Analysis of Non-Ionizing Radiation for a 5.0-Meter Earth Station System

This report analyzes the non-ionizing radiation levels for a 5.0-meter earth station system. The analysis and calculations performed in this report comply with the methods described in the FCC Office of Engineering and Technology Bulletin, No. 65 first published in 1985 and revised in 1997 in Edition 97-01. The radiation safety limits used in the analysis are in conformance with the FCC R&O 96-326. Bulletin No. 65 and the FCC R&O specifies that there are two separate tiers of exposure limits that are dependant on the situation in which the exposure takes place and/or the status of the individuals who are subject to the exposure. The Maximum Permissible Exposure (MPE) limits for persons in a General Population/Uncontrolled environment are shown in Table 1. The General Population/Uncontrolled MPE is a function of transmit frequency and is for an exposure period of thirty minutes or less. The MPE limits for persons in an Occupational/Controlled environment are shown in Table 2. The Occupational MPE is a function of transmit frequency and is for an exposure period of six minutes or less. The purpose of the analysis described in this report is to determine the power flux density levels of the earth station in the far-field, near-field, transition region, between the subreflector or feed and main reflector surface, at the main reflector surface, and between the antenna edge and the ground and to compare these levels to the specified MPEs.

Table 1. Limits for General Population/Uncontrolled Exposure (MPE)

Frequency Range (MHz)	Power Density (mW/cm^2)
30-300	0.2
300-1500	Frequency (MHz)*(0.8/1200)
1500-100,000	1.0

Table 2. Limits for Occupational/Controlled Exposure (MPE)

Frequency Range (MHz)	Power Density (mW/cm^2)
30-300	1.0
300-1500	Frequency (MHz)*(4.0/1200)
1500-100,000	5.0

Table 3. Formulas and Parameters Used for Determining Power Flux Densities

Parameter	Symbol	Formula	Value	Units
Antenna Diameter	D	Input	5.0	m
Antenna Surface Area	$A_{surface}$	$\pi D^2 / 4$	19.63	m^2
Subreflector Diameter	D_{sr}	Input	35.6	cm
Area of Subreflector	A_{sr}	$\pi D_{sr}{}^2/4$	995.38	cm^2
Frequency	F	Input	2056	MHz
Wavelength	λ	300 / F	0.145914	m
Transmit Power	P	Input	37.90	W
Antenna Gain (dBi)	G_{es}	Input	39.0	dBi
Antenna Gain (factor)	G	$10^{Ges/10}$	7943.3	n/a
Pi	π	Constant	3.1415927	n/a
Antenna Efficiency	η	$G\lambda^2/(\pi^2 D^2)$	0.69	n/a

1. Far Field Distance Calculation

The distance to the beginning of the far field can be determined from the following equation:

Distance to the Far Field Region $R_{ff} = 0.60\ D^2 / \lambda$ (1)
$= 102.8$ m

The maximum main beam power density in the far field can be determined from the following equation:

On-Axis Power Density in the Far Field $S_{ff} = G\ P / (4\ \pi\ R_{ff}^{\ 2})$ (2)
$= 2.267$ W/m^2
$= 0.227$ mW/cm^2

2. Near Field Calculation

Power flux density is considered to be at a maximum value throughout the entire length of the defined Near Field region. The region is contained within a cylindrical volume having the same diameter as the antenna. Past the boundary of the Near Field region, the power density from the antenna decreases linearly with respect to increasing distance.

The distance to the end of the Near Field can be determined from the following equation:

Extent of the Near Field $R_{nf} = D^2 / (4\ \lambda)$ (3)
$= 42.8$ m

The maximum power density in the Near Field can be determined from the following equation:

Near Field Power Density $S_{nf} = 16.0\ \eta\ P / (\pi\ D^2)$ (4)
$= 5.292$ W/m^2
$= 0.529$ mW/cm^2

3. Transition Region Calculation

The Transition region is located between the Near and Far Field regions. The power density begins to decrease linearly with increasing distance in the Transition region. While the power density decreases inversely with distance in the Transition region, the power density decreases inversely with the square of the distance in the Far Field region. The maximum power density in the Transition region will not exceed that calculated for the Near Field region. The power density calculated in Section 1 is the highest power density the antenna can produce in any of the regions away from the antenna. The power density at a distance R_t can be determined from the following equation:

Transition Region Power Density $S_t = S_{nf}\ R_{nf} / R_t$ (5)
$= 0.529$ mW/cm^2

Region between the Main Reflector and the Subreflector

Transmissions from the feed assembly are directed toward the subreflector surface, and are reflected back toward the main reflector. The most common feed assemblies are waveguide flanges, horns or subreflectors. The energy between the subreflector and the reflector surfaces can be calculated by determining the power density at the subreflector surface. This can be determined from the following equation:

Power Density at the Subreflector $S_{sr} = 4000\ P / A_{sr}$ (6)
$= 152.303\ mW/cm^2$

4. Main Reflector Region

The power density in the main reflector is determined in the same manner as the power density at the subreflector. The area is now the area of the main reflector aperture and can be determined from the following equation:

Power Density at the Main Reflector Surface $S_{surface} = 4\ P / A_{surface}$ (7)
$= 7.721\ W/m^2$
$= 0.772\ mW/cm^2$

5. Region between the Main Reflector and the Ground

Assuming uniform illumination of the reflector surface, the power density between the antenna and the ground can be determined from the following equation:

Power Density between Reflector and Ground $S_g = P / A_{surface}$ (8)
$= 1.930\ W/m^2$
$= 0.193\ mW/cm^2$

6. Summary of Calculations

Table 4. Summary of Expected Radiation levels for Uncontrolled Environment

Region	Calculated Maximum Radiation Power Density Level (mW/cm^2)		Hazard Assessment
1. Far Field (R_{ff} = 102.8 m)	S_{ff}	0.227	Satisfies FCC MPE
2. Near Field (R_{nf} = 42.8 m)	S_{nf}	0.529	Satisfies FCC MPE
3. Transition Region ($R_{nf} < R_t < R_{ff}$)	S_t	0.529	Satisfies FCC MPE
4. Between Main Reflector and Subreflector	S_{sr}	152.303	Potential Hazard
5. Main Reflector	$S_{surface}$	0.772	Satisfies FCC MPE
6. Between Main Reflector and Ground	S_g	0.193	Satisfies FCC MPE

Table 5. Summary of Expected Radiation levels for Controlled Environment

Region	Calculated Maximum Radiation Power Density Level (mW/cm^2)		Hazard Assessment
1. Far Field (R_{ff} = 102.8 m)	S_{ff}	0.227	Satisfies FCC MPE
2. Near Field (R_{nf} = 42.8 m)	S_{nf}	0.529	Satisfies FCC MPE
3. Transition Region ($R_{nf} < R_t < R_{ff}$)	S_t	0.529	Satisfies FCC MPE
4. Between Main Reflector and Subreflector	S_{sr}	152.303	Potential Hazard
5. Main Reflector	$S_{surface}$	0.772	Satisfies FCC MPE
6. Between Main Reflector and Ground	S_g	0.193	Satisfies FCC MPE

It is the applicant's responsibility to ensure that the public and operational personnel are not exposed to harmful levels of radiation.

7. Conclusions

Based on the above analysis it is concluded that harmful levels of radiation will not exist in regions normally occupied by the public or the earth station's operating personnel. The transmitter will be turned off during antenna maintenance so that the FCC MPE of 5.0 mW/cm2 will be complied with for those regions with close proximity to the reflector that exceed acceptable levels.

The applicant agrees to abide by the conditions specified in Condition 5208 provided below:

> *Condition 5208 - The licensee shall take all necessary measures to ensure that the antenna does not create potential exposure of humans to radiofrequency radiation in excess of the FCC exposure limits defined in 47 CFR 1.1307(b) and 1.1310 wherever such exposures might occur. Measures must be taken to ensure compliance with limits for both occupational/controlled exposure and for general population/uncontrolled exposure, as defined in these rule sections. Compliance can be accomplished in most cases by appropriate restrictions such as fencing. Requirements for restrictions can be determined by predictions based on calculations, modeling or by field measurements. The FCC's OET Bulletin 65 (available on-line at www.fcc.gov/oet/rfsafety) provides information on predicting exposure levels and on methods for ensuring compliance, including the use of warning and alerting signs and protective equipment for worker.*

Analysis of Non-Ionizing Radiation for a 2.7-Meter Yagi Antenna Earth Station System

This report analyzes the non-ionizing radiation levels for a 2.7-meter earth station system. The analysis and calculations performed in this report comply with the methods described in the FCC Office of Engineering and Technology Bulletin, No. 65 first published in 1985 and revised in 1997 in Edition 97-01. The radiation safety limits used in the analysis are in conformance with the FCC R&O 96-326. Bulletin No. 65 and the FCC R&O specifies that there are two separate tiers of exposure limits that are dependant on the situation in which the exposure takes place and/or the status of the individuals who are subject to the exposure. The Maximum Permissible Exposure (MPE) limits for persons in a General Population/Uncontrolled environment are shown in Table 1. The General Population/Uncontrolled MPE is a function of transmit frequency and is for an exposure period of thirty minutes or less. The MPE limits for persons in an Occupational/Controlled environment are shown in Table 2. The Occupational MPE is a function of transmit frequency and is for an exposure period of six minutes or less. The purpose of the analysis described in this report is to determine the power flux density levels of the earth station in the far-field, near-field, transition region, and between the antenna edge and the ground and to compare these levels to the specified MPEs.

Table 1. Limits for General Population/Uncontrolled Exposure (MPE)

Frequency Range (MHz)	Power Density (mW/cm^2)
30-300	0.2
300-1500	Frequency (MHz)*(0.8/1200)
1500-100,000	1.0

Table 2. Limits for Occupational/Controlled Exposure (MPE)

Frequency Range (MHz)	Power Density (mW/cm^2)
30-300	1.0
300-1500	Frequency (MHz)*(4.0/1200)
1500-100,000	5.0

Table 3. Formulas and Parameters Used for Determining Power Flux Densities

Parameter	Symbol	Formula	Value	Units
Ant Largest Dimension	D	Input	2.7	m
Ant Equiv Surface Area	$A_{surface}$	17 elements	3.4#	m^2
Frequency	F	Input	450	MHz
Wavelength	λ	300 / F	0.666	m
Transmit Power	P	Input	7.9	W
Antenna Gain (dBi)	G_{es}	Input	16.5	dBi
Antenna Gain (factor)	G	$10^{Ges/10}$	44.668	n/a
Pi	π	Constant	3.1415927	n/a
Antenna Efficiency	η	$G*\lambda^2/(4*\pi)/A_{surface}$	0.463	n/a

For a Yagi Antenna with 17 elements the surface area of each element is estimated to be 0.2 m^2
Total surface area is 3.4 m^2

1. Far Field Distance Calculation

The distance to the beginning of the far field can be determined from the following equation:

Distance to the Far Field Region $R_{ff} = 0.60\ D^2 / \lambda$ (1)
$= 6.6$ m

The maximum main beam power density in the far field can be determined from the following equation:

On-Axis Power Density in the Far Field $S_{ff} = G\ P / (4\ \pi\ R_{ff}{}^2)$ (2)
$= 6.445\ W/m^2$
$= 0.06445\ mW/cm^2$

2. Near Field Calculation

Power flux density is considered to be at a maximum value throughout the entire length of the defined Near Field region. The region is contained within a cylindrical volume having the same surface area as the antenna. Past the boundary of the Near Field region, the power density from the antenna decreases linearly with respect to increasing distance.

The distance to the end of the Near Field can be determined from the following equation:

Extent of the Near Field $R_{nf} = D^2 / (4\ \lambda)$ (3)
$= 2.73$ m

The maximum power density in the Near Field can be determined from the following equation:

Near Field Power Density $S_{nf} = 4^*\ \eta^*\ P / A_{surface}$ (4)
$= 4.30\ W/m^2$
$= 0.430\ mW/cm^2$

3. Transition Region Calculation

The Transition region is located between the Near and Far Field regions. The power density begins to decrease linearly with increasing distance in the Transition region. While the power density decreases inversely with distance in the Transition region, the power density decreases inversely with the square of the distance in the Far Field region. The maximum power density in the Transition region will not exceed that calculated for the Near Field region. The power density calculated in Section 2 is the highest power density the antenna can produce in any of the regions away from the antenna. The power density at a distance R_t can be determined from the following equation:

Transition Region Power Density $S_{tz} = S_{nf}{}^*R_{nf} / R_{nf}$ (5)
$= 0.300\ mW/m^2$

R_{nf} is calculated at a distance of 4 meters from the antenna.

4. Region between the Antenna and the Ground

Assuming uniform illumination of the antenna surface, the power density between the antenna and the ground can be determined from the following equation:

Power Density between Antenna and Ground $S_g = P / A_{surface}$ (6)

$= 2.32\ W/m^2$

$= 0.232\ mW/cm^2$

5. Summary of Calculations

Table 4. Summary of Expected Radiation levels for Uncontrolled Environment

Region	Calculated Maximum Radiation Power Density Level (mW/cm^2)		Hazard Assessment
1. Far Field (R_{ff} = 6.60 m)	S_{ff}	0.0645	Satisfies FCC MPE
2. Near Field (R_{nf} = 2.73 m)	S_{nf}	0.430	Potential Hazard
3. Transition Region ($R_{nf} < R_t < R_{ff}$)	S_t	0.300	Potential Hazard
4. Between Reflector and Ground	S_g	0.232	Satisfies FCC MPE

Table 5. Summary of Expected Radiation levels for Controlled Environment

Region	Calculated Maximum Radiation Power Density Level (mW/cm^2)		Hazard Assessment
1. Far Field (R_{ff} = 6.60 m)	S_{ff}	0.0645	Satisfies FCC MPE
2. Near Field (R_{nf} = 2.73 m)	S_{nf}	0.430	Satisfies FCC MPE
3. Transition Region ($R_{nf} < R_t < R_{ff}$)	S_t	0.200	Satisfies FCC MPE
6. Between Reflector and Ground	S_g	0.232	Satisfies FCC MPE

It is the applicant's responsibility to ensure that the public and operational personnel are not exposed to harmful levels of radiation.

6. Conclusions

Based upon the above analysis, it is concluded that FCC RF Guidelines have been exceeded in the Near Field and a portion of the Transition Zone of the Uncontrolled (Table 4) environment. In the Controlled (Table 5) environments none of the regions have levels that exceed the FCC RF Guidelines. The applicant proposes to comply with the Maximum Permissible Exposure (MPE) limits of 0.3 mW/cm**2 for the Uncontrolled Areas, and the MPE limits of 1.5 mW/cm**2 for the Controlled Areas.

The earth station Yagi antenna will be mounted on a platform; so the applicant agrees that the antenna will be in an area secured from the public and worker personnel not familiar with the earth station system. Non-assigned worker personnel and the general public must be accompanied by knowledgeable earth station personnel when they enter the earth station secured area.

The earth station’s secured area will be marked with the required radiation hazard signs as described in the recent FCC R&0 13-39. The area in the vicinity of the earth station secured area will also have signs to inform those in the general population and those who may be working in the area or otherwise present that they are close to a RF System capable of producing hazardous levels.

The applicant agrees to abide by the conditions specified in Condition 5208 provided below:

> *Condition 5208 - The licensee shall take all necessary measures to ensure that the antenna does not create potential exposure of humans to radiofrequency radiation in excess of the FCC exposure limits defined in 47 CFR 1.1307(b) and 1.1310 wherever such exposures might occur. Measures must be taken to ensure compliance with limits for both occupational/controlled exposure and for general population/uncontrolled exposure, as defined in these rule sections. Compliance can be accomplished in most cases by appropriate restrictions such as fencing. Requirements for restrictions can be determined by predictions based on calculations, modeling or by field measurements. The FCC's OET Bulletin 65 (available on-line at www.fcc.gov/oet/rfsafety) provides information on predicting exposure levels and on methods for ensuring compliance, including the use of warning and alerting signs and protective equipment for worker.*