ARRAY TRANSDUCERS
For Industrial Ultrasonic Testing

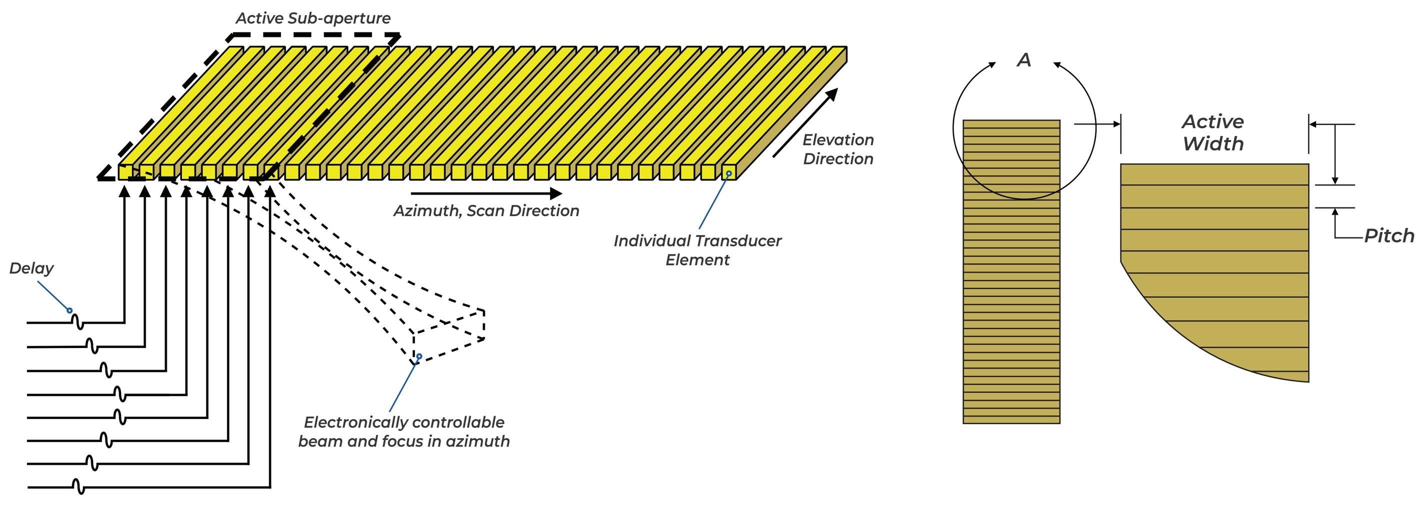
Introduction to Array Transducers

Array transducers for Industrial Ultrasonic Testing (UT) are commercially available in a wide range of frequencies, # of elements, sizes, shapes, and configurations. ***Since the transducer can enable and/or optimize any UT exam****, it is one of the most important components in a test system. The transducer or "probe" works in concert with a PAUT instrument, software, operator, calibration block & test procedure to inspect any industrial component. Arrays, whether linear, circular, matrix (2D), or other, are often used to increase inspection productivity while also improving POD (Probability of Detection) for anomalies in the test part. PAUT also enables 2D or 3D imaging of the test part thereby allowing users to make better-informed decisions on the component's fitness-for-service. Array transducers and their delay-lines or wedges are available in many "off-the-shelf" models and can also be customized and designed/fabricated to further enable a unique inspection.*

Linear Array

The linear array is the most common form factor used in industrial phased array testing, including TFM/FMC applications. This configuration allows one to achieve electronic control of one plane of the transducer as defined by the Azimuth and Depth axes. This plane could be further described/defined as the "active plane" of the transducer. On this plane, electronic control via conventional phased array and/or TFM/FMC processes can alter the steering angle, depth of focus, and position of the sound beam.

When considering the selection of an array geometry, it is important to give consideration to the parameters that define both the active plane (pitch, # elements) and the passive plane (elevation width, focusing lens) to achieve optimum imaging results.



This shows a linear array geometry showing electronic control over a sub-aperture of the array which allows electronic control of the beam. Elevation performance is fixed by the frequency, aperture size, and the potential addition of a focusing lens.

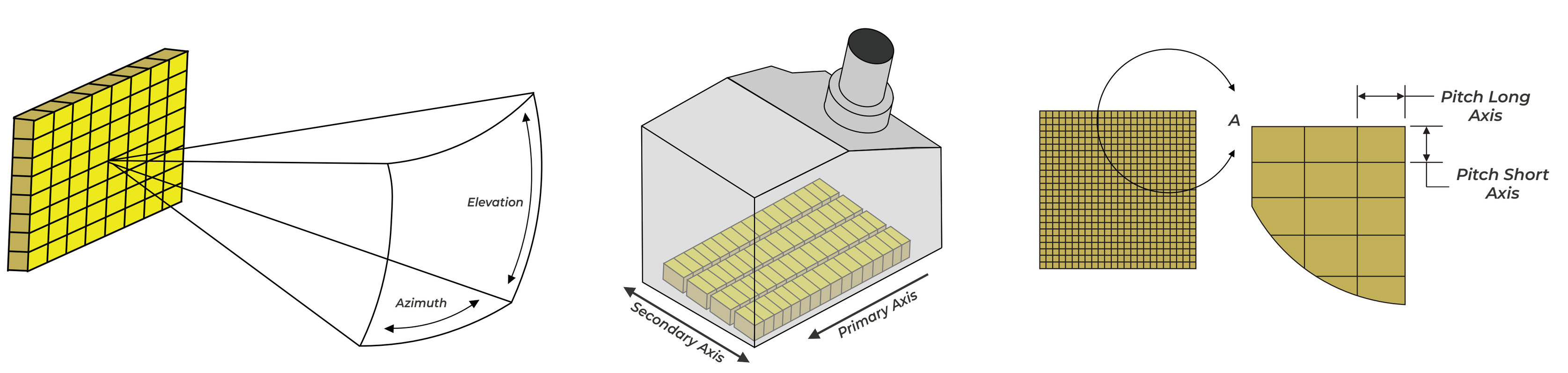
The ***active aperture*** *is one of the critical features used to define a phased-array transducer. It is the total active transducer length, and can be calculated by the following formula:*

Active aperture = N x P
N = number of elements in the transducer
P = element pitch

Matrix Array

In a traditional sense, the 2D array is one where the element pattern is placed in a rectilinear grid with an equal pitch in azimuth and elevation directions. This allows equal steering and focusing performance in both azimuth and elevation planes but does so with a maximum amount of system channels.

However, often the requirements for steering and/or focusing in the elevation direction are not as stringent as what is needed in the azimuth direction. This allows for alternative array patterns such as 1.25D, 1.5D, and 1.75D which give some amount of control over the elevation plane but with relaxed requirements on channel/element counts.

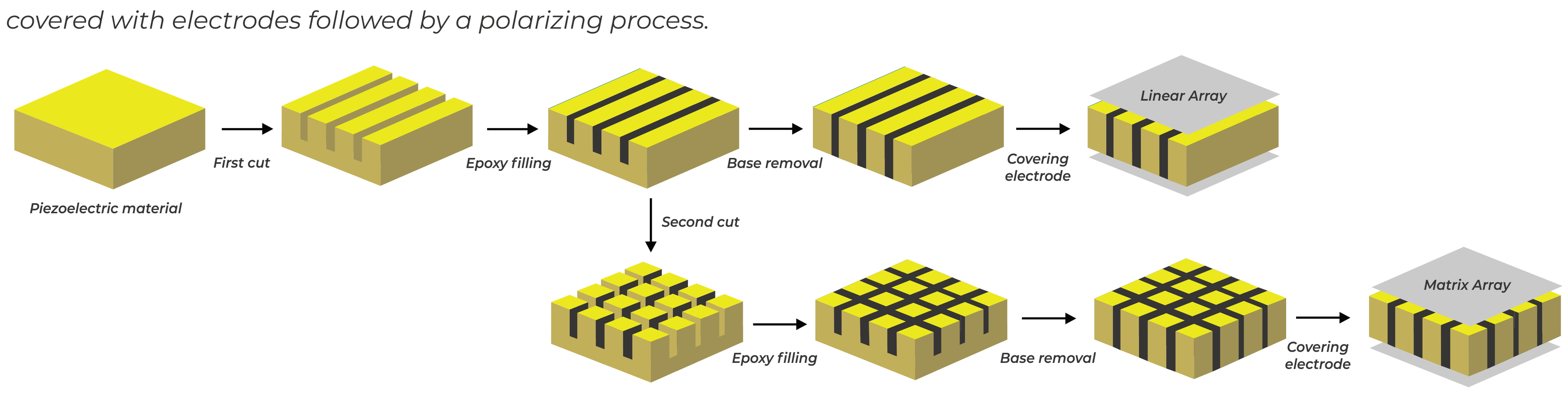


Active aperture = (N x P Primary axis) x (N x P Secondary axis)
N = number of elements in the transducer
P = element pitch

Fabrication Process

Piezocomposite materials are one of the options for the "active element" in an ultrasonic transducer. Because of the unique construction and properties that are achieved with piezocomposites, they are often used as the active elements for industrial transducer arrays. Piezocomposites are advantageous in that the properties are readily tailored, have high electromechanical coupling efficiency, and lower acoustic impedance. This allows improved impedance matching to water or plastic and can be segmented into arrays by electrode patterning.

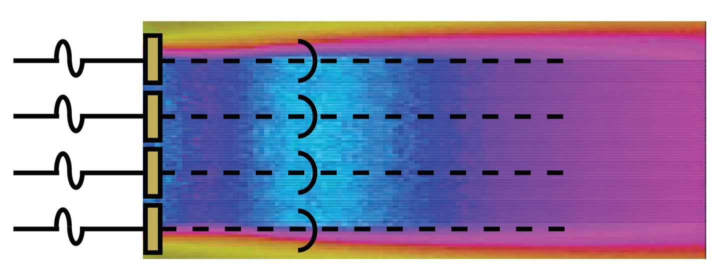
The fabrication of an array consists of a series of parallel cuts on a piece of piezoelectric material with a precision mechanical dicing saw. The gaps are then filled with epoxy and the base ceramic is removed. Afterwards, both sides are covered with electrodes followed by a polarizing process.



Principles of Phased-Array Transducers

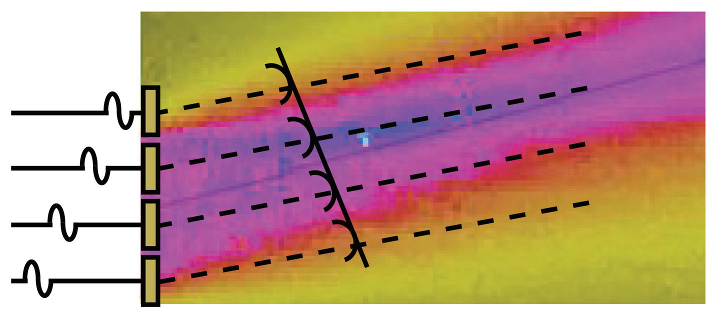
Phased-array transducers are composed of multiple piezoelectric elements that can be pulsed/ fired individually at different times. This allows the ultrasonic beam to be focused or steered in a specific direction. By precisely controlling the delays between the elements, beams of various angles, focal distances, and focal spot sizes can be produced.

Linear Scanning



The beam is electronically translated by alternately firing a given number of elements of a phased array transducer. Only one angle is introduced but is introduced multiple times throughout the length on the array.

Beam Steering



By alternating the timing sequence of the pulses, the direction of the transmitted beam can be varied to any desired scan angle. This allows for multiple angle inspections, using a single transducer. The ***maximum steering angle*** *(at -6 dB) in a given case is derived from the equation:*

$$\sin \theta_{st} = 0.514 \frac{\lambda}{e}$$

θ_{st} = sine of maximum steering angle
λ = wavelength in test material
e = element width

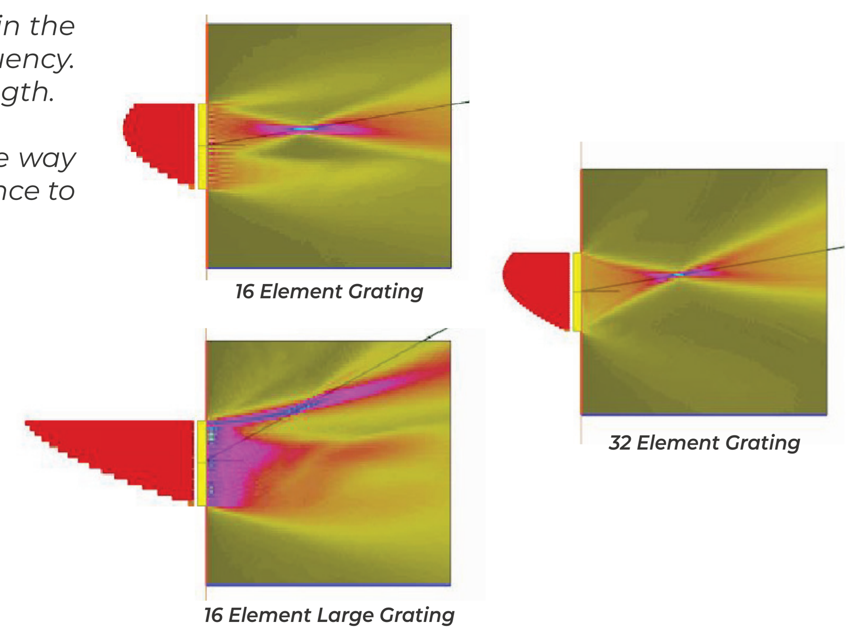
In some cases, when an array is steered, grating lobes appear in the beam pattern at frequencies lower than twice the center frequency. Grating lobes will not appear if the pitch is less than ½ wavelength.

Grating lobes *can interact with the inspected part in the same way as the main beam. This can generate echoes causing interference to the inspection.*

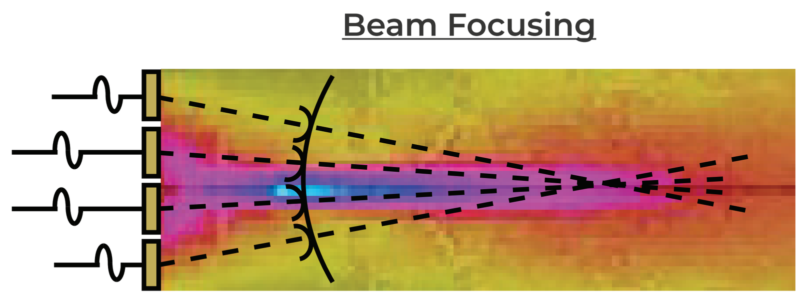
The angle of grating lobes in relation to the main beam is given by the following formula:

$$\sin \theta k = k \cdot \lambda / p - \sin \theta$$

θ = refracted angle of the main beam
θk = refracted angle of the grating lobe k (kc integer)
p = inter-element pitch (p) of the linear transducer
λ = wavelength in the medium under consideration



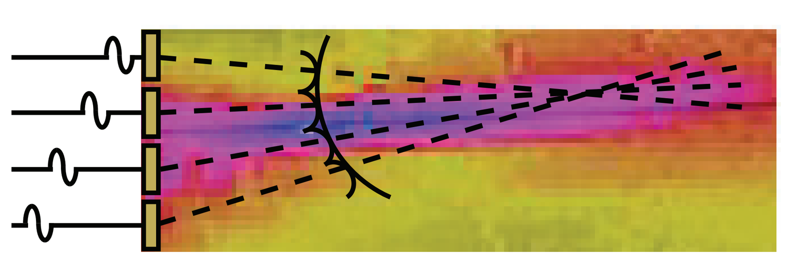
Beam Focusing



The beam is electronically focused by applying symmetrical delay laws to the different elements of a transducer. This technique can be combined with beam steering to produce both angled and focused beams.

Focusing can only occur within the near-field of the transducer. The ***near-field*** *gives the maximum depth of usable focus for a given array and can be calculated by the following formula:*

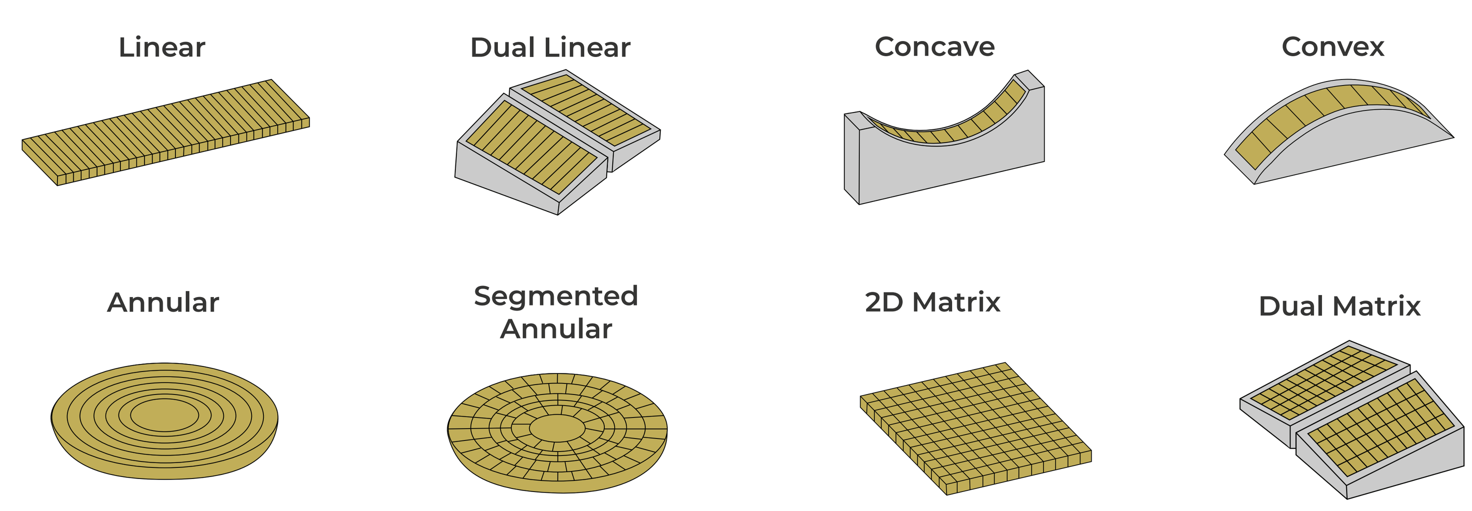
Beam Steering and Focusing



$$\frac{1.35D^2 f}{4V}$$

D = size of aperture (# of elements in virtual probe x pitch)
f = frequency
V = material velocity

Types of Arrays

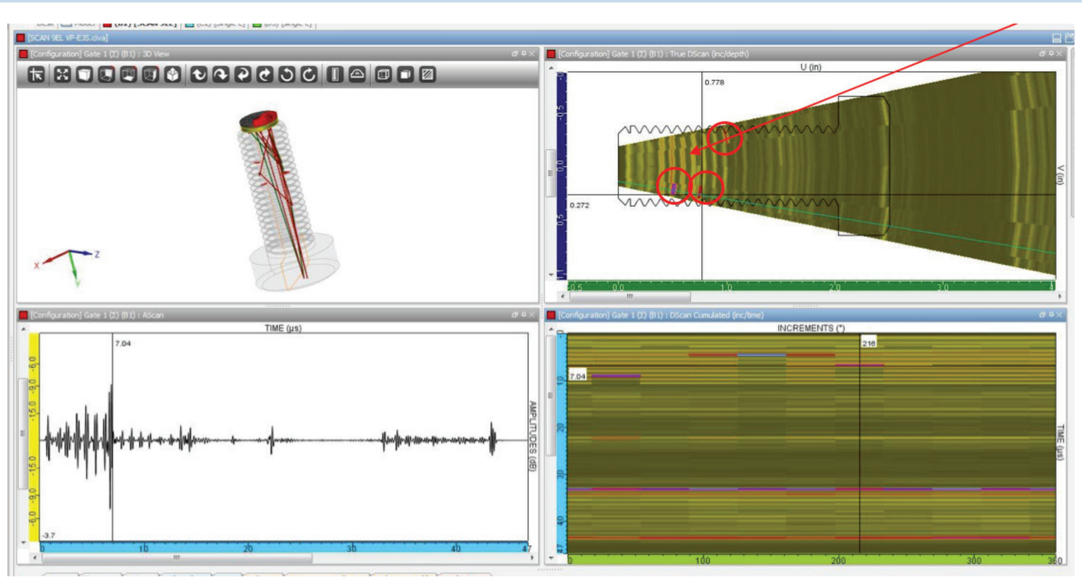


CIVA Acoustic Modeling

Acoustic beam modeling and delay law calculations for phased arrays allow for 1, 2, and 3D computer simulation of the sound beam within a component's geometry and material.

Acoustic modeling allows for a faster and more cost-effective optimization of a solution prior to the actual fabrication of a transducer.

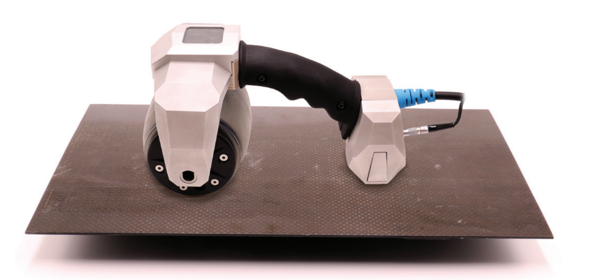
This graphic shows an acoustic modeling of a segmented annular bolt inspection array.



Applications

Welds: *Perfect for conducting inspections on varios weld, plate, and forging applications.*

Corrosion Mapping: *Dual-linear arrays in 16 or 32 pairs of send / receive elements combined with replaceable delay lines are perfect for scanning large surface areas for pitting or general corrosion / erosion.*



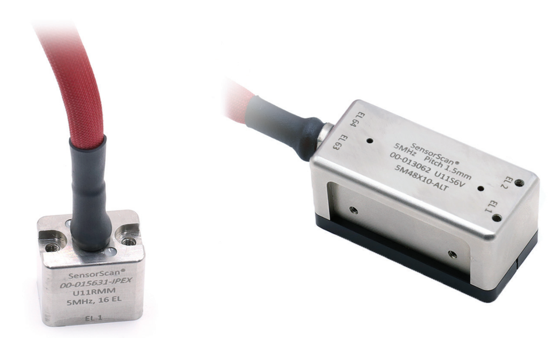
Composite Material: *32-or 64-element linear array configured in a captive water column, the compliant WheelArray is used with minimal couplant for inspecting aerospace and wind blade composite components.*

Heavy Wall Forgings: *Large aperture, high-element-count (up to 1,000) matrix arrays allow beam focusing over a very wide range of thickness.*

Rotor Disc: *High-element count linear array with couplant irrigation ports and compound-radii integral wedge for scanning of aerospace discs.*

Nuclear: *6 x 8: 48-element matrix with replaceable wear face helps with decontamination process for contact inspections.*

Bolts: *Round, segmented-annular arrays are ideal for the interrogation of threaded zones on studs and bolts of almost any size.*



High Temperature: *Linear and dual-linear transducers & wedges designed to operate over a temperature range of 0- to 200-deg. C continuous duty cycle permits ISI of operating assets.*

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