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General Research Institute for Nonferrous Metals

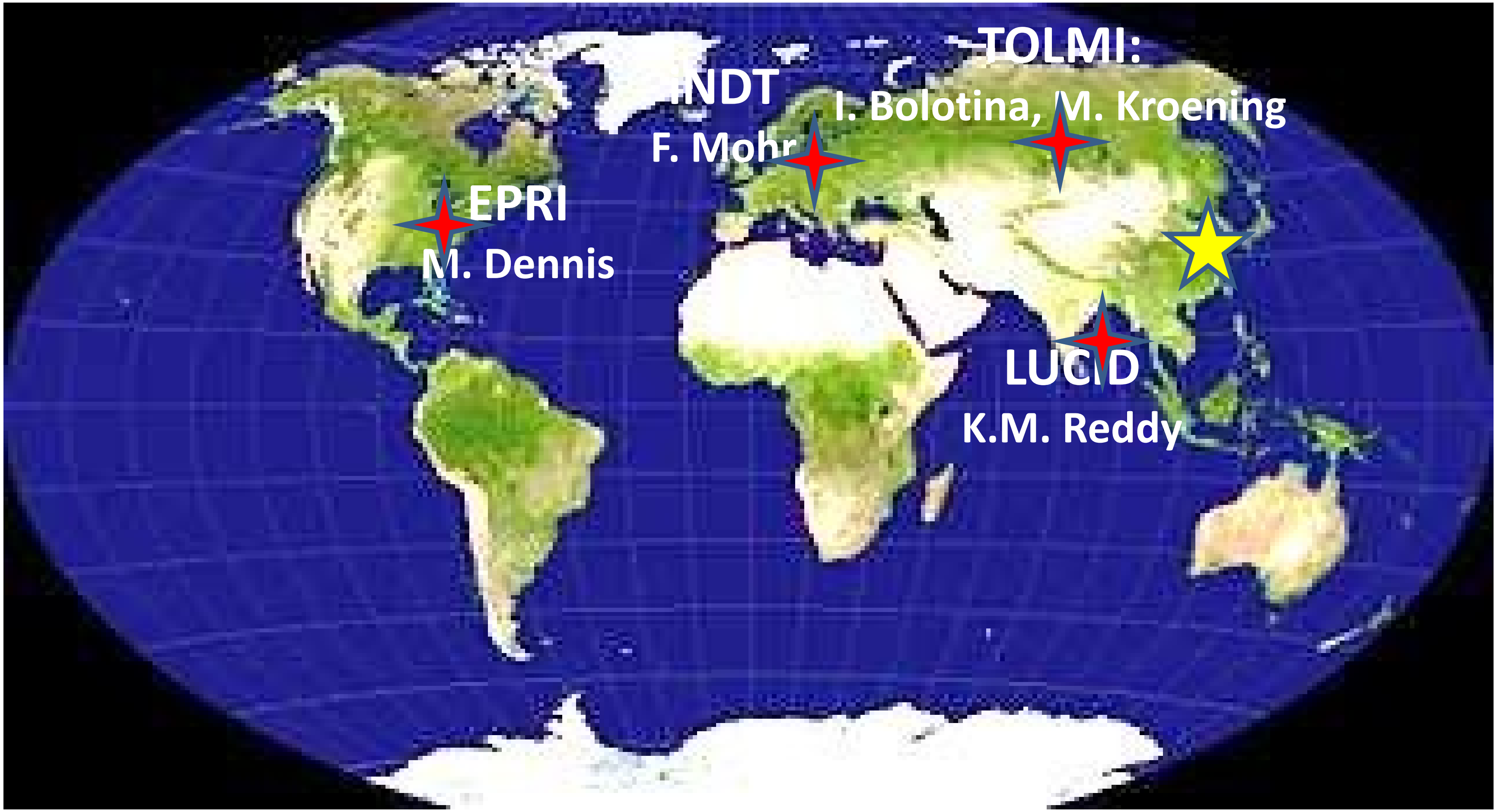
SEMINAR

R&D Laboratory on Industrial Demand

TOLMI

Advanced UT Systems

Michael Kröning



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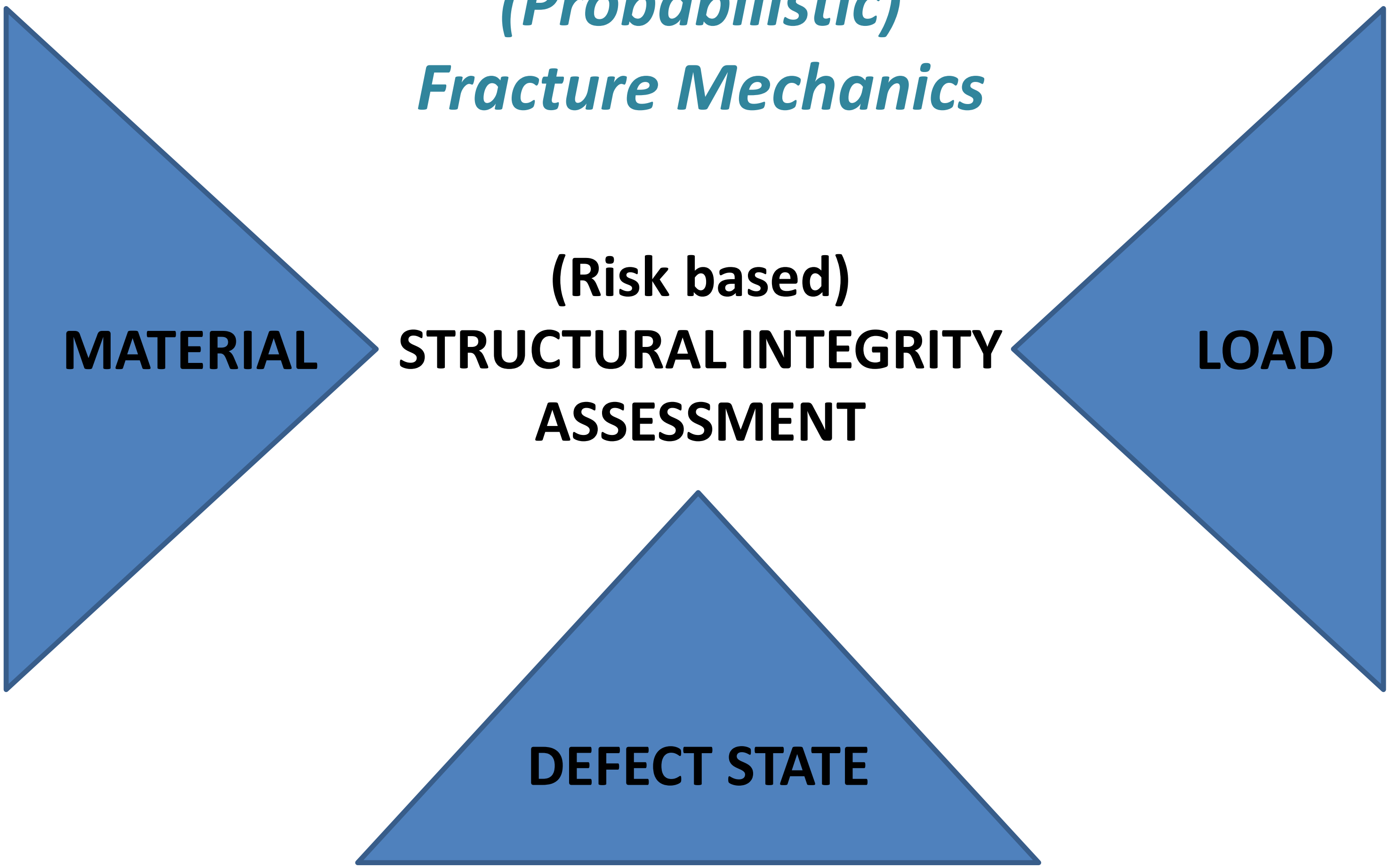
MOTIVATION

(Probabilistic)
Fracture Mechanics



Advanced UT Systems

(Quantitative)
ULTRASONIC TESTING

Contrast Sensitivity

DETECTION & EVALUATION of PLANAR FLAWS

Resolution Sensitivity

DEFECT STATE

PROBABILITY OF DETECTION

PoD (planar flaws) = f(Performance) X f(Contrast)

VALIDATION

f(Performance)	f(Contrast)
HUMAN ERROR	FLAWS & MATERIAL
AUTOMATION	ULTRASOUND
SCAN COVERAGE	ORIENTATION COVERAGE
Scan Index & Beam Spread	Direction of Incidence

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FLAW EVALUATION

There are many experts and procedures
We rely on ultrasonic high resolution imaging

HUMAN ERROR

AUTOMATION

FLAW COVERAGE

All Flaws are imaged

VALIDATION

INDEPENDENT EXPERT EVALUATION

WAVE PHYSICS (MIGRATION)

HIGH RESOLUTION FLAW SCAN

3-D Scan and 3-D imaging

CHALLENGE

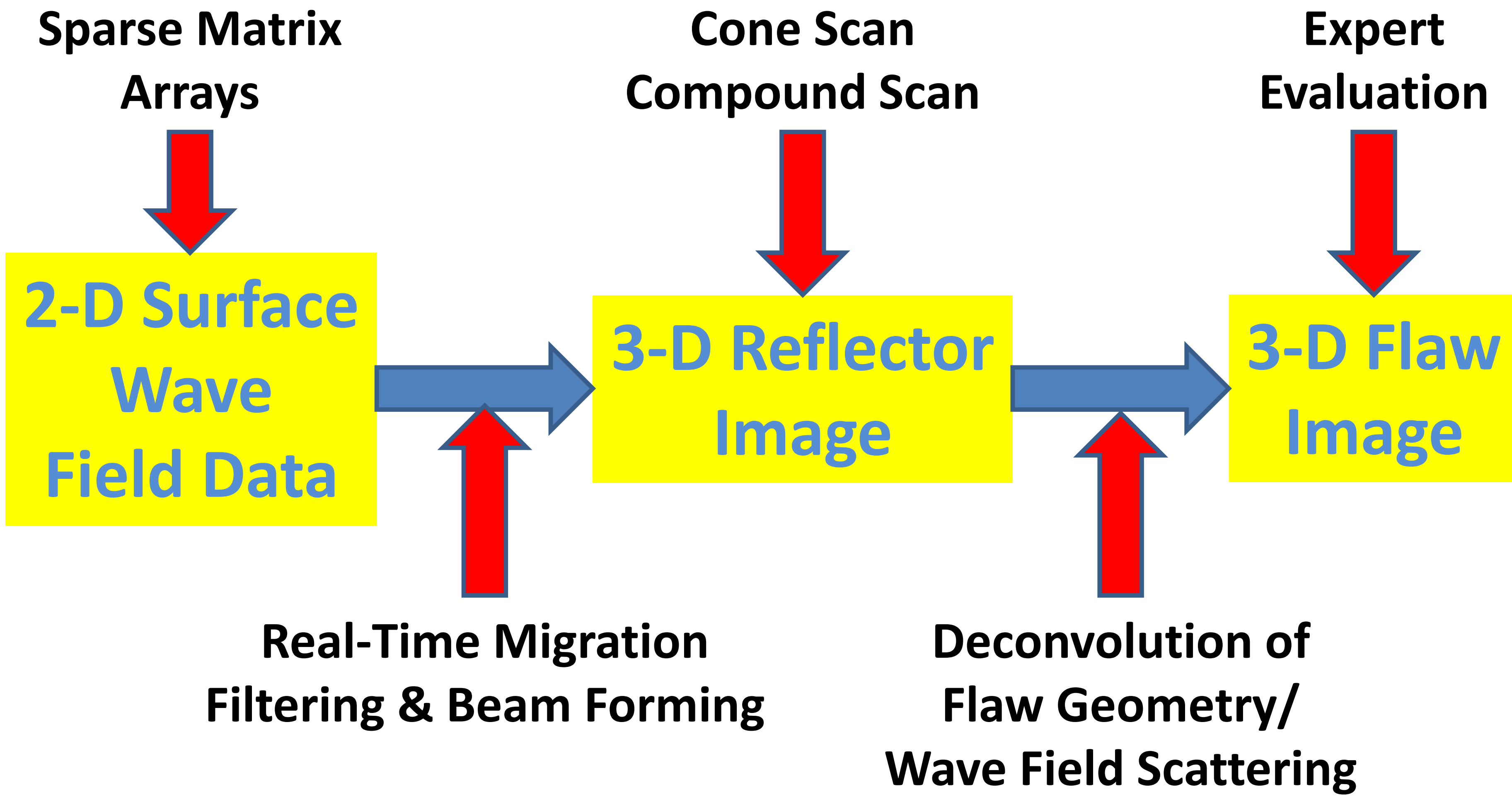
Contradicting Requirements

High Contrast Sensitivity	High Resolution Sensitivity
Space Coverage of Intromission Angles	Resolution in Space 3-D Imaging
Large Beam Spread	3-D Focussing

DEFECT STATE

(Quantitative)
ULTRASONIC TESTING

R&D OBJECTIVES



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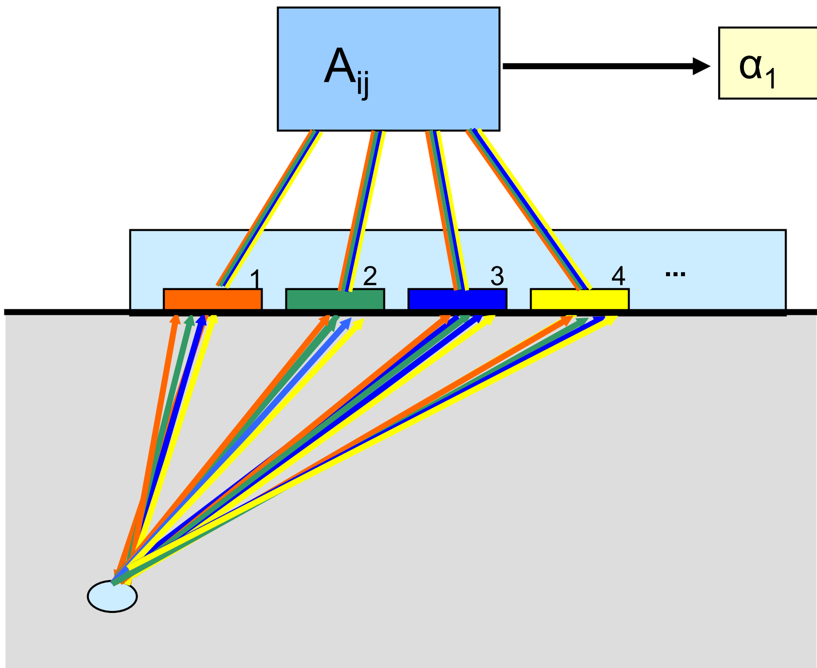
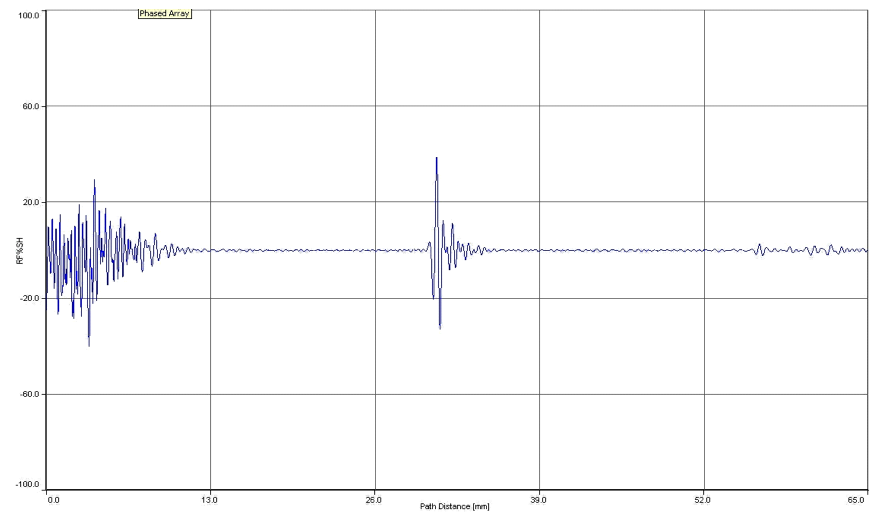


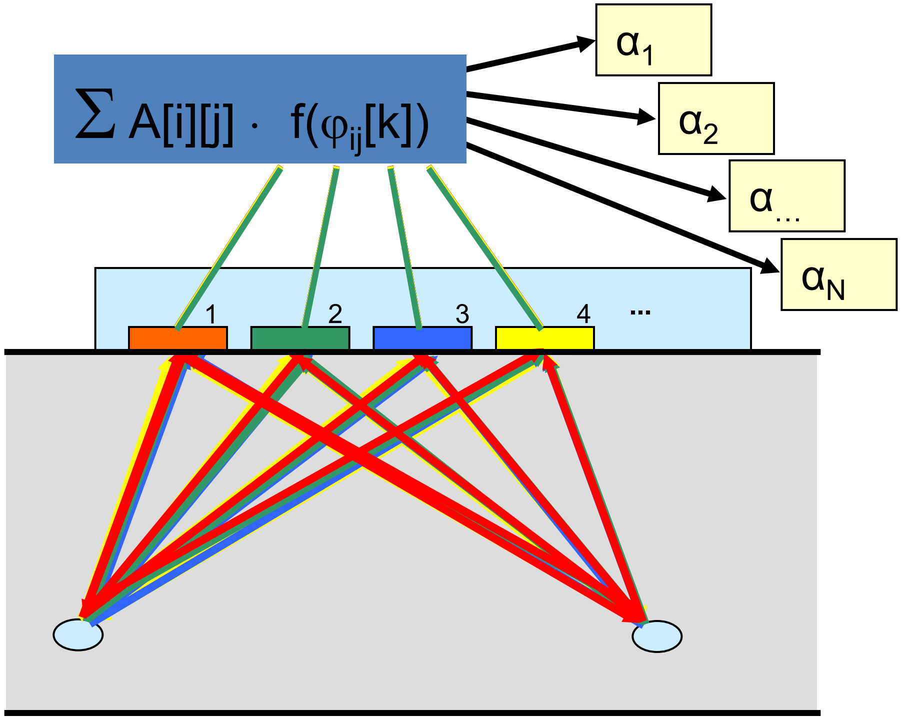
A-SCAN: $A_\alpha(t)$

α – Beam Angle



Signal Generation Using Conventional PA

$\varphi_{ij}[k]$ **– corresponding phase delay for beam angle α**



Information Matrix A_{ij}

i – transmitter number
j – receiver number

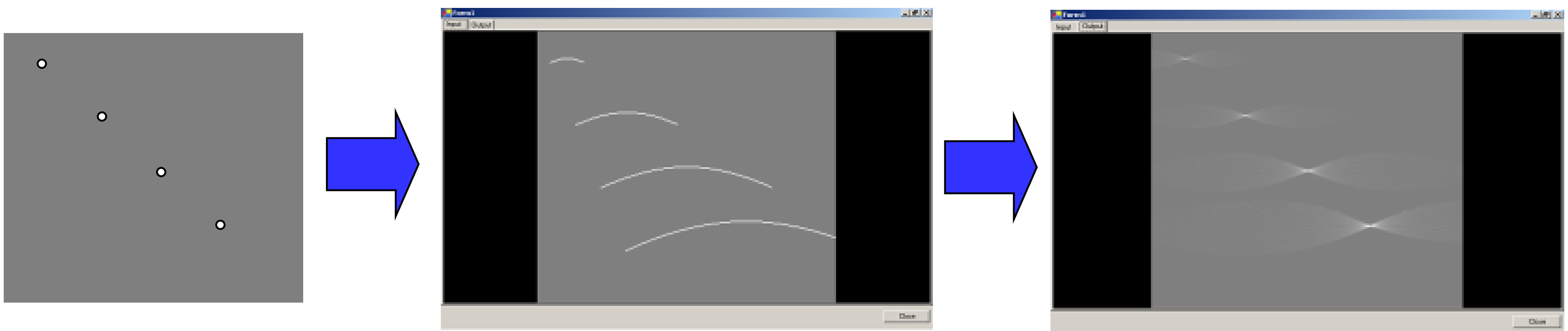
A_{11}	A_{12}	A_{13}	A_{14}
A_{21}	A_{22}	A_{23}	A_{24}
A_{31}	A_{32}	A_{33}	A_{34}
A_{41}	A_{42}	A_{43}	A_{44}

Notation: **m** x **n**
m – number of active transmitters
n – number of active receivers

Sampling PA Signal Generation

Synthetic Aperture - SAFT

SAFT Reconstruction



A_{11}	A_{12}	A_{13}	A_{14}
A_{21}	A_{22}	A_{23}	A_{24}
A_{31}	A_{32}	A_{33}	A_{34}
A_{41}	A_{42}	A_{43}	A_{44}

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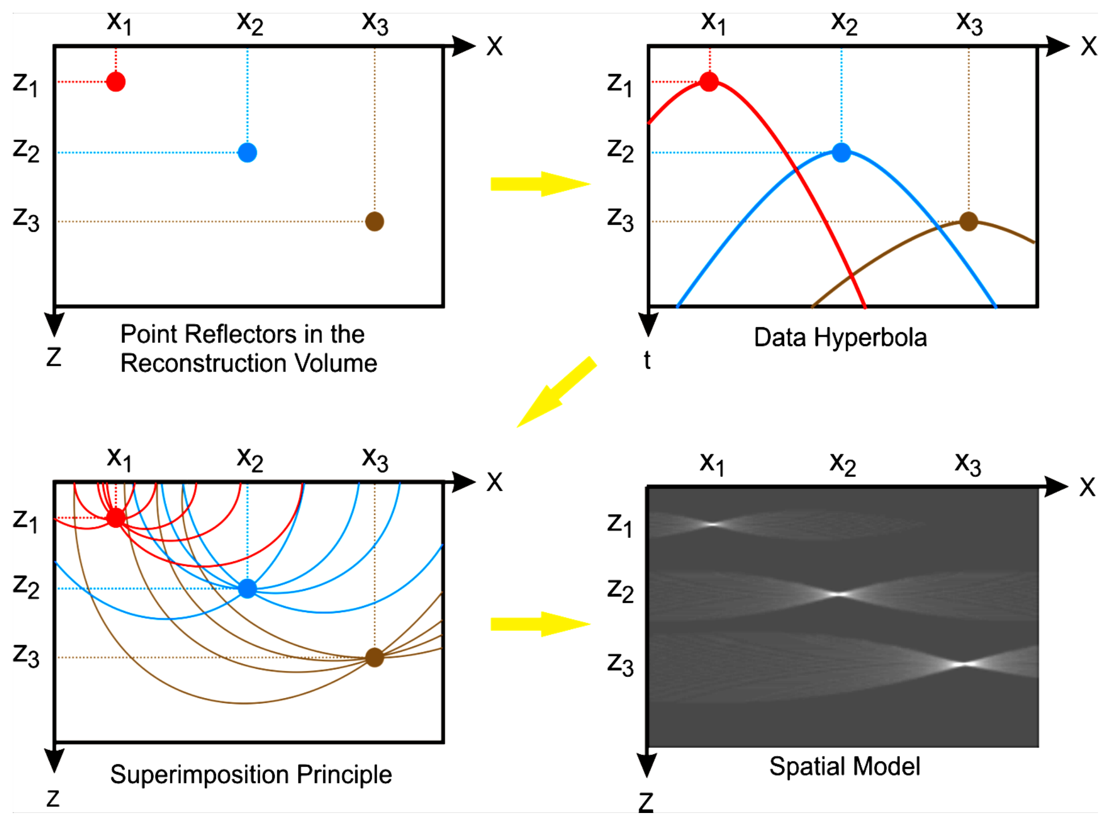
ACOUSTIC MIGRATION

(As Realized for NDT Applications)

Kirchhoff Ansatz:

$$C(t) = G\sum_{i} w_i A_i(t - t_i)$$



x_i : element position

z_j : depth position

C(*t*) : computed RF echo return

A_i(*t*) : returned signal

w_i : weight assigned to $A_i(t)$

t_i : time delay for element i.

G: goodness of fit enforcement (SynFoc© by LucidSoft)

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THAT'S WHAT WE WANT!

Resolution Sensitivity:

- depends on the element aperture in the near field of the array aperture (synthetic focusing)
- is close to the Rayleigh limit for λ/2 element apertures
- can be increased by super resolution techniques

Contrast Sensitivity:

- Matrix arrays:
  sensitive to all space directions within the chosen cone angle
- Linear Arrays:
  covers all angle of incidence of the chosen sector scan angel including angles beyond the first critical angle (shear mode)

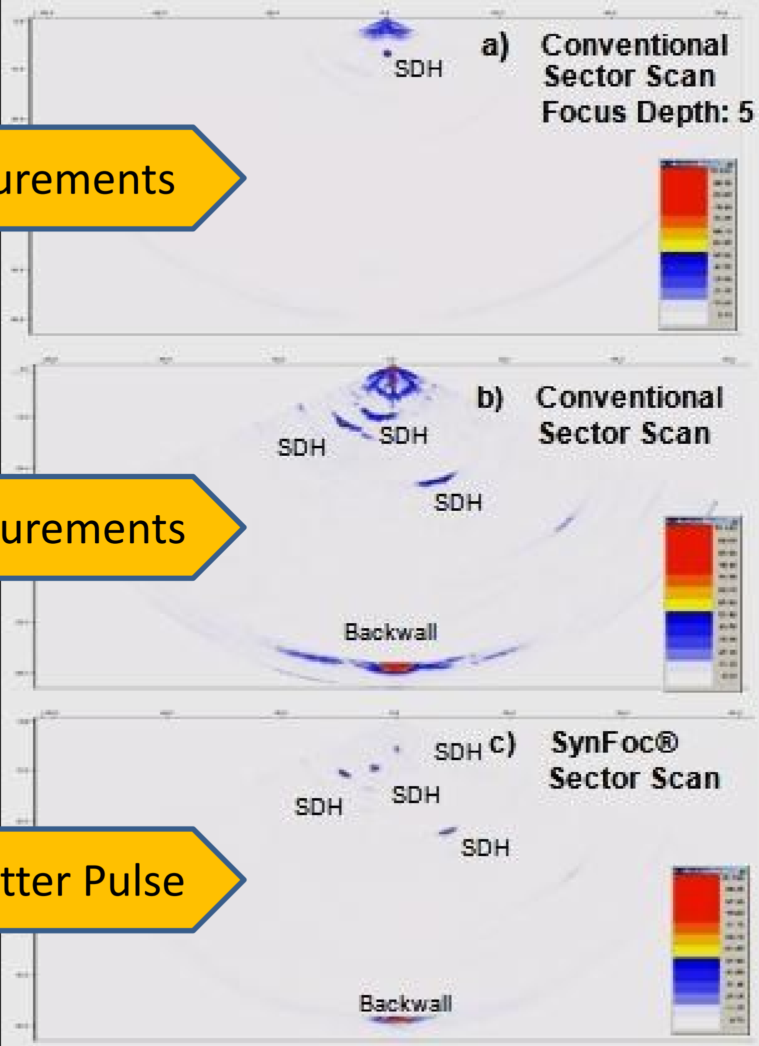
ACOUSTIC MIGRATION

(As Realized for NDT Applications)

71 Measurements

71 Measurements

1 Transmitter Pulse



Experimental Data:

Test Specimen: Steel 55 mm thick
SDH Ø: 1mm
Linear Array Transducer:
F = 5 MHz; 16 Elements

Partial View of Test Specimen with Transducer

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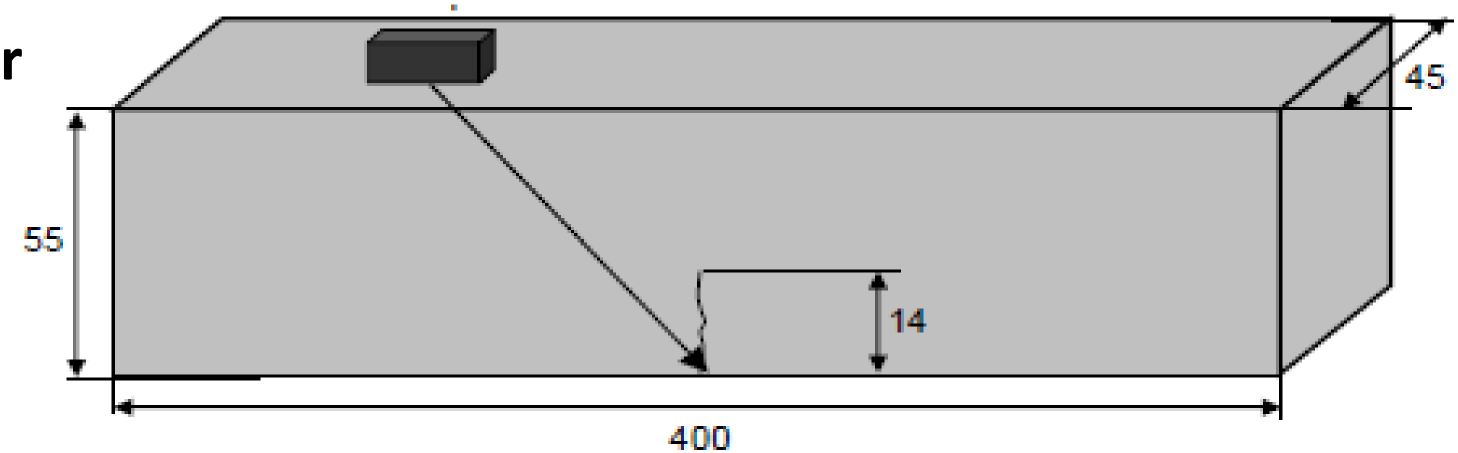
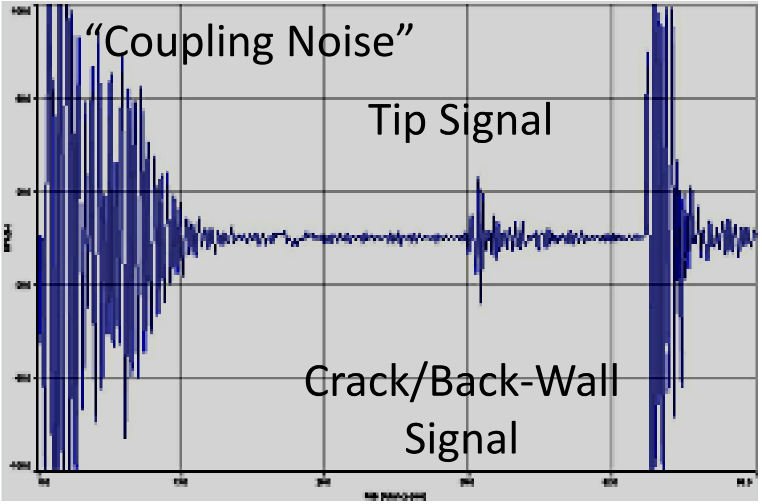
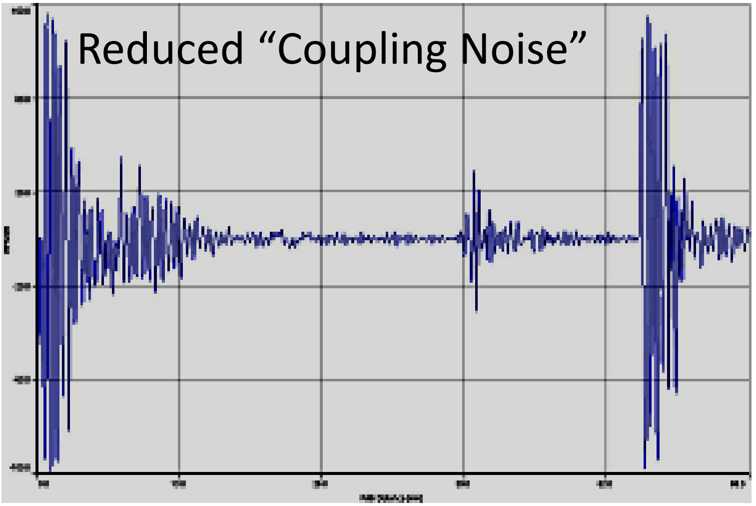
Transducer

Linear Array
64 elements
16 used
f = 5MHz
Longitudinal





Phased Array Mode 45° long.



Migration Mode
Reconstructed A-Scan 45° long.

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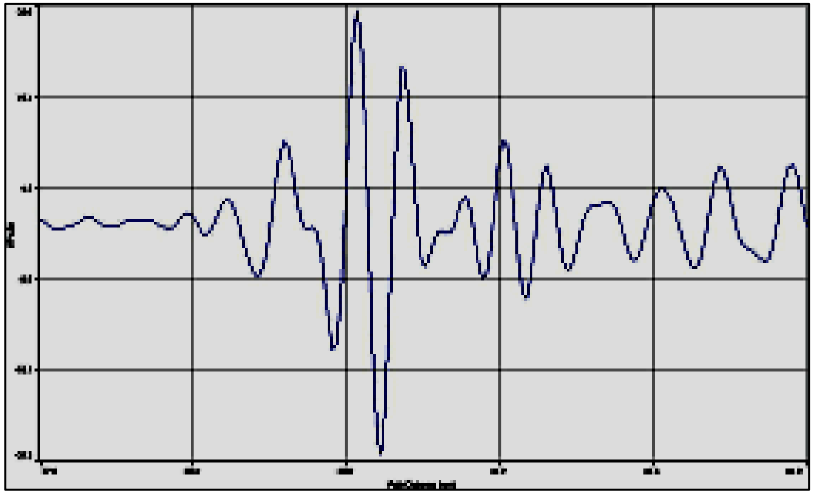
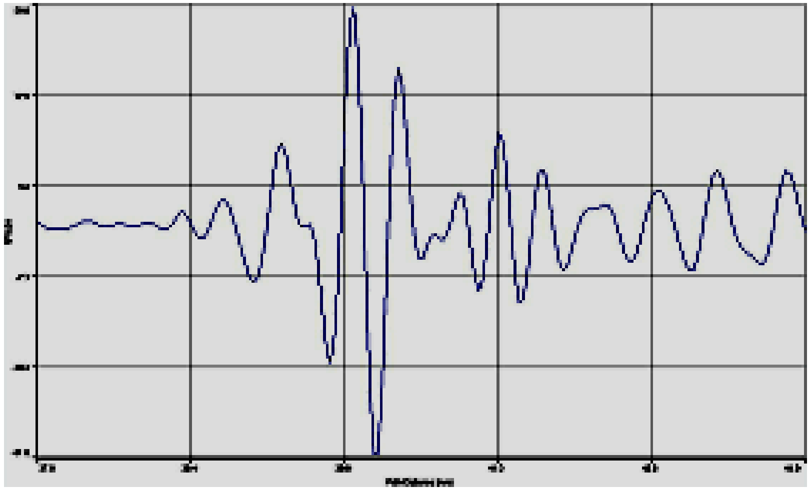
Zoomed Crack Tip Signals



Phased Array Mode



Migration Mode

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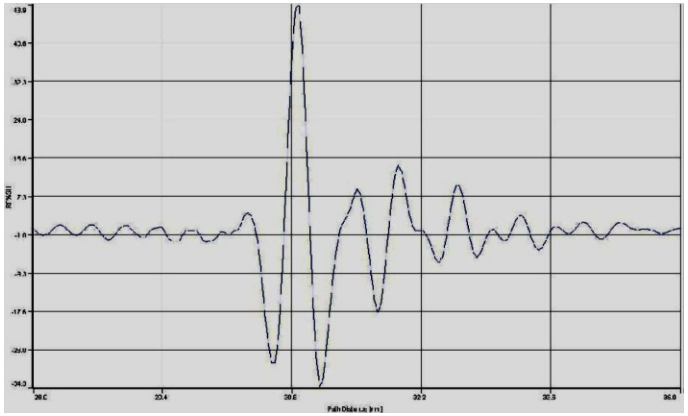
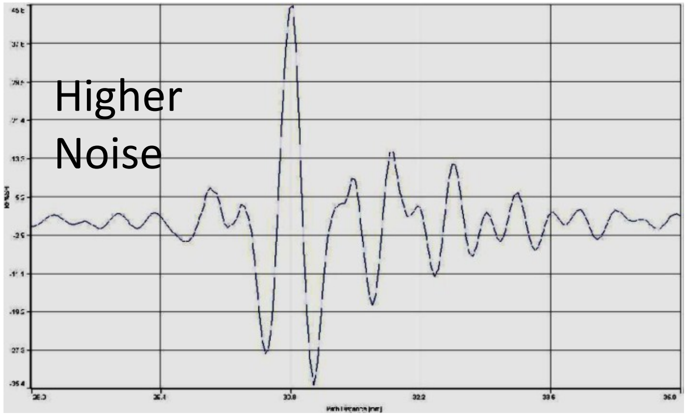
REAL-TIME MIGRATION

All 16 elements used as transmitter in sampling mode by multiplexing

Only 1 element used as transmitter in 1 transducer position





All 16 elements used as receiver simultaneously in parallel mode

Transducer:
5 MHz Linear Array
64 elements
with 16 used

POINT REFLECTOR SIGNALS
(Reconstructed A-Scans 45° long)

TECHNICAL CHALLENGES
(we are working on it)

LARGE ARRAY APERTURES
FOR LONG DISTANCE FOCUSING

- Reasonably low number of array elements
  - ➢ SPARSE APERTURES

λ/2 ARRAY ELEMENTS
FOR HIGH RESOLUTION SENSITIVITY

- Reasonably efficient array elements
  - ➢ STACKED ELEMENTS (3 LAYERS)

SPARSE APERTURES

An example for consideration

Phased Array Transducer:

8x8 (16x16) Matrix Array with 64 (256) λ/2 elements
f = 3 MHz
Array Aperture: (8x8) (16x16)mm^2
in compliance with Sampling Theorem

- Near Field Distance: ~ 7.5 (30)mm

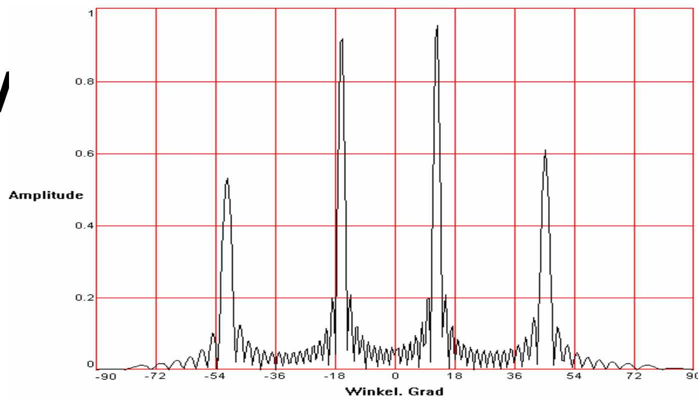
Migration Array Transducer

with reasonably low number of elements
and large near field distance:
8x8 λ/2 elements with an aperture of (32x32)mm^2
in sparse arrangement (Distribution Factor 4)

- Near Field Distance: ~ 130 mm

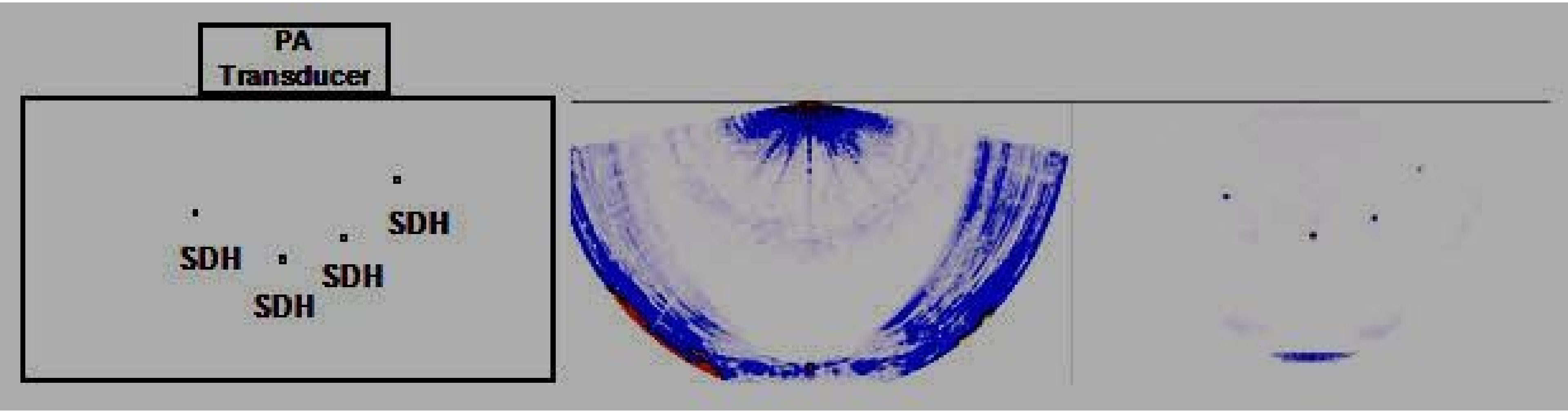
TRANSDUCER:

64 element linear array
16 elements used
f = 5 MHz
Distribution Factor: 4
(Element Skip: 2λ)



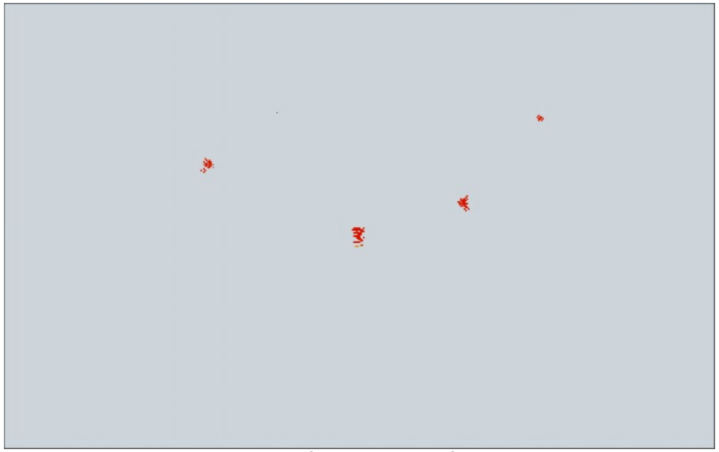
BEAM PROFILE

Phased Array mode
Phase control: 0°



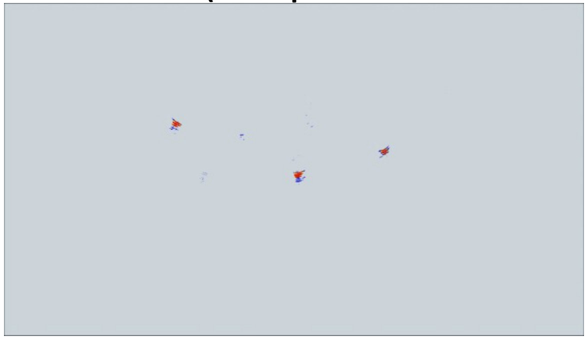
Test specimen | Phased Array sector scan | Migration image

SPARSE ARRAY SECTOR SCANS

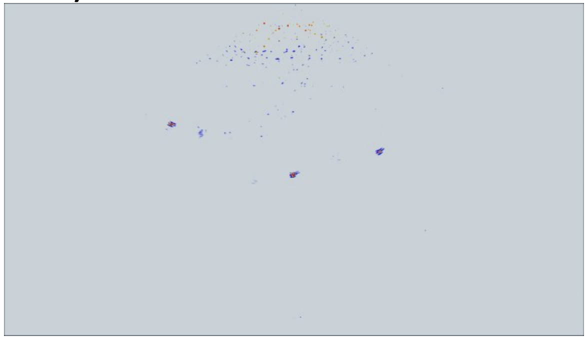


Migration by 64 elements
(full possible information)

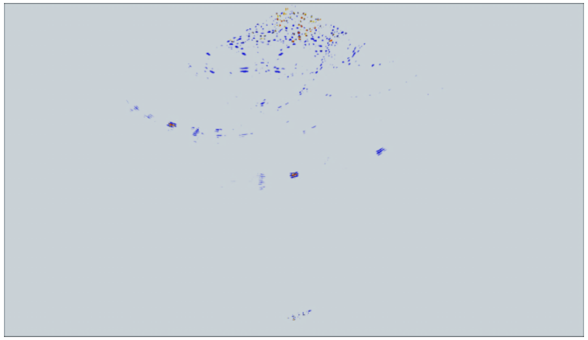
Migration by 6 elements
stochastic distribution



Migration by 16 elements
homogeneous, DF = 4



Migration by 8 elements
homogeneous, DF = 8



Migration by 6 elements
homogeneous, DF = 10

SPARSING LIMITS

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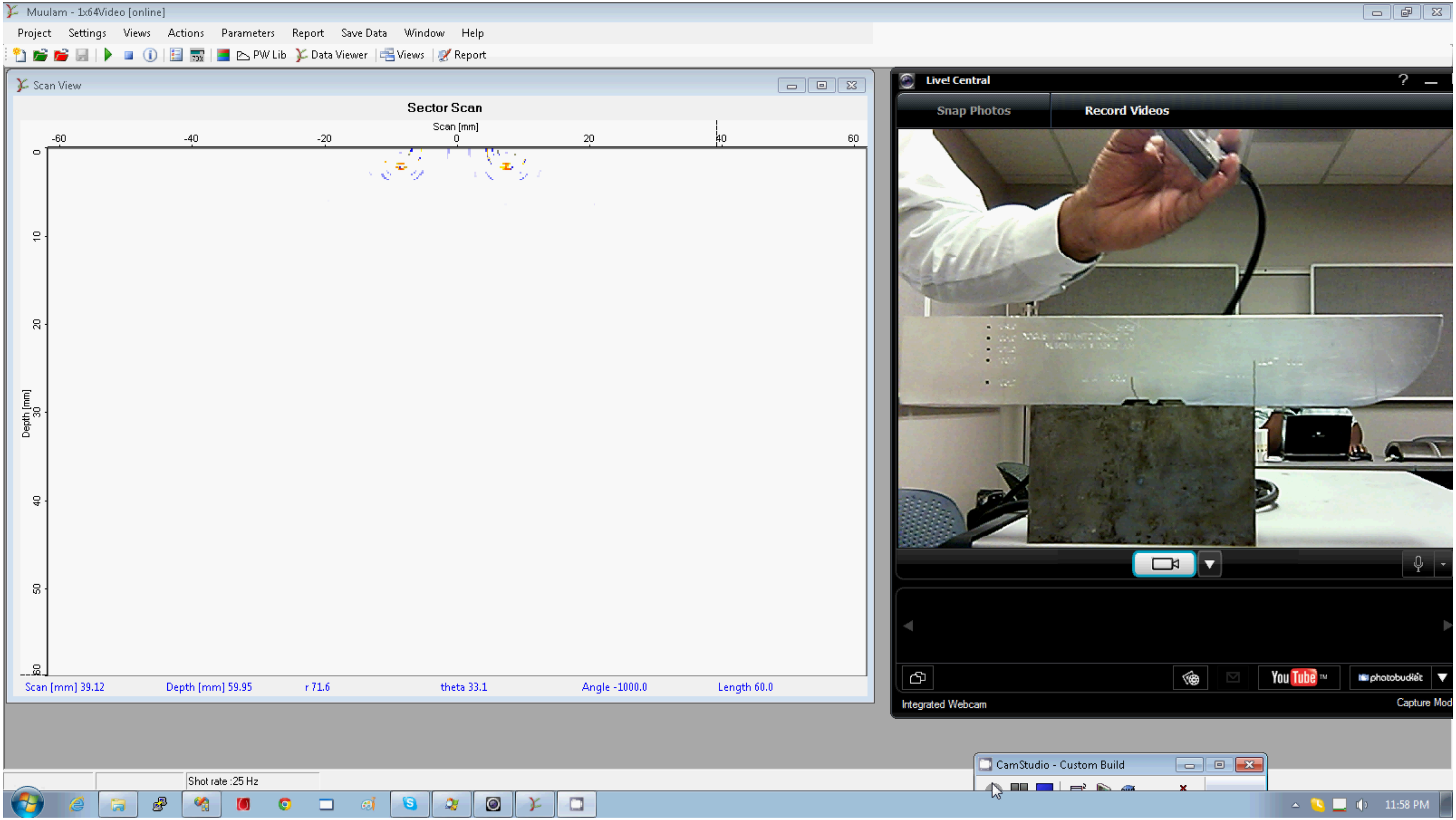

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APPENDIX I: COMPOUND SCAN RECONSTRUCTION

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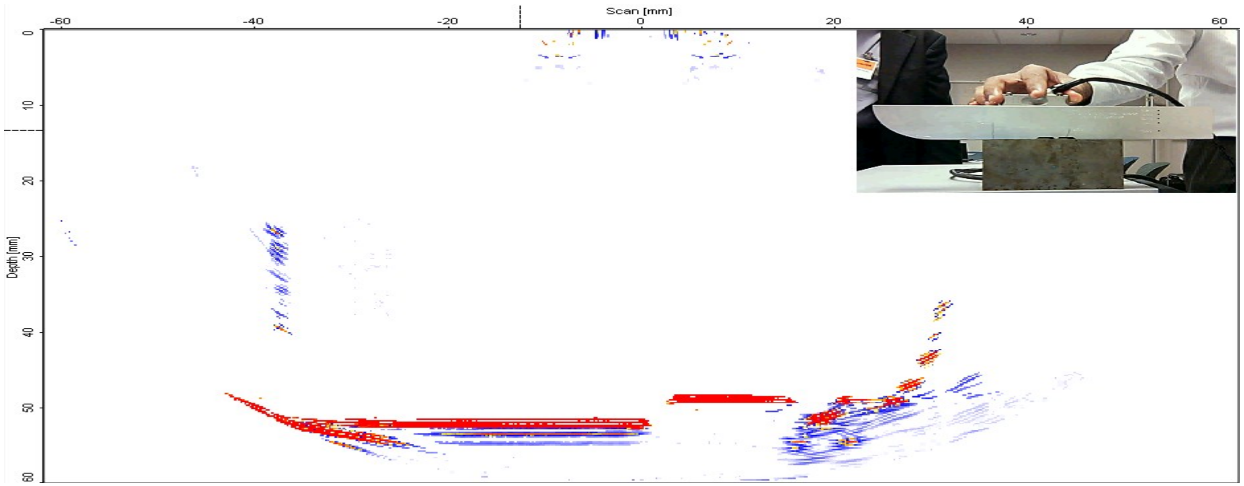
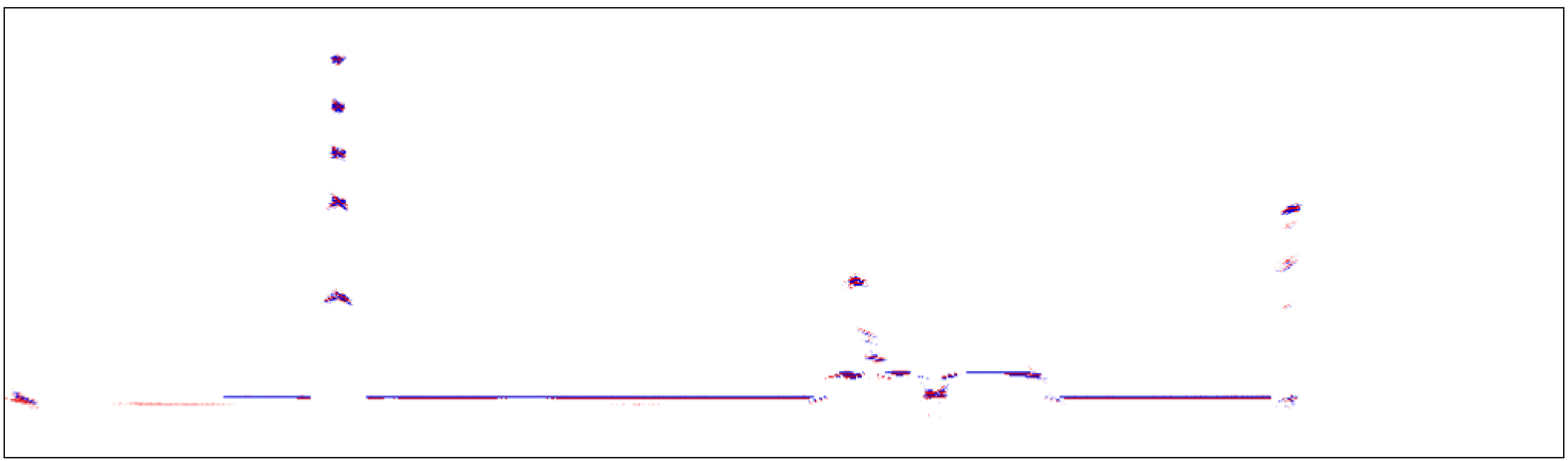


Sector scan reconstruction of Alu block with side drilled hole



B-Scan reconstruction of Aluminium block

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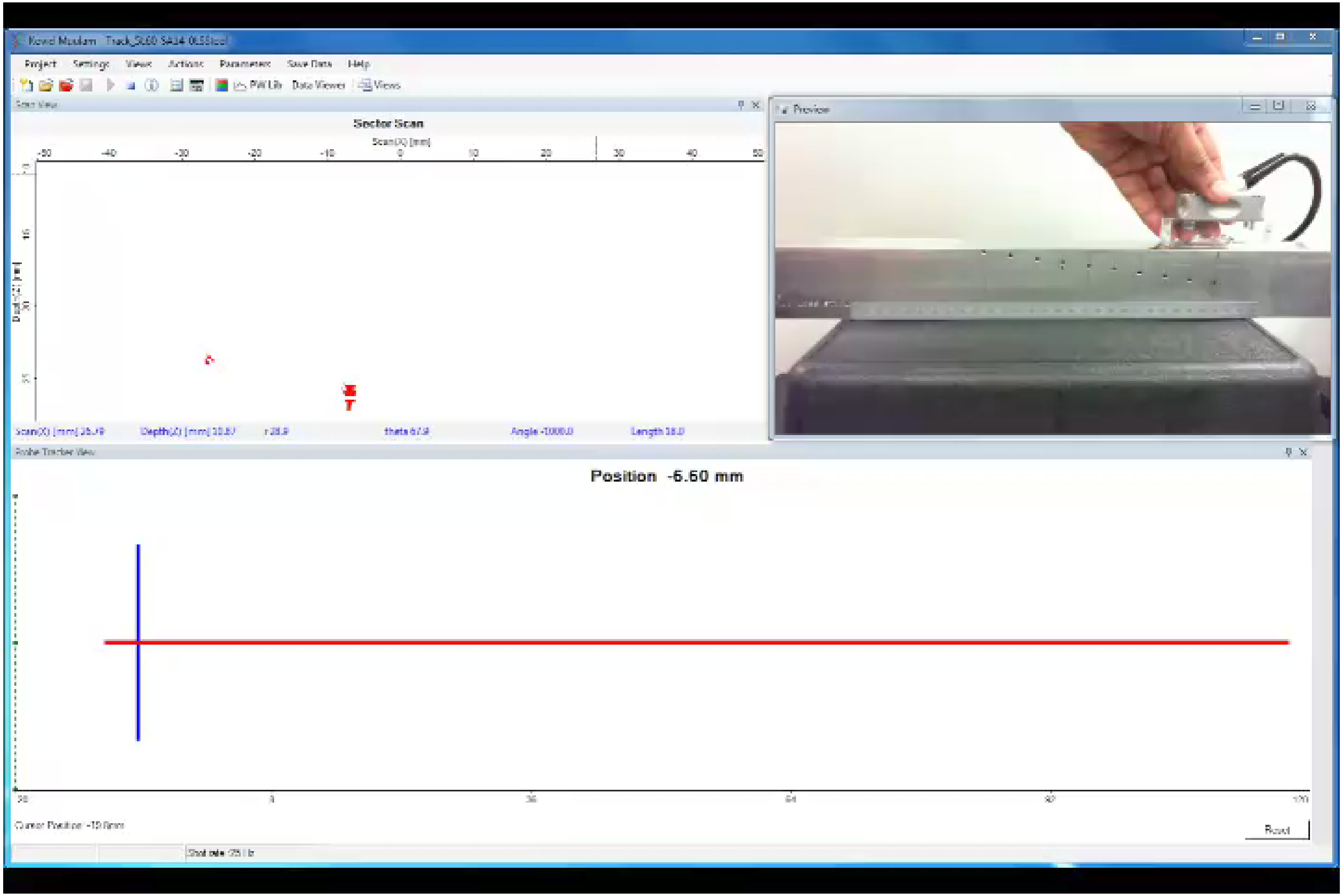

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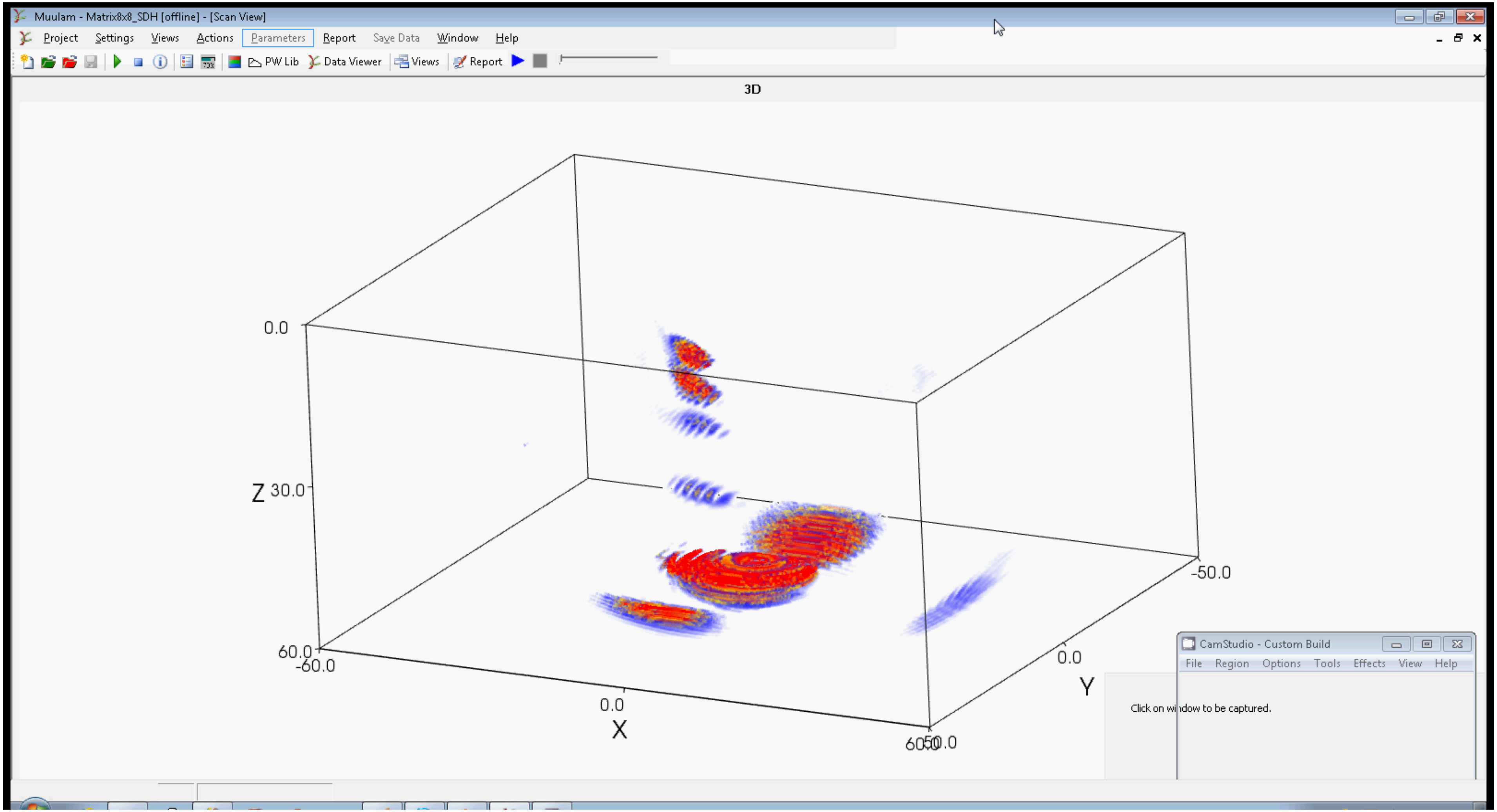

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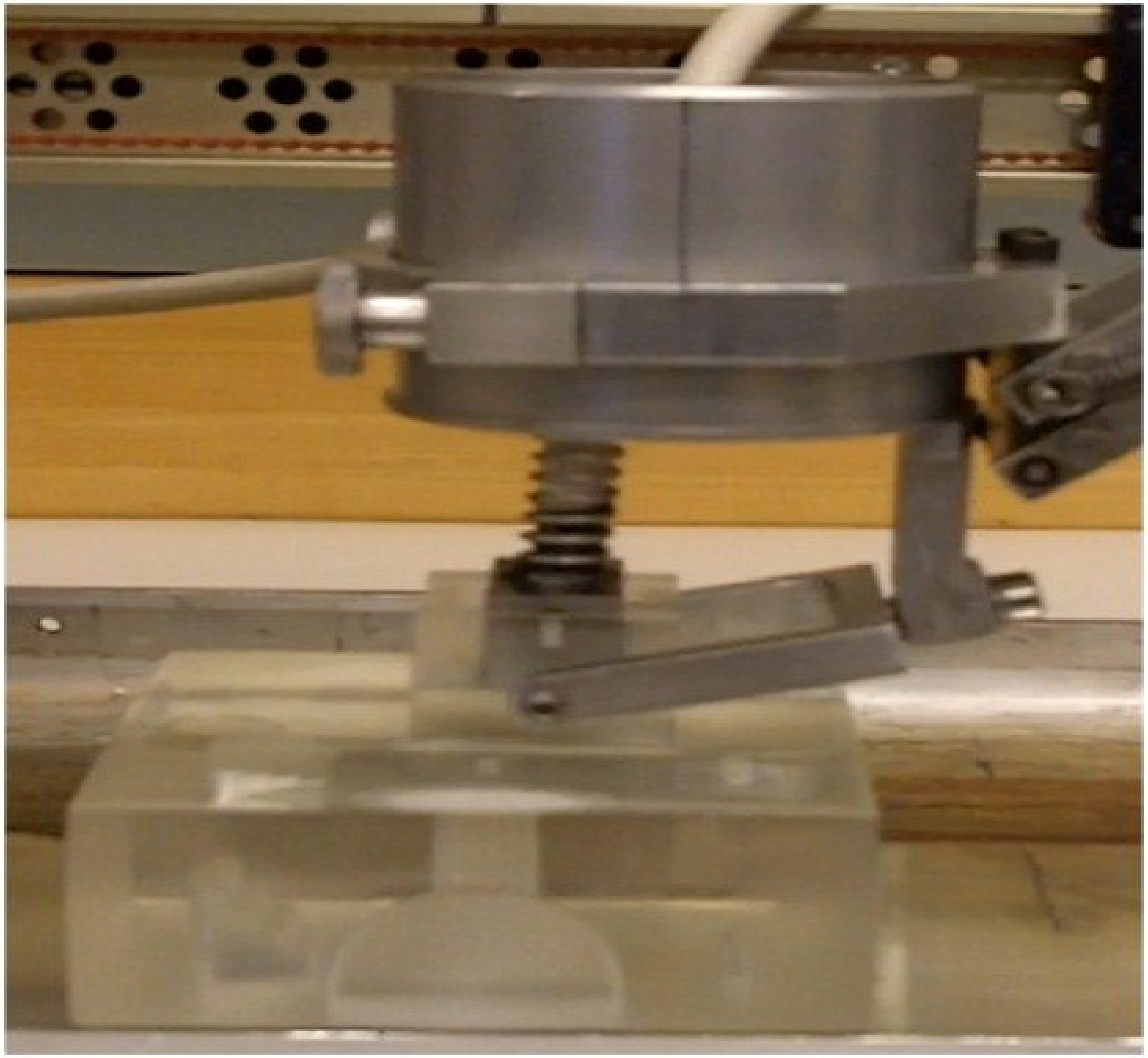

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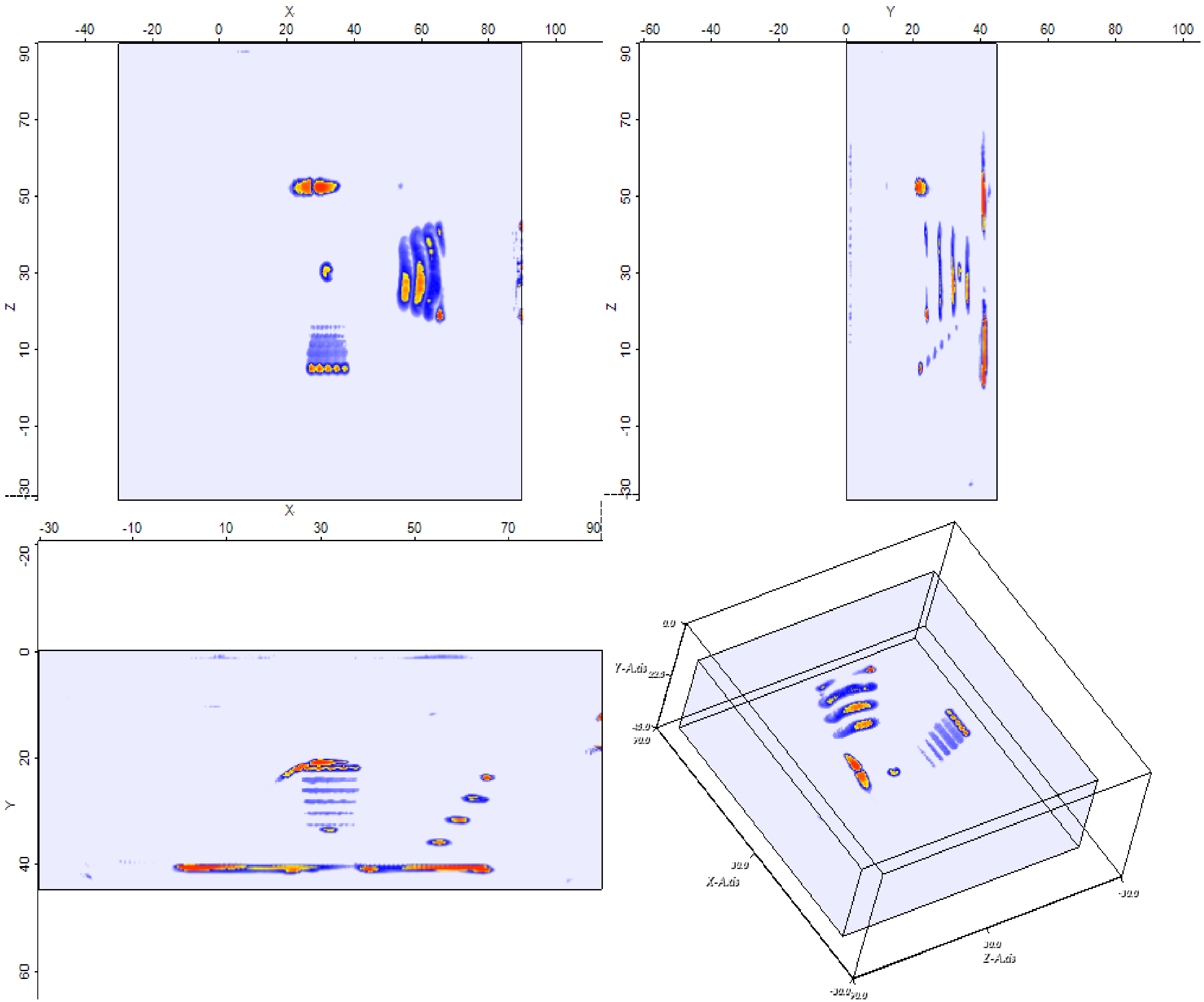

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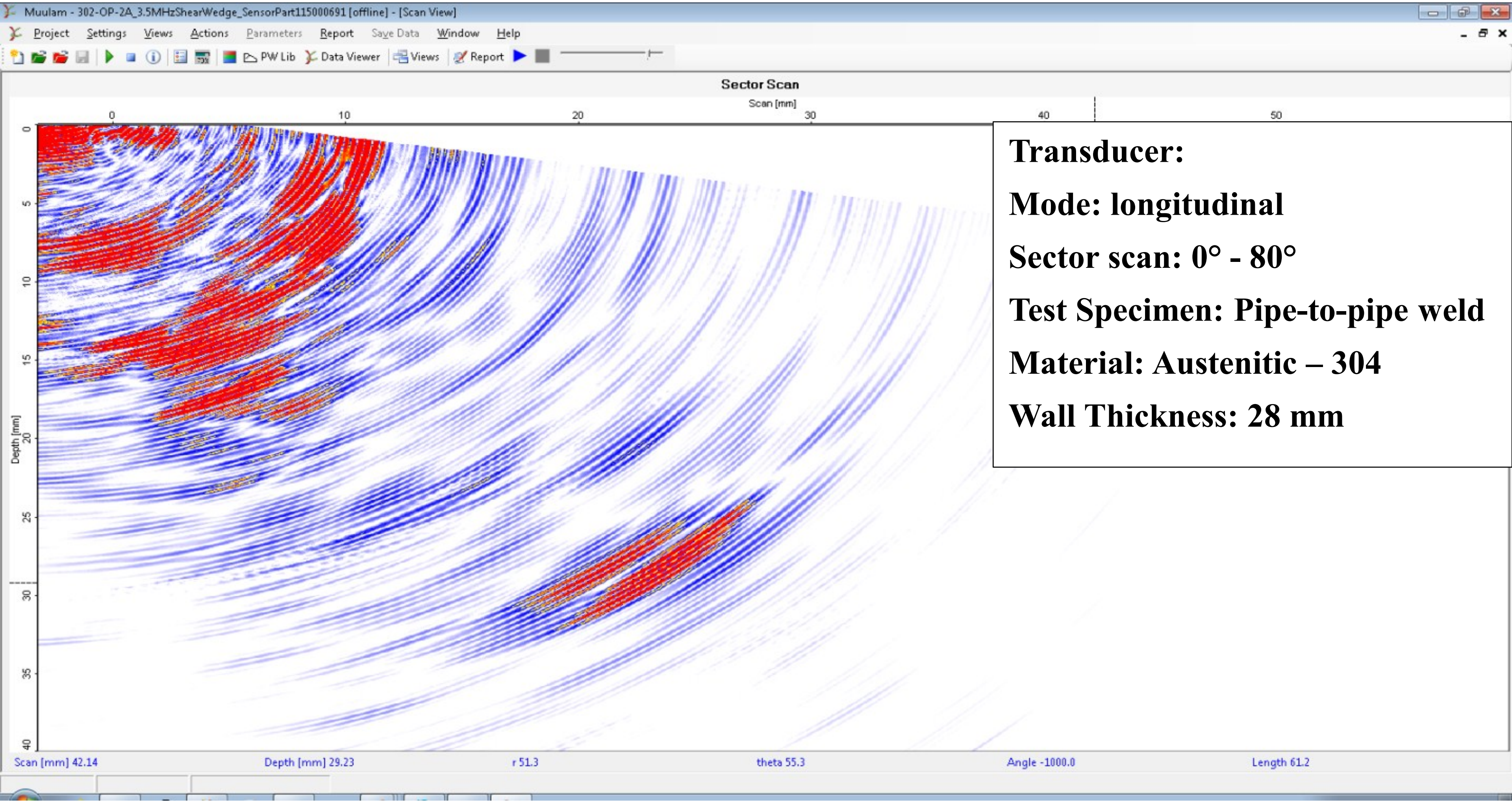

Transducer:

Mode: longitudinal

Sector scan: 0° - 80°

Test Specimen: Pipe-to-pipe weld

Material: Austenitic – 304

Wall Thickness: 28 mm

ACOUSTIC NOISE FILTER

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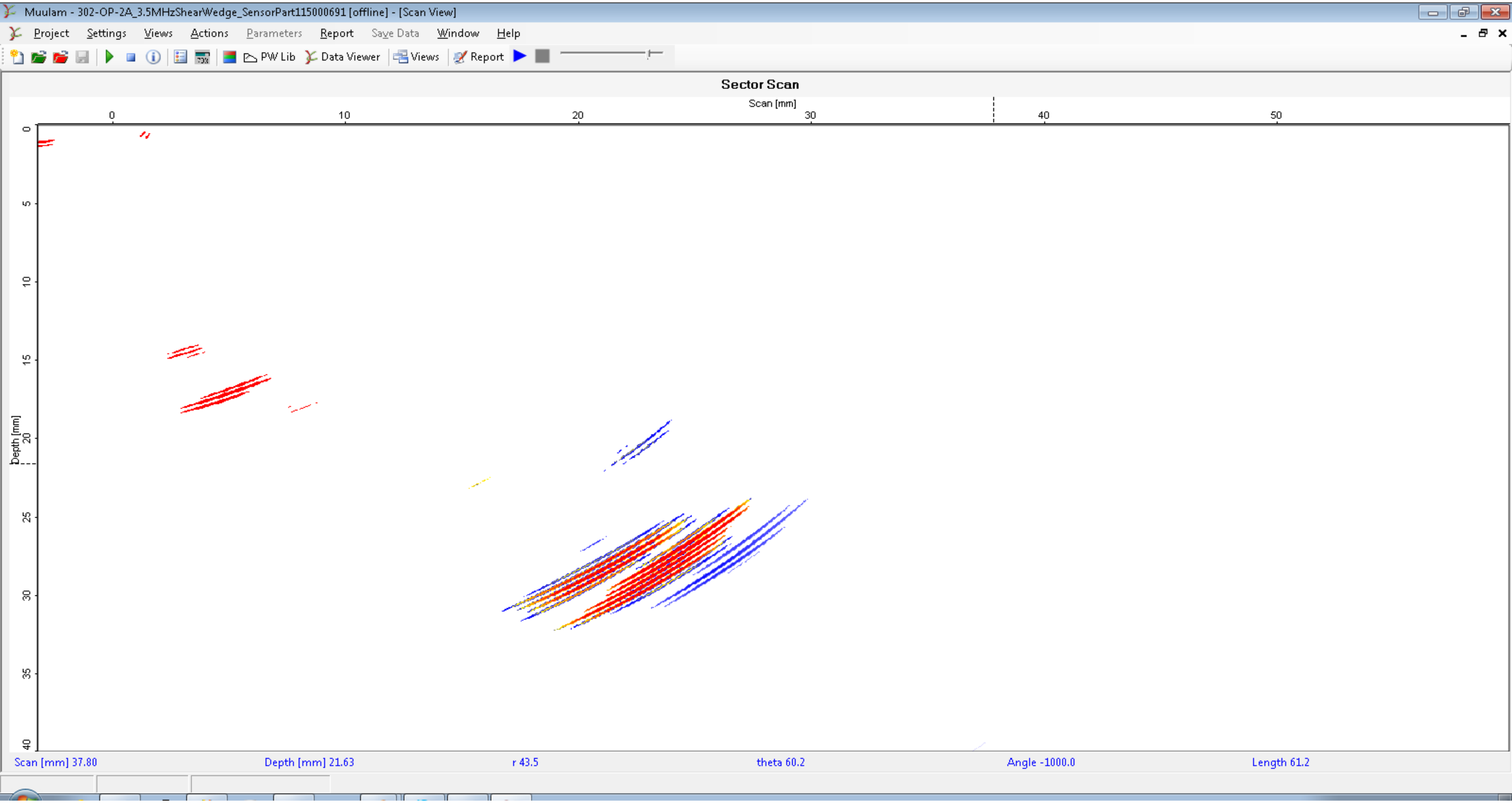

ACOUSTIC NOISE FILTER

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THANK YOU
For
YOUR ATTENTION

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Day 2:	Organization and Networks	Speaker
9.00	Welcome Address with Minutes of Last Day	NN
9.30	Recommended Laboratory Structure of Activities	Kröning
10.00	Human Resources – Ethics, Responsibilities, Education, Training and Certification	Klimenov
10.30	Coffee Break	
11.00	Methods I - ET, MT, PT, TT, VT	Vavilov
11.30	X-ray, Betatron	Klimenov
12.00	UT, µ-NDT, NDT Systems	Kröning
12.30	Open Round Discussion (Questions)	all
13.00	Lunch Break	
14.00	Applied Technologies and Capability Networks	Kröning
14.30	Knowledge Strategies and Education	Klimenov
15.00	Coffee Break	
15.30	Added Value Chain in Applied Science	Vavilov
16.00	R&D Driven by Demand – a Project Analysis	Kröning
16.30	Concluding Minutes	to be appointed
17.00	End of Second Day	

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Day 3:	CASE STUDIES & NEXT STEPS	Speaker
9.00	Welcome Address with Minutes of Last Day	NN
9.30	Case Studies: Betatron for NDT	Klimenov
10.00	Advanced UT and New Instruments	Kröning
10.30	Coffee Break	
11.00	Thermography for Surface Characterization	Vavilov
11.30	NDT System for In-line NDT	Kröning
12.00	International Cooperation Practice	Klimenov
12.30	Open Round Discussion (Questions)	all
		NN
13.00	Lunch Break	
14.00	Next Steps and Seminar Evaluation	
16.00	End of Third Day	