Analysis of Near-Field of Circular Aperture Antennas with Application to Study of High Intensity Radio Frequency (HIRF) Hazards to Aviation from JPL/NASA Deep Space Network Antennas

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Abstract— This work includes a simplified analysis of the radiated near to mid-field from JPL/NASA Deep Space Network (DSN) reflector antennas and uses an averaging technique over the main beam region and beyond for complying with FAA regulations in specific aviation environments. The work identifies areas that require special attention, including the implications of the very narrow beam of the DSN transmitters. The paper derives the maximum averaged power densities allowed and identifies zones where mitigation measures are required.

I. 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. 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 ultra-sensitive low-noise amplifiers (LNAs) and high-power transmitters – these are required due to the extreme distances needed for communications with spacecraft at deep space.

The DSN radiation environment is rather unique. It is characterized by large reflector antennas (34m and 70m in diameter) that move very slowly, with large transmitters (up to 500 kW) , very narrow beams, and mechanically steered.

This work describes the FAA regulations and the analysis required to assure DSN compliance and provides results for a single combination of antenna and transmitter – specifically, for the case of a 34m beam waveguide antenna dual-reflector antenna, with an 80 kW transmitter, and for HIRF Environment I. In reality, as part of the process, this analysis is repeated for each combination of DSN antenna and transmitter and for each FAA HIRF Environment, but is not included here.

II. 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).

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" radiations.
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).

A DOT/FAA/AR-98/69 report prepared by the Naval Air Warfare Center [Ref. 1], and SAE International (SAE) Aerospace Recommended Practice/ European Organization for Civil Aviation Equipment [Ref. 2] assume 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.

III. ANALYSIS TO ASSURE DSN COMPLIANCE

Figure 1 shows a simple diagram 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 as shown, 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 2 below.

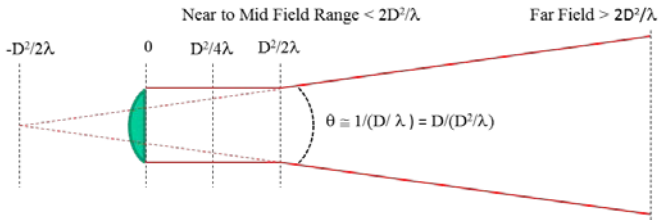

Figure 1. A simple model of radiation from a reflector antenna

Figure 2 shows the finer structure of the field, normalized to the field limit for Environment I. A more refined version of methodolgy used in Refs [3-4] which is edtende away from the axis and extended to several beamwidth is employed for calculation (A future paper will detail this analysis).

In this figure, 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.

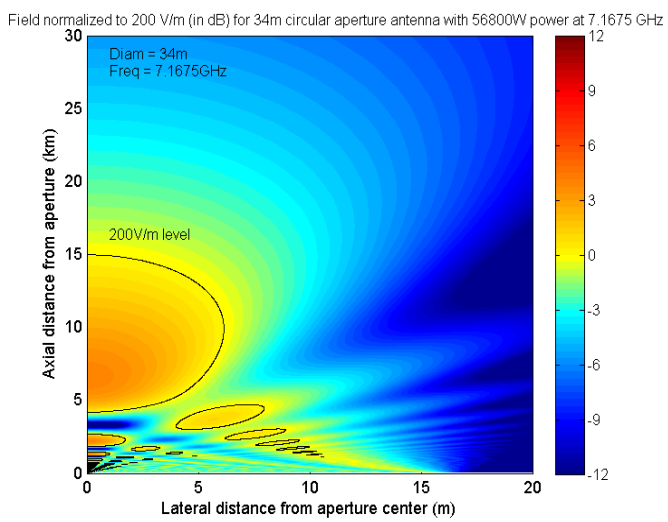

Figure 2. Example of Detailed Field Strength

In applying the power to this figure, the "Effective Power" radiated out of the antenna aperture, accounting for losses after the measuring point (load switch) which include losses from the transmitter switch to the feed horn and those after feed through sub and main reflectors (including Ohmic, leakage, blockage, surface errors, etc.) losses to aperture, is calculated. Thus, the "effective power" for the 80 kW transmitter is determined to be 56.8 kW.

Subsequently the average field is calculated. This averaging computation is rather complicated and time consuming and its details will be provided in a future paper. Time Averaging is performed 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).

Figure 3 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.

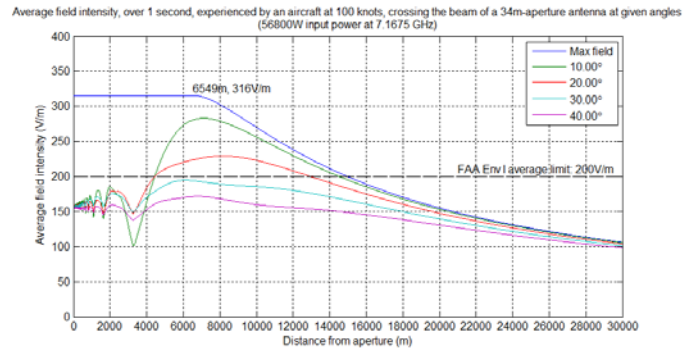

Figure 3. Peak and Average Field, 80 kW/X-band/34m, referenced to Environment I.

IV. Concluding Remarks

The paper presents a sample summary of the results of the analyses of the DSN transmitters. The methodology and the assumptions used in the DSN emitter analyses are consistent with the HIRF environment evaluation and assumptions used in the literature. The analysis presented here has been applied to other combinations of transmitters and antenna in DSN, and has been incorporated in a published procedure [Ref 5].

Acknowledgement

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References

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