1.2.2.2 above.

The application of this methodology requires some assumptions on the scenarios likely to characterize the aggregate interference environment created by all GSO FSS or GSO BSS networks, in particular on the average orbital spacing between GSO FSS or GSO BSS networks serving the same area or areas adjacent to that served by the wanted non-GSO FSS system. Assumptions are also required on the geographic distribution of the earth stations in these networks. Realistic assumptions also need to be taken concerning the maximum pfd level radiated by the GSO FSS or GSO BSS space stations. On the basis of a representative scenario, it was found that the non-GSO systems would be sufficiently protected at the level of the criteria mentioned in § 3.1.2.2.2 if the off-axis e.i.r.p. density levels proposed in § 3.1.2.2.4 were to be adopted as limits to be included in

Article **S22**. However it does not necessarily follow that less stringent off-axis e.i.r.p. density levels would not adequately protect the non-GSO FSS systems.

3.1.2.2.4 Results of studies relating to the off-axis e.i.r.p. density limits

Section VI of Article **S22** contains off-axis e.i.r.p. density limits, which have been suspended, for GSO and non-GSO FSS earth stations operating in the frequency bands 12.75-13.25 GHz and 13.75-14.50 GHz. Review of these limits has resulted in the following considerations if they were to be included in the Radio Regulations:

- the values in Section VI could be increased by 3 dB while still providing protection to the non-GSO FSS systems from earth stations operated with GSO FSS satellites;
- such limits should impose a minimum of constraints on existing and future GSO networks, knowing that GSO earth stations would then have to meet a regulatory requirement, which is not the case at present;
- in particular, special attention should be given to existing earth stations or earth stations planned to be operated in the near future together with TT&C transmissions;
- it was agreed that the inclusion in the RR of FSS earth station off-axis e.i.r.p. density limits in all the plane orientations with regard to the GSO, should not lead to a situation where the GSO operators would have to provide information on the typical performance of their earth stations in more than two orthogonal planes.

Recommendation ITU-R S.524 [Doc. 4/66] provides maximum permissible levels of off-axis e.i.r.p. density from GSO FSS earth stations in the frequency bands 12.75-13.25 GHz and 13.75-14.50 GHz with these levels applying within ±3° of the GSO arc. Some existing or future GSO FSS earth stations may exhibit off-axis e.i.r.p. density levels higher than those specified in Recommendation ITU-R S.524 [Doc. 4/66] in directions beyond ±3° of the geostationary arc due to off-set feeds and spillover effects. In recognition of this characteristic it was agreed that the off-axis e.i.r.p. density levels for GSO earth stations at angles greater than 3° from the GSO should reflect a 3 dB relaxation relative to the levels which are currently recommended in Recommendation ITU-R S.524 [Doc. 4/66] within 3° of the GSO arc.

Regarding the off-axis e.i.r.p. density limits for GSO FSS earth stations operating in the frequency bands 12.75-13.25 GHz and 13.75-14.50 GHz included in No. **S22.26** and currently suspended, these levels have been reviewed for GSO FSS earth stations and agreed for communication links as follows. It has to be noted that these levels are 3 dB higher than those defined in Recommendation ITU-R S.524 [Doc. 4/66].

Off-axis angle	Maximum e.i.r.p. density	
$3° \leq \varphi \leq 7°$	42-25 logφ	dB(W/40 kHz)
$7° < \varphi \leq 9.2°$	21	dB(W/40 kHz)
$9.2° < \varphi \leq 48°$	45-25 logφ	dB(W/40 kHz)
$48° < \varphi \leq 180°$	3	dB(W/40 kHz)

For FM-TV emissions with energy dispersal, the limits above may be exceeded by up to 3 dB provided that the off-axis total e.i.r.p. of the transmitted FM-TV carrier does not exceed the following values:

Off-axis angle	Maximum e.i.r.p.
$3° \leq \varphi \leq 7°$	56-25 logφ dBW
$7° < \varphi \leq 9.2°$	35 dBW
$9.2° < \varphi \leq 48°$	59-25 logφ dBW
$48° < \varphi \leq 180°$	17 dBW

For FM-TV carriers, which operate without energy dispersal, should be modulated at all times with programme material or appropriate test patterns. In this case, the total off-axis e.i.r.p. of the emitted FM-TV carrier shall not exceed the following values:

Off-axis angle	Maximum e.i.r.p.
$3° \leq \varphi \leq 7°$	56-25 logφ dBW
$7° < \varphi \leq 9.2°$	35 dBW
$9.2° < \varphi \leq 48°$	59-25 logφ dBW
$48° < \varphi \leq 180°$	17 dBW

If limits were to be included in Section VI of Article **S22**, the following would apply to the Telecommand and Ranging carriers:

- Telecommand and ranging carriers transmitted to geostationary satellites would be allowed to exceed the limits by up to 16 dB when used in the normal mode of operation of the satellite (i.e. earth station transmitting telecommand and ranging carriers to a directive receiving antenna on the space station).
- In other modes of operation of the GSO satellite, telecommand and ranging carriers would be exempted from the limits.

With regard to provisions for grandfathering of existing earth stations, these should be developed such that the levels defined above are not applied to earth station antennas which have been brought into operation at any time and have been operating with a satellite network in the fixed-satellite service for which complete coordination or notification information has been received before 2 June 2000. Additionally, provisions should also ensure that any subsequent operation of earth stations put into operation before the specified date, to other satellite networks in the FSS, does not result in greater levels of off axis e.i.r.p. than those resulting from the previous operation to the above-mentioned network.

As an alternative to the inclusion of limits in Section VI of Article **S22,** two options have been identified:

– One would be the suppression of Section VI of Article **S22.** However, administrations may be encouraged to use applicable ITU-R Recommendations. Thus no FSS earth station off-axis e.i.r.p. density limits would be included in the Radio Regulations. This would have the advantage of imposing no additional technical or regulatory constraints on GSO FSS earth stations. On the other hand, this would not provide protection for GSO and non-GSO networks, in particular since Recommendation ITU-R S.524 is applicable only within 3° of the GSO arc in the 14 GHz band. It would not provide clear guidelines to non-GSO system designers, thus not ease sharing of spectrum between users.

– The second would consist in incorporating by reference in Section VI of Article **S22** the maximum permissible e.i.r.p. values contained in Recommendation ITU-R S.524, as appropriately modified.

3.1.2.2.5 Off-axis e.i.r.p. density limits applicable to GSO FSS earth stations operating in the frequency band 27.5-30.0 GHz

ITU-R studies to date have been carried out only for the band 29.5-30.0 GHz and in the context of GSO/GSO sharing. The results are reflected in the revision of Recommendation ITU-R S.524 [Doc. 4/66] in *recommends* 4 and the associated notes. No off-axis e.i.r.p. masks have yet been developed for the case of GSO FSS earth stations operating in the frequency range 27.5-29.5 GHz for which work is ongoing.

In *considering further h),* Resolution **130 (WRC-97)** states that non-GSO FSS systems have been proposed in some of these bands which could meet these limits and would not require specific protection from existing and future GSO FSS systems, provided that minimum constraints are applied to GSO FSS systems, such as off-axis earth station e.i.r.p. limits.

ITU-R has developed Recommendation ITU-R S.524 [Doc. 4/66] which recommends off-axis e.i.r.p. levels. This Recommendation was based on studies between GSO systems. These levels may also be used to form the basis for providing guidance to non-GSO system designers.

In order not to constrain the development of GSO systems and also to provide the necessary guidance to non-GSO system designers, the following off-axis e.i.r.p. limits may be included in the Radio Regulations, if it is considered appropriate by WRC-2000:

Off-axis angle	Maximum e.i.r.p. density	
$3° \leq \varphi \leq 7°$	28-25 logφ	dB(W/40 kHz)
$7° < \varphi \leq 9.2°$	7	dB(W/40 kHz)
$9.2° < \varphi \leq 48°$	31-25 logφ	dB(W/40 kHz)
$48° < \varphi \leq 180°$	-1	dB(W/40 kHz)

These limits apply to earth stations operating with networks in the GSO FSS in the frequency band 29.5-30.0 GHz and should apply for any angle φ in any direction outside 3° of the GSO arc.

The *Notes* 14 to 22 found in the revision of Recommendation ITU-R S.524 [Doc. 4/66] should be read in conjunction with the above.

It is noted that these values are 6 dB higher than the corresponding values in Recommendation ITU-R S.524 [Doc. 4/66], and that the impact of these higher values on non-GSO FSS systems has not been studied.

The same alternatives to inclusions of limits in Section VI of Article **S22** as identified at the end of § 3.1.2.2.4 would also apply in the 29.5-30 GHz band.

3.1.2.2.6 Off-axis e.i.r.p. density limits applicable to non-GSO FSS earth stations

The view was expressed that having some off-axis e.i.r.p. density limits applied to non-GSO earth stations would help the sharing between non-GSO networks. It was proposed that, in the bands 12.75-13.25 GHz, 13.75-14.5 GHz, 27.5-28.6 GHz and 29.5-30.0 GHz, the levels that would apply to earth stations operating with GSO would also apply to earth stations operating with non-GSO.

To date there have been no technical studies on the need for establishing off-axis e.i.r.p. limits applicable to non-GSO FSS earth stations. There was agreement that the only possible reason for establishing such limits would be to facilitate sharing between non-GSO FSS systems. The view was expressed that if such limits are applied to the earth stations of a given non-GSO network, they would possibly be helpful only in decreasing the amount of interference affecting its own satellites (internal interference) and not in facilitating sharing between non-GSO FSS systems. Further study is needed to confirm these points prior to WRC-2000. In addition, all technical studies conducted by the ITU-R apply only to GSO FSS earth stations, as clearly indicated by the scope of Recommendation ITU-R S.524 [Doc. 4/66], which summarizes the work performed to date by the ITU-R on this topic.

Sharing in the non-GSO environment depends on a wide variety of factors (e.g. orbits and number of satellites in each constellation, hand-over strategies, in-line avoidance techniques, and traffic patterns). Therefore, there is a need to study the whole interference environment before concluding whether any potential benefit of establishing limits would justify constraining, possibly unnecessarily, non-GSO FSS systems. Moreover, in some cases having off-axis limits would in fact make sharing between non-GSO FSS systems more difficult, because it would prevent the introduction of link balancing, which has been recognized as an efficient mitigation technique to promote sharing (see draft new Recommendation ITU-R S.[Doc. 4/65]).

Therefore, no consensus could be reached on whether off-axis e.i.r.p. should be established for earth stations transmitting to non-GSO satellites. Further studies are required on this issue.

3.1.2.3 Feasibility of the limits and constraints on the development of the systems and services involved

3.1.2.3.1 $EPFD_{up}$ and $EPFD_{is}$ Limits

No significant problems are foreseen, either for non-GSO FSS systems to meet the proposed $EPFD_{up}$ and $EPFD_{is}$ limits, or for GSO FSS systems to be adequately protected by them.

3.1.2.3.2 $EPFD_{down}$ Limit Masks

a) Introduction

The results of studies reported in § 3.1.2 of this Report enabled the CPM to reach the following conclusions as to the appropriate power limits to be placed on non-GSO FSS systems, in order to provide the desired protection to GSO FSS and GSO BSS networks without causing undue constraints to any of the systems and services sharing these frequency bands.

b) Consequences for GSO Systems

The introduction of power limits into Article **S22**, to share frequencies with non-GSO FSS systems, represents the acceptance of a burden on the part of the GSO FSS networks: i.e. the establishment now of acceptable interference levels from non-GSO FSS systems into all present and future GSO FSS networks, and the quantification of the protection provided for GSO FSS under No. **S22.2** in the relevant bands.

In order to ensure protection of GSO systems, a number of worst-case circumstances have been assumed in drawing up the specification for the BR compliance verification software. The $EPFD_{down}$ mask used to calculate the impact of non-GSO downlink emissions on each link in the CR92/CR116 database is based on a combination of conservative assumptions which for individual links has a low probability of occurring.

Taking into account the fact that the above assumptions have had to be made, attention is drawn to the following factors:

- The ITU-R analyses were conducted with the aim of protecting as many of the CR92/CR116 links as possible.
- The $EPFD_{down}$ limits must be met for every location on the Earth's surface and for any pointing direction towards the GSO. However, under normal circumstances, some non-GSO FSS constellations will generate their maximum $EPFD_{down}$ level in only a modest proportion of the Earth's surface. Computer simulations have shown that due to orbit perturbations, these non-GSO FSS constellations may generate their maximum $EPFD_{down}$ levels over a larger proportion of the Earth's surface, but this will result in fewer interference events in any given location. For each earth station location the maximum interference peaks will be relatively infrequent. Also, $EPFD_{down}$ levels below the maximum may be a problem for some GSO links. Quantification of these factors depends heavily on the characteristics of the non-GSO FSS system.
- ITU-R antenna reference patterns, including the pattern in draft new Recommendation ITU-R S.[Doc. 4/57], are employed for GSO earth stations, in both the ITU-R analyses and the BR software specification. These reference patterns necessarily err on the side of caution, and in practice the roll-off of the GSO earth station antenna main beam is likely to be rather faster than modelled. Also, in the models of non-GSO satellite antennas used in the analyses, the side-lobe gain assumed is likely to be somewhat higher than reality. These factors lead to conservative estimates of the durations and levels of interference peaks.
- The methodologies used to derive EPFD masks lead to conservative results because the only sources of short-term degradation taken into account are rain fading and non-GSO interference. It is noted that the rain fade models used are long-term averages, and that the rain attenuation varies substantially from year to year.
- The EPFD limits have to be met by the non-GSO system on a worldwide/GSO arc basis. The resulting EPFD mask is an envelope of all possible worst-case situations and each EPFD distribution produced by the examination software must be within the EPFD limit mask. The EPFD distribution of any single non-GSO system will therefore not follow exactly the EPFD limit mask.
- With the use of orbital avoidance, the highest $EPFD_{down}$ levels are expected to be caused by the non-GSO satellite antenna side lobes. Non-GSO systems typically use phased array antennas. Side-lobe levels for these antennas vary over the anticipated life of the non-GSO satellite due to element failures and phase and amplitude errors. These errors tend to increase satellite side lobes and change their pointing directions. It is expected that the parameters used to generate the pfd/e.i.r.p. mask correspond to the performance of the non-GSO satellite over its anticipated lifetime.
- The simulation methodology developed by ITU-R, for verification of compliance with Article **S22** of the EPFD levels produced by a non-GSO FSS system, involves the generation of a power flux-density mask (pfd mask) which corresponds to the envelope of the power radiated by each non-GSO space station, independently of the resource allocation scheme used by the non-GSO system, and independently of the traffic carried by the non-GSO system. In particular land masses and oceans are assumed to be served with maximum traffic capability at each time step of the simulation. This pfd mask is then used by the software to calculate the EPFD radiated into a given GSO earth station, by assuming, at each time step, that all the satellites contributing to interference operate at this maximum pfd level. Although

this approach may be appropriate, although still conservative, to calculate the worst-case EPFD level that may be generated at the worst-case location of the Earth, it results in an overestimation of the statistical distribution of the EPFD levels at a given point of the Earth. This also highlights that the overall impact of the interference at the GSO system level will also be overestimated as all the earth stations of a given GSO system will actually experience different EPFD statistics, the upper bound of which is the EPFD mask specified in Article **S22**.

- The methodologies used to derive the pfd masks that are input into the BR compliance examination software use what is by definition a "worst-case" scheduling algorithm for beam pointing. A study has shown that under certain circumstances the curve of EPFD statistics run over a large number of Earth points with a more realistic scheduling algorithm such as pointing in the direction of the cells that result in the highest elevation angle beams, is within 0.3 dB of the worst-case statistics obtained with the worst-case algorithm.

For those individual links which are not fully protected by the $EPFD_{down}$ validation masks, the operational limits and the additional operational limits, various ways of compensating for any shortfall in protection were considered and it was concluded that the most convenient one would usually be an increase in the satellite e.i.r.p. allocated to the GSO link, where feasible. Most of the links in the CR92/CR116 database which the $EPFD_{down}$ limits do not protect according to the 10% criterion or synchronization loss avoidance criterion are characterized by large earth station antennas and small margins.

Employing hard limits without a coordination procedure is a common practice for the FSS in the Radio Regulations in those instances where the cost of the constraints accepted by the services involved are outweighed by the benefit of coexistence without the need for coordination. Studies demonstrate that the provisional $EPFD_{down}$ limits and associated percentages of time for the large dish sizes considered by WRC-97 may not adequately protect their individual GSO FSS links terminating in very large earth station antennas as defined in § 3.1.2.4.4. $EPFD_{down}$ limits and associated percentages of time that would provide sufficient protection to GSO networks having very large earth station antennas would be substantially more stringent than limits that would protect the largest dishes considered at WRC-97. Coordination would provide an alternative sharing arrangement without placing undue constraints on the design of non-GSO systems, although it is noted that it would prove an additional burden on such systems. However, for coordination to be a satisfactory solution for the non-GSO system operators there should be very few cases requiring coordination, and the protection requirements should be clearly defined. Therefore, the thresholds for triggering coordination must be set such that in reality coordination is triggered in very few cases. The ITU-R proposed that coordination should be triggered for GSO FSS networks having very large earth station antennas and meeting a combination of thresholds as described in § 3.1.2.4.4.

c) Consequences for non-GSO Systems

The decision to operate a non-GSO FSS system in bands where $EPFD_{down}$ limits apply is based on balancing the benefits and costs of the associated economic, technical and other considerations of such operation.

The consequences for non-GSO systems of implementing $EPFD_{down}$ limits in a given band must be considered in two parts. First is the impact on the non-GSO system of having to implement satellite diversity to protect GSO systems in general. This burden has been documented in ITU-R (see CPM-97 Report). Second is the relative impact of compliance with $EPFD_{down}$ limits vs. coordination

with individual GSO systems. $EPFD_{down}$ limits do provide the benefit to present and future non-GSO systems of avoiding individual negotiations with every GSO system. However, this benefit is granted at the cost of increased constraints imposed on non-GSO FSS systems (to protect GSO FSS networks) that depend on the protectiveness of the power limits adopted. $EPFD_{down}$ limits that are too tight would result in protecting the entire GSO arc to a greater degree than would be necessary if individual coordinations were completed with each GSO system.

The following sections describe the sensitivity of these burdens to variations in the level of the power limits:

- **Lower non-GSO satellite antenna side lobes**

  The use of non-GSO satellite antennas with the best available radiation patterns will lead to the most efficient use of the radio-frequency spectrum. Antenna design can become complex and there are costs associated with developing antennas with low side lobes. Antennas with fixed boresight pointing can normally achieve lower side-lobe levels than electronically-steered antenna beams that require large scan angles.

  Most non-GSO satellites use multiple beams. The aggregate antenna side-lobe level is dependent both on the single beam side-lobe performance and the number of co-frequency active beams. Assuming a given antenna design, aggregate side-lobe improvement will require a reduction in the number of active beams and, consequently, the capacity of the non-GSO system. For example; a 1 dB tightening of the maximum EPFD limit, where non-GSO satellite side lobe into GSO earth station main beam is the highest EPFD case, may reduce the non-GSO system capacity up to 20% if no other measures were used.

  To design the satellite antennas to produce side-lobe levels lower than the current state of technology and meet more stringent short-term EPFD limits may be possible but would lead to a significant increase in complexity, mass and cost due to the larger number of radiating elements and of controllable devices (variable phase shifters, variable power dividers, variable attenuators) per antenna, as well as the consequent increase in the size and number of radiating elements. It would also result in substantially increased program costs, technical risks, and launch costs.

- **Decrease in carrier power levels to meet short-term EPFD limits**

  Decrease in non-GSO satellite carrier power will result in a reduction in capacity (e.g. "1 dB capacity", i.e. 20% reduction in capacity for 1 dB of tightening, in the case of CDMA systems) or will cause a need to increase earth station terminal size that may limit the ability to provide service in certain areas.

- **Modification of waveform to reduce power spectral density**

  In the case of spread signals, this would result in an increase in bandwidth, which could result in decreased capacity and higher production cost. In cases where non-GSO carriers utilize the entire allocated band, reduced power spectral density would be achieved only if additional spectrum was made available.

- **Increase in exclusion angle (GSO arc avoidance)**

  Increase in exclusion angle will either decrease the non-GSO system coverage if the constellation is unchanged, or increase the number of satellites and/or increase the number of beams per satellite in the constellation to maintain coverage.

3.1.2.4 Regulatory and procedural considerations

The existing text in the RR (e.g., those Resolutions **130 (WRC-97)**, **131 (WRC-97)**, and **538 (WRC-97)** (incorporated by reference), and Articles **S5**, **S9**, **S11**, **S21**, **S22**, and Appendices **S4** and **S5**) was reviewed and some possible options were identified for modifications to these provisions.

In reviewing the current regulatory provisions in the current *resolves* contained in Resolutions **130 (WRC-97)**, **131 (WRC-97)**, and **538 (WRC-97)**, possible modifications, suppressions or transfers to Articles in the RR were identified. Examples of possible modifications to Resolutions **130 (WRC-97)** and **538 (WRC-97)** are included in Annex 5 to this Chapter. Possible changes were also identified to Articles **S5**, **S9**, and **S22** and Appendices **S4** and **S5** in order to reflect the results of ITU-R studies. Examples of possible modifications to footnotes in Article **S5** as a result of determinations to be made with regard to Resolutions **130 (WRC-97)** and **538 (WRC-97)** are included in Annex 6 to this Chapter. It is anticipated that revised Resolutions **130 (WRC-97)**, **131 (WRC-97)**, and **538 (WRC-97)**, or other resolutions, will be required i) to cover the transition period of the provisional limits between WRC-97 and WRC-2000 and ii) to implement the revised Article **S22** at the end of WRC-2000. It was also noted that the *instructs the Radiocommunication Bureau* of Resolutions **130 (WRC-97)** and **538 (WRC-97)** states that "as of the end of WRC-99, to review and, if appropriate, revise, any finding previously made on the compliance with the limits contained in Article **S22** of a non-GSO FSS system for which notification information has been received between 22 November 1997 and the end of WRC-99. This review shall be based on the values in Article **S22**, as revised, if appropriate, by WRC-99". A regulatory procedure may be required to implement "this review of the findings".

Additionally, the following were specifically identified as areas that may require possible procedural/regulatory actions:

a) inclined geostationary orbits;

b) very large receive earth station antennas;

c) off-axis e.i.r.p. density;

d) software;

e) operational limits to the $EPFD_{down}$ by non-GSO systems in certain frequency bands;

f) GSO TT&C (space-to-Earth); and

g) possible misapplication of single-entry limits.

3.1.2.4.1 Article S5

Due to modifications to Resolutions **130 (WRC-97)** and **538 (WRC-97)**, consequential changes will be required to the footnotes in Article **S5** that make reference to these Resolutions. (See Annex 6.)

3.1.2.4.2 Article S22, Section II

Based on the work of ITU-R, there will be a need to revise Article **S22**, Section II. It is noted the tables in Article **S22** contain references to ITU-R Recommendations and, if it is determined that this is not acceptable (incorporation by reference), then an annex to Article **S22** containing the necessary information from the ITU-R documents will be required. Annex 1 provides examples of possible modifications to Article **S22**, Section II.

3.1.2.4.2*bis* Appendix S4, Annex 2A

Based on the work of ITU-R, there will be a need to revise Appendix **S4**, Annex 2A. Annex 9 contains the proposed changes.

3.1.2.4.3 Inclined geostationary orbits

ITU-R agreed that the $EPFD_{down}$ masks adopted for the protection of non-inclined GSO links would also protect links using satellites in slightly inclined orbits up to 2.5° inclination. Operation of GSO links up to 4.5° could be provided by operational limits as in Table **S22-4**. Where the actual orbital inclination of a GSO satellite exceeds 4.5°, some other regulatory procedure would be required.

3.1.2.4.4 Very large receive earth station antennas

§ 3.1.2.1.2 e) states that some very large earth station antennas may not be adequately protected by the $EPFD_{down}$ limits in proposed Annex 1 and a coordination procedure may be necessary. Implementation of this coordination procedure may include additions or modifications to Articles **S9** and **S22** and Appendices **S4** and **S5**. Annex 3 contains example regulatory and procedural text for coordination between non-GSO FSS transmitting space stations and GSO receive earth stations with very large antennas.

3.1.2.4.5 Off-axis e.i.r.p. density

§§ 3.1.2.2.4 to 3.1.2.2.5 of this Report address the results of studies relating to off-axis e.i.r.p. density limits for GSO/FSS earth stations.

Three options were identified for the consideration of off-axis e.i.r.p. issue in the Radio Regulations. Considerations associated with these options are addressed in §§ 3.1.2.2.4 and 3.1.2.2.5.

- **Option 1**

  Suppress the current Section VI of Article **S22** of the Radio Regulations. Thus no FSS earth station off-axis e.i.r.p. limits would be included in the Radio Regulations.

- **Option 2**

  Include FSS earth station off-axis e.i.r.p. limits in Section VI of Article **S22** for the following frequency bands: 12.75-13.25 GHz, 13.75-14 GHz, 14-14.5 GHz and 29.5-30.0 GHz.

- **Option 3**

  Incorporate by reference an ITU-R Recommendation, when available. This option would provide a mechanism for updating the off-axis e.i.r.p. values as appropriate.

Annex 7 of this Chapter contains examples of possible modifications to Section VI of Article **S22** that reflects three options above.

3.1.2.4.6 Software

The examination software intended for use by the BR would be used to compute EPFD statistics from a constellation of non-GSO satellites at specific GSO earth station locations. The cumulative probability distribution function (CDF) curves of EPFD for a single non-GSO system produced by the software would then be tested against the EPFD limits in the Radio Regulations for a decision as to whether the non-GSO system satisfied or failed the EPFD limits. It is envisioned that any non-GSO system that did not meet the EPFD limits and associated time percentages would receive an unfavourable finding from the Bureau. Regulatory and procedural work is needed regarding the examination process and results, including the following:

a) procedure for using the software;

b) definition of additional required input information by modification of Appendix **S4** or another method, and Bureau examination of input data for correctness and completeness before the data is used as software input. Administrations would provide BR with only the additional information that is useful to BR to regenerate the pfd/e.i.r.p. mask. Procedural work will be necessary to distinguish between "incorrect or incomplete information" and other changes in the system;

c) a transition plan, including identification of the date by which the required input information must be received from administrations having non-GSO FSS systems for which Appendix **S4** data was previously received by the Bureau and which now must submit new information. Provisions will also be needed to determine whether the new information is within the envelope of the existing Appendix **S4** information and the system would maintain the original date priority;

d) in order to determine the need for coordination under the proposed ADD **S9.7A** and ADD **S9.7B**, the Bureau would determine the $EPFD_{down}$ radiated by the non-GSO FSS system into earth stations employing very large antennas when the antenna is pointed toward the wanted GSO satellite. This examination would be one of the steps in determining the need for coordination. Although this examination is likely to be carried out by the Bureau's software, these results would have no impact on the determination of whether a non-GSO system met the EPFD limits;

e) publication requirements for input and output information;

f) outputs from the software, including basic outputs available to all administrations and detailed outputs that the Bureau could make available on request to the administration submitting the application, for their internal use and/or for use in case of a dispute;

g) procedure to allow administrations having GSO FSS networks the opportunity to comment on the findings of the Bureau under No. **S9.12** within four months after publication. This may include identification of a limited number of GSO earth station locations where it believes that the EPFD limits in Article **S22** are exceeded. The results from these test locations could also be employed when operational EPFD levels are examined;

h) procedures to allow the Bureau and administration concerned to inspect the detailed output.

3.1.2.4.7 Operational limits to the $EPFD_{down}$ by non-GSO systems in certain frequency bands

$EPFD_{down}$ masks have been developed to fulfil the protection criteria defined in Recommendation ITU-R S.1323 [Doc. 4/69]. These masks include limits, not to be exceeded for 100% of the time, which are being referred to below as the "validation limits". Recognizing that the validation limits may not fully protect some links from occasional synchronization loss, it is recommended that the following principles be applied:

i) An additional limit would be imposed on the actual $EPFD_{down}$ produced by a non-GSO FSS system. This "operational limit" is lower than the validation limit ($EPFD_{down}$ for 100% of the time). A non-GSO FSS system would be deemed to have fulfilled its obligations under No. **S22.2** as long as its $EPFD_{down}$ into operational GSO earth stations as defined in § 3.1.2.1.4 never exceeds the operational limit.

ii) The validation limits and operational limit would be included directly in Article **S22**. However the BR/ITU, under **S9.35** and **S11.31**, would verify non-GSO FSS compliance only with the $EPFD_{down}$ masks corresponding to the validation limits.

iii) Should an operating non-GSO FSS system exceed the operational EPFD limit into an operational GSO earth station, all necessary steps to ensure that interference caused to that GSO earth station is restored to levels at or below the operational EPFD limit would have to be taken by the non-GSO network as expeditiously as possible.

iv) The determination of whether a non-GSO FSS system is exceeding the operational EPFD limit would be made by individual administrations and their GSO system operators. A reliable means of measuring the actual interference corresponding to the EPFD produced by a non-GSO FSS system would assist administrations in this regard. This is expected to be developed in ITU-R as a draft new Recommendation prior to WRC-2000.

v) The contents of this section (§ 3.1.2.4.7) would not apply to very large antennas as defined in § 3.1.2.1.2 e). The principles in iii) and iv) above also apply to the additional operational limits in Tables **S22-4A1** and **S22-4A2** in Annex 1.

Therefore, based on the above considerations, the CPM proposes that a maximum "operational" EPFD limit as shown in Table **S22-4** in Annex 1 be included in the Radio Regulations to protect GSO networks against sync-loss.

Additional regulatory work to develop a procedure based on this concept may be needed.

3.1.2.4.8 Additional $EPFD_{down}$ limits to protect GSO FSS in the bands 10.7-11.7 GHz (in all Regions), 11.7-12.2 GHz (Region 2), 12.2-12.5 GHz (Region 3), and 12.5-12.75 GHz (Regions 1 and 3)

With respect to any GSO FSS antenna of 3 or 10 metres that is operational in the above bands, the additional operational $EPFD_{down}$ levels described in § 3.1.2.1.4 were agreed.

These additional limits would be included as limits on non-GSO FSS system operation within Article **S22**. As the limits are operational in nature, it is proposed to include them as additional tables to be considered under Table **S22-4** (see Annex 1). An administration proposing a non-GSO FSS system would have to commit that the proposed system will meet the limits that are described in this section (e.g. through inclusion of a requirement in Appendix **S4**). A method of assessing interference levels for intermediate antenna sizes should also be developed within ITU-R (see § 3.1.2.1.3 c)).

To assist administrations, further study is required within ITU-R to develop a methodology (either in a new Recommendation or a modification to an existing Recommendation) to determine the time distribution of the actual EPFD levels radiated by a non-GSO FSS system into a 3 to 10 metre GSO FSS antenna. It was agreed that a Resolution by WRC-2000 to undertake these studies as a matter of urgency would be appropriate.

ITU-R also agreed that it is essential to develop, as a matter of urgency, Recommendations to permit administrations to check compliance with the operational limits that are described in this section (as well as those operational limits described in § 3.1.2.4.7 above).

3.1.2.4.9 GSO TT&C (space-to-Earth)

The ITU-R agreed that depending on the final $EPFD_{down}$ values, there may be a need to develop provisions to protect GSO TT&C carriers in the space-to-Earth direction.

3.1.2.4.10 Possible misapplication of single-entry limits

The ITU-R identified the desirability of identifying regulatory solutions to the possible misapplication of single-entry limits by dividing a non-GSO system into several smaller non-GSO systems which independently meet the limits. It was agreed that that such misapplication would invalidate the entire basis of the derivation of the single-entry limits.

3.1.3 Sharing between non-GSO FSS and GSO BSS systems in the bands 11.7-12.5 GHz (Region 1), 11.7-12.2 GHz and 12.5-12.75 GHz (Region 3), 12.2-12.7 GHz (Region 2), 17.3-18.1 GHz (Regions 1 and 3) and 17.8-18.1 GHz (Region 2)

3.1.3.1 Protection of GSO BSS systems

Resolution **538 (WRC-97)** introduced provisional EPFD and APFD (which is re-defined as $EPFD_{up}$) limits for non-GSO FSS systems in certain bands intended to protect GSO BSS systems operating co-frequency, and requested ITU-R to conduct the appropriate technical, operational and regulatory studies to review the regulatory conditions relating to the coexistence of non-GSO FSS and GSO BSS systems.

ITU-R developed a draft new Recommendation ITU-R BO.[Doc. 11/138], referred to as BSS draft new Recommendation in the rest of § 3.1.3. This Recommendation addresses protection criteria, contains the BSS links to be protected, and descriptions of methodologies to be used in verifying protection of the BSS. The work was performed under the following principles:

a) that the equivalent power flux-density limits as defined in Article **S22** of the RR and applicable respectively to non-GSO FSS systems to be operated in the 12 GHz bands shared with BSS and in the 17 GHz frequency bands shared with BSS feeder links be derived and specified in such a way:
   - that they satisfy the criteria in *recommends* 1.1 and 1.2 of the above draft new Recommendation when applied to a set of representative GSO BSS and associated feeder-link system characteristics, as provided in Annex 1 to this Recommendation;
   - that the apportionment of the aggregate interference allowance specified in *recommends* 1.1 and 1.2 to derive single entry limits be based on the effective number of non-GSO FSS systems that are anticipated to share the same frequency bands;
   - that these limits are specified by continuous curves of cumulative density function for a range of representative GSO receiving antenna sizes.

3.1.3.1.1 Characteristics of the GSO BSS

In performing the studies requested by Resolution **538 (WRC-97)**, it was clearly impracticable for ITU-R to gather and analyse data on all existing and planned GSO BSS networks using the frequency bands covered by Appendices **S30** and **S30A**. In Circular Letters CR/92 (14 April 1998) and CR/116 (15 February 1999), administrations were therefore invited to supply data on a set of representative GSO BSS links. A number of administrations responded to these letters, ITU-R has assembled those responses received prior to 22 March 1999 into a database of GSO BSS parameters.

This database includes the detailed characteristics of more than 300 BSS links. Bearing in mind that it includes sensitive BSS links with respect to interference from non-GSO FSS systems, it was considered as the appropriate basis to assess the adequacy of the current limits, as well as alternative

candidate limits, to ensure protection of GSO BSS links so as not to cause undue constraints on any of the systems involved, and has been used for this purpose.

The complete set of submitted links is contained in Annex 1 of draft new Recommendation ITU-R BO.[Doc. 11/138]. This database of links includes both reference parameter links, operational links and links representing future technologies. They represent links employing both digital modulation techniques and FM analogue modulation techniques. The range of earth station sizes is from 30 cm to 450 cm.

One important BSS characteristic used to calculate $EPFD_{down}$ statistics is the BSS receive antenna pattern. To provide reference patterns for this purpose, ITU-R developed a draft new Recommendation ITU-R BO.[Doc. 11/137]. This Recommendation provides a unified set of reference antenna patterns for all regions. A set of three reference patterns are provided: one for $D/\lambda > 100$, one for $25.5 < D/\lambda \leq 100$, and one for $11 \leq D/\lambda \leq 25.5$. These patterns should be used when determining $EPFD_{down}$ statistics.

3.1.3.1.2 Protection criteria

Recommendation ITU-R BO.[Doc. 11/137] outlines the protection criteria for BSS from non-GSO FSS interference. It is noted that the criteria to protect GSO BSS systems from interference caused by non-GSO FSS systems are similar to those adopted for the protection of GSO FSS systems.

3.1.3.1.3 Methodologies used to assess the adequacy of the limits to protect GSO BSS

As discussed in the previous sections, there are two criteria for the protection of GSO BSS from non-GSO FSS interference.

ITU-R developed two methodologies to determine whether the first criterion, a 10% increase of the BSS link unavailability, was met. These two methodologies are described in detail in Annexes 2 and 3 of draft new Recommendation ITU-R BO.[Doc. 11/138]. *Recommends* 3 of BSS draft new Recommendation establishes that both of these methodologies could be used in assessing the impact on the GSO BSS from non-GSO FSS systems.

ITU-R also developed a methodology for assessing whether the second criterion, loss of video picture continuity, was met. This methodology is described in detail in Annex 4 of draft new Recommendation ITU-R BO.[Doc. 11/138].

In addition, it was agreed to use the method of § 3.1.2.1.3 b) to go from aggregate $EPFD_{down}$ mask to single entry $EPFD_{down}$ mask or vice versa. Since the BSS earth station antenna sizes are less than 10 m, it was decided to restrict this methodology to the power addition zone and the time addition zone.

Consistent with the approach of § 3.1.1.1 d), a value of 3.5 for "$N_{effective}$" was adopted in order to relate the single entry masks to the aggregate masks. It is noted that "$N_{effective}$" is used for computation purposes only and is not a representation of the actual number of non-GSO FSS systems that can share a given frequency band.

3.1.3.1.4 Results of studies relating to the review/revision of the provisional power limits appearing in Section II of Article S22 for the protection of GSO BSS systems subject to Appendix S30 plans and associated feeder links

a) $EPFD_{up}$ and $EPFD_{is}$ limits

The concepts of $EPFD_{up}$ and $EPFD_{is}$ limits were agreed. The first set of limits is to protect the GSO BSS feeder links receive space stations from interference caused by non-GSO FSS transmit earth stations using an Earth-to-space allocation. The second set is to protect the GSO BSS feeder links receive space stations from interference caused by non-GSO FSS space stations using a space-to-Earth allocation.

The agreed single entry $EPFD_{up}$ limit is -160 dB(W/(m^2.40 kHz)). This $EPFD_{up}$ limit applies to the bands 17.3-18.1 GHz (Regions 1 and 3) and 17.8-18.1 GHz (Region 2). It is proposed that, the above-mentioned limit be also applicable to the frequency band 17.3-17.8 GHz (Region 2), in order to protect BSS feeder links in Region 2 from non-GSO FSS uplinks in Regions 1 and 3. With regard to the 17.3-17.8 GHz allocation to non-GSO FSS (uplink) in Region 2 see 3.2.2.

The agreed single entry $EPFD_{is}$ limit is -160 dB(W/(m^2.40 kHz)). This $EPFD_{is}$ limit applies to the bands 17.8-18.1 GHz.

b) $EPFD_{down}$

It was agreed that $EPFD_{down}$ masks specified by continuous curves of cumulative density function, as called by *recommends* 2.3 of the draft new Recommendation ITU-R BO.[Doc. 11/138], would be used rather than masks specified by discrete EPFD points as used in the provisional limits. Such continuous masks, specifying the maximum allowed level of $EPFD_{down}$ as a function of the percentage of time, would provide a more realistic fit to the interference caused by non-GSO FSS systems into GSO BSS systems.

The procedure described in § 3.1.3.1.3 above has been applied on the GSO BSS link included in the database reported in § 3.1.3.1.1 above for the 12 GHz band, in order to assess the compliance of candidate $EPFD_{down}$ limits with the protection criteria considered under § 3.1.3.1.2 above. The limits considered above for $EPFD_{up}$ and/or $EPFD_{is}$, as applicable, were also included in the calculations (aggregate value of -153 dB(W/(m^2.40 kHz)), which took into account the impact of non-GSO FSS interference on the overall GSO BSS links (feeder link + downlink).

Tables in Annexes 1 and 2 provide the $EPFD_{down}$ masks in terms of the allowable single entry and aggregate EPFD levels compatible with an effective number of 3.5 non-GSO FSS interfering systems into the various antenna sizes that may be considered for the receive earth station antenna.

These masks were agreed for all antenna diameters, i.e. 30 cm, 45 cm, 60 cm, 90 cm, 120 cm, 180 cm, 240 cm and 300 cm. This agreement reflects the compromise reached between the parties by not imposing unacceptable constraints on any of them. This agreement is based on the following:

- Validation $EPFD_{down}$ masks for the above BSS earth stations antennas diameter.
- Latitude dependent validation 100% of the time $EPFD_{down}$ limits for 180 cm, 240 cm and 300 cm BSS earth stations antennas.
- Operational 100% of the time single entry $EPFD_{down}$ limits for 240 cm BSS antenna diameters in a certain northern high latitude area of Region 2.

The limit in the third bullet is required because the power of BSS transmissions that can be radiated toward certain northern high latitude area of Region 2 is limited by the existing pfd limits

section 5c) of Annex 1 to Appendix **S30**. This leads to the use of larger BSS earth station antennas in this geographical area and more sensitive links. But the protection of a limited area should not impose worldwide constraints on non-GSO FSS. This limit may be implemented during a transition period if the pfd limits in section 5c) of Annex 1 to Appendix **S30** are relaxed, taking into account the lifetime of operational BSS spacecraft and those to be launched in a short term. Information on operational limit is provided in sections 3.1.2.4.7 and 3.1.6.2.

To assist administrations, further study is required within ITU-R to develop a methodology (either in a new Recommendation or a modification to an existing Recommendation) to determine the actual EPFD level radiated by the non-GSO FSS systems into a 240 cm GSO BSS antenna. It was agreed that a Resolution by WRC-2000 to undertake these studies as a matter of urgency would be appropriate.

3.1.3.2 Interference to non-GSO FSS systems from BSS systems

The use by non-GSO FSS systems of the frequency bands subject to Appendices **S30** and **S30A** Plans at 12 and 17 GHz was addressed by WRC-97 (Resolution **538 (WRC-97)**). It should be noted that *considering c)* of Resolution **538 (WRC-97)** states that "non-GSO systems should not be entered into these Plans and therefore should not apply the procedures associated with the Plans and should not be protected by these procedures".

A study presented to WRC-97 (Document CMR-97/62) advised that the interference from Appendices **S30** and **S30A** Plans into non-GSO FSS systems sharing the same bands would be acceptable, assuming that the e.i.r.p. levels of the assignments in the Plan do not exceed the levels of the 1977 and 1983 Plans.

On this basis, the ITU-R, noting that the plan modification process would in practice limit the possibility of exceeding these levels, concluded that there would be no need to introduce specific provisions to protect non-GSO FSS systems from modifications to Appendices **S30** and **S30A** Plans.

Further study on this issue may be required in the future if higher power levels appeared to be necessary in the BSS and BSS feeder links in Appendices **S30** and **S30A** Plans.

Concerning the interference that may be caused into non-GSO FSS uplinks by GSO BSS feeder links in the 17.8-18.1 GHz band in Region 2 and, should WRC-2000 decide an allocation to non-GSO FSS (Earth-to-space) in this band, in the 18.1-18.4 GHz band in all three Regions, it was concluded that off-axis e.i.r.p. limits similar to those considered for the 13.75-14.5 GHz might be appropriate. Further study is required however, to determine the appropriate level for these limits.

3.1.3.3 Regulatory and procedural considerations

There is a need to ensure that the aggregate EPFD produced by all co-frequency non-GSO FSS systems does not exceed the maximum interference levels, as determined by the agreed to aggregate EPFD masks, that are necessary to protect these GSO BSS systems.

Some of the considerations in § 3.1.2.4 (including 3.1.2.4.9) apply also in this case.

3.1.4 Sharing between non-GSO FSS systems and terrestrial and space science services in the bands 10.7-12.75 GHz, 12.75-13.25 GHz, 13.75-14.5 GHz, 17.3-18.4 GHz (Earth-to-space), 17.7-19.3 GHz (space-to-Earth), and 27.5-28.6 GHz

3.1.4.1 Protection of fixed-service systems from interference caused by non-GSO FSS space stations in bands covered by Article S21

3.1.4.1.1 Protection of the fixed service in the 10.7-12.75 GHz band

a) Characteristics of the fixed-service systems in the 10.7-12.75 GHz band

The FS characteristics used for the evaluation of pfd limits for non-GSO FSS satellites in the 10.7-12.75 GHz band are given in the following:

Elevation angles	0 and 0.2°
Antenna height	0 metres
Antenna gain	45 and 49 dBi
Antenna pattern	Recommendation ITU-R F.1245
Latitudes	25, 45 and 60°
Gaseous attenuation	Recommendation ITU-R SF.1395
Feeder loss	3 dB
Polarization loss	Note 7 of Recommendation ITU-R F.1245
Receiver thermal noise	-140 dB(W/MHz)

These characteristics are representative of a majority of links in that frequency range.

b) Fixed service protection criteria in the 10.7-12.75 GHz band

The aggregate FS protection criteria in the 10.7-12.75 GHz range are given as follows in draft new Recommendation ITU-R F.[Doc. 9A/TEMP/65] to be submitted to RA-2000 for approval:

- Maximum I/N = +20 dB
- Long-term interference: D_{ltEPO} or FDP (see Recommendation ITU-R F.1108-2) of 10%,

  where:

$$D_{ltEPO} = (0.89 \times \int_{10^{-6}}^{1} \frac{I(t)}{N} dt) \times 100\%$$

D_{ltEPO} is the error performance objective degradation due to long-term interference.

I(t)/N is the interference-to-noise ratio that could be exceeded during no more than "t" fraction of any month time.

These aggregate FS interference criteria have been derived from considerations of the allowable degradation of Error Performance Objective (EPO) due to interference from systems operating co-primary, on typical FS links using ATPC features.

c) Methodologies used to assess the adequacy of the limits to protect the fixed service in the 10.7-12.75 GHz band

Many analyses using the pfd mask simulation method have been used for assessing the adequacy of the pfd limits for the protection of the FS. In this method, the statistics of the theoretical aggregate power levels received at an FS station are calculated by applying pfd limits under consideration to each visible satellite of the non-GSO FSS constellation[1].

In the derivation of the pfd limits defined in § 3.1.4.1.1 d), it was determined that if the calculated FDP results exceed the criteria of § 3.1.4.1.1 b) by no more than a few per cent for worst-case geometries, this does not mean that the FS links would actually be impaired. It must be noted that the pfd mask analysis is overly conservative in that it computes interference (both long term and

[1] Annex 1 of Recommendation ITU-R F.1108-2 provides guidance on the calculation of visibility statistics of space stations operating in circular non-GSO orbits as seen by a terrestrial station.

short term) that exceeds what would be produced by an operating non-GSO FSS system. This is because the analysis assumes that all the visible satellites of the non-GSO FSS constellation radiate simultaneously the maximum pfd limit in the direction of the FS system under consideration, which is unrealistic. In addition, such an assumption does not take into account the patterns of real satellite antennas, the power limitation of each satellite or the restrictions that self-interference would impose on a non-GSO FSS system.

Calculations are made assuming that the FS receiver antenna is pointing in the direction of the worst-case azimuth for the non-GSO constellation under consideration, since in that pointing direction, the long-term and short-term power levels generated by the non-GSO constellation into the FS receivers are maximum.

Studies in other bands that have considered a more realistic modelling of a similar problem have produced results providing further evidence supporting that the pfd limits defined in § 3.1.4.1.1 d) are adequate. The method used takes into account some fundamental operational constraints of non-GSO FSS systems by using more realistic downlink models developed to generate pfd distribution profiles for a range of arrival angles which are used in place of the maximum-allowed pfd mask.

Given the methodology and assumptions used for evaluating the pfd limits, it can be assumed that the FS aggregate interference criteria given in draft new Recommendation ITU-R F.[Doc. 9A/TEMP/65], can be applied for each single non-GSO FSS constellation. These conclusions remain valid if the number of co-frequency non-homogeneous non-GSO FSS systems were in the range three to five.

d) Results of studies relating to the review/revision of the power limits appearing in Article S21 in the 10.7-12.75 GHz band

The current Article **S21** per satellite pfd limits, as defined below and as discussed more fully in draft new Recommendation ITU-R SF.[Doc. 4-9S/AI] (submitted to RA-2000 for approval), are adequate for the protection of the FS in the 10.7-12.75 GHz band from aggregate interference from three assumed non-homogeneous, non-GSO FSS systems. Moreover, the contribution of GSO interference to the sharing has been shown as not being significant. Studies support and validate this conclusion. These results would remain valid if the number of non-GSO FSS systems were in the range three to five.

- In the 10.7-11.7 GHz band:

-126	dB(W/(m^2·MHz)) for $0° \leq \delta < 5°$
$-126 + (\delta - 5)/2$	dB(W/(m^2·MHz)) for $5° \leq \delta < 25°$
-116	dB(W/(m^2·MHz)) for $25° \leq \delta < 90°$

where δ is the angle of arrival above the horizontal plane.

- In the 11.7-12.75 GHz band:

-124	dB(W/(m^2·MHz)) for $0° \leq \delta < 5°$
$-124 + (\delta - 5)/2$	dB(W/(m^2·MHz)) for $5° \leq \delta < 25°$
-114	dB(W/(m^2·MHz)) for $25° \leq \delta < 90°$

where δ is the angle of arrival above the horizontal plane.