Interferometric Plasma Density Measurement in GOLEM Tokamak

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Introduction

Electron density measurement is one of the standard diagnostics in the field of plasma physics.
The goal of this project was to adapt the old CASTOR implementation of the standard line-averaged electron density measurement via microwave interferometry to the new environment of the GOLEM Tokamak. This consisted of several steps

- Building the waveguide system
- Calibrating the diagnostic hardware
- Developing a set of analytical and control scripts

Frequency Modulation

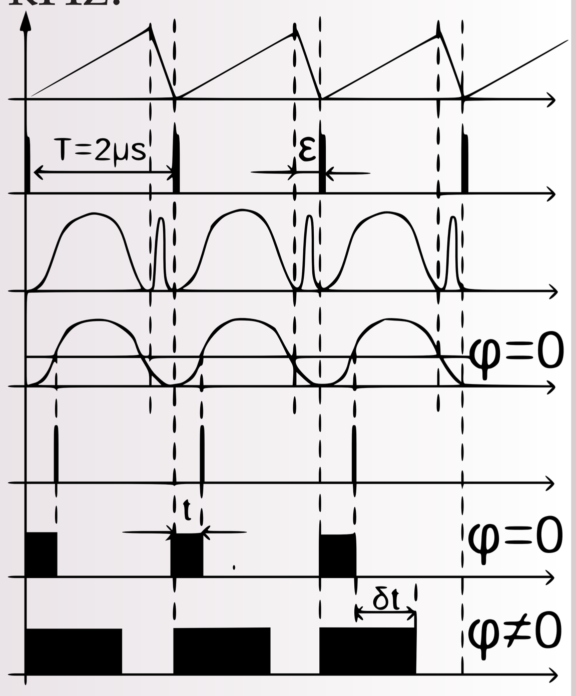
The frequency of the MW generated by the Gunn diode is periodically and progressively increased by Δf via a saw-tooth voltage generator.
As the path covered by the probing wave is longer by ΔL, the two interfering waves have a different frequency which produces beats. The absolute value of beats' amplitude oscillates with the frequency $f_{mod} = 500$ kHz of the saw-tooth signal, provided that

$$\Delta f = \frac{c}{\Delta L} \qquad (2)$$

This signal is then selectively amplified for frequencies $f_{mod} \pm 20$ kHz

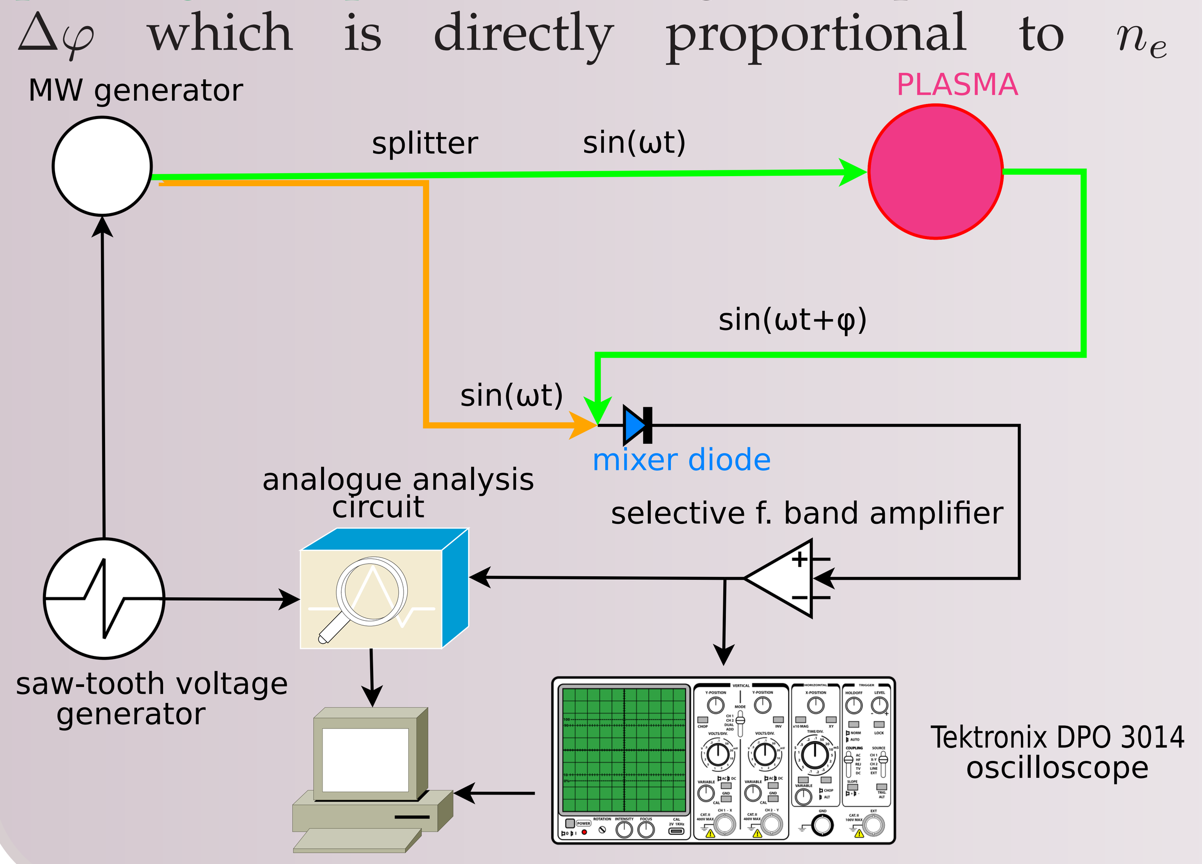
Analogue Analysis Circuit

A set of logical gates compares the 500 kHz synchronised trigger signal with the next root of the sine signal and deduces the current phase shift and then processed with (1). This happens for every eighth trigger signal, so the time resolution is only 62,5 kHz.



Microwave Interferometry

The refractive index of plasma n is dependent on the electron density n_e. Therefore, a microwave beam with $f \sim 75$ GHz probing the plasma undergoes a phase shift $\Delta\varphi$ which is directly proportional to n_e



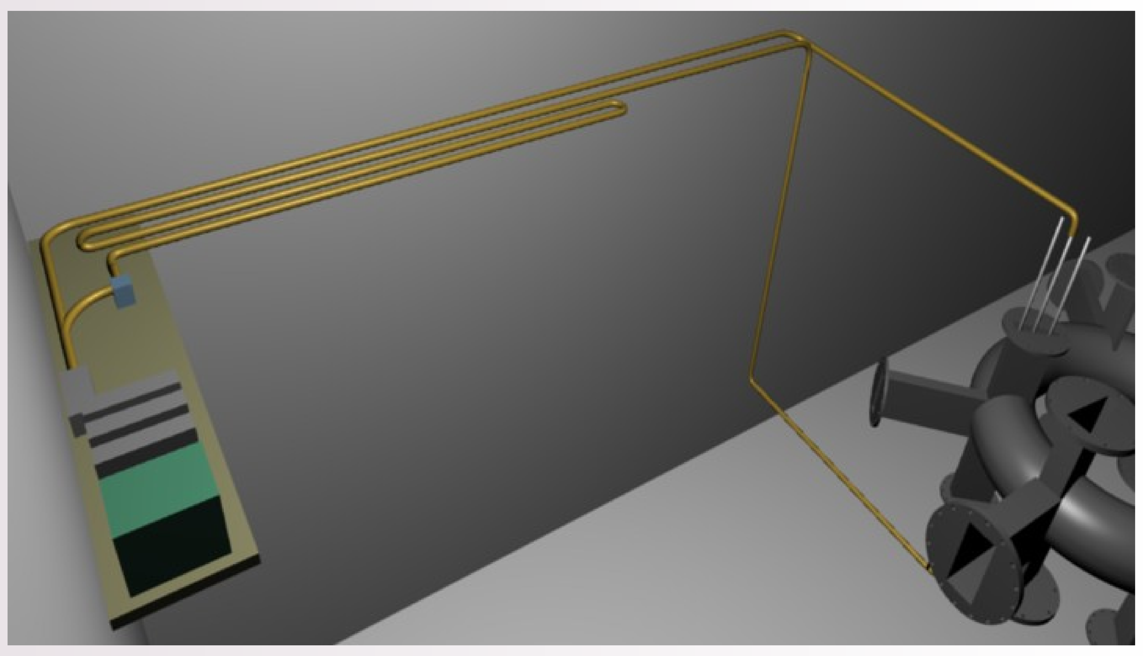
$\Delta\varphi$ is extracted from the interference of the reference beam and the probing beam from which the reference beam was split off, thus the ref. beam has the same phase as the probing beam had before entering the plasma.

$$\overline{n_e} = \frac{n_{crit}\lambda_0}{d\pi}\Delta\varphi \qquad (1)$$

- $\overline{n_e}$ is the electron density line-averaged over the distance d that the MW with a wavelength in vacuum λ_0 travels through plasma
- n_{crit} is the critical density above which the MW cannot propagate through plasma $f \sim 75\,\text{GHz} \ldots n_{crit} \sim 6,9 \cdot 10^{19}\text{cm}^{-3}$

Waveguide System

The new waveguide system had to have approximately the same length as the one built for CASTOR, because all the analogue hardware had been designed specifically for it. At the same time it had to fit into the modest room where the Tokamak is located.
The total length is close to 10 m, which was achieved by constructing a "trombone-like" bend as seen in the Figure.



Oscilloscope Digitization

The amplified signal is digitized with a sampling frequency of 25 MHz and then processed on a computer. The data sample is then fitted to a function $f(t) = A \cdot \sin(2\pi \cdot 5e5t + \varphi)$ and φ is extracted and processed with (1).
Only ranges of points close to 0 are processed, because there the signal is assumed to be the least influenced by amplitude dampening.

Future Plans

- Overcome possible coupling with the chamber by using a new and well grounded saw-tooth voltage and trigger generator
- Further study of the influence of plasma stability once the Mirnov coils based plasma position stabilization system is operational

References

MATĚJŮ, Michael. *Měření hustoty plazmatu metodami mikrovlnné interferometre.* FJFI, 2008.

Acknowledgements

Ing. Vojtěch Svoboda . . . project supervisor

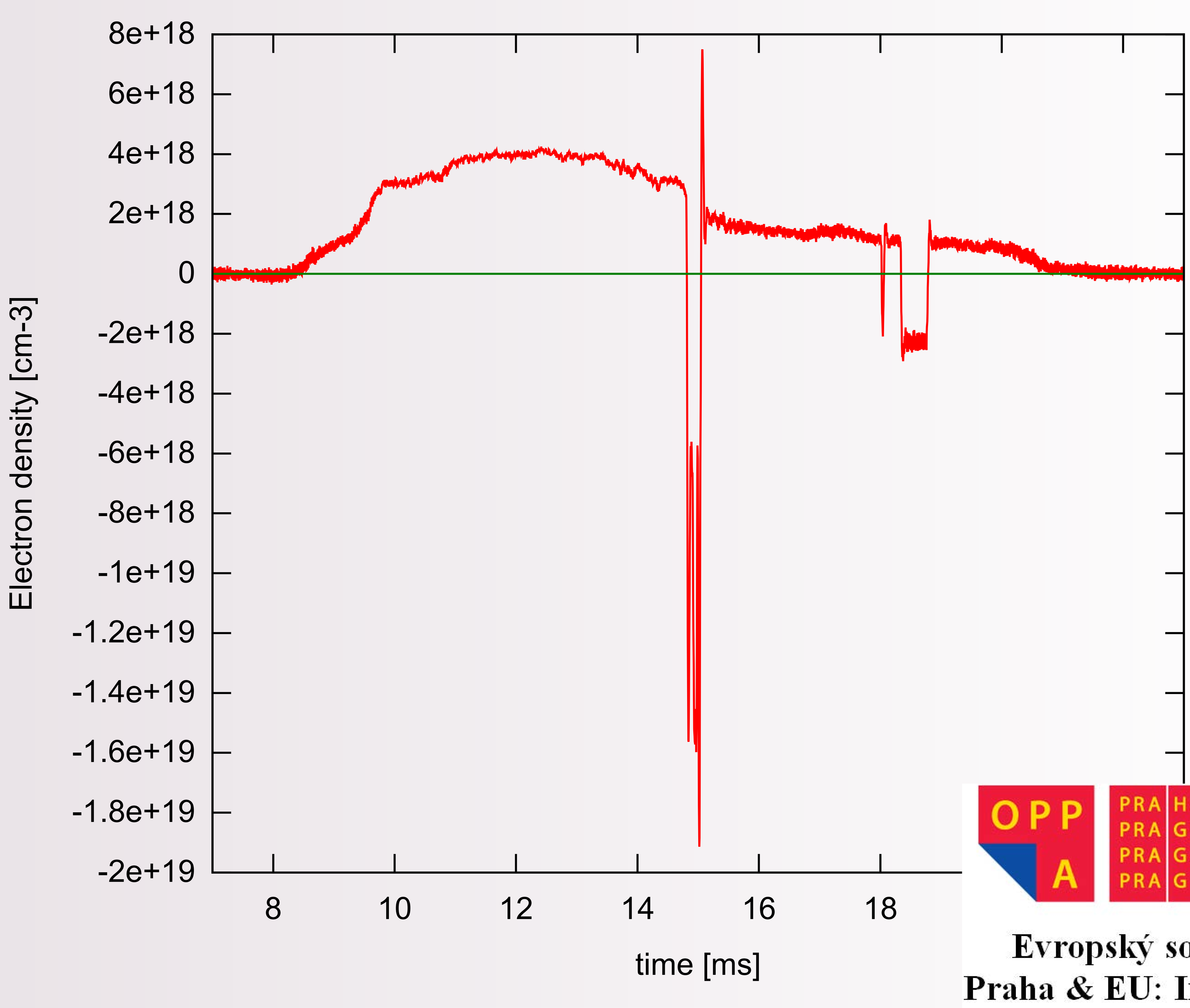
Signal Disturbances

During many discharges the frequency of the amplified signal suddenly increases and then returns back to normal. Both methods of analysis interpret this as sudden jumps in density, sometimes even to negative values.
These higher frequency signals also are not fully amplified and thus may not be correctly analysed.
A possible explanation is that there is a coupling of the chamber and the diagnostic hardware through the waveguide system which results in a change of f_{mod} and/or Δf.

- a change in f_{mod} means the frequency of the amplified signal also changes. At the same the frequency of the trigger signal would change
- a change in Δf would disrupt (2), hence only the frequency of the amplified signal would change

A clear connection to the behaviour of plasma has been observed

- Increasing the stability of the discharge by increasing the temperature of the chamber has proven to reduce the number of disturbances
- These disturbances occur usually after the initial exponential rise in density at the beginning of the discharge



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