RF Radiation Analysis for Datron FSS-4180-LC And Datron FSS-4180-IP Ku Band Communications-on-the-Move (COTM) Antenna Systems

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Table of Contents

List of Figures

List of Tables

1.0 INTRODUCTION

This report is in response to the original 1985 FCC adoption of the 1982 American National Standards Institute (ANSI) guidelines and the further 1993 adoption of the 1992 ANSI and 1991 Institute of Electrical and Electronics Engineers (IEEE) guidelines[1] for evaluating exposure to RF transmitters licensed and authorized by the FCC. In 1996, the FCC adapted a modified version of its original proposal[2], which also fulfills the requirements of the Telecommunications Act of 1996 RF exposure guidelines[3].

The Maximum Permissible Exposure (MPE) radiation limit specifies two separate tiers as shown in ***Table 1***:

- **(A) Occupational/Controlled Exposure**: The time-averaged exposure period is 6 minutes.
- **(B) General Population/Uncontrolled Exposure**: The time-averaged exposure period is 30 minutes.

Table 1 - Maximum Permissible Exposure Limits

(A) Controlled Exposure (6-Minute Average)				***(B) Uncontrolled Exposure (30-Minute Average)***		
Frequency Range (MHz)	***Electric Field Strength (E) (V/m)***	***Magnetic Field Strength (H) (A/m)***	***Power Density (S) (mW/cm²)***	***Electric Field Strength (E) (V/m)***	***Magnetic Field Strength (H) (A/m)***	***Power Density (S) (mW/cm²)***
0.3-3.0	614	1.63	(100)*			
3.0-30	1842/f	4.89/f	(900/f²)*			
0.3-1.34				614	1.63	(100)*
1.34-30				824/f	2.19/f	(180/f²)*
30-300	61.4	0.163	1.0	27.5	0.073	0.2
300-1500	--	--	f/300	--	--	f/1500
1,500-100,000	--	--	**5**	--	--	**1.0**

F = frequency in MHz
* = Plane Wave equivalent Power Density
-- = Not specified.

[1] ANSI/IEEE C95.1-1992 (IEEE Standard for Safety Levels with Respect to Human Exposure to RF Electromagnetic Fields, 3 kHz to 300 GHz)
[2] Refer to ET Docket 93-62 References 55 and 56, and FCC Office of Engineering (OET) Bulletin 65 Reference 57 Edition 97-01 for detailed information.
[3] See Section 704(b) of the Telecommunications Act of 1996, Pub. L No 104-104, Stat 56.

The satellite earth stations being analyzed in this report **(FSS-4180-LC and FSS-4180-IP)** are identical dual optics parabolic antennas that communicate via geosynchronous Ku band[4] satellites. They are designed to be mounted on the rooftop of vehicles and operate while the vehicle is in motion over rough terrain. Precision tracking methods using an Inertial Navigation Unit and GPS tracking maintain the antenna pointing accuracy to within a few 10ths of a degree of boresight. The antennas are protected from the elements by an RF translucent radome. The earth stations are intended to support receive data rates in excess of 1.544 Mbps, and 512 kbps for transmit.

Sophisticated software algorithms include the **automatic shutdown of RF transmissions** when the following conditions exist:

1. When the antenna **boresight error** is greater than a several 10ths of a degree. This error is in Azimuth or Elevation, or a combination of both. This is a settable parameter.
2. When the **elevation angle** goes below a preprogrammed value (usually 5^o to 20^o) or mask.
3. When the **received signal** is no longer available (blocked) and the demodulator fails to lock onto the signal.

The purpose of this analysis is to determine the Power Flux Density (S) for the earth stations and to compare these levels to the specified MPE's of ***Table 1***. Several formulas and parameters to be used for determining the Power Flux Densities are provided in ***Table 2***.

Table 2 - Formulas and Parameters Used in this Document

20130128m02v01_FSS4180LC_Rad_HazCalcs.xls

Parameter	Symbol	Formula	Value	Units
Frequency	F	Input	14,500	MHz
Wavelength	λ	C/F	0.0207	m
Antenna Diameter (inches)				
Major (Azimuth)	D_1		18	inches
Minor (Elevation)	D_2		18.0	inches
Antenna Diameter (m)				
Major (Azimuth)	D_1		0.46	m
Minor (Elevation)	D_2		0.46	m
Antenna Radius				
Major (Azimuth)	R_1		0.23	m
Minor (Elevation)	R_2		0.23	m
Antenna Reflector				
Antenna Surface Area (plane)	$A_{surface}$	area of an ellipse, π*R_1*R_2	0.16	m^2
Equivalent Diameter (as if circular)	De	2*sqrt($A_{surface}$/π)	0.46	m
Subreflector				
Sub-reflector Diameter	D_{sr}	Input	5	cm
Area of Subreflector	A_{sr}	π*R_1*R_2	0.0079	m^2
Power Amplifier				
Transmit Power - saturated	Psat		41.6	dBm
Line Losses between SSPA output and feed input	L	Measured	0.93	dB
Net Power Into Feed	P	Measured	40.7	dBm
Net Power Into Feed	P		12	Watts

4 13.75 to 14.50 GHz Transmit, 10.95 to 12.75 GHz Receive

1.1 Assumptions used for this Analysis

This antenna systems are designed to be mounted on the rooftop of vehicles that can communicate, while on-the-move, with a hub antenna via Ku band satellites. It is important to identify the majority of the types of vehicles that are destined to be the platform for these antennas, and to analyze the antenna profile as it applies to those vehicles.

The primary usage is the US Military, particularly the Army and Marine divisions. The vehicles include, but are not limited to, the HMMWV, the Stryker, and the Bradley. A possibility of other vehicles of a commercial nature could also be chosen; in particular, emergency vehicles, such as ambulances and paramedic rescue vehicles. Photos of these vehicles are presented in ***Figures 1***, ***2***, ***3*** and ***4***. The vehicle height is shown in each of these photos.

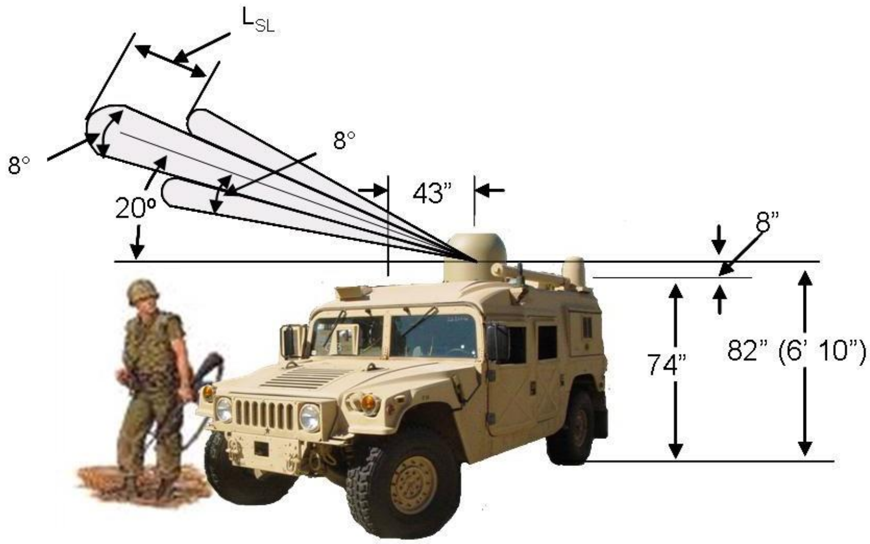


Figure 1- Mounting of COTM Antenna on a HMMWV

Figure 2 - Height at the Platform of a Stryker

Figure 3 - Height at the Platform of a Bradley

Figure 4 - Height at the Rooftop of an Ambulance (Type III)

The lowest profile vehicle of the vehicles considered here is the Army’s and Marine’s HMMWV. It is this vehicle that is the basis for the following analysis. In the HMMWV photo, ***Figures 1***, is shown the antenna in question, overlaid with an approximate radiation pattern of the main lobe and its two significant sidelobes.

The HMMWV has a height of **74”** (6’ 2”) measured from ground to the rooftop. Secondly, the antenna boresight (if pointed at 0^o elevation) rises another **8”** above the platform (rooftop). The total width of the vehicle is 86”, so the center of the rooftop to the vehicle edge is **43”**. Assuming that the lowest elevation angle (relative to the vehicle rooftop) that the antenna system is allowed to transmit is 20^o, the height of the beam at boresight is calculated with the following formula:

Height of boresight @ vehicle edge is = 43” * TAN 20^o
= 15.7”

However, the elevation beamwidth of the **main lobe** is 8^o (null to null), or $\mathbf{4^o}$ on each side of boresight. So the minimum height of the main beam @ vehicle edge is:

43” * Tan (20^o – 4^o) = 12.3”

The elevation sidelobes on either side of boresight are at $\mathbf{8^o}$ (main lobe axis to 2nd null). So the minimum height of the lower sidelobe @ vehicle edge becomes:

43” * Tan (20^o – 8^o) = 9.1”

Adding these heights to the vehicle height plus the antenna boresight from the platform thus becomes:

Minimum main beam height @ vehicle edge	74" + 8" + 12.3" = 94.3", or ~ **7' 10"**
Minimum sidelobe height @ vehicle edge	74" + 8" + 9.1" = 91.1", or ~ **7' 7"**

The height of the main beam at a distance of 10' away from the center of the antenna would be as follows:

Height of boresight @ 10'	120" *Tan (20^o -4^o) = 34.4
Minimum main beam height @ 10'	74" + 8" + 34.4" = 116.4", or ~ **9' 8"**

The height of the sidelobe at a distance of 10' away from the center of the antenna would be as follows:

Height of sidelobe @ 10'	120" *Tan (20^o -8^o) = 25.5"
Minimum sidelobe height @ 10'	74" + 8" + 25.5" = 107.5", or ~ **8' 12"**

This analysis shows that it is not easy to prevent the general public (Uncontrolled Exposure) or the occupational (Controlled Exposure) from maintaining a safe distance away from the vehicle. Further, those personnel entering and exiting the vehicle are well within the high power of the main beam and lower adjacent sidelobes of the antenna. It is this area that poses the greatest hazard. It is further exacerbated by the protective dome that surrounds the antenna, since it totally conceals the antenna's direction. Those who may be in close proximity to the vehicle could be in a direct path of the main beam, and be exposed to harmful RF radiation.

As a safety measure, the manufacturer of the antenna shall:

- pre-set a 20^o elevation (relative to the vehicle rooftop) transmit limit on the antenna
- provide warnings to the operator in the manual and in the GUI should the operator choose to override or change these settings

2.0 ANALYSIS

NOTE: Both FSS_4180_LC and FSS_4180_IP antennas have the same aperture and operate at the same power level. The analysis below is therefore common to each antenna type.

2.1 Far Field Distance Calculation

In the Far Field or Fraunhofer region of the antenna, the power density decreases inversely with the ***square*** of the distance from the main reflector. The distance to the beginning of the far field is[5,6]:

2.1 Far Field Distance Calculation				
Distance to the **Far Field Region**	R_{ff}	$0.6*D^2 / \lambda$		
	R_{ff}	$0.6*(D_1D_2) / \lambda$	6.1	m
	R_{ff}		20	ft

The maximum main beam power density at the beginning of the far field is[7]:

On-Axis Power Density (PD) in the Far Field	S_{ff}	$P G / (4 \pi R_{ff}^2)$	92	W/m^2
			9	mW/cm^2

2.2 Safe Far Field Distance Calculation

It is important to know the minimum distance from the center of the antenna to where the Uncontrolled Exposure ***Power Density (S)*** in ***(mW/cm²)*** is considered safe. Per FCC OET Bulletin 65, a safe limit for uncontrolled exposure is **1.0 mW/cm²**. For a 0° elevation angle, the minimum distance at which this level is achieved is:

2.2 Safe Far Field Distance Calculation				
Uncontrolled Exposure ***Power Density (S)*** in ***(mW/cm²)*** is considered safe	Sffsd		1	mW/cm^2
	Sffsd		10	W/m^2
Safe Distance away from Antenna Center	R_{ffsd}	$\sqrt{(P G / (4 \pi S_{ffsd}))}$	18	m
			60	ft

2.3 Near Field Distance Calculation

In the radiating Near Field region, the average power density remains fairly constant at different distances from the antenna, although there are localized energy fluctuations. This area is called the Fresnel Region, or the focusing region of the antenna.

The distance to the end of the Near Field is[8]:

2.3 Near Field Distance Calculation				
Extent of the **Near Field**	R_{nf}	$= D^2 / (4 \lambda)$		
		$= (D_1D_2) / (4 \lambda)$	3	m
			8	ft

[5] OET Bulletin 65 Edition 97-01 dated August 1997, Formula (16).
[6] D_1 = Width; D_2 = Height
[7] OET Bulletin 65 Edition 97-01 dated August 1997, Formula (18).
[8] OET Bulletin 65 Edition 97-01 dated August 1997, Formula (12).

The maximum power density in the Near Field is[9]:

On-Axis Near Field Power Density	S_{nf}	$= 16\ \eta\ P / (\pi\ D^2)$	216	W/m^2
		$1000\ mW/W / (10000\ cm^2/m^2)$	21.6	mW/cm^2

2.4 Transition Region Calculation

The area between the Near and Far Field regions is called the Transition region. Power density in this region decreases inversely with the distance from the antenna. This region extends from R_{nf} to R_{ff}. The power density at a distance R_t in this region can be determined from the following equation[10]:

2.4 Transition Region Calculation				
Transition Region Power Density	S_t	$= S_{nf} R_{nf} / R_t$, Rt=**Rnf**	216	W/m^2
		$1000\ mW/W / (10000\ cm^2/m^2)$	21.6	mW/cm^2
		$= S_{nf} R_{nf} / R_t$, Rt=**Rff**	90	W/m^2
		$1000\ mW/W / (10000\ cm^2/m^2)$	9.0	mW/cm^2

2.5 Region between Main Reflector and Sub-reflector

The energy between the sub-reflector and the main reflector of a Cassegrain antenna can be calculated by determining the Power Density at the sub-reflector surface. This can be determined from the following equation:

2.5 Region between Main Reflector and Subreflector				
Power Density at Subreflector	S_{sr}	= 4P / Asr	5984	W/m^2
		$1000\ mW/W / (10000\ cm^2/m^2)$	598	mW/cm^2

2.6 Main Reflector Region

Power Density in the main reflector can be determined from the following equation[11]:

2.6 Main Reflector Region				
Power Density at Main **Reflector Surface**	S_{mr}	$= 4\ P / A_{surface}$	286	W/m^2
		$1000\ mW/W / (10000\ cm^2/m^2)$	28.6	mW/cm^2

2.7 Region between Main Reflector and Ground

Assuming uniform illumination of the main reflector surface, the Power Density between the antenna and the ground can be determined from the following equation:

2.7 Region between Main Reflector and Ground				
Power Density between Reflector and Gnd	S_g	$= 4P / A_{surface}$	286	W/m^2
		$1000\ mW/W / (10000\ cm^2/m^2)$	28.6	mW/cm^2

[9] OET Bulletin 65 Edition 97-01 dated August 1997, Formula (13).
[10] OET Bulletin 65 Edition 97-01 dated August 1997, Formula (17).
[11] OET Bulletin 65 Edition 97-01 dated August 1997, Formula (11).

2.8 Safe Distances from Antenna

Following are calculations for determining the minimum safe distance a person must be away from the transmitting antenna. Per FCC OET Bulletin 65, a safe limit for uncontrolled exposure is **1.0 mW/cm²**. At the distances to be calculated, the power density will be less than or equal to 1.0 mW/cm².

For the following calculations, it is assumed that a person would be at or below the level of the antenna.

- With **no elevation limits**, personnel must be over **61 ft away** from the main beam. Since a radome covers the antenna, one would not be certain where the antenna is pointing.
- With **elevation limits of 20°** or greater, a safe distance would be **2 ft away** from the antenna in any direction as long as personnel are below the level of the antenna.

Note that if the vehicle is not level with the ground, it is possible for personnel to be at or above the antenna level. As a precaution, the operator must ensure that personnel are over 65 feet away if they are at or above the antenna level.

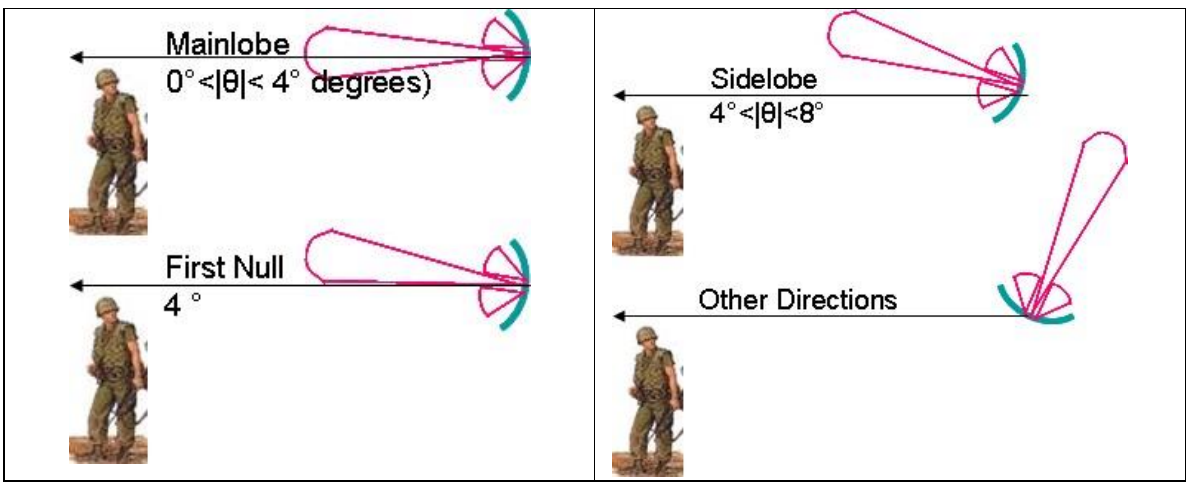


Figure 5 - Antenna Beam Relative to Personnel

20130128m02v01_FSS4180LC_Rad_HazCalcs.xls				
Main Beam				
Main Beam, 0°<|elevation|<4°, 0°<|azimuth|<4°				
Antenna Gain (dBi) @14.5 GHz	G_{es}	Measured	35.6	dBi
Antenna Gain (main lobe factor)	G	$10^{Ges/10}$	3631	n/a
Theoretical Gain	Gt	$4\pi A / \lambda^2$	4820	n/a
Antenna Efficiency	η	G / Gt	75%	%
Antenna Gain with Line Losses @ 14.5 GHz	$G_{es\ total}$	G_{es} - L	*34.67*	*dBi*
Safe Distance (1 mW/cm²)		$\sqrt{(P G / (4 \pi S_{ffsd}))}$	**61**	ft

Elevation Pattern (Azimuth=0)				
4°<|θ|<8° SideLobe (Elevation Pattern)				
Sidelobe Discrimination/Loss (from main beam)	L_{SL}	Measured	20	dB
Antenna Gain @ sidelobes	$G_{es\ sidelobe}$	$Ges – L_{SL}$	15.6	dBi
Antenna Gain (main lobe factor)	G	$10^{Ges/10}$	36	n/a
Safe Distance (1 mW/cm^2)		$\sqrt{(P\,G / (4\,\pi\,S_{ffsd}))}$	**7**	ft
8°<|θ|<20°, (Elevation Pattern)				
Sidelobe Discrimination/Loss (from main beam)	L_{SL}	Measured	35	dB
Antenna Gain	$G_{es\ sidelobe}$	$Ges – L_{SL}$	0.6	dBi
Antenna Gain	G	$10^{Ges/10}$	1	n/a
Safe Distance (1 mW/cm^2)		$\sqrt{(P\,G / (4\,\pi\,S_{ffsd}))}$	**2**	ft
20°<|θ|<50°, (Elevation Pattern)				
Sidelobe Discrimination/Loss (from main beam)	L_{SL}	Measured	35	dB
Antenna Gain	$G_{es\ sidelobe}$	$Ges – L_{SL}$	0.6	dBi
Antenna Gain	G	$10^{Ges/10}$	1	n/a
Safe Distance (1 mW/cm^2)		$\sqrt{(P\,G / (4\,\pi\,S_{ffsd}))}$	**2**	ft
50°<|θ|<90° (Elevation Pattern)				
Antenna Gain	$G_{es\ sidelobe}$	$Ges – L_{SL}$	0	dBi
Antenna Gain	G	$10^{Ges/10}$	1.0	n/a
Safe Distance (1 mW/cm^2)		$\sqrt{(P\,G / (4\,\pi\,S_{ffsd}))}$	**2**	ft

Azimuth Pattern (Elevation=0)				
4°<|θ|<8° SideLobe (Azimuth Pattern)				
Sidelobe Discrimination/Loss (from main beam)	L_{SL}	Measured	*20*	dB
Antenna Gain @ sidelobes	$G_{es\ sidelobe}$	$Ges – L_{SL}$	15.6	dBi
Antenna Gain (main lobe factor)	G	$10^{Ges/10}$	36	n/a
Safe Distance (1 mW/cm^2)		$\sqrt{(P\,G / (4\,\pi\,S_{ffsd}))}$	**7**	ft
8°<|θ|<20°, (Azimuth Pattern)				
Sidelobe Discrimination/Loss (from main beam)	L_{SL}	Measured	*35*	dB
Antenna Gain	$G_{es\ sidelobe}$	$Ges – L_{SL}$	0.6	dBi
Antenna Gain	G	$10^{Ges/10}$	1	n/a
Safe Distance (1 mW/cm^2)		$\sqrt{(P\,G / (4\,\pi\,S_{ffsd}))}$	**2**	ft
20°<|θ|<50°, (Elevation Pattern)				
Sidelobe Discrimination/Loss (from main beam)	L_{SL}	Measured	*35*	dB
Antenna Gain	$G_{es\ sidelobe}$	$Ges – L_{SL}$	0.6	dBi
Antenna Gain	G	$10^{Ges/10}$	1	n/a
Safe Distance (1 mW/cm^2)		$\sqrt{(P\,G / (4\,\pi\,S_{ffsd}))}$	**2**	ft
50°<|θ|<180° (Azimuth Pattern)				
Antenna Gain	$G_{es\ sidelobe}$	$Ges – L_{SL}$	*0*	dBi
Antenna Gain	G	$10^{Ges/10}$	1.0	n/a
Safe Distance (1 mW/cm^2)		$\sqrt{(P\,G / (4\,\pi\,S_{ffsd}))}$	**2**	ft

The following figures show the area that personnel must stay out of to be at or below **1.0 mW/cm^2**.

Figure 6 - Radiation Keep out Zone - No Elevation Limit

- Red shows keep out zone
- Green Shows a simplified keep out zone

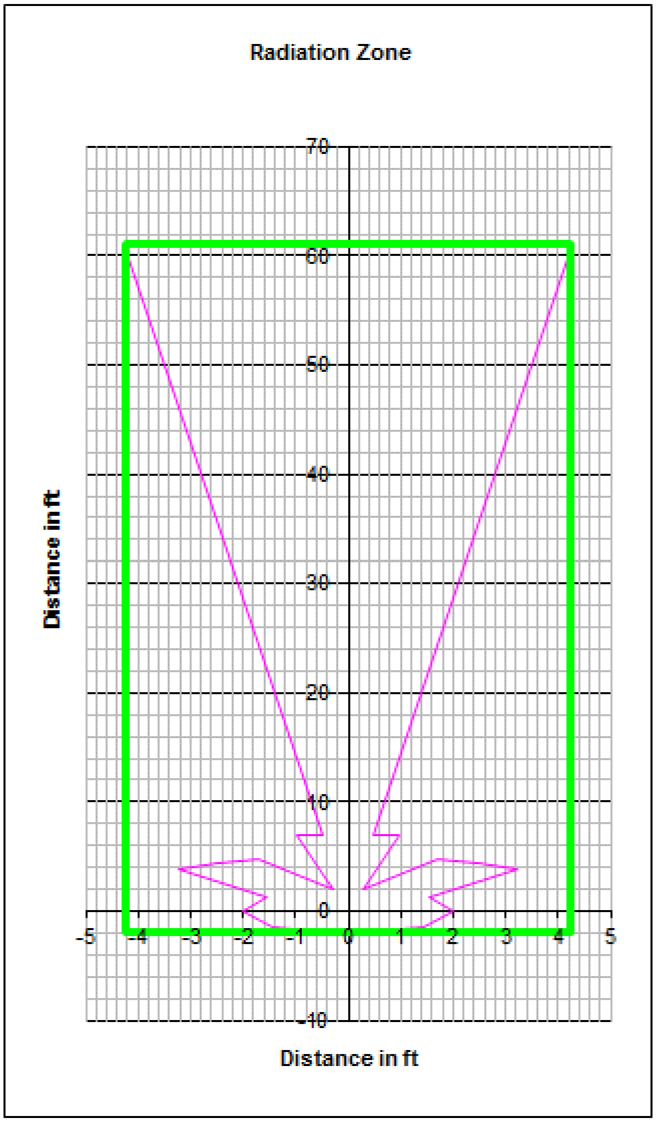
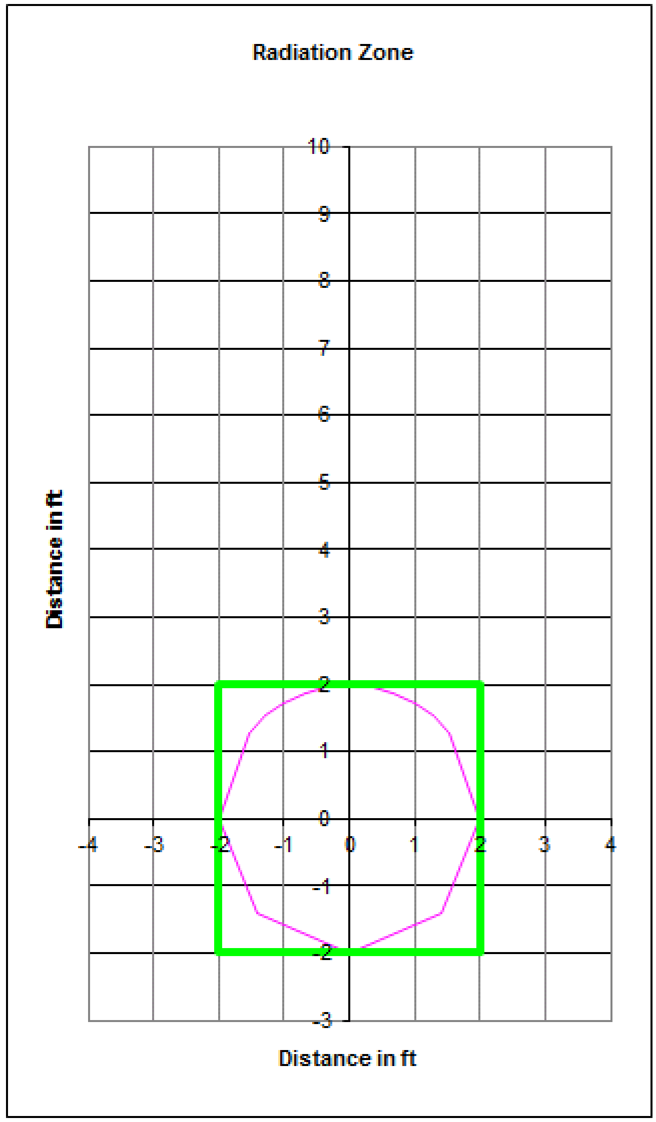


Figure 7 - Radiation Keep out Zone - 20° Elevation Limit

- Red shows keep out zone
- Green Shows a simplified keep out zone



3.0 SUMMARY AND CONCLUSIONS

3.1 Conclusions

The following summary **applies to both** the FSS-4180-LC and FSS-4180-IP antenna types.

Table 3 provides the summary of the previous calculations and the expected radiation levels.

Based upon the above analysis, it is concluded that harmful levels of radiation levels exist in all regions identified in ***Table 3***. This hazardous exposure applies to those who may be around the antenna while it is transmitting.

Table 3 - Summary of Expected Radiation Levels

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Region	**distance (ft)**		**Power Density(mW/cm2)**		
Far Field - Main Beam	20	S_{ff}	9	mW/cm^2	Potential Hazzard
Far Field - Side Lobe	20	S_{nf}	0	mW/cm^2	Satisfies MPE for Controlled Environment
Transition Region	transition	S_t	22	mW/cm^2	Potential Hazzard
Near Field	8	S_{nf}	22	mW/cm^2	Potential Hazzard
Main Reflector	at surface	S_{mr}	29	mW/cm^2	Potential Hazzard
Sub Reflector	at surface	S_{sr}	598	mW/cm^2	Potential Hazzard
Between Main Reflector and Subreflector		S_{mr}	29	mW/cm^2	Potential Hazzard
Between Main Reflector and Ground		S_g	29	mW/cm^2	Potential Hazzard

Table – 4 provides a simplified summary of the radiation hazard area. It is recommended that the operator perform radiation flux density measurements around the antenna during typical operation to verify the area of hazard to personnel and ensure that personnel are restricted from entering the hazard area.

Table 4 - Radiation Hazard Area

<table>
<tr><th colspan="2">Radiation Hazard Area</th></tr>
<tr><td>IF
no elevation limits are used
or if personnel are at or above the level of the antenna</td><td>IF
elevation limits of 20º or greater are used
and personnel are below the level of the antenna</td></tr>
<tr><td>THEN
Keep a distance of 61 ft or more
This area shall be roped off around the antenna, and radiation hazard signs shall be posted during the operation of this antenna.
Operator shall perform measurements to verify hazard area.</td><td>THEN
Keep a distance of 2 ft or more
Access to this area shall be restricted and radiation hazard signs shall be posted during the operation of this antenna.
Operator shall perform measurements to verify hazard area.</td></tr>
</table>

3.2 Manufacturer Responsibility

1. The manufacturer shall advise the owner/operator to have or seek sufficient knowledge on the safe operation of radio transmitters.
2. The manufacturer shall be responsible for installing permanent RF hazard warning labels on the antenna housing, similar to the one in ***Figure 5***.
3. Radiation hazard warnings signs shall be of sufficient size and in clear view of personnel nearby.
4. Labels shall include a **diagram** (similar to **Figures 6, 7**) showing the regions around the earth station where the levels could exceed 1.0 mW/cm^2.
5. The manufacturer shall include warnings in the Operation, Installation, and Maintenance Manuals furnished with each antenna system regarding the potential hazard from RF radiation.
6. The manufacturer shall impose elevation restrictions that turns off the RF transmission when the antenna elevation movements fall below the above specified limits (Table-4).
7. The manufacturer shall pre-program the antenna system with elevation restrictions (Table-4) before delivery.
8. The manufacturer shall provide safety warnings to the operator regarding reducing or removing elevation restrictions.
9. The manufacturer shall maintain this document particularly if parameters of the transmission system change which could impact safety.
10. If a system is delivered that includes a modem and an antenna system, the manufacturer shall ensure that the system is muted within 3 seconds if it is not locked to a receive signal.
11. The manufacturer shall include warnings that an operational system shall include a modem that mutes its transmitter within 3 seconds if it is not locked to a receive signal.
12. The manufacturer shall provide updated labels and documentation to all customers if the safety information is revised.
13. The manufacturer shall recommend that the operator perform a **radiation safety test** of the areas in which personnel will be located during transmission. If radiation exceeds recommended levels, all transmission shall cease until radiation levels have been corrected.

Figure 8 - Radiation Hazard Warning Label Sample

3.2 Operator Responsibility

1. The operator shall have sufficient knowledge or seek training on the safe operation of radio transmitters.
2. The operator shall adhere to the warnings provided by the manufacturer’s labels, manuals, updates, or other documentation.
3. The operator shall keep the labels on the antenna platform in good shape and within clear view of anyone within close proximity.
4. The operator shall ensure that individuals will be prevented from straying within the hazard region (Table-4) by means of signs, fencing or caution tape, verbal warnings, and placement of the earth station or other appropriate means so as to minimize access to the hazardous region.
5. The operator shall perform a visual inspection of the area around the antenna within the hazard area to ensure that all personnel are below the antenna base and removed from the hazard area (Table-4) during transmission.
6. The operator shall ensure that the antenna system is configured with elevation restrictions (Table-4) that turn off the RF transmission when the antenna elevation falls below the above specified limits (Table-4).
7. The operator shall ensure that the system mutes its transmitter within 3 seconds if it is not locked to a receive signal.
8. The operator shall perform a **radiation safety test** of the areas in which personnel will be located during transmission. If radiation exceeds recommended levels, all transmission shall cease until radiation levels have been corrected.