RADIATION HAZARD ANALYSIS OF THE IRIDIUM CERTUS TERMINAL

JULY 26, 2017

TABLE OF CONTENTS

TABLE OF EQUATIONS

LIST OF TABLES

1 INTRODUCTION

The purpose of this document is to provide the results of radiation hazard analysis calculations, per FCC OET65, for Iridium's Certus subscriber terminal. We begin by describing the Iridium network at a very high level including the antenna associated with the Iridium Certus terminal, as well as the various Iridium Certus terminal waveforms, and the power levels and emission codes associated with those waveforms. From this information, the power density in three regions is calculated; specifically, on the antenna's surface, in the near field region and in the far field region. The power density in the near and far field regions is calculated at four elevation angles: zenith, i.e. straight up; to the horizon plane; and at two elevation angles in between, specifically, at the most probable elevation angle of 16 degrees and the elevation angle corresponding to the greatest EIRP, and therefore greatest power density, which occurs at 39 degrees elevation angle. Finally, the minimum far field separation distance from the antenna for uncontrolled population MPE compliance is calculated for these four elevation angles for the waveform that presents the highest power densities. The analysis based on worst case assumptions shows that the minimum separation distance for general population/uncontrolled maximum permissible exposure (MPE) compliance is only approximately 48 centimeters (cm), i.e. 19 inches, from the antenna. We discuss the measures taken to keep general population and controlled person exposure within permitted levels.

2 IRIDIUM DESCRIPTION

The Iridium satellite constellation is comprised of 66 low-earth-orbit (LEO) satellite vehicles (SV) that continually orbit 778 km above the earth. The SVs orbit in six planes, eleven SVs per plane, that intersect at the north and south poles providing communications coverage everywhere on the earth. The Iridium network is a time division duplex (TDD) one with the SVs and subscriber terminals transmitting on the same frequency but at different times. Time is segmented into 90 millisecond (ms) frames and in each frame there are four contiguous transmit time slots and four contiguous receive time slots, with each time slot 8.28 ms in duration. A subscriber terminal can transmit on one to four time slots depending upon the service provided. Authority is sought in the applications this analysis accompanies to operate in the frequency spectrum from 1618.725 MHz to 1626.5 MHz.

3 IRIDIUM CERTUS TERMINAL DESCRIPTION

The Iridium Certus antenna is an active phased array comprising a number of right hand circularly polarized antenna elements oriented in a specific geometry within a circle with a diameter of 31.2 centimeters (cm) and a height of 13 cm. Each antenna element has associated with it a power amplifier for transmit and a low noise amplifier (LNA) for receive. The antenna elements can be phased to provide 61 beams that cover the entire sky from horizon-to-horizon over a 360 degree range of azimuth angles, i.e. the entire 2π steradian hemisphere. This provides the ability for the Iridium Certus terminal to point a high gain beam in the direction of the SV as it traverses the sky from horizon-to-horizon. However, an individual Iridium SV will be utilized only for terminal elevation angles from 8.2 degrees above the horizon, through zenith, and down to 8.2 degrees above the other horizon. From a terminal's point-of-view at a fixed point on the earth an Iridium SV has a most probable elevation angle at 16 degrees above the horizon during its approximate 10 minute travel time from horizon-to-horizon.

The Iridium Certus terminal provides a variety of services and supports a multiplicity of waveforms of varying bandwidths and data rates. Additionally, two modulations are utilized, i.e. 16APSK and QPSK. An Iridium Certus terminal may transmit a single carrier of each waveform and for two of the waveforms may also transmit two carriers simultaneously. Table 1, below, lists the various emission designators, channel bandwidths, and equivalent average input power[1], per time slot, to the antenna.

Table 1 — Iridium Certus Terminal Emissions

Emission Designator	333KQ7W (2 carriers)	333KQ7W (2 carriers)	333KQ7W	333KQ7W	83KQ7W	41KQ7W	41KQ7W
Channel Bandwidth (kHz)	2*333	2*333	333	333	83.336	41.667	41.667
Equivalent Average Power per Time Slot (Watts)	5.13	1.23	2.57	0.62	0.62	0.62	0.62

4 Power Density Calculations

Table 2, below, defines the parameters used in the power density calculations. All calculations are done at 1621 MHz. Because the gains of the 61 beams are not identical, the power density is evaluated for four different elevation angles covering the entire range of the antenna in elevation. As noted in Table , the gain at 39 degrees elevation is the greatest and, therefore, will present the greatest power density. Although the Iridium SVs are not used at the horizon, i.e. they are used only above 8.2 degrees elevation angle, the power density is calculated at the horizon to show the worst-case power density in the horizontal plane of the antenna. The antenna efficiency is calculated at each of the elevation angles using Equation (14) of OET65 as below:

$$\eta = \frac{\left(\frac{G\lambda^2}{4\pi}\right)}{\left(\frac{\pi D^2}{4}\right)}$$

Equation 1

[1] This radiation hazard analysis supersedes the analysis that was filed on April 13, 2017, and expands upon and corrects calculations that were provided in the original analysis by (among other things) taking average power rather than peak power into account. The required separation distance specified in the installation guide/user manual has been adjusted based on these corrections.

Table 2 — Parameters for Power Density Calculations

Parameter	Symbol	Value
Antenna area (cm^2)	A	760.4
Antenna diameter (cm)	D	31.2
Frequency (GHz)	f	1.621
Wavelength (cm)	λ	18.5
Gain at zenith (dBi)	G_z	10.3
Gain at 39° elevation (dBi)	$G_{39°}$	11.8
Gain at 16° elevation (dBi)	$G_{16°}$	10.5
Gain at horizon (dBi)	G_h	8.0
Antenna efficiency at zenith	η_z	0.382
Antenna efficiency at 39° elevation	$\eta_{39°}$	0.539
Antenna efficiency at 16° elevation	$\eta_{16°}$	0.400
Antenna efficiency at horizon	η_h	0.225

The power densities are calculated for each of the waveforms because each has a different average power over a single time slot. For the power density calculations, the powers listed in Table 1 are multiplied by the duty cycle corresponding to four 8.28 ms transmit time slots over the 90 ms frame as:

$$P_{frame} = P_{TS}\frac{4 * 8.28}{90}$$

Equation 2

which represents the duty cycle which will yield the greatest power density.

Table 3 lists the results of the power density calculations for the surface of the antenna, $S_{surface}$, the near field, S_{nf}, for the four elevation angles, and the far field, S_{ff}, again for the four elevation angles. The surface power density is calculated per Equation (11) from OET65 as:

$$S_{surface} = \frac{4P}{A}$$

Equation 3

The near field power density is calculated per Equation (13) from OET65 as:

$$S_{nf} = \frac{16\eta P}{\pi D^2}$$

Equation 4

at a distance that defines the beginning of the near field region. This distance is calculated to be 13.2 cm from the antenna per Equation (12) from OET65 as:

$$R_{nf} = \frac{D^2}{4\lambda}$$

Equation 5

The far field power density is calculated per Equation (18) from OET65 as:

$$S_{ff} = \frac{PG}{4\pi R^2}$$

Equation 6

at a distance that defines the beginning of the far field region. This distance is calculated to be 31.6 cm from the antenna per Equation (16) from OET65 as:

$$R_{ff} = \frac{0.6D^2}{\lambda}$$

Equation 7

Table 3 — Power Density Calculated Results for Iridium Certus Terminal

Emission Designator		333KQ7W (2 carriers)	333KQ7W (2 carriers)	333KQ7W	333KQ7W	83KQ7W	41KQ7W	41KQ7W
Power Density at antenna surface (mW/cm^2)	$S_{surface}$	9.93	2.38	4.98	1.19	1.19	1.19	1.19
Near Field Power Density at zenith (mW/cm^2)	$S_{nf\text{-}z}$	3.77	0.90	1.89	0.45	0.45	0.45	0.45
Near Field Power Density at 39° elevation (mW/cm^2)	$S_{nf\text{-}39°}$	5.33	1.28	2.67	0.64	0.64	0.64	0.64
Near Field Power Density at 16° elevation (mW/cm^2)	$S_{nf\text{-}16°}$	3.95	0.95	1.98	0.47	0.47	0.47	0.47
Near Field Power Density at horizon (mW/cm^2)	$S_{nf\text{-}h}$	2.22	0.53	1.11	0.27	0.27	0.27	0.27
Far Field Power Density at zenith (mW/cm^2)	$S_{ff\text{-}z}$	1.62	0.39	0.81	0.19	0.19	0.19	0.19
Far Field Power Density at 39° elevation (mW/cm^2)	$S_{ff\text{-}39°}$	2.28	0.55	1.14	0.27	0.27	0.27	0.27
Far Field Power Density at 16° elevation (mW/cm^2)	$S_{ff\text{-}16°}$	1.69	0.41	0.85	0.20	0.20	0.20	0.20
Far Field Power Density at horizon (mW/cm^2)	$S_{ff\text{-}h}$	0.95	0.23	0.48	0.11	0.11	0.11	0.11

The power densities that exceed the general population/uncontrolled MPE of 1 mW/cm^2 are colored in blue in Table 3 while the power densities that exceed the controlled MPE requirement of 5 mW/cm^2 are colored in red in Table 3. Only two instances exceed the controlled MPE requirement, and that is for the emission designator 333KQ7W in the two-carrier case at the antenna surface and at the beginning of the near field, i.e. at a distance of 13.1 cm, for the 39 degree elevation angle. The calculations show that the far field power density at the horizon is below the uncontrolled (general population) MPE requirement in all cases.

The minimum separation distances in the far field for uncontrolled MPE compliance for the waveform that exhibits the highest power densities, i.e. for the emission designator 333KQ7W in the two-carrier case, are calculated from Equation (18) of OET65 by setting S_{ff} equal to 1.0 mW/cm^2 and solving for *R*. These distances are shown below in Table .

Table 4 — Far Field Distances for Uncontrolled MPE Compliance

Far Field Distance (cm) for 1 mW/cm^2 at zenith		40.12
Far Field Distance (cm) for 1 mW/cm^2 at 39º elevation		47.68
Far Field Distance (cm) for 1 mW/cm^2 at 16º elevation		41.05
Far Field Distance (cm) for 1 mW/cm^2 at horizon		30.78

From Table 4 it is shown that at a distance greater than 47.7 cm, or 19 inches, the uncontrolled MPE requirement is met for all antenna orientation angles and for all of the emissions supported by the Iridium Certus terminal. The installation manual/user guide specifies a distance of 60 cm as a safe distance for radiation hazard, thereby providing margin in excess of 25%.

5 PROTECTION AGAINST HARMFUL RADIATION EXPOSURE

A thorough analysis of the power density of the Iridium Certus Terminal at the surface of its antenna, at a minimum near field distance of its antenna and at the minimum far field distance of its antenna has been provided at four elevation angles and for each of the waveforms that the Iridium Certus terminal supports. The analysis has followed the guidelines of FCC OET65.

The analysis indicates that at a distance 47.7 cm (19 inches) or greater from the antenna the general population/uncontrolled MPE of 1 mW/cm^2 is not exceeded. The installation guide/user manual for the Iridium Certus Terminal specifies 60 cm as the minimum required distance from the antenna for radiation hazard reasons, providing more than 12 cm of safety margin. The User Manual also informs workers to turn the terminal off when they need to get closer than 60 cm to work on the terminal, eliminating any radiation hazards at the controlled population MPE level, since a separation distance that satisfies the more restrictive uncontrolled population MPE level of necessity also satisfied the controlled population MPE level. Additionally, the antenna radome has radiation hazard warnings on it.

As shown below, the nature of the Iridium Certus terminal installations ensures that installers will be able to satisfy the 47.7 cm minimum separation called for by FCC OET65, as well as the 60 cm minimum separation specified in the installation manual/user guide. The three scenarios envisioned for Iridium Certus terminal use are:

- Aviation
- Maritime
- Land Mobile

For the aviation scenario, the antenna needs to be mounted at a location on the exterior of the aircraft that has a clear view of the sky for best operation with the Iridium network. For any given aircraft, there will be locations that are not accessible to the general population and are at least the required distance from persons in the cabin and cockpit. Similarly, for the maritime scenario the antenna will need to be mounted at a location on the vessel that is sufficiently elevated to permit a clear view of the sky. For any given vessel, there will be locations that are not accessible to the general population and are at least the required distance from public portions of the vessel. Finally, for the land mobile scenario the antenna should be located on the roof of vehicle for a clear view of the sky. For any given vehicle, there will be locations at the center of the roof that are at least the required distance from passengers in the vehicle, passengers in adjacent vehicles, and pedestrians.