COMSOL CONFERENCE TAIPEI 2013

The Electrical Impedance Image Reconstruction Using COMSOL MULTIPHYSICS

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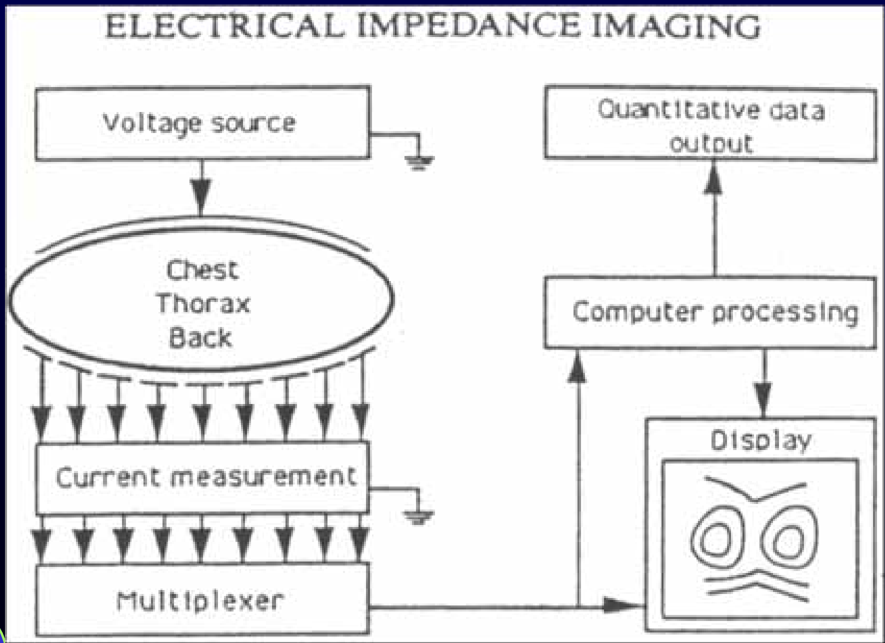
BME, NCKU

INTRODUCTION

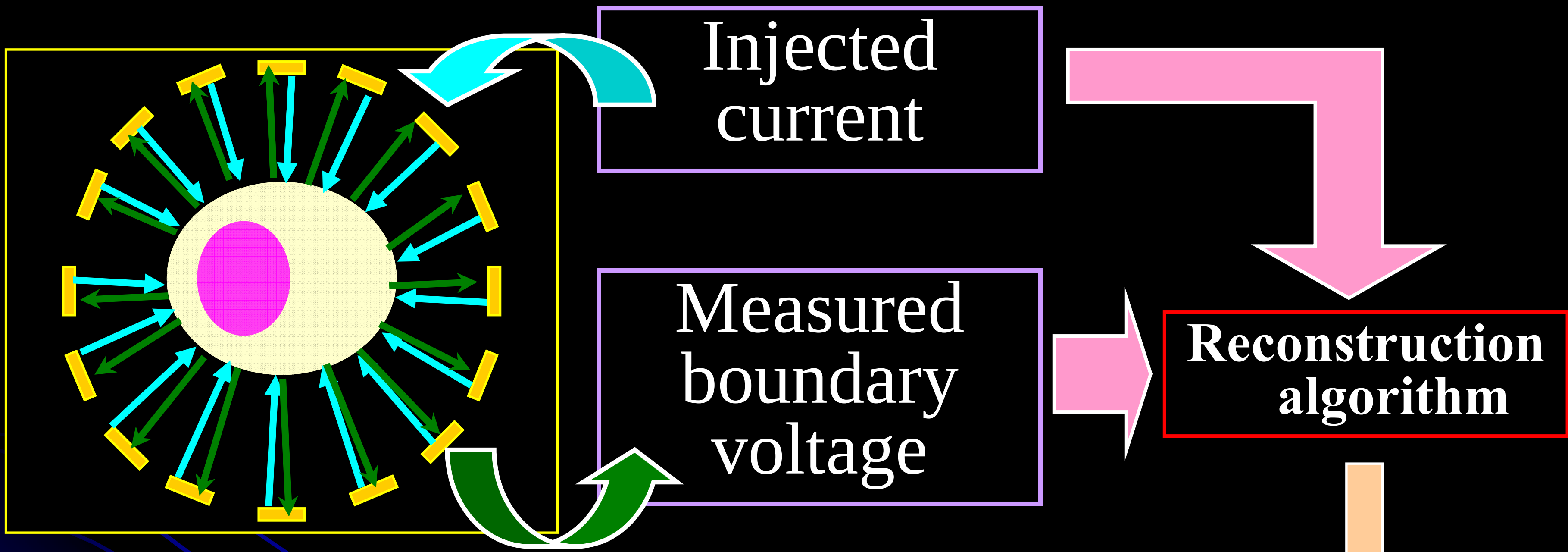
- Swanson(1976) proposed the first frontal plane impedance image technique
- Henderson and Webster (1978) designed the impedance camera

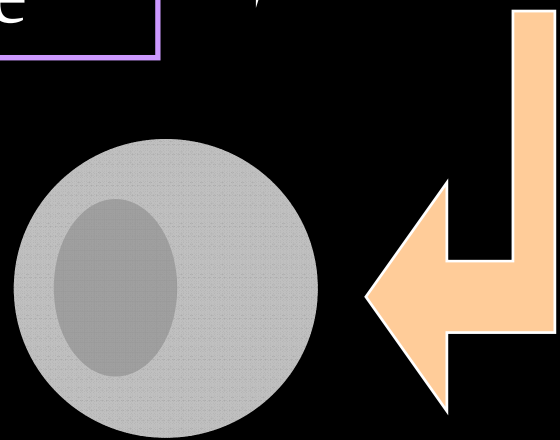


J. G. Webster, electrical impedance tomography, New York: Adam Higler, pp 3-4, 1990.

INTRODUCTION

Electrical Impedance Tomography





Advantages:

- **Non-invasive imaging**
- **Low cost system**
- **No radiation hazard**
- **Long term monitoring**

Problem Description

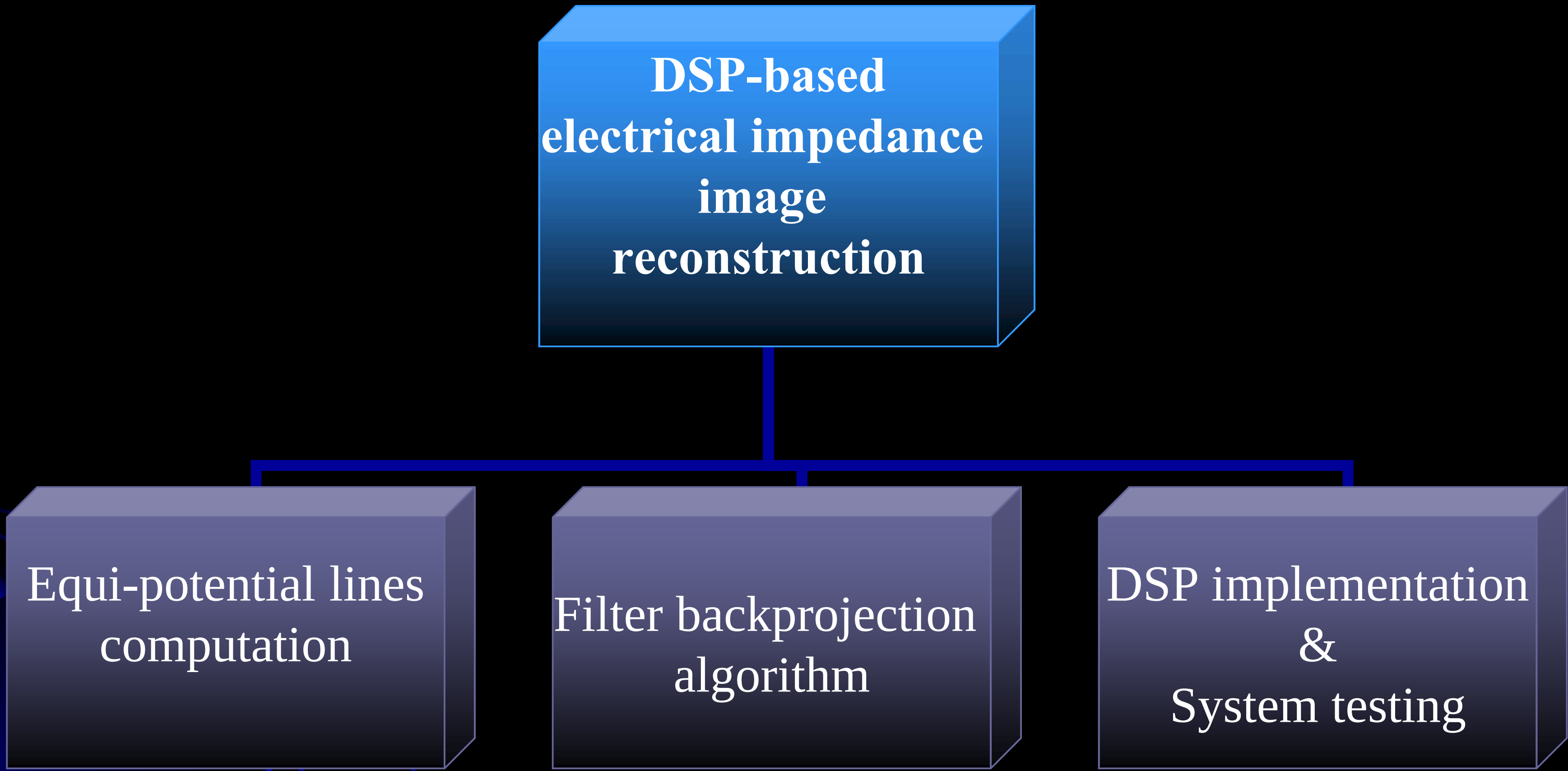
- Current pattern plays an important role in EIT. It may affects
  - Spatial resolution
  - Computation complexity
- Information needed for image reconstruction
  - The applied current pattern
  - The measured boundary voltage pattern

- Current patterns
  - Adjacent-pair current patterns
  - Opposite-pair current patterns
  - Trignonometric current patterns
- Reconstruction algorithms
  - NOSER
  - Backprojection

EIT4 (BME, NCKU)

	Specification	
Data Acquisition	Number of electrodes	32
	Carrier frequency	*Multi-Frequency* 1 kHz-1 MHz
	Current channels	32
	Voltage channels	1
	Measurement method	2-electrode, differential mode
	Resolution	16 bits
	Current pattern	Sinusoidal current patterns
	Sampling rate	500 kHz
Forward solver	FEM	
Inverse solver	Backprojection	
Image type	*Dynamic*	

RESEARCH FRAMEWORK

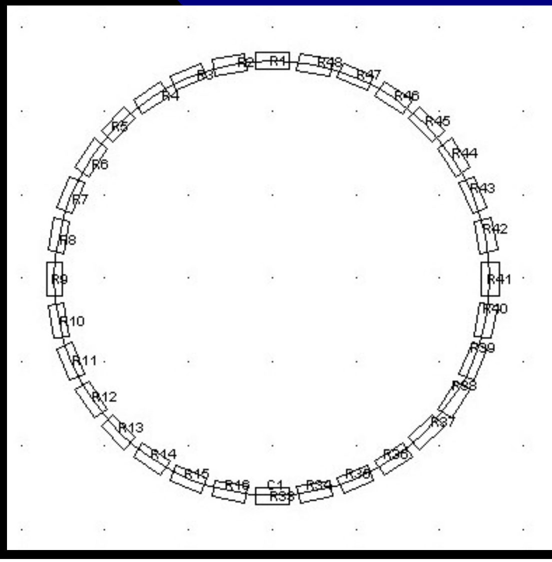


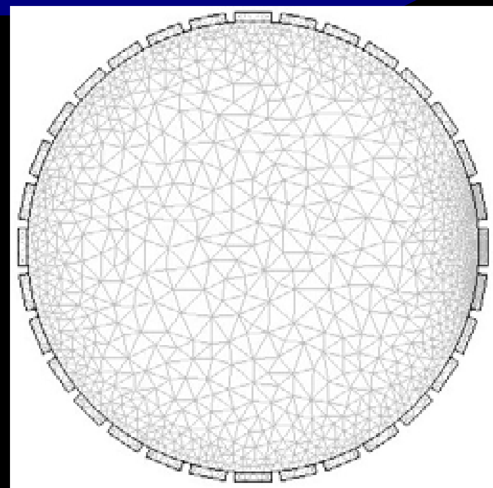
Equi-potential lines computation

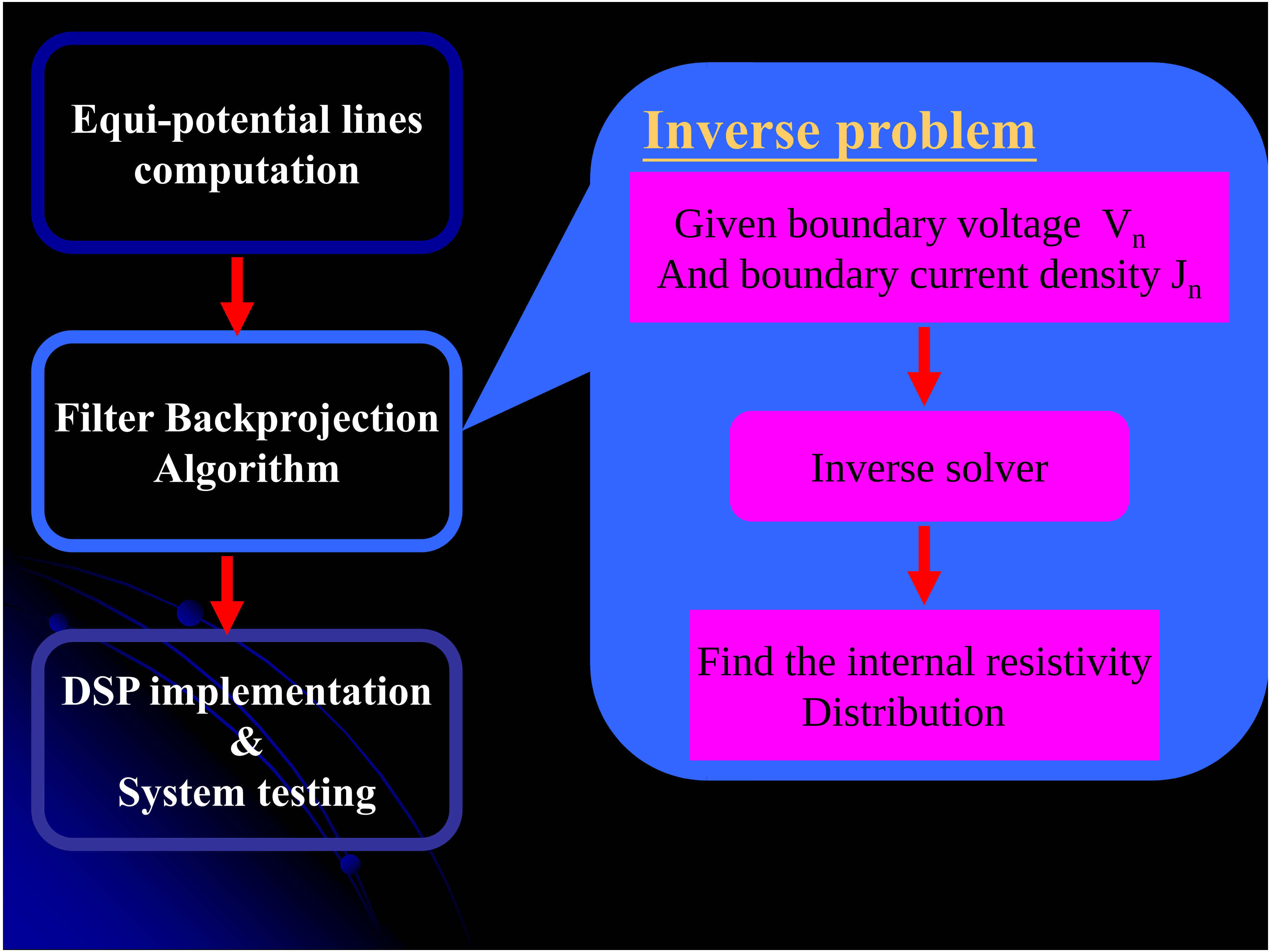
Filter Backprojection Algorithm

DSP implementation & System testing

1. To design torso model
2. To build FEM model using COMSOL
3. To apply current patterns
4. To compute voltages
5. To find the equi-potential lines






Equi-potential lines computation
Filter Backprojection Algorithm
DSP implementation & System testing
Inverse problem
Given boundary voltage V_n
And boundary current density J_n
Inverse solver
Find the internal resistivity Distribution

Equi-potential lines computation

↓

Filter Backprojection Algorithm

↓

DSP implementation & System testing

- TMS320C6713
  - -32-bit command/cycle
  - -High efficiency
  - -Floating point
- High speed

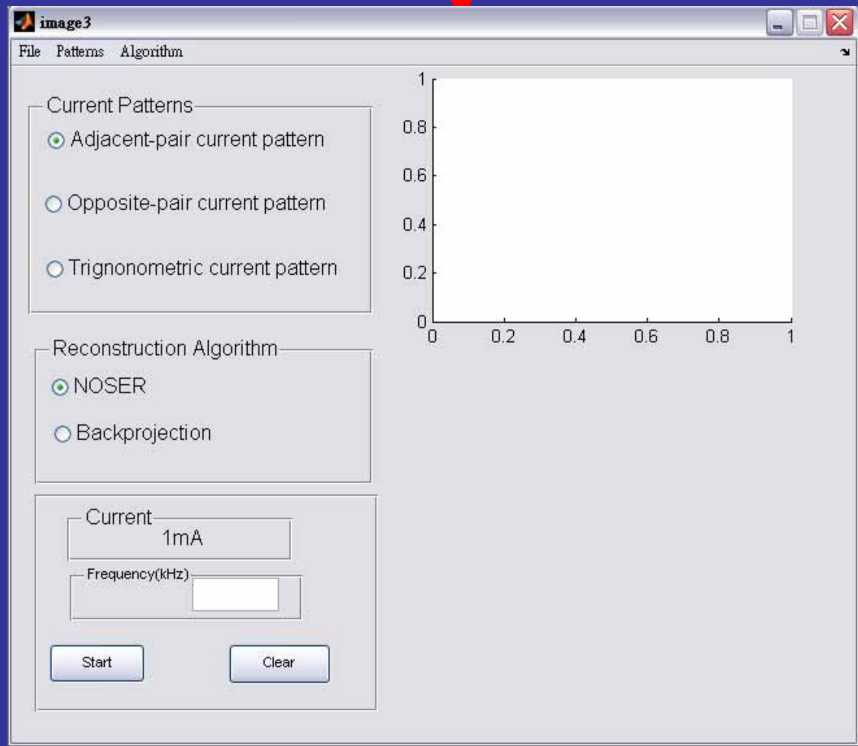
Equi-potential lines computation

Filter Backprojection Algorithm

DSP implementation & System testing

32 Electrodes array

JTAG



bits

0k Hz

l: 1

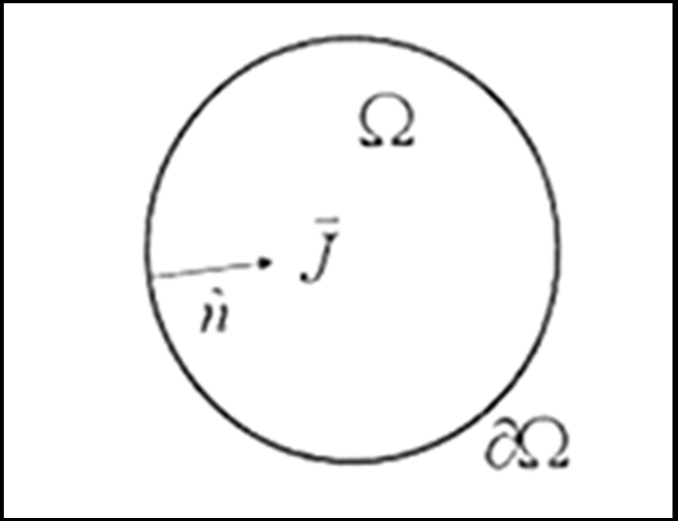
METHODS & MATERIALS

- Finite Element Method in EIT
  - The governing equations

$$\nabla \cdot \vec{J} = 0 \qquad \vec{J} = \sigma \vec{E}$$

$$\vec{E} = -\nabla U$$

$$\Rightarrow \nabla^2 U = 0 \quad with \quad \vec{J} \bullet \hat{n} = -\sigma_0 \frac{\partial U}{\partial n} = -j$$



  - In a polar coordinate system

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 U}{\partial \theta^2} = 0 \quad \& \quad \sigma_0 \frac{\partial U}{\partial r} = j$$

$\bar{J}$: current density

$\bar{E}$: electric field

σ : conductivi ty

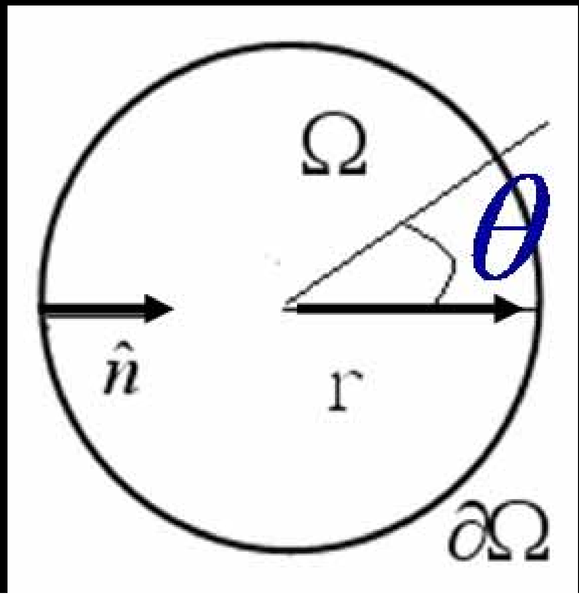
$\hat{n}$: outward unit normal vector

➢ **Boundary conditions**

$$Dirichlet \quad condition: \; U = U_0 \quad on \quad \partial\Omega$$

$$Neumann \quad condition: \; \sigma_0 \frac{\partial U}{\partial n} = j \quad on \, \partial\Omega$$

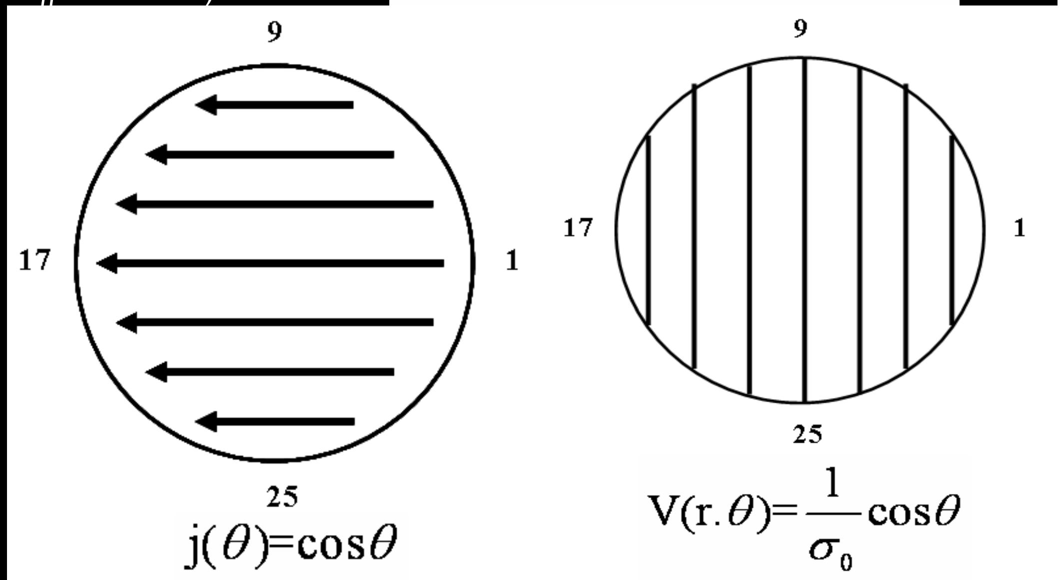
$$U(r,\theta) = \frac{r_0}{\sigma_0} \sum_{n=1}^{\infty} \frac{1}{n} \left(\frac{r}{r_0} \right)^n \left(C_n \cos n\theta + S_n \sin n\theta \right)$$



$$\vec{J}(\theta) = \cos\theta$$

$$Let \quad r = r_0, \quad n = 1$$

$$\Rightarrow U(r,\theta) = \frac{1}{\sigma_0} \cos\theta$$



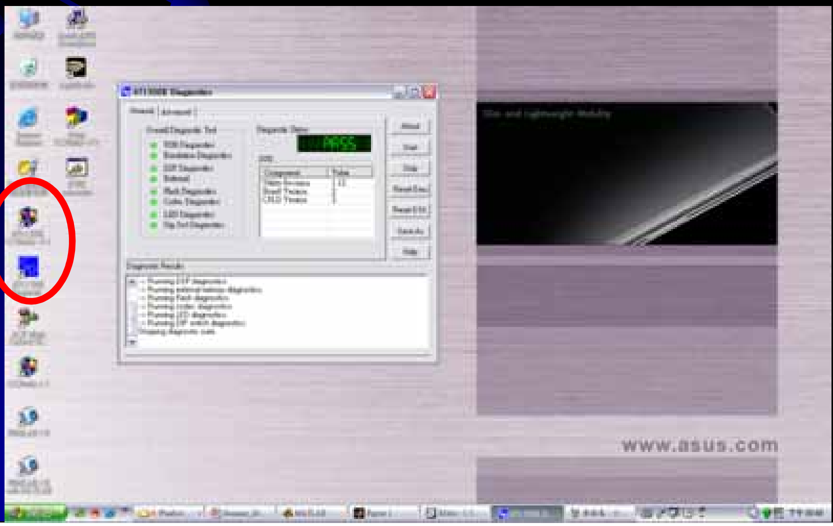
n : spatial frenqency

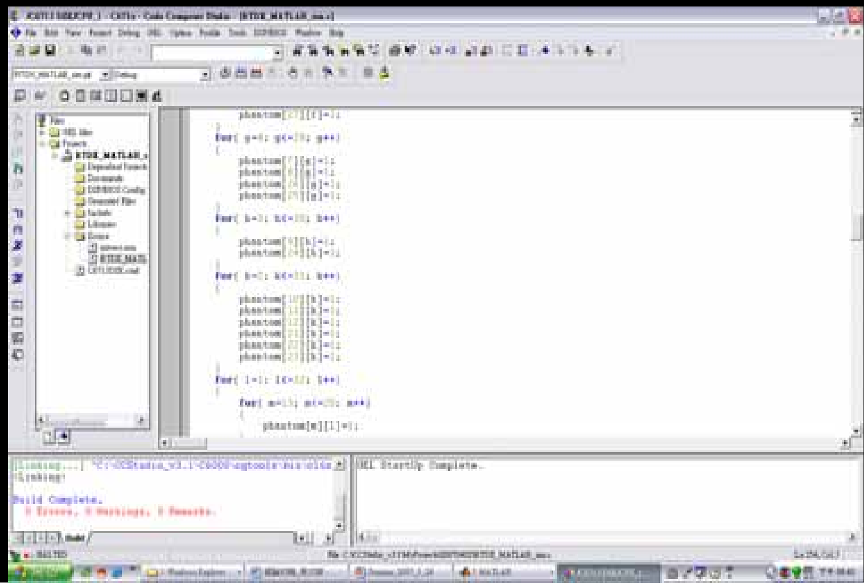
σ : conductivi ty

$\hat{n}$: outward unit normal vector

METHODS & MATERIALS

- TI C6713 DSK
  - DSP &PC link: 6713 DSK Diagnostics Utility v3.1 (USB)
  - Developmental surrounding: CCStudio 3.1
  - Language: C Langue
  - Compiler: CCStudio 3.1



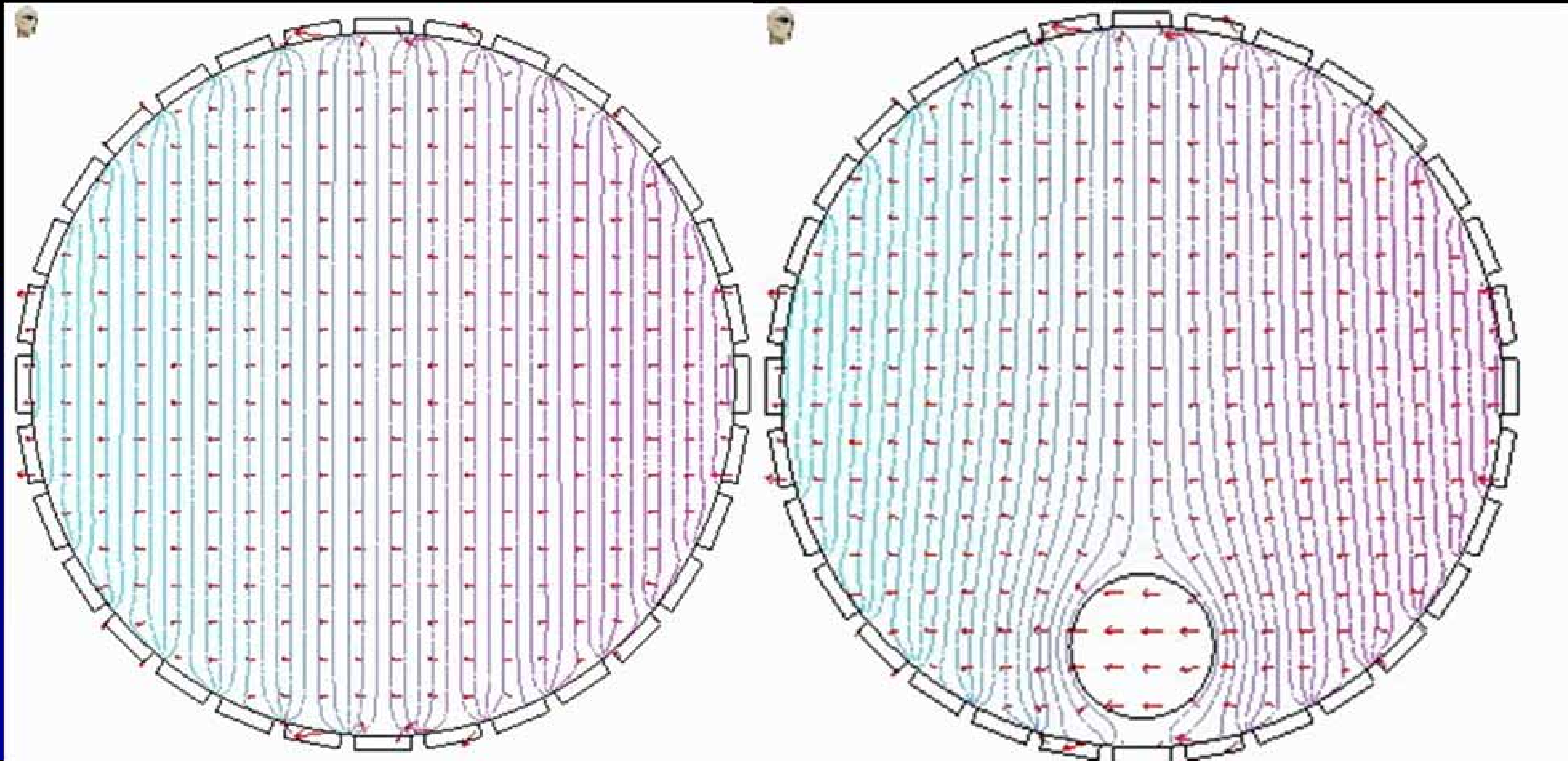


RESULTS & DISCUSSIONS

SINUSOIDAL CURRENT PATTERN SIMULATION

- **Equi-potential lines computation with COMSOL**

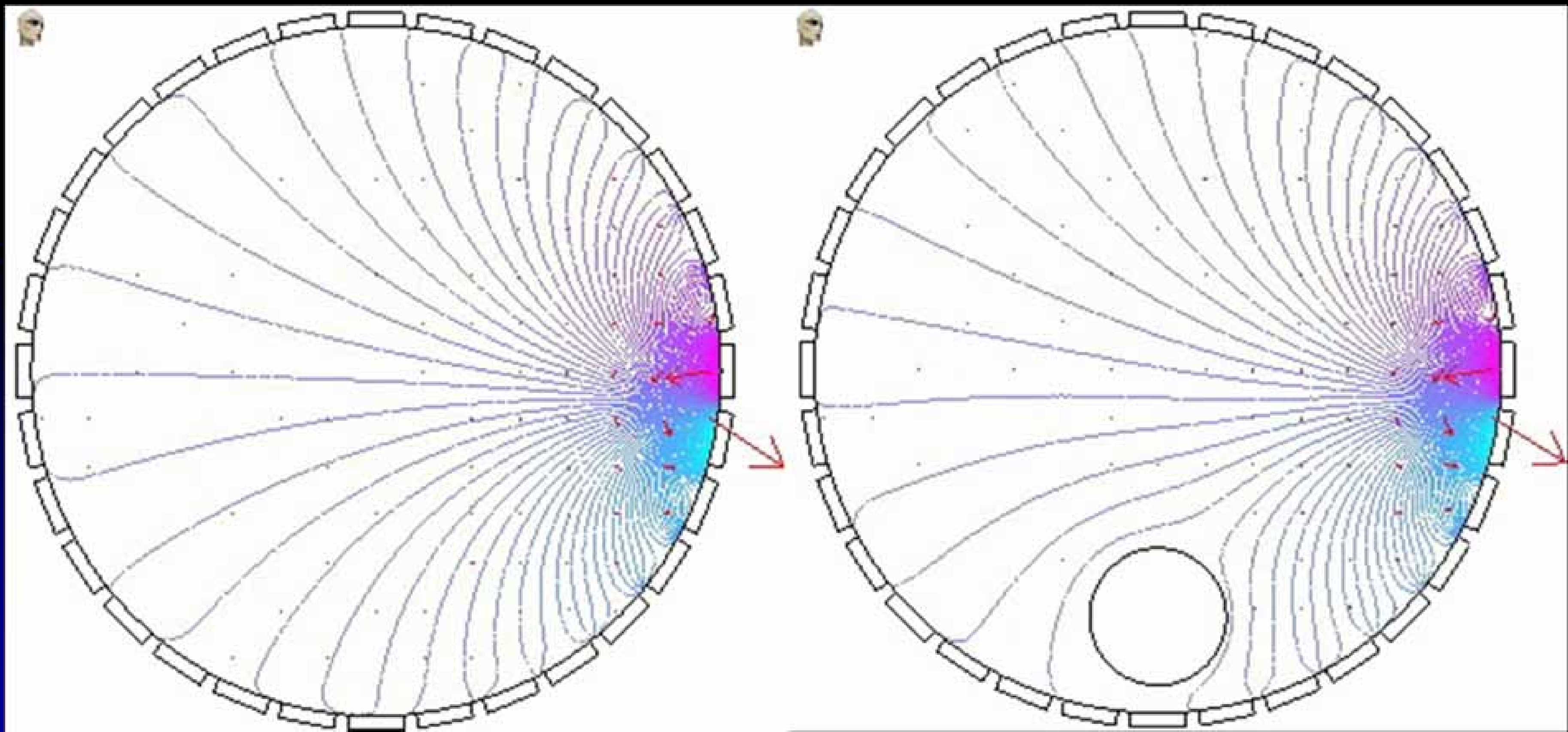
Homogenous　　　　　　Non-homogenous



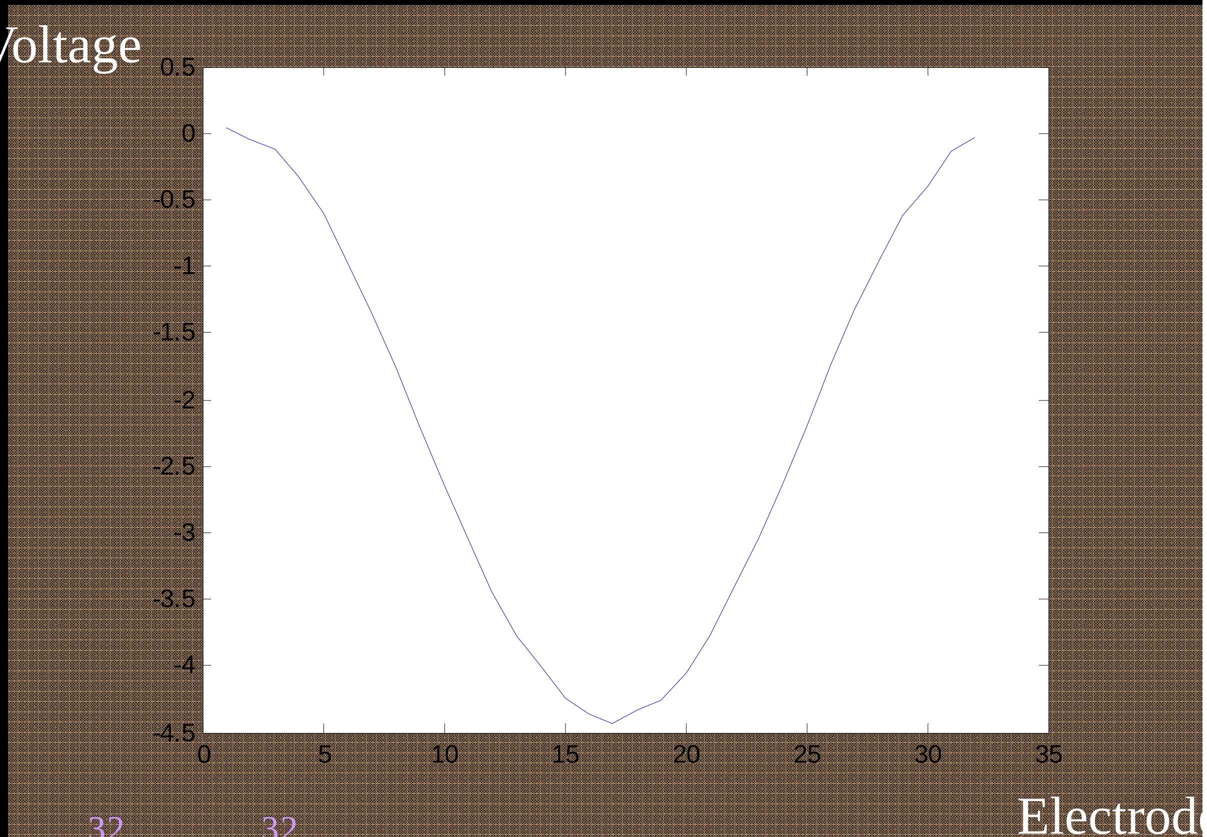
SINUSOIDAL CURRENT PATTERN SIMULATION

- **Equi-potential lines computation with COMSOL**

Homogenous Non-homogenous



- Verification



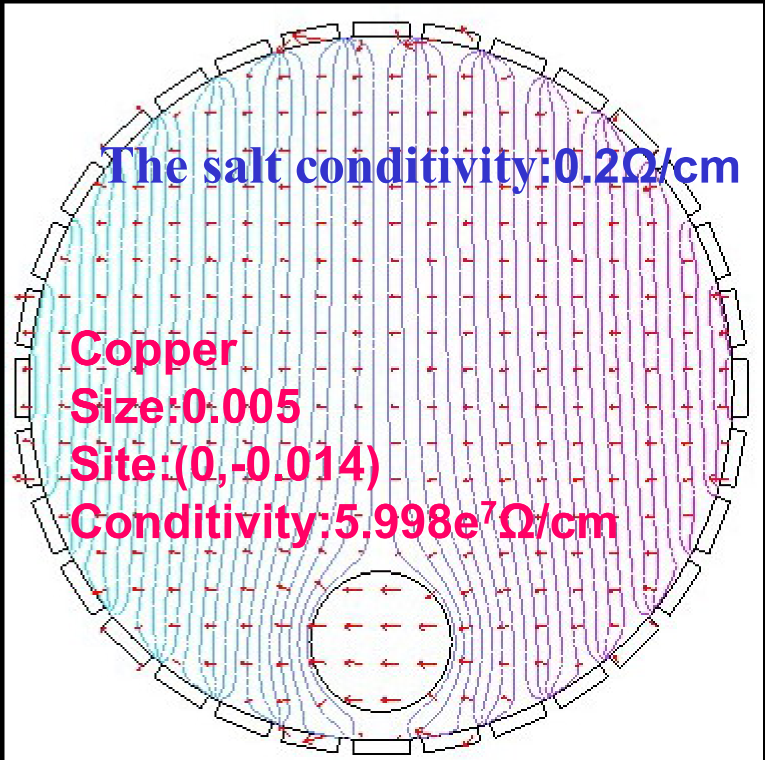
$$\sum_{i=1}^{32} V_i = 0$$

$$\Rightarrow V_{32} = \sum_{i=1}^{31} V_i$$

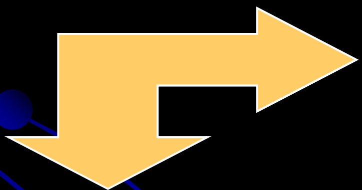
$$\Rightarrow \sum_{i=1}^{32} V_i^m = \sum_{i=1}^{32} (V_i - V_{32}) = \sum_{i=1}^{32} V_i - \sum_{i=1}^{32} V_{32} = 0 - 32 \times V_{32}$$

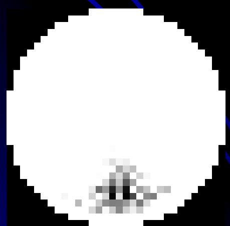
$$\therefore V_i = V_i^m + V_{32}$$

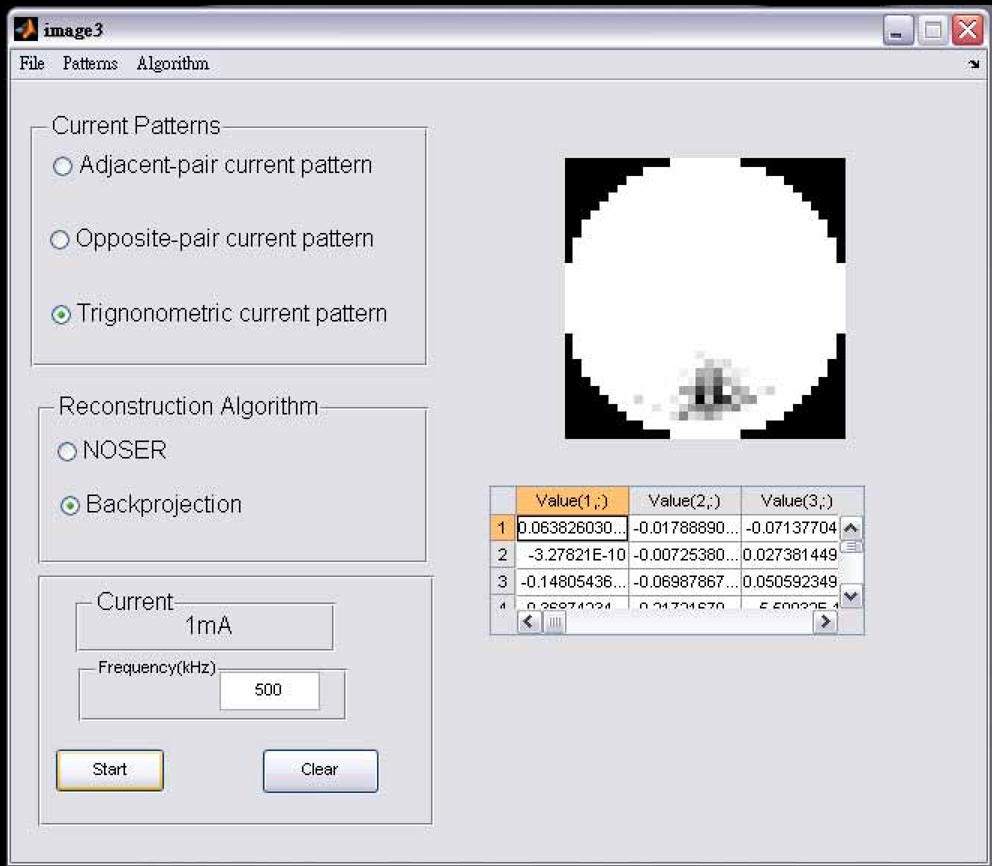
l: electrode
m: rotation

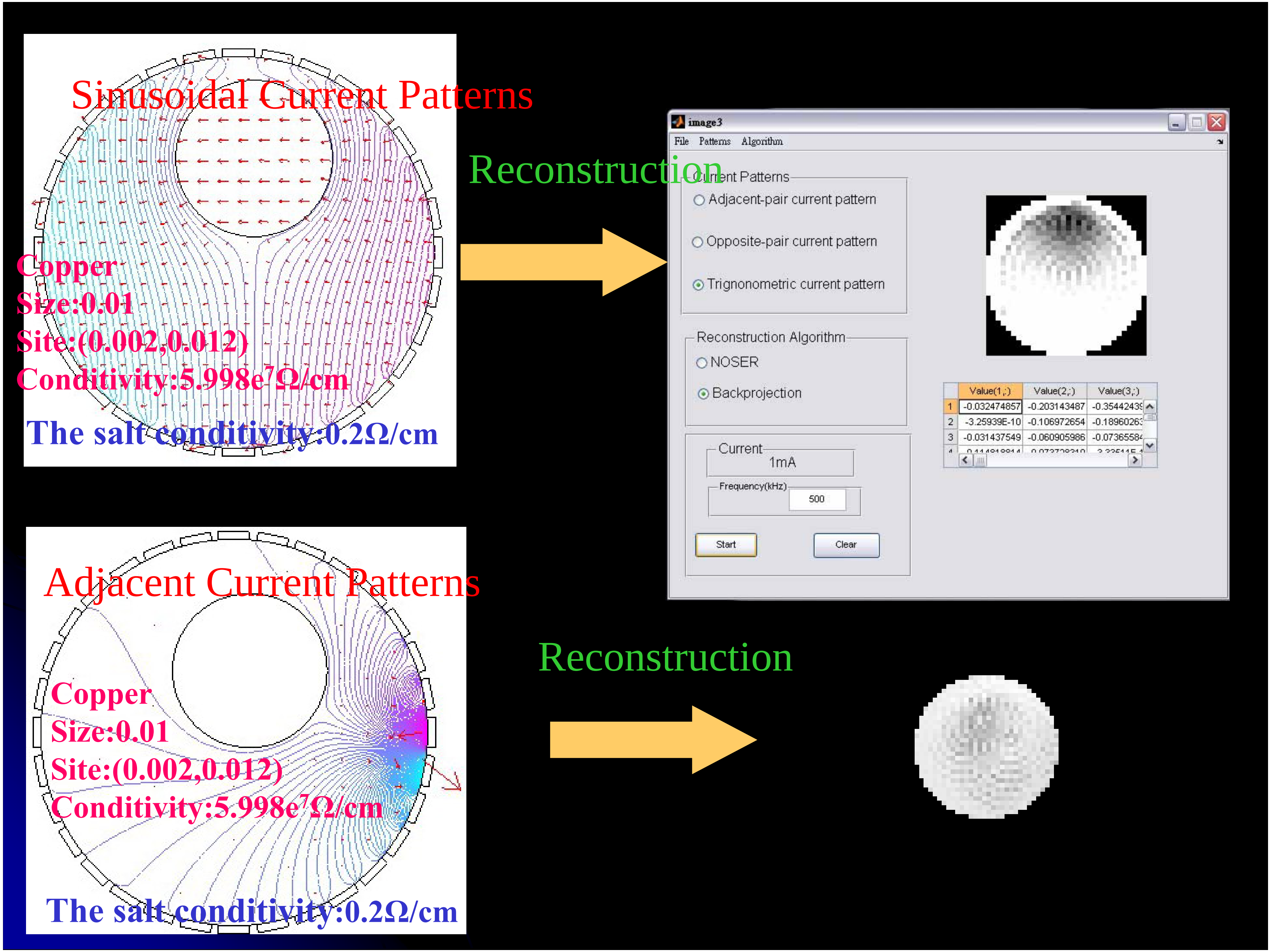


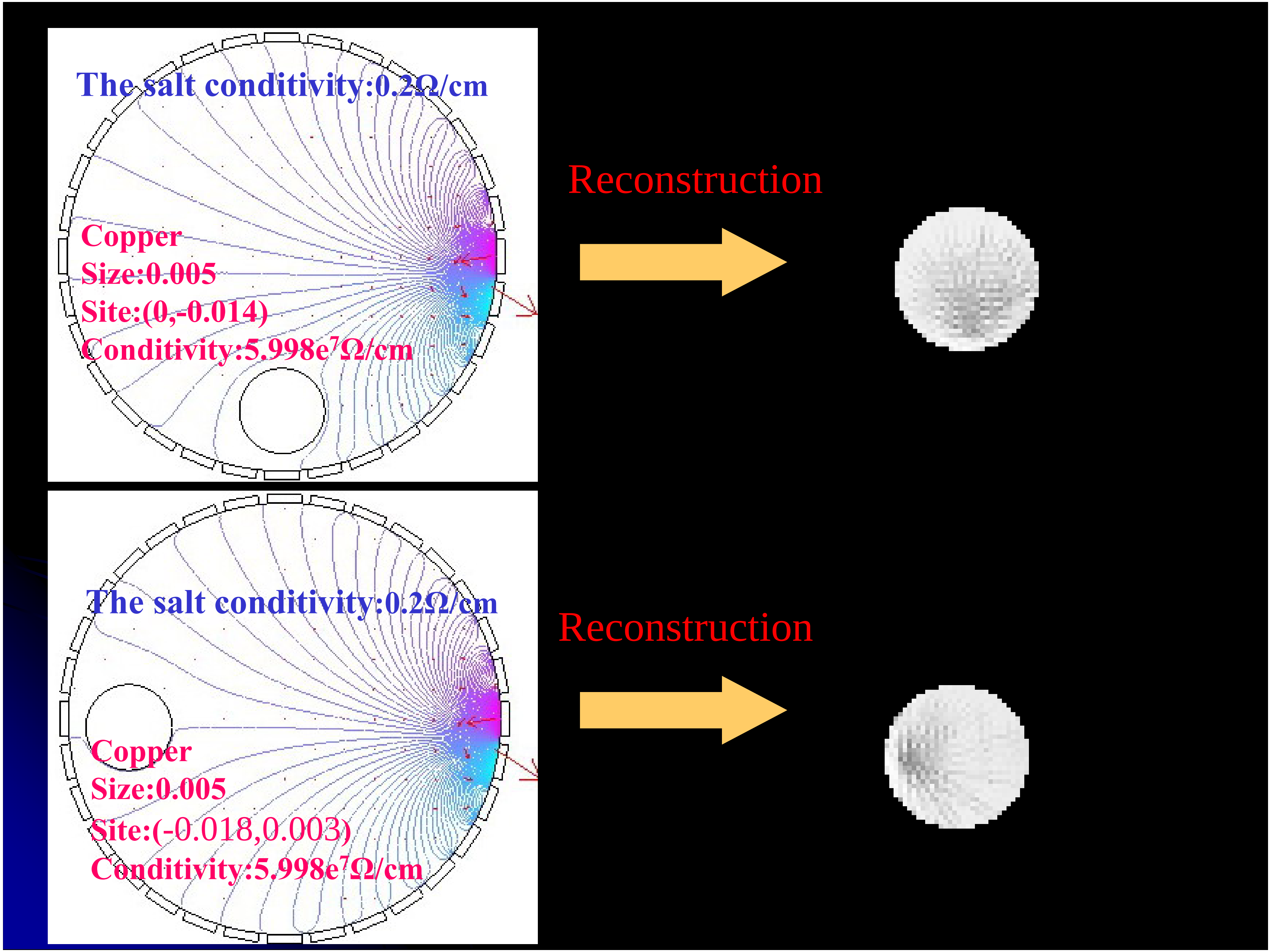
SIMULATION & RECONSTRUCTION

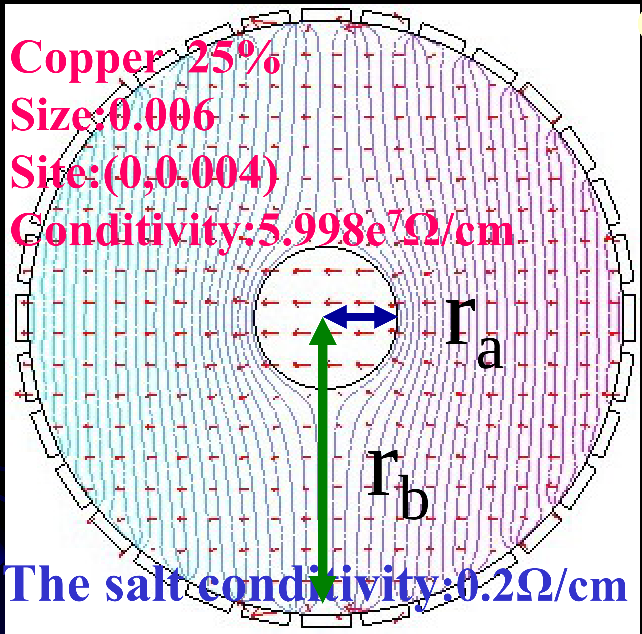






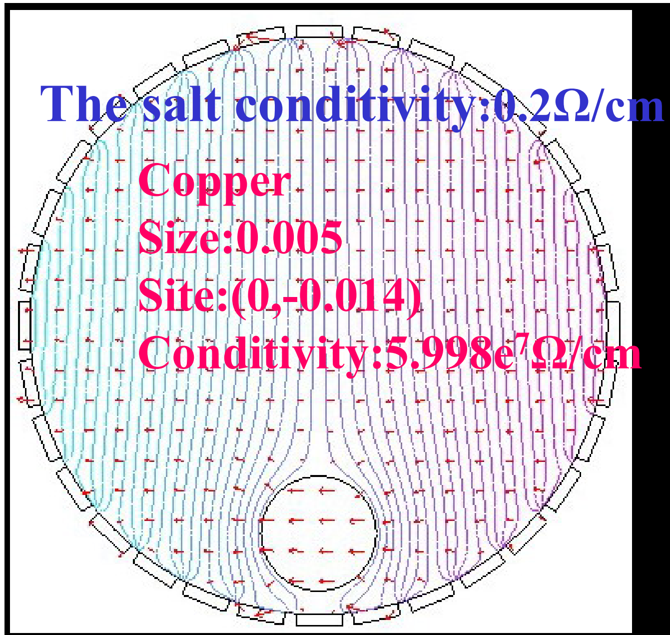

Sinusoidal Current Patterns
Copper
Size:0.01
Site:(0.002,0.012)
Conditivity:5.998e7Ω/cm
The salt conditivity:0.2Ω/cm
Reconstruction
image3
File Patterns Algorithm
Current Patterns
Adjacent-pair current pattern
Opposite-pair current pattern
Trignonometric current pattern
Reconstruction Algorithm
NOSER
Backprojection
Current
1mA
Frequency(kHz)
500
Start
Clear
Value(1,:) Value(2,:) Value(3,:)
1 -0.032474857 -0.203143487
2 -3.25939E-10 -0.106972654
3 -0.031437549 -0.060905986
Adjacent Current Patterns
Copper
Size:0.01
Site:(0.002,0.012)
Conditivity:5.998e7Ω/cm
The salt conditivity:0.2Ω/cm
Reconstruction

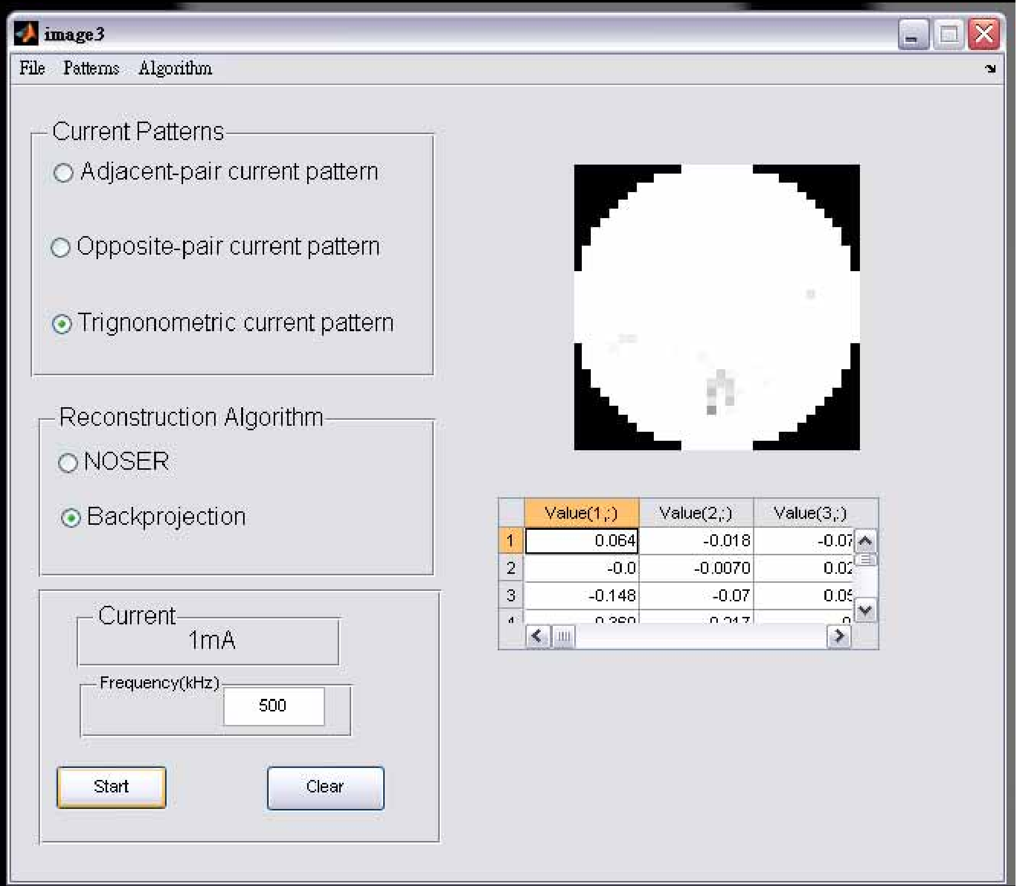

The salt conditivity:0.2Ω/cm
Copper
Size:0.005
Site:(0,-0.014)
Conditivity:5.998e7Ω/cm
Reconstruction
The salt conditivity:0.2Ω/cm
Copper
Size:0.005
Site:(-0.018,0.003)
Conditivity:5.998e7Ω/cm
Reconstruction



- Spatial resolution= r_a/r_b
  - Sinusoidal current pattern Spatial resolution = 0.25
  - Adjacent-pair current pattern

  Spatial resolution = 0.45

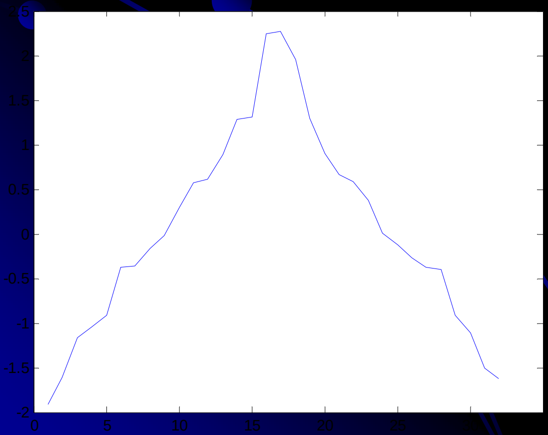




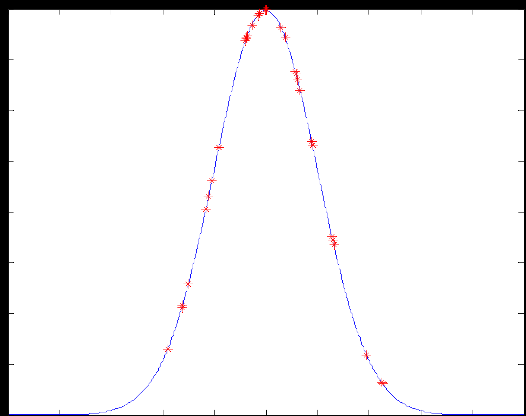
Reconstruction

\+ Noise

Error: ± 1%



Verification



CONCLUSION

- Sinusoidal current pattern is better than adjacent current patterns in resolution.
- The image reconstruction time needed for the sinusoidal current pattern is the same as the adjacent current pattern.
- DSP based impedance image reconstruction system works well in the simulation experiments.

Thanks for your attention