Instrumental modelling of Mutual Impedance experiments and validation tests in plasma chamber

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Mutual impedance experiments are in situ plasma diagnostic techniques used for measuring the density and electron temperature of space plasmas. Different versions of mutual impedance experiments were included in past (e.g. RPC-MIP instrument onboard the ESA Rosetta spacecraft), present (e.g. PWI/AM2P instrument onboard the JAXA Mio spacecraft for the joint ESA-JAXA BepiColombo mission), and future (e.g. RPWI/MIME instrument onboard the ESA JUICE spacecraft and DFP/COMPLIMENT instrument onboard the ESA Comet Interceptor spacecraft) space exploration missions. New versions are currently being designed to fit nanosatellite platforms that will facilitate future multi-satellite missions.

In preparation for the future space application of mutual impedance experiments, we extend our understanding of mutual impedance experiments and focus on the impact of three different contributions to the plasma density and electron temperature diagnostic performance of the experiment. These are: (i) non-linear plasma interactions, (ii) small-scale plasma inhomogeneities (e.g. the plasma sheath), and (iii) the mutual impedance emission duration

This investigation is performed both numerically, using a fully kinetic Vlasov-Poisson model to simulate mutual impedance measurements, and experimentally, using a plasma chamber to perform mutual impedance tests in typical Earth and planetary ionospheric conditions.

The results of the investigation are the following. (i) The maximum mutual impedance emission amplitude that ensures strong signal-to-noise ratios while maintaining negligible non-linear perturbations on the mutual impedance diagnostic performance corresponds to electric-to-thermal energy ratios in the plasma of 0.1. (ii) Small-scale inhomogeneities – if ignored – do not perturb the plasma density diagnostic but significantly impact the electron temperature diagnostic. Therefore, the plasma sheath needs to be accounted for when computing the electron temperature from mutual impedance measurements. (iii) We defined new MI experimental procedures that perform measurements up to 20 times faster than nominal procedures, while maintaining the same diagnostic performance.