Design of an AC Transformer in the MHz Range

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INTRODUCTION: Atmospheric plasmas require high voltages of clearly more than 1 kV/mm for ignition. The available voltage of a commercial MHz-power supply is typically in the range of a few hundred volts only and requires therefore a MHz-transformer.

Transformer design in this frequency range is challenging because all electronic components, particularly parasitic capacities and inductances, influence the resonance frequency of the transformer and plasma setup.

COMPUTATIONAL METHODS: The COMSOL® AC/DC module and Electrical Circuit physics have been used to implement the coils and the electrical connections to the plasma reactor. The output of these simulations have been compared with LT-Spice simulations, performed to evaluate the impact of the electrical parameters. For the time dependent simulations, the time steps of 1/13 of a period have been used. An ordinary office PC has been used.

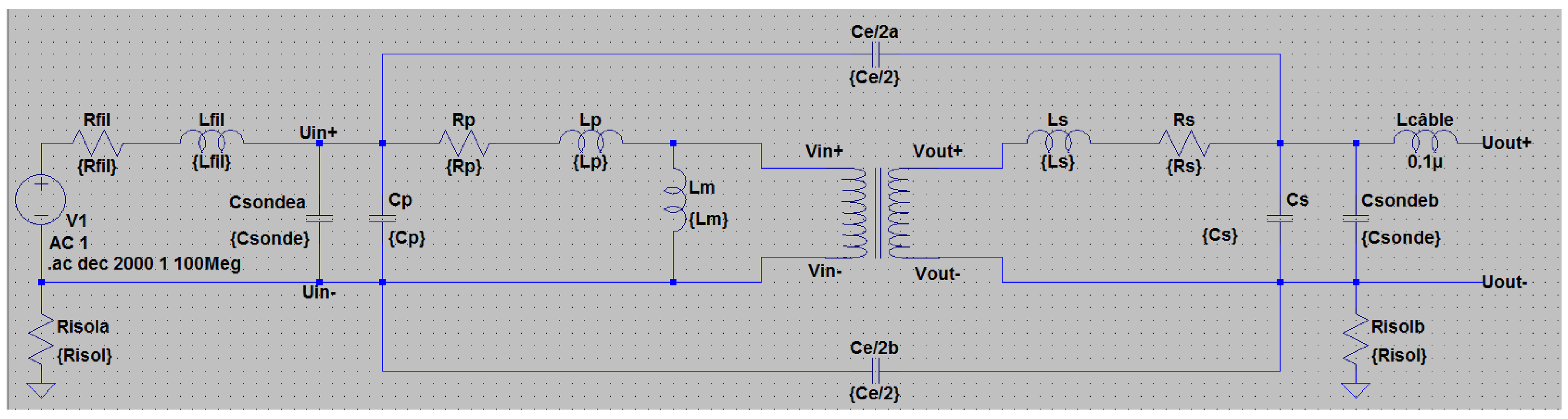

Figure 1. LT-Spice schematics of the transformer and the electrical connections. All parasitic capacitances and inductances have an influence on the resonance frequencies in the MHz-range.

EXPERIMENTAL SETUP: The transformer consists of a PVC core (I-shaped, Ø = 6 mm, L = 30 mm) with N_1 = 12 primary and N_2 = 44 secondary windings. The relative permeability μ_r was chosen to be 1 in order to maintain the resonance in the MHz range and to reduce losses in the core.

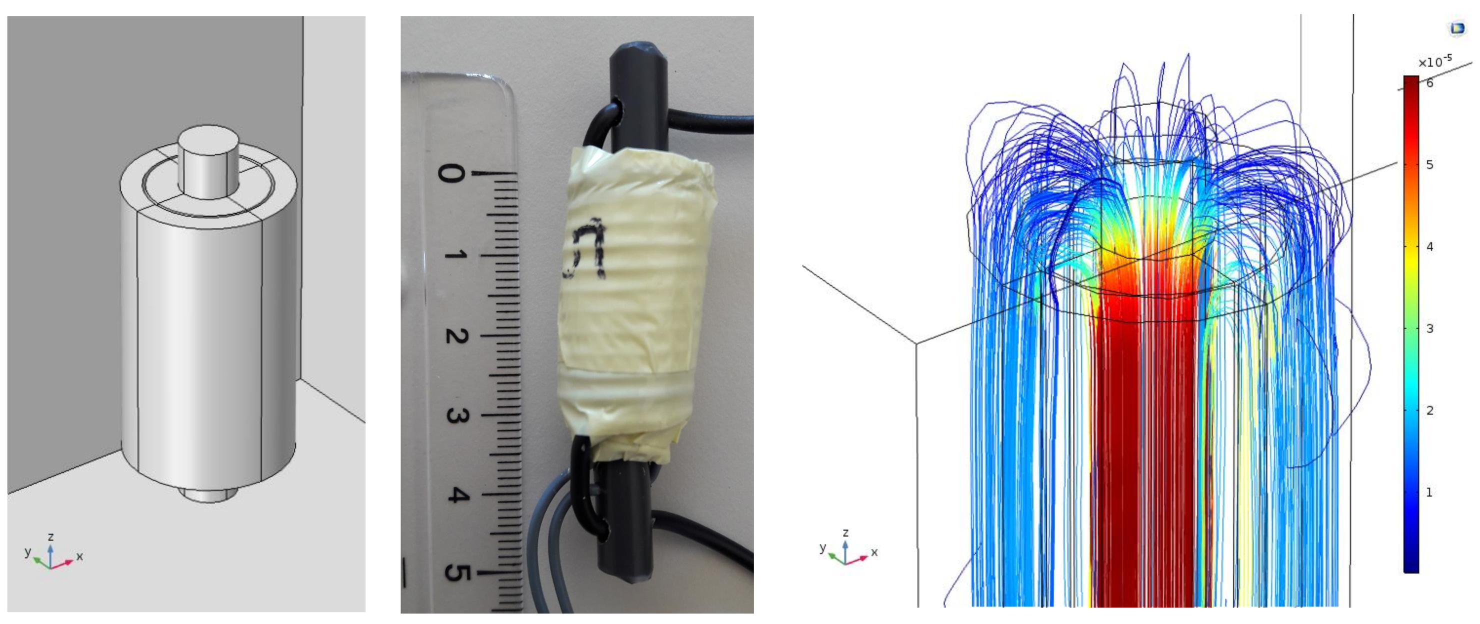

Figure 2. ***Left***: Geometry of the I-core transformer. The secondary winding is close to the core. ***Middle:*** Photo of the home-build experimental transformer. ***Right***: 3D-image of the magnetic flux density B.

RESULTS: The COMSOL® simulation exhibits a saturation of the B-field in the PVC-core at an extremely low value of $B_{sat} = 1.6 \cdot 10^{-4}\ T$ for $\mu_r \to 1000$ (figure 4). The frequency behavior is qualitatively reproduced using COMSOL® when compared to results from LT-Spice and experiment (figure 5). However, long time windows of 200 periods (required to reach stable voltage and current behavior, since at t = 0 capacitances are discharged and B = 0) at 10 MHz took about 2 hours computational time.

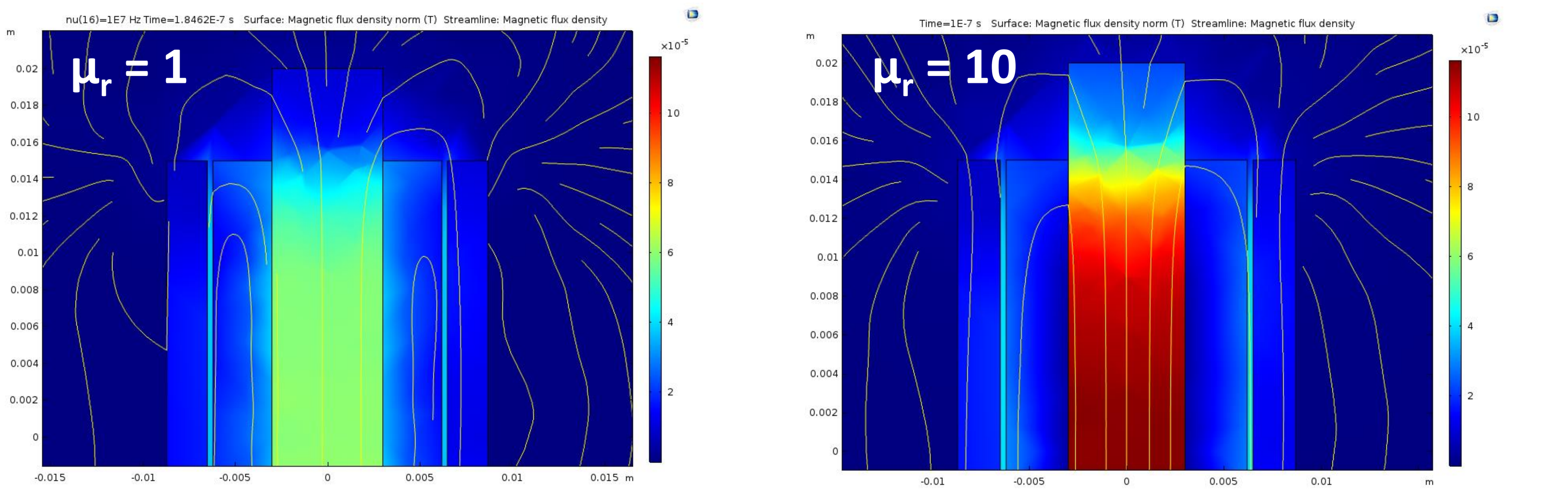

Figure 3. Magnetic flux density for different core relative permeability μ_r. The magnetic field lines concentrate in the core, increasing the B-field, and reducing the losses in the surroundings.

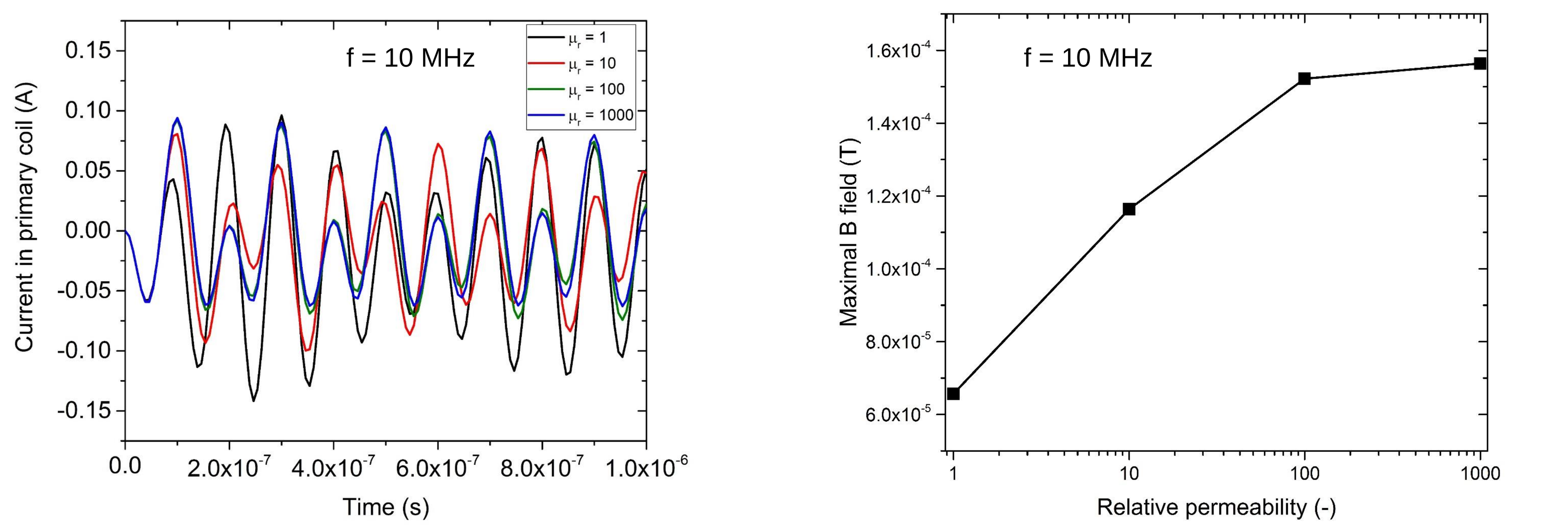

Figure 4. L***eft***: Current in the primary winding for different μ_r.
Right: Maximum of the B field in the core for different μ_r. Note, that the B-field saturates at extremely low values.

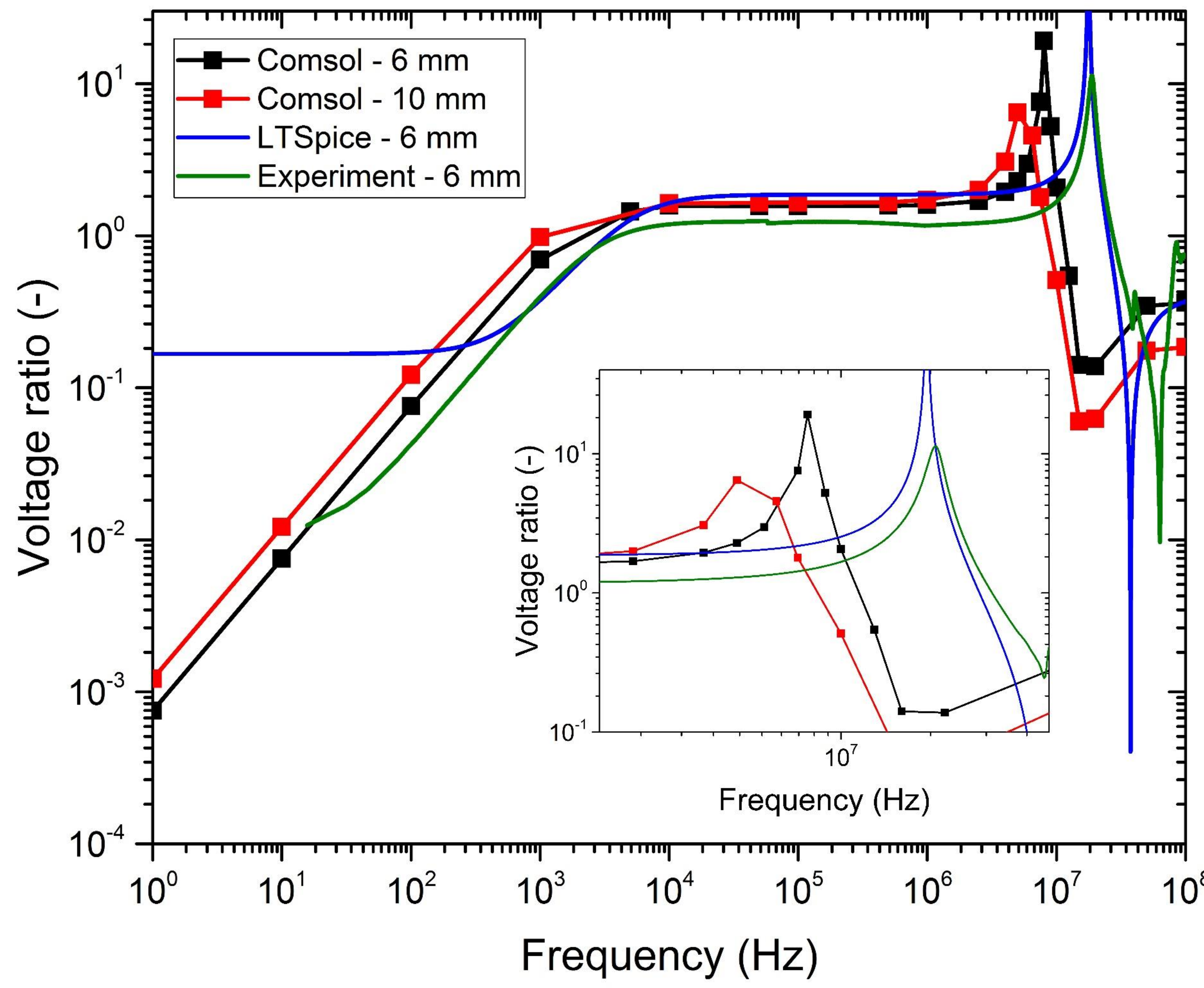

Figure 5. Frequency behavior of the transformer, comparison between simulations and experiment. The resonance frequency obtained from COMSOL® simulations is a factor of two lower than from experiment or LT-spice.

CONCLUSIONS: COMSOL® simulations were performed in order to find the origin of transformer losses and parasitic inductances or capacitances. The frequency behavior of the measured transformer could be qualitatively reproduced, however, large quantitatively deviations still remain.

The following issues of the simulations should be solved:

- How to perform long time series simulations in a short calculation time ?
- How to determine the B field loss, not caught by the secondary winding ?
- How to determine the windings capacitances and inductances to compare them to experiment ?
- Why does the B-field saturate already at 0.16 mT ?

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