# Simulation of the interaction between microwave antennas and the plume of a Hall thruster integrated on small spacecraft

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CubeSats have a number of advantages. First, they are easier and cheaper to manufacture than conventional satellites. Lighter and smaller, they allow a simplified deployment but at the expense of the miniaturization of their sub-systems, including their propulsion system. Electrical micropropulsion systems have recently gained a lot of attention due to their ability to produce a high velocity increment with a higher specific impulse [1]. Among them, Hall thrusters (HET) are one of the main candidates for miniaturization in CubeSats. However, they may lead to new integration constraints, particularly in terms of electromagnetic compatibility (EMC) [2].

Within the CubeSat, the Hall thruster must coexist with several antennas that use a part of the radio frequency (RF) and microwave spectrum for Telemetry Tracking and Control (TT&C), or positioning applications. However, the plasma plume exhausted from the thruster is a complex electromagnetic medium that can disrupt these wireless RF and microwave systems. Studies have already been carried out on large satellites, and slight disturbances due to the presence of the plume were observed, namely a distortion of the antenna gain pattern, a degradation of the polarization of the propagating EM waves, but also an increase of the noise floor [3,4]. It was concluded that it was best to move the thruster as far as possible from the antennas.

For a CubeSat, which is obviously smaller, the distance between these sub-systems is greatly reduced. In this context, we propose a multiphysics method to study the possible interactions between the plume of a low power Hall thruster and microwave antennas.

The numerical analysis of the integrated antennas is here performed with Ansys HFSS, i.e. a finite element analysis of time-harmonic Maxwell's equations. The Hall thruster plume is thus represented as a dispersive medium with a complex equivalent local relative permittivity $\varepsilon_p(r)$ given by the Drude model:

$$\varepsilon_p(r) = 1 - \frac{\omega_{p,e}^2(r)}{\omega(\omega - j\nu_{e-n})} \quad (1)$$

with ω the angular frequency of the wave interacting with the plasma, $\nu_{e-n}$ the electron-neutral collision frequency, $\omega_{p,e}(r) = \sqrt{n_e(r)e^2/m_e\varepsilon_0}$ the local electron plasma pulsation where $n_e(r)$ is the local electron density, $e$ the elementary charge, $m_e$ the electron mass, and $\varepsilon_0$ the vacuum permittivity. In the non-collisional approximation ($\nu_{e-n} \ll \omega$) which is the case for a plume at RF and microwave frequencies, the permittivity of the plasma is only a function of the local electron density $n_e(r)$ and of the angular frequency of the signal $\omega$. In order to implement the plume in Ansys HFSS, it is then necessary to know the local electronic density at any point of the plasma.

In this context the JET2D simulation code was used [5]. JET2D is based on a plasma jet model of a Hall thruster. It is a hybrid model where the ions are processed in a particular way by the Montecarlo particle in cell (PIC) model and the electrons are processed in a fluid way by the local electron density linked to the local potential by Boltzmann's law. The electric field is recalculated at each time step by assuming quasi neutrality. The potential is then deduced from Boltzman's law where the electron density is assumed to be equal to the ionic density. JET2D was originally developed and experimentally validated for standard SPT100 type Hall thrusters used on satellites larger than those of our interest. Thanks to the JET2D input parameters like gas flow rate, specific impulse, discharge current, ion current to total current ratio, and ejection angle we can still approach the conditions of a representative plume of a micropropulsion Hall thruster. Therefore, the input parameters of JET2D have been optimized so that the simulated current density is the closest to the measured current density of 100 W class Hall thruster [6].

Figure 1-a shows the design of a UHF dipole antenna mounted on the middle of the side face of a simplified 6U CubeSat. The Hall thruster plume consists of the assembly of 1097 toroids with square cross-section of size $\Delta x \ll \lambda_{UHF}$ of relative permittivity $\varepsilon_p(r)$ calculated with (1) considering a frequency of 436 MHz and the distribution $n_e(r)$ obtained from JET2D. The relative permittivity is here between -28 and 0.95. Beyond, the medium is considered to be vacuum (i.e., $\varepsilon_p = 1$). The OFF condition of the thruster corresponds to the same design but without the plume.

Figure 1-b shows the simulated antenna gain patterns as a function of the angle θ in the planes φ=0°, 90° for the ON and OFF conditions. In these two planes, a decrease in gain up to 1 dB is observed for θ closed to 180°, namely towards the position of the plume. Since there is no loss in the plasma due to the non-collisional assumption, the energy is not absorbed by the plasma. The decrease in gain is due to a change in the antenna directivity pattern since the plume, because of its permittivity gradient, behaves as a refracting medium that can modify the antenna far-field radiation characteristics.

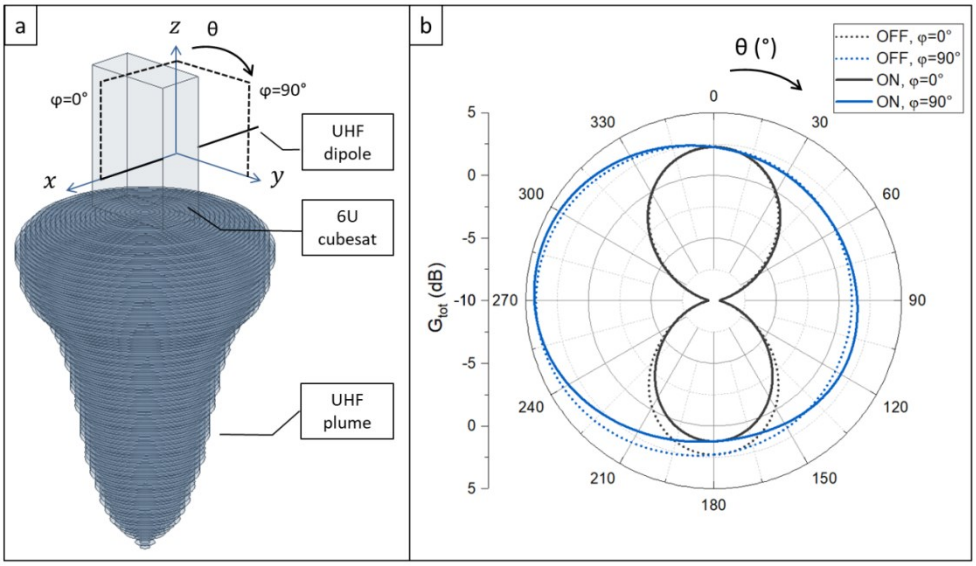


Fig. 1: a- HFSS CAD of a UHF dipole (436 MHz) on a 6U CubeSat with the HET ON
b- Associated 2D gain patterns (θ, φ=0°, 90°), ON vs OFF

Subsequently, circularly polarized planar L and S band antennas will be simulated in order to investigate the influence of the presence of the plume on their radiation properties. Besides, several relative positions antennas / thruster will be tested.

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