Capacitive Proximity Sensing

Project-oriented Physics Lab for Undergraduate Students

Physics Lab
ETH zürich

Concept

Our goal is to explore the influence of the geometric properties of circular copper electrodes on their applicability as a capacitive proximity sensors by analyzing the relationship between their capacitance to the environment and their distance to a grounded metal plate. Employing four copper discs of distinct diameters and adjustable spacing to the plate controlled by spacer discs, we systematically measured the capacitance for varying distances and compare the experimental data to numerical simulations.

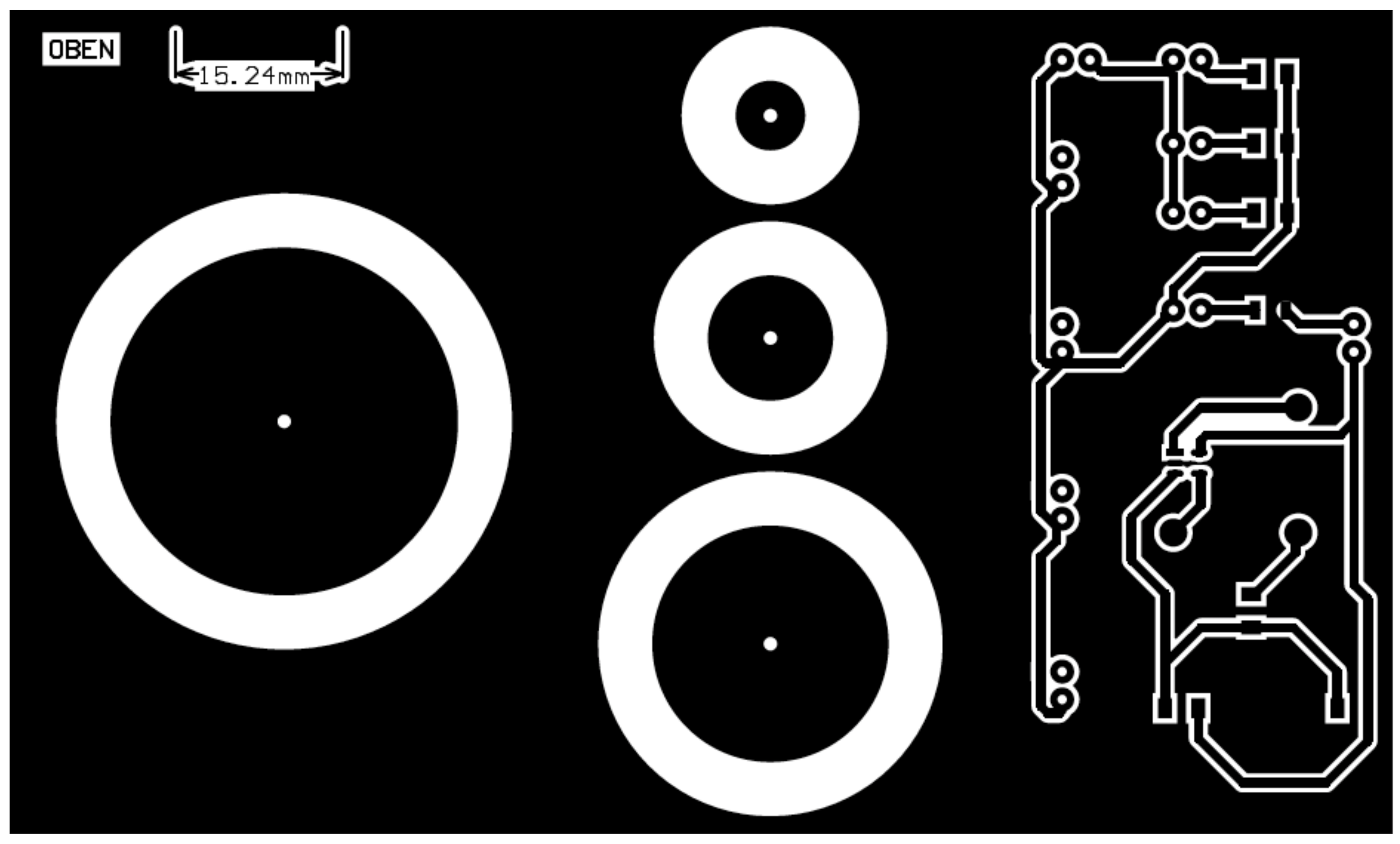


Figure 1: PCB with copper areas colored black. The copper discs have diameters: 0.5, 1, 2, 3, 5, 10 mm and a 1.27 mm center hole

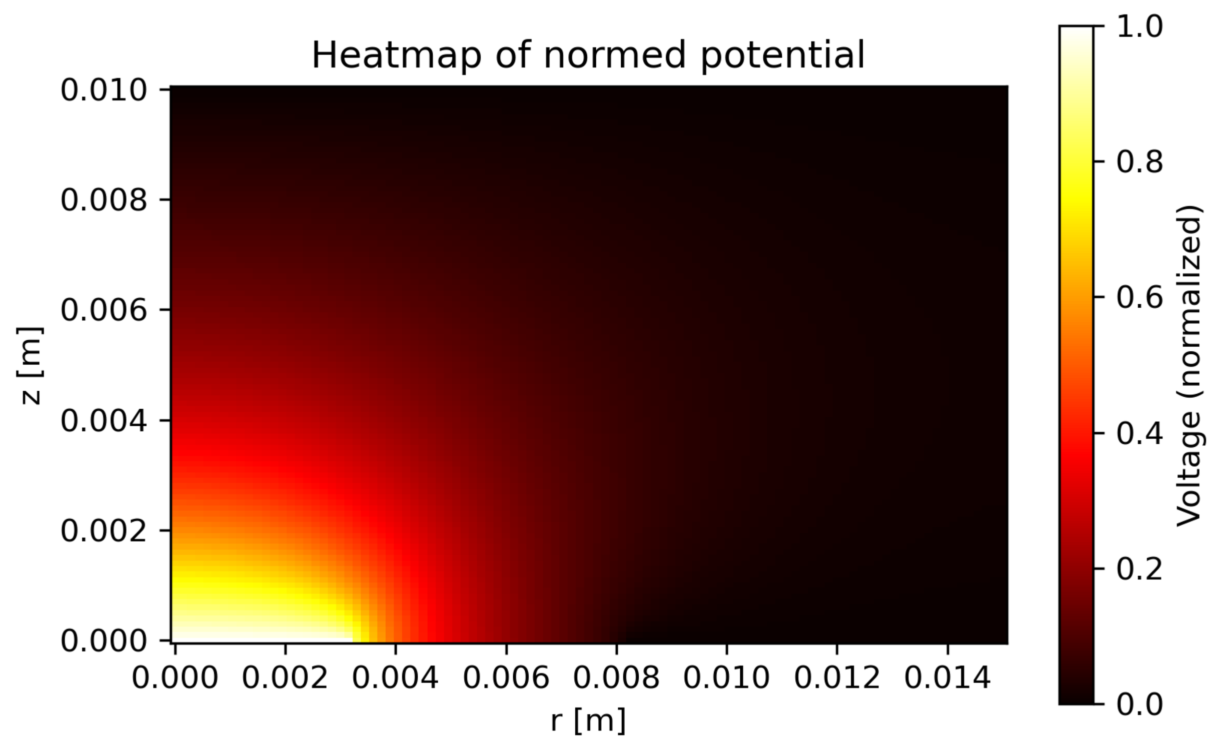


Figure 2: Heatmap of the voltage between the smallest sensor and the conducting plate. The voltage of the sensing plate is set to 1 and the voltage of the ground plate and conducting plate to 0.

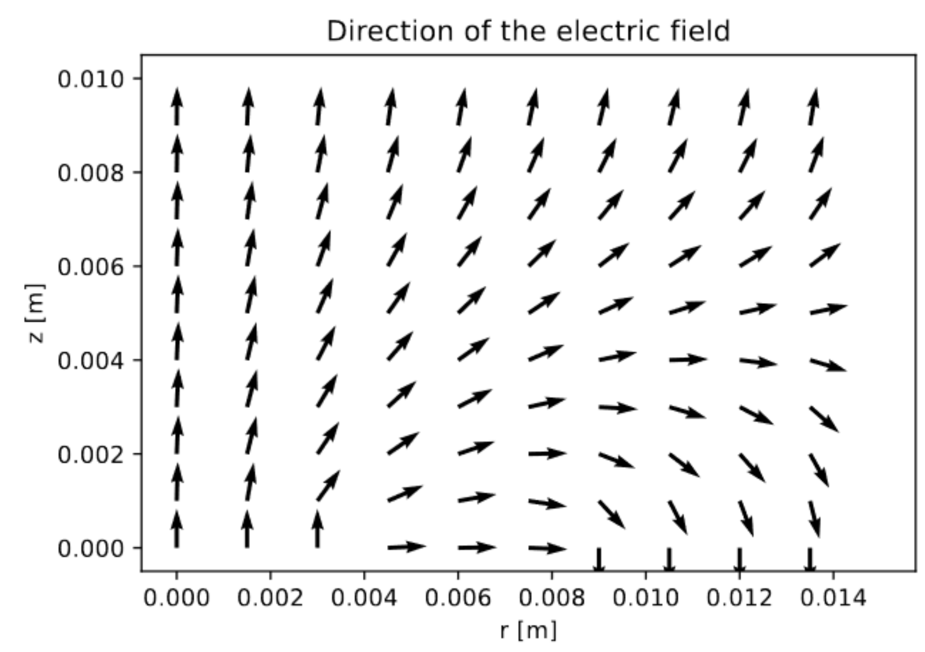
Setup

Our setup consists of a series of four copper discs of distinct diameters on a single PCB and a grounded metal plate. The spacing of the plate is adjusted using spacer discs. Using a relaxation oscillator circuit fed with a DC-source at 5V and a picoscope, we measure the capacitance of the discs to its environment. To minimize parasitic capacitances and inductances, we keep them constant over the measurements by fixing the position of both PBC and cables, which is ideal for measuring low capacitances.

Numerical Model

As a comparison to our measurements, we also developed a numerical model to compute the capacitance. Our numerical analysis of the capacitance consists of first solving the Dirichlet problem, then computing the electric field, which allows us to calculate the stored energy and finally, determining the capacitance. To minimize the computation symmetrical arguments through cylindrical coordinates were used.

Figure 3: Direction of the electric field between the sensor and the conducting plate.



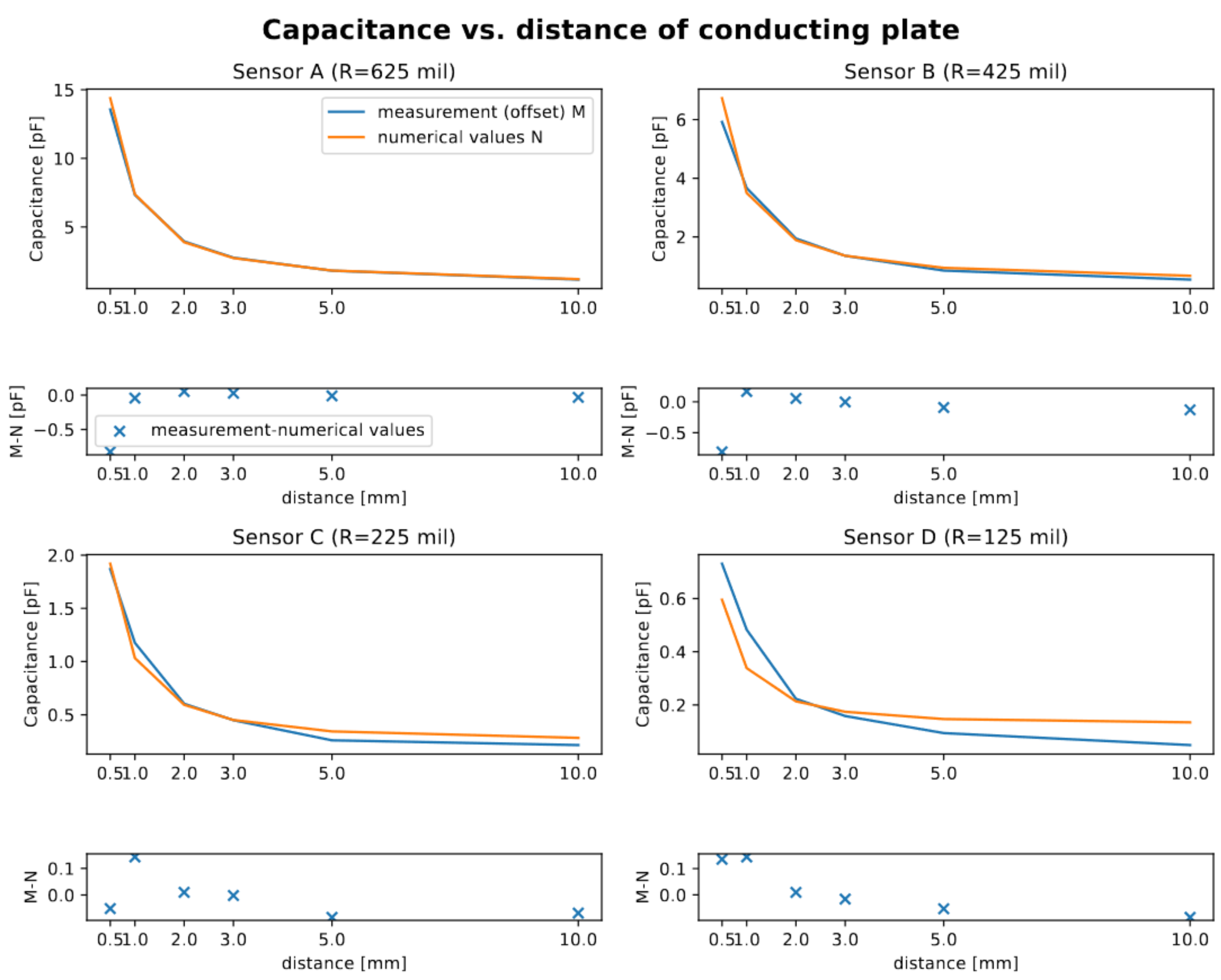


Figure 4: Plots of the measured and computed capacitance values with the ground plate at different distances for each sensor.

Results

The data shows minimal noise and a consistent parasitic capacitance in the circuit. The sensor's behavior aligns well with the numerical model. The residual difference between measured and numerical values, after accounting for the circuit's own capacitance, is due to the simulation only considering the electric field on the top side of the disk, while the constant offset from the bottom side field is ignored. A jump at 0.5 mm distance might be due to solder drops connecting wires through the sensing disks. Both experimental and numerical data indicate that a larger radius results in a greater change in capacitance when a conducting plate is present. The numerical model also shows that a greater distance between the sensing electrode and the ground plane increases sensitivity.

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