Analysis of Non-Ionizing Radiation for a C-band UAV Antenna System

This report analyzes the non-ionizing radiation levels for a C-band antenna system which supports UAV communications. Two transmitting antennas are utilized as part of this system, one for the ground-to-air link and one for the air-to-ground link.

Operation of the transmitting system associated with this antenna system may occur while the aircraft is on the ground in addition to normal operation in flight. Therefore, RF radiation may be present while ground crew is servicing the aircraft.

The FCC's Office of Engineering Technology's Bulletin No. 65 specifies that there are two separate tiers of exposure limits that are dependant upon the situation in which the exposure takes place and/or the status of the individuals who are subject to the exposure. The two tiers are General Population / Uncontrolled environment, and an Occupational / Controlled environment.

The applicable exposure limit for the General Population / Uncontrolled environment, i.e., areas that people may enter freely, at this frequency of operation is 1 mW/cm^2 average power density over a 30 minute period.

The applicable exposure limit for the Occupational / Controlled environment, i.e., areas that only authorized / trained personnel have access to, at this frequency of operation is 5 mW/cm^2 average power density over a 6 minute period.

Summary of expected radiation levels for an Uncontrolled environment

Air-to-Ground	**Maximum Power Density**	**Hazard Assessment**
Safe region range ≥ 0.282 m	1.0 mW/cm^2	Satisfies FCC MPE
Ground-to-Air	**Maximum Power Density**	**Hazard Assessment**
Safe region range ≥ 4.091 m	0.835 mW/cm^2	Satisfies FCC MPE

Summary of expected radiation levels for a Controlled environment

Air-to-Ground	**Maximum Power Density**	**Hazard Assessment**
Safe region range ≥ 0.126 m	5.0 mW/cm^2	Satisfies FCC MPE
Ground-to-Air	**Maximum Power Density**	**Hazard Assessment**
Safe region range ≥ 1.704 m	2.809 mW/cm^2	Satisfies FCC MPE

Conclusions

Access to the UAV and to the transmitting ground-to-air antenna is controlled and not available to the general public, and therefore the controlled environment limits apply.

Due to the small distance of 0.126 m (4.96 in) or greater where the exposure limits are met, it is very unlikely that ground crew will be exposed to non-compliant RF exposure levels. In the event that maintenance on the UAV requires closer proximity to the transmitting antenna than 0.126 m, the RF subsystem will be disabled.

Similarly, while operating the ground-to-air transmitter, access will be restricted to distances greater than 2.809 m.

Analysis – C-band Button Antenna

The analysis and calculations that follow in this report are performed in compliance with the methods described in the OET Bulletin No. 65.

Definition of terms

The terms are used in the formulas here are defined as follows:

S_{ff} = power density in the far field (on axis)
R_{ff} = distance to the beginning of the far-field
R = distance to point of interest

P_a = 5 W	maximum power amplifier output
L_{fs} = 0 dB	loss between power amplifier and antenna feed
P = 5.0 W	power fed to the antenna in Watts
A = 8.553 cm^2	physical area of the aperture antenna
G = 2.0	power gain relative to an isotropic radiator
D = 3.3 cm	diameter of antenna in meters
F = 4600	frequency in MHz
λ = 6.517 m	wavelength in meters ($300/F_{MHz}$)
η = 0.79	aperture efficiency

Far-Field Region. The power density on-axis of the far-field or Fraunhofer region of the antenna pattern decreases inversely as the square of the distance. The distance to the start of the far field can be calculated by the following equation:

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

$$= \frac{(0.6 \bullet 3.3 cm^2)}{6.571 cm}$$

$$= 10.026 \ mm$$

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

$$S_{ff} = \frac{(P \bullet G)}{(4 \bullet \pi \bullet R_{ff}{}^{2})}$$

$$= \frac{(5.0\,W \bullet 2.0)}{(4 \bullet \pi \bullet 10.026\,mm^{2})}$$

$$= 791.787\,\frac{mW}{cm^{2}}$$

Safe Region for Uncontrolled Access. As given above, the power density on-axis of the far field region of the antenna pattern decreases inversely as the square of the distance. The distance to the point where the power density equals the 1 mW/cm^2 level can be determined by the equation:

$$R_{1\,mW} = \sqrt{\frac{(P \bullet G)}{\left(4 \bullet \pi \bullet 1\,\frac{mW}{cm^{2}} \bullet 10\right)}}$$

$$= \sqrt{\frac{(5\,W \bullet 2.0)}{\left(125.66\,\frac{mW}{cm^{2}}\right)}}$$

$$= 0.282\,m$$

Safe Region for Controlled Access. As given above, the power density on-axis of the far field region of the antenna pattern decreases inversely as the square of the distance. The distance to the point where the power density equals the 5 mW/cm^2 level can be determined by the equation:

$$R_{5mW} = \sqrt{\frac{(P \bullet G)}{\left(4 \bullet \pi \bullet 5\,\frac{mW}{cm^{2}} \bullet 10\right)}}$$

$$= \sqrt{\frac{(5\,W \bullet 2.0)}{\left(628.3\,\frac{mW}{cm^{2}}\right)}}$$

$$= 0.126\,m$$

Analysis – C-band 2 ft (61 cm) Antenna

The analysis and calculations that follow in this report are performed in compliance with the methods described in the OET Bulletin No. 65.

Definition of terms

The terms are used in the formulas here are defined as follows:

S_{ff} = power density in the far field (on axis)
R_{ff} = distance to the beginning of the far-field
R = distance to point of interest

P_a = 5 W	maximum power amplifier output
L_{fs} = 0 dB	loss between power amplifier and antenna feed
P = 5.0 W	power fed to the antenna in Watts
A = 0.292 m^2	physical area of the aperture antenna
G = 501.7	power gain relative to an isotropic radiator
D = 61 cm	diameter of antenna in meters
F = 5500	frequency in MHz
λ = 5.451 m	wavelength in meters ($300/F_{MHz}$)
η = 0.41	aperture efficiency

Far-Field Region. The power density on-axis of the far-field or Fraunhofer region of the antenna pattern decreases inversely as the square of the distance. The distance to the start of the far field can be calculated by the following equation:

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

$$= \frac{(0.6 \bullet 3716 cm^2)}{5.451 cm}$$

$$= 4.91\, m$$

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

$$S_{ff} = \frac{(P \bullet G)}{(4 \bullet \pi \bullet R_{ff}^{\ 2})}$$

$$= \frac{(5.0\, W \bullet 501.7)}{(4 \bullet \pi \bullet 4.91\, m^2)}$$

$$= 0.828\, \frac{mW}{cm^2}$$

Safe Region for Uncontrolled Access. Because the power level is just less than 1 mW/cm^2 at the start of the far field, the start of the far field will be used as the safe region for uncontrolled access.

Safe Region for Controlled Access. The power level at the end of the near field (1.7 m) is 2.81 mW/cm^2. Therefore the end of the near field will be used as the safe region for controlled access:

The range to the end of the near field is calculated by:

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

$$= \frac{3716\, cm^2}{4 \bullet 5.451\, cm}$$

$$= 1.704\, m$$

The power level at the end of the near field is calculated by:

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

$$= \frac{(16 \bullet 0.41 \bullet 5\, W)}{(\pi \bullet 3716\, cm^2)}$$

$$= 2.809\, \frac{mW}{cm^2}$$