Abstract

The radiation patterns of satellite antennas may be highly influenced by scattering in the satellite, its payload and its solar array. By ray tracing techniques and applying orbit data it is shown how it is possible to model the link signal to a given earth station taking into account that the solar array follows the direction to the sun.

Introduction

The signal from antennas mounted on a satellite may be influenced by scattering from the satellite payload and the solar array as well as from the body of the satellite itself. Especially the radiation from the TTC antennas may be disturbed as these are designed for a full spherical coverage.

Due to its size, it is in particular the solar array which might shadow and reflect the antenna radiation. This adds a new dimension to the predictions as the orientation of the solar array is designed to follow the direction to the sun while the satellite itself is oriented towards the earth. The orientation of the solar array thus depends on the position in orbit of the satellite.

Geometrical ray tracing with application of GTD (Uniform Geometrical Theory of Diffractions) is very useful for such scattering predictions. For this, an extended version of GRASP9 has been applied. From a file the time varying distance and the relative orientation between the satellite and the ground station are read. This input includes the orientation of the solar array and is applied to rotate the array from time step to time step in the computations.

The method has been implemented for the European environmental satellite ENVISAT. The satellite geometry has been modelled and the link signal has been predicted for different passages of the Kiruna ground station. The results are compared to measurements of actual link signals.

Geometry

ENVISAT is a 10 m long satellite with several payload instruments of which the 10 m wide panel of the Advanced Synthetic Aperture Radar (ASAR) is a major scattering element. To this adds the solar array which reaches out to 16 m from the satellite body, Figure 1.

Figure 1. Electromagnetic model of the ENVISAT satellite with the solar array shown at 0° and 90° rotation.
S-band antennas

We will in the present paper consider the disturbances in the radiation of the 2.2 GHz TTC antennas. The satellite is equipped with two such antennas, S1 on the earth or nadir side of the spacecraft and S2 on the zenith side, Figure 1. S1 is LHC polarised and S2 is RHC polarised. The antennas are fed with equal power.

The free-space co-polar pattern of antenna S1 is given in Figure 2a. This and the following patterns are given in standard spherical $(\theta, \phi)$-coordinates in the satellite coordinate system which means that the earth is in the lower part of the diagram, namely for $117^\circ \leq \theta \leq 180^\circ$. This LHC pattern is – when not shadowed by the satellite – disturbed by the LHC pattern of S2 (its cross-polar pattern), Figure 2b.

Antenna S1 and S2 are very much alike apart from their opposite polarisation and opposite orientation upon the satellite. This means that the RHC pattern of S1 and S2 are like the patterns in Figure 2b and 2a, respectively, but turned upside down.

Illumination analysis

When the antennas are mounted upon the satellite the geometry shadows as shown in Figure 3a and 3b for antenna S1 and S2, respectively. The shadowed parts of the patterns appear as reflections as shown in Figure 4a and 4b (RHC field reflected as LHC), the body of the satellite giving the largest contribution. The solar array is rotated to $\gamma = 61^\circ$. Diffractions are so far not included.
The total field with all contributions added, direct, reflected and diffracted fields from both antennas, is shown in Figure 5.

![Figure 5. Total field in LHC. Shown is also (for a sample orbit) the path of Kiruna as seen from the satellite.](image)

**Orbit calculation**

When the satellite passes an earth station then the direction to this station will describe a path over the satellites \((\theta, \phi)\)-sphere. An example on such a path for Kiruna is shown in Figure 5. Kiruna is first seen at \((\theta, \phi) = (117^\circ, 285^\circ)\), passes \(\phi = 360^\circ/0^\circ\) and disappears at \((\theta, \phi) = (117^\circ, 75^\circ)\). It is seen that the path crosses regions with reflections from S1 in the satellite body as well as from S2 in the solar array, Figure 4. It is also seen from Figure 3 that the direct field from S1 is not blocked while a direct signal from S2 only will occur during the late part of the passage (\(30^\circ \leq \phi \leq 75^\circ\)).

The path is given as a set of directions to Kiruna (one for each satellite position) at fixed time intervals. For each time the orientation of the solar panel is also given and the scattering may be computed for the geometry at this time as illustrated in the following figures.

In Figure 6 we have depicted the GO contributions, namely the direct field from antenna S1 and the field from S1 reflected in the satellite body. These occur for the full passage. Further, we have the direct field from antenna S2 and the field from S2 reflected in the inner panels of the solar array (numbered from 1 and onward). These contributions occur only for the last part of the passage.

![Figure 6. GO field contributions in LHC, direct fields (S1 and S2) and reflections from the objects stated. Dashed curves are S2 contributions.](image)

It is seen that the reflections from antenna S2 in the panels of the solar array are at levels comparable to the desired main field (the direct field from the earth oriented antenna, S1) and severe interference must be expected. The direct field from S2, as well as the field from S1 reflected in the satellite body, are 15-20 dB below the direct field of S1 and will only cause minor ripples in the main field from S1.

![Figure 7. Diffractions are added to the GO fields giving the scattering, object by object (LHC).](image)

The GO contributions give an idea about the most significant field contributions. Correct contributions require the diffractions to be added, Figure 7, but the general level of the field contributions are not changed.

Finally, the total field - given by adding all field contributions - is presented in Figure 8 showing the severe disturbances during the last part of the passage.
Illustration of the rays

GO and GTD is a ray based technique and it is possible to visualize the individual ray paths contributing to the field. An example is given in Figure 10 at the time t=1940 sec at which reflections in panel 1 and 6 of the solar array occur, cf. Figure 6.

Conclusions

The direct and scattered fields of two S-band antennas on a satellite have been determined by conventional diffraction theory. The link signal for a given passage of an earth station has been modelled as function of time taking into account the rotation of the solar array. The result is in agreement with measured data.

A thorough understanding of the coverage of the individual ray contributions has been obtained by an intensive application of graphical tools.

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