Radiation Hazard Study

The study in this section analyzes the potential RF human exposure levels caused by the Electro Magnetic (EM) fields of an Orbit AL-7103-Ka, 1.20 m antenna, operating with a maximum power at the flange of 20 Watts. The mathematical analysis performed below complies with the methods described in the FCC Office of Engineering and Technology (OET) Bulletin No. 65 (1985 rev. 1997) R&O 96-3 26 in "Evaluating Compliance with FCC Guideliness for Human Exposure to RF EM Fields, OET Bulletin 65 (Edition 97-01), Supplement B, FCC Office of Engineering & Technology, November 1997".

Maximum Permissible Exposure

There are two separate levels of exposure limits. The first applies to persons in the general population who are in an uncontrolled environment. The second applies to trained personnel in a controlled environment. According to 47 C.F.R. § 1.1310, the Maximum Permissible Exposure (MPE) limits for frequencies above 1.5 GHz are as follows:

* General Population / Uncontrolled Exposure: 1.0 mW/cm^2
* Occupational / Controlled Exposure: 5.0 mW/cm^2

The purpose of this study is to determine the power flux density levels for the earth station under study as compared with the MPE limits. This comparison is done in each of the following regions:

1. Far-field region
2. Near-field region
3. Transition region
4. The region between the feed and the antenna surface
5. The main reflector region
6. The region between the antenna edge and the ground

Input Parameters

The following input parameters were used in the calculations:

Input Parameter	Value	Unit	Symbol
Antenna Diameter	1.20	m	D
Antenna Transmit Gain	48.50	dBi	G
Transmit Frequency	29100.0	MHz	f
Antenna Feed Flange Diam.	6.00	cm	d
Power Input to the Antenna	20.00	Watts	P

Calculated Parameters

The following values were calculated using the above input parameters and the corresponding formula:

Calculated Parameter	Value	Unit	Symbol	Formula
Antenna Surface Area	1.13	m^2	A	$\pi D^2/4$
Area of Antenna Flange	28.3	cm^2	a	$\pi d^2/4$
Antenna Efficiency	0.53	real	η	$g\lambda^2/(\pi^2 D^2)$
Gain Factor	70795	real	g	10^(G/10)
Wavelength	0.010	m	λ	300/f

Behavior of EM Fields as a Function of Distance

The behavior of the characteristics of EM fields varies depending on the distance from the radiating antenna. These characteristics are analyzed in three primary regions: the near-field region, the far-field region and the transition region. Of interest also are the region between the antenna main reflector and the subreflector, the region of the main reflector area and the region between the main reflector and ground.

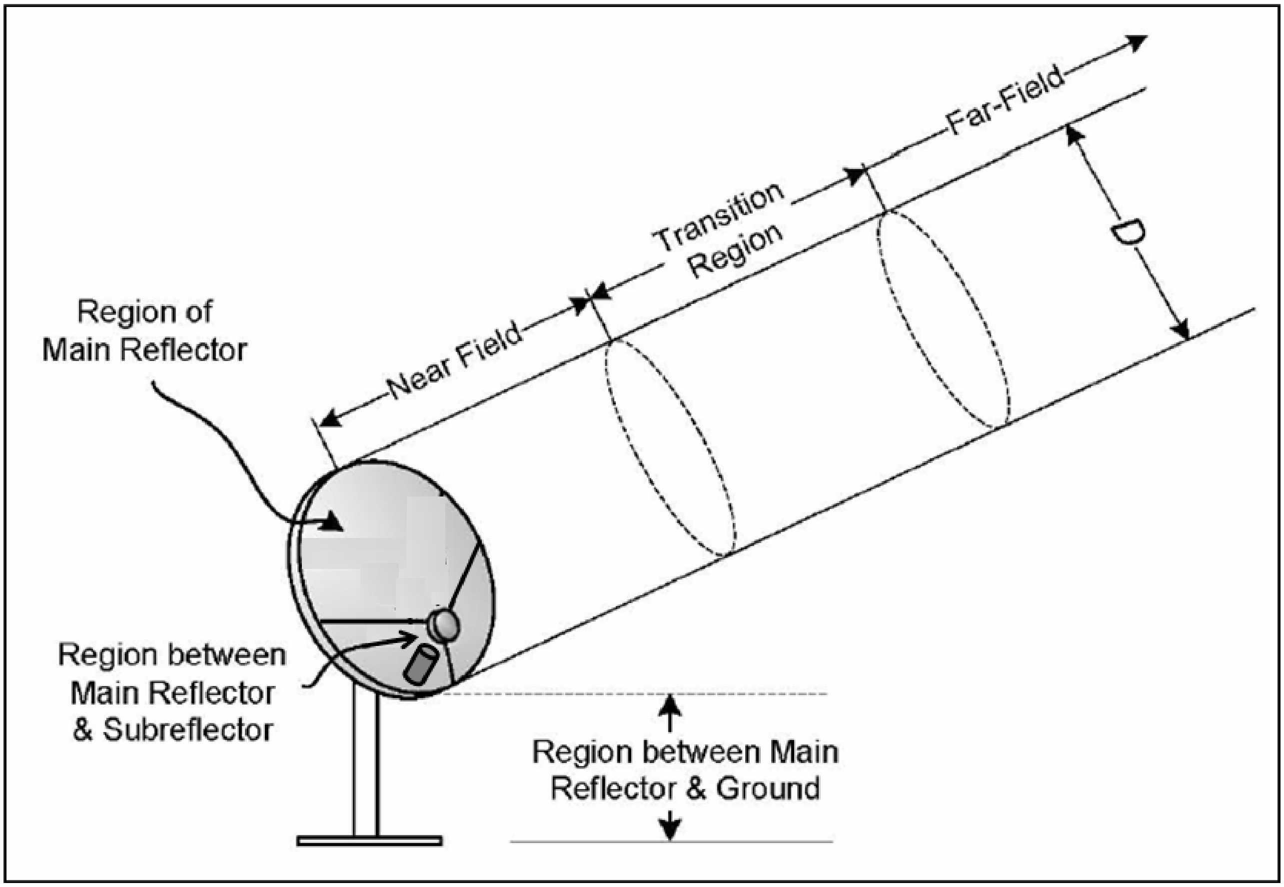


Figure 1. Electro-Magnetic Fields as a Function of Distance

For parabolic aperture antennas with circular cross sections, such as the antenna under study, the near-field, far-field and transition region distances are calculated as follows:

Calculated Parameter	**Value**	**Unit**	**Symbol**	**Formula**
Near-Field Distance	34.92	m	Rnf	$D^2/(4\lambda)$
Distance to Far-Field	83.81	m	Rff	$0.6D^2/\lambda$
Distance of Transition Region	34.92	m	Rt	Rt=Rnf

The distance in the transition region is between the near and far fields. Thus, Rnf ≤ Rt ≤ Rff . However, the power density in the transition region will not exceed the power density in the near-field. Therefore, for purposes of the present analysis, the distance of the transition region can equate the distance to the near-field.

Power Flux Density Calculations

The power flux density is considered to be at a maximum through the entire length of the near-field. This region is contained within a cylindrical volume with a diameter, *D*, equal to the diameter of the antenna. In the transition region and the far-field, the power density decreases inversely with the square of the distance. The following equations are used to calculate power density in these regions:

Calculated Parameter	**Value**	**Unit**	**Symbol**	**Formula**
Power Density in the Near-Field	3.74	mW/cm^2	Snf	$16\eta P/(\pi D^2)$
Power Density in the Far-Field	1.60	mW/cm^2	Sff	$gP/(4\pi Rff^2)$
Power Density in the Transition Region	3.74	mW/cm^2	St	Snf*Rnf/Rt

The region between the main reflector and the subreflector is confined to within a conical shape defined by the feed assembly. The most common feed assemblies are waveguide flanges. This energy is determined as follows:

Calculated Parameter	**Value**	**Unit**	**Symbol**	**Formula**
Power Density at the Feed Flange	2829.4	mW/cm^2	Sfa	4P/a

The power density in the main reflector is determined similarly to the power density at the feed flange; except that the area of the reflector is used.

Calculated Parameter	**Value**	**Unit**	**Symbol**	**Formula**
Power Density at Main Reflector	7.07	mW/cm^2	Ssurface	4P/A

The power density between the reflector and ground, assuming uniform illumination of the reflector surface, is calculated as follows:

Calculated Parameter	**Value**	**Unit**	**Symbol**	**Formula**
Power Density between Reflector & Gnd	1.77	mW/cm^2	Sg	P/A

Summary of Calculations

Table 1 below summarizes the calculated power flux density values for each region. In a controlled environment, the only regions that exceed FCC limitations are the regions between the main reflector and the sub-reflector as well as the main reflector region. These regions are only accessible by trained technicians who, as a matter of procedure, turn off transmit power before performing any work in these areas.

Table 1. Power Flux Density for Each Region:

Calculated Parameter	Unit	Exposure Limit	Exposure Limit
		Uncontrolled	Controlled
Power Densities	mW/cm²	Environment	Environment
		≤ 1 mW/cm²	≤ 5 mW/cm²
Far Field Calculation	1.60	Exceeds limitations	Satisfies FCC MPE
Near Field Calculation	3.74	Exceeds limitations	Satisfies FCC MPE
Transition Region	3.74	Exceeds limitations	Satisfies FCC MPE
Region between Main & Subreflector	2829.4	Exceeds limitations	Exceeds limitations
Main Reflector Region	7.07	Exceeds limitations	Exceeds limitations
Region between Main Reflector & Gnd	1.77	Exceeds limitations	Satisfies FCC MPE

In conclusion, the results show that the antenna, in a controlled environment, and under the proper mitigation procedures, meets the guidelines specified in § 1.1310 of the Regulations.

Radiation Hazard Study

The study in this section analyzes the potential RF human exposure levels caused by the Electro Magnetic (EM) fields of an Orbit AL-7107-Ka, 2.2 m antenna, "OceanTrx7" operating with a maximum power at the flange of 40 Watts. The mathematical analysis performed below complies with the methods described in the FCC Office of Engineering and Technology (OET) Bulletin No. 65 (1985 rev. 1997) R&O 96-3 26 in "Evaluating Compliance with FCC Guideliness for Human Exposure to RF EM Fields, OET Bulletin 65 (Edition 97-01), Supplement B, FCC Office of Engineering & Technology, November 1997".

Maximum Permissible Exposure

There are two separate levels of exposure limits. The first applies to persons in the general population who are in an uncontrolled environment. The second applies to trained personnel in a controlled environment. According to 47 C.F.R. § 1.1310, the Maximum Permissible Exposure (MPE) limits for frequencies above 1.5 GHz are as follows:

* General Population / Uncontrolled Exposure: 1.0 mW/cm^2
* Occupational / Controlled Exposure: 5.0 mW/cm^2

The purpose of this study is to determine the power flux density levels for the earth station under study as compared with the MPE limits. This comparison is done in each of the following regions:

1. Far-field region
2. Near-field region
3. Transition region
4. The region between the feed and the antenna surface
5. The main reflector region
6. The region between the antenna edge and the ground

Input Parameters

The following input parameters were used in the calculations:

Input Parameter	Value	Unit	Symbol
Antenna Diameter	2.15	m	D
Antenna Transmit Gain	52.70	dBi	G
Transmit Frequency	29100.0	MHz	f
Antenna Feed Flange Diam.	8.00	cm	d
Power Input to the Antenna	40.00	Watts	P

Calculated Parameters

The following values were calculated using the above input parameters and the corresponding formula:

Calculated Parameter	Value	Unit	Symbol	Formula
Antenna Surface Area	3.63	m^2	A	$\pi D^2/4$
Area of Antenna Flange	50.3	cm^2	a	$\pi d^2/4$
Antenna Efficiency	0.43	real	η	$g\lambda^2/(\pi^2 D^2)$
Gain Factor	186209	real	g	10^(G/10)
Wavelength	0.010	m	λ	300/f

Behavior of EM Fields as a Function of Distance

The behavior of the characteristics of EM fields varies depending on the distance from the radiating antenna. These characteristics are analyzed in three primary regions: the near-field region, the far-field region and the transition region. Of interest also are the region between the antenna main reflector and the subreflector, the region of the main reflector area and the region between the main reflector and ground.

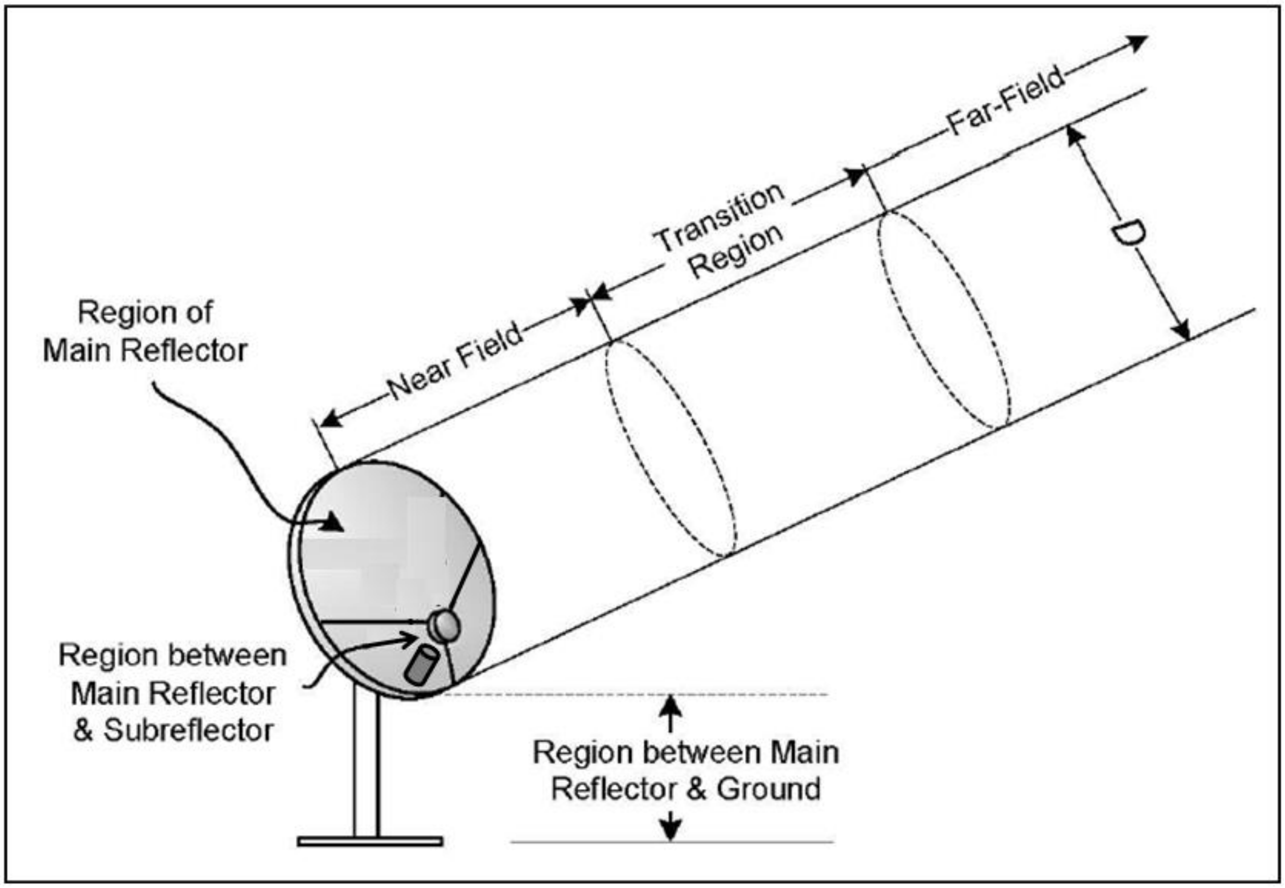


Figure 1. Electro-Magnetic Fields as a Function of Distance

For parabolic aperture antennas with circular cross sections, such as the antenna under study, the near-field, far-field and transition region distances are calculated as follows:

Calculated Parameter	**Value**	**Unit**	**Symbol**	**Formula**
Near-Field Distance	112.10	m	Rnf	$D^2/(4\lambda)$
Distance to Far-Field	269.03	m	Rff	$0.6D^2/\lambda$
Distance of Transition Region	112.10	m	Rt	Rt=Rnf

The distance in the transition region is between the near and far fields. Thus, Rnf ≤ Rt ≤ Rff . However, the power density in the transition region will not exceed the power density in the near-field. Therefore, for purposes of the present analysis, the distance of the transition region can equate the distance to the near-field.

Power Flux Density Calculations

The power flux density is considered to be at a maximum through the entire length of the near-field. This region is contained within a cylindrical volume with a diameter, *D*, equal to the diameter of the antenna. In the transition region and the far-field, the power density decreases inversely with the square of the distance. The following equations are used to calculate power density in these regions:

Calculated Parameter	**Value**	**Unit**	**Symbol**	**Formula**
Power Density in the Near-Field	1.91	mW/cm^2	Snf	$16\eta P/(\pi D^2)$
Power Density in the Far-Field	0.82	mW/cm^2	Sff	$gP/(4\pi Rff^2)$
Power Density in the Transition Region	1.91	mW/cm^2	St	Snf*Rnf/Rt

The region between the main reflector and the subreflector is confined to within a conical shape defined by the feed assembly. The most common feed assemblies are waveguide flanges. This energy is determined as follows:

Calculated Parameter	**Value**	**Unit**	**Symbol**	**Formula**
Power Density at the Feed Flange	3183.1	mW/cm^2	Sfa	4P/a

The power density in the main reflector is determined similarly to the power density at the feed flange; except that the area of the reflector is used.

Calculated Parameter	**Value**	**Unit**	**Symbol**	**Formula**
Power Density at Main Reflector	4.41	mW/cm^2	Ssurface	4P/A

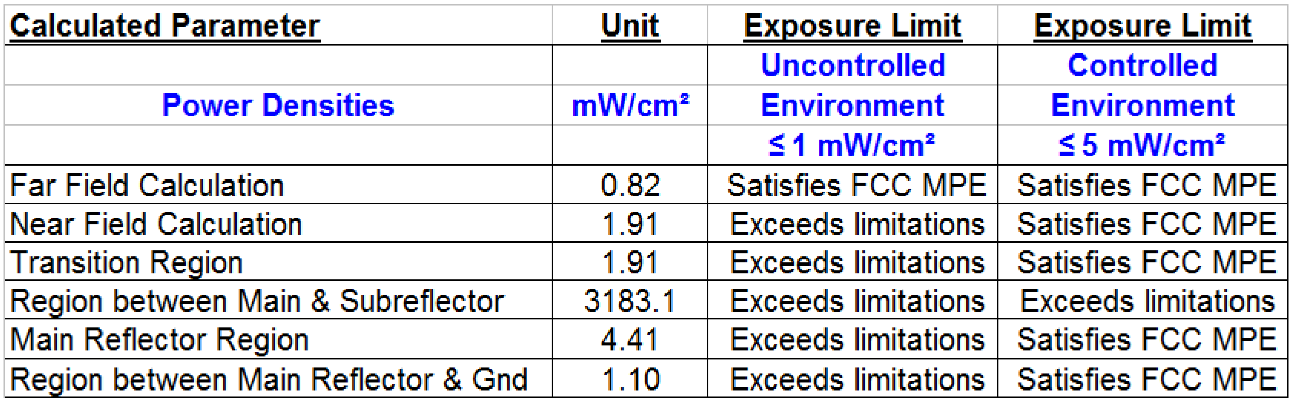
The power density between the reflector and ground, assuming uniform illumination of the reflector surface, is calculated as follows:

Calculated Parameter	**Value**	**Unit**	**Symbol**	**Formula**
Power Density between Reflector & Gnd	1.10	mW/cm^2	Sg	P/A

Summary of Calculations

Table 1 below summarizes the calculated power flux density values for each region. In a controlled environment, the only regions that exceed FCC limitations are the regions between the main reflector and the sub-reflector as well as the main reflector region. These regions are only accessible by trained technicians who, as a matter of procedure, turn off transmit power before performing any work in these areas.

Table 1. Power Flux Density for Each Region:



Calculated Parameter	**Unit**	**Exposure Limit**	**Exposure Limit**
		Uncontrolled	**Controlled**
Power Densities	**mW/cm²**	**Environment**	**Environment**
		≤ 1 mW/cm²	**≤ 5 mW/cm²**
Far Field Calculation	0.82	Satisfies FCC MPE	Satisfies FCC MPE
Near Field Calculation	1.91	Exceeds limitations	Satisfies FCC MPE
Transition Region	1.91	Exceeds limitations	Satisfies FCC MPE
Region between Main & Subreflector	3183.1	Exceeds limitations	Exceeds limitations
Main Reflector Region	4.41	Exceeds limitations	Satisfies FCC MPE
Region between Main Reflector & Gnd	1.10	Exceeds limitations	Satisfies FCC MPE

In conclusion, the results show that the antenna, in a controlled environment, and under the proper mitigation procedures, meets the guidelines specified in § 1.1310 of the Regulations.

RADIATION HAZARD STUDY

When applying for a license to construct and operate, modify, or renew an earth station, it is understood that licensees must certify whether grant of the application will have significant environmental impact as defined in the Federal Communications Commission's (FCC) rules, 47 C.F.R., Section 1.1307.

In this report O3b Limited ("O3b") provides analysis of the maximum radiofrequency (RF) levels emitted from the satellite communications antenna described below. The reference document for this study is OET Bulletin No. 65, Edition 97-01, *Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields*, August 1997.

I. Antenna Near-Field Power Density Calculation

The extent of the near-field is defined by the following equation:

$$R_{near} = (D_{ant})^2 / (4\lambda)$$

where: R_{near} = extent of the near-field (in meters)
D_{ant} = diameter of the antenna main reflector (in meters)
λ = wavelength of the RF transmit frequency (in meters)

The maximum on-axis power density within near-field is defined by the following equation:

$$S_{near} = \{(16\eta P_{feed}) / [\pi(D_{ant})^2]\} / 10$$

where: S_{near} = maximum on-axis power density within the near-field (in milliwatts per square centimeter)
η = antenna aperature efficiency
P_{feed} = maximum power into antenna feed flange (in watts)
D_{ant} = diameter of the antenna main reflector (in meters)

II. Antenna Far-Field Power Density Calculation

The distance to the beginning of the far-field region is defined by the following equation:

$$R_{far} = [0.6(D_{ant})^2] \; / \; \lambda$$

where: R_{far} = distance to beginning of far-field (in meters)
D_{ant} = diameter of the antenna main reflector (in meters)
λ = wavelength of the RF transmit frequency in (meters)

The maximum on-axis power density within the far-field is defined by the following equation:

$$S_{far} = [(P_{feed}\, G_{ant}) / 4\pi(R_{far})^2] / 10$$

where: S_{far} = maximum on-axis power density in the far-field (in milliwatts per square centimeter)
P_{feed} = maximum power into antenna feed flange (in watts)
G_{ant} = antenna main beam gain at RF transmit frequency (in watts)
R_{far} = distance to beginning of far-field (in meters)

III. Antenna Transition Region Power Density Calculation

By definition, the maximum on-axis power densitiy in the transition region will never be greater than the maximum on-axis power densities in the near-field:

$$S_{tr} \leq S_{near}$$

where: S_{tr} = maximum on-axis power density in the transition region (in milliwatts per square centimeter)
S_{near} = maximum on-axis power density in the near-field (in milliwatts per square centimeter)

IV. Antenna Feed-Flange (or Subreflector) Power Density Calculation

The maximum power density at the antenna feed-flange (or subreflector surface) is defined by the following equation:

$$S_{feed(sub)} = 1000 \{[4(P_{feed})] / \{[\pi(D_{feed(sub)})^2] / 4\}\}$$

where: $S_{feed(sub)}$ = maximum power density at the antenna feed-flange or subreflector surface (in milliwatts per square centimeter)
P_{feed} = maximum power into antenna feed flange (in watts)
$D_{feed(sub)}$ = diameter of the antenna feed-flange or subreflector (in centimeters)

V. Antenna Main Reflector Power Density Calculation

The maximum power density in the main reflector region of the antenna is defined by the following equation:

$$S_{ant} = \{[2(P_{feed})] / \{[\pi(D_{ant})^2] / 4\}\} / 10$$

where: S_{ant} = maximum power density in the antenna main reflector region (in milliwatts per square centimeter)
P_{feed} = maximum power into antenna feed flange (in watts)
D_{ant} = diameter of the antenna main reflector (in meters)

VI. Power Density Calculation between the Antenna Main Reflector and the Ground

The maximum power density between the antenna main reflector and the ground is defined by the following equation:

$$S_{ground} = \{P_{feed} / \{[\pi(D_{ant})^2] / 4\}\} / 10$$

where: S_{ground} = maximum power density between the antenna main reflector and the ground (in milliwatts per square centimeter)
P_{feed} = maximum power into antenna feed flange (in watts)
D_{ant} = diameter of the antenna main reflector (in meters)

VII. Summary of Calculated Radiation Levels

O3b understands the licensee must ensure people are not exposed to harmful levels of radiation.

Maximum permissible exposure (MPE) limits for general population/uncontrolled exposure were not considered in this analysis for several reasons. The main-beam orientation and height above ground of this highly directional antenna significantly limit exposure to the general population. Furthermore, access to O3b stations is limited to authorized personnel who have been appropriately briefed and advised.

MPE limits for occupational/controlled exposure, however, were considered in this analysis. It is standard practice for our technical staff to cease transmissions whenever maintenance is performed in close proximity to antenna reflector regions with potentially hazardous power density levels. Based on the results (see above) and our standard practices within our controlled antenna environment, the earth station operators / technicians should not be exposed to radiation levels exceeding 5 mW/cm^2 power density over a six minute averaging time.

REPORT TITLE:

Non-Ionizing Radiation Hazard Analysis

PREPARED BY:
Randy Taylor

APPROVED BY:
Gary Mattie

SCOPE/TEXT (ATTACH ADDITIONAL SHEETS AS REQUIRED)

This report analyzes non-ionizing radiation levels for O3b's 2.4m Tier 2 MEO earth stations. Calculations are performed in accordance with FCC Office of Engineering and Technology's "Bulletin No. 65 Edition 01-01 Supplement C" with regard to the frequencies and antenna types being used. Maximum Permissible Exposure (MPE) limits at O3b uplink frequencies include two exposure situations with limits as described below.

General Population/Uncontrolled Exposure (MPE), averaging window of 30 minutes or less:

1500-100,000 (MHz) = **1.0 mW/cm^2**

Occupational/Controlled Exposure (MPE), averaging window of 6 minutes or less:

1500-100,000 (MHz) = **5.0 mW/cm^2**

This analysis compares MPE limits to the calculated power flux densities at the antenna feed, main reflector surface, between the edge of the main reflector and the ground, near-field region, transition region, and the beginning of the far field.

The result of the analysis is a summary table which describes the power flux densities at key locations and the strategy for limiting General Population and Occupational exposure.

Non-Technical Data. Authorized for Export.

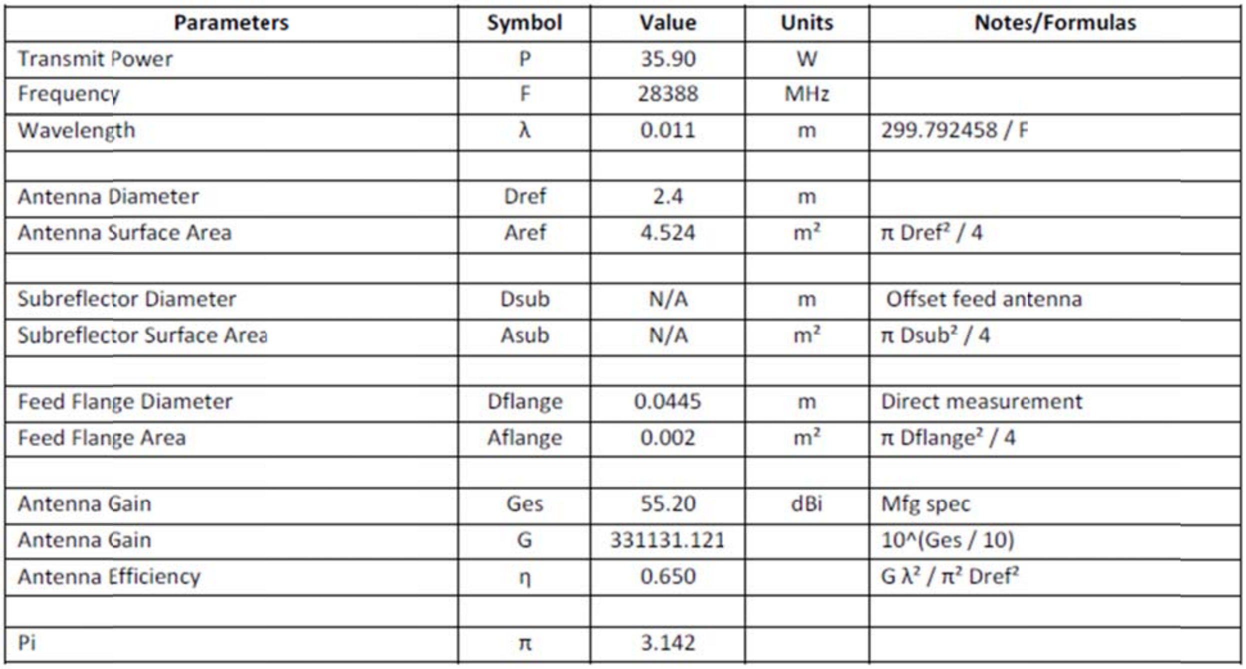
DISTRIBUTION

B. Holz
J. Bloom
S. Blumenthal
G. Mattie
M. Carpenter

J. Mowat
K. Mentasti

1. Formulas and Parameters Used

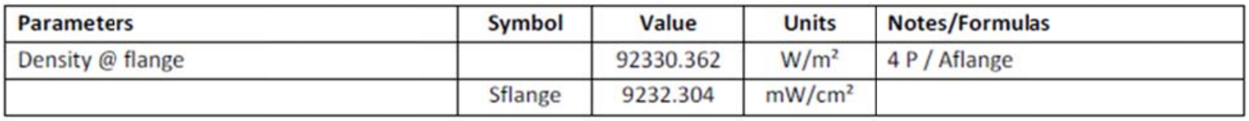
The following data is used throughout the analysis:



Parameters	Symbol	Value	Units	Notes/Formulas
Transmit Power	P	35.90	W	
Frequency	F	28388	MHz	
Wavelength	λ	0.011	m	299.792458 / F
Antenna Diameter	Dref	2.4	m	
Antenna Surface Area	Aref	4.524	m²	π Dref² / 4
Subreflector Diameter	Dsub	N/A	m	Offset feed antenna
Subreflector Surface Area	Asub	N/A	m²	π Dsub² / 4
Feed Flange Diameter	Dflange	0.0445	m	Direct measurement
Feed Flange Area	Aflange	0.002	m²	π Dflange² / 4
Antenna Gain	Ges	55.20	dBi	Mfg spec
Antenna Gain	G	331131.121		10^(Ges / 10)
Antenna Efficiency	η	0.650		G λ² / π² Dref²
Pi	π	3.142		

2. Density at Feed Flange

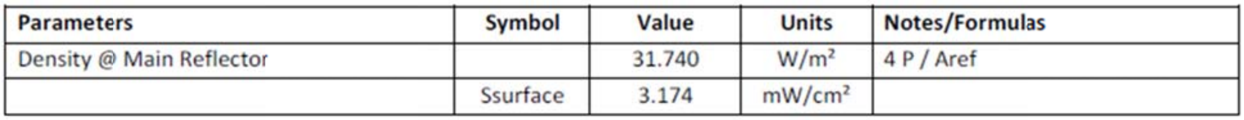
The maximum power flux density at the surface of the feed flange is as follows:



Parameters	Symbol	Value	Units	Notes/Formulas
Density @ flange		92330.362	W/m²	4 P / Aflange
	Sflange	9232.304	mW/cm²	

3. Density at Main Reflector

The maximum power flux density at the surface of the main reflector is as follows:



Parameters	Symbol	Value	Units	Notes/Formulas
Density @ Main Reflector		31.740	W/m²	4 P / Aref
	Ssurface	3.174	mW/cm²	

4. Density between Main Reflector and Ground

The maximum power flux density in the area between the edge of the main reflector and the ground is as follows

Parameters	Symbol	Value	Units	Notes/Formulas
Density, Main Reflector/Ground		7.935	W/m^2	P / Aref
	Sground	0.794	mW/cm^2	

5. Density within the Near Field

The Near Field environment for a parabolic reflector antenna is contained within a cylinder with the same diameter as the main reflector which extends to a distance called the Near Field Extent

Power within the Near Field is constant with the following maximum flux density:

Parameters	Symbol	Value	Units	Notes/Formulas
Range to Near Field Extent	Rnf	136.357	m	$Dref^2 / 4 \lambda$
Density within the Near Field		20.619	W/m^2	$16.0 \eta P / \pi Dref^2$
	Snf	2.062	mW/cm^2	

6. Density at Transition Region

The Transition Region is the area between the Near Field and Far Field regions where power decreases linearly with distance.

The maximum power flux density within the Transition Region is located at the Near Field extent range and is calculated as follows:

Parameters	Symbol	Value	Units	Notes/Formulas
Range to Transition Region	Rt	136.357	m	Occurs at near field extent
Density @ Transition		20.619	W/m^2	Snf Rnf / Rt
	Snf	2.062	mW/cm^2	

7. Density at Beginning of the Far Field

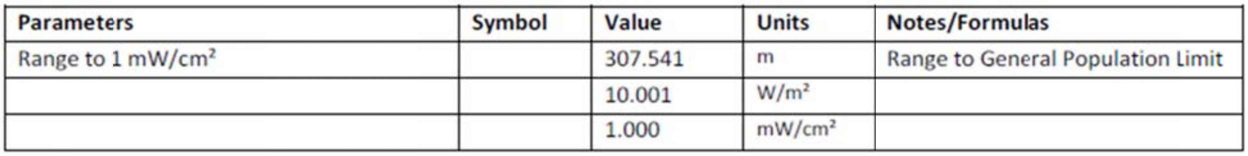
The Far Field region is the range at which power decreases inversely with the square of the distance. The maximum power flux density within the Far Field region occurs at the Far Field Boundary and is calculated as follows:

Parameters	Symbol	Value	Units	Notes/Formulas
Range to Far Field Boundary	Rff	327.256	m	$0.6 D^2 / \lambda$
Density @ Far Field Boundary		8.832	W/m^2	$P G / 4 \pi Rff^2$
	Sff	0.883	mW/cm^2	

8. Range to Far Field General Population Exposure Limit

In addition to the power flux density calculations at key locations, it’s valuable to locate the specific range at which MPE limits are reached to aid in managing exposure control.

The following calculation shows the range at which the Far Field General Population MPE limit occurs:

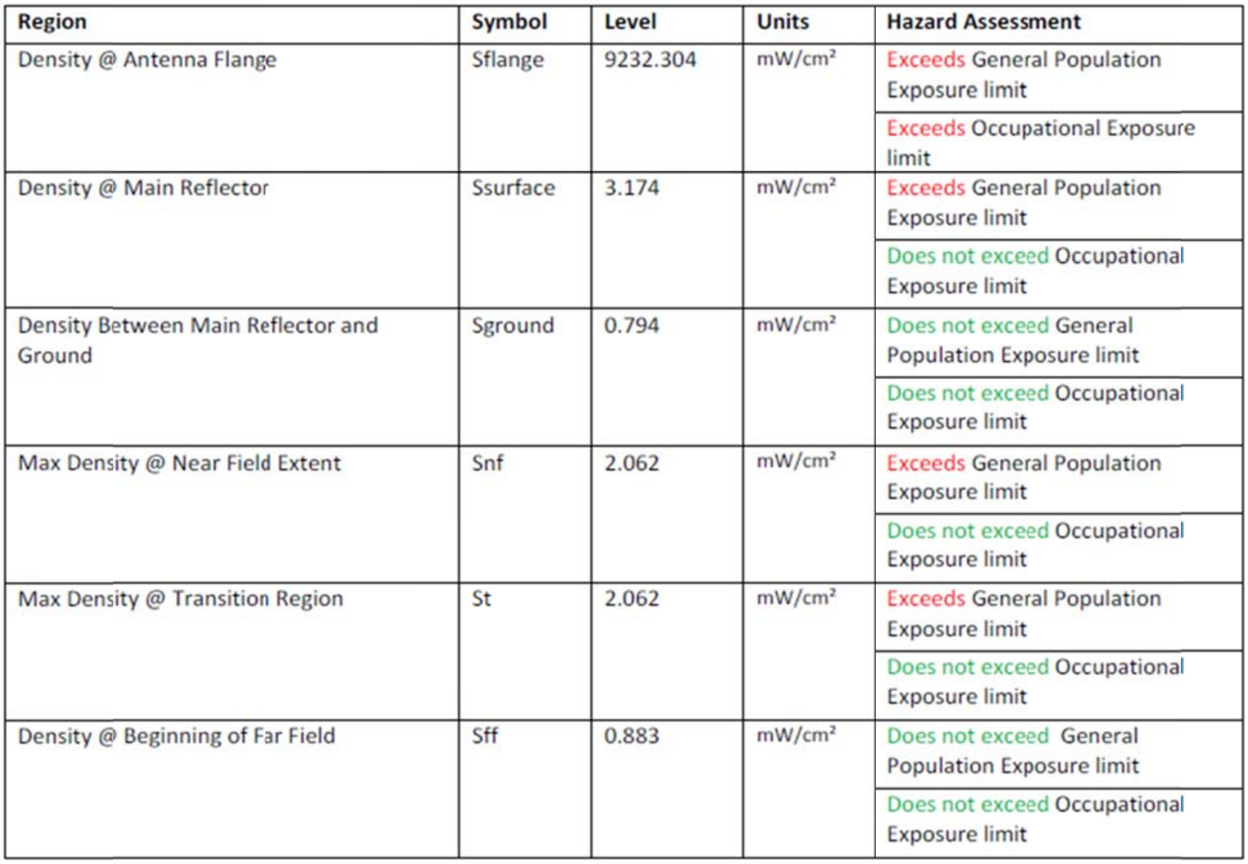


Parameters	Symbol	Value	Units	Notes/Formulas
Range to 1 mW/cm^2		307.541	m	Range to General Population Limit
		10.001	W/m^2	
		1.000	mW/cm^2	

9. Non-Ionizing Radiation Summary

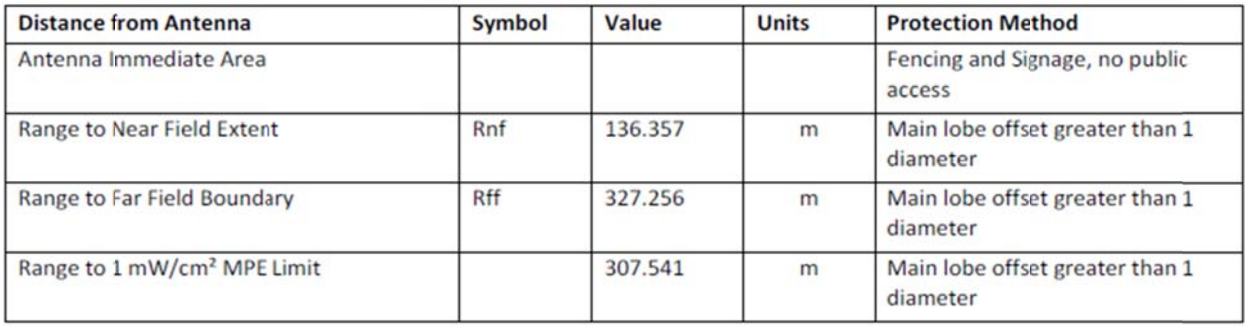
Flux Densities & Exposure Limits

General Population Exposure Limit = 1.0 mW/cm^2
Occupational Exposure Limit = 5.0 mW/cm^2



Region	Symbol	Level	Units	Hazard Assessment
Density @ Antenna Flange	Sflange	9232.304	mW/cm^2	Exceeds General Population Exposure limit
				Exceeds Occupational Exposure limit
Density @ Main Reflector	Ssurface	3.174	mW/cm^2	Exceeds General Population Exposure limit
				Does not exceed Occupational Exposure limit
Density Between Main Reflector and Ground	Sground	0.794	mW/cm^2	Does not exceed General Population Exposure limit
				Does not exceed Occupational Exposure limit
Max Density @ Near Field Extent	Snf	2.062	mW/cm^2	Exceeds General Population Exposure limit
				Does not exceed Occupational Exposure limit
Max Density @ Transition Region	St	2.062	mW/cm^2	Exceeds General Population Exposure limit
				Does not exceed Occupational Exposure limit
Density @ Beginning of Far Field	Sff	0.883	mW/cm^2	Does not exceed General Population Exposure limit
				Does not exceed Occupational Exposure limit

Range to Key Points and General Population Exposure Limit Avoidance Methods



Distance from Antenna	Symbol	Value	Units	Protection Method
Antenna Immediate Area				Fencing and Signage, no public access
Range to Near Field Extent	Rnf	136.357	m	Main lobe offset greater than 1 diameter
Range to Far Field Boundary	Rff	327.256	m	Main lobe offset greater than 1 diameter
Range to 1 mW/cm² MPE Limit		307.541	m	Main lobe offset greater than 1 diameter

10. Conclusion

The above analysis confirms the presence of potentially hazardous power flux densities at the O3b Tier 2 MEO terminals which will require physical and operation protections to manage General Population and Occupational Exposure.

As appropriate, O3b will use fencing, signage, and other measures to limit access to the relevant area. Procedures will be in place requiring that transmit power be turned off before work on the 2.4m antenna is performed. Where an enclosed area is necessary, the size of the enclosed area will consider the RF hazards and the surrounding terrain. The signage will clearly state the standard Radiation Hazard warning.

Personnel with access to the antenna will be trained to ensure that the antennas are off before working in the vicinity or on the antenna systems directly.