High Resolution Electrical Capacitance Volume Tomography with Applications to Multi-Phase Flow Systems

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Introduction

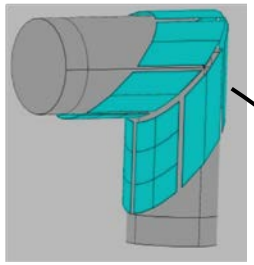
- Electrical Capacitance Volume Tomography (ECVT) is a 3D imaging technique for Multi-phase flow imaging.
- ECVT is among few know non-invasive imaging tools that can be used for commercial applications (low cost, suitable for scale-up, fast, and safe)
- Higher ECVT resolution is required for wider adoption of the technology.
- Adaptive ECVT is a new innovative advancement that responds to the higher resolution requirements and more.

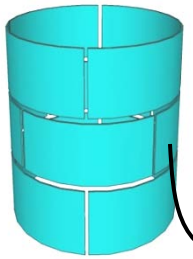
Complete ECVT System

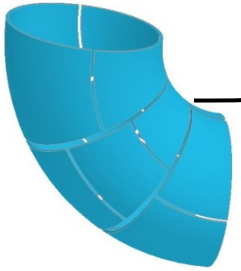
Sensors

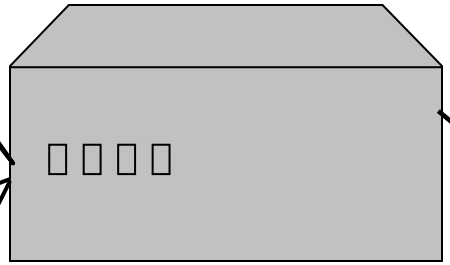
Data Acquisition

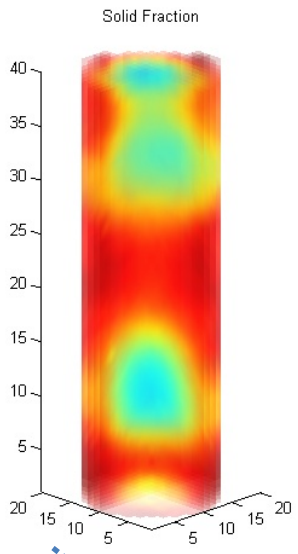
Reconstruction& Viewing

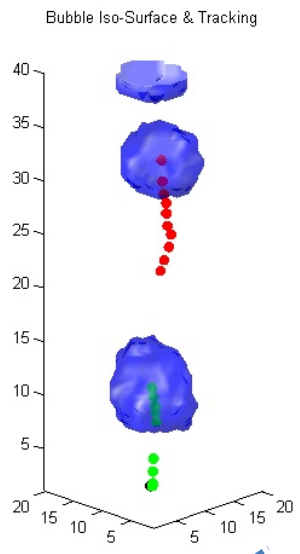


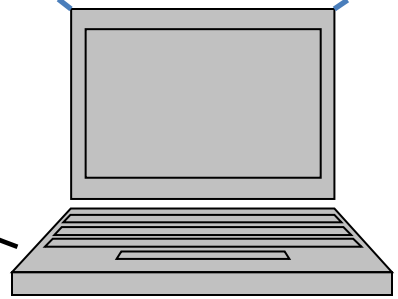






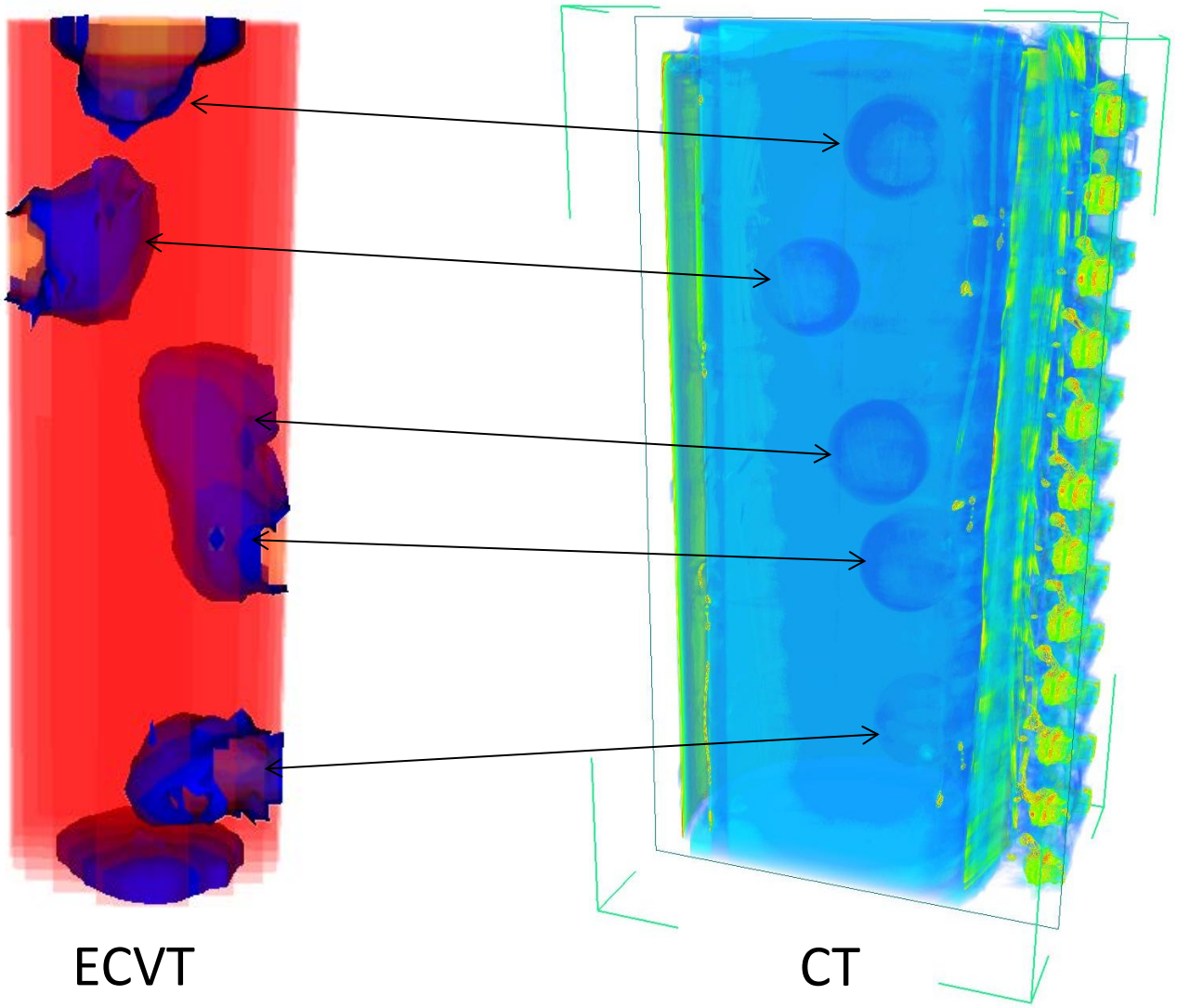






CT Scanned ECVT

Ping pong balls in a bed of 185um glass beads.

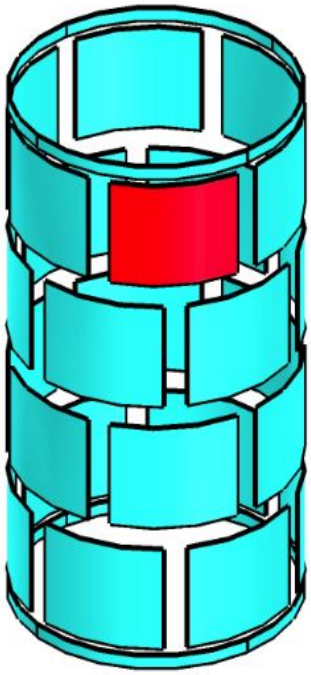


ECVT

CT

Courtesy of DOE NETL

High Resolution Through Increased Number of Plates



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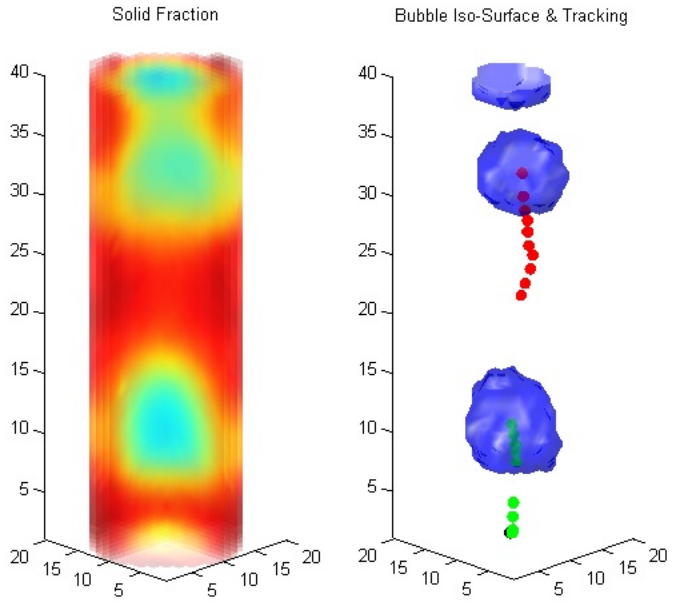


Sensor→

Design & Number of Channels

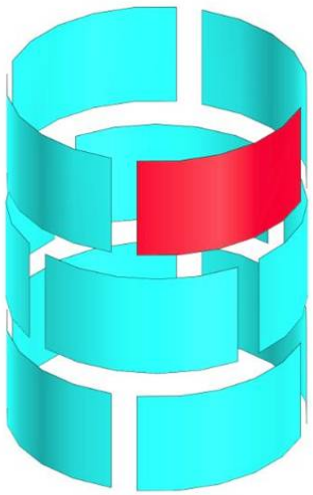
DAS→

Number of Channels & SNR

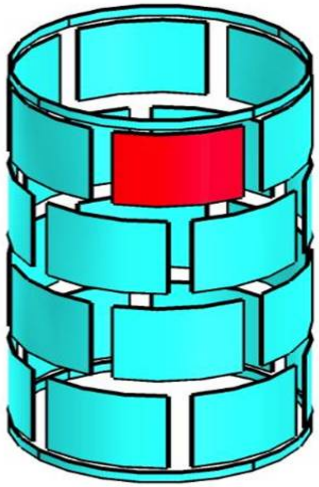
Reconstruction→

Algorithm , Number of Channels & Parameters

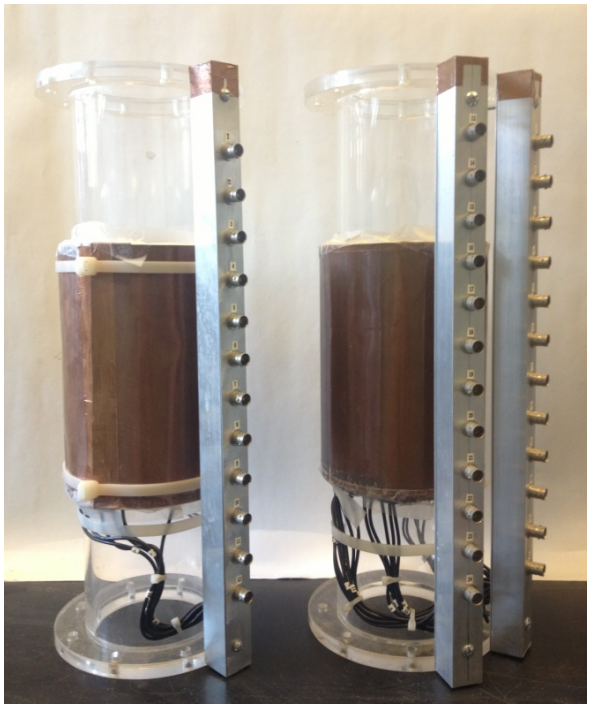
Two Sensors Under Investigation: 12 & 24 Channels



12 channel Sensor

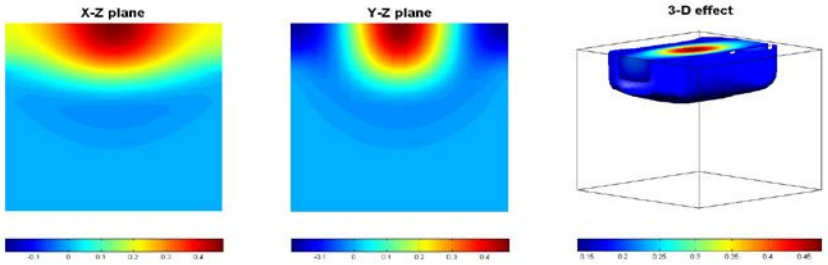


24 channel Sensor

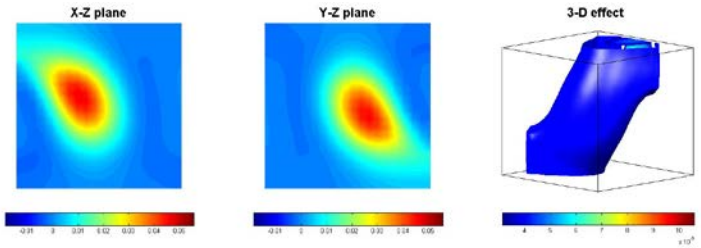


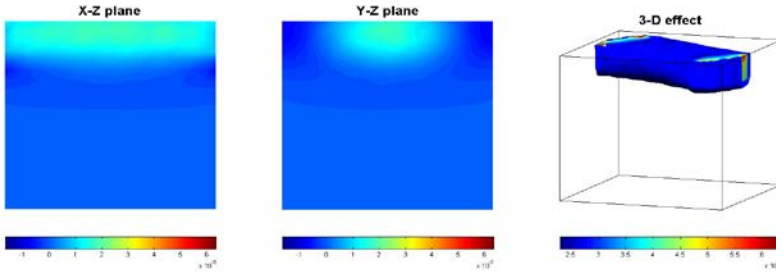
Iso-surface of Sensitivity Matrix

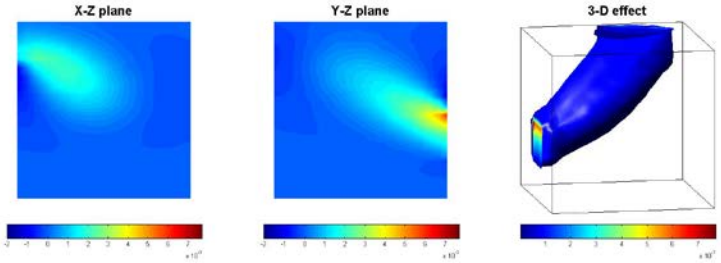
12 Channels



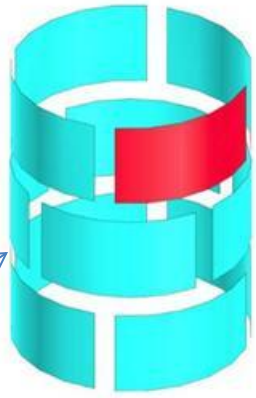
24 Channels





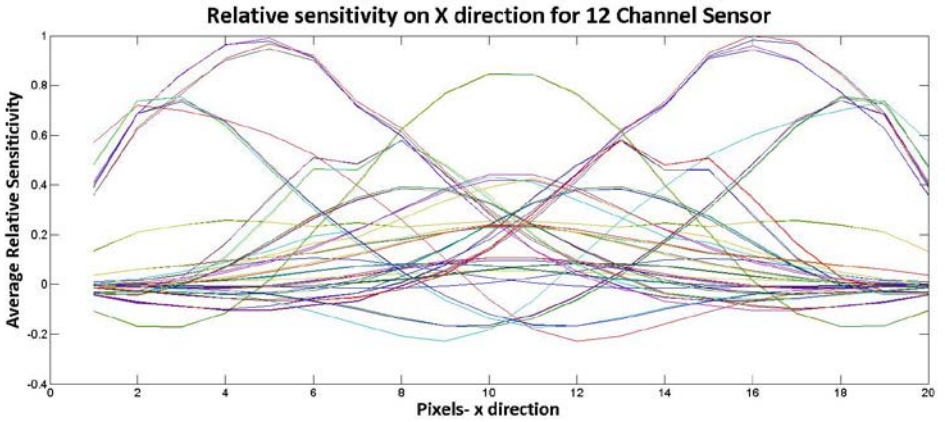


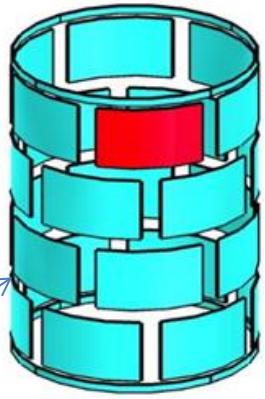
Sensitivity Matrix Along X-Direction



X-direction

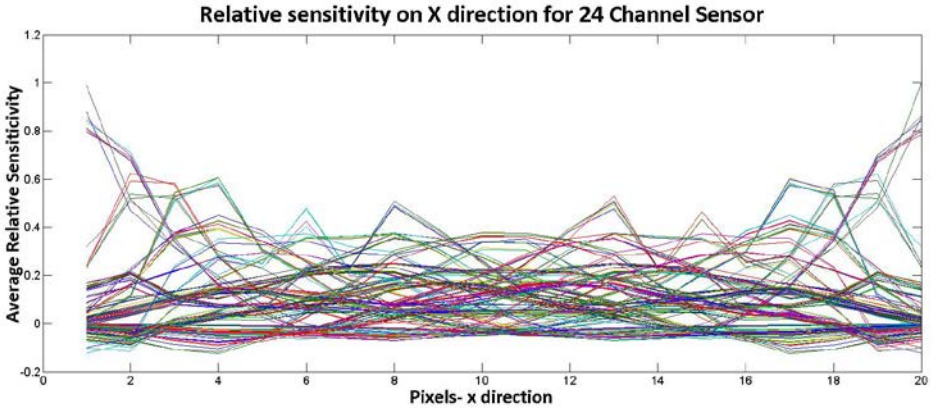
12 channel Sensor





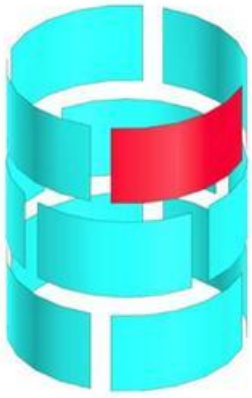
X-direction

24 channel Sensor

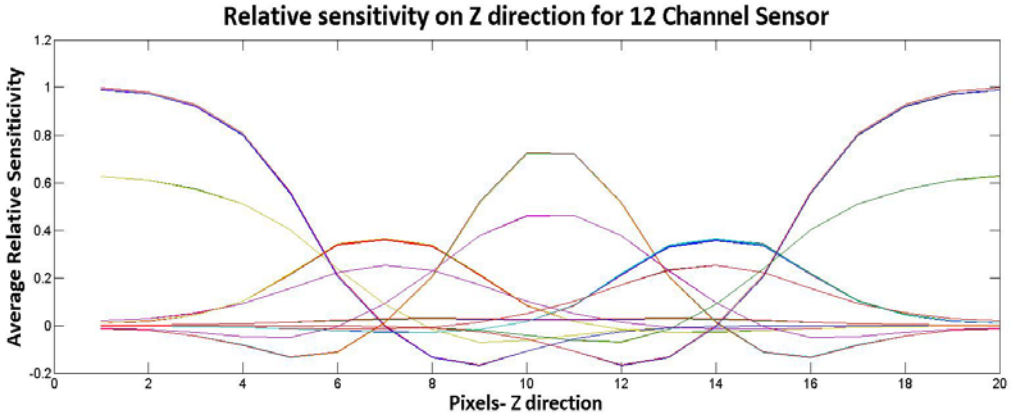


Sensitivity Matrix Along Z-Direction

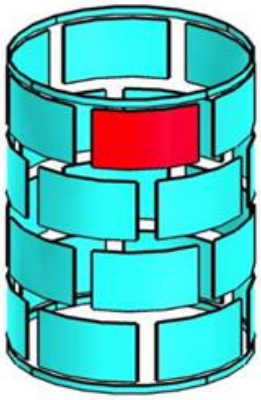
Z-direction



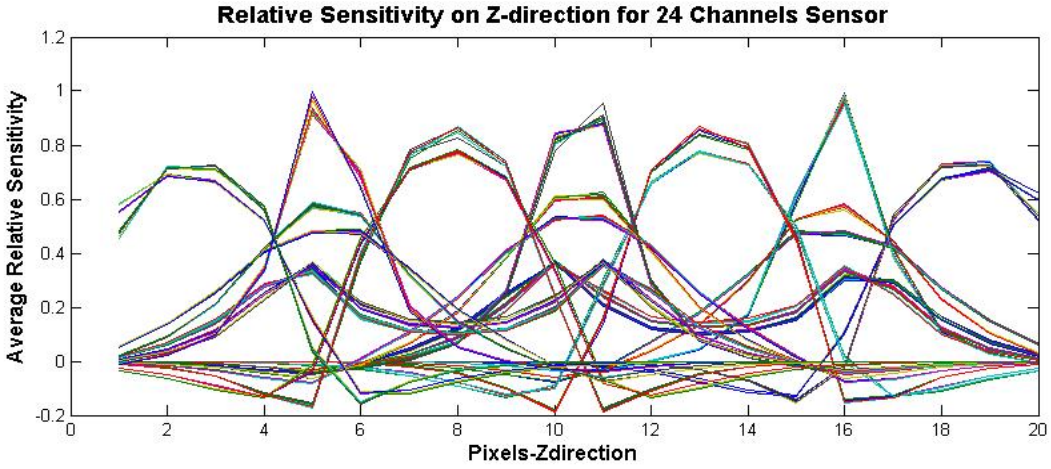
12 channel Sensor



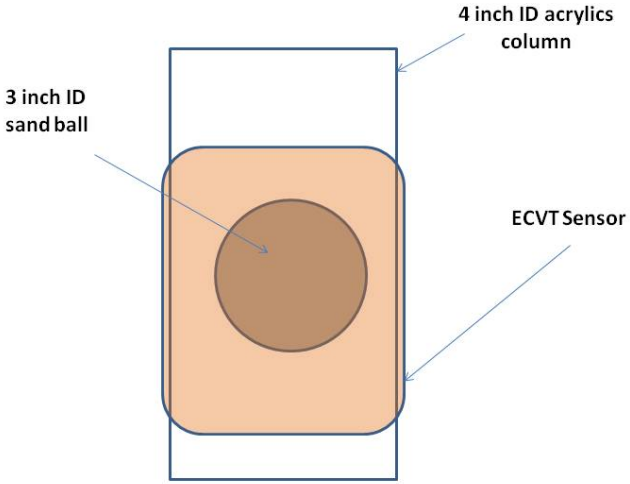
Z-direction



24 channel Sensor



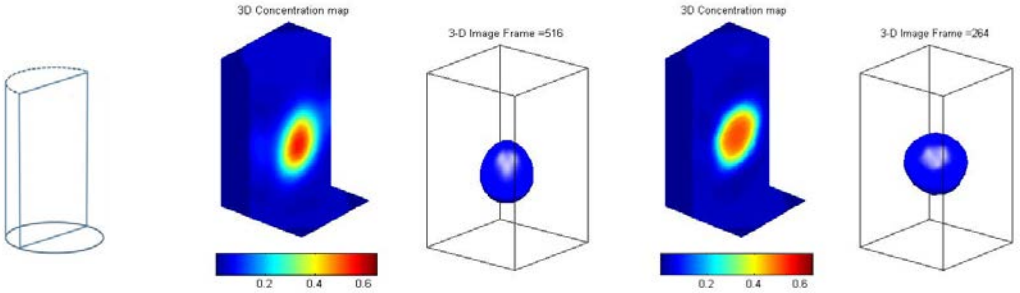
Experiment with Single Object



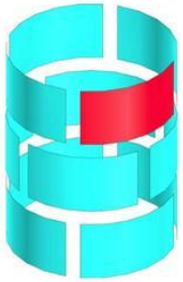
$$V_{ob} = \frac{m}{M} * V$$

$$V = \frac{1}{4}\pi D^2 H = \frac{1}{4}\pi \times 4.5^2 \times 8 = 127.2\ inch^3$$

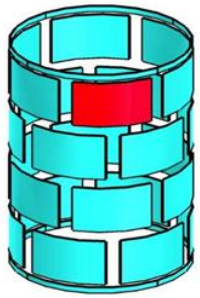
$14.14\ inch^3$



Sensor	12-channel	24-channel	real object
Volume ()	13.56	14.40	14.14
Error (%)	-4.1%	1.8%	_____

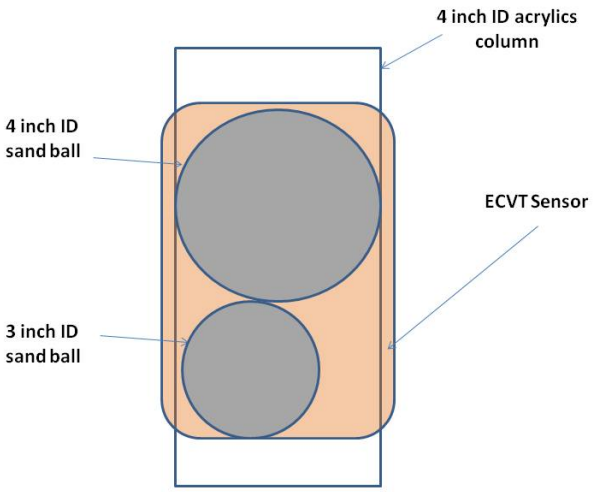


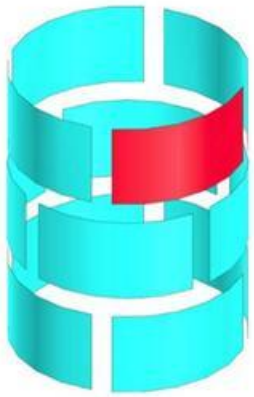
12 channel Sensor



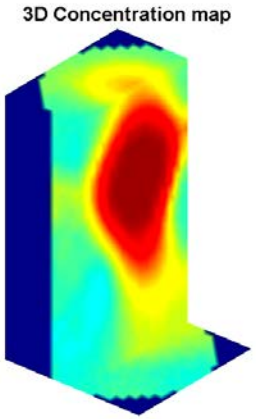
24 channel Sensor

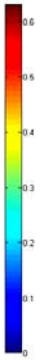
Two Sphere Experiment

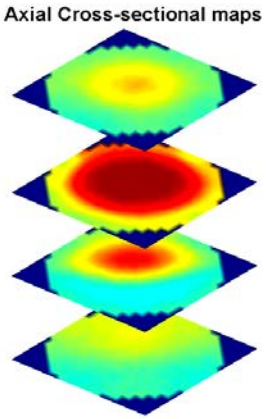


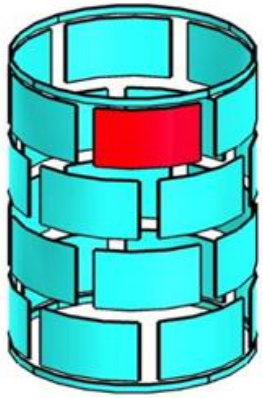


12 channel Sensor

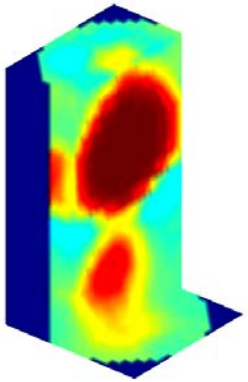


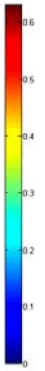


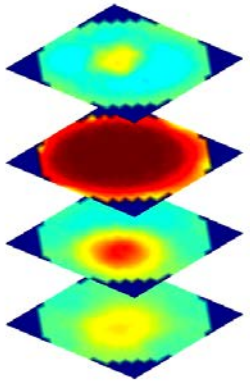




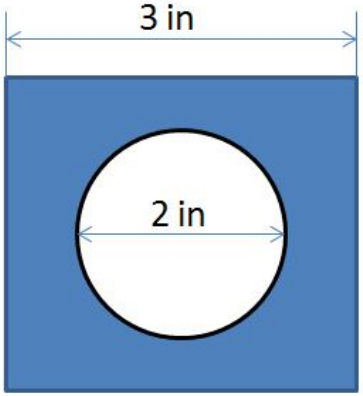
24 channel Sensor

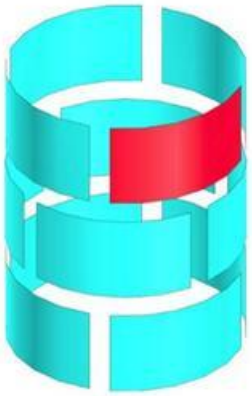






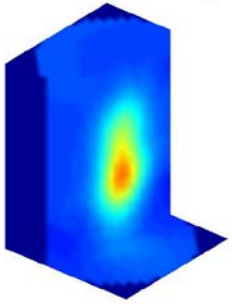
Irregular Shape Experiment

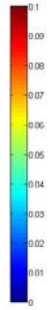




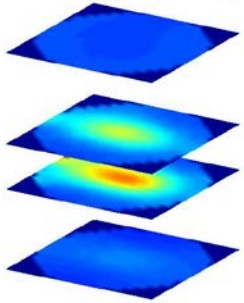
12 channel Sensor

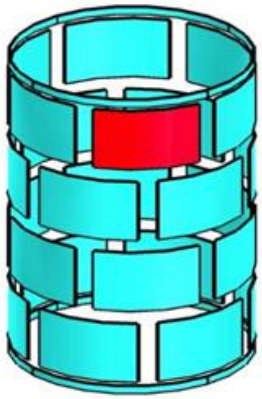
3D Concentration map





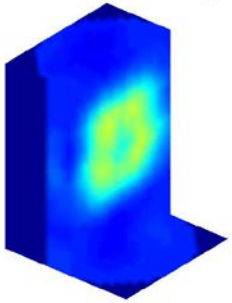
Axial Cross-sectional maps

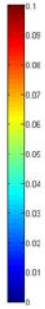




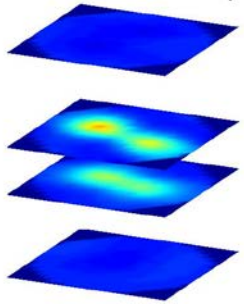
24 channel Sensor

3D Concentration map

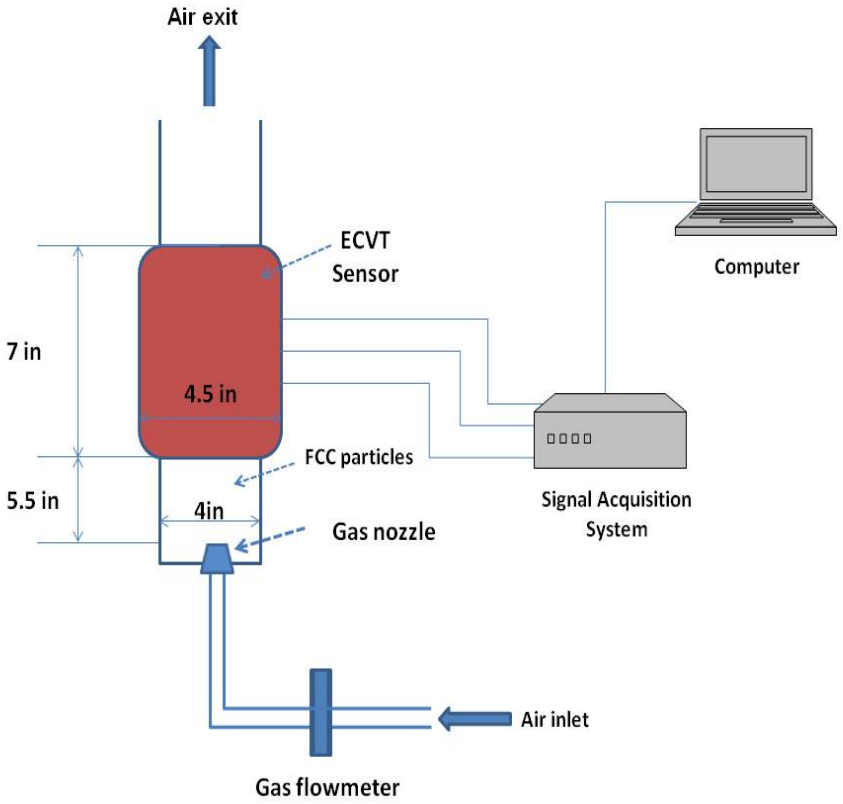


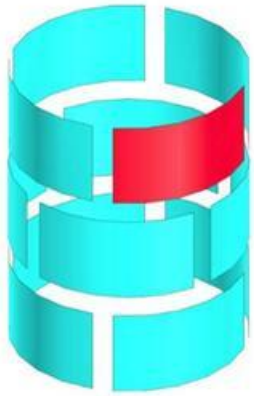


Axial Cross-sectional maps

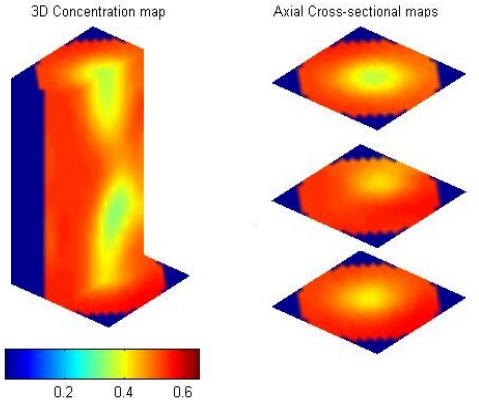


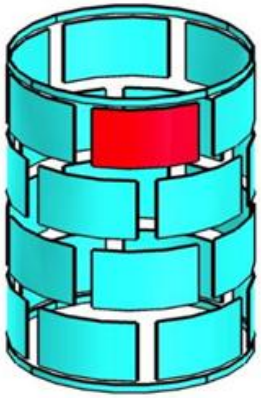
Gas-Solid Experiment



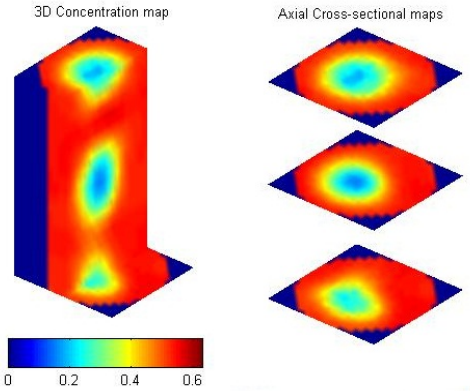


12 channel Sensor

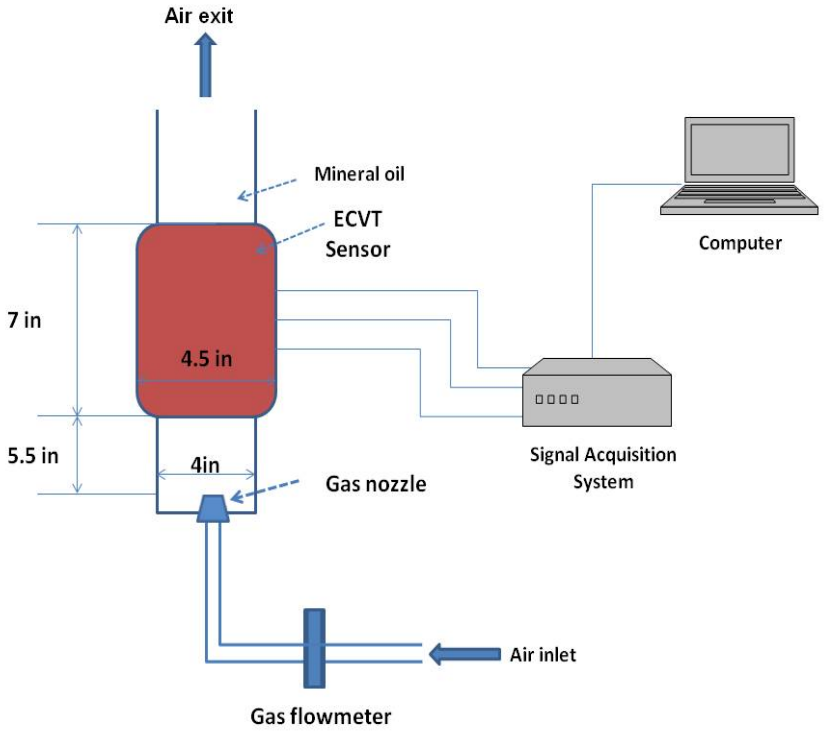


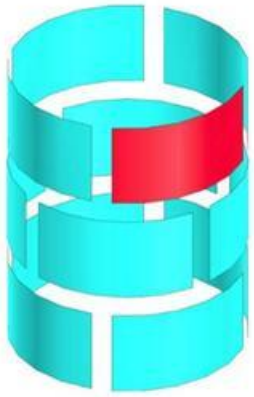


24 channel Sensor

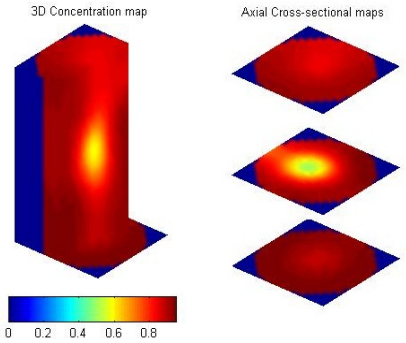


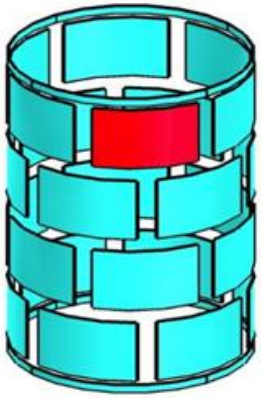
Gas-Liquid Experiment



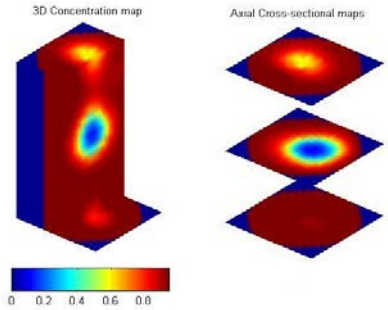


12 channel Sensor

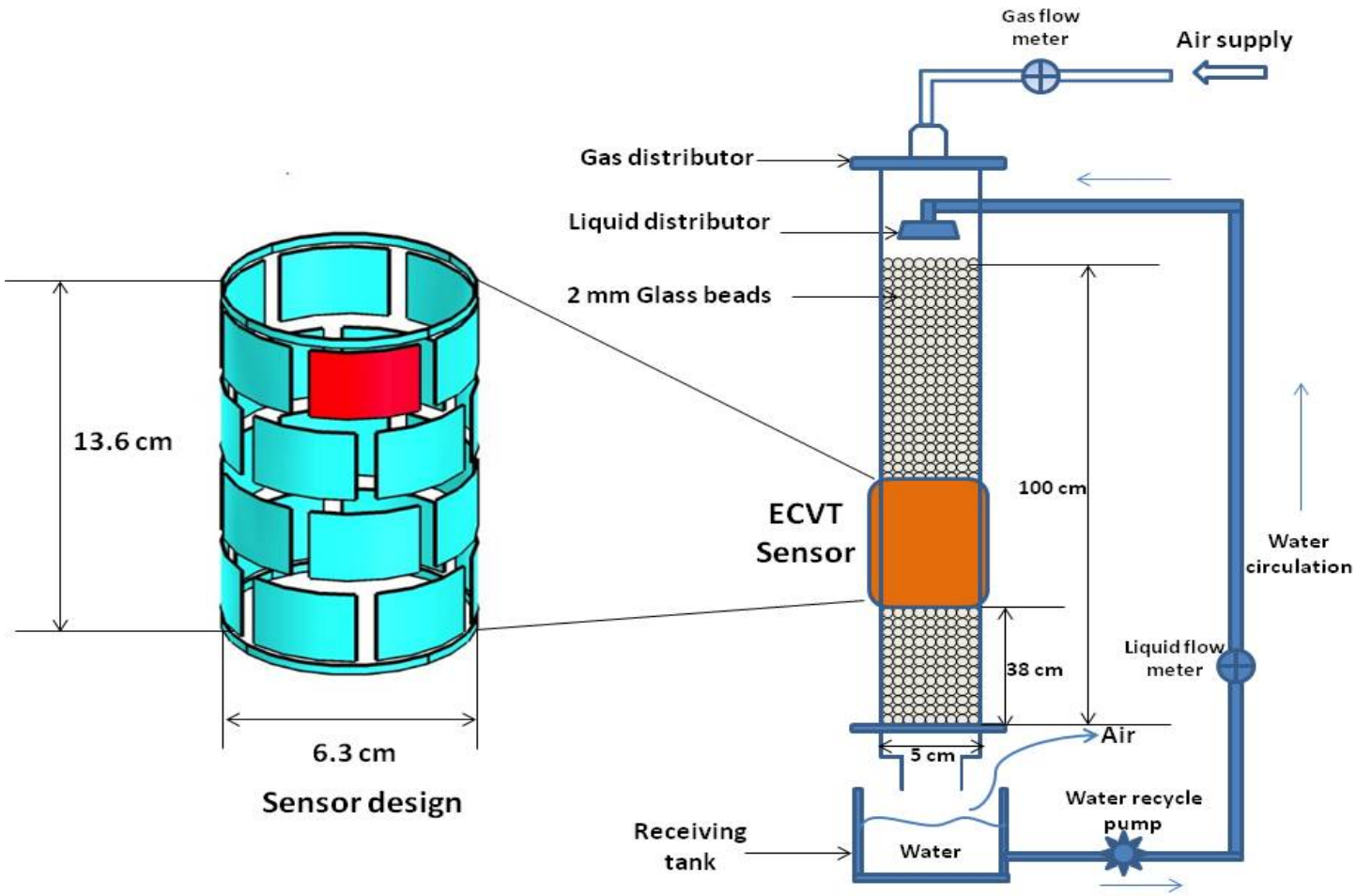




24 channel Sensor

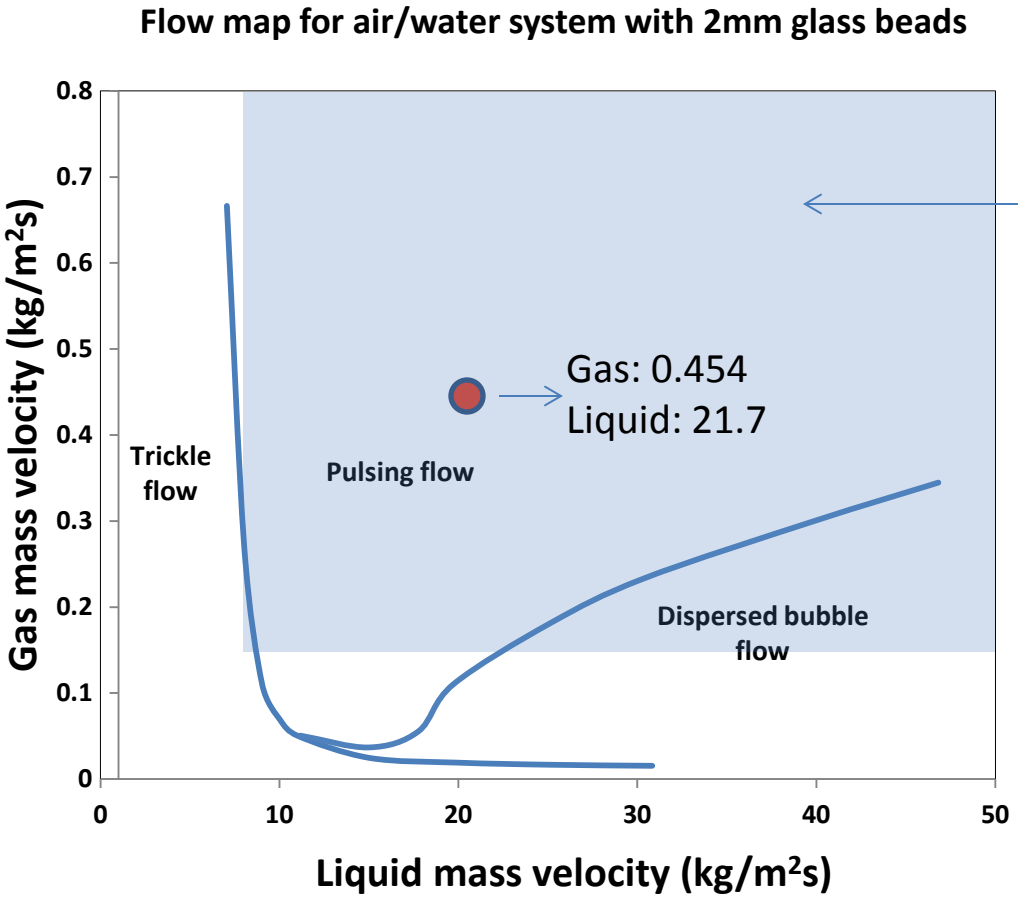


Example : Trickle Bed Pulsing Flow



Liquid: water
Gas: air
Particles: 2 mm diameter glass beads

Flow Regime Map

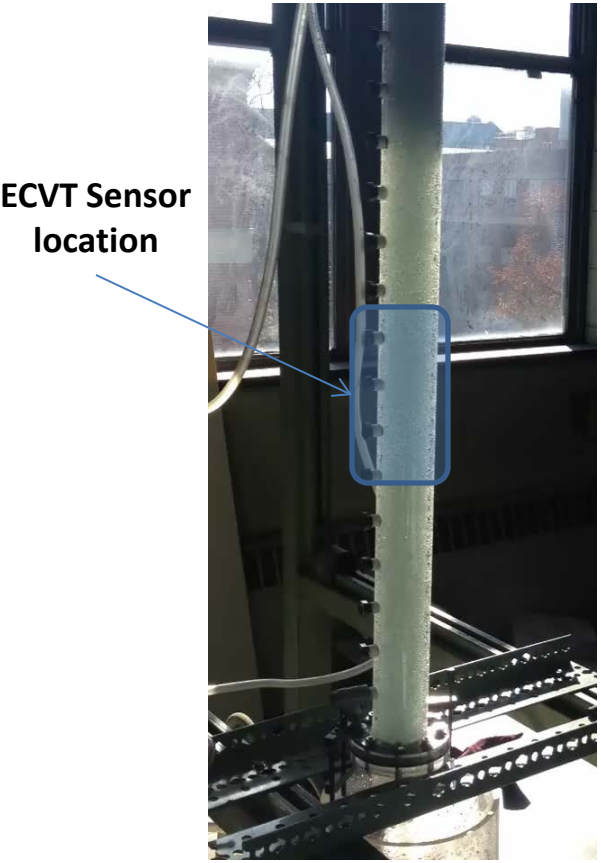


Region of interest, mainly pulsing flow

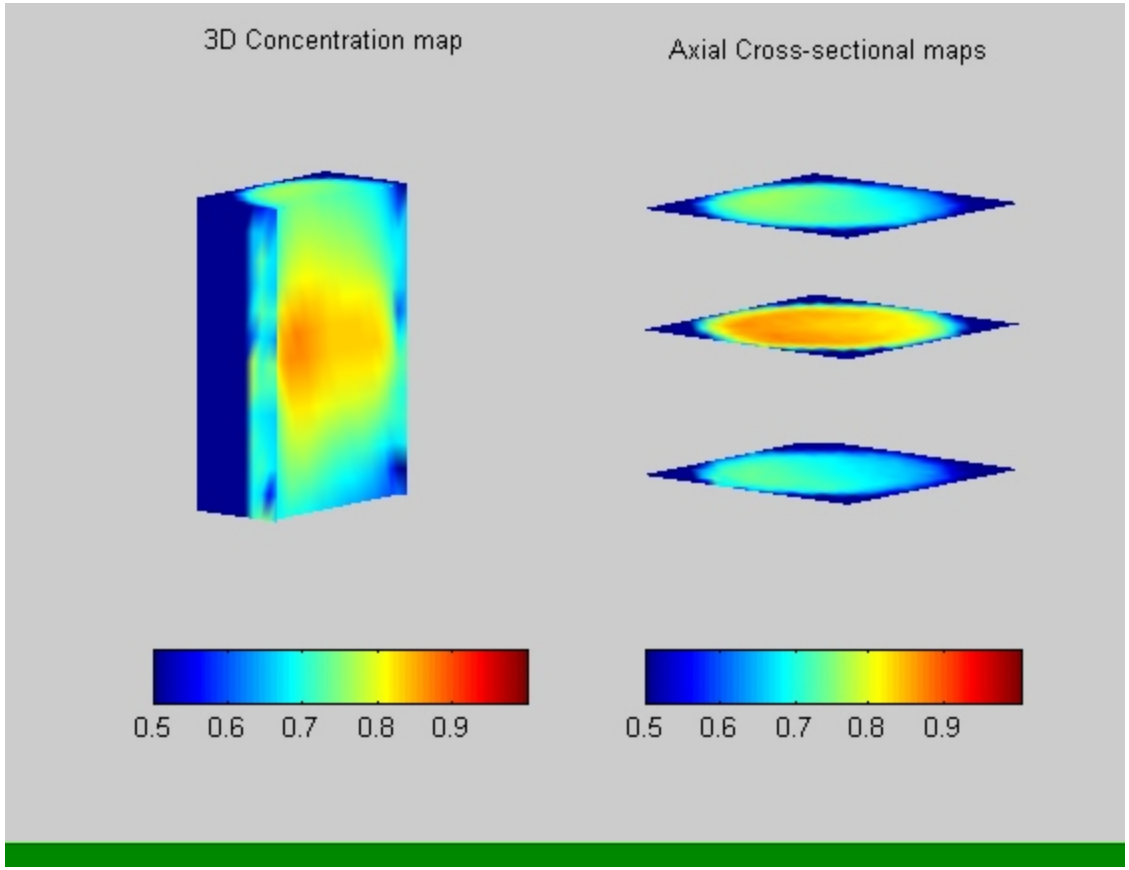
From Guray Tosun's paper

Videos For Pulsing Flow

(G: 0.454 kg/m^{2}s, L:21.7 kg/m^{2}s)



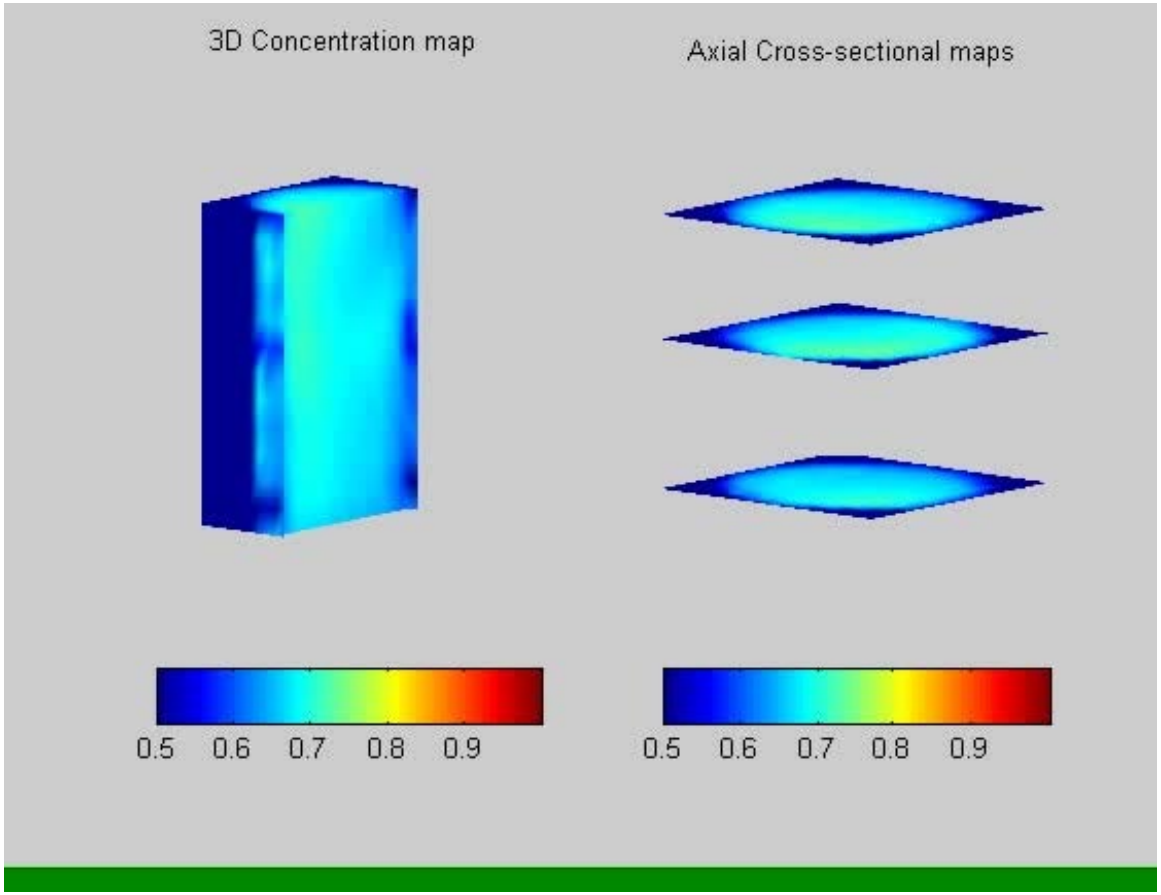
Original video in normal speed



ECVT reconstructed video in normal speed (50fps)

Slow motion (0.1X of original speed, 5fps)

(G: 0.454 kg/m^{2}s, L:21.7 kg/m^{2}s)



Observations:

1.

The pulse & interval lengths are not the same, not in a stable status.

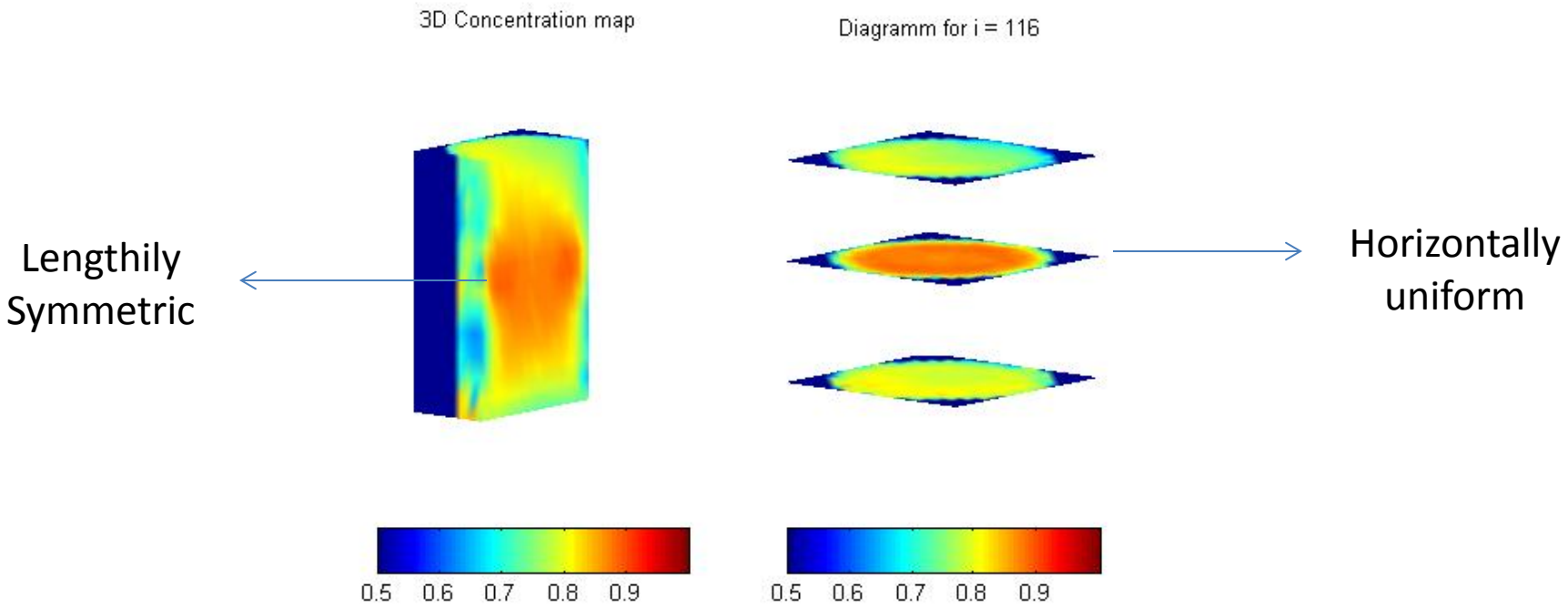
2.

Pulse: Liquid rich region with some gas

Interval: Liquid scarce region with lot of gas

Pulse Shape

Under mild flow rates, the pulse is basically symmetric along the length of the column.



Snap shot of a mild pulse (G: 0.252 kg/m^{2}s, L:24.8 kg/m^{2}s)

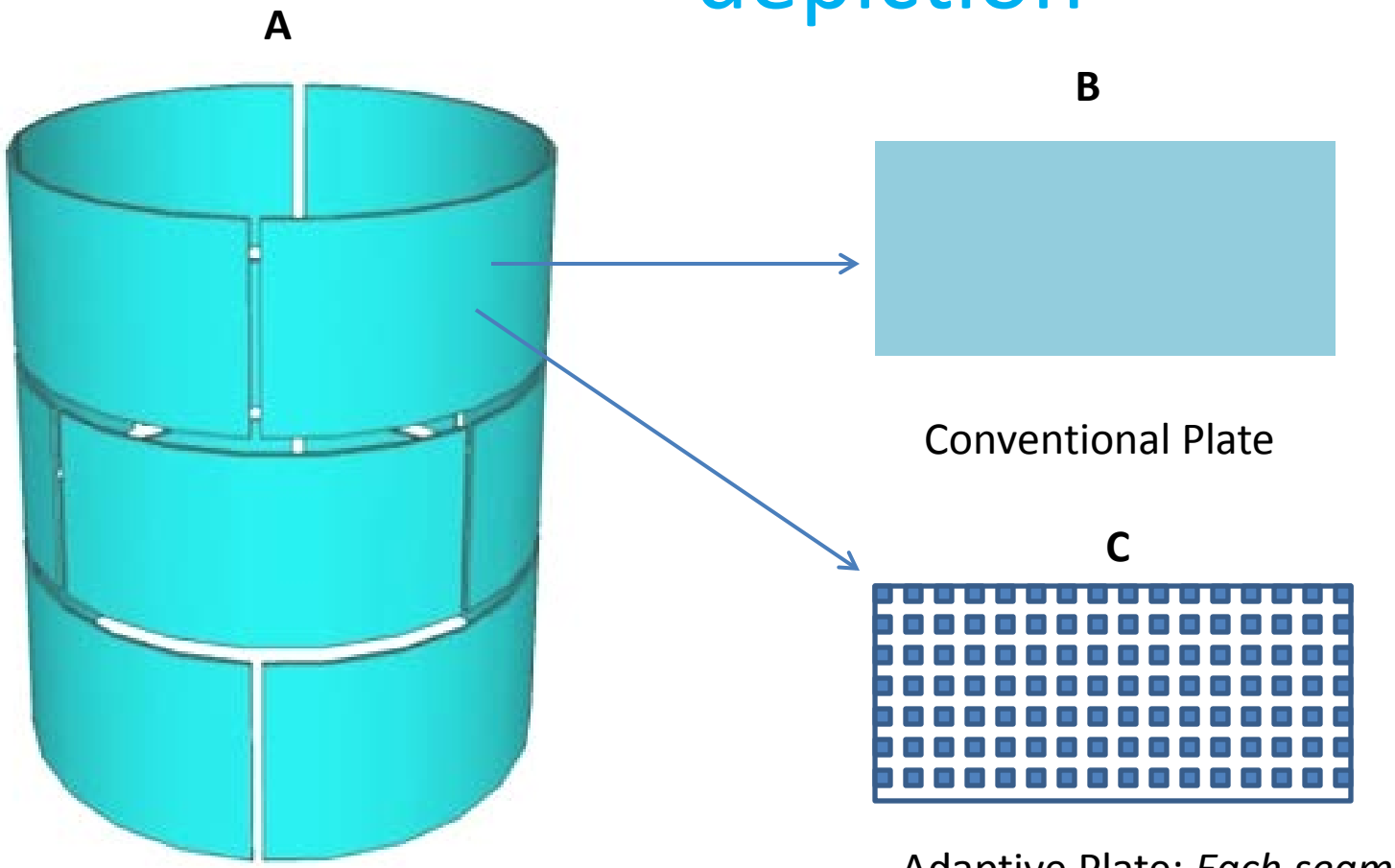
Requirements For Higher Resolution

- Increased number of plates
- High SNR of measuring electronics
- Well-posed reconstruction problem
- Well-conditioned reconstruction problem
- Advanced reconstruction algorithms

A Breakthrough Toward Higher Resolution: **Adaptive Electrical Capacitance Volume Tomography**

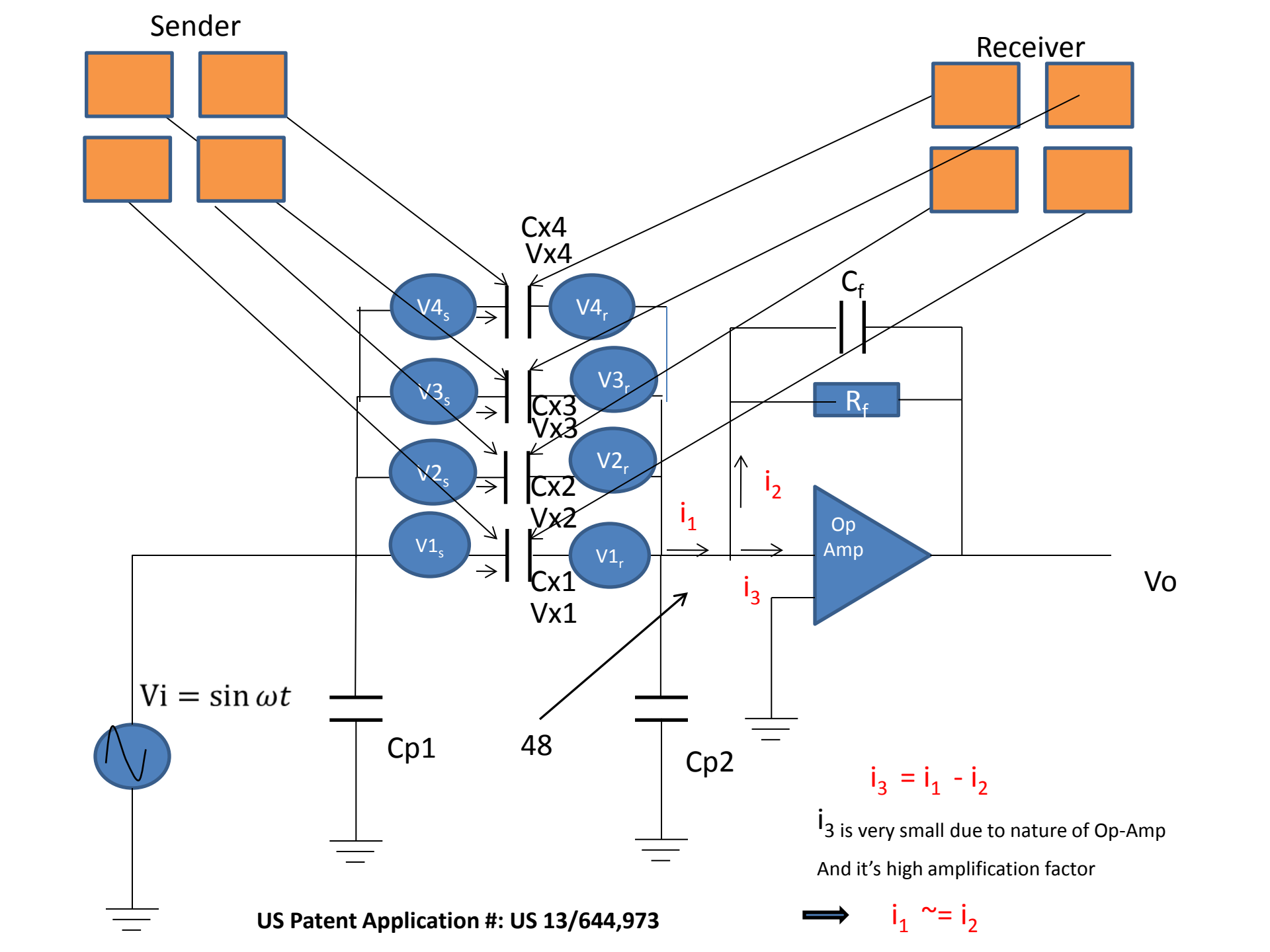
- Virtually infinite number of independent capacitance measurements
- High SNR for accurate measurements
- Zooming!
- Beaming!
- Controlled Resolution!

Adaptive and conventional plates in 2D depiction



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

US Patent Application #: US 13/644,973



$i_3 = i_1 - i_2$

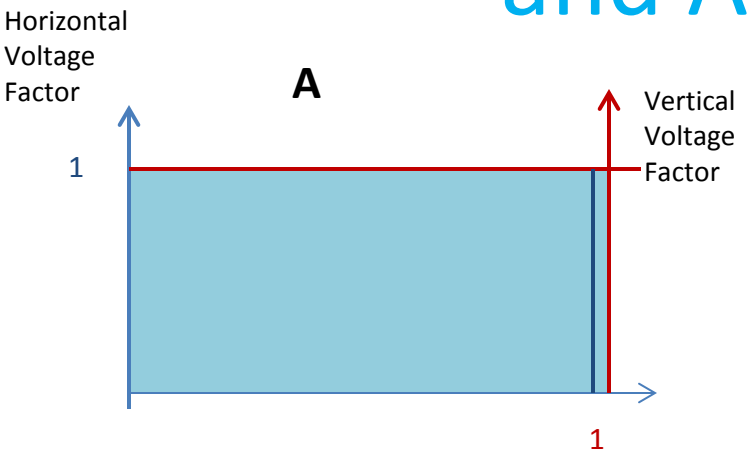
i_3 is very small due to nature of Op-Amp

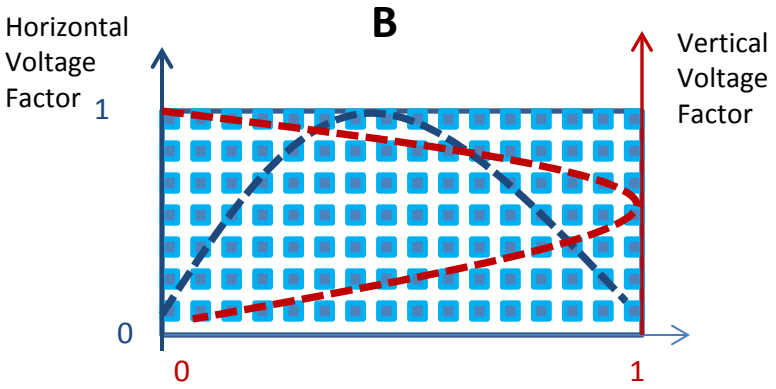
And it's high amplification factor

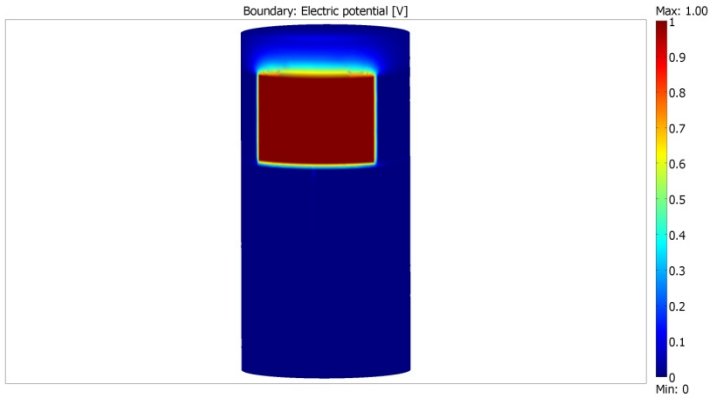
$\Rightarrow$ $i_1 \sim= i_2$

US Patent Application #: US 13/644,973

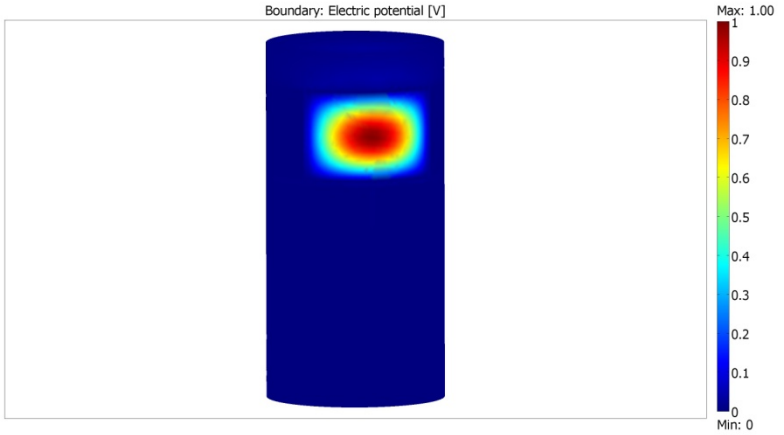
Voltage distributions: Conventional and Adaptive, case 1







Voltage distribution on conventional plate

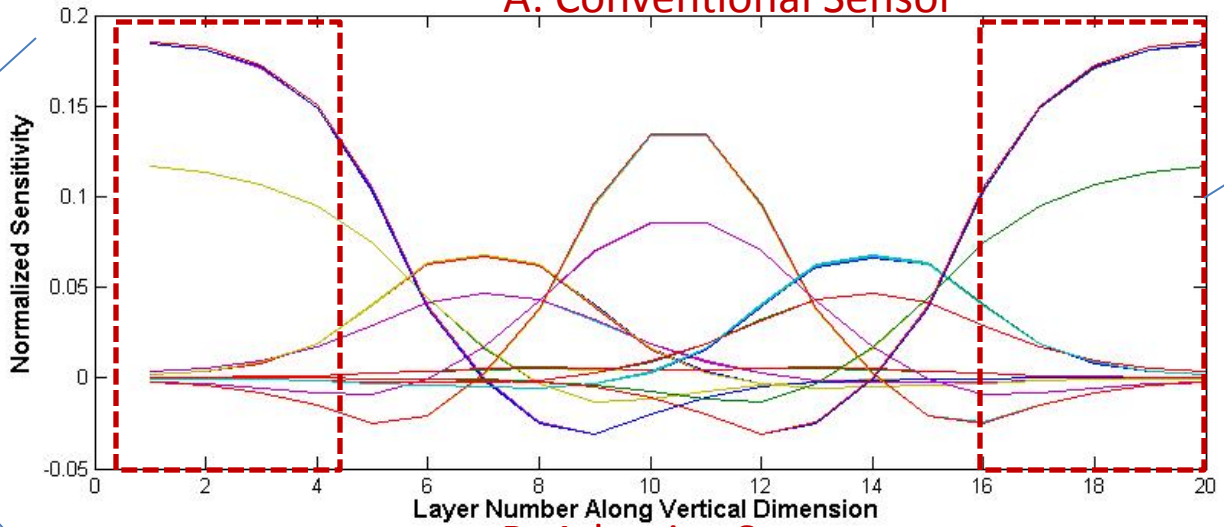


Voltage distribution on adaptive plate

US Patent Application #: US 13/644,973

Voltage distributions: Conventional and Adaptive, Case 2

A: Conventional Sensor

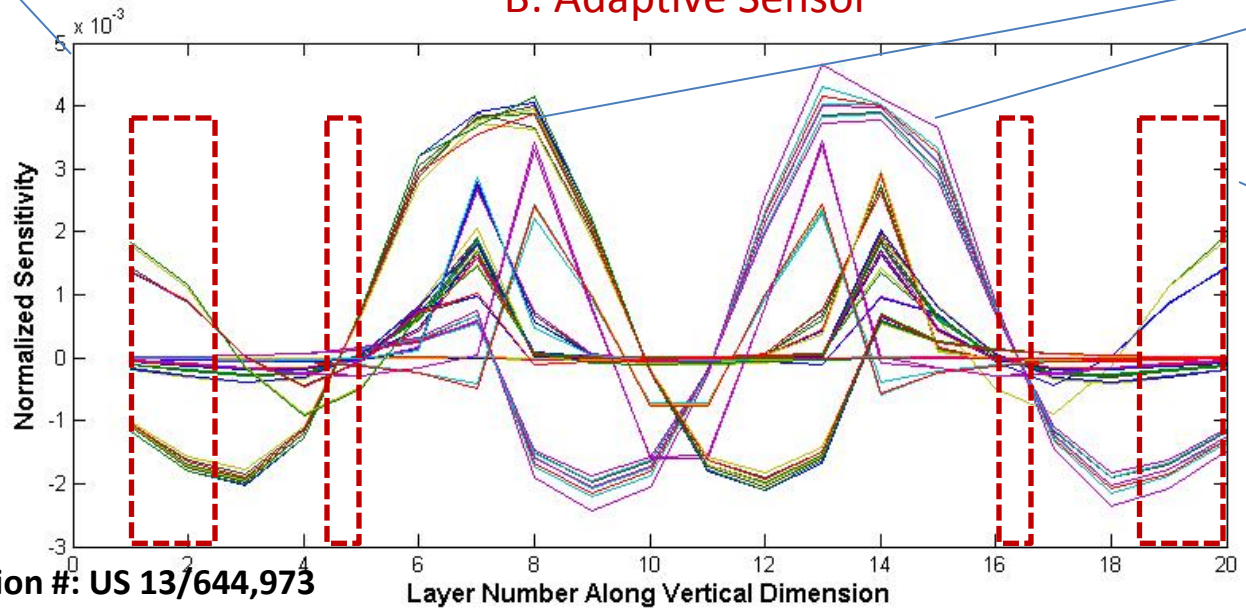


Weak Sensitivity zone

Sensitivity Value

High Sensitivity (Focus) zones

B: Adaptive Sensor

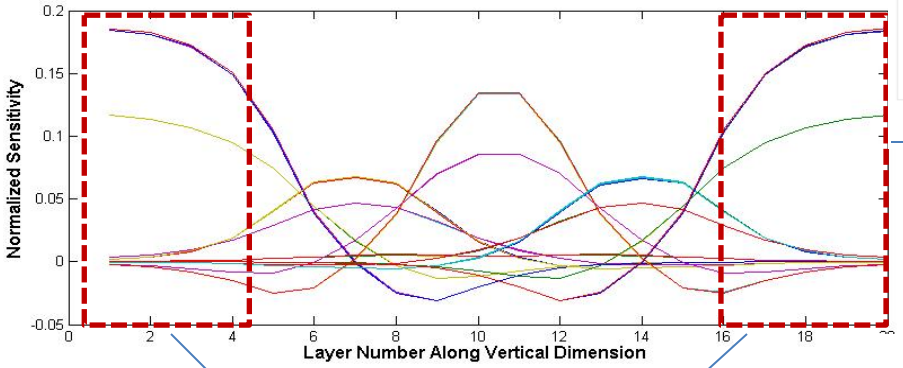


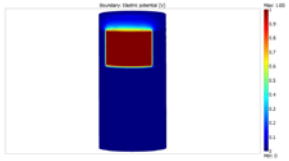
Weak Sensitivity zone

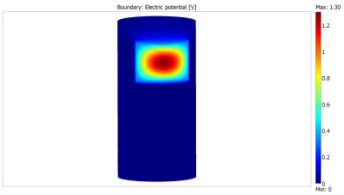
US Patent Application #: US 13/644,973

Example for higher resolution

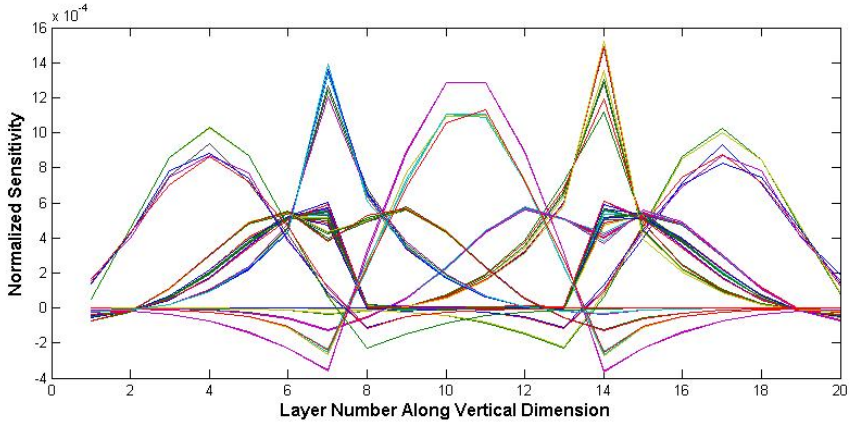
A





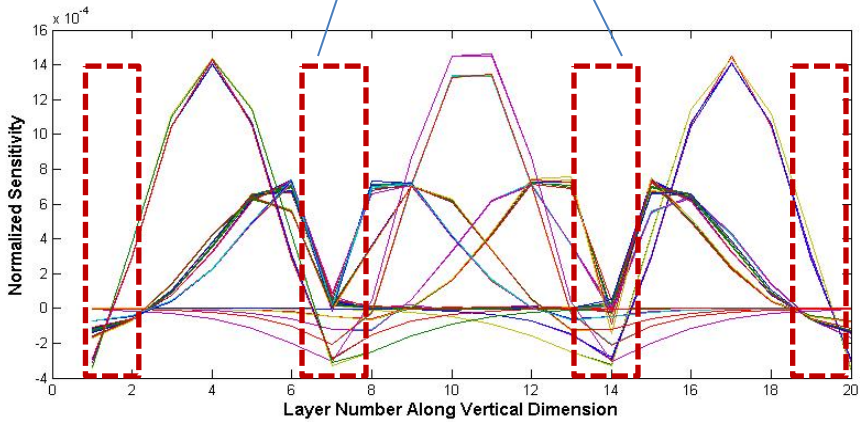


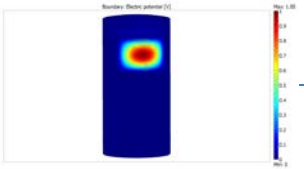
C



Dead Zones

B





US Patent Application #: US 13/644,973

Conclusion

- Higher ECVT resolution is directly proportional to increased number of plates
- 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