Adaptive Electrical Capacitance Volume Tomography for Real Time Measurement of Solid Circulation Rate at High Temperatures

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Project Goals & Objectives

- The main technical objective of Phase II A is to continue development of a functional AECVT demonstration system for real-time imaging and measurement of multiphase flows at high temperature.

Year 1 Milestones:

1. 1- Fabricate AECVT sensor material and design/fabrication process- end of 3rd quarter.
2. Fabricate test chamber for gas-solid applications- end of 3rd quarter.
3. Develop software GUI - end of 4th quarter.

Year 2 Milestones:

1. Development of reconstruction and feature extraction algorithms- end of 7th quarter.
2. Develop and demonstrate software and GUI- end of 8th quarter.
3. Demonstrate integrated system- end of 8th quarter.

Presentation Outline

- Introduction to ECVT & AECVT
- Algorithms
- Electronic Design & Sensor
- Schedule

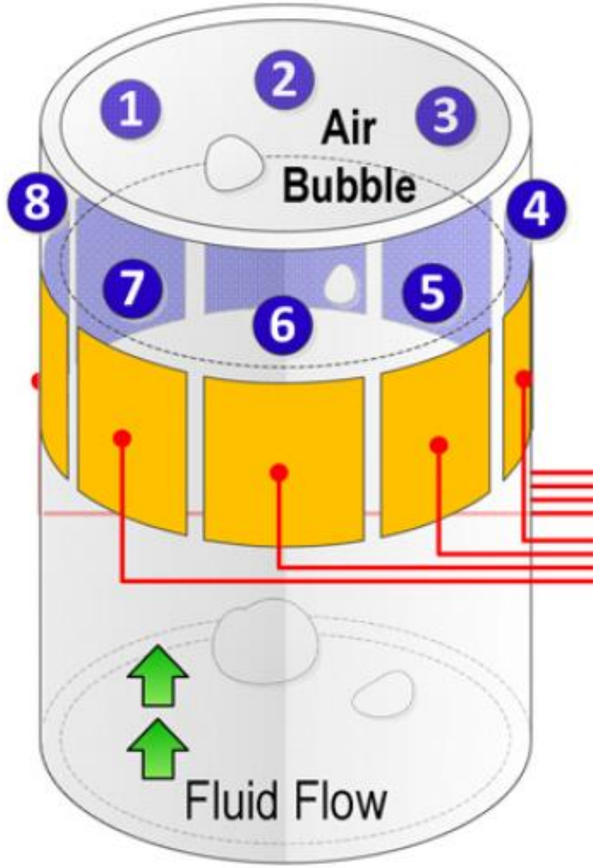
Electrical Capacitive Volume Tomography

- ❖Electrical Capacitance Volume Tomography (ECVT) is a low cost noninvasive imaging technique to find the volumetric dielectric distribution from inter-electrode capacitance measurements.

- ❖Electrodes respond differently to the change in permittivity distribution inside the sensing domain. These mutual capacitances are used to reconstruct the dielectric distribution in the sensing domain.

- ❖ECVT is used in nondestructive testing, imaging of multiphase flows and for imaging of combustion flames and fluidized beds.

- ❖Adaptive ECVT (AECVT) is a high resolution sensor formation that can form many electronic synthetic plates.



ECVT Sensor Model

The inter electrode capacitance is computed by

$$\boxed{C = -\frac{1}{V}\iint_{\Gamma} \varepsilon(x,y)\nabla\phi(x,y)\cdot n dS\,.}$$

The first order linear approximation $\Delta C = \frac{d\xi}{d\varepsilon}(\Delta\epsilon) + O((\Delta\epsilon)^{2})$

$$\boxed{\mathbf{C}_{\mathbf{M}\times\mathbf{1}} = \mathbf{S}_{\mathbf{M}\times\mathbf{N}}\mathbf{G}_{\mathbf{N}\times\mathbf{1}},}$$

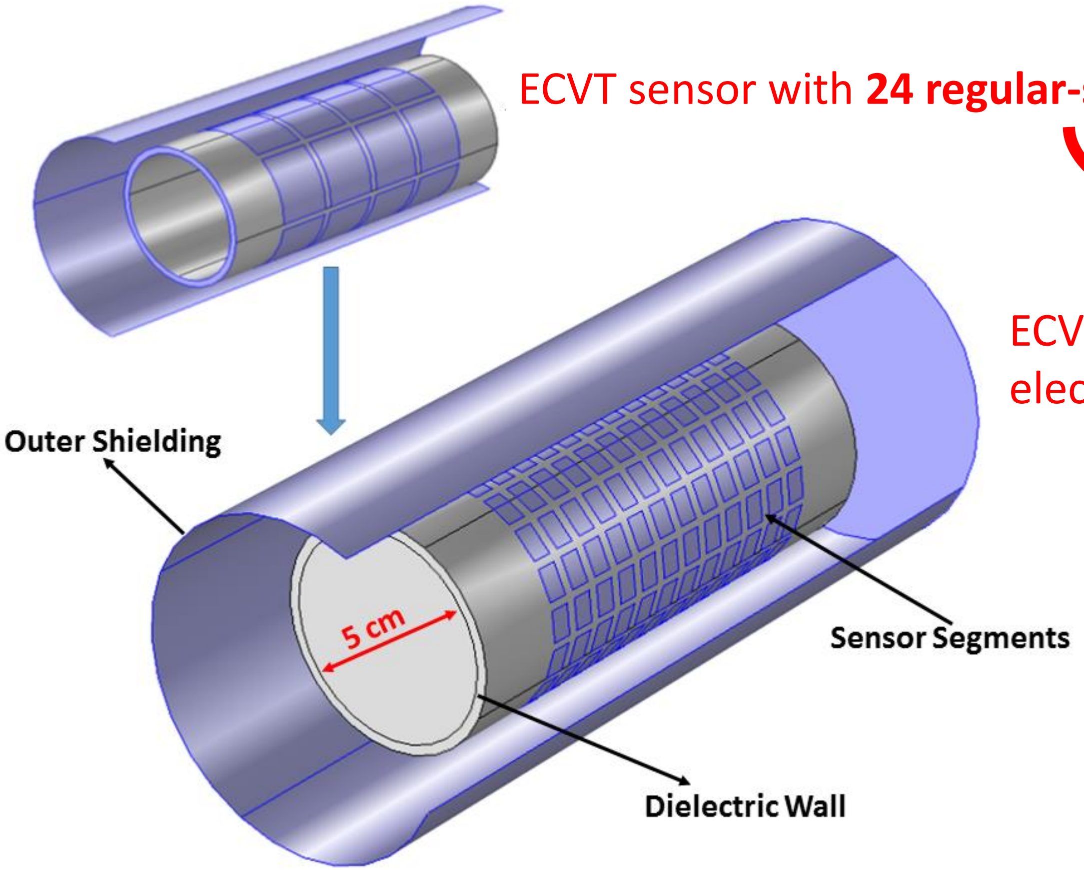
Where $M = \frac{n(n-1)}{2}$ are the number of independent sensor measurements, N is the number of pixels in the sensing domain and the sensitivity matrix $\mathbf{S}$ is defined as

$$\boxed{S_{ij}[n] = \frac{1}{V_i V_j}\int_{v[n]} \nabla\varphi_i \cdot \nabla\varphi_j dv}$$

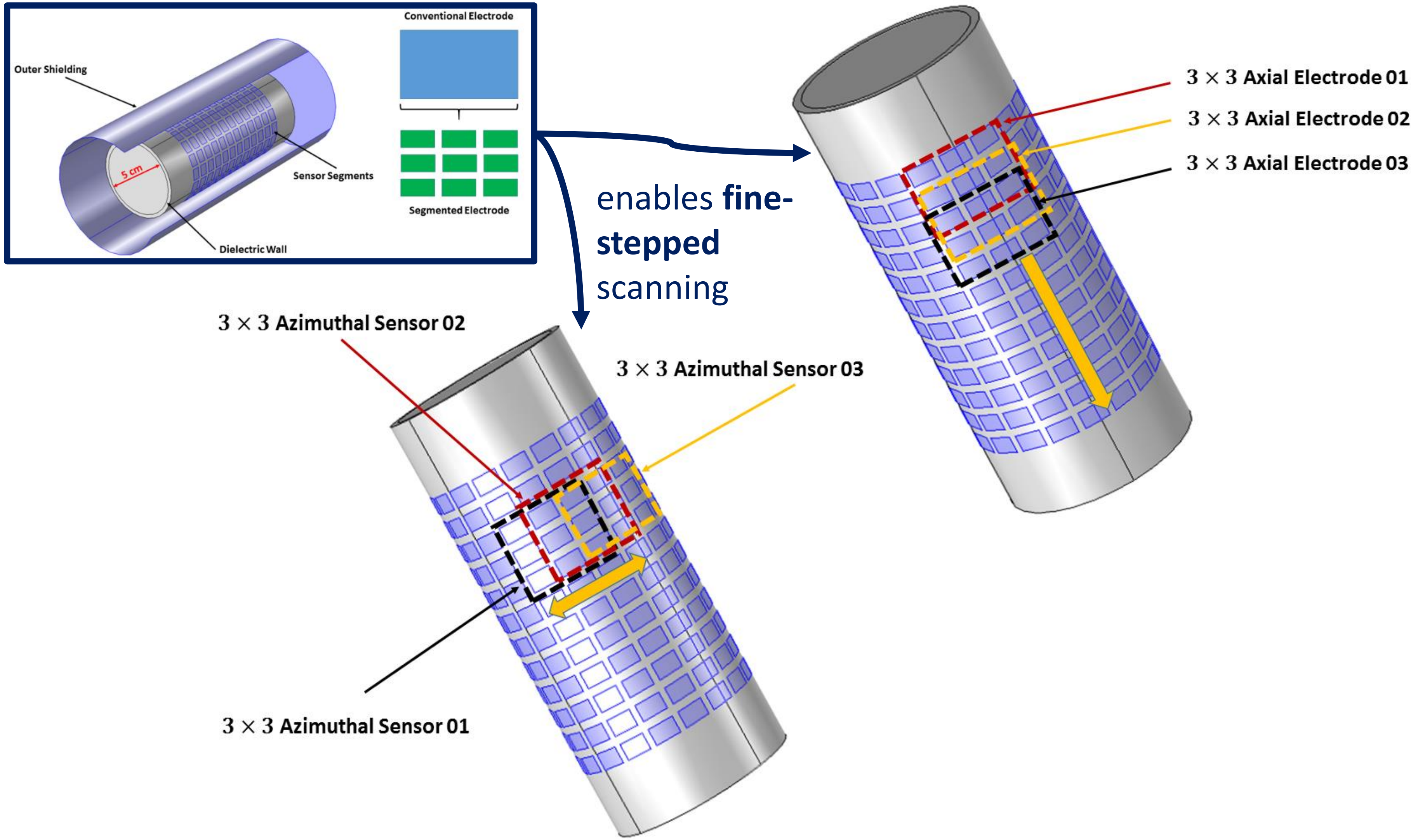
Fundamental idea of the Adaptive ECT/ECVT

ECVT sensor with **24 regular-size** electrodes

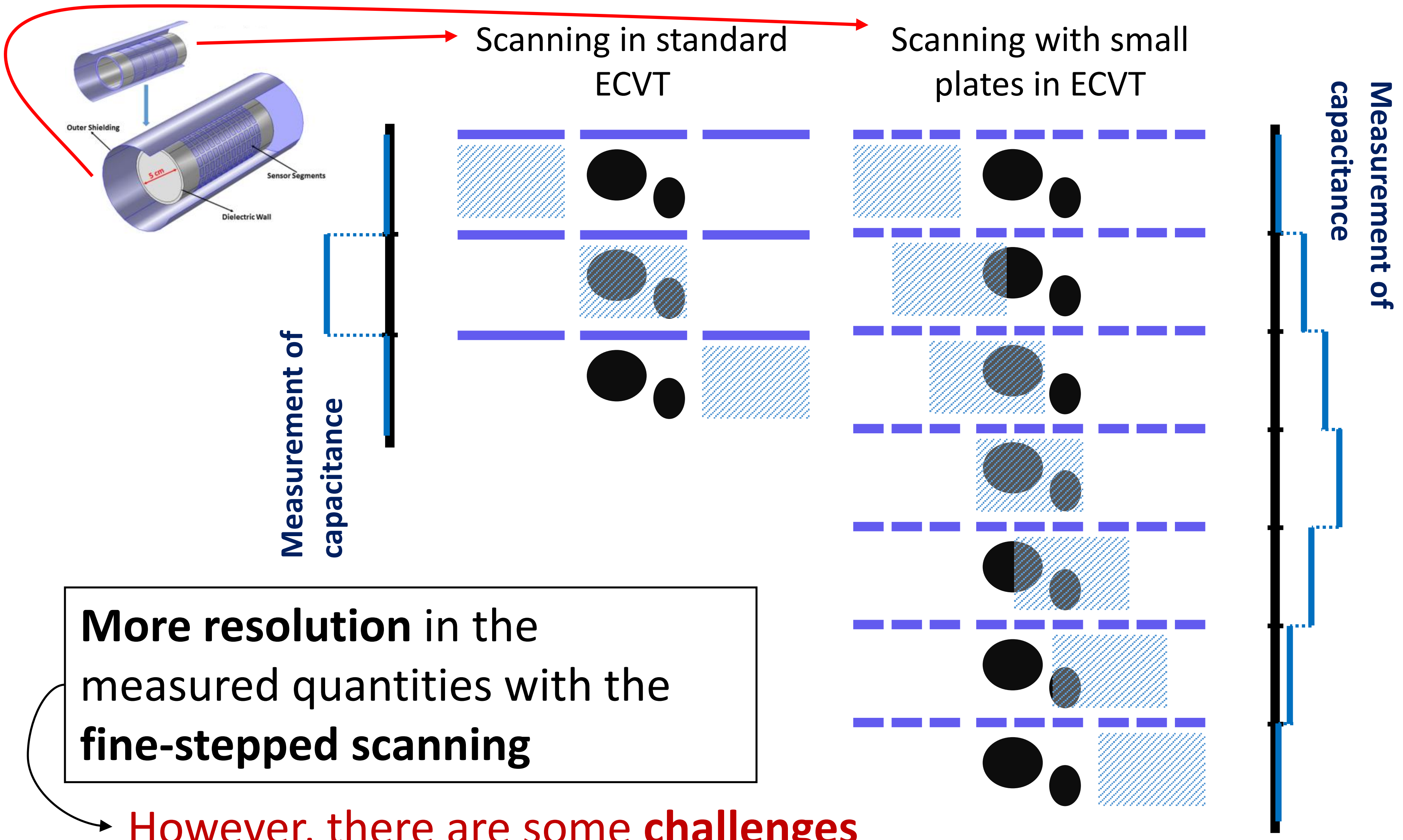
ECVT sensor with **216 small** electrodes



Fundamental idea of the Adaptive ECT/ECVT



Fundamental idea of the Adaptive ECT/ECVT (3)



More resolution in the measured quantities with the **fine-stepped scanning**

However, there are some **challenges**

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ECVT Challenges

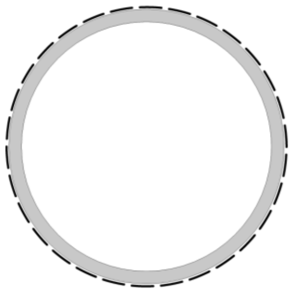
- ECT image reconstruction is an ill-posed and ill-conditioned inverse problem.
- Solution is very sensitive to measurement errors.
- Number of independent measurements are limited due to SNR considerations (setting a minimum electrode plate size) hence problem is underdetermined.
- Image reconstruction algorithm does not cater for soft-field nature of the ECT sensing field (quasi-static Laplacian field).
- Limited spatial resolution.
- Fast and robust reconstruction algorithms for real time applications.

Future Algorithm work

The biggest **issue** that we have is the **exhaustive search** on $\mathcal{L}$ that we need to do to **find the sensitivity vector**

Examples

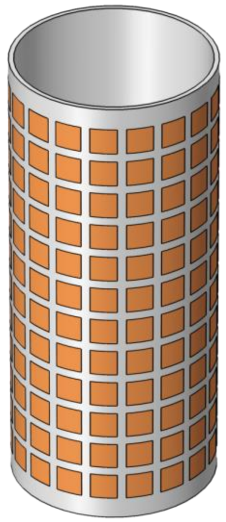
For **ECT** with **30 small electrodes**



- **1626 possible measurements** with electrode **combinations** of **1, 2, 3, 5, 6, 10, 15** electrodes
- **813 possible measurements** with electrode **combinations** of **3, 5, 6, 10, 15** electrodes

For **ECVT** with **216 small electrodes**

- **233843 possible measurements** with electrode **combinations** of **1, 2, 3, 4, 6,…,108** electrodes
- **102105 possible measurements** with electrode **combinations** of **9, 12, 18, 24,…,108** electrodes

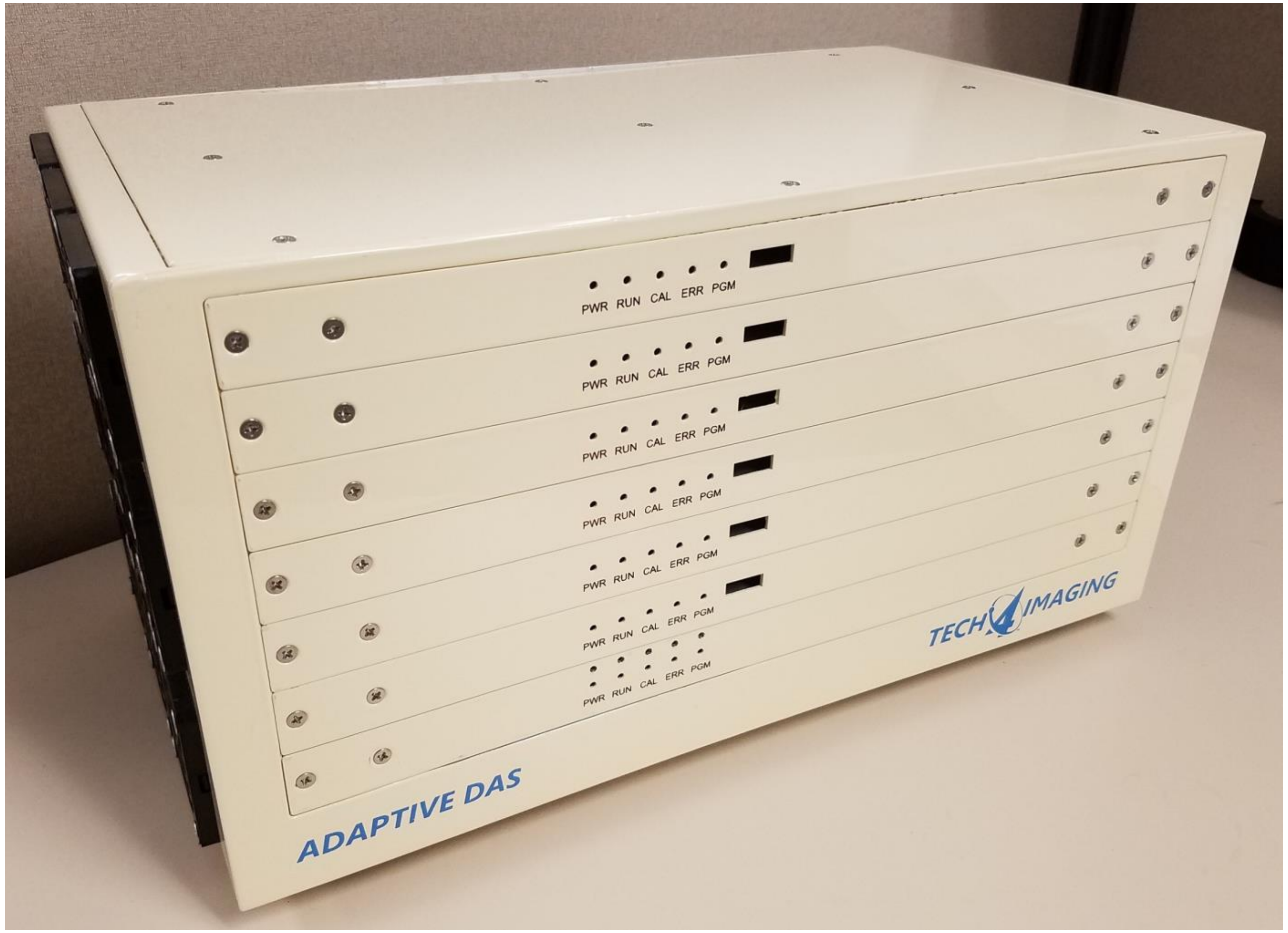


We need to find an **approximation procedure** that allows to **reduce** the **size** of the **search**

Adaptive DAS Features

- 288 Plates
- Creation of Transmit and Receive Meta-Plates
- Excitation frequency from 62.5kHz to 4Mhz
- 10V Excitation

Front View



Back View

24 Plate Connector

(1 of 12)

Connector inserted in Adaptive DAS
(1 of 12)

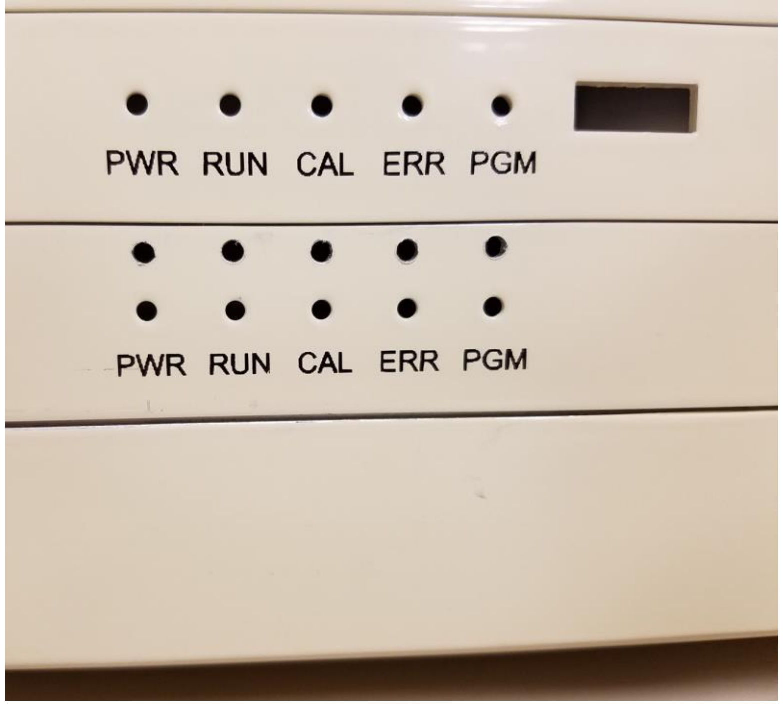
36 x 2 Sensor

Chassis

- ✓ Assembles Properly
- ✓ Structure is rigid
- ✓ Supports circuit boards
- ✓ Mounting interfaces align

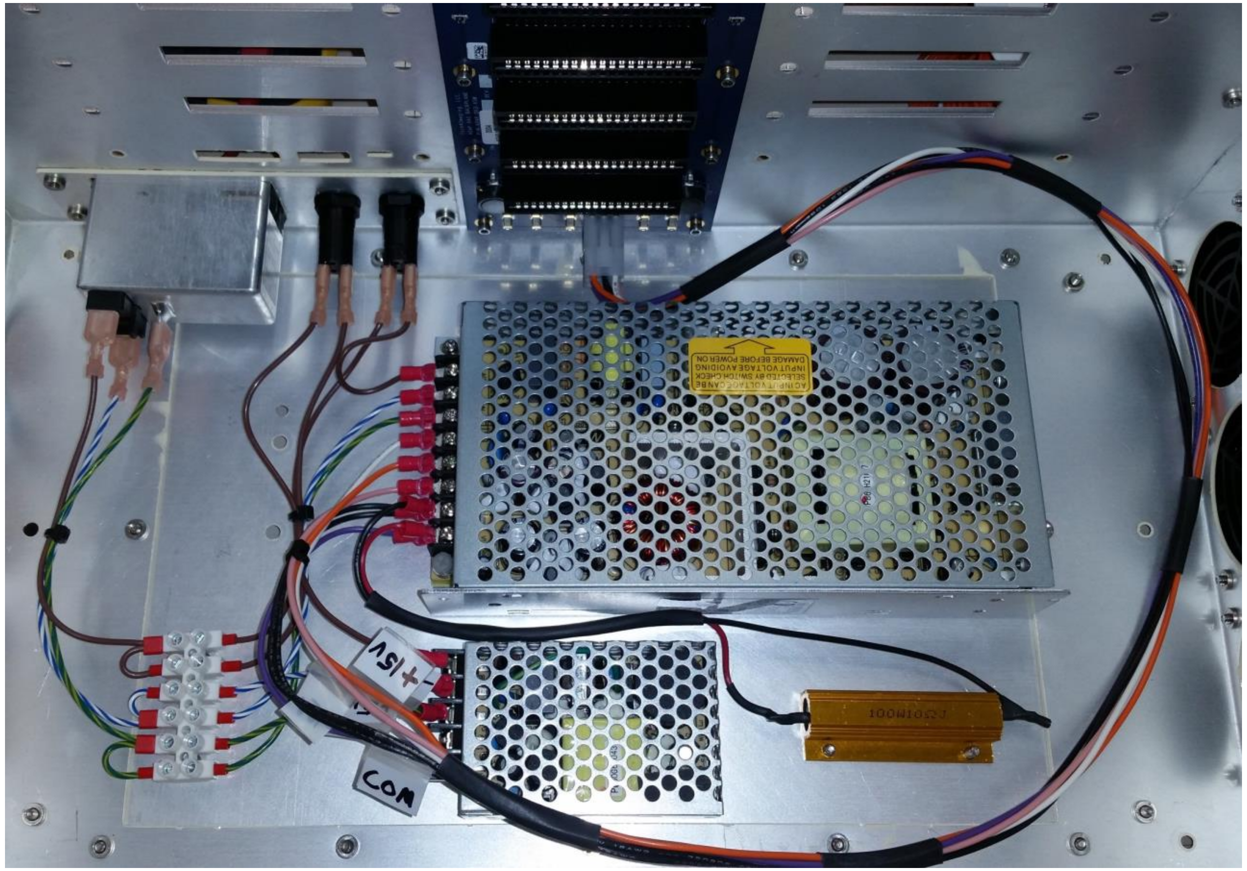
Updates needed:

- ❑ Controller Board indicator light holes need moved
- ❑ Receiver board connector holes need enlarged



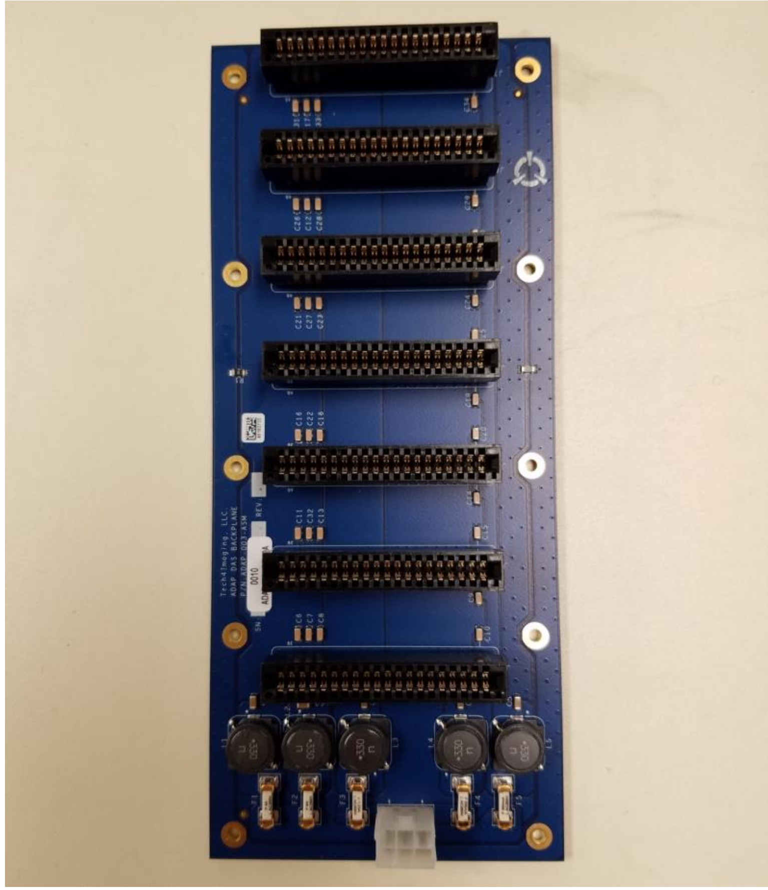
Power Supplies

- ✓ Powers on
- ✓ Voltages are properly distributed
- ✓ Power supplies are not overloaded
- ✓ Does not overheat

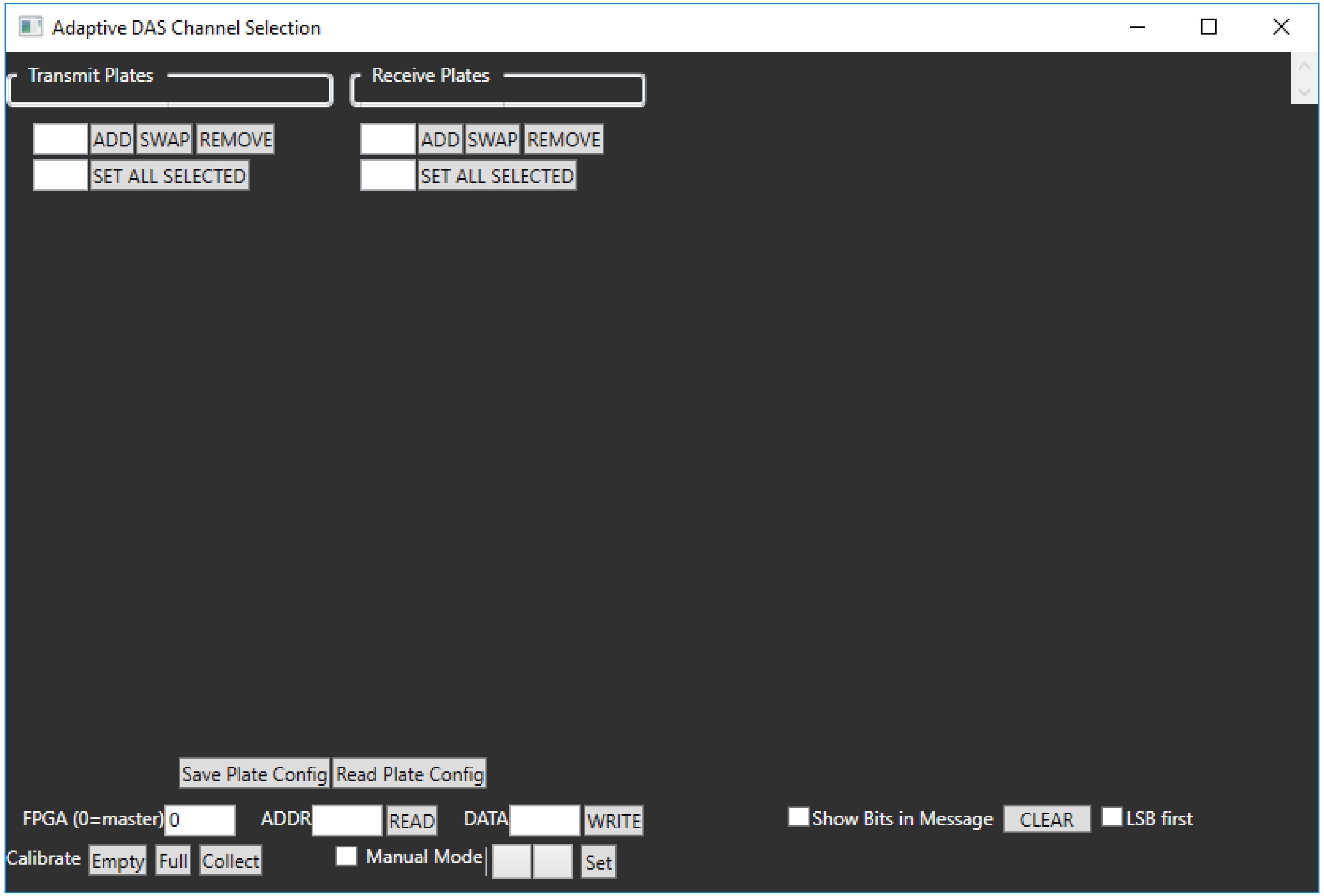


Backplane

- ✓ Aligns with the controller and 6 receiver boards
- ✓ Signals properly routed

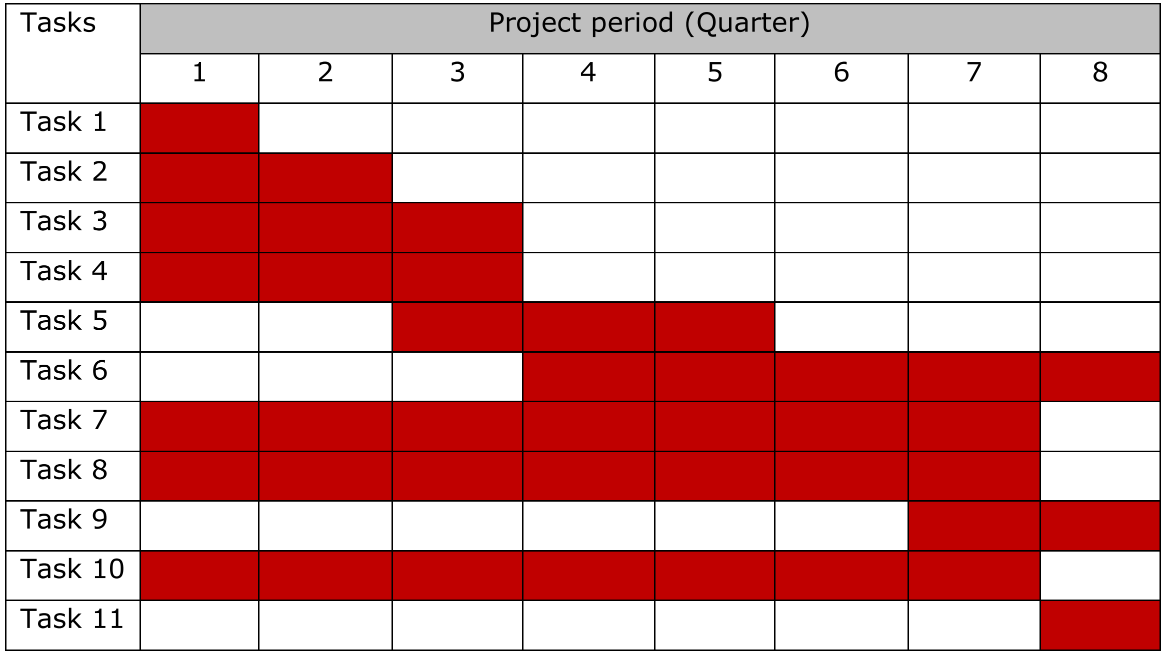


Testing Software



Phase II A Schedule

Task 1: *Electrical design of AECVT sensor for high temperatures*
Task 2: *ECVT sensor mechanical design for high temperatures*
Task 3: *ECVT sensor fabrication*
Task 4: *Build test chamber*
Task 5: *Data Acquisition System (DAS) firmware and electronic design*
Task 6: *Testing*
Task 7: *Implement image reconstruction algorithm based on developed SART technique*
Task 8: *Develop feature extraction*
Task 9: *System integration and testing in real-time*
Task 10: *Software interface*
Task 11: *Finalize demonstration unit*



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Conclusion

- Higher ECVT resolution is directly proportional to increased number of plates.
- Adaptive ECVT (AECVT) is based on substantial increase in number of synthetic plates using plate segmentation.
- Adaptive ECVT is a new technology at the frontier of higher resolution capacitance imaging:
  - Infinite options of plate arrangements and independent number of measurements
  - Maintain High SNR of acquired measurements
  - Ability to beam ECVT resolution toward a desired region
  - Ability to Zoom ECVT resolution toward a desired region
- More work is required for Algorithm development and testing, an integrated system will be ready by end of Phase IIA.