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

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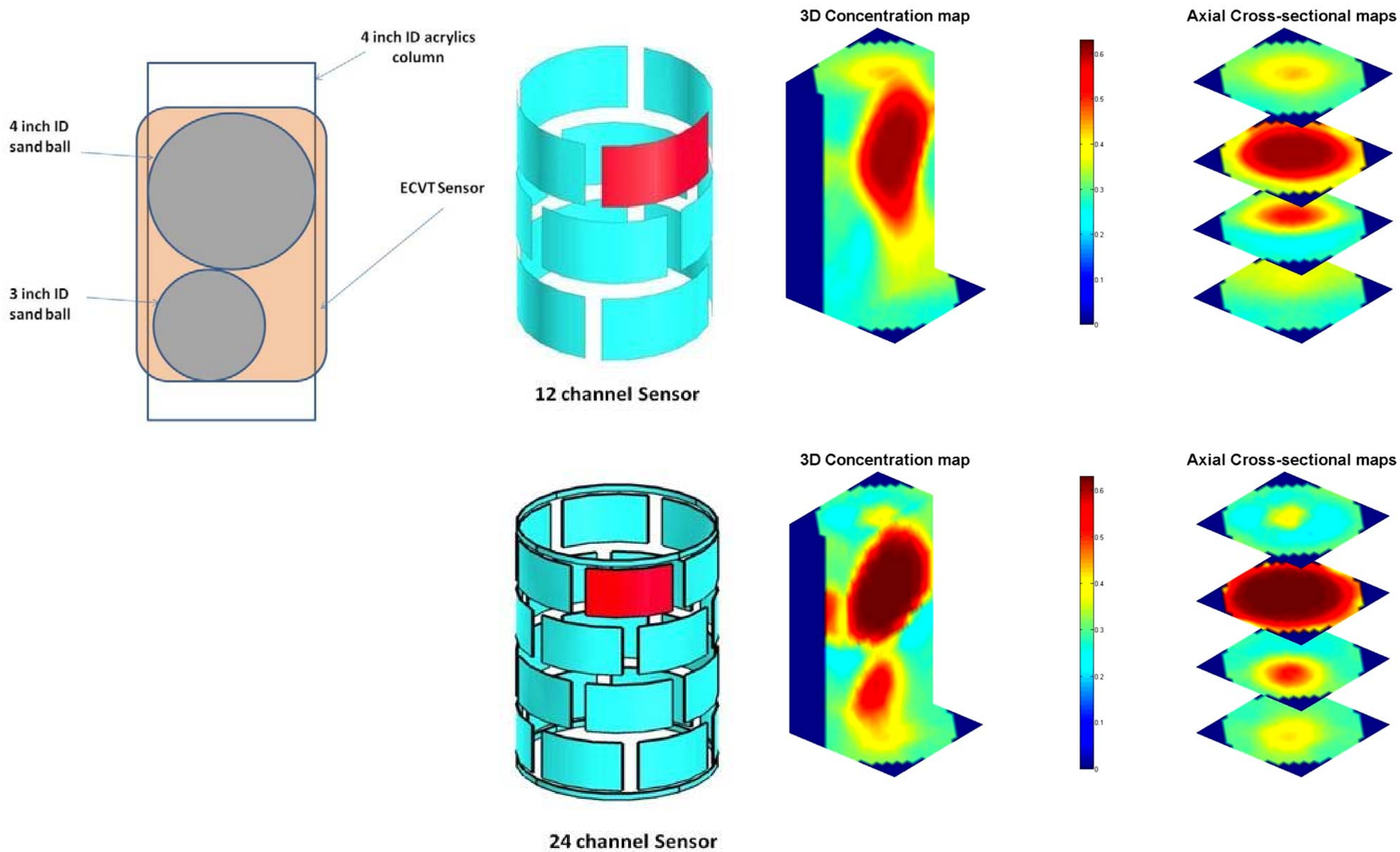
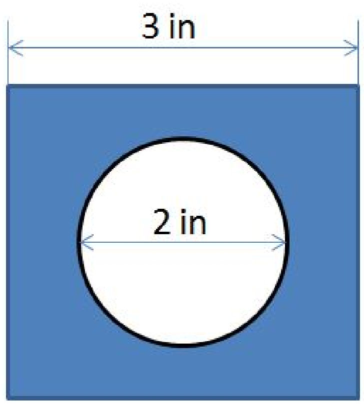
Introduction

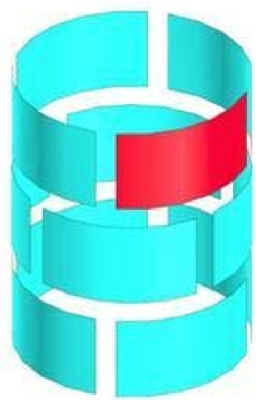
- Adaptive Electrical Capacitance Volume Tomography (AECVT) is a 3D imaging technique for Multi-phase flow measurement.
- AECVT offers substantially higher imaging resolution compared to the conventional ECVT
- New image reconstruction algorithms are developed to exploit increase in measurements using AECVT sensors.
- An AECVT system and sensor is being developed as part of this SBIR Phase II effort.

AECVT Motivation: Two Sphere Experiment

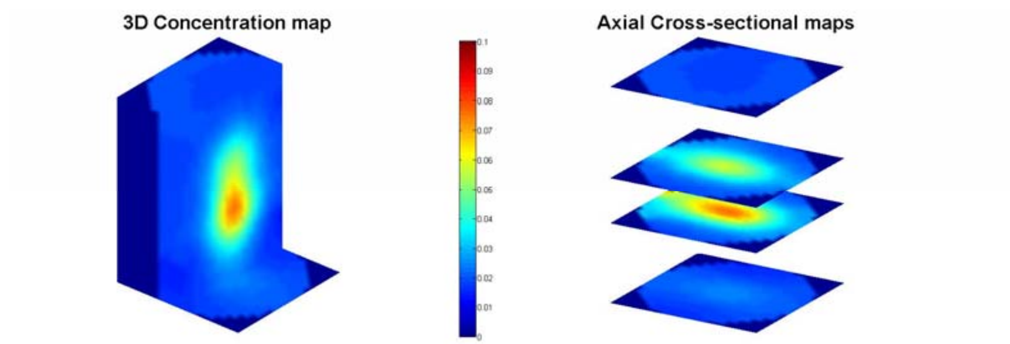


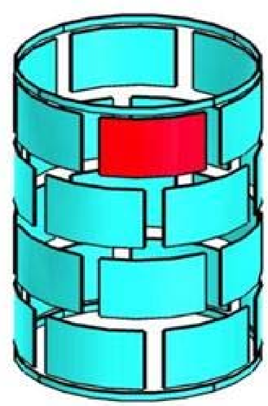
Irregular Shape Experiment



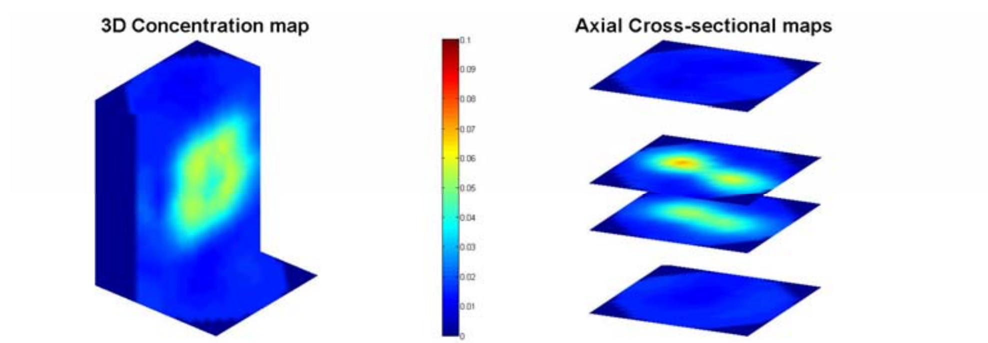


12 channel Sensor

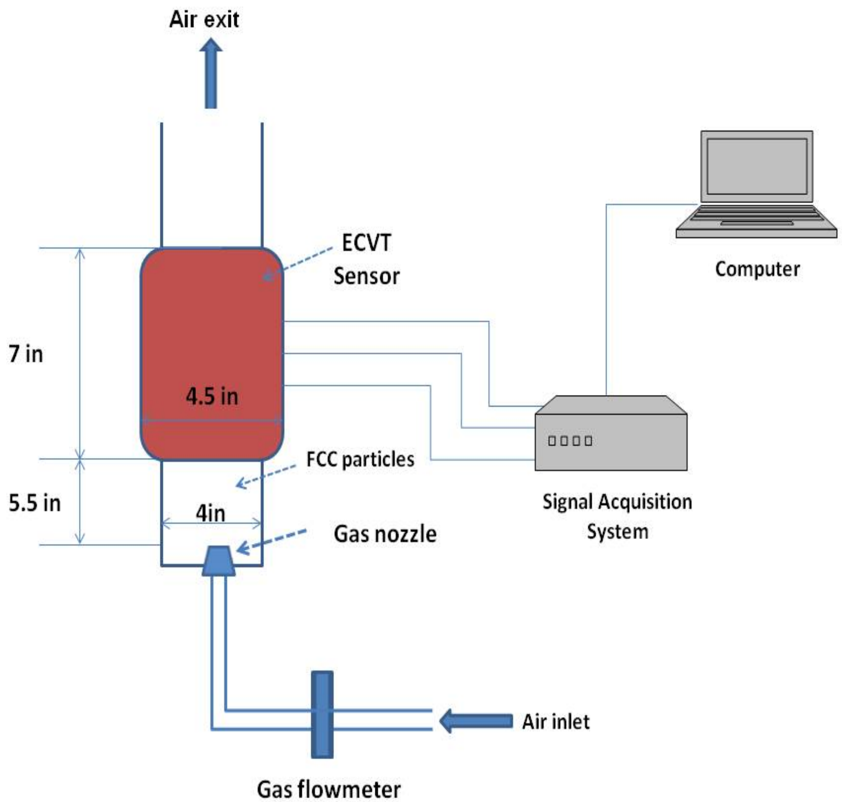


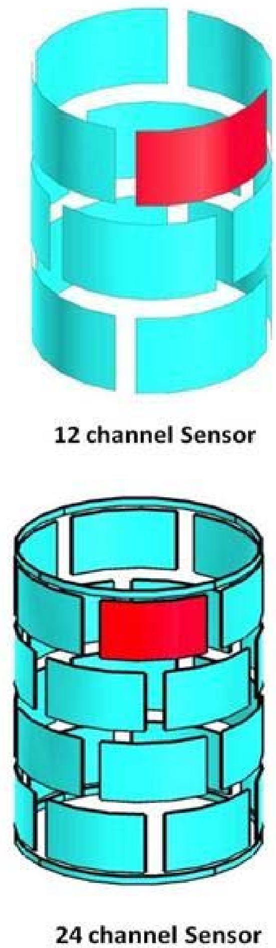


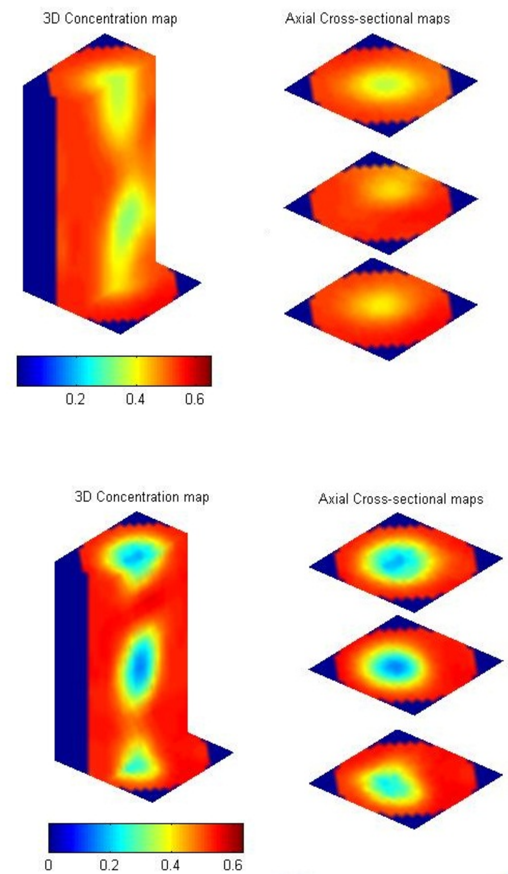
24 channel Sensor



Gas-Solid Experiment

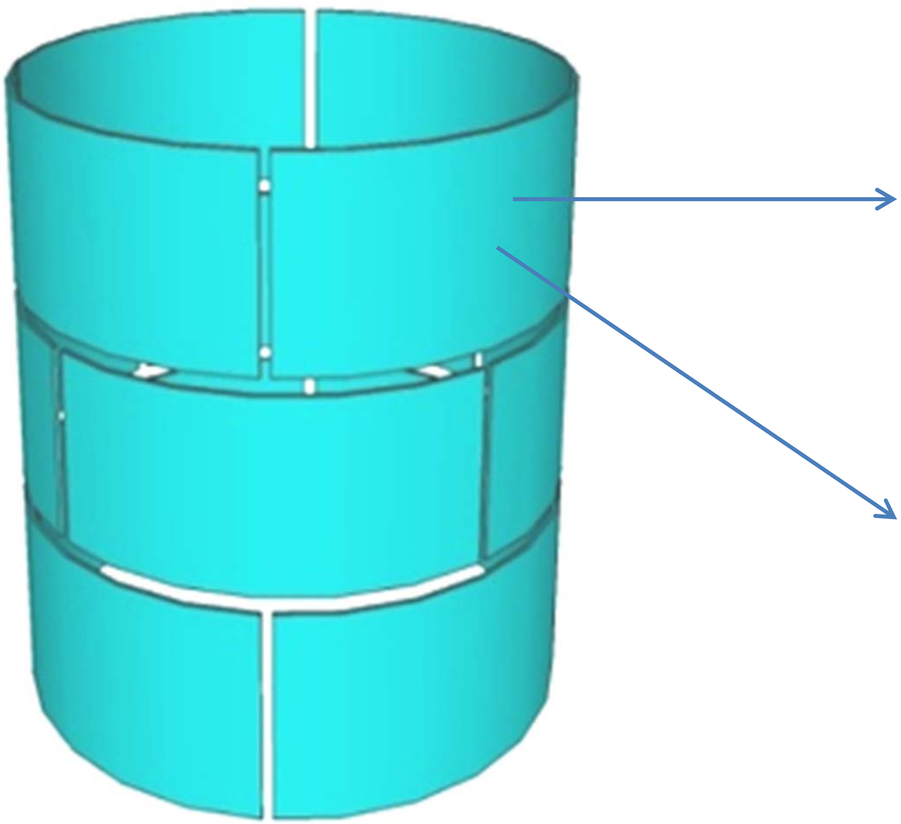






Adaptive and conventional plates in 2D depiction

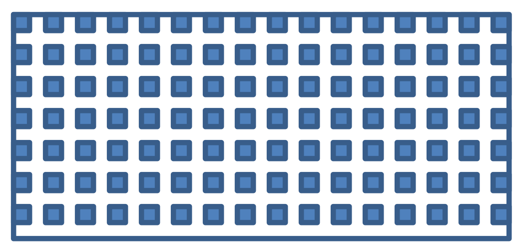
A



B

Conventional Plate

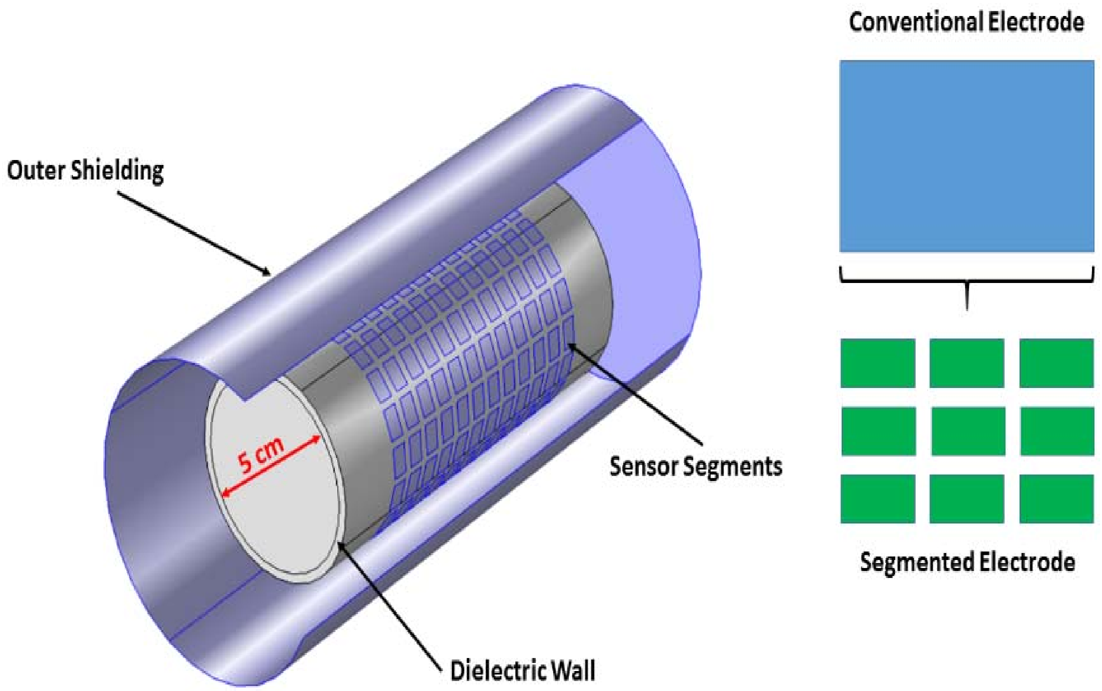
C



Adaptive Plate: *Each segment is activated With different levels of amplitude and phase*

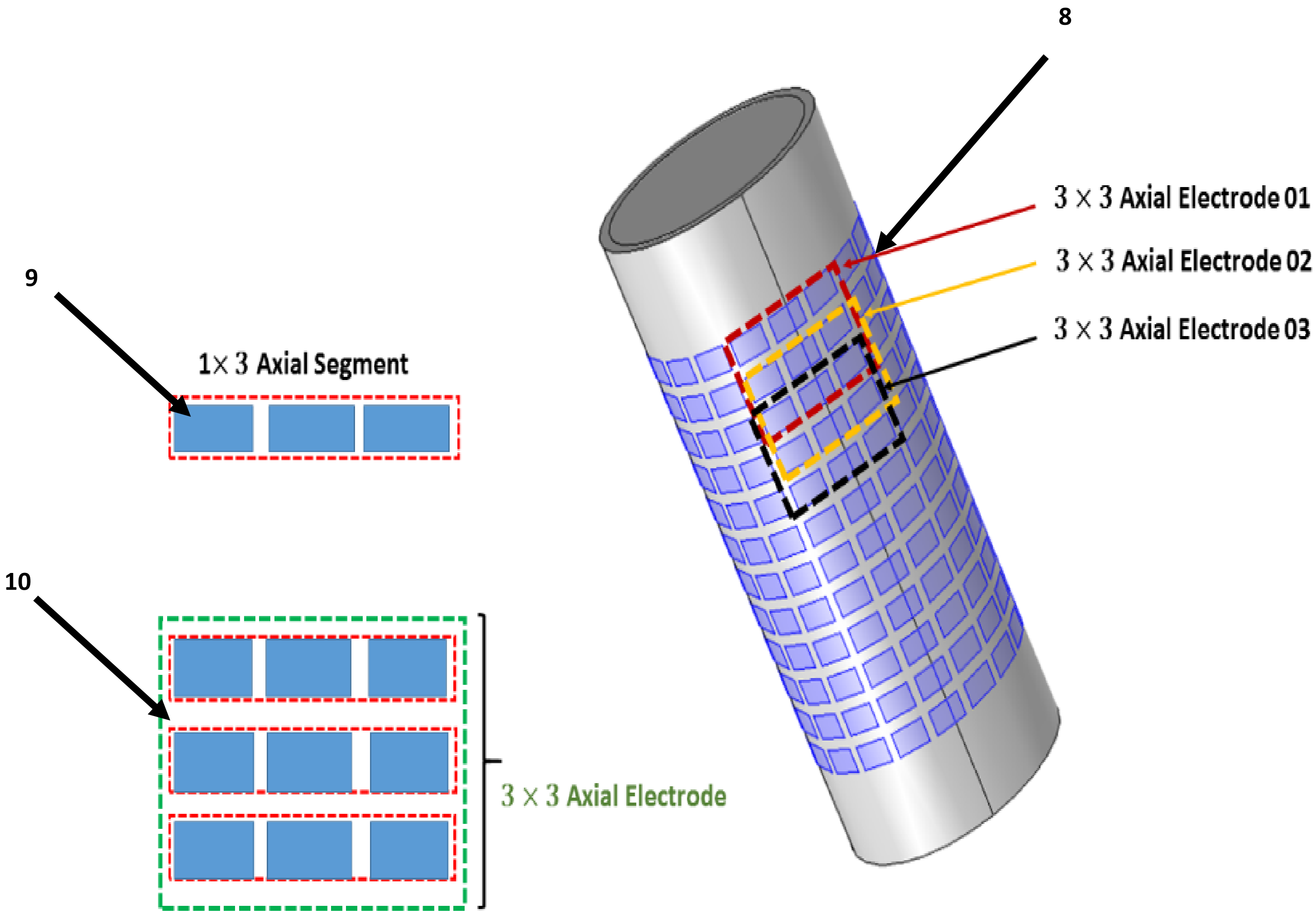
US Patent Application #: US 13/644,973

Excitation Implementation

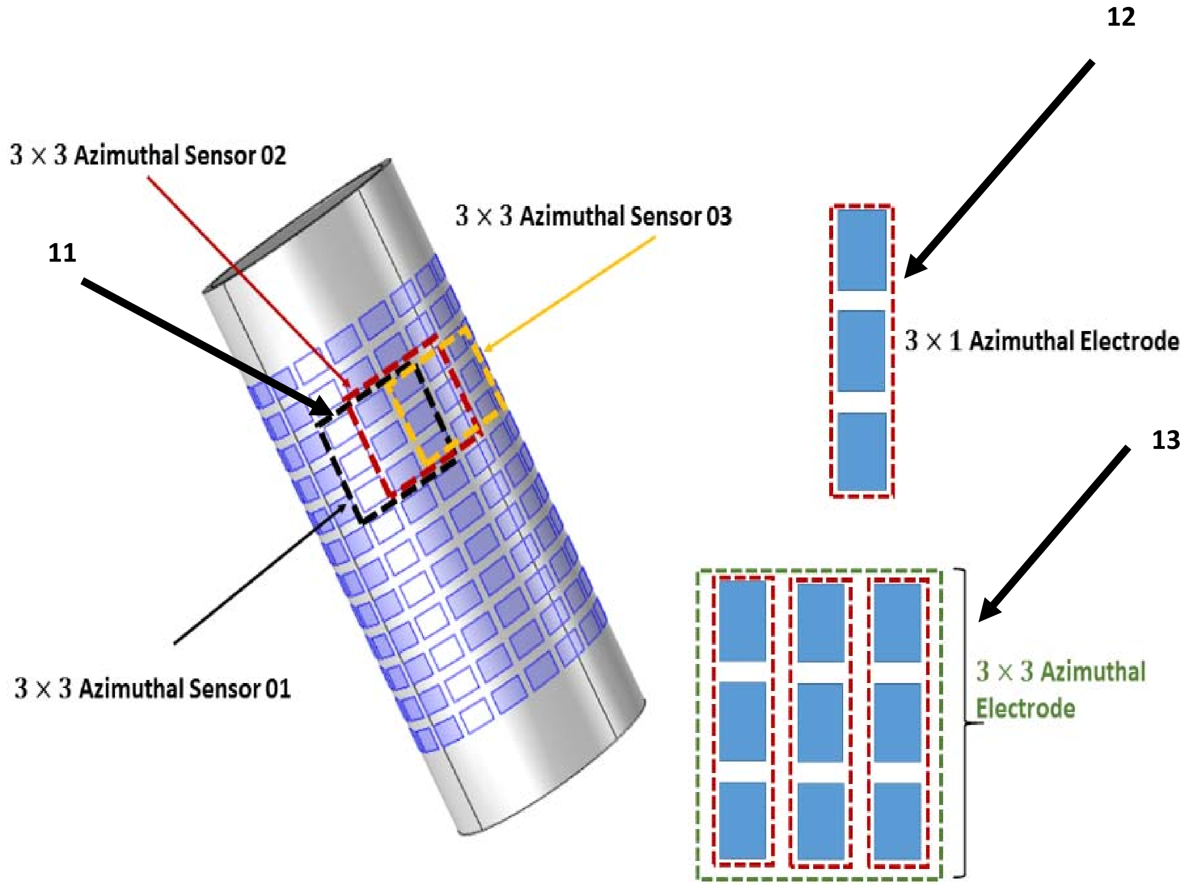


Space Adaptive Excitation and Reconstruction

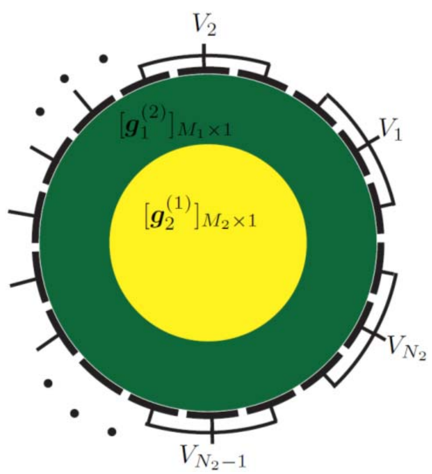
Axial Excitation

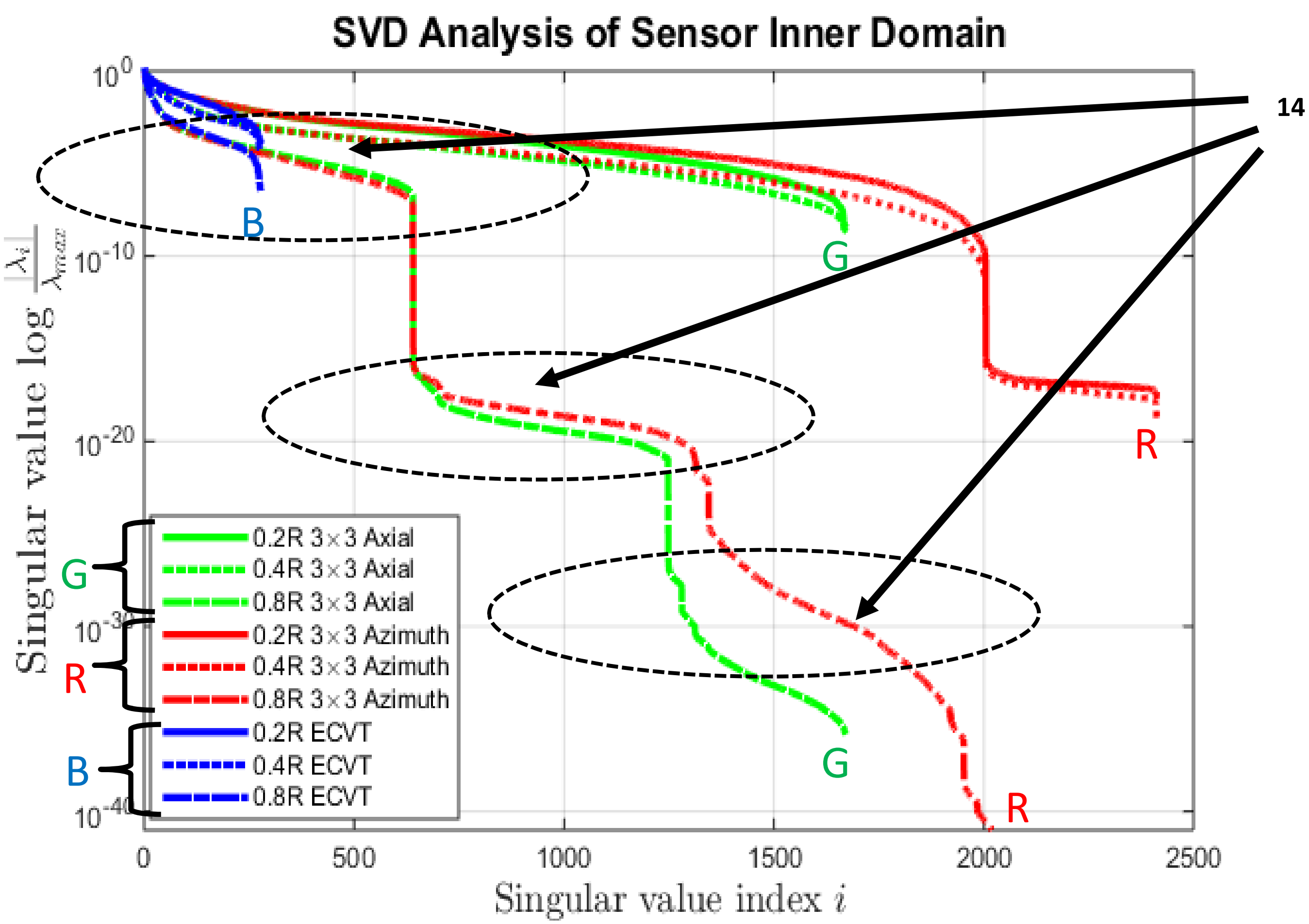


Azimuthal Excitation

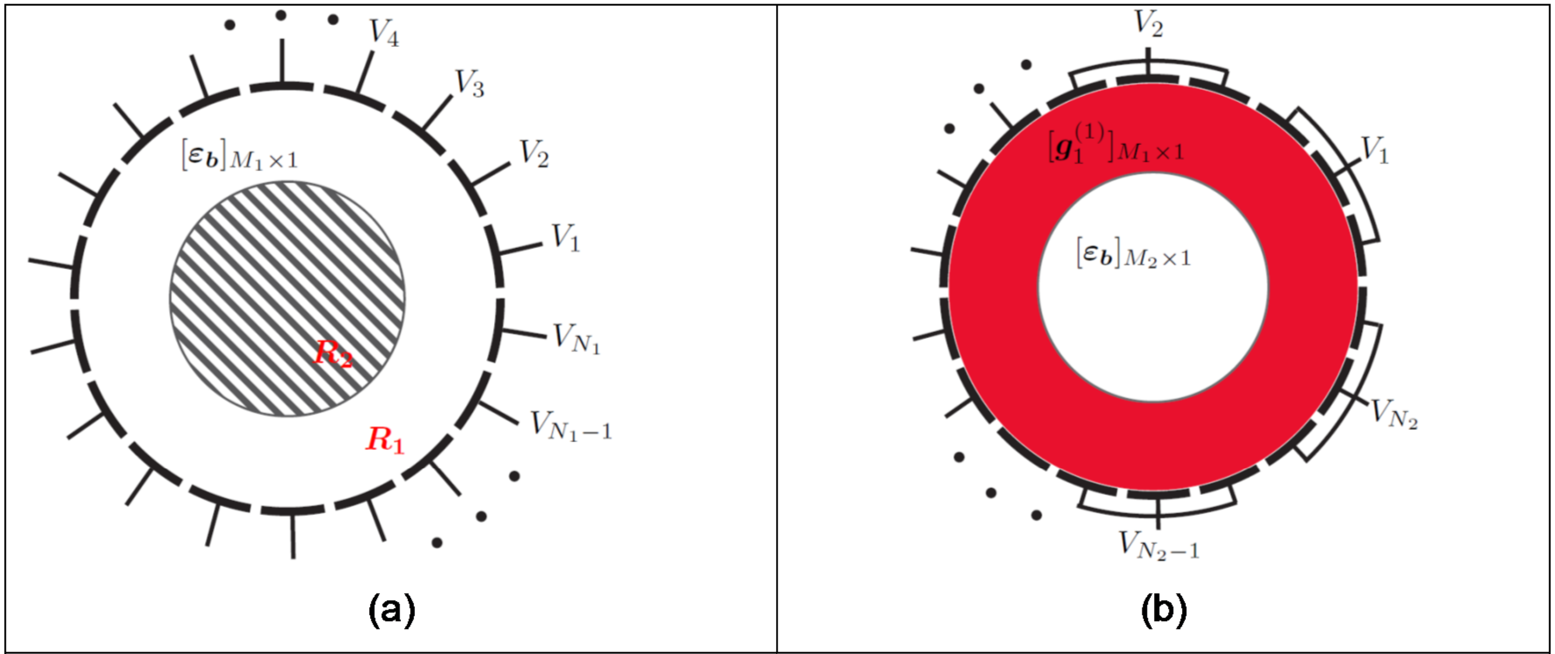


Singular Value Markers





Space Adaptive Reconstruction Technique



Basics of two-step SART: (a) Step 1, where acquisition mode 1 is used to image the periphery region indicated in white color. (b) Step 2, where acquisition mode 2 is used to image the center region in white color using the reconstruction results of Step 1 in red color as input (a priori) data. Multiple steps, involving more than two spatial regions, can also be employed.

Singular Value Markers

Step 1. The permittivity reconstruction of the outer shell region R_1 can be done by employing LBP (for example) and acquisition mode 1, shown in Fig. (a), so that

$$\left[\boldsymbol{g}_{\mathbf{1}}^{(1)}\right]_{M_1\times 1} = \left[\boldsymbol{S}_{\mathbf{1}}^{(1)}\right]^T_{M_1\times P_1} [\boldsymbol{C}_{\mathbf{1}}]_{P_1\times 1}$$

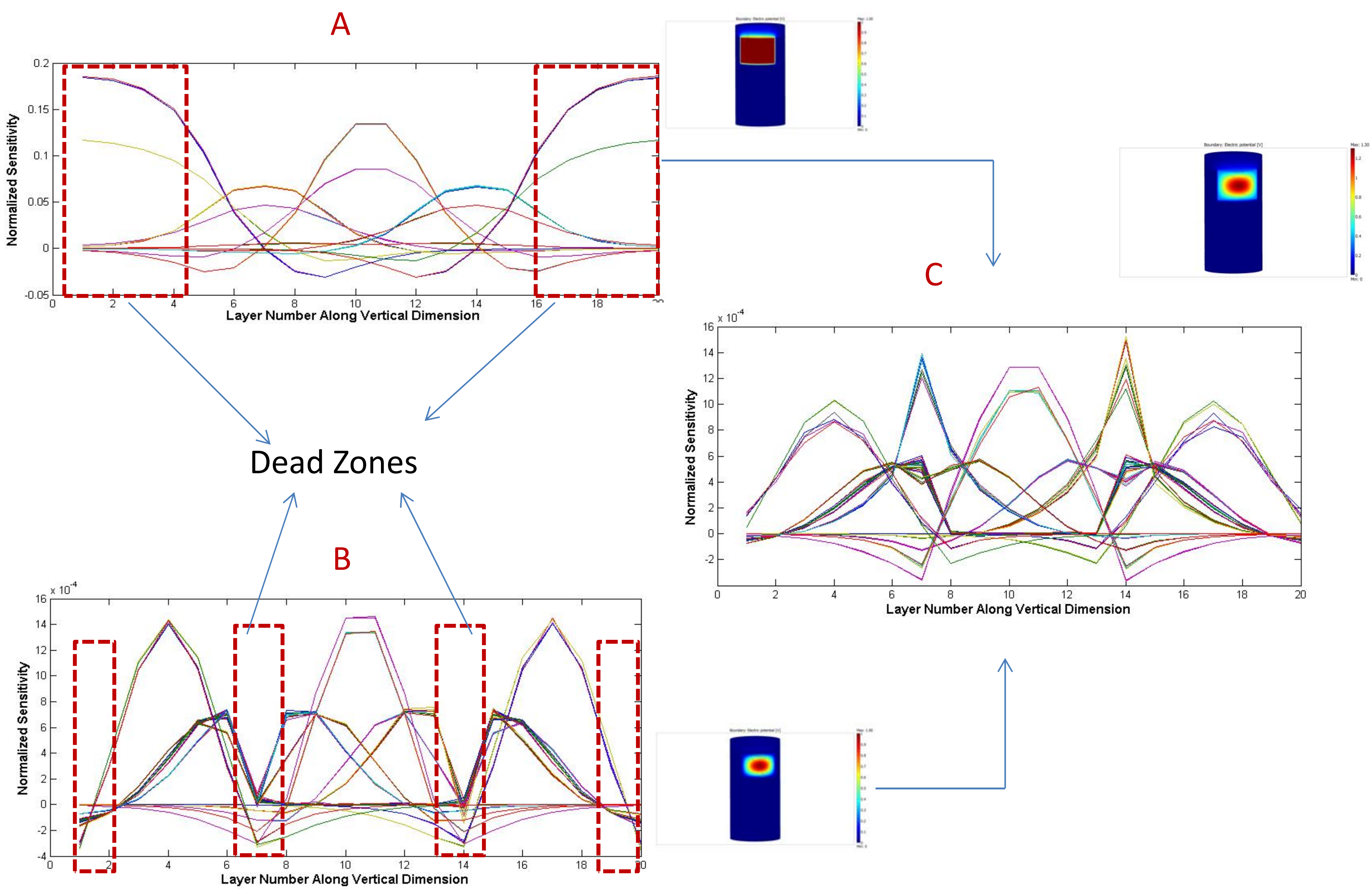
Step 2. The permittivity reconstruction of the center region R_2 can be achieved by employing the LBP method and by using the reconstructed permittivity profile of R_1 region found in Step 1 as a 9input) background permittivity in the forward solver together with acquisition mode 2, shown in Fig. (b). Assuming again LBP reconstruction, this can be expressed as

$$\left[\boldsymbol{g}_{\mathbf{2}}^{(1)}\right]_{M_2\times 1} = \left[\boldsymbol{S}_{\mathbf{2}}^{(1)}\right]^T_{M_2\times P_2} [\boldsymbol{C}_{\mathbf{2}}]_{P_2\times 1}$$

Step 3. After step 1 and step 2, the first iteration of SART is completed with reconstructed permittivity profiles for regions R_1 and R_2, denoted as $\boldsymbol{g}_{\mathbf{1}}^{(1)}$ and $\boldsymbol{g}_{\mathbf{2}}^{(1)}$, respectively. A residual error functional is next evaluated in order to determine the quality of reconstructed permittivity profile as:

$$RRE = \frac{\sum_{i=1}^{P_1} |C_i - C_{1_i}^{(j)}|}{\sum_{i=1}^{P_1} |C_i|}$$

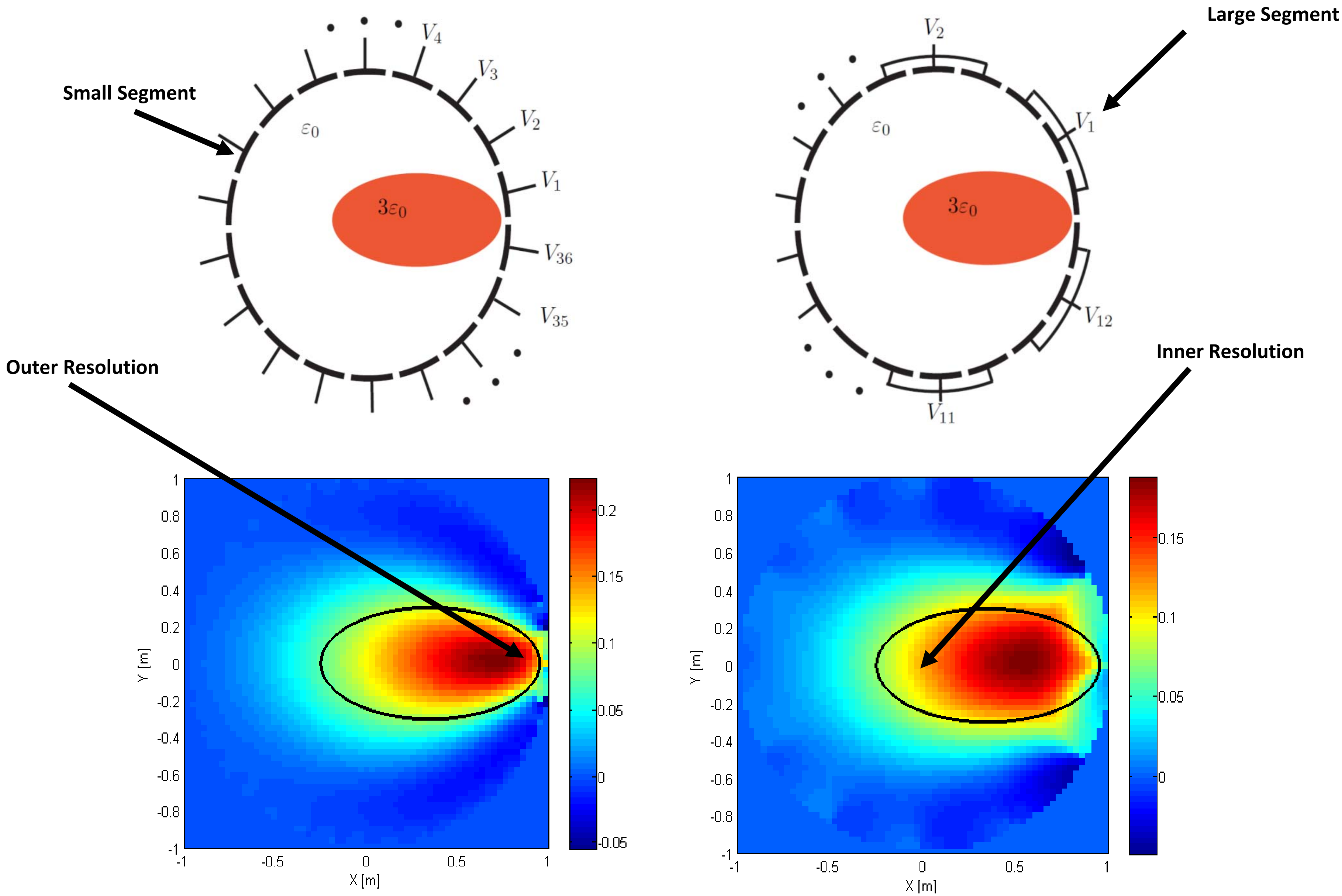
Sensor Design



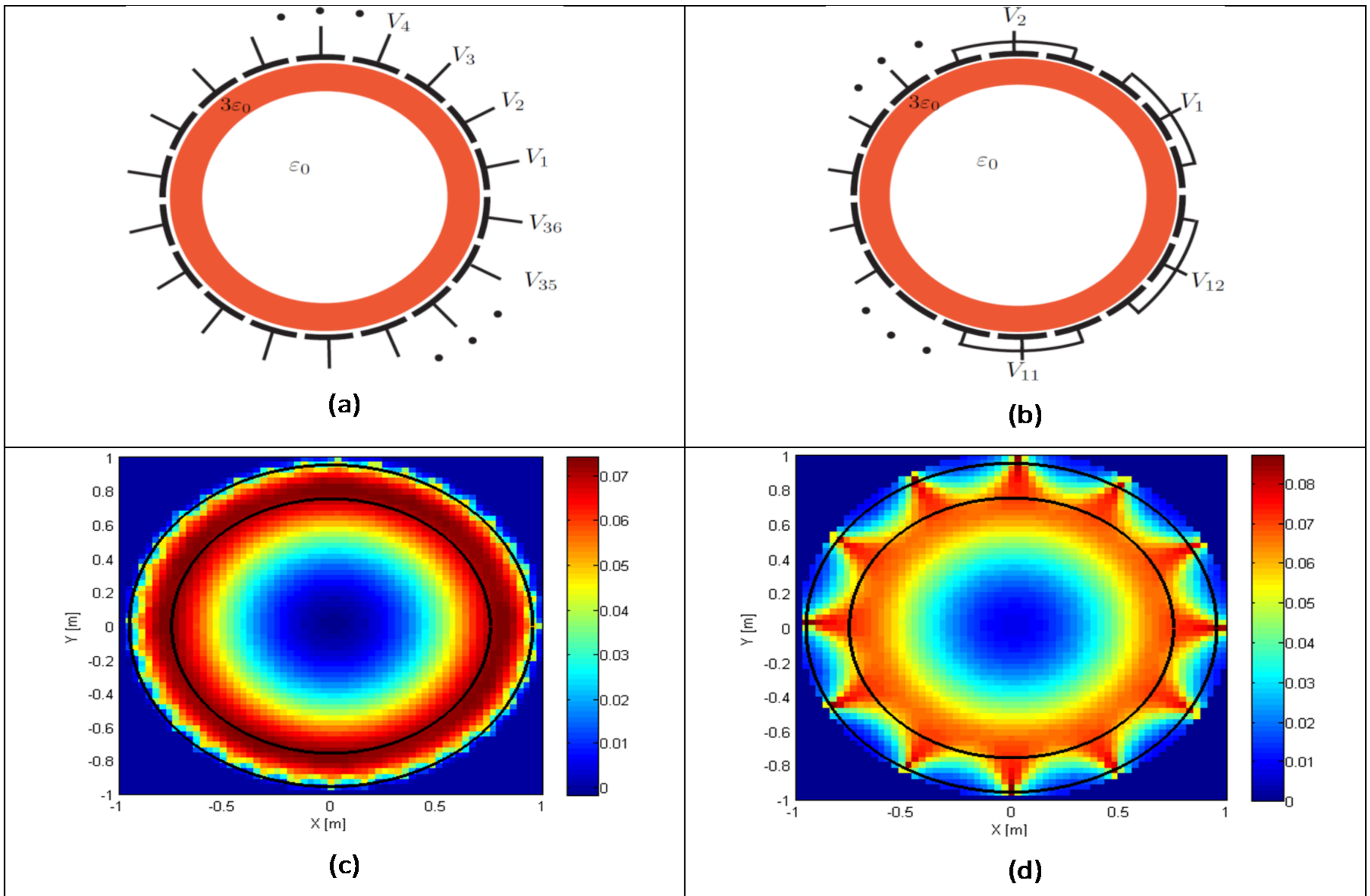
Q. Marashdeh[2], F. Teixeira, and L.-S. Fan, "Adaptive Electrical capacitance volume tomography" *IEEE Sensors,* Volume 14, P 1253-1259, 2014

US Patent Application #: US 13/644,973

SART implementation

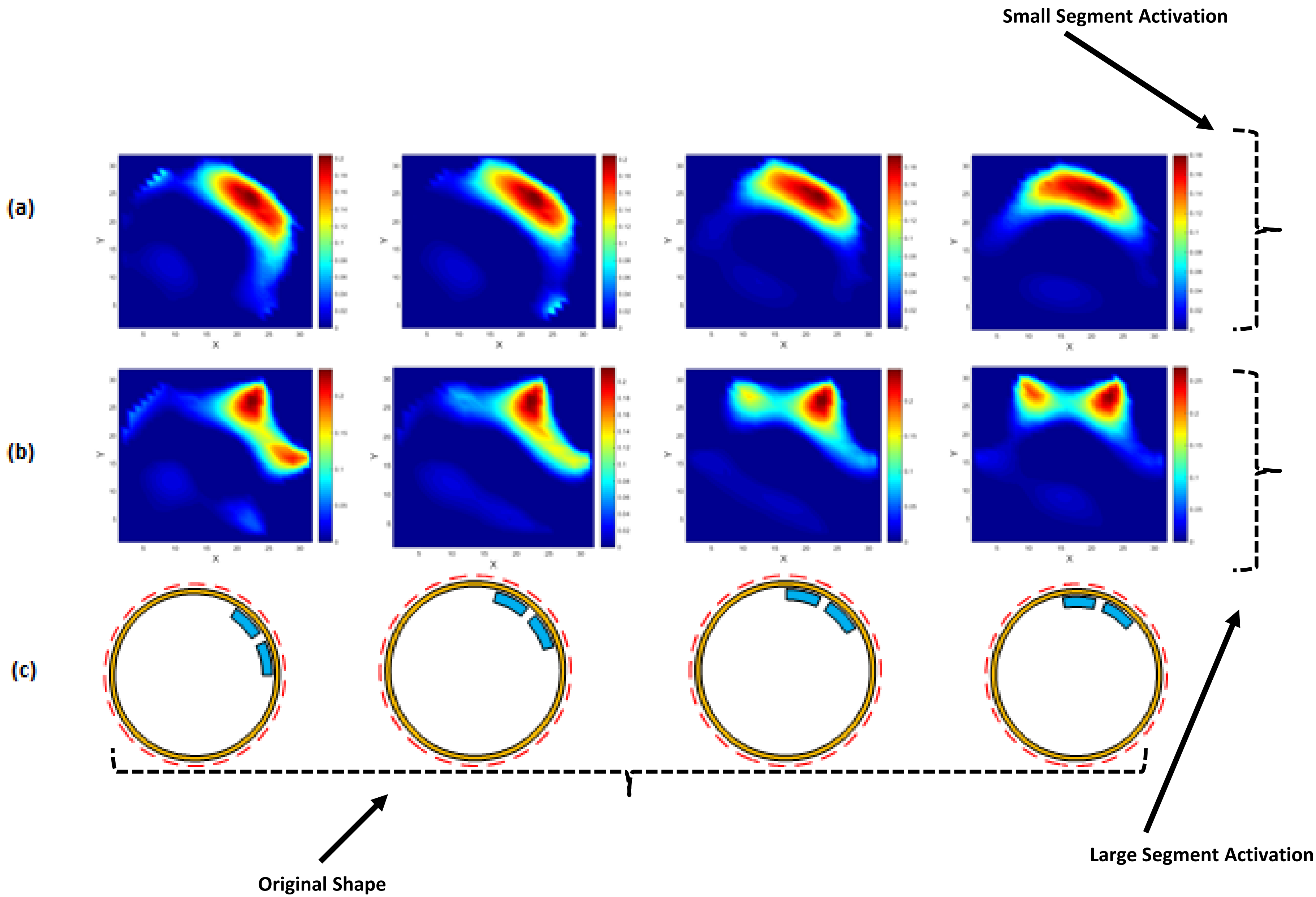


SART implementation



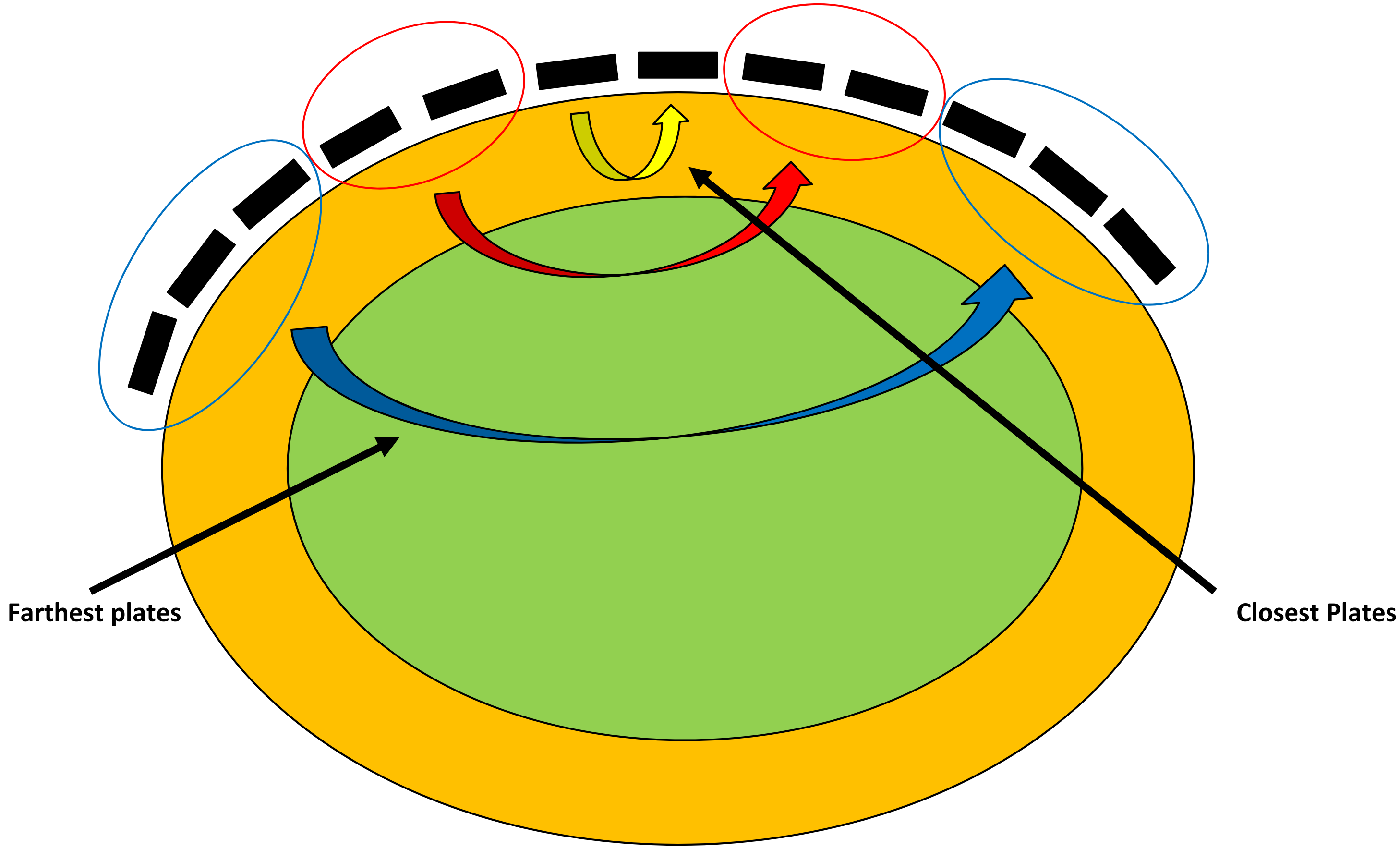
(a) Imaging setup of a ring-shaped object, located at r=0.85m and with thickness is 0.2m, with 36 capacitor plate segments, where the plates are placed around in a 1 m radius circle around the imaging domain with 2^{o} separation between each plate. (b) Simulation setup for the same ring object with 12 synthetic plates composed of 3 segments each. (c) Image reconstruction result for case (a). (d) Image reconstruction result for simulation case (b).

Example

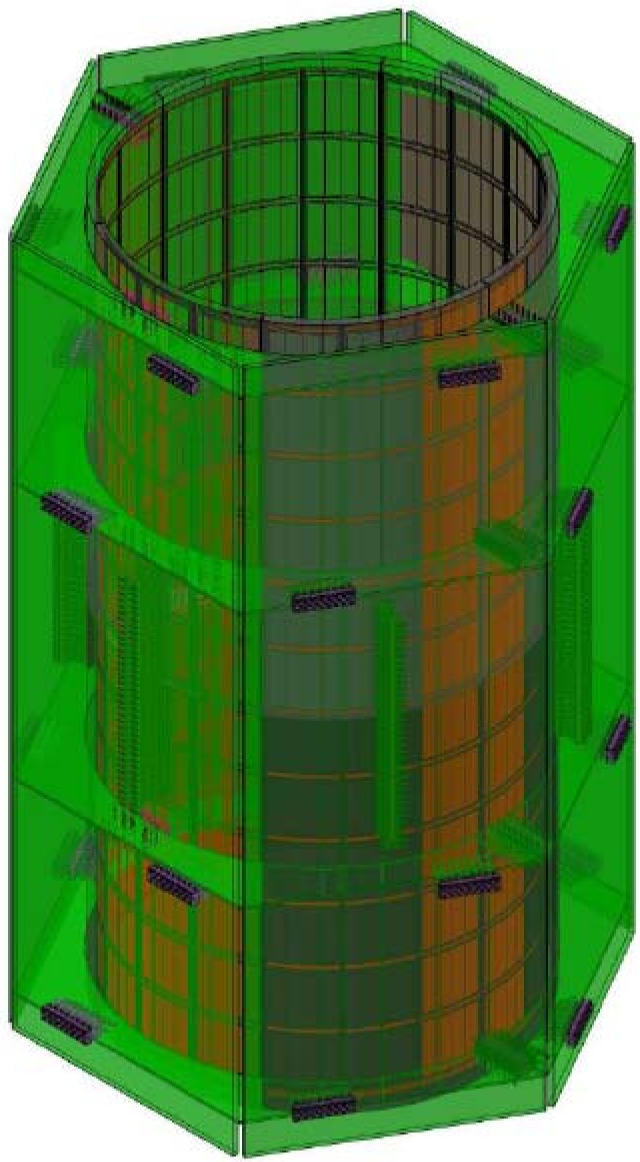


Small Segment Activation
(a)
(b)
(c)
Original Shape
Large Segment Activation

Sensor Geometry and Singular values

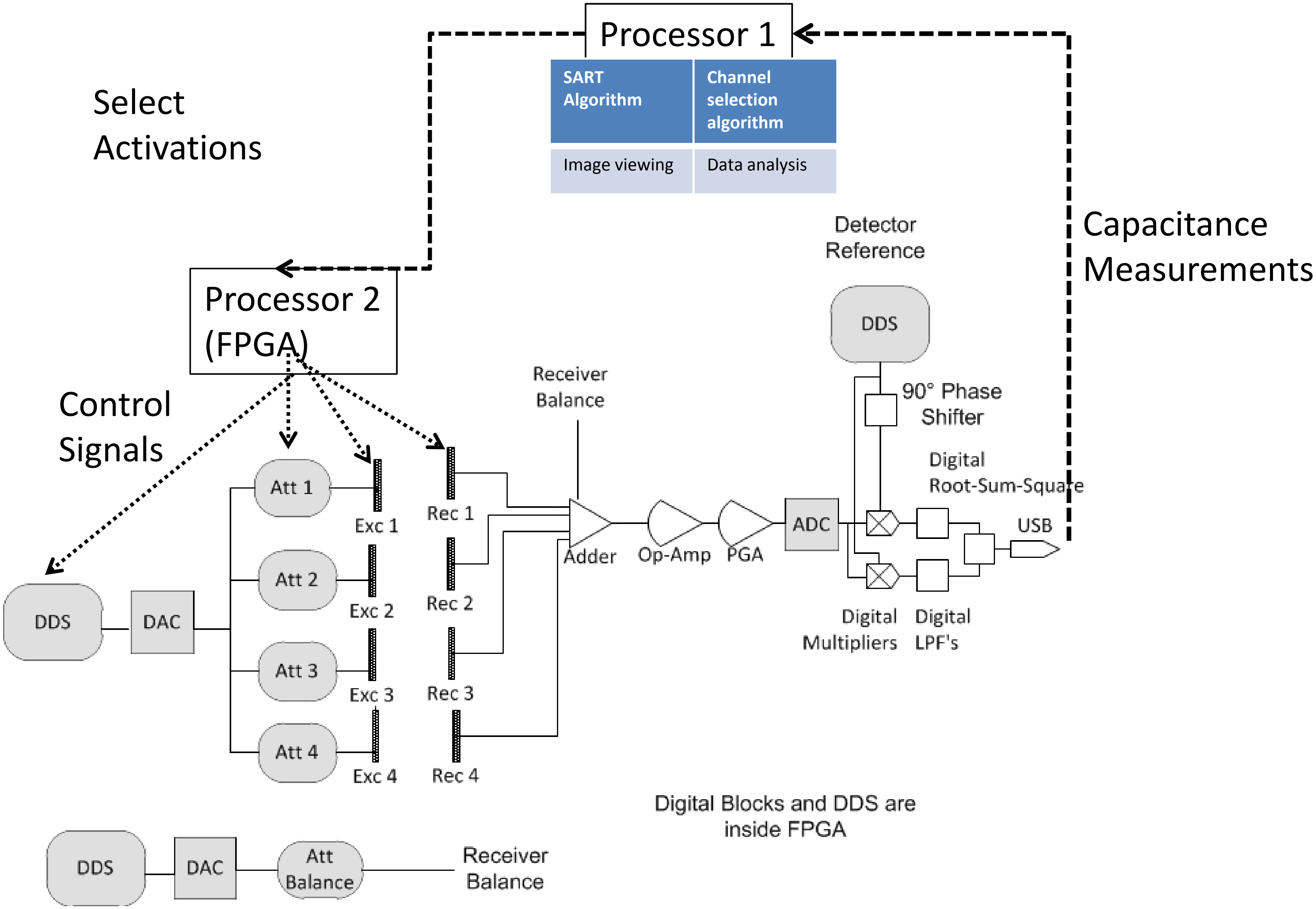


Sensor Design



Cylindrical
216 segments
Modular Acquisition
Variable voltage excitation
Programmable voltage patterns

Activation Scheme



Phase II 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*

Tasks	Project period (Quarter)							
	1	2	3	4	5	6	7	8
Task 1	■							
Task 2	■	■	■	■				
Task 3	■	■	■	■	■			
Task 4	■	■	■	■	■			
Task 5	■	■	■	■	■			
Task 6						■	■	■
Task 7	■	■	■	■	■	■	■	
Task 8					■	■	■	
Task 9							■	■
Task 10						■	■	■
Task 11								■

Phase II Milstones

Year 1 Milestones:

1. Finalize AECVT sensor design- end of 2nd quarter.
2. Development of software for SART reconstruction technique- end of 4th quarter.
3. Fabrication of adaptive data acquisition system- end of 5th quarter.

Year 2 Milestones:

1. Fabrication of AECVT sensor- end of 5th quarter.
2. Finalize image reconstruction and feature extraction- end of 7th quarter.
3. Demonstrate integrated system- end of 7th quarter.
4. Finalize GUI- end of project.
5. Finalize demonstration unit and develop virtual experience- end of project.

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
- Feasibility of AECVT was established in Phase I effort.
- In this Phase II, realization of a full AECVT system for high resolution solid mass flow gauging will be realized.