

# Multichannel electrical conductivity sensor for gas-liquid flow imaging

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## Summary:

Gas-liquid flows are ubiquitous in various industries, including oil and gas, chemical processing, and steel making. Accurate measurement of these flows is essential for optimizing process efficiency and ensuring safety. This work introduces a novel multichannel electrical conductivity sensor capable of directly imaging gas-liquid flows, eliminating the need for image reconstruction. The sensor offers a reliable, cost-effective, and robust solution for flow visualization. Validation against high-speed camera footage demonstrates excellent agreement.

**Keywords:** conductivity sensor, multichannel, flow imaging, two-phase flow

## Introduction

Gas-liquid flow is found in many industries, such as oil and gas production, chemical reactors, or steel production. The flow itself often determines the efficiency and/or safety of processes, making online flow monitoring crucial for control purposes. In both cases, whether for in-line use or pilot plant studies, flow monitoring requires increasingly sophisticated flow sensors, with flow imaging offering the most detailed visualization of flow phenomena.

Process tomography has been widely used, but there is no universal technology that can measure the variety of situations [1]. Different tomography technologies have been used in the past. Optical tomography uses light to illuminate the flow field and capture images. While it provides high spatial resolution, it is limited to transparent or translucent fluids. Ultrasound tomography uses sound waves to probe the flow. It can penetrate opaque fluids and is relatively robust to interference. However, its spatial resolution is poor. X-ray tomography provides high-resolution images of the internal structure of opaque objects. However, X-ray sources can be expensive and require shielding, limiting their suitability for real-time monitoring of rapidly changing flow phenomena. Another promising technique for flow visualization is electrical tomography. By applying electrical currents to electrodes placed around the flow and measuring the resulting voltage differences, it can provide information about the electrical conductivity distribution within the flow. However, due to the inherent ill-posed

nature of the inverse problem, image reconstruction can be quite complex.

In this paper, we present a multichannel conductivity sensor capable of generating images of gas-liquid flow, but without the need for image reconstruction. The idea is based on the work of [2], but the sensor is developed based on printed circuit technology (PCB), which is integrated into the sensor electronics, thus allowing a very simple integration into flow tubes via a flange system. In addition, the integration of the sensor into the sensor PCB allows for very good signal quality and therefore very fast measurements.

## Multichannel electrical conductivity sensor (MECS)

The sensor consists of an excitation ring and a measurement ring, with the latter segmented into 16 electrodes of uniform size distributed evenly around the circumference of the pipe (Fig. 1). To determine the resistance between the excitation ring and an electrode on the measurement ring, an auto-balancing bridge, in conjunction with square wave excitation and an analog-to-digital converter is employed. For details on the electronic circuits see [3].

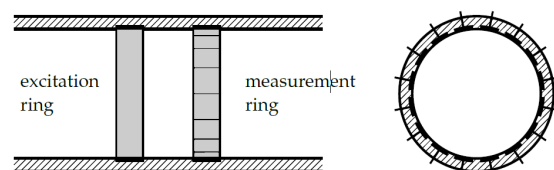


Fig. 1. Schematic illustration of the multichannel electrical conductivity sensor for flow visualization.

A technique known as side-plating, where the edges of the printed circuit board (PCB) are metallized, allows for the direct integration of electrodes into the PCBs. Figure 2 illustrates the installation of the sensor PCBs within a pipe using flanges. This installation mechanism considerably simplifies the production and assembly of the sensor by eliminating the need for manually attaching electrodes inside the pipe.

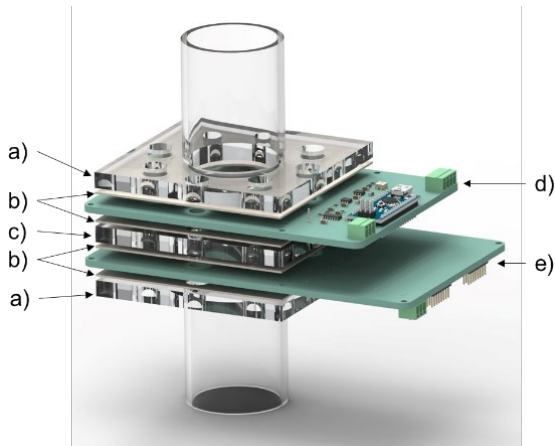


Fig. 2. Illustration of developed sensor attached to a pipe: a) Pipe with flange, b) Paper gasket, c) Spacer plate (8mm), d) Excitation PCB: generates symmetrical square wave signal, e) Measuring PCB: 16 measuring electrodes.

## Results

The sensor's performance was rigorously tested through a series of experiments, including testing the measurement principle using a non-conductive object, comparing measurements in distilled and tap water, and examining its ability to detect bubbles and localize them using synchronized camera footage as a reference.

Figure 3 presents a side-by-side comparison of a camera image and a MECS surface plot, with the normalized electrode signals conventionally plotted below. To visualize the MECS measurements, the signals of the electrodes, which are positioned around the pipe's circumference, are flattened and displayed as surface plots. The horizontal red line in the surface plot indicates the sensor's position, corresponding to a specific moment in the camera recording. The color scheme ranges from blue (0, indicating water) to red (1, indicating air). Due to the lack of bubble velocity information, which requires two sensors and signal cross-correlation, the visualization time is set to an arbitrarily chosen value of 2.4 s.

The results showed a clear correlation between the sensor readings and the observed flow regimes, confirming the sensor's capability to distinguish between different flow patterns. Data processing techniques were applied to eliminate hardware irregularities such as excitation asymmetries and variations in the auto-balancing

circuits. The resulting MECS signals are independent of the conductivity of the liquid phase, have the same baseline level, and are normalized such that a signal value of 0 corresponds to liquid and 1 to gas.

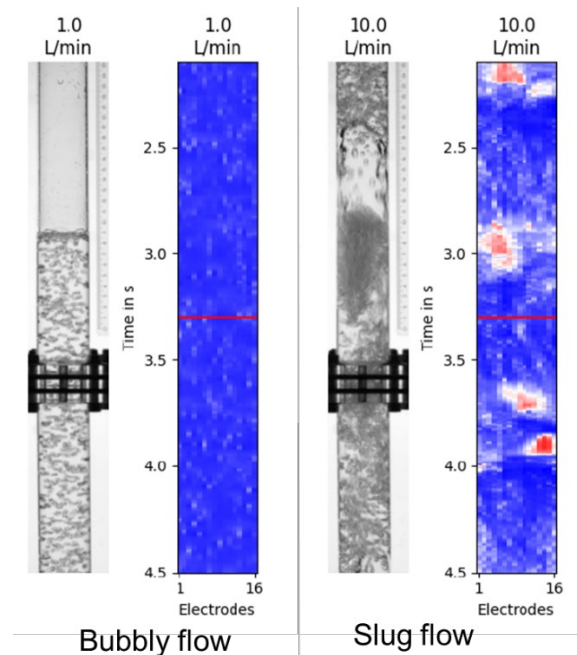


Fig. 3. Comparison of camera images and MECS measurements for two different flow rates and flow regimes.

## Conclusions

This study presents a novel multichannel conductivity sensor that offers a reliable, cost-effective, and robust solution for flow visualization. The sensor's compact design and ease of integration into pipe systems make it suitable for a wide range of industrial applications. Future research will focus on automating flow regime identification using machine learning algorithms and validating computational fluid dynamics simulations with experimental data. Additionally, incorporating a second excitation plane will enable velocity measurements of flow structures, further enhancing the capabilities of this sensor.

## References

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