Radiation Hazard Analysis Report
For the KaStream 5000 System

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Summary

This analysis calculates the non-ionizing radiation levels for a TECOM KaStream 5000 aeronautical mobile earth station (ESAA) terminal. The calculations performed in this analysis comply with the methods described in FCC Office of Engineering Technology (OET) Bulletin Number 65. This analysis demonstrates that the TECOM KaStream ESAA terminals are compliant and will not result in exposure levels exceeding the applicable radiation hazard limits when nominal safe zones are observed.

Introduction

The OET Bulletin 65 guidelines incorporate two separate tiers of exposure limits that are dependent on the situation in which the exposure takes place and/or the status of the individuals who are subject to exposure. Limits are determined for persons who are exposed due to their employment and who are made fully aware of the potential for exposure, and exposure limits are also set forth for the general population who may not be aware of the potential for exposure. TECOM ESAA terminals are typically installed on commercial airliners or business aircraft where access to the area around the aircraft is a controlled environment but not all personnel may be aware of the exposure risk. Accordingly, both exposure limits are discussed in this report.

FCC Limits on RF Radiation Intensity Levels

FCC regulations (FCC document, OET Bulletin 65) specify maximum RF radiation levels for occupational and general public exposure. The allowed limits are given in terms of a level and exposure time. A person in either designated category may be exposed to higher levels for shorter exposure times, as long as the time-averaged level is below the constant level allowed for the specified time interval. The levels allowed by the FCC are shown below in Table 1.

Table 1: FCC Limits for RF Radiation Intensity Levels (1.5 – 100 GHz)

Environment Type	Population Category	RF Level (mW/cm^2)
Reflection Free	Occupational	5
	General Public	1
Maximum Reflection	Occupational	1.25
	General Public	0.25

Explanation of the Exposure Calculation

OET Bulletin 65 provides equations for calculating the RF field power density with respect to the aperture location. The equations for near field radius and far field radius are:

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

R near: = range for near field

D: = diameter of circular dish reflector antenna

λ: = wavelength

$R_{near} < R_{(Transition)} < R_{far}$; (The area between near field and far field is the transition field).

$R_{far} = 0.6 * D^2 / (\lambda)$

R far: = range for beginning of far field

D: = diameter of circular dish reflector antenna

λ: = wavelength

The equations for power density, near field and far field are:

$S_{near} = 16 * \eta * P / (\pi * D^2)$

S near: = Power Density in near field

P: = power input to antenna

D: = diameter of circular dish reflector antenna

η: = aperture efficiency

π = 3.1416

$S_{(Transition)} = (S_{near}) * (R_{near}) / R$

$S_{far} = P * G / (4\pi * R^2)$

S far: = Power Density in far field

P: = power input to antenna

G: = antenna gain (linear)

R: = distance from antenna

π = 3.1416

In addition to the trained operator and general public environment limits, the two cases to consider in ensuring public safety are: 1) operation in an open environment, and 2) operation into a surface which acts as a reflector to the RF incident energy (e.g., aluminum hanger door). The worst case is in the presence of a reflector, which depending on the distance to the reflector, could result in the effective RF power density being four times that present in a non-reflective environment. The safe zone plots included in this report are for the worst case reflective environment. All four environments are presented in the tabular data shown in Table 3. For additional information on how a reflecting surface affects power density, see Section 2, "Equations for Predicting RF Fields" in the FCC document, OET Bulletin 65.

The actual value of the signal power density (S) will depend on the distance from the antenna to the point of interest, the antenna gain along the line-of-sight between that point and the antenna, and on the RF power supplied to the antenna. The field strength will be estimated using near field, transition field, or far field equations.

ESAA Terminal Description

The KaStream 5000 ESAA terminal is similar to other small airborne terminals currently authorized with blanket license approval. The ESAA terminal uses transmitted power control to reduce uplink interference and improve system throughput. At maximum linear power, the ESAA terminal transmits with 10 watts. Operation can be up to 100% duty cycle, however the duty cycle is normally set to a fraction of this rate by the network loading conditions.

The ESAA incorporates a feature that limits the potential for human exposure. A condition for enabling transmitter operation is receiving the signal from the network satellite above a decoding threshold. The receive and transmit antenna patterns are collinear and any loss of connectivity in the receive path will shut down the transmitter in less than one second. Transmissions will not resume until downlink communications have been reestablished for approximately four seconds.

Gain plots for the aperture are shown in Figures 7 through 16 across ±180 degrees. The terminal is capable of both RHCP (Right Hand Circular Polarization) and LHCP (Left Hand Circular Polarization), and so antenna gain patterns are shown for both polarizations.

TECOM Antenna Parameters

For the TECOM antenna, the following values are used:

Highest Transmit frequency (F): 31 GHz

Minimum Wavelength (λ = c/F): 0.9 cm

Aperture diameter (D): 29 cm (11.5 inches)

Aperture main beam gain (G): 5888.4 (37.7 dBic)

Aperture side lobe gain (G): 158.5 (22 dBic)

Aperture back lobe gain (G): 0.1 (-10 dBic)

Aperture Maximum Power Input: 20 Watts (43 dBm)

Aperture efficiency (η): 0.75

Table 2: Zone Field Calculations for Near, Transition, and Far Field

(cm)	$S_{ff}=\frac{PG}{4\pi R^2}$	$S_{nf}=\frac{16\eta P}{\pi D^2}$ (mW/cm^2)	$S_t=\frac{S_{nf}R_{nf}}{R}$
Dist	Far Field	Near Field	Transition
1	9.37E+06	89.54	19735.21
2	2.34E+06	89.54	9867.61
3	1.04E+06	89.54	6578.40
4	5.86E+05	89.54	4933.80
5	3.75E+05	89.54	3947.04
6	2.60E+05	89.54	3289.20
7	1.91E+05	89.54	2819.32
8	1.46E+05	89.54	2466.90
9	1.16E+05	89.54	2192.80
10	93717.38	89.54	1973.52
11	77452.38	89.54	1794.11

(cm)	$S_{ff}=\frac{PG}{4\pi R^2}$	$S_{nf}=\frac{16\eta P}{\pi D^2}$ (mW/cm^2)	$S_t=\frac{S_{nf}R_{nf}}{R}$	
Dist	Far Field	Near Field	Transition	
221	191.88	89.54	89.30	← End of Near Field Zone (Beginning of Transitional Zone)
222	190.16	89.54	88.90	
223	188.46	89.54	88.50	
224	186.78	89.54	88.10	
225	185.12	89.54	87.71	
475	41.54	89.54	41.55	← Beginning of modified equation zone
476	41.36	89.54	41.46	
477	41.19	89.54	41.37	
478	41.02	89.54	41.29	
479	40.85	89.54	41.20	
480	40.68	89.54	41.12	
525	34.00	89.54	37.59	
526	33.87	89.54	37.52	
527	33.74	89.54	37.45	
528	33.62	89.54	37.38	
529	33.49	89.54	37.31	← End of Transition Zone (End of modified equation zone)
530	33.36	89.54	37.24	
531	33.24	89.54	37.17	
532	33.11	89.54	37.10	
533	32.99	89.54	37.03	
534	32.87	89.54	36.96	
535	32.74	89.54	36.89	

A simplified conservative antenna gain limit for the KaStream 5000 is shown in Appendix A Figures 7 through 16, and is referenced as "Mask". The actual gain will always be below this level, and therefore it provides a worst case value for the calculation of a safe distance for field tests, and for general population exposure.

The hazard level can be considered for four Antenna Gain Regions defined by the orientation relative to the aperture: Main beam, First Side Lobes, Forward Off Angle, and Back Lobes. The Main Beam -3 dB width is 2.2 degrees and reduces to -10 dB at 3.8 degrees width (+/- 1.9 degrees extent). The First Sidelobes peak at +/- 3.6 degrees. Forward Off Angle covers the region between -10 to -110 and +10 to +110 degrees. The back lobes extend from the 180 degree position to +110 and -110 degrees relative to the main beam peak.

Calculation of Signal Power Density (S)

To simplify calculations, the far field calculations are used for all cases. The far field calculations always provide a conservative estimate of the field levels, except for a small zone between 475 cm and 529 cm (end of transition region). In presenting Table 3, all distances which are within this small zone are set to the far field distance of 529 cm (17.36 feet). Beyond this distance the far field calculations are accepted. Comparisons of the three sets of equations for the field strengths (mW/cm^2) are shown in Table 2 evaluated at all distances. Transition points are also indicated showing the distance at which one region stops and another region begins.

Example:

Input power to aperture: 43.0 dBm = 19,953 mW

Antenna Gain = 37.7 dB (main beam) (power ratio = $10^{(37.7/10)}$ = 5888.4)

FCC maximum allowed power density for public exposure in front of a reflector = 0.25 mW/cm^2

Min allowed distance from antenna R = SQRT [19953 x 5888.4/ (4π*0.25)] = 6115.4 cm = 200.6 feet

A worst case transmit power (highest power level) analysis is shown below for tail mount:

Input power to aperture: 20 Watts = 20,000 mW

Distance from aircraft tail: 8 feet

Antenna mounted 14 feet above ground level.

Height of individual: 6' 2"

Angle off of antenna center beam (Antenna pointed at horizon): atan[(14-6.167)/8] = 44.4°

Distance from antenna to individual R = SQRT (8^2+$(14-6.167)^2$) = 11.2 feet = 341.3 cm

Antenna Gain at exposure angle (using conservative mask) = 1.54 dB

FCC maximum allowed power density for public exposure in front of a reflector = 0.25 mW/cm^2

RF radiation power density $S = P*G / (4\pi*R^2) = 20{,}000*1.43/(4\pi*341.3^2) = 0.0195$ mW/cm^2

The calculated power level is well within FCC Limits.

A graph showing the worst case conditions (reflectors) for an aircraft parked on the tarmac is shown in Figure 1.

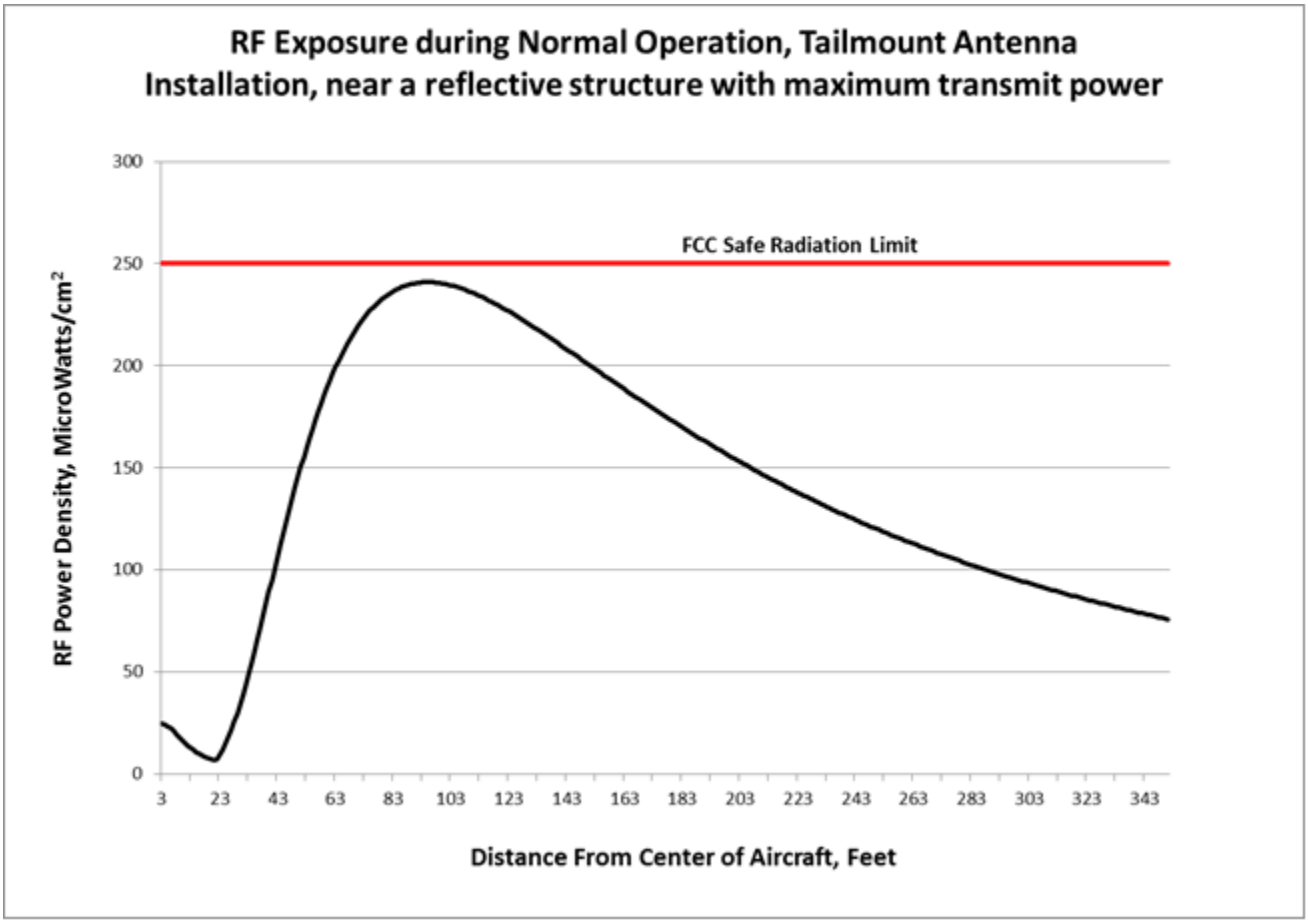

Figure 1*: RF Radiation Intensity on the ground for maximum transmit power.*

Results of Analysis

Polar plots of the safe zones are shown in Figures 3, 4, 5, and 6. Tabular data for the safe zone distance calculated using the simplified conservative antenna gain plot is shown in Table 3.

Operators and technicians working in and around the equipment will receive training specifying the areas of high exposure. Procedures will be established to ensure that all transmitters are turned off before this area may be accessed by operators, maintenance and/or other authorized personnel. A safety feature of the system turns off the transmitter within 100 milliseconds any time the aperture is blocked, thus preventing any more than brief exposure to the transmit radiation.

Commissioning and testing of the TECOM antenna will only be conducted by trained personnel in a controlled environment. In test and development the antenna testing area will be cordon off according to the safe zone areas presented in Figure 3 through 6. This will prevent the general public from being exposed to excessive levels of RF energy. Test personnel will be trained to establish a level of understanding and test protocol that will deter accidental exposure to excessive levels of RF energy.

Label Requirements

The results of this report establishes that harmful levels of RF radiation are produced by the KaStream 5000 system, and that careful distance requirements for personnel and public exposure are important limits that must be controlled. In addition to the operating guidelines provided in Appendix C, warning labels will be displayed on the equipment, and on any radome covering the equipment to ensure that personnel and the general public are made aware of the dangers involved in close proximity to the immediate location and surrounding areas. Typical warning labels are shown in Figure 2 for both the equipment/radome, and for the safe zone boundary region.

Figure 2*: Typical warning label for RF radiation conditions*

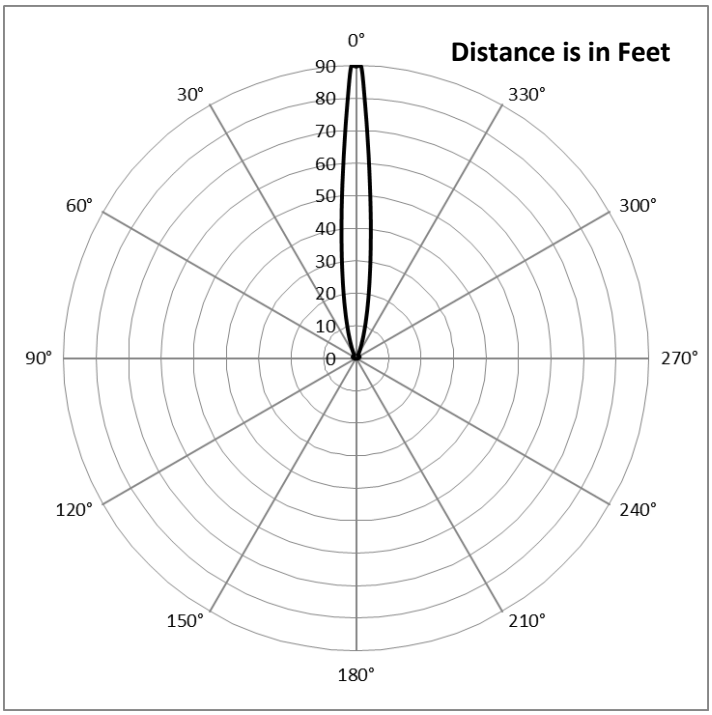

Figure 3*: Safe zone distance requirements for the occupational access zone*

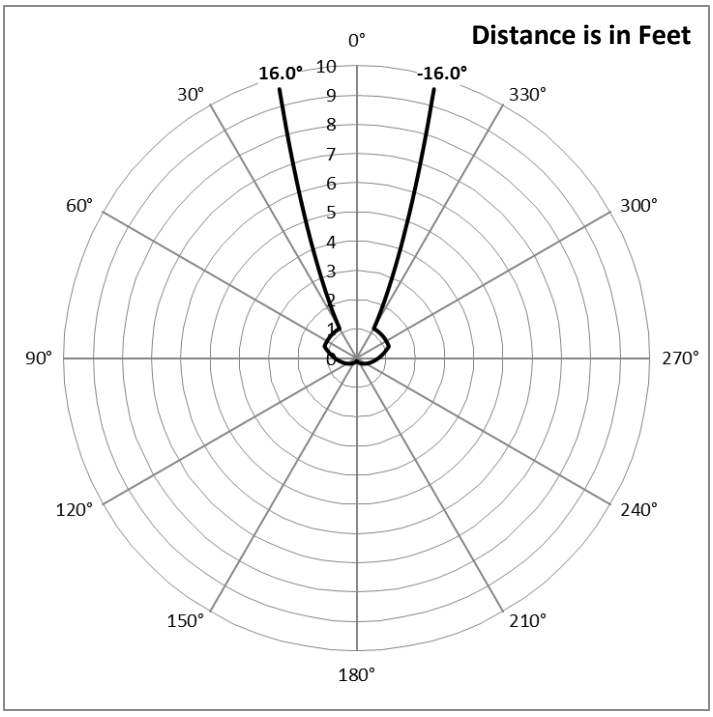

Figure 4*: Expanded view of safe zone distance requirements for the occupational access zone*

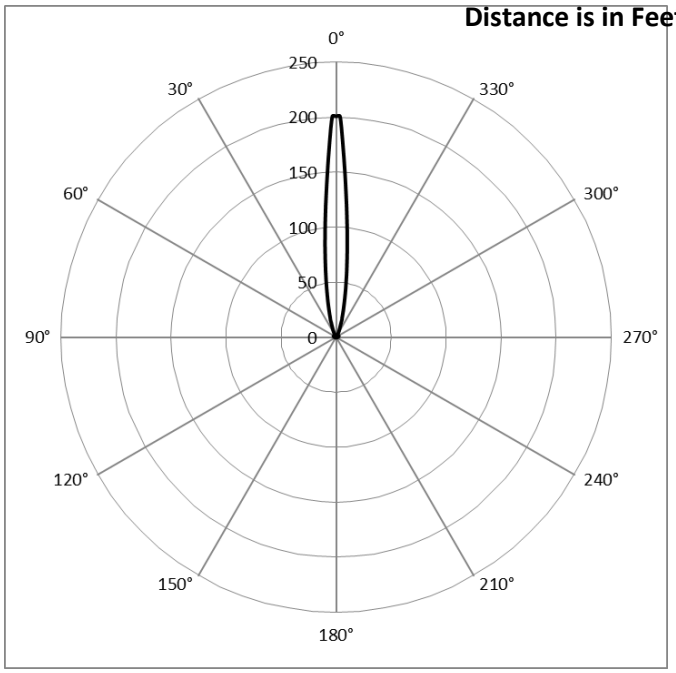

Figure 5*: Safe zone distance requirements for the general public access zone*

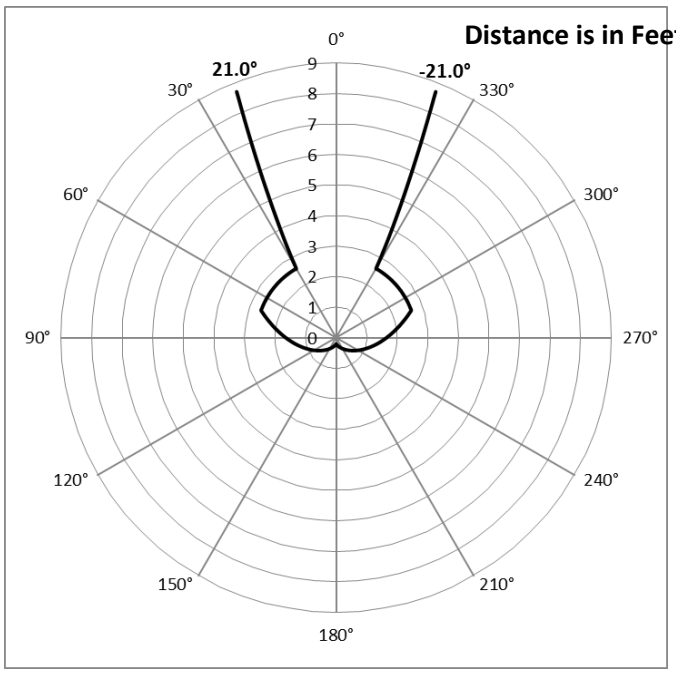

Figure 6*: Expanded view of safe zone distance requirements for the general public access zone*

Table 3: Tabular data of safe zone distance from antenna

Angle	Free Space Requirements		Standing in Front of a Reflector	
	Occupational/ Controlled Safe Distance (Ft)	General Population/ Uncontrolled Safe Distance (Ft)	Occupational/ Controlled Safe Distance (Ft)	General Population/ Uncontrolled Safe Distance (Ft)
-180	0.046	0.104	0.093	0.208
-175	0.052	0.117	0.104	0.233
-170	0.058	0.131	0.117	0.261
-165	0.066	0.147	0.131	0.293
-160	0.074	0.165	0.147	0.329
-155	0.083	0.185	0.165	0.369
-150	0.093	0.207	0.185	0.414
-145	0.104	0.232	0.208	0.465
-140	0.117	0.261	0.233	0.522
-135	0.131	0.293	0.262	0.585
-130	0.147	0.328	0.294	0.657
-125	0.165	0.368	0.330	0.737
-120	0.185	0.413	0.370	0.827
-115	0.207	0.464	0.415	0.928
-110	0.233	0.520	0.466	1.041
-105	0.261	0.584	0.522	1.168
-100	0.293	0.655	0.586	1.310
-95	0.329	0.735	0.658	1.470
-90	0.369	0.825	0.738	1.650
-85	0.414	0.926	0.828	1.851
-80	0.464	1.038	0.929	2.077
-75	0.521	1.165	1.042	2.330
-70	0.585	1.307	1.169	2.615
-65	0.585	1.307	1.169	2.615
-60	0.585	1.307	1.169	2.615
-55	0.585	1.307	1.169	2.615
-50	0.585	1.307	1.169	2.615
-45	0.585	1.307	1.169	2.615
-40	0.585	1.307	1.169	2.615
-35	0.585	1.307	1.169	2.615
-30	0.585	1.307	1.169	2.615
-25	1.239	2.770	2.478	5.540
-20	2.625	5.870	5.250	11.740
-15	5.562	12.438	11.125	24.876
-10	11.787	26.356	23.573	52.712
-5	24.976	55.847	49.951	111.695
0	44.864	100.318	89.727	200.637

Angle	Free Space Requirements		Standing in Front of a Reflector	
	Occupational/ Controlled Safe Distance (Ft)	General Population/ Uncontrolled Safe Distance (Ft)	Occupational/ Controlled Safe Distance (Ft)	General Population/ Uncontrolled Safe Distance (Ft)
5	24.976	55.847	49.951	111.695
10	11.787	26.356	23.573	52.712
15	5.562	12.438	11.125	24.876
20	2.625	5.870	5.250	11.740
25	1.239	2.770	2.478	5.540
30	0.585	1.307	1.169	2.615
35	0.585	1.307	1.169	2.615
40	0.585	1.307	1.169	2.615
45	0.585	1.307	1.169	2.615
50	0.585	1.307	1.169	2.615
55	0.585	1.307	1.169	2.615
60	0.585	1.307	1.169	2.615
65	0.585	1.307	1.169	2.615
70	0.585	1.307	1.169	2.615
75	0.521	1.165	1.042	2.330
80	0.464	1.038	0.929	2.077
85	0.414	0.926	0.828	1.851
90	0.369	0.825	0.738	1.650
95	0.329	0.735	0.658	1.470
100	0.293	0.655	0.586	1.310
105	0.261	0.584	0.522	1.168
110	0.233	0.520	0.466	1.041
115	0.207	0.464	0.415	0.928
120	0.185	0.413	0.370	0.827
125	0.165	0.368	0.330	0.737
130	0.147	0.328	0.294	0.657
135	0.131	0.293	0.262	0.585
140	0.117	0.261	0.233	0.522
145	0.104	0.232	0.208	0.465
150	0.093	0.207	0.185	0.414
155	0.083	0.185	0.165	0.369
160	0.074	0.165	0.147	0.329
165	0.066	0.147	0.131	0.293
170	0.058	0.131	0.117	0.261
175	0.052	0.117	0.104	0.233
180	0.046	0.104	0.093	0.208

Conclusion

The system when properly installed and operated will not subject personnel to excess RF energy. The analysis presented covers all possible environments during which personnel and/or the public will be exposed. Typical aircraft operation (tail mounted) will prevent direct exposure to the main beam of the aperture. Possible exposure may occur through antenna sidelobe emissions. An analysis of a typical operational scenario detailed in Appendix B, demonstrates that the RF radiation levels are well within the acceptable range for individuals walking around the aircraft.

Reference Documents

OET Bulletin No. 65, “Evaluating Compliance with FCC Guidelines for Human Exposure to Radio Frequency Electromagnetic Fields”, Edition 97-01.

APPENDIX A – Aperture Gain Patterns for the TECOM Tail Mount Antenna

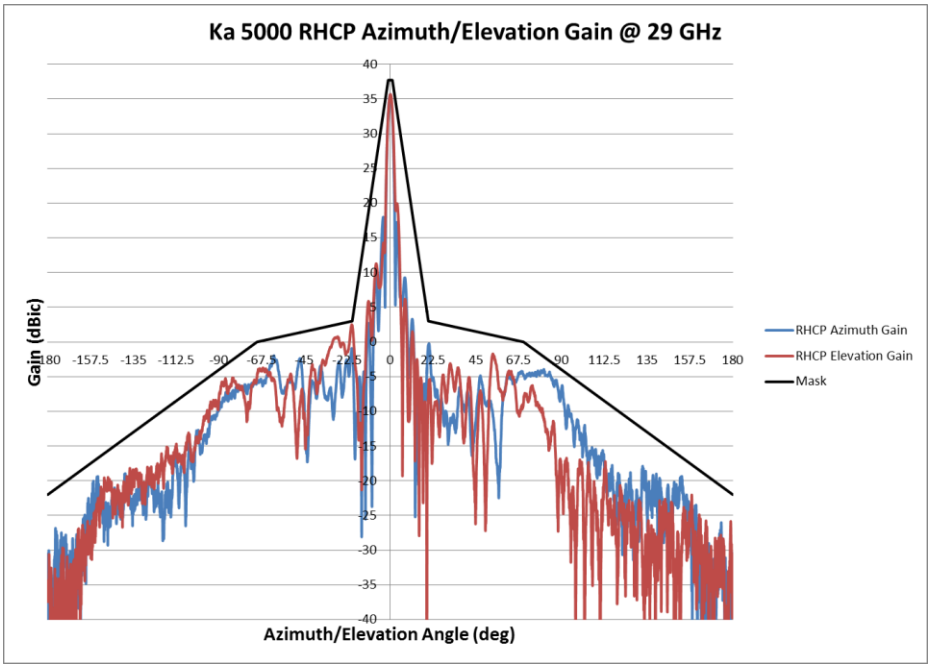

Figure 7*: Co-polarized Gain at 29 GHZ, RHCP*

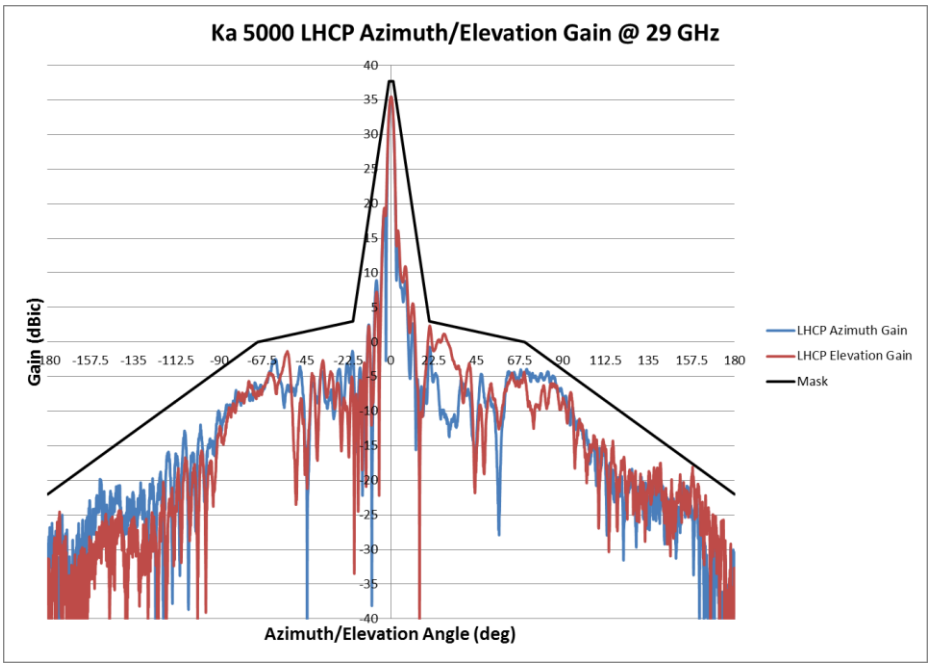

Figure 8*: Co-polarized Gain at 29 GHZ, LHCP*

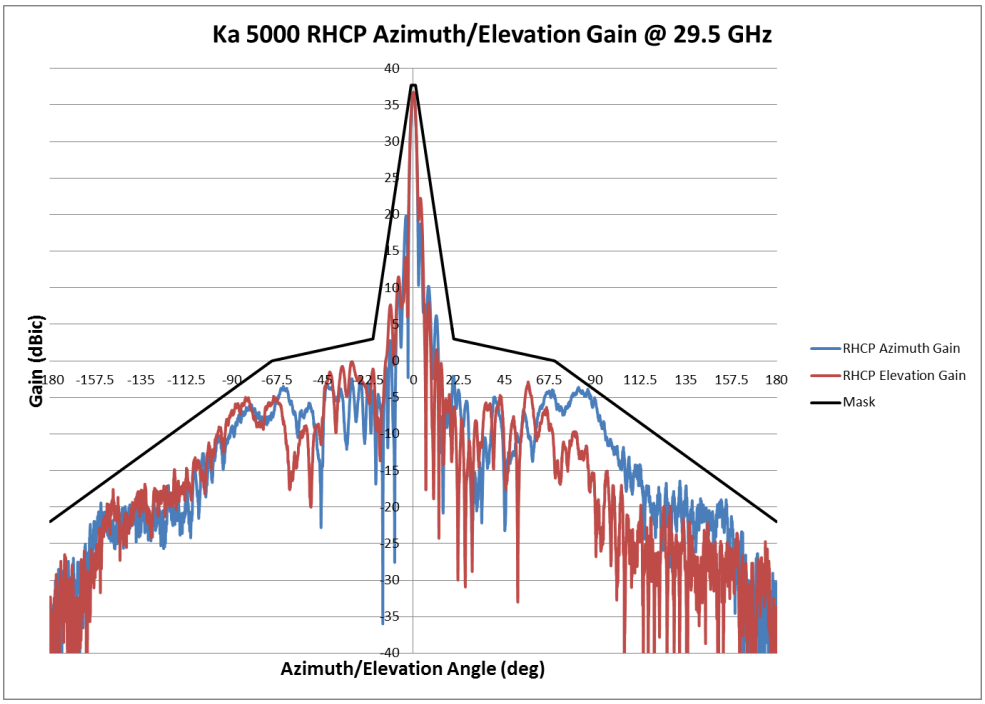

Figure 9*: Co-polarized Gain at 29.5 GHZ, RHCP*

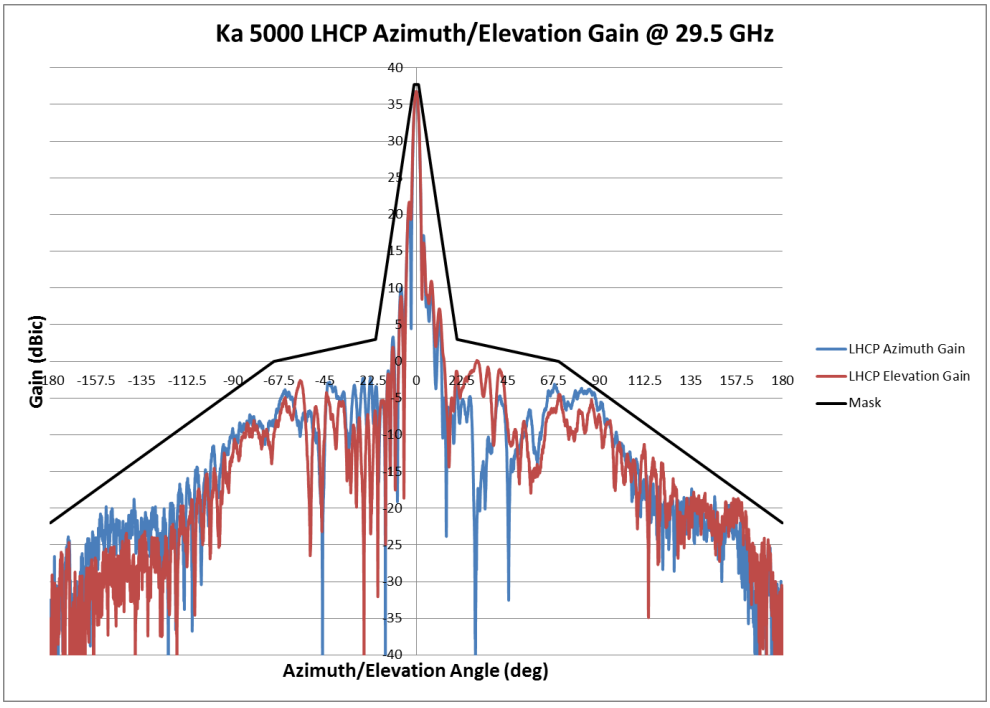

Figure 10*: Co-polarized Gain at 29.5 GHZ, LHCP*

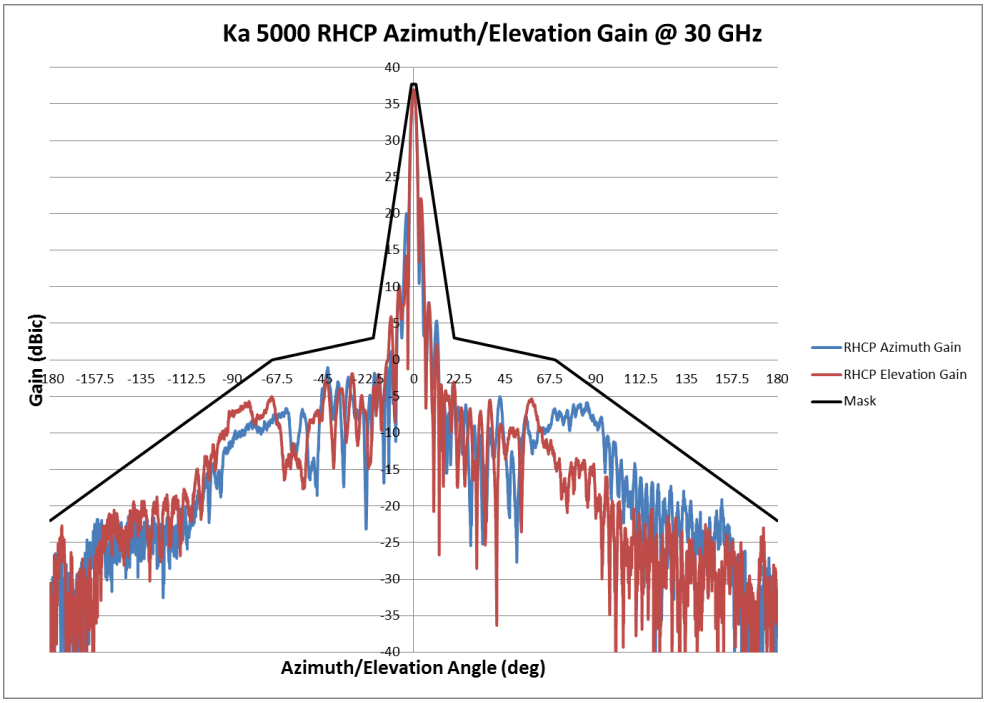

Figure 11*: Co-polarized Gain at 30 GHZ, RHCP*

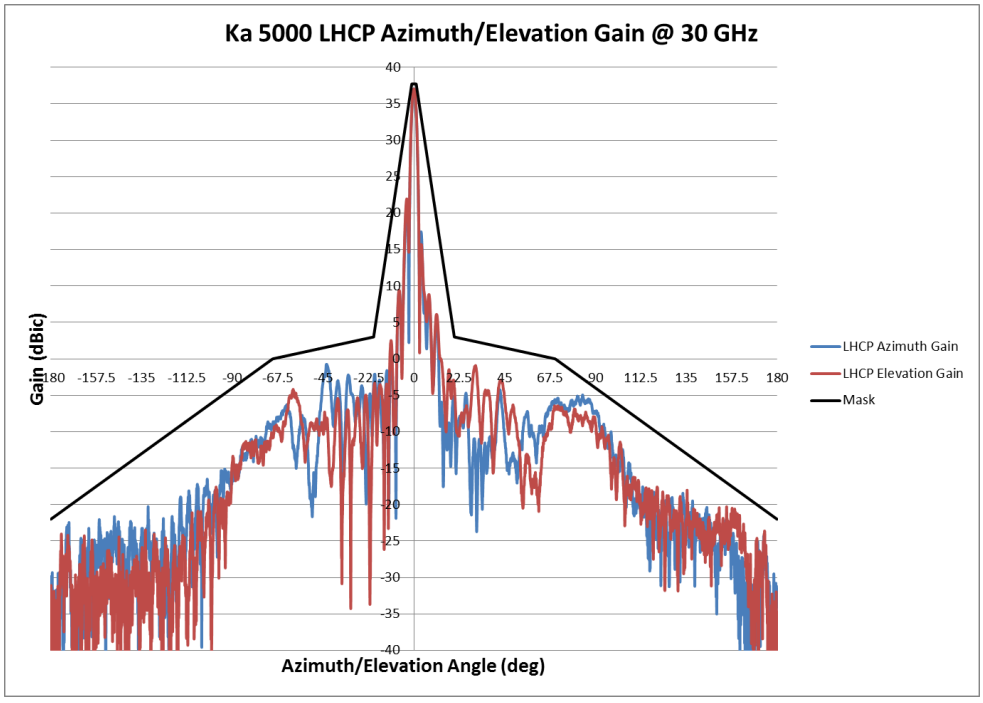

Figure 12*: Co-polarized Gain at 30 GHZ, LHCP*

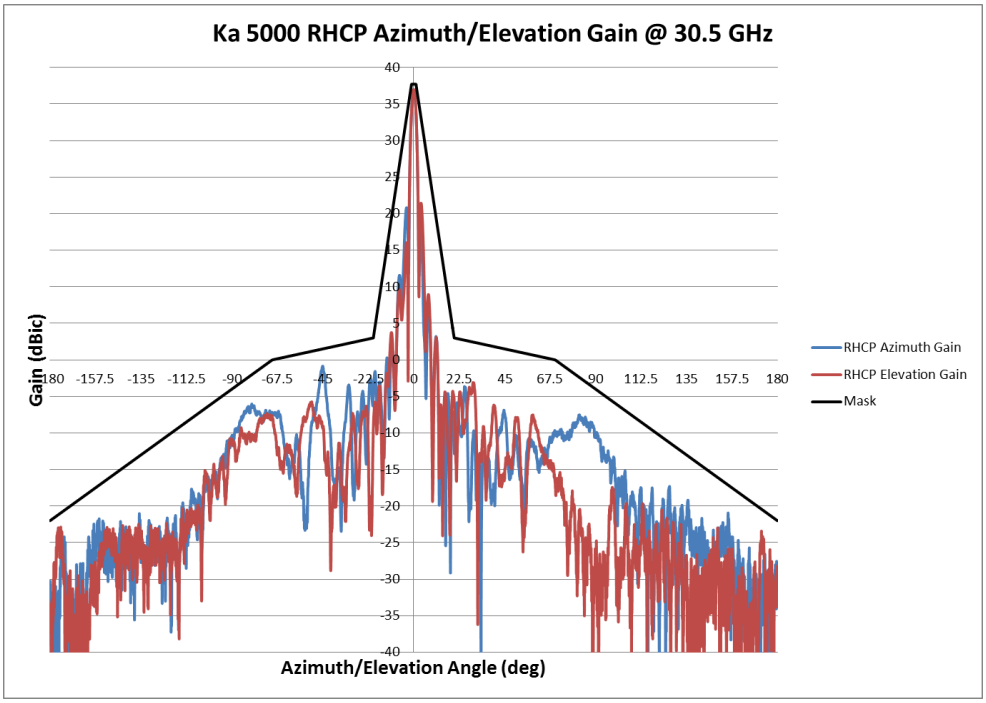

Figure 13*: Co-polarized Gain at 30.5 GHZ, RHCP*

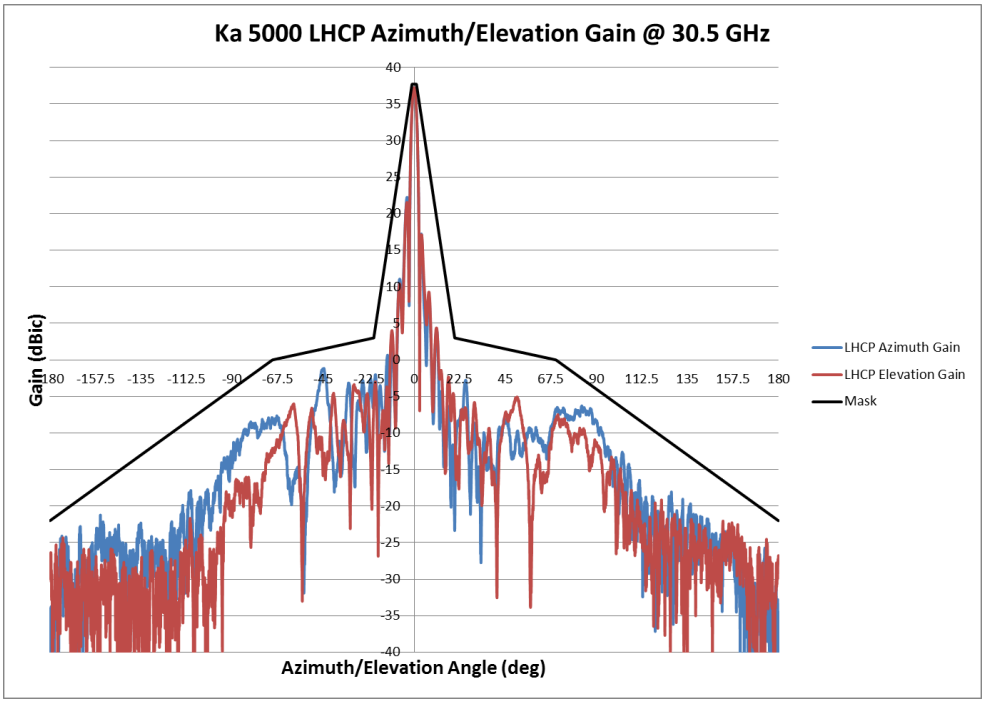

Figure 14*: Co-polarized Gain at 30.5 GHZ, LHCP*

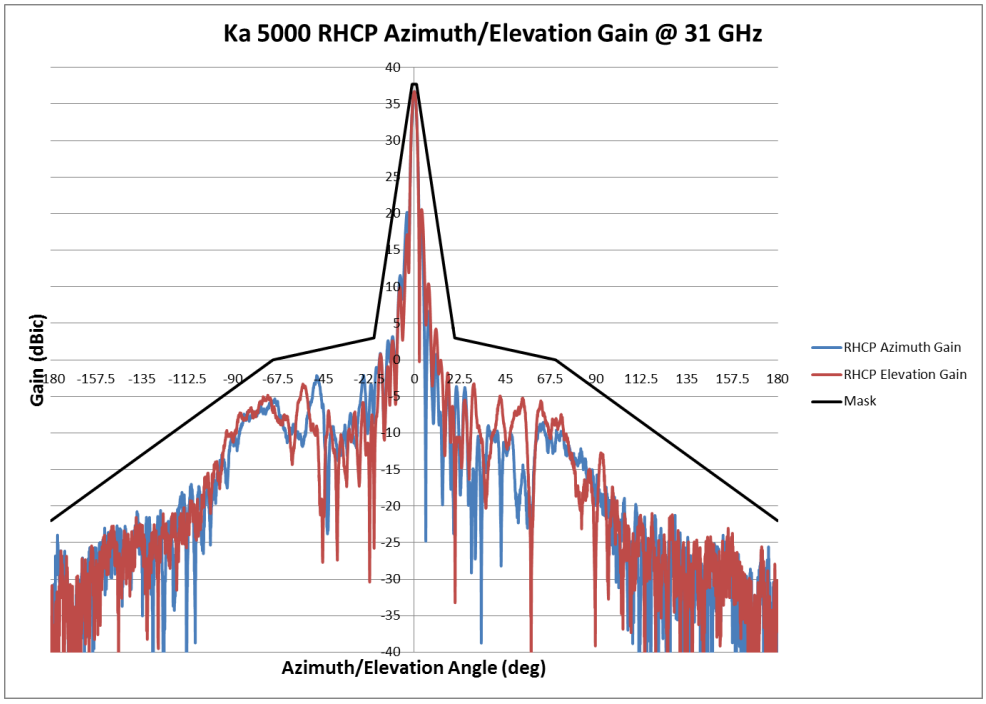

Figure 15*: Co-polarized Gain at 31 GHZ, RHCP*

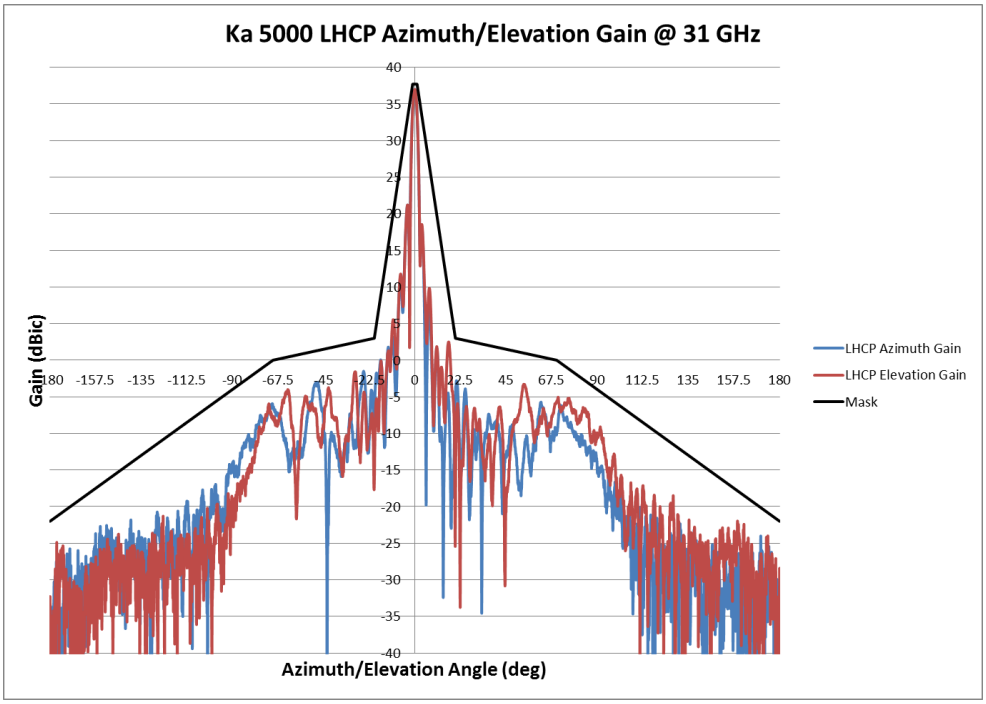

Figure 16*: Co-polarized Gain at 31 GHZ, LHCP*

APPENDIX B – RF Radiation Hazard for a Typical Tail Mount Application

Figure 17*: Typical tail mount for SatCom satellite system.*

Figure 17 shows a typical tail mount configuration for the SatCom transceiver. For an analysis of this typical tail mounted configuration, we will assume:

1. The top of the tail is 14 feet, 10 inches from the ground (Beechcraft King Air 250).
2. The lowest pointing angle is zero degrees (horizon).
3. Nominal RF power into antenna is 10 Watts.
4. Average height of personnel/general public working or walking around the aircraft is 6 ft., 2 in.

Using these conditions, the RF radiation intensity level will be within the allowed worst case scenario (general public, reflectors present) as shown in Figure 18. The allowed limit is 0.25 mW/cm^2, or equivalently, 250 microwatts/ cm^2. As shown in Figure 18, the actual levels never exceed the allowed level.

The case of nearby buildings being illuminated by the main beam of the antenna will be discussed next. According to FCC document, OET Bulletin 65, "it is also important to note that exposures inside a building can be expected to be reduced by at least 10-20 dB due to attenuation caused by building materials in the walls and roof". If there were reflective surfaces inside the building, the allowed RF level would be < 0.25 mW/ cm^2. Due to building material attenuation, we

only need to achieve levels of < 2.5 mW/ cm^2 (a result of having 10 dB of building material attenuation) at the outside surface of the building. This level is achieved with main beam illumination at a distance of 44.9 feet from the transmitter. We should also consider that for normal operation of the system, the main beam must be pointed at the satellite for transmission to occur. Any blockage or inaccurate pointing of the antenna will cause the transmitter to shut-down (mute) within 100 milliseconds after loss of a satellite signal.

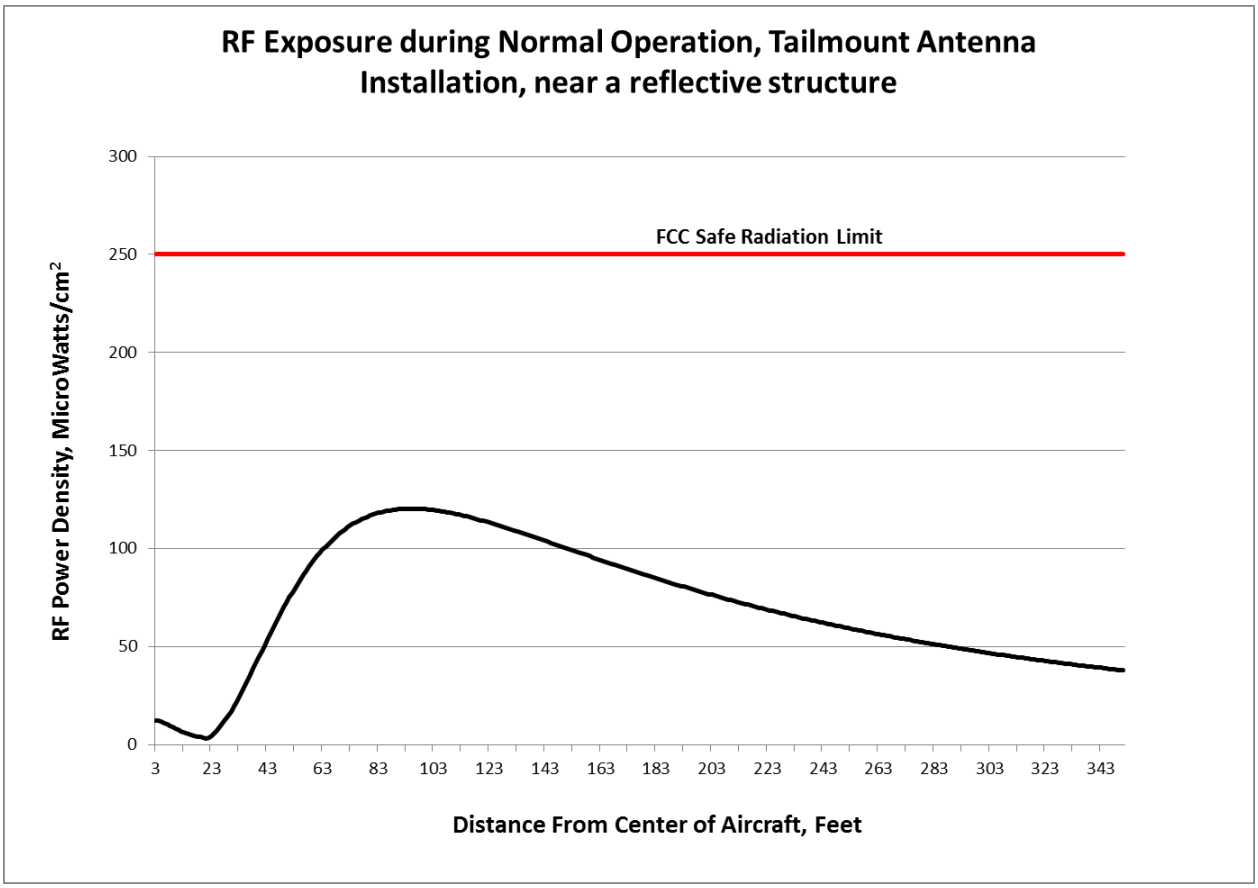

Figure 18*: RF Radiation Intensity on the ground for a typical tail mount system.*

APPENDIX C – Operational Safety Instructions

Note: This guide cannot cover all possible situations. The requirements set out in the Occupational Health and Safety Act must be complied with, and they should be referred to when this guideline is used.

Before Operation:

- Select the site for operation. If possible choose a location away from buildings and reflective structures. An area with restricted access by customers and untrained personnel is preferred. Determine the satellite that will be used and the pointing directions and angles. From these criteria, select the correct table to determine the safe approach distances.
- Train the operators and other maintenance personnel that will have access in safe operation and activity around an active transmitter. Read and understand the content of this report.
- Mark the hazardous area with notice of RF Radiation Hazard placards and/or keep-out ropes. Warning signs must be in clear view and of sufficient size to be easily legible.

During Operation:

- Restrict the operational area from access by untrained personnel.
- Assume the transmitter is active until it is positively secured.
- Terminate transmission if the safe area is accidently violated by any personnel.
- Terminate transmissions when the system is unattended.
- Terminate transmission when any fault is detected that may cause abnormal RF emissions.
- If instrumentation is available, check the RF level at the established perimeter to validate the safe zone.

After Operation:

- Secure the terminal to avoid operation by untrained personnel. The System power can be turned off at the system circuit breaker. Transmission can be further disabled by toggling the TX Enable switch to OFF.

During Other Maintenance:

- When maintenance personnel will be occupying the area above the fuselage / level with the antenna, secure the transmitter. The System power must be turned off at the system circuit breaker. Transmission must be further disabled by toggling the TX Enable switch to OFF. Transmission should be double disabled during aircraft washing, deicing, maintenance of upper antennas, removal of the terminal radome, or other activity that occupies areas where the antenna beam could be pointed while activated.

Note: The terminal requires the MODEM to be locked to the Satellite on Receive before activating Transmit. If the Receive path is interrupted, transmission will be disabled within 0.10 seconds.

In Case of Accidental Exposure:

First Aid

- Remove exposed worker from exposure area to a cool environment and provide cool drinking water.
- Apply cold water or ice to any burned areas.
- Seek immediate medical attention.
- Severe MW or RF overexposure may damage internal tissues without apparent skin injury, so a follow-up physical examination is advisable.