



Diagnostic Sonar

Recent advances in aerospace
inspection with ultrasonic
phased arrays



David Lines

Chief Engineer, Diagnostic Sonar Ltd., UK

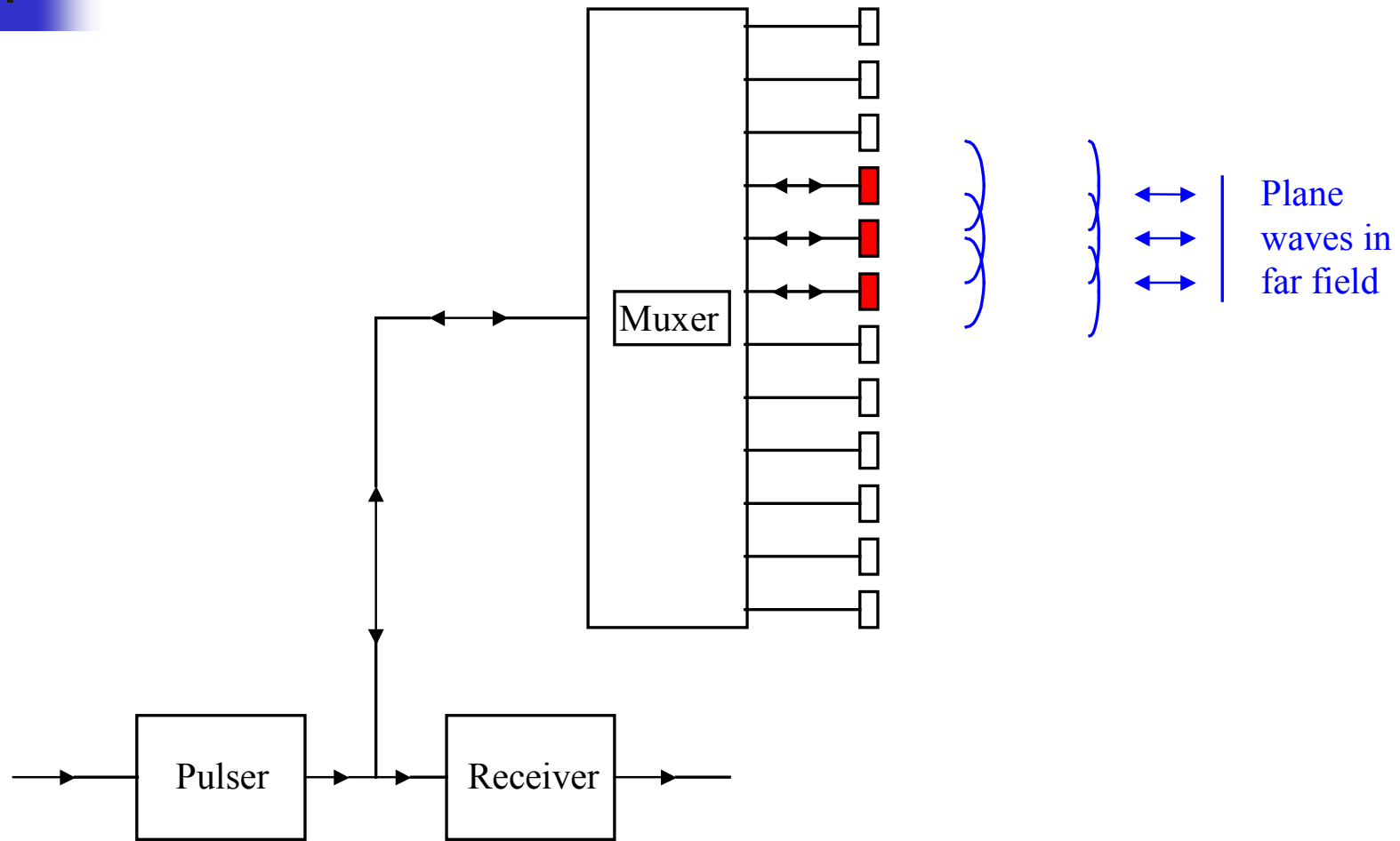
AeroNDT SEMINAR, Aerospace Testing Expo2007
27th-29th March 2007, Munich



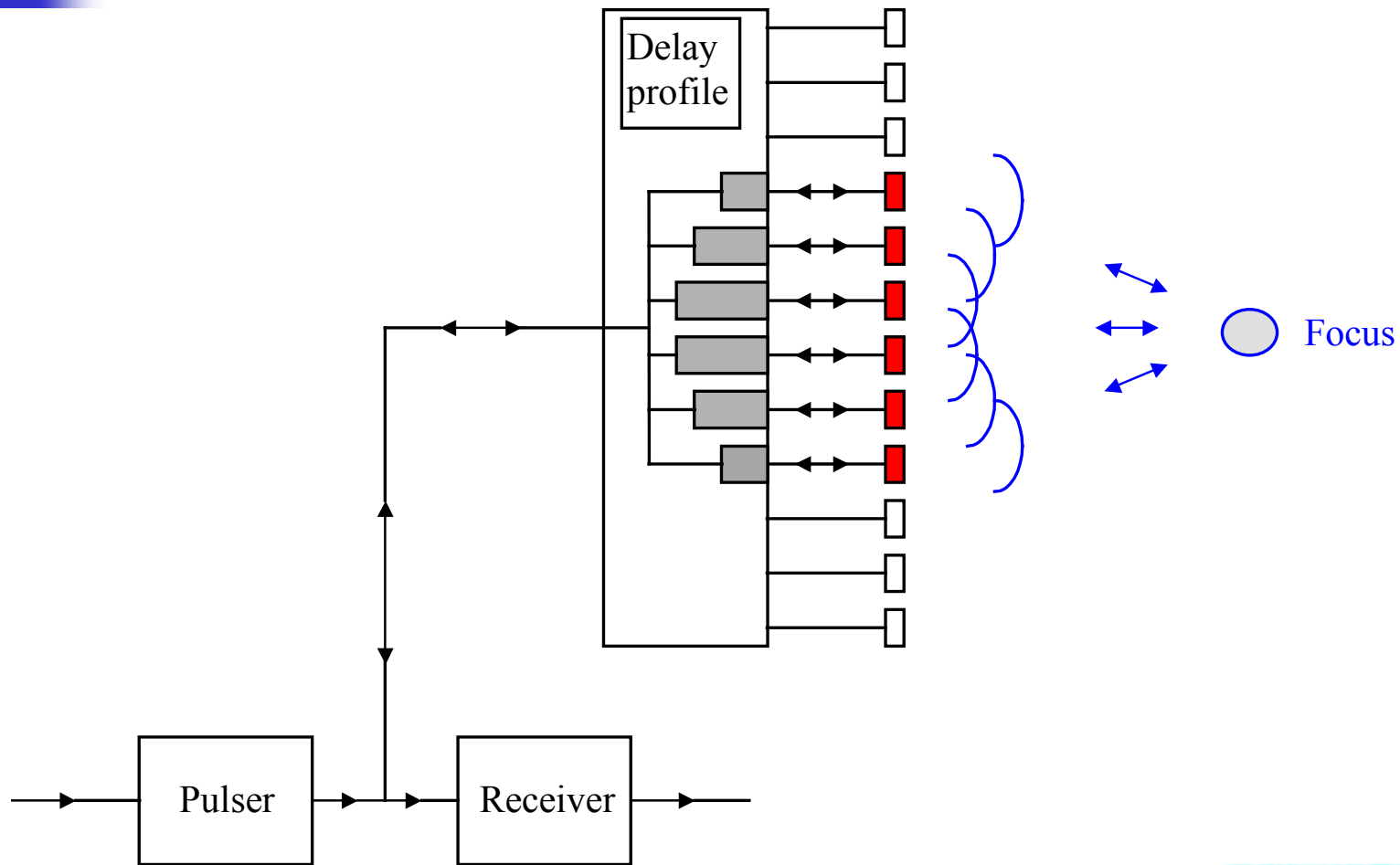
Content

- Background
 - Arrays and real-time imaging
 - Advanced acquisition techniques
 - New possibilities of Full Raw Data (FRD)
- Application Examples
 - Non-linear processing
 - Composite spar inspection
 - 2nd layer crack detection

Arrays – Stepped scanning

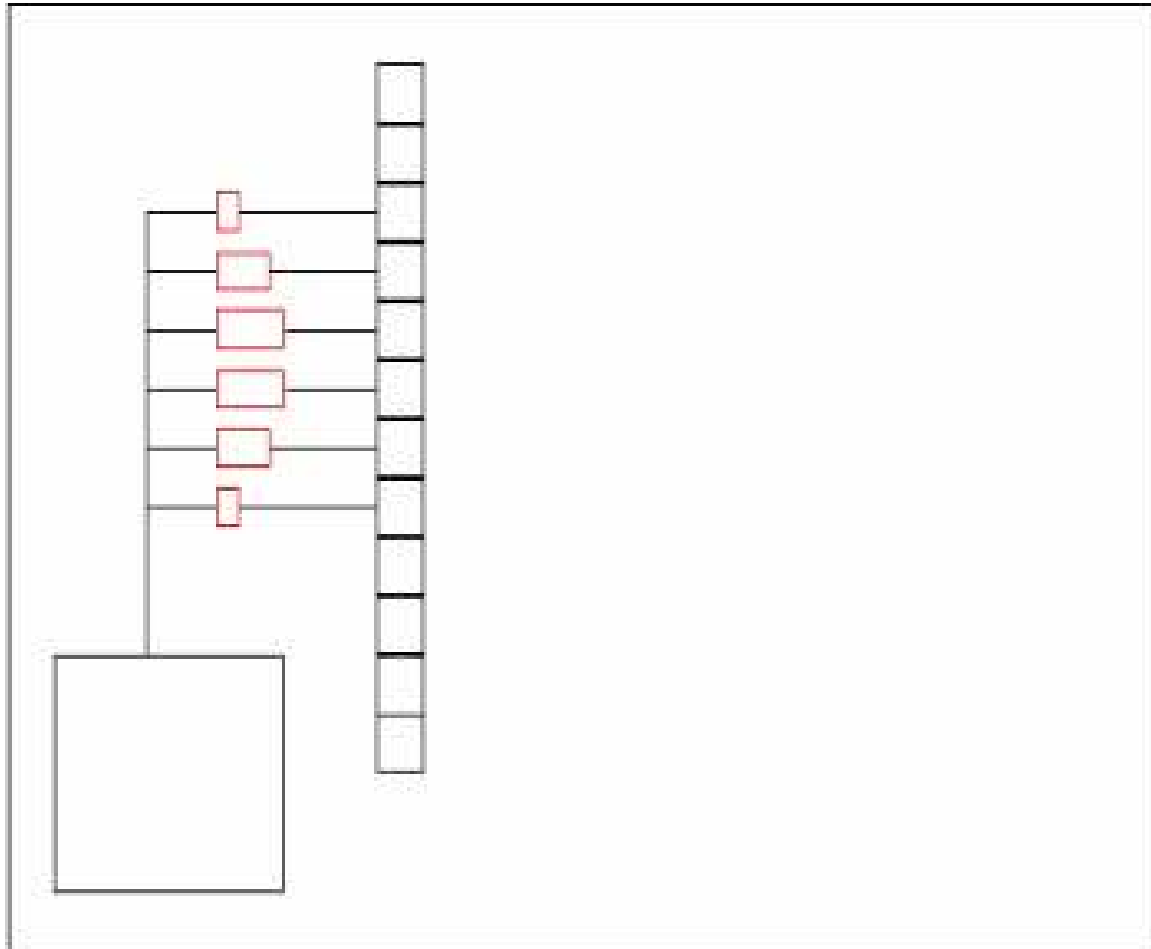


Arrays – Electronic focusing



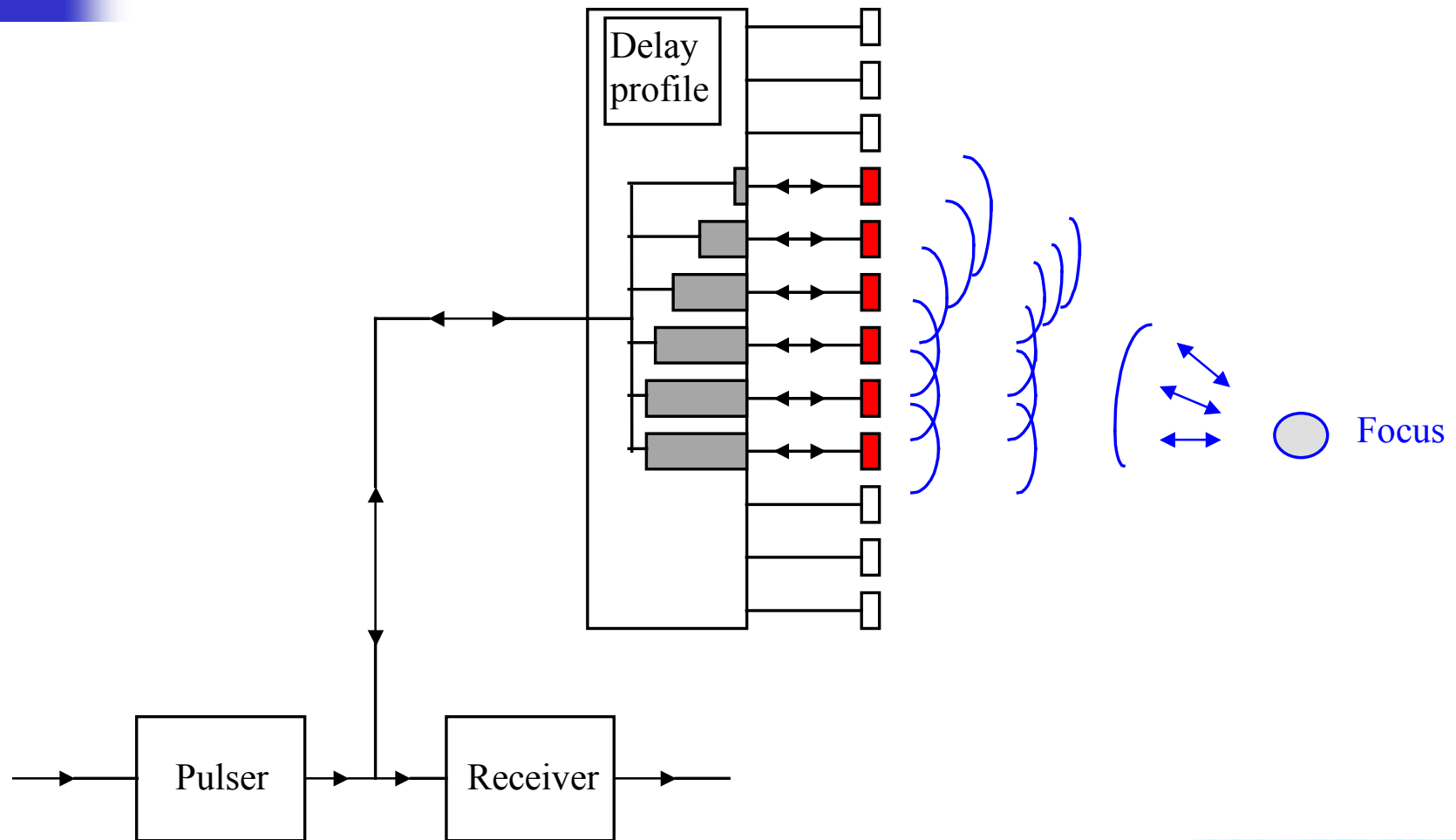
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Dynamic focusing



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Arrays – Steered and focused



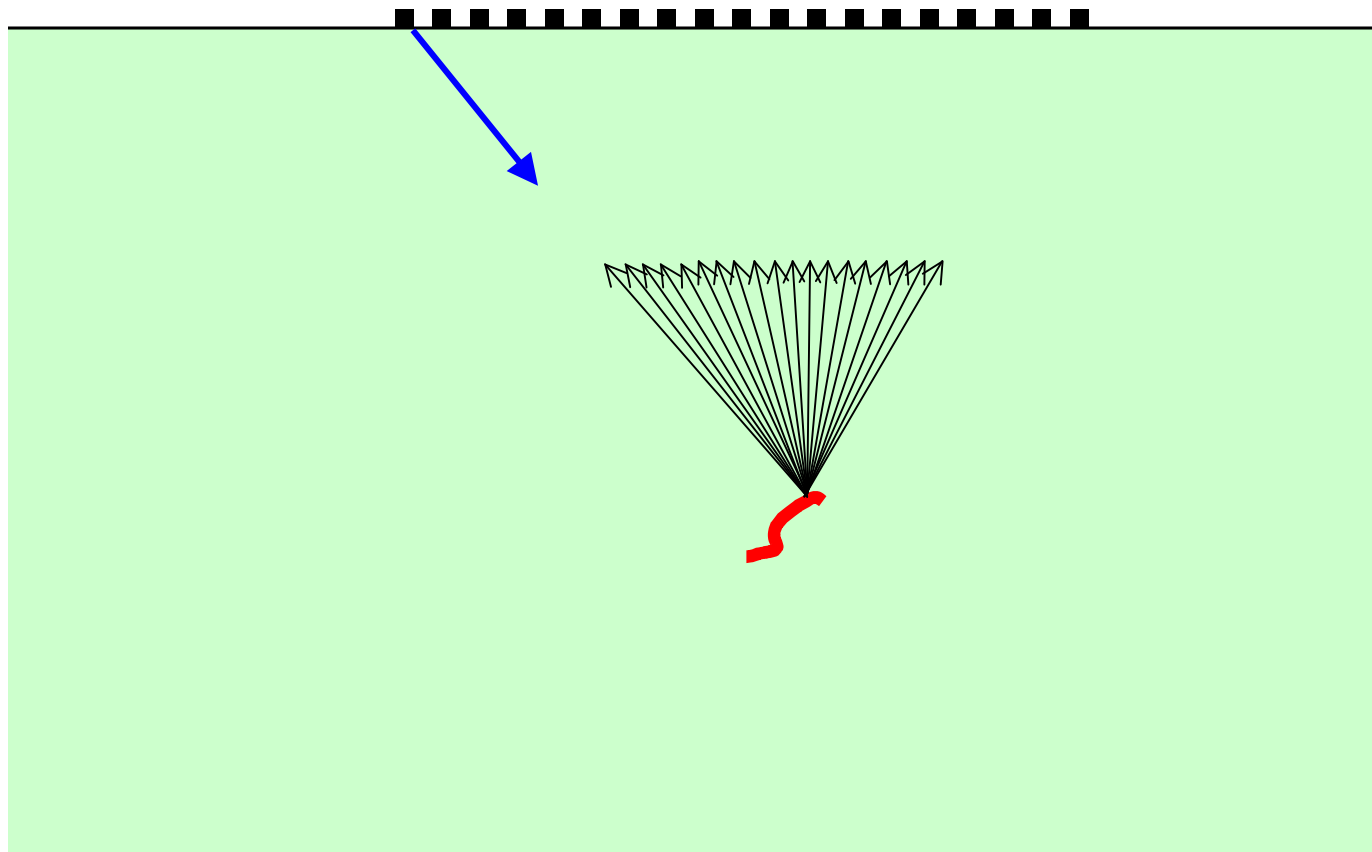
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What is Distributed Data Collection?

- Coherent RF data set composed of pitch-catch combinations from different locations
- In general
 - No restriction in location in any dimension
 - Tx and Rx sensors can have different beam properties
- Common characteristics
 - Tx and Rx sensor beam properties usually same
 - Beam width is usually much wider than for imaging. Images are then generated by beamforming on the RF data

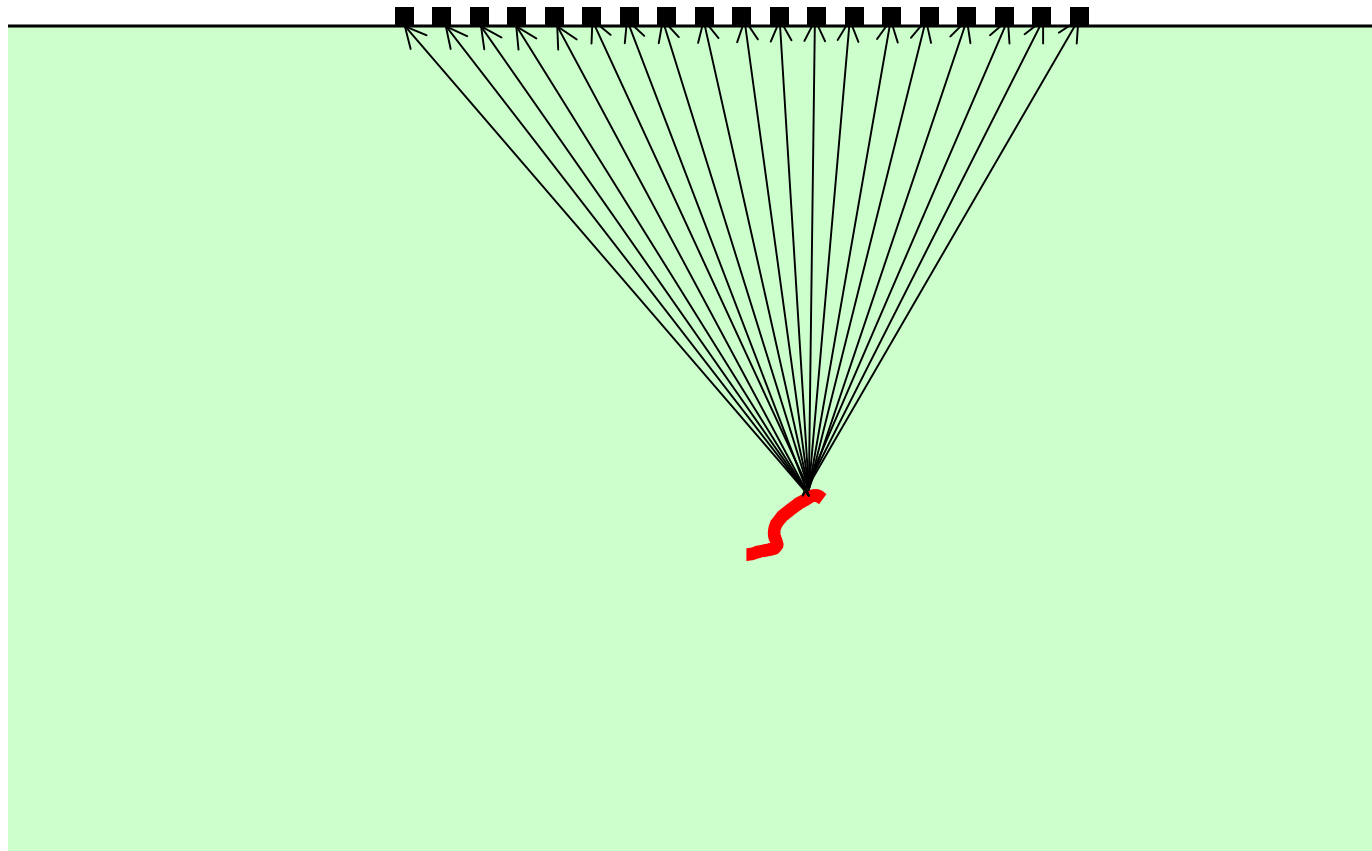
Array distributed data collection



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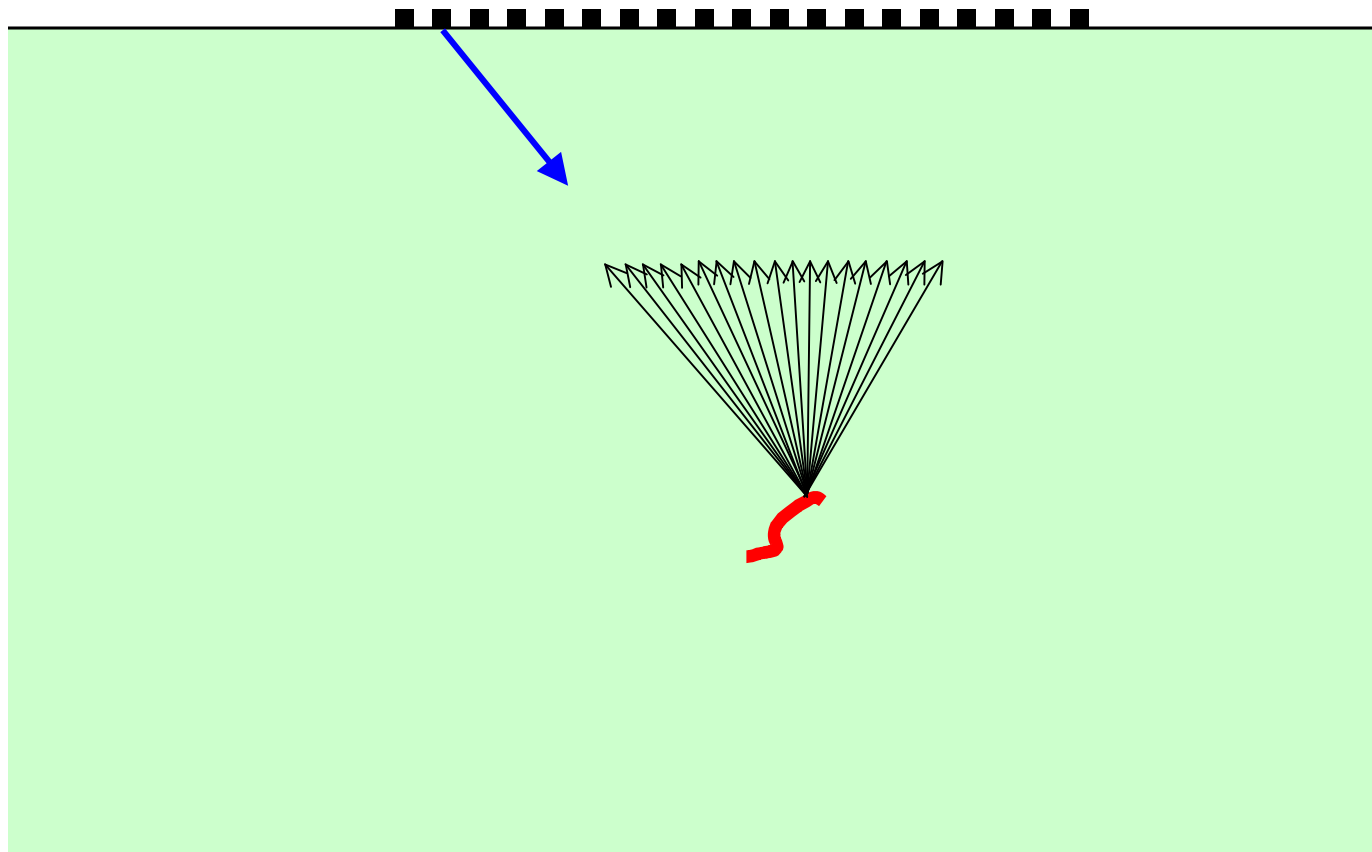


Array distributed data collection



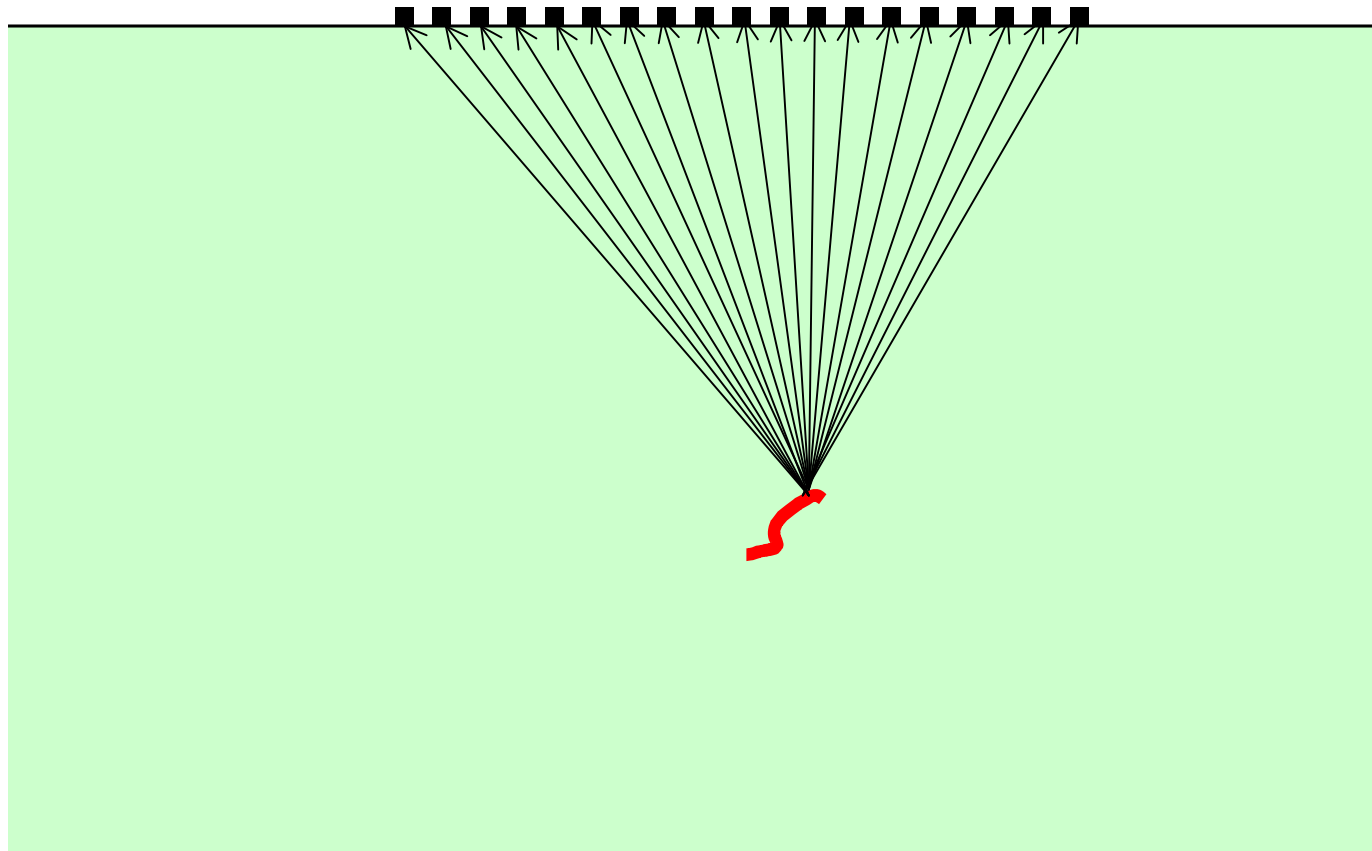
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Array distributed data collection



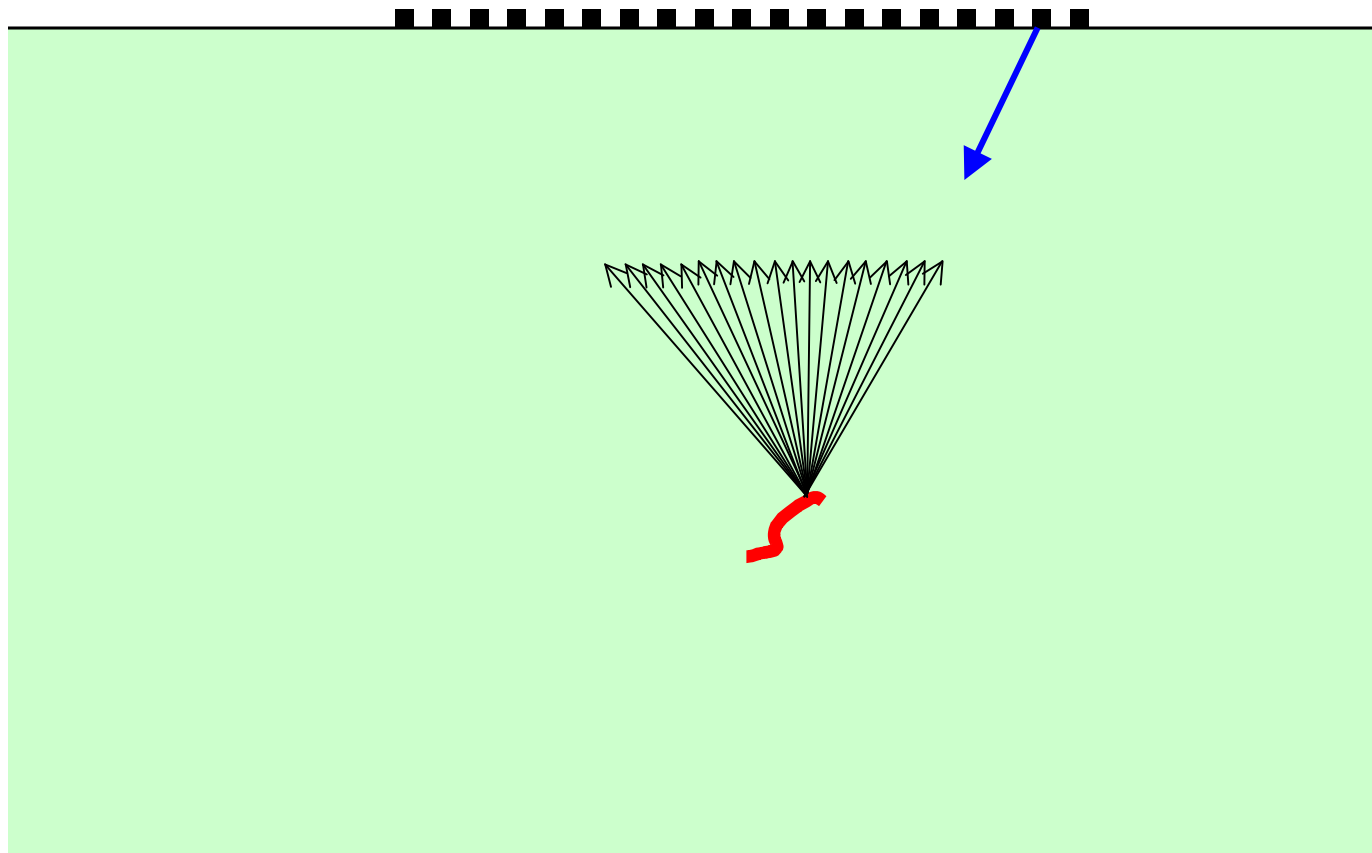
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Array distributed data collection



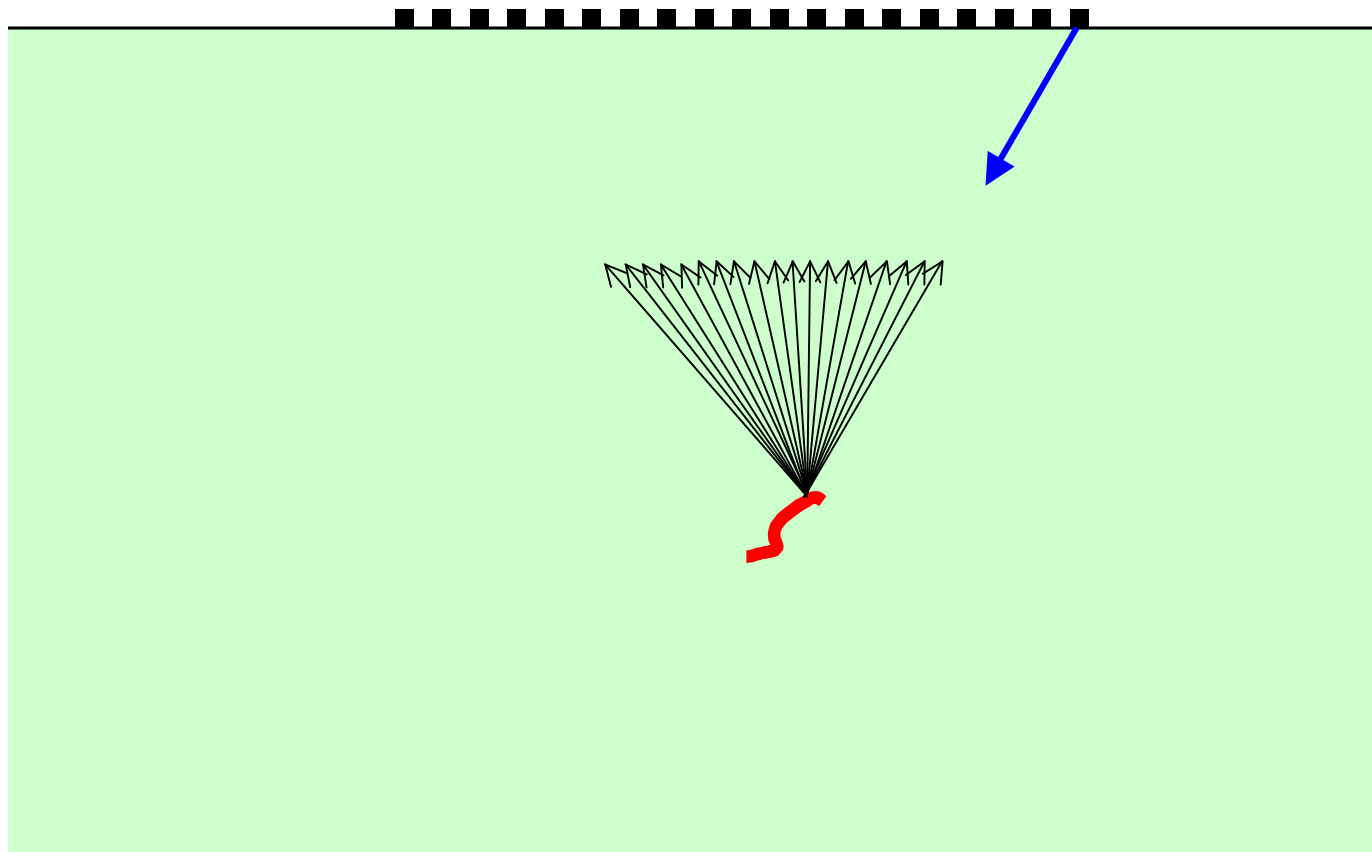
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Array distributed data collection



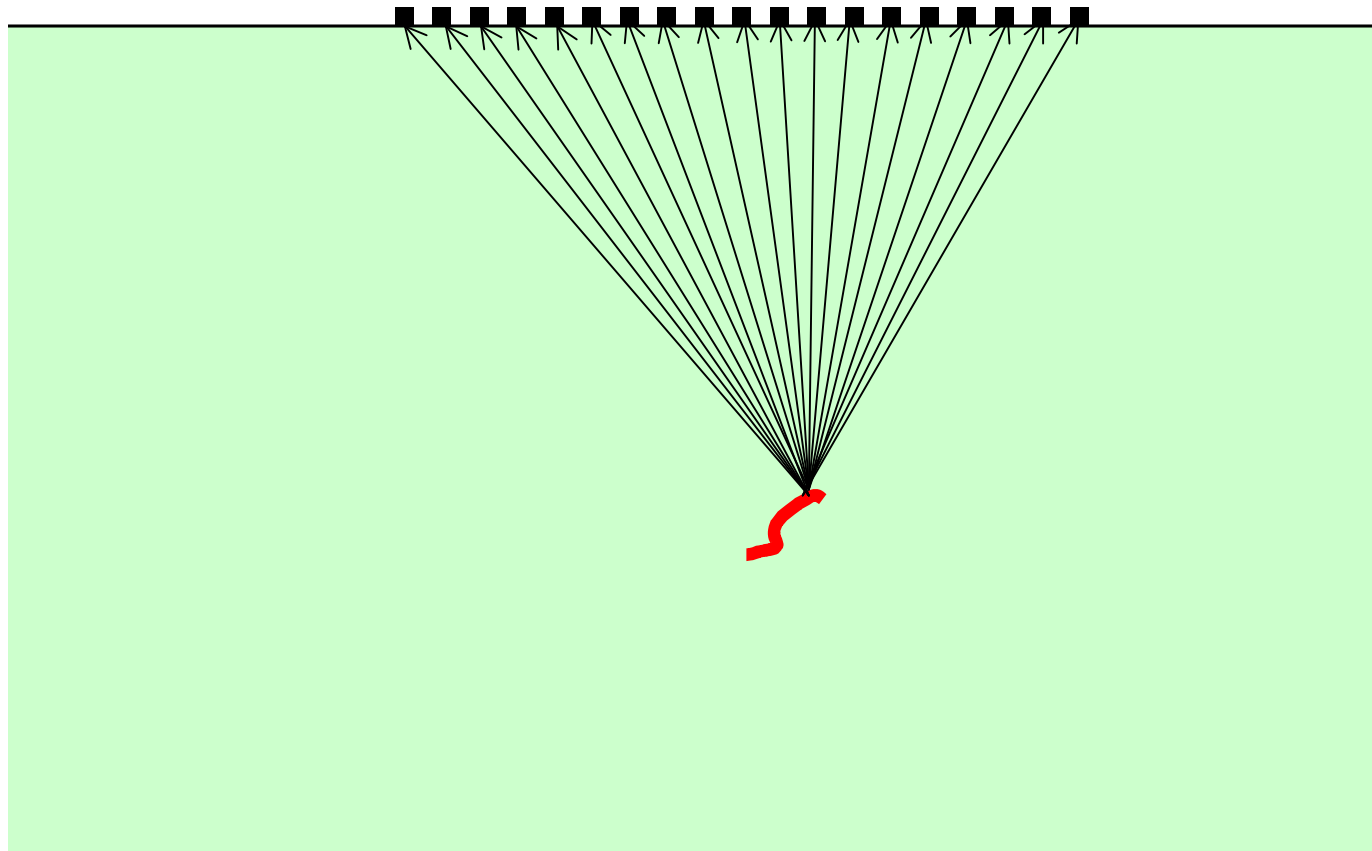
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Array distributed data collection



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Array distributed data collection



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Why do Distributed Data Collection?

- Can now implement operations, currently only possible at acquisition, as post-processing
 - Steer angle
 - Focus
 - Aperture size and shading
- New operations, including:
 - Dynamic Transmit Focusing
 - Compounding
 - Non-linear
- Data storage
 - Separation of acquisition and processing



Key requirements for field use

- Rapid acquisition essential for:
 - Maintaining area coverage rate
 - Real-time response for interactive scanning
 - Maintaining coherence across data when array moving with respect to target



Constraints - Dynamic range

- Reduced excitation aperture
 - Wider transmit beam
- Greatly reduced energy reflected

Beamforming can recover SNR as long as:

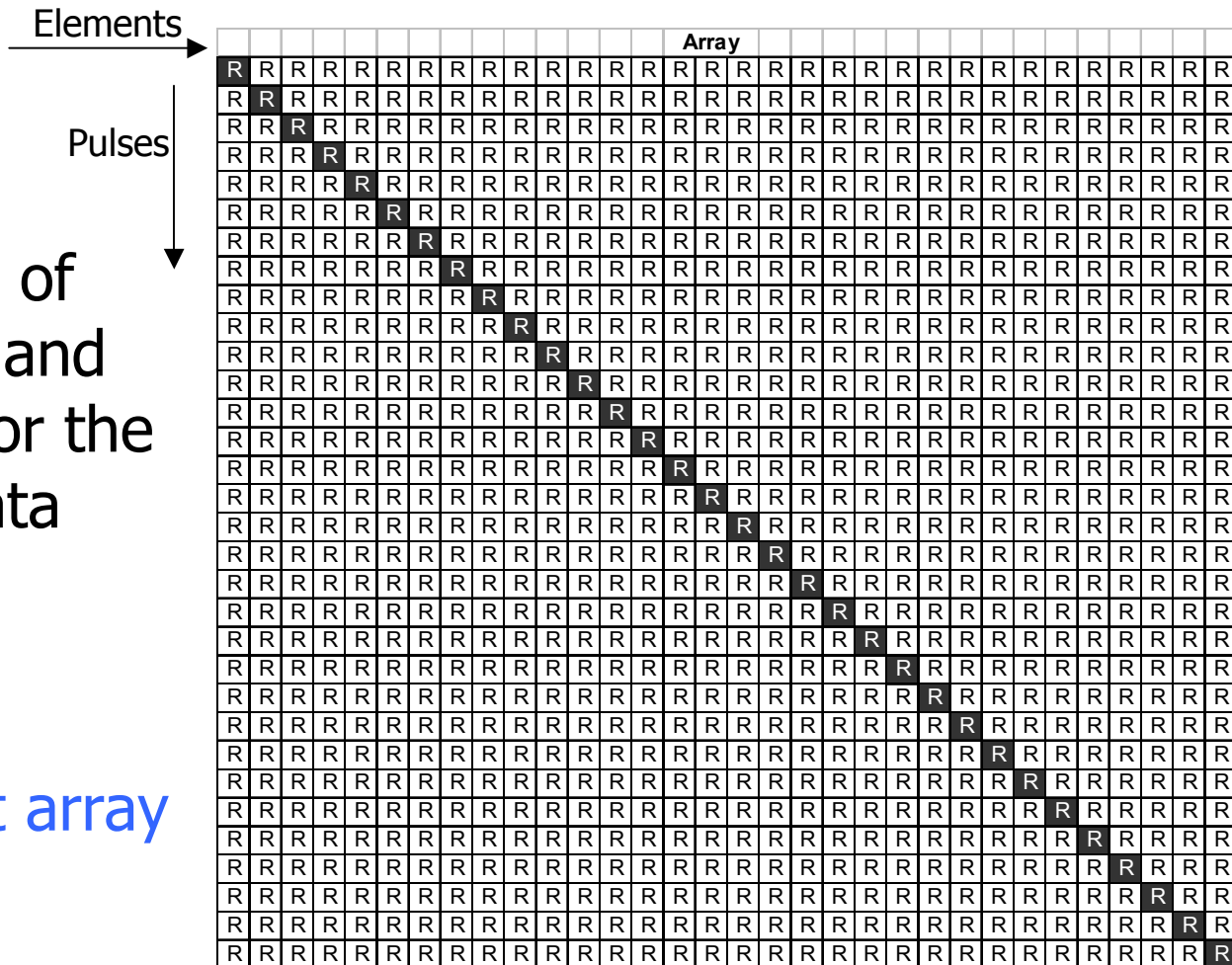
- Adequate amplitude resolution
- No saturation



Constraints - PRF

- Aim is maximum PRF compatible with material properties
- Constrained by velocity, attenuation and geometry of target material (and of any acoustic delay line)
- Zero inertia of electronic scanning allows interlaced beam sequencing for arrays
- However, the broader transmit beam means interlacing offers much less benefit for Distributed Data Collection

Scan sequence - complete



Combinations of Transmit "■" and Receive "R" for the ultimate in data acquisition

N x N pairs
for N element array





FRD frame rate example

- 64 element 5MHz 67mm array
 - 33mm max reconstruction aperture
 - 8 parallel acquisition channels
- 208 pulses per FRD frame
- 96Hz frame rate for 20kHz PRF



Modular implementation

- Array interface
 - Independent control of Tx and Rx positions
 - Programmable beam sequencing
 - Tx beamformer for directional capability
- Digitizer
 - High PRF capability
 - Full waveform acquisition
 - Capable of parallel channel acquisition
- System
 - Position sensing for volume coverage
 - Real-time reconstruction on-the-fly
 - Networking and high density storage



File format

- Requirements
 - Flexible enough for acquisition sequences
 - Must handle volume data sets
 - Open source for application specific algorithms
- Solution
 - Based on extension of AVI file format
 - Matched configuration file holding data on: array, AVI line sequence, aperture and beamformer



Potential Applications

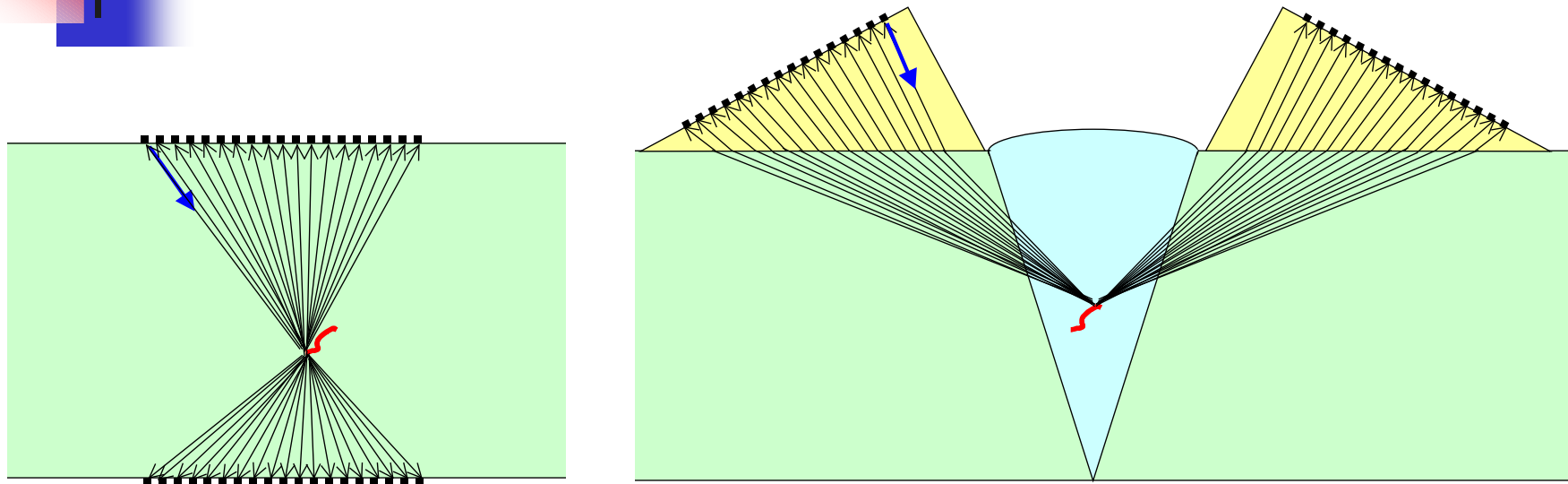
- Optimised imaging
- Complex/multiple array processing
- Target-dependent processing
- Non-linear processing
- Compounding
- Multi-angle skewing for crack detection



Optimised imaging

- Dynamic focus on transmit
 - Continuous rather than zoned
 - No longer needs exact properties at Tx
- Variable steer angle
- Aperture control
 - Variable / dynamic aperture
 - Optimised shading
- Correction of array non-uniformities

Multiple arrays



- Conventional pulse echo images from each
 - Thru-transmission / Pitch-Catch images
 - Customized processing
- ... and all from same single-pass data set



Target-dependent processing

- Progressive focusing dependent on properties of each layer
- Adaptive reduction of unwanted echoes
 - Cancellation of repeat echoes
 - Null-steering
- Adaptive correction for surface roughness and coupling variation



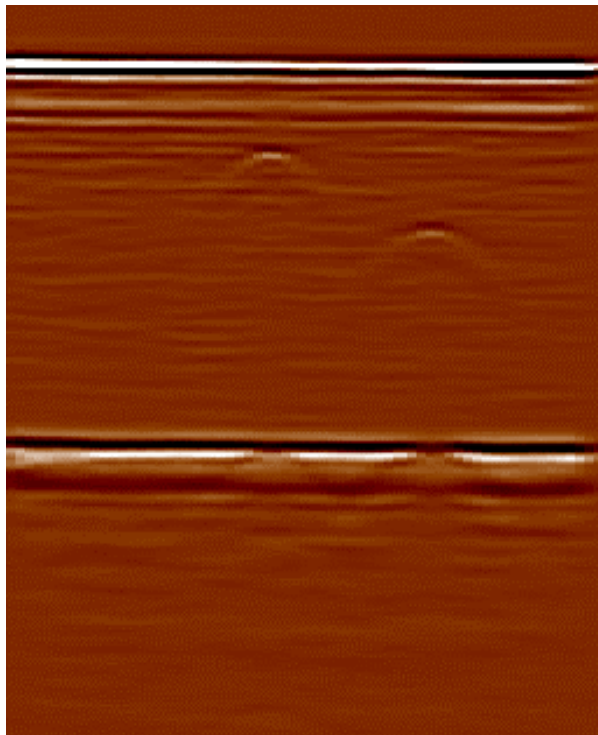
Non-linear processing

- Conventional beamforming is linear sum of contributions across aperture
- Non-linear combination
 - e.g. multiplicative (log \rightarrow sum \rightarrow antilog)
- Features
 - Enhanced resolution
 - Lobe suppression
 - Good for discrete targets but anomalies when echoes from multiple targets interact

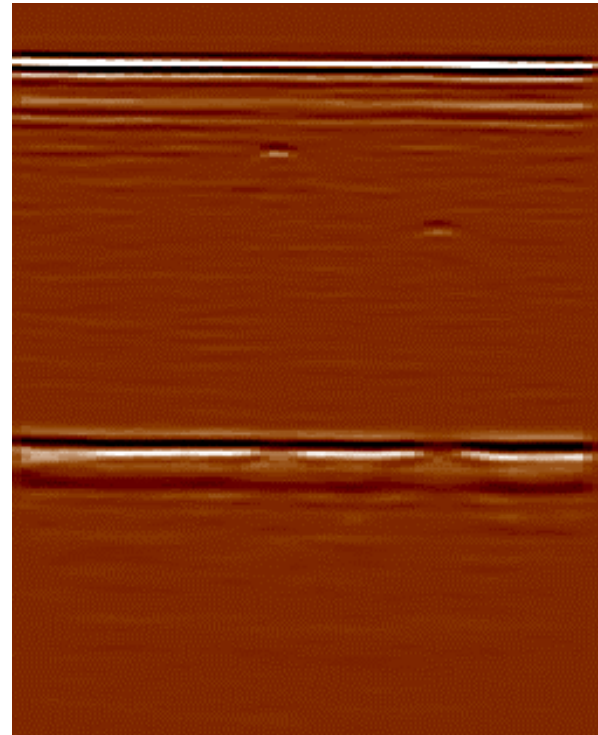
Non-linear processing example#1

Carbon fibre Composite

5MHz RF image of 2 side-drilled holes in CFC block with 6mm aperture



Standard processing



Non-linear processing

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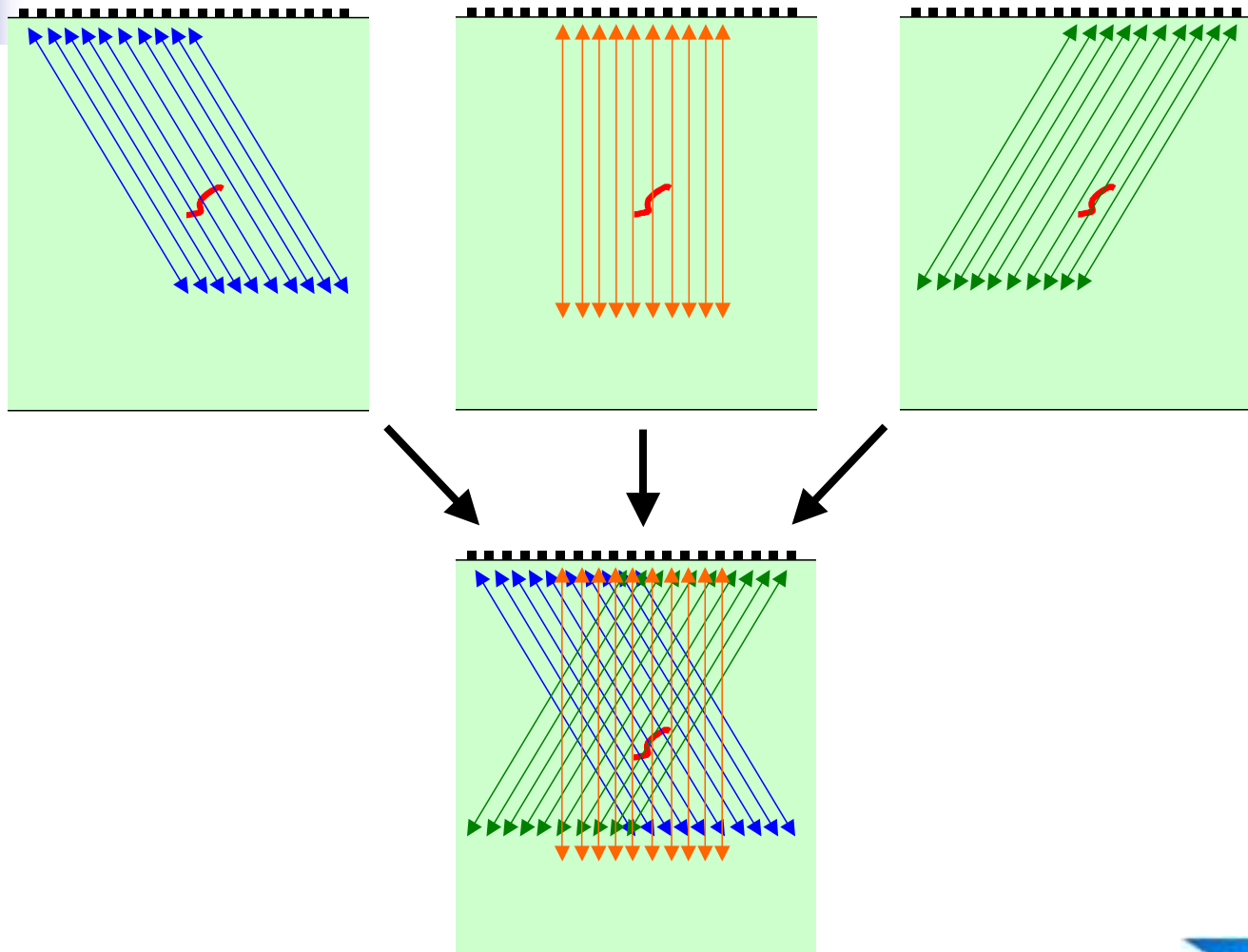




Compounding

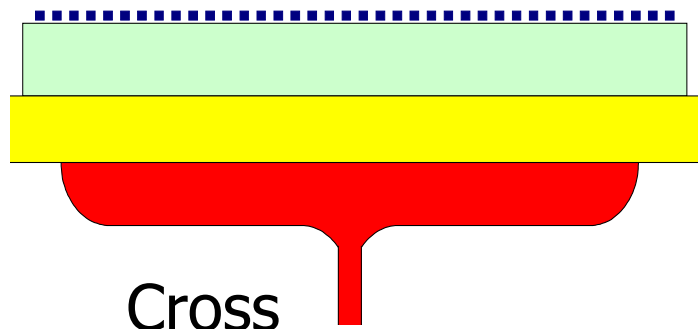
- Fusion of data from different views
- Combination options
 - Incoherent - better view and measurement
 - Coherent - enhanced resolution
- Benefits
 - Improved detection and characterizing of specular reflectors
 - Reduction of speckle artifacts
 - Enhanced resolution and measurement

“Conventional” compounding

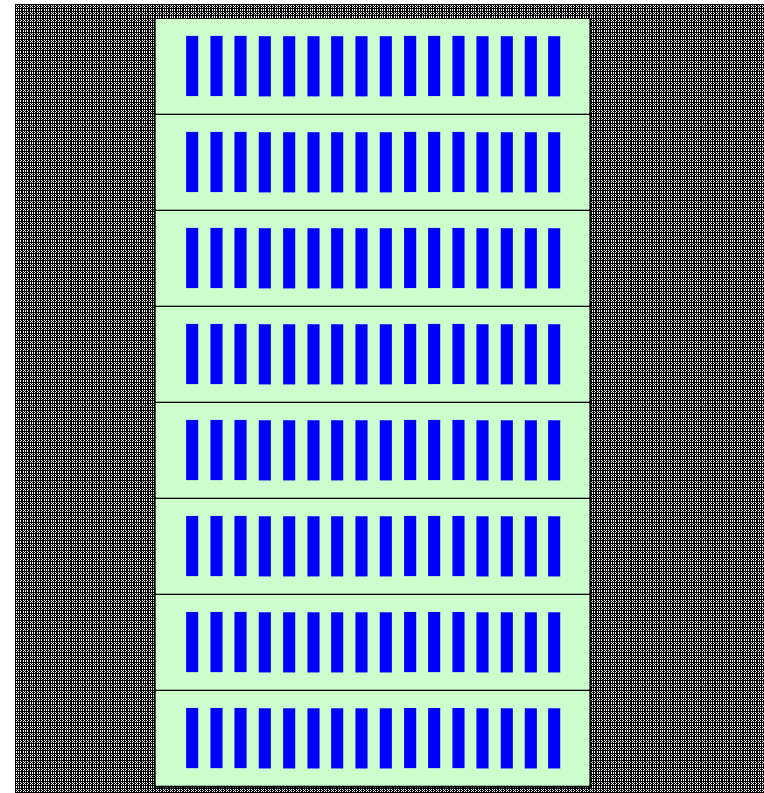


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Compounding for Spar Inspection



Cross
section
view

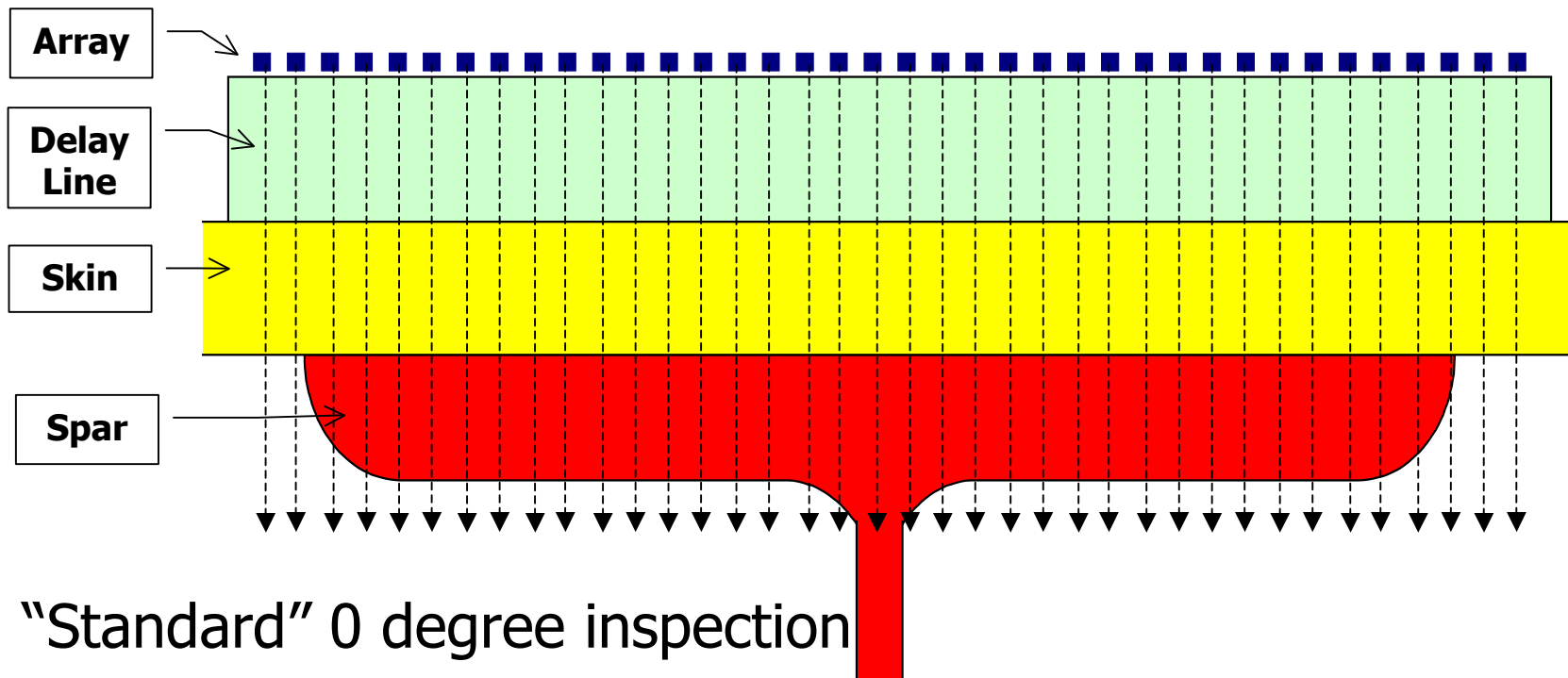


Plan view

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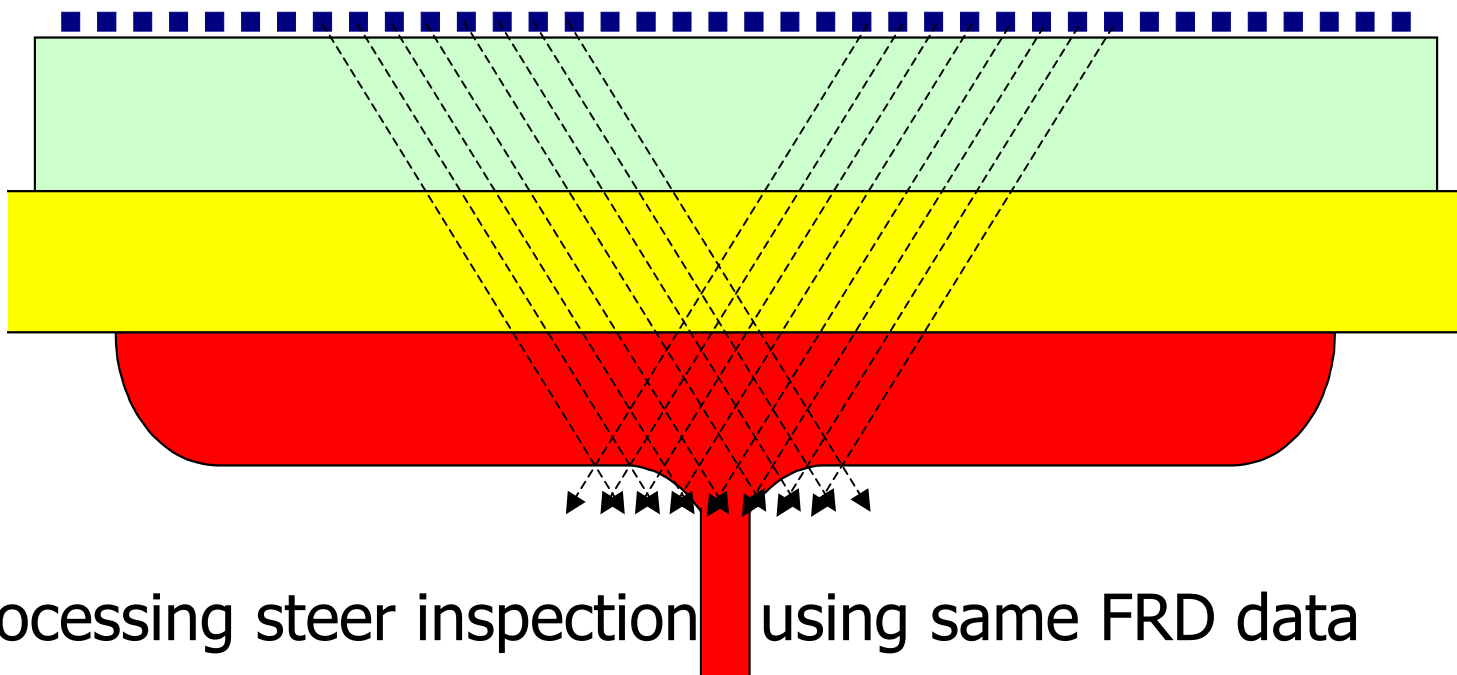
Compounding for Spar Inspection



"Standard" 0 degree inspection

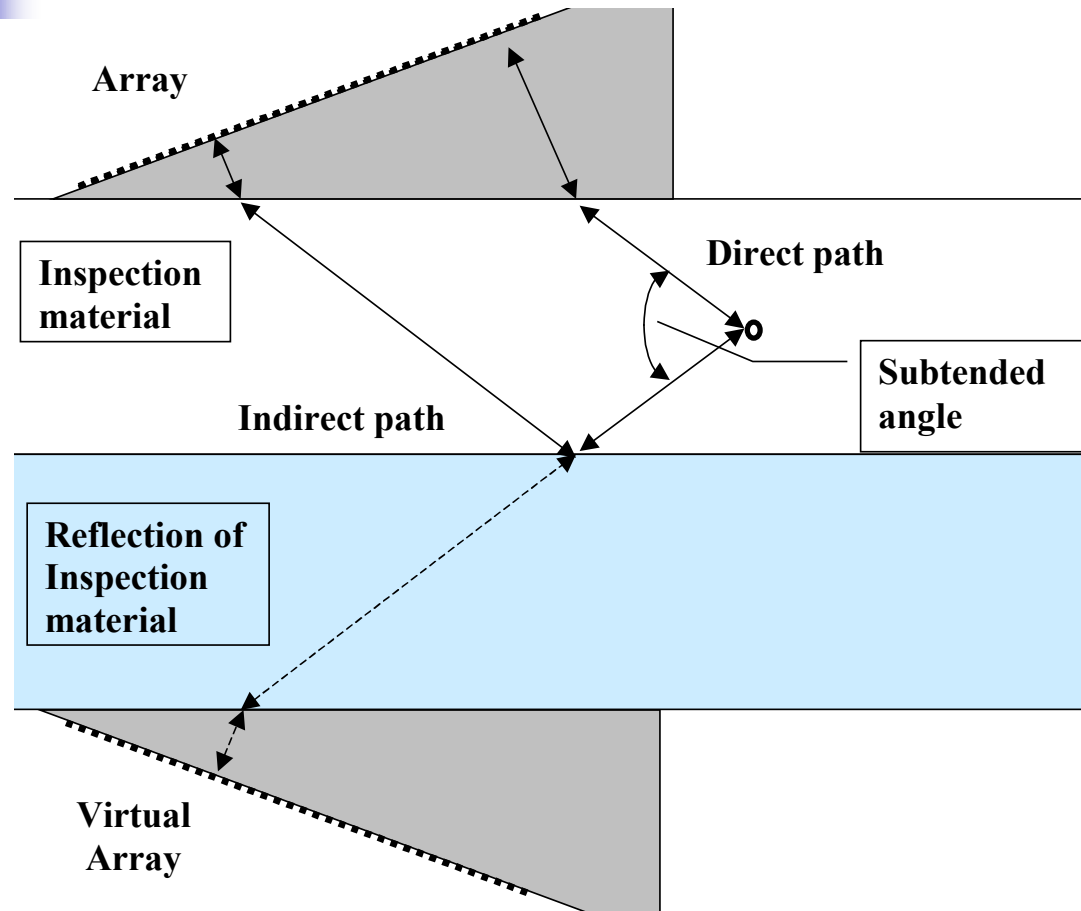
Checks for bond integrity, porosity and damage

Compounding for Spar Inspection



Post-processing steer inspection using same FRD data
Checks for problems in corners

Compounding with virtual array

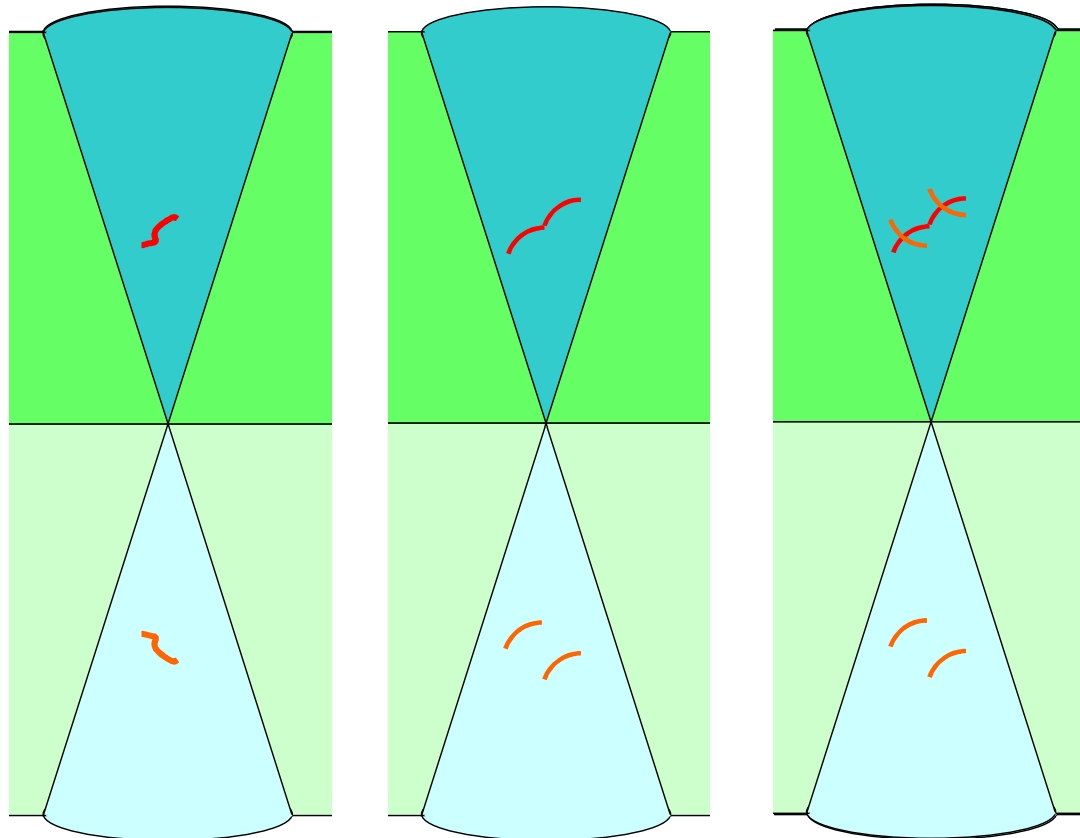


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Incoherent compounding

Direct echoes



Virtual image

Echoes

Processed

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Incoherent compounding Results

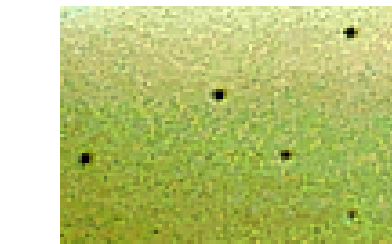
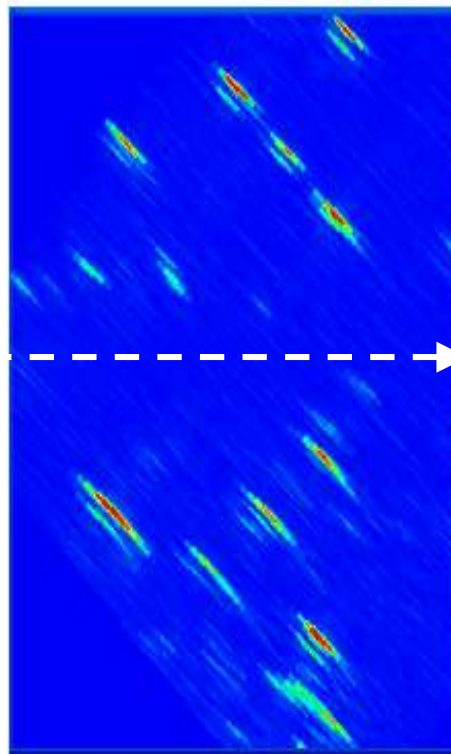


Photo of side-drilled holes in test block

B-Scan of test block

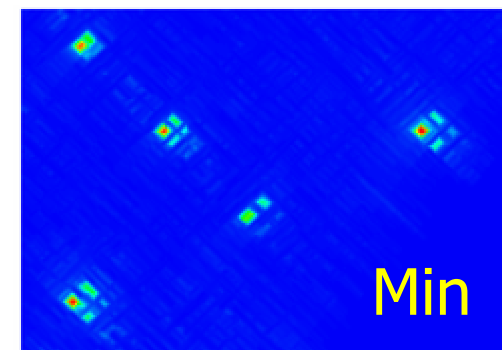
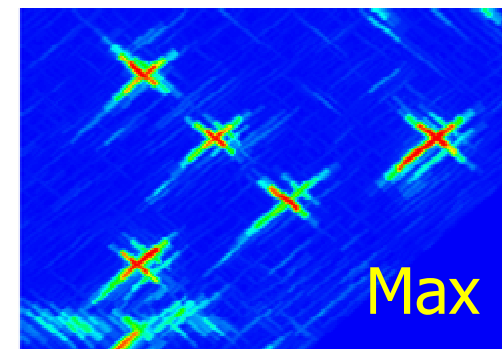


Direct image

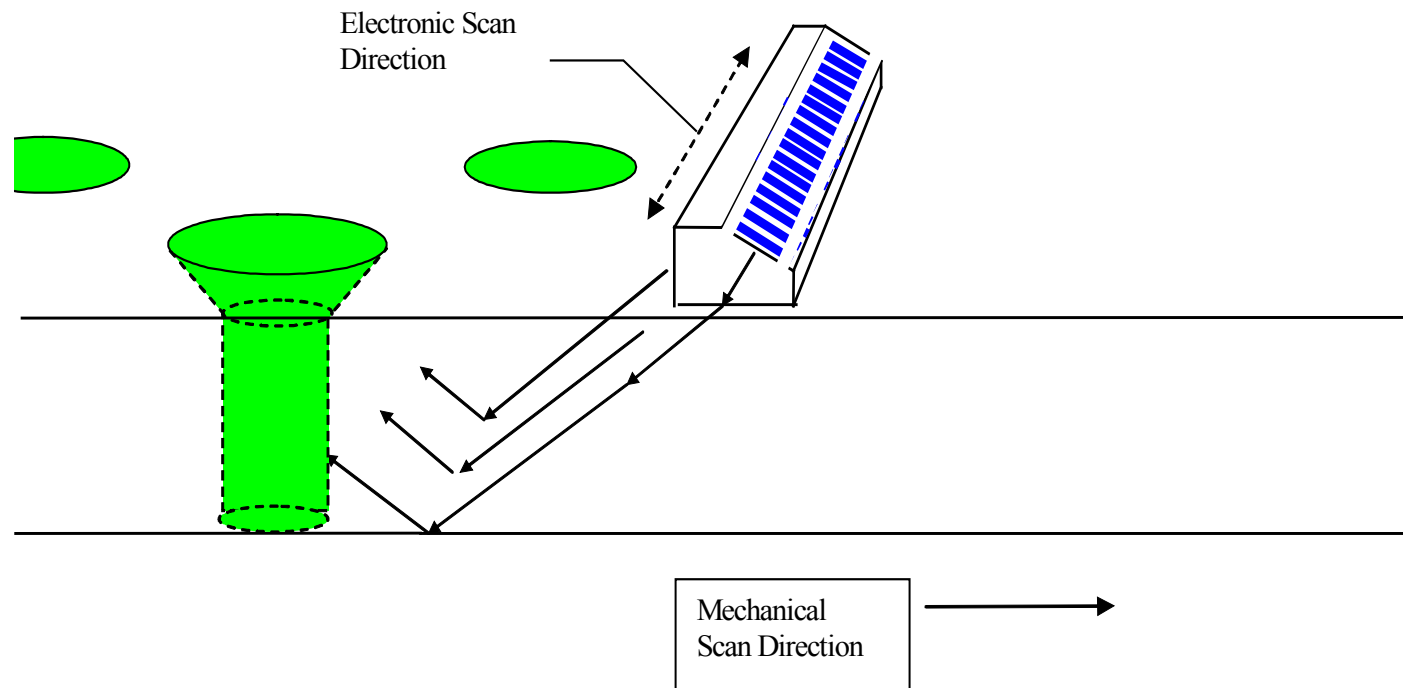
back wall

Reflected (virtual) image

Processed Results

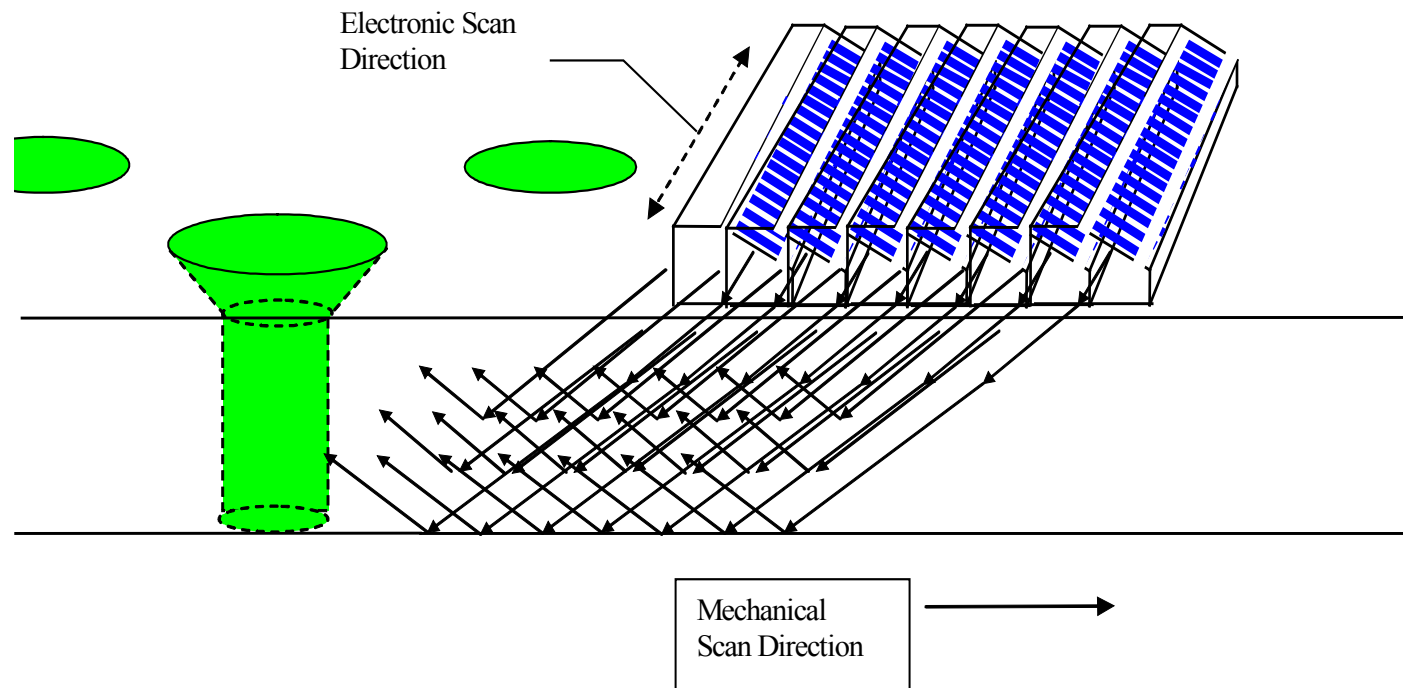


Crack detection Longitudinal Scan



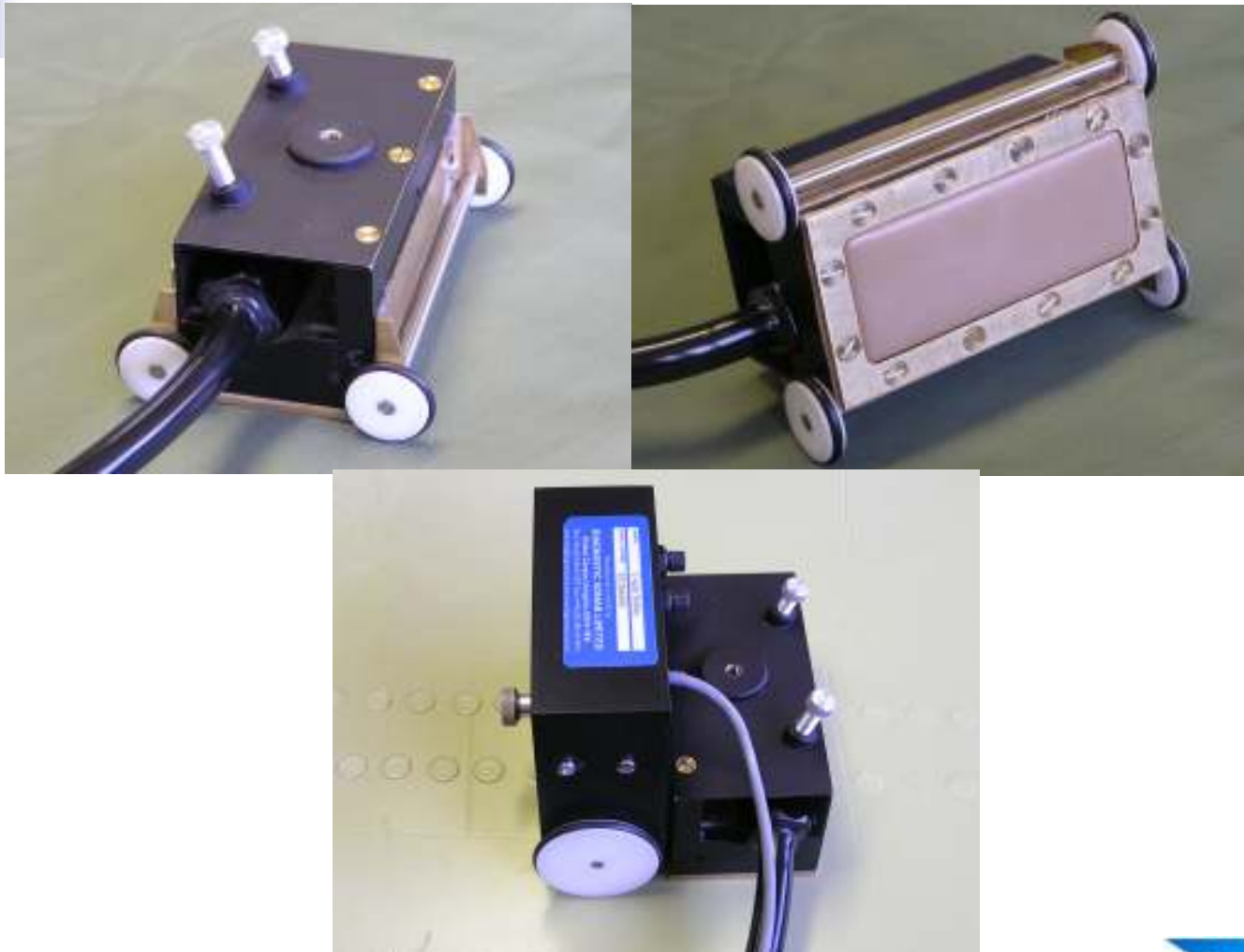
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Crack detection Longitudinal Scan



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Angled beam configurations Longitudinal Scan



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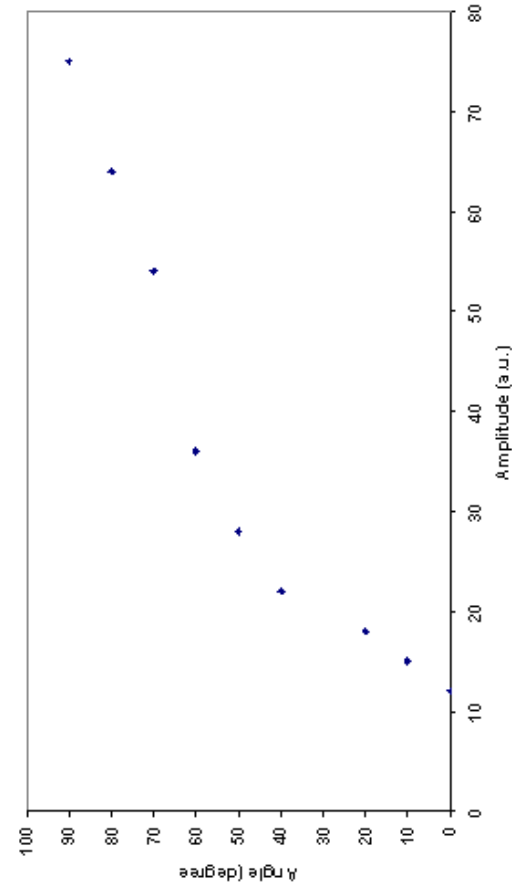
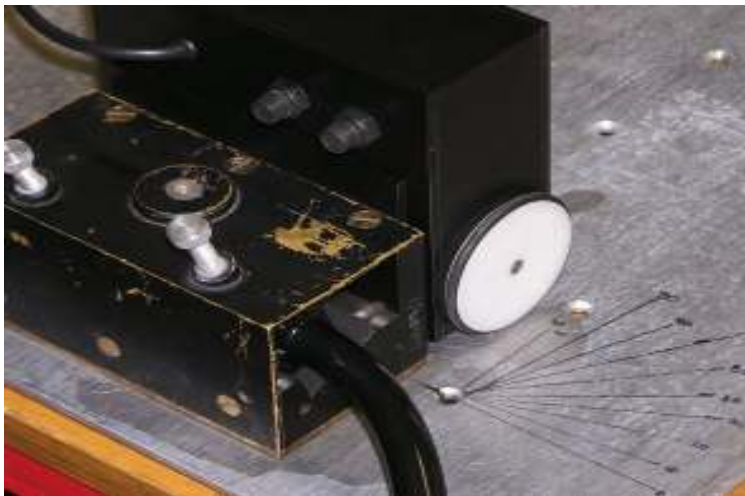
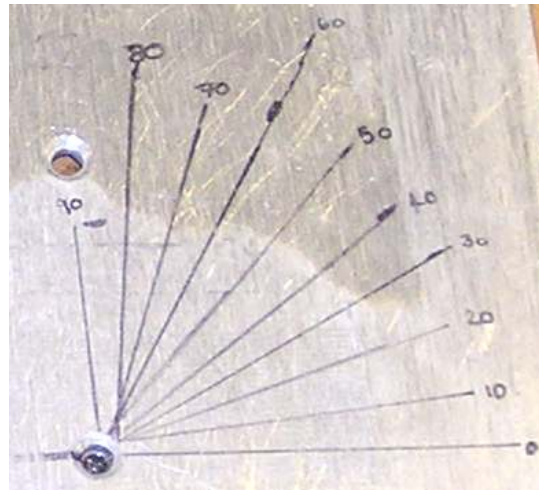
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Response for cracks at any orientation

- Must inspect at multiple angles unless cracks are at a known orientation
- Skewed beams from array reduces number of mechanical scans
- Number of discrete angles depends on:
 - Flaw response vs. angle
 - Acceptable threshold (for false call rate)

Crack response vs. angle



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Advantages of FRD for cracks

- Conventional beam forming
 - Multiple frames scanned at different angles
 - Trade-offs from discrete angles
 - Number of false calls vs. number of angles
 - Number of angles vs. scan speed
- FRD acquisition
 - As many angles as required from single scan so no trade-off with false calls
 - Potential benefits from other processing

Flexibility – Freehand inspection FlawInspecta[®] and ANDSCAN[®]

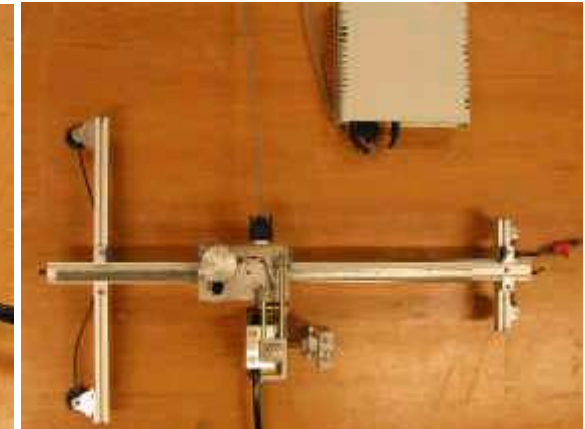
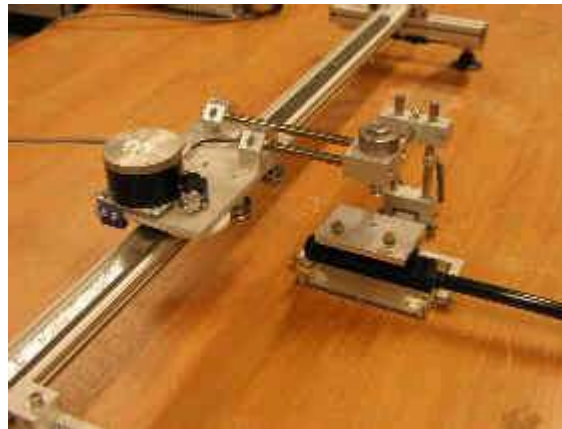
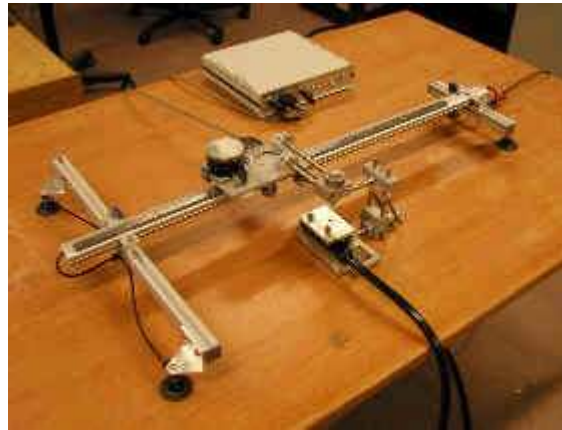


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Flexibility – semi-automated scan FlawInspecta® and KitScanner™

- Made from light-weight extrusions
- Measures probe pointing direction
- Probe scanned in single axis

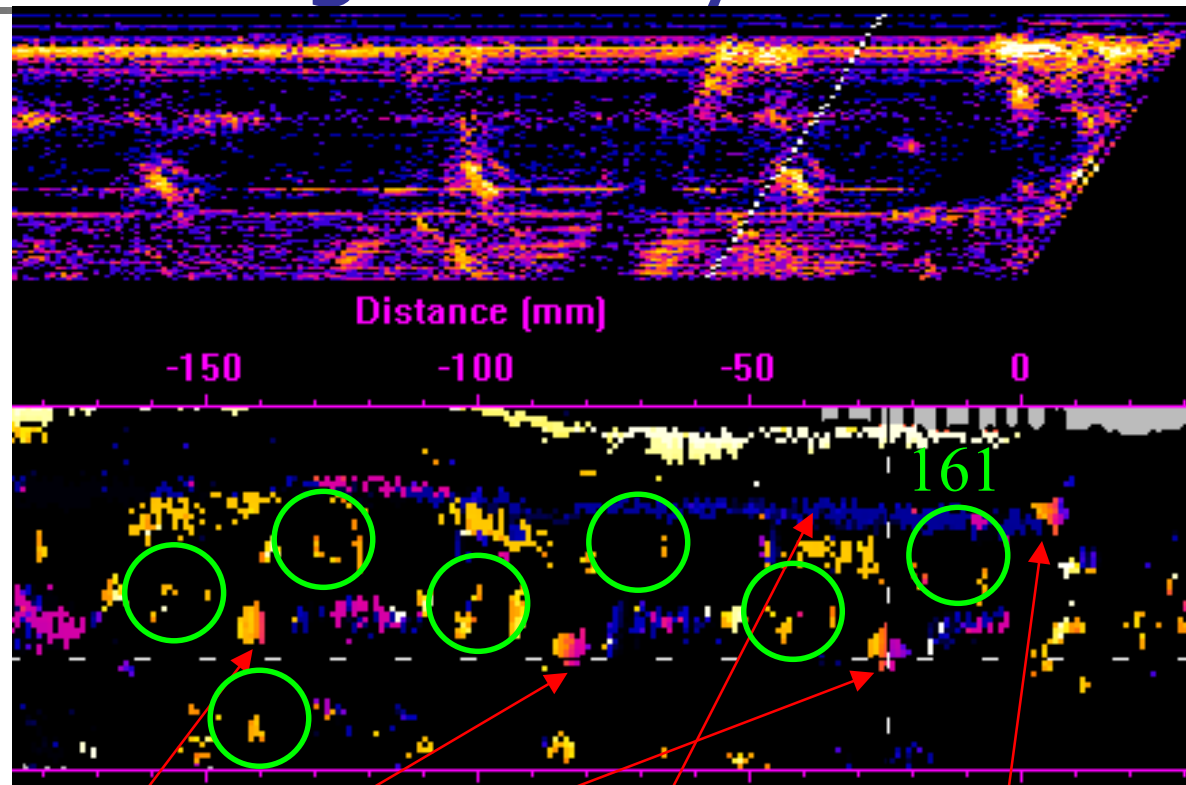
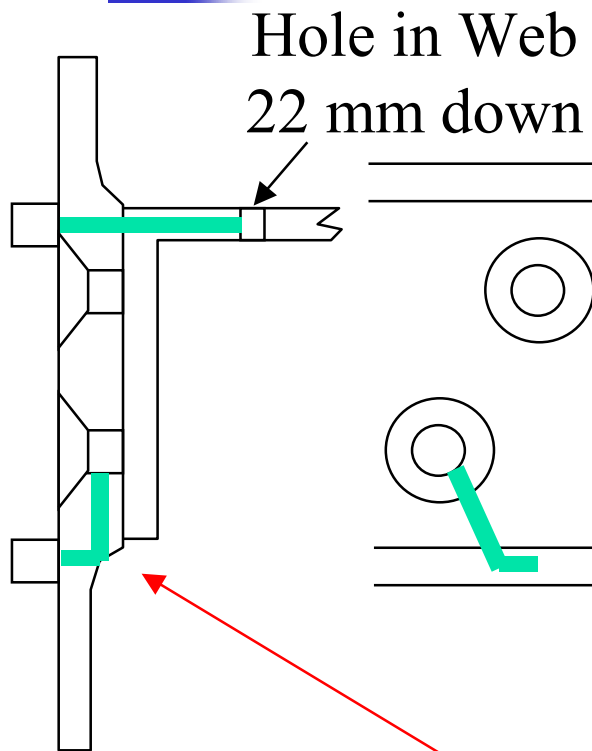


Light-weight Single-axis KitScanner™ + ANDSCAN® software

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Problems with interpretation due to complicated geometry



Complex reflections

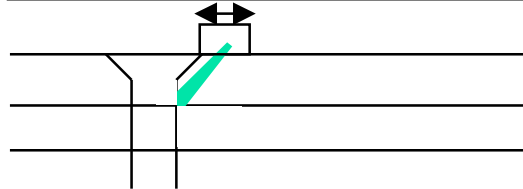
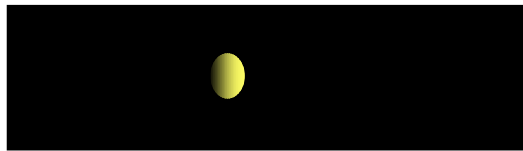
Web

Hole in Web

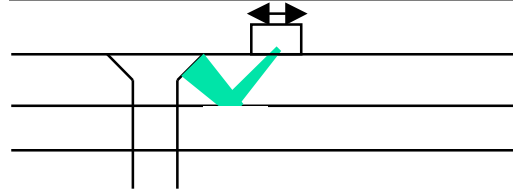
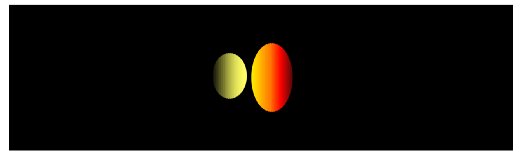
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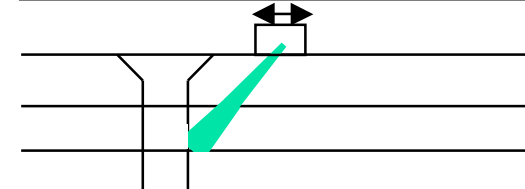
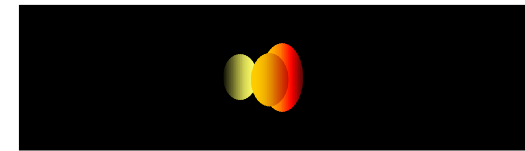
Multi-layer Ultrasonic Crack Detection



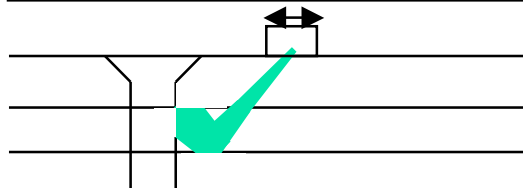
1/2 skip to back of 1st layer



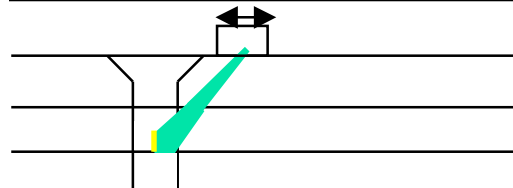
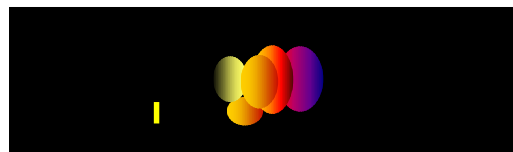
Full skip to Countersink



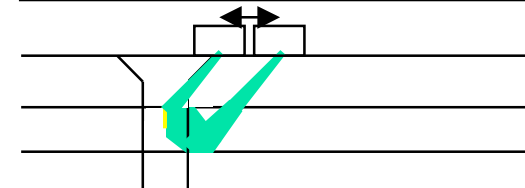
1/2 skip to back of 2nd layer



Full skip to front of 2nd layer



Crack at front of 2nd layer



Crack at back of 2nd layer

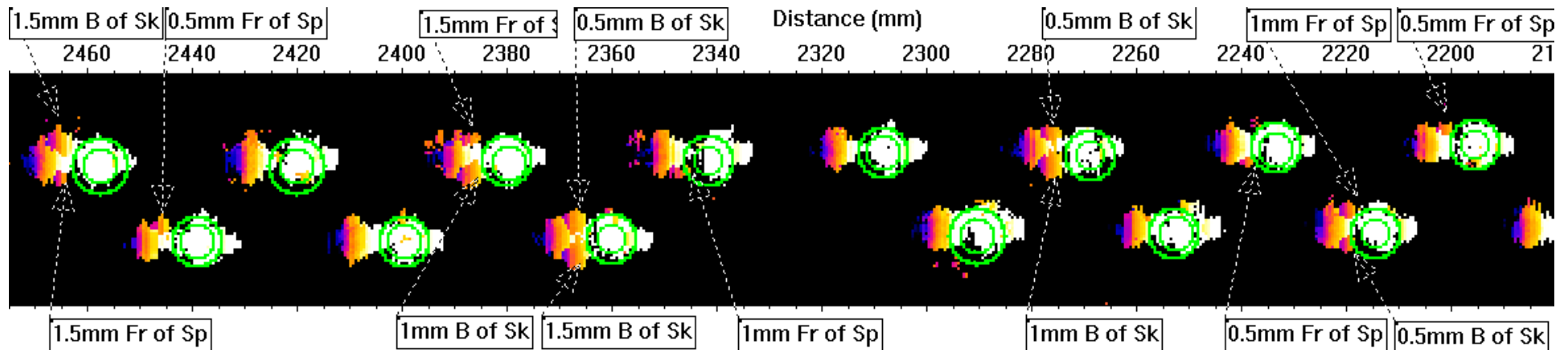
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Results

5MHz 17mm Aperture (ERM)

- All 14 Spark-eroded slots found:
 - 6 off 0.5 mm
 - 4 off 1.0 mm
 - 6 off 1.5 mm

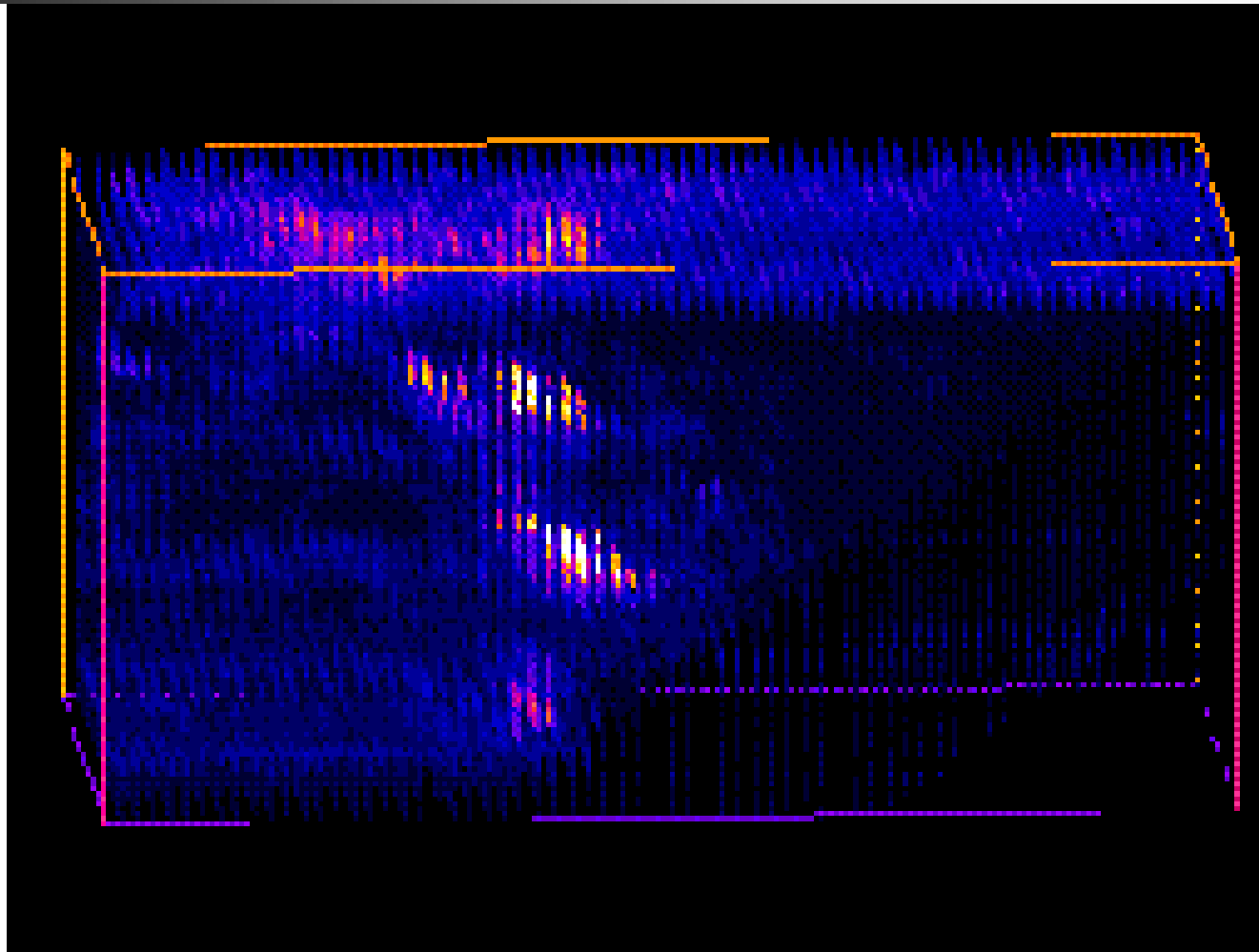


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3D Visualisation



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Summary

- Full Raw Data collection is logical step after FWC
 - Extended post-processing capability
 - Many additional non-imaging processing options
- Separate acquisition and reconstruction
- Rapid acquisition essential for field use
- Implemented in modular hardware
- Open file format for user-generated algorithms
- Many applications - some already “work in progress”
- Commercial implementation



Acknowledgements

- QinetiQ Ltd., NDE Group, Farnborough
 - Robert Smith, Lyn Jones, David Edgar, Jamie Bending
- University of Paisley, Microscale Sensors
 - Irene Pettigrew