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Acoustic Imaging
Designing with COMSOL

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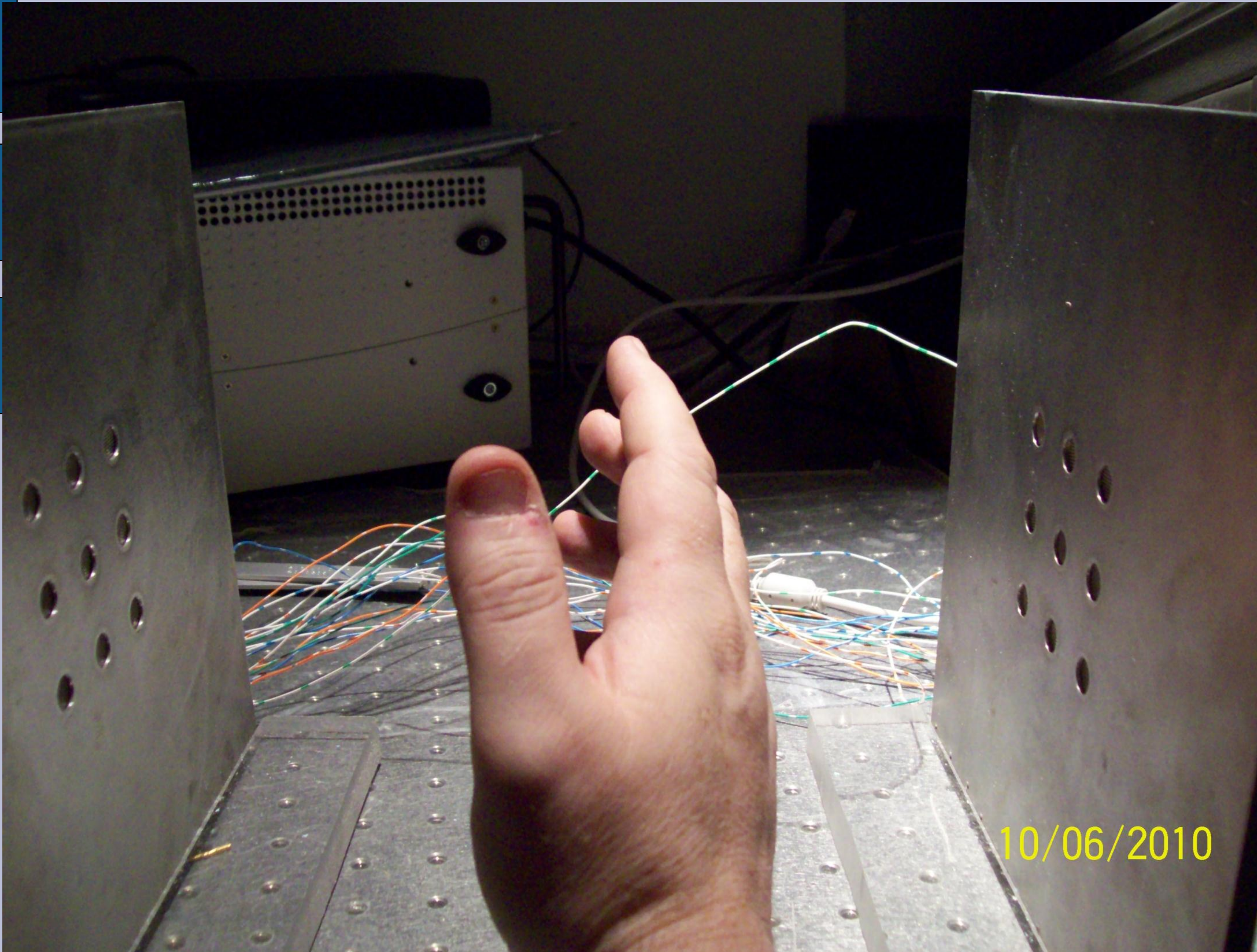
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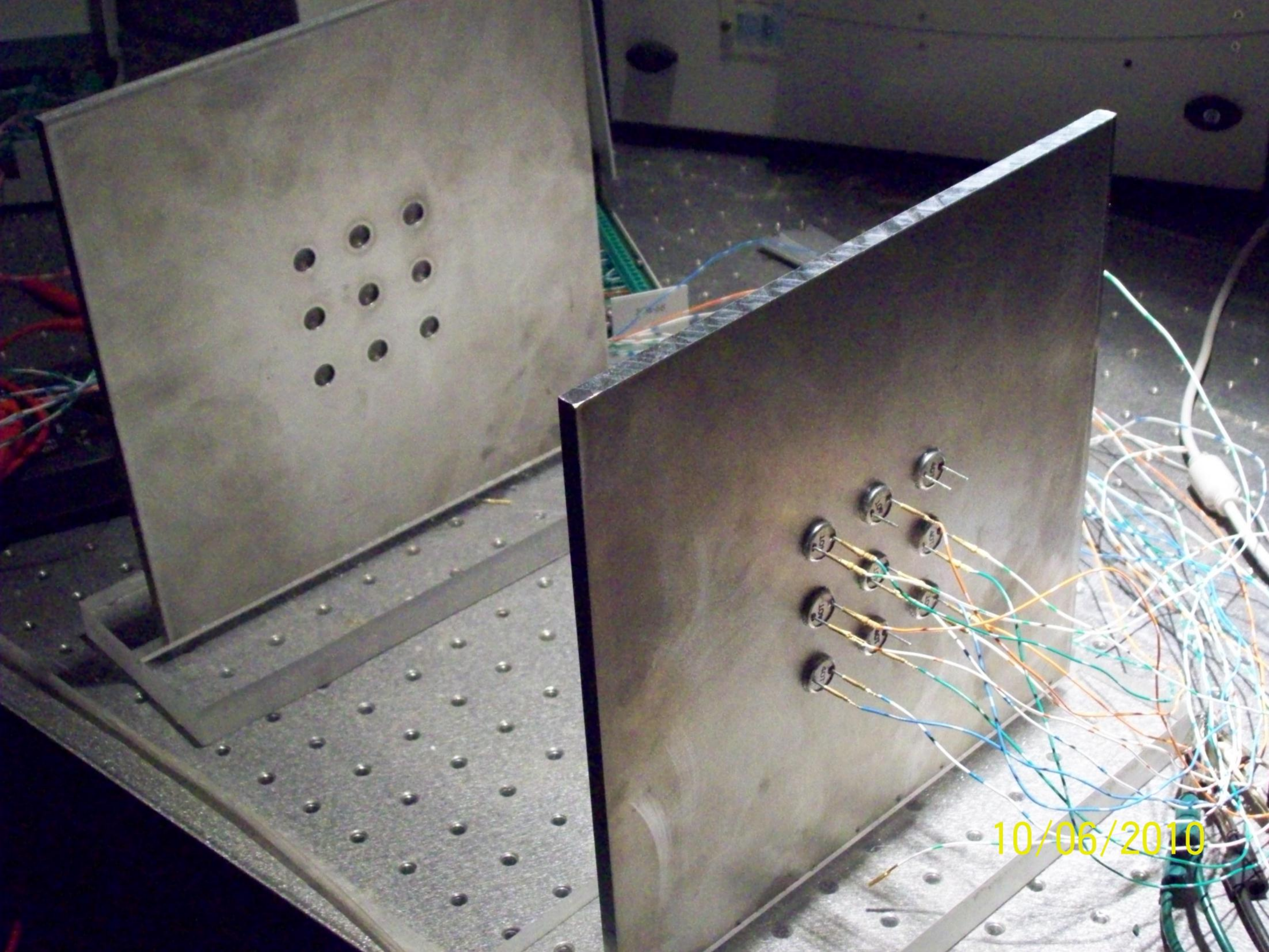
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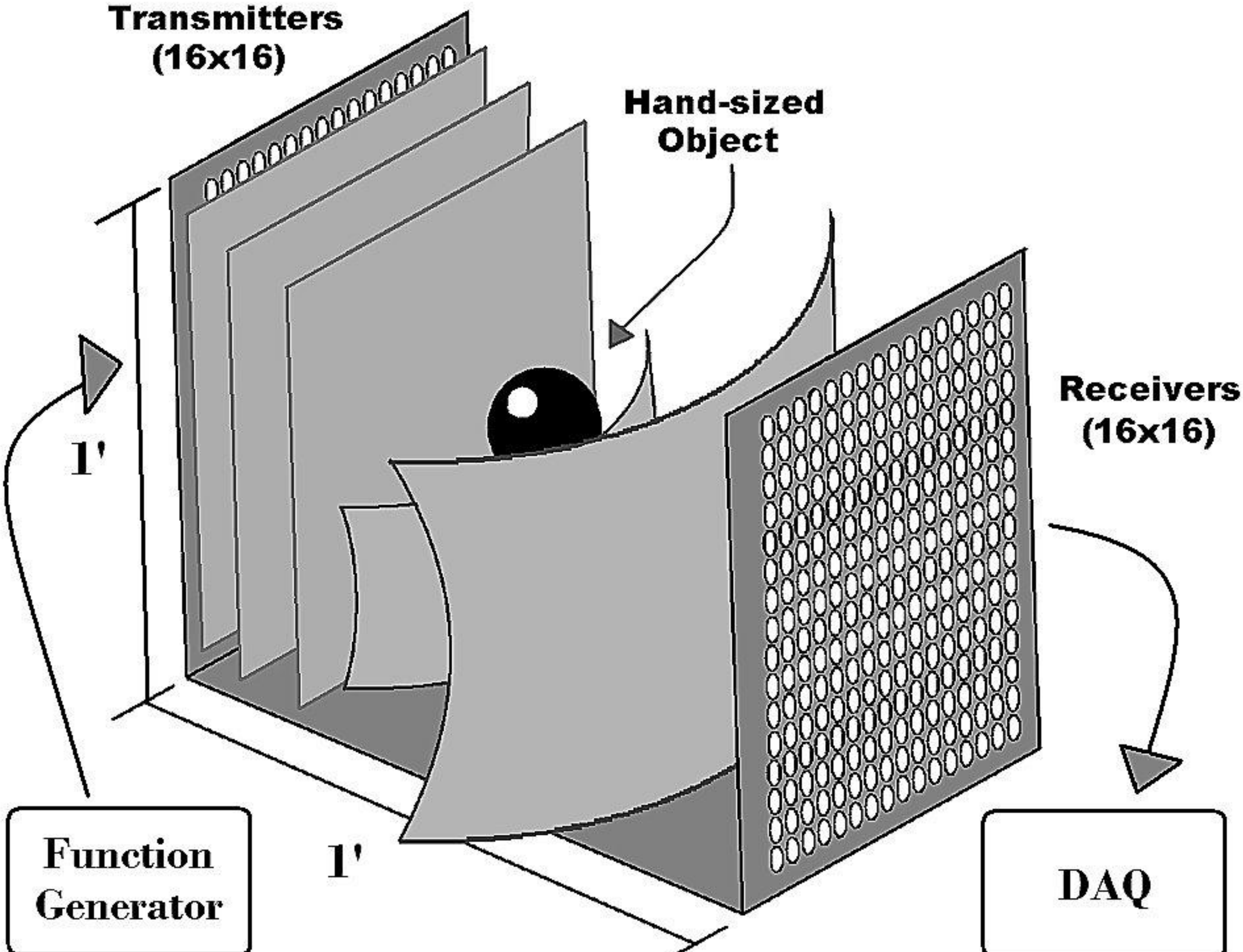

Transmitters
(16x16)
Hand-sized
Object
Receivers
(16x16)
1'
1'
Function
Generator
DAQ

Overview

- Motivation
- Description
- Design Considerations
- Operational Considerations
- Technique Employed
- COMSOL's role
- Matlab's interactions

Motivation

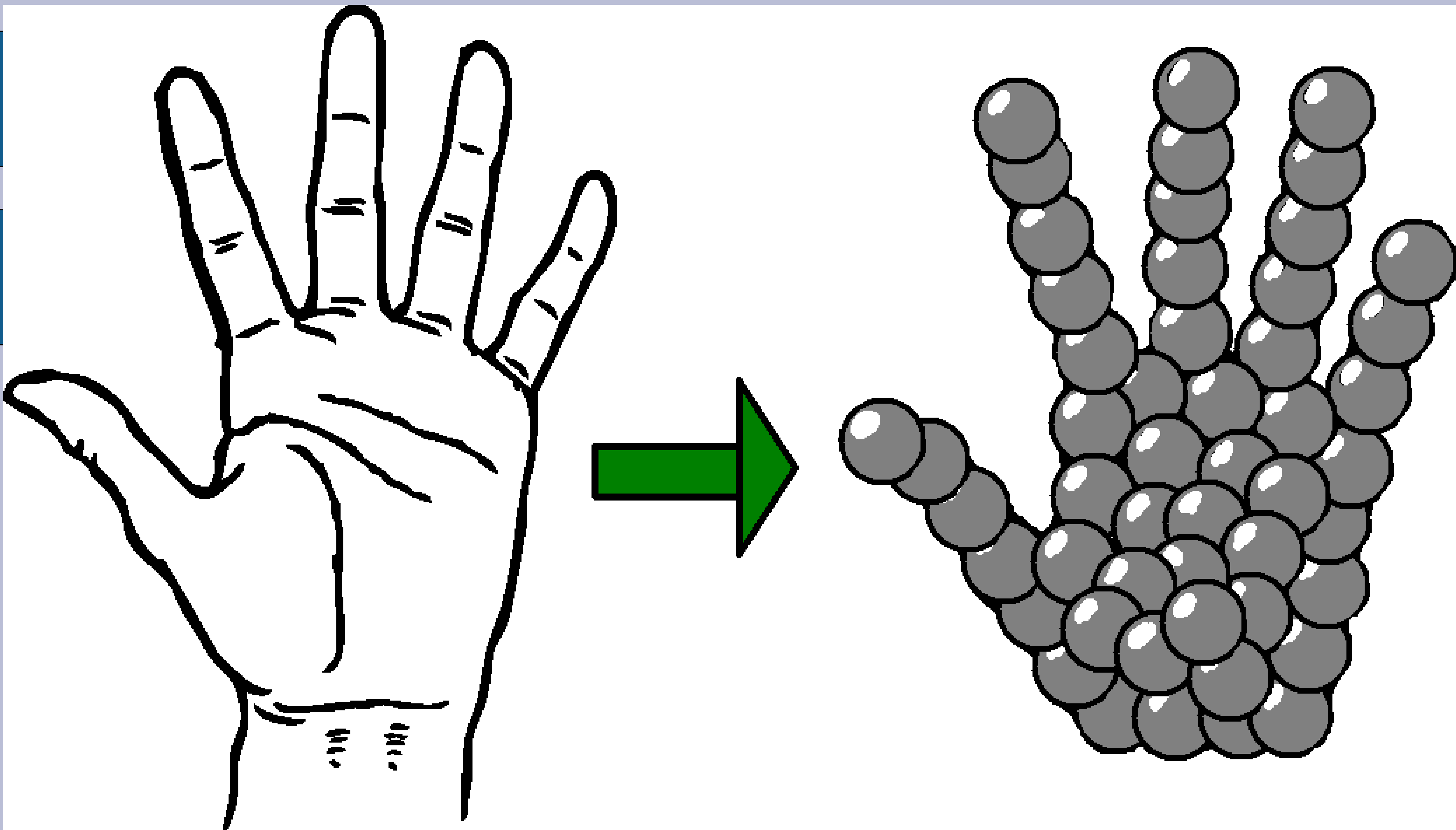
- Career in Nuclear Experimental Physics
  - Polarized electron scattering from Helium-3
  - Nuclear structure/Nucleon structure
  - NSF grant (2003-2006)
  - Public statement
- Scattering – comparison between Acoustic and Nuclear scattering
- Mechanical-less controller – Wii, Move, Kinetic – accelerometer/video based
- 2.5D vs 3D – body vs hand motion detection

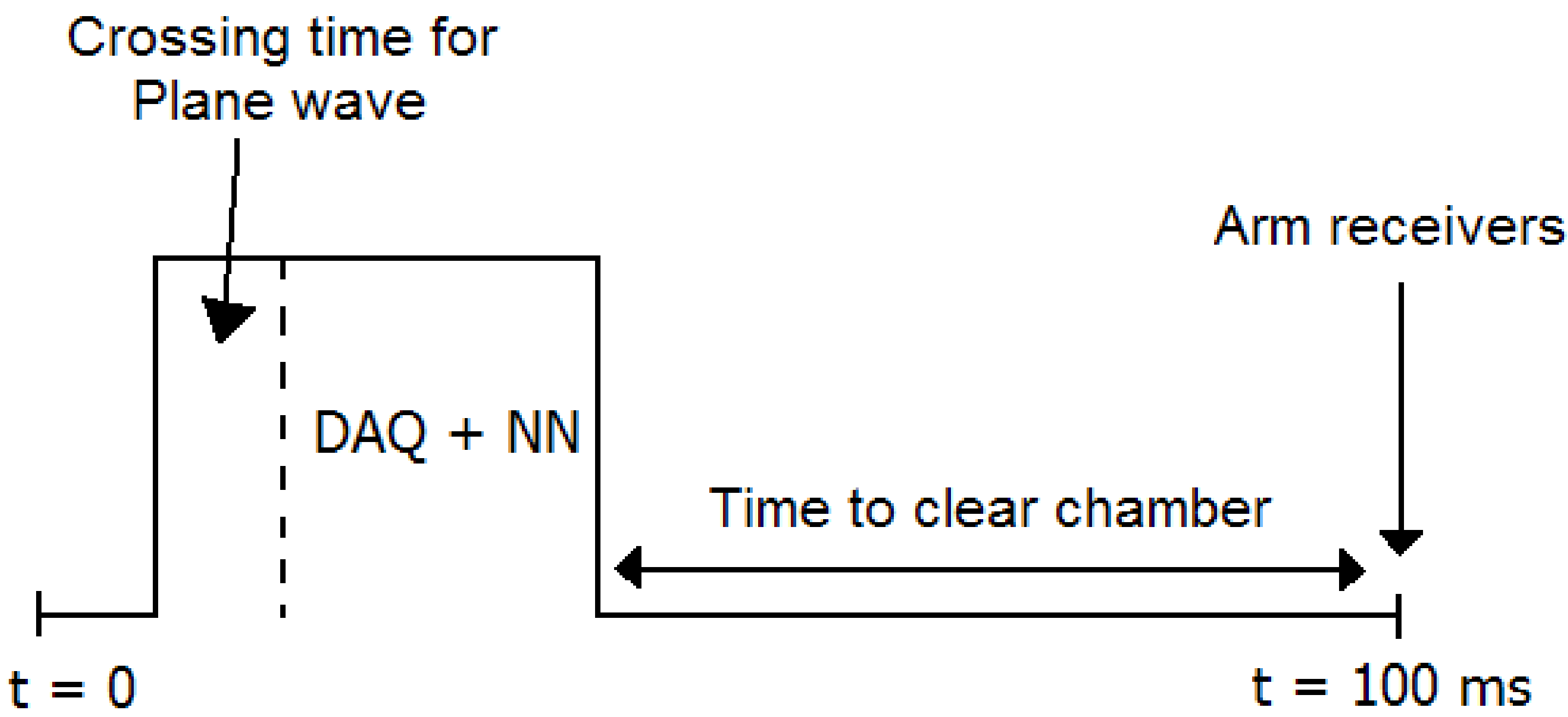
Description

- 12”x12”x12” cube open on three sides
- Transmission plate
- Receiving Plate
- Acoustic Plane wave propagates from transmission to receiver
- Any objects blocking the path cause acoustic diffraction
- Recording arrival times of wavefronts via DAQ
- Map arrival times to objects position or orientation

Design Considerations

- Velocity = wavelength * frequency
- Object size should be larger than wavelength
- Human interaction times slower than 20 Hz
- Ultrasonic microphones cheaply available at 25 and 40 kHz ($\lambda = 1.37$cm and 0.86cm)
- Transit time over 12” = 0.89ms
- 12”x12”x12” gives ample manuevering space for fine hand controls (not video games)
- Typical human finger size is ~1cm, palm>2cm




Crossing time for
Plane wave
Arm receivers
DAQ + NN
Time to clear chamber
t = 0
t = 100 ms

Operational Considerations

- System must perform in real-time (20Hz)
- Accurate results for range of hand positions
- Database of results should be extendable
- Neural Networks are robust pattern match solvers
- Requires a large database of training pairs (input – target vectors)
- Problem is sufficiently non-analytic to warrant using COMSOL as a production solver
- Timing constraints require precision hardware – National Instruments DAQ using FPGA's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USNA MINOR PROPERTY
0016106209
NI PXI-1042
NATIONAL INSTRUMENTS
ExpressCard
TRIG
NATIONAL INSTRUMENTS
NI PXI-7813R
Reconfigurable I/O
NATIONAL INSTRUMENTS
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NI PXI-5412
14-Bit 100 MS/s AWG
ACCESS
ACTIVE
CH 0
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PFI 0
PFI 1
NATIONAL INSTRUMENTS
NI PXI-5105
12-Bit 60 MS/s Digitizer
CH 0
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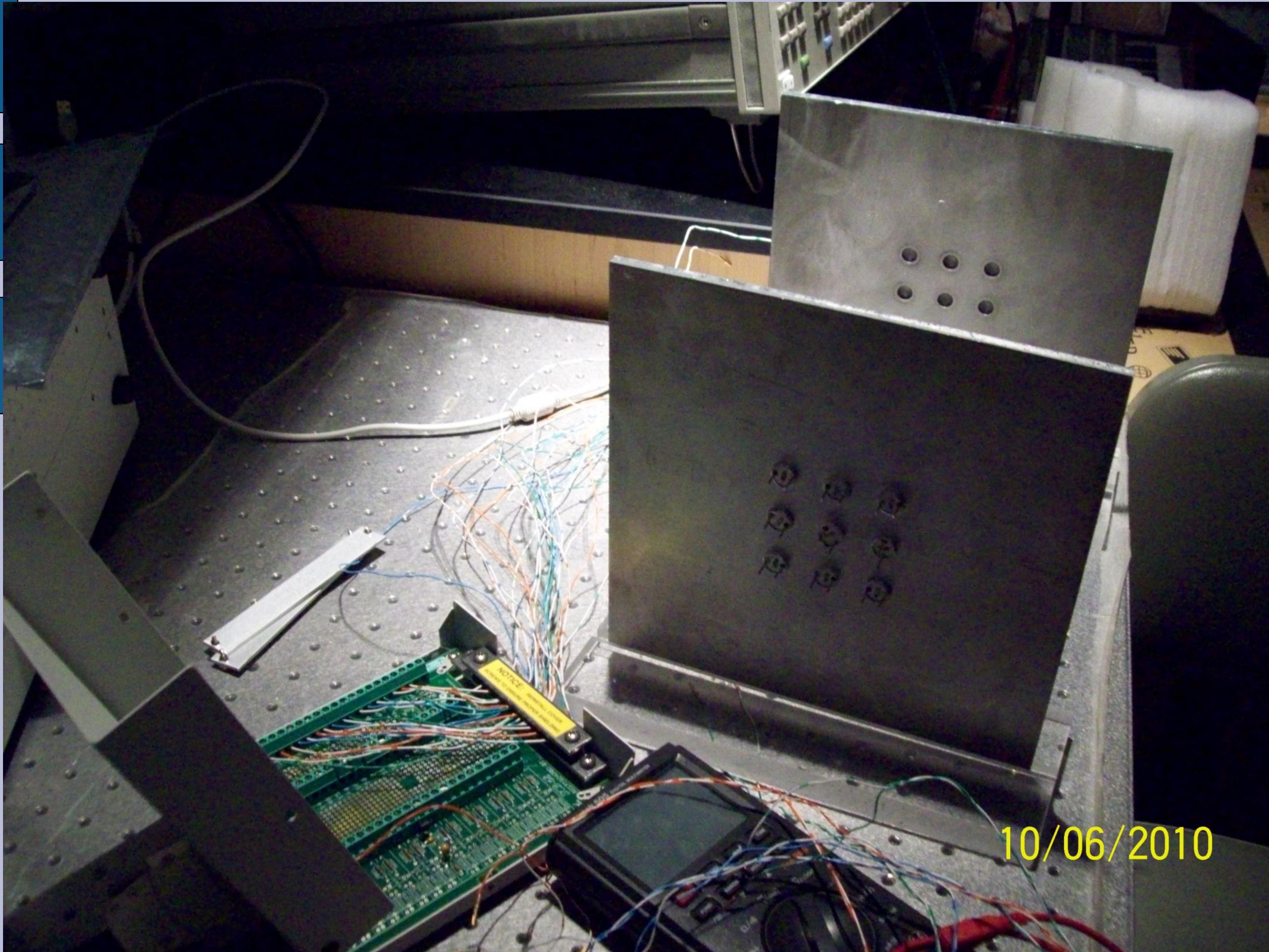
NOTICE:
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Technique Employed

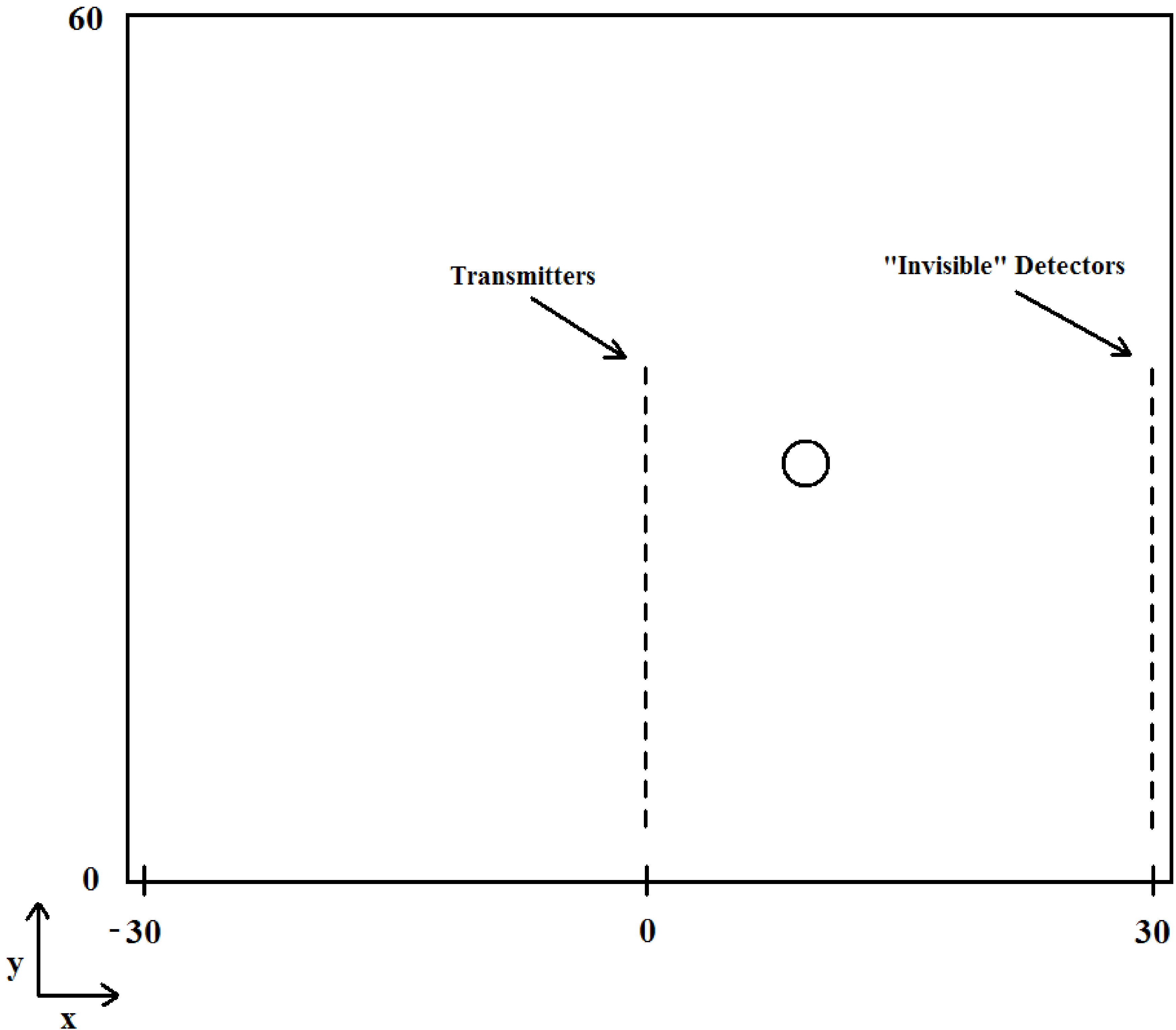
- At present: 2D, single diffraction source
- Randomly place scattering center within domain
- Run COMSOL from within Matlab, generating a large set of training paired vectors (~2800)
  - Input vectors – (Δt_i's)
  - Target vectors - (r_i's)
- Extract timing information at receivers
- Record time of amplitude > threshold value
- Train neural net using sets of input/target vectors
- After training, neural net provides position information about hand/fingers

COMSOL's role

- COMSOL as a design tool
  - 2D wave equation used
  - 16 linear wave sources used to create plane wave
  - How to model
    - Transmitters
    - Recievers – is this necessary?
    - Plates
    - Open interfaces – prevent reflections from reaching receivers
- Speed/efficiency
  - Only model what's needed
  - Keep mesh as simple as possible
- Future work
  - COMSOL 3D wave equation
  - Multiple diffraction sources

Matlab's Role

- Framework for production calculation
- Export solution from COMSOL to Matlab
- Solution exists at COMSOL's mesh locations
- NEED solution at the position of the receivers
- COMSOL solves wave equation at fixed time intervals
- Use "xmeshinfo(fem)" to extract full solution at mesh locations
- Use "griddata" to spatially interpolate fem solution onto the positions of the receivers
- Use "interp1" to interpolate the solution in time to find time of crossing threshold

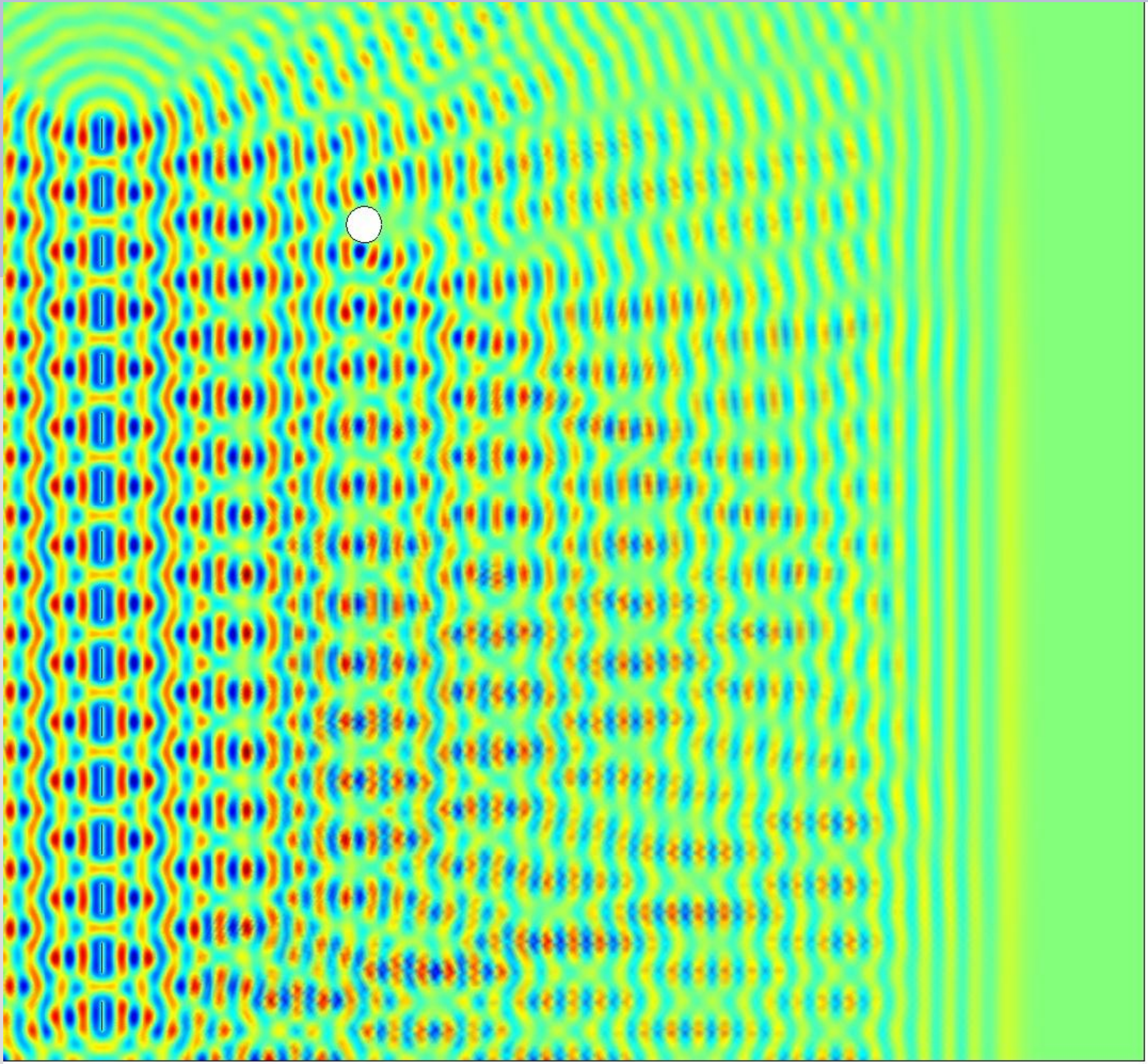

60
Transmitters
"Invisible" Detectors
0
-30
0
30
y
x

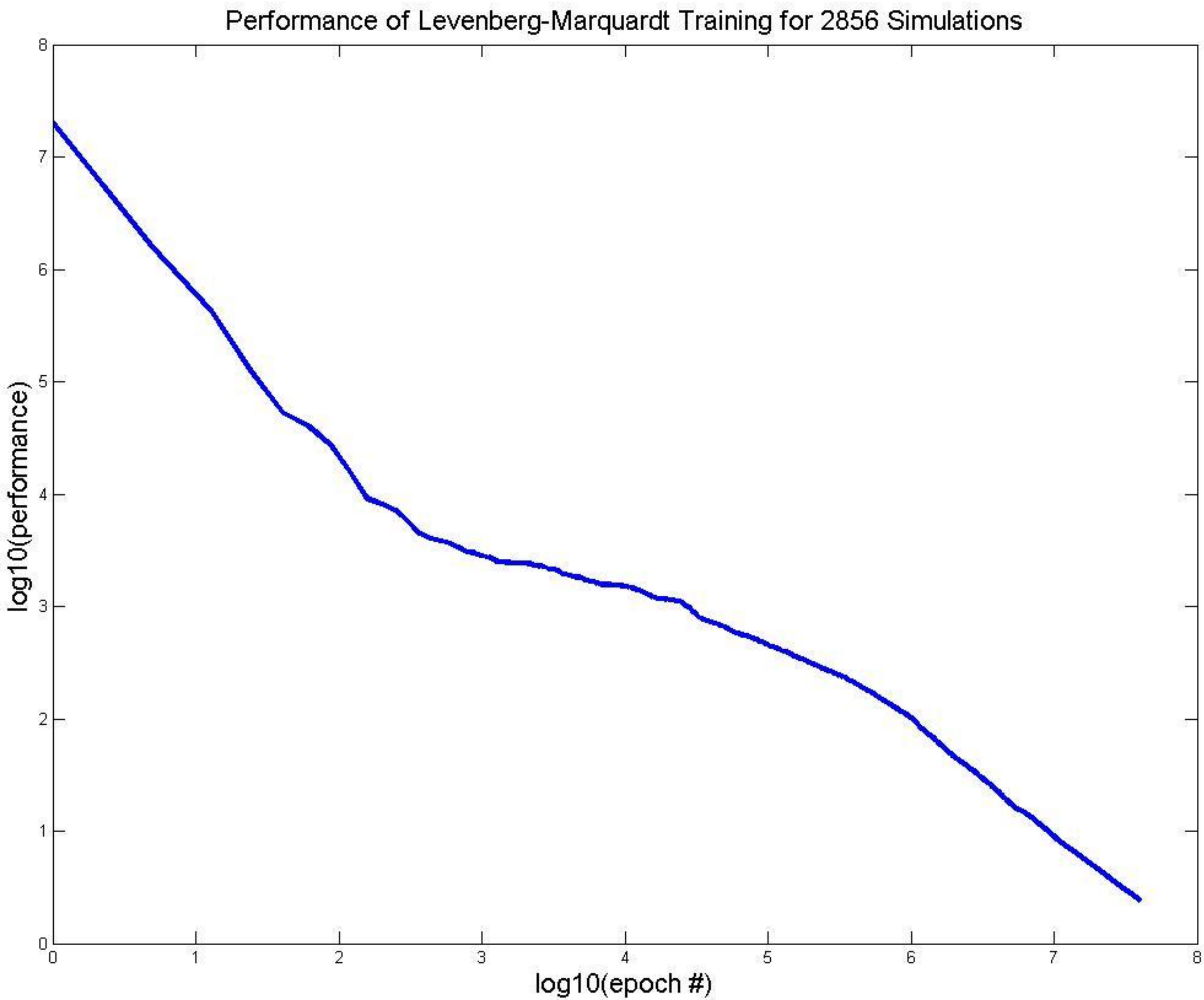
Neural Network's Role

- Use Matlab's excellent Neural Network Toolbox
- Optimization techniques considered:
  - Scaled Con jugate Gradient (“SCG”) - fast
  - One Step Seca nt (“OSS”) - fast
  - Broyden, Fletcher, Goldfarb, and Sh annon (“BFGS”)
  - Levenberg-Marquardt (“LM”) -slow
- Simultaneous solution to zero error (LM) – slowest
- Traditional gradient descent – fastest
- Train using 1000 pairs, use rest of set of training pairs as a control set
- Alternate training techniques and 1000-set pairs

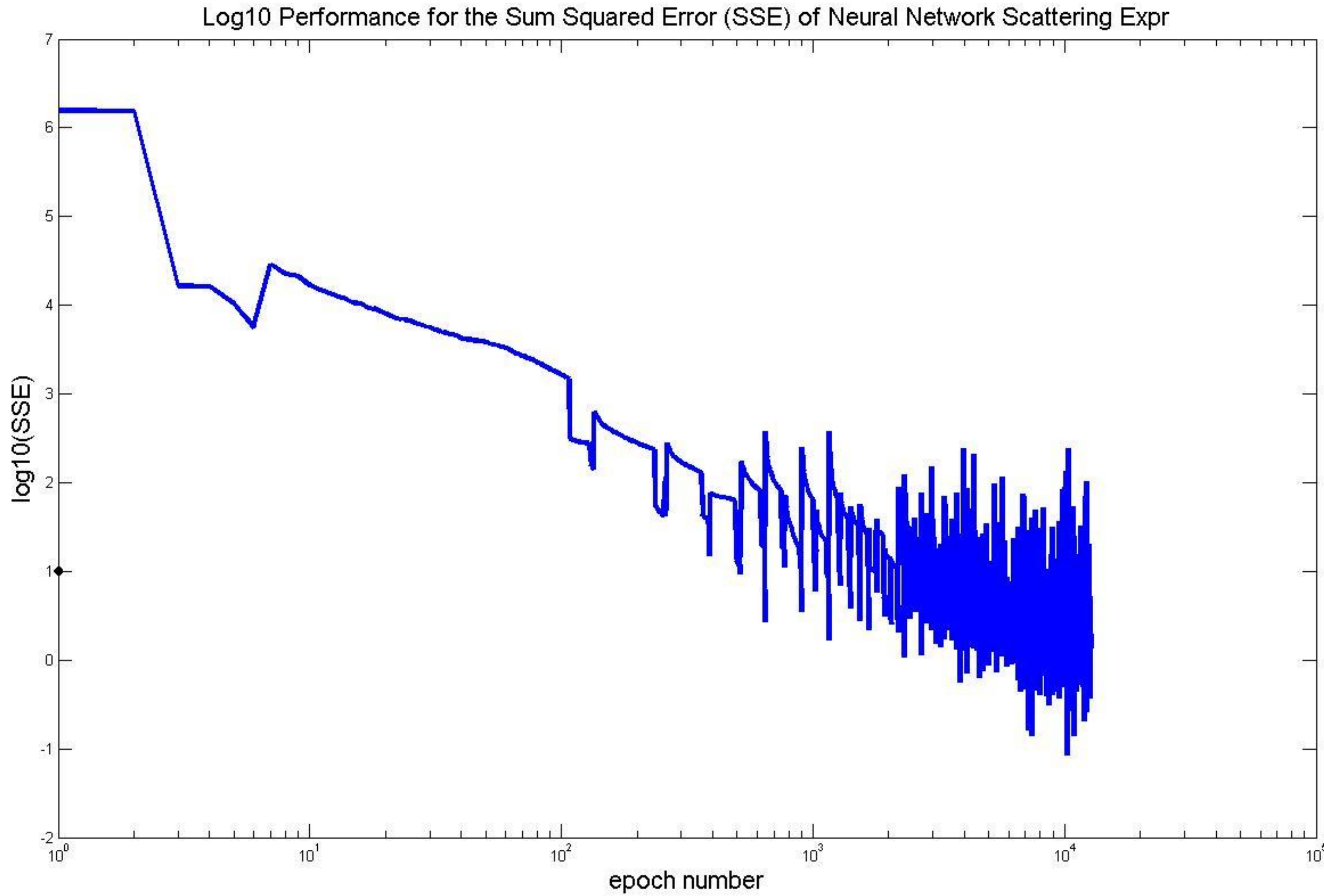
Results

- At present – 2D – single source can be reconstructed to a 2% relative error in position using the techniques described here
- This year, multiple sources will be simulated and trained
- 2D-->3D modeling will begin – much longer processing time

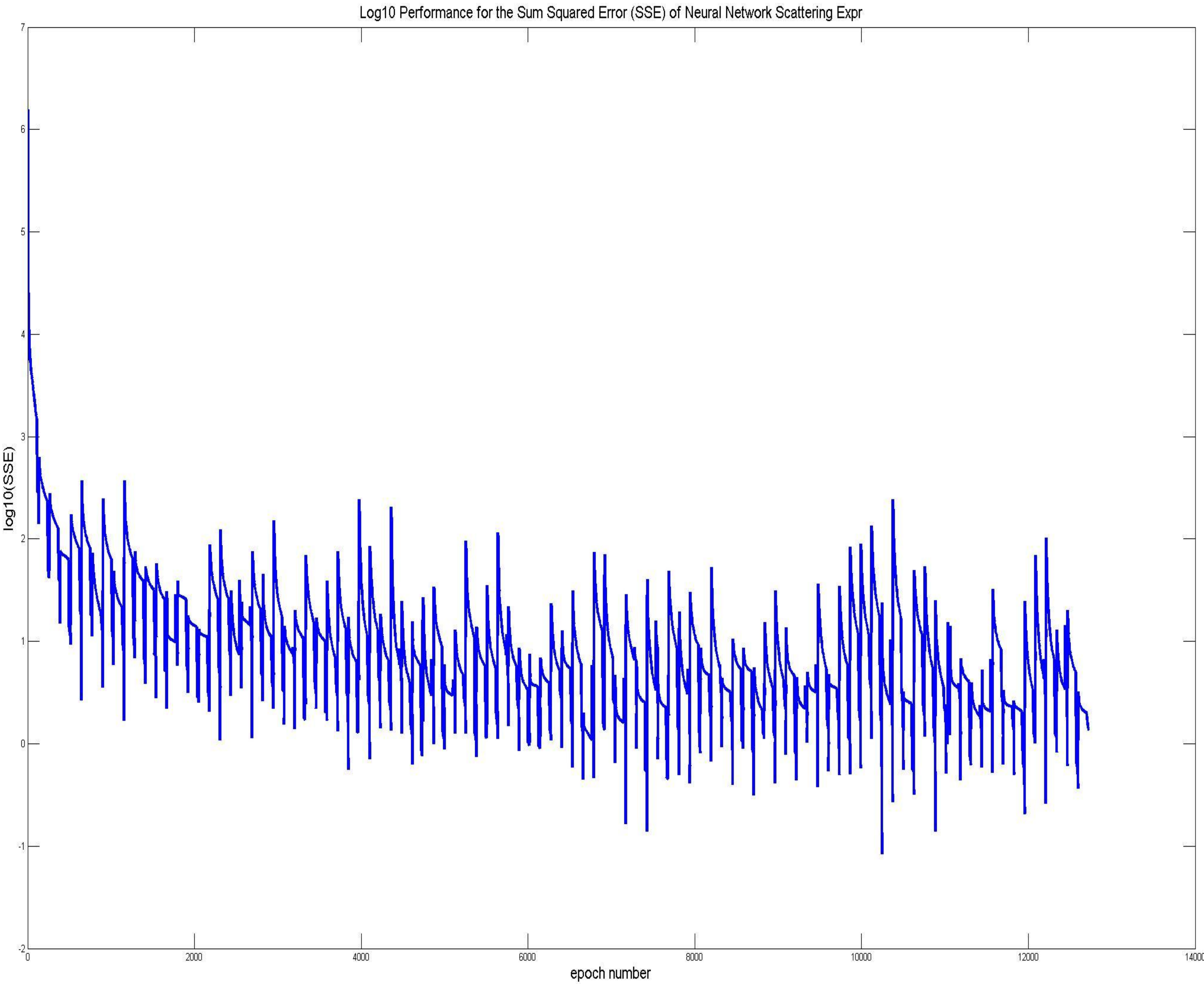




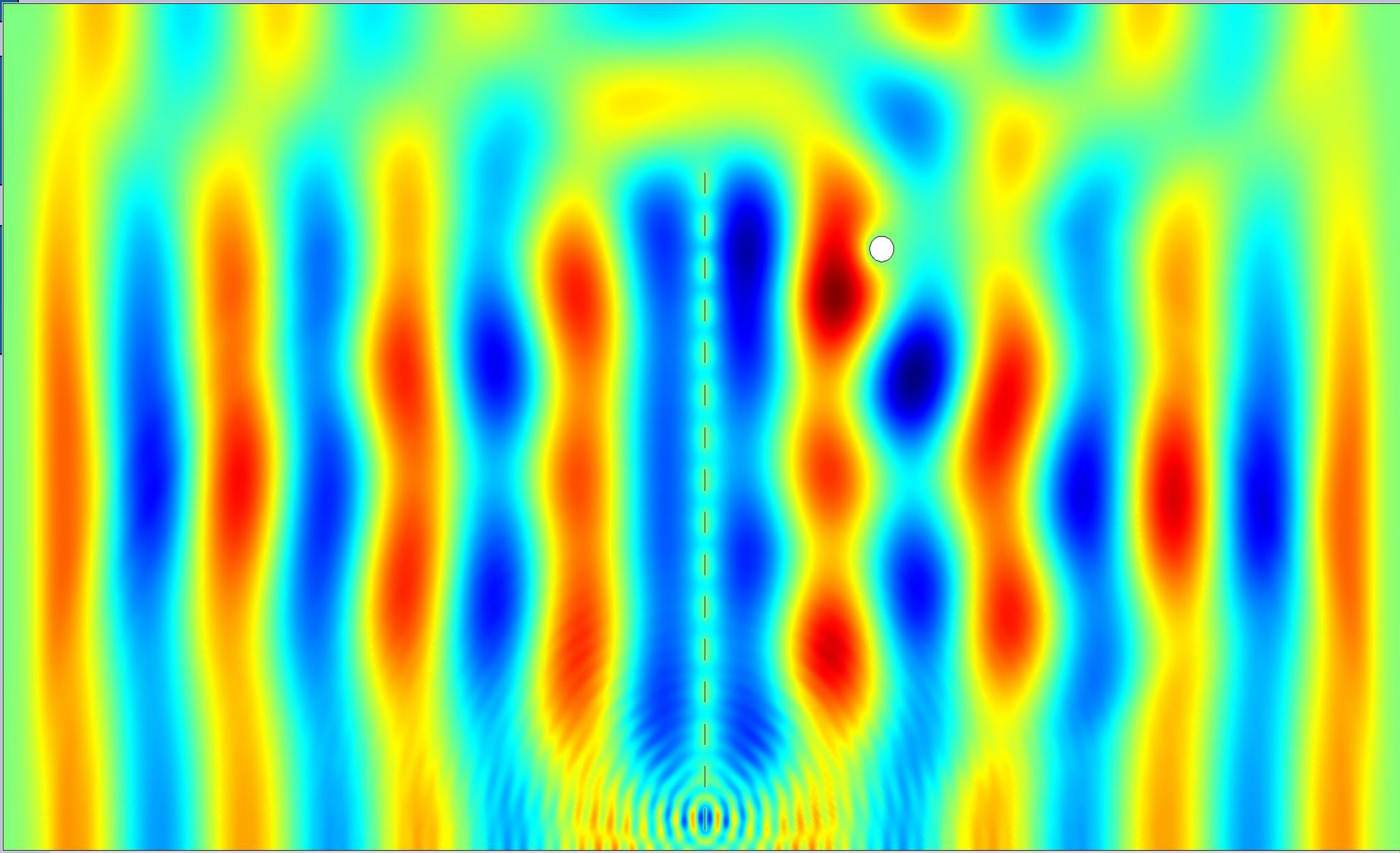
Performance of Levenberg-Marquardt Training for 2856 Simulations
log10(performance)
log10(epoch #)
0
1
2
3
4
5
6
7
8



Log10 Performance for the Sum Squared Error (SSE) of Neural Network Scattering Expr
log10(SSE)
epoch number
7
6
5
4
3
2
1
0
-1
-2
10^0
10^1
10^2
10^3
10^4
10^5

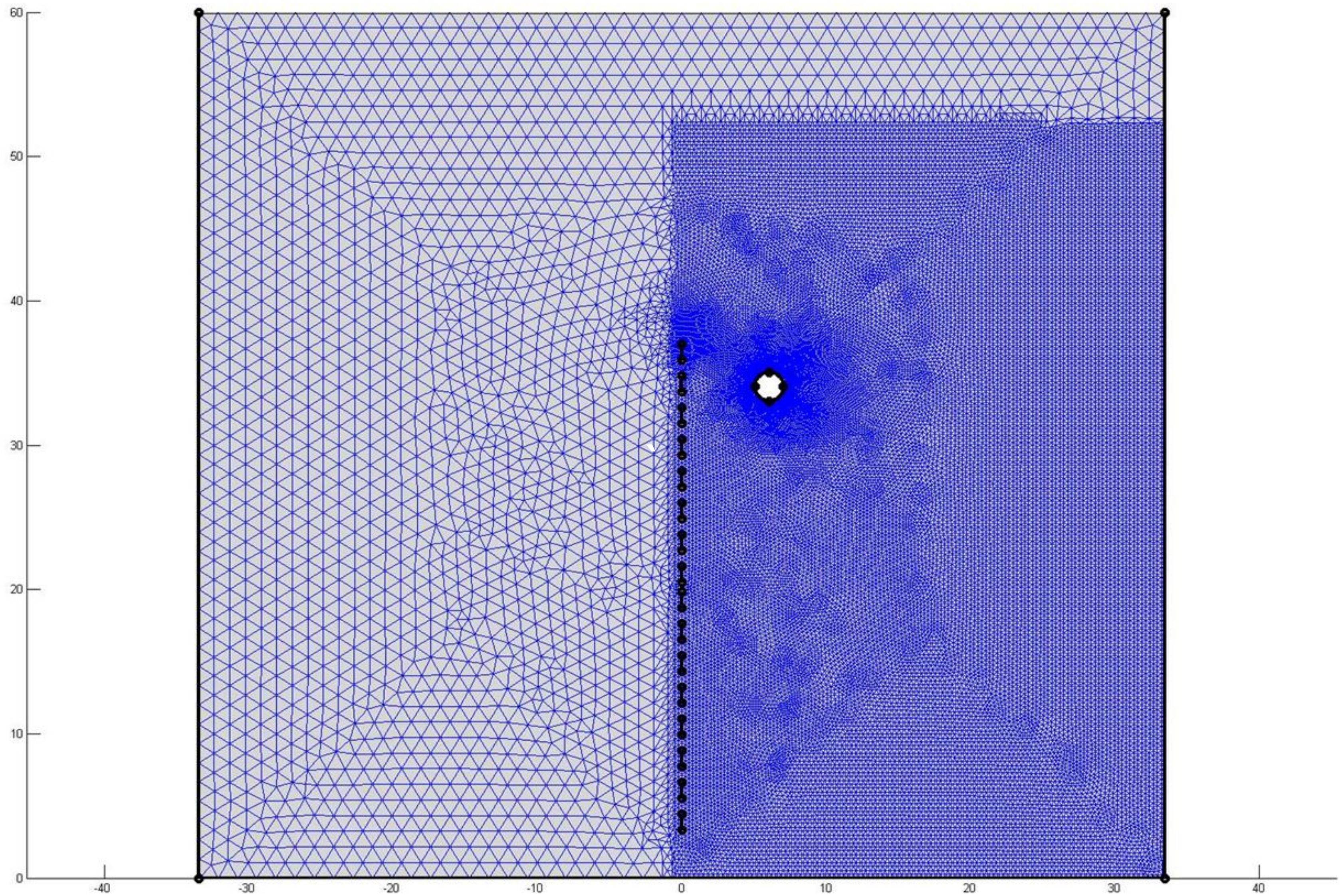


Log10 Performance for the Sum Squared Error (SSE) of Neural Network Scattering Expr
log10(SSE)
epoch number
7
6
5
4
3
2
1
0
-1
-2
0
2000
4000
6000
8000
10000
12000
14000



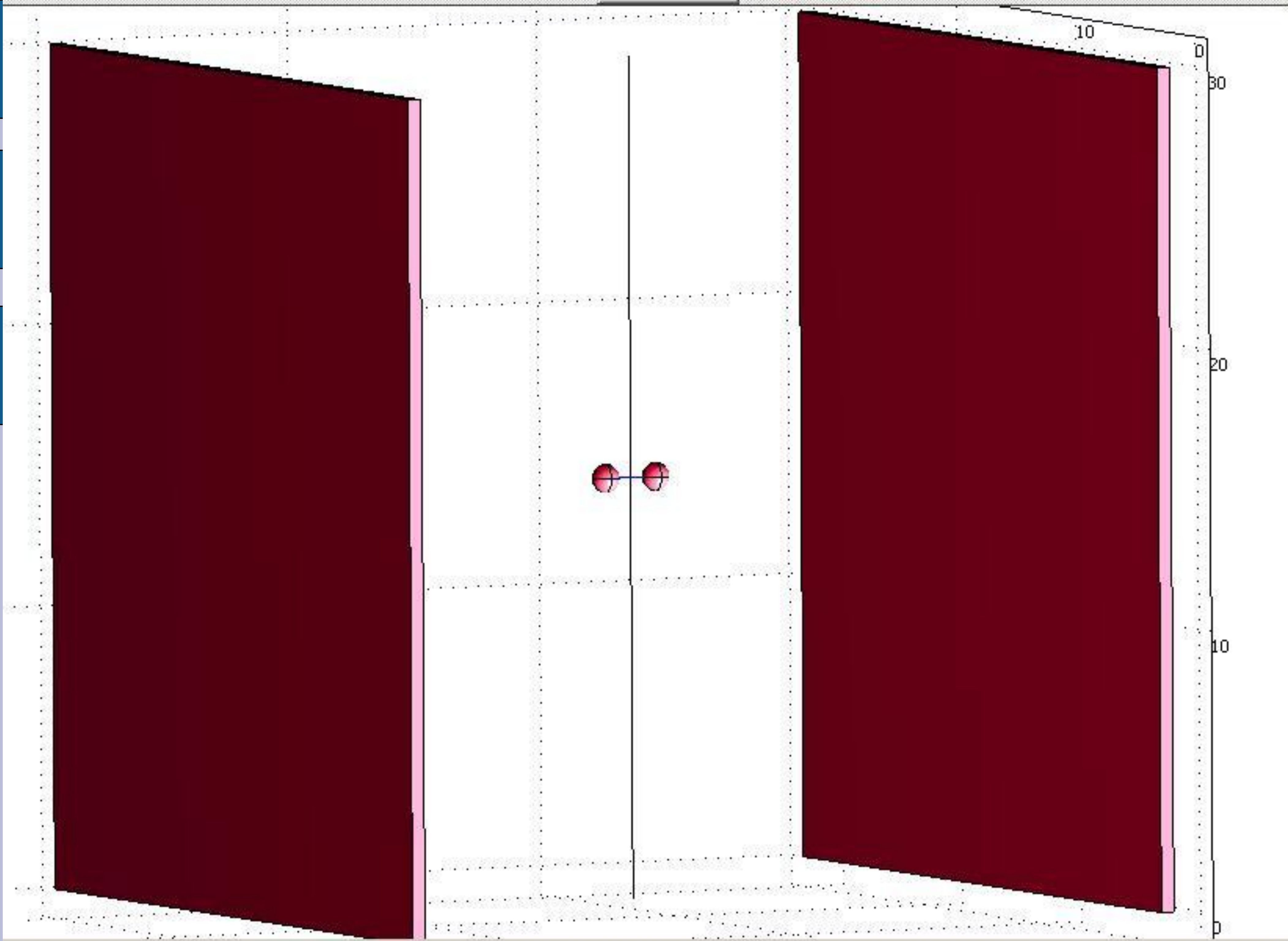
Comments

- Don't actually want positions, we want vectors (θ_i,ϕ_i) – various hand sizes
- Don't "over model/simulate"
  - Design needed to make sure waves
    - Diffracted from sources
    - Reached receivers with little interference as possible
  - Reflections will be present, but ignored from
    - Back plate
    - Receiver Plate
    - Sky
  - Reflections from floor cannot be ignored
  - No need to model the receivers as they are accounted for in the Matlab interpolation


60
50
40
30
20
10
0
-40
-30
-20
-10
0
10
20
30
40

Pedagogy

- Independent of using the “Mii” as a controller
- Solve acoustic analog problems of quantum mechanics
  - Consider a “dumbbell” with 1cm diameter balls
  - Suspended by a thread too small to diffract
  - Image the balls
- Now – consider if the dumbbell is rotating:
  - Slowly – simply images the balls as separate scattering centers
  - Very fast – images the balls as a statistical “blob”
  - Medium speed – can acoustic waves become “trapped” between the balls – like a resonance?



10
0
30
20
10
0