RECOMMENDATION ITU-R S.1673

Methodologies for the calculation of the worst-case interference levels from non-geostationary fixed-satellite service systems using highly-elliptical orbits into geostationary fixed-satellite service satellite networks operating in the 10 to 30 GHz frequency bands

(Question ITU-R 236/4)

(2003)

The ITU Radiocommunication Assembly,

considering

a) that many FSS frequency bands may be used for both GSO and non-GSO satellite networks in accordance with the Radio Regulations (RR);

b) that non-GSO FSS systems shall not cause unacceptable interference to GSO FSS networks in accordance with the provisions of RR No. 22.2;

c) that in some FSS frequency bands, studies have been initiated at WRC-97 to quantify the application of RR No. 22.2 and the new provisions (RR Nos. 22.5C and 22.5D) were adopted at WRC-2000 based on the study results;

d) that administrations may need to calculate the interference levels, including the worst-case interference level, that are generated from a non-GSO system into any GSO network in the FSS frequency bands other than those to which the provisions of RR Nos. 22.5C and 22.5D are applied;

e) that methodologies have been developed considering the provisions of RR Nos. 22.5C and 22.5D for the evaluation of interference levels;

f) that the methodologies in *considering* e) were based mainly on low- and medium-altitude circular orbit non-GSO FSS systems and a more simplified methodology might be appropriate for the calculation of interference from non-GSO FSS systems using highly-elliptical orbits (HEOs) (see Note 1), in which limited portions of the orbit are used as "active" arcs for operation which are spatially separated from the GSO, into GSO FSS networks,

noting

a) that studies on implementation of non-GSO FSS systems using HEOs in the FSS in the 10 to 30 GHz frequency range have also been made;

b) that RR No. 22.2 is an operational provision which is to be applied between administrations, and it is up to the affected administrations to determine whether a non-GSO FSS system is causing unacceptable interference to a GSO FSS network;

c) that the type of HEO non-GSO FSS systems referenced in *noting* a) are characterized by the use of limited operational or "active" arcs that, while differing in size from system-to-system, are spatially separated from the GSO, *recommends*

1 that the worst-case interference level, from a non-GSO FSS system of the type described in the *noting* above into a GSO FSS network, be calculated by considering that all co-frequency non-GSO satellites in such a system that are transmitting towards the same geographic region of the Earth are producing their maximum pfd levels;

2 that for non-GSO FSS systems using highly-elliptical orbits in some frequency bands between 10 and 30 GHz, where RR Nos. 22.5C and 22.5D are not applicable (see Note 2), the methodology in Annex 1 to this Recommendation should be used for the calculation of the worst-case levels of interference into GSO FSS networks from these non-GSO FSS systems (see Notes 3, 4 and 5);

3 that for non-GSO FSS systems using HEOs in some frequency bands between 10 and 30 GHz, where RR Nos. 22.5C or 22.5D are applicable (see Note 2), the methodology in Annex 2 to this Recommendation should be used for the calculation of the worst-case levels of interference into GSO FSS networks from these non-GSO FSS systems (see Notes 4 and 6).

NOTE 1 – For the purpose of this Recommendation a satellite system using either of the following orbits is categorized as a highly-elliptical non-geostationary-satellite system. Satellites in the system are operational only in the active arc:

– an orbit with an eccentricity of at least 0.05, an inclination between 35° and 145°, an apogee of at least 18 000 km, and a period that is the geosynchronous period (23 h, 56 min) multiplied by *m*/*n* where *m* and *n* are integers (the ratio *m*/*n* may be less than, equal to, or greater than one); or

– a circular orbit (with an eccentricity of at most 0.005), with the geosynchronous period (23 h, 56 min) and an inclination between 35° and 145°.

NOTE 2 – RR Nos. 22.5C and 22.5D, apply to the frequency bands 10.7-13.25, 13.75-14.5, 17.3-18.6, 19.7-20.2, 27.5-28.6 and 29.5-30.0 GHz.

NOTE 3 – The methodology in Annex 1 is complementary to the methodology in Recommendation ITU-R S.1560 for the 4 and 6 GHz frequency bands.

NOTE 4 – The methodologies in this Recommendation use worst-case assumptions that overestimate the actual levels of interference. For some systems, especially those with variations in beam pointing, frequency, power, path loss, and/or number of satellites simultaneously illuminating a service area, the overestimation could be considerable. More refined analysis techniques could be used to assess the interference profiles in more detail in order to determine realistic interference levels and their associated probabilities of occurrence.

NOTE 5 – Annex 3 gives an example of the use of the methodology in *recommends* 2 for a non-GSO FSS system operating in geosynchronous elliptical orbit.

NOTE 6 – Annex 4 gives an example of the use of the methodology in *recommends* 3 for a non-GSO FSS system operating in geosynchronous elliptical orbit.

Annex 1

Methodology for the calculation of the worst-case interference levels from non-geostationary FSS systems using HEOs into geostationary FSS networks operating in some frequency bands between 10 and 30 GHz where RR Nos. 22.5C and 22.5D are not applied

The following methodology should be used for the calculation of the potential levels of interference into GSO FSS networks operating in some frequency bands between 10 and 30 GHz where RR Nos. 22.5C and 22.5D are not applied from the co-frequency operation of non-GSO FSS systems using HEOs.

The calculation methodology described in this Annex could overestimate the actual levels of interference. In particular, for the downlink interference assessment, it is assumed that each of the transmitting non-GSO FSS satellites is located at the minimum angular separation from the line-of-sight (LoS) between the GSO FSS earth station and its associated GSO FSS satellite. In a realistic situation, if one of the non-GSO FSS satellites is located at this minimum angular separation, the other non-GSO satellites will be located at some larger angular separation and the interference contributions from these other satellites will be lower. Hence, the overall calculated $\Delta T/T$ degradation would be less than those calculated using this methodology. For both the uplink and the downlink interference assessments, the number of transmitting satellites or earth stations used in this analysis of maximum interference is that at the time when a handoff is occurring. This handoff will only occur for short periods of time (generally, about 0.1%) and will result in an over-estimation of the maximum interference that would occur for the majority of the time. More refined analysis techniques could be used to assess the interference profiles in more detail.

1 Data concerning the non-GSO FSS system

The following information is required concerning the non-GSO FSS system:

Space-to-Earth transmissions

$\theta_{D\text{-}min}$: Minimum angular separation at a GSO FSS earth station between the LoS to the active transmitting non-GSO satellites and the LoS to the associated GSO satellite (degrees).

$pfd_{D\text{-}non\text{-}GSO\text{-}max}$: Maximum pfd at the location on the Earth's surface of the earth station of the GSO FSS network caused by transmissions from each non-GSO satellite in the constellation (dB(W/(m^2 · Hz))).

N_D: Maximum number of co-frequency non-GSO satellites in a satellite system using HEOs transmitting towards the same geographic region of the Earth. An indication of the number of such satellites as a function of the percentage of time is needed.

Earth-to-space transmissions

$\theta_{U\text{-}min}$: Minimum angular separation at a transmitting non-GSO FSS earth station between the LoS to the GSO orbit and the LoS to the associated non-GSO satellite (degrees).

$e.i.r.p_{non\text{-}GSO\text{-}max}$: Maximum off-axis e.i.r.p. spectral density from the transmitting non-GSO earth station corresponding to the minimum angular separation ($\theta_{U\text{-}min}$) (dB(W/Hz)).

N_U: Maximum number of co-frequency transmitting non-GSO earth stations in a satellite system using HEOs within a geographic region of the Earth that is likely to be received by a single GSO satellite receive beam.

2 Data concerning the GSO FSS network

The following information is required concerning the GSO network:

Receive earth station sensitivity

$G_{GSO\text{-}ES\text{-}max}$: The assumed maximum off-axis gain of the GSO receive earth station in the direction corresponding to the minimum angular separation ($\theta_{D\text{-}min}$) of the non-GSO satellite when it is actively transmitting (dBi). Recommendation ITU-R S.1428 for the frequency bands between 10.7 GHz and 30 GHz provides a reference in this respect.

$T_{GSO\text{-}ES}$: Assumed clear-sky receive system noise temperature (including receive antenna noise) of the GSO downlink. To err on the conservative side this need not include degradations caused to the overall link resulting from the uplink (K).

Satellite receive sensitivity

$G_{GSO\text{-}SS\text{-}max}$: Assumed maximum GSO satellite receive antenna gain (dBi).

$T_{GSO\text{-}SS}$: Assumed clear-sky receive system noise temperature of the GSO uplink. To err on the conservative side this need not include the overall link including downlink (K).

3 Calculation of downlink interference into the GSO network

The following three steps are performed to calculate the degradation to the GSO network downlink receive system noise temperature from one non-GSO satellite system:

Step D1: Calculate the maximum interfering signal power spectral density (PSD) ($I_{0\text{-}ES}$) from a single non-GSO satellite at the GSO earth station antenna output:

$$I_{0\text{-}ES} = pfd_{D\text{-}non\text{-}GSO\text{-}max} + G_{GSO\text{-}ES\text{-}max} + 10 \log\left(\frac{\lambda^2}{4\pi}\right) \quad \text{dB(W/Hz)} \qquad (1)$$

where λ is the wavelength (m).

Step D2: Calculate the noise PSD (N_0) at the GSO earth station antenna output:

$$N_{0\text{-}ES} = 10 \log(k\, T_{GSO\text{-}ES}) \qquad \text{dB(W/Hz)} \tag{2}$$

where k is Boltzmann's constant.

Step D3: Calculate the degradation to downlink receive system noise temperature ($\Delta T/T_D$) from the constellation of non-GSO satellites:

$$\Delta T/T_D = N_D 10^{\left(\frac{I_{0\text{-}ES} - N_{0\text{-}ES}}{10}\right)} \tag{3}$$

4 Calculation of uplink interference into the GSO FSS network

The following four steps are performed to calculate the degradation to the GSO network uplink receive system noise temperature due to interference from one non-GSO FSS system:

Step U1: Calculate the maximum pfd spectral density (spfd) at the GSO space station ($pfd_{U\text{-}non\text{-}GSO\text{-}max}$) from a single non-GSO transmitting earth station: Note that this equation assumes that the non-GSO transmitting earth station is located at the minimum distance from a GSO satellite. It should be noted that at this earth station location, the resultant separation angle will be greater than the minimum separation angle that is used in the analysis. Thus, this will overestimate the interference that is received.

$$pfd_{U\text{-}non\text{-}GSO\text{-}max} = e.i.r.p_{non\text{-}GSO\text{-}max} - 10 \log(4\pi(35786)^2) - 60 \qquad \text{dB(W/(m}^2 \cdot \text{Hz))} \tag{4}$$

Step U2: Calculate the interfering signal PSD ($I_{0\text{-}SS}$) at the GSO space station antenna output:

$$I_{0\text{-}SS} = pfd_{U\text{-}non\text{-}GSO\text{-}max} + G_{GSO\text{-}SS\text{-}max} + 10 \log\left(\frac{\lambda^2}{4\pi}\right) \qquad \text{dB(W/Hz)} \tag{5}$$

where λ is the wavelength (m).

Step U3: Calculate the noise PSD (N_0) at the GSO space station antenna output:

$$N_{0\text{-}SS} = 10 \log(k\, T_{GSO\text{-}SS}) \qquad \text{dB(W/Hz)} \tag{6}$$

where k is Boltzmann's constant.

Step U4: Calculate degradation to uplink receive system noise temperature ($\Delta T/T_U$):

$$\Delta T/T_U = N_U\, 10^{\left(\frac{I_{0\text{-}SS} - N_{0\text{-}SS}}{10}\right)} \tag{7}$$

5 Multiple non-GSO FSS systems

The above methodology is useful for the calculation of a single entry interference from a system. The methodology, if applied to the situation where there are M multiple non-GSO FSS systems of this type which share the same frequency bands, is not appropriate because the maximum interfering signal PSD levels from the non-GSO FSS systems and the minimum angular separation from the GSO arc may be different among systems.

To apply the principle of the aforementioned methodology to the multiple non-GSO FSS system case, the following should be considered:

– After steps D1 and U2, aggregate interfering signal PSD levels in downlink and uplink should be calculated by the summation of each single entry levels from *M* multiple non-GSO FSS systems, respectively as follows:

Step D1m: Calculate the maximum aggregate interfering signal PSD, ($I_{A\text{-}0\text{-}ES}$) (dB(W/Hz)), from non-GSO satellites in the *M* multiple non-GSO systems at a GSO FSS the earth station antenna output:

$$I_{A\text{-}0\text{-}ES} = 10 \log \sum_{m=1}^{M} 10^{\left[\frac{I_{0\text{-}ES\text{-}m}}{10}\right]} \qquad \text{dB(W/Hz)} \tag{8}$$

$I_{0\text{-}ES\text{-}m}$ is the maximum aggregate interfering signal PSD from non-GSO satellites in the *m*-th non-GSO system. This is obtained by using the following equation:

$$I_{0\text{-}ES\text{-}m} = I_{0\text{-}ES} + 10 \log N_{D\text{-}m} \qquad \text{dB(W/Hz)} \tag{9}$$

$N_{D\text{-}m}$ is the maximum number of co-frequency satellites in the *m*-th non-GSO FSS system using HEOs transmitting towards the same geographic region of the Earth.

Step D3m: $\Delta T/T_{Dm}$ in the case of *N* multiple non-GSO FSS systems can be calculated as follow by using the values which are obtained using steps D1m and D2.

$$\frac{\Delta T}{T_{Dm}} = 10^{\left[\frac{I_{A\text{-}0\text{-}ES} - N_{0\text{-}ES}}{10}\right]} \tag{10}$$

Step U2m: Calculate the maximum aggregate interfering signal PSD ($I_{A\text{-}0\text{-}SS}$) (dB(W/Hz)) from earth stations in the *M* multiple non-GSO systems at the GSO space station antenna output:

$$I_{A\text{-}0\text{-}SS} = 10 \log \sum_{m=1}^{M} 10^{\left[\frac{I_{0\text{-}SS\text{-}m}}{10}\right]} \qquad \text{dB(W/Hz)} \tag{11}$$

$I_{0\text{-}SS\text{-}m}$ is the maximum aggregate interfering signal PSD from earth stations in the *m*-th non-GSO systems. This is obtained by using the following equation:

$$I_{0\text{-}SS\text{-}m} = I_{0\text{-}SS} + 10 \log N_{U\text{-}m} \qquad \text{dB(W/Hz)} \tag{12}$$

$N_{U\text{-}m}$ is the maximum number of co-frequency transmitting earth stations in the *m*-th non-GSO FSS system using HEOs within a geographic region of the Earth that is likely to be received by a single GSO satellite receive beam.

Step U4m: Degradation to uplink receive system of *M* multiple non-GSO FSS systems, $\Delta T/T_{Um}$, can be calculated as follows by using the values which are obtained using steps U2m and U3.

$$\frac{\Delta T}{T_{Um}} = 10^{\left[\frac{I_{A\text{-}0\text{-}SS} - N_{0\text{-}SS}}{10}\right]} \tag{13}$$

Annex 2

Methodology for the calculation of the worst-case interference levels from non-GSO FSS systems using HEOs into GSO FSS satellite networks operating in some frequency bands between 10 and 30 GHz where RR Nos. 22.5C or 22.5D are applicable

The following methodology should be used for the calculation of the worst-case levels of interference into GSO FSS networks operating in some frequency bands between 10 and 30 GHz, where RR Nos. 22.5C or 22.5D are applicable, resulting from the co-frequency operation of non-GSO FSS systems using HEOs.

The calculation methodology described in this Annex could overestimate the actual levels of interference. In particular, for the downlink interference assessment, it is assumed that each of the transmitting non-GSO FSS satellites is located at the minimum angular separation from the LoS between the GSO earth station and its associated GSO satellite. In a realistic situation, if one of the non-GSO satellites is located at this minimum angular separation, the other non-GSO satellites will be located at some larger angular separation and the interference contributions from these other satellites will be lower. Hence, the overall calculated epfd levels would be less than those calculated using this methodology. For both the uplink and the downlink interference assessments, the number of transmitting satellites or earth stations used in this analysis of maximum interference is that at the time when a handoff is occurring. This handoff will only occur for short periods of time (generally, about 0.1%) and will result in an overestimation of the maximum interference that would occur for the majority of the time. More refined analysis techniques could be used to assess the interference profiles in more detail.

1 Data concerning the non-GSO FSS system

The following information is required concerning the non-GSO FSS system:

Space-to-Earth transmissions

$\theta_{D\text{-}min}$: Minimum angular separation at a GSO FSS earth station between the LoS to the active transmitting non-GSO satellites and the LoS to the associated GSO satellite (degrees).

$pfd_{D\text{-}non\text{-}GSO\text{-}max}$: Maximum pfd at the location on the Earth's surface of the earth station of the GSO FSS network caused by transmissions from each non-GSO satellite in the constellation (dB(W/(m^2 · Hz))).

N_D: Maximum number of co-frequency non-GSO satellites in a satellite system using HEOs transmitting towards the same geographic region of the Earth. An indication of the number of such satellites as a function of the percentage of time is needed.

Earth-to-space transmissions

$\theta_{U\text{-}min}$: Minimum angular separation at a transmitting non-GSO FSS earth station between the LoS to the GSO orbit and the LoS to the associated non-GSO satellite (degrees).

$e.i.r.p._{non\text{-}GSO\text{-}max}$: Maximum off-axis e.i.r.p. spectral density from the transmitting non-GSO earth station corresponding to the minimum angular separation ($\theta_{U\text{-}min}$) (dB(W/Hz)).

N_U: Maximum number of co-frequency transmitting non-GSO earth stations in a satellite system using HEOs within a geographic region of the Earth that is likely to be received by a single GSO satellite receive beam.

2 Data concerning the GSO FSS network

The following information is required concerning the GSO network:

Receive earth station sensitivity

$G_{GSO\text{-}ES\text{-}max}$: The assumed maximum off-axis gain of the GSO receive earth station in the direction corresponding to the minimum angular separation ($\theta_{D\text{-}min}$) of the non-GSO satellite when it is actively transmitting (dBi). Recommendation ITU-R S.1428 for the frequency bands between 10.7 GHz and 30 GHz provides a reference in this respect.

$G_{GSO\text{-}ES}$: Assumed maximum GSO receive earth station antenna gain (dBi).

Satellite receive sensitivity

$G_{GSO\text{-}SS\text{-}max}$: Assumed maximum off-axis GSO satellite receive antenna gain (dBi).

$G_{GSO\text{-}SS}$: Assumed maximum GSO satellite receive antenna gain (dBi).

3 Calculation of downlink interference into the GSO FSS network

The following two steps are performed to calculate the epfd↓ levels at the GSO FSS network earth stations from one non-GSO FSS system:

Step D1: Calculate the single satellite epfd↓ level at the GSO earth station antenna output:

$$epfd_{\downarrow} = pfd_{D\text{-}non\text{-}GSO\text{-}max} + G_{GSO\text{-}ES\text{-}max} - G_{GSO\text{-}ES} \quad \text{dB(W/(m}^2 \cdot \text{Hz))} \quad (14)$$

Step D2: Calculate the epfd↓ levels at the GSO earth station antenna output from the constellation of non-GSO satellites:

$$epfd_{\downarrow} = epfd_{\downarrow} + 10 \log N_D \quad \text{dB(W/(m}^2 \cdot \text{Hz))} \quad (15)$$

Note that the epfd↓ in equation (15) is for 1 Hz reference bandwidth. To obtain the epfd↓ for the reference bandwidth of *F* kHz, the value of 10 log(1000*F*) (dB) is added.

4 Calculation of uplink interference into the GSO FSS network

The following three steps are performed to calculate the epfd↑ levels at the GSO FSS network satellite from one non-GSO FSS system:

Step U1: Calculate the maximum spfd at the GSO space station ($pfd_{U\text{-}non\text{-}GSO\text{-}max}$) from a single non-GSO transmitting earth station: Note that this equation assumes that the non-GSO transmitting earth station is located at the minimum distance from a GSO satellite. It should be noted that at this earth station location, the resultant separation angle will be greater than the minimum separation angle that is used in the analysis. Thus, this will overestimate the interference that is received.

$$pfd_{U\text{-}non\text{-}GSO\text{-}max} = e.i.r.p._{non\text{-}GSO\text{-}max} - 10\log(4\pi(35786)^2) - 60 \qquad \text{dB(W/(m}^2 \cdot \text{Hz))} \quad (16)$$

Step U2: Calculate the maximum epfd↑ at the GSO space station antenna output:

$$epfd_{\uparrow} = pfd_{U\text{-}non\text{-}GSO\text{-}max} + G_{GSO\text{-}SS\text{-}max} - G_{GSO\text{-}SS} \qquad \text{dB(W/(m}^2 \cdot \text{Hz))} \quad (17)$$

Step U3: Calculate the aggregate epfd↑ at the GSO space station antenna output:

$$Aggregate\ epfd_{\uparrow} = epfd_{\uparrow} + 10\log N_u \qquad \text{dB(W/(m}^2 \cdot \text{Hz))} \quad (18)$$

Note that the aggregate epfd↑ in equation (18) is for 1 Hz reference bandwidth. To obtain the aggregate epfd↑ for the reference bandwidth of *F* kHz, the value of 10 log(1000*F*) (dB) should be added.

5 Multiple non-GSO FSS systems

The above methodology is useful for the calculation of a single entry interference from a system. The methodology, if applied to the situation where there are *M* multiple non-GSO FSS systems of same type sharing the same frequency bands, is not appropriate because the maximum interfering signal epfd levels from the non-GSO FSS systems and the minimum angular separation from the GSO arc may be different among systems.

To apply the principle of the aforementioned methodology to the case of multiple non-GSO FSS systems, the following should be considered:

– After steps D2 and U3, aggregate interfering signal epfd levels (aggregate $epfd_m$ in downlink and uplink) should be calculated by the summation of single entry levels from *M* non-GSO FSS systems as follows:

Step D2m:

$$Aggregate\ epfd_{m\downarrow} = 10\log\sum_{m=1}^{M} 10^{\left[\frac{epfd\,(m)\downarrow}{10}\right]} \qquad \text{dB(W/(m}^2 \cdot \text{Hz))} \quad (19)$$

$epfd(m)_{\downarrow}$ is the maximum interfering signal epfd levels at the GSO earth station from non-GSO satellites in the *m*-th non-GSO system. This is obtained by using equation (15).

Note that the "$Aggregate\ epfd_{m\downarrow}$" in equation (19) is for 1 Hz reference bandwidth. To obtain the "$Aggregate\ epfd_{m\downarrow}$" for the reference bandwidth of *F* kHz, the value of 10 log(1000*F*) (dB) should be added.

Step U3m:

$$Aggregate\ epfd_{m}\uparrow = 10 \log \sum_{m=1}^{M} 10^{\left[\frac{epfd\ (m)\uparrow}{10}\right]} \qquad \text{dB(W/(m}^2 \cdot \text{Hz))} \tag{20}$$

$epfd(m)\uparrow$ is the maximum interfering signal epfd levels at the GSO space station from non-GSO earth stations in the m-th non-GSO system. This is obtained by using equation (18).

Note that the aggregate $epfd_m\uparrow$ in equation (20) is for 1 Hz reference bandwidth. To obtain the aggregate $epfd_m\uparrow$ for the reference bandwidth of F kHz, the value of 10 log(1000F) (dB) should be added.

Annex 3

Example of the application of the methodology in the Annex 1 to this Recommendation to the calculation of the worst-case interference levels from a non-GSO FSS system operating in geosynchronous elliptical orbits into GSO FSS networks in the 19/29 GHz frequency bands

1 Non-GSO system under consideration

The type of non-GSO FSS system considered here proposes to use geosynchronous elliptical orbits in order to ensure a large angular separation of the active satellites from the GSO orbit. The system, hereafter referred to as System-1, would provide FSSs to small earth stations such as very small aperture terminals (VSAT).

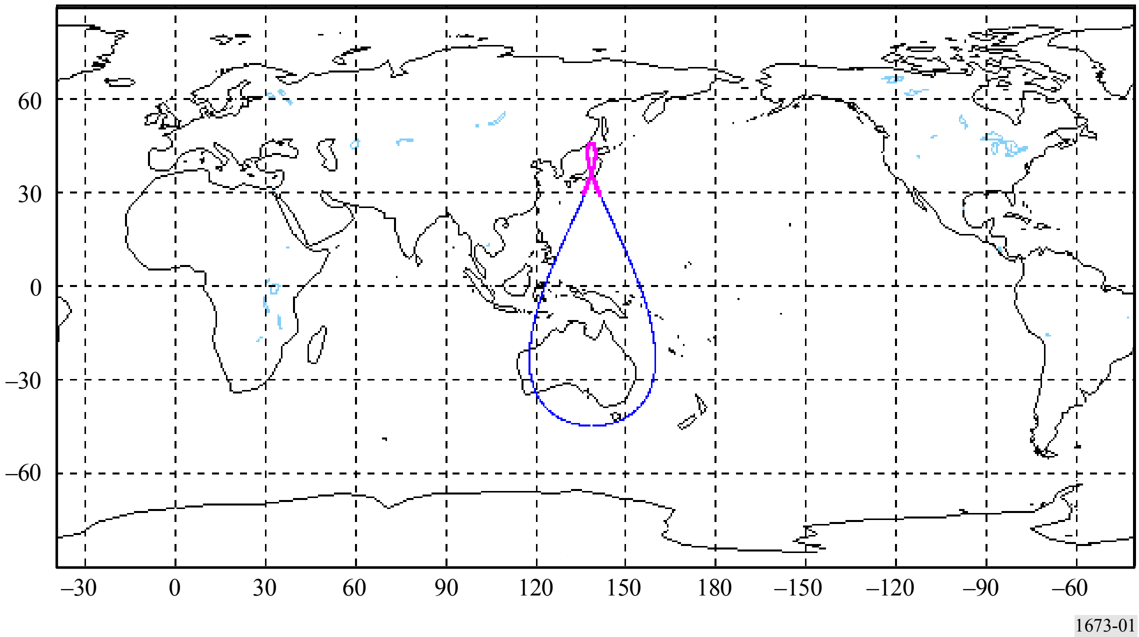
The system is comprised of three or four-satellites that have repeating ground tracks. Figure 1 shows a sub-satellite ground track of the System-1, with the active service arcs indicated by the bold lines. The system is designed so that the satellites are "active" (i.e. transmit or retransmit and receive radiocommunication signals) only when in the portion of the orbit near apogee, where the satellite is travelling at the slowest rate of speed. The "active arc" for the constellation occurs only when the satellites are at latitudes above 30° N. It should be noted that there are times when two satellites are in a given active arc (one at the beginning and one at the end) in order to perform housekeeping and handover activities. This system design results in the active satellites being separated from the geostationary LoS by at least 30° at all times. The System-1 thus achieves an optimized combination of very high elevation angles, low-signal propagation delays compared to geostationary satellites, limited satellite handovers, and high angular separation from the GSO orbit.

2 Frequency bands

The System-1 is proposed to operate in the 500 MHz portion of 28.6-29.1 GHz frequency band (Earth-to-space) and the 500 MHz portion of 18.8-19.3 GHz frequency band (space-to-Earth). Each satellite in the system provides "bent pipe" communications channels in these bands.

FIGURE 1

Sub-satellite ground tracks of System-1



3 Key parameters for calculation of interference into GSO FSS networks in the 19/29 GHz frequency bands

For the type of non-GSO FSS system considered in this example the following parameters are necessary for the assessment of interference into co-frequency GSO FSS networks:

Downlink interference into GSO FSS networks

D1: Minimum angular separation of the active transmitting non-GSO satellites from the LoS between the GSO earth station and its associated GSO satellite (see the definition of $\theta_{D\text{-}min}$ in Annex 1).

D2: Maximum pfd at the Earth's surface caused by transmissions from each non-GSO satellite in the constellation (see the definition of $pfd_{D\text{-}non\text{-}GSO\text{-}max}$ in Annex 1).

D3: Maximum number of co-frequency non-GSO satellites transmitting towards the same geographic region of the Earth. An indication of the number of such satellites as a function of the percentage of time is needed (see the definition of N_D in Annex 1).

D4: The assumed off-axis gain of the GSO receive earth station towards the active non-GSO satellites (see the definition of $G_{GSO\text{-}ES\text{-}max}$ in Annex 1). Recommendation ITU-R S.1428 provides guidance in this respect.

D5: Assumed clear-sky receive system noise temperature (including receive antenna noise) of the GSO downlink (see the definition of $T_{GSO\text{-}ES}$ in Annex 1). To err on the conservative side this need not include degradations caused to the overall link resulting from the uplink.

Uplink interference into GSO FSS networks

U1: Minimum angular separation of the GSO orbit from the LoS between the transmitting non-GSO earth station and its associated non-GSO satellite (see the definition of $\theta_{U\text{-}min}$ in Annex 1).

U2: Maximum off-axis e.i.r.p. spectral density from the transmitting non-GSO earth station (see the definition of $e.i.r.p._{non\text{-}GSO\text{-}max}$ in Annex 1).

U3: Maximum number of co-frequency transmitting non-GSO earth stations within a geographic region of the Earth that is likely to be received by a single GSO satellite receive beam (see the definition of N_U in Annex 1).

U4: Assumed off-axis GSO satellite receive antenna gain (see the definition of $G_{GSO\text{-}SS\text{-}max}$ in Annex 1).

U5: Assumed clear-sky receive system noise temperature of the GSO uplink (see the definition of $T_{GSO\text{-}SS}$ in Annex 1). To err on the conservative side this need not include the downlink noise.

4 Calculation of downlink interference to the GSO networks

For the non-GSO system considered here (System-1) the values of the key parameters necessary for this interference calculation are as follows:

D1: The minimum angular separation of the active transmitting non-GSO satellites from the LoS between the GSO earth station and its associated GSO satellite is never less than 40°.

D2: The maximum pfd at the Earth's surface caused by transmissions from each non-GSO satellite in the constellation is not greater than –140 dB(W/(m^2 · 4 kHz)).

D3: The maximum number of co-frequency non-GSO satellites transmitting towards the same geographic region of the Earth is two. This situation can occur for very short periods of handover between the "setting" and the "rising" non-GSO active satellite (handover occurs typically for a duration of 10 s every 8 or 6 h depending on the number of satellites in the non-GSO satellite system). A duration of 10 s is less than 0.05% of the time.

D4: The assumed off-axis gain of the GSO receive earth station towards the active non-GSO satellites follow Recommendation ITU-R S.1428.

D5: The assumed clear-sky receive system noise temperature (including receive antenna noise) of the GSO downlink is conservatively taken as 500 K. This represents a fairly high performance downlink, and disregards any degradations caused to the overall link resulting from the uplink.

Using the above values for the key parameters the calculation of worst-case downlink interference from the non-GSO system into any co-frequency GSO network is given in Table 1.

TABLE 1

Example of worst-case (short-term) downlink interference calculation from System-1 into a GSO earth station in the 19 GHz frequency band

Parameter	Units	Value
Maximum pfd of System-1 satellite in 4 kHz	dB(W/(m^2 · 4 kHz))	–140
GSO orbit avoidance angle	degrees	30
GSO Rx earth station gain towards System-1 satellite	dBi	–7
Frequency	GHz	19
Effective aperture of GSO Rx earth station towards System-1 satellite (5 m)	dBm^2	–54
GSO Rx earth station interfering signal power in 4 kHz	dB(W/4 kHz)	–194
GSO Rx earth station interfering signal PSD	dB(W/Hz)	–230
Increase in interference due to two simultaneously visible System-1 satellites	dB	3
GSO Rx earth station interfering signal PSD (two System-1 satellites)	dB(W/Hz)	–227
GSO Rx earth station system noise temperature	K	300
GSO Rx earth station system noise PSD	dB(W/Hz)	–203.8
I_0/N_0 at GSO Rx earth station input (short term)	**dB**	**–23.2**
$\Delta T/T$ degradation to GSO Rx earth station (short term)	**%**	**0.48**

The analysis in Table 1 starts with the maximum downlink pfd of the System-1 satellite, as given in data item D2. Then based on the minimum 30° GSO orbit avoidance angle (data item D1), the off-axis gain of the GSO receive earth station antenna which is calculated based on Recommendation ITU-R S.1428 (data item D4) is assumed –7 dBi. This gain is converted to an effective aperture (dBm^2) using an appropriate receive frequency of 19 GHz. The use of the effective aperture then allows a simple calculation of the received interfering signal power, in a 4 kHz bandwidth, from a single System-1 satellite. After allowing for two simultaneously visible System-1 satellites (which is the worst-case, short-term value), and adjusting to a reference bandwidth of 1 Hz, this aggregate interfering signal power is compared to the inherent noise power of the GSO earth station receiver (resulting from data item D5). Based on this the interference-to-noise power density ratio, I_0/N_0, is calculated to be –23.2 dB, which is also expressed as an equivalent $\Delta T/T$ degradation to the GSO receive earth station performance of 0.48%.

In previous sections of this Annex, it has been noted that the above analysis will overestimate the actual interference because the assumed two interfering satellites will not all be located at the minimum separation angle to a given GSO earth station location.

5 Calculation of uplink interference to the GSO networks

For the candidate non-GSO system considered here (System-1) the values of the key parameters necessary for this interference calculation are as follows:

U1: The minimum angular separation of the GSO orbit from the LoS between the transmitting non-GSO earth station and its associated non-GSO satellite is never less than 30°.

U2: The maximum off-axis e.i.r.p. spectral density from the transmitting non-GSO earth station is computed from the maximum input PSD (–21 (dB(W/4 kHz)) in clear sky and −11 dB(W/4 kHz) in rain fades due to the use of uplink power control) and the maximum off-axis gain of the non-GSO transmitting earth station in the direction of the GSO arc. The maximum off-axis gain is assumed to follow Recommendation ITU-R S.1428.

U3: There is a direct relationship between the maximum number of co-frequency transmitting non-GSO earth stations within a geographic region of the Earth that are likely to be received by a single GSO satellite receive beam, and the assumed maximum GSO satellite receive gain (see item U4). When the GSO satellite receive beamwidth is smaller than the non-GSO satellite receive beamwidth (as measured on the surface of the Earth), the maximum number is generally one. Only when the GSO satellite receive beamwidth is greater than the non-GSO satellite beamwidth there will be the possibility of multiple co-frequency emissions from the non-GSO transmitting uplinks. However, in this case the peak gain of the GSO satellite receive beam will be reduced, thereby resulting in less uplink sensitivity and lower levels on non-GSO interference per transmitting non-GSO earth station. Therefore the likely worst-case scenario is a high gain GSO receive spot beam, whose beamwidth (as measured on the surface of the Earth) is significantly less than the beamwidth of the non-GSO satellite receive beam. In the calculation only one co-frequency non-GSO transmitting earth station is to be considered for the uplink interference. However, in order to address the handover situation, the analysis for the worst-case uplink interference actually assumes two such stations.

U4: See comments in data item U3 in relation to the assumed GSO satellite receive antenna gain towards System-1 earth station.

U5: The assumed clear-sky receive system noise temperature of the GSO uplink is conservatively taken as 500 K. This represents a fairly high performance satellite receiver, and conservatively disregards any degradations caused to the overall link resulting from the downlink.

Using the above values for the key parameters the calculation of worst-case uplink interference from the non-GSO system into any co-frequency GSO network is given in Table 2. This shows two columns for the calculation: one for the clear-sky condition and one for rain conditions where the uplink power control causes the maximum available increase in transmit power to overcome the rain fade. In fact the clear-sky calculation provides the most realistic assessment of the uplink interference situation because, for the rain fade condition, the interfering signal path can also be assumed to be faded by approximately the same amount as the wanted signal path in the System-1. The interference levels shown in the rain condition could only occur if the LoS from the System-1 transmitting earth station to the GSO satellite was unfaded while the LoS to the System-1 satellite was fully faded. Such a condition would be extremely rare, and if it ever existed at all would be of extremely short duration.

TABLE 2

Example of worst-case uplink interference calculation from System-1 transmitting earth station into GSO satellite receiver in the 29 GHz frequency band

Parameter	Value (Clear sky)	Value (Rain)	Units
Maximum PSD into System-1 earth station antenna in 4 kHz	–21	–11	dB(W/4 kHz)
GSO orbit avoidance angle	30	30	degrees
System-1 Tx earth station gain towards GSO satellite	–7	–7	dBi
System-1 Tx earth station e.i.r.p. spectral density towards GSO satellite in 4 kHz	–28	–18	dB(W/4 kHz)
pfd at the GSO satellite in 4 kHz	–190.1	–180.1	dB(W/(m^2 · 4 kHz))
Frequency	29	29	GHz
Assumed gain of GSO satellite Rx towards System-1 earth station	44	44	dBi
Effective aperture of GSO satellite Rx towards System-1 earth station	–7	–7	dBm^2

TABLE 2 (*end*)

Parameter	Value (Clear sky)	Value (Rain)	Units
GSO satellite Rx interfering signal power in 4 kHz	–197.1	–187.1	dB(W/4 kHz)
GSO satellite Rx interfering signal PSD (one System-1 earth station)	–233.1	–223.1	dB(W/Hz)
GSO satellite Rx interfering signal PSD (two System-1 earth stations)	–230.1	–220.1	dB(W/Hz)
GSO satellite Rx system noise temperature	500	500	K
GSO satellite Rx system noise PSD	–201.6	–201.6	dB(W/Hz)
I_0/N_0 at GSO satellite Rx input (short term)	**–28.5**	**–18.5**	**dB**
$\Delta T/T$ degradation to GSO satellite Rx (short term)	**0.14**	**1.41**	**%**

In Table 2 the calculation methodology is similar to that used for the downlink (Table 1) and described above, using the data items U1 to U5.

As noted above, the $\Delta T/T$ values produced by this analysis would only be received in the short term (about 10 s every 8 or 6 h depending on the number of satellites in the non-GSO satellite system, or less than 0.05% of the time). The long-term I_0/N_0 values would be a minimum of 3 dB less since the non-GSO earth station would only be transmitting to one satellite. This 3 dB reduction would result in $\Delta T/T$ values of 0.14% for clear sky and 1.41% for power control used in rain fade situations.

Annex 4

Example of the application of the methodology in Annex 2 to this Recommendation to the calculation of the worst-case interference levels from a non-GSO FSS system operating in geosynchronous elliptical orbits into GSO FSS networks in the 18/28 GHz frequency bands

1 Candidate non-GSO system under consideration

The type of non-GSO FSS system considered here proposes to use geosynchronous elliptical orbits in order to ensure a large angular separation of the active satellites from the GSO orbit. The system, hereafter referred to as System-2, would provide fixed-satellite services to small earth stations such as VSAT terminals.

The system is comprised of three or four-satellites that have repeating ground tracks. Figure 1 shows also the sub-satellite ground track of the System-2, with the active service arcs indicated by the bold lines. The system is designed so that the satellites are "active" (i.e. transmit or retransmit and receive radiocommunication signals) only when in the portion of the orbit near apogee, where the satellite is travelling at the slowest rate of speed. The "active arc" for the constellation occurs only when the satellites are at latitudes above 30° N. It should be noted that there are times when there will be two satellites in a given active arc (one at the beginning and one at the end) in order to perform housekeeping and handover activities. This system design results in the active satellites being separated from the geostationary LoS by at least 30° at all times. The System-2 thus achieves an optimized combination of very high elevation angles, low-signal propagation delays compared to geostationary satellites, limited satellite handovers, and high angular separation from the GSO orbit.

2 Frequency bands

The System-2 is proposed to operate in 28 GHz frequency band (Earth-to-space) and 18 GHz frequency band (space-to-Earth). Each System-2 satellite provides "bent pipe" communications channels in these bands.

3 Key parameters for calculation of interference to GSO FSS networks in the 18/28 GHz frequency bands

For the type of non-GSO system considered in this example the following parameters are necessary for the assessment of interference into co-frequency GSO FSS networks:

Downlink interference into GSO networks

D1: Minimum angular separation of the active transmitting non-GSO satellites from the LoS between the GSO earth station and its associated GSO satellite (see the definition of $\theta_{D\text{-}min}$ in Annex 2).

D2: Maximum pfd at the Earth's surface caused by transmissions from each non-GSO satellite in the constellation (see the definition of $pfd_{D\text{-}non\text{-}GSO\text{-}max}$ in Annex 2).

D3: Maximum number of co-frequency non-GSO satellites transmitting towards the same geographic region of the Earth, as well as an indication of the number of such satellites as a function of the percentage of time (see the definition of N_D in Annex 2).

D4: The assumed maximum and off-axis antenna gains of the GSO receive earth station (see the definition of $G_{GSO\text{-}ES\text{-}max}$ in Annex 2). Recommendation ITU-R S.1428 provides guidance in this respect.

Uplink interference into GSO networks

U1: Minimum angular separation of the GSO orbit from the LoS between the transmitting non-GSO earth station and its associated non-GSO satellite (see the definition of $\theta_{U\text{-}min}$ in Annex 2).

U2: Maximum off-axis e.i.r.p. spectral density from the transmitting non-GSO earth station (see the definition of $e.i.r.p._{non\text{-}GSO\text{-}max}$ in Annex 2).

U3: Maximum number of co-frequency transmitting non-GSO earth stations within a geographic region of the Earth that is likely to be received by a single GSO satellite receive beam (see the definition of N_U in Annex 2).

U4: Assumed maximum and off-axis GSO satellite receive antenna gains (see the definition of $G_{GSO\text{-}SS\text{-}max}$ in Annex 2).

4 Calculation of downlink interference to the GSO networks

For the candidate non-GSO system considered here, System-2, the values of the key parameters necessary for this interference calculation are as follows:

D1: The minimum angular separation of the active transmitting non-GSO satellites from the LoS between the GSO earth station and its associated GSO satellite is never less than 30°.

D2: The maximum pfd at the Earth's surface caused by transmissions from each non-GSO satellite in the constellation is not greater than –140 dB(W/(m^2 · 4 kHz)).

D3: The maximum number of co-frequency non-GSO satellites transmitting towards the same geographic region of the Earth is two. This situation can occur for very short periods of handover between the "setting" and the "rising" non-GSO active satellite (handover occurs typically for a duration of 10 s every 8 or 6 h depending on the number of satellites in the non-GSO satellite system). A duration of 10 s is less than 0.05% of the time.

D4: The assumed maximum and off-axis antenna gains of the GSO receive earth station follow Recommendation ITU-R S.1428.

Using the above values of the key parameters the calculation of worst-case downlink interference from the non-GSO system into any co-frequency GSO network is given in Table 3.

TABLE 3

Example of worst-case (short-term) downlink interference calculation from System-2 into a GSO earth station in the 18 GHz frequency band

Parameter	Units	Value
Maximum pfd of System-2 satellite in 4 kHz	dB(W/(m^2 · 4 kHz))	–140
GSO orbit avoidance angle	degrees	30
Frequency	GHz	18
Maximum GSO Rx earth station gain (5 m)	dBi	57.9
GSO Rx earth station gain towards System-2 satellite	dBi	–7
GSO Rx earth station interfering signal epfd↓ levels in 4 kHz	dB(W/(m^2 · 4 kHz))	–204.9
GSO Rx earth station interfering signal epfd↓ levels in 40 kHz	dB(W/(m^2 · 40 kHz))	**–194.9**
Increase in interference due to two simultaneously visible System-2 satellites	dB	**3**
GSO Rx earth station interfering signal epfd↓ levels in 40 kHz (2 System-2 satellites)	dB(W/(m^2 · 40 kHz))	**–191.9**
RR No. 22.5C	dB(W/(m^2 · 40 kHz))	**–185.4**

The analysis in Table 3 starts with the maximum downlink pfd of the System-2 satellite, as given in data item D2. Then based on the minimum 30° GSO orbit avoidance angle (data item D1), the off-axis gain of the GSO receive earth station antenna which is calculated based on Recommendation ITU-R S.1428 (data item D4) is assumed –7 dBi. The use of the maximum and off-axis antenna gain then allows a simple calculation of the received interfering signal epfd↓ levels, in a 4 kHz bandwidth, from a single System-2 satellite. After allowing for two simultaneously visible System-2 satellites (which is the worst-case, short-term value), and adjusting to a reference bandwidth of 40 kHz, this aggregate interfering signal epfd↓ levels in 40 kHz can be obtained.

In previous sections of this Annex, it has been noted that the above analysis will overestimate the actual interference because the assumed two interfering satellites will not all be located at the minimum separation angle to a given GSO earth station location.

5 Calculation of uplink interference to a GSO FSS network

For the non-GSO system considered here (System-2) the values of the key parameters necessary for this interference calculation are as follows:

U1: The minimum angular separation of the GSO orbit from the LoS between the transmitting non-GSO earth station and its associated non-GSO satellite is never less than 30°.

U2: The maximum off-axis e.i.r.p. spectral density from the transmitting non-GSO earth station is computed from the maximum input PSD (–21 dB(W/4 kHz) in clear sky and –11 dB(W/4 kHz) in rain fades due to the use of uplink power control) and the maximum off-axis gain of the non-GSO transmitting earth station in the direction of the GSO arc. The maximum off-axis gain is assumed to follow Recommendation ITU-R S.1428.

U3: There is a direct relationship between the maximum number of co-frequency transmitting non-GSO earth stations within a geographic region of the Earth that are likely to be received by a single GSO satellite receive beam, and the assumed GSO satellite receive gain towards System-2 earth station (see item U4). When the GSO satellite receive beamwidth is smaller than the non-GSO satellite receive beamwidth (as measured on the surface of the Earth), the maximum number is generally one. Only when the GSO satellite receive beamwidth is greater than the non-GSO satellite beamwidth there will be the possibility of multiple co-frequency emissions from the non-GSO transmitting uplinks. However, in this case the peak gain of the GSO satellite receive beam will be reduced, thereby resulting in less uplink sensitivity and lower levels on non-GSO interference per transmitting non-GSO earth station. Therefore the likely worst-case scenario is a high gain GSO receive spot beam, whose beamwidth (as measured on the surface of the Earth) is significantly less than the beamwidth of the non-GSO satellite receive beam. In the calculation only one co-frequency non-GSO transmitting earth station is to be considered for the uplink interference. However, in order to address the handover situation, the analysis for the worst-case uplink interference actually assumes two such stations.

U4: See comments in data item U3 in relation to the assumed GSO satellite receive antenna gain towards System-2 earth station. The maximum GSO satellite receive antenna gain is also required. To err on the conservative side for the uplink interference calculation this maximum antenna gain is assumed to be equal to the gain towards System-2 earth station.

Using the above values for the key parameters the calculation of worst-case uplink interference from the non-GSO system into any co-frequency GSO network is given in Table 4. This shows two columns for the calculation: one for the clear-sky condition and one for rain conditions where the uplink power control causes the maximum available increase in transmit power to overcome the rain fade. In fact the clear-sky calculation provides the most realistic assessment of the uplink interference situation because, for the rain fade condition, the interfering signal path can also be assumed to be faded by approximately the same amount as the wanted signal path in the System-2. The interference levels shown in the rain condition could only occur if the LoS from the System-2 transmitting earth station to the GSO satellite was unfaded while the LoS to the System-2 satellite was fully faded. Such a condition would be extremely rare, and if it ever existed at all would be of extremely short duration.

TABLE 4

Example of worst-case uplink interference calculation from System-2 transmitting earth station into GSO satellite receiver in the 28 GHz frequency band

Parameter	Value (Clear sky)	Value (Rain)	Units
Maximum PSD into System-2 earth station antenna in 4 kHz	–21	–11	dB(W/4 kHz)
GSO orbit avoidance angle	30	30	degrees
System-2 Tx earth station gain towards GSO satellite	–7	–7	dBi
System-2 Tx earth station e.i.r.p. spectral density towards GSO satellite in 4 kHz	–28	–18	dB(W/4 kHz)
pfd at the GSO satellite in 4 kHz	–190.1	–180.1	dB(W/(m^2 · 4 kHz))
Frequency	28	28	GHz
Assumed gain of GSO satellite Rx towards System-2 earth station	44	44	dBi
Maximum GSO satellite gain	44	44	dBi

TABLE 4 (*end*)

Parameter	**Value (Clear sky)**	**Value (Rain)**	**Units**
GSO satellite Rx interfering signal epfd↑ levels in 4 kHz	–190.1	–180.1	dB(W/(m^2 · 4 kHz))
GSO satellite Rx interfering signal epfd↑ levels in 40 kHz (one System-2 earth station)	**–180.1**	**–170.1**	dB(W/(m^2 · 40 kHz))
GSO satellite Rx interfering signal epfd↑ levels in 40 kHz (two System-2 earth stations)	**–177.1**	**–167.1**	dB(W/(m^2 · 40 kHz))
RR No. 22.5D	**–162**	**–162**	dB(W/(m^2 · 40 kHz))

In Table 4 the calculation methodology is similar to that used for the downlink (Table 3) and described above, but using the data items U1 to U4.

As noted above, the epfd↑ levels produced by this analysis would only be received in the short term (about 10 s every 8 or 6 h depending on the number of satellites in the non-GSO satellite system, or less than 0.05% of the time). The long-term epfd↑ levels would be a minimum of 3 dB less since the non-GSO earth station would only be transmitting to one satellite.