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| **Report ITU-R S.2174**  **(07/2010)** |
| **Guidelines that may be used in the design of satellite networks for assessing the impact of rain attenuation on the carrier to noise plus interference ratios of the FSS Plan allotments** |
| **S Series**  **Fixed satellite service** |

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| ***Note****: This ITU-R Report was approved in English by the Study Group under the procedure detailed   in Resolution ITU-R 1.* |

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REPORT ITU-R S.2174

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for assessing the impact of rain attenuation on  
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(2010)

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# 1 Introduction

In 2007, the World Radiocommunication Conference (WRC-07) adopted a revised FSS Plan (contained in Appendix 30B to the Radio Regulations), in which a number of technical parameters and criteria were modified. The above-mentioned Plan provides all ITU Members with protected orbital-frequency resources. In the FSS Plan, the criterion for the carrier-to-noise ratio (*C/N*) is defined under rain-faded conditions but the criterion for the carrier-to-interference (*C/I*) is defined in clear-sky conditions. In some cases, as a consequence of approved technical criteria and unavoidable signal attenuation due to rain, the energy balance of planned allotments in the 13/10‑11 GHz frequency bands may become substantially worse.

All mathematical computations made in this Report are based on the assumption that the uplink power is designed to strictly achieve a *C*/*N* ratio of 21 dB under rain-faded conditions. It should be noted that test points of some allotments have higher faded *C*/*N* values in the uplink (i.e. greater than 21 dB).

Throughout this Report, the following notation is used:



Annex 1 to this Report provides supplementary information which examines two additional impacts of rain attenuation on system margin which are not taken into account by the FSS Plan. Annex 2 contains all the terms and their respective definitions used in the Report and in Annex 1.

# 2 The criteria approved in the FSS Plan

The overall link *C*/*N* is set to 14 dB (on the basis of the following balance: an uplink *C*/*N* ratio set to 21 dB and a downlink *C*/*N* ratio set to 15 dB) for 99.9% of the year on both uplink and downlink directions in the 13/10-11 GHz bands. It should be noted that these values are guaranteed for the carrier-to-thermal noise ratios and not for the carrier-to-noise-plus-interference ratios (*C/*(*N+I*)).

As decided by WARC Orb-88 and confirmed by WRC-07, to increase homogeneity between various allotments, the increase of the space and earth transmitter power, necessary to compensate for the attenuation, is limited to 8 dB. For achieving the same purpose, the minimum earth station transmitter power density was limited to −60 dB(W/Hz) averaged over the necessary bandwidth of the modulated carrier. Therefore, on the uplink, while some allotments may not be guaranteed a minimum *C*/*N* ratio of 21 dB for 99.9% of the year, others may exhibit a *C*/*N* ratio strictly greater than 21 dB even under rain-faded conditions.

The carrier to interference ratio *C*/*I* for the overall communication link should not be lower than 21 dB for aggregate interference and 25 dB for single-entry interference under free-space conditions.

An allotment or an assignment is considered as being affected by a proposed new allotment or assignment if at least one of the following three conditions is not satisfied:

1. the calculated Earth-to-space single-entry carrier-to-interference ratio (*C*/*I*)*up, SE* must be greater than or equal to a reference value of 30 dB;

2. the calculatedspace-to-Earth single-entry carrier-to-interference ratio(*C*/*I*)*down, SE* must be greater than or equal to a reference value of 26.65 dB;

3. the calculated overall aggregate carrier-to-interference ratio *(C*/*I)agg* must be greater than or equal to a reference value that is 21 dB.

The aggregate interference is not specified separately for the uplink and downlink. Taking into account that, for the overall link, the difference between the aggregate and single-entry interference is equal to 4 dB, it is assumed that the minimum downlink aggregate carrier-to-interference ratio (*C*/*I*)*down, agg* is equal to 22.65 dB and the minimum uplink carrier-to-interference ratio (*C*/*I*)*up, agg* to 26 dB.

In this Report, it is assumed that rain fading on the wanted and interfering downlinks is completely correlated since both wanted and interfering signals are received by the earth station at the same point on the Earth’s surface. On the contrary, on the uplink, the wanted and interfering signals are transmitted by different earth stations, which are generally located in geographically separated areas, and rain fading on the wanted and interfering signals is not correlated.

# 3 The effect of the limited increase of the space and earth station transmitter power to 8 dB

Due to the limited increase of the space and earth station transmitter power to 8 dB, when signal attenuation ∆ for any test point is greater than 8 dB, the faded carrier to noise ratio (*C*/*N*)*faded* is reduced to:

(*C*/*N*)*faded* = (*C*/*N*)*nom* − (∆ − 8)                dB

where (*C*/*N*)*nom* is the nominal value for the carrier-to-noise ratio specified in the Plan for this allotment (i.e. at a minimum, the reference value under rain-faded conditions).

So, on the uplink, knowing that the nominal value of the carrier-to-noise ratio (*C*/*N*)*up, nom* is equal to 21 dB, the faded carrier-to-noise ratio (*C*/*N*)*up,faded* is:

(*C*/*N*)*up, faded* = 21 – (∆*up* − 8) = 29 − ∆*up*                dB

On the downlink, knowing that the nominal value of the carrier-to-noise ratio (*C*/*N*)*down, nom* is equal to 15 dB, the faded carrier to noise ratio (*C*/*N*)*down, faded* is[[1]](#footnote-1):

(*C*/*N*)*down, faded* = 15 – (∆*down* − 8) = 23 − ∆*down*                dB

The formulas below clarify the relationship between Δ and (*C/N*) for the uplink and downlink:

When ∆*up* ≤ 8dB, (*C*/*N*)*up, faded*= (*C*/*N*)*up, nom*

When ∆*down* ≤ 8dB, (*C*/*N*)*down, faded*= (*C*/*N*)*down, nom*

# 4 The effect of the interference and signal attenuation on the uplink energy balance of the planned allotments

The energy balance of the communication link is defined by the ratio:

*Cup, faded*/(*N* + *Iup, agg*)

where:

*Cup, faded* : wanted signal power at the input of the space station receiver with the signal attenuation in the atmospheric gases and precipitation, which corresponds to an availability of 99.9% of the year in the 13/10-11 GHz bands

*N* : thermal noise power of the space station receiver taking into account the Earth noise radiation. In the FSS Plan, this value is set at N = 550 K in the 13 GHz band

*Iup, agg* : aggregate interference at the input of the space station receiver from all other allotments and assignments in the Plan and List.

## 4.1 Case where the attenuation ∆*up* is less than or equal to 8 dB

In this case, the value of the uplink carrier-to-noise ratio (*C*/*N*)*up*, *nom* is determined in order to achieve the required *C*/*N* of 21 dB under rain-faded conditions:



or equivalently:



where:

 = 21 dB and

 = 26 dB.

For example when Δ*up* = 5 dB:

 and 18 dB

which is 3 dB less than the *C*/*N* value established in Appendix 30B. See also Fig. 1.

## 4.2 Case where the attenuation ∆*up* is greater than 8 dB

In this case the value of the uplink carrier-to-noise ratio (*C*/*N*)*up,nom* is partly restored, only by 8 dB, therefore:



or equivalently:



because  and .

For example, if ∆*up* = 10 dB:

,  and 

which is 6.8 dB less than the *C*/*N* value of 21 dB established in RR Appendix 30B for the uplink planned allotments.

As another example, if ∆*up* = 21 dB:

,  and 

which is 17.8 dB less than the *C*/*N* value of 21 dB established in RR Appendix 30B for the uplink planned allotments. See also Fig. 1.

FIGURE 1

Display for the case where the attenuation ∆*up* is less than or equal to 8 dB



FIGURE 2

Display for the case where the attenuation ∆*up* is greater than 8 dB



# 5 The independence of rain events on the uplink and downlink

Section 2.2.4.1 of Recommendation ITU-R P.618-10 provides a methodology to estimate the joint probability that it is raining at both the uplink and downlink sites. This methodology can be used to determine the probability that both the uplink and downlink margins will be required to overcome rain attenuation. It should be noted that such probability is normally low for FSS satellite links for the cases where the uplink station is far from the downlink station.

Annex 1  
  
Effect of rain attenuation on satellite links

# 1 Introduction

When the FSS Plan was developed, two additional impacts on system margin due to rain attenuation were not taken into account. These two impacts are:

1 the effect of rain attenuation on the earth station thermal noise from a rain fade on the downlink, and

2 the effect of uplink rain fading on the downlink.

The increase in earth station noise temperature during a downlink rain fade causes a decrease in the downlink carrier-to-noise ratio that was not taken into account in the development of the Plan.

The impact of uplink rain fading on the downlink is also not taken into account in the Plan. The Plan does not distinguish whether conventional transparent transponders or remodulating transponders with onboard signal processing are used. At the time of preparation of this Report, conventional transparent transponders are widely used on most satellite networks. Section 3 of this Annex considers the effect of uplink rain fading on the downlink on satellite networks when transparent transponders are used. In addition, the calculation of uplink margins for satellite networks when using Recommendation ITU-R P.618-10 should take into account the effect of uplink rain attenuation on the downlink as per § 3. In many cases, the use of uplink fade compensation techniques, where feasible, will mitigate the impact of not taking into account the effect of uplink fading on the downlink carrier-to-noise plus aggregate interference.

# 2 The effect of the rain attenuation on the earth station thermal noise (downlink)

Since the earth station noise *TES* increases as a result of the raining conditions according to the formula:



the downlink carrier-to-noise ratio (*C*/*N*)*down, rain* is reduced to:



where:

(*C*/*N*)*down, clear-sky*:value of the downlink carrier-to-noise ratio in clear-sky conditions determined in the Plan for this allotment

*ТES, clear-sky*:equal to 125 K in the 10-11 GHz band

*Tm*:effective temperature of the medium, usually 260-280 K (Recommendation ITU-R P.618). For simplicity it has been assumed that the temperature of the medium is constant during rain and clear-sky conditions

*down*:downlink attenuation due to rain.

It should be noted that this effect was not taken into account when determining required satellite e.i.r.p. levels for downlink planned allotments during the development of the FSS Plan.

# 3 The effect of uplink rain attenuation on the downlink

Many modern satellite communications networks using transparent transponders implement one or more methods for mitigating the effects of fading (typically due to rain) on the uplink to improve overall end-to-end link performance. These fade mitigation techniques include uplink power control (UPC) typically used at frequencies of 13 GHz and higher, and automatic level control (ALC), a technique which can be used at any frequency band. Some satellite networks employ the use of both techniques simultaneously to further improve link availability. Other techniques exist, such as, adaptive coding and modulation (ACM), whereby the level of throughput as measured by the information rate is varied according to the propagation conditions on the wanted path such that the spectral efficiency as measured in bit/s/Hz is highest under clear-sky conditions. The choice of which uplink fade compensation technique, if any that can be used depends on a number of factors. A discussion of the relative merits of different uplink fade compensation techniques is considered to be beyond the scope of this Report.

## 3.1 Impact of UPC on downlink

UPC can be accomplished in a number of ways including through the sensing of a beacon on the satellite or from a feedback loop which may be implemented using a co-located receiving earth station that detects changes in the level of the received signal level transmitted from the satellite. In either case, “tracking” the detected fade and compensating for the level of uplink fade experienced on the uplink path is not perfect due to any one or a combination of the following effects:

– HPA power limitations;

– satellite propagation delay;

– processing delay; and

– estimation errors.

For the discussion below, it will be assumed that the UPC wanted carrier compensation tracking is “perfect” within the UPC limit (i.e., maximum additional power as determined by the HPA output power capability). Therefore, for the purposes of this discussion, it is assumed that there is no necessity to carry any static fade margin on the link.

## 3.2 Impact of ALC on downlink

ALC allows the satellite to re-transmit the carrier on the downlink at a constant power over a range of received carrier levels at the input to the satellite receiver. If the satellite operator makes the satellite receiver very sensitive by minimizing the attenuation on the input to the satellite receiver, the ALC range, or the range of input signal levels over which the satellite can produce a constant fixed output power, can be maximized. At the same time, however, when the received signal level at the satellite is at the minimum of the ALC range (referred to as the ALC threshold), the uplink carrier-to-thermal noise may be quite low which will consume some of the overall link fade margin. For the purposes of the discussion below, it will be assumed that the downlink e.i.r.p. of the wanted signal will be at its clear-sky values provided the uplink rain fade on the received wanted uplink signal does not degrade it to below the ALC threshold (i.e., the uplink fade does not exceed the ALC range).

## 3.3 Calculation of the impact of uplink rain attenuation on the downlink

In order to simplify the analysis demonstrating the impact of an uplink fade on the downlink in the case of a satellite with transparent transponders, it is assumed that perfectly linear amplifiers are used (i.e., a change in input back-off results in an identical change in output back-off). In practical transponders, however, the reduction in transponder output power (measured in dB) will be less than the reduction in the received signal level at the satellite input due to transponder non-linearities near the transponder operating point and will depend on:

1 the number of carriers in the transponder,

2 the operating point,

3 the type of transponder amplifier (SSPA or TWTA), and

4 whether or not the transponder is linearized.

Also, in the analysis that follows, the 8 dB rain fade limit imposed by the Plan on uplink fading has been ignored.

In the case of a rain fade on the wanted uplink path, when it is assumed that no uplink fade compensation techniques are employed, any fade on the uplink (∆*up*) will be experienced equally on the downlink such that the downlink carrier-to-thermal noise ratio (*C/N*)*down* will be reduced by a corresponding amount as provided in the following expression:

(*C*/*N*)*down*, *up**faded* = (*C*/*N*)*down*, *clear-sky* – ∆*up*

If uplink fade compensation techniques are employed, the reduction in the degradation to the downlink carrier-to-thermal noise ratio can be reduced or eliminated. When a fade on the uplink path during a rain fade on the uplink results in a fade on the downlink, assuming that there are clear‑sky conditions on the downlink, both the thermal noise and the aggregate interference will be unchanged. If we let ∆*\** be the resulting fade on the downlink when there is a rain fade on the uplink, the expressions for (*C/N*)*down*, (*C/I*)*agg* and the downlink carrier-to-noise plus interference when there is an uplink rain fade of ∆*up* on the wanted uplink path are given by:

(*C*/*N*)*down*, *up faded* = (*C*/*N*)*down*, *clear-sky* – ∆\*

(*C*/*I*)*down*, *agg*, *up faded* = (*C*/*I*)*down*, *agg* – ∆\*



where ∆*\** is calculated in accordance with Table 1.

TABLE 1

Determination of fade (∆*\**) on (*C*/*N*)*down* when wanted uplink experiences a rain fade of ∆*up*

|  |  |  |  |
| --- | --- | --- | --- |
| Uplink fade compensation | Condition | Downlink fade | Value of fade (Δ\*) on downlink |
| None | U/L fade = Δ*up* | Δ*up* | Δ*up* |
| ALC only | ALC – Δ*up* ≥ 0 ALC – Δ*up* < 0 | 0 Δ*up* – ALC | –Min(ALC-Δ*up*, 0) |
| UPC only | UPC – Δ*up* ≥ 0  UPC – Δ*up* < 0 | 0 Δ*up* – UPC | –Min(UPC-Δ*up*, 0) |
| ALC and UPC | Δ*up* – UPC < ALC Δ*up* – UPC ≥ ALC | 0 Δ*up* – (UPC + ALC) | –Min(ALC+UPC-Δ*up*, 0) |

Recalling from § 2 of this Report that on the uplink, the wanted and interfering signals are transmitted by different earth stations, which are generally located in geographically separated areas, and thus rain fading on the wanted and interfering signals is not correlated, the faded uplink carrier-to-noise plus aggregate interference ratio can be calculated using the following expression:



Ignoring the negligible probability of simultaneous rain fading on both the uplink and the downlink, the rain fade on the uplink ∆*up* is determined such that the following equation holds true:



NOTE 1 − The parameter (*C/N*)*Thresh* (see Annex 2) is not a parameter in the FSS Plan.

Annex 2  
  
Terms and definitions used in this Report

*ТES, rain*: Earth station noise temperature in rain-faded conditions (K).

*ТES, clear-sky*: Earth station noise temperature in clear-sky conditions (K).

*Tm*:Effective temperature of the medium (see Recommendation ITU-R P.618) (K).

∆:Attenuation with normalised probability due to rain (dB).

∆*up*: Uplink attenuation due to rain (dB).

*down*: downlink attenuation due to rain (dB).

*Cup, faded*: Wanted carrier power at the input of the space station receiver under rain‑faded conditions (dB).

*N*:Thermal noise power of the space station receiver taking into account the Earth noise radiation (dBW).

*Iup, agg*:Aggregate interference at the input of the space station receiver from all other allotments and assignments in the Plan and List (dBW).

(*C/N*)*down, clear-sky* :Downlink carrier-to-noise ratio in clear-sky conditions determined in the Plan for an allotment (dB).

(*C*/*N*)*down, rain*:Downlink carrier-to-noise ratio under rain-faded conditions (dB).

(*C*/*N*)*nom*: Nominal value for the carrier-to-noise ratio specified in the Plan for an allotment (dB).

(*C*/*N*)*up, nom*: Nominal value for the uplink carrier-to-noise ratio specified in the Plan for an allotment (dB).

(*C*/*N*)*down, nom*: Nominal value for the downlink carrier-to-noise ratio specified in the Plan for an allotment (dB).

(*C*/*N*)*faded*: Rain-faded carrier-to-noise ratio (dB).

(*C*/*N*)*up, faded*: Rain-faded uplink carrier-to-noise ratio (dB).

(*C*/*N*)*down, faded*: Rain-faded downlink carrier-to-noise ratio (dB).

(*C*/*I*): Carrier-to-interference ratio (dB).

(*C*/*I*)*up, SE*: Uplink single-entry carrier-to-interference ratio (dB).

(*C*/*I*)*down, SE*: Downlink single-entry carrier-to-interference ratio (dB).

(*C*/*I*)*up, agg*: Uplink aggregate carrier-to-interference ratio (dB).

The following are supplementary input parameters relating to satellite networks that use transparent transponders:

ALC: Automatic Level Control range over which the downlink carrier power is maintained at a constant output level (dB).

UPC: Uplink Power Control – amount by which uplink carrier power can be faded by rain such that the power received by the satellite is maintained at a constant level (dB).

∆*\**: Resulting attenuation on the downlink due to rain fading on the uplink (dB).

: Wanted carrier power at the input of the earth station receiver with rain faded conditions on the uplink and clear-sky conditions on the downlink (dB).

(*C*/*N*)*down, up faded*: Downlink carrier-to-noise ratio, rain-faded uplink (dB).

(*C*/*I*)*down, agg*: Downlink aggregate carrier-to-interference ratio (dB).

(*C*/*I*)*down, agg, up faded*: Downlink aggregate carrier-to-interference ratio, rain-faded uplink (dB).

: Carrier-to-noise threshold ratio, where noise is understood to include thermal noise plus all interferences, to achieve a specified bit error rate (dB)[[2]](#footnote-2).

1. It is noted that in the equation above when (*C*/*N*)*down, faded* value is calculated under rain-faded conditions, increase of earth station noise temperature due to increased rain attenuation is not considered. This effect, which is considered in Annex 1, was actively discussed at the WRC-07. In order to keep the entire integrity of the WARC Orb-88 Plan, the Conference decided to apply the same assumptions as the WARC Orb-88 and to not consider this effect. [↑](#footnote-ref-1)
2. The carrier to noise plus interference threshold is not a parameter in the FSS Plan. [↑](#footnote-ref-2)