

EPFD and Recommendation ITU-R S.1503

Abstract: Non-GSO satellite networks wishing to operate in parts of C, Ku and Ka band must meet interference thresholds in the Radio Regulations defined using the Equivalent Power Flux Density (EPFD) metric. But what is EPFD and why is it used for these types of satellite networks? This White Paper describes the background to EPFD and its regulatory framework, in particular the algorithm in Recommendation ITU-R S.1503 which describes how to calculate the EPFD generated by a specific non-GSO FSS network.

What is EPFD?

EPFD stands for the Equivalent Power Flux Density, and is defined in Article 22.5C.1 of the Radio Regulations. At first sight this equation looks daunting, but at its core it is relatively straight-forward and builds on the concept of the power flux density or PFD.

The PFD can be calculated from a transmitter's EIRP as follows:

$$PFD = \frac{EIRP(\theta)}{4\pi d^2}$$

It can be seen to represent the power density of the radio signal as it passes through a square unit of distance (typically metres) at a distance d from the transmitter. As the EIRP could vary depending upon the direction (for example if the transmitter didn't use an isotropic antenna), the term depends upon angle, here identified using θ .

The idea of the EPFD is that in many cases the victim receiver has a directional antenna and so the impact of PFD on its performance will depend upon the relative gain towards the interfering station.

Hence:

$$EPFD = PFD \cdot G_{r,rel}(\varphi) = \frac{EIRP(\theta)}{4\pi d^2} G_{r,rel}(\varphi)$$

Now the EIRP in Watts can be calculated from the transmit power P in dBW and transmit gain as follows:

$$EIRP(\theta) = 10^{10} \cdot \frac{P}{G_t(\theta)}$$

Also the relative receive gain is the ratio of the receive gain in the required direction to the peak receive gain:

$$G_{r,rel}(\varphi) = \frac{G_r(\varphi)}{G_{r,max}}$$

The final stage is to note that the EPFD is an aggregate term and so must be summed over all contributing transmitting stations.

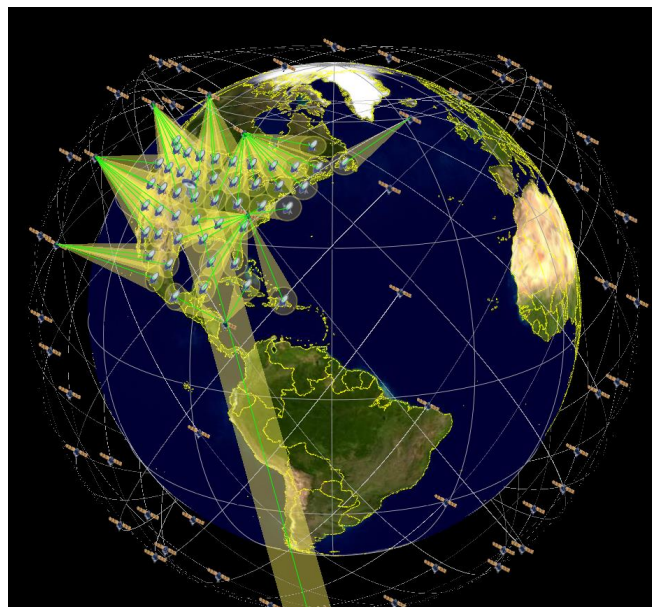
The result is the equation that defines EPFD in Article 22.5C.1 of the Radio Regulations:

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

Note that this in effect a measure of the level of interference at the victim receiver.

Why was EPFD introduced?

The history of EPFD is linked to the development of non-GSO fixed satellite service (FSS) satellite networks in the 1990s, in particular the SkyBridge system shown in the figure below:



SkyBridge non-GSO FSS Constellation

SkyBridge was proposed during the 1990s as an 80 satellite constellation operating in low earth orbit (LEO). It would have provided broadband data services on a near global basis.

To keep satellite and use equipment costs down it was proposed to use parts of Ku band already widely used by GSO satellites. The 1995 Radio Regulations (RR) Article 22.2 included an obligation for non-GSO space stations to “cease or reduce to a negligible level their emissions ... whenever there is unacceptable interference” to GSO satellite systems.

This caused two problems for the non-GSO operator, namely:

- How to define “unacceptable interference”?

- How to get the agreement of all of the many GSO operators?

There was a consequential concern to the GSO operators:

- How to ensure their systems would be protected from interference from the non-GSO network?

EPFD was the solution to these three questions:

- It defined what would be an acceptable level of interference in terms of the EPFD metric
- Any non-GSO network that met these limits were considered to have met their requirements under Article 22.2 to protect the GSO
- These limits were not to be exceeded for any location for any GSO network, hence providing GSO operators the protection they needed.

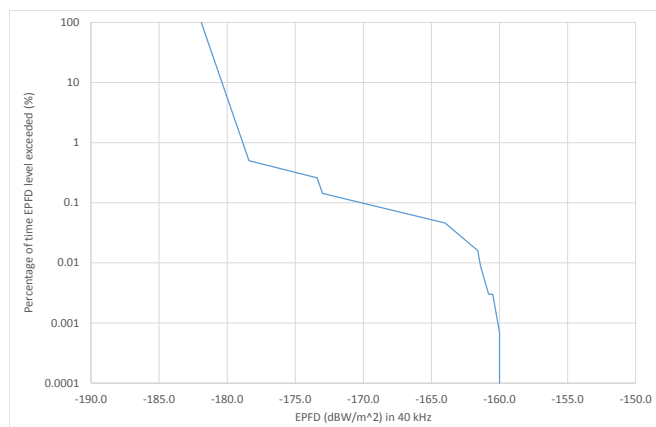
Different types of EPFD

It should be noted that there are different types of EPFD which provide different levels of protection. Firstly there are a number of different interference paths that need to be considered:

- EPFD(down): interference from the non-GSO satellite's downlink into the GSO system's downlink
- EPFD(up): interference from the non-GSO satellite's uplink into the GSO system's uplink
- EPFD(is): intersatellite interference from the non-GSO satellite's downlink into the GSO system's uplink

There are therefore in Article 22 of the RR three sets of EPFD "hard limits" which the non-GSO might have to meet, depending upon the frequency band(s) used.

The EPFD thresholds varied by frequency band, percentage of time and also receive antenna. A set of curves of EPFD vs. percentage of time are defined in the RR for the receive antenna gain patterns to be protected. An example is shown in the figure below:



EPFD(down) Thresholds for Ku band 1.8m Diameter Earth Stations

These EPFD levels are to be calculated using simulation (as discussed in the following section). The GSO operators also wanted to have mechanisms to manage measured levels of interference, such that if there were a drop in performance they could check the levels of interference detected from the non-GSO satellite network against expected levels.

These measured EPFD levels are in general slightly tighter than the hard EPFD thresholds and are called "operational EPFD limits" to distinguish them from the hard limit EPFD thresholds.

This White Paper focusses mostly on the hard limit EPFD limits rather than the operational (or indeed the additional operational) EPFD limits.

Article 22 vs. 9.7A and 9.7B

As well as the hard limits in Article 22, Appendix 5 also identifies situations where EPFD is used as a trigger for coordination under Articles 9.7A and 9.7B.

The conditions for Ku band at or below 12.75 GHz (and in brackets for frequencies above) are:

- Frequency overlap
- ES antenna gain ≥ 64 dBi (68 dBi)
- G/T ≥ 44 dB/K
- Emission bandwidth ≥ 250 MHz (800 MHz)

These are what are called the "Large Earth Stations" or LESs.

If these conditions are met then there are additional EPFD limits to check against. For Ku band at or below 12.75 GHz they are:

- -174.5 dBW/m²/40 kHz if the non-GSO satellites are at or below 2,500 km altitude
- -202 dBW/m²/40 kHz if the non-GSO satellites are above 2,500 km altitude

Both limits are for 100% of time and, as noted earlier, are coordination triggers rather than hard limits.

Calculating EPFD: Rec. S.1503

Article 22 of the Radio Regulations defines hard limits that non-GSO FSS networks must meet – and which the ITU Radiocommunication's Bureau (BR) must check – but how are they to do that?

The answer is the algorithm specified by Recommendation ITU-R S.1503: *Functional description to be used in developing software tools for determining conformity of non-geostationary-satellite orbit fixed-satellite system networks with limits contained in Article 22 of the Radio Regulations*

This document, mostly written by Transfinite consultants, defines how to calculate the EPFD levels that would be generated by a non-GSO network given parameters filled with the BR according to Appendix 4.

A key inputs are the power levels emitted by the non-GSO satellite and its earth stations, and the way these are defined depends upon the EPFD direction:

- EPFD(down): via a satellite emission PFD mask
- EPFD(up): via an ES EIRP mask and deployment density
- EPFD(IS): via a satellite EIRP mask

The reason for using masks is it permits the non-GSO to change their operational systems as long as they do not exceed the mask filled with the BR. In particular the use of the PFD mask for EPFD(down) simplifies the EPFD calculation to:

$$EPFD = PFD \cdot G_{r,rel}(\varphi)$$

This PFD mask can be defined in a number ways, including:

- α = alpha angle and difference in longitude
- X angle and difference in longitude
- Azimuth and elevation at the non-GSO satellite

The α angle is a key concept in Rec. S.1503 and it is defined as the minimum angle between:

- The line from the GSO ES to the non-GSO satellite
- The line from the GSO ES and any test point on the visible GSO arc

The X angle is similar but defined at the non-GSO satellite.

Rec. S.1503 comprises a number of key stages:

1. Identifying from the data filed and the EPFD thresholds in Article 22.2 what runs are required
2. For each run, identifying what location of GSO satellite and ES should be used in the run, defined as the Worst Case Geometry (WCG)
3. For each run, using the WCG locations for the GSO satellite and ES, simulating the non-GSO satellite system for sufficient time to get statistics of EPFD
4. Comparing the EPFD statistics calculated against the EPFD thresholds to get a pass/fail decision

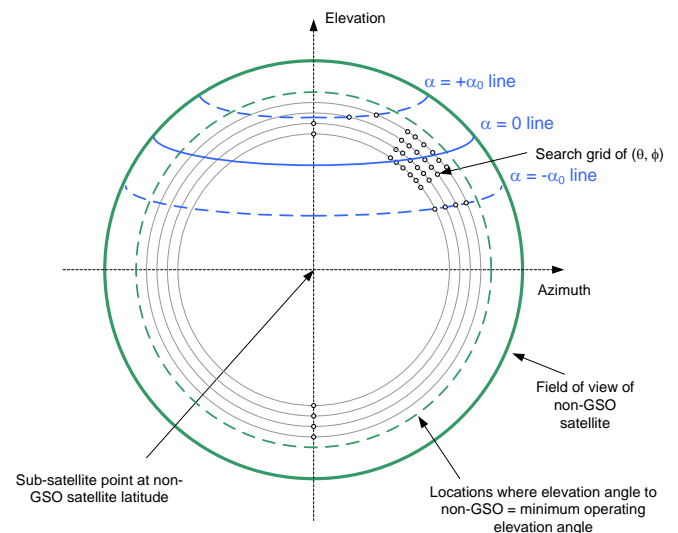
The Worst Case Geometry

A key concept in the algorithm in Rec. S.1503 is to select the location of the GSO satellite and ES that is the “worst” case. Here worst is interpreted as giving the highest single entry EPFD or, if there are multiple locations with equally high single entry EPFD, the one that would have this EPFD value for the largest percentage of time.

This can be very complex to calculate given the wide range of possible inputs! It depends upon:

- The PFD mask
- The satellite network’s orbit parameters
- The run’s ES antenna pattern
- The system’s operating parameters such as minimum elevation angle and number of co-frequency satellites etc

Typically it is necessary to search across the field of view of the non-GSO satellite, a task complicated by the use of the non-linear α angle as shown in the figure below:



EPFD(down) Search for Worst Case Geometry

Visualyse EPFD

We have been using EPFD as a metric in our main simulation study tool, Visualyse Professional, for many years prior to the inclusion of EPFD in the Radio Regulations. Many of the studies of the SkyBridge system in the 1990s were undertaken using our software products.

But the algorithm in Recommendation ITU-R S.1503 is highly specialised and in particular the user interface requirements are very different.

Visualyse Professional is what we call a “Study Tool” – you can ask “what if?” questions and see what the outcome would be, undertaking sharing studies between a very wide range of service types. This means that the user interface has been designed for flexibility, allowing almost any input parameter to be modified.

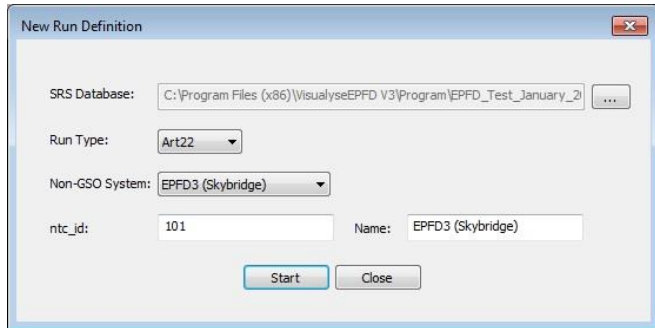
However analysis under Rec. S.1503 is in principle a lot simpler because:

- The inputs are defined by Appendix 4 and captured in the ITU’s SRS database

- The output is a yes/no decision together with supporting results such the EPFD cumulative distribution functions (CDFs)

We therefore decided to develop a tool that specifically implements the algorithm in Rec. S.1503, and that product is called Visualyse EPFD.

The input is a selection of the network to analyse as shown in the figure below:



Network and Run Type Selection

From this Visualyse EPFD queries the thresholds in Article 22 of the RR to develop the runs required as in the list below:

Run	Frequency	Antenna	Service	Gain Pattern	Bandwidth
Up					
At Start	12.500	4.000	FSS	ITU-R S.672, Ls -20	40.000
At Start	17.300	4.000	FSS	ITU-R S.672, Ls -20	40.000
At Start	27.500	1.550	FSS	ITU-R S.672, Ls -10	40.000
At Start	29.500	1.550	FSS	ITU-R S.672, Ls -10	40.000
Down					
At Start	10.700	0.600	FSS	ITU-R S.1428	40.000
At Start	10.700	1.200	FSS	ITU-R S.1428	40.000
At Start	10.700	3.000	FSS	ITU-R S.1428	40.000
At Start	10.700	10.000	FSS	ITU-R S.1428	40.000
At Start	17.800	1.000	FSS	ITU-R S.1428	40.000
At Start	17.801	1.000	FSS	ITU-R S.1428	1000.000
At Start	17.800	2.000	FSS	ITU-R S.1428	40.000
At Start	17.801	2.000	FSS	ITU-R S.1428	1000.000
At Start	17.800	5.000	FSS	ITU-R S.1428	40.000
At Start	17.801	5.000	FSS	ITU-R S.1428	1000.000
At Start	19.700	0.700	FSS	ITU-R S.1428	40.000
At Start	19.701	0.700	FSS	ITU-R S.1428	1000.000
At Start	19.700	0.900	FSS	ITU-R S.1428	40.000
At Start	19.701	0.900	FSS	ITU-R S.1428	1000.000
At Start	19.700	2.500	FSS	ITU-R S.1428	40.000
At Start	19.701	2.500	FSS	ITU-R S.1428	1000.000
At Start	19.700	5.000	FSS	ITU-R S.1428	40.000
At Start	19.701	5.000	FSS	ITU-R S.1428	1000.000
At Start	11.700	0.300	BSS	ITU-R BO.1443	40.000
At Start	11.700	0.450	BSS	ITU-R BO.1443	40.000
At Start	11.700	0.600	BSS	ITU-R BO.1443	40.000
At Start	11.700	0.900	BSS	ITU-R BO.1443	40.000
At Start	11.700	1.200	BSS	ITU-R BO.1443	40.000
At Start	11.700	1.800	BSS	ITU-R BO.1443	40.000
At Start	11.700	2.400	BSS	ITU-R BO.1443	40.000
At Start	11.700	3.000	BSS	ITU-R BO.1443	40.000
IS					
At Start	10.700	4.000	FSS	ITU-R S.672, Ls -20	40.000
At Start	17.800	4.000	FSS	ITU-R S.672, Ls -20	40.000

Example Run Schedule

For run Visualyse EPFD calculates the WCG (though see discussion below) and run duration time step size.

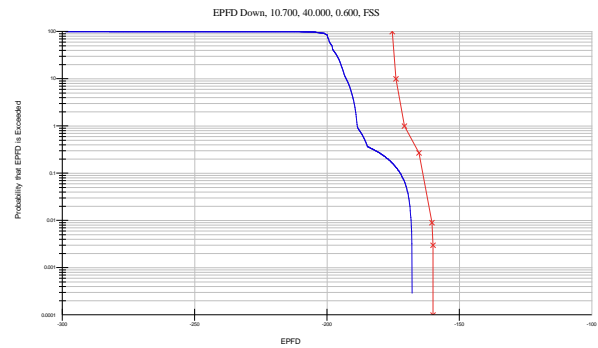
Each run can then be started independently or all in one go. The software includes a graphical user interface

(GUI) that shows the location of each of the satellites and gives feedback as to the intermediate values of the EPFD calculation:



Visualyse EPFD Run Map View

At the end of each run the CDF of EPFD is compared against the threshold in Article 22 of the RR to give a pass / fail decision:



Resulting EPFD CDF (blue) and Threshold (red)

Updates to S.1503

During the development of Visualyse EPFD, a number of updates were identified to improve the algorithm in S.1503. In particular there were two areas requiring updating:

1) The Worst Case Geometry Algorithm

The original version of the WCG in S.1503 was found to be insufficient to analyse all cases and implementation was therefore limited. A revised WCG algorithm was therefore developed by Transfinite consultants.

2) New non-GSO FSS Networks

The original focus of Rec. S.1503 were SkyBridge style networks: satellites in circular orbit providing global coverage. However recently there have been proposals for a wider range of orbit types and architectures, including equatorial orbits and highly elliptical orbits.

These two changes to the algorithm were documented in a DRR to Rec. S.1503 which was approved by ITU Study Group 4 towards the end of 2013 as S.1503-2. The next step is to update our software to include these new algorithms.

How we can help

We are world experts on EPFD and the verification of non-GSO networks against the limits in Article 22 of the Radio Regulations.

We can help GSO and non-GSO operators in a number of ways including:

Consultancy Work

Our consultants can assist you by:

- Checking a non-GSO network meets the EPFD limits in Article 22 of the RR given a PFD mask
- Calculation of the PFD mask for a non-GSO network
- Optimisation of the PFD mask so that it meets the EPFD limits while maximising service
- Checking a non-GSO network would meet the EPFD limits for a specific GSO network
- Undertaking coordination work between the large ESs and non-GSO networks
- Supporting the filing of non-GSO network's parameters with the ITU
- Undertaking detailed EPFD analysis using Visualyse Professional
- Non-GSO network systems design and coverage analysis

Regulatory Support

- We can provide a range of services to support regulatory activities including licensing and representation at international and regional meetings (e.g. ITU and CEPT).
- We have detailed experience in developing ITU-R Recommendations and approval at ITU-R Study Groups and Working Parties

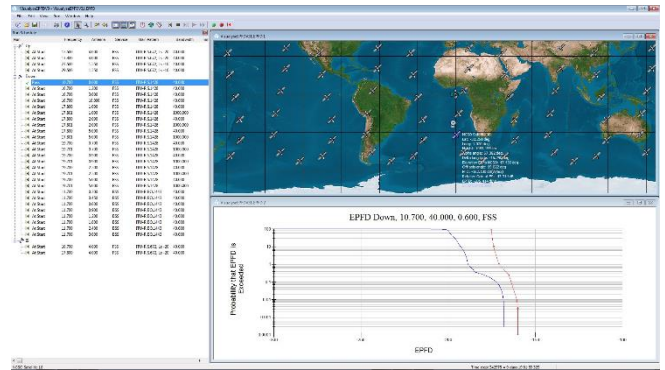
Visualyse EPFD

Our Visualyse EPFD software is the leading implementation of the algorithm in Rec. ITU-R S.1503. It has been verified during testing with the ITU BR and can calculate:

- EPFD(up)
- EPFD(down)
- EPFD(IS)

It can also analyse both the Article 22 and Articles 9.7A and 9.7B cases.

It is available in two versions, one the ITU's "black-box" for pass/fail decisions and the other a product with graphical user interface that provides feedback on the calculation process and allows additional options to be modified.



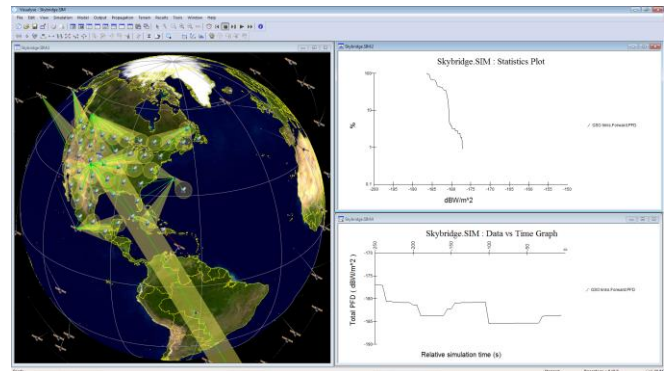
Visualyse EPFD Screenshot

Visualyse Professional

Our desktop study tool Visualyse Professional can be used to analyse radio systems including both GSO and non-GSO networks.

Unlike Visualyse EPFD which uses the PFD mask approach in Rec.S.1503, Visualyse Professional calculates EPFD using a full simulation approach that models each beam and the tracking strategies involved.

This can model actual operation and include all the three EPFD cases of up, down and intersatellite. It could, for example, be used during the coordination triggered by Article 9.7A and 9.7B of the RR.



Visualyse Professional Screenshot

Visualyse GSO

We have developed Visualyse GSO to support satellite coordination tasks, in particular for GSO satellites. It includes IFIC checking, detailed C/I calculations and integrates with ITU databases such as the SRS/IFIC and GIMS. It can be also used to identify coordination requirements of non-GSO satellites.

Contact us

If you have any questions or comments about this White Paper or would like more information please do not hesitate to contact us at:

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