Intorduction

This analysis predicts the RF radiation levels around a multi-band satellite communication system comprised of a 6.3 meter diameter cassegrain type antenna having a sub reflector dimension of approximately 30 cm in diameter. Swappable feeds permit various operational bands and the principal frequencies of interest here are; for Ku band with center frequency at 14.25 GHz and for Ka Band with center frequency at 29.5 GHz.

The analysis described in this report follows, in part, the methodology established in FCC Office of Engineering and Technology Bulletin, No. 65 as revised and is used to determine the free space equivalent power density 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 Maximum Permissible Exposure as promulgated for the controlled an uncontrolled environment.

The system itself is mounted on a raised platform and the antenna is housed within a radome atop of a building. Access to the building and radome is controlled as depicted in Figure 1.

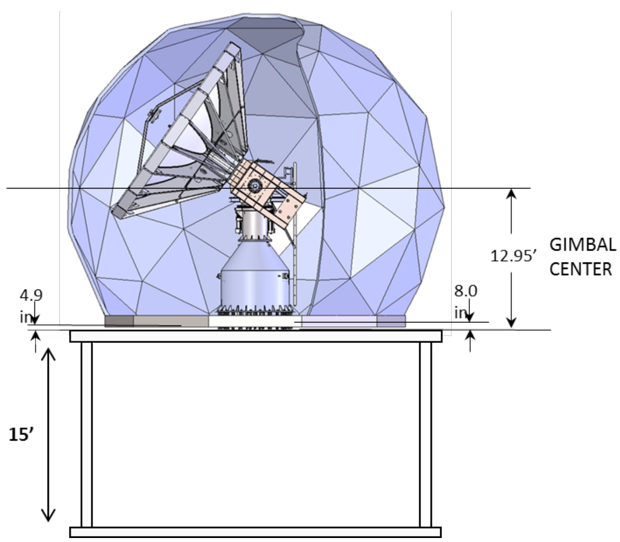

Figure 1: Antenna and relative elevations.

RF Exposure Limits

When evaluating for Health and Safety compliance, it is the practice that the most conservative standard be applied. Under most conditions, this would be the Massachusetts Radiation Control Program (Ma RCP 105 CMR 122.000) regulations based on the FCC standard 1977; however, in some circumstances the most recent IEEE (IEEE C95.1-2005) standard is more conservative particularly for the General Public at certain frequencies, which IEEE has re-termed the Action Level. The Department of Defense through the DoD instruction process has issued DoD Instruction 6055.11, “Protection of DoD Personnel from Electromagnetic Fields,” August 19, 2009 which is identical to the current IEEE standard.

The Basic restriction as set forth by the FCC/IEEE is based on the specific Absorption Rate (SAR), which is difficult to quantify practically, hence the derived quantities listed for the FCC/IEEE MPEs are rms electric (E) and magnetic (H) field strengths or plane-wave equivalent power density values . The derived quantities listed for the IEEE/FCC MPEs are rms electric (E) and magnetic (H) field strengths for frequencies below 400 and 300 MHZ respectively. Above these frequencies, the derived standard is based on the RMS power density both for the electric and magnetic fields. The FCC/ IEEE state that compliance with these MPEs ensures compliance with the basic restrictions on whole-body averaged SAR. For non-uniform exposure over the length of the body, the FCC/IEEE recommends that the electric or magnetic field strength be spatially averaged over this length. More commonly, the free space power density is used across all frequency ranges for convenience since this can be related to the electric or magnetic field strength by the free space impedance

The basic restrictions also permit for time averaging for the uncontrolled/general public (30 mins) and the controlled (6 mins) environs. Controlling the exposure time for individuals whether it be for an informed worker or for the member of the public is generally not considered to be an acceptable means for demonstrating compliance since documentation of the time individuals are in the field or when a given emitter is radiating is generally not taken into account except for specific cases and generally for a retrospective evaluation. However, time averaging with respect to pulsed operation (duty factors) and moving antennas may be considered appropriate especially for the former.

The free space power density MPE for each band is provided in Table 1. The highlighted values represent the more conservative of the two standards evaluated and will be used.

Tablel 1. MPE values for FCC/MDPH and IEEE/DoDI

Band	Center Frequency (GHz)	FCC/MDPH – RCP MPE (mW cm^{-2})		IEEE 95.1-2005/DoDI-6055.11-2009 MPE (mW cm^{-2})	
		Controlled	General Public	Controlled	Action Level
Ku	14.25	5	1	10	1
ka	29.5	5	1	10	1

In considering calculations other than numerical, most are based on far field conditions where a plane wave is presumed to exist and extrapolating to distances close in to the aperture can significantly overestimate the free space power density at these distances. This is particularly true for large apertures and small wavelengths.

On Axis Far Field Region

For far field conditions the following relationship may be applied (OET 65 Equation 3):

$$S_{ff} = \frac{P_{ave}G}{4\pi r^2}$$

Where: S_{ff} is the power density in the far field at distance r,
P_{ave} is the average power being transmitted, and
G is the antenna gain.

The Far field is said to exist at a distance described by the relationship

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

Where: R_{ff} is the distance at which the far field is said to begin,
D is the antenna diameter, and
λ is the corresponding wavelength for a given frequency.

Power Density Estimate at the Face of the Aperture

The maximum Power density directly in front of the aperture may be estimated as follows (OET 65 equation 11):

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

Where: $S_{surface}$ = maximum power density at the antenna surface,
P = power fed to the antenna, and
A = physical area of the aperture antenna.

Power Density Estimate within the Near Field

At distances away from the surface of the aperture but less than the extent of the near field, the maximum value of the near-field, on-axis power density can be expressed as follows (OET 65 Equation 13):

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

Where: S_{nf} = maximum near-field power density,
η = aperture efficiency, typically 0.5-0.75,
P = power fed to the antenna, and
D = antenna diameter.

The aperture efficiency can be approximated by the following relationship.

$$\eta = \frac{G_{abs}\lambda^2}{\pi^2 D^2}$$

Where: λ = is the wavelength,
G_{abs} = the numerical (absolute) gain which may be obtained from $G_{abs} = 10^{(Gdbi/10)}$, and
All other parameters as previously defined.

The extent of the near field may be determined from the following.

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

Where: R_{nf} = the extent of the near field and all other parameters are as previously defined.

In the region between the extent of the near field to the beginning of the far field is described as the transition field and on a first order approximation the free space power density falls off linearly with distance from the extent of the near field to the beginning of the far field.

Power Density in the transition region

The free space power density in this region follows the following relationship.

$$S_t = S_{nf} \frac{R_{nf}}{R_t}$$

Where: S_t is the power density in the transition region at a distance of interest R_t,
S_{nf} is the power density in the near field, and
R_{nf} is the extent of the near field.

Power density Estimates in the region between the Sub Reflector and the Main Reflector

Transmissions from the feed horn are directed toward the subreflector surface, and are confined within a conical shape defined by the feed horn. The relationship for the power density between the main reflector and the subreflector is cast in the same relationship as that for the power density at the plane of the reflector and can be expressed as follows:

$$S_{sr} = \frac{4P}{A_{sr}}$$

Where: S_{sr} is the power density between the subreflector and the main reflector,
A_{sr} is the area of the sub reflector, and
P is the power at the feed.

Power Density Estimates from the edge of the reflector surface to ground

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

$$S_g = \frac{P}{A}$$

Where: S_g is the power density between the reflector and the ground,
and all other terms are as previously defined.

It should be recognized that this is a conservative value as this system provides for a tapered edge and thus this representation is conservative.

Off Axis Power Density in the Far Field

Within the far field the radiation field is characterized by a series of maxima and minmum referfered to as side lobes as a function of the off-axis angle from the boresite. Theoretical antntenna patterns that describe the antenna gain as a function of this angle results in gains that are significantly less than the main beam gain. If the main beam in the far fieldis less than the applicable MPE, then likewise any sidelobes (including back lobes, would result in power densities being below that MPE for any off axis condition. Alternatively, an antenna gain pattern envelope could be used in needed and is expressed in the following form suitable for these type of systems:

$$G_{oa} = 32 - 25\,Log(\theta)$$

Where: G_{oa} is the off axis gain envelope, and θ is the off axis angle relative the main beam

Thus, the power density off axis from the main beam in the far field may be determined by the ratio of the relative gains times the on-axis power density in the far field as expressed here:

$$S_{oa} = S_{ff}\frac{G_{oa}}{G}$$

Near Field Off Axis Power Density

For off-axis calculations in the near-field and in the transition region, it can be assumed that, if the point of interest is at least one antenna diameter removed from the center of the main beam, the power density at that point would be at least a factor of 100 (20 dB) less than the value calculated for the equivalent distance in the main beam. Should the near field free space equivalent Power density be less than the MPE, then all areas off axis will be likewise, otherwise it may be worth considering this reduction in a hazard evaluation.

Summary and Conclusions:

Using the methods described above, hazard assessments were evaluated and are summarized in Tables 2 and 3 for the analysis shown in Tables 4 and 5. Graphical depictions of the RF free space equivalent power levels as a function of down range distance along the boresite of the antenna are presented in Figures 2 and 3. All areas are below the respective MPEs (Controlled and Uncontrolled) with the exception of the region describe as being between the sub reflector and the main reflector at the plane of the main reflector for the uncontrolled environment only.
These areas are not accessible to members of the general public. The antenna is maintained within a radome that is access controlled and thus access to the area between the subreflector and the main reflector is prohibited during operation.

It should be stated that the underlying assumptions used in the application of OET 65 tends to be conservative in that the presumption of uniform illumination of the main reflector prevails, whereas for this configuration an edge taper exists providing for tighter and greatly reduce sidelobes.

Table 2: Hazard Summary for Uncontrolled environment

Region	Ku Band		Ka Band	
	Radiation Level mW/cm^2	Hazard Assessment	Radiation Level mW/cm^2	Hazard Assessment
Far Field	0.35	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE	0.36	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE
Near Field	0.82	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE	0.85	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE
Transition Region	Equal to or less than Near field	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE	Equal to or less than Near field	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE
Main Reflector Region (Plane)	1.28	Potential Hazard	1.28	Potential Hazard
Between Main Reflector and Subreflector	565.9	Potential Hazard	565.9	Potential Hazard
Power Density Between Reflector and Ground	0.32	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE	0.32	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE
Far Field Off Axis		Satisfies FCC/MDPH and IEEE C95.1-2005 MPE		Satisfies FCC/MDPH and IEEE C95.1-2005 MPE
Near Field Off Axis	0.0082	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE	0.0085	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE

Table 3: Hazard Summary for Controlled Environment

Region	Ku Band		Ka Band	
	Radiation Level mW/cm^2	Hazard Assessment	Radiation Level mW/cm^2	Hazard Assessment
Far Field	0.35	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE	0.36	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE
Near Field	0.82	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE	0.85	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE
Transition Region	Equal to or less than Near field	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE	Equal to or less than Near field	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE
Main Reflector Region (Plane)	1.28	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE	1.28	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE
Between Main Reflector and Subreflector	565.9	Potential Hazard	565.9	Potential Hazard
Power Density Between Reflector and Ground	0.32	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE	0.32	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE
Far Field Off Axis		Satisfies FCC/MDPH and IEEE C95.1-2005 MPE		Satisfies FCC/MDPH and IEEE C95.1-2005 MPE
Near Field Off Axis	0.0082	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE	0.0085	Satisfies FCC/MDPH and IEEE C95.1-2005 MPE

Figure 2: Graphical Depictions of the RF Free Space Equivalent Power Levels as a Function of Down Range Distance along the Boresite of the Antenna for Ka Band

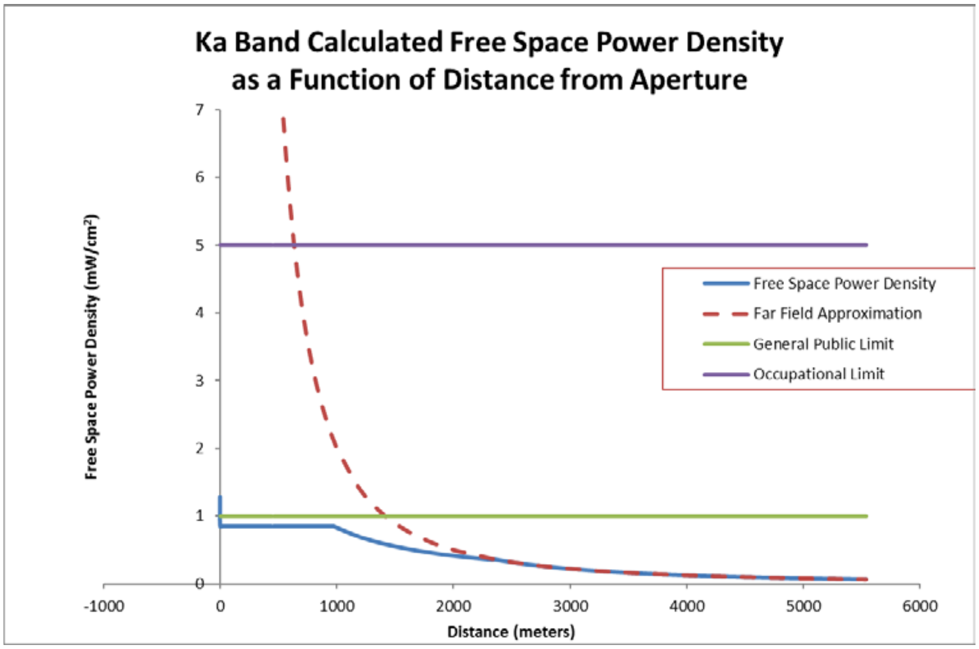

Figure 3: Graphical Depictions of the RF Free Space Equivalent Power Levels as a Function of Down Range Distance along the Boresite of the Antenna for Ku Band

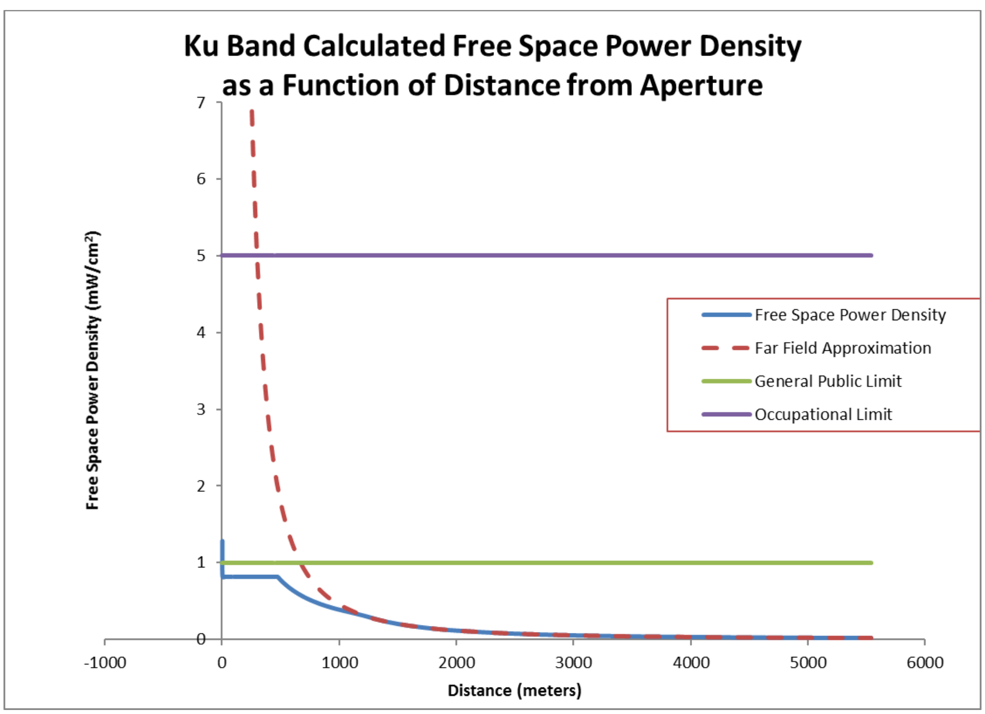

Table 4: RF Analysis for Ka Band

Comm Ka @ 29.5 GHz					
Information Provided			Converted Values		
Center Frequency	29.5	GHz	29500	MHz	
Dish Diamenter	248.0314961	inches	6.3	m	
Transmit Power	1.00E+02	W	100	W	
Antenna Gain	64	dBi	64	dBi	
Duty Factor	1		1		
Diameter of Subreflector	30	cm	0.3	m	
Limits (S_L)	MDPH		IEEE C95.1-2005/DoDI 6055.11 - 2009		
	General Public	Occupational	Action	Controlled	
(mW/cm^2)	1	5	1	10	
Parameter	**Symbol**	**Formula**	**Value**	**Units**	
Antenna Diameter	D	*Input*	6.3	m	
Antenna Surface Area	A	$\pi D^2/4$	31.172454	m^2	
Sub Reflector Diameter	D_{sr}	*Input*	0.3	m	
Sub rflector Surface Area	A_{sr}	$\pi D^2/4$	0.0706858	m^2	
Frequency	f	*Input*	29500	MHz	
Wavelength	λ	300/f	0.0101695	m	
Transmit Power	P	*Input*	100	W	
Antenna Gain (dBi)	G	*Input*	64	dBi	
Duty Factor	DF	*Input*	1		
Average Power	P_{ave}	*P*DF*	100		
Antenna Gain(factor)	G_{abs}	$10^{G/10}$	2511886.4	N/A	
Pi	π	Constant	3.1415927	N/A	
Antenna Efficiency	η	$G_{abs}\lambda^2/(\pi^2 D^2)$	0.6631589	N/A	
Distance to Far Field	R_{ff}	$0.6D^2/\lambda$	2341.71	m	
Power Denisty at Reflector Surface	S_r	4P/A	12.831842	W/m^2	
			1.2831842	mW/cm^2	
On-Axis Power Density at Far Field	S_{ff}	$G_{abs}P/4\pi R_{ff}^2$	3.6452214	W/m^2	
			0.3645221	mW/cm^2	
Extent of Near Field	R_{nf}	$D^2/4\lambda$	975.7125	m	
Near Field Power Density	S_{nf}	$16.0\eta P/(\pi D^2)$	8.5095506	W/m^2	
			0.8509551	mW/cm^2	
Transition Region Power Density	S_t	$S_{nf}R_{nf}/R_t$			
Power density between the sub reflector and main reflector	S_{sr}	$4P/A_{sr}$	5658.8424	W/m^2	
			565.88424	mW/cm^2	
Power density between antenna and ground	S_g	P/A	3.2079605	W/m^2	
			0.3207961	mW/cm^2	

Table 5: RF Analysis for Ku Band

Ku @ 14.25 GHz					
Information Provided			Converted Values		
Frequency	14.25	GHz	14250	MHz	
Dish Diamenter	248.0314961	inches	6.3	m	
Transmit Power	1.00E+02	W	100	W	
Antenna Gain	57.5	dBi	57.5	dBi	
Duty Factor	1		1		
Diameter of Subreflector	30	cm	0.3	m	
Limits (S_L)	MDPH		IEEE C95.1-2005/DoDI 6055.11 - 2009		
	General Public	Occupational	Action	Controlled	
(mW/cm^2)	1	5	1	10	
Parameter	**Symbol**	**Formula**	**Value**	**Units**	
Antenna Diameter	D	*Input*	6.3	m	
Antenna Surface Area	A	$\pi D^2/4$	31.172454	m^2	
Sub Reflector Diameter	D_{sr}	*Input*	0.3	m	
Sub rflector Surface Area	A_{sr}	$\pi D^2/4$	0.0706858	m^2	
Frequency	f	*Input*	14250	MHz	
Wavelength	λ	300/f	0.0210526	m	
Transmit Power	P	*Input*	100	W	
Antenna Gain (dBi)	G	*Input*	57.5	dBi	
Duty Factor	DF	*Input*	1		
Average Power	P_{ave}	*P*DF*	100		
Antenna Gain(factor)	G_{abs}	$10^{G/10}$	562341.33	N/A	
Pi	π	Constant	3.1415927	N/A	
Antenna Efficiency	η	$G_{abs}\lambda^2/(\pi^2 D^2)$	0.636256	N/A	
Distance to Far Field	R_{ff}	$0.6D^2/\lambda$	1131.165	m	
Power Denisty at Reflector Surface	S_r	4P/A	12.831842	W/m^2	
			1.2831842	mW/cm^2	
On-Axis Power Density at Far Field	S_{ff}	$G_{abs}P/4\pi R_{ff}^2$	3.4973429	W/m^2	
			0.3497343	mW/cm^2	
Extent of Near Field	R_{nf}	$D^2/4\lambda$	471.31875	m	
Near Field Power Density	S_{nf}	$16.0\eta P/(\pi D^2)$	8.1643371	W/m^2	
			0.8164337	mW/cm^2	
Transition Region Power Density	S_t	$S_{nf}R_{nf}/R_t$			
Power density between the sub reflector and main reflector	S_{sr}	$4P/A_{sr}$	5658.8424	W/m^2	
			565.88424	mW/cm^2	
Power density between antenna and ground	S_g	P/A	3.2079605	W/m^2	
			0.3207961	mW/cm^2	