

RECOMMENDATION ITU-R S.1558

Methodologies for measuring $\text{epfd}_{\downarrow}$ caused by a non-geostationary-satellite orbit space station to verify compliance with operational $\text{epfd}_{\downarrow}$ limits

(Question ITU-R 236/4)

(2002)

The ITU Radiocommunication Assembly,

considering

- a) that the World Radiocommunication Conference (Istanbul, 2000) (WRC-2000) adopted a combination of single-entry validation, single-entry operational and, for certain antenna sizes single-entry additional operational equivalent power-flux density $\downarrow$ ($\text{epfd}_{\downarrow}$) limits, all of which are now contained in Article 22 of the Radio Regulations (RR), and also adopted the aggregate limits in Resolution 76 (WRC-2000), which apply to non-geostationary-satellite orbit fixed-satellite service (non-GSO FSS) systems to protect GSO networks in parts of the frequency range 10.7-30 GHz;
- b) that the operational $\text{epfd}_{\downarrow}$ limits were adopted by WRC-2000 to protect operational GSO FSS networks from interference levels which may result in severe degradation in performance;
- c) that operational $\text{epfd}_{\downarrow}$ limits were also adopted by WRC-2000 to protect operational GSO FSS networks employing adaptive coding from interference levels which may result in loss of capacity, which is considered a severe degradation;
- d) that Resolution 137 (WRC-2000) invites the ITU-R to develop, with the aim of completion by 2003, measurement methods which may be used by administrations to verify compliance of an individual non-GSO FSS system with these operational limits;
- e) that, as a consequence of those measurements, a non-GSO system causing interference may have to reduce its $\text{epfd}_{\downarrow}$ power levels towards the affected GSO earth station to meet the single-entry operational $\text{epfd}_{\downarrow}$ limits unless otherwise agreed by the concerned administrations;
- f) that compliance of a non-GSO FSS system with the single-entry operational $\text{epfd}_{\downarrow}$ limits is not subject to verification by the ITU-R;
- g) that the determination of whether a non-GSO FSS system is exceeding the operational $\text{epfd}_{\downarrow}$ limit into an operating GSO earth station would be made by individual administrations and their GSO network operators;
- h) that the worst-case occurrences of events exceeding the operational limits are likely to be of short duration (from a fraction of a second to a few seconds) with a repeat period ranging from several days to weeks, depending on the orbital characteristics of the non-GSO system;
- j) that the loss of synchronization or severe degradation may be used as a trigger for the application of a methodology for checking whether the operational limits are met;

k) that a reliable means of measuring the actual interference corresponding to the $\text{epfd}_{\downarrow}$ produced by a non-GSO FSS system into the operational GSO earth station experiencing interference would assist administrations and operators in determining whether a non-GSO system is exceeding the operational $\text{epfd}_{\downarrow}$ limit;

l) that measurement procedures have inherent accuracy and operational limitations which have to be taken into account during the measurement process,

noting

a) that regulatory procedures are being developed to enable the quick resolution of any proven instance of the operational $\text{epfd}_{\downarrow}$ limits being exceeded;

b) that Recommendation ITU-R S.1527 has been developed enabling the identification of satellites belonging to a particular non-GSO system;

c) that Recommendation ITU-R S.1554 has been developed in order to assess the overall accuracy of $\text{epfd}_{\downarrow}$ measurements,

recommends

1 that the methodologies described in Annex 1 be used by individual administrations and their GSO system operators to determine if non-GSO FSS interference exceeds the operational $\text{epfd}_{\downarrow}$ limits into an operating GSO earth station.

NOTE 1 – Other measurement methods may be identified. In due course it may be appropriate to add such methods to this Recommendation.

ANNEX 1

1 Introduction

This Annex provides methodologies to enable the measurement of the power flux-density (pfd) level emitted from a non-GSO space station incident at the antenna aperture of an operational GSO earth station receiver sharing the same frequency bands. This level can then be compared with operational $\text{epfd}_{\downarrow}$ limits provided in RR Article 22 to determine whether the non-GSO space station is exceeding these limits. These limits should be met in order to comply with RR No. 22.5I and also to protect GSO FSS links from suffering loss of synchronization or degraded performance¹ due to the passage of non-GSO satellites close to or within the main beam of the GSO earth station antenna.

Three methods have been identified, each having advantages and disadvantages. Details of each method are provided in Sections 2, 3 and 4.

One or more of these methods can be invoked if a loss of synchronization or degraded performance occurred at a GSO earth station at an unexpected time (i.e. not obviously caused by a high rain or scintillation fade, a sun outage event, a terrestrial interference source such as radar, or an event caused by equipment failure and/or associated switch-over). The GSO satellite operator would then

¹ This includes protection of GSO FSS systems employing adaptive coding from loss of capacity.

determine, via ephemeris data whether an in-line or near in-line event had occurred at the location of the site incurring the loss of synchronization and communicate the results of the measurement to the non-GSO operator concerned.

It is expected that the occurrence of in-line or near in-line events will be rare and it is essential that either the methods described in Sections 2, 3 and 4 are fully automated or that the time of a repeat occurrence can be accurately determined.

The method in Section 2 is a procedure for identifying that there may be a loss of synchronization or severe degradation problem and that the operational $\text{epfd}_{\downarrow}$ limits may be exceeded. If it is judged that the problem may be due to peak interference from a non-GSO system, Method 2 or 3 may be employed to measure the peak $\text{epfd}_{\downarrow}$ level. Method 1 requires a minimal use of staff and equipment resources.

More detailed methods are presented in Sections 3 and 4. These can either be used as standalone methods of determining the $\text{epfd}_{\downarrow}$ more accurately or as a follow-on procedure from the method in Section 2. None of these methods assume the presence of a dedicated non-GSO pilot signal.

In Section 3 the interference level is measured in frequency bands between adjacent carriers which have suffered loss of synchronization or degraded performance¹. These methods assume that the interfering traffic carrier is sufficiently broadband to include both the affected carrier and the guardband between it and the adjacent carrier, and that the carrier sideband level is sufficiently attenuated to be able to measure the interference power level in the guardband. The method is also valid for the case where multiple carriers, of the non-GSO system in frequency division multiple access (FDMA), span both the affected carrier and the guardband. If the non-GSO carrier is sufficiently broadband or there are multiple non-GSO carriers in FDMA, the effects due to Doppler frequency shift on the non-GSO carrier are minimized. The preferred realization of this approach uses a reference earth station (e.g. a carrier system monitor (CSM) earth station). The key advantage of using the CSM earth station is that it avoids the need to know the gain of the affected earth station receive chain.

Section 4 contains some techniques which make use of auto- and cross-correlation techniques to derive the interference level from a measurement of the non-GSO carrier in the presence of the affected GSO carrier when the non-GSO carrier level is well below the GSO carrier level. The choice of which technique in Section 4 to use depends on the level of the *a priori* knowledge of the non-GSO satellite signal being separately available. These techniques are more complicated for the GSO operator to carry out because they are accomplished at the centre frequency of the GSO carrier.

Calibration is an important factor in assessing the overall accuracy of each of these techniques. Recommendation ITU-R S.1554 includes some information on this matter.

2 Method 1: A rapid technique based on loss of synchronization

The following method is a simplified procedure for identifying a possible exceedance of the operational $\text{epfd}_{\downarrow}$ limits. This technique is sufficient to show that the operational limits may have been exceeded in the case where a loss of synchronization in the operating GSO carrier has

¹ This includes protection of GSO FSS systems employing adaptive coding from loss of capacity.

occurred. More comprehensive measurement procedures may be required to accurately determine the $\text{epfd}_{\downarrow}$ levels generated by the non-GSO system into the operational GSO earth station antenna.

The following steps will lead to a determination of whether the operational limits have been exceeded by a non-GSO system.

Step 1: Record the date and coordinated universal time (UTC) of the loss of synchronization as accurately as possible, as well as the duration of the loss of synchronization under clear sky and nominal operating conditions (see Note 1) (no sun outage, no switch-over, equipment failure etc.).

Step 2: Correlate the time of the loss of synchronization with the presence of the non-GSO satellite close to or within the main beam of the GSO earth station antenna by using the ephemeris data (see Note 2) of the non-GSO and GSO satellite systems.

Step 3: Verify the C/N of the GSO carrier during clear sky conditions and verify the C/N threshold at which loss of synchronization of the demodulator (see Note 3) occurs to ensure that there are not any technical problems with the earth station.

Step 4: Compute the $\text{epfd}_{\downarrow}$ received at the antenna aperture during the synchronization loss in Step 1 using: the link budget of the GSO carrier, the C/N synchronization loss threshold of the receiving demodulator and the G/T of the earth station.

Step 5: Establish the times of subsequent non-GSO satellite passes and go back to Step 1 until the correlation between the event of non-GSO satellite pass close to or through the GSO earth station main beam and a loss of synchronization appears to be confirmed.

Step 6: If there is correlation between the event of a non-GSO satellite pass and a loss of synchronization, and the calculation of the $\text{epfd}_{\downarrow}$ made in Step 4 shows that the non-GSO system is probably exceeding the operational $\text{epfd}_{\downarrow}$ limits, the GSO operator may decide to use a more comprehensive method to determine the $\text{epfd}_{\downarrow}$ levels generated by the non-GSO system into its operational earth station more accurately. The GSO operator may also decide to advise the non-GSO system operator that his system is causing a degradation to the GSO earth station.

This method contains inherent uncertainties not present in the other methods, i.e. uncertainty in the $C/(N+I)$ at which a demodulator loses synchronization for a given bit rate, type of modulation and forward error correction (FEC), uncertainty in the C/N ratio during an in-line event, and variation in C/N threshold, at which loss of synchronization occurs, with the duration of interference peak.

However, when a loss of synchronization is recorded and correlated with ephemeris data, an in-line event can be assumed to have occurred.

NOTE 1 – It will be important to note the weather for the GSO earth station location.

NOTE 2 – It is assumed that the non-GSO ephemeris data is available.

NOTE 3 – This can be done by checking the E_b/N_0 readout of the demodulator.

3 Method 2: $\text{epfd}_{\downarrow}$ measurement technique using a calibrated reference earth station

3.1 Principle of the measurement procedure

The measurement of the $\text{epfd}_{\downarrow}$ at an earth station requires the calibration of the receive earth station receive chain to provide a conversion factor that enables the translation of power measurements taken at an RF or IF point in the receive chain into an $\text{epfd}_{\downarrow}$ value at the receive antenna aperture. The power level measurement is made either in absolute terms or relative to some known reference

level. The latter approach is used in the methods described in Section 3 through the cooperation of a well-calibrated reference earth station. This eliminates the need to know the precise antenna gain and receive chain gain for the earth station under test.

The standard approach for satellite system monitoring involves a power measurement using either a power meter, spectrum analyser or a digital signal processing (DSP) device. The measurements consist of four basic parts:

- gain calibration of the receive signal path;
- non-GSO interference plus noise measurement;
- noise power measurement to determine the earth station noise level;
- fade measurement using GSO beacon or telemetry channel.

Several of these measurements have to be done in rapid succession, before the environment changes. Section 3 describes a preferred realization of this methodology which makes use of a well-calibrated reference earth station.

This measurement procedure requires the cooperation of a well-calibrated GSO FSS earth station that, simultaneously with the affected GSO earth station, can accurately measure the equivalent isotropically radiated power (e.i.r.p.) of the GSO carrier and/or a GSO beacon signal. Most GSO FSS satellite operators have CSM earth stations that measure the e.i.r.p. of each operational carrier to ensure the satellite transponder is operating at its planned input and output back-off point. By accurately calibrating the peak e.i.r.p. of the wanted carrier at the satellite, the e.i.r.p. in the direction of the interfered with GSO earth station can be calculated. This procedure takes advantage of the accurate e.i.r.p. measurements of the CSM by calibrating the e.i.r.p. of the interfered with GSO FSS carrier or a GSO beacon. The GSO beacon could be either one generated on the satellite or an unmodulated carrier inserted between the two carriers by an uplink earth station. If a reference earth station is not available, the affected earth station may be able to incorporate equipment to accurately calibrate the gain of its receive signal path.

The following are the steps which could be undertaken in implementing this procedure:

Step 1: Firstly, the GSO carrier level or beacon signal is monitored and the carrier-to-noise (C_{GSO}/N) level is derived from a measurement of $(C_{GSO} + N)/N$ using a suitable power measuring device (see equation (1)). This measurement can be carried out automatically and preferably shortly before and immediately following a measured burst of non-GSO interference. This level relates to the pfd incident on the antenna from the GSO satellite, which is easily calculated (see equation (2)).

The mathematical relationship between $(I + N)/N$ ratio ($I_{non-GSO} + N)/N$ (dB) and I/N ratio ($I_{non-GSO} + N)/N$ (dB) is given in equation (1):

$$\frac{I_{non-GSO}}{N} = 10 \log \left(10^{0.1 \left(\frac{I_{non-GSO} + N}{N} \right)} - 1 \right) \quad \text{dB}$$

$$\frac{I_{non-GSO} + N}{N} = 10 \log \left(10^{0.1 \left(\frac{I_{non-GSO}}{N} \right)} + 1 \right) \quad \text{dB} \quad (1)$$

$$pfd_{GSO} = E_s - (L_s + L_{abs}) \quad \text{dB(W/m}^2\text{)} \quad (2)$$

where:

pfd_{GSO} : pfd of the received GSO signal at antenna aperture

E_s : GSO satellite e.i.r.p. in the direction of the receiving test antenna (dBW)

L_{abs} : gaseous atmospheric absorption (dB)

L_s : spreading loss, which is calculated using the equation:

$$L_s = 10 \log(4\pi d^2) \quad \text{dB(m}^2\text{)}$$

where d is the distance from test antenna to GSO satellite (m).

Step 2: The second step is to measure the peak non-GSO interference noise level and then subtract the background GSO satellite noise and other noise contributions. The noise level due to the non-GSO interference can then be referenced to the measured level from the GSO satellite carrier or beacon and, as the gains and losses throughout the entire receive chain are the same for both measurements performed sufficiently close together in time and frequency, the non-GSO $epfd_{\downarrow}$ level can then be reliably calculated. The calculation of non-GSO $epfd_{\downarrow}$ from $(I_{non-GSO} + N)/N$ (dB) measurements is given in equation (3). The whole of this process can be automated – this is an essential requirement of such a method in an unmanned station or where multiple measurements have to be taken.

$$epfd_{non-GSO} = pfd_{GSO} + \left(\frac{I_{non-GSO}}{N} - \frac{C_{GSO}}{N} \right) \quad \text{dB(W/(m}^2 \cdot 40 \text{ kHz))} \quad (3)$$

A typical measurement configuration for this technique is shown in Fig. 1.

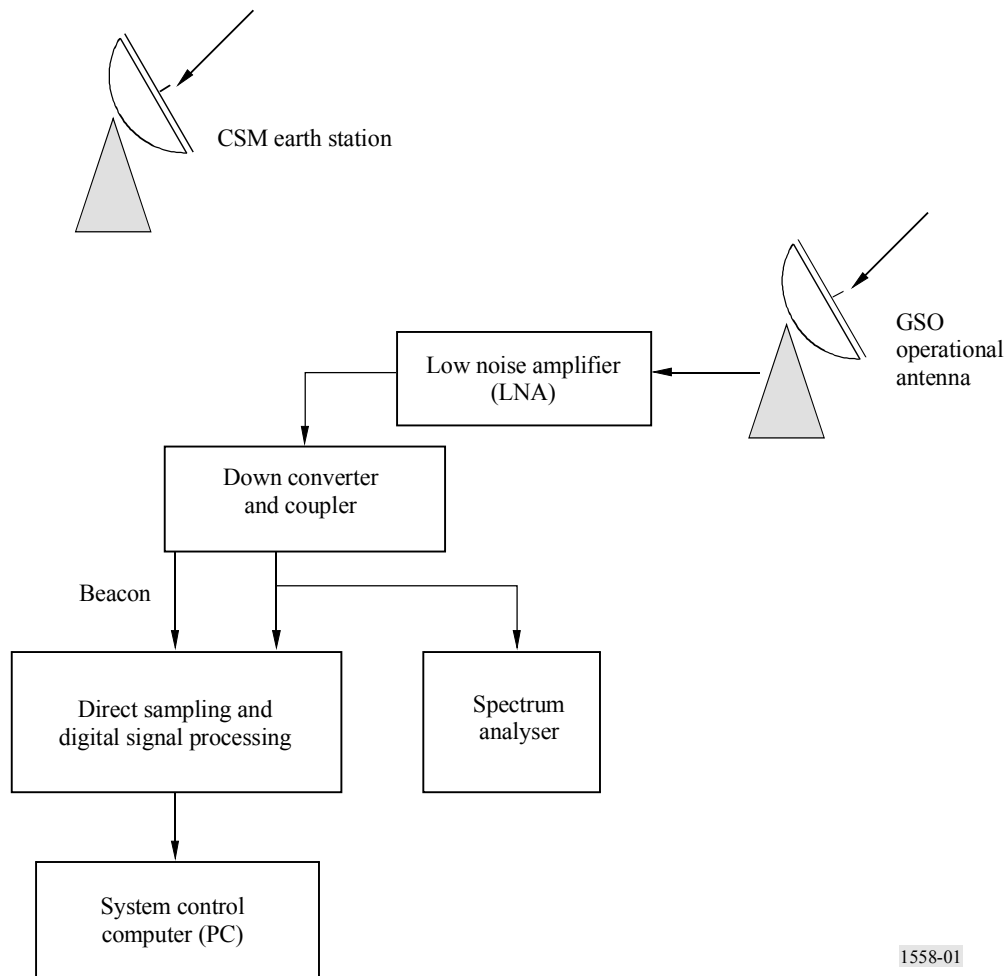
3.2 Noise + interference power measurement

As described above, if a reference (CSM) earth station is available this measurement procedure does not require the absolute measurement of the carrier power but only an accurate $(C + N)/N$ measurement.

This method assumes that the interference level is measured at frequency bands between adjacent GSO carriers which have suffered loss of synchronization. Since the GSO signal cannot be turned off, the bands between carriers provide the next best measurement opportunity after the option of measuring the affected carrier frequency. However, in some cases it may not be possible to measure between the carriers, and the next closest carriers should be used. In this case, inaccuracies due to frequency scaling should be taken into account.

With the approach described in Section 3, the level of $epfd_{\downarrow}$ which can be measured is limited because the interference is assumed to be wideband digital with uniform power spectral density (psd). The only way that the interference could be measured with improved margin above the noise floor and thus with improved accuracy would be for the non-GSO to provide a downlink beacon. This non-GSO beacon would have to be narrow-band and have high power spectral density and be related to the power in a carrier representing the 100% loading situation by some constant value. The trade-off between the gains in improved ease of measurement and accuracy, and the increased complexity in non-GSO satellite design, has not yet been studied. To enable this, the GSO community would have to vacate a 40 kHz (40 kHz is for the 10-11 GHz band and 40 kHz or 1 MHz are for the 20 GHz band) slot and the non-GSO operator would have to design its overall frequency plan to insert the beacon into each downlink beam on every satellite.

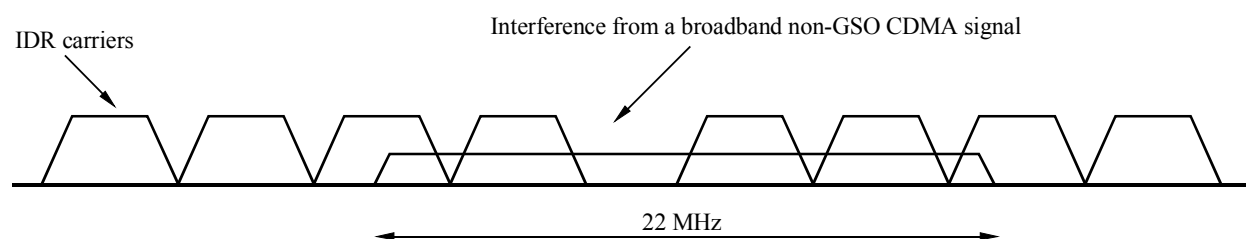
FIGURE 1
Typical measurement configuration



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A typical measurement configuration is shown in Fig. 1. It is assumed that the interfering non-GSO signal is broadband and would cover more than one GSO FSS carrier, as shown in Fig. 2. The power measurements of the carrier plus noise ($C + N$), and noise levels would be taken in a 40 kHz bandwidth in the time period immediately before and after the interference event. These power measurements could be taken with a high quality analogue spectrum analyser or a sophisticated vector/spectrum analyser with a digital sampling system (DSS) as shown in Fig. 1.

FIGURE 2
Typical frequency plan for a 14/11 GHz band transponder loaded with GSO 2 Mbit/s carriers and interference from a broadband non-GSO code division multiple access (CDMA) signal



IDR: intermediate data rate

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Figure 3 shows the power spectrum of two 2 Mbit/s digital carriers as measured by a DSS. The spectrum shown spans across a frequency range of 2 MHz and was taken in between two adjacent digital carriers of 2 MHz each. The guardband between the two carriers is now visible and this area represents the noise floor of the received signal. This Figure shows that a good estimate of the signal power and the noise floor in a 40 kHz bandwidth can be measured within as short a period as 64 ms, which would be required for a 10 m antenna with a beamwidth of a few tenths of a degree.

FIGURE 3
DSS measurements with external noise interference

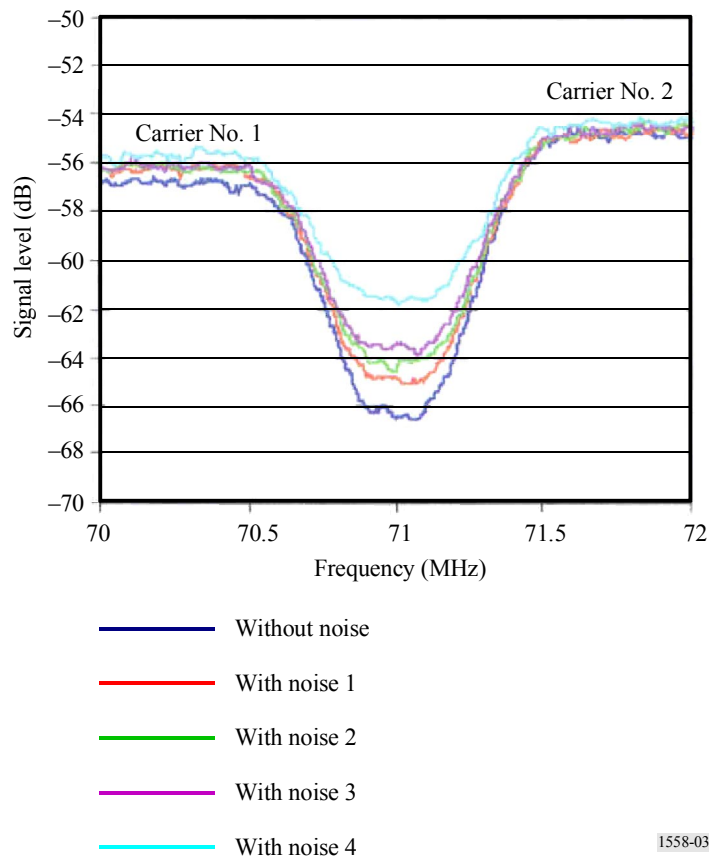


Figure 3 also shows the increase in the power density level between the carriers as the interference adds to the receiver noise. This measurement illustrates how the low level interference signals in an unoccupied area of a satellite transponder would be used to measure the interference. The I/N for the four cases are: -3.9 , -1.6 , 0.0 and 2.8 dB.

3.3 Non-GSO and GSO satellite ephemeris data

An important factor in this measurement procedure is the determination of the predicted non-GSO interference event. The determination of the interference event using the most up-to-date publicly available ephemeris data would be essential to allow accurate $\text{epfd}_{\downarrow}$ measurement of all expected peak levels since the noise and signal levels must be monitored immediately before and after the interference event. A calibration of the receive chain of the affected GSO earth station by the CSM earth station would need to be carried out near in time to the peak interference event. Since most test equipment has limited memory capabilities the measurement window is critical in ensuring the recording time of the measurements will cover the interference event.

Further information on the procedure to correlate the non-GSO in-line or near in-line event with the GSO main beam is given in Recommendation ITU-R S.1527.

3.4 GSO satellite beacon measurement

During the non-GSO $\text{epfd}_{\downarrow}$ measurements, fading or variations in the carrier and noise could occur. To ensure the $\text{epfd}_{\downarrow}$ measurements are carried out under clear-sky conditions, both the interfered with earth station and the CSM earth station would continuously monitor the GSO satellite beacon. If there are several beacons, the closest beacon to the interference frequency would be used. Variations in the level of the beacon could indicate rain or atmospheric affects, satellite or earth station tracking variations, etc. Depending on the cause of the variations and whether they would affect the interference measurement, the measurement may have to be repeated.

3.5 Effect of antenna size on the ability to perform measurements of operational $\text{epfd}_{\downarrow}$ levels

The smaller the GSO earth station antenna, the more difficult it will be to perform the measurement of the interference power relating to the $\text{epfd}_{\downarrow}$ incident on the antenna. This is because the levels of interference power density received from non-GSO FSS systems conforming to the operational limits in the Tables of RR Article 22 are likely to be below the thermal noise floor for the smaller antennas.

Table 1 shows the unwanted I/N ratios which correspond to the operational single entry $\text{epfd}_{\downarrow}$ limits in RR Article 22.

TABLE 1

Operational limits expressed as unwanted I/N which may be measured during an in-line event⁽¹⁾

Frequency band (GHz)	$\text{epfd}_{\downarrow}$ level (not to be exceeded for 100% of the time)	GSO earth station antenna diameter (m) or antenna gain (dBi)	Unwanted interference power density/noise power density ratio ⁽²⁾ (I/N) (dB)
10.7-12.75	-163 dB(W/(m ² · 40 kHz))	3 m	4.4
10.7-12.75	-166 dB(W/(m ² · 40 kHz))	6 m	7.5
10.7-12.75	-167.5 dB(W/(m ² · 40 kHz))	9 m	9.5
10.7-12.75	-169.5 dB(W/(m ² · 40 kHz))	≥ 18 m	≥ 13.5
17.8-18.6	-150 dB(W/(m ² · MHz))	≥ 49 dBi	≥ -3
19.7-20.2	-143 dB(W/(m ² · MHz))	≥ 49 dBi	≥ 3.2
19.7-20.2	-143 dB(W/(m ² · MHz))	43 dBi	-2.8

(1) The limits in Table 1 apply to GSO satellites having orbital inclinations of $\leq 2.5^\circ$.

(2) The actual I/N will be lower due to additional intra-system noise on both the downlink of the wanted GSO and interfering non-GSO satellites which will add to the thermal noise of the reference antenna and its receiver. Digital modulation and an occupied bandwidth at least equal to reference bandwidth on the non-GSO interference has been assumed in all cases. A receiving antenna efficiency of 65% and a receiving system noise temperature of 150 K for the 10.7-12.75 GHz frequency range and 250 K for the 17.8-20.2 GHz frequency range have been assumed in all cases.