Globalstar GSP-1620 Satellite Packet Data Modem

Article 3.1a

Health and Safety Analysis Report

80-99280-1 X1

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Analysis of Maximum Permissible Exposure from Globalstar Satellite Packet Data (SPD) Modem Passive-Tx Outdoor Unit (ODU) Dielectric Resonator Antennas (DRA s)

The purpose of this report is to analyze the non-ionizing electromagnetic (EM) radiation levels of the passive-Tx ODU dielectric resonator antennas employed in Satellite Packet Data Modems (SPDM s) operating as special purpose Globalstar (GS) User Terminals (UT s), and to compare the predicted levels with established maximum permissible exposure (MPE) levels, to determine the minimum permissible separation distance from those antennas.

Within the United States, the governing regulations are those promulgated by the FCC in 47 CFR Ch. 1 (10-1-99 Edition) Part 1, Sections 1.1310 and 2.1091 [1] (unchanged from 10-1-96 Edition). Table 1 (B) in Section 1.1310 defines the MPE levels for domestic/uncontrolled exposure to RF radiation over the frequency range from 300 kHz to 100 GHz. The MPE limits are applicable to transmitting structures used at distances greater than 20 cm from the body and thus are appropriate for SPDM modules, which are used remotely or on the user s desk top.

The MPE requirements are a hybridization of those recommended by the American National Standards Institute (ANSI) in association with the Institute of Electrical and Electronic Engineers (IEEE) in ANSI/IEEE C95.1-1992 [2] and of the earlier recommendations by the National Council on Radiation Protection (NCRP) in Chapter 17 of NCRP Report No. 86, 1986 [3]. These recommended exposure limits are also similar to those defined in the IRPA Guidelines on Protection Against Non-Ionizing Radiation, 1991 [4], which are reportedly in the process of being adopted in the European Union, as codified in European Pre-Standard ENV 59166-2, approved by CENELEC in 1994.

This report uses the above standards to establish the minimum safe separation distance between radiating GS SPD Modem antenna structures and people in proximity to those antennas, during GS SPD transmissions. In this report we ve determined the power flux densities in the far field in free space, above a reflecting ground plane, and below the antenna horizon, off the edge of a reflecting ground. These values may be used to determine the minimum safe distance from the antenna for US and International uncontrolled (general population) exposure environments.

The analytical methodology employed is that defined in the FCC s Office of Science and Technology Bulletin, No. 65, October 1985 [5].

For reference, Table 1 presents the maximum permissible exposure limits and averaging times for the above-described standards across the authorized transmission frequency band (1610-1621.35 MHz) for Globalstar UT antennas. As can be seen in the table, the IRPA limits represent the most severe limits in the Globalstar transmit band and subsequent discussions of limits and margins will be with respect to the IRPA limits, except where explicitly stated otherwise.

Table 1. Maximum Permissible Exposure Level Requirements at Globalstar Transmit Frequencies

MPE Limit	Frequency (MHz)	Wavelength (cm)	FCC /1.1310 1997 (mW/cm^2)	ANSI/IEEE C95.1-1992 (mW/cm^2)	IRPA 1991 (mW/cm^2)
Uncontrolled Environment	300-1500	¥	f/1500	¥	¥
	1500-100,000	¥	1.0	¥	¥
	300-15000	¥	¥	f/1500	¥
	400-2000	¥	¥	¥	f/2000
	2000-300,000	¥	¥	¥	1.0
	1610	**18.63**	**1.00**	**1.073**	**0.805**
	1618	18.54	1.00	1.078	0.809
	1621.35	18.50	1.00	1.081	0.811
	1626.5	18.44	1.00	1.084	0.813

Notes:
1. f = frequency in MHz
2. Averaging time for uncontrolled exposure environments is 30 minutes for FCC and ANSI/IEEE C95.1-1992, and 6 minutes for IRPA 1991.

UT Transmitter and Antenna Characteristics

Salient GS SPDM Transmitter and Antenna characteristics used in this analysis are presented in Tables 2, 3, and 4 and are similar to those for Globalstar Car Kit DRA Outdoor Units (ODU s). It should be noted that although the effective isotropic radiated power (EIRP) value shown in the table is higher than that specified in the Globalstar Air Interface (GAI) Specification (Reference 6), it is none-the-less a value which could be encountered in operation, depending on the transmitter power amplifier (PA) and antenna gain calibration tolerance stackups. The value is conservative, as is appropriate for a safety analysis.

Table 2. GS SPDM Transmitter and Antenna Physical Characteristics

UT Characteristic	Value
Transmitter Power (P_t)	26.5 dBm (446.7 mW)
UT Maximum Antenna Gain (G_t)	7.0 dBic
Calibration Error Tolerance (Tol)	1.0 dB
EIRP (P_t + G_t + Tol)	34.5 dBm
Antenna Diameter (D)	2.5 cm (Characteristic Dimension)
Antenna Depth (d)	1.0 cm
Antenna Height Above Base	5.0 cm

Antenna Gain

Since these are omnidirectional DRA antennas designed to communicate with overhead satellites, their maximum gain is in directions well above the antenna horizon — at zenith for the GS SPDM antenna. Typical DRA antenna gainvalues as a function of elevation angle are presented in Table 3. There is a peak gain variation of less than 0.5 dB across the UT transmit band, with the highest in-band gain at the upper band edge, 1626.5 MHz, and those are the gain values presented in Table 3 and used in the analysis. The antenna gain is strongly direction dependant and the gain toward the ground plane beneath the antenna is substantially less than the gain in all directions above the horizon.

Table 3. GS SPDM Antenna Gain as a Function of Elevation

Elevation Angle (deg.)	Gain (dBic)	Gain Delta (dB)
90	6.9	-0.1
85	7.0	0.0
80	6.8	-0.2
75	6.7	-0.3
70	6.5	-0.5
65	6.3	-0.7
60	5.9	-1.1
55	5.5	-1.5
50	5.0	-2.0
45	4.7	-2.3
40	4.1	-2.9
35	3.6	-3.4
30	2.9	-4.1
25	2.4	-4.6
20	1.5	-5.5
15	1.1	-5.9
10	0.2	-6.8
5	-0.2	-7.2
0	-1.2	-8.2
-5	-2.0	-9.0
-10	-3.1	-10.1
-15	-4.0	-11.0
-20	-5.3	-12.3
-25	-6.4	-13.4
-30	-7.9	-14.9
-35	-8.3	-15.3
-40	-10.0	-17.0
-45	-9.9	-16.9
-50	-10.7	-17.7
-55	-11.7	-18.7
-60	-12.7	-19.7
-65	-12.6	-19.6
-70	-12.4	-19.4
-75	-13.6	-20.6
-80	-16.6	-23.6
-85	-16.3	-23.3
-90	-17.1	-24.1

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Far-Field Power Density Calculations

Since the maximum below horizon gain is -2.0 dBic, comparatively little energy is reflected from any ground plane below the antenna, at all far field distances above the antenna, and even less energy is seen at positions below the antenna horizon. Worst case for the DRA antenna is directly above the antenna, at or near zenith, where the antenna gain is greatest. But, the effect of the reflected EM wave, from the ground plane on which the DRA housing rests, does have some small effect on the total power density and should be accounted for. The analysis geometry is presented in Figure 1.

The calculations presented herein are strictly valid only in the antenna s far field region but are generally conservative at closer distances, in the radiating near field. True near-field power density calculations for an antenna in the presence of a ground plane could be done using various numerical simulation techniques, but they are quite time consuming, and would have to be done parametrically (results are strongly dependent on the heights of the antenna and field point and on their mutual separation distance from eachother).

Closed-form far-field calculations like those presented herein are simpler and provide more easily interpretable and mathematically transparent results. (Since the far field results which follow yield minimum permissible approach distances substantially larger than the distance to the far-field breakpoint, there is no need to calculate possibly-higher near-field power densities at lesser separation distances.)

The Fraunhoefer far-field breakpoint distance is generally defined as follows:

$$r_{ff} = \frac{2D^2}{\lambda}$$

where: r_{ff} = Distance from Antenna Center in cm

D = Antenna Dimension in cm

λ = Wavelength in cm

This distance is the approximate lateral distance where the phase difference between an EM wave from the center of the antenna and from the end of the antenna is equal to 1/16 of a wavelength.

Per References 8 and 9, there is a degree of arbitrariness in the definition of the far field break point. For purposes of MPE calculations, far field equations may be employed at distances half that calculated using the above standard equation, albeit with a decrease in accuracy. Per Reference 9, antenna pattern measurement accuracy is 99% (relative to that measured at a much greater distance) at a distance of 2 D^2/λ and 94% at a distance of D^2/λ (which could be considered a far field breakpoint distance based on an eighth wavelength phase difference criterion).

Results of Far-Field MPE Minimum Allowable Separation Distance Analysis

Referring to Table 1, the most severe MPE Limit is the IRPA Limit at the UT transmit frequency lower band edge of 1610 MHz, where the maximum permissible exposure is a power density of 0.8 mW/cm^2 for 6 minutes continuous exposure, with slightly higher values at higher UT transmit frequencies.

This MPE limit can be comfortably met at distances of 21.5 cm from the surface of the ODU shell surrounding the antenna above a proximate conductive ground plane, per the results presented in Table 3. The somewhat higher FCC MPE Limit of 1.0 mW/cm^2 for 30 minutes continuous exposure can be met at a distance of 19 cm, near a reflective metal ground plane. In free space, remote from any conductive ground plane, the IRPA MPE Limit can be met at a distance of 15.5 cm from the ODU, while the FCC MPE Limit can be met at a distance of 14 cm.

For field points located below the antenna horizon, such as off the edge of a metal desk, the IRPA and FCC MPE Limits are met by the SPDM antenna at a distance of 5 cm.

Calculations (described in the next section) show that GS SPDM antenna power density levels are highest directly above the antenna and in general increase as the antenna and field point heights decrease.

Derivation of Far-Field Power Density Equations

The calculations presented in Table 3 give upper bounds on the minimum allowable separation distances at which the IRPA and FCC MPE limits are satisfied, independent of ground reflectivity and antenna height. Where more accurate calculations are desired for specific combinations of transmit and receive antenna heights, the following far-field equations are derivable from first principles using the vector geometry in Figure 2 (see Reference 10).

<u>For E-Field Polarized Parallel to Plane of Incidence:</u>

Direct Line-of-Sight EM Wave Power

$$PD_d = \frac{P_t G_t}{4\pi r_d^2}\left|\left(\cos(\theta_d)\,\hat{\boldsymbol{h}} - \sin(\theta_d)\hat{\boldsymbol{v}}\right)\exp^{\left(j\frac{\omega}{c}r_d\right)}\right|^2$$

Reflected EM Wave Power Density

$$PD_r = \frac{P_t G_t}{4\pi r_r^2}\left|R\,\Delta_g\left(\cos(\theta_r)\,\hat{\boldsymbol{h}} - \sin(\theta_r)\hat{\boldsymbol{v}}\right)\exp^{\left(i\frac{\omega}{c}r_r\right)}\right|^2$$

Total Power Density Above Ground Plane (Parallel Polarized E-Field)

$$PD_{TP} = \frac{P_t\,G_t}{4\,\pi}\left[\left(\frac{1}{r_d}\right)^2 + \left(\frac{R\,\Delta_g}{r_r}\right)^2 + \frac{2\,R\,\Delta_g}{r_d\,r_r}\cos\left(\frac{\omega}{c}\left[r_r - r_d\right]\right)\cos\left(\theta_r - \theta_d\right)\right]$$

$$\varphi = \frac{\omega}{c}\left(r_r - r_d\right)$$

where: Geometric parameters are as defined in Figure 1, dimensions in cm

- P_t = Transmit Power in mW
- G_t = Peak Transmit Antenna Gain
- R = Ground Plane Reflection Coefficient (Max = 1.0)
- Δ_g = Reduction in Antenna Gain in Direction of Ground Plane
- ω = 2 π frequency
- c = 3 *10^{10} cm/s (speed of light)
- h = horizontal (tangential) unit vector (in plane of incidence)
- v = vertical unit vector
- φ = Phase Angle

<u>For E-Field Polarized Normal to Plane of Incidence (Horizontal Polarization):</u>

Reflected EM Wave Power Density

$$PD_r = \frac{P_t G_t}{4\pi r_r^2}\left| -R\,\Delta_g \hat{\boldsymbol{h}}\,\exp^{\left(i\frac{\omega}{c}r_r\right)}\right|^2$$

Total Power Density Above Ground Plane (Normal Polarized E-Field)

$$PD_{TN} = \frac{P_t G_t}{4\pi}\left| \frac{\exp^{\left(i\frac{\omega}{c}r_d\right)}}{r_d} - \frac{R\Delta_g \exp^{\left(i\frac{\omega}{c}r_r\right)}}{r_r}\right|^2$$

$$PD_{TN} = \frac{P_t\, G_t}{4\,\pi}\left[\left(\frac{1}{r_d}\right)^2 + \left(\frac{R\,\Delta_g}{r_r}\right)^2 - \frac{2\,R\,\Delta_g}{r_d\, r_r}\cos\left(\frac{\omega}{c}\left[r_r - r_d\right]\right)\right]$$

From the foregoing, it is apparent that an upper bound on the power density above a ground plane may be established under the following conditions:

1. Horizontal separation distance (S) large compared to antenna and field point heights: S >> h_s, h_f, $\theta_r \approx 0$¡
2. Heights are approximately equal: $h_s \approx h_f$, $\theta_d \approx 0$¡
3. Reflected and direct EM waves add in phase

   (Phase angle an odd multiple of pi for E-Field polarized normal to plane of incidence; an even multiple of pi for E-Field polarized parallel to plane of incidence.)

Upper Bound on Total Power Density, Assuming In-Phase Addition:

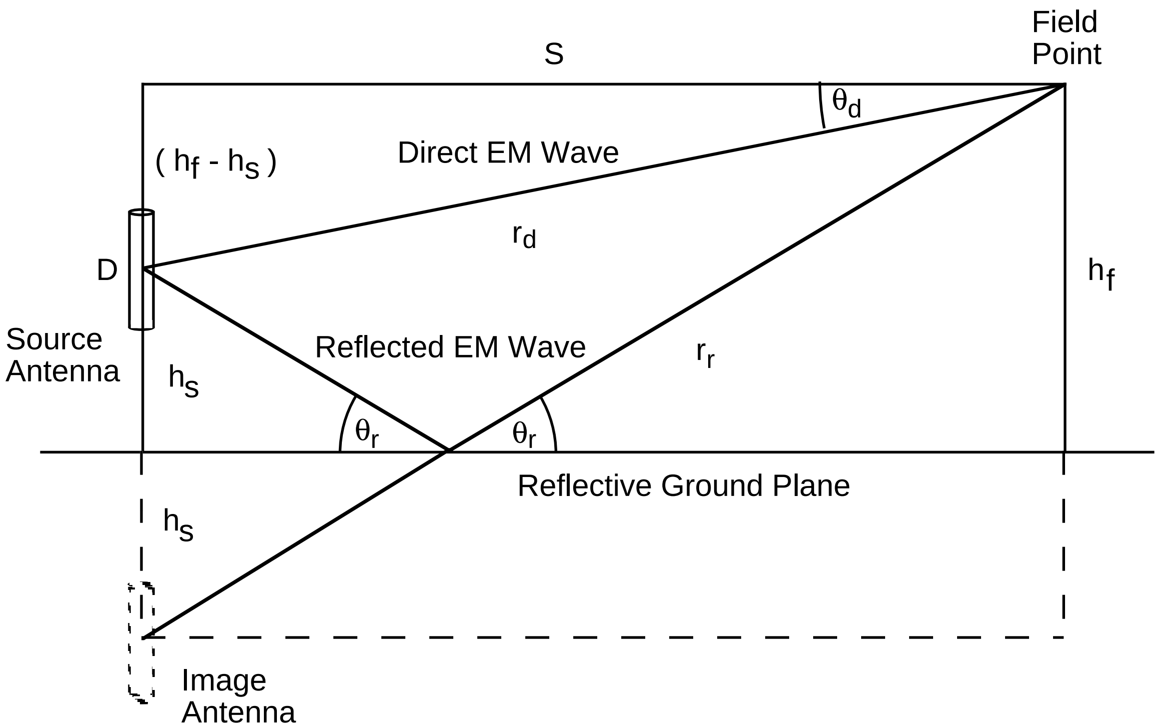
$$PD_{UB} = \frac{P_t\, G_t}{4\,\pi}\left[\left(\frac{1}{r_d}\right)^2 + \left(\frac{R\,\Delta_g}{r_r}\right)^2 + \frac{2\,R\,\Delta_g}{r_d\, r_r}\right]$$

Although a very simple equation, this upper bound power density formula is explicitly dependent on both the lateral (horizontal) separation distance between the transmit antenna and the field point and on their respective heights above the ground plane. A simpler and still more conservative upper bound equation may be obtained by replacing the direct and image antenna separation distances in the numerators of the above equation with the separation distance (now written as r , with no subscript). Doing this we get the simplified upper bound equation for the far field power density above a ground plane that was used in generating Table 3:

$$PD_{UB} = \frac{P_t\, G_t}{4\,\pi\, r^2}\left[1 + R\,\Delta_g\right]^2$$

Summary and Conclusions:

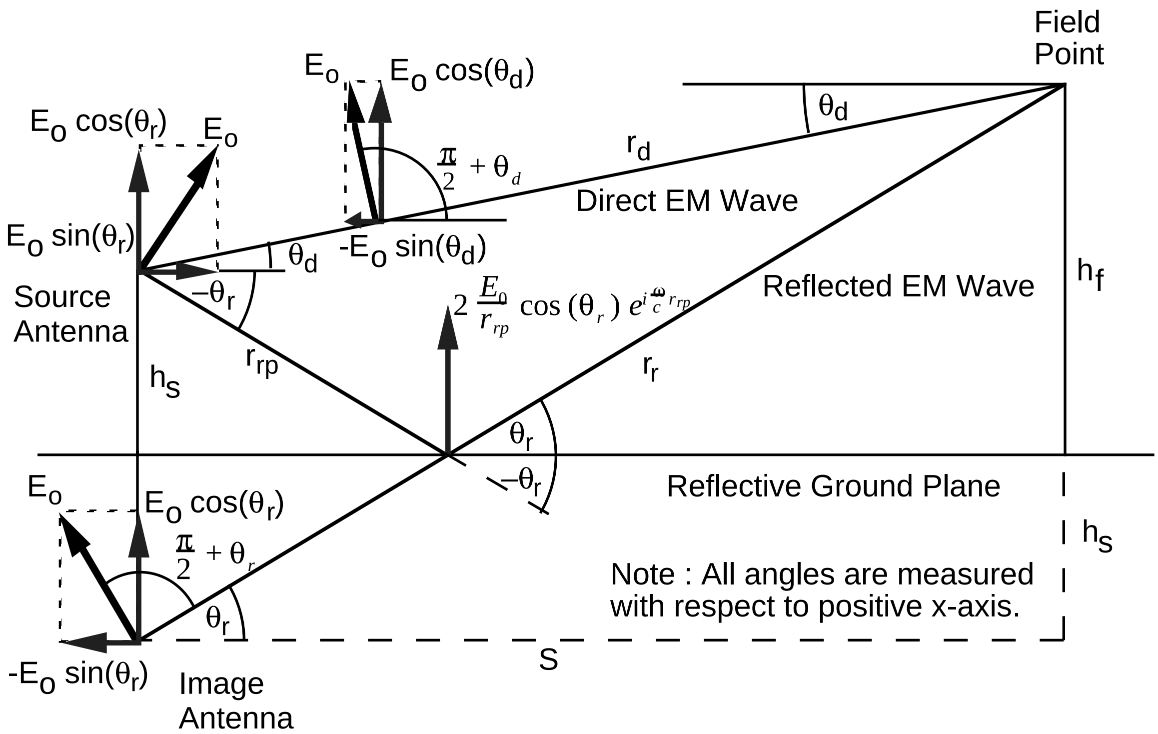
As shown in Table 4, the minimum acceptable separation distance from a GS SPDM DRA ODU, when the antenna is transmitting at full power, ranges from 15.5-21.5 cm, depending on presence or absence of, and distance from, a proximate reflective ground plane. (Calculated distances in Table 4 are with respect to the center of the radiating antenna element within the housing, approx.1.3 cm in from the outer surface of the ODU radome.) User manuals include instructions that the module be installed in a configuration that ensures a minimum line-of-sight separation distance of 21.5 cm (8.5 inches) between the ODU antenna and any personnel in order to comply with the most stringent MPE Limit.



$$r_r = \sqrt{S^2 + (h_f + h_s)^2} \qquad r_d = \sqrt{S^2 + (h_f - h_s)^2}$$

$$\theta_r = atan\left(\frac{h_f + h_s}{S}\right) \qquad \theta_d = atan\left(\frac{h_f - h_s}{S}\right)$$

Figure 1. UT MPE Calculation Geometry



Distance to Ground Plane Reflection Point $r_{rp} = h_s \csc(\theta_r)$

Phase Difference $\varphi = \frac{\omega}{c}(r_r - r_d)$

Horizontal Component

$$E_H^2 = \left| -E_0 \sin(\theta_r)\frac{e^{i\varphi}}{r_r} - E_0 \frac{\sin(\theta_d)}{r_d} \right|^2 = E_0^2 \left[\left(\frac{\sin(\theta_r)}{r_r}\right)^2 + \left(\frac{\sin(\theta_d)}{r_d}\right)^2 + 2\frac{\sin(\theta_r)\sin(\theta_d)}{r_r r_d}\cos(\varphi) \right]$$

Vertical Component

$$E_V^2 = \left| E_0 \cos(\theta_r)\frac{e^{i\varphi}}{r_r} + E_0 \frac{\cos(\theta_d)}{r_d} \right|^2 = E_0^2 \left[\left(\frac{\cos(\theta_r)}{r_r}\right)^2 + \left(\frac{\cos(\theta_d)}{r_d}\right)^2 + 2\frac{\cos(\theta_r)\cos(\theta_d)}{r_r r_d}\cos(\varphi) \right]$$

Total

$$E_T^2 = E_H^2 + E_V^2 = E_0^2 \left[\left(\frac{1}{r_r}\right)^2 + \left(\frac{1}{r_d}\right)^2 + \frac{2}{r_r r_d}\cos(\theta_r - \theta_d)\cos(\varphi) \right]$$

Figure 2. Method of Images for Isotropic Radiator (E-Field Parallel to Plane of Incidence)