SPT100 PLASMA JET EFFECTS ON GEOSTATIONARY SATELLITE COMMUNICATIONS

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Abstract

Alcatel Space Industries has to ensure the compatibility between plasmic thruster and communication antennas. SPT100 plasma is a dielectric environment which relative permittivity is directly connected to plasma density and communication frequency. The wave transmission may be affected by plasma in term of gain loss and phase shift.

Two software have been used to perform the calculations of interference. ISP (Interaction Spacecraft for Propulsion). This software enables the calculation of plasma density. It has been developed in collaboration between ALCATEL SPACE Industries and MAI (Moscow Aviation Institute, Russia). PlasEM software allows the calculation of planar wave interaction when crossing a slice of plasma (monodimensional calculation). It has been developed by ALCATEL SPACE Industries. The interaction modeling has been validated through test results using simple configurations between plasma jet and wave source.

ISP Software overview

ISP has been developed in collaboration between Alcatel Space Industries and Moscow Aviation Institute[1] to quantify the interactions between a plasma jet and spacecraft surfaces. It is capable to predict various interactions such as disturbance torques and forces, surface heating, erosion and re-deposition of sputtered materials.

An accurate discretization of velocity distribution function is used to represent plasmic plume for both Xe^+ and Xe^{++}. This model has been correlated with measurements performed 500 mm far from thruster exit[1] for particle densities, current densities and energies of ions. Next, the jet parameters are assumed to vary with opposite square distance from thruster exit. Plasmic plume current density evolution versus divergence angle has shown a good agreement with other published test campaigns[2,3,4,5]. More over, experiments[6] carried out at Michigan university have shown a good correlation between predicted and measured surface heating.

For the validation of interaction modeling, Alcatel Space Industries has proceeded to two main test campaigns. The first one took place in Russia to assess sputtering rates on specific spatial materials[7]. The second one happened in France in P.I.V.O.I.N.E. test facility[8] and enables the validation of predicted disturbance forces[9].

PlasEM Software overview

PlasEM has been developed by ALCATEL SPACE Industries to enable the calculation of electric field gain and phase while a Radio-Frequency planar wave is crossing a slice of a dielectric environment where the permittivity ε is variable. The software user may enter as many permittivity values as necessary. The only constraint is to respect the proportion between wave length and variations in permittivity. The Maxwell equations are solved exactly. No limitation in signal frequency exists. All incidence angles for planar wave are allowable.
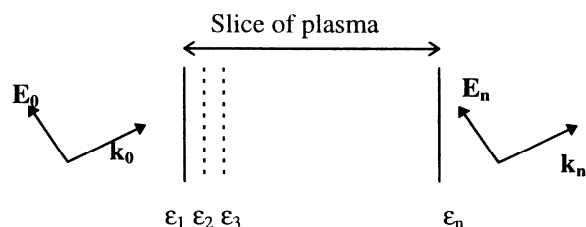

Figure 1 : RF signal crossing a slice of plasma

Interaction modeling validation

Plasmic plume modeling

ISP software enables the prediction of plasma electronic density n_e anywhere in the plume. The plume is considered axisymmetrical. Electronic density has been mapped in the equatorial plane of the thruster. A compromise accuracy/size of database has been found by making the choice to have a point of calculation every 10 cm in each direction, and to interpolate by cubic splines between the reference points.

The plasma relative permittivity worths :

$$\varepsilon_r = 1 - 81\frac{n_e}{f^2}$$

where   f is the incident wave frequency

Then, it is convenient to draw iso-lines of permittivity in the SPT100 equatorial plane(Figure 2)

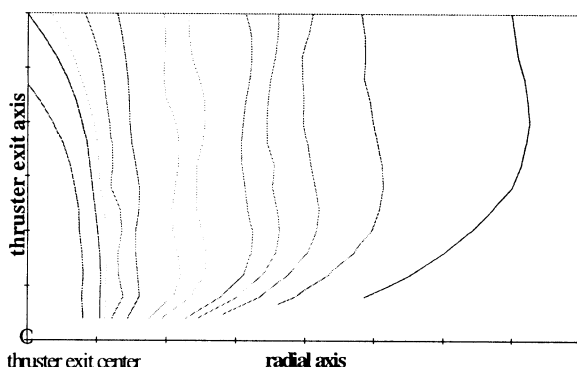lines of iso-permittivity in the SPT100 equatorial half-plane - frequency=10 GHz

Figure 2 : lines of iso-permittivity (f=10 GHz) in the SPT100 plume (equatorial half-plane)

Test cases

The selected test cases for validation of plasmic plume density model have been extracted from publications[10,11,12,13,14].Three test cases configurations are presented in Figures 3, 4 and 5. All tests have been performed with 6.2 GHz signal frequency. As the square of signal frequency is high compared to the plume density, no signal attenuation is obtained (the plasma relative permittivity is close to the vacuum permittivity).

Table 1 compares the experimental results with PlasEM/ISP predicitions.
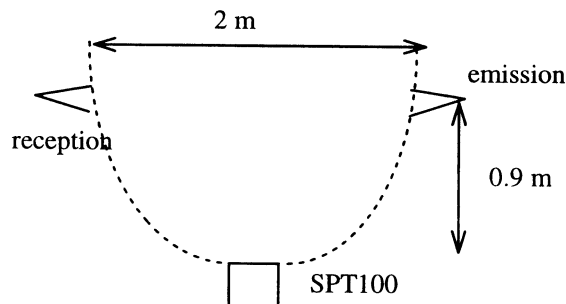

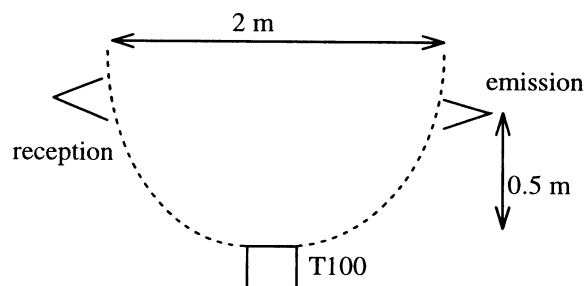Figure 3 : radio-frequency wave crossing SPT100 plume (f= 6.2 GHz) - Case 1

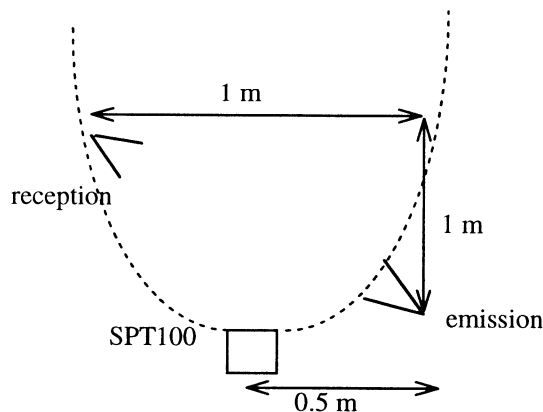Figure 4 : radio-frequency wave crossing T100 plume (f= 6.2 GHz) - Case 2

Figure 5 : radio-frequency wave crossing SPT100 plume (f= 6.2 GHz) - Case 3

phase shift (°)	Case 1	Case 2	Case 3
PlasEM/ISP	25	44	62
tests	27	45	52

Table 1 : comparison between predicted phase shifts and measured shifts

The difference between prediction and calculation in case 3 is explained by the fact that the horn cannot collect the whole signal (the expected shift is higher than the measured one).

Interaction between SPT100 plasma jet and geostationary communication antenna

Omni-directional Ku-band communication antennas are mounted on geostationary telecommunication satellites to ensure the station acquisition. In the Ku-band range, no signal attenuation is expected. The emission cone of some antennas may cross the SPT100 plasmic jet leading to signal phase shift. Nevertheless, the interaction is located enough far from emission horn to assess a planar wave interaction. As the central part of the plume is the most dense, it is easy to identify the area of maximal signal disturbance. With the help of 3D vizualiser, you can identify and plot the worse trajectory for interaction between the plasmic jet and the emission cone.
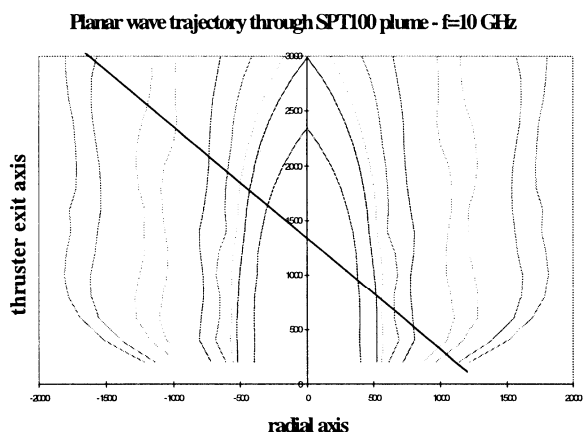

Figure 6 : communication antenna planar wave crossing SPT100 jet (f=10 GHz)

Once the trajectory of planar wave is identified, you can estimate the variation of permittivity in the field of interaction (Figure 7).
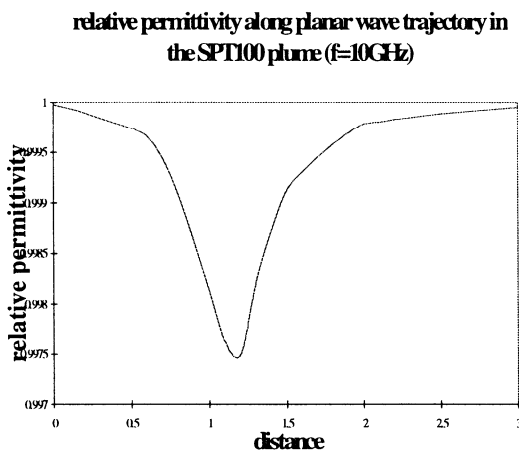

Figure 7 : relative permittivity variation along planar wave trajectory in the SPT100 plume (f=10 GHz)

The maximum phase shift is close to 10°. This value is acceptable by earth receivers : no signal decay is expected.

Future investigations

The current organisation of payload antennas on Alcatel Space Industries geostationary spacecraft do not lead to significant interference with the plasmic plume. Indeed, the closest antenna wave field cross the very enlarged plasmic plume in a zone where the permittivity should be so close to the vacuum permittivity that the interference should be too weak to have any impact. Nevertheless, an interference calculation has been conducted on a fictitious case with the help of EM2R software to ensure future satellite safe designs. EM2R has been developed and validated by Alcatel Space Industries. It enables the exact solving of Maxwell equations through an integral method for any kind of signal crossing an axisymmetrical environment with any incidence angle. Many validations[15,16] have been performed (SRSR in metallic case for antennas, measurements on a candle antenna and self validations) and EM2R is today a reference in terms of accuracy and size of its application domain.

Conclusion

Whatever organisation of telecommunication antennas on future Alcatel Space Industries satellites, the possible interference between plasmic plume and Radio-Frequency signal will be calculated for any frequency and any incidence angle to ensure the maximum safety to the selected design.

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