Fixed Site 2.4m Antenna

FCC Radiation Hazard Analysis

Document Number RHA-02

Revision 01

Lockheed Martin Integrated Systems & Solutions
700 North Frederick Avenue
Gaithersburg, MD 20879

PUBLICATION INFORMATION

Revision Number	Date Released	Comment
01	February 2, 2007	Document released in support of FCC Form 312

This document was prepared for:

The Federal Communications Commission
445 12th Street SW
Washington, DC 20554
USA

This document was prepared by:

Lockheed Martin IS&S
700 North Frederick Avenue
Gaithersburg, Maryland 20879

FOREWORD

This document has been prepared by Lockheed Martin Integrated Systems & Solutions as part of the Application for Earth Station Authorization (Form 312) submitted to the Federal Communications Commission. This document is provided to the FCC to show that the radiation hazard levels associated with the fixed site 2.4m Ku-band antenna are within the FCC guidelines.

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1. INTRODUCTION

1.1 SCOPE

This document is an attachment to the Application for Earth Station Authorization (Form 312) under a Special Temporary Authority (STA) submitted to the Federal Communications Commission by Lockheed Martin Integrated Systems & Solutions (LM IS&S). This document is provided to the FCC to show that the radiation hazard levels associated with the fixed site 2.4m Ku-band antenna are within the FCC guidelines. Calculations for the radiation hazard analysis were based on the FCC Office of Engineering & Technology (OET) Bulletin 65, Edition 97-01, dated August 1997.

Information on the 2.4m fixed site antenna was based on the data supplied by the vendor of the antenna and is deemed to be accurate.

1.2 GLOSSARY

The following abbreviations are used in this document.

CONUS	Contiguous United States
EIRP	Effective Isotropically Radiated Power
FCC	Federal Communications Commission
LM IS&S	Lockheed Martin Integrated Systems & Solutions
MPE	Maximum Permissible Exposure
OET	Office of Engineering & Technology
RF	Radio Frequency
SSPA	Solid State Power Amplifier
W	Watts

1.3 DOCUMENTS

The following are the applicable and reference documents:

1.3.1 Applicable Documents

Document ID	Document Title
Form 312	Application for Earth Station Authorization submitted to the FCC by LM IS&S

1.3.2 Reference Documents

Document ID	Document Title
OET Bulletin 56	Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields

2. FIXED SITE ANTENNA OVERVIEW

2.1 ANTENNA DESCRIPTION

The fixed site antenna that is being analyzed for radiation hazards is pictured in Figure 1. This antenna consists of a carbon fiber composite reflector, elevation and azimuth positioners, and an aluminum support structure. The fixed site antenna communicates with a mobile satcom antenna mounted on a vehicle via a satellite link.

The antenna will be situated on the grounds of Lockheed Martin Space Systems Company site at 1111 Lockheed Martin Way, Sunnyvale, CA 94089.

Technical details on the antenna performance are provided in Table 1.

2.2 LINK BUDGET

The forward link budget for the satcom-on-the-move system is shown in Figure 2. The space segment used is the SES Americom AMC-9 satellite. Both the fixed site and the mobile site are assumed to be at Sunnyvale, CA. Most parameters are based on the terminal data provided by the vendor and satellite data provided by SES Americom.

Even though the solid state power amplifier (SSPA) at the fixed site is 50W, the actual SSPA power utilized for the forward link is very small, with the power delivered to the antenna (post waveguide), taking into effect the reduction caused by the 3 dB backoff, is about 1.90 Watts, as follows:

From Figure 2, power delivered to the antenna = $10^{(\text{EIRP-Antenna Gain})/10} = 10^{(51.8-49.01)/10} = 1.90$ Watts.

3. RADIATION HAZARD ANALYSIS

The radiation hazard analysis for the 2.4m fixed site antenna uses the suggested calculation methods from the FCC OET Bulletin 65 for aperture antennas. Various calculations are presented below as instructed in the bulletin.

Figure 1. Photograph of the Vertex Model 2.4 SF Fixed Site 2.4m Ku-band Antenna

3.1 MAXIMUM POWER DENSITY AT THE ANTENNA SURFACE

The maximum power density directly in front of the antenna at the antenna surface is approximated by the following equation:

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

where: $S_{surface}$ = maximum power density at the antenna surface

P = power fed to the antenna

A = physical area of the antenna aperture

Table 1. Technical Parameters of the Fixed Site 2.4m Ku-band Antenna

	C-Band 2-Port Linear Polarized		C-Band 2-Port Circular Polarized		X-Band 2-Port Circular Polarized		Ku-Band 2-Port Linear Polarized		Ku-Band 4-Port Linear Polarized	
Electrical	Receive	Transmit	Receive	Transmit	Receive	Transmit	Receive	Transmit	Receive	Transmit
Frequency (GHz)	3.625 - 4.200	5.850 - 6.425	3.625 - 4.200	5.850 - 6.425	7.250 - 7.750	7.900 - 8.400	10.950 - 12.750	13.750 - 14.500	10.950 - 12.750	13.750 - 14.500
Antenna Gain at Midband	38.20 dBi	42.00 dBi	38.06 dBi	42.10 dBi	43.40 dBi	44.00 dBi	47.19 dBi	49.00 dBi	47.20 dBi	48.40 dBi
Antenna Noise Temperature										
5° Elevation	49 K		51 K		66 K		63 K		85 K	
10° Elevation	38 K		50 K		56 K		60 K		75 K	
20° Elevation	33 K		49 K		52 K		56 K		69 K	
40° Elevation	34 K		48 K		52 K		55 K		68 K	
Typical G/T at 4.0 and 7.5 GHz										
20° Elevation, Clear Horizon										
C-Band 35° K LNA	19.5 dB/K									
X-Band 55° K LNA					23.1 dB/K					
Typical G/T at 4.0 and 10.95 GHz										
10° Elevation, Clear Horizon										
C-Band 35° K LNA			18.8 dB/K							
C-Band 50° K LNA			18.1 dB/K							
Ku-Band 70° K LNA							25.4 dB/K			
Ku-Band 90° K LNA							24.7 dB/K			
Typical G/T at 11.85 GHz										
20° Elevation, Clear Horizon										
Ku-Band 70° K LNA									25.8 dB/K	
Ku-Band 90° K LNA									25.2 dB/K	
Pattern Beamwidth (in degrees at midband)										
-3 dB Beamwidth	2.12	1.37	2.09	1.35	1.13	1.05	0.72	0.60	0.70	0.62
-15 dB Beamwidth	4.45	2.88	4.39	2.84	2.37	2.20	1.51	1.26	1.47	1.30
Sidelobe Performance										
For Angle A from 2° to 30° (typical)							24-25 Log A (Az plane) 29-25 Log A (in general)		24-25 Log A (Az plane) 29-25 Log A (in general)	
For Angle A beyond mainbeam to 20°	29-25 Log A		29-25 Log A		29-25 Log A					
For Angle A from 30° to 140°									-10 dBi	-10 dBi
For Angle A from 140° to 180°									0 dBi	0 dBi
Cross Polarization										
On Axis	30 dB	30 dB	19.7 dB	27.3 dB	21.3 dB	21.3 dB	35 dB	35 dB	35 dB	35 dB
Within 1.0 dB Beamwidth	28 dB	28 dB	19.7 dB	27.3 dB	21.3 dB	21.3 dB	27 dB	35 dB	27 dB	35 dB
VSWR	1.30:1	1.30:1	1.30:1	1.30:1	1.30:1	1.30:1	1.35:1	1.25:1	1.35:1	1.35:1
Axial Ratio			1.81 dB	0.75 dB	1.50 dB	1.50 dB				
Port-to-Port Isolation										
Rx/Tx (Rx frequency)	0 dB	-30 dB	0 dB	-50 dB	0 dB	-110 dB	0 dB	-30 dB	0 dB	-50 dB
Tx/Rx (Tx frequency)	-60 dB	0 dB	-100 dB	0 dB	-110 dB	0 dB	-85 dB	0 dB	-85 dB	0 dB
Feed Insertion Loss	0.15 dB	0.15 dB	0.40 dB	0.20 dB	0.40 dB	0.40 dB	0.30 dB	0.20 dB	0.60 dB	0.45 dB
Output Waveguide Flange Interface	CPR-229G	CPR-137G	CPR-229G	CPR-137G	CPR-112G	CPR-112G	WR-75 Flat	WR-75 Flat	WR-75 Flat	WR-75 Flat
Total Power Handling Capability		2 kW CW		2 kW CW		2 kW CW		1 kW CW		2 kW CW
RF Specification	975-2837		975-2712		975-1701		975-1575		975-1708	

Using data from Figure 2, with P as 1.90W (from Section 2.2) and A as 4.52 square meters for a 2.4m antenna, we get:

$$S_{surface} = 1.68 \text{ W/m}^2$$

3.2 NEAR-FIELD REGION

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

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

where: R_{nf} = the extent of the near-field

D = maximum dimension of the antenna

λ = wavelength of the radiated wave

Using data from Figure 2, with D as 2.4 meters and λ as = speed of light/frequency = 2.9979E08/14.140E09 = 0.0212 meter, we get:

$$R_{nf} = 67.92 \text{ meters}$$

3.3 MAGNITUDE OF THE NEAR-FIELD ON-AXIS MAIN BEAM POWER DENSITY

The maximum value of the near-field on-axis (main beam) is described by the following equation:

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

where: S_{nf} = maximum near-field power density

η = aperture efficiency of the antenna

P = power fed to the antenna

D = maximum dimension of the antenna

Using data from Figure 2, with η as 0.63 (from vendor data), P as 1.90 W and D as 2.4 meters, we get:

$$S_{nf} = 1.06 \text{ Watts/m}^2$$

3.4 MAGNITUDE OF THE TRANSITION REGION

The distance to the beginning of the far-field region can be approximated by:

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

where: R_{ff} = distance to beginning of far-field

D = maximum dimension of the antenna

λ = wavelength of the radiated wave

Using data from Figure 2, with D as 2.4 meters and λ as 0.0212 meter, we get:

$$R_{ff} = 163.01 \text{ meters}$$

CARRIER

Carrier Info. Rate	**1024.0**	kbit/s
FEC Code Rate	**0.50**	
Transmission Bit Rate	2048.0	kbit/s
Modulation Format	**BPSK**	
Number of Bits/Symbol	**1**	Bit
Framing Overhead	**0**	kbit/s
Transmission Symbol Rate	2048	ksym/s
BT Product	**1.4**	
Spread Factor	**2**	
Occupied Bandwidth	5734.4	kHz
Noise Equiv. Occupied BW	4096.0	kHz
Allocated Bandwidth	**7000.0**	kHz

SES AMERICOM AMC-9 83W PARAMETERS*

Uplink Beam	**SPOT**	
Uplink Frequency Tpr 7-V	**14.140**	GHz
Downlink Beam	**SPOT**	
Downlink Frequency Tpr 7-H	**11.840**	GHz
Transponder Bandwidth	**36**	MHz
Saturation EIRP (CA)	**49.5**	dBW
Transponder Output Backoff	**3.8**	dB
Available EIRP (for alloc. BW	38.6	dBW
Saturation Flux Density (CA)	**-97.5**	dBW/m^2
Transponder Input Backoff	**7.3**	dB
Additional Input Backoff	**0.0**	dB
Operating Flux Density	-111.9	dBW/m^2
Forward Link Pattern Adv	**0.0**	dB
Receive G/T (CA)	**2.0**	dB/K
Gain Step	**High**	

TRANSMIT EARTH STATION - Vertex Model 2.4 SF

Antenna Diameter	**2.40**	meter
Antenna Area	4.52	meter^2
Antenna Efficiency	**63.0**	%
Antenna Gain	49.01	dBi
Antenna Pointing Loss	**0.5**	dB
Elevation Angle (CA)	**30.6**	degrees

RECEIVE EARTH STATION - Vertex Model 20-18

Dish Antenna Diameter*	**0.457**	meter
Antenna Area	0.16	meter^2
Antenna Efficiency	**57.8**	%
Antenna Gain	32.70	dBi
Antenna Pointing Loss	**0.5**	dB
Wet Radome Loss	**1.0**	dB
LNA Noise Figure	**0.7**	dB
LNA Noise Temperature	50.7	K
Clear Sky Noise Temp.	19.9	K
Increase in Sky Temp w/rain	107.4	K
System Noise Temp	112.2	K (no rain)
Receive G/T	12.20	dB/K
Elevation Angle (CA)	**30.6**	degrees

UPLINK LOSSES

Free Space Path Loss	207.2	dB
Atmospheric Attenuation	**0.5**	dB
Feed Loss (data sheet)	**0.3**	dB

DOWNLINK LOSSES

Free Space Path Loss	205.6	dB
Atmospheric Attenuation	**0.2**	dB
Feed Loss	**0.5**	dB

RAIN FADE MARGINS for simultaneous fades

Uplink Fade	**2.1**	dB
Downlink Fade	**2.1**	dB

FORWARD LINK BUDGET SUMMARY

	With Clear Sky		Up-Link Fade	D-Link Fade	Both Fades
UPLINK BUDGET					
Operating Flux Density	-111.9	dBW/m^2	-114.0		-114.0
Total Transmit EIRP	51.8	dBW			
Path, Atm. & Point. Losses	208.2	dB			
Satellite Receive G/T	2.0	dB/K			
Boltzmann's Constant	-228.6	dBW/K/Hz			
Total Uplink C/No	74.2	dB-Hz	72.1		72.1
Number of Active Carriers	1		1		1
Uplink C/No per carrier	74.2	dB-Hz	72.1	74.2	72.1
DOWNLINK BUDGET					
Satellite EIRP	38.6	dBW	36.5	38.6	36.5
Path, Atm. & Point. Losses	206.3	dB	206.3	206.3	206.3
Receive Antenna G/T	12.2	dB/K	12.2	8.3	8.3
Boltzmann's Constant	-228.6	dBW/K/Hz	-228.6	-228.6	-228.6
Total Downlink C/No	73.0	dB-Hz	70.9	67.0	64.9
Number of Active Carriers	**1**		1	1	1
Downlink C/No per carrier	73.0	dB-Hz	70.9	67.0	64.9
OVERALL FORWARD LINK ANALYSIS (Per Carrier)					
C/IMo	111.6	dB-Hz	109.5	111.6	109.5
C/Io (CCI)	82.7	dB-Hz	82.7	82.7	82.7
C/Io (ASI-uplink)	100.0	dB-Hz	102.1	100.0	102.1
C/Io (ASI-downlink)	100.0	dB-Hz	100.0	100.0	100.0
C/Io (Terrestrial)	100.0	dB-Hz	100.0	100.0	100.0
C/I (CDMA)	100.0	dB	100.0	100.0	100.0
C/Io (CDMA) noise equiv. B	166.1	dB-Hz	166.1	166.1	166.1
Overall Link C/(No+Io+IMo)	70.3	dB-Hz	68.3	66.2	64.1
Information Rate	60.1	dB-Hz	60.1	60.1	60.1
Available Eb/No	10.2	dB	8.2	6.1	4.0
Required Eb/No	4.0	dB	4.0	4.0	4.0
System Margin	6.2	dB	4.2	2.1	0.0

REQUIRED Eb/No

Required BER	**1.0E-06**		
Theoretical Eb/No (Turbo)	**3.1**	dB	From MIL-STD-188-EEE NCW Spec.
Modem Loss	**0.9**	dB	To bring it up to the next dB level
Required Eb/No	4.0	dB	

REQUIRED SSPA SIZE FOR HUB

Required Hub Operating EIRP	51.8	dBW
Feed Losses	0.3	dB
Antenna Gain	49.0	dBi
SSPA Output Backoff	**3.0**	dB
Reqd SSPA Size	4.06	W

Actual SSPA Size (W)	Max EIRP (dBW)
50.0	65.7

Max EIRP Density/4 kHz	Max Power (Watts)
35.60	46.66

OUTBOUND LINK EIRP DENSITY

SSPA Output Power after backoff	3.1	dBW	
Feed Loss	-0.3	dB	Operating Pwr
Tx Antenna Gain at 2.5° off-axis (per Verte	19.1	dB	(Watts)
Occupied Bandwidth (noise equiv.)	-66.1	dB-Hz	---> 1.90
CCIR Reference Bandwidth (40 kHz)	46.0	dB-Hz	Operating ERF
Outbound Link EIRP Density at 2.5° off-ax	1.7	dBW/40 kHz	(dBdW)
Outbound Link EIRP Density at 2.5° off-ax	-8.3	dBW/4 kHz	49.65
Outbound Link EIRP Density at Horizon	-35.5	dBW/4 kHz	Uses FCC 29-25log(theta)
CCIR EIRP Density Limit at 2.5° off-axis	29.1	dBW/40 kHz	Per ITU-R 524-7 for E/S
CCIR EIRP Density Limit at 2.5° off-axis	23.1	dBW/40 kHz	Per ITU-R 728-1 for VSATs
FCC EIRP Density Limit at 2.5° off-axis	5.1	dBW/4 kHz	Per FCC Part 25.209/212
EIRP Density Margin (relative to ITU 728-1	21.3	dB	
EIRP Density Margin (relative to FCC)	13.3	dB	

INTERFERENCE TO TERRESTRIAL NETWORKS

Power Flux Density at Earth's surface	-154.2	dBW/m^2/4K	per CCIR 358-3
Power Flux Density Limit at Earth's surfac	-135.2	dBW/m^2/4K	
Power Flux Density Margin	19.0	dB	

*From Vertex Model 20-18 data sheet

Figure 2. Forward Link Budget for the 2.4m Antenna

3.5 FAR-FIELD REGION

The power density in the far-field region of the radiation pattern can be estimated by:

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

where: S_{ff} = far-field power density (on-axis)

P = power fed to the antenna

G = power gain of the antenna in the direction of interest relative to an isotropic radiator

R = distance to that point of interest

Using data from Figure 2, with P as 1.90 Watts, G as 79675.96 [= $10^{(49.01/10)}$, with the exact values used in the spreadsheet] and R as 163.01 meters for the start of the far-field region, we get, for a direction of interest on-axis along the main beam:

$$S_{ff} = 0.454 \text{ Watts/m}^2$$

3.6 POWER DENSITY AT MINIMUM ELEVATION ANGLE

The operating elevation angle with the Lockheed Martin location at Sunnyvale, CA, and the AMC-9 satellite at 83W longitude is 30.6 degrees. The typical minimal elevation angle used in satellite link budgets is 10° above the horizon, and this will be used for the limiting case. The 2.4m antenna will be located on the ground. From Figure 4, the center of the antenna is located at (124.75 – d/2) inches from the ground, where d is the radius of movement, seen as 94.75” from the top half of Figure 4. Thus, the center of the antenna is located about 77.38 inches or 1.96m from the ground, as shown in Figure 3.

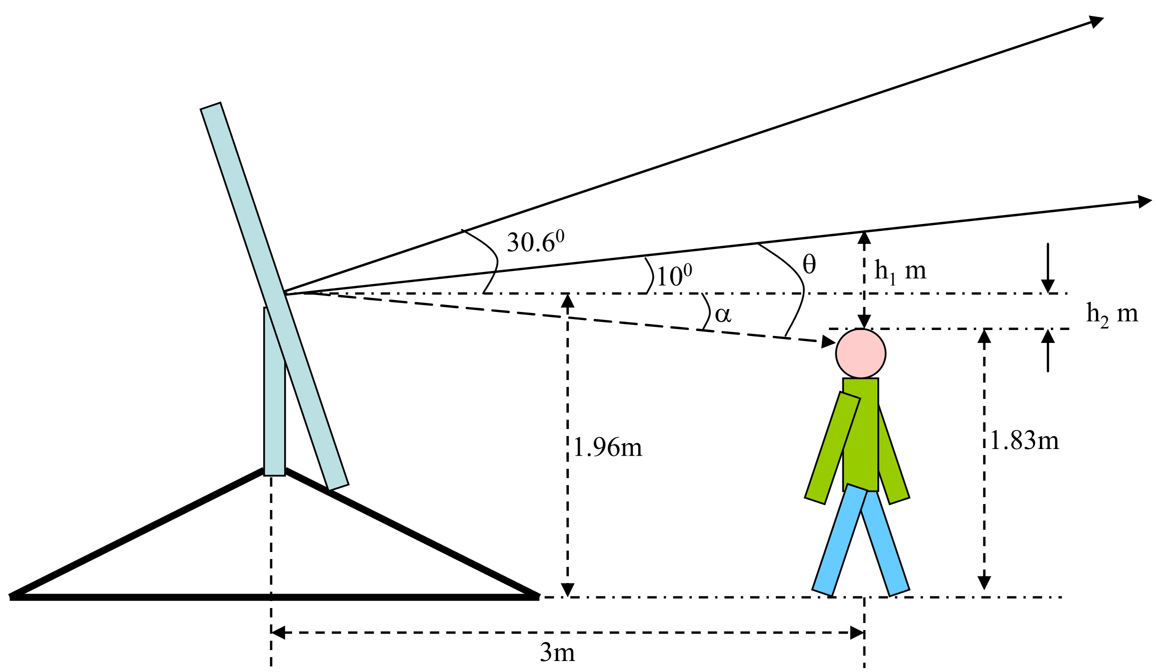

Figure 3. Illustration Of Off-Axis Exposure To Humans

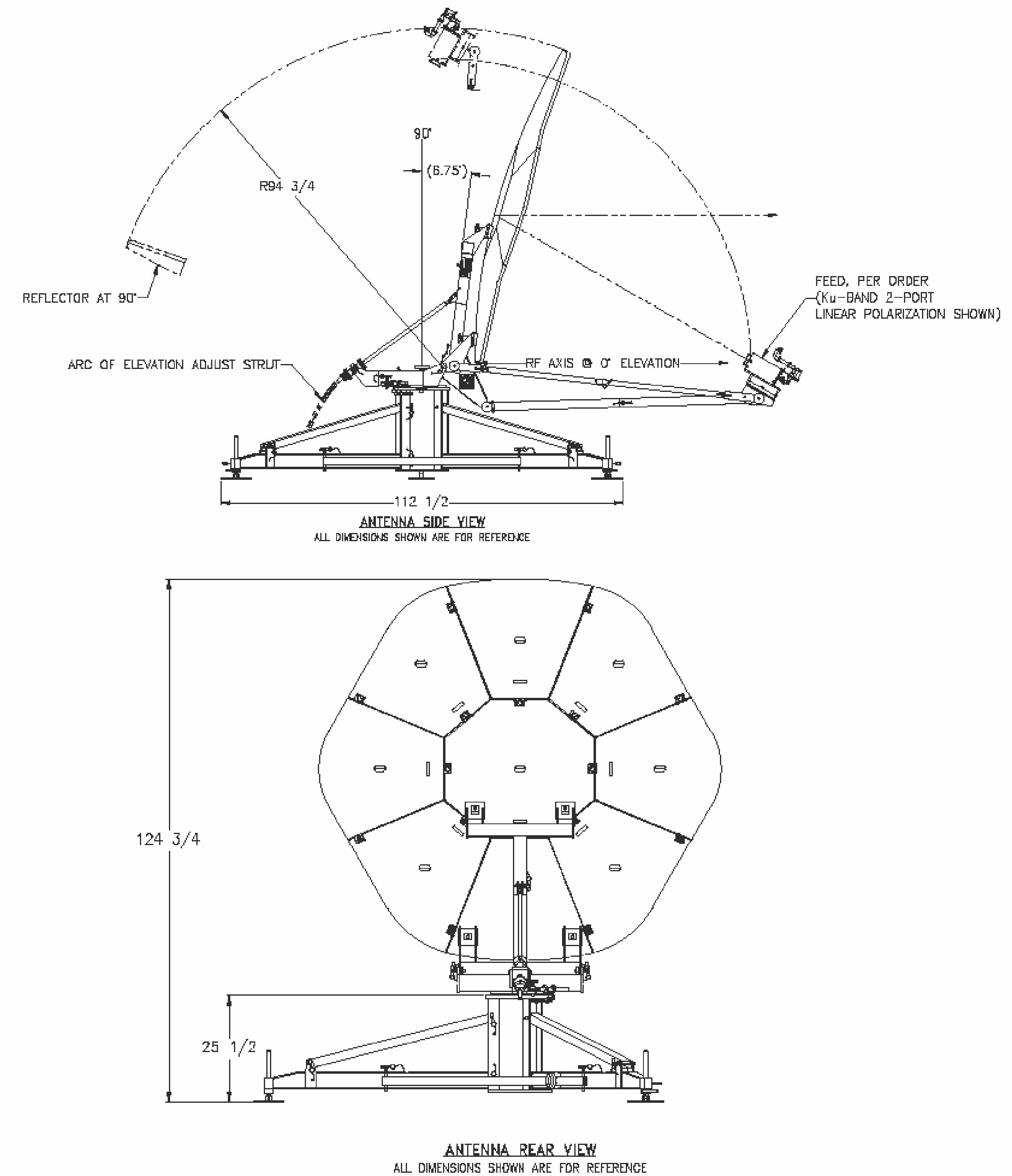

Figure 4. Mechanical Dimensions of the 2.4m Antenna

Assuming that a six feet tall (1.83m) human is standing 3 meters from the antenna, the distance, h_1, of the human head from the boresight axis of the antenna is given by:

$$h_2 = (1.96 - 1.83) = 0.13 \text{ m}$$

$$h_1 = h_2 + 3\tan(10^\circ) = 0.66 \text{ meters}$$

$$\alpha = \tan\text{-}1\left(\frac{h_2}{3}\right) = 2.48 \text{ degrees}$$

Minimum off-axis angle to person's head, $\theta = 10 + 2.48 = 12.48$ degrees at minimum elevation angle

Since the subject's distance of 3 meters is within the near-field range of 68.4 meters, we need to use the calculations for off-axis power density in the near-field. Based on vendor data in Table 1, the off-axis gain is computed from: $G(\theta) = 29 - 25\log(\theta)$, for 2º ≤ θ ≤ 30º. However, to be more conservative, the equation from OET Bulletin 56 is used, which gives:

$$G(\theta) = 32 - 25\log(\theta)\text{, } 1^\circ \le \theta \le 48^\circ$$

Using θ = 12.48º, we get G(12.48º) = 4.59 dBi

Drop in gain in the direction of the person's head = 49.01 – 4.59 = 44.42 dB

Using the maximum value of the near-field on-axis main beam power density, S_{nf}, as the worst case, the power density at the location of the human's head is then no higher than S_{nf} reduced by 44.42 dB, or $1.06 * 10^{(-44.42/10)}$ = 3.83E-05 Watt/m^2.

3.7 PHYSICAL BARRIERS TO ACCESS

The fixed site 2.4m antenna will be located on the grounds of the Lockheed Martin building. The Lockheed Martin site is a controlled-access site, where only employees and escorted visitors may gain entrance. Any casual observer from the outside is not permitted on the grounds. A perimeter guard barrier will be erected at a distance of 3 meters around the antenna to prevent any person from getting close to the antenna. Warning signs will be posted on all four sides of the barrier indicating a radiation hazard and to keep safe distance. A warning light will turn on indicating when the SSPA is energized. A power-off switch will be located near the equipment to cut power to the antenna should there be a need to do so. The antenna will be sited so that the look angle to the satellite is clear of all buildings. These measures are expected to be adequate to ensure the safety of employees who may cross the area near the antenna.

3.8 COMPARISON TO THE FCC RADIATION EXPOSURE GUIDELINES

Based on the controlled access to the antenna, the applicable FCC radiation exposure guidelines are taken to be for Occupational Exposure listed in Appendix A, Table 1(A) of the OET Bulletin 65. For Ku-band frequencies in the range 14.0 to 14.5 GHz, the limit for maximum permissible exposure (MPE) for occupational/controlled exposures is **5 mW/cm^2**.

Using the calculation from above, the compliance with the FCC guidelines for the maximum permissible exposure is shown in Table 2, where the conversion factor mW/cm^2 = 0.1 x W/m^2 is used.

Two sets of calculations are performed, one with the operational power fed to the antenna and the other with worst case power fed to the antenna in the event of a controller failure. For a very conservative calculation, the maximum near-field power density is used at the site of the human, recognizing that the actual levels will be considerably less than that calculated.

Table 2. Compliance Table for the Maximum Permissible Exposure With Operating Levels

Location	Power Density (Watts/m^2)	Power Density (mW/cm^2)	FCC Limit (mW/cm^2)	Exposure Within Limits?
Antenna Surface	1.68	0.168	5	Yes
Near-Field maximum	1.06	0.106	5	Yes
Far-Field at 163m	0.453	0.0453	5	Yes
Off-axis at 3m	3.83E-05	3.83E-06	5	Yes

Note that the above calculations employed the SSPA operating power levels as indicated in the link budget shown in Figure 2.

If, however, one were to assume the worst case of an SSPA controller failure, where the maximum SSPA power of 50W was applied to the antenna without any backoff, then the calculations would be the same as the above with the substitution of P as 50W minus a loss of 0.3 dB for the feed, or $P_{max} = 50x10^{(-0.3/10)} =$ 46.66 Watts. Since the power fed to the antenna was taken as 1.90 Watts, P_{max} is greater than this by a factor of 46.66/1.90 = 24.56.

For this worst case, therefore, one can derive the worst case maximum power densities by multiplying the previously calculated nominal power densities by a factor of 26.36, as shown in Table 3.

Table 3. Worst Case Compliance Table for the Maximum Permissible Exposure (SSPA controller failure)

Location	Power Density (Watts/m^2)	Power Density (mW/cm^2)	FCC Limit (mW/cm^2)	Exposure Within Limits?
Antenna Surface	41.26	4.126	5	Yes
Near-Field maximum	26.03	2.603	5	Yes
Far-Field at 168m	11.13	1.113	5	Yes
Off-axis at 3m	9.41E-04	9.41E-05	5	Yes

Therefore, even for the worst case, the maximum permissible exposure guidelines are met.

4. CONCLUSIONS

The radiation hazard analysis for the 2.4m fixed site antenna using the suggested calculation methods from the FCC OET Bulletin 65 for aperture antennas shows full compliance with the FCC Occupational/Controlled Exposure limits for the Maximum Permissible Exposure for both the nominal SSPA operating point as obtained from the link budget, and the worst case SSPA maximum operating point, using extremely conservative calculations.

Therefore, no radiation hazard is presented to humans from the planned use of this fixed site 2.4m antenna.