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Recommendation ITU-R S.2157-0

(09/2023)

S Series: Fixed-satellite service

Procedures for the evaluation of interference from any non-geostationary-satellite system into a global set of the generic geostationary-satellite reference links in the frequency bands 37.5-39.5 GHz (space-to-Earth), 39.5-42.5 GHz (space-to-Earth), 47.2-50.2 GHz (Earth-to-space) and 50.4-51.4 GHz (Earth-to-space)

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

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SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
TF	Time signals and frequency standards emissions
V	Vocabulary and related subjects

Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R S.2157-0

Procedures for the evaluation of interference from any non-geostationary-satellite system into a global set of the generic geostationary-satellite reference links in the frequency bands 37.5-39.5 GHz (space-to-Earth), 39.5-42.5 GHz (space-to-Earth), 47.2-50.2 GHz (Earth-to-space) and 50.4-51.4 GHz (Earth-to-space)

(2023)

NOTE – Approval of this Recommendation should not be construed that ITU-R expressed any views, directly or indirectly, in favour of any of the Methods included in the CPM Report on WRC-23 agenda item 7, Topic G[1].

Scope

This Recommendation provides procedures for assessment of compliance for any non-*geostationary-satellite orbit (non-*GSO*)* system with No. **22.5L** of the Radio Regulations *(RR)* in order to ensure the protection of *geostationary-satellite orbit (*GSO*)* satellite networks in the frequency bands 37.5-39.5 GHz (space-to-Earth), 39.5-42.5 GHz (space-to-Earth), 47.2-50.2 GHz (Earth-to-space) and 50.4-51.4 GHz (Earth-to-space).

Keywords

Single-entry permissible interference, link performance degradation, adaptive coding and modulation, generic GSO reference links, availability and spectral efficiency, precipitation fade

Abbreviations/Glossary

ACM Adaptive coding and modulation

CDF Cumulative distribution function

EPFD Equivalent power flux-density

PDF Probability density function

Related ITU Recommendations, Reports

Recommendation ITU-R P.618 – Propagation data and prediction methods required for the design of Earth-space telecommunication systems

Recommendation ITU-R S.1503 – Functional description to be used in developing software tools for determining conformity of non-geostationary-satellite orbit fixed-satellite service systems or networks with limits contained in Article 22 of the Radio Regulations

Recommendation ITU-R S.2131 – Method for the determination of performance objectives for satellite hypothetical reference digital paths using adaptive coding and modulation

The ITU Radiocommunication Assembly,

considering

a) that geostationary-satellite orbit (GSO) and non-geostationary-satellite orbit (non-GSO) fixed-satellite service (FSS) networks may operate in the frequency bands 37.5-39.5 GHz (space-to-Earth), 39.5-42.5 GHz (space-to-Earth), 47.2-50.2 GHz (Earth-to-space) and 50.4-51.4 GHz (Earth-to-space);

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[1] *Note by the Secretariat:* This Note will be removed after WRC-23.

b) that WRC-19 has adopted Nos. **22.5L** and **22.5M**, which contain single-entry and aggregate limits for non-GSO FSS systems in the frequency bands 37.5-39.5 GHz (space-to-Earth), 39.5-42.5 GHz (space-to-Earth), 47.2-50.2 GHz (Earth-to-space) and 50.4-51.4 GHz (Earth-to-space) to protect GSO networks operating in the same frequency bands,

recognizing

a) that the ITU Radiocommunication Sector (ITU-R) has developed a methodology, contained in Recommendation ITU-R S.1503, that results in the equivalent power flux-density (epfd) generated by any non-GSO FSS system considered;

b) that, in accordance with calculations utilizing Recommendation ITU-R S.1503, verification of the worldwide epfd interference of any non-GSO system can be carried out by a set of generic GSO reference link budgets having characteristics that encompass global GSO network deployments that are independent of any specific geographic locations;

c) that Resolution **769 (WRC-19)** addresses the protection of GSO networks from aggregate emissions from non-GSO systems,

recommends

that the procedures specified in Annexes 1 and 2 should be considered to assess compliance for any non-GSO system with No. **22.5L** of the Radio Regulations in order to ensure the protection of GSO satellite networks in the frequency bands 37.5-39.5 GHz (space-to-Earth), 39.5-42.5 GHz (space-to-Earth), 47.2-50.2 GHz (Earth-to-space) and 50.4-51.4 GHz (Earth-to-space).

Annex 1

Procedure for use by the Bureau in checking compliance of non-GSO FSS systems with No. 22.5L of the Radio Regulations in the frequency bands 37.5-39.5 GHz (space-to Earth), 39.5-42.5 GHz (space-to-Earth), 47.2-50.2 GHz (Earth-to-space) and 50.4-51.4 GHz (Earth-to-space)

This Annex provides an overview of the process to validate compliance with the single-entry permissible interference of a non-GSO satellite system into GSO satellite networks using the generic GSO reference link parameters in Annex 1 to Resolution **770 (WRC-19)** and the interference impact using the latest version of Recommendation ITU-R S.1503. The procedure to determine compliance with the single-entry permissible interference relies on the following principles.

Principle 1: The two time-varying sources of link performance degradation considered in the verification are link fading (from rain) using the characteristics of the generic GSO reference link described in Resolution **770 (WRC-19)** and interference from a non-GSO system. The total *C*/*N* in the reference bandwidth for a given carrier is:

$$C/N = C/(N_T + I) \quad (1)$$

where:

- C : wanted signal power (W) in the reference bandwidth, which varies as a function of fades and also as a function of transmission configuration
- N : noise power (W) in the reference bandwidth

N_T : total system noise power (W) in the reference bandwidth

I : time-varying interference power (W) in the reference bandwidth generated by other networks.

Principle 2: The calculation of spectral efficiency is focused on satellite systems utilizing adaptive coding and modulation (ACM) by calculating the throughput degradation as a function of C/N, which varies depending on the propagation and interference impacts on the satellite link over the long term.

Principle 3: During a fading event in the downlink direction the interfering carrier would be attenuated by the same amount as the wanted carrier under the assumption of co-polarized carriers. This principle results in slight underestimation of the impact of the downlink interference.

Implementation of verification algorithm

The generic GSO reference link parameters described in Annex 1 to Resolution **770 (WRC-19)** should be used as described in the following algorithm to determine if a non-GSO FSS network is compliant with No. **22.5L** of the Radio Regulations.

Within the parametric analysis there are a range of values for each of the following parameters in section 2 of Tables 1 and 2 in Annex 1 to Resolution **770 (WRC-19)**:

– e.i.r.p. density variation
– elevation angle (degrees)
– rain height (m)
– latitude (degree)
– 0.01% rain rate (mm/hr)
– height of Earth station (m)
– Earth station noise temperature (K) or satellite noise temperature (K), as appropriate.

A set of generic GSO reference links should be created using one per service case identified in section 1 of Tables 1 and 2 in Annex 1 to Resolution **770 (WRC-19)**, and one value from each of the parametric analysis parameters in section 2 of Tables 1 and 2. Then, with this set of generic GSO reference links, the following process should be undertaken:

The frequency that should be used in the following steps except for step 2 are 37.5 GHz for the space to Earth direction and 47.2 GHz in the Earth to space direction. The frequency f_{GHz}, that should be used in step 2 is determined by applying the methodology in Recommendation ITU-R S.1503 to the non-GSO system filed frequencies and the frequency bands for which No. ***22.5L*** *of the Radio Regulations applies*

For each of the generic GSO reference links

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Step 0: Determine if this generic GSO reference link is valid and select the appropriate threshold.

If the generic GSO reference link is valid, then

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Step 1: Derive the probability density function (PDF) of the rain fade to use in the convolution

Step 2: Recommendation ITU-R S.1503 should be used to derive the PDF of the EPFD from the non-GSO FSS system

Step 3: Perform a modified convolution (space-to-Earth) or convolution (Earth-to-space) with the PDF of the rain fade and the PDF of the EPFD. This convolution yields a PDF of C/N and C/(N_T+I)

Step 4: Use the C/N and C/(N_T+I) PDFs to determine compliance with No. ***22.5L*** *of the Radio Regulations*

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If the non-GSO system under examination is found to comply with No. ***22.5L*** *of the Radio Regulations with respect to all generic GSO reference links, then the result of the evaluation is favourable finding otherwise it is an unfavourable finding.*

Each of these steps are described further in Attachments 1 and 2 to this Annex for the space-to-Earth and Earth-to-space procedures, respectively.

Attachment 1
to Annex 1

Steps to be applied in the space-to-Earth direction in the frequency bands 37.5-39.5 GHz and 39.5-42.5 GHz to determine compliance with No. 22.5L of the Radio Regulations

By applying the following steps, the single-entry interference impact from a non-GSO system on the availability and spectral efficiency of a generic GSO reference link is determined. The generic GSO reference link parameters of Annex 1 to Resolution **770 (WRC-19)** are used, considering all possible parametric permutations, in conjunction with the worst-case geometry (WCG) epfd output of the latest version of Recommendation ITU-R S.1503. The output of Recommendation ITU-R S.1503 is a set of interference statistics that a non-GSO system creates. These interference statistics are then used to determine the effect of the interference into each generic GSO reference link.

Step 0: Verification of the generic GSO reference link and selection of *C/N* threshold

The following steps should be used to determine if the generic GSO reference link is valid and if so, which of the thresholds $\left(\frac{C}{N}\right)_{Thr,i}$ should be used. It is assumed that R_s = 6 378.137 km, R_{geo} = 42 164 km, k_{dB} = −228.6 dB(J/K) and $c = 2.99792458 \times 10^5$ km/s.

Note that the term "cumulative distribution function" is meant to include the concept of the complementary cumulative distribution function depending upon context.

1) Calculate the peak gain of the Earth station antenna in dBi using:

for $20 \leq D/\lambda \leq 100$

$$G_{max} = 20 \log \left(\frac{D}{\lambda}\right) + 7.7 \qquad \text{dBi}$$

for $D/\lambda > 100$

$$G_{max} = 20 \log \left(\frac{D}{\lambda} \right) + 8.4 \qquad \text{dBi}$$

2) Calculate the slant distance in km using:

$$d_{km} = R_s \left(\sqrt{\frac{R_{geo}^2}{R_s^2} - \cos^2(\varepsilon)} - \sin(\varepsilon) \right)$$

3) Calculate the free-space path loss in dB using:

$$L_{fs} = 92.45 + 20\log(f_{GHz}) + 20\log(d_{km})$$

4) Calculate the wanted signal power in the reference bandwidth in dBW accounting for additional link losses:

$$C = eirp + \Delta eirp - L_{fs} + G_{max} - L_o$$

5) Calculate the total noise power in the reference bandwidth in dBW/MHz using:

$$N_T = 10\log(T \cdot B_{MHz} \cdot 10^6) + k_{dB} + M_{ointra} + M_{ointer}$$

6) For each threshold $(C/N)_{Thr,i}$, derive the margin available for precipitation for that case in dB:

$$A_{rain,i} = C - N_T - \left(\frac{C}{N} \right)_{Thr,i}$$

7) If for each threshold $(C/N)_{Thr,i}$ the margin $A_{rain,i} \leq A_{min}$, then this generic GSO reference link is not valid.

8) For each of the thresholds $(C/N)_{Thr,i}$ for which $A_{rain,i} > A_{min}$, undertake step 9.

9) Using the precipitation model in Annex 2 to this Recommendation together with the selected rain rate, Earth station height, rain height, Earth station latitude, elevation angle, frequency, calculated rain fade margin and an assumed polarization of vertical, calculate the associated percentage of time, $p_{rain,i}$.

10) If for each threshold $(C/N)_{Thr,i}$ the associated percentage of time is not within the range:

$$0.01\% \leq P_{rain,i} \leq 10\%$$

then this generic GSO reference link is not valid.

11) If at least one threshold meets the criteria in steps 7 and 10, then the lowest threshold, $(C/N)_{Thr}$ that meets these criteria is used in the analysis.

NOTE – A_{min} is 3 dB.

Step 1: Generation of precipitation fade PDF

The precipitation fade PDF should be generated using Annex 2 to this Recommendation from the selected rain rate, Earth station height, Earth station latitude, rain height, elevation angle, frequency (summarized in Table 2 of Annex 2) and an assumed polarization of vertical as follows:

1) Calculate the maximum fade depth $A_{rain}(p)$ using $p = p_{min}$, noting that p_{min} is provided in Annex 2.

2) Create a set of N bins of 0.1 width bins of precipitation fade A_{rain} between 0 dB and round to one digit to the right of the decimal point of $(A_{rain}(p_{min})) + 0.1$ dB.

3) For each of the bins, determine the associate probability p to create a cumulative distribution function (CDF) of A_{rain}

$$CDF_n = Probability\ that\ A_{rain} \geq \big((n-1) * 0.1\big)dB \qquad for\ n < N$$

$$CDF_n = 0\% \qquad for\ n = N$$

with n = 1, 2, 3, …N.

4) For each of the bins, convert this CDF into a PDF of A_{rain}

$$PDF_n = \frac{CDF_n - CDF_{n+1}}{100} \qquad for\ n < N$$

$$PDF_n = 0\% \quad for\ n = N$$

with: $\sum_{n=1}^{N} PDF_n = 1$

A bin size of 0.1 dB should be used to ensure consistency with the output from Recommendation ITU-R S.1503. Each bin of the CDF contains the probability that the precipitation fade is at least A_{rain} dB. Each bin of the PDF contains the probability that the precipitation fade is between A_{rain} and A_{rain} + 0.1 dB.

Step 2: Generation of epfd PDF

Recommendation ITU-R S.1503 should be used to determine the epfd CDF from the non-GSO FSS parameters and the frequency, dish size and Earth station antenna gain pattern. The epfd CDF will be calculated at the worst-case geometry from Recommendation ITU-R S.1503. The epfd CDF will be composed of N bins spaced by 0.1 dB.

The epfd CDF should then be converted into a PDF as follows:

1) Ensure than the percentage of time of the first bins of the epfd CDF is 100% and the last bins is 0%

2) For each of the bins, convert this CDF into a PDF of epfd

$$PDF_n = \frac{CDF_n - CDF_{n+1}}{100} \qquad for\ n < N$$

$$PDF_n = 0 \quad for\ n = N$$

with: $\sum_{n=1}^{N} PDF_n = 1$

Each bin of the epfd CDF contains the probability that the epfd is at least X dB W/m^2 in the reference bandwidth. Each bin of the PDF contains the probability that the epfd is between X and X + 0.1 dB.

Step 3: Creation of *C*/*N* and *C*/(*N*+*I*) CDFs by modified convolution of precipitation fade PDF with epfd PDF

For the selected generic GSO reference link, the C/N and $C/(N+I)$ PDFs should be generated using the following steps to undertake the modified discrete convolution:

Initialize the C/N and C/(N+I) distributions with bin size of 0.1 dB

Calculate the effective area of an isotropic antenna at wavelength λ using:

$$A_{ISO} = 10\log\left(\frac{\lambda^2}{4\pi}\right)$$

Calculate the wanted signal power accounting for additional link losses and antenna gain at edge of coverage:

$$C = eirp + \Delta eirp - L_{fs} + G_{max} - L_o$$

Calculate the system noise power using:

$$N_T = 10\log(T \cdot B_{MHz} \cdot 10^6) + k_{dB} + M_{ointra}$$

For each value A_{rain} in the precipitation fade PDF

{

Calculate the faded wanted signal power using:

$$C_f = C - A_{rain}$$

Calculate the C/N using:

$$\frac{C}{N} = C_f - N_T$$

Update the C/N distribution with this C/N and the probability associated with this A_{rain}

For each value EPFD in the EPFD PDF

{

Calculate the interference from the EPFD taking into account the precipitation fading using:

$$I = EPFD + G_{peak} + A_{iso} - A_{rain}$$

Calculate the noise plus interference using:

$$(N_T + I) = 10\log\left(10^{N_T/10} + 10^{I/10}\right)$$

Calculate the C/(N+I) using:

$$\frac{C}{N+I} = C_f - (N_T + I)$$

Identify the relevant C/(N+I) bin for this C/(N+I) value

Increment this bin's probability with the product of the probabilities of this precipitation fade and EPFD

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Step 4: Use of *C/N* and *C/(N+I)* distributions with the criteria in No. 22.5L of the Radio Regulations

The *C/N* and *C/(N+I)* distributions should then be used to check against the availability and spectral efficiency criteria in No. **22.5L** of the Radio Regulations as follows:

Step 4A: Check on unavailability increase

Using the selected threshold $\left(\frac{C}{N}\right)_{Thr}$ for the generic GSO reference link, determine the following:

U_R = Sum of the probabilities from all bins for which $C/N < \left(\frac{C}{N}\right)_{Thr}$

U_{RI} = Sum of the probabilities from all bins for which $C/(N+I) < \left(\frac{C}{N}\right)_{Thr}$

Then the condition to be verified for compliance is:

$$U_{RI} \leq 1.03 \times U_R$$

Step 4B: Check on the time-weighted average spectral efficiency decrease

Determine the long-term time-weighted average spectral efficiency, SE_R, assuming precipitation only by:

Set $SE_R = 0$

For all bins in the C/N PDF above the threshold $\left(\frac{C}{N}\right)_{Thr}$

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Equation (3) in Annex to Recommendation ITU-R S.2131-1 should be used to convert the C/N to a spectral efficiency

Increment SE_R *by the spectral efficiency multiplied by the probability associated with this C/N*

}

Determine the long-term time-weighted average spectral efficiency, SE_{RI}, assuming precipitation and interference by:

Set $SE_{RI} = 0$

For all bins in the C/(N+I) PDF above the threshold $\left(\frac{C}{N}\right)_{Thr}$

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Equation (3) of Annex to Recommendation ITU-R S.2131-1 should be used to convert the C/(N+I) to a spectral efficiency

Increment SE_{RI} *by the spectral efficiency multiplied by the probability associated with this C/(N+I)*

}

Then the condition to be verified for compliance is:

$$SE_{RI} \geq SE_R * (1 - 0.03)$$

Attachment 2
to Annex 1

Algorithm steps to be applied in the Earth-to-space direction in the frequency bands 47.2-50.2 GHz and 50.4-51.4 GHz to determine compliance with No. 22.5L of the Radio Regulations

By applying the following steps, the single-entry interference impact from a non-GSO system on the availability and spectral efficiency of a generic GSO reference link is determined. The generic GSO reference link parameters of Annex 1 to Resolution **770 (WRC-19)** are used, considering all possible parametric permutations, in conjunction with the worst-case geometry (“WCG”) epfd output of the latest version of Recommendation ITU-R S.1503. The output of Recommendation ITU-R S.1503 is a set of interference statistics that a non-GSO system creates. These interference statistics are then used to determine the effect of the interference into each generic GSO reference link.

Step 0: Verification of the generic GSO reference link and selection of *C*/*N* threshold

The following steps should be used to determine if the generic GSO reference link is valid and if so, which of the thresholds $\left(\frac{C}{N}\right)_{Thr,i}$ should be used. It is assumed that R_s = 6 378.137 km, R_{geo} = 42 164 km, k_{dB} = −228.6 dB(J/K) and $c = 2.99792458 \times 10^5$ km/s.

Note that the term cumulative distribution function is meant to include the concept of the complementary cumulative distribution function depending upon context.

1) Calculate the slant distance in km using:

$$d_{km} = R_s\left(\sqrt{\frac{R_{geo}^2}{R_s^2} - \cos^2(\varepsilon)} - \sin(\varepsilon)\right)$$

2) Calculate the free-space path loss in dB using:

$$L_{fs} = 92.45 + 20\log(f_{GHz}) + 20\log(d_{km})$$

3) Calculate the wanted signal power in the reference bandwidth in dBW accounting for additional link losses and antenna gain at edge of coverage:

$$C = eirp + \Delta eirp - L_{fs} + G_{max} - L_o + G_{rel}$$

4) Calculate the total noise power in the reference bandwidth in dBW/MHz using:

$$N_T = 10\log(T \cdot B_{MHz} \cdot 10^6) + k_{dB} + M_{ointra} + M_{ointer}$$

5) For each threshold $(C/N)_{Thr,i}$, derive the precipitation margin for that case in dB:

$$A_{rain,i} = C - N_T - \left(\frac{C}{N}\right)_{Thr,i}$$

6) If for each threshold $(C/N)_{Thr,i}$ the margin $A_{rain,i} \le A_{min}$, then this generic GSO reference link is not valid.

7) For each of the thresholds $(C/N)_{Thr,i}$ for which $A_{rain,i} > A_{min}$, undertake step 8.

8) Using the precipitation model in Annex 2 together with the selected rain rate, Earth station height, rain height, Earth station latitude, elevation angle, frequency, calculated precipitation fade margin and an assumed polarization of vertical, calculate the associated percentage of time, $p_{rain,i}$.

9) If for each threshold $(C/N)_{Thr,i}$ the associated percentage of time is not within the range:

$$0.01\% \le p_{rain,i} \le 10\%$$

then this generic GSO reference link is not valid.

10) If at least one threshold meets the criteria in steps 6 and 9, then the lowest threshold, $(C/N)_{Thr}$ that meets these criteria should be used in the analysis.

NOTE – A_{min} is 3 dB and the antenna gain relative to peak towards the Earth station, G_{rel} = −3 dB.

Step 1: Generation of precipitation fade PDF

The precipitation fade PDF should be generated using Annex 2 to this Recommendation from the selected rain rate, Earth station height, Earth station latitude, rain height, elevation angle, frequency and an assumed polarization of vertical as follows:

1) Calculate the maximum fade depth $A_{rain}(p)$ using $p = p_{min}$, noting that p_{min} is provided in Annex 2.

2) Create a set of *N* bins of 0.1 dB width between 0 dB and round to one digit to the right of the decimal point of $(A_{rain}(p_{min}))$ + 0.1 dB.

3) For each of the bins, determine the associate probability p to create a cumulative distribution function (CDF) of A_{rain}

$$CDF_n = Probability\ that\ A_{rain} \geq \left((n-1) * 0.1\right) dB \qquad for\ n < N$$

$$CDF_n = 0\% \qquad for\ n = N$$

with n = 1, 2, 3, …N.

4) For each of the bins, convert this CDF into a PDF of A_{rain}

$$PDF_n = CDF_n - CDF_{n+1} \qquad for\ n < N$$

$$PDF_n = 0\% \quad for\ n = N$$

with: $\sum_{n=1}^{N} PDF_n = 100\%$

A bin size of 0.1 dB should be used to ensure consistency with the output from Recommendation ITU-R S.1503. Each bin of the CDF contains the probability that the precipitation fade is at least A_{rain} dB. Each bin of the PDF contains the probability that the precipitation fade is between A_{rain} and A_{rain} + 0.1 dB.

Step 2: Generation of epfd PDF

Recommendation ITU-R S.1503 should be used to determine the epfd CDF from the non-GSO FSS parameters and the frequency, dish size and Earth station antenna gain pattern. The epfd CDF will be calculated at the worst-case geometry from Recommendation ITU-R S.1503.

The epfd CDF should then be converted into a PDF.

Step 3: Creation of *C*/*N* and *C*/(*N*+*I*) CDFs by convolution of precipitation fade PDF with epfd PDF

For the selected generic GSO reference link, the *C*/*N* and *C*/(*N*+*I*) PDFs should be generated using the following steps to undertake the discrete convolution:

Initialize the C/N and C/(N+I) distributions with bin size of 0.1 dB

Calculate the effective area of an isotropic antenna at wavelength λ using:

$$A_{ISO} = 10 \log\left(\frac{\lambda^2}{4\pi}\right)$$

Calculate the wanted signal power accounting for additional link losses and antenna gain at edge of coverage:

$$C = eirp + \Delta eirp - L_{fs} + G_{max} - L_o + G_{rel}$$

Calculate the system noise power using:

$$N_T = 10 \log(T \cdot B_{MHz} \cdot 10^6) + k_{dB} + M_{ointra}$$

For each value A_{rain} in the precipitation fade PDF

{

Calculate the faded wanted signal power using:

$$C_f = C - A_{rain}$$

Calculate the C/N using:

$$\frac{C}{N} = C_f - N_T$$

Update the C/N distribution with this C/N and the probability associated with this A_{rain}

For each value EPFD in the EPFD PDF

{

Calculate the interference from the EPFD:

$$I = EPFD + G_{peak} + A_{iso}$$

Calculate the noise plus interference using:

$$(N_T + I) = 10\log\left(10^{N_T/10} + 10^{I/10}\right)$$

Calculate the C/(N+I) using:

$$\frac{C}{N+I} = C_f - (N_T + I)$$

Identify the relevant C/(N+I) bin for this C/(N+I) value

Increment this bin's probability with the product of the probabilities of this precipitation fade and EPFD

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Step 4: Use of *C/N* and *C*/(*N*+*I*) distributions with the criteria in No. 22.5L of the Radio Regulations

The *C/N* and *C/(N+I*) distributions should then be used to check against the availability and spectral efficiency criteria in No. **22.5L** of the Radio Regulations as follows:

Step 4A: Check on unavailability increase

Using the selected threshold $\left(\frac{C}{N}\right)_{Thr}$ for the generic GSO reference link, determine the following:

U_R = Sum of the probabilities from all bins for which $C/N < \left(\frac{C}{N}\right)_{Thr}$

U_{RI} = Sum of the probabilities from all bins for which $C/(N+I) < \left(\frac{C}{N}\right)_{Thr}$

Then the conditions to be verified for compliance are:

$$U_{RI} \leq 1.03 \times U_R$$

Step 4B: Check on the time-weighted average spectral efficiency decrease

Determine the long-term time-weighted average spectral efficiency, SE_R, assuming precipitation only by:

Set $SE_R = 0$

For all bins in the C/N PDF above the threshold $\left(\frac{C}{N}\right)_{Thr}$

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Equation (3) in Annex to Recommendation ITU-R S.2131-1 should be used to convert the C/N to a spectral efficiency

Increment SE_R *by the spectral efficiency multiplied by the probability associated with this C/N*

}

Determine the long-term time-weighted average spectral efficiency, SE_{RI}, assuming precipitation and interference by:

Set $SE_{RI} = 0$

For all bins in the C/(N+I) PDF above the threshold $\left(\frac{C}{N}\right)_{Thr}$

{

Equation (3) in Annex to Recommendation ITU-R S.2131-1 should be used to convert the C/(N+I) to a spectral efficiency

Increment SE_{RI} *by the spectral efficiency multiplied by the probability associated with this C/(N+I)*

}

Then the conditions to be verified for compliance are:

$$SE_{RI} \geq SE_R * (1 - 0.03)$$

Annex 2

Calculation of precipitation fade statistics

The long-term statistics of the precipitation fade to be used are provided by the following equation:

$$\begin{array}{cc} A_{rain}(p_{min}) & \text{for } 0\% \leq p \leq p_{min} \\ A_{rain}(p) & \text{for } p_{min} < p \leq p_1 \\ A_{rain}(p_1)(\log_{10}(p) - 1)/(\log_{10}(p_1) - 1) & p_1 < p \leq p_{max} \\ 0 \text{ dB} & p_{max} < p \leq 100\% \end{array}$$

where p_{max} is the probability of rain fade higher than 0 dB (see parameter of 2.9 in Tables 1 and 2 in Annex 1 to Resolution **770 (WRC-19)**); $A_{rain}(p)$ is calculated using § 2.2.1.1 of Recommendation ITU-R P.618-13; and p_1 and p_{min} are provided in Table 1 for the GSO space-to-Earth direction (*F* = 37.5 GHz), in Table 2 for the GSO Earth-to-space direction (*F* = 47.2 GHz) and the rain index and the associated rain conditions for both directions are provided in Table 3.

TABLE 1

p_1 and p_{min} to be used for the space-to-Earth direction (downlink)

Index	P_1 (%)	p_{min} (%)	Index	P_1 (%)		p_{min} (%)	Index	P_1 (%)	p_{min} (%)	Index	P_1 (%)	p_{min} (%)
1	2.4116	0.002233	15	2.27683		0.001509	29	2.5255	0.001016	43	2.1999	0.001004
2	2.43056	0.002184	16	2.132474		0.002155	30	2.5531	0.001021	44	2.22281	0.001006
3	2.45185	0.002007	17	2.15401		0.002046	31	2.24996	0.002127	45	2.24985	0.001
4	2.17104	0.004299	18	2.17912		0.001918	32	2.26854	0.002023	46	2.53394	0.001595
5	2.1888	0.004098	19	2.62353		0.001001	33	2.28952	0.001914	47	2.5582	0.001529
6	2.20875	0.003859	20	2.692		0.001006	34	2.14671	0.002772	48	2.58521	0.001417
7	2.072122	0.005539	21	2.8211		0.001015	35	2.16454	0.002648	49	2.20414	0.003914
8	2.08942	0.005269	22	2.37672		0.001007	36	2.184672	0.002505	50	2.22922	0.003662
9	2.10884	0.005003	23	2.43951		0.001006	37	2.56214	0.001013	51	2.25721	0.003423
10	2.46476	0.001003	24	2.5431		0.001004	38	2.59324	0.001005	52	2.05972	0.005707
11	2.48883	0.001012	25	2.276		0.001	39	2.62902	0.001013	53	2.08493	0.005346
12	2.5169	0.001008	26	2.33666		0.001003	40	2.30243	0.001005	54	2.113093	0.004968
13	2.22858	0.001696	27	2.43675		0.001007	41	2.3264	0.001			
14	2.25085	0.001597	28	2.50513		0.001055	42	2.35466	0.001008			

TABLE 2

p_1 and p_{min} to be used for the Earth-to-space direction (uplink)

Index	P_1 (%)	p_{min} (%)	Index	P_1 (%)	p_{min} (%)	Index	P_1 (%)	p_{min} (%)	Index	P_1 (%)	p_{min} (%)
1	2.33455	0.002786	15	2.20921	0.001796	29	2.44635	0.001235	43	2.131202	0.001002
2	2.35384	0.002625	16	2.066286	0.002558	30	2.4716	0.001185	44	2.155341	0.001001
3	2.37551	0.002469	17	2.08869	0.002422	31	2.1799	0.002555	45	2.183783	0.001003
4	2.1054	0.005082	18	2.1148	0.002274	32	2.199252	0.002421	46	2.4509	0.002042
5	2.123611	0.004846	19	2.54793	0.00101	33	2.22109	0.002291	47	2.47605	0.001865
6	2.144072	0.004584	20	2.6164	0.001009	34	2.07934	0.003305	48	2.50405	0.001724
7	2.010594	0.006442	21	2.7466	0.001009	35	2.098044	0.003155	49	2.13059	0.004723
8	2.0284	0.006179	22	2.3119	0.001003	36	2.119153	0.002987	50	2.15691	0.004433
9	2.048392	0.005855	23	2.3766	0.001002	37	2.47937	0.001004	51	2.18624	0.004149
10	2.38588	0.001116	24	2.48305	0.001007	38	2.5116	0.00101	52	1.988883	0.00683
11	2.4105	0.001048	25	2.21479	0.001002	39	2.5486	0.001013	53	2.01554	0.006349
12	2.4392	0.001007	26	2.27762	0.001005	40	2.23144	0.001003	54	2.045274	0.005903
13	2.159292	0.002035	27	2.38105	0.001003	41	2.25648	0.001006			
14	2.18234	0.001915	28	2.42572	0.001315	42	2.28598	0.001003			

TABLE 3

Rain index and corresponding rain conditions

Rain index	ε	h_{rain}	Lat	$R_{0.01}$	h_{ES}	Rain index	ε	h_{rain}	Lat	$R_{0.01}$	h_{ES}
1	20	5 000	0	10	0	28	55	5 000	0	10	0
2	20	5 000	0	10	500	29	55	5 000	0	10	500
3	20	5 000	0	10	1 000	30	55	5 000	0	10	1 000
4	20	5 000	0	50	0	31	55	5 000	0	50	0
5	20	5 000	0	50	500	32	55	5 000	0	50	500
6	20	5 000	0	50	1 000	33	55	5 000	0	50	1 000
7	20	5 000	0	100	0	34	55	5 000	0	100	0
8	20	5 000	0	100	500	35	55	5 000	0	100	500
9	20	5 000	0	100	1 000	36	55	5 000	0	100	1 000
10	20	3 950	30	10	0	37	55	3 950	30	10	0
11	20	3 950	30	10	500	38	55	3 950	30	10	500
12	20	3 950	30	10	1 000	39	55	3 950	30	10	1 000
13	20	3 950	30	50	0	40	55	3 950	30	50	0
14	20	3 950	30	50	500	41	55	3 950	30	50	500
15	20	3 950	30	50	1 000	42	55	3 950	30	50	1 000
16	20	3 950	30	100	0	43	55	3 950	30	100	0
17	20	3 950	30	100	500	44	55	3 950	30	100	500
18	20	3 950	30	100	1 000	45	55	3 950	30	100	1 000
19	20	1 650	61.8	10	0	46	90	5 000	0	10	0
20	20	1 650	61.8	10	500	47	90	5 000	0	10	500
21	20	1 650	61.8	10	1 000	48	90	5 000	0	10	1 000
22	20	1 650	61.8	50	0	49	90	5 000	0	50	0
23	20	1 650	61.8	50	500	50	90	5 000	0	50	500
24	20	1 650	61.8	50	1 000	51	90	5 000	0	50	1 000
25	20	1 650	61.8	100	0	52	90	5 000	0	100	0
26	20	1 650	61.8	100	500	53	90	5 000	0	100	500
27	20	1 650	61.8	100	1 000	54	90	5 000	0	100	1 000