Acertara Technical Publications Series

A Guidebook for Understanding and Using Ultrasound QA Phantoms

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Rev 1.0

ULTRASOUND GUIDEBOOK SERIES

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Introduction and Scope

This Guidebook was designed and developed to provide Sonographers, HTMs, Medical Imaging Physicists, and others responsible for the care and maintenance of ultrasound systems and transducers/probes, with the necessary technical information to understand the design, function, and use of a contemporary quality assurance (QA) ultrasound phantom.

Definitions of Several Key Terms Used in Text

- *Detail Resolution*: A measure of the minimum spacing of distinguishable point targets.
- *Point-Spread-Function (PSF)*: see **note** below.
- *Contrast Resolution (Tissue)*: A measure of the minimum echogenicity difference of distinguishable neighboring soft tissue regions.
- *Contrast Resolution (Anechoic Objects)*: A measure of detectability of anechoic objects in the presence of strong off-axis objects.
- *Sensitivity*: A measure of the minimum detectable echogenicity.
- *Temporal Resolution*: A measure of the fastest detectable object motion relative to the transducer.
- *Dynamic Range*: A measure of the maximum echogenicity difference of targets simultaneously detectable.
- *Attenuation*: The systematic reduction in acoustic energy as it passes through various media within the body.
- *Artifact*: A B-mode imaging artifact is an echo reflection displayed in a different location than its corresponding reflector in the body.
- *Grating lobes*: Unwanted acoustic energy deviating from the main acoustic beam that causes objects that are not directly in front of the transducer to be displayed incorrectly in the lateral position.

NOTE: The point spread function (PSF) is often analyzed to determine the image quality of an ultrasound system. The formation of PSF is determined by practical factors such as transducer aperture, element directivity, apodization, pitch, imaging position and steering angle. Conventional numerical simulations provide an iterative approach to examine those factors' effects but cannot explain the inherent mechanism of PSF formation. However, the effects can be observed when using a high-quality Tissue Mimicking Phantom (TMP)

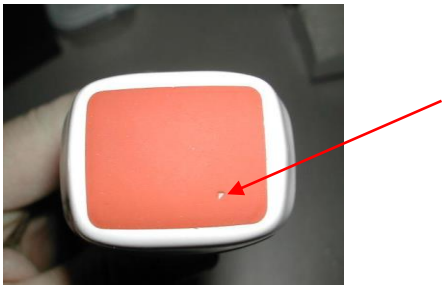
What is the Role of Tissue Mimicking Phantoms in a QA Program?

"*Although daily QA steps done by sonographers do not require a phantom, more detailed checks of image display and performance are best done using a phantom or other test device. With a tissue-mimicking phantom, periodic test results are compared with initial baseline results of machine or transducer performance. The baseline results are obtained either when a machine is accepted or when the QA program is initiated. Records are maintained of baseline and periodic test results, and Goodsitt et al, provide examples of forms for this purpose. Another example of a form that includes checks of cleanliness and safety is included below. Goodsitt et al, also list tolerance and action levels that guide clinical users if periodic QA test results vary from baseline levels. Equipment manufacturers may also recommend tolerance levels for some tests. Users should follow the phantom manufacturer's guidelines when storing and caring for their phantoms. Phantoms have been known to deteriorate over time, so it is important to follow the phantom manufacturer's recommendation for certification or recertification schedules. It is recommended that the date of production and dates of recommended recertification of a phantom's properties be clearly indicated on the device*."

Reference: Methods for Specifying Acoustic Properties of Tissue-Mimicking Phantoms and Objects 2nd Edition, AIUM Technical Standards Committee

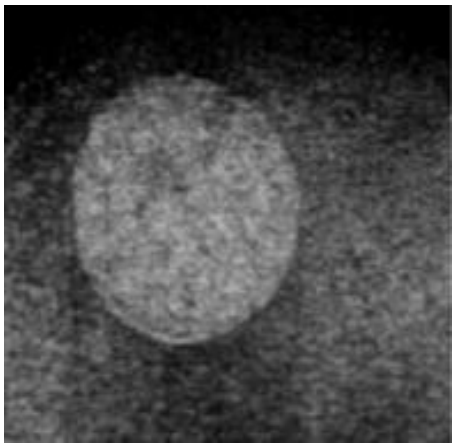
Probe testing should always begin with a visual inspection of the transducer contact or wear-surface (e.g., the acoustic lens). Frequent probe use coupled with cleaning and high-level disinfection, can wear or damage (e.g., pin-prick hole in the lens as shown below) this surface, permitting caustic fluids, gels, or microorganisms' ingress to the inner portions of the probe. A simple 10x magnifying glass, or loupe, is optimal for this visual inspection. It is important to understand that Quality Assurance (QA), Quality Control (QC), and Preventative Maintenance (PM) are often interchanged words but are not functionally the same. The focus for this Guidebook is testing fully integrated probes that are separated from the sonograph but still part of an operating system.

Always ensure prior to using a tissue mimicking phantom that the probe has been thoroughly cleaned and disinfected. After the test make sure the probe is cleaned from acoustic gel and that the gel used with the phantom is also cleaned from the phantom surface. Place the phantom on a solid level surface prior to testing.



The Anatomy of an Ultrasound QA Phantom

Ultrasound phantoms (phantoms) have played a central role in the performance evaluation of both ultrasound systems and probes since the late 1970s. They were then and are now used to establish a baseline of performance for the ultrasound system and probe(s) when the products were first received by the end user, and as a QA tool for on-going life-cycle performance testing. Since their inception more than 40 years ago phantoms have evolved in design parallel with technological advances in both ultrasound systems and probes. Because ultrasound devices in the late 1970s used analog scan converters that tended to drift as a function of time, early use of phantoms was limited to measuring geometries of embedded targets to ensure that circles were circles and ovals were ovals when displayed on the ultrasound monitor, see image below. If they showed distortion, then the service technician would re-calibrate the scan converter to correct the displayed geometry. With the advancement of digital scan converters and expansion of gray scale display electronics phantoms were developed to look more closely at reflections that resembled what was being seen in patient scans. Phantoms became known as tissue mimicking phantoms and were designed accordingly using tissue mimicking materials and targets.



Although it is beyond the scope of this guidebook to discuss in detail each topic listed below, the Author recommends for those who want more detail on each subject to obtain and read the AIUM reference document listed below.

Basics of a Tissue Mimicking Phantom (TMP):

- A test object containing Tissue Mimicking Material (TMM) that simulates certain acoustic and physical properties of human tissue,
- May also contain various types of embedded reflective objects/targets,
- To assess diagnostic ultrasound system and probe performance over time – QA

Simulated properties of TMPs:

- Speed of Sound
- Attenuation Coefficient
- Backscatter Coefficient or Relative Contrast
- Elasticity
- Thermal Properties
- Mechanical Properties

Important Properties for Ultrasound Quality Assurance

- Speed of Sound
- Attenuation Coefficient
- Backscatter Coefficient

Reference: Methods for Specifying Acoustic Properties of Tissue-Mimicking Phantoms and Objects 2nd Edition, AIUM Technical Standards Committee, go to www.aium.org

Various Types of materials used for TMP Targets

Wires

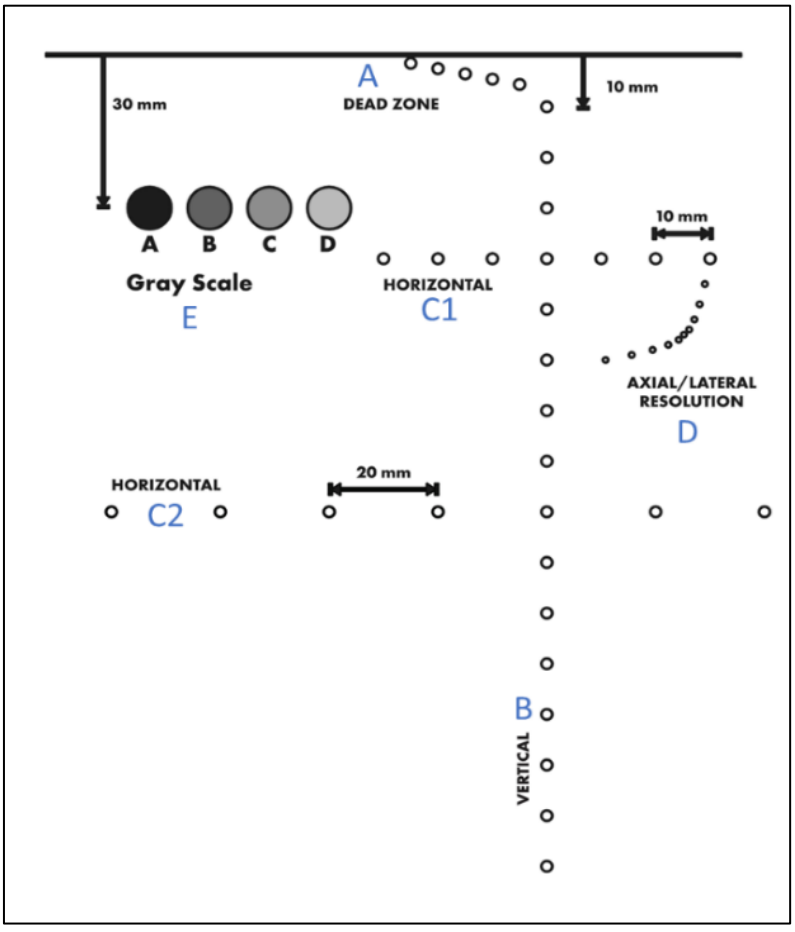
Properties

- 0.1mm -0.3mm diameter
- Nylon monofilament
- Stainless steel

Cylindrical & Spherical Anthropomorphic Objects

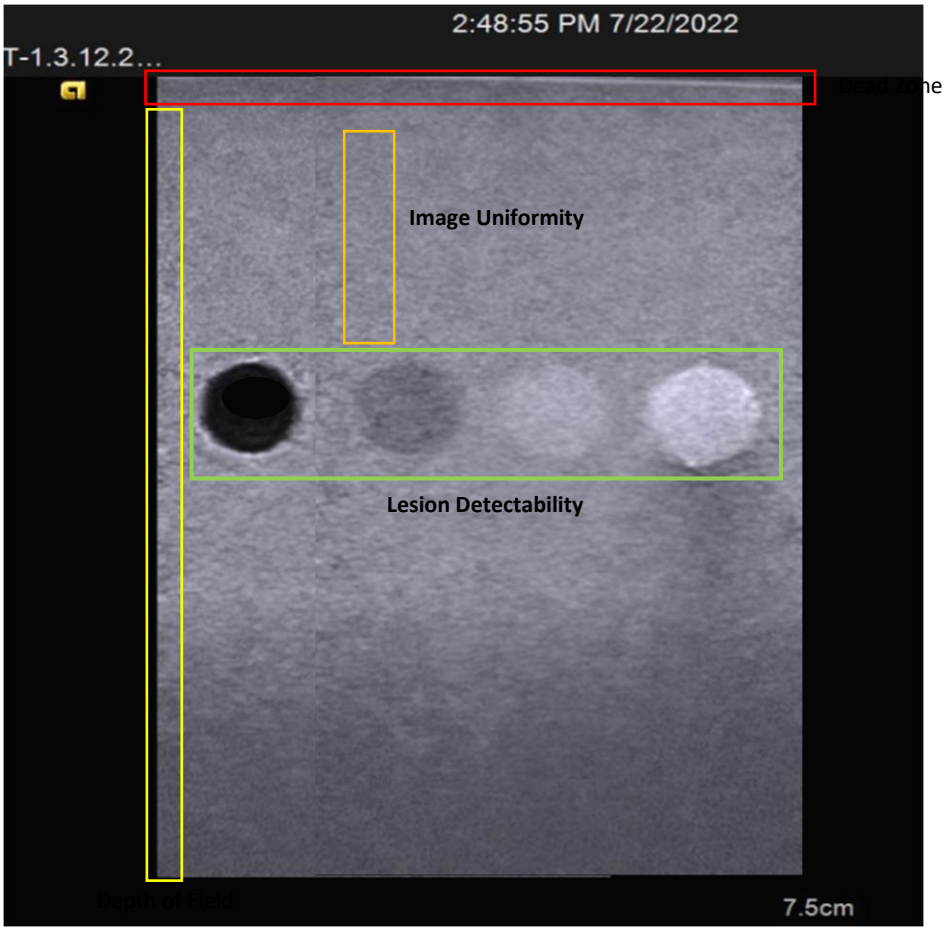
Properties

- >1mm diameter
- Varying contrast relative to background
- Varying stiffness relative to background material



Typical Tissue Mimicking Phantom Quality Assurance (QA) Measurements

B-Mode Parameters
- Image Uniformity
- Depth of Penetration (aka Depth of Visualization)
- Axial and Lateral Resolution (**see Page 10**)
- Near Field/Dead Zone
- Lesion Detectability
  - high contrast (anechoic objects
  - low contrast (gray scale objects)



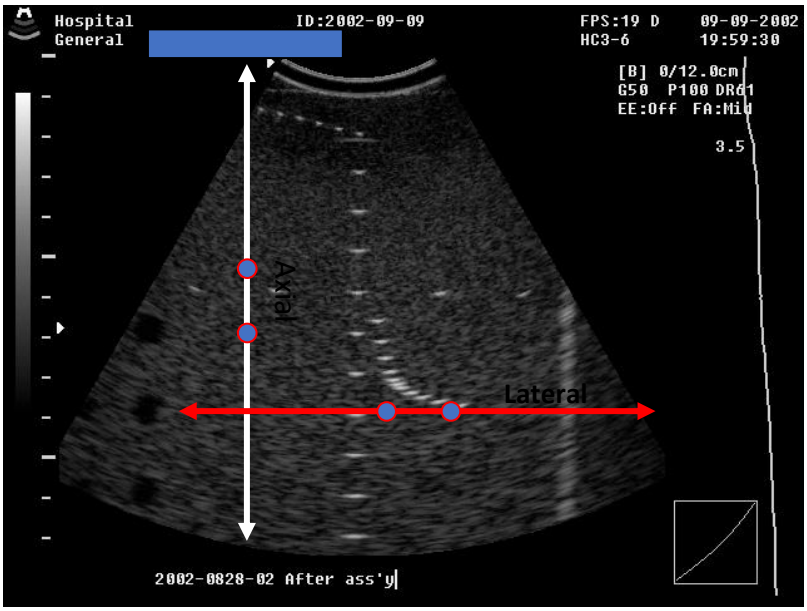
NOTE: The dead zone is the distance from the front face of the transducer to the first identifiable echo at the phantom/patient interface. The dead zone occurs because an imaging system cannot send and receive data at the same time. Therefore, no clinical data can be collected in this region. The depth of the dead zone depends upon the frequency and performance of the transducer and the pulsing/receiving section of the system.

Core Parameters of Image Quality When Using a Tissue Phantom

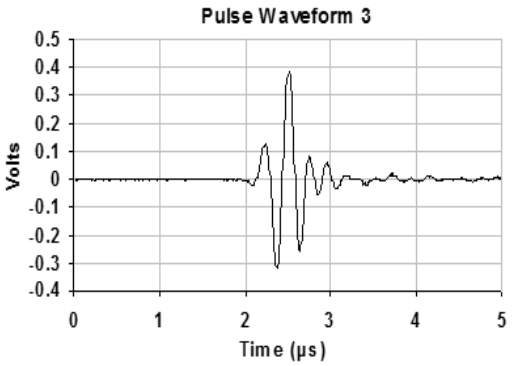
Before determining how to assess the performance of a probe we need to take just a few moments and detail what is generally agreed to make an ultrasound image a “good” image. It is well known that, even though ultrasound image quality is thought of as subjective in nature, there are certain parameters of the image that can be objectively measured, and act as surrogate indicators of good “image quality”. For the sake of brevity, this Guidebook will focus on seven of the most important acoustic parameters that can be observed using a contemporary tissue mimicking phantom:

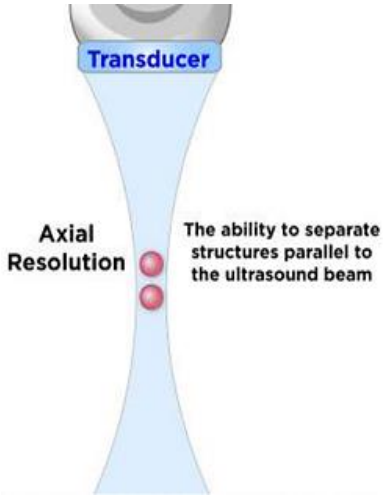
(1) spatial resolution,
(2) point-spread-function (PSF) also referred to as “beam spread”,
(3) contrast resolution,
(4) sensitivity,
(5) attenuation,
(6) depth of field, and
(7) image uniformity.

Spatial Resolution, also referred to as detail resolution, refers to the ability to clearly distinguish small structures in both the axial and lateral planes, see image below.

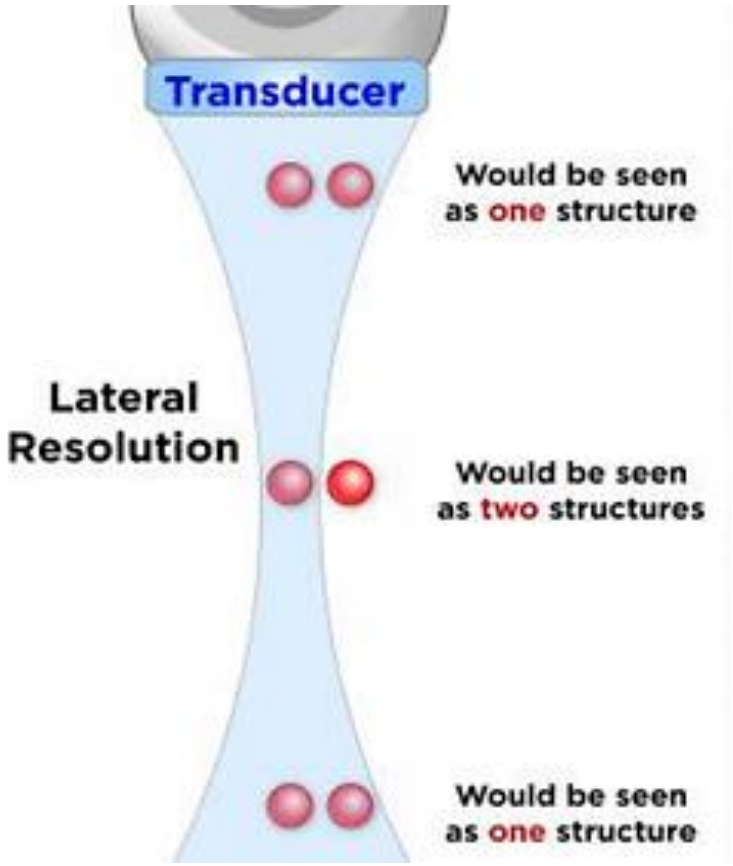


Axial resolution refers to the ability to discern two separate objects that are adjacent to each other and parallel to the ultrasound beam. Axial resolution is equal to one-half the spatial pulse length (SPL). A typical pulse waveform is shown to the right. To reduce clutter in the near field of the image the ringdown time of the pulse is kept to a minimum.

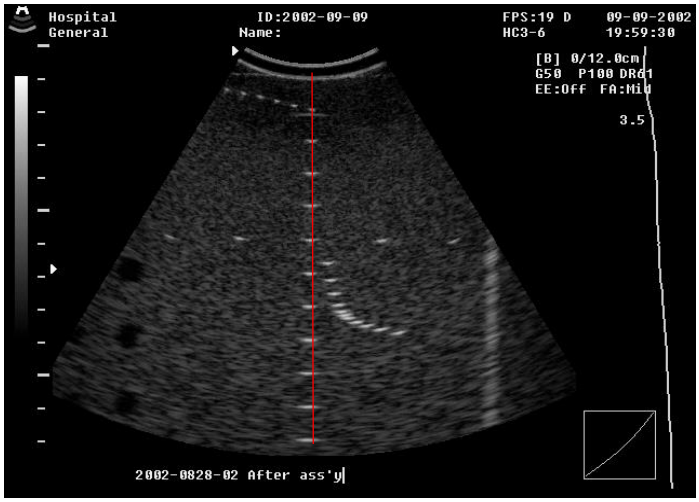


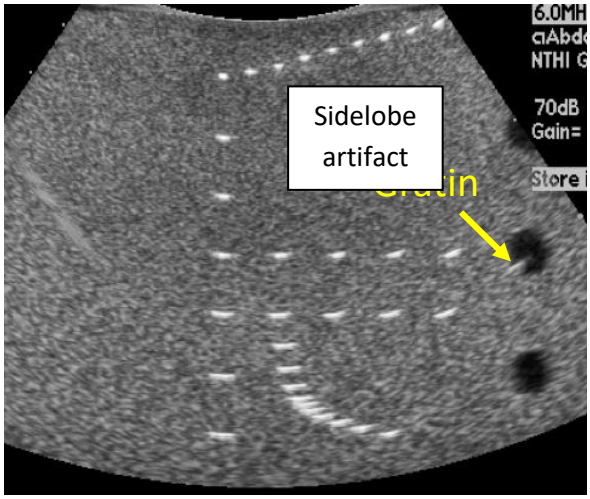


Lateral Resolution refers to the ability to discern two separate objects that are adjacent to each other and perpendicular to the ultrasound beam. Lateral resolution is roughly four times worse than axial resolution. It is primarily determined by the width of the ultrasound beam. The beam shape can also be materially affected by dead elements in the probe array and/or lens delamination. See the discussion of Beam Spread on the following page.



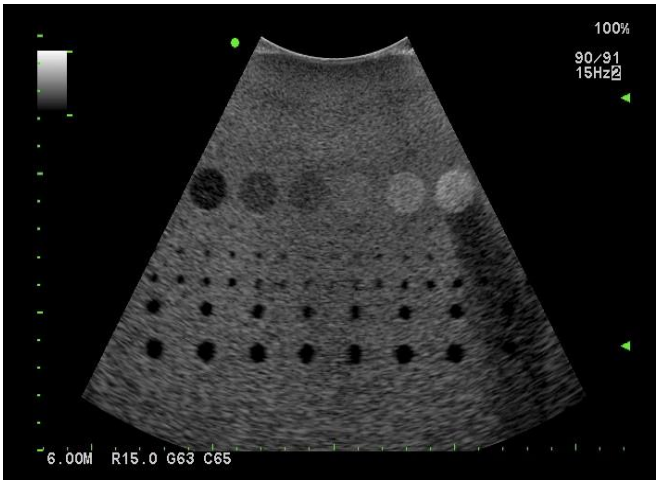
Beam Spread, or point-spread-function (PSF). In the image below you can observe that as a function of depth the point targets appear to spread in the lateral dimension although the wire targets are physically the same size. Beam spread occurs even with new probes and is a function of the beam width which enlarges distal to the focal point of any given probe. Dead elements in the probe array, as well as various lens failures have shown an impact on the fidelity of the acoustic beam and will alter its' focusing characteristics thereby reducing spatial resolution as well as introducing image artifacts such as sidelobes (see image below). In an ultrasound QA program, all probes should be tested with a phantom prior to being placed into clinical use and documented with a photo. This will establish a performance baseline for that probe that can be re-tested over time for comparison to spot any image degradation.



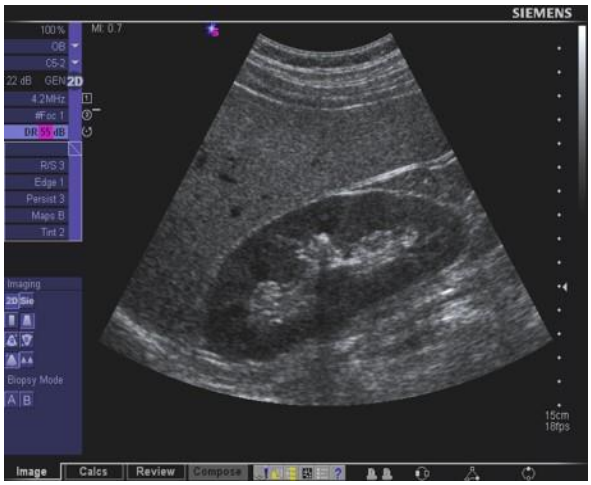


Contrast Resolution (CR), is related to both tissue as well as anechoic (e.g., cysts and blood vessels) targets. Acoustic clutter from off-axis objects tend to fill in images of anechoic objects and reduce their detectability. Sources of acoustic clutter can be produced either from a defective probe (e.g., side lobes created by dead elements) or from naturally occurring phenomenon such as tissue aberration. The TMP image below shows multiple levels of gray scale fill in a cyst simulation. The large one on the far left of a completely anechoic cyst should be purely black, it is not because of image clutter. Testing CR is also a good baseline test to perform on probes prior, as is often mentioned in this paper, to placing them in clinical service. Two clinical examples are shown below.

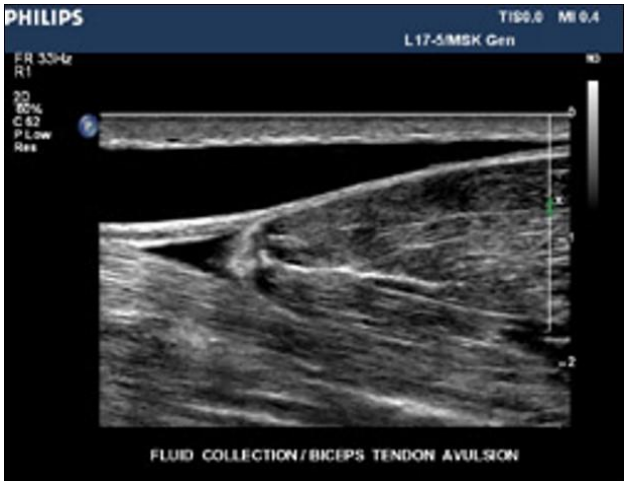
The other type of contrast resolution is related to tissue and the ability to distinguish echogenicity differences between neighboring soft-tissue regions, e.g., different types of tissue side-by-side, for example liver/kidney, liver/bowel, etc. The examples below demonstrate this with a kidney/liver image, and fluid collection around an injured tendon.



Cyst Simulation on TMP



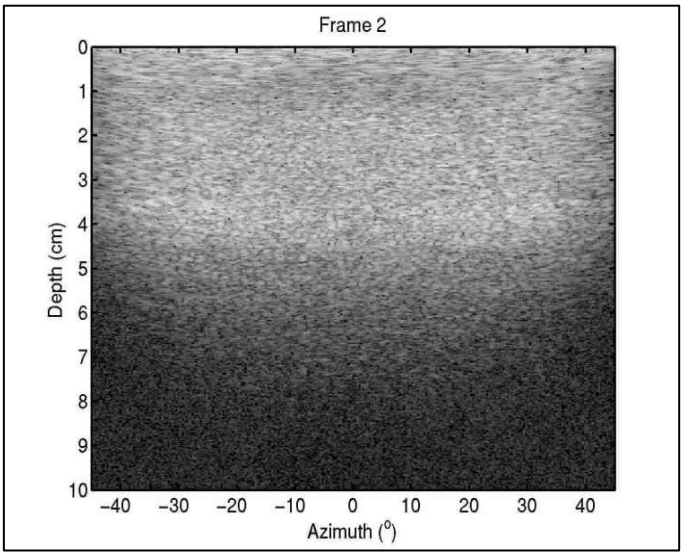
Tissue Contrast kidney/liver interface

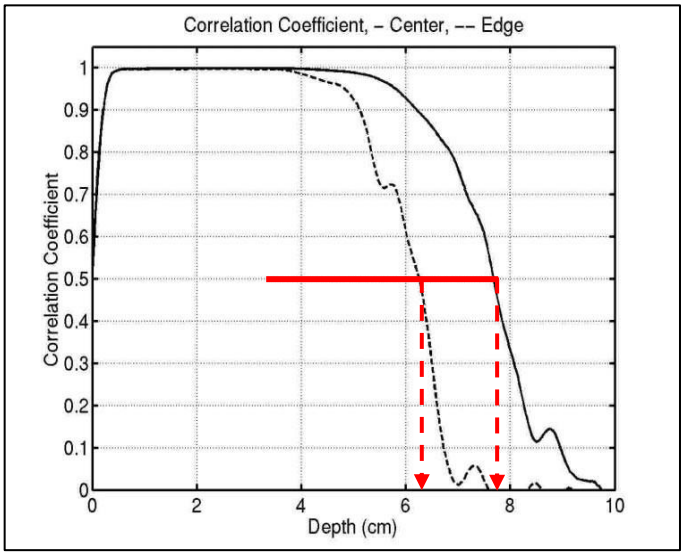


Anechoic Region/Tissue interface

Sensitivity is a measure of the minimum detectable echogenicity, specifically it is a measure of the signal-to-noise ratio. In an ultrasound image what we are looking for is the depth of penetration where echoes can still be seen above the noise floor. Due to the manner in which various types of arrays are pulsed there is normally some non-uniformity in the depth of penetration from one side of the image to the other, an example is explained below.

The image to the right is from a standard tissue mimicking phantom using a high-frequency linear array probe. One can see the strength of the image sensitivity is higher in the center of the aperture and then reduces as you move to the edge of the image (see Image on following page). This is normal. To demonstrate, the graph below shows one line of image at the edge and one line of image in the center of the aperture; we will call this the correlation coefficient (CC). At the point where the CC reaches 0.5 for each line is where the maximum depth is for echo detection. One can readily see the line from the center of the aperture produces echoes to almost 8cm, while the line from the edge only goes to a little over 6cm. This is a good test to run on new probes and use this data as a baseline for future tests as part of an effective QA program. This also means that the effect of dead elements on the image will be most profound if they occur in the center portion of the array.



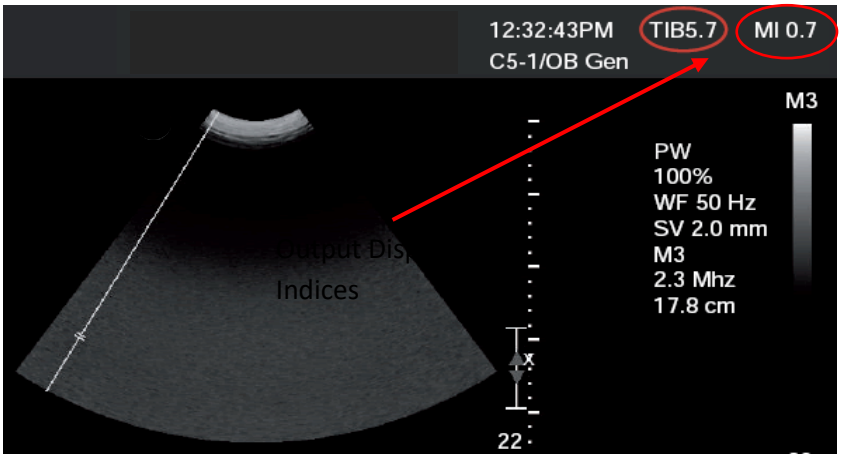


NOTE: Please review Routine Quality Assurance for Diagnostic Ultrasound Equipment 2.0, an AIUM Publication, 2022, www.aium.org

Attenuation is the reduction of ultrasonic energy within the transmitted beam as it propagates through various media within the body, i.e., air, water, body fluid, soft tissues, blood, and bone. The amount of energy lost at any given point is a function of the density of the media it passes through. The acoustic energy lost in this process is given up as heat. Table 1 below shows an example of the approximate attenuation rate in several media. Commercial ultrasound systems sold in the United States use a calculated average propagation of velocity of 1540m/s. In the United States the maximum level of propagated acoustic energy allowed from an ultrasound transducer is 720mW/cm^2. This level is based upon thresholding of potential in-vivo bio-effects such as cavitation (Mechanical Index, or MI) and thermal (Thermal Index, or TI) rise[1] related to exposure to an acoustic field. The values of these two indices are displayed on the ultrasound system monitor as shown below. When using a tissue phantom for QA it is prudent to use the factory installed clinical preset associated with the ultrasound probe under test. This will establish a functional baseline of performance for that probe for the intended use and can then be monitored over time to discover any decrease in performance.

TISSUE	Propagation Velocity, m/s	Attenuation Rate dB/cm/MHz
Blood	1550	0.18
Fat (adipose tissue)	1480	0.64
Liver	1585	0.95
Kidney	1570	0.99
Spleen	1578	1.10
Heart Muscle	1580	1.80

Table 1



[1] American Institute of Ultrasound Medicine (AIUM), Medical Ultrasound Safety, Bioeffects and Biophysics. www.aium.org

Depth of Field is the range in which we can visualize actual reflected targets within a tissue phantom as a function of depth. Figure 1 below shows the relationship between the transducer center frequency, wavelength, and depth of penetration. Image 1 below demonstrates how using different frequencies can impact depth of field, resolution, and other qualities of image production.

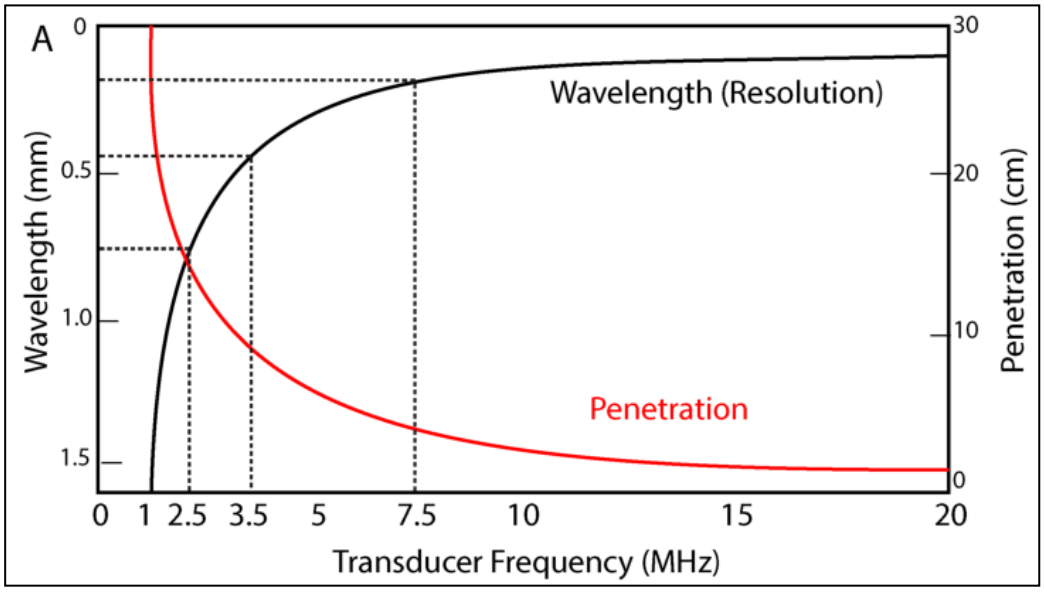
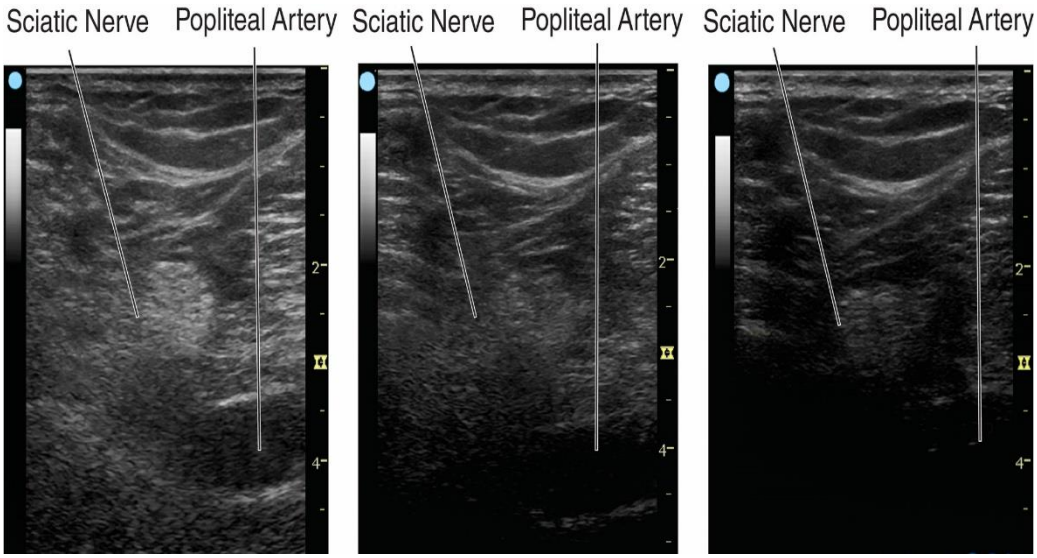


Figure 1



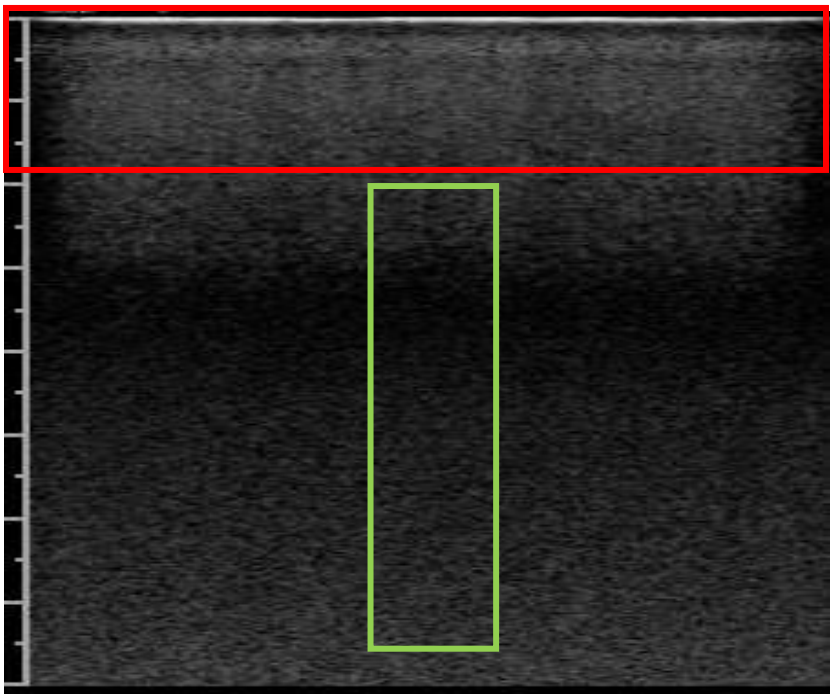
8MHz 10MHz 12MHz

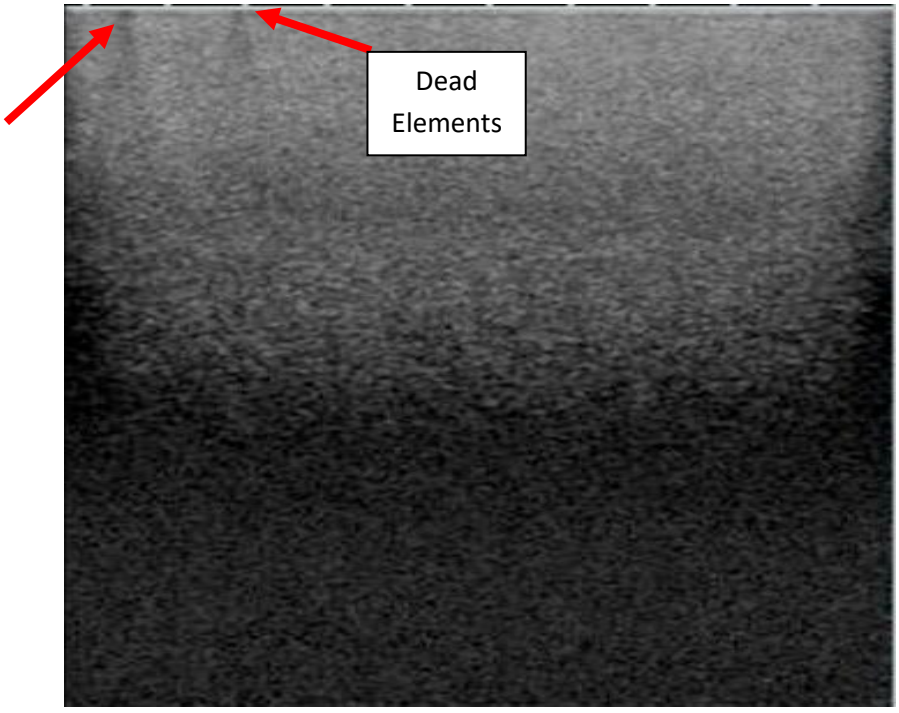
Image 1

Image Uniformity is maintaining the homogeneity of the backscatter targets throughout the field of view. This is essential in creating an acceptable diagnostic level ultrasound image – it is a measure of the system and probe's ability to provide substantially equivalent detail and contrast resolution throughout the field of view. A classic example can be seen on the TMP image shown below – Ideally the spot size of these backscatter targets would be substantially equivalent at all depths as shown in the image below (blocked in red). Image uniformity is perhaps one of the most challenging and complex of image quality parameters to quantify. Historically it has not been easily implemented in any ultrasound imaging system. Uniformity testing with a TMP is ideally performed when the probes are brand new so changes in uniformity can more readily be discerned as a function of probe use and time. Dead elements, delaminating lens, and matching layer separation in the acoustic stack can all contribute to reducing the uniformity of an image.

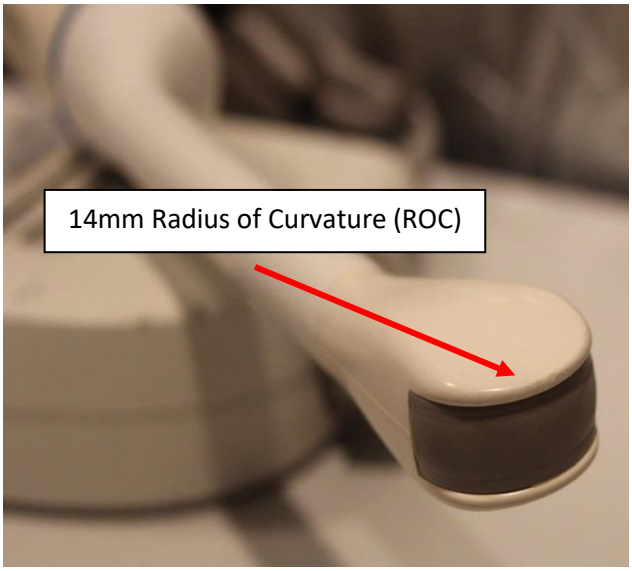
Image uniformity throughout depth of field

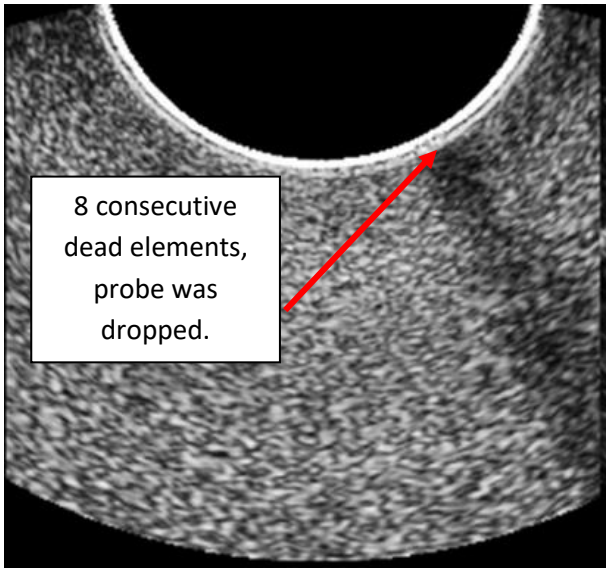
As previously noted, non-uniformity within an image is often caused by multiple dead elements in the transducer array, or lens delamination. As an example, note in the image below line streaking at the aperture skin contact area, blocked in red, and the impact on image uniformity blocked in green. The second image shows the effect of two dead elements (shown by the arrows below) with resultant line streaking/shadowing in the near field of the image.





Dead Elements are often caused by a traumatic event to the probe, such as dropping or banging on a hard surface. Endocavitary probes are the most susceptible to traumatic events due to the tight radius of curvature of the array, shown below. Transesophageal probes (TEE) are the most susceptible to element damage among the phased-array probes. Damage to TEE arrays is commonly associated with non-automated cleaning and high-level disinfection (HLD) practices. Although uncommon, static electrical discharge can also damage an element. Another common cause of image drop-out shown on the following page that can be readily observed and documented using the Acertara tissue phantom, occurs with a failure known as lens delamination. Lens delamination generally occurs over time and has often been traced to using non-recommended gels or using non-recommended cleaning and HLD agents (see reference below). Unlike many traumatic events involving the array, lens delamination cases can normally be economically repaired, and the probe returned to service.

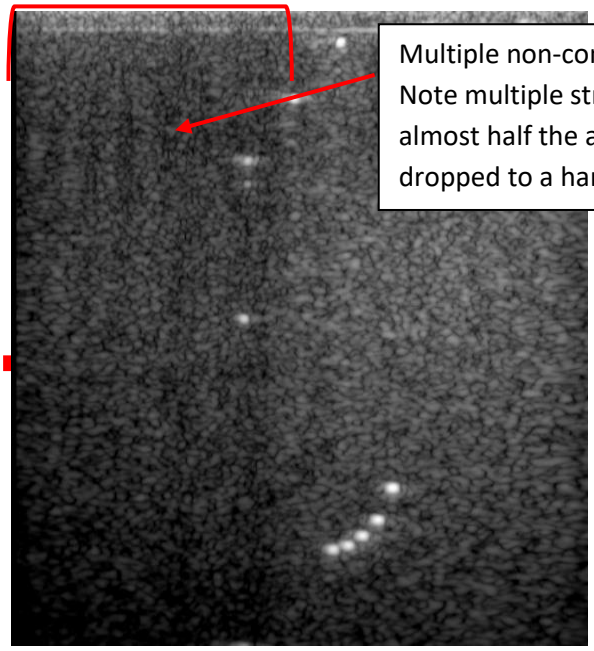


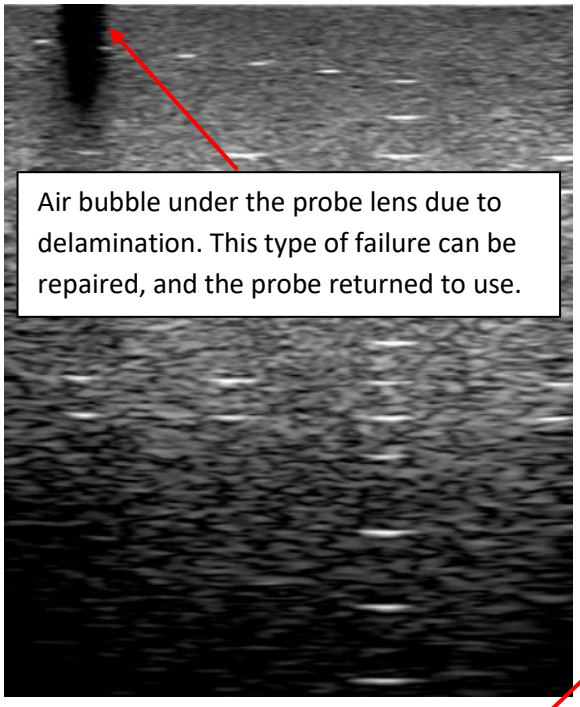


Reference

Guidelines for Cleaning and Preparing External- and Internal-Use Ultrasound Transducers and Equipment Between Patients as Well as Safe Handling and Use of Ultrasound Coupling Gel – AIUM Official Statement, Dec 5, 2022, www.aium.org.

Dead Elements (Element Droput) and Lens Delamination - Examples





Note: Lens delamination, or holing, can allow fluid ingress into the probe housing. Do not use a probe with a delaminated or holed lens until it has been repaired, it is a potential electrical leakage and bio cross-contamination hazard.

Conclusion

Throughout this short Guidebook we have underlined the importance of testing probes and documenting the results with a high-quality contemporary TMP when they are brand new, the reason is simple – the probe will never perform better than when it is new! Establishing baseline imaging performance for new probes is essential in managing them properly over time and will generally provide the sonographer with early warning indications of the onset of probe disfunction or loss of image fidelity.

Acertara designed and developed the Advantage phantom, shown below, to address the evolving needs of ultrasound QA in the hospital and in the field. Advantage materials and targets match the performance of the newest technologies being used in ultrasound probes, such as cMUT, pMUT, single crystal composites, and high bandwidth/high frequency arrays.

A few helpful general ultrasound QA references

Beate Weigang, G. Wayne Moore, et al; “The Methods and Effects of Transducer Degradation on Image Quality and the Clinical Efficacy of Diagnostic Ultrasound”, Journal of Diagnostic Medical Sonography, 19:3-13 January/February 2003

G. Wayne Moore, Amanda Gessert and Mark Schafer; “The Need for Evidence-Based Quality Assurance in the Modern Ultrasound Clinical Laboratory”, Journal of the British Medical Ultrasound Society, Volume 13 Number 3 pp. 158-162

The AIUM Routine Quality Assurance of Clinical Ultrasound Equipment Version 2.0, 2022

ACERTARA

Advantage™

Ultrasound Tissue Mimicking Phantom

Delivering Optimal
Phantom Images

Every Time

Long-lasting: Built with materials suitable for up to 10 years of continual use, the Advantage™ Phantom is meant for long-term application — with no loss in image quality

Reliable: Ultrasound users can easily verify the functionality of their equipment.

Lightweight: With a low physical weight of less than 5.5lbs/2.5kg, a small footprint, and a budget friendly price point, Advantage is the ideal QA phantom for the busy ultrasound lab.

Ready to go: Advantage requires no calibration or other downtime maintenance.

Key Features

Acoustic Properties

+ Speed of sound: 1500±50 m/s
+ Attenuation: 0.6±0.15 dB/cm/MHz between 2 and 10 MHz (ambient temperature 21±3°C)

Image Quality

+ Bright, easy-to-see targets with uniform homogenous backscatter field.

See the Advantage™ Phantom in action! Contact us today:
303.834.8413 | Sales@Acerteralabs.com

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Longmont, CO 80501
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