Prepared by: Mikael Borin	Confirmed by: Magnus Andersson	Approved by: Fredrik Jonsson	Rev: D	Date issued: 2012-11-29

RF Radiation Hazard Analysis for Suitcase CCT Satellite Communication Terminal

1 Introduction

This analysis follows the guidelines proposed by the Federal Communications Commission Office of Engineering & Technology in OET Bulletin 65, Edition 97-01, August 1997: "Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields."

The limit for Maximum Permissible Exposure (MPE) is a Power Density of $5mW/cm^2$ in the frequency band under consideration. This limit is for Occupational/ Controlled Exposure and implies that the public must be aware of there exists a potential hazard.

The satellite earth station considered here has an antenna with aperture diameter 0.9 x 0.588 m and the maximum on-axis EIRP (Equivalent Isotropically Radiated Power) is 54.7 dBW in the frequency band 13.75 – 14.5 GHz.

2 Power density calculations

- Frequency (f): 14.25 GHz
- Wavelength (λ): 0.02105 m
- Antenna aperture diameter: 0.9 x 0.66 m
- Equivalent antenna aperture diameter (D): 0.72746 m
- Antenna gain (G_0): 39.4 dBi
- Antenna aperture efficiency (η): 0.739
- Maximum output power at antenna (P): 15.3 dBW
- On-axis EIRP (G_0 x P): 54.7 dBW @ P1dB

If the distance from the antenna (R) is greater than several wavelengths ($R >> \lambda$), the on-axis gain as function of the distance R can be expressed as:

$$G = G_0 [\sin(x)/x]^2 \qquad (1a)$$

there

$$x = \pi D^2 / 8R\lambda \qquad (1b)$$

and the far field gain $[\sin(x)/x \rightarrow 1]$

$$G_0 = \eta(\pi D/\lambda)^2 \qquad (1c)$$

The on-axis power density (S):

$S = PG/4\pi R^2 = (16\eta P/\pi D^2)\sin^2 x$ (2)

2.1 Near-field region (Fresnel region)

$R \leq D^2/4\lambda$

$R \leq 6.285$ m

In this region, the on-axis power density will vary between maximums [$x=(n-1/2)\pi$] and minimums [$x=n\pi$] depending on the distance (R). The last maximum (n=1) will occur at the near-field limit ($R=D^2/4\lambda$). Outside the near-field region the on-axis power density will decrease with distance.

As a conservative estimate, the on-axis power density can be set to the maximum value throughout the entire near-field region:

$S_{nf}=16\eta P/\pi D^2 = 240\ W/m^2 = 24{,}0\ mW/cm^2$

Off-axis, at a distance from the center of the main beam of at least one antenna diameter, the power density is reduced with more than 20 dB (a factor of 100).

$S_{nf}^{off\text{-}axis} < 0.24\ mW/cm^2$

2.2 Transition region

$D^2/4\lambda < R < 0.6\ D^2/\lambda$

6.285 m <R< 15.08 m

In this region the power density will decrease approximately as the distance (R) from the antenna.

$S_t = S_{nf}\ R_{nf}/R$ (3)

The on-axis power density at the end of the transition region will then be:

$S_t^{min}=10.0\ mW/cm^2$

Alternatively, we can use the more exact formula (2) and find:

$S_t^{min}=8.9\ mW/cm^2$

The approximation in (3) is the most conservative.

Off-axis, at a distance from the center of the main beam of at least one antenna diameter, the power density in this region is also reduced with more than 20 dB (a factor of 100).

$S_t^{off\text{-}axis} < 0.10\ mW/cm^2$

2.3 Far-field region

$R \geq 0.6\ D^2/\lambda$

$R \geq 15.08$ m

This is not the far-field distance normally used in antenna gain and radiation pattern measurements ($R \geq 2D^2/\lambda$ or 50.3 m). From (1), we can observe that the on-axis gain is still considerably lower than the true far-field gain, but as a conservative estimate, we can use the far-field approximation to estimate the on-axis power density.

$S = PG_0/4\pi R^2 = EIRP/4\pi R^2$ (4)

$S_{ff} < 10.3$ mW/cm^2

The more exact formula (2) gives:

$S_{ff} < 8.9$ mW/cm^2

To find the distance from the antenna when the on-axis power density is below 5mW/cm^2; we can use formula (2) or (4):

R > 21.6 m (or R >21.8 m)

2.4 Immediate vicinity of the antenna

For a uniform illumination of the aperture, the power density in front of the antenna will be:

$S \approx P/A$ (5)

A: Area of antenna aperture

$S \approx 8.1$ mW/cm^2

Close to the main reflector surface (with double field intensity) the power density will be:

$S \approx 4P/A$ (6)

$S \approx 32.5$ mW/cm^2

The tapered illumination of the main reflector of the Suitcase CCT antenna will give lower values close to the main reflector rim.

- r: Distance from aperture center normal to the beam-axis
- D_a: Aperture diameter

Just outside the main reflector rim ($r = D_a/2$), the power density will be at least 6 dB lower than the average power density (5) due to diffraction.

Outside the main reflector rim:

$S < 2.03$ mW/cm^2

Near the focal region, between the sub- and main-reflector and at the feed-horn aperture, we can have very high field intensities.

3 Safety area around the antenna

Off-axis, in the near-field region, outside a cylinder with cross section radius $r = D_a$ and with center along the main-beam axis, the power density will be at least 20 dB lower than the on-axis power density. As a conservative estimate, the power density at the outside of a cylinder with the antenna aperture cross section area ($r = D_a/2$), will be at least 6 dB lower than the maximum on-axis power density.

An approximation with a second order function ($r \leq D_a$):

$S(r)=S_{on\text{-}axis}[1/\Delta+(1-r/D_a)^2]/(1+1/\Delta)$ (with: $\Delta=99$) (7)

For $S(r)<5$ mW/cm^2, we will have $r>0.552\ D_a$

If we are setting the safety distance to $r=0.58\ D_a$, we will have a power density less than 4.5 mW/cm^2.

Inside the cylinder with this cross section radius and center along the main-beam axis, there can be a potential radiation hazard. The safety distance in front of the antenna will then be a function of antenna elevation angle.

At the back of the antenna, there exist no radiation hazard, but an area should be shielded to prevent people touching the antenna surface or rim.

To the side of the antenna no radiation hazard will exist outside 0.52 m from the center of the aperture ($0.58\ D_a$). Below (and above) the beam-axis in the near-field region this distance will be 0.34 m, as the antenna has an elliptical aperture.

The safety distance in front of the antenna can be found with the following assumptions:

- Above the safety height (H) from ground, there may be a potential radiation hazard.
- This safety height must be set large enough to prevent public access to the area with too high power density.
- The lower rim of the main reflector must at least be a distance H_a above ground.

$$h=H-\Delta h \qquad (8a)$$

with

$$\Delta h= D_a/2 + H_a -0.58\ D_a \qquad (8b)$$

The safety distance (s) in front of the antenna will be:

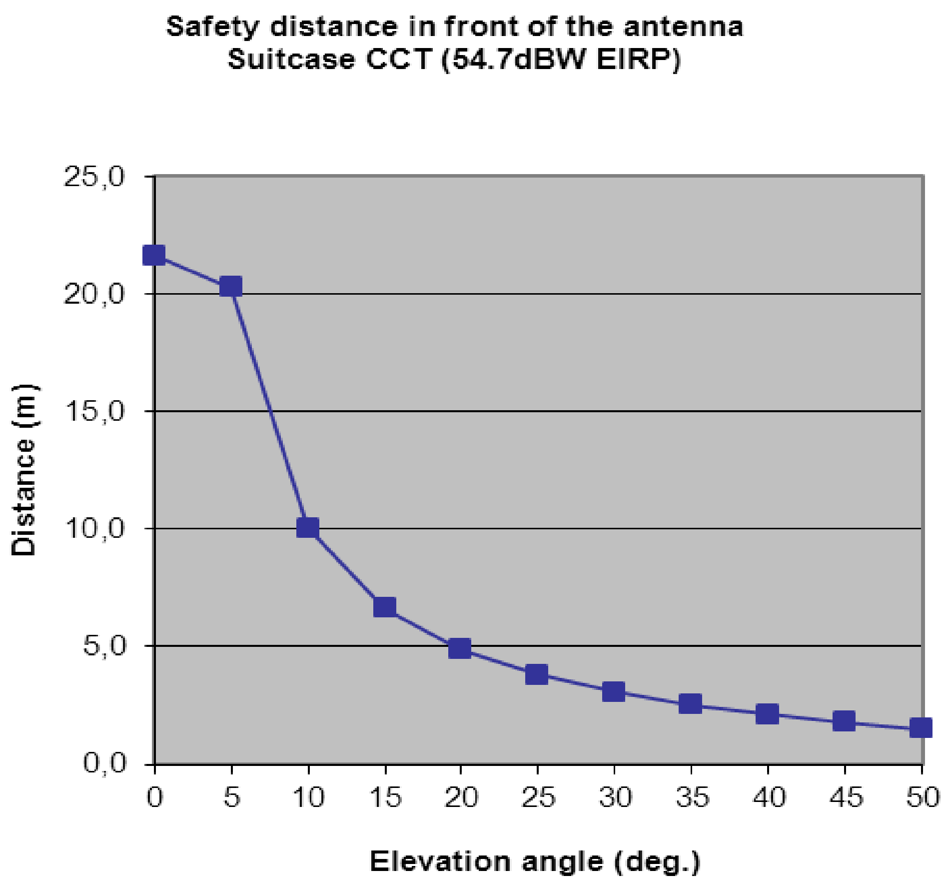
$$s=h/\tan\theta \qquad (9)$$

(θ: Elevation angle towards the satellite.)

If the safety height (H) is 2.0 m, and the minimum height above ground for the main reflector lower rim (H_a) is 0.3 m, table 1 shows the safety distance in front of the antenna as a function of elevation angle. The minimum distance (for high elevation angles) is set to 1 m. This should prevent access to the high power density areas near the sub reflector.

Table 1: Safety distance in front of antenna.

Elevation angle (θ) [deg.]	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
Safety distance (s) [m]	**21.6**	**20.1**	**10.0**	**6.6**	**4.8**	**3.8**	**3.0**	**2.5**	**2.1**	**1.8**	**1.5**



Conclusion

A potential radiation hazard (Power density: S>5 mW/cm^2) can exist on-axis (in antenna pointing direction) out to a distance of about 21.6 m and also close to the antenna (especially between sub- and main- reflector).

Inside an elliptical cylinder with cross section radius 0.58D_a (aperture diameter) around the main-beam, there is also a potential radiation hazard in the near-field region.

A safety distance in front of the antenna can then be found as a function of antenna elevation angle.

These calculations are based on the guidelines from FCC.