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Recommendation ITU-R S.2158-0

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S Series: Fixed-satellite service

Methodology for examining the compliance of an aeronautical earth station in motion communicating with geostationary space stations in the fixed-satellite service in the 27.5-29.5 GHz band with a set of pre-established pfd limits on the Earth's surface

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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.2158-0

Methodology for examining the compliance of an aeronautical earth station in motion communicating with geostationary space stations in the fixed-satellite service in the 27.5-29.5 GHz band with a set of pre-established pfd limits on the Earth's surface

(2023)

Scope

This Recommendation provides a methodology for use by the ITU Radiocommunication Bureau to conduct examination of the characteristics of an aeronautical earth station in motion (A-ESIM) operating with geostationary satellite networks with respect to conformity with power flux-density limits specified in Part II, Annex 3 of Resolution **169 (WRC-19)** of the Radio Regulations.

Keywords

Aeronautical ESIM, A-ESIM, GSO, pfd, methodology

Abbreviations/Glossary

A-ESIM	Aeronautical earth station in motion
GSO	Geostationary orbit

Related ITU Recommendations, Reports

Recommendation ITU-R P.676 – Attenuation by atmospheric gases and related effects

Report ITU-R M.2221 – Feasibility of MSS operations in certain frequency bands

The ITU Radiocommunication Assembly,

considering

a) that WRC-19 adopted, in Resolution **169 (WRC-19)** of the Radio Regulations (RR), the power flux-density (pfd) limits applicable to aeronautical earth station in motion (A-ESIM) communicating with geostationary space stations in the fixed-satellite service (FSS) systems in the frequency range 27.5-29.5 GHz in order to ensure the protection of terrestrial services;

b) that in accordance with *resolves* 1.2.5 of Resolution **169 (WRC-19)**, the Bureau shall examine the characteristics of A-ESIM communicating with GSO FSS satellites with respect to conformity with pfd limits on the Earth's surface as specified in Part II of Annex 3 of Resolution **169 (WRC-19)** and publish the results of such examination in the BR IFIC;

c) that in the absence of an appropriate methodology, the Bureau is unable to examine the conformity specified in *considering b)*;

d) that, in Resolution **169 (WRC-19)**, WRC-19 invited the ITU-R to conduct relevant studies to determine a methodology with respect to the examination referred to in *considering b)*,

recognizing

that *resolves* 1.2.4 of Resolution **169 (WRC-19)** stipulates that "the provisions in this Resolution, including Annex 3, set the conditions for the purpose of protecting terrestrial services from unacceptable interference from aeronautical and maritime ESIMs in neighbouring countries in the frequency band 27.5-29.5 GHz; however, the requirement not to cause unacceptable interference to,

or claim protection from, terrestrial services to which the frequency band is allocated and operating in accordance with the Radio Regulations remains valid",

recommends

1 that the methodology specified in the Annex should be considered for the calculation of the pfd produced by emissions from an A-ESIM communicating with GSO FSS satellites on the Earth's surface and assess compliance with the pfd limits specified in Part II, Annex 3 of Resolution **169 (WRC-19)**;

2 that the following Notes should be regarded as part of this Recommendation.

NOTE 1 – For the implementation of this Recommendation *recognizing a)* above should be taken into account.

NOTE 2 – For the operation of emission bandwidth smaller than the reference bandwidth, this methodology is applicable provided that the notifying administration confirms that A-ESIM operates only one emission within the reference bandwidth. If there is no such confirmation, this methodology is not applicable.

NOTE 3 – The result of the examination should be published in accordance with the output format specified in the Annex.

Annex

Methodology to examine the pfd on the surface of the Earth produced by emissions from an A-ESIM communicating with GSO FSS satellites and the conformity with pre-established pfd limits

1 Overview

The methodology below is a functional description to conduct examination of A-ESIM operating with GSO satellite networks and their conformity with pfd limits specified in Part II of Annex 3 to Resolution **169 (WRC-19)**.

2 A-ESIM parameters required for the examination

To conduct the relevant examination of A-ESIM and their conformity with respect to the pfd limits, the following parameters are required:

– Satellite network name
– GSO satellite longitude
– GSO service area latitude bounds
– GSO service area longitude bounds
– A-ESIM peak antenna gain
– A-ESIM power density and bandwidth as given in Table 1
– Fuselage attenuation mask expressed as a function of the angle below the horizon of the A-ESIM based on ITU-R Reports or ITU-R Recommendations.

3 Examination methodology

3.1 Introduction

An A-ESIM can operate at different locations defined by latitude, longitude and altitude. This methodology determines the maximum allowable Power $\mathbf{P_j}$ for an A-ESIM transmitter communicating with a GSO FSS satellite to ensure compliance with the pre-established pfd limits to protect terrestrial services, at all positions, for a defined set of altitude ranges. The methodology derives the $\mathbf{P_j}$ taking into account the relevant loss and attenuation in the geometry considered.

The methodology then compares the computed $\mathbf{P_j}$ with the range of notified power for the A-ESIM emission. The minimum and the maximum powers values of the emission $P_{\min\ \_emission,j}$ and $P_{\max\ \_emission,j}$ of the A-ESIM are calculated from the data included in the Appendix **4** Notification information of the GSO satellite network with which the A-ESIM communicates and from the A-ESIM characteristics.

A-ESIM are evaluated over a number of predefined altitude ranges in order to establish a number of $\mathbf{P_j}$ levels.

An examination by the Bureau should apply this methodology for the defined altitude range, to determine whether the A-ESIM operating under a given GSO satellite network complies with the pre-established pfd limits to protect terrestrial services.

3.2 Parameters and geometry

Considering a hypothetical GSO FSS network, Table 1 below provides an example of emissions that are included in one Group associated to the "UO" class of earth station transmitting in the 27.5-29.5 GHz band. Tables 2 to 4 provide additional assumptions, and Fig. 1 illustrates the geometry involved in the examination.

TABLE 1

Example of a Group of A-ESIM emissions
(with reference to relevant RR Appendix 4 data fields)

Emission No.	C7a Designation of emission	$BW_{emission}$ (MHz)	C8c3 minimum power density (dB(W/Hz))	C8a2/C8b2 maximum power density (dB(W/Hz))
1	6M00G7W--	6.0	−69.7	−66.0
2	6M00G7W--	6.0	−64.7	−61.0
3	6M00G7W--	6.0	−59.7	−56.0

TABLE 2

Additional example assumptions

ID	Parameter	Notation	Value	Unit
1	Frequency assignment	f	29.5	GHz
2	Reference bandwidth of pfd mask	BW_{Ref}	1.0 or 14.0, depending on the altitude under examination	MHz
3	GSO satellite longitude	GSO_{lon}	13.0	degrees E
4	GSO service area latitude bounds	GSO_srv_{Lat}	(23.55, 63.55)	degrees N
5	GSO service area longitude bounds	GSO_srv_{Lon}	(−9.72, 30.28)	degrees E
6	A-ESIM antenna peak gain	G_{max}	37.5	dBi
7	A-ESIM antenna gain pattern	-	As per Rec. ITU-R S.580 (see C.10.d.5.a)	

TABLE 3

Additional assumptions defined in the methodology

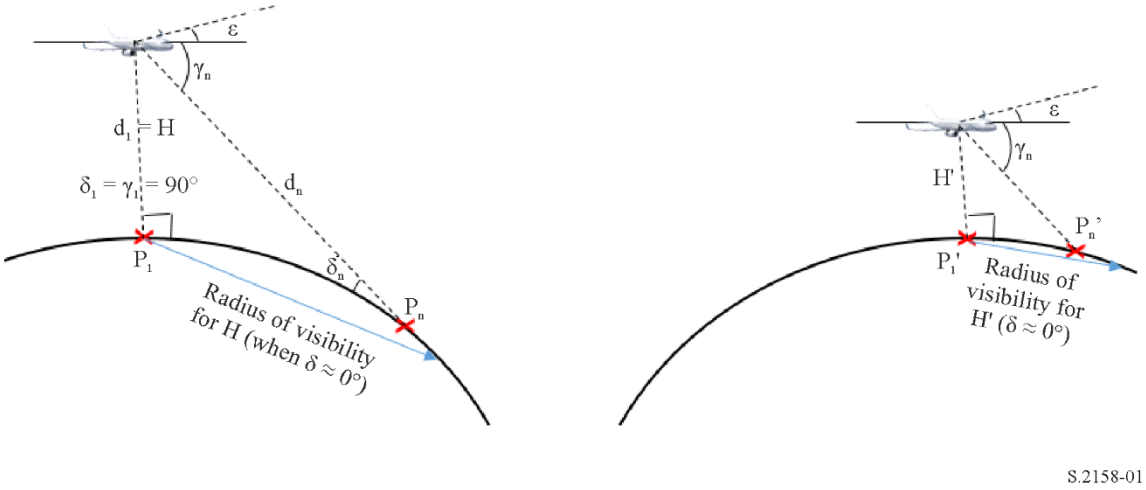
ID	Parameter	Notation	Value	Unit
8	A-ESIM minimum elevation angle towards GSO satellite	ε	10	degrees
9	Atmospheric attenuation	L_{atm}	Computed with Rec. ITU-R P.676 (see Note below)	dB
10	Angle of arrival of the incident wave on the Earth's surface	δ	Specified by the pre-established sets of pfd limits, variable from 0 to 90	degrees
11	Minimum examination altitude	H_{min}	0.01	km
12	Maximum examination altitude	H_{max}	15.0	km
13	Examination altitude spacing[1]	H_{step}	1.0	km
14	Fuselage attenuation	L_f	Computed based on ITU-R Reports or Recommendations (see Table 4)	dB

NOTE – The atmospheric attenuation is computed with Recommendation ITU-R P.676, with the mean annual global reference atmosphere as defined in Recommendation ITU-R P.835.

[1] The fourth altitude value (H_4) computed in accordance with this H_{step} is adjusted to 2.99 km to facilitate the examination of compliance with the two sets of predefined pfd values indicated in Tables 5 and 6.

FIGURE 1

Geometry for the examination of compliance for two different A-ESIM altitudes



S.2158-01

TABLE 4

Fuselage attenuation model

$L_{fuse}(\gamma) = 3.5 + 0.25 \cdot \gamma$	dB	for	$0° \leq \gamma \leq 10°$
$L_{fuse}(\gamma) = -2 + 0.79 \cdot \gamma$	dB	for	$10° < \gamma \leq 34°$
$L_{fuse}(\gamma) = 3.75 + 0.625 \cdot \gamma$	dB	for	$34° < \gamma \leq 50°$
$L_{fuse}(\gamma) = 35$	dB	for	$50° < \gamma \leq 90°$

Notes:

- This fuselage attenuation model is based on measurements made at 14.2 GHz (see Fig. 3.6-14 in Report ITU-R M.2221).

  Tables 5 and 6 are taken from Part II of Annex 3 to Resolution **169 (WRC-19)**. The reference bandwidth for the sets of pfd limits included in Table 5 and Table 6 are 1 MHz and 14 MHz, respectively.

TABLE 5

Required conformance pfd mask for altitudes up to 3 km

pfd(δ) = −136.2	(dB(W/(m^2 · 1 MHz)))	for $0° \leq \delta \leq 0.01°$
pfd(δ) = −132.4 + 1.9 · log δ	(dB(W/(m^2 · 1 MHz)))	for $0.01° < \delta \leq 0.3°$
pfd(δ) = −127.7 + 11 · log δ	(dB(W/(m^2 · 1 MHz)))	for $0.3° < \delta \leq 1°$
pfd(δ) = −127.7 + 18 · log δ	(dB(W/(m^2 · 1 MHz)))	for $1° < \delta \leq 12.4°$
pfd(δ) = −108	(dB(W/(m^2 · 1 MHz)))	for $12.4° < \delta \leq 90°$

TABLE 6

Required conformance pfd mask for altitudes above 3 km

$pfd(\delta) = -124.7$	(dB(W/(m^2 · 14 MHz)))	for $0° \leq \delta \leq 0.01°$
$pfd(\delta) = -120.9 + 1.9 \cdot \log \delta$	(dB(W/(m^2 · 14 MHz)))	for $0.01° < \delta \leq 0.3°$
$pfd(\delta) = -116.2 + 11 \cdot \log \delta$	(dB(W/(m^2 · 14 MHz)))	for $0.3° < \delta \leq 1°$
$pfd(\delta) = -116.2 + 18 \cdot \log \delta$	(dB(W/(m^2 · 14 MHz)))	for $1° < \delta \leq 2°$
$pfd(\delta) = -117.9 + 23.7 \cdot \log \delta$	(dB(W/(m^2 · 14 MHz)))	for $2° < \delta \leq 8°$
$pfd(\delta) = -96.5$	(dB(W/(m^2 · 14 MHz)))	for $8° < \delta \leq 90.0°$

3.3 Calculation algorithm

This section includes a step-by-step description of how the examination methodology would be implemented.

START

i) For each A-ESIM altitude, it is necessary to generate as many δ_n angles (angle of arrival of the incident wave) as required in order to test the full compliance with the applicable set of pfd limits. The *N* angles δ_n must be comprised between 0° and 90° and have a resolution compatible with the granularity of the pre-established pfd limits. Each of the angles δ_n will correspond to as many *N* points on the ground.

ii) For each altitude $H_j = H_{min}, H_{min} + H_{step}, \ldots, H_{max}$:

a) set the altitude of the *A_ESIM* to H_j

b) compute the angles below the horizon $\gamma_{j,n}$ as seen from the A-ESIM for each of the *N* angles δ_n generated in i) using the following equation:

$$\gamma_{j,n} = \arccos\left(\frac{R_e \cdot \cos(\delta_n)}{(R_e + H_j)}\right) \quad (1)$$

where R_e is the mean earth radius.

c) Compute the distance $D_{j,n}$, in km, for $n = 1, \ldots, N$ between the A-ESIM and the tested point on the ground:

$$D_{j,n} = \sqrt{R_e^2 + \left(R_e + H_j\right)^2 - 2\,R_e\left(R_e + H_j\right)\cos\left(\gamma_n - \delta_n\right)} \quad (2)$$

d) Compute the fuselage attenuation $L_{f\,j,n}$ (dB) with $n = 1, \ldots, N$ applicable to each of the angles $\gamma_{j,n}$ computed in b) above.

e) Compute the gaseous absorption $L_{atm\_j,n}$ (dB) with $n = 1, \ldots, N$ applicable to each of the distances $D_{j,n}$ computed in c) above, using the applicable sections of Recommendation ITU-R P.676.

iii)

a) For each altitude $H_j = H_{min}, H_{min} + H_{step}, \ldots, H_{max}$, and each angle below the horizon $\gamma_{j,n}$, compute the maximum emission power in the reference bandwidth $P_{j,n}(\delta_n, \gamma_{j,n})$ for which the pfd limits are met using the following algorithm:

$$P_{j,n}(\delta_n, \gamma_{j,n}) = pfd(\delta_n) + 10\log_{10}\left(4\pi(D_{j,n} \cdot 1\,000)^2\right) + L_{f\,j,n} + L_{atm_{j,n}} - Gtx(\gamma_{j,n} + \varepsilon)$$

with $Gtx(\gamma_{j,n} + \varepsilon)$ being the transmit antenna gain with the off-axis angle from the boresight, consisting of the summation of both angles $\gamma_{j,n}$ and minimum elevation angle ε of 10 degrees as defined in Table 3.

b) Compute the minimum P_j across all values calculated at the previous step,

$$P_j = \text{Min}\left(P_{j,n}(\delta_n, \gamma_{\text{j,n}})\right)$$

The output of this step is the maximum power in the reference bandwidth that can be used by the A-ESIM to ensure it complies with the pfd limits indicated in Table 5 or Table 6, as applicable, with respect to all angles δ_n at the altitude H_j, and the elevation indicated in Table 3. There will be one P_j for each of the H_j altitudes considered.

The output of step b) is summarised in Table 7.

TABLE 7

Computed P_j values

H_j ***(Altitude)*** **(km)**	***P_j*** (*Maximum power in the reference bandwidth that can be used at minimum elevation)* **(dB(W/BW))**
0.01	*TBD*
1.0	*TBD*
2.0	*TBD*
2.99	*TBD*
4.0	*TBD*
5.0	*TBD*
6.0	*TBD*
7.0	*TBD*
8.0	*TBD*
9.0	*TBD*
10.0	*TBD*
11.0	*TBD*
12.0	*TBD*
13.0	*TBD*
14.0	*TBD*
15.0	*TBD*

c) For each altitude $H_j = H_{min}, H_{min} + H_{step}, \ldots, H_{max}$, and each of the emissions of the groups of emissions under examination, compute the minimum and the maximum powers of the emission in the reference bandwidth:

$$P_{\text{min }\_emission,j} = Minimum\ Power\ density(Emission, dBW/Hz) + 10 * \log_{10}(BW)$$

$$P_{\text{max }\_emission,j} = Maximum\ Power\ density(Emission, dBW/Hz) + 10 * \log_{10}(BW)$$

BW in Hz is:

BW_{Ref} if BW_{Ref} =1 MHz

BW_{Ref} if BW_{Ref} =14 MHz and $BW_{emission} >= BW_{Ref}$

$BW_{emission}$ if BW_{Ref} =14 MHz and $BW_{emission} < BW_{Ref}$

d) For each of the emissions of the groups of emissions under examination check if there is at least one altitude H_j for which:

$$P_{\max\_emission,j} > P_j > P_{\min\_emission,j}$$

The results of this check are illustrated in Table 8.

TABLE 8

Example comparison between P_j and ($P_{\min\_emission,j}$; $P_{\max\_emission,j}$)

Emission No.	C7a Designation of emission	$BW_{emission}$ MHz	C8c3 minimum power density dB(W/Hz)	C8a2/C8b2 Maximum power density dB(W/Hz)	Lowest altitude H_j (km) for which $P_{\max\_emission,j} > P_j > P_{\min\_emission,j}$
1	6M00G7W--	6.0	–69.7	–66.0	TBD
2	6M00G7W--	6.0	–64.7	–61.0	TBD
3	6M00G7W--	6.0	–59.7	–56.0	TBD

e) Based on the test detailed in iii)d) above applied to all emissions of the group under examination, the results of the Bureau's examination for that group is favourable, after removing emissions that have failed the examination, otherwise it is unfavourable (i.e. all emissions have failed).

iv) The output of this methodology should, at a minimum, include:

– those resulting parameters as contained in Table 7;

– the examination results for each group;

– for those cases when some emissions successfully pass and some do not, the examination results for resulting new group that includes only those emission(s) which successfully passed the examination.