# A numerical and experimental study of the curling probe and its application to ECR and ICP plasma sources for electron density measurements

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The diagnosis of plasma parameters, such as the electron density and temperature, is a key issue in understanding and controlling electric propulsion systems. To date, electron density is mostly measured with electrostatic probes, such as Langmuir probes, which could be quite invasive, or with spectroscopy methods, such like Thomson scattering, though needing complex optical benches and long acquisition times when applied to low dense plasma ($<10^{10}$ cm$^{-3}$). In 1976, Stenzel [1] proposed a microwave resonant probe, known as *hairpin*, a U-shaped antenna which is to be immersed in plasma and whose spatial resolution is constraint by its antenna length. In 2011, Liang et al. [2] proposed a new type of microwave resonant probe, the *curling probe*, a spiral slot-type antenna, which has several advantages: compactness, embeddable in a reactor/thruster wall and capacity to perform electron density measurements through a dielectric wall. Later works [3, 4, 5] show the interests and capabilities of such diagnostic tool.

We present here a numerical and experimental study on the curling probe and its application to the electron density measurement in an electrodeless plasma thruster (Electron Cyclotron Resonance) and in an inductive coupled plasma (ICP) source. The measurable electron density range, the probe accuracy and the sensitivity to sheath effect are found to be limited by the probe natural frequency and by the spiral resonator geometry. A procedure based on solid dielectric etalons is proposed for the absolute calibration of the probe. Electron density is measured by immersion of the probe in the plasma jet and through the dielectric wall of both the ECR and ICP sources. Both immersed-in-plasma and wall-embedded measurements are found in agreement with Langmuir and hairpin probe results. The density reduction due to sheath formation is accounted with a correction method that is under validation and could also be employed to estimate parallel and perpendicular electron temperature. Finally, the curling probe is used to 2D-map the magnetic nozzle of the ECR thruster for several operating conditions, helping to achieve a better phenomenological understanding of this novel technology.

## References

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