ATTACHMENT E
Astro Digital U.S., Inc.
FCC Form 312, Exhibit 43

ANALYSIS OF LANDMAPPER INTERFERENCE POTENTIAL TO FEDERAL AND INTERNATIONAL DRS GEO SATELLITE SYSTEMS

We concern ourselves in this analysis with the interference potential from the Landmapper Remote Sensing Constellation system to domestic and international data relay satellites (like TDRSS) located in geostationary orbit. The ITU has addressed interference limits from NGSO EESS systems to DRS GEO systems in two ITU-R Recommendations, namely, SA.1862 and SA.1278. Adherence to these two recommendations is made compulsory by ITU FN 5.536A (although we note that SA.1278 has been withdrawn from the latest publication of International Radio Regulations. Section II.F.2 of our Exhibit 43 cites the relevant portion of both of these recommendations. Specifically, *Recommends 5* of SA.1862 and *Recommends 1* of SA.1278 establish PFD limits for NGSOs operating in the EESS to DRS systems in geostationary orbit. Of these two recommendations SA.1278, *Recommends 1* establishes the more stringent PFD limit at -155 dBW/m^2/1 MHz of bandwidth. We will, therefor utilize this limit as the basis for our analysis.

I. Geometric Analysis: SA.1862 notes that there are two potential geometries where NGSO systems could interfere, under co-channel conditions, with a GEO DRS system. These are:

Case 1.) When the victim GEO system is directly above the NGSO system and the NGSO system is transmitting to it's intended Earth station, and the NGSO radiating antenna back-lobe is projected toward the GEO system.

and,

Case 2.) When the victim GEO system is directly in-line with the NGSO station and the receiving Earth station. Then, the NGSO satellite is at very low elevation angles (near 0 degrees) and has begun its downlink transmission to its intended Earth Station. This geometry is shown in Figures E-1a, E-1b, and E-1c of this analysis.

Astro Digital has investigated these two orbit geometries. Our only Earth station for receiving our 26.8 GHz signal is at Svalbard, Norway, situated at 78.23° N and 15.41° E. From this location the satellite-to-satellite geometry can never satisfy condition a.) above. As our primary Earth station is nearly at the North Pole there is no practical geometry where one of the Landmapper satellites could view the GEO arc in such a way that the victim GEO system would be behind the Landmapper satellite so that the back lobe from the NGSO satellite antenna could be projected toward the

GEO arc. Hence, case a.) is not applicable to the Landmapper system, which only turns ON its Ka-band transmitter when it is very nearly in view of Svalbard (and hence in the vicinity of the North pole of the Earth).

Case b.) from SA.1862, however, can and will occur for very short periods of time on some orbits. This geometry can be visualized using the following figures.

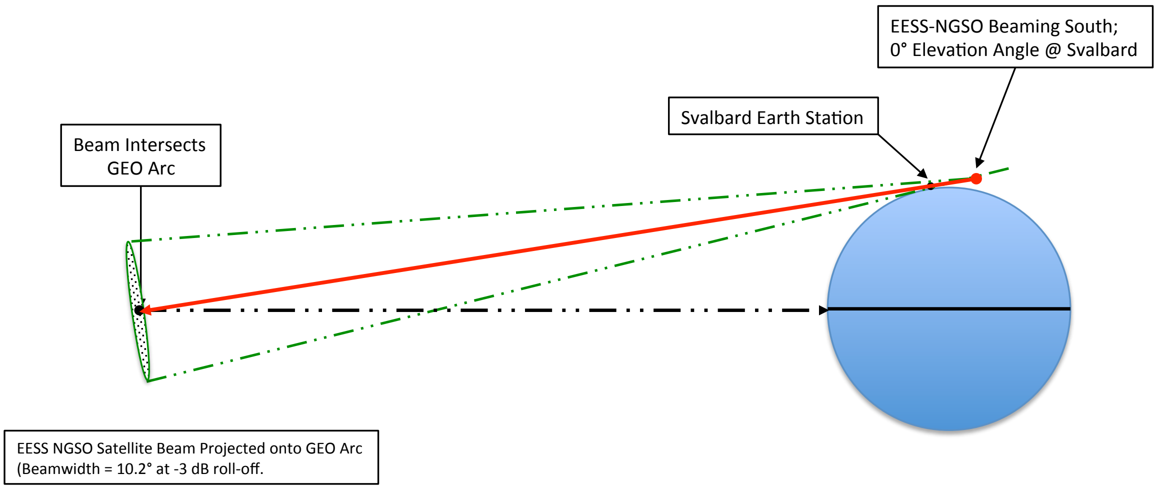


Figure E-1a. : Case 2.) Illumination of the GEO Arc from a Transmitting Landmapper Spacecraft (Viewed from within Geostationary Orbit Plane)

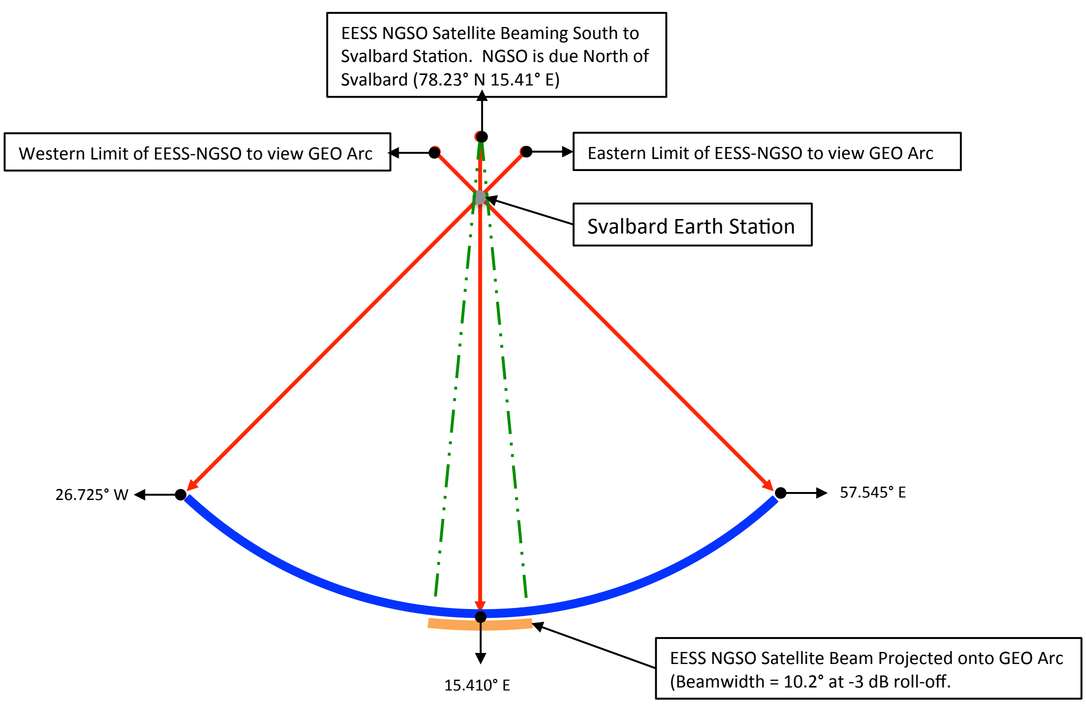


Figure E-1b. : Case 2.) Illumination of the GEO Arc from a Transmitting Landmapper Spacecraft (View approximately Normal to GEO Plane; NGSO beaming due South)

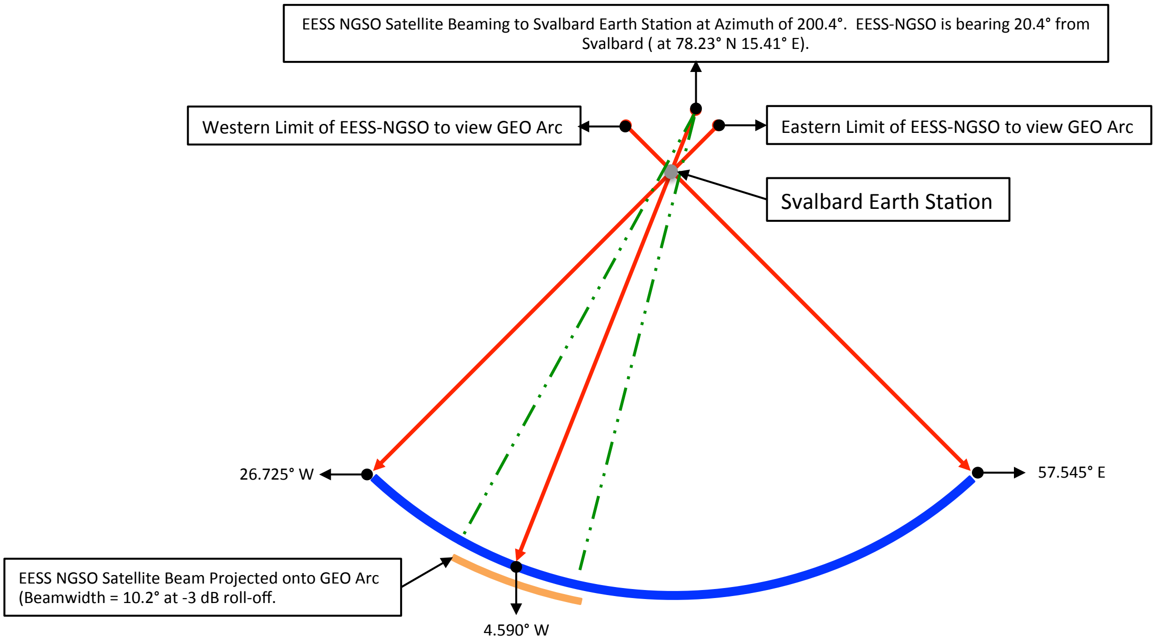
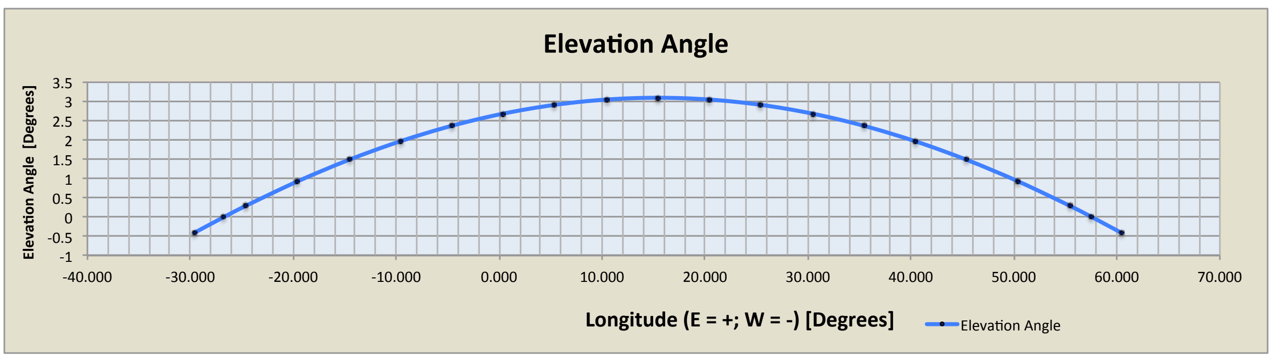


Figure E-1c.: Case 2) Example when During a Landmapper Satellite Pass the Satellite is Directing its Beam to an Azimuth Value of 200.4°. The NGSO Beam illuminates the GEO Arc at 4.6° W ± 5.1° Elevation angle at this time is 2.4°.

What can be observed from these three figures is that during times when a Landmapper satellite is beaming nearly South and is at very low elevation angles relative to Svalbard station, RF energy from a Landmapper, will also be directed past Svalbard at grazing angle and will arrive at the GEO arc. This can occur at very near the beginning of a pass and very near the end, as the spacecraft is rising or setting at Svalbard. During the geometric case where a spacecraft is due North of Svalbard, the narrow directed beam from the Landmapper not only illuminates Svalbard but, passes on to the GEO arc and illuminates the Arc at 15.4°E. The beamwidth of a Landmapper Ka-band spacecraft antenna is 10.2° and so the GEO arc will be illuminated at this time and condition, from 10.31° E to 20.51° E. These are the two locations on the arc where the PFD from the Landmapper system will be 3 dB below the peak value which will occur at 15.41° E. At this particular location for the Landmapper (when it is at just 0° elevation angle to Svalbard, the GEO satellite at 15.41° E will be at an elevation angle from Landmapper of 3.1 °. This is the highest elevation angle ever seen by a Landmapper directing a beam toward the arc. As this satellite rises above the horizon at Svalbard the satellite beam will be directed downward, and further and further away from the arc. Within approximately 60 seconds of AOS (acquisition of signal) or LOS (loss of signal) at Svalbard, the beam will have rolled off by more than 10 dB as seen at the GEO arc. Hence, the opportunity for this alignment to occur at this GEO arc location is approximately 2 minute per day per satellite and will occur when, 1.) the transmitters are ON and 2.) if the GEO system has it's receive beam directed toward Svalbard and 3.) if there is a co-channel use condition existing.

Other Landmapper satellites may be directing their beams at very low elevation angles toward Svalbard but, from other positions other than with their satellite antennas beaming due South. These satellites will also see the GEO arc but, for an even shorter duration. Figure E-1c shows an example of a Landmapper satellite beaming south at an Azimuth Bearing of 200.4°. Using a similar calculation, this Landmapper satellite will illuminate the arc (at -3 dB or higher w.r.t. to peak PFD) from 9.7° W to 0.51° E longitude. However, the elevation angle to this GEO arc segment is never more than 2.4°. Hence, it will be visible in this narrow elevation gap for only about 80 seconds per satellite per day (two orbits at 40 seconds per event).

Figure E-2 demonstrates that the GEO arc using this Case 2) geometry can be illuminated by Landmapper satellites over the portion of the arc that extending from 26.7° W to 57.5° E. These conditions exist for up to about 1 minute per day per satellite within any given 10 degree sector of the GEO arc segment just identified.



<u>Figure E-2</u>: Elevation Angle to GEO arc from Landmapper Spacecraft as a Function of GEO Arc Location

II. Power Flux Density Analysis:

A. Range Calculation: The lowest altitude orbit ever occupied by satellites in the Landmapper system when in operation will be 300 km. This orbit will produce a slightly worst-case lower bound range distance. During the time when the Landmapper satellites are in the position where they can illuminate the GEO arc at highest elevation angle the Range to the satellite is approximately:

$$\mathbf{R_{SR} \approx R_{GEO} + R_{NGSO}}$$

Where:

R_{SR} = Total Slant Range to GEO Arc Position

R_{GEO} = Range from Position on GEO Arc to Svalbard, Norway

R_{NGSO} = Range from Svalbard to Landmapper Spacecraft at 0° [1]

The range R_{SR} can be calculated by routine formulas given in the literature. [2] The range R_{NGSO} is a constant for the 300 km circular orbit and at 0 degree elevation angle and is equal to 1979 km.

B. Power Flux Density (PFD) Calculation:

The PFD value for the range R_{SR} can be given by:

$$\mathbf{PFD[W/m^2/MHz] = EIRP\ (dBW) -71 -20log_{10}\ (R_{SR}) -10log_{10}(BW/10E+6)}$$

Where:

EIRP = The effective isotopic radiated power (from Exhibit 43, Section II.E.) = 23.4 dBW

BW = The symbol rate bandwidth of the Ka-band TX emission (from Exhibit 43, Section II.E.) = 72,000,000 Hz.

The PFD received at the GEO arc can then be calculated as a function of position along the arc. These values, along with other important parameters associated with this interference case, are summarized in Table E-1a and E-1b.

Table E-1a. : PFD at the GEO Arc From a Landmapper Spacecraft at 0° El. Angle

E.S. = Svalbard, Norway	E.S. Lat.	78.23° N	E.S. Long.	15.41° E	GEO Sat. Slot (Nom.)		15.41° E	Reference Location (Due South of Svalbard)	
	Δlong. from Sat. Stn.: (degrees)	GEO Arc Longitude: (degrees)	E.S. Antenna Elevation: (degrees)	E.S. Antenna Azimuth to GEO Arc (degrees)	E.S. Antenna Azimuth to NGSO Sat. (degrees)	Range (GEO Arc to Svalbard): (kilometers)	Range (NGSO to GEO): (kilometers)	PDF: (dBW/m^2/MHz)	Signal Level: (dBW)
	-45.0	-29.590	-0.407	225.609	45.609	41724.3	43703.4	-158.98	-190.44
	-42.1	-26.725	0.000	222.741	42.741	41679.0	43658.1	-158.97	-190.43
	-40.0	-24.590	0.290	220.601	40.601	41646.7	43625.8	-158.97	-190.42
	-35.0	-19.590	0.920	215.574	35.574	41576.7	43555.8	-158.95	-190.41
	-30.0	-14.590	1.477	210.573	30.573	41514.8	43493.9	-158.94	-190.39
	-25.0	-9.590	1.958	205.470	25.47	41461.6	43440.7	-158.93	-190.38
	-20.0	-4.590	2.358	200.394	20.394	41417.4	43396.5	-158.92	-190.38
	-15.0	0.410	2.673	195.307	15.307	41382.6	43361.7	-158.92	-190.37
	-10.0	5.410	2.899	190.210	10.21	41357.6	43336.7	-158.91	-190.36
	-5.0	10.410	3.036	185.107	5.107	41342.5	43321.6	-158.91	-190.36
Nominal Vector South to GEO Arc	0.0	15.410	3.082	180.000	0.000	41337.4	43316.5	-158.91	-190.36
	5.0	20.410	3.036	174.893	354.893	41342.5	43321.6	-158.91	-190.36
	10.0	25.410	2.899	169.790	349.79	41357.6	43336.7	-158.91	-190.36
	15.0	30.410	2.673	164.693	344.693	41382.6	43361.7	-158.92	-190.37
	20.0	35.410	2.358	159.606	339.606	41417.4	43396.5	-158.92	-190.38
	25.0	40.410	1.958	154.530	334.53	41461.6	43440.7	-158.93	-190.38
	30.0	45.410	1.477	149.470	329.47	41514.8	43493.9	-158.94	-190.39
	35.0	50.410	0.920	144.426	324.426	41576.7	43555.8	-158.95	-190.41
	40.0	55.410	0.290	139.399	319.399	41646.7	43625.8	-158.97	-190.42
	42.1	57.545	0.000	137.259	317.259	41679.0	43658.1	-158.97	-190.43
	45.0	60.410	-0.407	134.391	314.391	41724.3	43703.4	-158.98	-190.44

[1] Spacecraft is in sun-synchronous orbit at an altitude of 300 km.

[2] Morgan, W.L. and Gordon, G.D., Principles of Communicaitons Satellites, John Wiley

[2] Morgan, W.L. and Gordon, G.D., Principles of Communicaitons Satellites, John Wiley & Sons, Inc., 1993, Chapter 2 and pp.140-143.

Table E-1b. : PFD and Isotropic Power Level Calculation Critical Parameters:

EESS NGSO Satellite EIRP:	23.4 dBW
EESS NGSO Satellite Symbol Rate BW:	72,000,000.00
GEO Orbit Altitude:	35786 km
GEO Min. Slant Range to Svalbard:	41337 km
EESS NGSO Min. Orbit Altutude:	300 km
EESS NGSO Slant Range at 0° El. Angle:	1979 km
EESS NGSO Satellite Frequency:	26.800 GHz
EESS NGSO Satellite Wavelength:	0.0112 m

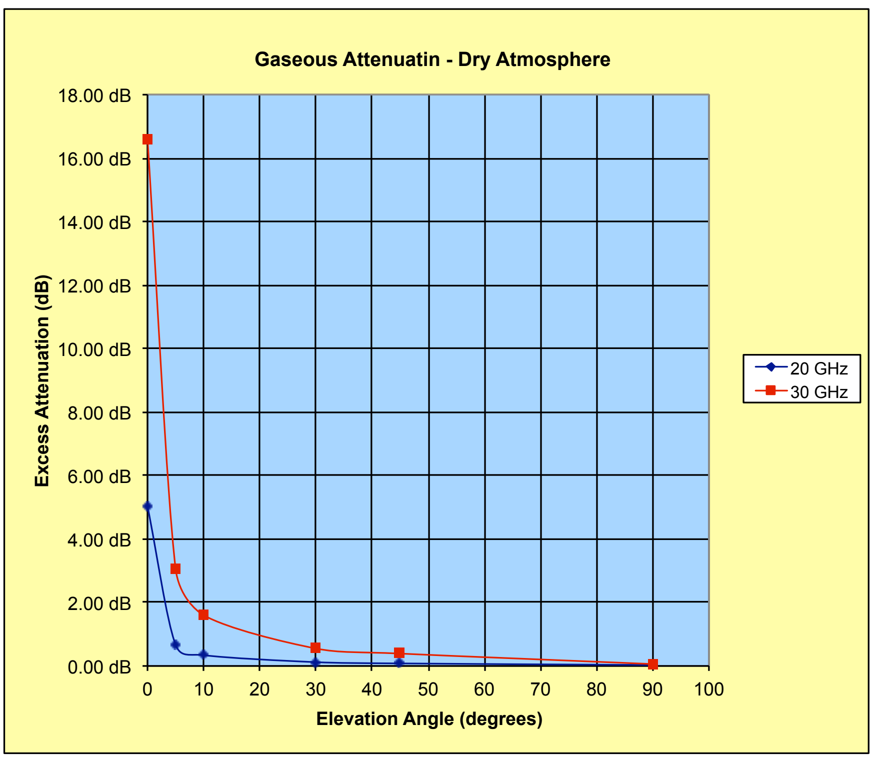
It can be seen from Table E-1a. the PDF from a Landmapper satellite to the GEO arc is approximately constant at a worst-case value of **-159 dBW/m²/MHz.** The allowable PFD limit in accordance with ITU-R Recommendation SA.1278, *Recommends 1*, is -155 dBW/m²/MHz. Therefore, the Landmapper system complies with SA.1278 as well as SA.1862, which allows a higher PFD level on a sustained basis.

Given that the *Recommends 1* limitation on PFD is met, the percentage of time when Landmapper might exceed the allowable PFD limit is not applicable. We wish to point out, however, that the amount of time that any single satellite in Case 2) sees the GEO arc within any 10° sector along the GEO arc, is almost exactly 0.1% of the time, based on using a NGSO EESS 300 km orbit. For a 600 km orbit this percentage would be slightly larger. Hence, even if the PFD level of SA.1278 were not met, we could easily make very small adjustments in our operating schedule to comply with *Recommends 2* of that Recommendation.

Astro Digital further notes that we fully comply with *Recommends 3* of SA.1278 as well. This was demonstrated in Section II.E. of Exhibit 43.

As a final note, satellite PFD analysis does not normally allow for consideration the inclusion of excess path loss resulting from meteorological factors in such a calculation. We understand that this inclusion would not be in the spirit of a worst-case analysis. However, in this circumstance, considering the frequency of our downlink (26.8 GHz) and the geometry involved in Case 2), whereby there is a grazing incidence path past the edge of the Earth from NGSO to GEO, it must be noted that this signal passes twice through the Earth's atmosphere along it's path from the NGSO to the GEO victim system. We present here what the excess path loss would be at two frequencies just above and below our proposed downlink frequency. This particular loss parameter is only the *gaseous absorption* component of the excess path loss. Rain and cloud attenuation and other atmospheric effects are additional losses but, in this instance, they are not considered as they are statistical parameters. We have taken this data from a long-standing and well known reference source and it is based on in-orbit measured data from NASA telecommunications program experiments at 20 and 30 GHz.[3] Presented here is the dry atmospheric case, which is applicable at the Svalbard Earth station. See Figure E-3.

Figure E-3: Gaseous Absorption at Low Elevation Angles at 20 and 30 GHz



[3] Ippolito, L.J.Jr., Radiowave Propagation in Satellite Communications, Van Norstrand Reinhold Co., 1986, Chapters 3 and 7.

Figure E-3: (Continued)

Atmospheric (Gaseous) Attenuation - Excess Path Loss

		DRY ATMOSPHERE		
To =	20 deg.C			
ρ_o =	0.001 g/m³			
R.H.=	10%	*Elevation Angle (degrees)*	*Gaseous Attenuation:*	
			20 GHz	*30 GHz*
		0	5.04 dB	16.60 dB
		5	0.67 dB	3.07 dB
		10	0.34 dB	1.60 dB
		30	0.12 dB	0.55 dB
		45	0.08 dB	0.39 dB
		90	0.03 dB	0.06 dB

From this data, it is evident that considerable excess path loss (as high as 30 dB) would exist in portions of the time while the signal transitions the lower atmosphere twice along the path from NGSO to GEO. While it is understood that typically, such excess path loss is not considered, Astro Digital believes that the non-statistical portion of this excess path loss (the atmospheric absorption component) should be included in such a PDF analysis.

The excess path loss argument, however, need not be included in our analysis, in order for Astro Digital to be found compliant with ITU-R SA.1278 and SA.1862. It is simply noted that even a conservative estimate of the PFD levels in this case, should include this specific excess path loss component.