Attachment 2
December 27, 2016 Supplement
Demonstration of EPFD Compliance

This analysis demonstrates that the Karousel NGSO system will operate in compliance with single-entry EPFD limits of No's 22.5C, 22.5D and 22.5F of the ITU Radio Regulations ("RR's") in Ku-band and Ka-band segments where access is requested. The Ku-band frequency segments include 10.7-12.7 (space-to-Earth) and 14-14.5 GHz (Earth-to-space). The Ka-band frequency segments include 17.3-19.3 GHz and 19.7-20.2 GHz (space-to-Earth) and 27.5-30 GHz (Earth-to-space).

1.0 EPFD Validation Software

The evaluation of EPFD limits was performed using the latest ITU EPFD validation software in compliance with ITU-R S.1503-2.[1] This software was developed to identify coordination requirements under No.'s 9.7A and 9.7B of the RR's and to verify that the NGSO system complies with the ITU Article 22 single-entry EPFD limits.

This software was used to generate the EPFD curves contained herein, and thereby demonstrate that the Karousel system is in compliance with the applicable ITU Article 22 EPFD limits. Along with this submission, Karousel is providing the Commission, the input files that allow independent verification that the Karousel system complies with the single-entry EPFD limits of No.'s 22.5C, 22.5D and 22.5F of the RR's in the applicable band segments. These input parameters include the orbital characteristics and transmission parameters of the Karousel system as well as the PFD and/or EIRP masks required by the ITU's EPFD validation software.

2.0 Downlink EPFD

The downlink PFD masks are provided in an Az/El format in accordance with the EPFD software manual. For this filing, the masks are expressed in terms of azimuth and elevation angles relative to the satellite's nadir (or sub-satellite) point. The PFD masks vary as a function of satellite latitude, but the EPFD software does not currently accept different masks for rising and falling satellites. As such, the mask is an upper envelope representing the maximum possible PFD for either rising or falling satellites. The mask also encodes the satellite latitude-based exclusion strategy that Karousel employs to facilitate sharing with GEO satellites; specifically, the PFD for satellite latitudes between 35 south and 35 north are set to be very low to simulate the satellite beams being non-operational.

For the Ku-band and lower frequency Ka-band beams (from 10.7 -12.7 GHz and 17.8 to 19.3 GHz), the mask files were generated to be consistent with steering the Karousel satellite beams anywhere on the visible earth. This worst-case behavior reflects the steerable nature of the spot beams and CONUS beam, and, since the PSD is higher for the spot beams than for the global horn, also captures the Karousel global horn. For each latitude in the mask file, the masks were generated assuming that constant PSD (consistent with the Schedule S information) was directed

[1] Equivalent Power Flux-Density Limits Validation Software Test Version: BR ITU, October 2016, Version 1.1; GIBC Version 9.0.0.28 EPFD November 2016.

at all visible earth-fixed locations. For azimuth and elevation angles which lie off the earth, the mask contains very low power because these directions are not required for the simulation of downlink EPFD. The PFD masks were generated using the worst-case power spectral density from the Schedule S, -22.7 dBW/Hz, although lower powers are used for some beams in Ku-band and for the CONUS beam.

For the upper Ka-band beams, this worst-case performance analysis does not comply with the EPFD sharing rules. To comply with the sharing limits in the 19.7-20.2 GHz downlink band (analyzed at 19.7 GHz), either lower powers are required (by approximately 3 dB) or restrictions on providing service near the extreme polar regions. The PFD masks simulated for this filing follow the latter strategy. For the Ka-band beams, the PFD masks are consistent with centering the Ka-band spot beam anywhere on the earth between 74 south and 74 north latitude. This allows Karousel to provide Ka-band service in this sub-band to the vast majority of the planet without any EIRP restriction.

For all runs, the minimum elevation angle for Karousel user terminals (and corresponding worst case peak of a Karousel beam) has been set to five degrees. In addition, the number of satellites transmitting simultaneously has been set to one since Karousel will be covering earth-fixed locations with just one satellite at a time.

The figures below show plots of the downlink EPFD cumulative distribution functions and limits as produced by the ITU-provided EPFD software. First presented are the plots for 11.7 GHz BSS (Figures 2-1 through 2-8), which are based on a BO.1443 antenna pattern. These limits are evaluated with the required fixed reference bandwidth of 40 kHz and eight different terminal sizes. Following the BSS plots are plots for 10.7 GHz FSS (Figures 2-9 through 2-12), which are evaluated for four different terminal sizes and a 40kHz reference bandwidth. After the 10.7 GHz FSS plots, we present results for 17.8 GHz FSS (Figures 2-13 through 2-18), which are evaluated for three different terminal sizes and the two required reference bandwidths (RB=40kHz and 1MHz). Finally, we present results for the 19.7 GHz FSS band (Figures 2-19 through 2-26), which is evaluated for four terminal sizes and the required two reference bandwidths (40 kHz and 1MHz). All FSS bands are evaluated using an ITU S.1428 antenna pattern. All plots have been generated by the ITU software based on the configurations provided.

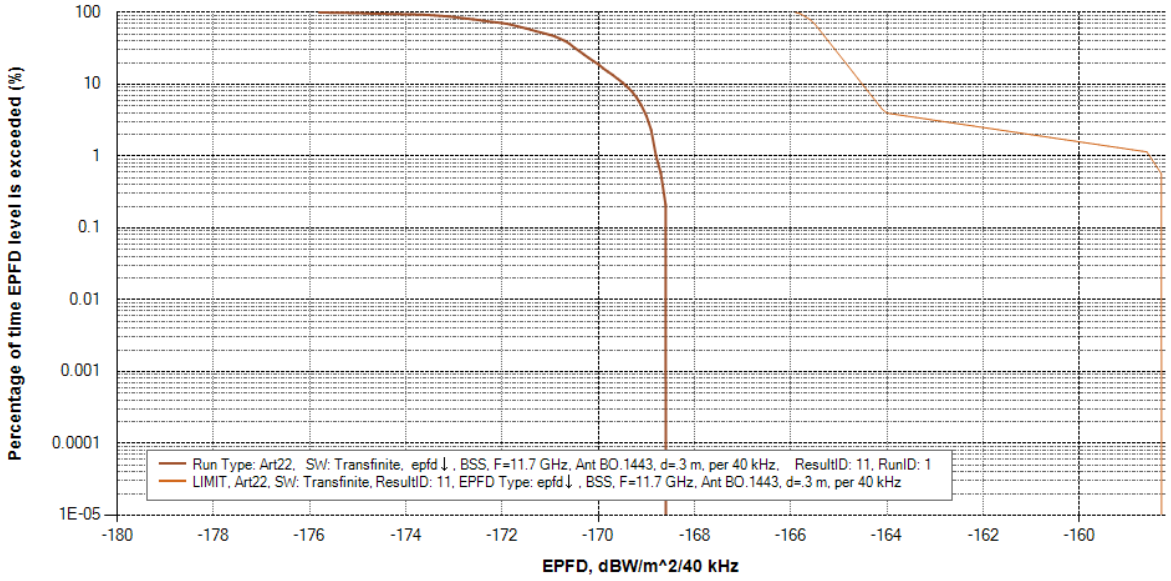

Figure 2-1. EPFD downlink validation at 11.7 GHz (BSS), RB=40 kHz and terminal size=30 cm

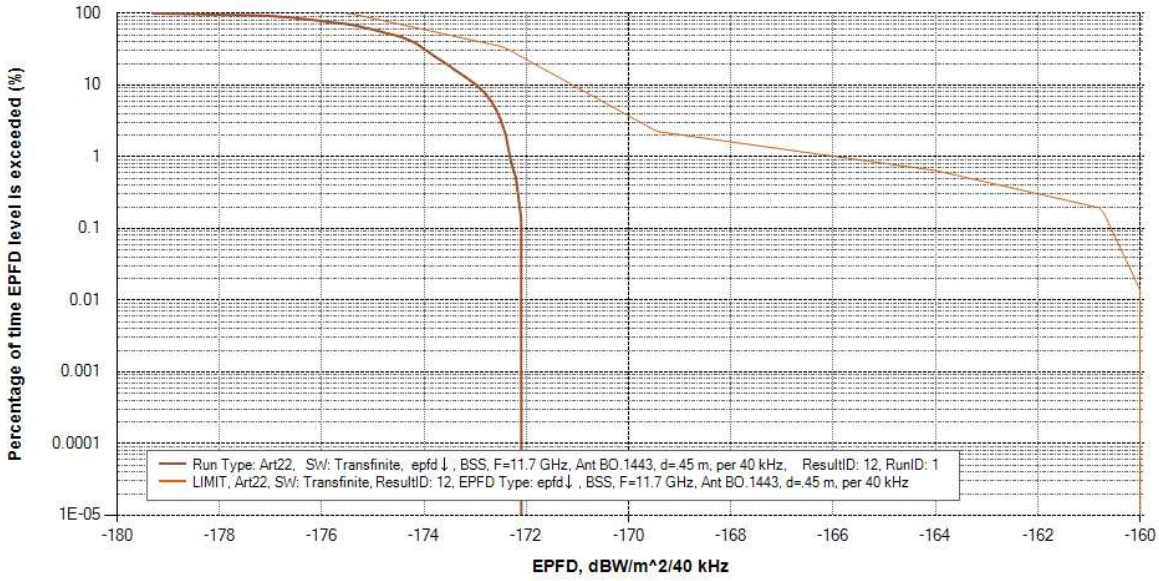

Figure 2-2. EPFD downlink validation at 11.7 GHz (BSS), RB=40 kHz and terminal size=45 cm

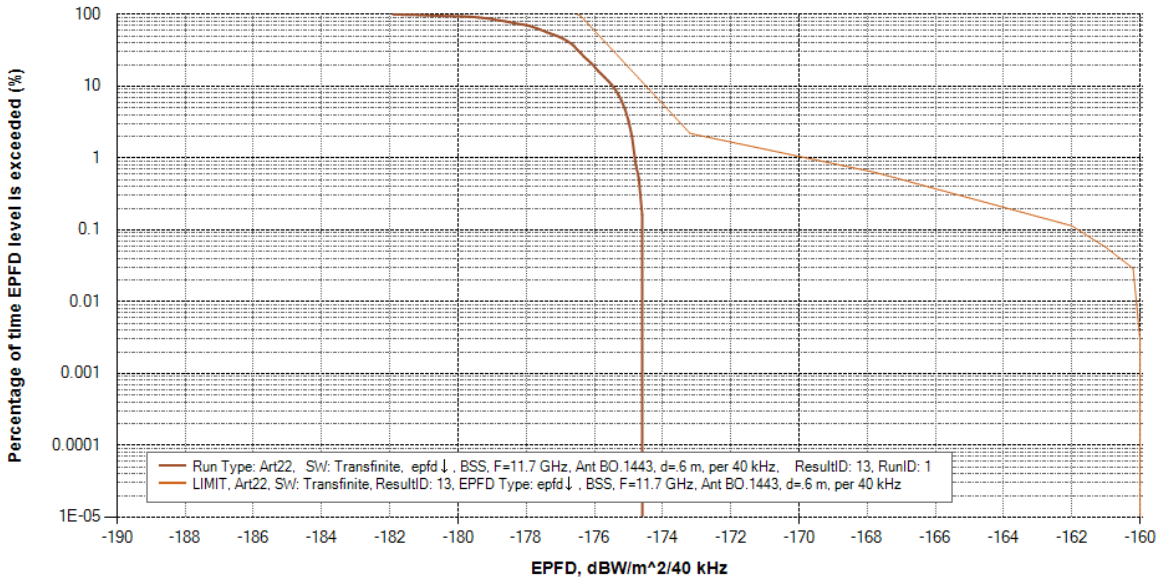

Figure 2-3. EPFD downlink validation at 11.7 GHz (BSS), RB=40 kHz and terminal size=60 cm

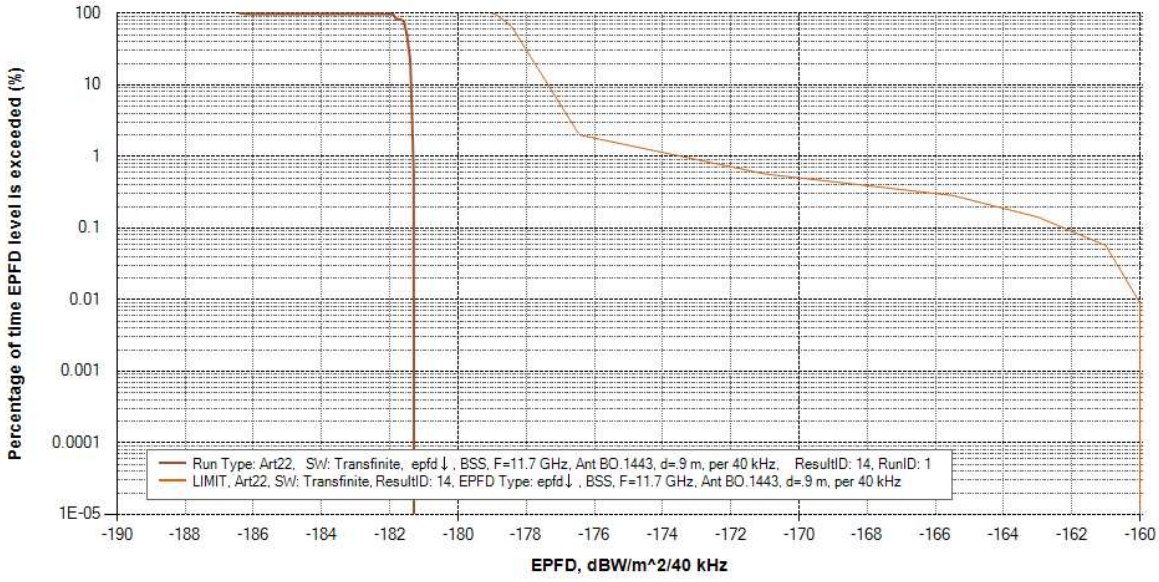

Figure 2-4. EPFD downlink validation at 11.7 GHz (BSS), RB=40 kHz and terminal size=90 cm

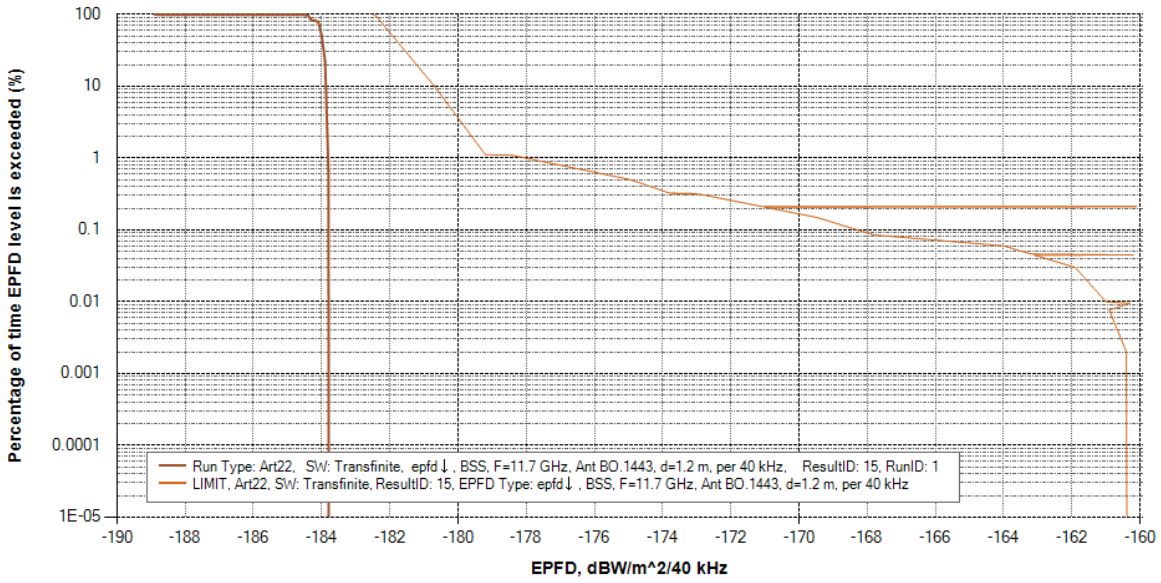

Figure 2-5. EPFD downlink validation at 11.7 GHz (BSS), RB=40 kHz and terminal size=1.2 m

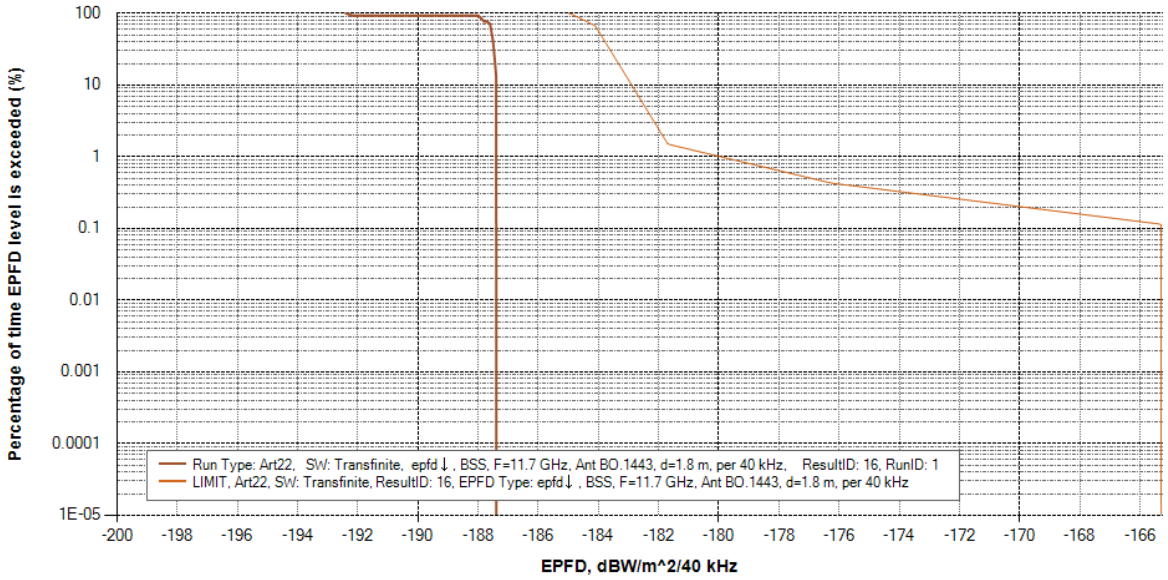

Figure 2-6. EPFD downlink validation at 11.7 GHz (BSS), RB=40 kHz and terminal size=1.8 m

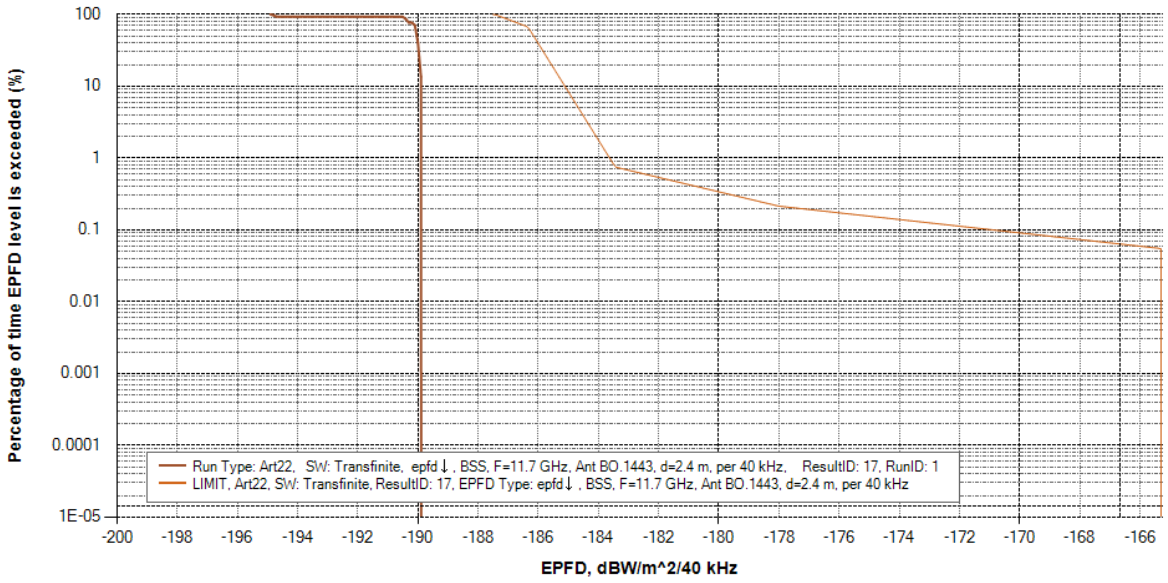

Figure 2-7. EPFD downlink validation at 11.7 GHz (BSS), RB=40 kHz and terminal size=2.4 m

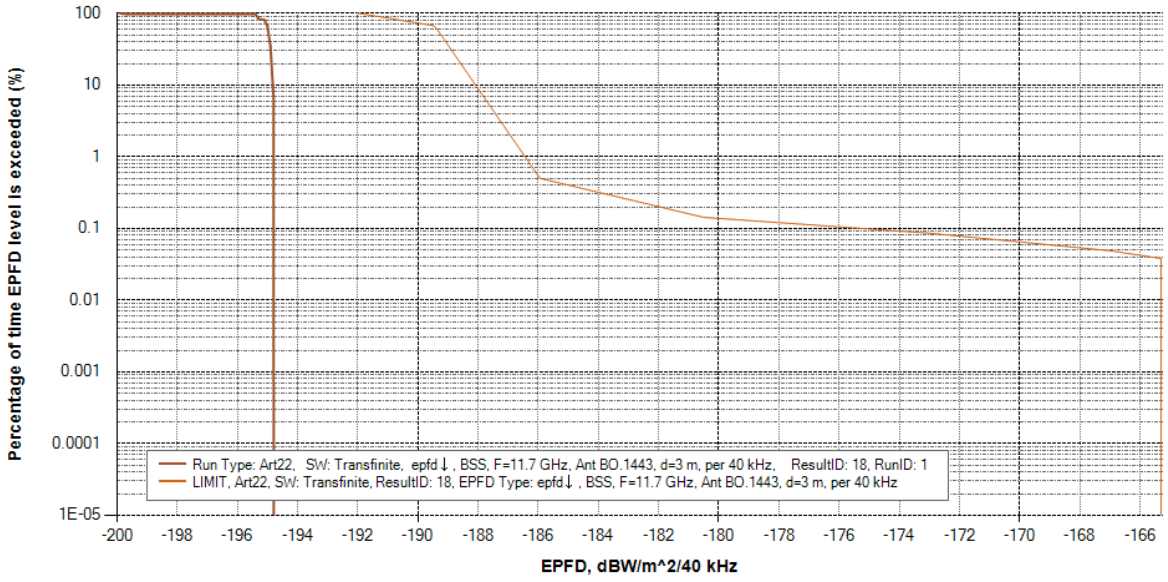

Figure 2-8. EPFD downlink validation at 11.7 GHz (BSS), RB=40 kHz and terminal size=3 m

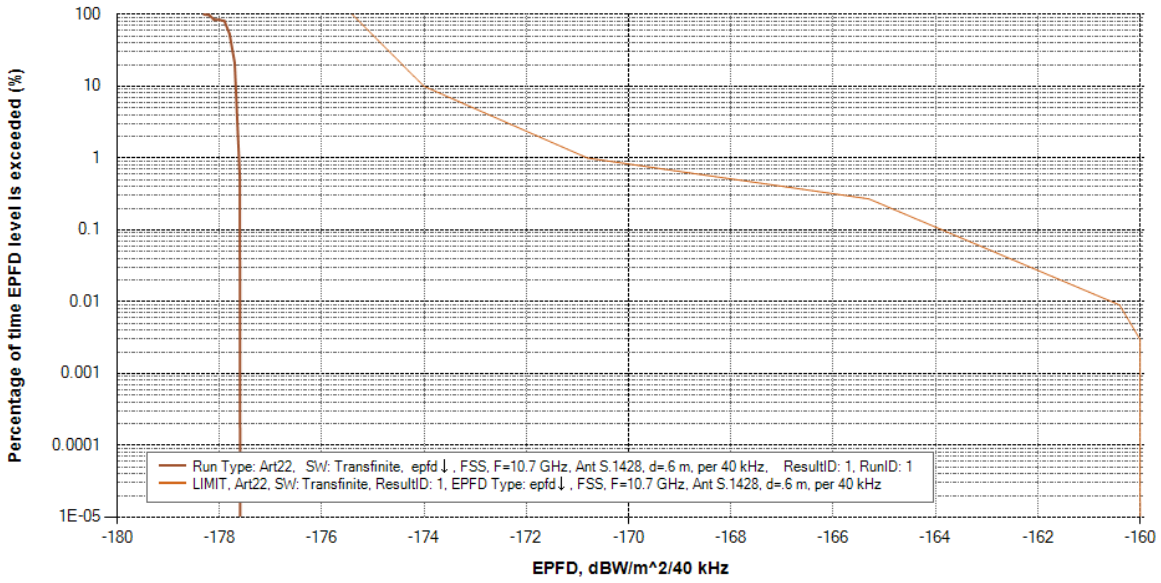

Figure 2-9. EPFD downlink validation at 10.7 GHz (FSS), RB=40 kHz and terminal size=60 cm

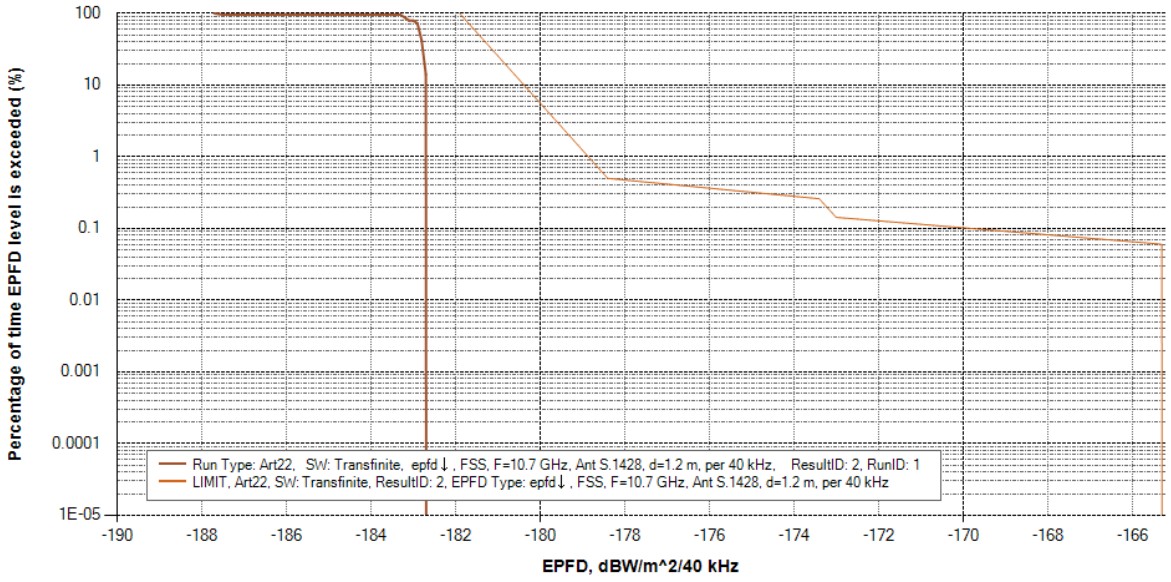

Figure 2-10. EPFD downlink validation at 10.7 GHz (FSS), RB=40 kHz and terminal size=1.2 m

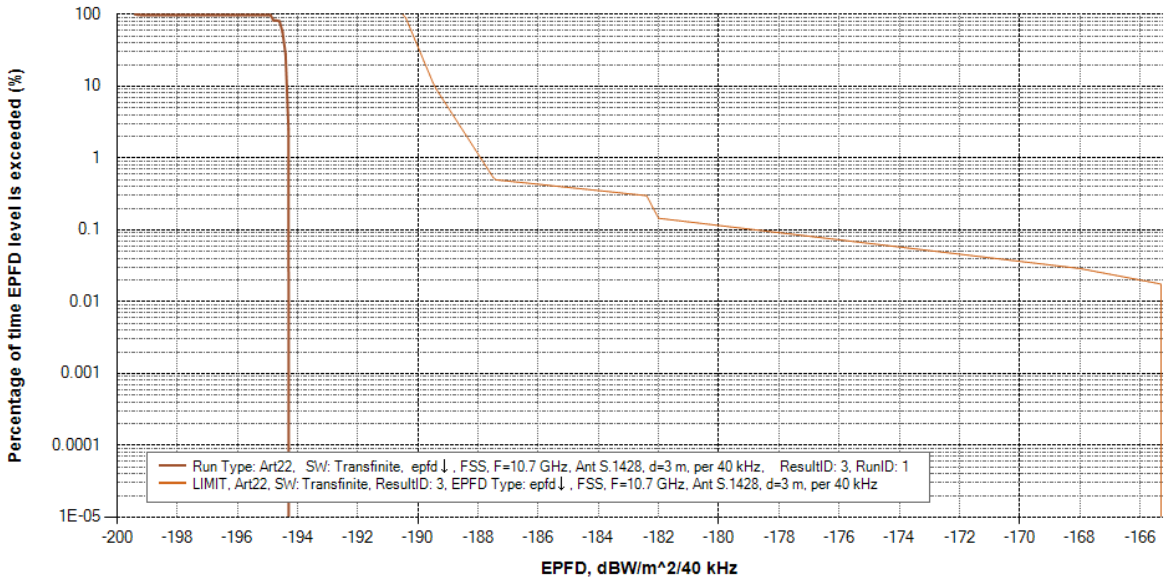

Figure 2-11. EPFD downlink validation at 10.7 GHz (FSS), RB=40 kHz and terminal size=3 m

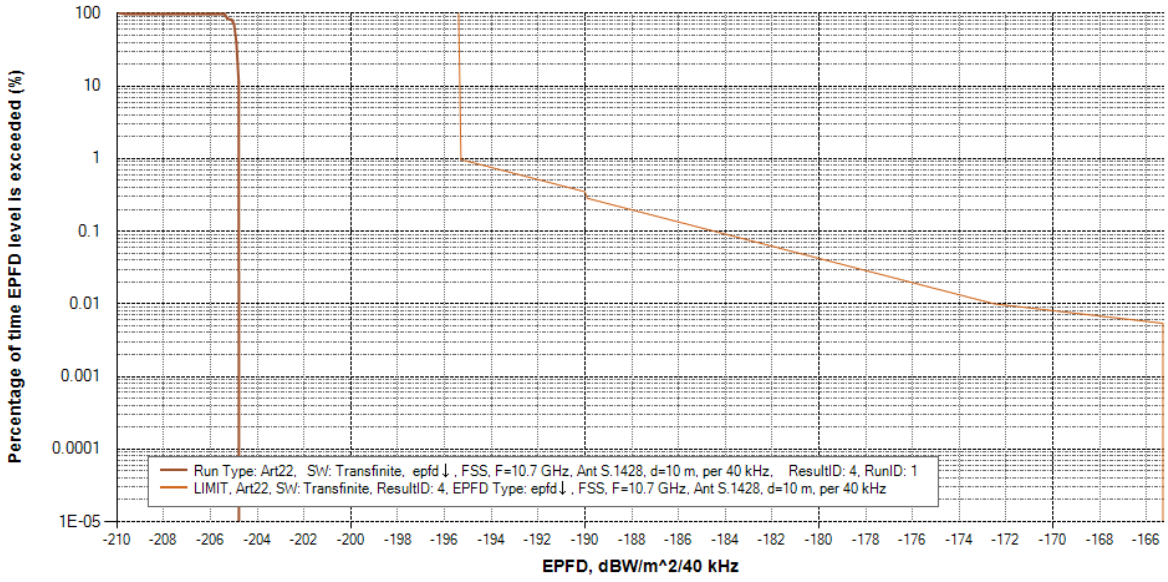

Figure 2-12. EPFD downlink validation at 10.7 GHz (FSS), RB=40 kHz and terminal size=10 m

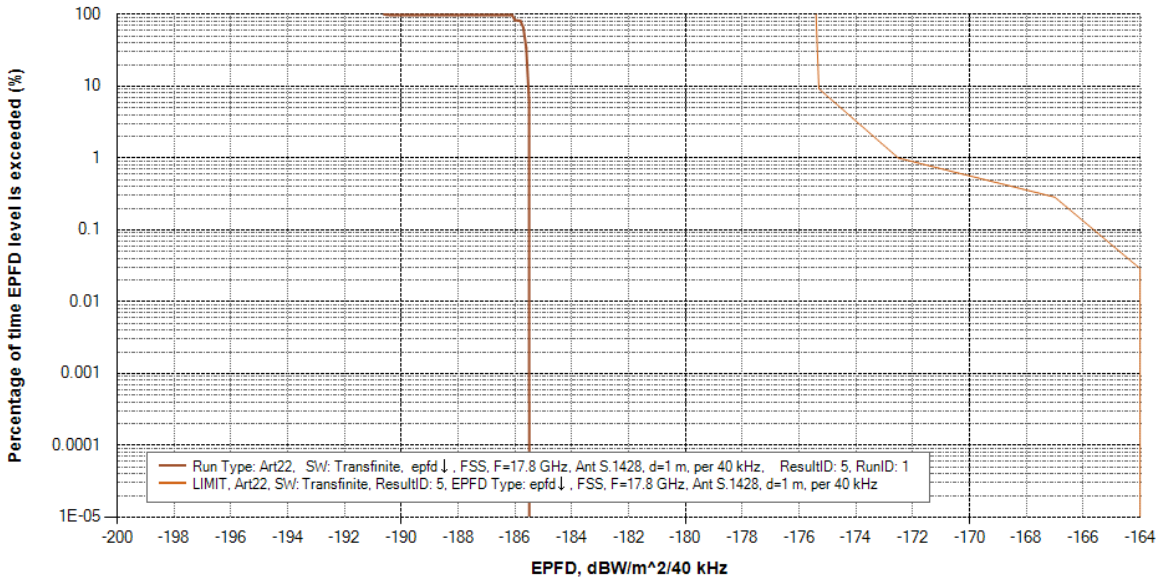

Figure 2-13. EPFD downlink validation at 17.8 GHz (FSS), RB=40 kHz and terminal size=1 m

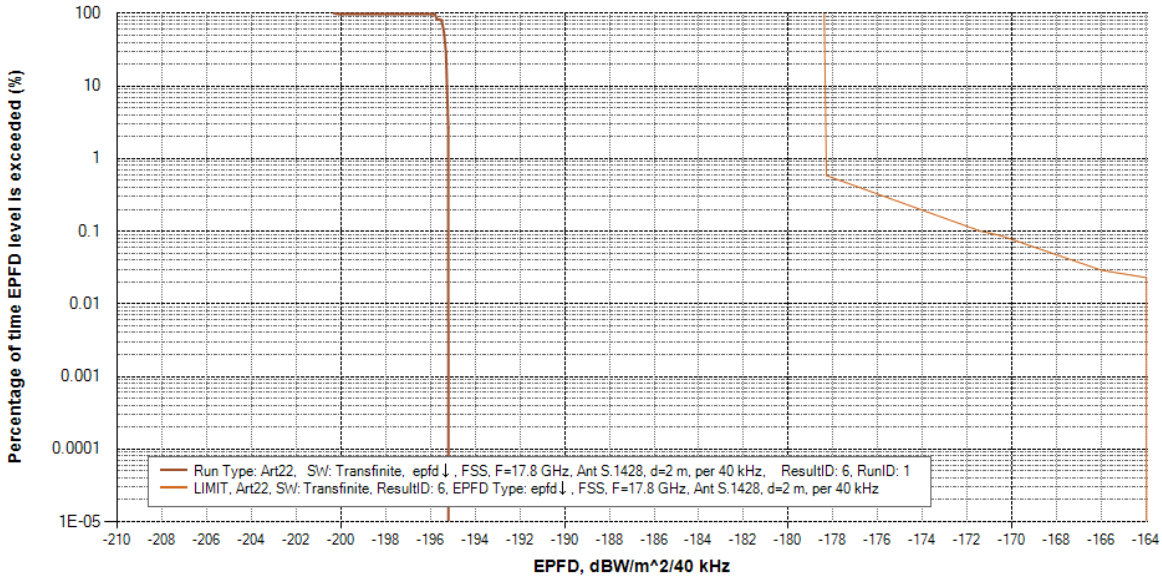

Figure 2-14. EPFD downlink validation at 17.8 GHz (FSS), RB=40 kHz and terminal size=2 m

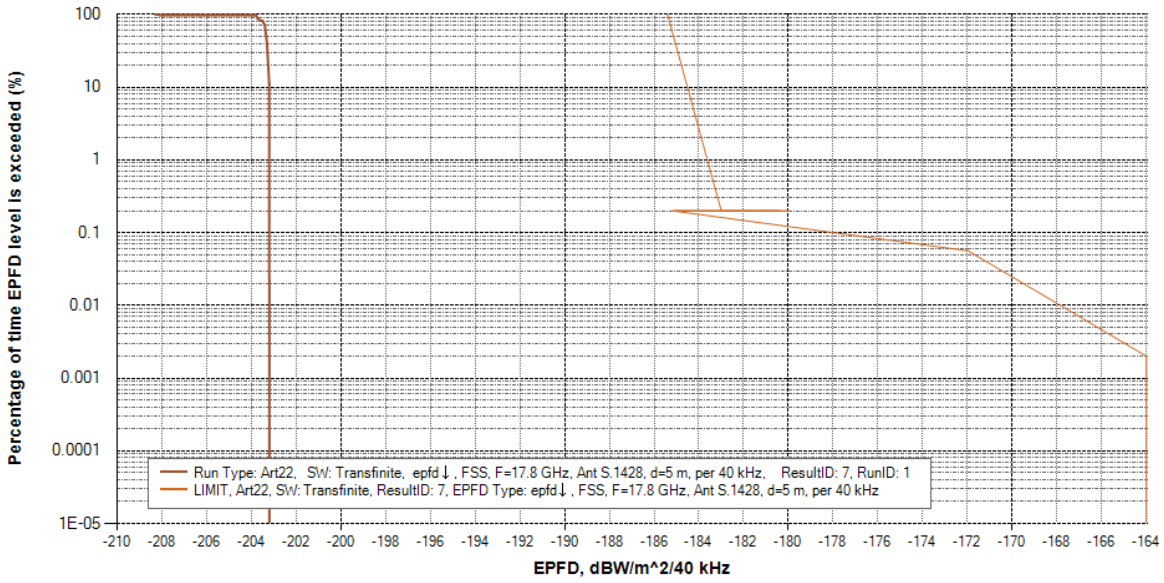

Figure 2-15. EPFD downlink validation at 17.8 GHz (FSS), RB=40 kHz and terminal size=5 m

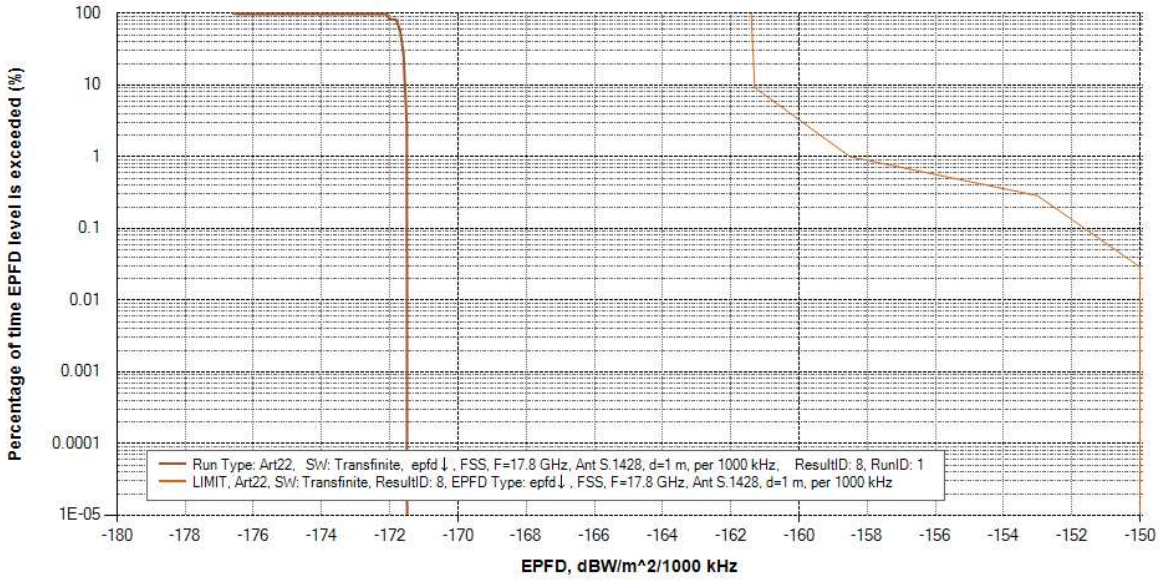

Figure 2-16. EPFD downlink validation at 17.8 GHz (FSS), RB=1 MHz and terminal size=1 m

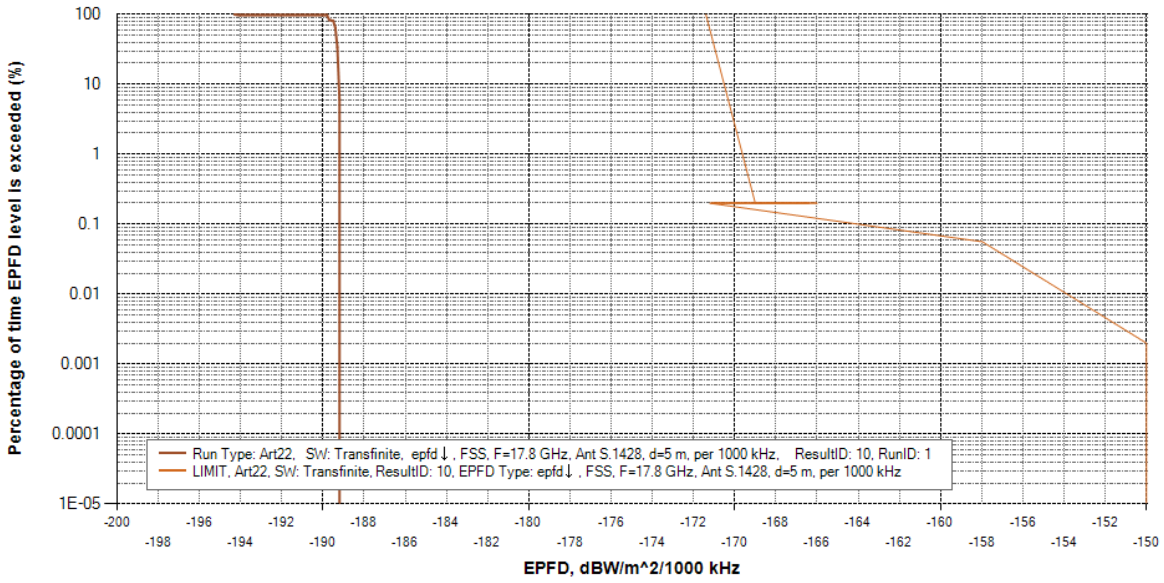

Figure 2-17. EPFD downlink validation at 17.8 GHz (FSS), RB=1 MHz and terminal size=5 m

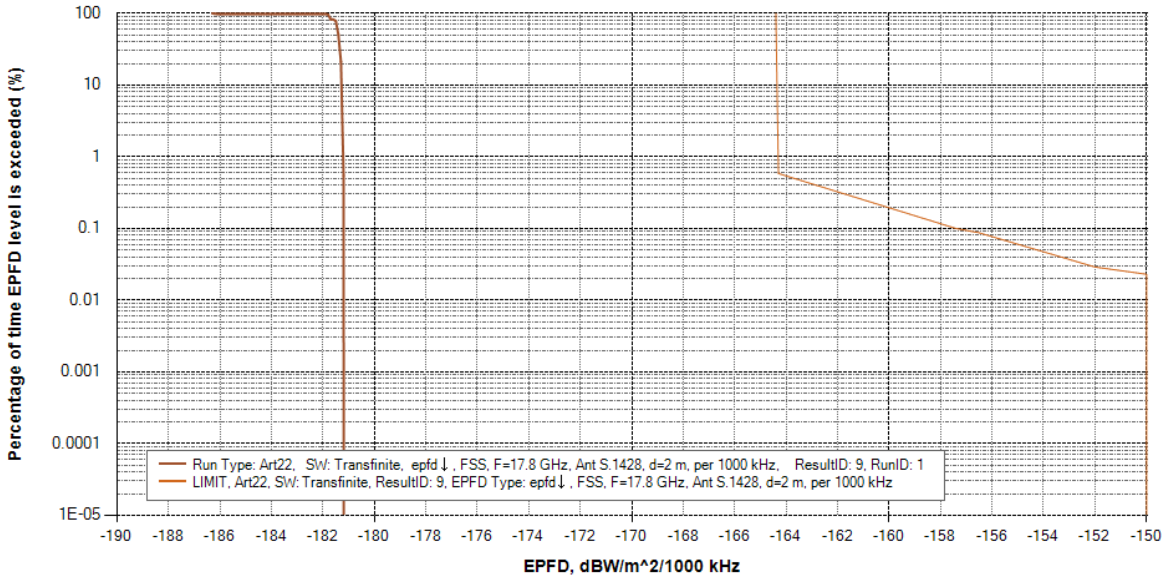

Figure 2-18. EPFD downlink validation at 17.8 GHz (FSS), RB=1 MHz and terminal size=2 m

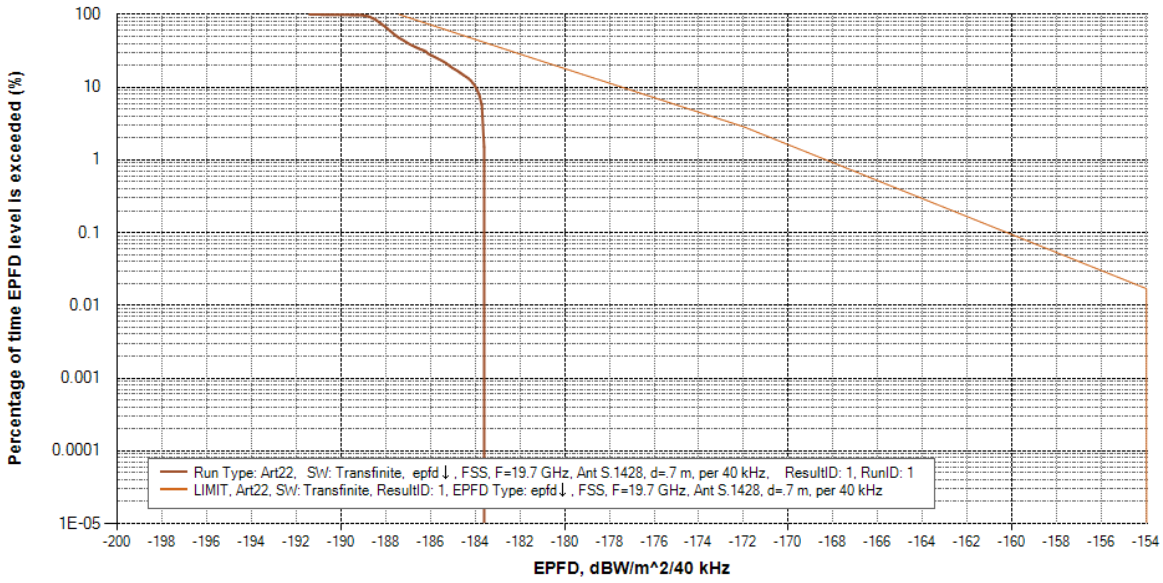

Figure 2-19. EPFD downlink validation at 19.7 GHz (FSS), RB=40 kHz and terminal size=70cm

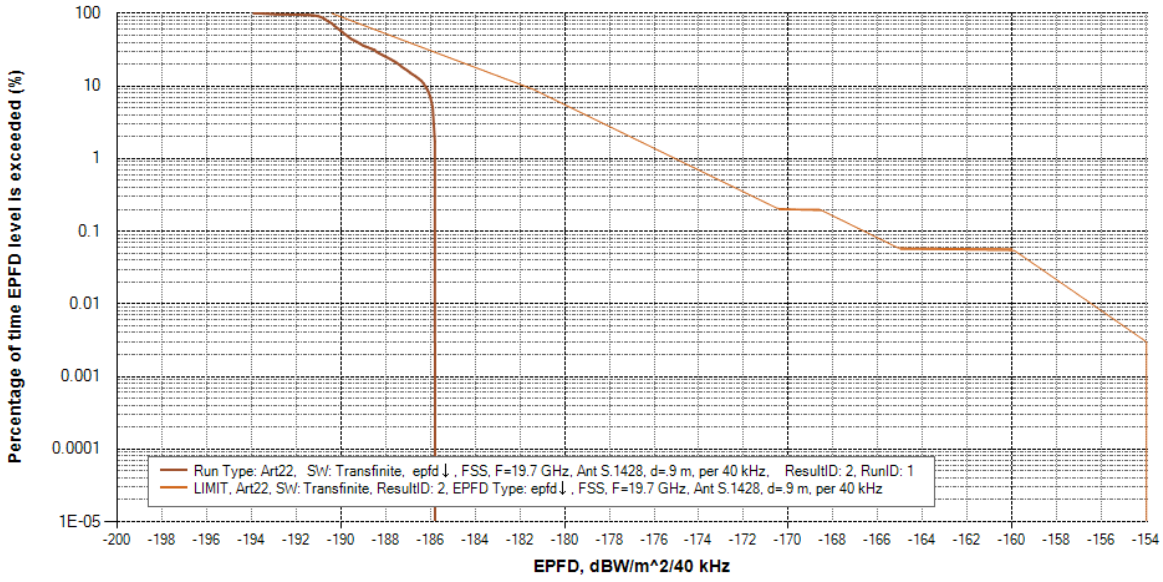

Figure 2-20. EPFD downlink validation at 19.7 GHz (FSS), RB=40 kHz and terminal size=90cm

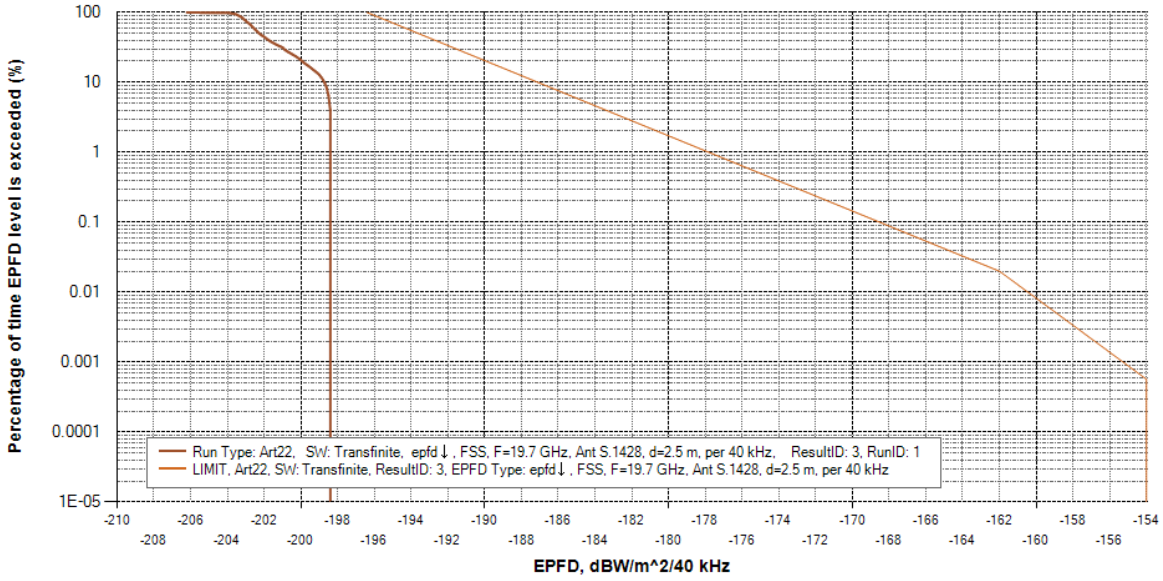

Figure 2-21. EPFD downlink validation at 19.7 GHz (FSS), RB=40 kHz and terminal size=2.5m

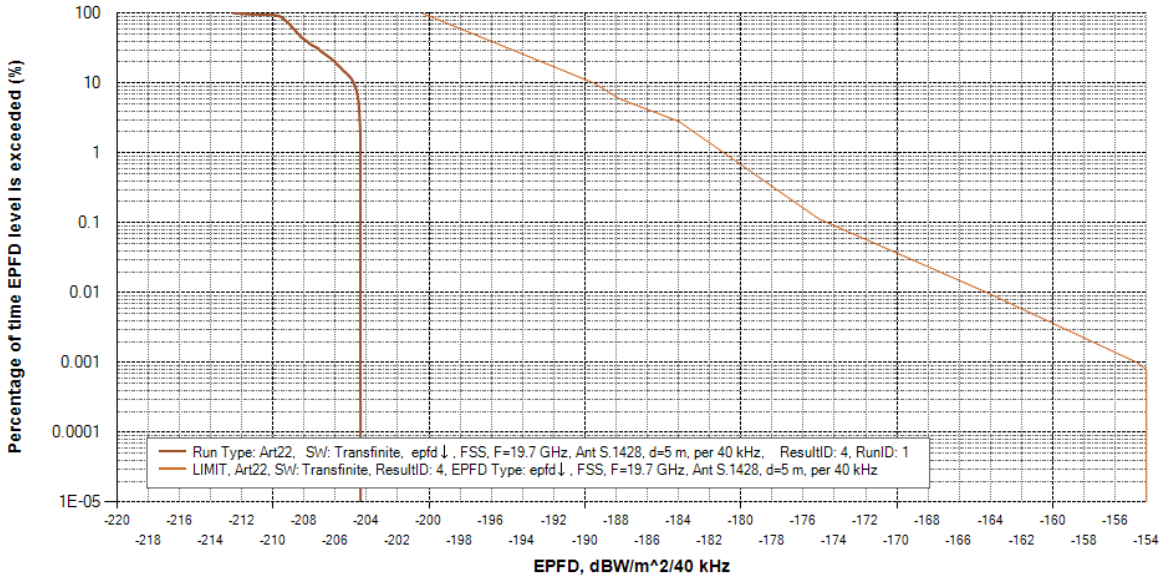

Figure 2-22. EPFD downlink validation at 19.7 GHz (FSS), RB=40 kHz and terminal size=5m

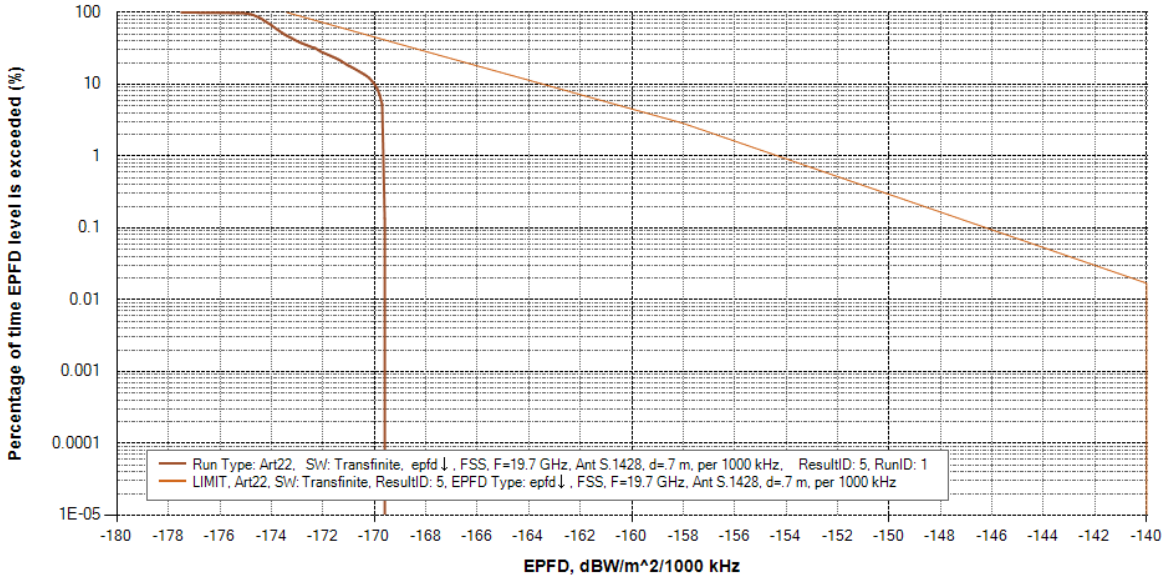

Figure 2-23. EPFD downlink validation at 19.7 GHz (FSS), RB=1 MHz and terminal size=70cm

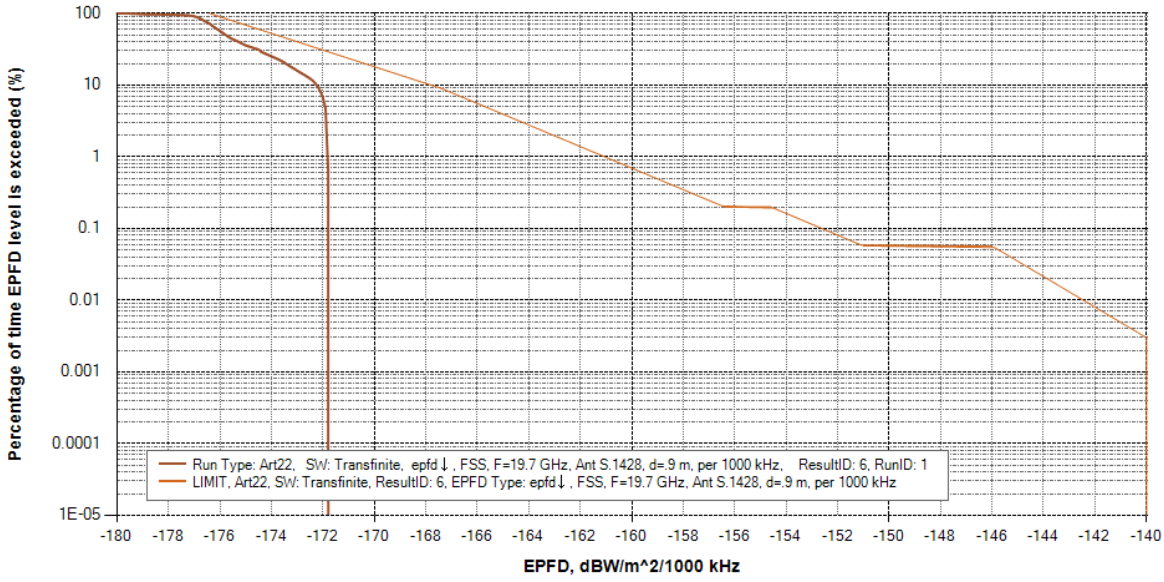

Figure 2-24. EPFD downlink validation at 19.7 GHz (FSS), RB=1 MHz and terminal size=90cm

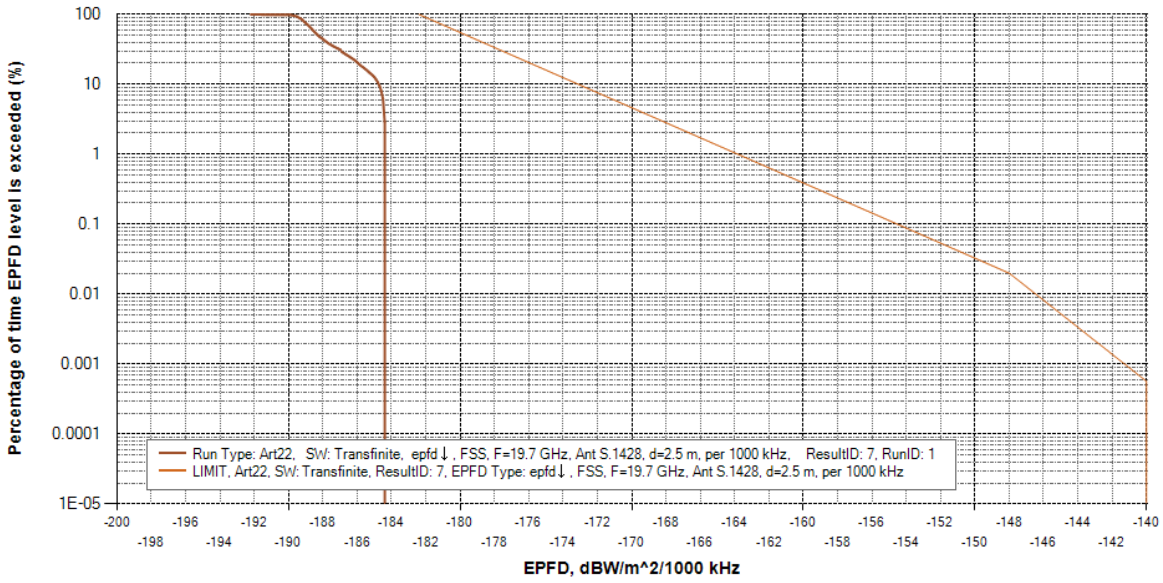

Figure 2-25. EPFD downlink validation at 19.7 GHz (FSS), RB=1 MHz and terminal size=2.5m

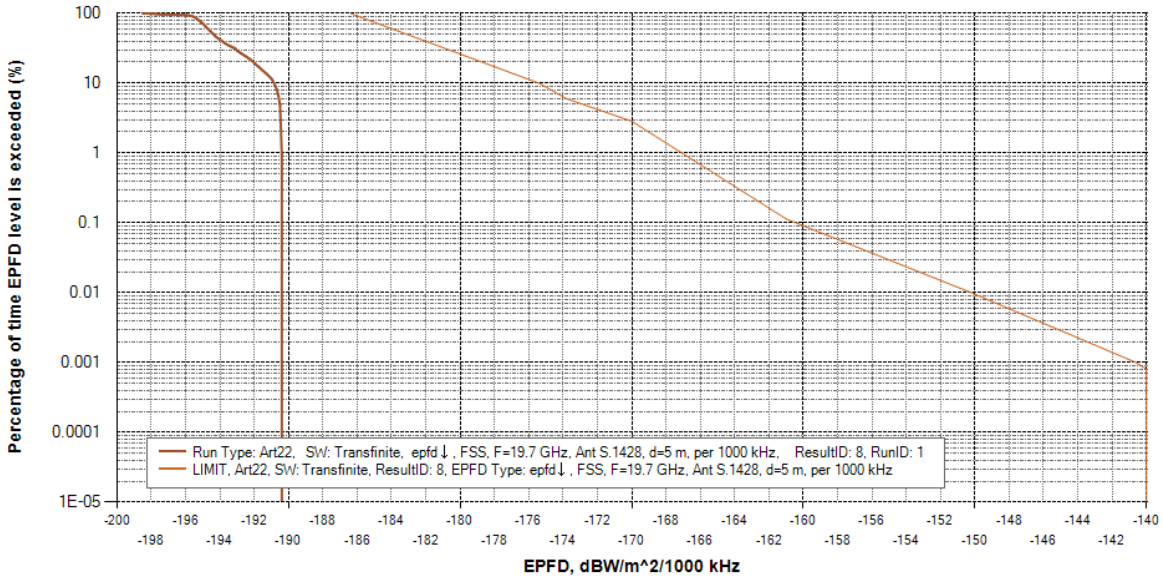

Figure 2-26. EPFD downlink validation at 19.7 GHz, RB=1 MHz and terminal size=5m

3.0 EPFD Inter-Satellite results

The inter-satellite analysis for Karousel has been performed based on two antenna models: One for the spot beams, which have high gain but relatively quick roll-off, and another for the global horn, which is lower gain and PSD, but has a slower roll-off. The masks supported for this type of analysis are limited by the ITU software to be radial masks of EIRP as measured at the NGSO satellite. The masks are allowed to vary as a function of longitude, but must be radially defined. To generate masks for the Karousel system, we followed a similar process as for the EPFD-down analysis: the beam was simulated fixing the beam at any earth-fixed location and then computed a radial mask that captures the highest EIRP power possible at each offset angle. In both cases, the mask is generated based on the 10.7 GHz beam roll-off, since this beam is larger and the inter-satellite limits are intended to capture interference off the earth. Since the coverage area of the Karousel system is asymmetric and hence not easily captured in this radial format, this mask is very conservative.

There are two inter-satellite limits which apply to the Karousel system: 10.7 GHz and 17.8 GHz. The plots below (Figures 3-1 through 3-4) show the results of both limits for the spot beam case and for the global beam case.

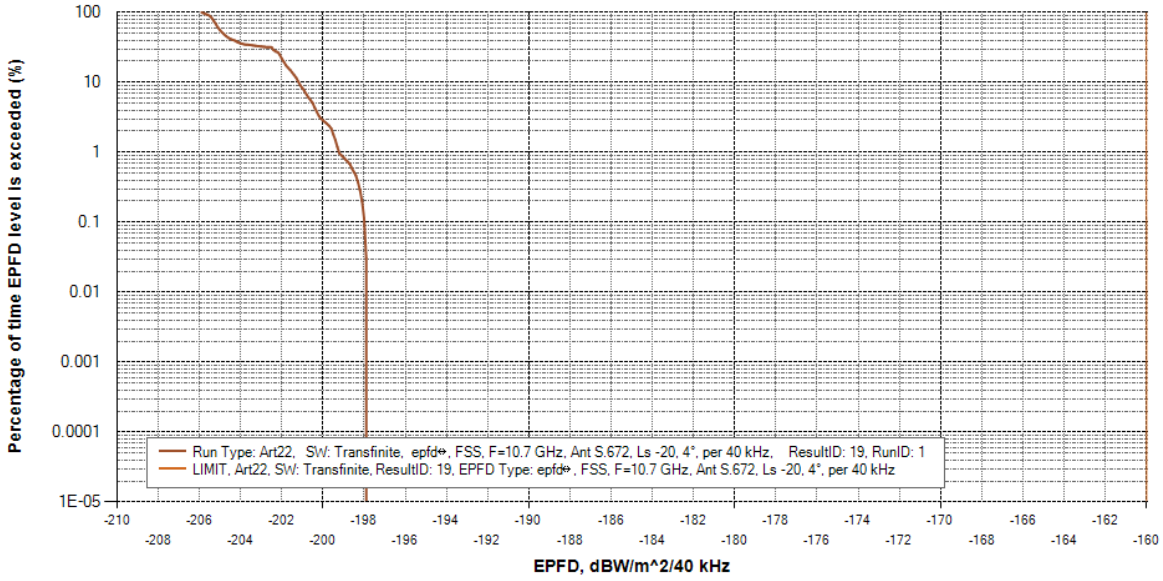

Figure 3-1. EPFD inter-satellite validation at 10.7 GHz, spot beam, and RB=40 kHz

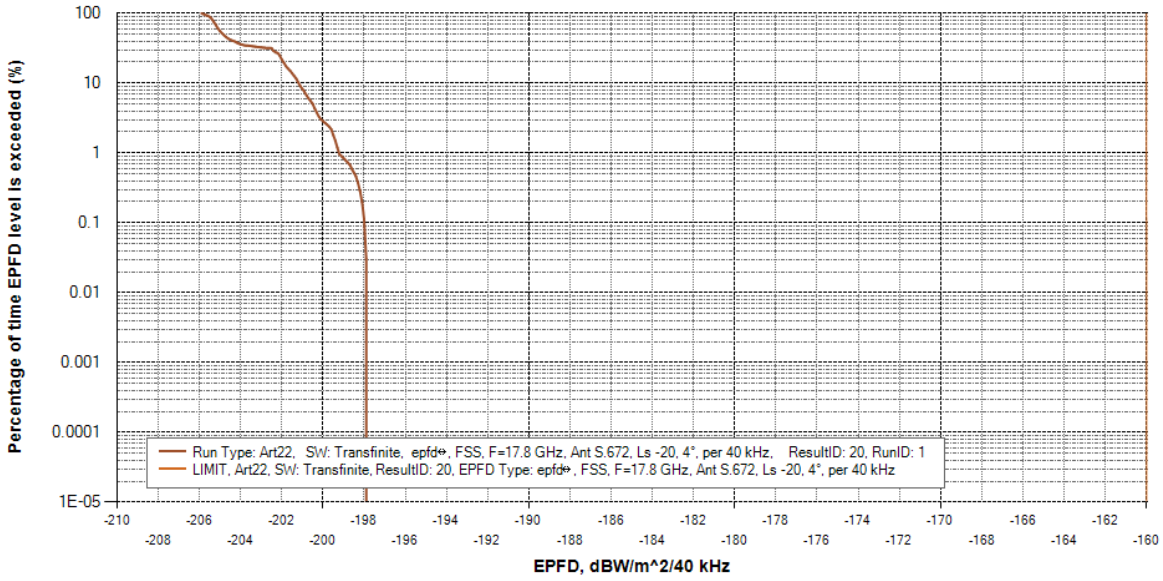

Figure 3-2. EPFD inter-satellite validation at 17.8 GHz, spot beam, and RB=40 kHz

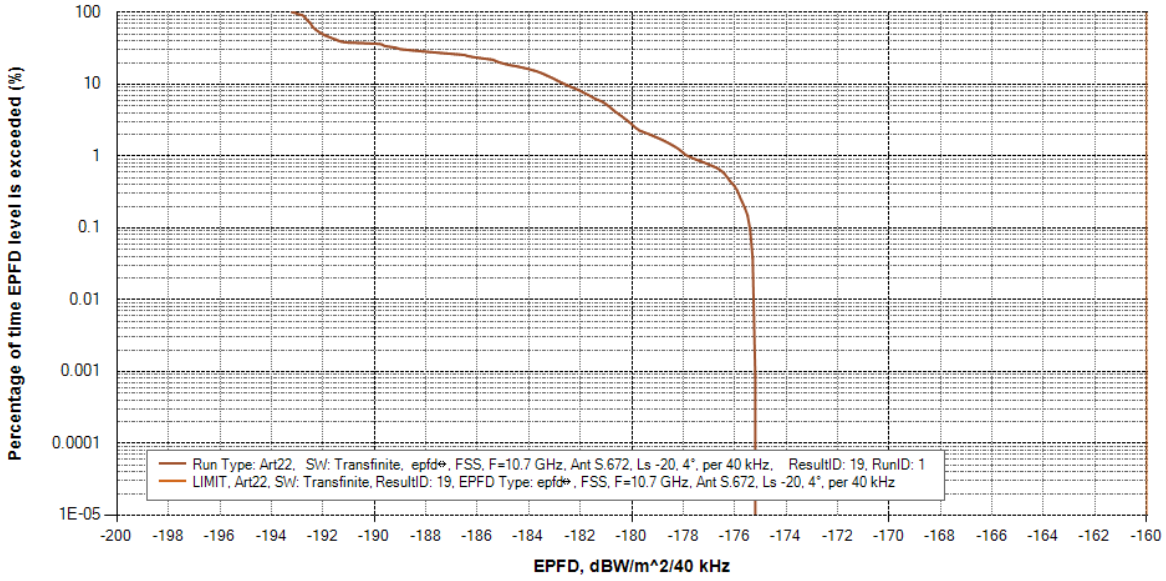

Figure 3-3. EPFD inter-satellite validation at 10.7 GHz, global beam, and RB=40 kHz

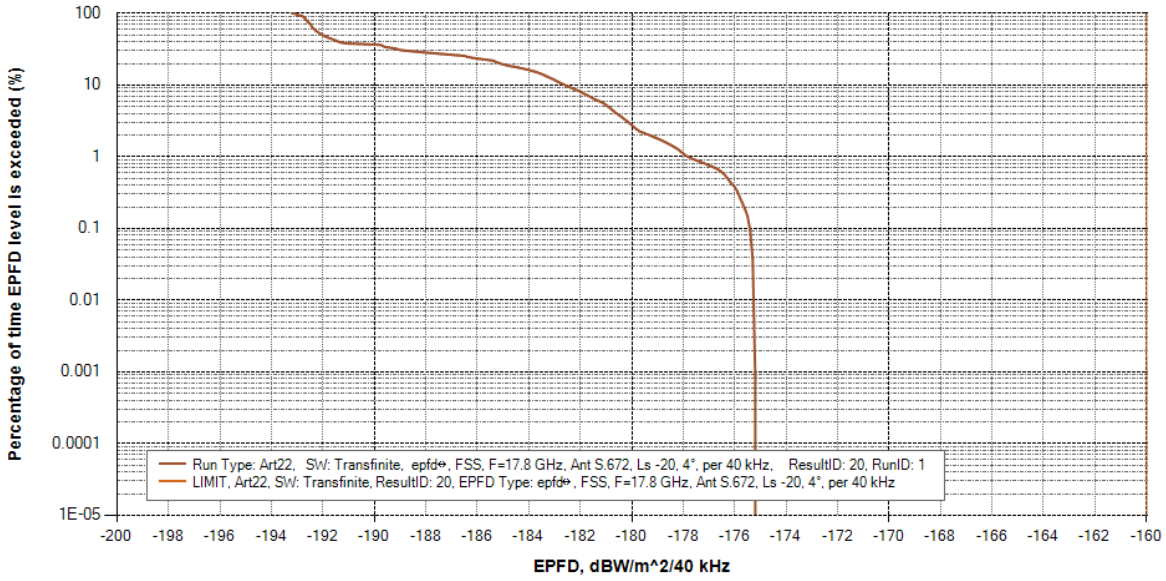

Figure 3-4. EPFD inter-satellite validation at 17.8 GHz, global beam, and RB=40 kHz

4.0 Uplink EPFD

The EPFDup validation software was run with an exclusion angle of 19 degrees. The exclusion angle is the minimum topocentric angle measured from an earth station between the NGSO space station and any point on the GSO arc. Although not explicitly allowed in the software this exclusion angle is designed to protect a GSO inclined 15 degrees with an additional 1 degree of uncertainty due to pointing error. Additionally, terminals have a minimum elevation angle restriction of 5 degrees.

For the calculation, NGSO earth station terminals were deployed, in a grid, over the field of view of a GEO satellite. Two parameters define the deployment of earth stations. These are the average distance between co-frequency points on a grid in kilometers and the density of earth stations per square kilometer. The density input into the program can easily be converted into the number of earth stations modeled at each grid point. The distance between grid points was assumed to be 1000 Km.

Separate EPFD validation runs were performed for the expected range of terminal sizes that are to be deployed. This includes gateway terminals between 7m and 13m and user terminals between 45cm and 75cm. Gateways were deployed 1 per grid point. Both low and high power EIRP masks were generated for user terminals. In low power mode, 200 terminals were deployed per grid point and in high power mode 20 user terminals were deployed per grid point. These deployments represent the maximum number of earth stations that will transmit co-frequency.

Figures 4-1 through 4-8 show the uplink EPFD results for the Karousel system using the ITU's EPFD validation software covering all uplink frequency bands (14-to-14.5 GHz and 27.5-to-30 GHz). Note that there is no frequency dependent term in the validation software. The masks are created for the bands of interest and the power flux density calculation at the GSO satellite depends only on range. Therefore, the EPFD limits at 12.5 GHz cover the 14 to 14.5 GHz band and the limits at 27.5 cover the 27.5-to-30 GHz band.

The figures show the calculated uplink EPFD levels relative to the EPFD limits. User terminals (45 cm and 75 cm) will operate in the 14-to-14.5 GHz band, while gateways will operate at 14-to-14.5 GHz and 27.5-to-30 GHz. In all cases the earth stations comply with the limits. Karousel will ensure that all antenna sizes used with the Karousel NGSO system will comply with uplink EPFD limits.

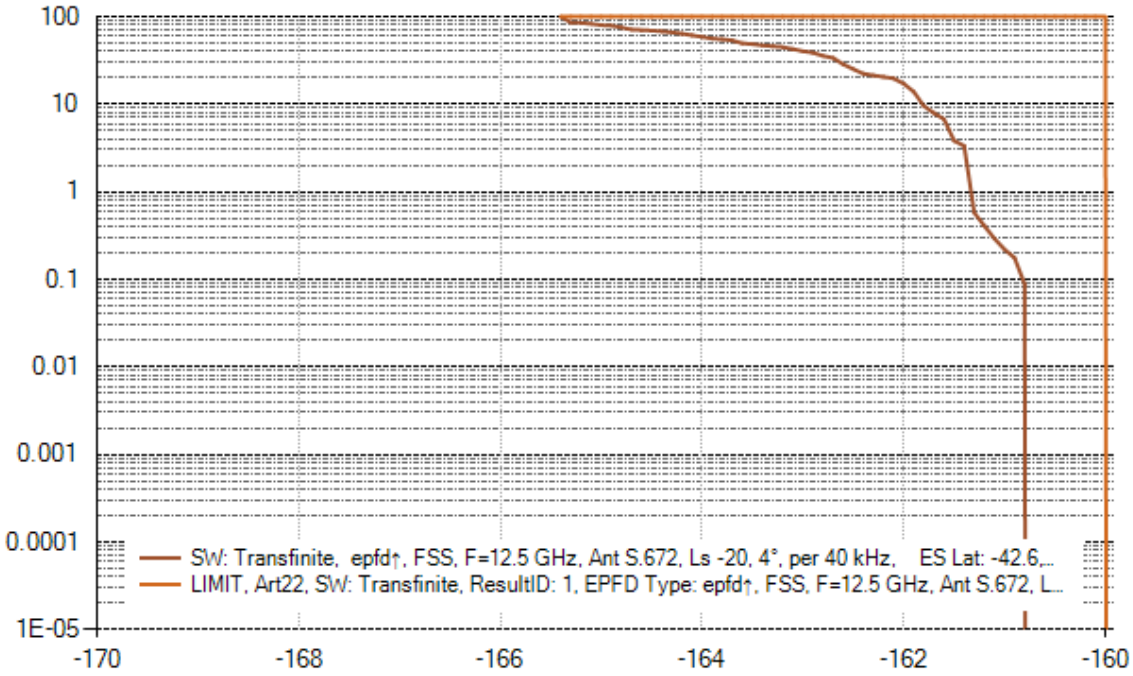

Figure 4-1. EPFD Uplink validation, 45cm Low power (-28 dBW/40 kHz), F=12.5 GHz, 200 users per point

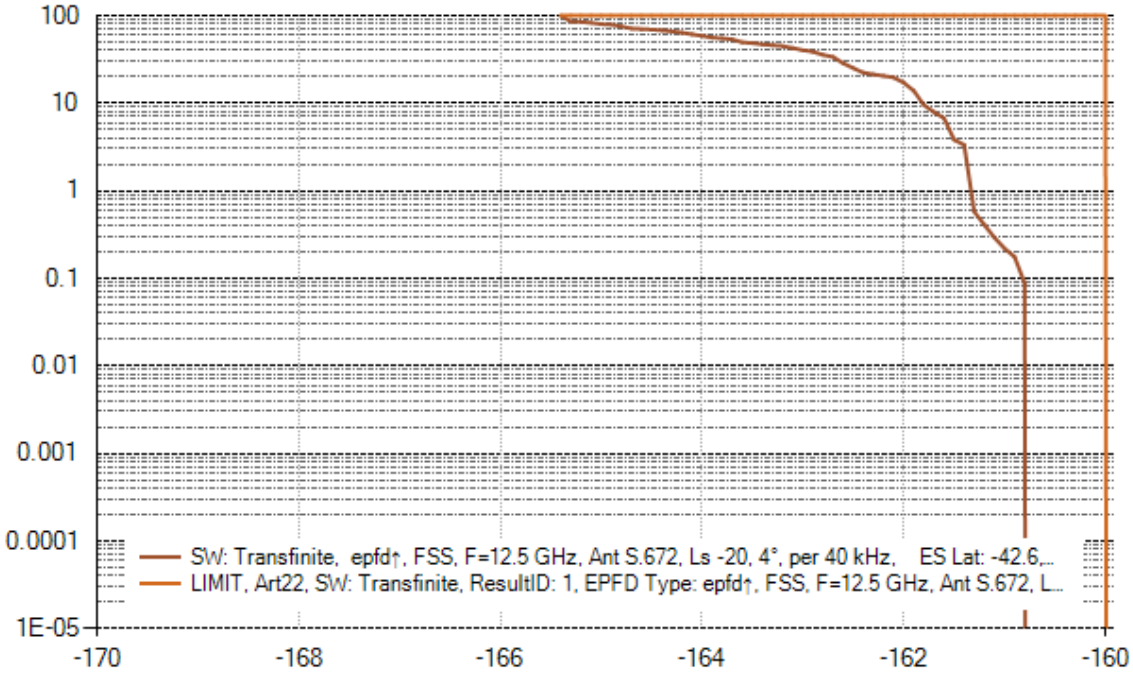

Figure 4-2. EPFD Uplink validation, 45cm high power (-18 dBW/40 kHz), F=12.5 GHz, 20 users per point

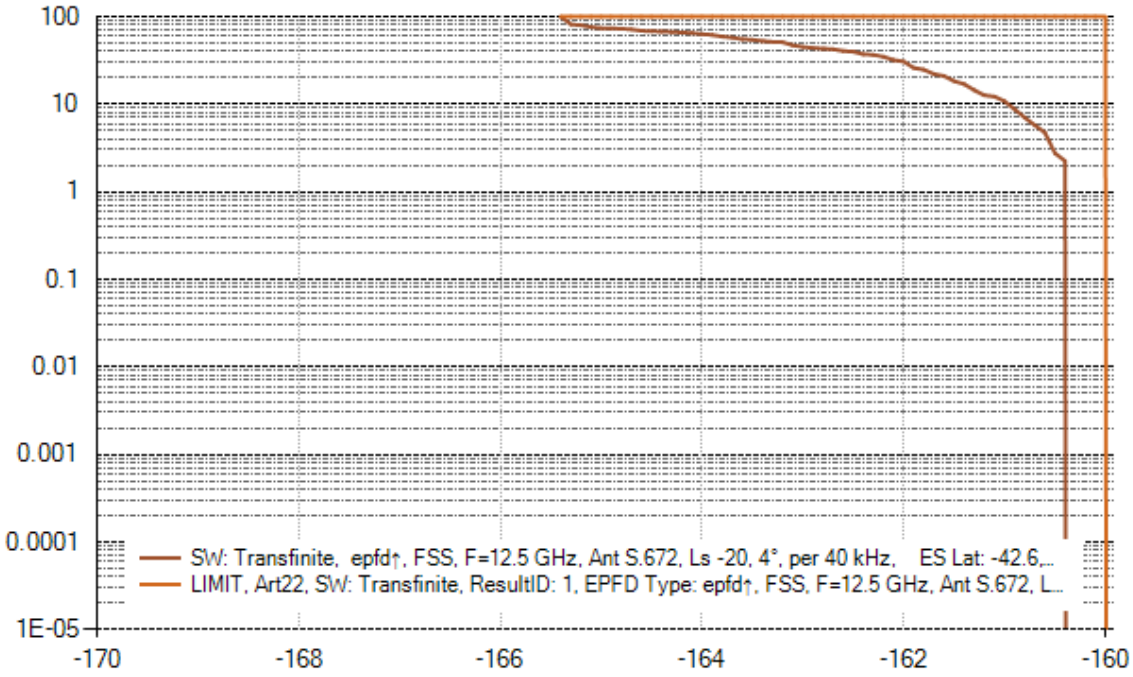

Figure 4-3. EPFD Uplink validation, 75cm low power (-28 dBW/40 kHz), F=12.5 GHz, 200 users per point

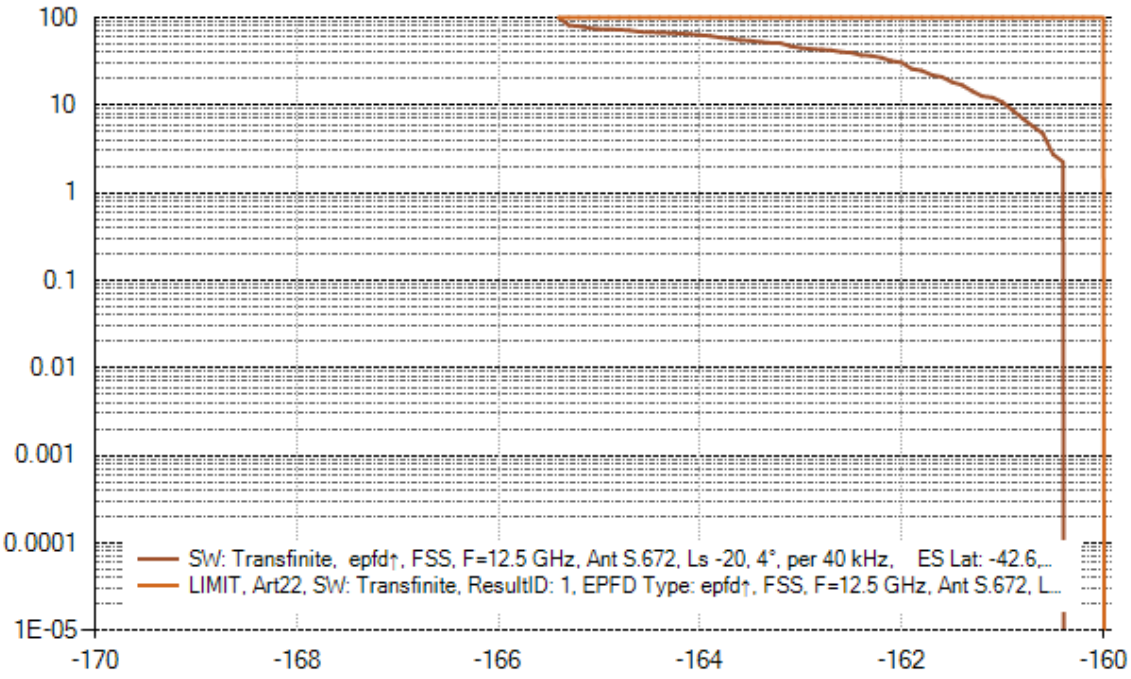

Figure 4-4. EPFD Uplink validation, 75cm high power (-18 dBW/40 kHz), F=12.5 GHz, 20 users per point

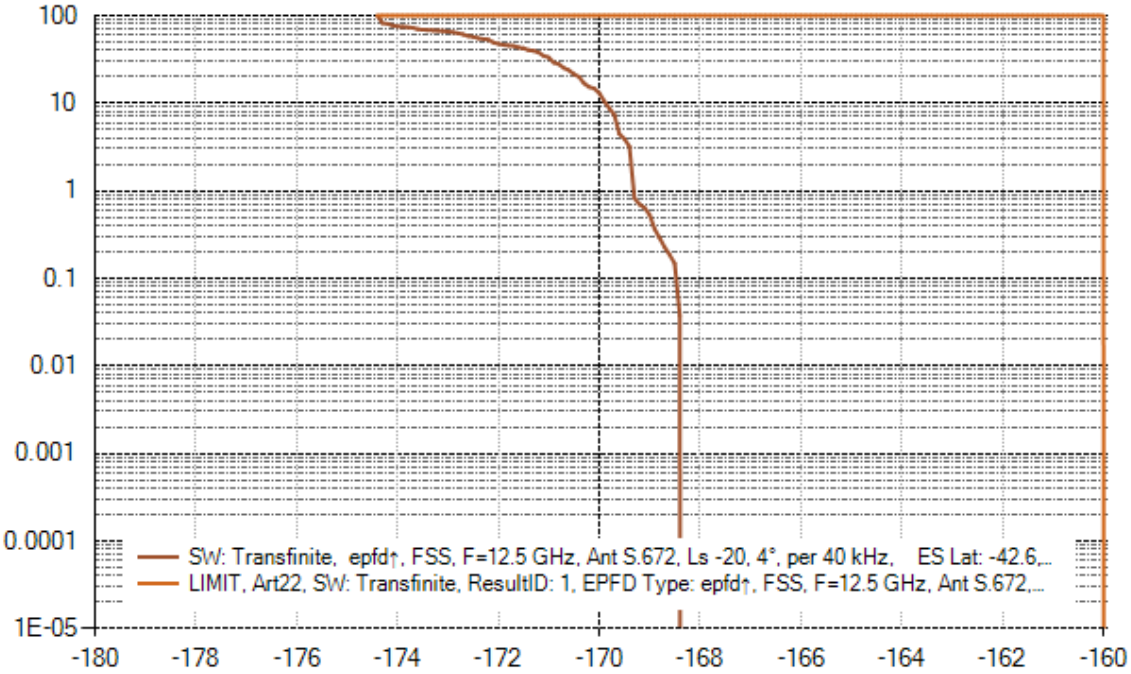

Figure 4-5. EPFD Uplink validation, 7m (-11 dBW/40 kHz), F=12.5 GHz, 1 users per point

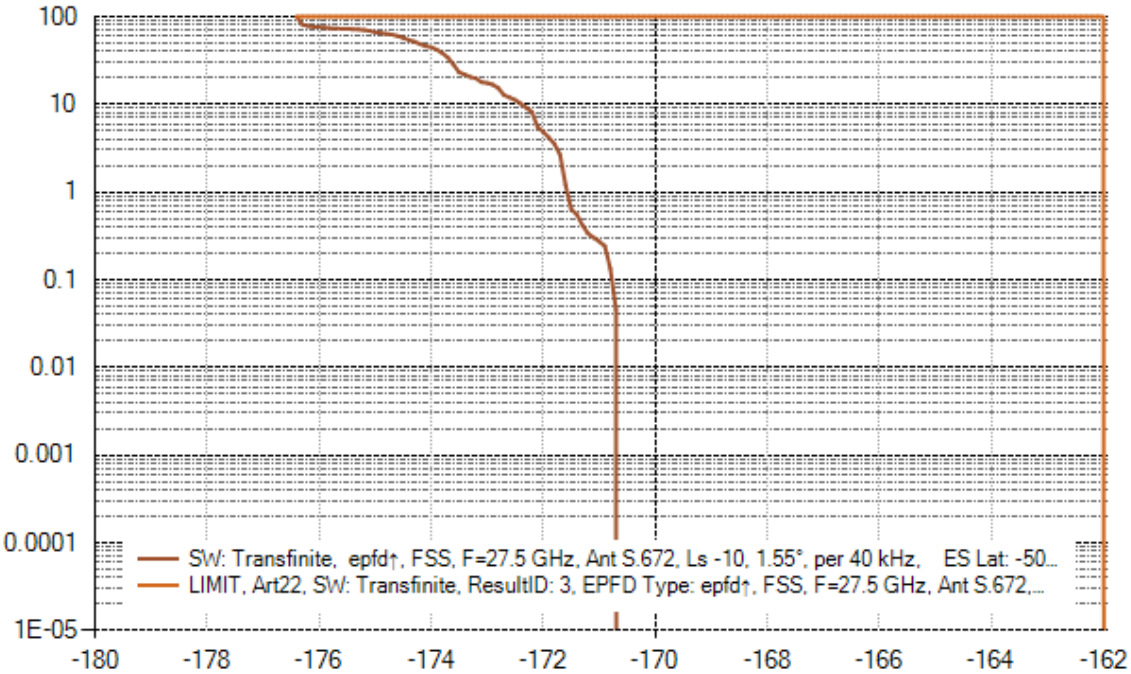

Figure 4-6. EPFD Uplink validation, 7m (-11 dBW/40 kHz), F=27.5 GHz, 1 users per point

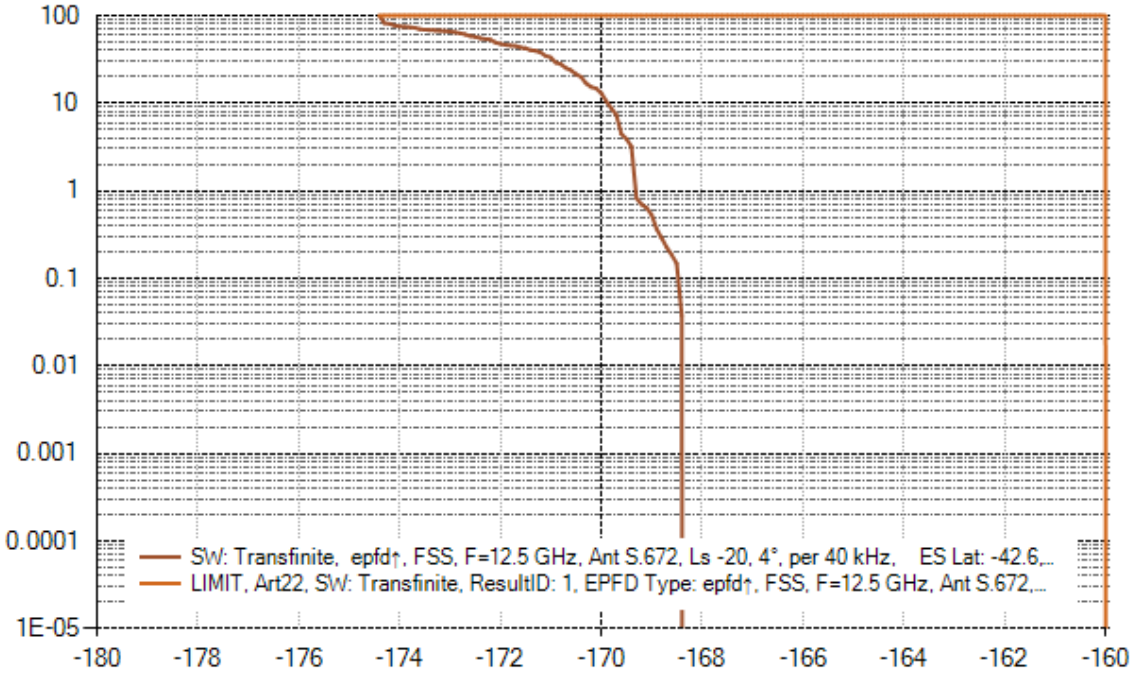

Figure 4-7. EPFD Uplink validation, 13m (-11 dBW/40 kHz), F=12.5 GHz, 1 users per point

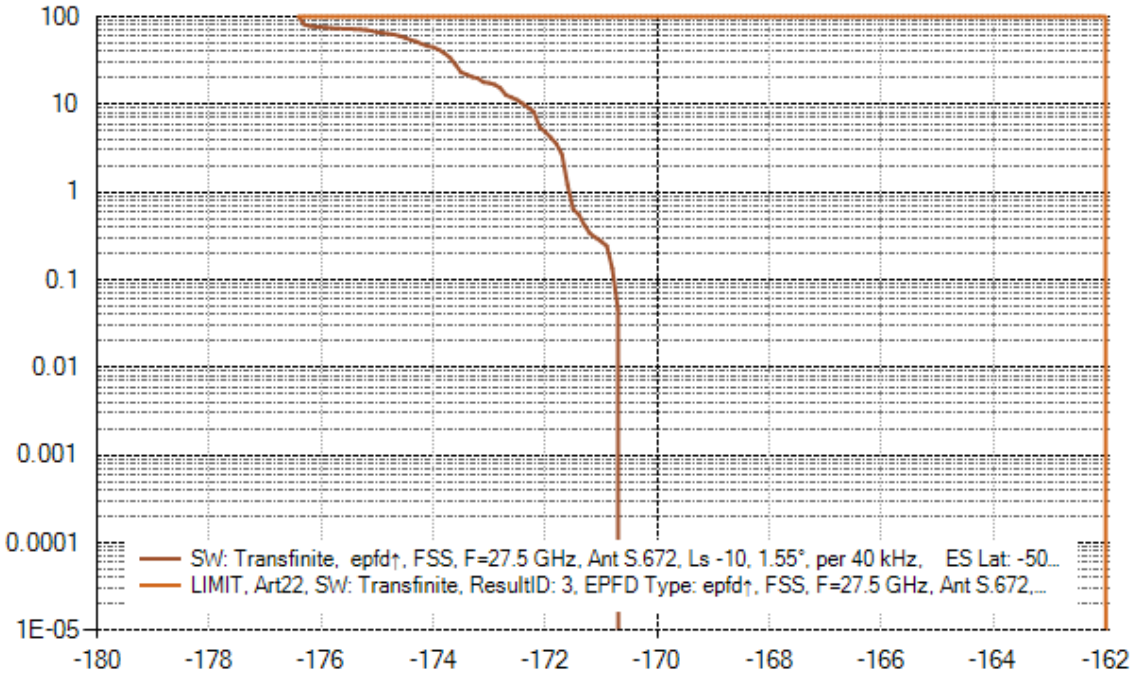

Figure 4-8. EPFD Uplink validation, 13m (-11 dBW/40 kHz), F=27.5 GHz, 1 users per point

5.0 EPFD Input Files Provided to the Commission

In order to allow independent verification regarding the compliance of the Karousel system with the applicable ITU EPFD limits, Karousel is providing the Commission with all the input files required by the ITU's EPFD validation software. The zipped file of required input files contains the following file types:

- EPFD input file in mdb format
- Associated PFD or EIRP mask file in mdb format

A list of the downlink EPFD files used to generate Section 2 results are listed in Table 5-1

Table 5-1: Downlink EPFD files provided to the Commission

Figure	SRS File	Mask File
2-1	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
2-2	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
2-3	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
2-4	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
2-5	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
2-6	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
2-7	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
2-8	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
2-9	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
2-10	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
2-11	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
2-12	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
2-13	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
2-14	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
2-15	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
2-16	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
2-17	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
2-18	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
2-19	karousel_kaband_srs.mdb	karousel_kabandmasks.mdb
2-20	karousel_kaband_srs.mdb	karousel_kabandmasks.mdb
2-21	karousel_kaband_srs.mdb	karousel_kabandmasks.mdb
2-22	karousel_kaband_srs.mdb	karousel_kabandmasks.mdb
2-23	karousel_kaband_srs.mdb	karousel_kabandmasks.mdb
2-24	karousel_kaband_srs.mdb	karousel_kabandmasks.mdb
2-25	karousel_kaband_srs.mdb	karousel_kabandmasks.mdb
2-26	karousel_kaband_srs.mdb	karousel_kabandmasks.mdb

A list of the inter-satellite EPFD files used to generate Section 3 results are listed in Table 5-2.

Table 5-2: Inter-satellite EPFD files provided to the Commission

Figure	SRS File	Mask File
3-1	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
3-2	karousel_kuband_srs.mdb	karousel_kubandmasks_spot_is.mdb
3-3	karousel_kuband_srs.mdb	karousel_kubandmasks_global_is.mdb
3-4	karousel_kuband_srs.mdb	karousel_kubandmasks_global_is.mdb

A list of the uplink EPFD files used to generate Section 4 results are listed in Table 5-3.

Table 5-3: Uplink EPFD files provided to the Commission

Figure	SRS File	Mask File
4-1	runDB45cm-40-1k-200.mdb	maskDB45cm.mdb
4-2	runDB45cmMax-40-1k-20.mdb	maskDB45cmMax.mdb
4-3	runDB75cm-40-1k-200.mdb	maskDB75cm.mdb
4-4	runDB75cmMax-40-1k-20.mdb	maskDB75cmMax.mdb
4-5	runDB7m-1k-1-14.mdb	maskDB7m14.mdb
4-6	runDB7m-1k-1-27.mdb	maskDB7m27.mdb
4-7	runDB13m-1k-1-14.mdb	maskDB13m14.mdb
4-8	runDB13m-1k-1-27.mdb	maskDB13m27.mdb