



**AN INTRODUCTION TO
ELECTRICAL CAPACITANCE VOLUME TOMOGRAPHY**



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Using its unique approach to development, Tech4Imaging has applied its expertise in industrial imaging technology to solve multi-phase flow or process problems in the energy, aerospace, infrastructure, and non-destructive testing industries. Our ECVT technology has been used for process engineering as a diagnostic and control tool; for Computational Fluid Dynamics (CFD) verification; and in a variety of academic and research applications. It is also an invaluable tool used in fluidized beds, chemical reactions, mixing, drying, filtration and industrial 3D imaging.

I. Executive Summary

Tech4Imaging is an engineering and research firm at the forefront of capacitance based measurement and imaging. Our multi-dimensional approach to development, pioneered by Tech4Imaging (T4I) engineers and researchers, has resulted in continuous scientific breakthroughs and inventions in the field, enabling us to solve multi-phase flow and process problems in multiple industries. Our unique approach enables the examination and measurement of 3D velocity profile, spatial distribution, and volume fraction of each phase in a multi-phase flow, resulting in a thorough understanding of a complex process and real-time information critical to decision-making and quality control.

II. Process Instrumentation

1. Limitations of Traditional Point Measurement

Instrumentation for industrial processes and multi-phase flow is primarily based on point measurements from intrusive sensors or probes for pressure, velocity, density, and temperature. Such sensors usually extend into the process domain, thus perturbing it. Moreover, local probes only report measurements at localized points of the overall process, thus limiting the ability of a process engineer to infer an overall behavior of the process. To better analyze, understand, design, and ultimately control industrial processes, noninvasive, real-time global measurements solutions are required.

2. Global Measurements Solutions

Attention to global solutions for industrial and multi-phase flow instrumentation has been on the rise. In particular, the ability to image multi-phase flow interactions in real time has always been a highly desirable capability to further understand the complex dynamics among interacting phases in any flow system. Such understanding is critical, for example, to effectively model, optimize, and scale up the reactors that host the process.

Electrical sensing techniques have attracted much attention as a noninvasive means for the imaging of multi-phase flow systems. The rates in which phase interactions occur often demand fast imaging modalities, again making electric sensing techniques a natural choice. Tech4Imaging is at the forefront of this revolution through its electrical capacitance volume tomography (ECVT) technology and multi-dimensional solutions approach. ECVT sensors exhibit favorable features of safety, scalability, suitability for high pressure and temperature applications, and ease of operation.

III. The Tech4Imaging Solution

1. Electrical Capacitance Volume Tomography

ECVT is a noninvasive, 3D sensing technology that has proven very successful for imaging and characterization of diverse multi-phase (gas/fluid/solid) flow systems and industrial processes and is also non-destructive. ECVT is a natural spin-off of the earlier 2D electrical capacitance tomography (ECT) technology. Because both ECT and ECVT employ an interrogating field that is a solution to Poisson's equation, they are suitable for a vast range of scales. Indeed, prior applications of ECT have included domains with diameters ranging from tens of microns to meters. As its name suggests, ECVT retrieves volumetric images of the dielectric material distribution on a 3D domain from capacitance measurements taken on its 2D boundary.

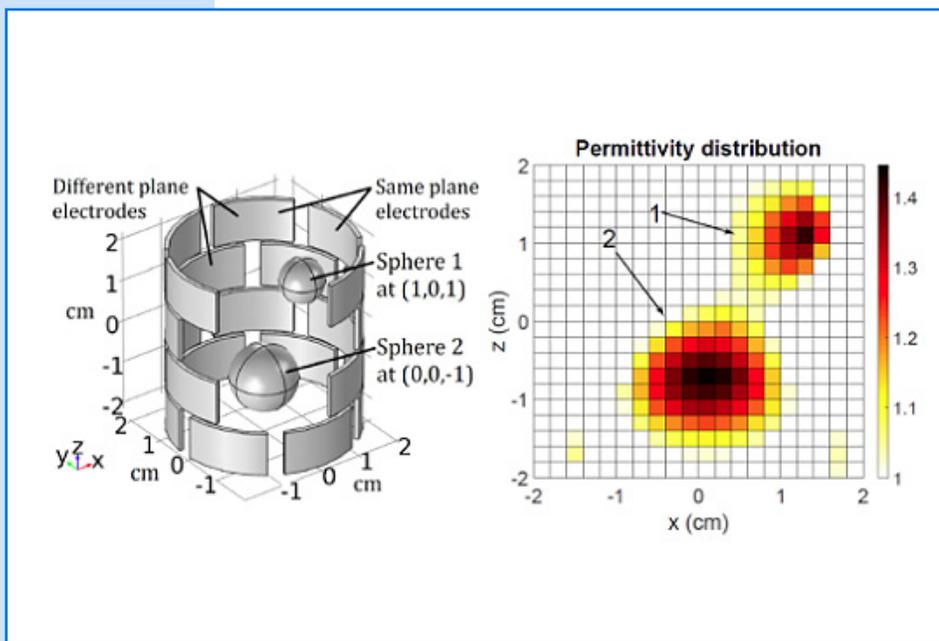


Figure 3-1.
ECVT Sensor and
Imaging

Computer Model
of ECVT Sensor and
Reconstructed Image

The capacitance sensor plates in ECVT are designed to “blanket” the imaging domain with various zones of enhanced (capacitance) sensitivity. The set of all capacitance pairs measured between the plates is sought to react differently to dielectric perturbations on each volumetric “voxel” in the imaging domain. With the aid of image reconstruction algorithms, the differences in the sensor responses are used to establish a volumetric profile, or image, of the dielectric distribution. (Fig. 3-1) However, challenges remain associated with such reconstruction, and Tech4Imaging has been advancing the technology steadily.

Tech4Imaging holds multiple issued and pending patents covering all aspects of our imaging technology including the sensor, data acquisition electronics, and image reconstruction techniques. We are leaders in the field. Please access our ongoing research findings and continued industry contributions via our abstracts and academic publications, available from our website at tech4imaging.com.

2. The Multi-dimensional Approach

Conventional capacitance based tomography uses the mutual capacitance between sensor plates to reconstruct a density image. This is called single dimension tomography. Tech4Imaging has pioneered the multi-dimensional approach in which the same ECVT sensors can be used to measure multiple dimensions, thus enabling the measurement and visualizations of processes previously deemed unmeasurable by process engineers.

This groundbreaking approach is based on multiple inventions by Tech4Imaging engineers and researchers including:

- ▶ the extension of 3D ECVT volume imaging from the conventional 2D technology;
- ▶ utilization of the frequency response of mixed materials to surface polarization phenomena;
- ▶ introduction of the displacement current phase as a means of measuring water-based processes and continuous phase flows; and
- ▶ adaptive sensor excitation for high imaging resolution.

Tech4Imaging engineers and researchers come from diverse backgrounds and experiences that enable them to develop program algorithms customized for specific applications. Their expertise spans the fields of fluid mechanics, electromagnetism, inverse problem solutions, electronic hardware, multi-phase flow, process engineering, and product and software development.

3. The Benefits of ECVT Sensors

What sets ECVT sensors apart from all other tomography modalities is that they are truly applicable to industrial settings. Among the features that make them highly favorable in industrial use is their suitability to a variety of process environments; scalability; flexibility; and an ability to be fabricated from a vast array of materials. Our sensors can operate in harsh environments, within temperatures of up to 900°C (Fig. 3-2) and pressures of up to 35MPa. For applications at ambient conditions, stretchable sensors are available (Fig. 3-3). Stretchable sensors are fast and simple to manufacture and provide a high level of versatility. They can stretch and shrink to accommodate a variety of scenarios, thus preventing the need to produce multiple sensors.



Figure 3-2.
High Temperature Sensor

Our sensors can operate in harsh environments, within temperatures of up to 900°C and pressures of up to 35MPa.

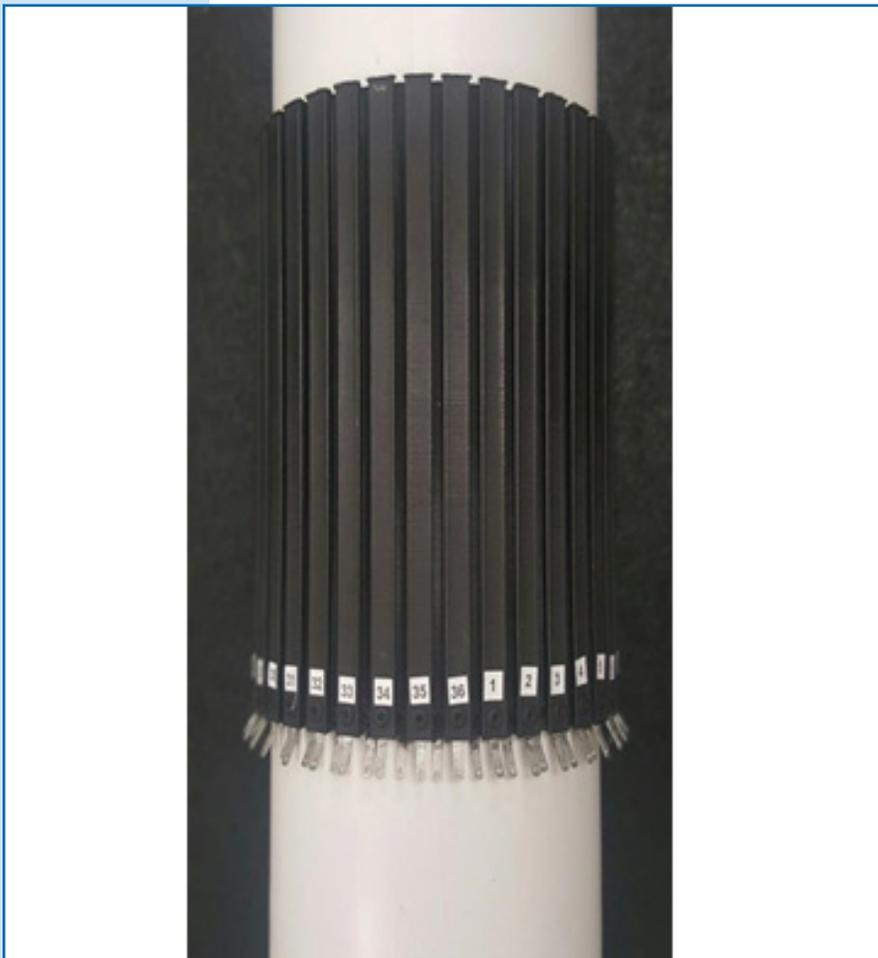


Figure 3-3.
Flexible and Stretchable Sensor.

Adaptable to ambient conditions, stretchable sensors are favorable for cold flow loops, for pipes of obscure or variable sizes and shapes, and for non-metallic pipes.

4. Data Acquisition System (DAS)

An ECVT system works by sequentially exciting an array of sensor plates, measuring the signals from the plates, and then processing the signals to obtain useful data and to make images. A Data Acquisition System (DAS) acts as the “brains” of ECVT, generating and reading the electric fields that penetrate the sensing region. (Fig. 3-4) This works with a host computer, typically supplied by the customer, which controls the DAS, displays its readings to the user, and stores saved data acquired from the unit via the *4Sight* software (see III.5).



Figure 3-4.
Tech4Imaging ECVT
System Components

The ECVT Data Acquisition System (DAS) (left) and an ECVT sensor (right) to be placed around a process pipe for imaging. One of the benefits of the T4I system is its small footprint.

The DAS is controlled by a Field Programmable Gate Array (FPGA), a common computer chip that can be programmed as many times as needed, making it easy for the DAS to be quickly upgraded in the field. Provided a user is under a continued service contract, this allows a customer to have the latest version of T4I technology without investing in new hardware. The FPGA generates all of the necessary waveforms and control signals to make the DAS function. It accumulates data and then packages it for transmission to the host computer.

The measurement process results in sequences of digitally-sampled sine waves. These are converted into amplitude and phase components using a process called quadrature synchronous demodulation. Excitation frequency choices are available in order to obtain more information about the medium that is being measured. In some cases, impurities such as iron oxide can be discriminated by comparing the magnitude and phase data at different excitation frequencies. The FPGA can be set up to use one specific excitation frequency or to use two or more in a specified sequence.

The setup can be performed within the user interface (UI) or can be programmed for a specific application.

Modularity has been T4I's biggest ally in developing the 4Sight Data Analysis Software. With the ability to swap out functionality at will, it becomes nearly effortless to customize the product for the client's unique process challenge. This has the added benefit of lowering future development cost, as outdated modules can be replaced with newer modules quickly and easily.

5. 4Sight Data Analysis Software

The ECVT system must not only gather the necessary process data, but it must also present it in a manner that it can be used, analyzed, and understood in order to provide necessary answers. Tech4Imaging has developed well-written and responsive software called 4Sight for this purpose.

Tech4Imaging works side-by-side with the client to understand what specific metrics should be monitored and then, working with our cross-functional team, it customizes a 4Sight software package to turn raw readings from our DAS into human-readable metrics. For example, if a client wants to know how fast a flow of water is moving, we will customize our algorithms and software to display a simple number that shows the user the speed of water flow in real time.

Tech4Imaging's 4Sight software is comprised of two components: 4Sight Service and 4Sight Client. 4Sight Service handles the communication between the host computer and the DAS, while 4Sight Client provides the user interface. One benefit to keeping the client as a separate component is that it can be used on a computer other than the host. Decoupling the two also allows for multiple clients to be connected to the same service so that more than one party can be watching the same acquisition simultaneously. This communication is supported by a TCP/IP connection hosted by the 4Sight Service and accessed through HTML WebSockets by the 4Sight Client(s).

The software has been designed with a simple and user-friendly interface and a unique, sleek design to engage the user. (Fig 3-5).

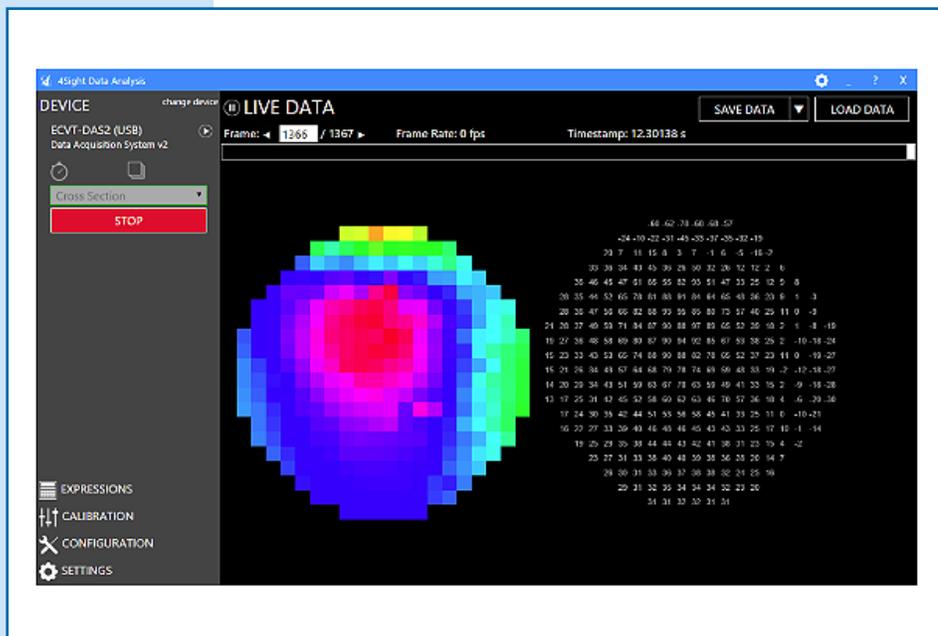


Figure 3-5.
4Sight Data Analysis Software

The sleek design and simple, user-friendly interface enhances the user's experience when performing data analysis.

Tech4Imaging views its clients as partners in the problem-solving process. We partner with companies to assist them in improving their processes by applying our technological expertise in process imaging. As a partner, your company can depend on Tech4Imaging to provide a customized process solution.

IV. Buyer's Guide

Tech4Imaging not only views our clients as customers, but also as engaged and participating partners. This relationship allows us to share an open and ongoing discussion with our clients, conducive to better understanding their needs and ultimately to assist them with a customized solution. Tech4Imaging currently offers three service packages:

- ▶ Complete Custom Solutions
- ▶ Contract Services
- ▶ Feasibility Studies

1. Complete Custom Solutions

With the purchase of a Complete Custom Solution, Tech4Imaging will build a custom sensor and software package designed for our partner's specific needs, facility, and process. With this package, our partner is matched with a team of engineers, as well as a project manager appointed to facilitate the overall effort. Our software package comes with a one year license and is renewable for purchase every year.

2. Contract Services

Tech4Imaging also has the ability to rent or lease a solution for a specified length of time through the purchase of Contract Services. Service agreements are typically one year in length. During this time, a team of engineers, under the direction of a project manager, is assigned to work with a partner and to set up and conduct experiments, to analyze results, and to produce a detailed final report based on T4I findings.

3. Feasibility Studies

Tech4Imaging can conduct a Feasibility Study for clients who are seeking specific answers to a process problem before they invest in instrumentation. These studies focus on answering essential questions that would help our potential partner better understand the Tech4Imaging solution and its applicability to the multi-phase problem at hand. All activities of the study are directed toward helping our potential partner make the best possible instrumentation decisions. Feasibility studies vary in their duration based upon the complexity of the application.

Connect with us today to get started with your solution or to learn more about how Tech4Imaging can help your company.

Visit our website at tech4imaging.com/contact or call our Business Solutions Team at 614-516-7877.

4. Partnering with T4I

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- ▶ Visit the *Contact Us* page of our website at www.tech4imaging.com/contact and send us an email. Include in it your company's information and the type of problem you're experiencing and the type of help you might need; or
- ▶ Call Tech4Imaging directly at 614-516-7877. A member of our Business Solutions Team will contact you within 24 hours to set up an initial call, the purpose of which will be to gather specific information about the nature of the application and to see if our solution is a good fit.

If we determine that our solution is right for your needs, then our Business Solutions Team will create a quote along with a Scope of Work for the services to be rendered. An engineering team will be assigned to your project, and a project manager will be named. If you have purchased a Complete Custom Solution or Contract Services package, your designs and fabrication will begin at this point. For Feasibility Studies, testing begins at this stage.

Depending on the project, design and fabrication can take from 3-6 months. Once fabrication is finished, a meeting for installation and training is set by the project manager. When work is completed, a final report is provided that details how our solution met your needs.

V. About the Company

Founded in 2007, Tech4Imaging is focused on developing new and innovative instrumentation solutions based on its ECVT technology, using a unique approach that distinguishes it from others in the field. This approach relies on creating new measurement dimensions from ECVT sensors to expand the use and scope of our technology. Among its many state-of-the-art contributions to imaging technology, our team is credited with the inventions of ECVT, DCPT, MPFD, and Velocimetry based on ECVT sensors. These proprietary and patented inventions enable T4I to provide solutions to process problems previously deemed unsolvable.