

Compliance with High-Intensity Radiated Fields Regulations - Emitter's Perspective

Joseph I. Statman and Vahraz Jamnejad
Jet Propulsion Laboratory

Lee Nguyen
Federal Aviation Administration

ABSTRACT

NASA's Deep Space Network (DSN) uses high-power transmitters on its large antennas to communicate with spacecraft of NASA and its partner agencies. The prime reflectors of the DSN antennas are parabolic, at 34m and 70m in diameter. The DSN transmitters radiate Continuous Wave (CW) signals at 20 kW - 500 kW at X-band and S-band frequencies. The combination of antenna reflector size and high frequency results in a very narrow beam with extensive oscillating near-field pattern. Another unique feature of the DSN antennas is that they (and the radiated beam) move mostly at very slow sidereal rate, essentially identical in magnitude and at the opposite direction of Earth rotation.

The DSN is in the process of revamping its documentation to provide analysis of the High Intensity Radiation Fields (HIRF) environment resulting from radio frequency radiation from DSN antennas for comparison to FAA regulations regarding certification of HIRF protection as outlined in the FAA regulations on HIRF protection for aircraft electrical and electronic systems (Title 14, Code of Federal Regulations (14 CFR) §§ 23.1308, 25.1317, 27.1317, and 29.1317).

This paper presents work done at JPL, in consultation with the FAA. The work includes analysis of the radiated field structure created by the unique DSN emitters (combination of transmitters and antennas) and comparing it to the fields defined in the environments in the FAA regulations. The paper identifies areas that required special attention, including the implications of the very narrow beam of the DSN emitters and the sidereal rate motion. The paper derives the maximum emitter power allowed without mitigation and the mitigation zones, where required.

Finally, the paper presents summary of the results of the analyses of the DSN emitters and the resulting DSN process documentation.

CITATION: Statman, J., Jamnejad, V. and Nguyen, L., "Compliance with High-Intensity Radiated Fields Regulations - Emitter's Perspective," *SAE Int. J. Aerosp.* 5(2):2012, doi:10.4271/2012-01-2148.

1. INTRODUCTION

NASA established in 1963 the Deep Space Network (DSN) to provide communications and navigation support to missions of NASA and its partner agencies in the USA and internationally.

As shown in [Figure 1](#), the DSN has facilities in the USA (GDSCC, near Goldstone, California), Spain (MDSCC, near Madrid) and Australia (CDSCC, near Canberra). Each of these facilities has large steerable antennas, 34m to 70m in diameter and extensive signal processing capabilities. The antennas are equipped with high sensitivity low-noise amplifiers and high-power transmitters - these are required due to the extreme distances needed for communications with missions at deep space.

The FAA established regulations in 14 CFR §§ 23.1308, 25.1317, 27.1317, and 29.1317, High-intensity Radiated Fields (HIRF) protection for Aircraft Electrical and Electronic Systems (Federal Register Vol. 72, No. 150, dated 8/6/2007) for protection of the operation of these aircraft systems when the aircraft is exposed to external HIRF environments. While the FAA does not regulate DSN antennas and transmitters, the process the DSN undergoes with spectrum agencies to obtain emitter certification involves a validation that the DSN emitters do not exceed the environment specified by the FAA or, if the DSN radiation exceeds that environment, appropriate mitigation (e.g. aircraft exclusion zones and/or coordination) is taken. Note that the specific rules are country- and agency-dependent, but the HIRF environments in the FAA regulations are harmonized with other national airworthiness authorities.

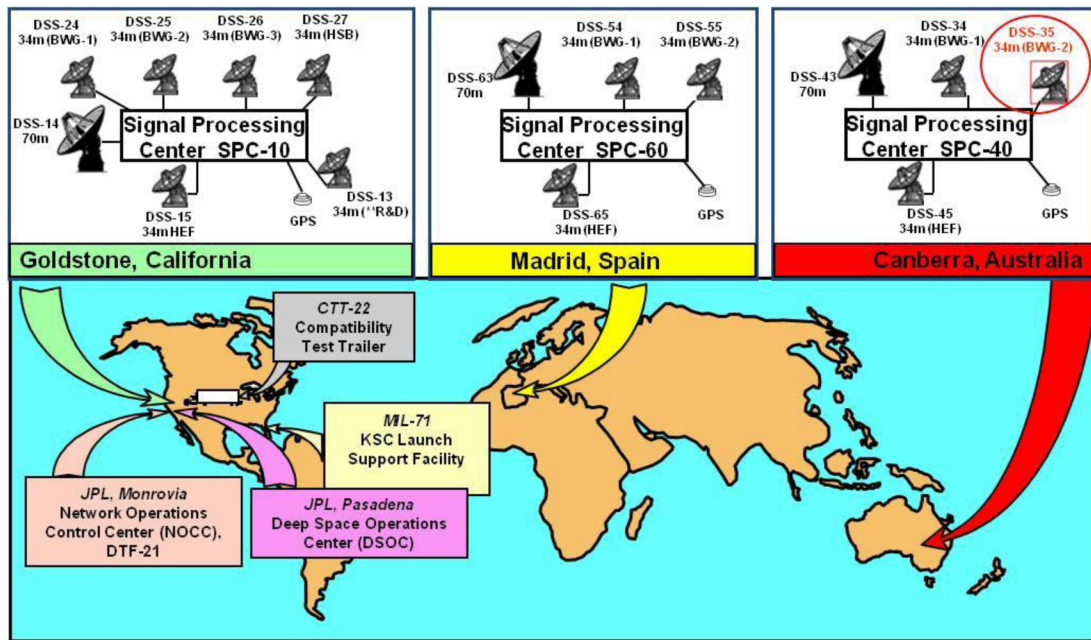


Figure 1. Configuration of the Deep Space Network (DSN)

The DSN radiation environment is unique. It is characterized by large antennas (34m and 70m in diameter) that move very slowly, large transmitters (up to 500 kW) and very narrow beams, mechanically (not electronically) steered, that are fixed with respect to the antennas.

This paper describes the FAA regulations (Section 2), the analysis required to characterize the DSN environment (Section 3), followed by a brief description of the resulting process and documentation upgrades incorporated in the DSN (Section 4). Section 3 provides a sample analysis, for a single combination of antenna and transmitter - specifically, for the case of a 34m beam waveguide antenna, 80 kW transmitter, and comparison to FAA HIRF Environment I. As part of the process, this analysis is repeated for each combination of DSN antenna and transmitter and for each FAA HIRF Environment.

2. FAA REGULATIONS

The FAA established Radio Frequency (RF) field strengths for certification of aircraft and their parts in a HIRF Environment. The criteria define the radiation environment the aircraft electrical and electronic systems have to withstand in HIRF Environment I (Certification HIRF Environment), HIRF Environment II (Normal HIRF Environment), and HIRF Environment III (Rotorcraft Severe Environment). Table 1 shows the FAA certification limits for Environment 1.

While these are FAA standards, they are harmonized with other national airworthiness authorities. In fact, the process to develop these environments consisted of collecting data in the US and Europe to establish the governing criteria. Unfortunately, the process did not identify the CDSCC and

MDSCC emitters and assumed that the GDSCC emitters are protected by an aircraft exclusion zone.

Table 1. FAA HIRF Environment I (Certification HIRF Environment)

FREQUENCY	FIELD STRENGTH (V/m)	
	PEAK	AVERAGE
10 kHz - 2 MHz	50	50
2 MHz - 30 MHz	100	100
30 MHz - 100 MHz	50	50
100 MHz - 400 MHz	100	100
400 MHz - 700 MHz	700	50
700 MHz - 1 GHz	700	100
1 GHz - 2 GHz	2,000	200
2 GHz - 6 GHz	3,000	200
6 GHz - 8 GHz	1,000	200
8 GHz - 12 GHz	3,000	300
12 GHz - 18 GHz	2,000	200
18 GHz - 40 GHz	600	200

In this table, the higher field strength applies at the frequency band edges.

In general, the FAA regulations assume that emitters are of the pulsed radar type and are characterized by a high-energy pulse followed by no transmission. Thus, the three environments are characterized by "Peak" field value, during the pulse, and "average" field value, over the period of the pulsed radar. Such transmitters have two types of effects on electrical and electronic equipment:

1. "Upsets" of memory cells, e.g. zeros to ones or the reverse, caused by the "peak" radiation.

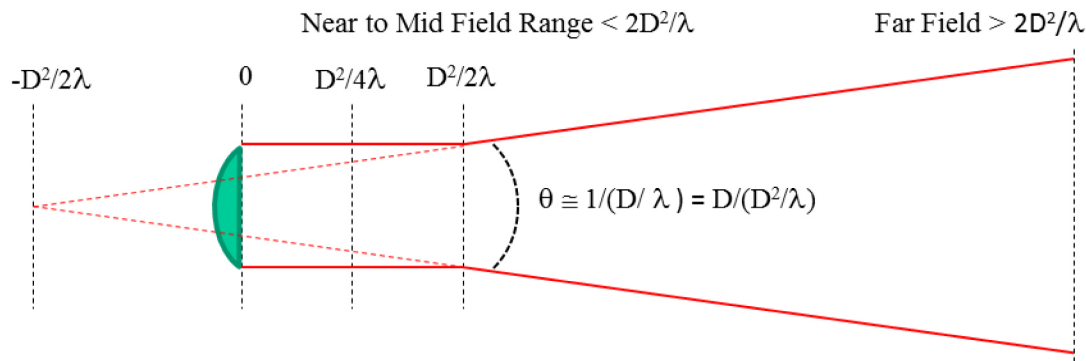


Figure 2. Model of radiation from a DSN antenna

2. Thermal effects, or malfunctions caused by increase in the temperature of electronic junctions, as a function of radiation over time (the FAA standard uses 1 second for fixed-wing aircraft and 3 seconds for rotorcraft).

The DOT/FAA/AR-98/69, NAWCADPAX-98-156-TM prepared by the Naval Air Warfare Center, December 1998 report [Ref. 1], and SAE International (SAE) Aerospace Recommended Practice (ARP)5583a / European Organization for Civil Aviation Equipment (EUROCAE) ED-107a "Guide to Certification of Aircraft in a High-Intensity Radiated Field (HIRF) Environment," June 2010 [Ref. 5] assumes that averaging is computed over time, using many cycles of the periodic/pulsed emitter. Because the DSN transmitters are CW transmitters, but impact the aircraft only during the short time it crosses the narrow beam, the main adjustment in the DSN procedure is that it allows for spatial averaging - averaging the field over the path that the aircraft passes through the beam.

Appendix A compares the assumptions in NAWC report to the assumptions used in this paper.

3. ANALYSIS TO EVALUATE DSN RADIATED FIELDS

Figure 2 shows the model of radiation from a DSN antenna. There are three zones: a near-field zone, modeled as a cylinder with diameter equal to antenna diameter, a far-field zone, modeled as a cone centered at the antenna, and a transition zone between the near-field and far-field zones. The detailed structure of the field is quite complex and varies as a function of the antenna diameter and transmitter frequency, as will be shown in Figure 3 below.

The simple model of the near-field is a cylinder, with the diameter of the antenna and centered on the antenna. Figure 3 shows the finer structure of the field, normalized to the average field strength level for Environment I. The horizontal axes plot the distance along the cylinder, while the vertical axes plot the distance from the antenna from the center of the cylinder outward. As expected, as the distance from the center of the cylinder reaches 17m, the radius of the cylinder, the field drops sharply. Notice further how the field is quite complex, fluctuating from point to point, in this case drawn to

30 km, well beyond the near field. Nevertheless, at no point does the field strength exceed the FAA "Peak" value, 1000 V/m for Environment I, 6-8 GHz.

How Figure 3 is derived. First, it is important to distinguish between the "nominal power" of a transmitter and the "effective power". "Nominal power", for the DSN, is the power as measured in the last measuring point in the uplink chain (for the 80 kW transmitter, "nominal power" is at the switch between the horn feed and the water load). "Effective power" is the power radiated out of the antenna aperture, accounting for losses after the measuring point (load switch) which include losses from the switch to the feed horn and those after feed through sub and main reflectors (including Ohmic, leakage, blockage, surface errors, etc.) losses to aperture which account for the efficiency of the antenna. Table 2 shows these values. Thus, the "effective power" for the 80 kW transmitter is determined to be 56.8 kW.

Next we need to compute the average field. We take the conservative approach - averaging over the minimum of 1 sec and the time required for crossing the beam. Because that time varies depending on the aircraft speed and antenna elevation angle, the "average field" plotted here for each elevation angle is the maximum over aircraft speed range (100-350 knots for fixed wing aircraft).

Table 3 shows the beam crossing time for a 34m antenna, for a variety of aircraft speed and antenna elevation. Note that unless there is a combination of low speed and low elevation, the crossing time is less than 1 second. This table assumes that aircraft fly horizontally since aircraft usually operate in level flight, and that the aircraft crosses through the center of the antenna beam, resulting in the longest crossing time. During ascent/descent, aircraft are restricted to 3 degrees slope except for emergencies (for example 14 CFR sec. 171.317 - Approach elevation performance requirements). The DSN complies with the ITU regulatory limit to assure that no transmission below 10 degrees and horizon mask occurs.

Figure 4 shows the resulting average field. For this case, we conclude that no mitigation is required if the antenna operates at elevations over 30 degrees or higher, and limited mitigation (e.g. exclusion zone and/or coordination) is required for lower elevation angles.