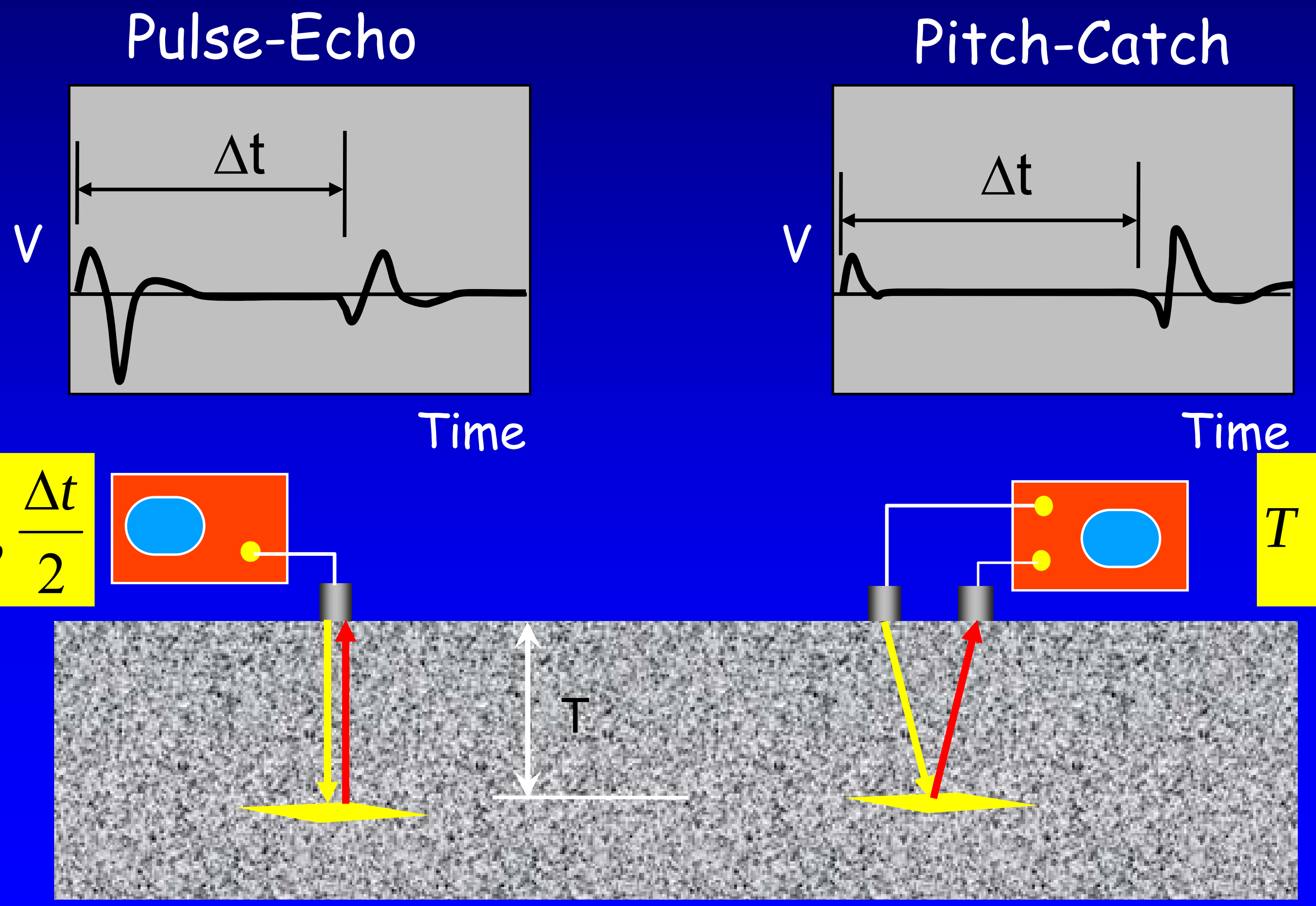
Workshop

- Ultrasonic pulse-velocity method
- Impact-echo method
- Impulse-response method
- Ultrasonic-echo method (MIRA Tomographer)

Ultrasonic Echo Methods

Measure round-trip "time of flight"



$$T = C_p \frac{\Delta t}{2}$$

$$T \approx C_p \frac{\Delta t}{2}$$

Ultrasonic-Echo Methods for Concrete

- Limited success before the 1990s
- Developments since the 1990s
  - Low frequency (50 to 100 kHz), broadband, dry coupled, point transducers
    - Compressional and shear waves
  - Availability of computing power
    - Use of transducer arrays
    - Digital signal processing
    - Visualization methods (tomographic images)

Shear-Wave Transducer Arrays

- Permit multiple transit time measurements to be made rapidly
- Can "look" at volume of concrete below the array

Shear-Wave
Dry, Point-Contact Transducers

- Shear-waves produce stronger reflections than P-wave in pitch-catch test with high angles of incidence/reflection
- Short duration pulse (<2 cycles)
- Coupling fluid not needed
- Spring loaded to conform to surface

DPC Transducer "Antenna"

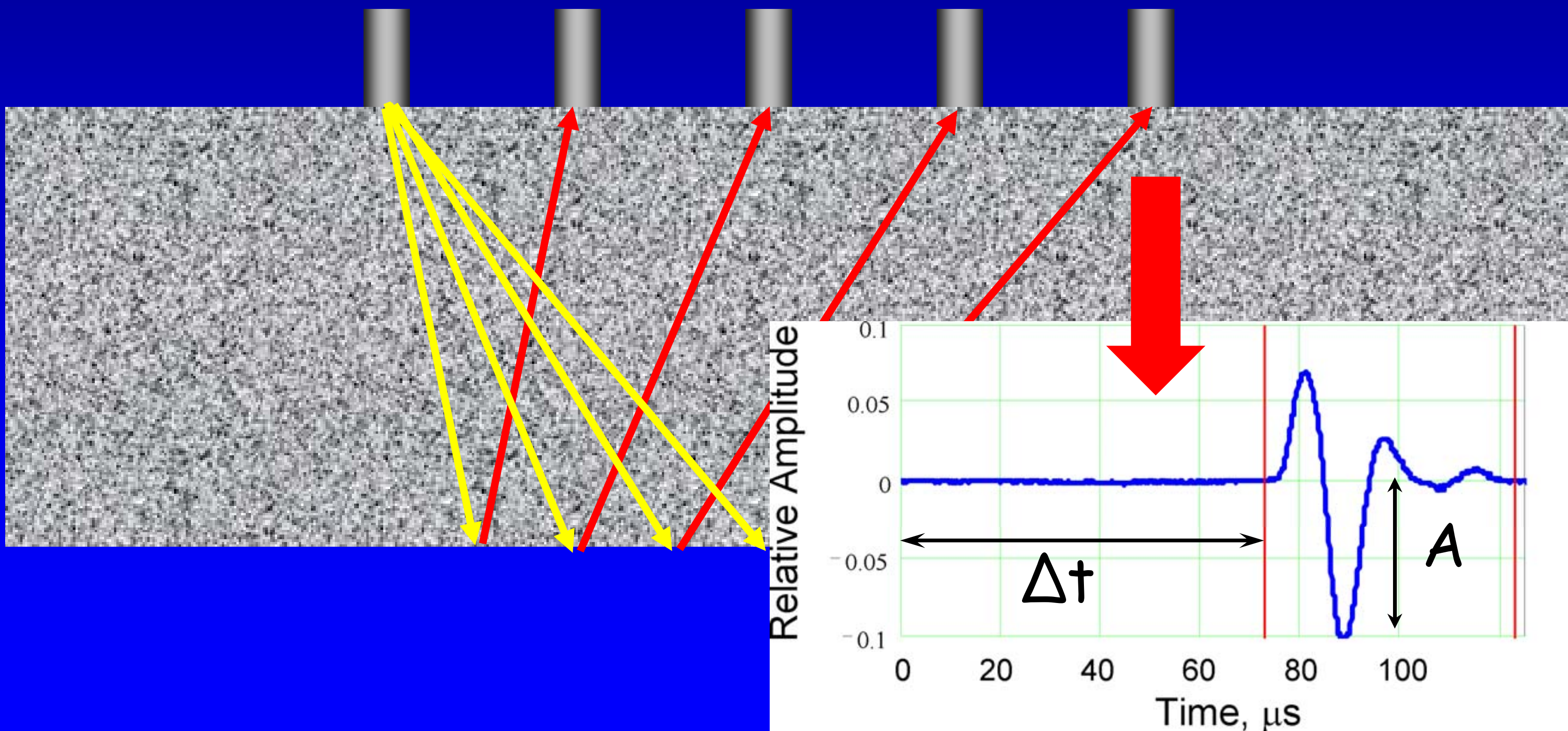
- Each spring-loaded DPC transducer functions alternately as a transmitter and receiver
- Built-in computer controls transducer operation

MIRA Tomographer

- Based on "pitch-catch" method
- 4 x 12 transducer array; many ray paths
- Onboard data analysis of 2-D image display

Transducer Array System

- Multiple pitch-catch tests
  - Measure time-of-flight and echo amplitude



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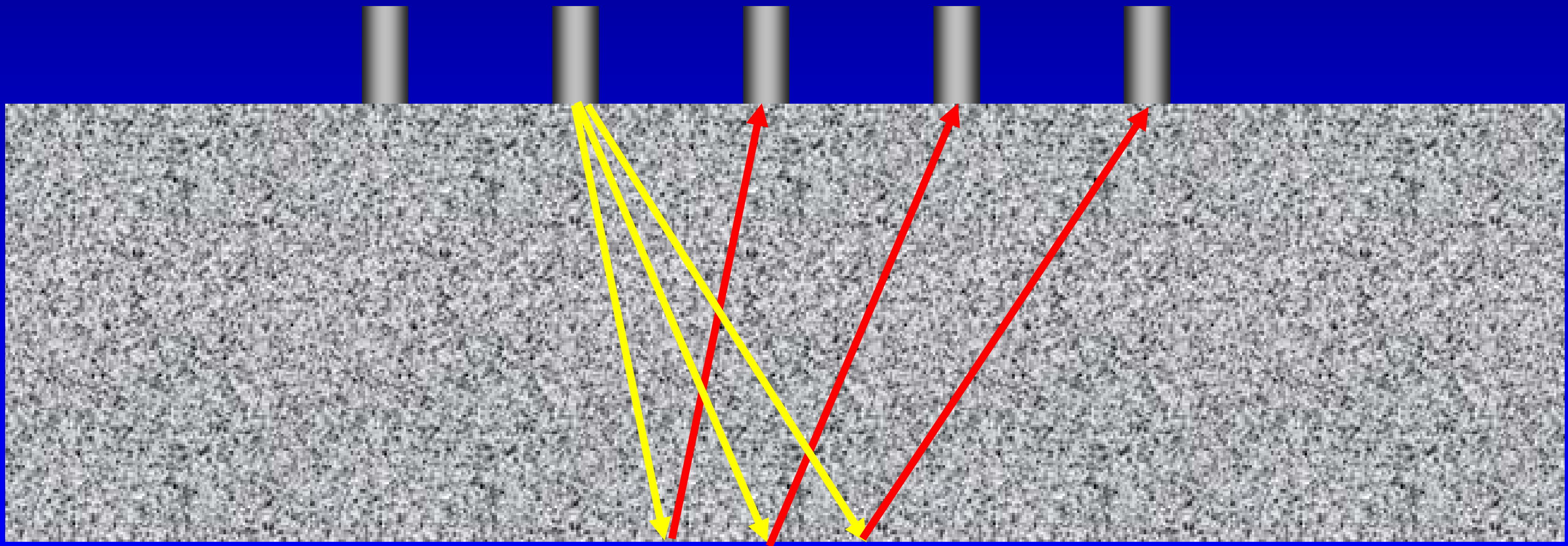
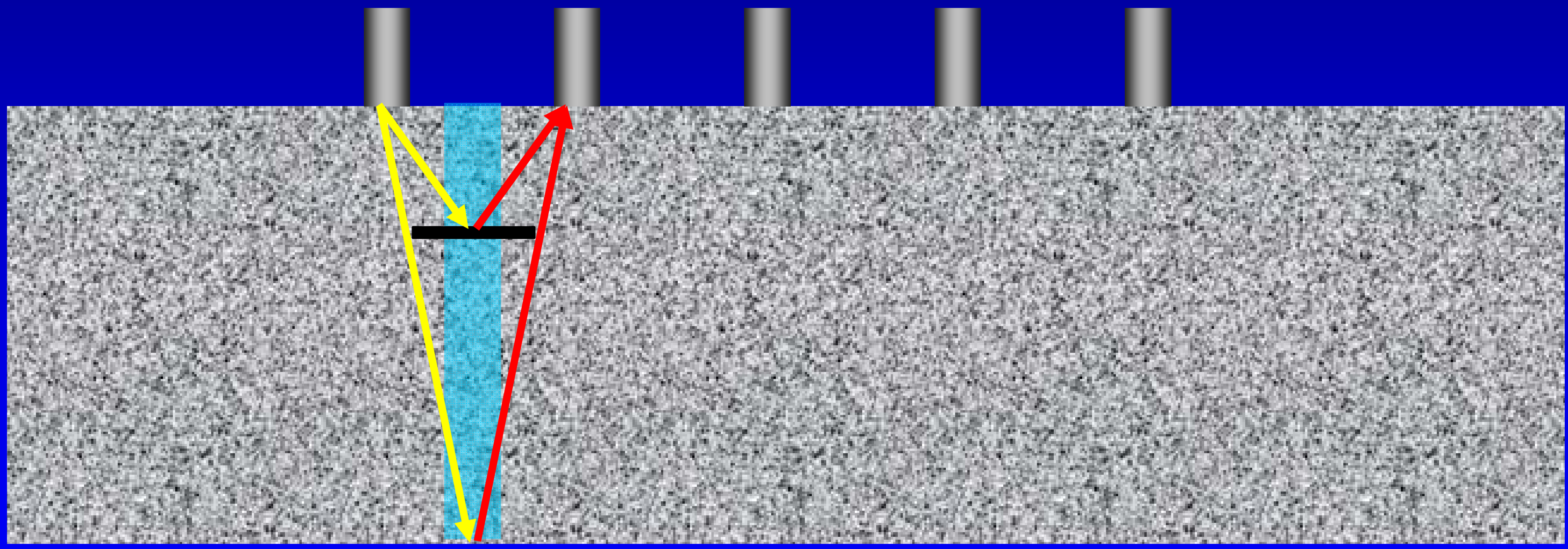
Transducer Array System

Transducers function as transmitters and receivers; result in multiple ray paths



Flaw Detection Regions

Reflecting interfaces located within regions near the midpoints of the transducer pairs are detected



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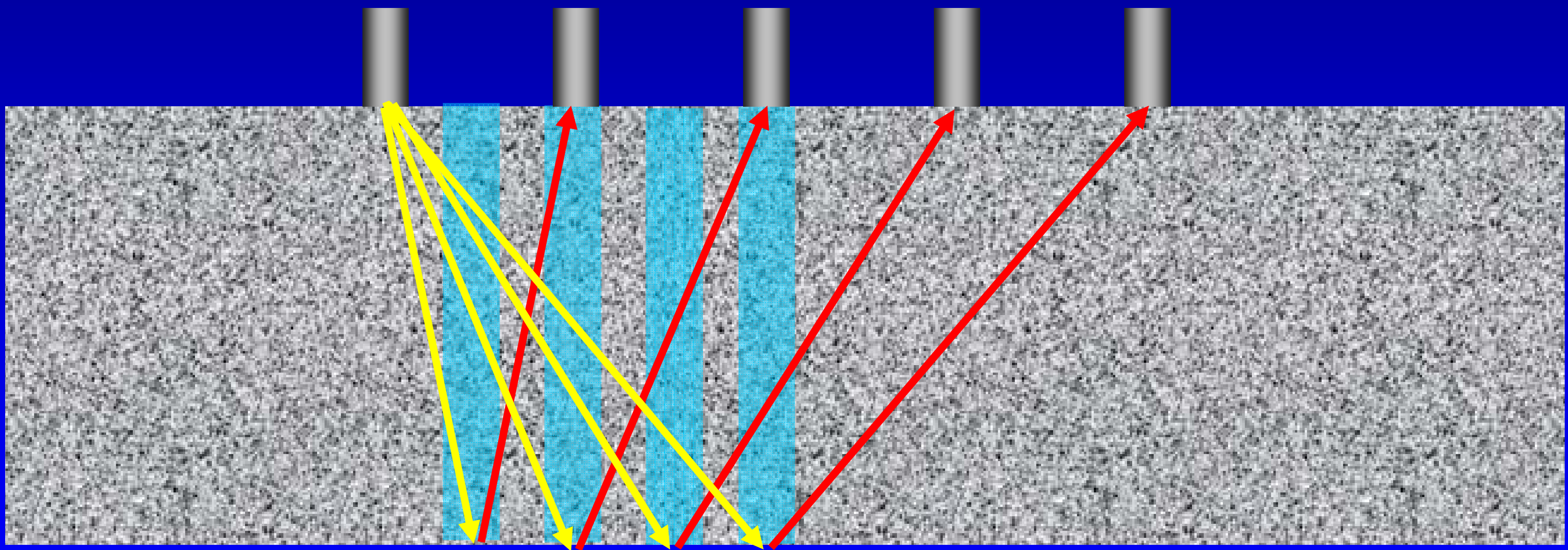
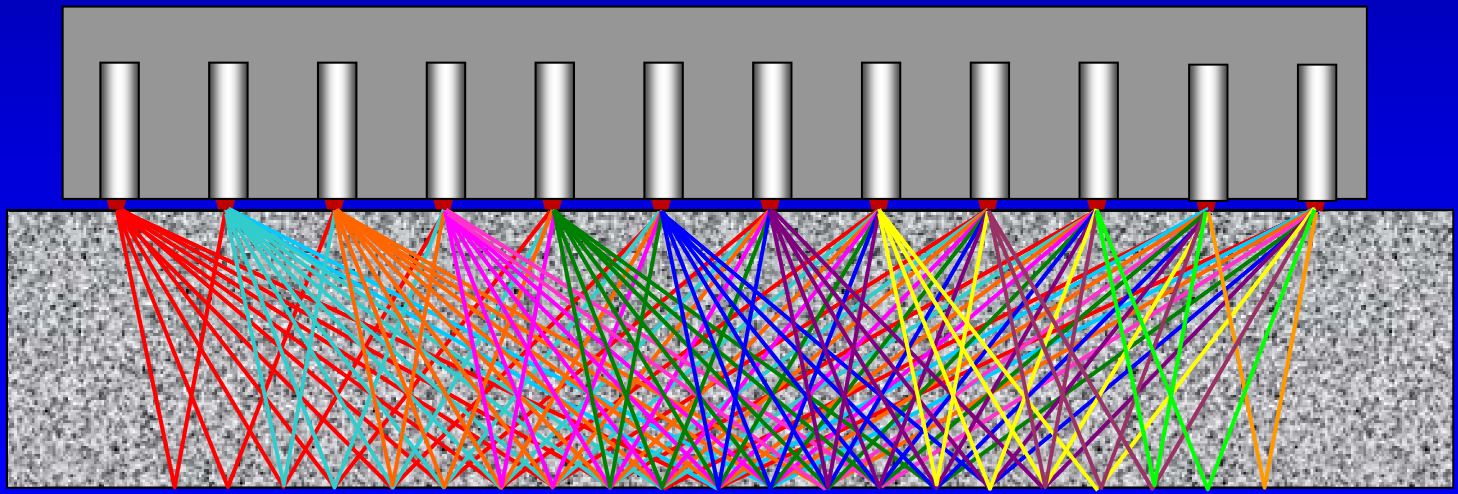


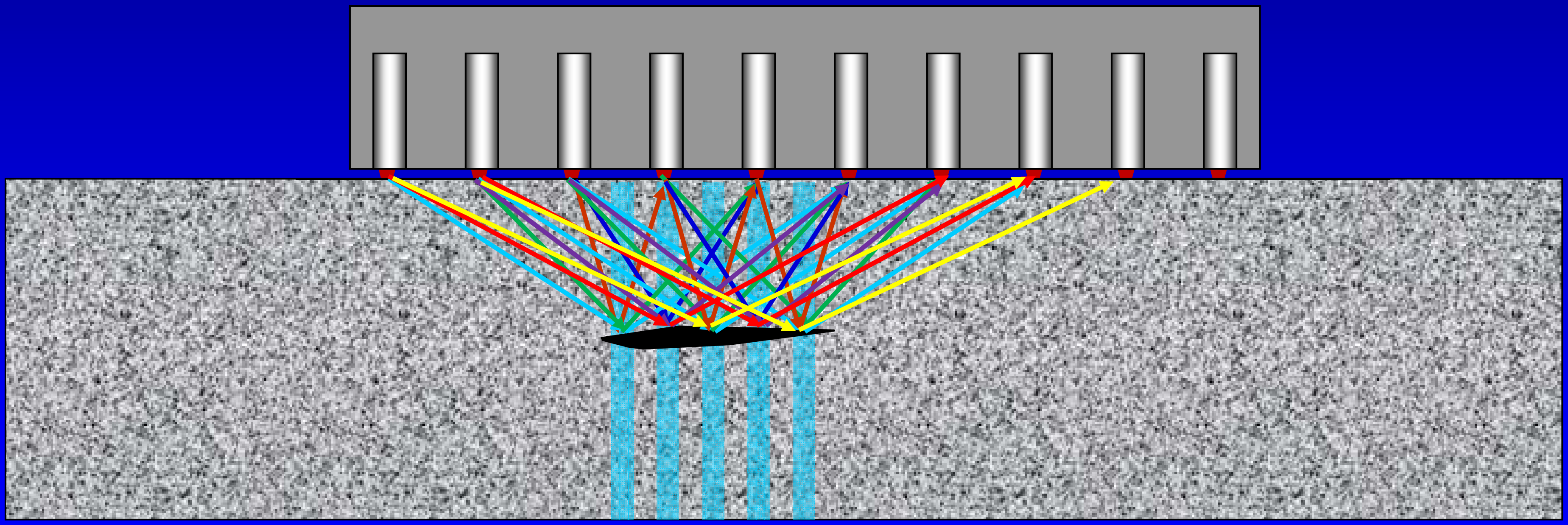
MIRA Operation

- Each row functions as a transmitter or receiver
- 66 ray paths per test
- 66 time-of-flight and amplitude measurements
- Data acquisition and processing < 3s



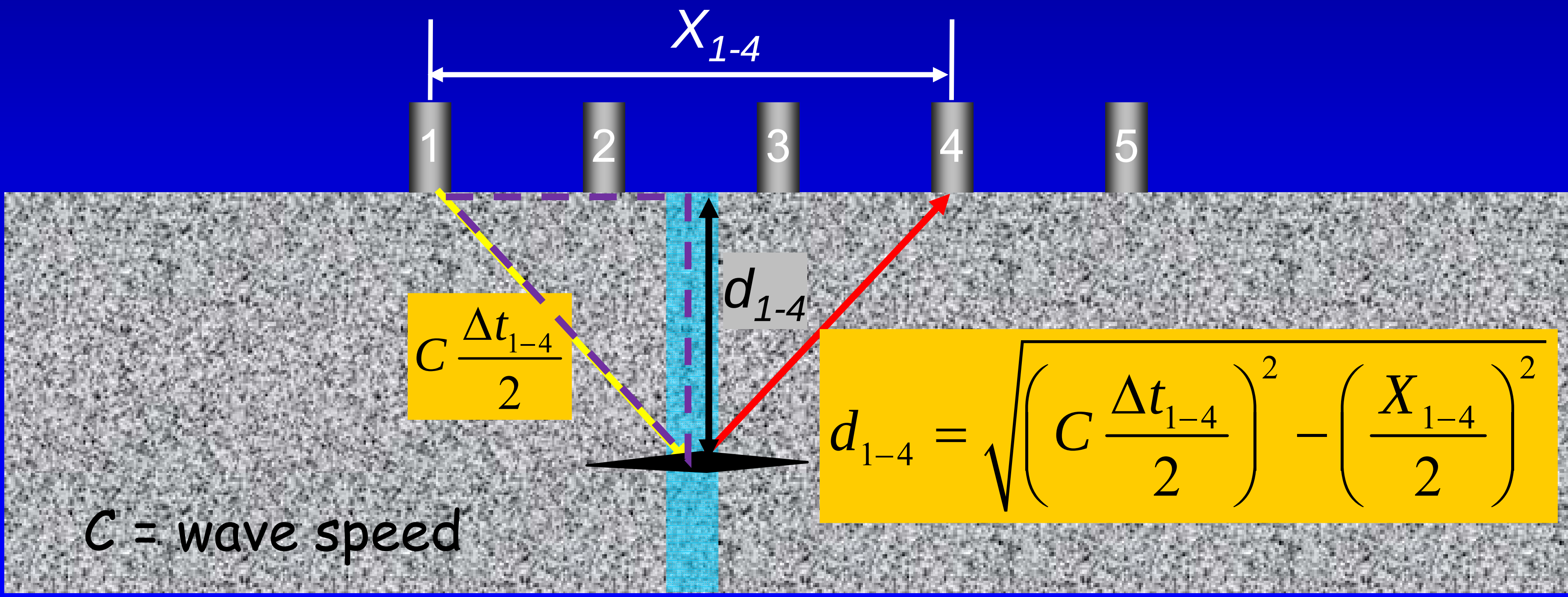
Flaw Detection

- Large reflecting interface is detected by multiple sensors
- Extent of flaw can be estimated



Flaw Depth Calculation

- Distances between transducer pairs (i-j) are known, $X_{i\text{-}j}$
- Flaw depth is calculated from the measured time-of-flight, $\Delta t_{i\text{-}j}$
- Example: What is depth for measured $\Delta t_{1\text{-}4}$?



$$C\frac{\Delta t_{1-4}}{2}$$

$$d_{1-4} = \sqrt{\left(C\frac{\Delta t_{1-4}}{2}\right)^2 - \left(\frac{X_{1-4}}{2}\right)^2}$$

Image Reconstruction

- For each transducer pair, signal is associated with reflection at interface located along midpoint
- Time-of-flight data are converted to "flaw depth" in accordance with method on previous slide
- Signal processing method uses this information to generate a 2-D image of the cross section below the antenna

Synthetic Aperture Focusing Technique (SAFT)

- Test object is represented by mesh of volume elements (voxels)
- Volume elements that correspond to locations of reflecting interfaces are assigned a color to indicate intensity of reflection from those elements—constructive superposition
- The result is a 2-D image of the internal reflectors below the antenna

Data Acquisition

X	t	A	d
--	--	--	--
--	--	--	--
--	--	--	--
--	--	--	--
--	--	--	--
--	--	--	--
--	--	--	--
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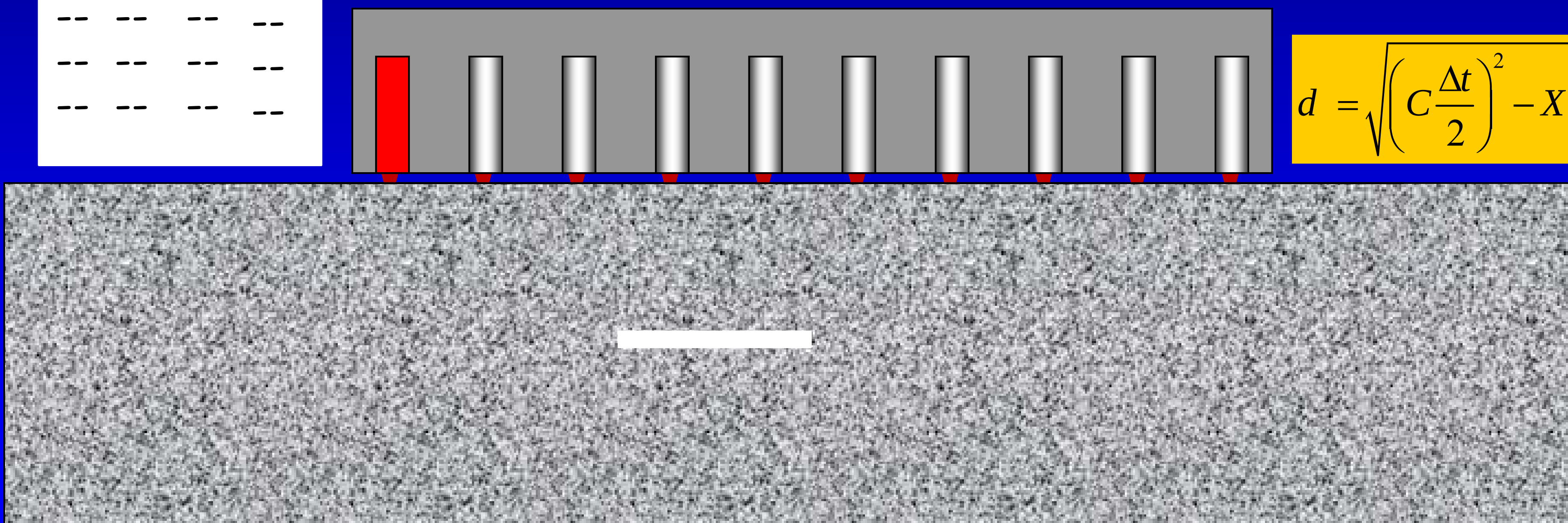
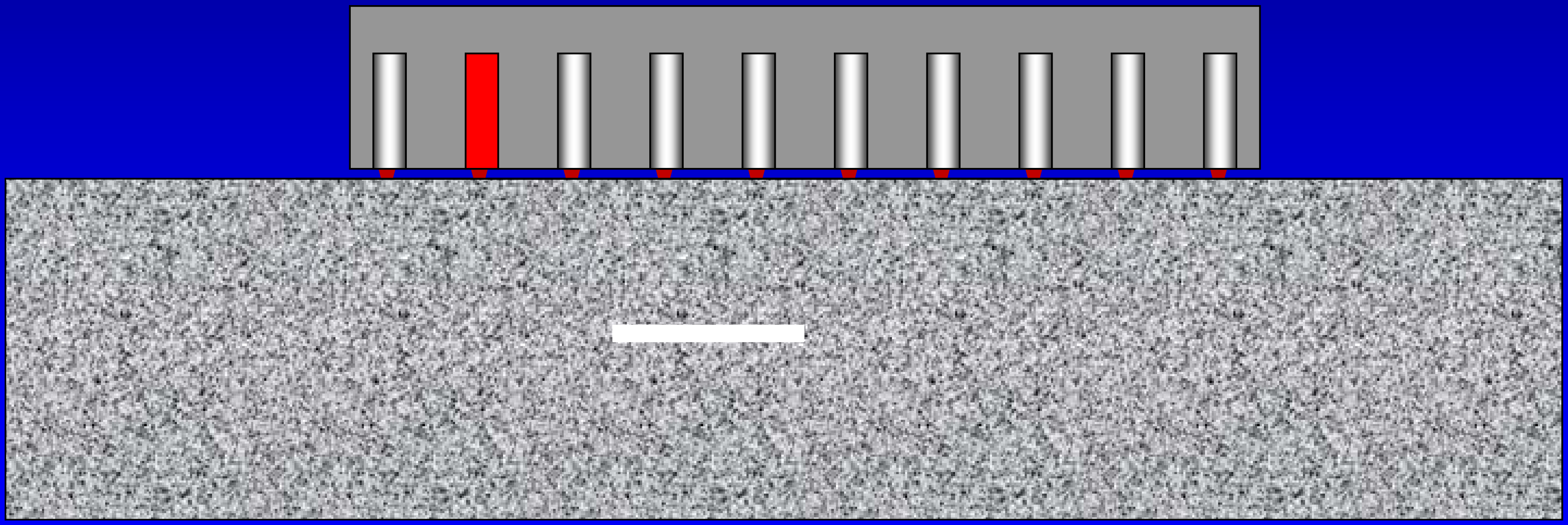
- The system measures the time-of-flight and signal amplitude for each transducer pair and computes the depth of the reflecting interface

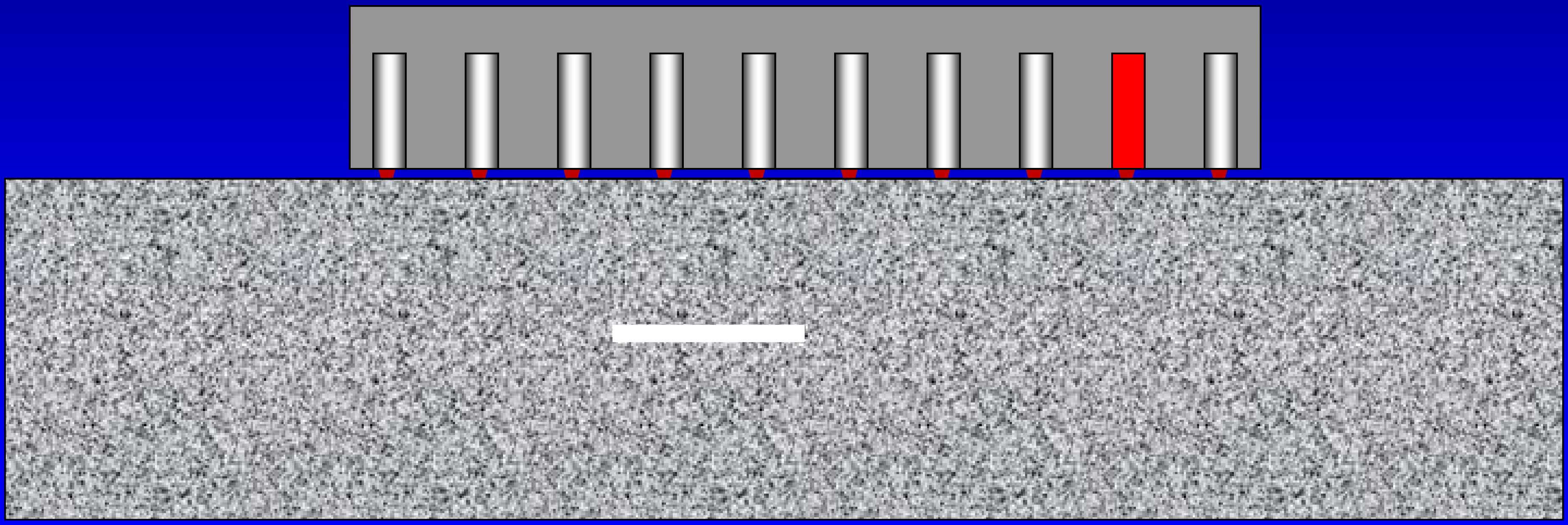


$$d = \sqrt{\left(C\frac{\Delta t}{2}\right)^2 - X^2}$$

Data Acquisition

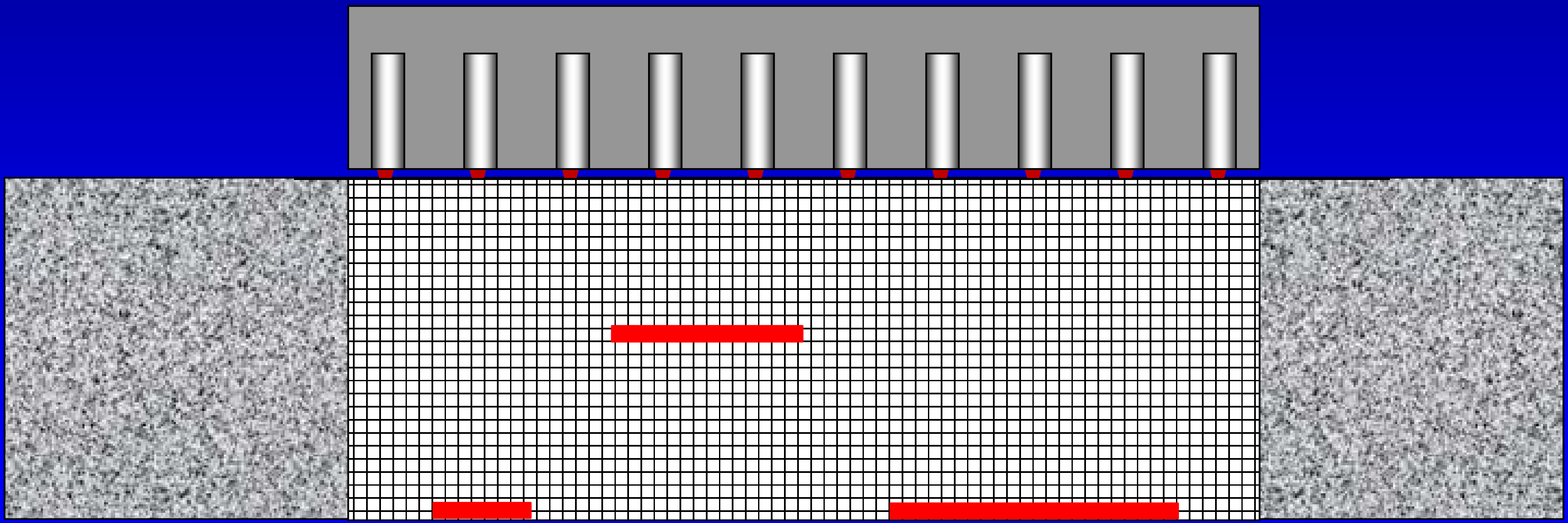


Data Acquisition



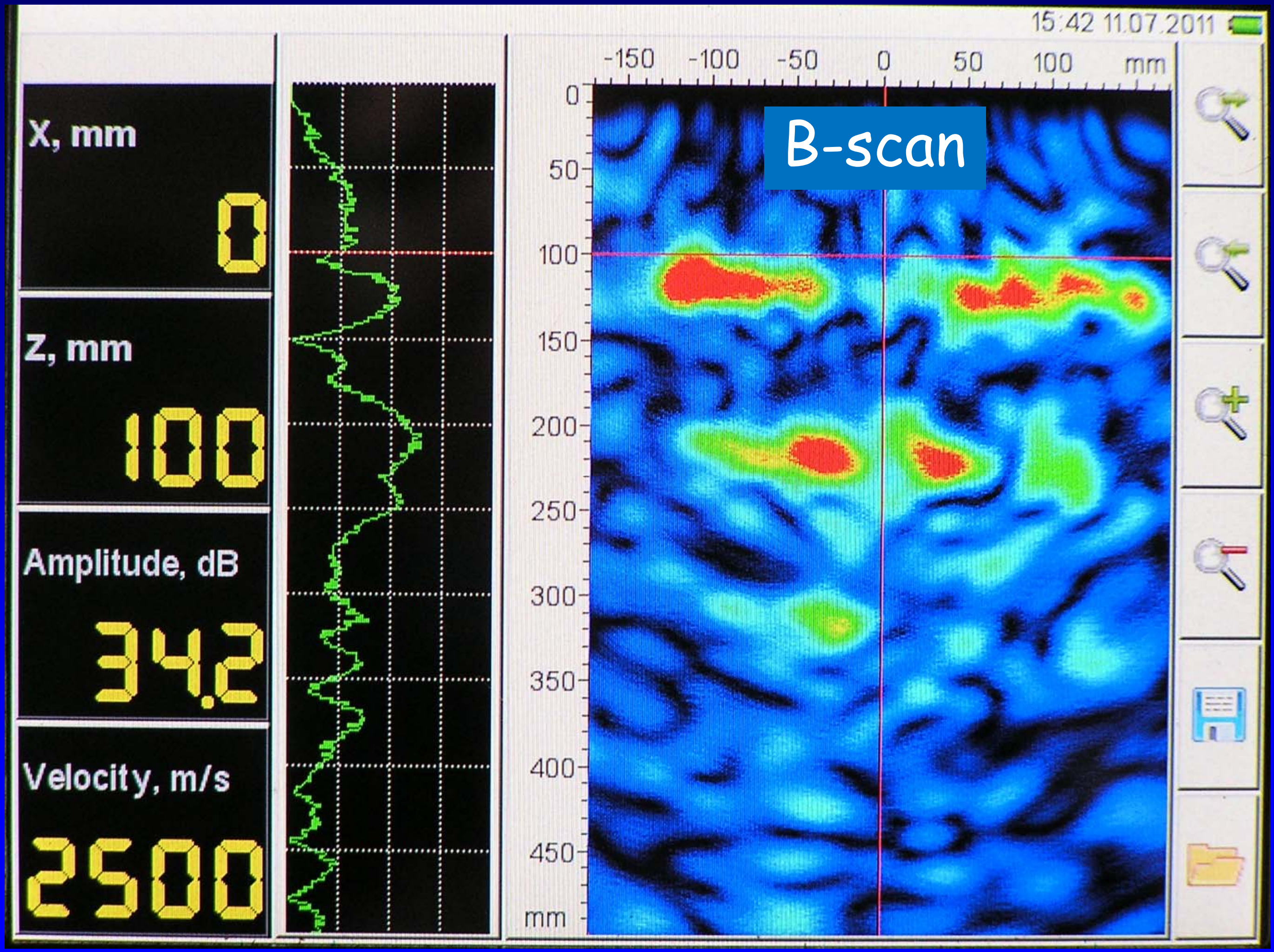
Constructive Superposition Using SAFT

The result is a 2-D image of the internal reflectors



MIRA Display

EXPLORE Mode



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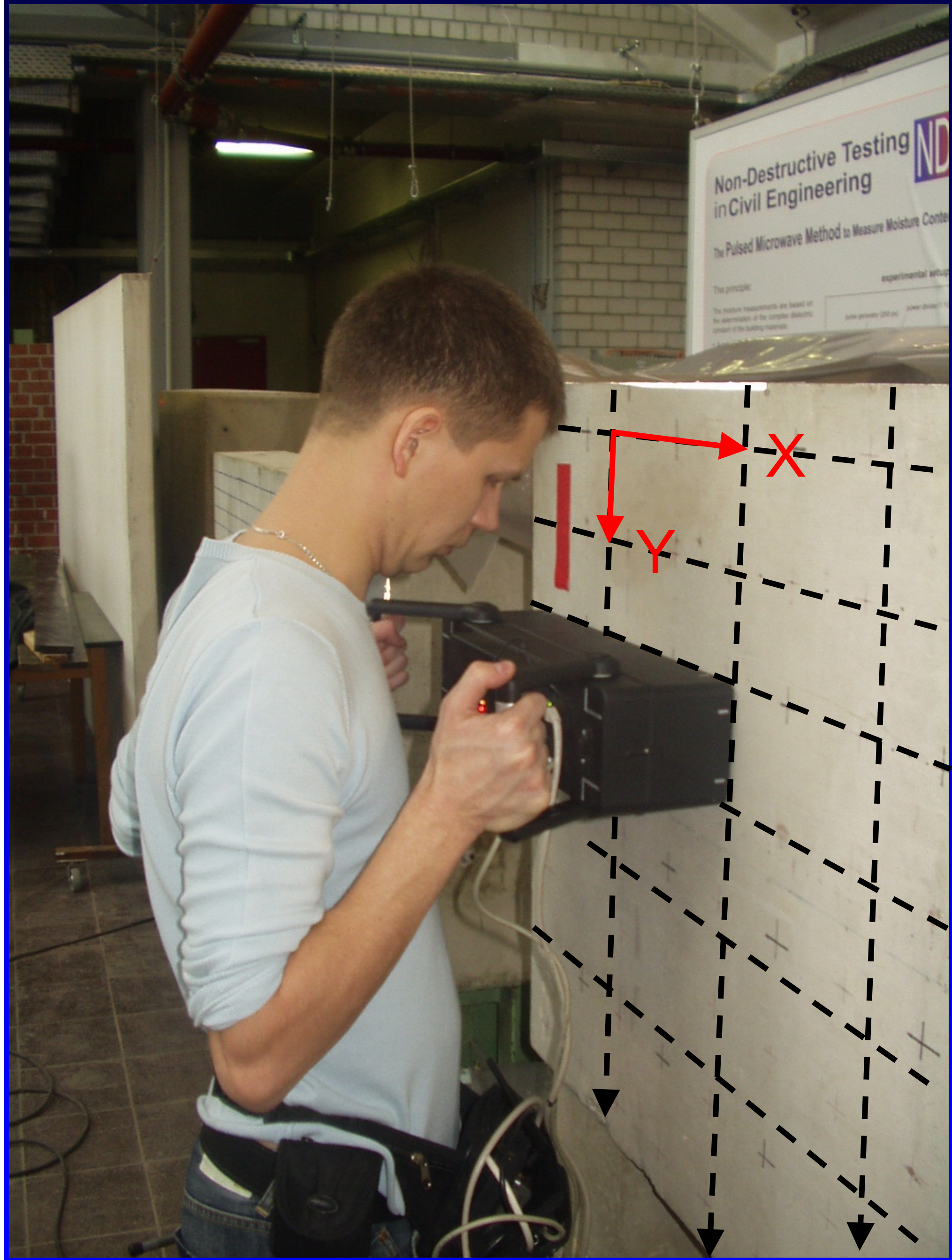
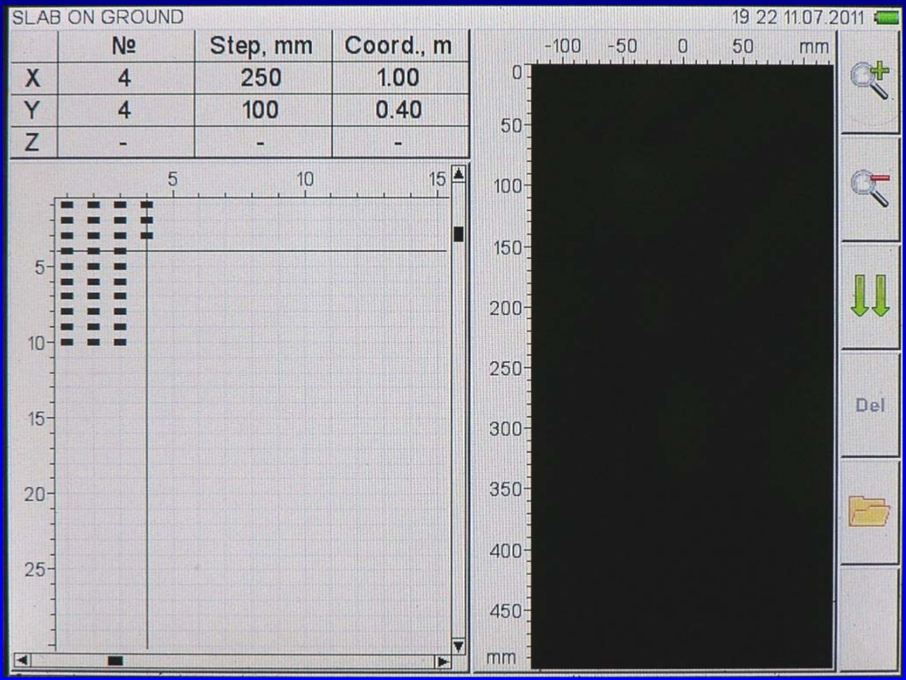


Scanning

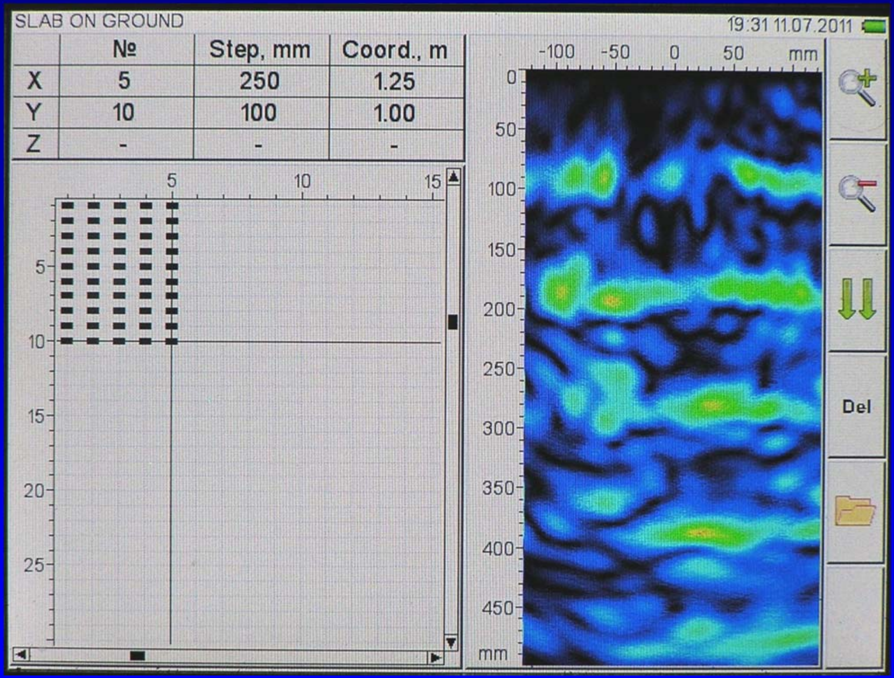
- Layout grid (x-step, y-step)
- Move antenna in steps in Y-direction
- Take data at each y-step
- Move to next vertical line (x-step)
- Repeat scan in y-direction

Scan Mode

Current test point (4,4)



Point (5,10) completed



Test smart – Build right

3-D Image Reconstruction

- MIRA 2-D images are transferred to a computer
- Software assembles the images to create a 3-D volume of the scanned region (analogous to "stitching" photos)
- User can manipulate the 3-D volume
  - Rotate the volume
  - View in three image planes (slices)

Image Planes

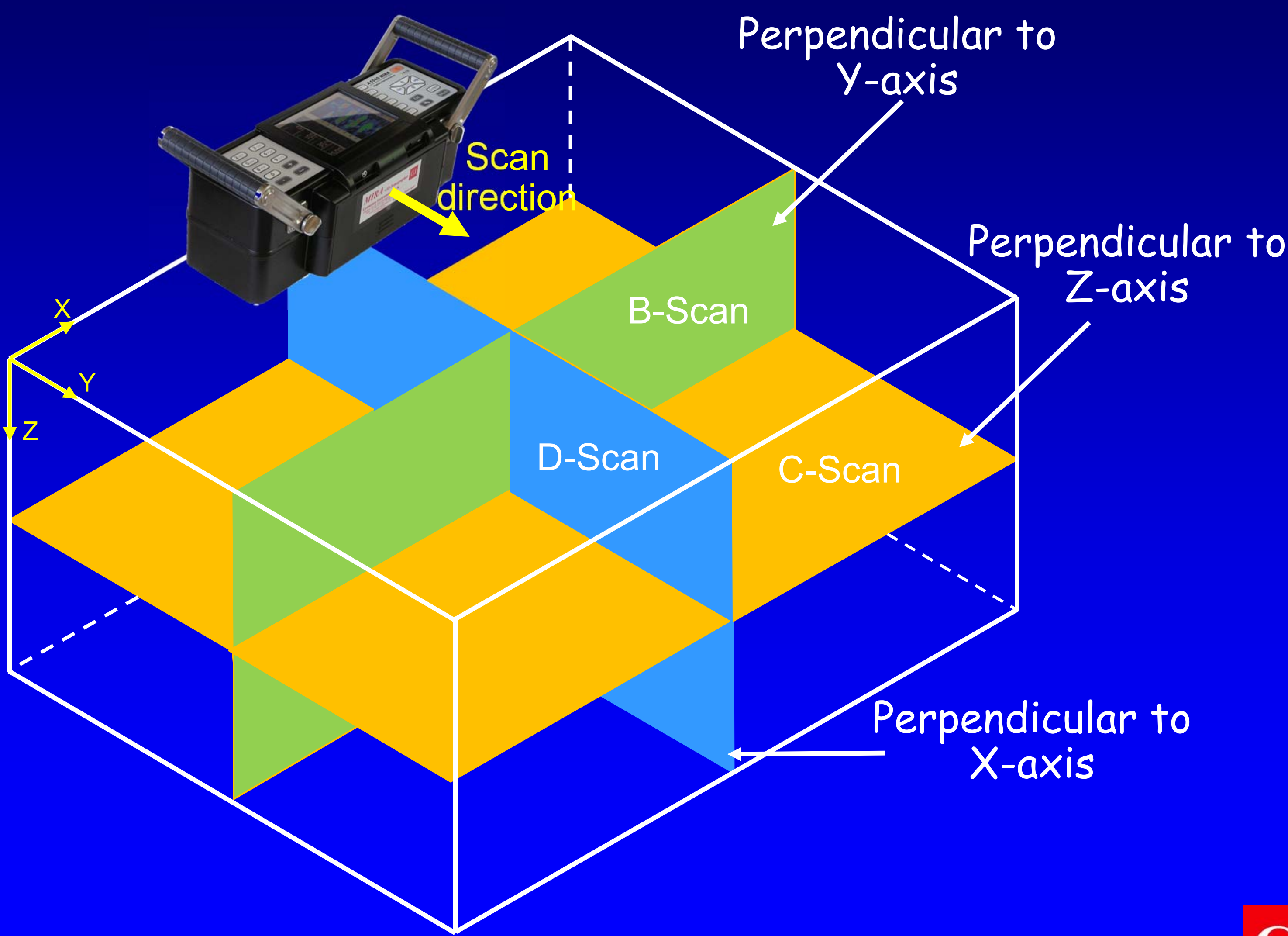


Image Planes

- B-scan: End view, created by MIRA using image reconstruction method (SAFT)
- C-scan: Plan view
- D-scan: side view
- C and D-scans created from B-scan data using visualization methods
  - Similar to 3-D medical imaging methods

3-D Visualization

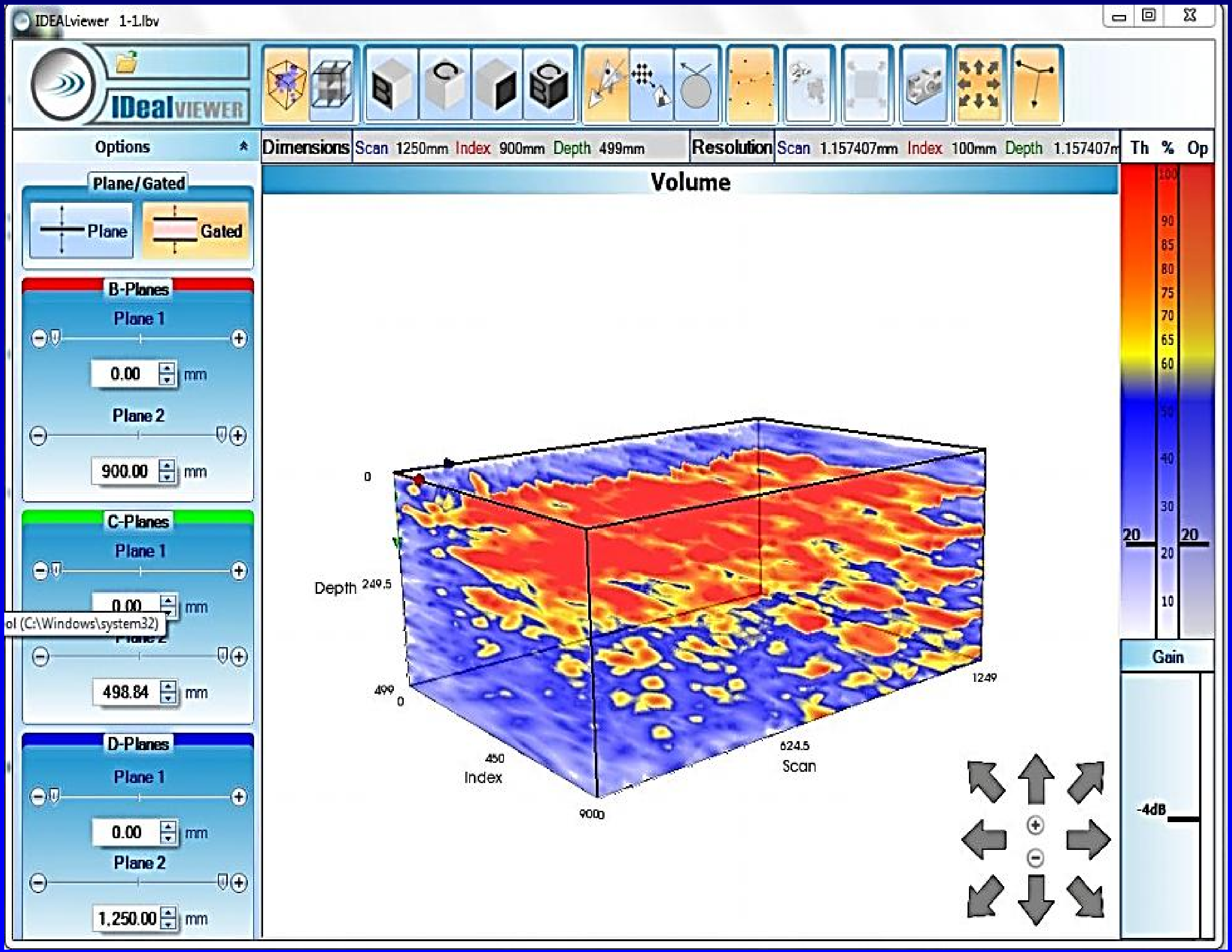


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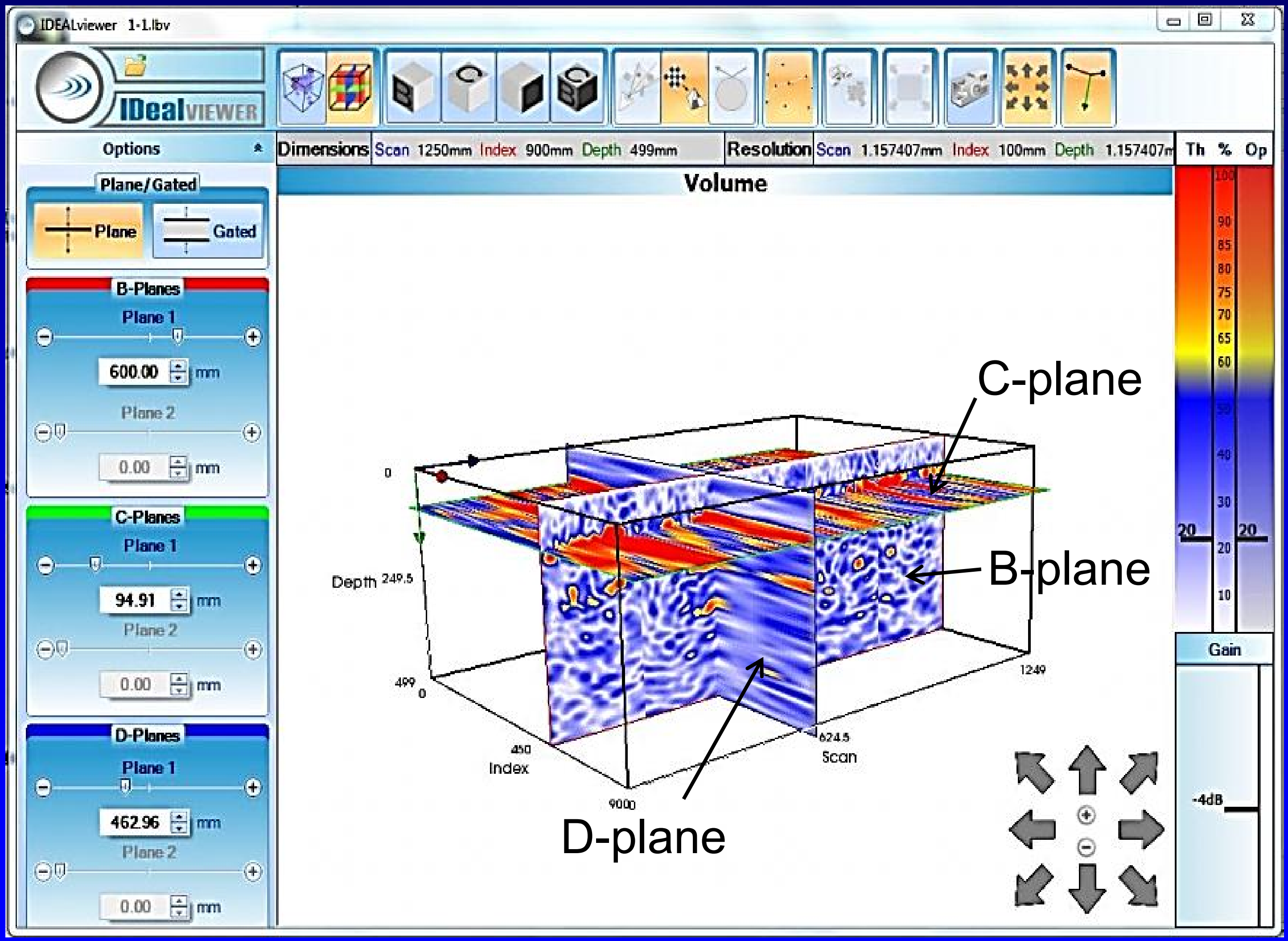
Image Planes



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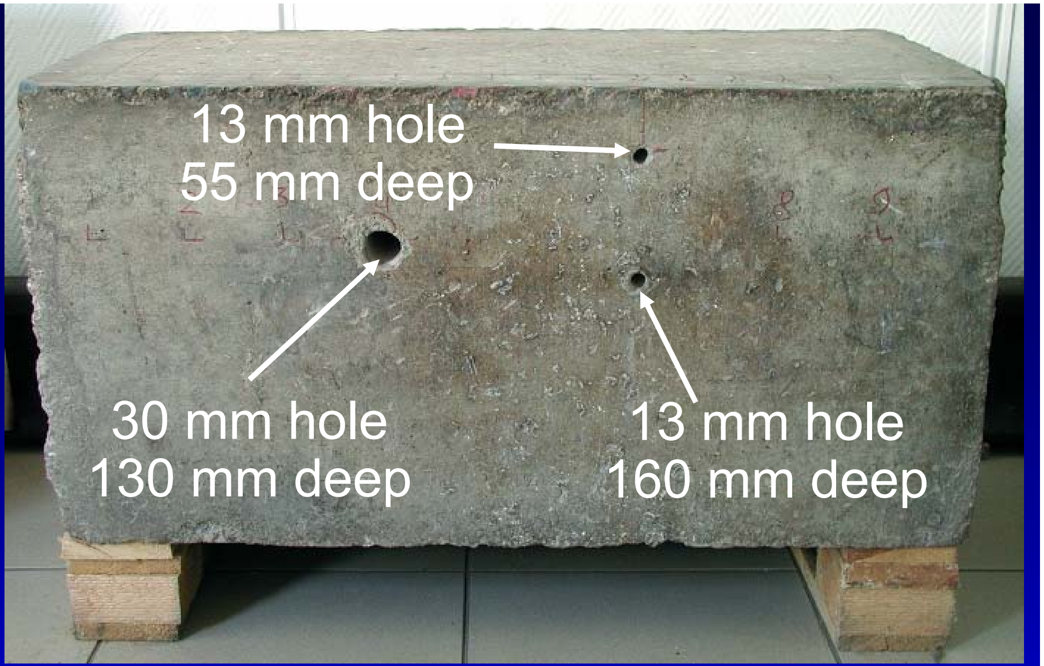
Example

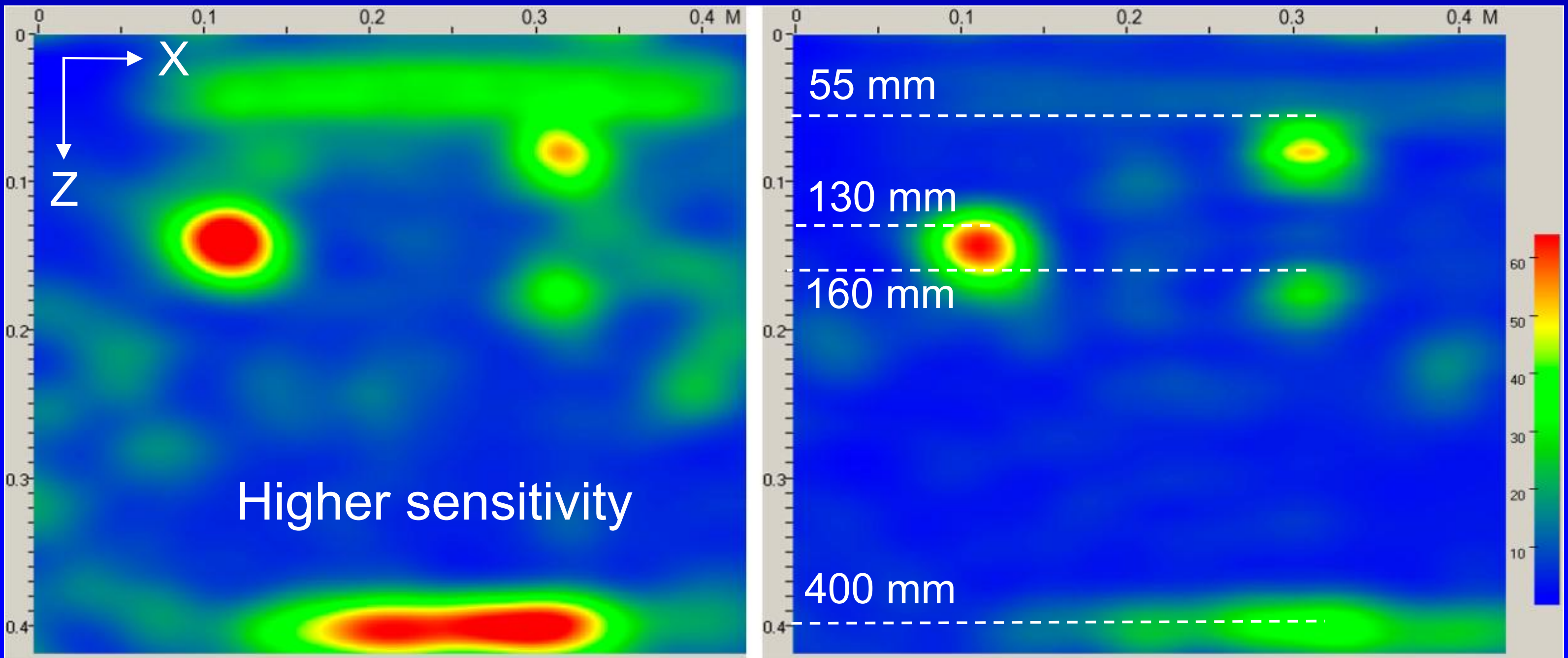
0.8 m x 0.4 m x 0.4 m

C_s= 2385 m/s

Original MIRA



B-Scan



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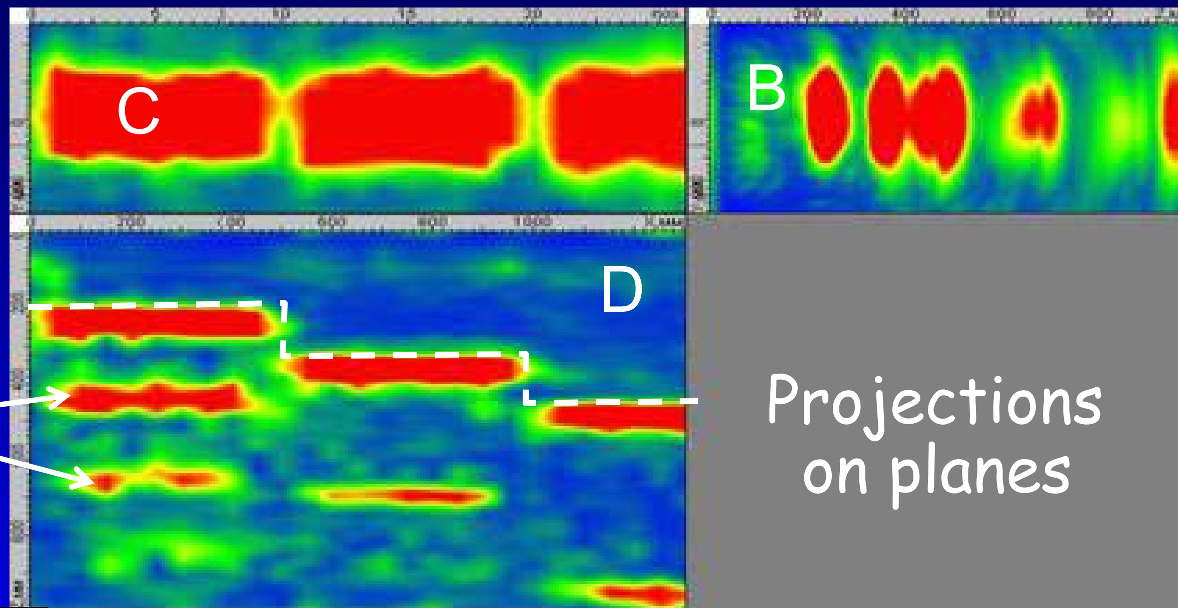
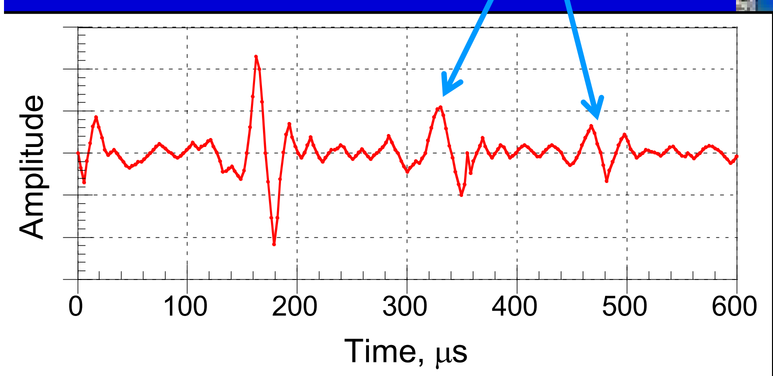
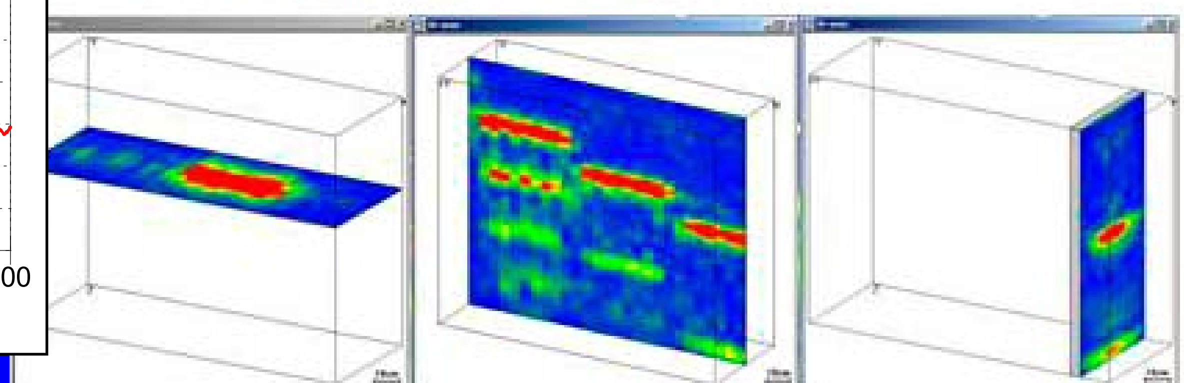
“Stepped” Slab



“Phantom” depths due to reverberations

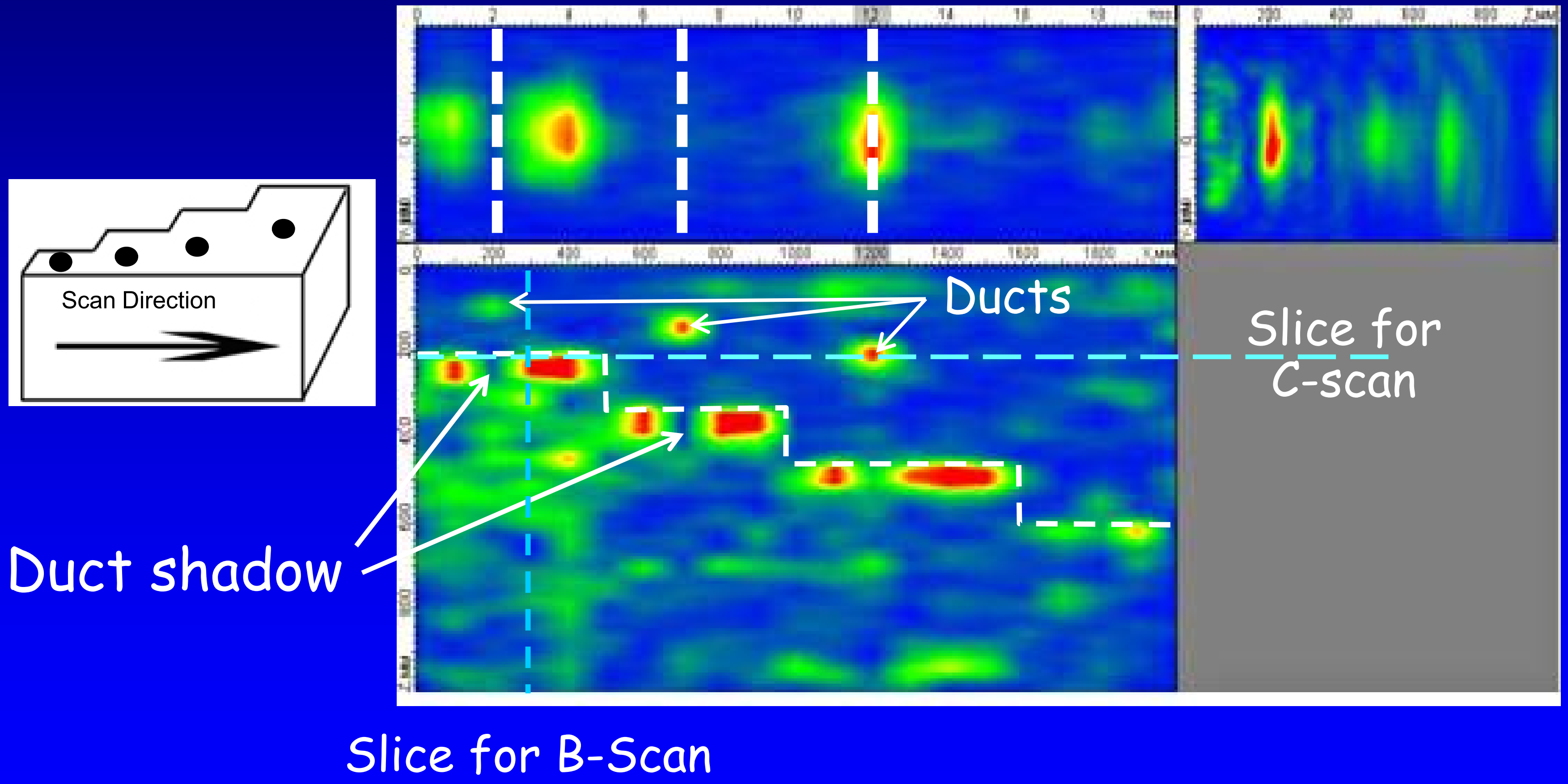




Slices

Stepped Slab With Empty Ducts

Stepped Slab With Empty Ducts



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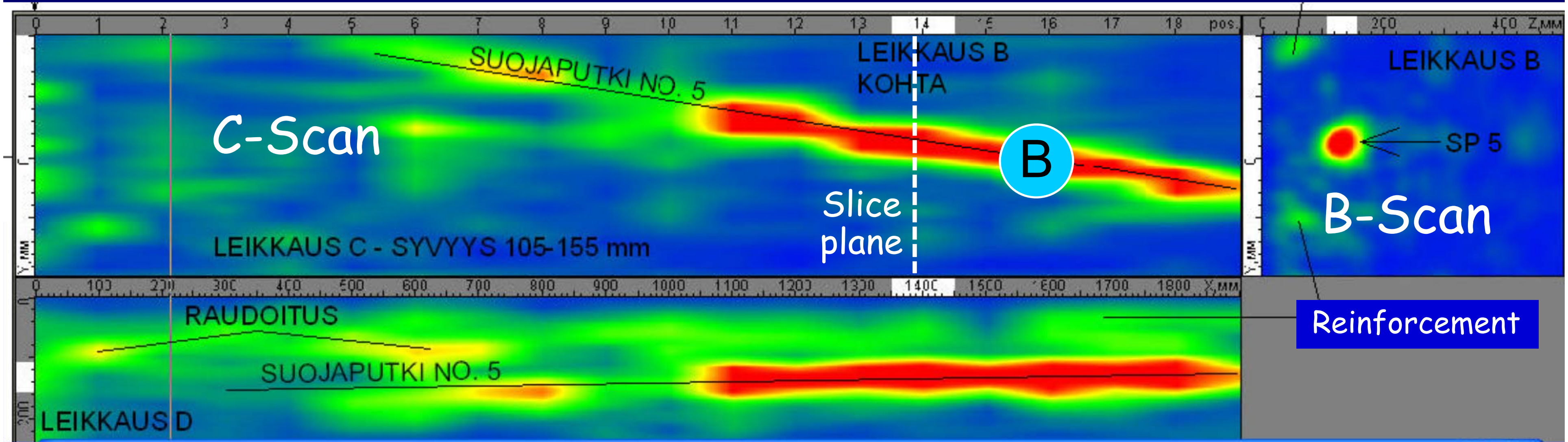
Voids in Tendon Ducts

Courtesy of: Ramboll-Finland

Results



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Voids Behind Tunnel Lining

400 mm Thick

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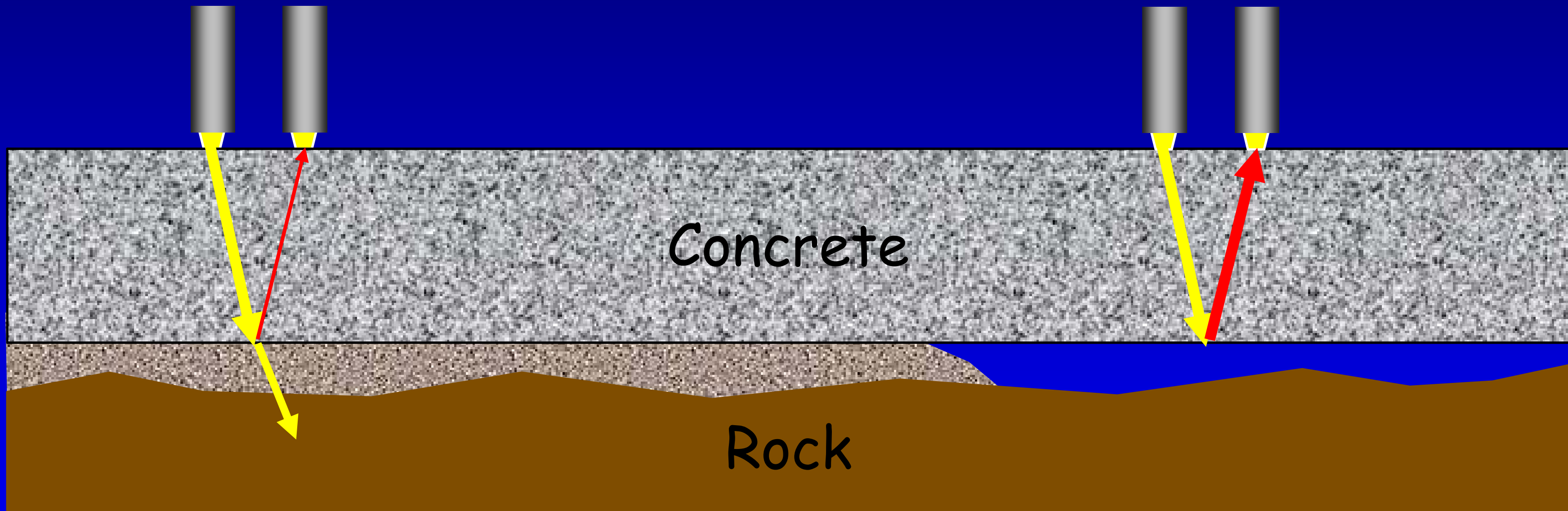
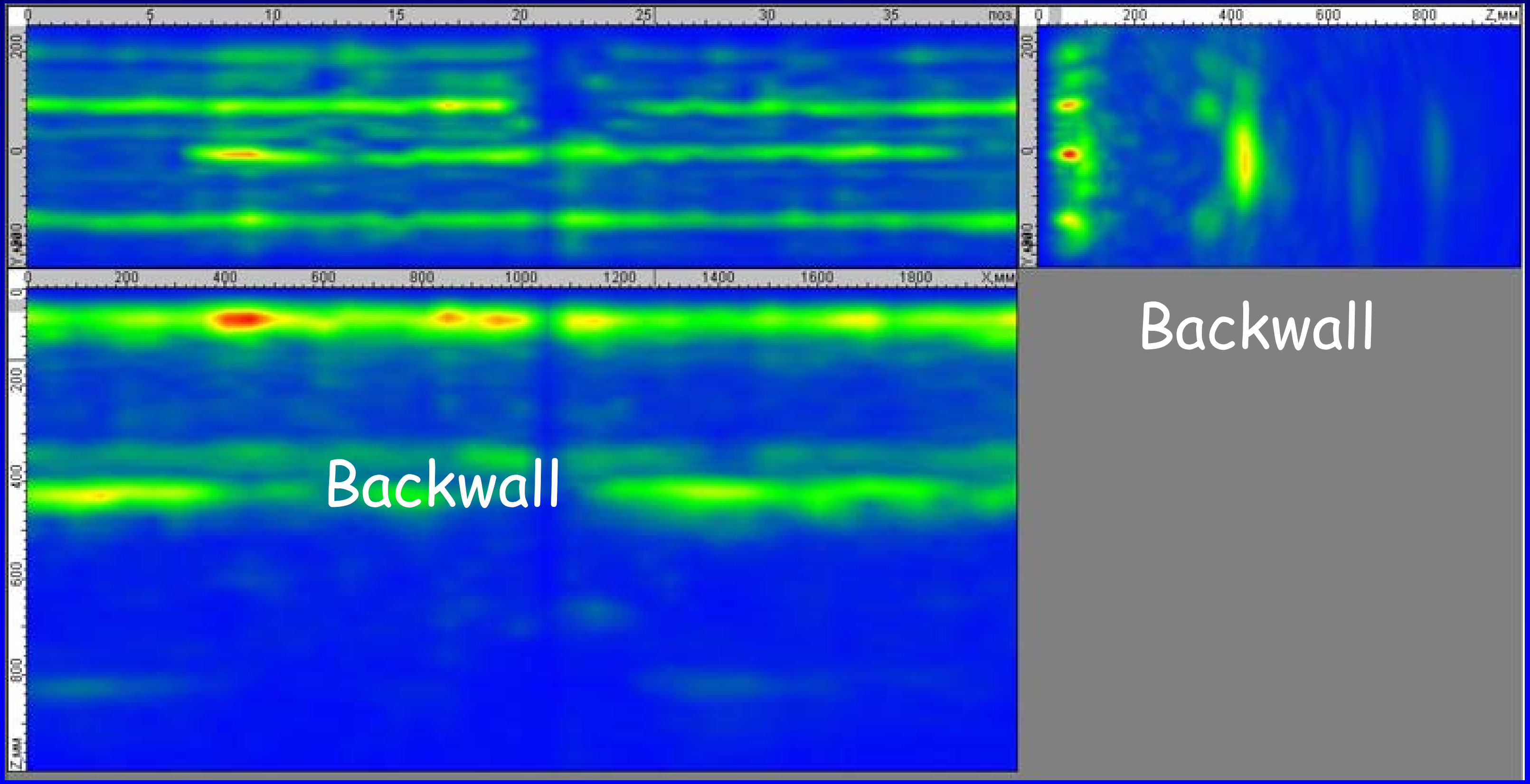
Expected Response



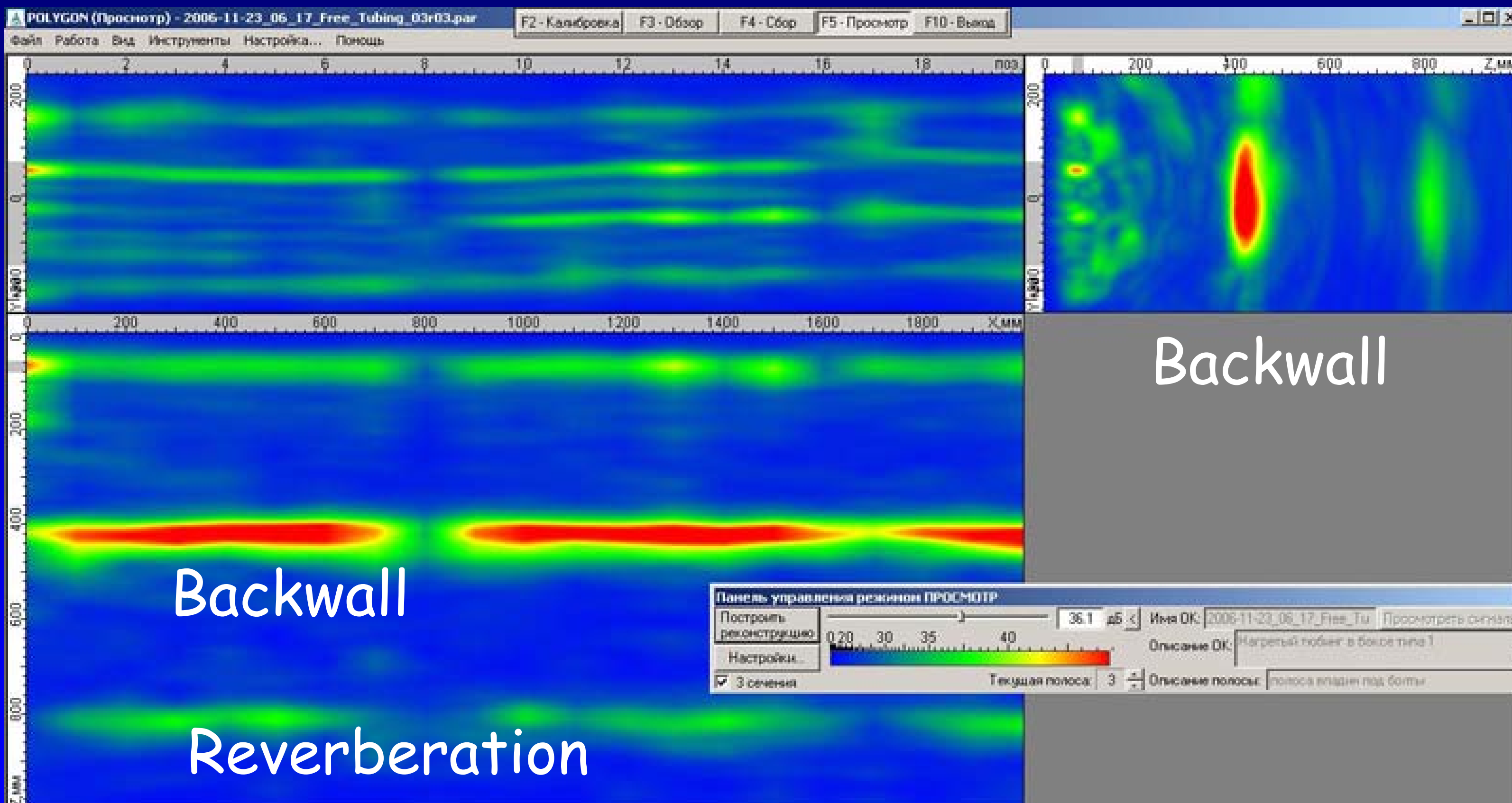
With Grout:
Weak Reflection

No Grout:
Strong Reflection

With Grout



No Grout


POLYGON (Просмотр) - 2006-11-23_06_17_Free_Tubing_03r03.par
F2 - Калибровка
F3 - Обзор
F4 - Сбор
F5 - Просмотр
F10 - Выход
Файл Работа Вид Инструменты Настройка... Помощь
Backwall
Backwall
Reverberation

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Summary

- MIRA Tomographer is based on the ultrasonic pitch-catch technique
- Uses shear-wave, point transducers that require no coupling fluid
- Array of transducers allows for many time-of-flight measurements to be made rapidly
- SAFT is used to reconstruct 2-D images of internal reflectors
- Visualization software creates 3-D volume

Summary

- Can look at images in different ways (projection on planes, slices, total 3-D)
- Very useful for inspection of grouted tendon ducts
- Like all other methods, results need to be confirmed by invasive methods
  - Drilling holes
  - Drilling cores

Stress-Wave Methods

Method	Display	Application
Ultrasonic pulse velocity: through transmission	Travel time between two transducers	Uniformity
Impact-echo: based on multiple reflections	Amplitude spectrum at test point	Point test: Thickness; voids; delamination
Impulse-response: based on structural vibration	Mobility spectrum at test point	Qualitative (1 m): voids; delamination; distributed cracking; support conditions
Ultrasonic-echo (MIRA): based on single reflection (time of flight measurement)	B-scan reconstruction of region below antenna	Voids; delamination; thickness; reinforcement