COOPERATION PROJECTS

DASEL is a young company, whose technological base has been developed by the Spanish National Research Council (CSIC).

PAST PROJECTS

CSIC is the largest public institution dedicated to research in Spain and the third largest in Europe.

2004

New protocols for the industrial application of SENDAS and AMPLIA technologies. Project for knowledge transference from GEND-CSIC group to DASEL.

2006

Design of Non-Destructive-Evaluation applications and systems. Nº IDI 2006 0651, founded by CDTI for the consolidation of the company DASEL and the launch of Ultrascope, DSR and SITAU technologies.

2008

PIE 611/2008, Ultrasonic flaw detector by time of flight diffraction.

2008

INNO 129-2008.- Conceptual design and technical development of failures analyzer equipment by Ultrasonic technology SITAU, tool development product design based on customer needs.

2008

PET 2008_0116_01 DIFRASCOPE. Nondestructive Evaluation Technologies for time of flight diffraction. Ultra-compact multichannel system for ultrasonic weld inspection, TOFD based technology.

2009

PIE 306/2009 Development FOCAL-SIM tool for the calculation and simulation of focal laws, applied to the design of Phased Array inspections.

ACTUAL PROJECTS

As a result of this cooperation, the company has obtained R&D agreements and contracts of different magnitude and with several partners.

2010

HANDY, Portable System platform, open development platform for integrating various technologies with the characteristics of: High portability, Lithium-ion battery, touch screen of 10.4 ".

2010

Artemis Project (Advanced real time multimodality medical imaging), granted by Madrid government, to develop a multi-modal medical imaging technology. Achieving real-time acquisition and tomography reconstruction in a real surgical scenario.

2011

DOOME, Development and optimization of guided wave technologies for the monitoring of critical structures. Guided-wave system approach for inspection of pipes and longitudinal structures.

2012

EUROSTARS E!6771, SAPHARI. Synthetic aperture and phase coherence for ultrasound images in real time, applied to NDT. A new inspection standard based on the patent Nº ES/200802402

2012

Grant Agreement: 315130 CHAPLIN: The overall aim of CHAPLIN is to develop and demonstrate an integrated technology solution for the efficient and cost-effective inspection of high power overhead transmission line cables.

2012

Grant Agreement: 314913. SkinDetectorApplication of the innovative data fusion based non-invasive approach for management of the diabetes mellitus.

ULTRASOUND ANDROID SMARTPHONE APPLICATIONS

ULTRASOUND- CALC, PHASED ARRAY-WIZARD AND TOFD-CALC

A series of handheld tools for NDT, based on Android Operating System

Descriptions:

Ultrasound Calc, Phased Array Wizard and TOFD-Calc contains all calculations which are frequently required in industrial applications by NDT technicians of levels II and III.

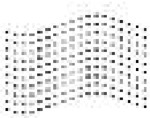
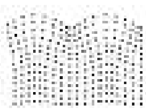
These applications turn your smart phone in a powerful calculator that simplifies the complexity of ultrasonic equations used to select a transducer or setup an inspection by menus of friendly interactive screens.

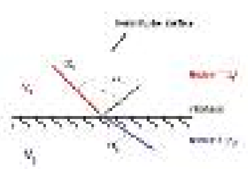
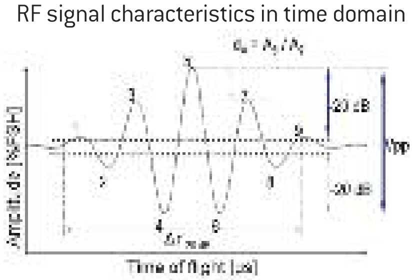
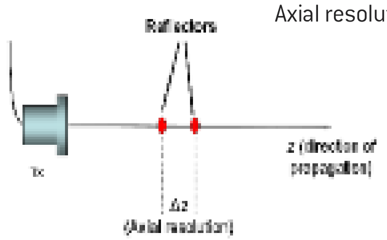
These applications have a database of material properties to look up longitudinal and shear wave velocity as well as impedance, density and wavelength for a given frequency

SPEED AND ATTENUATION OF WAVES IN SOLIDS

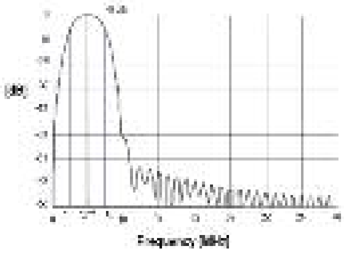
Materials	Speed of sound		Acoustic impedance
	c_L (Long.) 10^3 m/s	c_T (Trans.) 10^3 m/s	$Z = \delta$ cl 10^6 Kg/m^{2}s
Materials			
Aluminium	6.32	3.13	17
Berylium	12.87	8.90	23
Bismuth	2.18	1.10	21
Brass (58)	4.40	2.20	37
Cadmium	2.78	1.50	24
Cast iron	3.5 a 5.8	2.2 a 3.2	25 a 42
Constantan	5.24	2.64	46
Copper	4.70	2.26	42
German silver	4.76	2.16	40
Gold	3.24	1.20	63
Inconel	5.72	3.00	47
Stellite	6.8 a 7.3	4.0 a 4.7	77 a 102
Iron (steel)	5.90	3.23	45
Iron (cast)	4.80	2.60	33.2
Lead	2.16	0.70	25
Magnesium	5.77	3.05	10
Manganin	4.66	2.35	39
Mercury	1.45	-	20
Molybdenum	6.29	3.40	63.1
Monel	6.02	2.70	47.6
Nickel	5.63	2.96	50
Platinum	3.96	1.67	85
Silver	3.60	1.59	38
Steel, mild	5.92	3.23	46
Steel, stainless	5.80	3.10	45.4
Tin	3.32	1.67	24
Titanium	6.07	3.10	27.3
Tungsten	5.46	2.62	104
Uranium	3.37	2.00	63
Zinc	4.17	2.41	30
Non metals			
Aluminium oxide	9 a 11	5.5 a 6.5	32 a 43
Butyl	1.85	-	2.0
Epoxy resin	2.4 a 2.9	1.1	2.7 a 3.6
Glass, flint	4.26	2.56	15
Glass, crown	5.66	3.42	14
Ice	3.98	1.99	3.6
Paraffin wax	2.2	-	1.8
Acrylic resin (Perspex)	2.73	1.43	3.2
Polyamide (nylon, perlon)	2.2 a 2.6	1.1 a 1.2	2.4 a 3.1
Polystyrene	2.35	1.15	2.5
Porcelain	5.6 a 6.2	3.5 a 3.7	13
Plexiglass	2.76	1.10	3.1
Polyethylene	2.67	0.5	1.7
Polyurethane	1.90	-	1.9
Quartz glass (silica)	5.57	3.52	14.5
Rubber, soft	1.48	-	1.4
Rubber, vulcanized	2.3	-	2.8
Polytetrafluoroethylene (Teflon)	1.35	0.55	3.0
Liquids			
Glycerine	1.92	-	2.5
Methylene iodide	0.98	-	3.2
Diesel oil	1.25	-	1.0
Motor car oil (SAE 20 a. 30)	1.74	-	1.5
Water (20º C)	1.483	-	1.5

SUMMARY OF USEFUL FORMULAS

<table>
<tr><th colspan="4">Fundamental of ultrasound</th></tr>
<tr><th>Description</th><th colspan="3">Explanation</th></tr>
<tr><td>Ultrasonic waves</td><td colspan="3">Ultrasound can be defined as high frequency mechanical waves (>20Khz). In solids, ultrasound waves have different propagation modes, depending on of the way of vibration of the material particles.</td></tr>
<tr><td>Acoustic Impedance</td><td>$Z=\rho V$ [Kg/m^2s]</td><td colspan="2">Resistance offered to the propagation of an ultrasonic wave by a material. It is obtained by multiplying the density ρ of the material and the velocity V of the ultrasonic wave in the material.</td></tr>
<tr><td>Acoustic pressure</td><td>$P= Za$</td><td colspan="2">Denote the amplitude of alternating stresses on a material by a propagating ultrasonic wave. It is related to the acoustic impedance “Z” and the amplitude of the particle vibration “a”.</td></tr>
<tr><td>Acoustic intensity</td><td>$I=P^2/2Z=Pa/2$</td><td colspan="2">The amount of energy per unit area in unit time.</td></tr>
<tr><td rowspan="4">Types of ultrasonic waves</td><td></td><td colspan="2">In longitudinal waves particles vibrates along the direction of travel of the wave. Such waves can propagate in solids, liquids and gasses.</td></tr>
<tr><td></td><td colspan="2">Shear Waves or Transverse waves: the particle movement is at right angle or transverse to the propagation direction. Sound velocity in a material is usually different for shear and longitudinal waves.</td></tr>
<tr><td></td><td colspan="2">Surface waves or Rayleigh waves: are produced in a semi-infinite material. They can propagate in a region no thicker than about one wavelength below the surface material. Particles vibrate following an elliptical orbit.</td></tr>
<tr><td colspan="3">Lamb waves are generated when a second Boundary surface is introduced, i.e. a plate. They can produce symmetric or antisymmetric vibrations in plates with a thickness of several wavelengths. The particles follow an elliptical orbit.</td></tr>
<tr><td rowspan="4">Wave parameters</td><td rowspan="4">$\lambda= c/f = cT$</td><td colspan="2">λ – Wavelength [mm]: Distance traveled during the time period.</td></tr>
<tr><td colspan="2">f – Frequency [MHz]: Number of cycles per second</td></tr>
<tr><td colspan="2">c – Velocity [mm/us]: Speed at which energy is transported between two points in a medium.</td></tr>
<tr><td colspan="2">T – Period [1/f]: oscillation time.</td></tr>
<tr><td rowspan="3">Velocity of ultrasonic waves</td><td>Longitudinal</td><td>$V_L = \sqrt{\frac{E(1-\mu)}{\rho(1+\mu)(1-2\mu)}}$</td><td rowspan="3">E = Young’s modulus of elasticity [N/m2].
ρ = material density [Kg/m3].
μ = Poisson’s coefficient = (E-2G)G
G = modulus of rigidity.</td></tr>
<tr><td>Transverse</td><td>$V_T = \sqrt{\frac{E}{2\rho(1+\mu)}}$</td></tr>
<tr><td>Surface</td><td>$V_S = \frac{0.87+1.12\mu}{1+\mu} \approx 0.92 V_T$</td></tr>
</table>

Sound reflection Properties at an interface		
Description		Explanation
	Reflection	When a wave reaches a medium of different acoustic impedance (interface), part of the wave energy is reflected into the incident medium. The angle of incidence and the angle of reflection are related by: $\alpha_{(incidence)} = \alpha_{(reflection)}$
	Refraction	When a wave reaches a medium of different propagation velocity, the transmitted wave undergoes an abrupt change in direction following the Snell's law: $\frac{\sin(\alpha_1)}{V_1} = \frac{\sin(\alpha_2)}{V_2}$
First critical angle	It is the angle of incidence that creates a 90º refracted longitudinal wave	
Second critical angle	It is the angle of incidence that creates a 90º refracted shear wave (or Surface wave)	
% Reflected energy (E)	$E = 100\left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$	Where Z1 and Z2 are the acoustic impedance of media 1 and 2 respectively. To calculate the % of transmitted energy, the reflected energy must be subtracted from 100%
Reflection coefficient	$R = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$	R is the reflection coefficient and it is a dimensionless numerical value.
Transmission coefficient	$T = \frac{4Z_1 Z_2}{(Z_1 + Z_2)^2}$	T is the transmission coefficient and it is a dimensionless numerical value.
Attenuation	$Attenuation = \alpha_{absorption} f + \alpha_{scattering} f^4$	Reduction in energy as a result of friction absorption and scattering as the wave travels through a material.
Pulse width (PW)	$PW = \frac{1}{2 f_c}$	Duration of the high-voltage excitation pulse.
Characteristics of ultrasonic beam		
RF signal characteristics in time domain 		NP – Number of peaks CN – Number of cycles: CN = CP/2 Vpp – Peak-to-peak amplitude: Maximum deviation between peaks expressed in volts or % ΔT-20dB - Pulse duration or waveform length dA – Damping: relation between maximum amplitude and the adjacent peak.
Axial resolution 		Ability of an ultrasonic signal to distinguish two separated reflectors along the direction of the sound propagation (Δz).

RF signal characteristics in frequency domain



fL – lower frequency

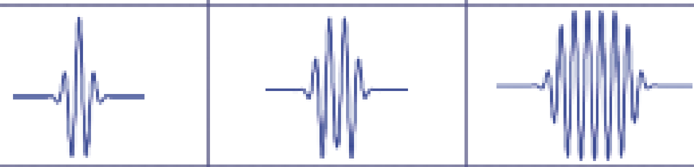
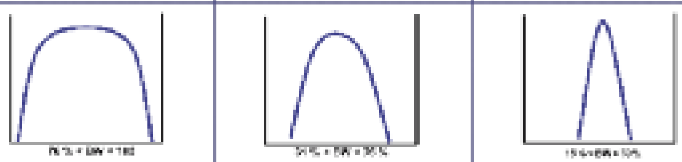
fU – upper frequency

fC – centre frequency: (fU-fL)/2

BW6dB[%] – Bandwidth: 100 *(fU-fL)/fC

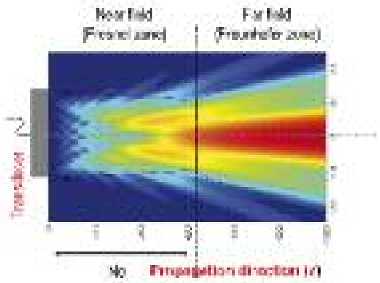
Transducer classification by its bandwidth

The transducer transforms electrical energy into mechanical vibrations and vice versa. Due to mechanical damping of the transducer element a damped oscillation is also produced -in the material.

High damping pulse – Wide band transducer 1 - 3 cycles	Medium damping pulse – Medium band transducer 3 - 5 cycles	Low damping pulse – Narrow band transducer 5 - 7 cycles
		
		
Axial resolution improves when pulse duration decreases	Reference Axial Resolution (Δz)	Axial resolution decreases when pulse duration increases

Ultrasonic field

Ultrasonic field



Transducer

Parameters:
D = Diameter, f = frequency V = velocity, λ=wavelength

Near field
z<No
(Circular Transducer)

The field intensity is irregular and the beam width is smaller than the transducer diameter.

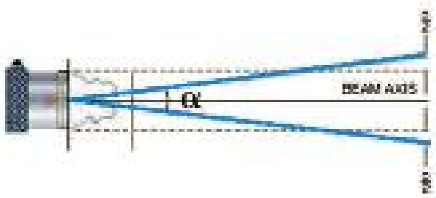
$$N_0 = \frac{D^2}{4\lambda} = \frac{D^2 f}{4V}$$

Near field
z<No
(Rectangular Transducer)

$$N_e = \frac{1}{\pi\lambda}(a^2+b^2)\left(1-\frac{a}{2b}\right)$$

where "a" is the shorter size of the transducer and "b" the largest size of the transducer

Beam spread
The beam spread can be reduced by selecting a transducer with a higher frequency, a larger element diameter or both

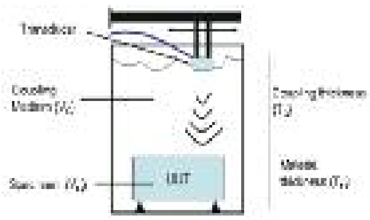
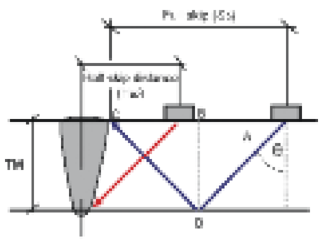
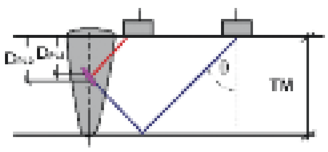


For flat transducers, the pulse-echo beam spread angle is given by:

$$\frac{\alpha}{2} = \sin^{-1}\left(k\frac{\lambda}{D}\right)$$

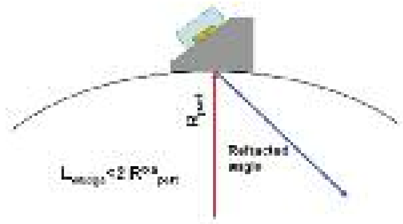
where: α/2 = Half angle spread.
"k" = constant value which depends on where the beam edge is defined
"k" = 0.51 gives the half beam width at -6dB drop in pulse-echo mode.

	"k" for Transmission mode	
Drop % dB	Circular transducer	Rectangular transducer
10% (20 dB)	1.08	0.60
50% (6 dB)	0.54	0.91
	"k" value for Pulse-echo	
10% (20 dB)	0.87	0.74
50% (6 dB)	0.51	0.44

Focused sound fields	The beam width can be reduced by focusing in the near-field zone using a lens $z_{foco} < N_0$ => zfoco: actual focal depth The focus position (zfoco) for a given lens radio is: $z_{foco} = \frac{R}{1-(V_M/V_L)}$ => VM: means de sound velocity in the specimen => VL: sound velocity in the lens material => R: lens curvature radius	
Focusing factor	A focused beam is characterized by: $S_{ac} = \frac{z_{foco}}{N_0}$	A focused beam can be classified by Sac as: 0.1 ≤ Sac ≤ 0.33 => strong focusing. 0.33 ≤ Sac ≤ 0.67 => medium focusing. 0.67 ≤ Sac ≤ 1.0 => weak focusing. Most of the industrial applications use: Sac < 0.6
Focusing Depth	$L_{focal} = 7\lambda\left(\frac{z_{foco}}{D}\right)^2$	The formula is only valid for Sac < 0.6
Focused beam diameter	$\Phi = S_{ac}\frac{D}{4} = \frac{z_{foco}D}{4N_0}$	The beam diameter in mm at -6dB drop
Inspection techniques		
Maximum thickness of specimen	$T_M = \frac{T_c V_M}{V_C}$	The maximum thickness of material (TM) that can be inspected is limited by coupling medium height (Tc), such as water, plexiglass, etc. VC => Sound velocity in coupling medium. VM => Sound velocity in specimen. 
Skip distance (SD)		The "skip distance" is the surface distance from the probe "index point" where the sound beam returns to the surface. This distance must be calculated to determine the probe distance to the weld to provide full inspection coverage for the component thickness. Probe angle => θ TM => Thickness material. $S_D = 2T_M tg(\theta)$
Half skip distance (HSD)		The "half skip distance" is the surface distance from the "probe index point" to the point on the surface above the point where the sound beam reaches the backwall of the component. $H_{SD} = T_M tg(\theta)$ Half-skip-beam-path length (HSBPL) = AD = TM/cos θ Full-skip-beam-path length (FSBPL) = AD + DC = 2TM/ cos θ
Flaw identifications		DPL1 => Flaw depth from the surface, considering the first leg SP => Sound path - without reflection on the backwall $D_{PL1} = S_P cos(\theta)$
		DPL2 => Flaw depth from the surface, considering the second leg SP => Sound path, including the reflection on the backwall TM => Material thickness $D_{PL2} = 2T_M - S_P cos(\theta)$

Testing round parts

Relationship between wedge length and part radius

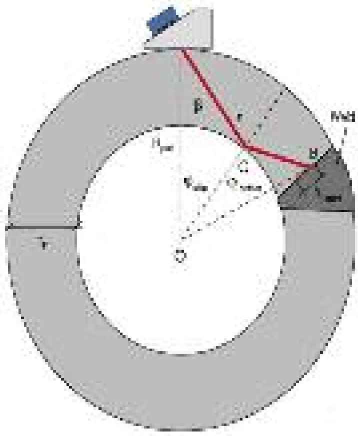


It is recommended, for contact inspections, that if the wedge is not shaped, the wedge length (LWedge)meets the following condition

$$R_{part} > \frac{L^2_{wedge}}{4}$$ => R_{part}: Outer radius

As a rule of thumb, the height between the wedge extremes and the round part must be ≤ 0.5mm

Ultrasonic examination of an axial weld pipe



The ultrasonic beam path and the reflected angle on the inner surface change when performing an inspection of an axial weld on a pipe.

$$\beta_{max} = \sin^{-1}\left(1 - \frac{T_P}{2R_{part}}\right)$$

$$\sin\varepsilon = \left[\frac{1}{(1-2T_P/R_{part})}\right]\sin\beta$$

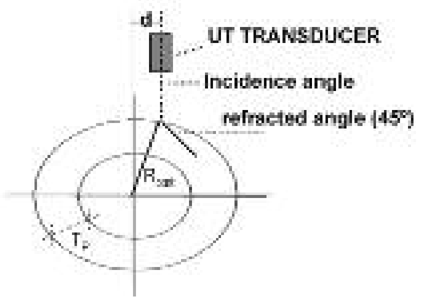
$$\varphi = \pi - (\beta + \varepsilon)$$

$$h_{defect} = OB - 0.5(R_{part} - 2T_P)$$

TP => Pipe thickness
RPart => Outer radius
βmax => Maximum probe angle
φ => Radial angle
hDefetc => Defect height
OB => The distance from the tube center to the top of the defect

Offset distance for generation of a 45º shear beam

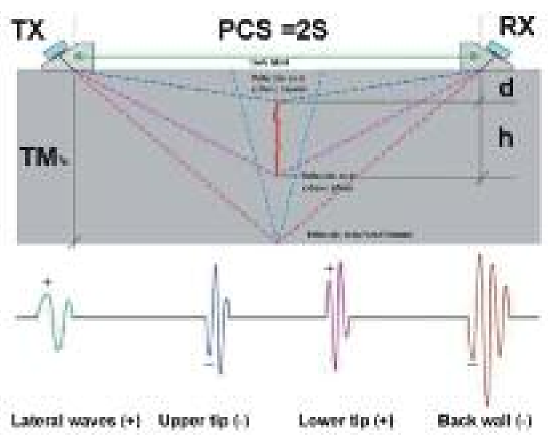
$$d = 0.707 R_{part} \frac{V_w}{V_T}$$



The inspection procedure must be carried out by immersion.

d => Offset distance from the centerline.
Rpart => Outer radius.
VW => Ultrasound longitudinal velocity in water.
VT => Velocity of refracted shear beam in the test material.
TP => Material thickness.

Time-of-flight difraction technique



$$T_{lat.wave} = \frac{PCS}{V_L} = \left(\frac{2S}{V_L}\right)$$

$$T_{uppertip} = \frac{2\sqrt{(S^2+d^2)}}{V_L}$$

$$T_{lowertip} = \frac{2\sqrt{(S^2+(d+h)^2)}}{V_L}$$

$$T_{BW} = \frac{2\sqrt{(S^2+TM^2)}}{V_L}$$

PCS => Probe center separation.

TLat.Wave => Time-of-flight lateral wave.

S => Distance from the probe index point to the weld center.

d => Upper ligament.

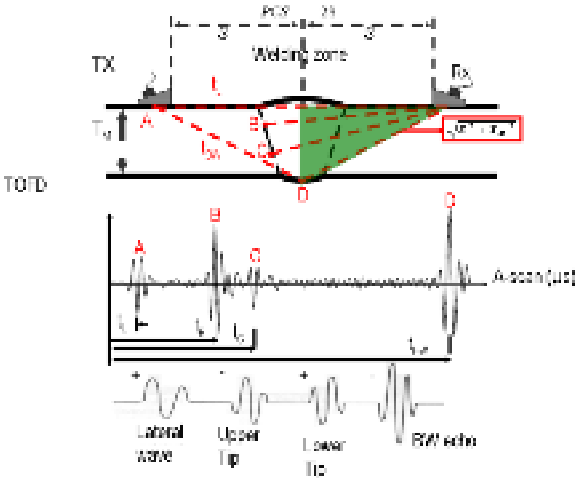
h => Defect height.

VL => Ultrasound longitudinal velocity.

TPP => Time-of-flight to the backwall.

TM => Material thickness.

Time-of-flight difraction technique



PCS => Probe center separation.

TM => Material thickness.

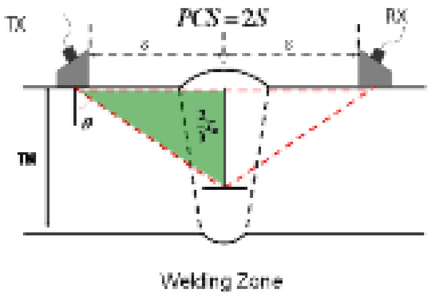
VL => Velocity of propagation of longitudinal waves in test material.

VT => Velocity of propagation of shear waves in test material.

* The time-of-flight of the lateral shear wave must be greater than the backwall time-of-flight.

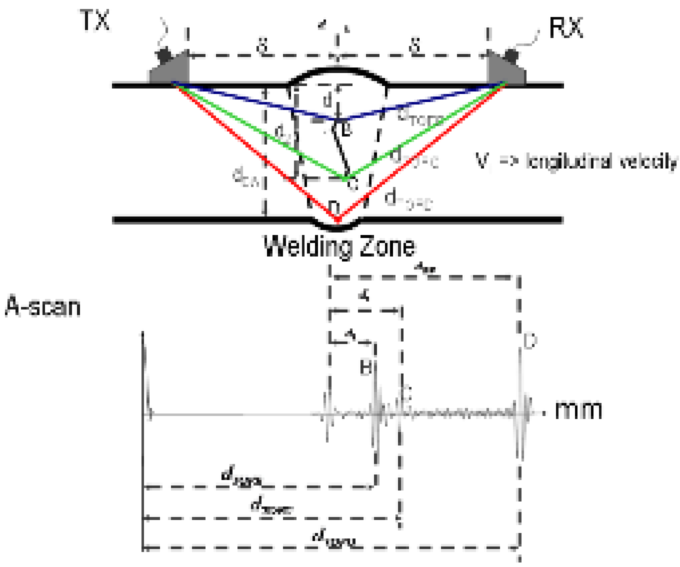
$$t_t(Transversal) > t_{bw}(Longitudinal)$$

$$\left.\begin{array}{l} \frac{2S}{V_T} > \frac{2\sqrt{S^2+T_M^2}}{V_L} \\ V_L \approx 2V_T \\ PCS = 2S \end{array}\right\} \Rightarrow PCS > \frac{2T_M}{\sqrt{3}}$$



The beam is incident at the selected input angle – θ - , in two-thirds of the material thickness - TM -

$$\left.\begin{array}{l} \tan\theta = \frac{S}{\frac{2}{3}T_M} \\ PCS = 2S \end{array}\right\} \Rightarrow PCS = \frac{4}{3}T_M \tan\theta$$



VL => Velocity of propagation of longitudinal waves in test material.

tB=> Time-of-flight echo coming from point B.

tC => Time-of-flight echo coming from point C.

tD => Time-of-flight echo coming from the backwall - point D.

dTOFB => Distance from B to the receiver transducer.

dTOFC => Distance from C to the receiver transducer.

dTOFD => Distance from the backwall to the receiver transducer.

d1=> Depth of point B.

d2=> Depth of point C.

dBW=> Depth of point D.

$$d_{TOFB} = \frac{V_L t_B}{2}$$

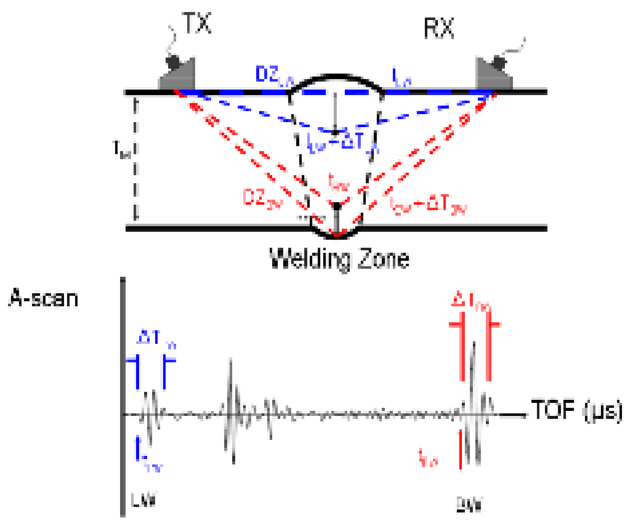
$$d_{TOFC} = \frac{V_L t_C}{2}$$

$$d_{TOFD} = \frac{V_L t_D}{2}$$

$$d_1 = \frac{1}{2}\sqrt{V_L^2 t_B^2 - 4S^2}$$

$$d_2 = \frac{1}{2}\sqrt{V_L^2 t_C^2 - 4S^2}$$

$$d_{BW} = \frac{1}{2}\sqrt{V_L^2 t_D^2 - 4S^2}$$



f => Emitting frequency of wide band transducers with a duration pulse of ΔTLW = 1.5/f.

TM => Material thickness.

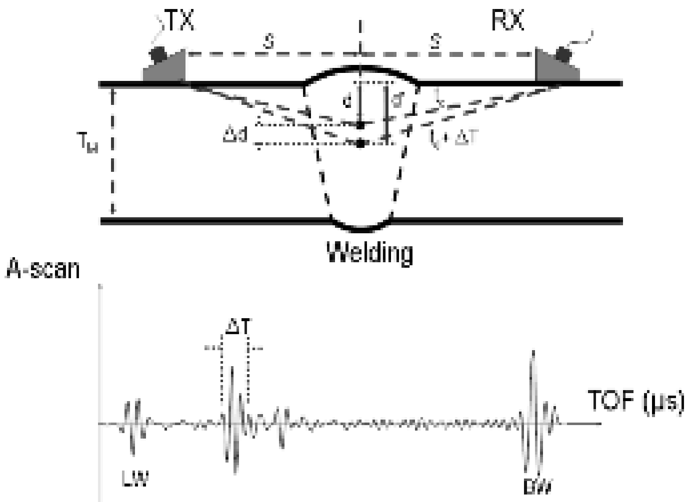
VL => Velocity of propagation of longitudinal waves in test material.

DZLW => Dead zone of the lateral wave INCREASES when frequency (f) DECREASES.

$$DZ_{LW} = \frac{1}{2}\sqrt{V_L^2\left(\frac{2.5}{V_L}+\frac{2}{f}\right)^2 - 4S^2}$$

DZBW => Dead zone of the backwall echo INCREASES when frequency (f) DECREASES.

$$DZ_{BW} = \sqrt{V_L^2\left(\frac{\sqrt{S^2+T_M^2}}{V_L}+\frac{1.5}{2f}\right)^2 - S^2} - T_M$$



The spatial resolution (Δd) is the ability of the ultrasonic signal to distinguish two separate reflectors along the depth of the test material. The spatial resolution (Δd) is a function of pulse duration (ΔT) that INCREASES as the depth (d) INCREASE.

$$\Delta d = d' - d$$

$$\Delta d = \frac{1}{2}\sqrt{V_L^2(t_o+\Delta T)^2 - 4S^2} - d$$

$$\Delta T = \frac{1.5}{f}$$

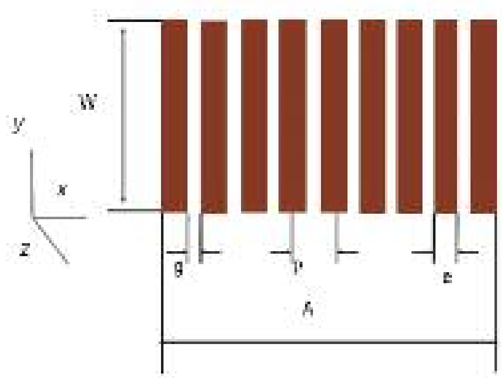
Phased array

Active aperture

$$A = (n-1)p + e$$

$$p = e + g$$

$$W = 1.4\sqrt{\lambda(F_{min}+F_{max})}$$



The Active Aperture is the total probe active length

A => Active aperture.

g => Gap between two adjacent elements

e=> Width of a single piezocomposite element, its typical value is ≤ λ/2.

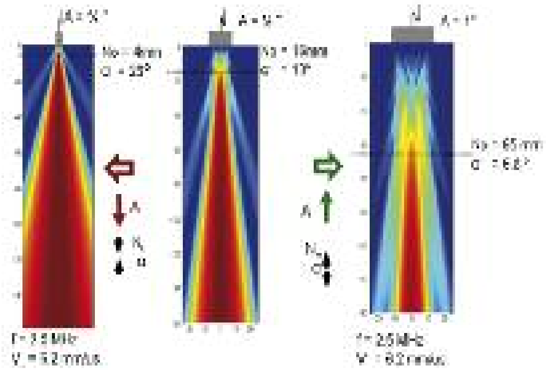
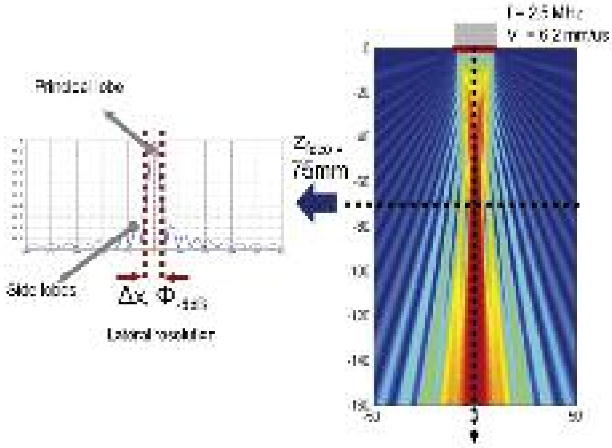
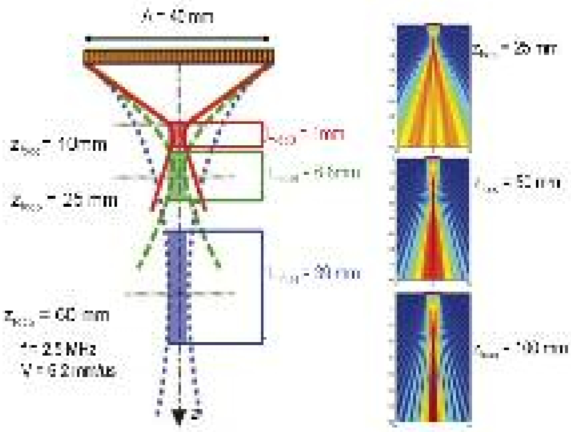
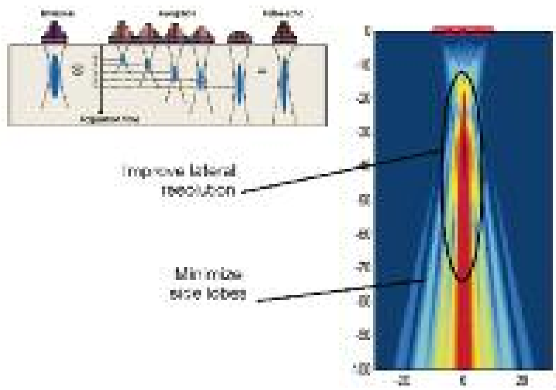
n => Number of elements.

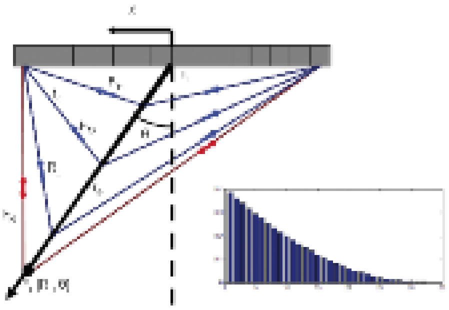
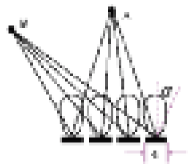
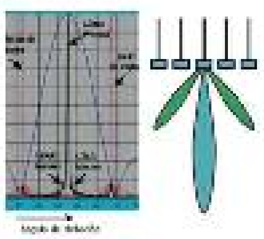
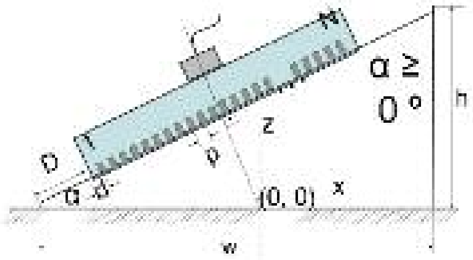
λ => Wavelength.

p (pitch) => It is the elementary distance between the centers of two adjacent elements.

W => Passive aperture is the element length or width. It determines the focal length on y-axis.

Fmin – Fmax => Maximum and minimum focal depths.

Near-field		The near field depends on the aperture size. $$No = \frac{A^2}{4\lambda}$$ A => Active aperture. No => Near field.
Beam width		The beam width depends on the focal depth and the active aperture size. $$\Phi_{-6dB} = K_{BW}\frac{z_{foco}A}{4No}$$ zfoco => Focal depth. κBW => Constant that depends on width criteria: κBW => 1 (Rayleigh criteria) κBW => 1.22 (FWHM - Full Width at Half Maximum - criteria) κBW=> 1.33(Sparrow criteria) Δx => Lateral resolution is defined by the beam width. Δz => Axial resolution is given by $$\Delta z = \frac{V\Delta T_{-20dB}}{2}$$ ΔT-20dB - Echo duration at a -20dB drop-off. V=> Sound velocity in the test material.
Focus depth		For a given aperture (A), the focus length (L) DECREASES as the focal distance (zfoco) DECREASES. $$L_{-6dB} = 7.2\lambda\left(\frac{z_{foco}}{A}\right)^2$$ The maximum focal distance (zfoco(MAX)) must be inside the near-field No. $$z_{focal(max)} < No$$ A => Active aperture. V => Velocity of propagation.
Dynamic Depth Focusing (DDF)		The DDF dynamically changes the focal distance as the signal returns to the phased array probe. It significantly increases the depth-of-field, resolution and SNR.

Calculation of emitting focal law – angular sweep	 $DLE = \frac{1}{V_M}\left(R_E - \sqrt{R_E^2 + x_i^2 - 2x_i R_E \sin\theta}\right)$ $DLR = \frac{1}{V_M}\left(F_{Rn} - \sqrt{F_{Rn}^2 + x_i^2 - 2x_i F_{Rn} \sin\theta}\right)$	DLE => Emission delay time. DLR => Reception delay time. θ => Steering direction. xi => Position of the element “i”. FE => Distance from the array centre to the emitting focal point in polar coordinates (RE,θ). FR1, FR2, FR3, ...=> Distance from the array centre to the reception focal point “n”. rin => Distance from the reception focal point “n” to the element “i” - round-time-of -flight VM=> Ultrasound velocity in the test material.
Max. steering angle	 $\sin(\theta_{STmax}) = 0.5\frac{\lambda}{e}$	Maximum steering angle depends on the element size θSTmax => Maximum steeering angle at -6dB. e => Width of a single array element. λ => Wavelength.
Grating lobes	 $\beta_{Grating} = \sin^{-1}\left(\frac{m\lambda}{p}\right)$ $m = \pm1, \pm2, \pm3, ...$	Grating lobes are generated by sub-sampling across the probe elements. Grating lobe amplitude depends on pitch size, number of elements, frequency and bandwidth. βGrating => Location of grating lobes. p => Pitch. λ => Wavelength.
Wedge Calculation	 $\alpha_i = \sin^{-1}\left(\frac{V_W \sin\beta_i}{V_M}\right)$ $E_h = (L_1 + L_2)\sin\omega + \left(H_i + \frac{p}{2}(n-1)\right)\sin\omega$ $P_w = \frac{E_h}{\cos\alpha_i}$ $D_w = \frac{2P_w}{V_W}$ $I_i = (L_1 + L_2)\cos\omega - H_w\tan\omega + P_w\sin\alpha_i$	αi => Incident angle for a specific refracted angle from snell's law. Eh => Height of the middle of the phased array probe – virtual emitting point. Pw => Ultrasound path in the wedge. Dw [μs] => Time-of-flight for specific angles in the wedges. Ii => The index point length is the distance from teh back – or front – of the wedge to the exit point of a specific angle. ω => Wedge angle. Hi => Height in the middle of the first element. Hw => Wedge height –back. βi => Refracted angle in the test material. p => Pitch. L1 => Distance from the middle of the first element to the emitting point. L2 => Distance from the emitting point to the intersection with the horizontal line – wedge contact surface. VW=> Ultrasound velocity in the wedge. VM=> Ultrasound velocity in the test material.
Data size	$Data = K_s \times D_L \times R_s$ $\frac{I_S}{S_{AR}} < A_R$	KS => Number of samples per line – S-scan length. DL => Number of acquired lines. RS => Number of triggers – C-Scan length. IS => Inspection speed [mm/s]. SAR => Scan axis resolution [mm]. AR => Acquisition rate [B-scan/s].