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LIMITS ON EQUIVALENT POWER-FLUX DENSITY (EPFD)

1 Introduction

Resolution **85 (WRC-03)** deals with the application of Article **22** of the Radio Regulations to the protection of geostationary fixed-satellite service and broadcasting-satellite service networks from non-geostationary fixed-satellite service systems.

Resolution **85 (WRC-03)** requires the Bureau to examine if the frequency assignments to:

a) FSS non-GSO satellite systems comply with the EPFD limits contained in Tables **22-1A**, **22-1B**, **22-1C**, **22-1D**, **22-1E**, **22-2 and 22-3** of RR Article **22**;

b) specific large earth station (under certain conditions) requires coordination under RR No. **9.7A** with respect to any existing non-GSO satellite systems using the coordination triggers in RR Appendix **5**, or

c) FSS non-GSO satellite systems requires coordination under RR No. **9.7B** with respect to any large earth station (under certain conditions) using the coordination triggers in RR Appendix **5**.

Application of these provisions is based of verification of the EPFD produced by non-GSO satellite systems.

This paper provides background information on application of EPFD limits focusing on regulatory situations involving sharing between non-GSO FSS and GSO FSS/BSS systems.

2 Non-geostationary satellite systems

Non-geostationary (non-GSO or NGSO) satellite systems are ideal for providing, real-time communications with a global coverage. Non-GSO fixed-satellite service (FSS) systems normally provide high-speed broadband services, including Internet connectivity, to homes and offices throughout the world including locations which cannot be reached using geostationary satellites. Typical non-GSO satellite system consists of one or several space stations located on low-Earth or medium-Earth orbit and the gateway stations. The gateways connect with terrestrial networks, to provide each user an access to the private or public networks.

In view of the shortage of suitable frequencies, and in order to take advantage of existing infrastructure non-GSO FSS systems are sharing frequency spectrum with the GSO FSS and GSO broadcasting-satellite service (BSS) systems. To optimize use of the available spectrum, regulatory provisions such as EPFD-limits in Article **22** are required to facilitate sharing between non-GSO FSS and GSO FSS systems.

Currently, a number of non-GSO systems are submitted for coordination and notification to the Bureau. All these system have different orbit geometry and constellation parameters.

Most of the systems have a large number of the satellites ranging from tens to several thousands. Even within one single satellite system several satellites could transmit simultaneously to one particular geographical area. This situation leads to a requirement to consider in calculating interference from non-GSO network to other fixed station on Earth or GSO that:

– we do not have any information in advance on the location of the interfering stations;
– due to the constant movement of the interfering source in relation to a fixed receiving station, the statistical properties of the interference should be considered;
– there could be several interfering stations transmitting simultaneously thus increasing the aggregate interference level.

These factors dictated the need to find appropriate criteria measuring interference from non-GSO FSS into the GSO FSS.

3 What is EPFD?

The EPFD concept was adopted by WRC-97 in order to facilitate introduction of non-GSO systems in fixed satellite service in certain Ku and Ka bands shared with GSO FSS.

WRC-97 adopted “hard” (never to be exceeded) limits on emission from non-GSO systems and defined them differently from power-flux density (PFD). The WRC-97 definition of equivalent power-flux density (EPFD) takes into account the aggregate of the emissions from all non-GSO satellites in the direction of any GSO earth station, taking into account the GSO antenna directivity. Such hard limits enable non-GSO FSS systems to share frequencies with and protect GSO systems without requiring individual coordination with all the systems worldwide.

Article **22** of RR defines EPFD as:

22.5C.1 The equivalent power flux-density is defined as the sum of the power flux-densities produced at a geostationary-satellite system receive station on the Earth’s surface or in the geostationary orbit, as appropriate, by all the transmit stations within a non-geostationary-satellite system, taking into account the off-axis discrimination of a reference receiving antenna assumed to be pointing in its nominal direction. The equivalent power flux-density is calculated using the following formula:

$$epfd = 10 \log_{10} \left[\sum_{i=1}^{N_a} 10^{\frac{P_i}{10}} \cdot \frac{G_t(\theta_i)}{4 \pi d_i^2} \cdot \frac{G_r(\varphi_i)}{G_{r,max}} \right]$$

where:

N_a: number of transmit stations in the non-geostationary-satellite system that are visible from the geostationary-satellite system receive station considered on the Earth's surface or in the geostationary orbit, as appropriate;

i: index of the transmit station considered in the non-geostationary-satellite system;

P_i: RF power at the input of the antenna of the transmit station, considered in the non-geostationary-satellite system (dBW) in the reference bandwidth;

θ_i: off-axis angle between the boresight of the transmit station considered in the non-geostationary-satellite system and the direction of the geostationary-satellite system receive station;

$G_t(\theta_i)$: transmit antenna gain (as a ratio) of the station considered in the non-geostationary-satellite system in the direction of the geostationary-satellite system receive station;

d_i: distance (m) between the transmit station considered in the non-geostationary-satellite system and the geostationary-satellite system receive station;

φ_i: off-axis angle between the boresight of the antenna of the geostationary-satellite system receive station and the direction of the *i*-th transmit station considered in the non-geostationary-satellite system;

$G_r(\varphi_i)$: receive antenna gain (as a ratio) of the geostationary-satellite system receive station in the direction of the *i*-th transmit station considered in the non-geostationary-satellite system;

$G_{r,max}$: maximum gain (as a ratio) of the antenna of the geostationary-satellite system receive station;

epfd: computed equivalent power flux-density (dB(W/m^2)) in the reference bandwidth. (WRC-2000)

FIGURE 1

EPFD calculation geometry on downlink

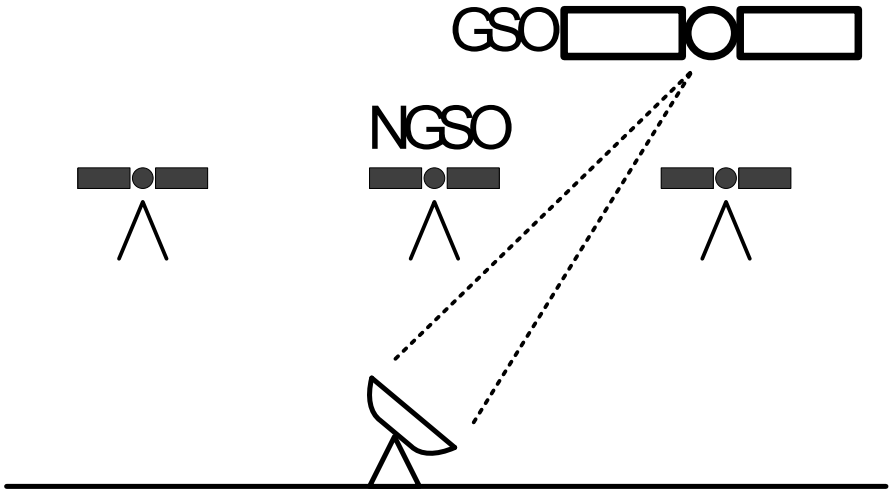


FIGURE 2

EPFD calculation geometry on uplink

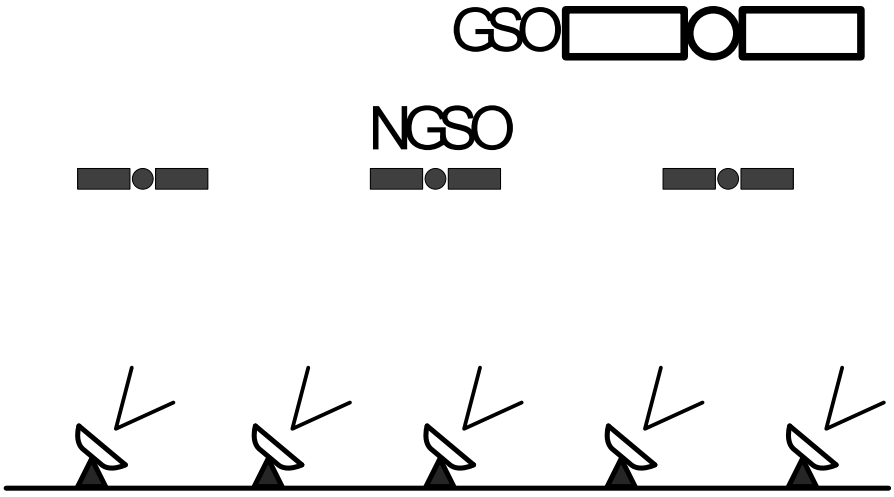
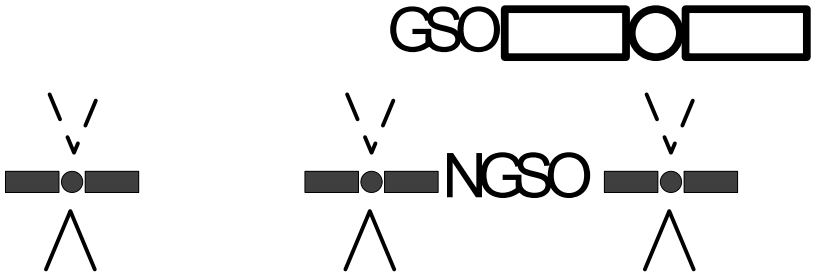


FIGURE 3

EPFD calculation geometry on inter-satellite path



Same as a PFD, the EPFD is calculated at the receiving antenna; however, contrary to PFD it takes into account the pointing of antenna with respect to every source of interference.

That is, when an antenna receives power, within its reference bandwidth, simultaneously from transmitters at various distances, in various directions and at various levels of incident pfd, the epfd is equivalent to the pfd which, if received from a single transmitter in the far field of the antenna in the direction of maximum gain, would produce the same power at the input of the receiver as is actually received from the aggregate of the various transmitters.

This concept allows very limited knowledge of parameters of receiving systems. In fact, only reference antenna pattern, antenna size and associated maximum antenna gain are needed to characterize interference for the specific class of receiving system, i.e. Article **22** contains limit masks for a number receiving earth station configurations including antenna size ranging from 30 cm to 5 metres and up to 15 metres for the special case in the band 3 700-4 200 MHz.

4 EPFD in Radio Regulations

Currently, EPFD is widely used in Radio Regulations in the following cases:

1) EPFD hard limits on FSS non-GSO satellite systems to protect GSO FSS/BSS in Article **22**
2) EPFD coordination trigger limits applicable for non-GSO FSS and GSO FSS under RR Nos. **9.7A** and **9.7B**
3) EPFD limits for systems in different radiocommunication services utilizing non-geostationary orbit to protect radioastronomy stations in a number of frequency bands. See Resolutions **739 (Rev.WRC-15)**, **741 (Rev.WRC-15)** and **743 (WRC-03)**
4) Protection of aeronautical radionavigation service systems from the EPFD produced by radionavigation satellite service networks and systems in the 1 164-1 215 MHz frequency band. See Resolution **609 (Rev.WRC-07)**.

However, only for the first two cases there is a requirement for the Bureau to examine if the frequency assignments to non-GSO system are in compliance with Article **22** limits.

For that purpose, WRC-2000 requested the Bureau to encourage administrations to develop the EPFD validation software which would be used by the Bureau to establish findings in application of Article **22** and Nos. **9.7A** and **9.7B**.

5 EPFD validation software

The methodology for the EPFD validation software is based on Recommendation ITU-R S.1503-2. This Recommendation contains detailed description of the input for calculating epfd limits and coordination triggers contained in Article **22** and Appendix **5** of the Radio Regulations.

The methodology is complex and in order to increase the confidence in any software tool, the Bureau felt that at least two independent implementations of Recommendation ITU-R S.1503 would be necessary. Accordingly, two commercial software development companies have developed EPFD tools for checking compliance under Article **22** or coordination requirements under Nos. **9.7A** and **9.7B**.

The Bureau finalized the software tools in accordance with Recommendation ITU-R S.1503-2.

Full details of the EPFD validation software which the Bureau will use to conduct its examination in accordance with the Resolution **85 (WRC-03)** can be found at

www.itu.int/ITU-R/go/epfd/en

Most of the information required to run software examinations are contained in the SRS database. However, because of the complex configurations of different non-GSO constellations it is difficult to simulate exact traffic configurations and transmitting parameters of the systems.

For that purpose Recommendation ITU-R S.1503-2 establishes a concept of a mask for pfd/e.i.r.p. produced by interfering non-GSO network stations. The mask would account for all the features of specific non-GSO systems arrangements.

These masks may contain very large amount of data. In order for administrations to submit the mask data electronically and for the EPFD software tool to use the submitted data directly the Bureau has developed an XML-format for the pfd and e.i.r.p. masks.

The EPFD validation software is integrated into BR GIBC software to conduct seamless examinations in a manner similar to current examinations in Appendix **8**/PFD modules of the GIBC software.