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TECHNICAL CONFERENCE

Phased Array Testing
Basic Theory for Industrial Applica

PAUT

Introduced by
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CEO MIZAT
ASNT LEVEL III
UT , RT , PT , VT , MT

Phased array general introduction

- Waves that combine in phase reinforce each other, while combine out of phase cancel each other.
- Phase shifting or phasing is in-turn away of controlling these inter shifting wave from that originate frame two or more source.
- It can be used to bend, steer, or focus of the energy of wave trou

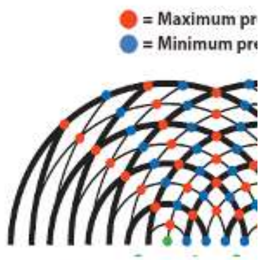

Figure 1-1 Two-point source ir

PHASED ARRAY PROBES (SYSTEM)

- P.A Probes consist of transducer assembly with 16 to as mauyas individual elements that can be pulsed separately.
- 2 MHZ to /10 MHZ most commonly use.
- Pa also includes a sophisticated is instrument that capable of
  - a) Diving multi elements probs .
  - b) Digitizing the returning that echo.
  - c) Platting that echo information in various standard format.
- P.A system can sweep a sound beam through
  - a) A range of refraction angel
  - b) A long with linear path
  - c) Dynamically focus at number of different depth

  A+B+C
- Increasing both flexibility and capability in inspection setup

Figure 1-

Fi

PHASED ARRAY PROBES (SYSTEM)

- P.A system utilizes the wave physics principle of phas
- This action adds or cancles energy in predictable wc effectively steer & shape the sound beam .
- The element are pulsed in groups “4-32” to improve sensitivity .

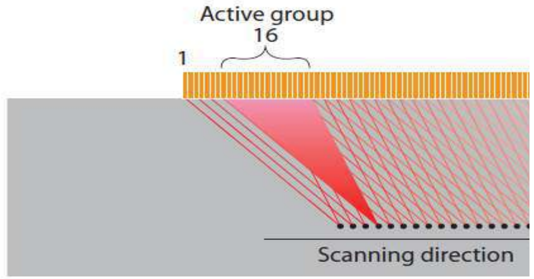

Figure 1-6 Example of focused angle bear

PHASED ARRAY PROBES (SYSTEM)

➢ **Focal law calculator(software)**

Establish specific delay times for firing each group of elements to desired beam shape, tacking into account [probe, wedge characte the geometry & acoustical properties of the test material.

➢ **Focal law**

The programmed pattern of time delays applied to pulsing and re individual elements of an array probes for steer and/or focus the r beam and echo response .

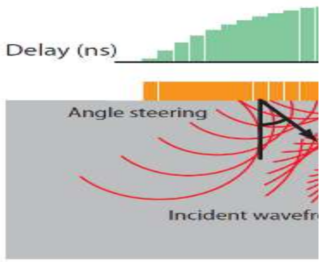

Figure 1-5 Example of an angle beam generate variable delay

PHASED ARRAY PROBES

➢ **Beam Profile**

- In fact , the actual beam profile is complex, with pressure transverse and axial durations in the beam profile red repr highest energy .

green &blue ⟶ lower energy

Figure 2-3 Areas of energy in the beam profil

FUNDAMENTAL (PROPERTIES OF SOUND WAVES)

1. Wave front formation.
2. Beam spreading:

if sound path > near field beam increase in diameter spread

For -6dB half beam spread (α)

$\infty = \sin^{-1}\left(\frac{0.514\,C}{FD}\right)$ OR

$\sin^{-1}\left(\frac{0.44\,\lambda}{L}\right)$

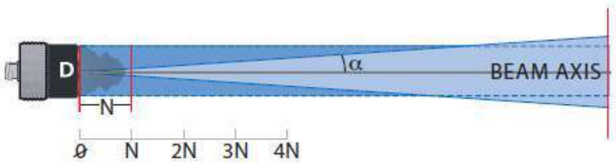

Figure 2-5 Beam spread

Figure 1-1 Two-

Phased array probe characteristics

- Array is organized arrangement of large quantities of
- For UT:

Series of several single elements transducers arranged as to increase inspection coverage and /or the speed o inspection

- simplest from PA. probs is series of individual eleme package
- Its piezoelectric element that has been divided into segments

Figure 2-16 Phased array probe

Figure 2-15 Phased array p

- P.A Probes constructed
- Piezocomposite materials mode of many thing, thin rods of pie
- P.A. probes are functionally categorized according to
  1. Type - angel – straight – direct contact – immersion pı
  2. Frequency 2 → 10MHZ
  3. Number of elements
     - Most have 16 → 128 some have 256 number ↑ — steering ↑
     - ↑area of coverage → ↑scan time price of syst
  4. Size of elements
     - Element width ↓ → ↑ bean steering capability — → system more price

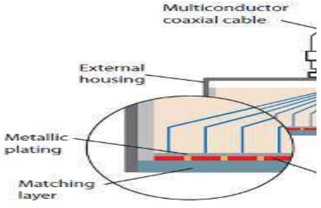

Figure 2-17 Phased arra

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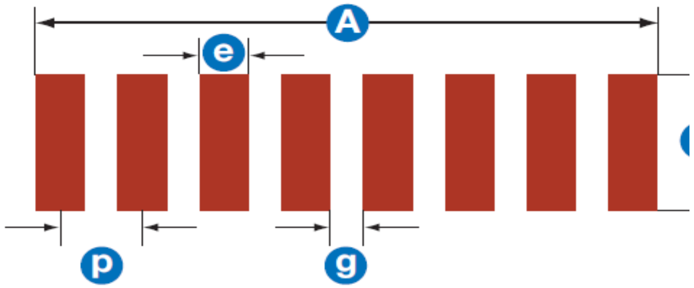

Figure 2-18 Dimensional parameters of a phased array pro

A = total aperture in steering of active direction
H = element height or elevation. Since this dimensi it is often referred to as the passive plane.
p = pitch, or center-to-center distance between twc elements
e = width of an individual element
g = spacing between active elements

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P.A. WEDGES

Some function of conventional single elements couplin
from the probe to the test piece in such way that it mo
on/or refract at desired angle in according to Snell's lav

Figure 2-19 Phased array probe wedges

Figure 2-20 A zero-degree wedge

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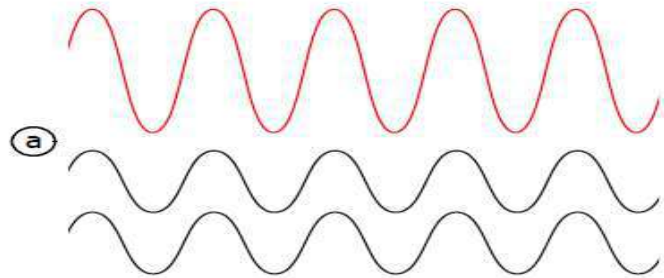
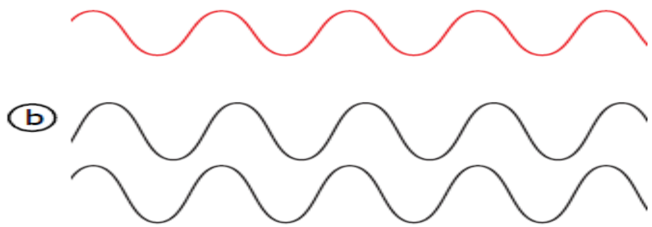


Waves in phase — Reinforcement

In phase or zero degree phase angle



Intermediate condition

Phase between 0˚-180˚ range between full addit cancellation

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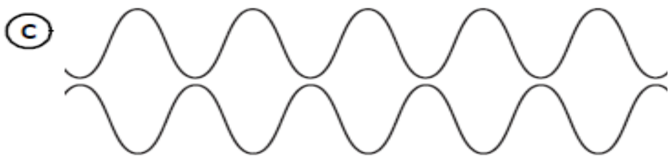

Waves out of phase — Cancellation

Phase degree 180° → full concertation

- By varying the timing of waves from large number of sou
  possible to use these effects to both steer and focus the
  combined wave front this is the essential principle behin

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- In phased array testing the predicable reinforcement and cancellation effect cau shape and steer the beam.
- Changing the pattern delays electronically beam steer and focus as required.
- Elements are pulsed in group of 4 to 32 improve effective sensitivity by inc
- Beam spread & enables sharper focusing
- The returning echoes are revived by various elements of groups of elements for then

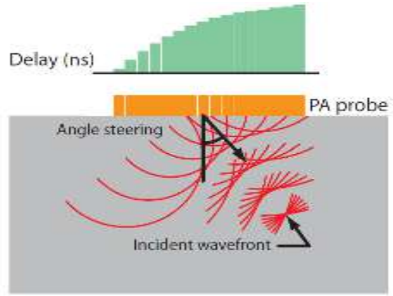

Figure 1-5 Example of an angle beam generated by a flat probe by means of the variable delay

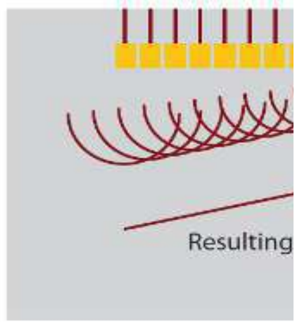

Figure 2-22 A

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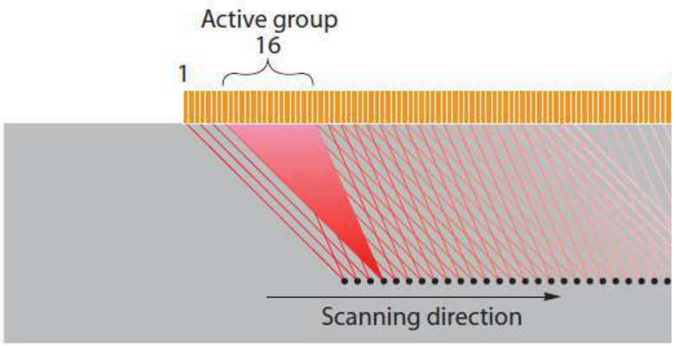

Figure 1-6 Example of focused angle beam linear scan

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- Software known as a focal law
- Calculator establishes delay times for firing each group o order to generate the desired beam shape through wave taking into account probe and wedge characteristic as we geometry and acoustical properties of the test material

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- **Pitch and aperture**
  - ❖ Pitch small → optimize steering range
  - ❖ Operator large → un wanted beam spreading
  - → strong focusing

Decreasing pitch and elements width with a constant number of elements	*Increases beam steering*
Increasing pitch or frequency	*Creates unwanted grati*
Increasing element width	*Creates side lobes (as in UT), reduces beam steer*
Increasing active aperture by using many small elements with small pitch	*Increases focusing facto beam)*

- ➢ P.A testing is an ultrasonic beam whose direction and foc steered electronically by varying the excitation delay of i elements or group of elements multiple angle and/or mu inspection from a single probe and a single probe positio
- ➢ PA probe behavior affected by
  - How smaller individual elements are positioned
  - Size and group to create a aperture required

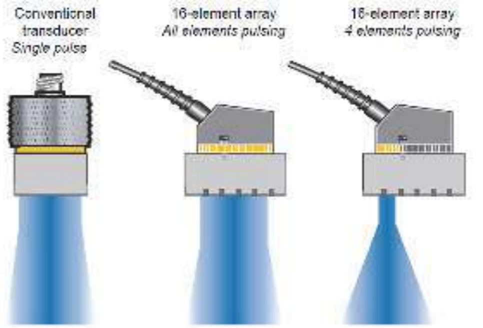


Figure 2-24 Effective aperture

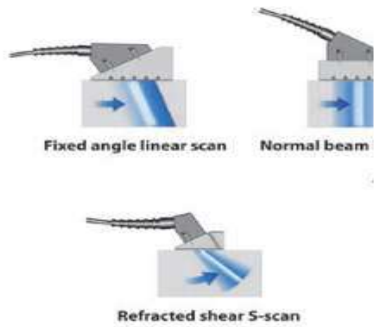


Figure 2-23 Focal law

➢Steering angle

➢ ↑Aperture

- ↑ Steering angle .
- ↓ Static coverage area.
- ↓Sensitivity, penetration and focusing ability .

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

where:

$\sin\theta_{st}$	= sine of the maximum steering angle
λ	= wavelength in test material
e	= element width

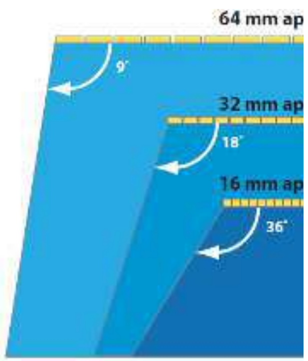


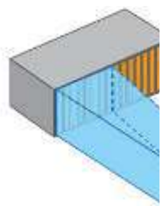
Figure 2-25 Beam steering limits: When
shown, the maximum beam steering angle i

BEAM FOCUSING WITH PA PROBES

➢The depth at which

- The beam form a phased array focuses can be varied pulse delay .

➢The near-field length in a given material defines the maximum sound beam can be focused



$$-6 \text{ dB beam diameter or width} = \frac{1.02\ Fc}{f D}$$

where:

F	= focal length in test medium
c	= sound velocity in test medium
D	= element diameter or aperture

Figure 2

- In case of most commonly used linear PA with rectangular elements the
  the steering direction and unfocused in the passive direction.
- Increase the apertured size increase the sharpness of the focused bean
  - The red area → highest sound pressure
  - The blue area → lower sound pressure

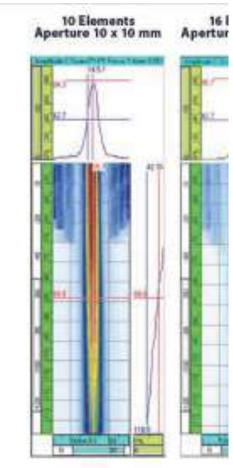


Figure 2-27 Beam focus

2.8 GRATING LOBES AND SIDE LOBES

- Caused by sound energy that spreads out from the probe at angles oth
  sound path.
- Gating lobes only occur in PA probes as a result for ray components ass
  regular, periodic spacing of the small individual elements .
  - Cause spurious indication on the image .
  - Affected by pitch size, number of elements frequency and b
  - Occur when ever the size of elements ≥ wave length .

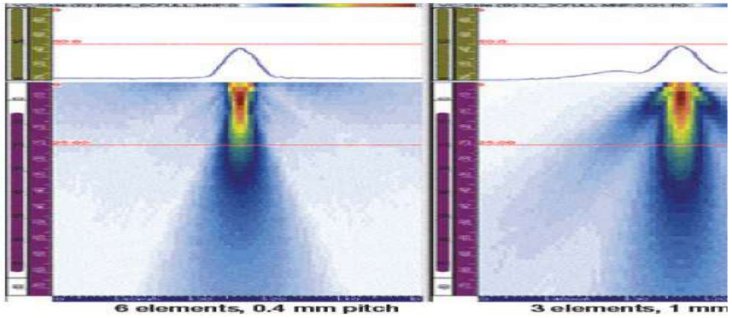


Figure 2-28 Beam profiles with different number of ele

2.9 P.A. PROBES SELECTION SUMMARY

- Designing phased array probes is always a compromise b selecting the proper pitch, element width and aperture, number of small elements to increase steering , reduce provides focusing, but can be limited by cost of manufact instrument complexity, most standard instruments suppo up 16 elements , separating elements at greater distance the easy way of gaining aperture size but this creates unv lobes

3- BASIC OF PA IMAGING

- **P.A instruments**
  - Multi channel provide excitation pattern (focal laws) t 16 to as many as 256 element
  - it can sweep sound beam from on probe through a ro refracted angel e.g linear path or dynamically focus different depth → ↑ both flexibility in inspection set an inspection by creating an image of the inspection z imaging →relative point to point changes and multa flow discrimination and sizing

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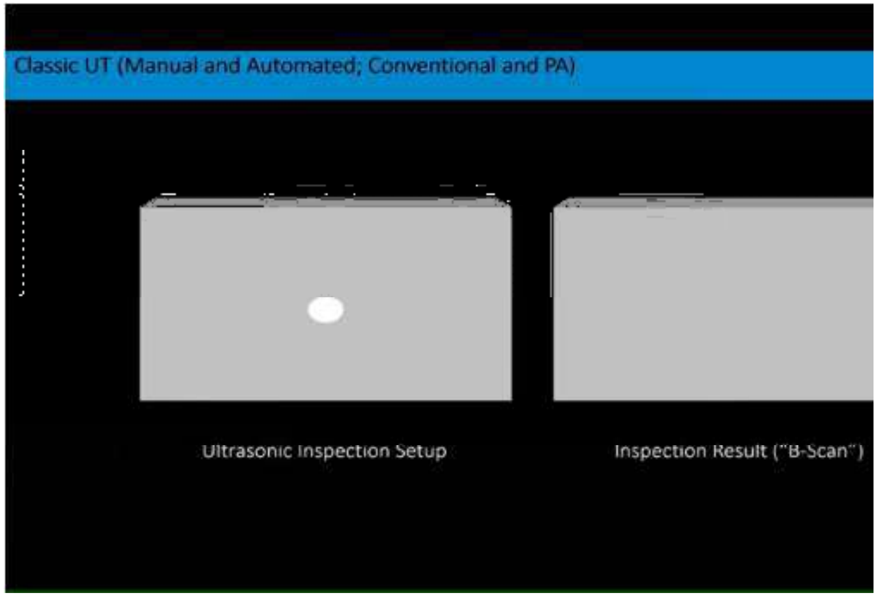

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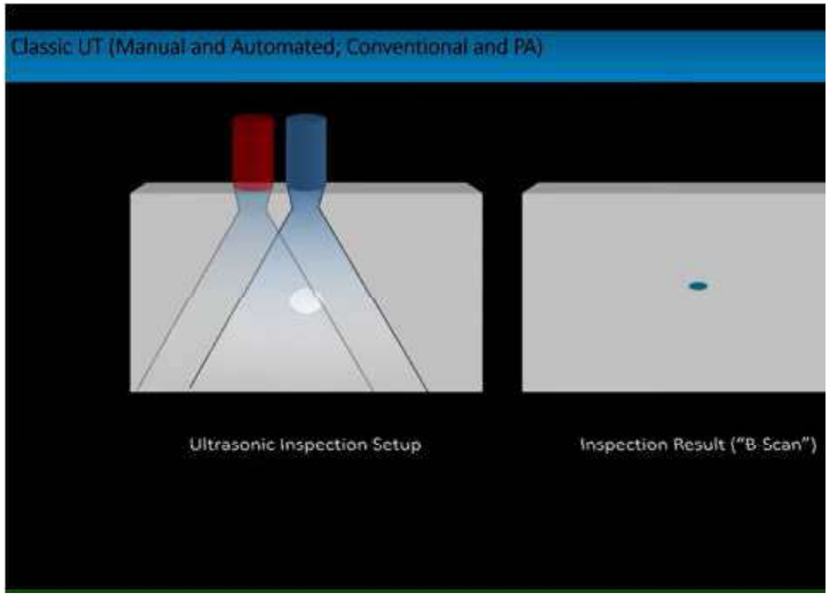

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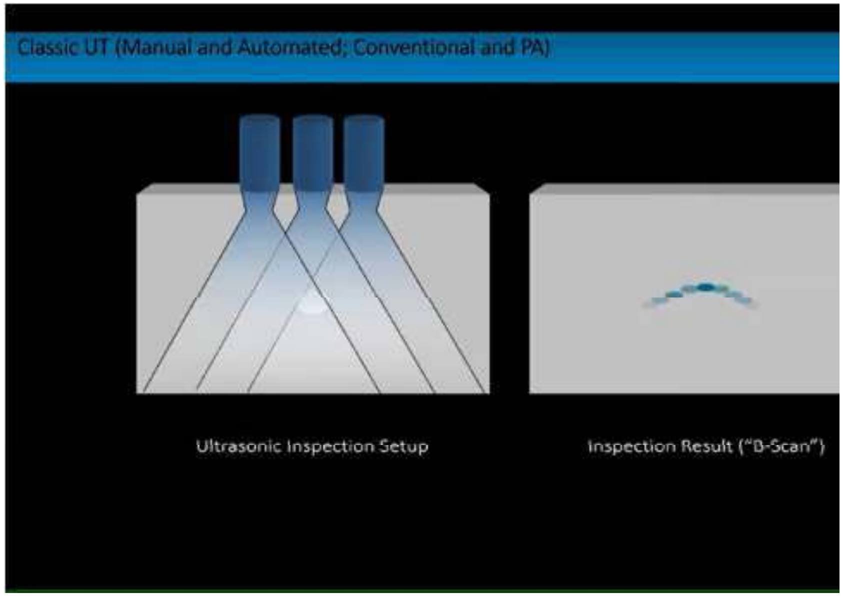

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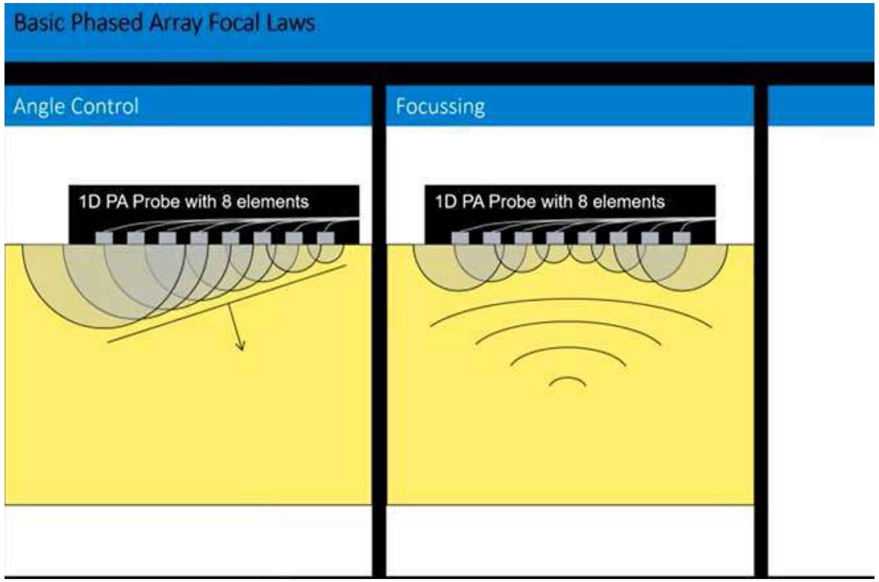

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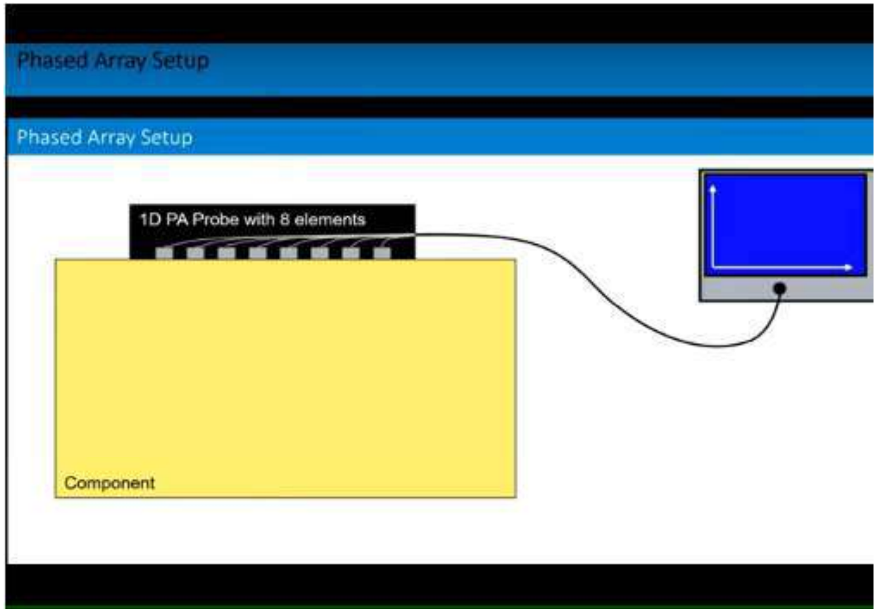

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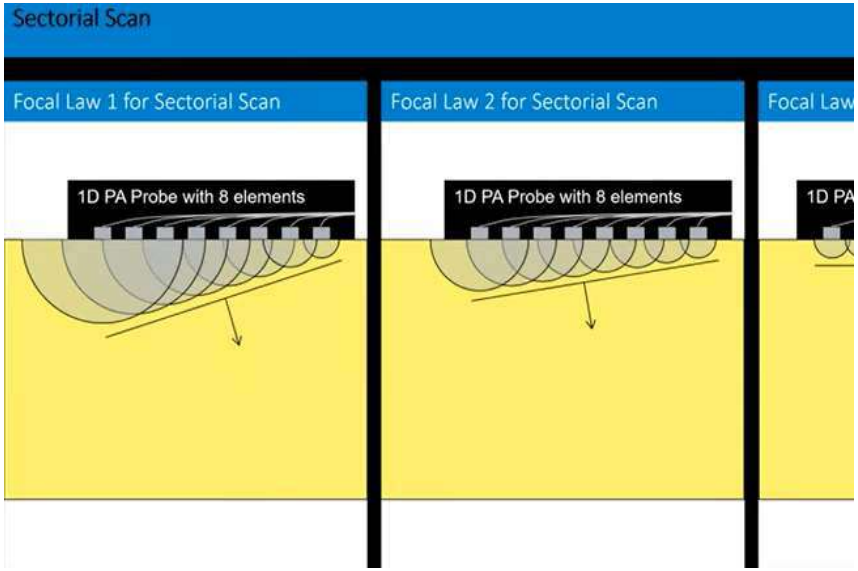

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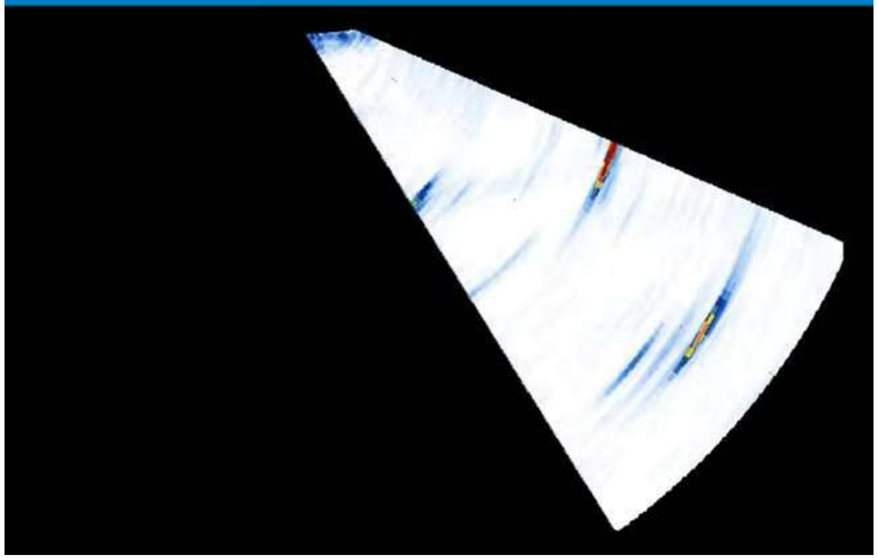
Sectorial Scan



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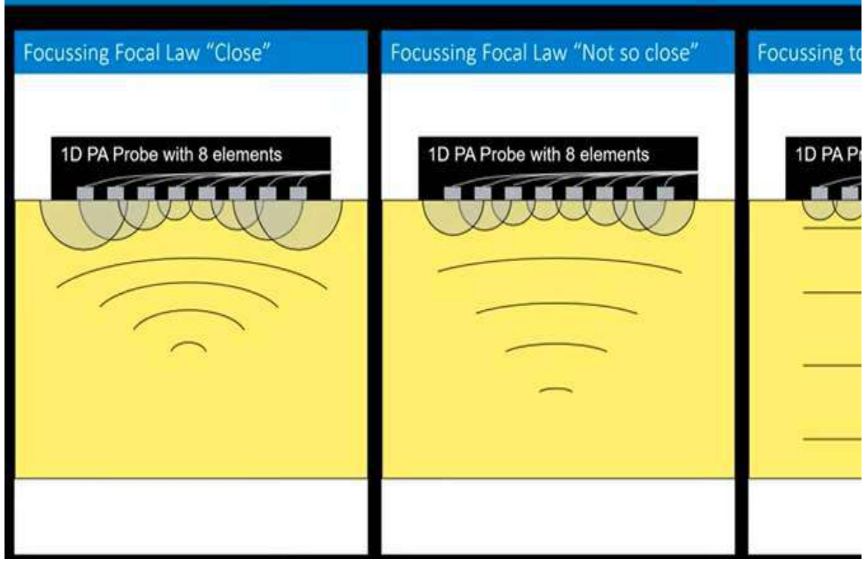
Focusing



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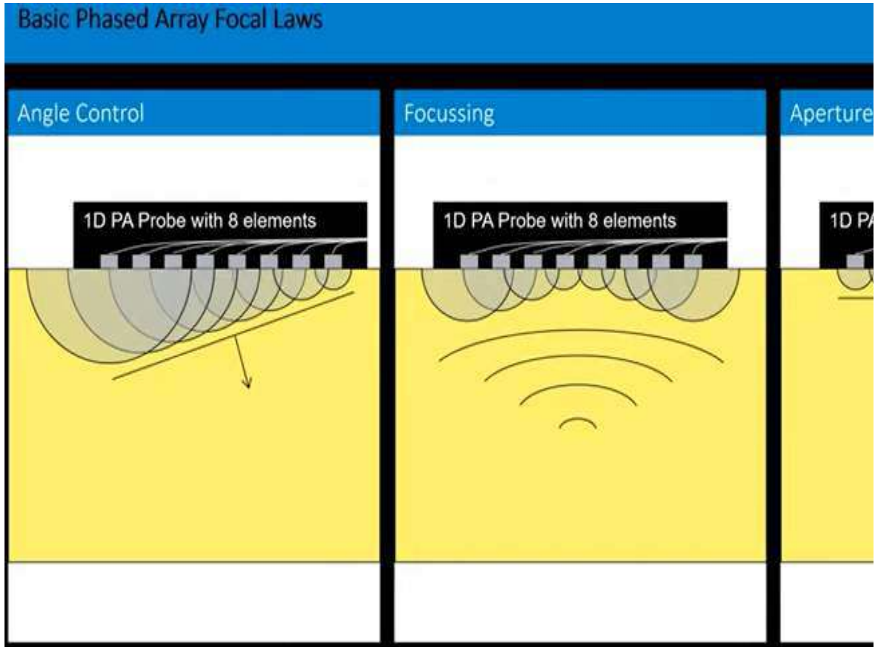

- **Cross-Sectional B-Scans**

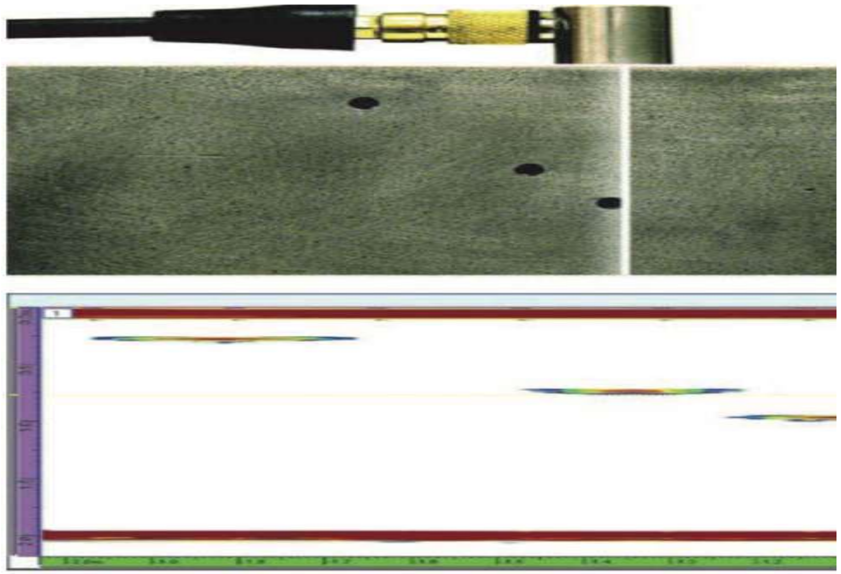

Figure 3-3 Cross-sectional B-scan

- **Linear Scans**

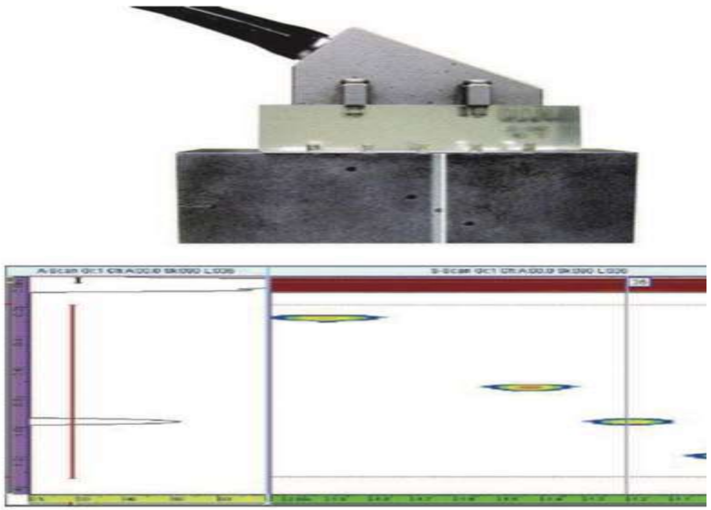

Figure 3-4 Normal beam linear scan

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- **Angle Beam Linear Scan**

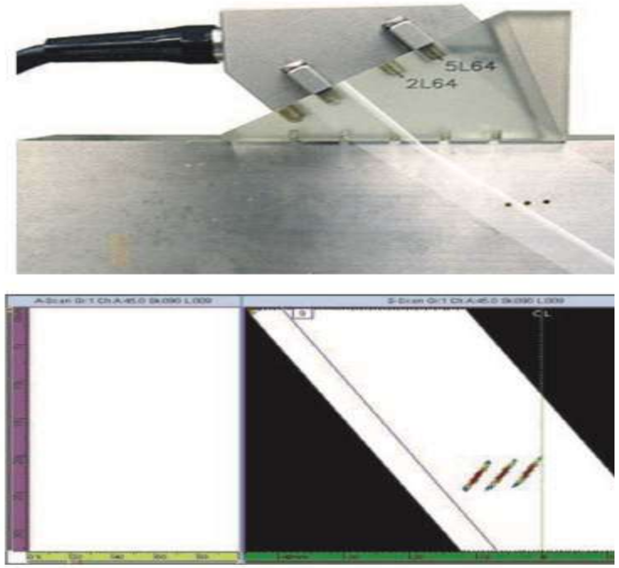

Figure 3-5 Angle beam linear scan

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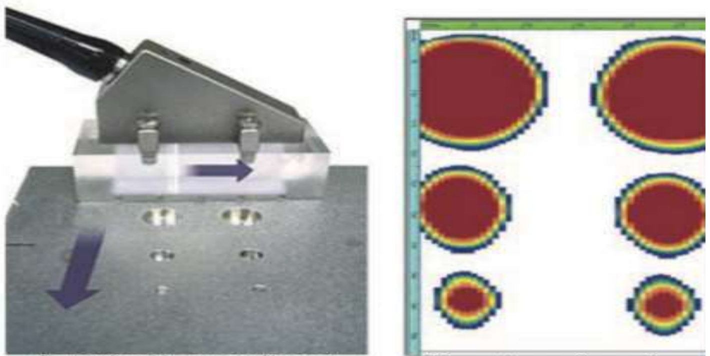
- **C -Scans**



Generalized beam profile and direction of motion

Phased array C-scan image showing hole position

Figure 3-6 C-scan data using 64-element linear phased array probe

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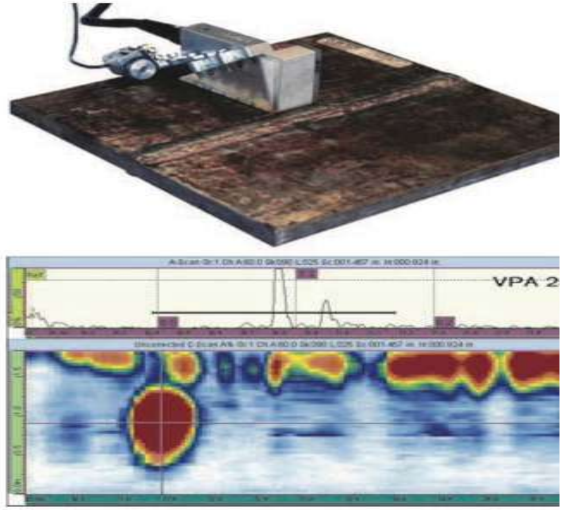

Figure 3-7 One-line scan for weld inspection using an encoded 2.2 element probe steered at 60 degrees

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- **S- Scan**

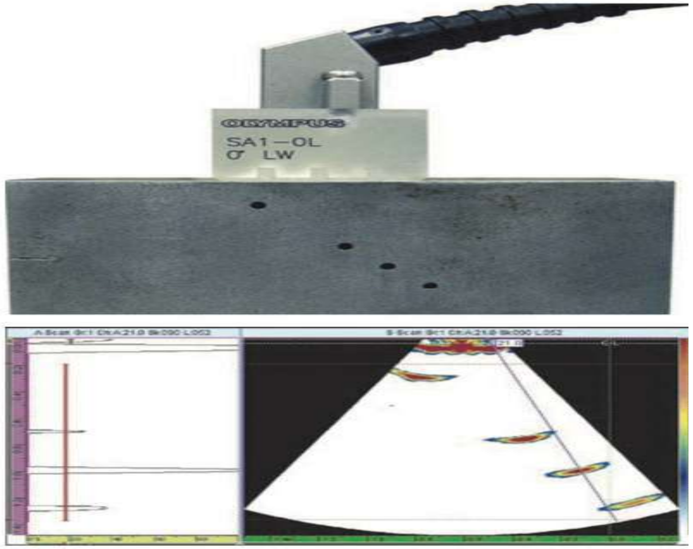

Figure 3-8 –30° to +30° S-scan

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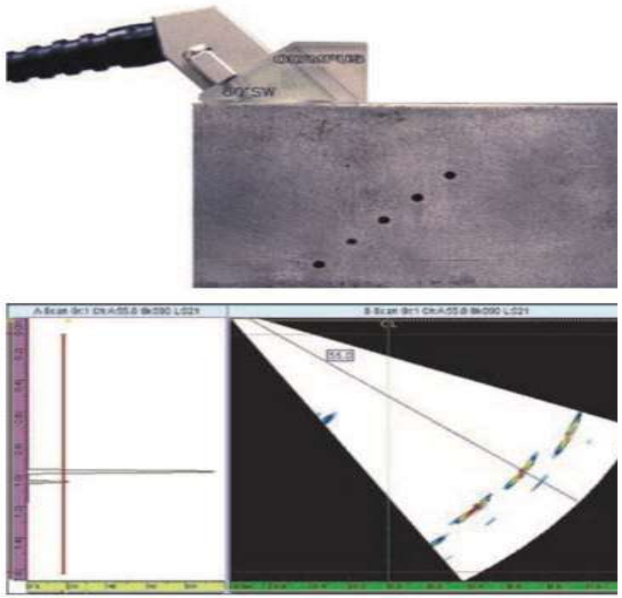

Figure 3-9 +35° to +70° S-scan

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- **Combined Image Format**

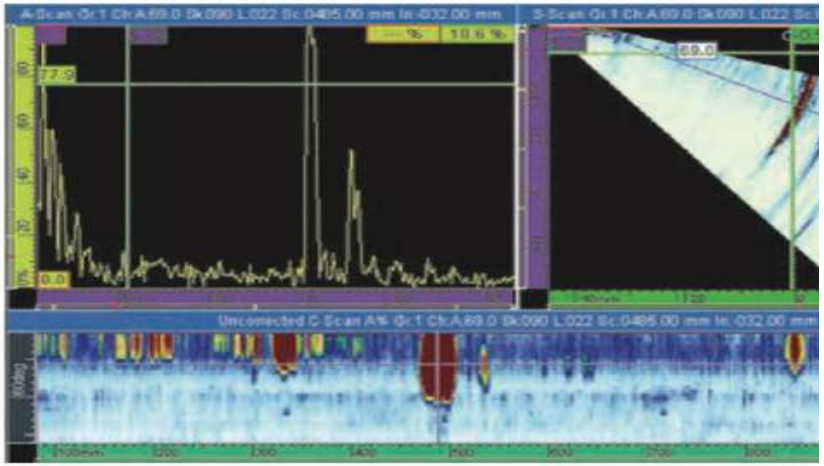

Figure 3-10 Multiple image types display

- **Scan Rate and Data Acquisition**

IMPORTANT

1. $\text{Acquisition rate} > \dfrac{\text{Scanning speed}}{\text{Scan axis resolution}}$
2. If the same PRF is set for all A-scans, then:
   $\text{Acquisition rate} < \dfrac{\text{Recurrence}}{\text{Number of focal laws}}$

$$\text{Acquisition rate} > \frac{\text{scanning speed}}{\text{encoder resolutions}}$$

Figure 3-11 Example of the scanning speed influence on acq

Important Specification

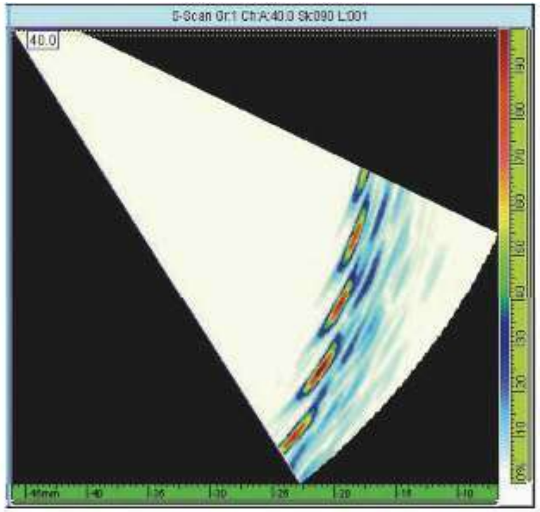

Figure 4-1 40 to 70 degrees S-scan: steering with 1 degree (31 laws) steps

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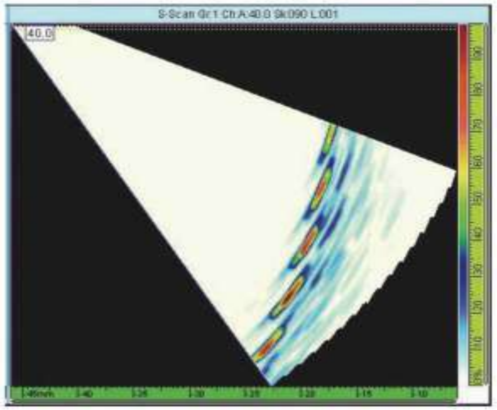

Figure 4-2 40 to 70 degrees S-scan: steering with 2 degree (16 laws) steps

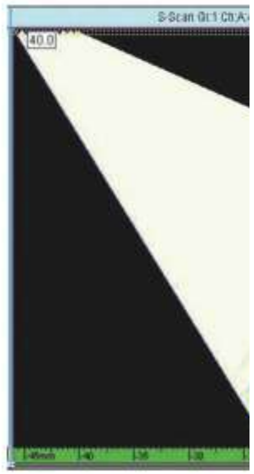

Figure 4-3 40 to 70 degrees S-scan:

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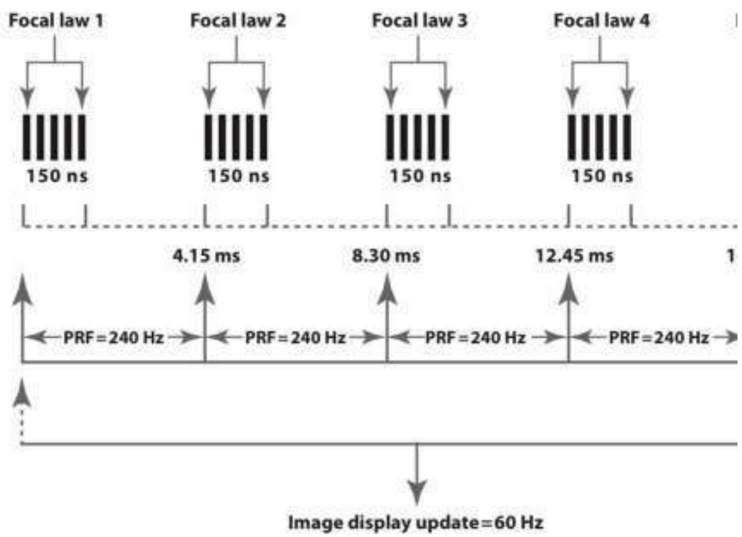

- **Encoding**

There are two classes of instruments generally available ma
encoded.

- **Reference Cursors**

Instruments Provide various cursors that can be used on an
for interpretation , sizing , and depth measurements .

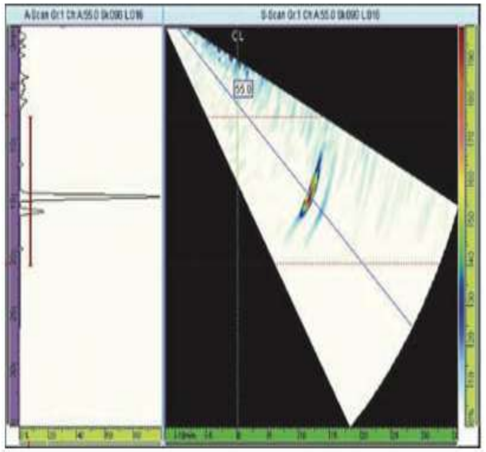

Figure 4-5 Angular cursor

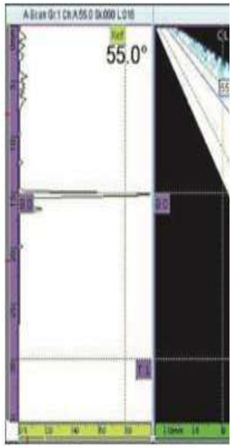

Figure 4-6 Angular a

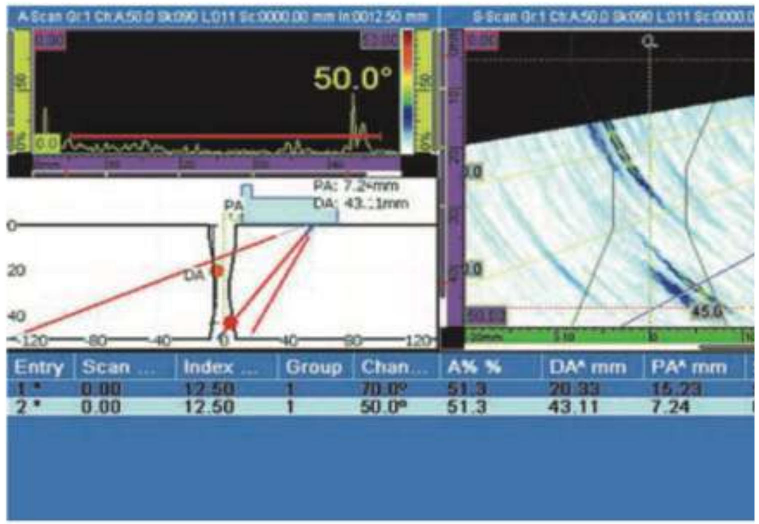

Figure 4-7 Multiple display formats

Figure 4-8 Response prior to gain normalization

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Figure 4-9 Response following gain normalization

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Phased Array Test Setup and Display Format

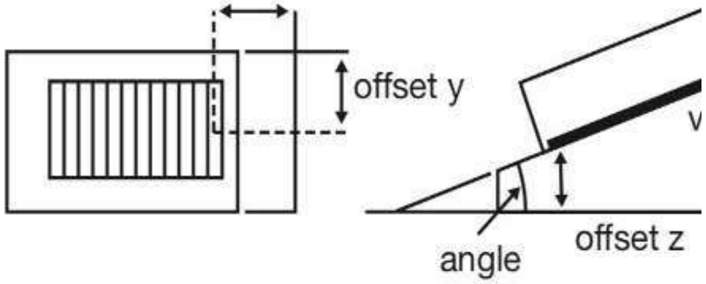

Figure 5-2 Wedge parameters

Normal Beam Linear Scans

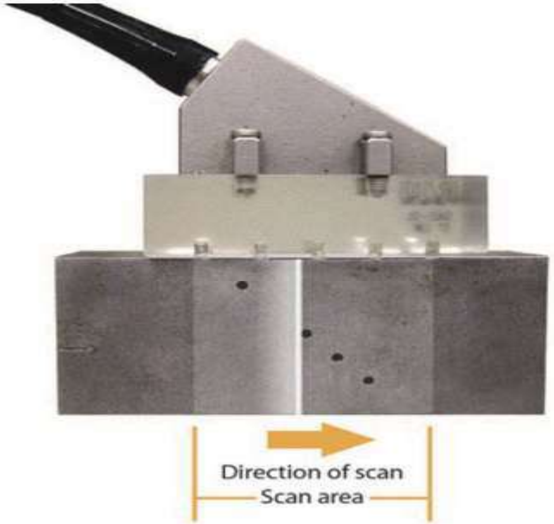

Figure 5-3 Normal beam linear scanning

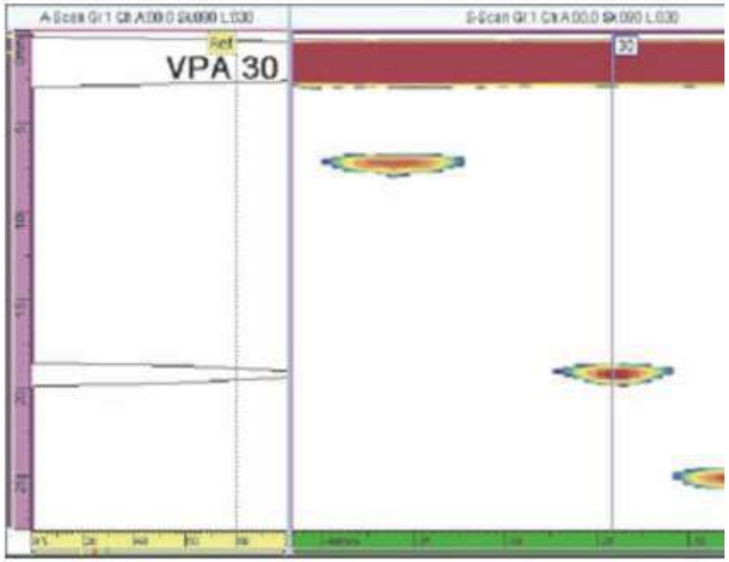

Figure 5-4 Normal beam linear scan

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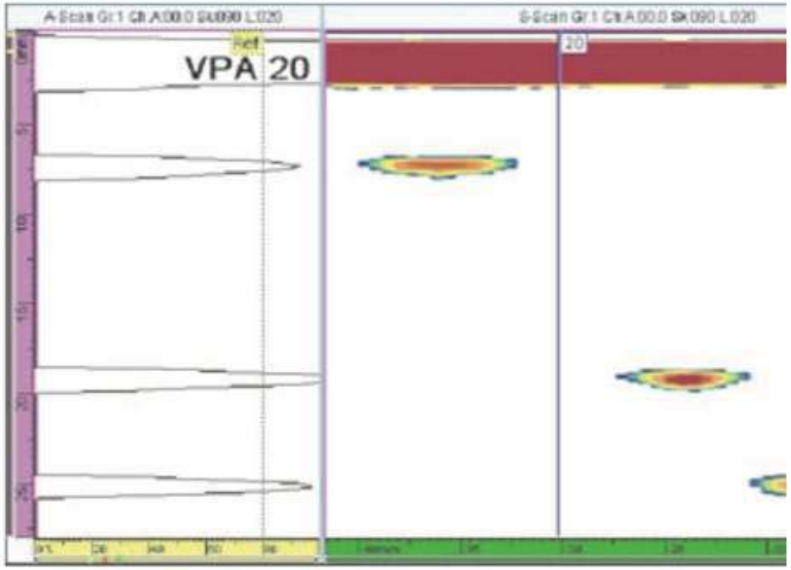

Figure 5-5 Normal beam linear scan image with all law

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Angle Beam Linear Scans

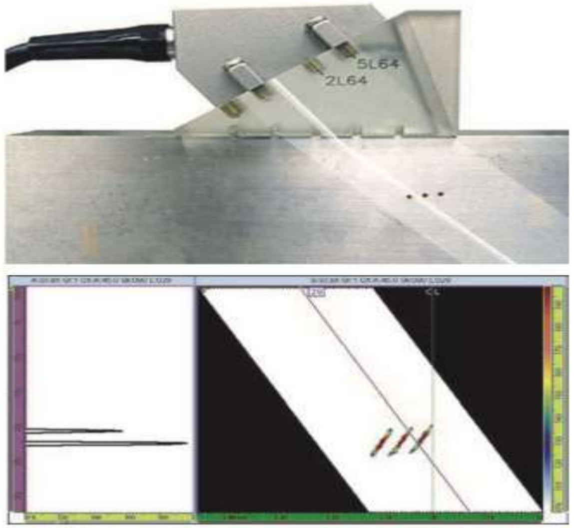

Figure 5-7 Angle beam linear scan (*top*), with A-scan and linear scan displ (*bottom*)

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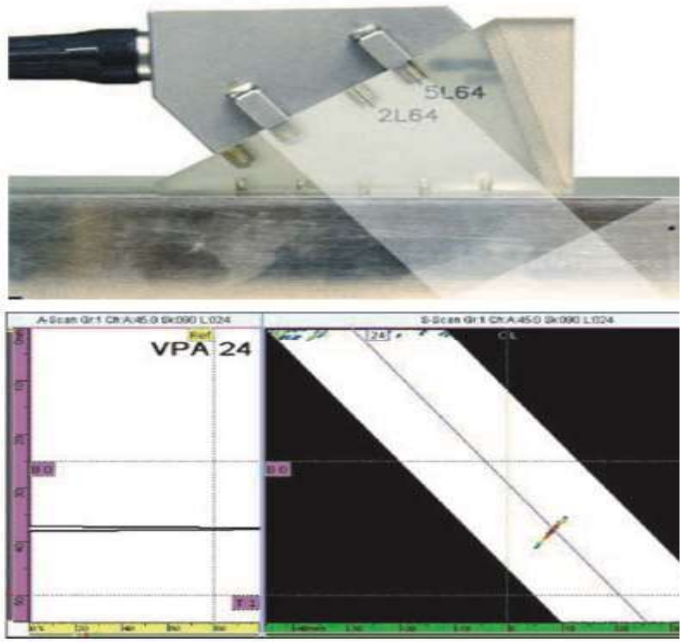

Figure 5-8 Measurement to second leg reflector

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S-Scan Display Examples

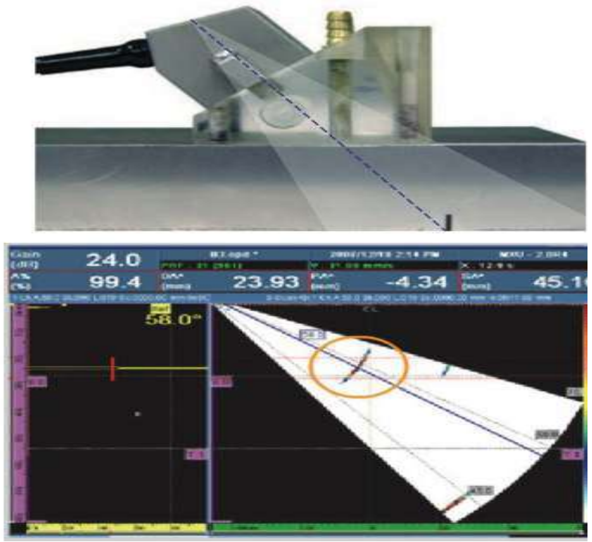

Figure 5-12 The 58° beam component

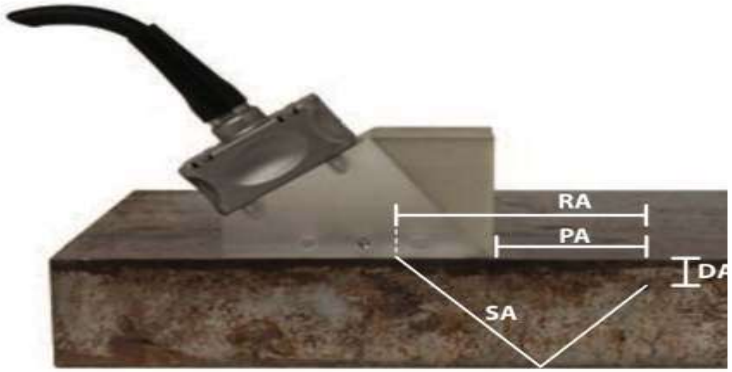

Figure 5-16 Dimensions for referencing a flaw po

DA = depth of the reflector in Gate A

PA = forward position of the reflector with res the wedge

RA = horizontal distance between the wedge and the reflector

SA = sound path length to the reflector

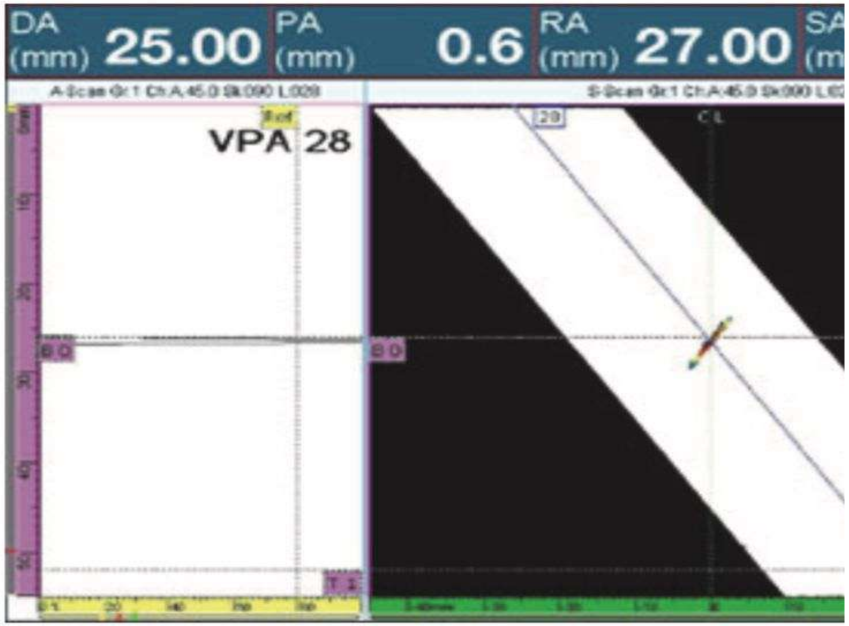

Figure 5-17 Bottom corner reflector

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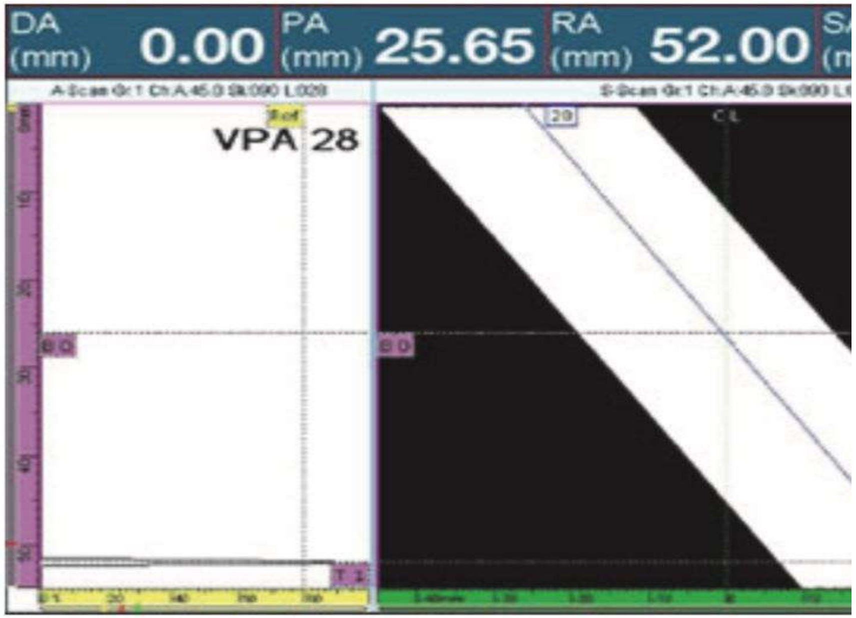

Figure 5-18 Top corner reflector

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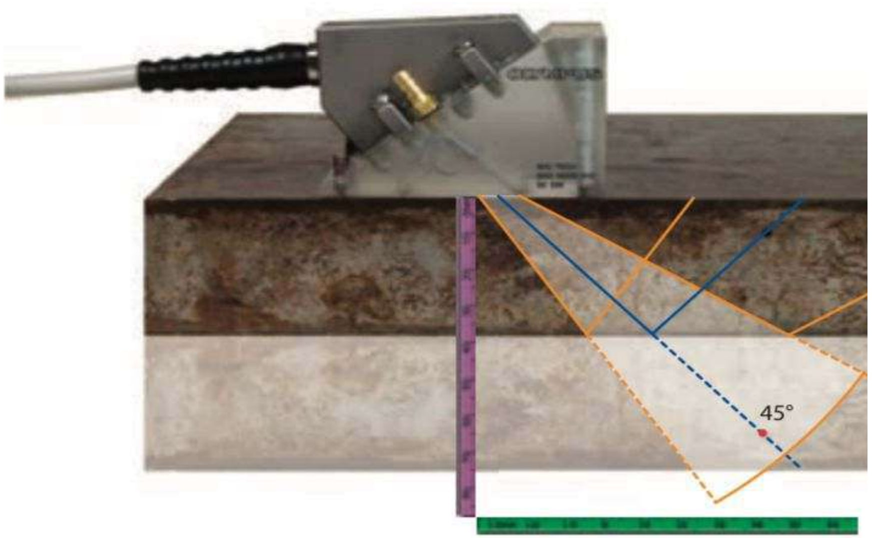

Figure 5-19 Display of the second leg compared to the pa

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Thank you

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