Application of Time Reversal Technique for the Inspection of Composite Structures

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Overview

- Inspection Challenge
- Concept of ‘Time Reversal’
- Inspection Solution
- Case Studies
- Advanced Analysis Features
- Conclusion

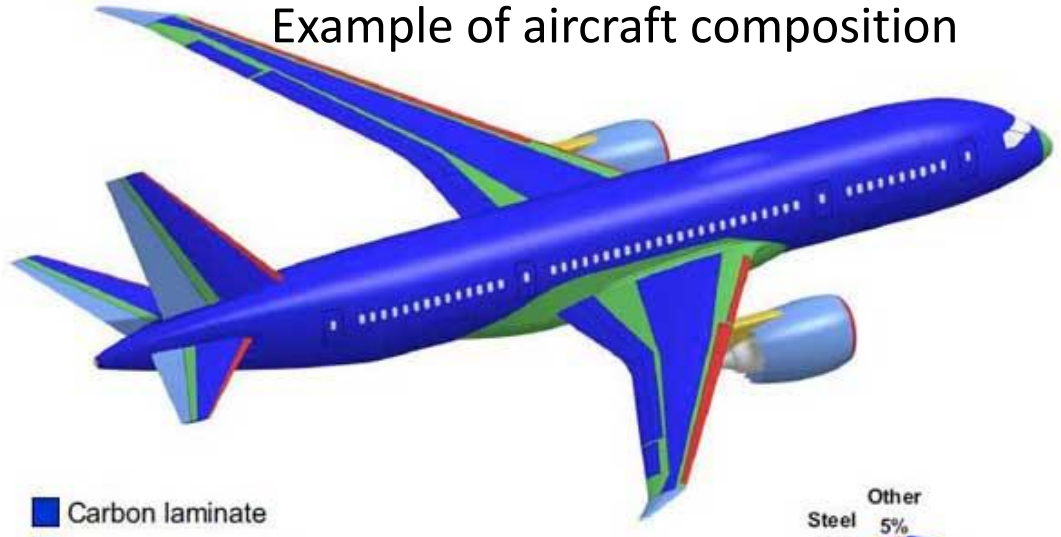
Inspection Challenge

- The commercial aircraft industry uses an increasing quantity of composite materials, for the manufacturing of lighter, more fuel-efficient and more comfortable airplane types : roughly 50% of materials are composites

- Composite structures in wings and fuselage have complex and variable geometries

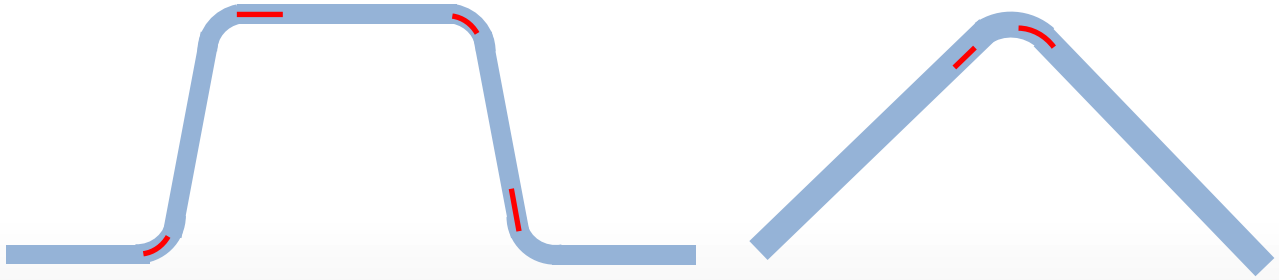
- Large manufacturing volumes demand high inspection speed in addition to high reliability

Example of aircraft composition

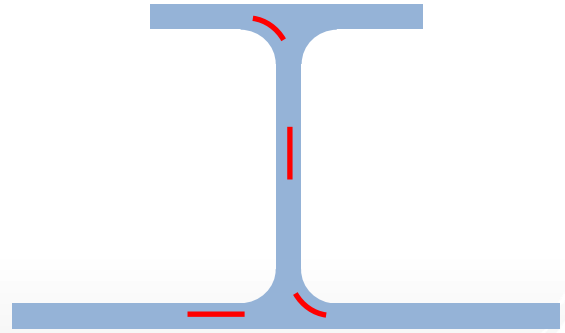


Inspection Challenge

- Inspections after manufacturing must be able to detect various defects introduced during manufacturing process: porosities, foreign bodies, and delaminations
- The Time Reversal Phased Array Ultrasound (PA UT) technique can improve coverage and detection capability while maintaining a high inspection speed



Laminations in composite stringers



Laminations in composite spars

Time Reversal - Concept

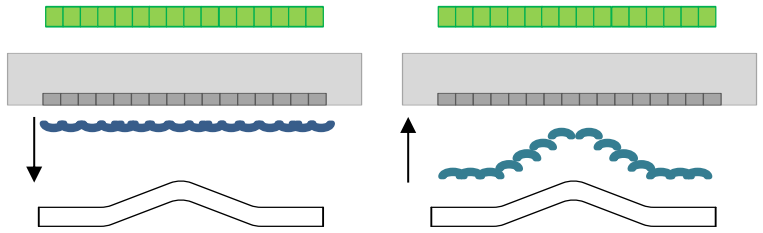
- Time Reversal is a real-time adaptive PA UT inspection technique
- Process is based on ***measurement*** and ***compensation*** of flight times of surface echoes of individual probe elements ➡ ***”Time Reversal”***
- Two step process, but performed real-time

Time Reversal - Concept

Step 1 - Profiling of the component surface

Delays

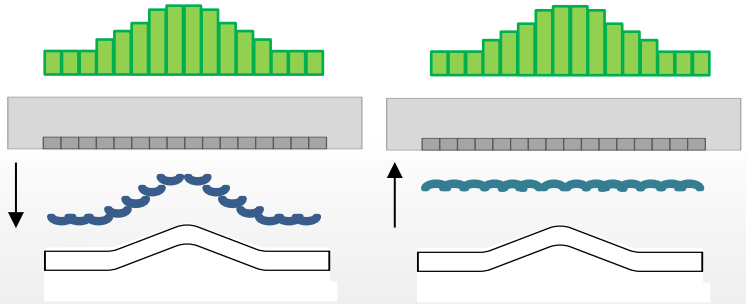
Sound wave



Determination of surface shape

Delays

Sound wave



Reverse TOF to fit surface profile

Measured TOF applied in new delay for each individual element ("Time Reversal")

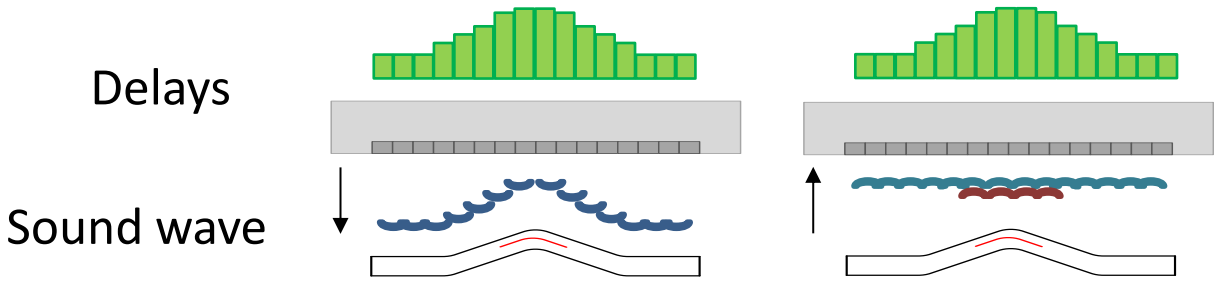
Emission $E_i = \frac{1}{2}\left[Max\left(t_i\right) - t_i\right]$

Reception $R_i = \left[Max\left(E_i\right) - E_i\right]$

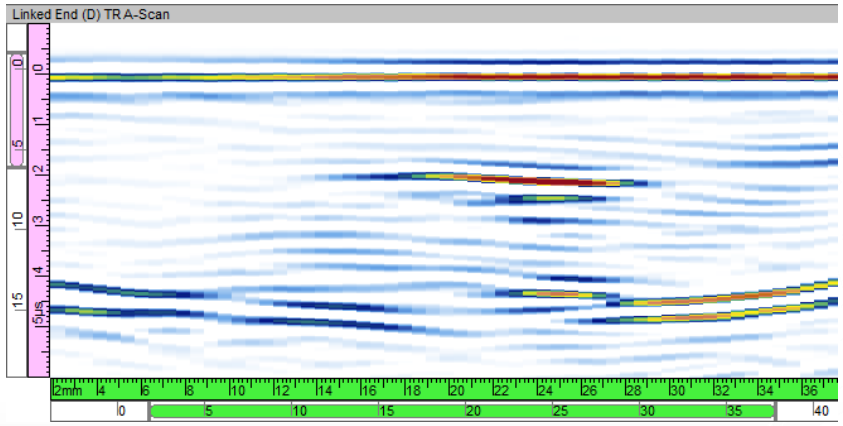
Time Reversal - Concept

Step 2 - Data Recording

Firing surface-adapted delay laws to obtain normal incidence over the complete component surface at each probe position



Data recording using surface-adapted delays



Profiling and data recording are performed real-time in a single scanning sequence

Inspection Solution

- Phased array UT probes
- UltraVision Classic or UltraVision Touch
- Advanced phased array UT systems, supporting Time Reversal technique
- Integration to manipulator or manual scanning

Phased Array UT Probes

- Inspections are mostly performed with essentially normal incidence (0LW) on the component surface
- Typically this requires a combination of :
  - Linear 1D PA Probes, for flat surfaces
  - Circular (Arc-shaped) 1D PA Probes, for convex and concave curved area
- Typical probe frequencies of 3.5MHz and 5MHz

Advanced PA UT Systems

- Time Reversal PA UT is now supported in :

TOPAZ 32

ZIRCON

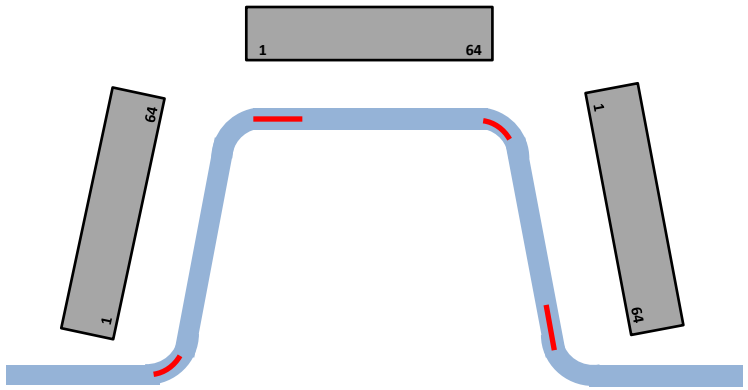
QUARTZ

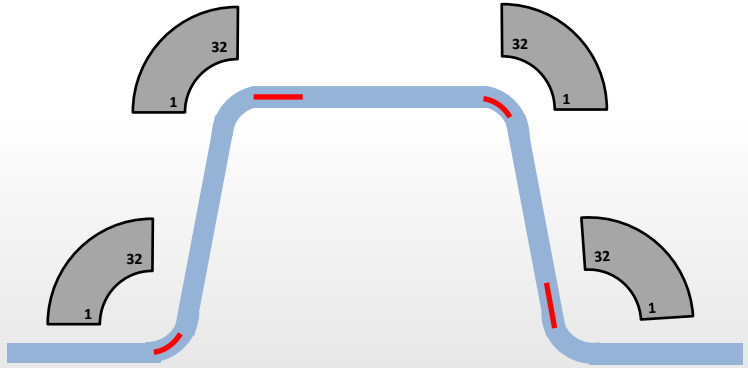
all driven by UltraVision and UltraVision Touch

- All systems have 32/128 configuration, some battery operated

- Up to 10 units can be connected to the same PC for high speed data recording, providing complete coverage

Advanced PA UT Systems

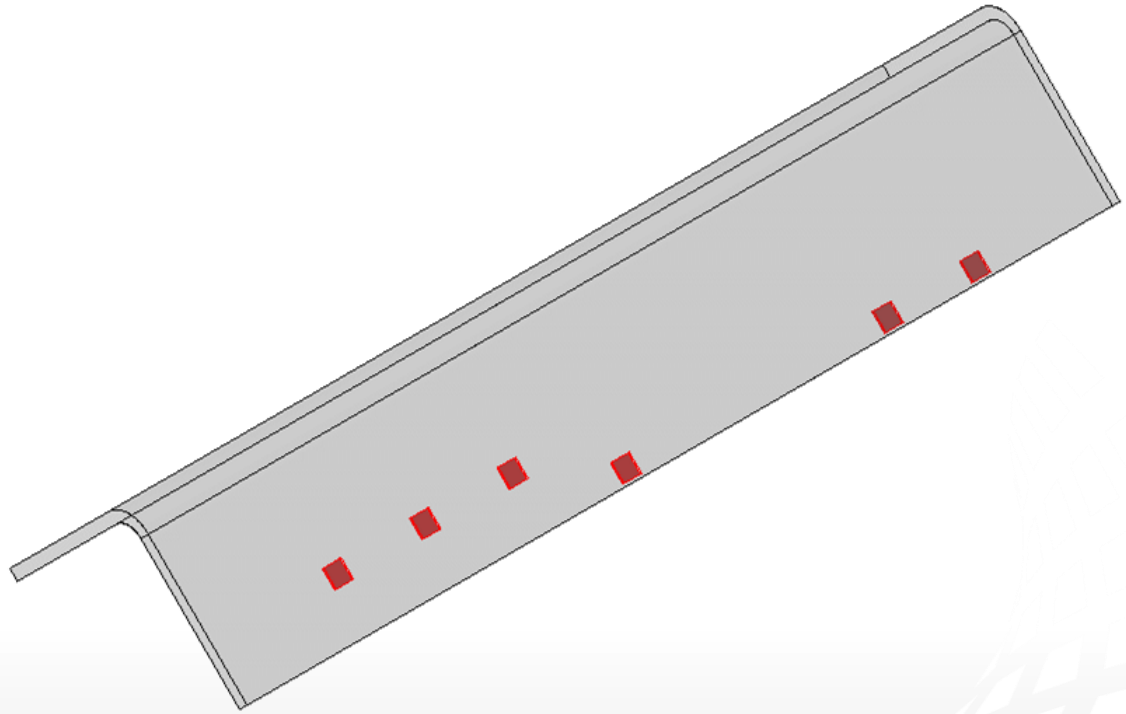




Splitter box 4 x 32 channels

Case Study – Test Specimen

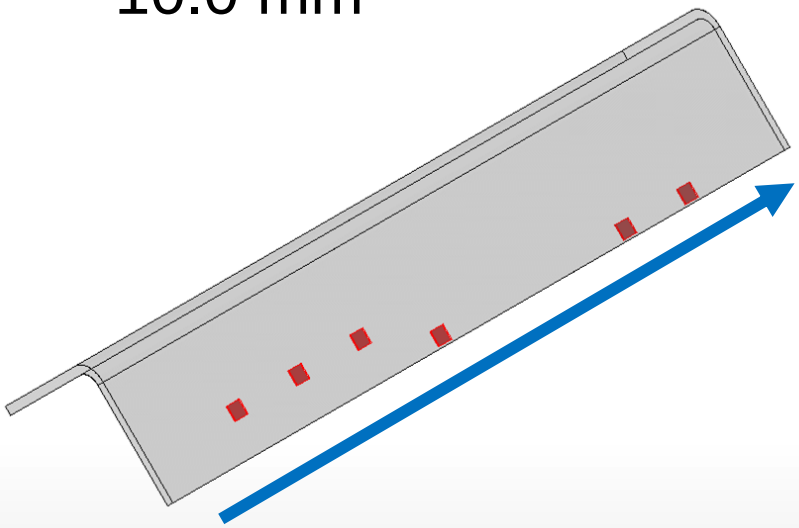
- CFRP material, manufactured for Zetec
- Representative geometry (stringer, spar), 6 mm thick
- With artificial brass inserts (10 x 10 mm), at various locations and depths



Case Study – Flat Area

Linear 1D array probe :

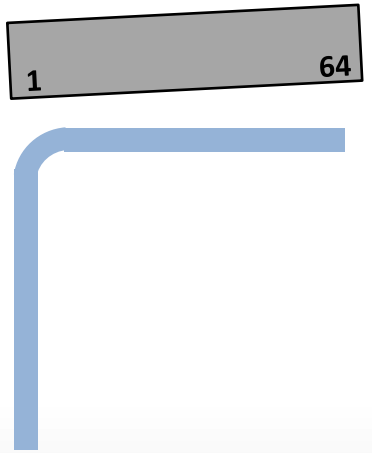
- width LM 5 MHz, 64 elements
- pitch 0.6 mm
- 10.0 mm



scanning along the component, using single axis scanner

Configuration :

- immersion tank
- water column

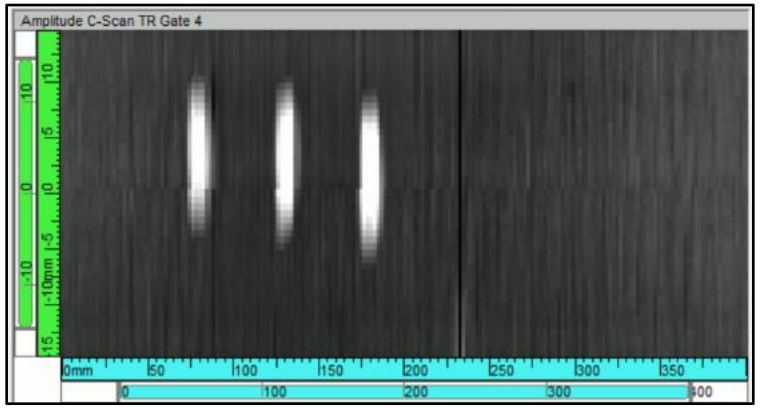


misalignment of the probe

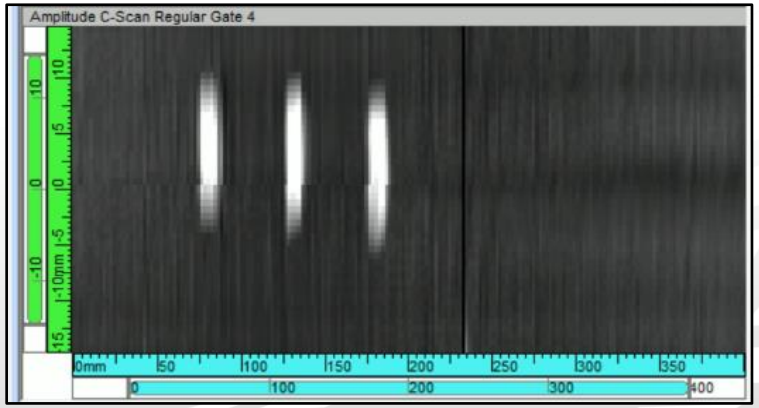
RDAU type PA system

Case Study – Flat Area, Probe Aligned

Time Reversal

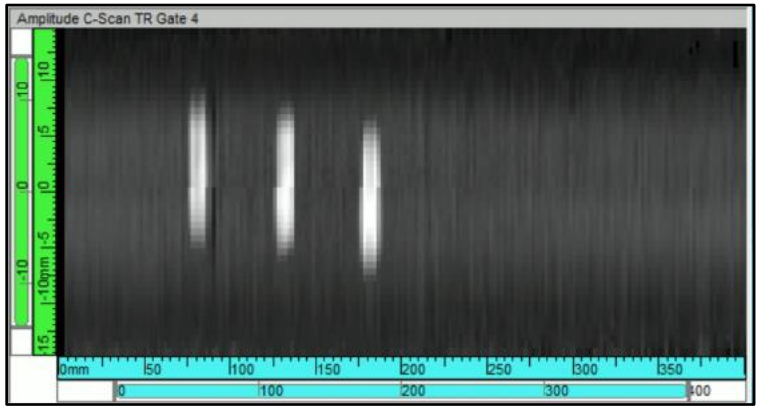


Standard Phased Array

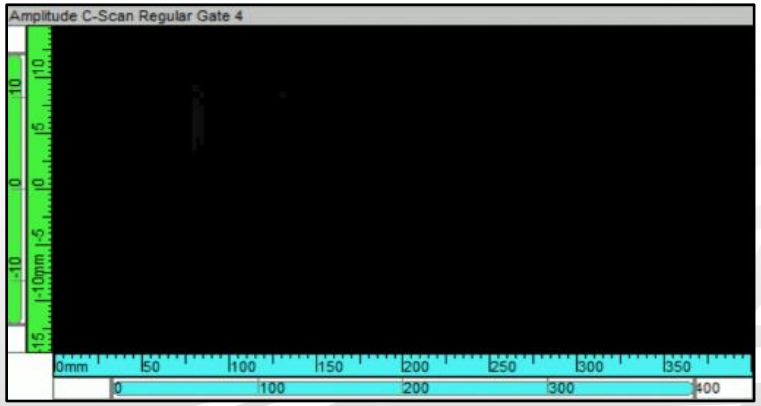


Case Study – Flat Area, Probe Misaligned

Time Reversal



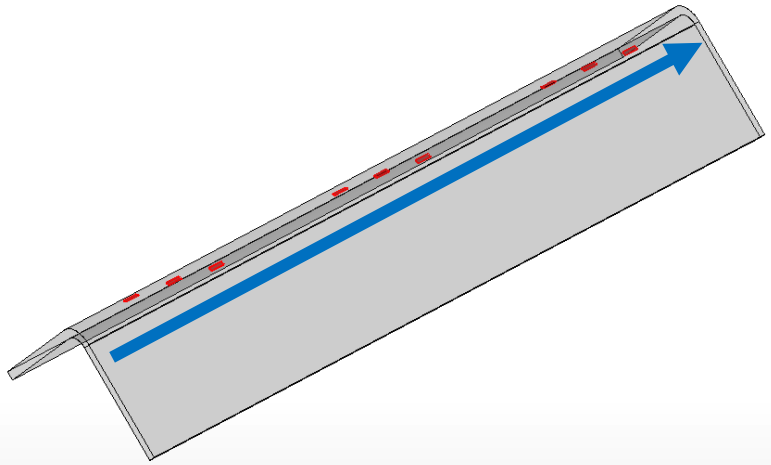
Standard Phased Array



Case Study – Curved Area

Arc-shaped 1D probe :

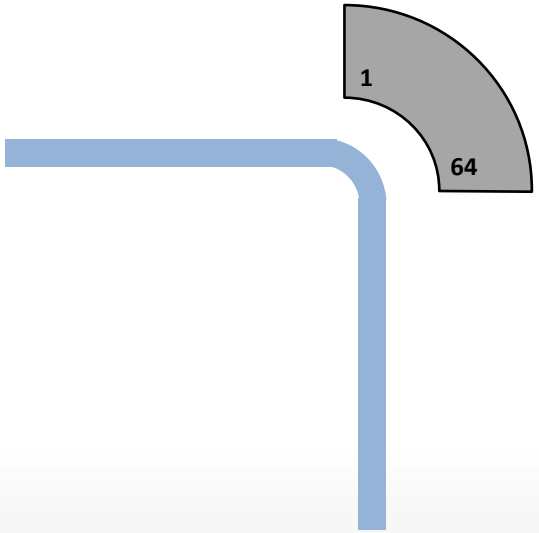
- 3.5 MHz, 64 elements
- pitch 0.65 mm
- width 8.0 mm



scanning along the component, manually driven

Configuration :

- immersion tank
- water column

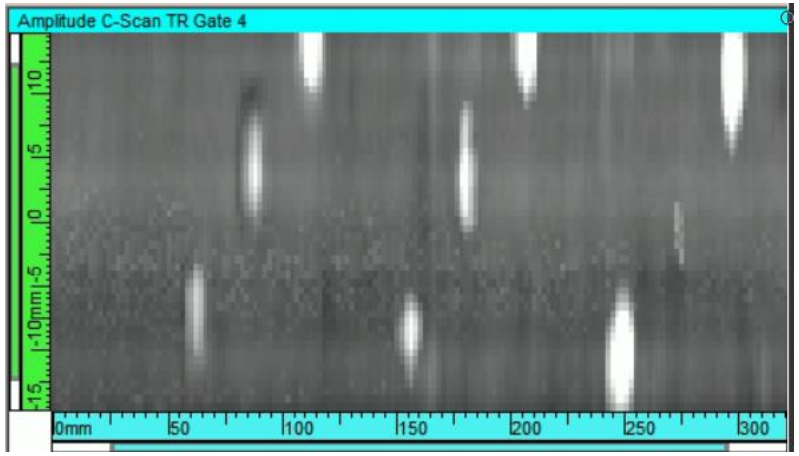


misalignment of the probe

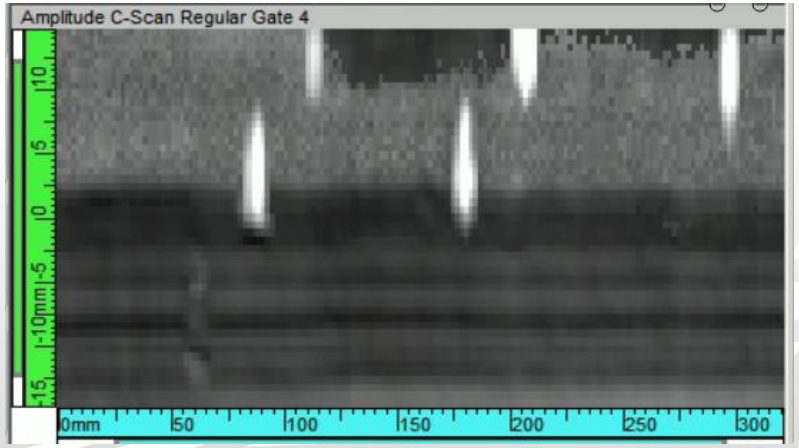
Integrated PA system

Case Study – Curved Area

Time Reversal



Standard Phased Array



Profiling

Advanced Analysis Features

- Signal-to-Noise Ratio (SNR) : Concept & Evaluation
- 3D Imaging
- Special Colors
- Assisted Analysis & Indication Table
- Matrix Filters

SNR Evaluation - Objective

- At various moments during an inspection campaign, the sensitivity of the complete inspection system must be verified to ensure conformance to performance criteria
- Performance is evaluated by measuring the SNR of known indications in a reference standard
- If every indication in the standard respects the minimum SNR value, the inspection system is validated

SNR Evaluation - Measurement

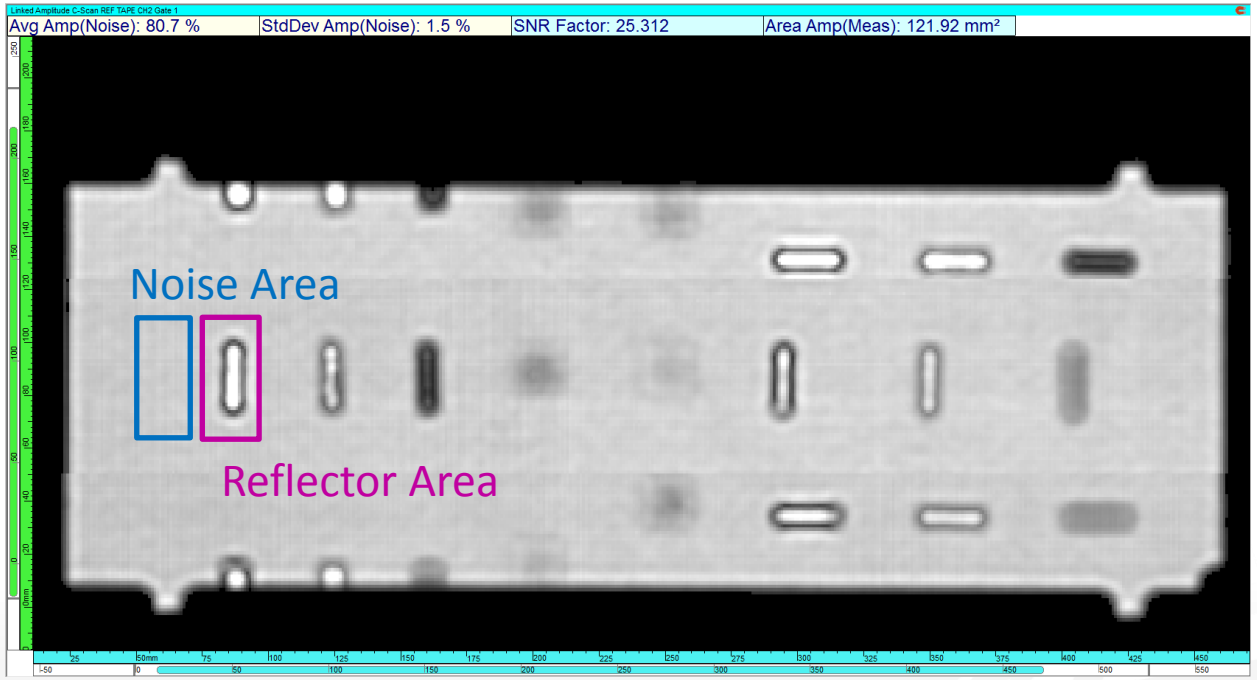
- Each reflector in the standard has a well-known length and width, from which a nominal surface area can be computed
  - *Nominal area = Length * Width*
- A minimum target area must be found for each reflector. This minimum area is often fixed at 75% of the nominal area
  - *Target area = Nominal Area * Ratio*
- Boxed indication pixels are evaluated against amplitude detection level. The detection level must be adjusted so that the measured area of the indication is just above the target area we are expecting
- The detection level and the noise parameters measured close to the indication are used to compute the SNR
  - *SNR factor = ABS (Boundary – Noise Average) / Noise StdDev*

SNR Evaluation on Flat Standard

- CFRP sample with reference indications
- Evaluation of SNR using ULTRAVISION COMPLETE UT AND PHASED ARRAY INSPECTION PACKAGE
- Applicable on
  - Amplitude C-Scan
  - Position C-Scan
- Special colors

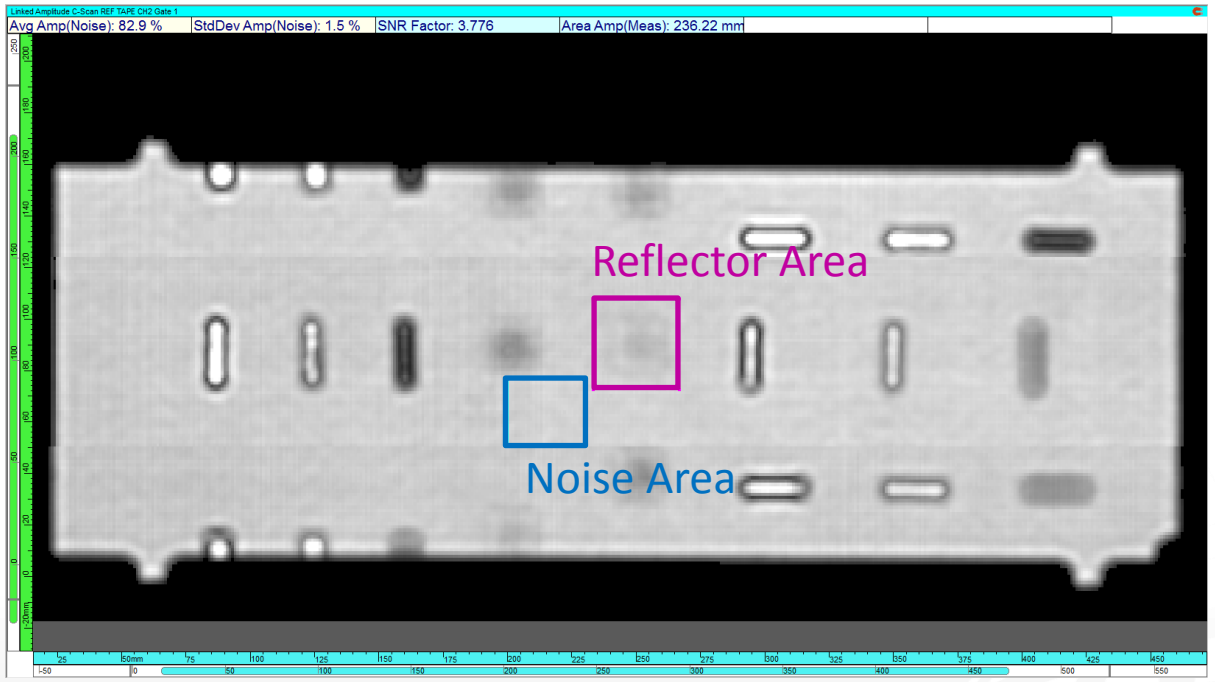
SNR Evaluation – Reflector #1

- Mark indication-free area
  - obtain Noise Average
  - obtain Noise StdDev
- Mark indication area
- Processing function can compute automatically
  - SNR for known indication size
  - indication size for given SNR



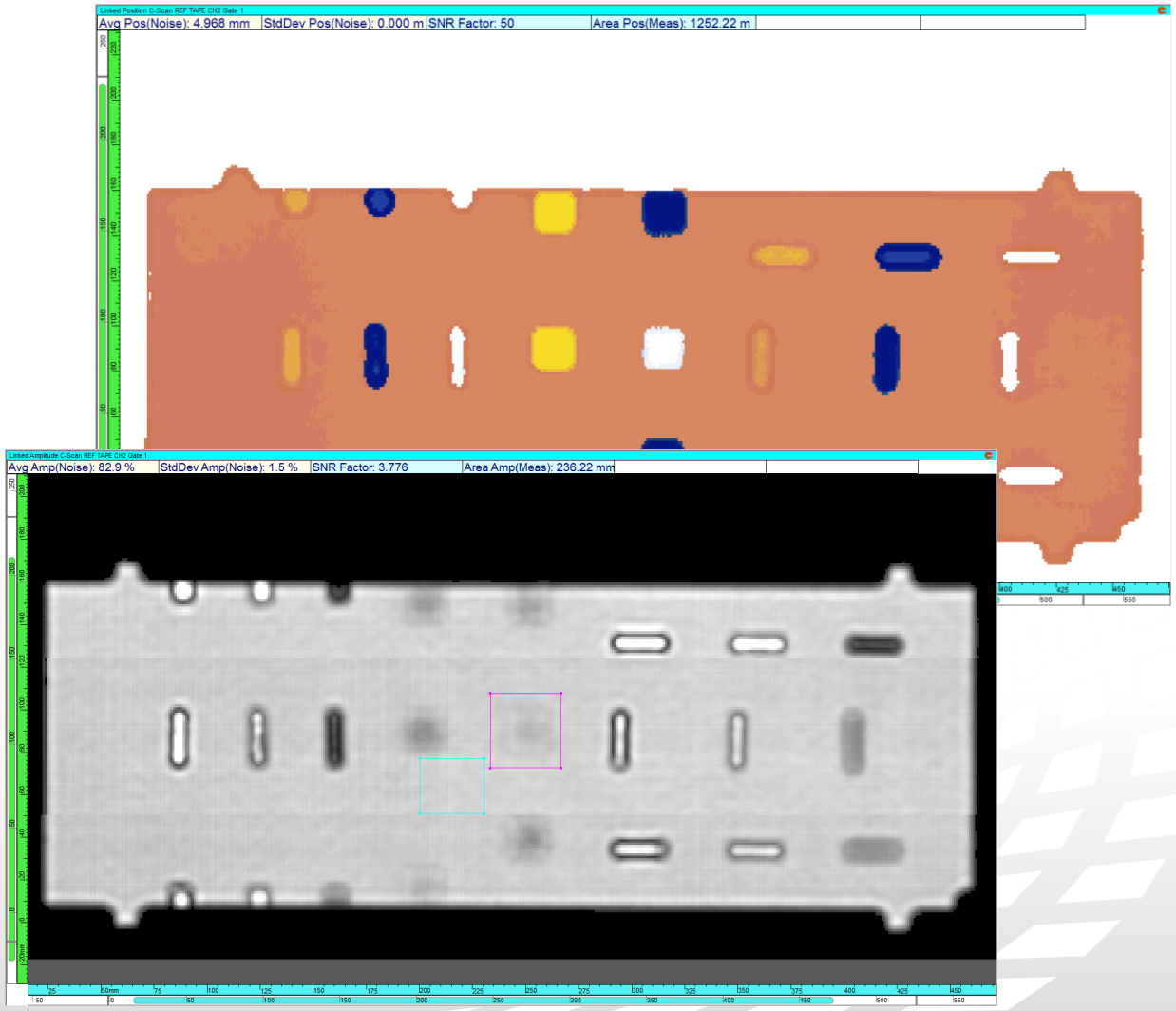
SNR Evaluation – Reflector #5

- Mark indication-free area
  - obtain Noise Average
  - obtain Noise StdDev
- Mark indication area
- Processing function can compute automatically
  - SNR for known indication size
  - indication size for given SNR



Amplitude vs. Depth Discrimination

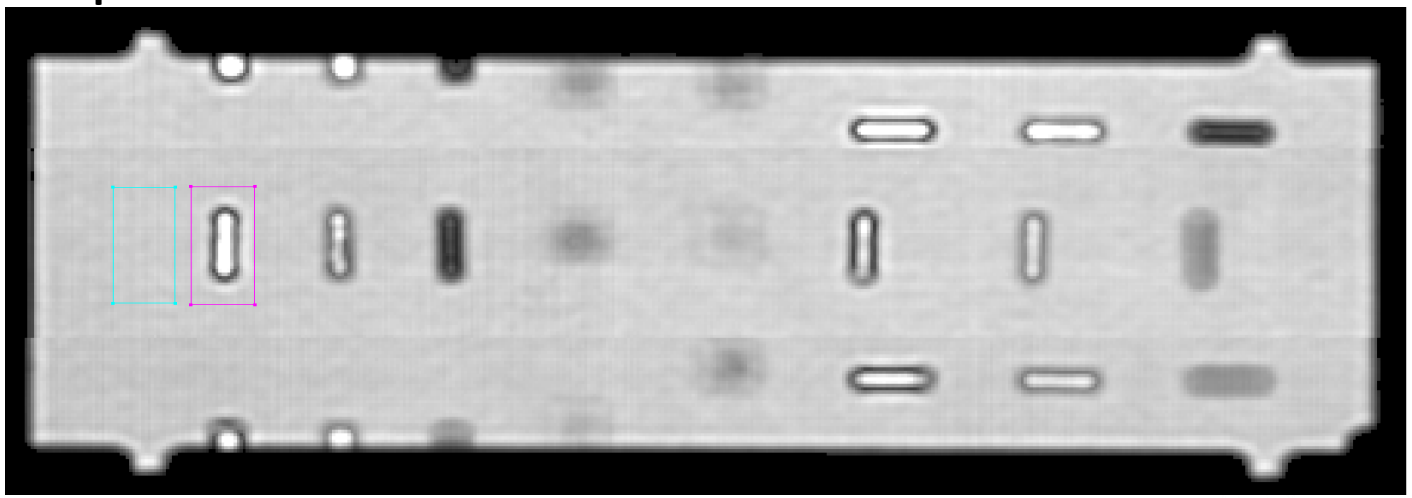
- Amplitude evaluation is often convenient, but not perfect in all situations
- Some indications with low SNR are difficult to discriminate from surrounding noise
- Depth evaluation can be used to supplement amplitude evaluation



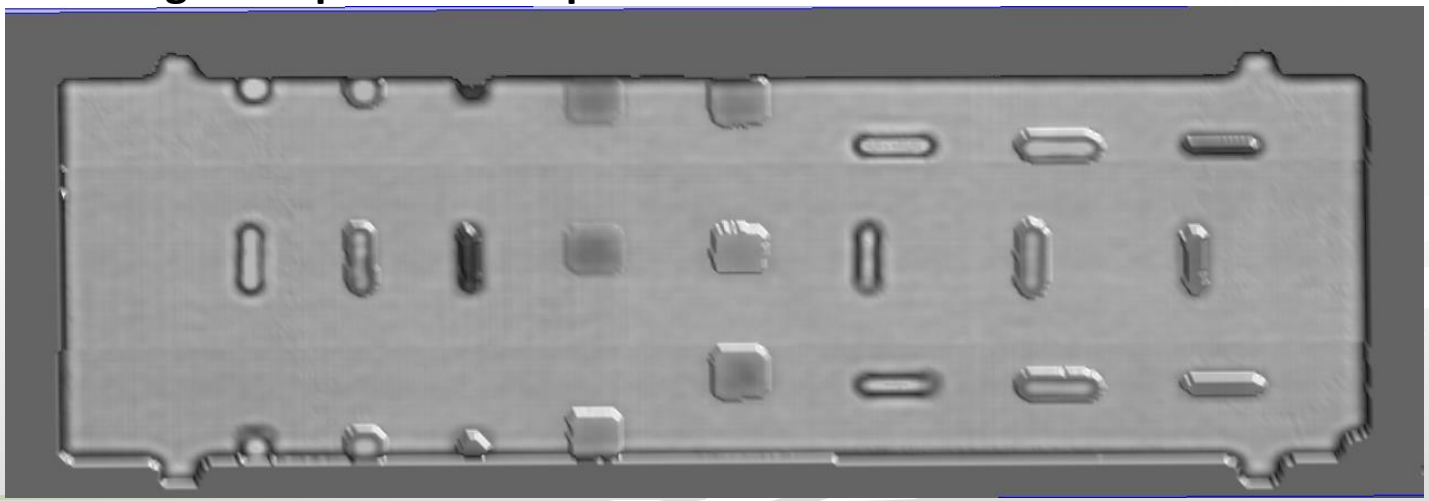
3D Imaging

- Combination of amplitude and depth information in a single image
- Can enhance contrast, for better discrimination of challenging indications

Amplitude C-Scan

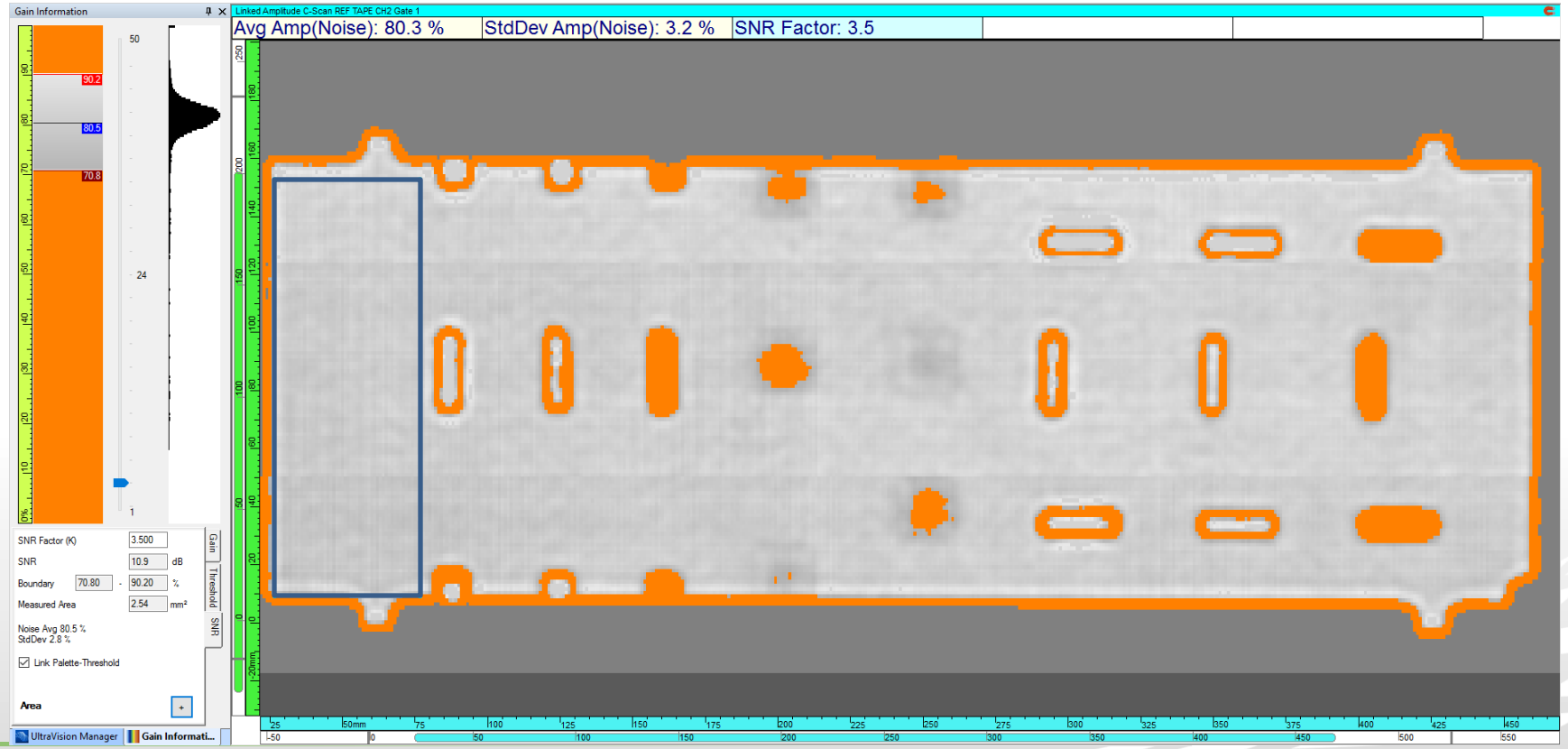


3D Image : Amplitude & Depth



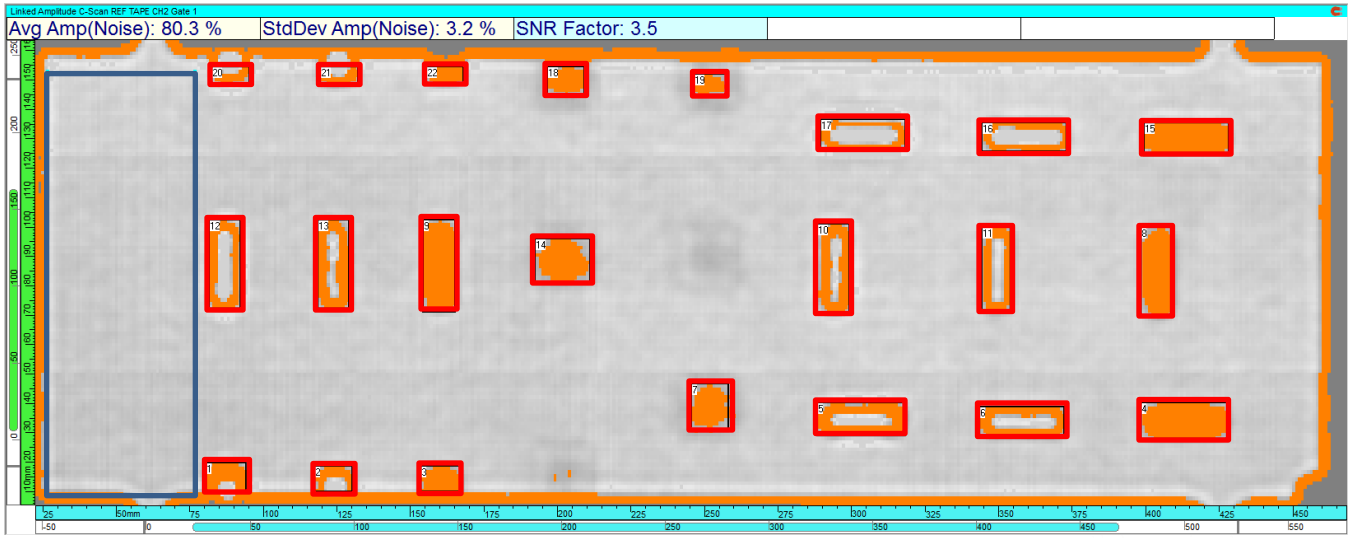
Highlighting Indications

- Special color, based on SNR boundary highlight inspected content
- Easy discrimination between indication and surrounding noise



Assisted Analysis

- Automated function can use
  - Noise definition
  - Indication SNR characteristics
- Produces a list of indications
  - Includes characteristic of indications in a report
  - Indication contours shown on view



Indication Table

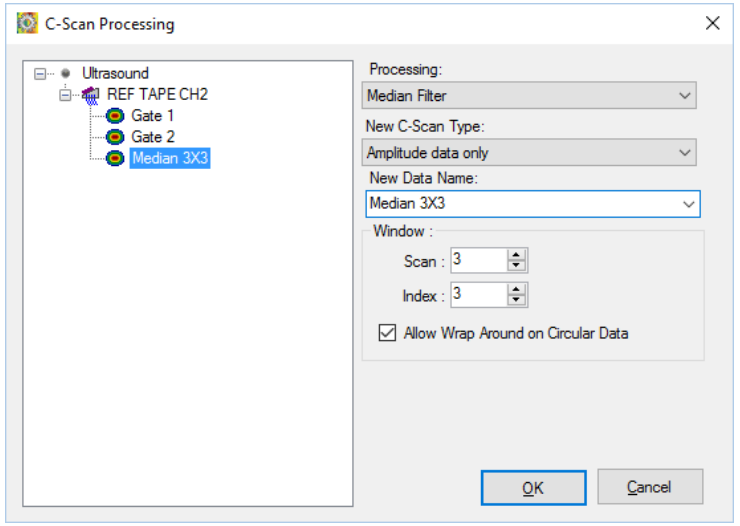
Id	Comments	Avg Amp(Noise)	StdDev Amp(Noise)	SNR Factor	Area(Min)	Area Amp(Meas)	Area(Nom)	Area(Ratio)	Gate	DataFile
023	Auto Value	80.3 %	3.2 %	3.5	216.75 mm²	-	289.00 mm²	75.0 %	Gate 1	Flat Reference Standard.UVData
1	AA - Flaw #1	80.3 %	3.2 %	3.5	216.75 mm²	111.76 mm²	289.00 mm²	75.0 %	Gate 1	Flat Reference Standard.UVData
2	AA - Flaw #2	80.3 %	3.2 %	3.5	216.75 mm²	63.50 mm²	289.00 mm²	75.0 %	Gate 1	Flat Reference Standard.UVData
3	AA - Flaw #3	80.3 %	3.2 %	3.5	216.75 mm²	105.41 mm²	289.00 mm²	75.0 %	Gate 1	Flat Reference Standard.UVData
4	AA - Flaw #4	80.3 %	3.2 %	3.5	216.75 mm²	334.01 mm²	289.00 mm²	75.0 %	Gate 1	Flat Reference Standard.UVData
5	AA - Flaw #5	80.3 %	3.2 %	3.5	216.75 mm²	236.22 mm²	289.00 mm²	75.0 %	Gate 1	Flat Reference Standard.UVData
6	AA - Flaw #6	80.3 %	3.2 %	3.5	216.75 mm²	179.07 mm²	289.00 mm²	75.0 %	Gate 1	Flat Reference Standard.UVData

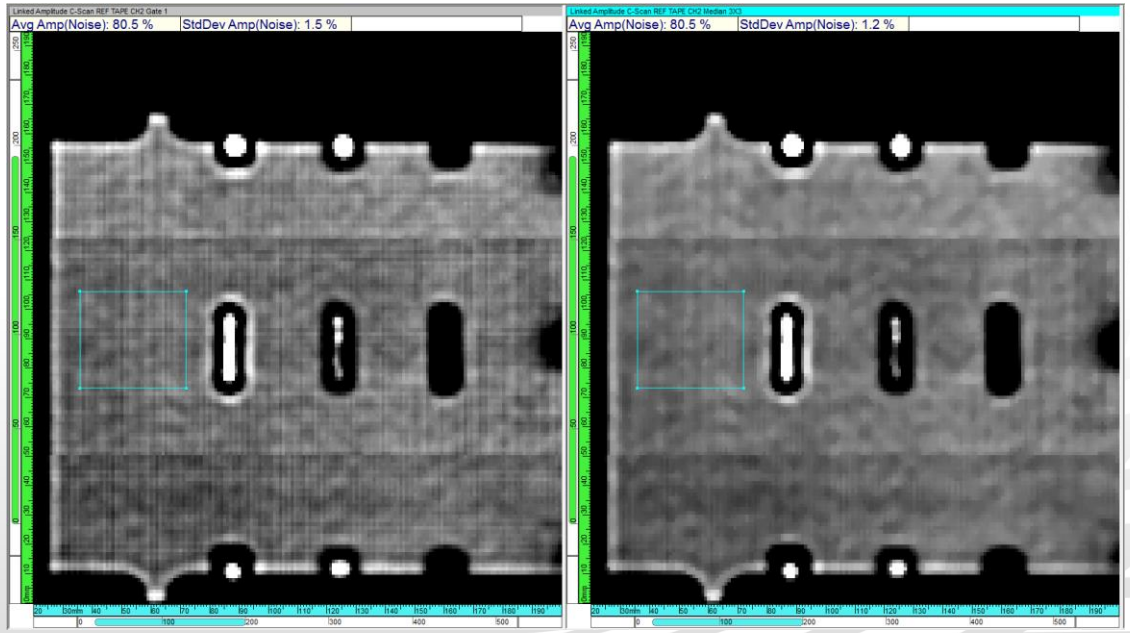
23 Export to TXT Merge Attachment... Fields

Matrix Filters

- Several Matrix Filter functions are available :
  - Averaging
  - Median filter
  - Etc…

- Such filter may reduce noise and improve SNR





Conclusion

Time Reversal technique :

- Improves signal quality when probe alignment with inspected component surface is not optimal
- Provides real-time adaptation of the phased array beam, and has almost no impact on inspection speed
- Can improve coverage and detection capability

Time Reversal is supported in commercially available phased array UT systems, either RDAU type or fully integrated units

Various dedicated tools have been included in the analysis software, to allow for a rapid and reliable data evaluation process