Ultrasonic Transducers for NDT

IMMERSION

TOFD

PHASED ARRAY

FLEXIBLE

SPECIAL
### SUMMARY

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Context

Non Destructive Testing (NDT) based on ultrasound is the use of ultrasonic waves to detect, locate and characterize defects in materials, components and assemblies. This technique has evolved enormously over fifty years and changes have been particularly rapid over the last twenty years.

Other NDT techniques (X Rays, Eddy Currents, Visual Inspection, Thermography, etc) complement ultrasonic techniques. Whichever technique is used, the purpose is to ensure that the materials, components or structures are of a satisfactory quality.

The evolution of the performance requirements of NDT has been determined by developments in quality requirements. The history [1] of the development of these techniques has thus been marked by the evolution in the objectives of inspections: the "zero defect" objective of the 1960s was replaced in the 1970s by the objective of detection of "critical defects", followed in the 1970s-1980s by the objective of improving the detectability of defects.

It should be noted that the term Non Destructive Evaluation (NDE) has developed for this evolution towards the characterization of defects.

The 1980s-1990s were then marked by the objective of continuous and improved NDT of the systems and structures that are subject to ageing.

In the 1990s-2000s appeared the needs to inspect very large areas, to monitor continuously the health of certain structures through Structural Health Monitoring (SHM), and, at the same time, to reduce the cost of inspections and other evaluations.

The quality requirements behind NDT techniques is currently centred on establishing the key parameters of dimension, shape, orientation and detectability of defects.

In the light of these objectives, the development of the performance of NDT systems plays an essential role in connection with the development of science and techniques in the related fields of material physics, design of components and structures, analysis of the constraints in the life of components and structures, fracture mechanics, reliability evaluation, economic demands, etc.

The techniques of NDT based on ultrasound is gaining interest for several reasons:
- they can be implemented without risk to operators or to the environment
- they can be used on an extremely large range of different materials and at a wide range of depths of use
- they have improved their performance, flexibility and speed through the Phased Array transducer concept and through progress in modelization, microelectronics and microcomputing.

For more than twenty years, IMASONIC has been contributing, with their customers and their partners, to the constant evolution in the techniques of ultrasonic NDT.

With piezocomposite technology, we have been able to increase, in particular:
- the performance in sensitivity
- the focusing capacity [without lens, including aspherical]
- the feasibility of custom-designed and custom-manufactured Phased Array transducers

This progress continues with the development of conformable solutions to improve the conditions of inspection for many components.

IMASONIC Overview

IMASONIC is an independent, privately-owned company that develops and produces ultrasonic transducers for high socio-economic added-value applications.

IMASONIC’s vocation can be summed up as follows:
- to act for the benefit of man and his environment, in particular in the interests of health, safety and quality
- to advance the profession of designer and manufacturer of ultrasound transducers and to do this creatively, innovatively and productively
- to increase recognition of the company and its leading position through the quality of its relationships with customers and partners.

IMASONIC’s vocation can also be seen in the willingness to collaborate over the long term with its customers and partners.

IMASONIC is ISO9001: 2008 certified.

80% of the total turnover is exported to all five continents.

Around 67% of the total turnover is dedicated to safety and quality applications, mainly for Non Destructive Testing and industrial measurement.

Customers for NDT transducers and probes are end users, service companies, equipment manufacturers and laboratories.

The main applications for NDT are: power generation, aeronautics, car industry, railways, petrochemicals and metallurgy.

Located in the east of France, close to Switzerland, in a region famous for its microtechnologies and watch industry, IMASONIC is founded on the skills of its team of 95 employees (2016).
Transducers for NDT applications based on ultrasounds

The IMASONIC offer

The wide variety of NDT applications and methods leads to a great range of needs. Over 25 years, IMASONIC has acquired considerable experience in the demands of NDT, and can offer the capacity to design and manufacture transducers adapted to this variety.

A transducer adapted to each application
IMASONIC offers customers its team's expertise and its design capacity to define with them the appropriate transducers for their applications. This service includes, in particular, feasibility studies associating simulation and/or prototyping. In addition, IMASONIC can also provide customers with access to their partner network of specialists for associated needs related to transducers.

"Customized" transducers
Some NDT needs require the development of transducers dedicated to a target application. IMASONIC proposes the production and characterization of "made-to-measure" transducers, defined according to detailed specifications. IMASONIC's piezocomposite technology has a very large capacity for adaptation to the most varied needs. Over twenty years, IMASONIC has developed a high level of expertise in providing for these types of needs.

"Standard" or "near-standard" transducers
Other NDT needs may be met with transducers whose design may be described as "standard" or "near-standard". For these needs, IMASONIC has developed a technological platform where, in a large number of cases, certain parameters on a predefined design base can be adapted. This approach offers very competitive prices and rapid delivery, while still offering a high level of quality, reliability and reproducibility.

Quantities
IMASONIC's industrial and commercial organisation is able to respond appropriately to requirements from just a few units up to production runs of several thousands of units.
IMASONIC’s commitments

In a context where the technical and economic performance stakes are high, IMASONIC makes the following commitments:

**Quality**
In order to provide the most appropriate response for the performance requirements, IMASONIC undertakes to seek from the customer the specific needs for each application. In seeking the highest quality, we also propose and implement solutions adapted to the different development stages, from feasibility studies to finished products destined for industrial applications with reproducibility requirements.

**Standards**
IMASONIC undertakes to identify with its customers the requirements that apply to the transducers. IMASONIC’s commitment is also demonstrated through their contribution to work on establishing industry standards.

**Transducer specifications**
IMASONIC undertakes to collaborate closely with its customers to identify the essential requirements, conformity criteria and verification conditions (tests and measurements). On delivery, these specifications are completed by recommendations on conditions of integration and use, to reduce any risks linked to an inappropriate use of the product.

**Characterization**
IMASONIC undertakes to verify conformity to essential requirements and acceptance criteria through tests and measurements. A formal report presents the results. IMASONIC also undertakes to offer characterization solutions that are reproducible and connected to the appropriate standards where they exist.

**Reliability and durability**
IMASONIC undertakes to collaborate with its customers to identify any risks of failure from the viewpoint of conditions of integration and use, and to check the reliability of the products in their using conditions.

**Confidentiality**
IMASONIC takes all necessary steps to protect the confidential information of its customers from unauthorized disclosure or use and thus to protect their interests. In particular, this commitment can be formalized by signing non-disclosure agreements.
Alerts
IMASONIC undertakes to alert its customers if any uncertainty arises regarding the relevance of a study or a manufacturing process in connection with the reliability of a transducer or the safety of its use.
### General Technical information

#### Transducers key components

**Piezocomposite material**
Specially designed piezocomposite structure is inserted in each type of probe. The composite components and geometry are defined according to the temporal and frequency response specifications, while retaining high sensitivity and signal-to-noise ratio level. For phased array probes, the piezocomposite structure is also designed to lower the cross-coupling between elements, which is necessary to properly steer the beam with electronic delay laws. Typical cross-coupling is lower than –30dB.

**Matching layers**
Taking into account the conditions of use of the probe (manual, automated, direct contact, contact with a wedge), the matching layer is designed to optimize the transfer of energy, to shorten the pulse width and to protect the piezocomposite.

**Backing material**
The backing material is designed to shorten the pulse width and to attenuate the back echo. Specially-designed backing materials allow an interesting trade-off with high damping and high attenuation in reduced dimensions.

**Housing**
The housing is designed to combine the required geometry with the strength and watertightness of the probe. It can be adapted to mechanical or manual use.

**Cable**
Performance of the cable is also a key parameter for the overall performance of the probe. Its attenuation must be as low as possible, in particular for high frequency probes. Its electrical impedance is matched with the probe and electronic characteristics. The bending capability is optimized to access small areas, while keeping high mechanical resistance and constant electrical properties.

**Connector**
The connector is most often defined by the electronic system the transducer will be connected to. However, it must be adapted to handling and environmental constraints (frequency of handling, immersion, vibrations, etc), while guaranteeing consistent quality for the electrical contacts.
Technical Information
Bandwidth or pulse width?

The bandwidth of the probe is generally one of the main specifications. However, it is often specified instead of the pulse width.

When the bandwidth has a Gaussian shape, it is closely linked to the pulse width and specifying the bandwidth is enough to get the pulse width. However, when the shape of the bandwidth is not Gaussian, a rather long pulse can be obtained, as well as a bandwidth of more than 100%.

Some applications really require bandwidth, for example, when the received signal is significantly shifted to the low frequencies due to the attenuation of the material, or for harmonic imaging.

Most applications actually require axial resolution using a short pulse width and in this case it is more appropriate to specify the pulse width than the bandwidth.

In addition, the pulse width and bandwidth largely depend on the driving signal, the electrical impedance and the environment of the pulsers.

IMASONIC probes are optimized for and measured with a negative square pulse with a length of T/2.

See also new acoustic solutions for phased array probes page 22.
Coupling method

**Immersion**
The transducer and the inspected piece are immersed in a vessel, and the coupling of the ultrasonic beam is done by the liquid, usually water. This method provides the highest level of acoustic performance due to the constancy of the coupling and to the low ultrasonic attenuation in water, with proper management of unwanted bubbles.

It allows working with complex geometry parts, and many types of transducers, including curved ones, with no other dimensional constraints than those related to the vessel itself. This method is cumbersome to implement and maintain in case of large components. It also implies the compatibility of inspected parts and the possible mechanical scanners with the immersion. It is not compatible with manual use.

The immersion is sometimes confined in a local water box positioned at the control location, thus reducing the size of the equipment. The immersion can also be implemented with water jets (squirters) in which the ultrasonic beams are guided. They require delicate tuning and are reserved for probes of relatively small dimensions. In both cases, a waste water management is necessary.

**Contact with wedge**
A mechanical part, generally in rigid plastics material, enables the ultrasonic coupling between the probe and the inspected object. A fluid couplant is required at the probe-wedge and wedge-component interfaces.

This method does not require equipment such as a water tank, it is quick and inexpensive to implement, and is compatible with manual and automated inspections. However wedges reduce acoustic performances compared to immersion:

- Attenuation is higher than in water, and the signal loss becomes sensitive beyond 5 MHz and very critical beyond 15 MHz.
- The wedge-probe and wedge-component interfaces create disturbances that degrade the signal if the thicknesses of couplant are not perfectly homogeneous or if the surface of the component is not regular.

The wedges are easy to implement for planar probes and flat or cylindrical components interfaces. They are difficult to implement with curved probes or with inspected components having complex or variable geometry.

**Integrated wedges**
An integrated wedge allows a transducer to be more compact and often better adapted to industrial conditions. The coupling between the active part and the wedge is guaranteed by being glued during manufacturing. Thus it is constant and homogeneous, requires no maintenance and guarantees a high level of performance.
Removable wedges
Removable wedges have great flexibility and enable the same transducer to be used in several different configurations. They can also be replaced easily if they show wear or are damaged.

Contact with conformable wedges - NEW - patent pending
A flexible and robust membrane filled with water is fitted between the probe and the piece to be inspected, to ensure the transmission of ultrasound by combining the advantages of the immersion and contact with a wedge.

- The coupling is possible on parts with variable or complex geometry
- The acoustic performance is similar to immersion, thanks to transmission through water and acoustically invisible membrane.
- Manual and automated use are possible, in similar conditions to those of conventional wedges.
- A wide range of probes can be used, including linear and matrix arrays. Their active part can be formed. See transducers with conformable wedges page 39.

Direct contact on inspected part
In some cases, contact transducers can be used without a wedge, for example, if there is not enough space available, or to avoid interference echoes from the wedge. In this configuration, the unseen area below the surface is larger because of the ringing of the excitation signal. Furthermore, deflection without grating lobes at high angles will require smaller spacing, and consequently a larger number of elements. Finally, in this case, shear waves with mode conversion between the wedge and the part to be inspected cannot be generated.

Hard face
Wear and tear on the front face may have unexpected effects on probes, such as water penetration or modification of electroacoustical properties. Conversely, placing a protective layer may alter the pulse width and sensitivity due to the additional interface. For this reason, IMASONIC has implemented a new hard face material that combines appropriate acoustical impedance for high energy transfer and ten times higher resistance to wear than a conventional front face. See Wedges page 44.
Immersion single elements

Applications

- Automated inspection of various parts and materials:
  - Tubes, bars, plates inline inspection
  - Pipeline
  - Machined and forged parts
  - Metals, composite materials, ceramics, plastics, etc.

General Characteristics*

- Piezocomposite
- Acoustically matched to water
- Centre frequency (-6dB): from 200 kHz to 20 MHz
- Active area from 1 mm to 300 mm
- Relative bandwidth (-6dB): 60 to 90 %
- Circular or rectangular active area
- Flat or focused active area
- Watertight stainless-steel housing
- Connector or integral cable

Options*

- Spherical, cylindrical, or aspherical (see page 15) focusing
- Temperature up to 180°C in continuous or 250°C over short periods
- Pressure up to 600 bars
- Compatibility with chemical agents, oil, sea water
- Halogen-free
- Nuclear radiation withstanding

* Some combinations of active size, frequencies, focusing and options may not be feasible.
Design notes for immersion transducers

Online design
On this page of our website, you can do an on-line simulation of the main characteristics of the ultrasonic beam for circular immersion probes, according to the frequency, the active diameter and the focus.

www.imasonic.com
Search for Online Design

Useful formulas
Valid for flat circular transducers

Near field distance

\[ N = \frac{D^2}{4\lambda} \]  

D = active diameter  
\( \lambda \) = wavelength

Half angle of divergence

\[ \sin \theta = K \frac{\lambda}{D} \]  

K = 0.51 for -6dB drop  
K = 0.87 for -20dB drop

Beam diameter at near field distance for flat transducer

\[ W (-6dB) = 0.26 \cdot D \]
Technical Information
Piezocomposite advantages for immersion transducers

**Very high sensitivity**
The acoustic impedance of IMASONIC piezocomposite materials can be adjusted from approximately 10 to 15 MRay. This impedance, much lower than that of ceramics, is closer to that of water. This results in a better energy transfer which, combined with high electro-acoustic efficiency, gives a sensitivity that is 10 to 32dB higher than that obtained with monolithic piezoelectric ceramics.

**Focusing by shaping**
Thanks to IMASONIC technology, the shaping of the active area enables the beam to be focused without resorting to using a lens that absorbs some of the energy and only gives an approximate focus because of the phenomena of aberration.

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**IM transducers**

- IMASONIC Piezocomposite technology
- Spherical focus on request
- Straight connector or integral cable
- Connectors: UHF, BNC, Lemo, Microdot

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<tr>
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<th>Centre frequencies available (MHz)</th>
<th>Housing diameter (mm)</th>
<th>Housing length (mm)</th>
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*Standard configurations*
Enhanced focusing - FERMAT concept

Applications
Inspection of critical components and detection of tiny defects.
- Multizone billets inspection
- Thick plates inspection
- Heavy forged parts inspection
- Nuclear vessel inspection

Principle
The aspherically-focused active area is calculated to obtain the best focusing effect at a given location in the material with a given refracted angle, through a flat, cylindrical or toric interface. Moreover, a large transducer aperture combined with Fermat concept allows very high lateral resolution and signal-to-noise ratio.

It is typical used in immersion with pulse echo technique, but can also be used in contact with a delay line.

Advantages
- Very high resolution and signal-to-noise ratio
- Beam profile very close to simulation thanks to IMASONIC piezocomposite technology
- Fermat concept may be implemented on phased array probes, allowing flexible high-resolution beam focusing and beam scanning

Main Characteristics
- IMASONIC piezocomposite FERMAT technology
- Centre frequency (-6dB): from 1 MHz to 15 MHz
- Relative bandwidth (-6dB): 60 to 90 %
- Acoustic impedance matched to water or delay line
- Watertight stainless steel housing

Options
- Custom wiring (cable length, type or positioning, Connector type)
- Housing adaptation to mechanical setup (probe holder, wedge, etc)
- Adaptation to environnemental contraints (Temperature, pressure, radiation, vibration, etc)
TOFD Transducers

Typical Applications
- Weld inspection, steel components
- Detection and sizing of cracks

Principle
Using the TOFD (Time Of Flight Diffraction) technique, cracks are detected, sized and monitored, irrespective of their type and/or orientation, by using the diffracted sound initiating from the flaw tips.
Two transducers are used to transmit and receive.
The beam divergence is enough to cover the whole thickness of the inspected part, which is displayed between the lateral wave (surface) and the back-wall echo.

Advantages
- Possibility of detecting and sizing the defects
- Reduced dead zone
- Fast technique

General Characteristics
- IMASONIC piezocomposite technology
- Nominal frequency from 1 to 20 MHz
- High resolution/sizing capability because of a short pulse width
- Very high sensitivity/detection capability
- High reliability over time thanks to a design that is watertight and resistant to corrosion, compatible with permanent immersion under a metre of water
Standard TOFD series

- IMASONIC piezocomposite technology
- High sensitivity
- Short pulse width
- Designed for field conditions
- Standard housing

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<td>3-6 mm</td>
<td>Short</td>
<td>Ø 9.5 x L 20</td>
<td>M12 X 1.75</td>
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<td>12 mm</td>
<td>Standard</td>
<td>Ø 17 x L 29</td>
<td>M20 X 1.5</td>
<td>Lemo 00</td>
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Options
- Standard TOFD wedges (45°, 60°, 70°)
- Integrated cable
- High-pressure resistance for offshore application
- Compatibility with oil and chemical agents
- Compatibility with high temperature
Extra-flat TOFD for CRD* inspection

*control rod drive

Application
Reactor vessel cover penetration tubes inspection..

Principle
The very low thickness of the probes, combined with their curvature, allows them to be inserted between the control bars and the guide tubes. The transducers can thus inspect the guide tube and peripheral welds (Jweld) in TOFD mode.

The orientation of the transducers enables longitudinal or circumferential defects to be detected.

Advantages
Inspection feasibility, sensitivity, bandwidth.

General Characteristics
These transducers are adapted individually to the inspection constraints, and in particular to the handling, plating and coupling mode.
- Thickness < 2.5 mm (down to 1.5 mm)
- Nominal frequency: 4 to 5 MHz
- Adjustable PCS (Probe Center Spacing)
- Refracted angle range: 45 to 70° LW
- Radius of curvature: 70 mm (typical)
- Longitudinal or circumferential orientation
- Integrated cable

Options
- Water distribution device for the coupling
- Halogen-free
- Mechanical plating solution
- Mechanical guidance solution
- Transducer at 0° for thickness measurement
TOFD transducers for tube inspection

**Application**
Internal inspection of tubes.

**Principle**
The cylindrical geometry of probes and their small possible diameter enable them to be inserted into tubes for inspection from the inside in TOFD mode. The orientation of the transducers enables longitudinal or circumferential defects to be detected.

**Advantages**
Inspection feasibility, sensitivity, bandwidth.

**General Characteristics**
These transducers are adapted individually to the inspection constraints, and in particular to the handling, plating and coupling mode.
- Diameter: down to 12 mm
- Nominal frequency: 4 to 10 MHz
- Refracted angle range: 45 to 70° LW
- Longitudinal or circumferential orientation
- Integrated cable

**Options**
- see Options for Extra flat TOFD probes (page 18)

**Custom TOFD transducers**
TOFD probes can be customized on request to meet the requirements of your application. Some examples are:
- Integrated miniature probes for small spaces / short PCS (probe center spacing)
- Custom housing

**Note:** The TOFD technique is also compatible with phased array probes. See phased array probes, page 20.
Phased Array summary

Since 1989, IMASONIC has offered the widest range of phased array probes for industrial applications.

- The standard phased array probes benefit from standardized design that combines reliability, accuracy, performance and competitiveness.
- Customized phased array probes offer numerous possibilities for adaptation to the most demanding applications.

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Phased Array transducers

Array types
Phased array transducers consist of several elements that can be activated independently (See Phased Array Principle, page 48). We have grouped them below according to the main types.

- 1D Linear array*
- Curved linear array* (Concave or convex)
- Focused linear array*
- 1,5D array*
- 2D matrix array*
- Annular sectorial array*
- Annular array*
- Daisy array*
- Circular array (convex)*
- Encircling array (concave)*

This list is not exhaustive and other types of geometry of the elements that could be associated with shaping the active area (cylindrical or spherical, or aspherical prefocusing) offer a very wide feasibility field.

* According to EN-16018
New acoustic solutions for IMASONIC phased array probes

IMASONIC now offers four types of standard acoustic designs for its linear array probes.

**How to choose?**

- Use in direct contact with abrasive surface
  - Yes: Wear Resistant
  - No

- The probe is always used with the same coupling medium
  - No: Versatile
  - Yes

- Sensitivity and s/n ratio are more critical than pulse duration
  - Yes: Dynamic
  - No: Accuracy
**Versatile:**
The acoustic design is matched to the coupling medium (water, plexiglas, rexolite, etc.). The performances are slightly affected if the probe is used with another coupling medium. The design is optimized for both high sensitivity and damping in the range of 2.5 cycles (20dB) on average. This technology has been proposed by IMASONIC for several years.

**Dynamic - NEW:**
The acoustic design is particularly optimized to gain about 6dB sensitivity on average compared to versatile design, while keeping the same pulse length. This optimization is valid for the nominal coupling medium. When using the probe with other coupling media, performances degrade faster than the versatile technology.

**Accuracy - NEW:**
The acoustic design is particularly optimized to gain 0.5 to 1 cycle in pulse length on average compared to versatile design, while keeping the same sensitivity. This optimization is valid for the nominal coupling medium. When using the probe with other coupling media, performances degrade faster than the versatile technology.

**Wear resistant:**
The acoustic design is optimized to keep equivalent performance level than versatile design while implementing a front face 10 times more resistant to abrasion.

<table>
<thead>
<tr>
<th></th>
<th>NEW</th>
<th>NEW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Versatile</td>
<td>Accuracy</td>
</tr>
<tr>
<td>Acoustic matching to the coupling medium (water, plexiglas, rexolite, etc.)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Pulse length (cycles at -20dB)</td>
<td>2.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>Ref.</td>
<td>Ref.</td>
</tr>
<tr>
<td>Performance alteration when using with other coupling medium</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

The above mentioned values are indicative and may change depending on probes characteristics, particularly frequency, element size, acoustic matching, cable length, excitation signal.
Linear Array Transducers for steering

Applications
All applications require variable angles and inspection depths:
- General NDT, welds
- Pressurized components, rotors, shafts

Standard Configurations

<table>
<thead>
<tr>
<th>Freq (MHz)</th>
<th>Nb elts</th>
<th>Pitch P (mm)</th>
<th>Active length L (mm)</th>
<th>Active width h (mm)</th>
<th>Housing size <em>(indicative value)</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>32</td>
<td>0.3</td>
<td>9.6</td>
<td>8</td>
<td>17x14x35</td>
</tr>
<tr>
<td>10</td>
<td>64</td>
<td>0.25</td>
<td>16</td>
<td>10</td>
<td>24x16x35</td>
</tr>
<tr>
<td>10</td>
<td>128</td>
<td>0.25</td>
<td>32</td>
<td>10</td>
<td>40x18x40</td>
</tr>
<tr>
<td>5</td>
<td>16</td>
<td>0.6</td>
<td>9.6</td>
<td>8</td>
<td>17x14x35</td>
</tr>
<tr>
<td>5</td>
<td>32</td>
<td>0.5</td>
<td>16</td>
<td>12</td>
<td>24x18x40</td>
</tr>
<tr>
<td>5</td>
<td>64</td>
<td>0.5</td>
<td>32</td>
<td>15</td>
<td>40x20x40</td>
</tr>
<tr>
<td>5</td>
<td>128</td>
<td>0.5</td>
<td>64</td>
<td>15</td>
<td>75x22x45</td>
</tr>
<tr>
<td>2.25</td>
<td>32</td>
<td>1</td>
<td>32</td>
<td>20</td>
<td>40x26x35</td>
</tr>
<tr>
<td>2.25</td>
<td>64</td>
<td>1</td>
<td>64</td>
<td>20</td>
<td>75x26x35</td>
</tr>
<tr>
<td>2.25</td>
<td>128</td>
<td>1</td>
<td>128</td>
<td>20</td>
<td>140x28x40</td>
</tr>
</tbody>
</table>

* dimensions valid for probes with removable wedges, without flanges

Standard probes come with 3m cable, top or side output.
Standard connectors are Hypertronix/FRB, ITT Canon, Tyco, Conec, Ipex

Typical interface for attaching wedges is lateral flanges with holes or M3 captive screws (the position of the lugs is adjustable and the distance can be optimized to fit with all your existing wedges).
**Principle**
Generally, linear arrays for steering combine electronic beam steering and focusing. To avoid grating lobes (see technical information page 48), they require a relatively small inter-element pitch. The number of elements is typically less than 128, and even 64, as electronic scanning is not often used.

**Advantages**
These transducers can work with angles and electronically-adaptable focusing depths, i.e. without changing or moving the transducer. This allows, in particular:
- a smaller number of probes to be used,
- faster inspection.
They also allow a refracted, non-zero incidence beam to be generated without using a wedge, which opens new possibilities for when there is no room to use a wedge.

**General Characteristics**
- Frequency from 500 kHz to 15 MHz
- Unlimited number of elements, typically 8 to 128
- **NEW** Optimized signal/noise ratio and pulse width thanks to new acoustic solutions, see page 22
- Reproducibility of the inspection through the homogeneity of performance between the elements of the same probe, and between different probes of the same type
- High reliability over time thanks to a robust, watertight design, compatible with difficult industrial environments

**Options**
- Hard face for use in direct contact
- Integrated wedge
- Housing customized for the mechanical environment (inspected parts, scanner, wedges, etc)
- Customized connection – page 46
- Adaptation to a particular environment (temperature, pressure, radiation, chemical compatibility)
- Halogen-free for nuclear environments
- Water inlets
- Compliance with EN 16392-2 standard

**Accessories**
- Wedges – page 44
- Cable extensions and adaptors – page 47
- **NEW** - Compatibility with conformable wedges, see page 45
Linear Array Transducers for scanning or for long range inspection

Applications
Automated high-performance inspection of submerged parts: metal plates, bars, pipes, composite materials, forged parts, etc.

Principle & Advantages
The scanned length (L) is maximised by combining a large number of elements (typically between 64 to 256) to the widest possible inter-element pitch (p).
Electronic focusing can be combined with scanning, for example, to inspect at different depths. In general, electronic deflection is little used for this type of application.
• Inspection time is reduced because of the high speed of the electronic scanning combined with a large scanning width
• The scanning mechanism is simplified

Standard Configurations

<table>
<thead>
<tr>
<th>Freq. (MHz)</th>
<th>Nb elts</th>
<th>Pitch p (mm)</th>
<th>Active size L x h (mm)</th>
<th>Housing size L x W x H (mm)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>64</td>
<td>0.5</td>
<td>32 x 10</td>
<td>40 x 16 x 35</td>
</tr>
<tr>
<td>10</td>
<td>128</td>
<td>0.5</td>
<td>64 x 10</td>
<td>75 x 20 x 40</td>
</tr>
<tr>
<td>5</td>
<td>64</td>
<td>1</td>
<td>64 x 15</td>
<td>75 x 20 x 40</td>
</tr>
<tr>
<td>5</td>
<td>128</td>
<td>1</td>
<td>128 x 15</td>
<td>140 x 25 x 45</td>
</tr>
<tr>
<td>2.25</td>
<td>128</td>
<td>1.5</td>
<td>192 x 20</td>
<td>205 x 30 x 45</td>
</tr>
<tr>
<td>2.25</td>
<td>64</td>
<td>2</td>
<td>128 x 20</td>
<td>140 x 30 x 35</td>
</tr>
</tbody>
</table>

* indicative values

Accessories – See page 44 to 47
• NEW - Compatibility with conformable wedges, see page 45
General Characteristics

- Frequency from 300 kHz to 20 MHz
- Unlimited number of elements, typically from 64 to 512
- **NEW** Optimized signal/noise ratio and pulse width thanks to new acoustic solutions, see page 22
- Reproducibility of the inspection because of the homogeneity of the elements of the same probe and the different probes of the same type
- High reliability over time thanks to a design that is watertight and stainless, compatible with permanent immersion under a metre of water

Options

- Prefocused active area (see below)
- Housing adapted to the probe holder
- Low profile and side cable for wheel probe
- Halogen-free for nuclear environments
- Customized cabling
- Adaptation to a particular environment (temperature, pressure, radiation, chemical compatibility)
- Compliance with EN 16392-2 standard

Technical Information

**Mechanical Pre-focusing**

On linear arrays, electronic focusing is possible only in the plane of incidence. However, in the perpendicular plane (passive aperture), it is possible to adjust focal depth and lateral resolution by using mechanical pre-focusing, by choosing the appropriate radius of curvature, active width (h) and water path.
Small Footprint Linear Arrays

Applications
These transducers are designed for applications with reduced transducer access, or with surfaces with complex geometry where good coupling is not possible:
- Inspection of turbines, blade roots and fine welds.

General Characteristics
- Footprint ≤ 8 x 8 mm²
- Center frequency 5 to 15 MHz
- Number of elements: 8 to 20
- Other characteristics similar to standard linear probes

Options
- Hard face for use in direct contact
- Integrated wedge
- Other options similar to standard linear probes

Standard Configurations

<table>
<thead>
<tr>
<th>Freq. (MHz)</th>
<th>Nb elts</th>
<th>Pitch P (mm)</th>
<th>Active length L (mm)</th>
<th>Active width h (mm)</th>
<th>Footprint* (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>10</td>
<td>0.31</td>
<td>3</td>
<td>3</td>
<td>5x6</td>
</tr>
<tr>
<td>10</td>
<td>16</td>
<td>0.25</td>
<td>4</td>
<td>4</td>
<td>6.5x6</td>
</tr>
<tr>
<td>10</td>
<td>16</td>
<td>0.31</td>
<td>5</td>
<td>5</td>
<td>7x7</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>0.31</td>
<td>6</td>
<td>6</td>
<td>8x8</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>0.5</td>
<td>4</td>
<td>4</td>
<td>6.5x6</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>0.6</td>
<td>5</td>
<td>5</td>
<td>7x7</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>0.5</td>
<td>6</td>
<td>6</td>
<td>8x8</td>
</tr>
</tbody>
</table>

* without flanges or wedge attachment interface
Low Profile Linear Arrays

Applications
These transducers are designed for inspecting components with a very limited vertical clearance:
- Boiler tubes
- Feeder tubes
- Blade roots of turbines (see picture below)

General Characteristics
- Housing height ≤ 10 mm
- Center frequency: 5 to 15 MHz
- Number of elements: up to 64
- Other characteristics similar to standard linear probes

Options
- Hard face for use in direct contact
- Integrated wedge
- Other options similar to standard linear probes
Matrix Arrays

**Applications**
- Weld inspection
- Inspection of parts with complex geometry
- General NDT

**Principle & Advantages**
Matrix array transducers allow 3D beam focusing and scanning, thus opening up new possibilities:
- Control of the focal zone diameter in 3D, cylindrical beam
- Inspection of volumes from limited points of access
- Detection of defects that may have multiple, un-predetermined orientations

**Typical configurations for steering**
The matrix array transducer configurations in table below are designed for use when steering capabilities are required. The pitch is minimized to offer good elementary directivity and steering capability. Consequently, for a given number of elements, the active area is reduced and the beam diameter is larger.

<table>
<thead>
<tr>
<th>Freq. (MHz)</th>
<th>Elementary active size (mm)</th>
<th>Total active size (mm)</th>
<th>Number of elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1,2 x 1,2</td>
<td>10 x 10</td>
<td>8 x 8 = 64</td>
</tr>
<tr>
<td>5</td>
<td>0,6 x 0,6</td>
<td>5 x 5</td>
<td>or 11 x 11 = 121</td>
</tr>
<tr>
<td>10</td>
<td>0,3 x 0,3</td>
<td>2,5 x 2,5</td>
<td>or 16 x 16 = 256</td>
</tr>
</tbody>
</table>

**Typical configurations for depth / resolution**
The matrix array transducer configurations in table below are designed for use when depth and resolution capabilities are required. The pitch is larger compared to steering configurations. The steering capability is reduced, but for a given number of elements, the active area is larger and the beam diameter (lateral resolution) is thinner.
General Characteristics
• Frequency from 500 kHz to 15 MHz
• Unlimited number of elements, typically 16 to 1024
• High S/N ratio and optimized pulse width thanks to acoustic matching to wedge material (Rexolite, Plexiglas, PEI, etc)
• Reproducibility of the inspection through the homogeneity of performance between the elements of the same probe and between different probes of the same type
• High reliability over time thanks to a robust, watertight design, compatible with difficult industrial environments

Options
• Hard face for use in direct contact
• Integrated wedge
• Housing customized for the mechanical environment (inspected parts, scanner, wedges, etc)
• Customized cabling
• Adaptation to a particular environment (temperature, pressure, radiation, chemical compatibility)
• Halogen-free for nuclear environments
• Water inlets

Accessories
• Wedges – page 44
• Cable extensions and adaptors – page 47
• NEW - compatibility with conformable wedges - see page 45

Simulation of 3D beam steering capability

2D arrays

<table>
<thead>
<tr>
<th>Freq. (MHz)</th>
<th>Elementary active size (mm)</th>
<th>Total active size (mm)</th>
<th>Number of elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2 x 2</td>
<td>22 x 22</td>
<td>8 x 8 = 64</td>
</tr>
<tr>
<td>5</td>
<td>1 x 1</td>
<td>11 x 11</td>
<td>or 11 x 11 = 121</td>
</tr>
<tr>
<td>10</td>
<td>0.6 x 0.6</td>
<td>10 x 10</td>
<td>or 16 x 16 = 256</td>
</tr>
</tbody>
</table>

Annular sectorial arrays

<table>
<thead>
<tr>
<th>Freq. (MHz)</th>
<th>Active diameter (mm)</th>
<th>Average pitch (mm)</th>
<th>Number of elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>10</td>
<td>1.2</td>
<td>64</td>
</tr>
<tr>
<td>5</td>
<td>16</td>
<td>1.4</td>
<td>128</td>
</tr>
<tr>
<td>2.25</td>
<td>23</td>
<td>2</td>
<td>128</td>
</tr>
</tbody>
</table>
Typical configurations for high resolution annular sectorial arrays

Inspection of thick parts, forged parts, complex interface parts and difficult materials (coarse grain, non homogeneous).

The shaping of the active surface in a 2D array allows 3D beam steering and 3D correction of the focus, which can compensate, for example, for the defocusing effect of a complex interface or an anisotropic material. Furthermore, matrix immersion transducers, like annular arrays, allow electronic focusing at different depths.

As an option, Fermat surface pre-focusing (See Fermat concept page 15).

<table>
<thead>
<tr>
<th>Freq. (MHz)</th>
<th>Nb els</th>
<th>Active diameter (mm)</th>
<th>Housing size diameter x height (mm)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>128</td>
<td>40</td>
<td>50 x 60</td>
</tr>
<tr>
<td>7.5</td>
<td>128</td>
<td>50</td>
<td>60 x 60</td>
</tr>
<tr>
<td>5</td>
<td>128</td>
<td>60</td>
<td>70 x 60</td>
</tr>
<tr>
<td>2.25</td>
<td>128</td>
<td>80</td>
<td>90 x 60</td>
</tr>
</tbody>
</table>

* indicative value
Annular Array Transducers

Applications
- Thick parts
- Forged parts

Principle & Advantages
Using electronic focusing, the focusing distance and the depth of field can be changed, thus enabling thick parts to be inspected with excellent lateral resolution over a large depth range, without changing the transducer.

General Characteristics
- Frequency from 300 kHz to 20 MHz
- High sensitivity and signal-to-noise ratio, thanks to the acoustic matching to water allowing a very good transfer of acoustic energy
- Good axial resolution, and reduction of the unseen area below the surface thanks to a short pulse width (See note page 9)
- High reliability over time thanks to a design that is watertight and stainless, compatible with permanent immersion under a metre of water

Standard Configurations

<table>
<thead>
<tr>
<th>Freq. (MHz)</th>
<th>Nb elts</th>
<th>Active diameter (mm)</th>
<th>Housing size diameter x height (mm)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>8</td>
<td>18</td>
<td>25 x 40</td>
</tr>
<tr>
<td>10</td>
<td>16</td>
<td>25</td>
<td>35 x 40</td>
</tr>
<tr>
<td>10</td>
<td>32</td>
<td>35</td>
<td>45 x 45</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>35</td>
<td>45 x 40</td>
</tr>
<tr>
<td>5</td>
<td>16</td>
<td>50</td>
<td>60 x 40</td>
</tr>
<tr>
<td>5</td>
<td>32</td>
<td>70</td>
<td>80 x 50</td>
</tr>
<tr>
<td>2.25</td>
<td>16</td>
<td>80</td>
<td>90 x 50</td>
</tr>
<tr>
<td>2.25</td>
<td>32</td>
<td>110</td>
<td>120 x 50</td>
</tr>
</tbody>
</table>

* indicative value

Options
- Spherical or bifocal mechanical pre-focusing
- Housing adapted to the probe holder
- Halogen-free for nuclear environments
- Customized cabling
- Adaptation to a particular environment (temperature, pressure, radiation, chemical compatibility)

Accessories – See page 44 to 47
**Typical Applications**

- Wrought / cast stainless steel components, austenitic structures
- Dissimilar metal welds
- Clad components
- Safe end / sub clad of nuclear vessel
- Pressurised welds

**Principle**

Transducers with separate emission and reception, one linear or matrix array on each side.

Linear transducers allow a variable refraction angle.

Matrix transducers also allow the beam crossing depth to be varied or the beam to be deflected laterally.

**Standard configuration**

Please contact us for the standard configurations corresponding to your application.
Advantages

• Possibility of steering and skewing (matrix only) the beam
• Absence of dead zone
• Focusing effect in the beam crossing region
• Improvement of defect response
• Reduction of the backscatter signal
• Improvement of signal to noise ratio

General Characteristics

• Frequency from 500 kHz to 5 MHz
• Unlimited number of elements, typically 2x16 to 2x64
• High S/N ratio and optimized pulse width thanks to acoustic matching to wedge material (Rexolite, Plexiglas, PEI, etc)
• High acoustic insulation between transmit and receive sides
• High reliability over time thanks to a robust, watertight design, compatible with difficult industrial environments

Options

• Integrated wedge
• Housing customized for the mechanical environment (inspected parts, scanner, wedges, etc)
• Customized connection
• Adaptation to a particular environment (temperature, pressure, radiation, chemical compatibility)
• Halogen-free for nuclear environments
• Water inlets

Accessories

• TRL Wedges – page 44
• Cable extensions and adaptors – page 47

TRL Probe Design

IMASONIC can help you to design your TRL probe, and particularly the incidence angle, roof angle and distance between transmit and receive transducers to reach the targeted focal zone with the desired refracted angle.

We can also simulate in detail the beam crossing area to evaluate the detection and sizing capabilities of the probes.

With the customer’s agreement, IMASONIC can collaborate with partner companies with experience in inspection methods based on TRL probes, to offer already-qualified solutions for various inspections.
Conformable Array Transducers

Applications
Contact inspection of parts with irregular geometry
- Welds, bends, pipe repairs in nuclear power stations
- Turbine blades, composite materials
- Nozzles

Principle
1D or 2D phased array transducers are flexible, and can thus ensure good coupling on the geometry of the inspected part. The sensor integrates real-time measurement of each element’s position, and thus of the surface, so when it is used with compatible electronics, the delay laws can be adapted in real time to steer the beam by compensating for the variations of the interface.

Advantages
- Feasibility of certain inspections
- Improvement in focusing quality by being freed from the interface geometry
- Increase in lateral resolution through the use of larger active dimensions

Patented Concept
The concept implemented in these transducers, of updating the delay laws in real time according to the real position of individual elements, is covered by a patent registered with the CEA (Atomic Energy Commission, France). IMASONIC holds the exclusive licence for the use of this patent in designing and manufacturing these transducers.
Smart Conformable Linear Arrays (1D)

The individual elements are mechanically articulated, allowing convex and concave active profile in the scanning direction.

Configurations already developed*

<table>
<thead>
<tr>
<th>Freq. (MHz)</th>
<th>Number of elements</th>
<th>Pitch (mm)</th>
<th>Total aperture (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>24</td>
<td>1.7 x 22</td>
<td>41 x 22</td>
</tr>
<tr>
<td>1.5</td>
<td>48</td>
<td>1.5 x 20</td>
<td>72 x 20</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>1.4 x 17</td>
<td>34 x 17</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>1.4 x 17</td>
<td>45 x 17</td>
</tr>
<tr>
<td>4</td>
<td>24</td>
<td>0.9 x 9</td>
<td>22 x 9</td>
</tr>
</tbody>
</table>

* These configurations have been developed and tested for given application. The list is not exhaustive, and the concept of 2D conformable transducers can be adapted to match other applications requirements.

Options
Inclinometer allowing to calculate the delay laws in real time taking into account the probe inclination.

Low profile Contact Linear Arrays (1D)

1D extra flat array adapted to convex or concave surface

Applications
The extra flat flexible probe are based on the same acoustic concept as the 1D smart conformable probes, but with low profile. The real-time delay law calculation device is not included in these probes. They can be used for thickness measurement / corrosion detection on tubes & pipes with various radii, from internal or external diameter. They can be also adapted to inspecting parts with restricted access and already known surface, with pre-registered delay.
Smart Conformable Matrix Arrays (2D)

The active elements are embedded in a flexible membrane which allows concave or convex deformation in two dimensions, to adapt complex and variable profiles.

Configurations already developed*

<table>
<thead>
<tr>
<th>Freq. (MHz)</th>
<th>Number of elements</th>
<th>Elementary Pitch (mm)</th>
<th>Elementary size (mm)</th>
<th>Total active aperture (mm)</th>
<th>Radius of curvature (mm)</th>
<th>Steering range (°)</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tot. 1st Axis 2nd Axis</td>
<td>1st Axis 2nd Axis 1st Axis 2nd Axis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>84 12 7</td>
<td>2.8 4 1.8 2.5</td>
<td>34 x 28</td>
<td>Spherical R 50</td>
<td>0-30</td>
<td>20-100</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>64 8 8</td>
<td>3.5 4 2.5 2.5</td>
<td>32 x 28</td>
<td>Spherical R 50</td>
<td>0-30</td>
<td>20-100</td>
<td></td>
</tr>
<tr>
<td>2.7</td>
<td>60 12 5</td>
<td>1.5 3 1.0 2.0</td>
<td>18 x 15</td>
<td>Spherical R 45</td>
<td>0-50</td>
<td>35-55</td>
<td>8-30</td>
</tr>
<tr>
<td>3.3</td>
<td>48 12 4</td>
<td>1.2 3.1 0.6 2.0</td>
<td>12.5 x 25</td>
<td>Spherical R 25</td>
<td>0</td>
<td>20-60</td>
<td>8-15</td>
</tr>
</tbody>
</table>

Low frequency Conformable Matrix Arrays (2D)

The active array is made of individual elements with 2 rotations and 1 translation axis, and allows concave and convex deformation in two dimensions.

The elements are encapsulated in metal housing and are compatible with halogen free requirements

Configurations already developed*

<table>
<thead>
<tr>
<th>Freq. (MHz)</th>
<th>Number of elements</th>
<th>Total active aperture (mm)</th>
<th>Radius of curvature (mm)</th>
<th>Steering range (°)</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tot. 1st Axis 2nd Axis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>60 10 6</td>
<td>125 x 109</td>
<td>Spherical R 120</td>
<td>0-45</td>
<td>70</td>
</tr>
<tr>
<td>0.6</td>
<td>60 10 6</td>
<td>75 x 76</td>
<td>Spherical R 50-80</td>
<td>0-45</td>
<td>50-60</td>
</tr>
</tbody>
</table>

* These configurations have been developed and tested for given application. The list is not exhaustive, and the concept of 2D flexible transducers can be adapted to match other applications requirements.
NEW: Transducers with conformable wedge

**Principle**

The conformability is obtained with a flexible membrane filled with water between the transducer and the inspected component. The coupling between the membrane and the component requires a small quantity of water or couplant.

**Advantages**

The conformable wedge combines (see coupling methods page 10)
- The acoustic performance of immersion technique with good coupling and low attenuation
- The flexibility and ease of use of contact technique
- The compliance with non-regular and/or variable surface geometry

**Main features**

- Compatible with most types of arrays (linear, matrix, focused, curved, etc.)
- Acoustic performance close to water thanks to acoustically invisible membrane
- Wear resistant membrane *
- Halogen free
- Bubble trap system
- Easy implementation and easy membrane replacement
- Good chemical stability

* No damage observed after a run of 0.5Km at 10cm/s over a corroded steel part with Ra of 20μm, with lubrication and load of 1Kg

**Options**

- Angled and 10° membranes
- Water inlets for coupling between wedge and inspected part
- Lateral guides for manual use
- Mechanical interface for automated use with scanner
Curved Linear Array Transducers

Applications
These transducers are an adaptation of flat linear arrays for the inspection of parts with circular symmetry. The linear scanning becomes circular to adapt to inspection of tubes, bars or sections.

Principle
360° or sector electronic beam scanning is combined with electronic focusing and beam steering.
- Scanning speed can be adapted to the water path.
- Focusing depth and inspection angle can be electronically selected depending on the tube/bar configuration.

General Characteristics
- Frequency from 1 MHz to 20 MHz
- Number of elements unlimited, typically 64 to 512
- High sensitivity and signal-to-noise ratio, thanks to the acoustic matching to water that allows a very good transfer of acoustic energy.
- Good axial resolution and reduction of the unseen area below the surface thanks to a short pulse width (See note page 9)
- Reproducibility of the inspection through the homogeneity of performance between the elements of the same probe, and between different probes of the same type.
- High reliability over time thanks to a watertight and corrosion-resistant design, compatible with permanent immersion in a metre of water in difficult industrial environments.

Standard Configuration
Actually there is no standard configuration. The frequency, the number of elements, the spacing and the radius of curvature are defined according to the tubes, bars or sections to be inspected, the defects to be detected and the desired inspection speed in particular.

Options
- Pre-focused active area (See page 27)
- Housing adapted to the probe holder
- Customized cabling
- Adaptation to a particular environment (temperature, pressure, radiation, chemical compatibility)
Technical Information
A single circle or multiple sectors?

For 360° inspection of tubes or bars, either a single encircling probe or an arrangement of several probes each covering a sector, typically 45° to 90°, can be considered.
Both possibilities offer various advantages and disadvantages.

The sectional probes require a certain overlap for a homogeneous inspection of the whole circumference. They must therefore be placed in at least two rows, which requires greater axial space. Because of the necessary overlap, a greater total number of electronic channels are also required. A single probe has the advantage of needing less space, and of optimizing the number of useful channels since no overlap is needed.

The inspection of bars or tubes often requires the use of several simultaneous beams on the same circumference. In the case of a single probe, the reflexions of a beam may cause interference to the inspection with other beams. Arranging the probes over several rows enables this effect to be limited where necessary.

Finally, while the purchase price of each option is not very different, the maintenance cost of the sectional curved probes is markedly lower, as only part of the circumference may need to be replaced.
Daisy Array Transducers

Application

Internal tube and bore inspection (fig. 1)
External tube inspection (fig. 2)

Principle

The ultrasonic beam is emitted by a flat circular transducer and is reflected on the part to be inspected using a mirror. Electronic scanning allows the beam to be turned through 360°, without rotating the probe or the mirror. The choice of the angle of the mirror enables the beam to be given a straight or oblique incidence.

General Characteristics

- Frequency from 5 to 15 MHz
- Number of elements: 32 to 256 (according to the tube diameter)
- Minimum internal tube diameter (for internal probes): 15 mm
- High sensitivity and signal-to-noise ratio, thanks to the acoustic matching to water that allows a very good transfer of acoustic energy
- Good axial resolution, and reduction of the unseen area below the surface thanks to a short pulse width [See note page 9]
- Reproducibility of the inspection through the homogeneity of performance between the elements of the same probe, and between different probes of the same type

Options

- Centring device
- Water input device
- Mechanical interfacing with the pusher-puller
- Customized connection
- Adaptation to a particular environment (temperature, pressure, radiation, chemical compatibility)
Circular Array Transducers

Application
Internal tube inspection

Principle
The circular active part with radial radiation allows 360° scanning of the inner wall of the tube, without a mirror and without mechanical rotation. The radiating part can be cone-shaped to give the beam a non-zero angle of incidence.

Specifications
The design of this type of probe must integrate the different constraints linked to the application in a very interdependent way:
• The geometry of the tubes to be inspected: the diameter, lengths, curvature, regularity of the geometry, defects to be detected and sizing;
• The inspection method: the method of centring the probe and of traction in the tube;
• The performance expected: the axial and lateral resolution and the inspection speed;
• The environmental constraints: the temperature pressure, radiation, pressure, coupling liquid, etc;
• The cable length required.

In general, this type of probe requires several design stages in order to validate the different points above.
For this reason, we do not propose a standard configuration, or even general characteristics, but we do recommend the preliminary drawing up of a set of specifications (See page 6) integrating the above specifications.

Do not hesitate to contact us for further information on this type of product, in particular to assess the relevance of using it for your application.
Phased Array Coupling Solutions

Wedges for Contact Transducers

IMASONIC offers a wide variety of wedges for contact probes, fully adaptable to transducers and their conditions of use.

**Main Characteristics**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Typical indicative values, can be changed on request</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incidence angle</td>
<td>35-70°SW in steel / 0-70° LW in steel / 0° (Delay line)</td>
</tr>
<tr>
<td>Material</td>
<td>Rexolite or Plexiglas</td>
</tr>
<tr>
<td>Transducer attachment</td>
<td>2 to 4 threaded metal inserts</td>
</tr>
<tr>
<td>Anti-reverberation system</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Options**

- Skew angle on request
- Customized contact face geometry to fit inspected parts or wedge focusing

<table>
<thead>
<tr>
<th>Option</th>
<th>Typical indicative values, can be changed on request</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface with probe holder</td>
<td>One hole on each lateral side on the wedge</td>
</tr>
<tr>
<td>Irrigation system</td>
<td>Two water inlets connected to a groove on the contact face</td>
</tr>
<tr>
<td>Wear pads</td>
<td>4 carbide inserts on the contact face to prevent excessive wear on wedge</td>
</tr>
<tr>
<td>High temperature</td>
<td>High temperature material and integrated water cooling system</td>
</tr>
</tbody>
</table>
Wedge interface
IMASONIC offers as standard design M3 captive screws. Thin flanges with or without holes remain available on request to fit all wedge designs.

Conformable wedges
Conformable wedges combine acoustic performance of immersion and ease of use of contact technique. Moreover, they comply with non-regular and variable surface geometry. See page 39.

Technical Information
Plexiglas or Rexolite?
These two materials are the most commonly used for ultrasonic probe wedges. Rexolite is a very interesting material with low attenuation and low sound velocity of 2350 m/s. It is thus well adapted for reduced-size wedges, thanks to its smaller angle, and for high frequency probes (7.5 MHz and more), thanks to low attenuation combined with shorter acoustic path. Plexiglas is more resistant to abrasion in some cases, its higher attenuation helps to attenuate internal reverberations in the wedge.
**Phased Array Connection Solutions**

**Cable Characteristics**
The standard IMASONIC cables offered on phased array transducers have been carefully selected for their mechanical and electrical properties.
- Little loss through attenuation or signal filtering
- Good flexibility
- Good mechanical resistance to handling
- Compatibility with most industrial environments

<table>
<thead>
<tr>
<th>Cable type</th>
<th>Multi-coaxial 50 Ohms cable with overall shielding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of channel</td>
<td>Up to 16</td>
</tr>
<tr>
<td>Up to 64</td>
<td></td>
</tr>
<tr>
<td>Up to 128</td>
<td></td>
</tr>
<tr>
<td>Up to 256</td>
<td></td>
</tr>
<tr>
<td>Cable diameter</td>
<td>4.1 mm</td>
</tr>
<tr>
<td>5.6 mm</td>
<td></td>
</tr>
<tr>
<td>7.8 mm</td>
<td></td>
</tr>
<tr>
<td>8.7 mm</td>
<td></td>
</tr>
<tr>
<td>Minimum static radius of curvature</td>
<td>25 mm</td>
</tr>
<tr>
<td>32 mm</td>
<td></td>
</tr>
<tr>
<td>50 mm</td>
<td></td>
</tr>
<tr>
<td>60 mm</td>
<td></td>
</tr>
<tr>
<td>Minimum dynamic radius of curvature</td>
<td>50 mm</td>
</tr>
<tr>
<td>64 mm</td>
<td></td>
</tr>
<tr>
<td>100 mm</td>
<td></td>
</tr>
<tr>
<td>120 mm</td>
<td></td>
</tr>
<tr>
<td>External jacket</td>
<td>Black PVC</td>
</tr>
<tr>
<td>Black PVC</td>
<td></td>
</tr>
<tr>
<td>or halogen free PU</td>
<td></td>
</tr>
<tr>
<td>Black PVC</td>
<td></td>
</tr>
<tr>
<td>Black PVC</td>
<td></td>
</tr>
</tbody>
</table>

Specific cable for high radiation or with low attenuation on request

**Cable Protection Options**
IMASONIC can offer several different cable protection options adapted to particular environments on request.

**Connector Protection Options**
An optional protective jacket can be placed on the connector.

**Connector Types**
IMASONIC phased array transducers are compatible with most systems on the market. The different standard connectors are available. Among them are the following: Hypertronix/FRB, Tyco, ITT Canon, Ipex, Conec, ODU [non-exhaustive list]. See on the left.
Cable extensions & Adaptors

In addition to phased array transducers, IMASONIC offers extension cables and adaptors, for connecting several probes to a system, or a probe and a system with different connectors.

The cable lengths and the number of channels are specified individually. The cable protection options are also available for extensions and adaptors (within the limit of technically possible lengths).

IMASONIC extensions and adaptors have all been tested electrically, to check that the cabling is in perfect order and that there are no short circuits.

Examples of cable extensions and adaptors
Phased Array Principle

The principle of phased array technology is to activate for each shot all or some of the transducer elements which, with the adapted delay laws, contribute collectively to the generation of the beam.

Electronic Commutation (Multiplexor)

The beam is electronically translated by alternatively firing a given number of elements of a linear or circular phased array transducer.

This technique is an alternative to the mechanical translation of a single element probe. The advantages are:
- Faster inspection
- No mechanical movement required, or reduction of scanline number
- Possibility of combining with electronic focusing and beam steering (See below and next page)

Delay Laws

Electronic Focusing

The beam is electronically focused by applying symmetrical delay laws to the different elements of a linear or annular phased array transducer.

This technique is an alternative to using several transducers to focus at different depths. The advantages are:
- Only one probe for focusing at each depth
- Dynamic focusing speeds up the inspection of thick pieces
- Electronic focusing can compensate for focusing aberrations due to refraction at interfaces
Electronic Steering
The beam is electronically deflected by applying delay laws to different elements of a linear, circular or matrix array. Linear and circular arrays allow for 2D beam steering, while matrix arrays allow for 3D beam steering.

This technique is an alternative to using several transducers at different angles. The advantages are:
- Only one transducer is required for inspection at variable angles
- Faster inspection of parts with complex geometry
- This technique can be combined with electronic focusing

Full Matrix Capture and Total Focusing Method
FMC (Full Matrix capture) is a specific data acquisition process; each element of an array is successively used as the transmitter, while all other elements are used as receivers.
The efficiency of this acquisition is linked to the directivity diagram of each element: the smaller the element, and the wider the directivity.
When the entire element has been fired, the data acquisition is complete and TFM can be used for data processing.

TFM (Total Focusing method) is a method where the array is focused in emission and reception at every point of the image. This gives very good resolution and high image quality, but does not provide any information on the nature of the defect.
Grating Lobes
When using a phased array transducer, delay laws are applied to each channel to generate
a beam with a given refraction angle and focal distance.
The ultrasonic beam is generated by the constructive interference of each transducer element’s
contribution in the desired direction.
In some cases, this interference can also be constructive in other directions.
These lobes of energy emitted outside the electronically driven direction are called grating lobes.
These energy lobes can interact with the part to be inspected in the same way as the main
beam, and thus generate echoes causing interference to the inspection. Therefore they have
to be avoided as much as possible.
The angle of the position of grating lobes in relation to the main beam is given
by the following formula:

$$\sin \Theta_k = k \cdot \frac{\lambda}{p} \cdot \sin \Theta$$

Note: this formula is only valid in the case of electronic deflection (linear delay law).
In the case of electronic focusing, the angular deviation between the main beam and
the grating lobes is reduced.

From the above formula, the following general rule can be obtained:

• If \( p < \frac{\lambda}{2} \), then no grating lobe is generated whatever the angle of the main beam
• If \( p > \lambda \), then there is always at least one grating lobe generated whatever the angle
  of the main beam
• Between these two values, the grating lobes appear progressively according to the angle
  of the main beam. The maximum pitch to avoid grating lobe is given by the formula:

$$p < \frac{\lambda}{1 + \sin \Theta}$$
In practice, for typical use in the 30-70° SW or LW range with a wedge for a 45° angle, a pitch of 1.0 \( \lambda \) gives good results.

**Lateral Resolution along the Plane of Incidence**

The following formula allows a good approximation to be made of the lateral resolution, and a quick check of the link between the active aperture and the lateral resolution.

\[
W = 0.44 \cdot \frac{\lambda}{\sin \left( \frac{\alpha}{2} \right)}
\]

\( W \) = focal spot or beam width (at –6dB in emission reception)

\( \lambda \) = wave length in the medium under consideration

\( \alpha \) = angle beneath which the active area is seen from the focal point

Note: This formula is a rough estimate valid when the hypothesis of electronic focusing at the focal point under consideration is made. It does not take into account the energy refraction/reflection law depending on the angle.

**Number of Elements**

Knowing the inter-element spacing required to avoid grating lobes and the width of the active aperture, the number of elements necessary can be rapidly deduced.

If the appropriate number of electronic channels is not available for technical or economic reasons, the best possible compromise must be found, by readjusting the inter-element spacing, the frequency, and/or the active aperture (and thus the lateral resolution).

Note: Some linear array transducers are also used for electronic scanning. In this case, the beam is generated by only some of the elements. To calculate the lateral resolution, only the size of the active area is taken into account.
These two pages illustrate other IMASONIC capabilities through examples of transducers dedicated to medical applications. These features can be adapted to NDT transducers for new or challenging applications.

Transducers for medical diagnosis

High frequency transducers for high resolution imaging
(eye and skin imaging, frequency up to 20 MHz)
very high sensitivity - direct focusing

Photoacoustic imaging
The technology developed by IMASONIC has important advantages for applications such as photoacoustic imaging, where the level of sensitivity in reception combined with a wide bandwidth is very important

Dual frequency transducers
These transducers are designed with two frequency peaks, as illustrated on the spectrum on the right, with 1 MHz and 2 MHz peaks.

This kind of feature can be used for application based on harmonic imaging or non linear acoustics. It can also comply with requirements of high attenuation materials that generate important filtering effects toward the low frequencies.
High power transducers for therapeutic applications

IMASONIC is the world leader for high power transducers dedicated to medical therapy through HIFU technology (High Intensity Focused Ultrasound).

HIFU is a state of the art acoustic ablation technique, using the power of ultrasound to accurately destroy deep-seated tissues without surgery, and without harming surrounding tissues.

IMASONIC high power technology combines high power capability, direct shaping of the active element, and compatibility with array patterns (see table below).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustic power surface</td>
<td>Up to 30W/cm²</td>
</tr>
<tr>
<td>Efficiency</td>
<td>50 to 70%</td>
</tr>
<tr>
<td>Frequency range</td>
<td>200 kHz to 10 MHz</td>
</tr>
<tr>
<td>Shaping capability</td>
<td>F number down to 0.5 (half sphere)</td>
</tr>
<tr>
<td>Size range</td>
<td>Up to 300mm</td>
</tr>
<tr>
<td>Array capability</td>
<td>Yes</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>30 to 70%</td>
</tr>
<tr>
<td>MRI compatibility</td>
<td>yes, on request</td>
</tr>
</tbody>
</table>

High power ultrasound can also be used for Vibroacoustography, a novel imaging for nondestructive inspection of materials. This is an ultrasound-based imaging technique that uses the dynamic (oscillatory) radiation force of low-frequency excitation (within kilohertz range) to remotely vibrate objects and detect the ensuing acoustic emission.

The generation of high power ultrasonic beams can also be used for application based on non linear-acoustics, like detection of closed cracks or lack of adhesion in composite structures.