How Phased Arrays Work

Why Phased Array?

- High speed electronic scanning without moving parts
- Improved inspection capabilities through software control of beam characteristics
- Inspection with multiple angles with single, electronically controlled probe
- Greater flexibility for inspection of complex geometries
  - Optimized focusing
  - Optimized beam angle

Phased arrays – A Definition

- A mosaic of transducer elements in which the timing of the elements' excitation can be individually controlled to produce certain desired effects, such as steering the beam axis or focusing the beam.

How Phased Arrays Work

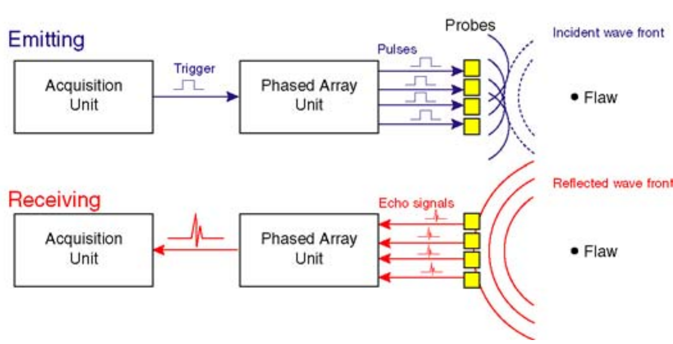
- Ultrasonic phased arrays consist of a series of individual elements, each with its own connector, time delay circuit, and A/D converter.
- Elements are acoustically insulated from each other.
- Elements are pulsed in groups with pre-calculated time delays for each element, i.e., "phasing."
- For economic reasons, pulsers are usually multiplexed. Instrumentation nomenclature such as a Omniscan PA 16/128 refers to an instrument with 16 multiplexed pulsers and a total of 128 ultrasonic channels.

Phased-Array Probe

Basically, a phased-array is a long conventional probe

cut into many elements.

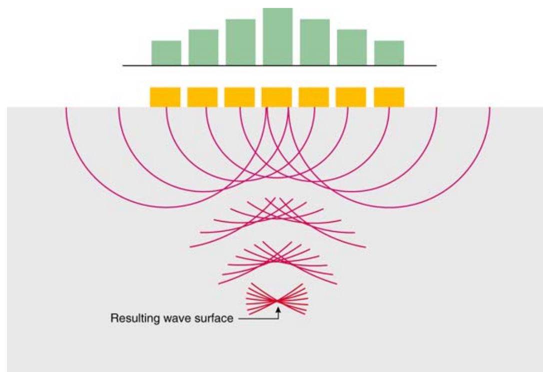
Phased Array Beamforming



- Beamforming requires precise pulsing and time delays. Receiving is the reverse of pulsing.

Illustration - Beam Generation and Focusing

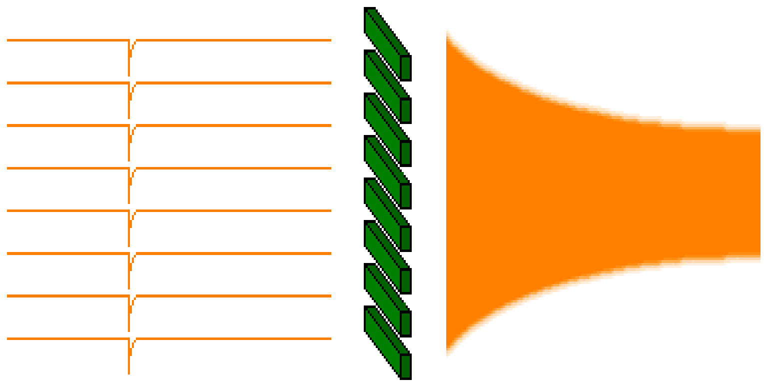
- Elements pulsed with different time delays. (Elements in the array are yellow; applied delay to each element is in green.)
- Time delays generate a focused normal beam in this instance.



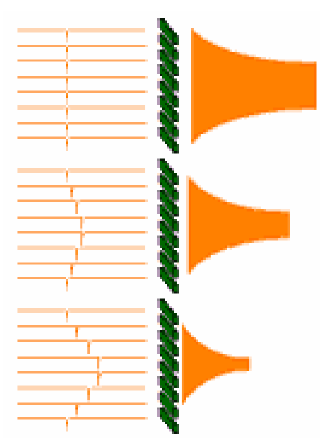
Beam Focusing

- Is the ***capability to converge the acoustic energy*** into a small focal spot
- Symmetrical (e.g., parabolic) focal laws (time delay vs. element position)
- Is limited ***to near-field only***
- Can ***only performed in the steering plane***, when using a 1D-array

Beam Focusing



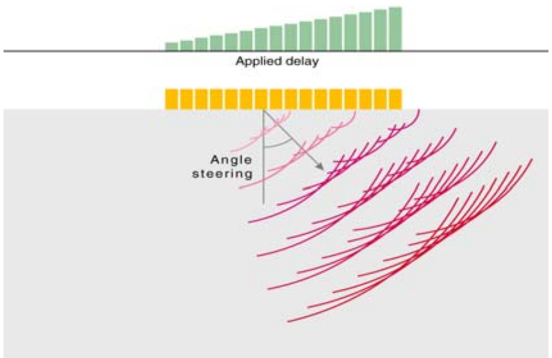
Beam Focusing



- Is the ***capability to converge the acoustic energy*** into a small focal spot
- Allows for ***focusing at several depths***, using a single probe
- Uses symmetrical (e.g. parabolic) focal laws for normal beam

Illustration - Beam Deflection

- For shear waves, the time delay pattern has a "slant" as shown here.
- Focusing can be performed by adding "parabolic" time delays to the slant.



Beam Steering

- Is the ***capability to modify the refracted angle*** of the beam generated by the array probe
- Allows for ***multiple angle inspections***, using a single probe
- Applies asymmetrical (e.g., linear) focal laws
- Can ***only be performed in steering plane,*** when using 1D-arrays
- Can generate both L (compression) and SV (shear vertical) waves, using a single probe

Beam Steering

- Steering capability is related to the width of an individual element of the array
- Maximum steering angle (at –6 dB), given by $\sin\theta_{st} = 0.5 \cdot \frac{\lambda}{e}$
- Steering range can be modified using an angled wedge

Beam Steering

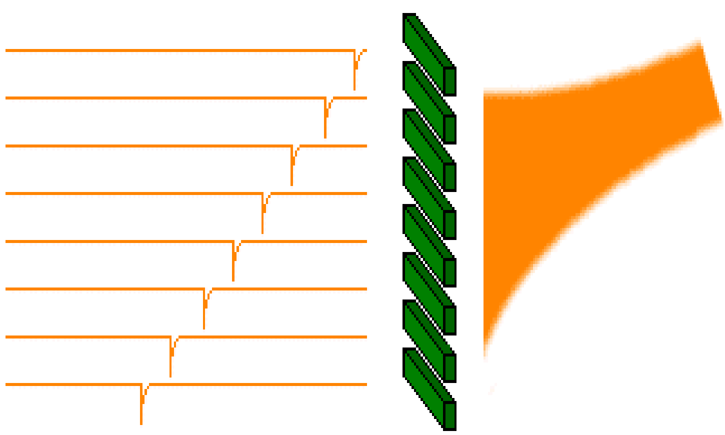
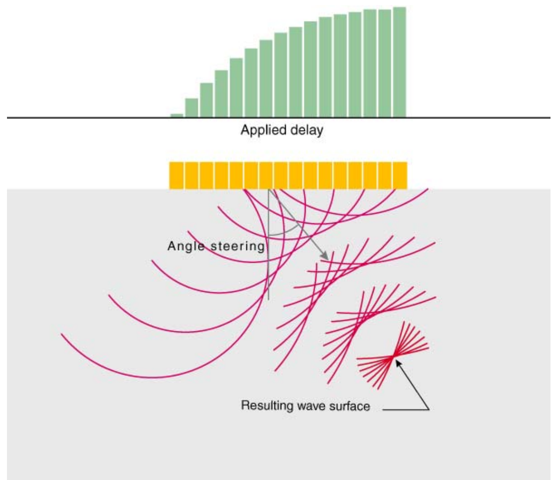


Illustration - Beam Deflection and Focusing

- Beams generated in very early stage, mid-stage, late stage and at focus.



Beam Steering

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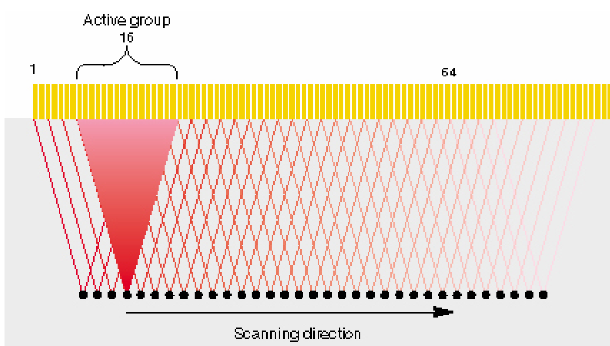
- Allows for ***multiple angle inspections***, using a single probe
- Applies asymmetrical (e.g. linear) focal laws

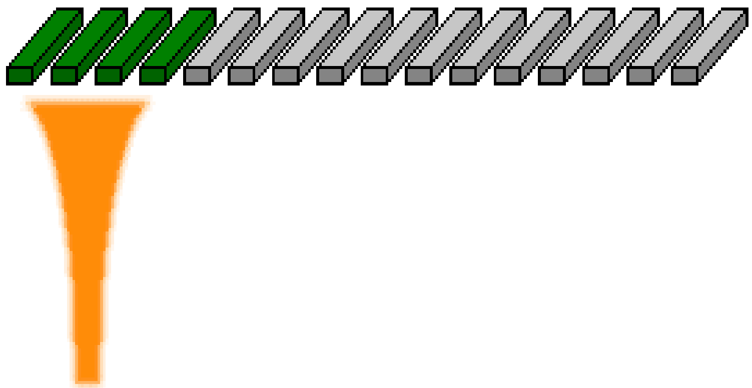
Electronic (Linear) Scanning

- Is the ***ability to move the acoustic beam*** along the axis of the array without any mechanical movement.
- The beam movement is performed by time multiplexing of the active elements
- Scanning extent is limited by:
  - number of elements in array
  - number of "channels" in acquisition system

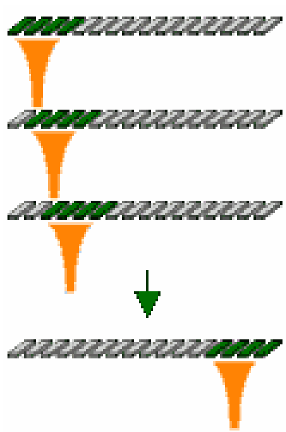
Electronic (Linear) Scanning



Electronic (Linear) Scanning



Electronic (Linear) Scanning



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Making Phased Arrays Functional

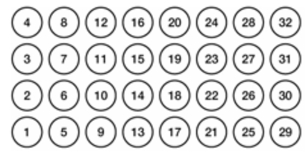
How Phased Arrays Work

- The elements are purchased as an “array” with known geometry.
- These arrays are manufactured using several “designs,” and each array is specifically built for the application, as with conventional ultrasonic transducers.
- Typical array designs are:
  - Linear
  - Matrix
  - Circular
  - Sectorial-annular

Common Probe Geometry

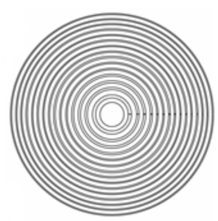
Linear

1D linear array

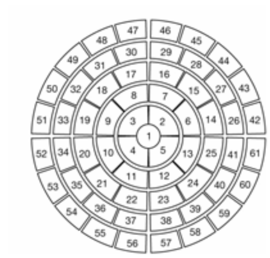


2D matrix

Circular



1D annular array



2D sectorial annular

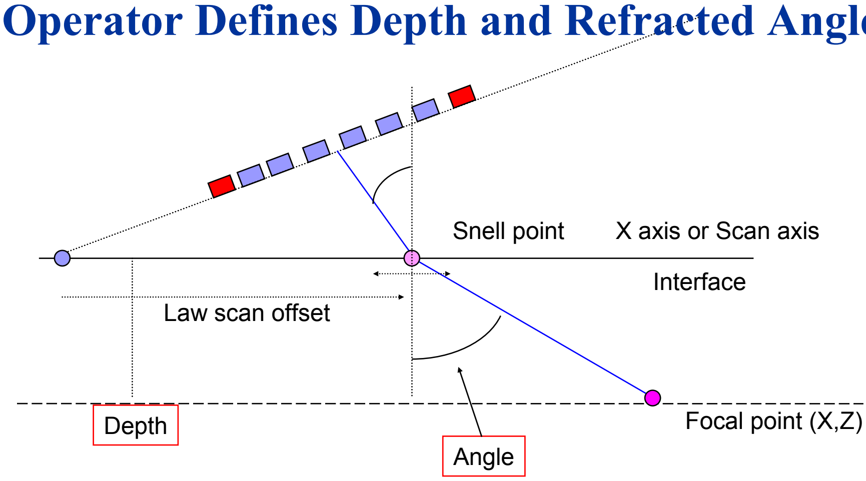
How Phased Arrays Work

- Linear arrays are the most common type, and can perform scanning in one dimension only. Linear arrays typically minimize the number of elements required, and hence, cost.
- Matrix arrays can scan in two dimensions, and offer considerably more flexibility, albeit at a price.
- Circular and sectorial-annular arrays are specific for normal beam inspections, e.g., billets, forgings.

How Phased Arrays Work

- The operator inputs the focal depth(s), inspection angle(s) and/or couplant, type of scan, plus how many and which elements are to be fired.
- The operator must also input details on the array and wedge. (This information is engraved on the side of the array and wedge.)
- The phased array calculator calculates what time delays to apply to each element.
- For standard scans (e.g., electronic or sectorial), the set-up is essentially straightforward.

Operator Defines Depth and Refracted Angle



The calculator searches the Snell point. It considers the center of the active aperture (from elements 2 to 7 in this example).
Then, the X, Z point of the focal point is determined.
The wedge delay is calculated and the focal law is offset accordingly.

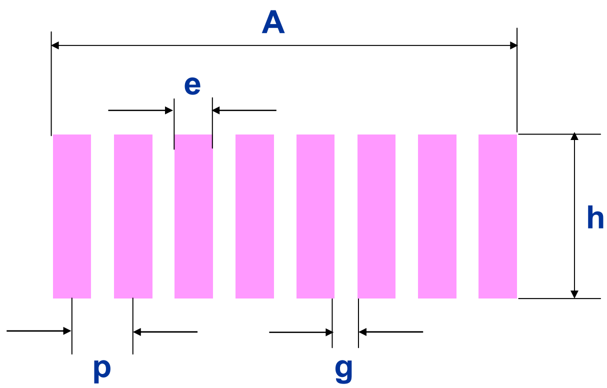
UT Phased Arrays

Principles and Capabilities

UT Phased Arrays
Principles and Capabilities

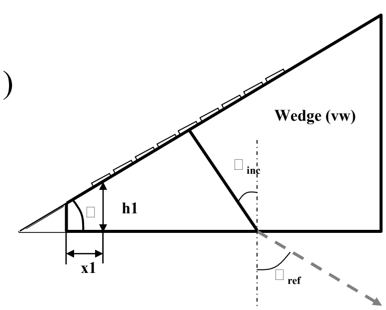
- OVERVIEW
  - Design parameters of phased-array probes
  - Beam focusing
  - Beam steering
  - Electronic (linear) scanning
  - Array lobes

Design Parameters of Phased-Array Probes



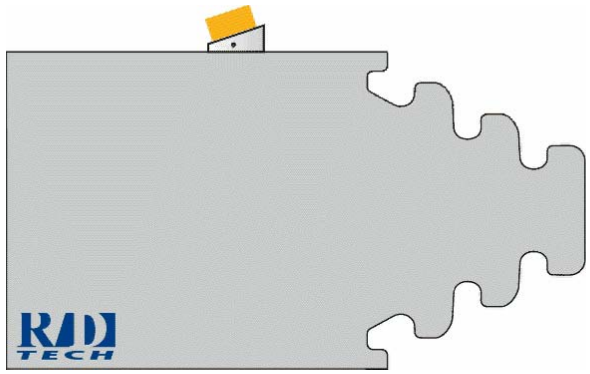
Design parameters of Phased-Array probes

- WEDGE PARAMETERS
  - Velocity in wedge (vw)
  - Wedge angle (ω)
  - Height of first element (h1)
  - Offset first element (x1)

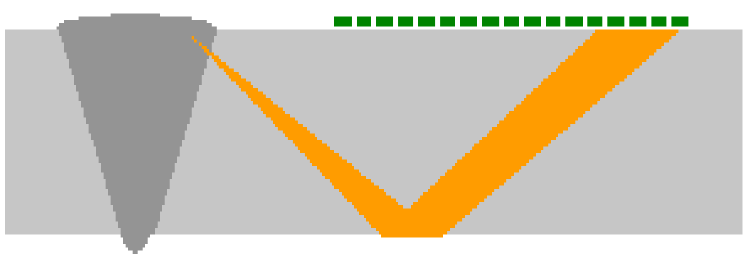


Sectorial Scanning Animation

This illustration shows a turbine blade root being inspected using S-scans (sectorial scanning).



Combined Beam Processing



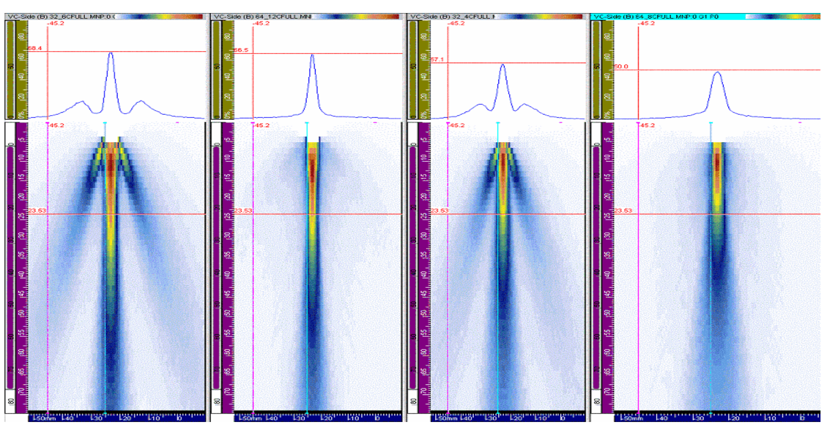
Linear combined with steering and focusing

Combined Beam Processing

- The phased-array technique allows for almost any combination of processing capabilities:
  - focusing + steering
  - linear scanning + steering

Design Issues

Equivalent Apertures, Grating Lobes



6 Elements (Pitch 1mm) 12 Elements (Pitch 0.4mm) 4 Elements (Pitch 1mm) 8 Elements (Pitch 0.4mm)