Acertara Technical Publications Series

A Guidebook for Diagnostic Ultrasound Probe Troubleshooting

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GUIDEBOOK SERIES

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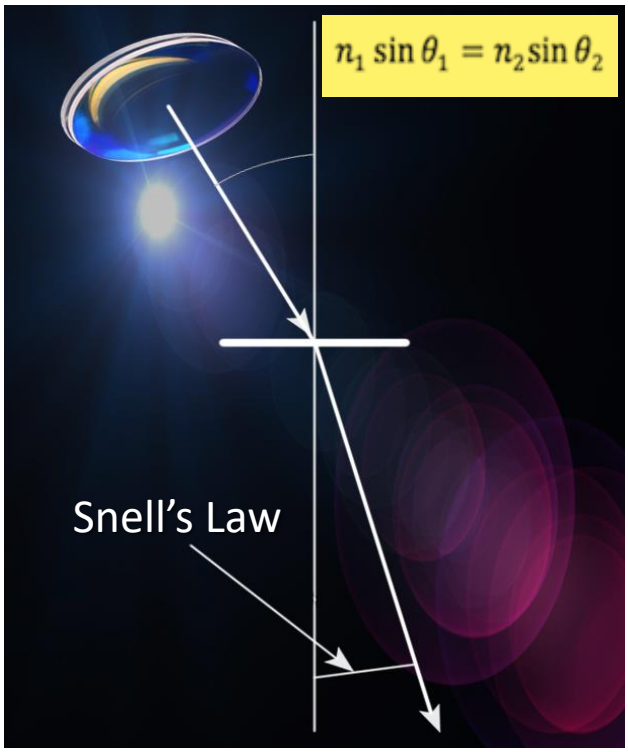


Introduction and Scope

This Guidebook was designed and developed to provide HTMs and others responsible for the care and maintenance of ultrasound systems and transducers (also referred to in this text as probes), with diagnostic troubleshooting and technical information necessary to inform decisions made regarding repair or replace options. In order to provide probe diagnostic and maintenance context this Guidebook will also provide the reader with needed safety, testing, and use information.

Definitions of Several Key Terms Used in Text

- *Detail Resolution*: A measure of the minimum spacing of distinguishable point targets.
- *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.
- *HAI*: Healthcare Associated Infection
- *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 cause objects that are not directly in front of the transducer to be displayed incorrectly in the lateral position.

The Anatomy of an Ultrasound Probe

Anticipating Transducer Problems

Based on an unscientific sampling of more than 10,000 transducers from a wide range of clinical sites worldwide, we have determined that approximately 25% to 30% of ultrasound probes currently in use have some form of structural, cosmetic, electrical, or acoustic performance compromise/defect. A major source of operational problems in the field is a traumatized probe, that is, an assembly that has been dropped or otherwise struck while in use or during transport within a clinical facility. Inside the injured probe, cracked transducing elements may still operate, but not like two isolated elements **(Figure 1**, FL is the fracture line). Their interaction acoustically is likely to produce unexpected and unsuspected anomalies in operation and performance.

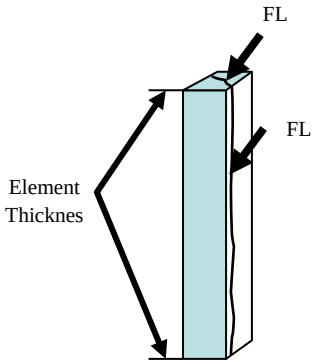
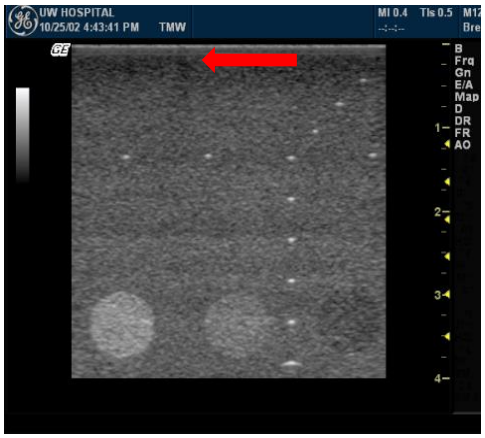


Figure 1

Fractured Array Element

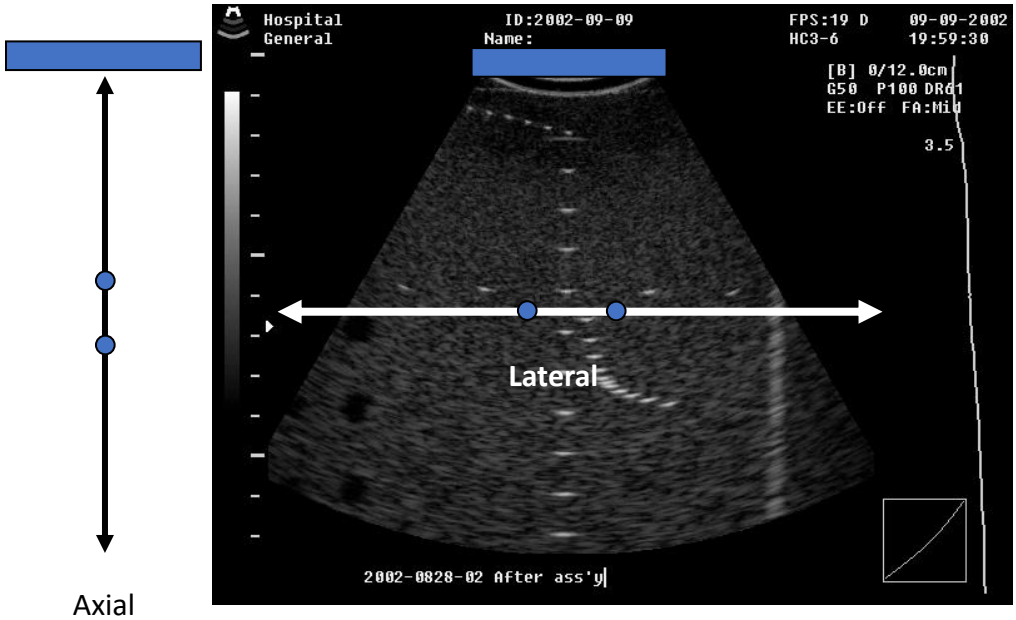
Very often the transducer elements are completely broken along with a loss of electrical continuity. These are “dead” elements whose absence distorts the primary wave front essential for beam formation and steering (grating lobes). The element response is very binary in this condition, i.e., the transducing element either works or does not. Multiple contiguous dead elements in an array will often produce visible dropout in the image as shown in the image directly below.



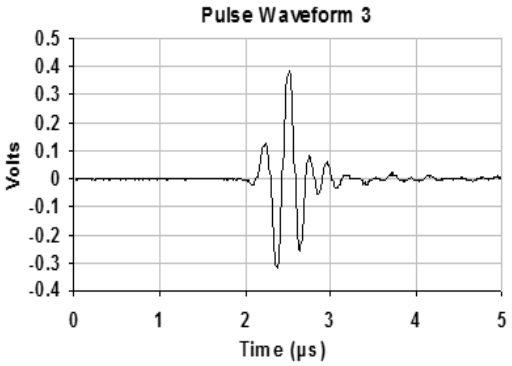
Basic Core Parameters of Image Quality

Before determining how to assess the performance of a probe we need to take just a few moments and detail what makes an ultrasound image a “good” image. It is well known that although ultrasound image quality is thought of as subjective in nature, there are certain parameters of the image that can be objectively measured. For the sake of brevity in this technical publication we will focus on the big four: (1) detail, or spatial resolution, (2) contrast resolution (two types, see definitions page), (3) sensitivity, and (4) uniformity throughout the depth of field of the image display.

Detail, or spatial resolution, refers to the ability to clearly distinguish small structures in both the axial and lateral planes (this is also referred to in the literature as the point-spread function), see tissue mimicking phantom (TMP) image below.

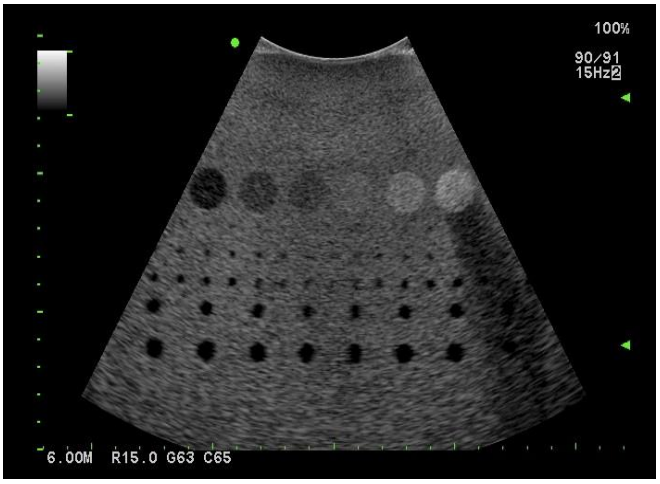


Axial resolution is equal to one-half the spatial pulse length (SPL) and lateral resolution is a function of the ultrasound beamwidth. A typical pulse waveform is shown to the right. To reduce clutter in the near field of the image the ringdown time of the pulse is kept to a minimum.

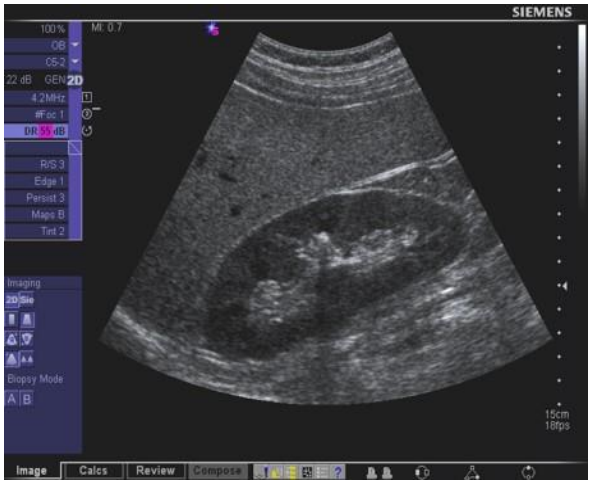


Contrast Resolution (CR), is related to both tissue as well as anechoic (e.g., cysts and blood vessels) targets. Acoustic clutter from off-axis objects tend to fill in images of anechoic objects and reduces their detectability. Sources of acoustic clutter can be produced either from a defective probe (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 when they are brand new. Two clinical examples are shown below.

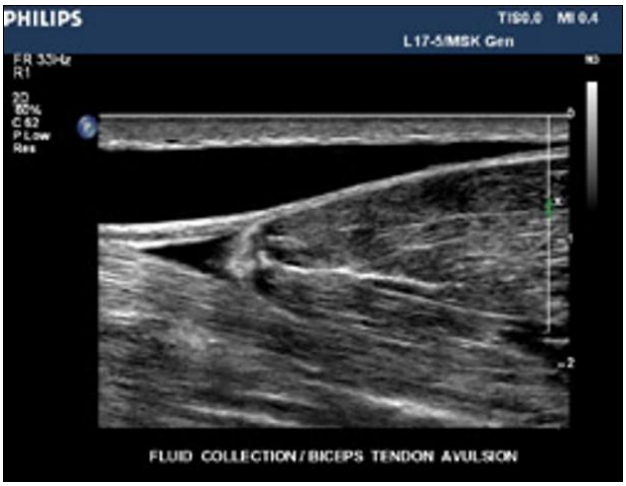
The other type of contrast resolution is related to tissue and the ability to distinguish echogenicity differences between neighboring soft-tissue regions, e.g., different types of tissue side-by-side, for example liver/kidney, liver/bowel, etc. The example below demonstrates this with a kidney/liver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



Cyst Simulation on TMP



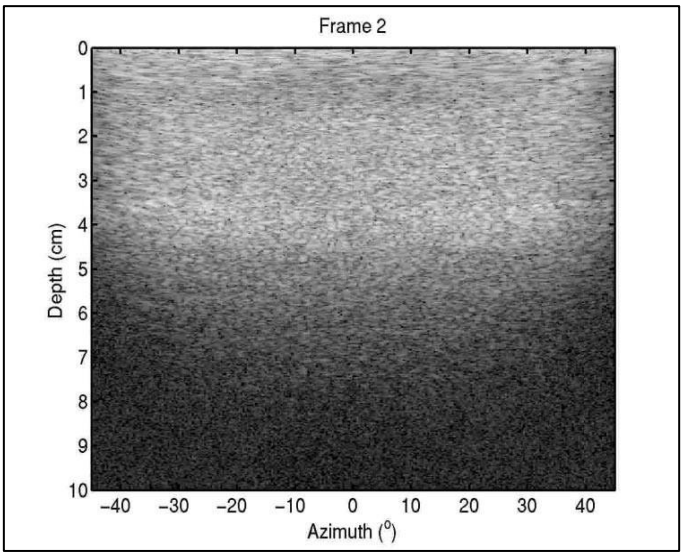
Tissue Contrast kidney/liver interface

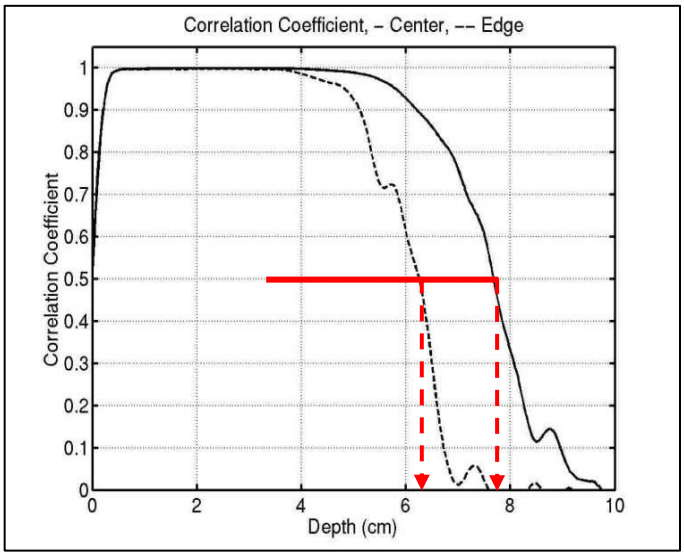


Anechoic Region/Tissue interface

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 at 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 not uniformity in the depth of penetration from one side of the image to the other, an example is explained below.

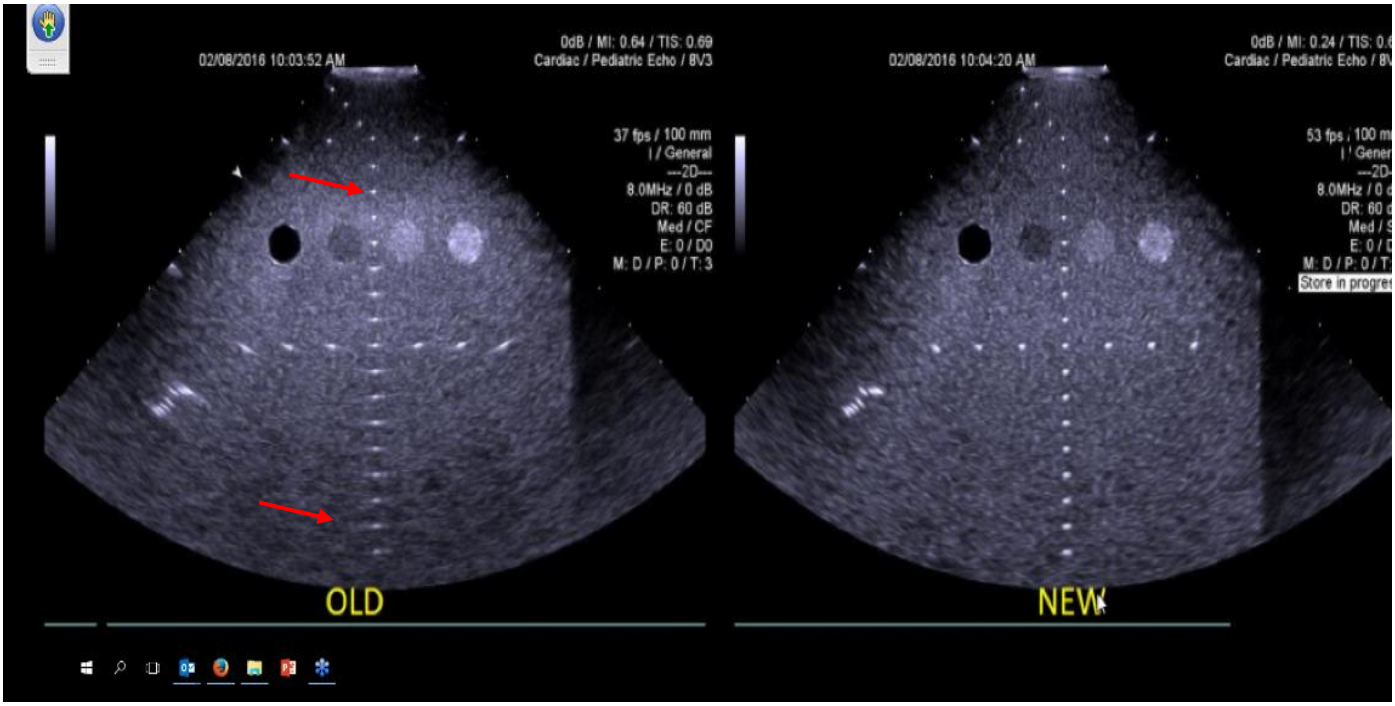
The image to the right is from a standard tissue mimicking phantom using a high-frequency linear array probe. One can see the strength of the image sensitivity is higher in the center of the aperture and then reduces as you move to the edge of the image. This is normal. To demonstrate, the graph below 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.





NOTE: See Routine Quality Assurance for Diagnostic Ultrasound Equipment, an AIUM Publication, 2008 ISBN 1-932962-12-3

Uniformity of the image quality throughout the field of view is essential to creating an acceptable ultrasound image – it is, therefore, 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 on the left shown below – look at the spot size of the point targets at the focal caret (set at ~ 3cm) compared to the spot size of the targets at 13 and 14cm, this spot size distortion is known as lateral smearing due to the variations in beam width throughout the depth of field. Ideally the spot size of these target would be substantially equivalent at all depths as shown in the image on the right. Image uniformity is perhaps one of the most challenging and complex image quality parameters, historically it has not been easily implemented in any ultrasound imaging system. A few very new ultrasound systems are incorporating a different method of beam transmission and processing and are achieving much more uniform resolution as shown in the right-hand image below. Uniformity testing is also ideally performed when the probes are brand new. Dead elements, delaminating lens, and matching layer separation in the acoustic stack can all contribute to reducing the uniformity of an image.



Quality Assurance for the Ultrasound System

Quality assurance testing for the complete sonograph (probe and signal processor) can rest on a tool such as a tissue mimicking phantom (TMP) with a known set of targets available to test overall system performance. The testing protocol can include the following: detail resolution (axial and lateral) (also known as the point spread function), contrast resolution, sensitivity, dynamic range, temporal resolution (frame rates, temporal filters, persistence, and compounding multiple frame averaging). All these tests, however, assume the probe to be working correctly. There is no easy way of moving from image quality to a detailed evaluation of the probe using a TMP. That requires a different tool, such as the Aureon electronic probe tester shown on Page 17.

Quality Assurance for the Probe

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. PM may include cleaning and inspection but often does not include detailed QA or QC testing. An original equipment manufacturer (OEM) may not move from an established PM program until the user complains about a reduction in image quality or a functional failure. In the process of developing, manufacturing, and using technology, two opportunities for quality assessment occur: 1) testing specific components of a technological ensemble such as a probe assembly during manufacturing; and 2) testing an integrated subsystem or the wholly integrated system such as a complete sonograph in clinical use. Testing modular components or a whole system (a sonograph), represents a Q*uality Assurance* (QA) program. Thus, a QA program is a protocol of tests designed to ensure that a sonograph is working to specifications within its clinical setting. In contrast, a *Quality Control* (QC) program focuses on ensuring that a sonograph and its transducers meet manufacturing specifications. QC is a set of rules different from testing a system in a clinical setting, which is QA. The focus for this Guidebook is testing fully integrated probes that are separated from the sonograph but still part of an operating system. The Figure on Page 23 depicts a flow chart that indicates when to call in the Biomedical Engineer to execute a detailed test of a suspected probe defect. The branching points are all binary (yes or no, pass or fail, etc.).

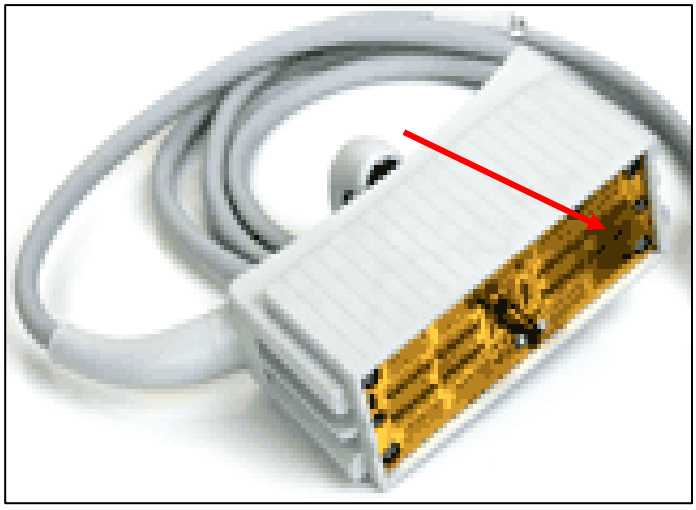
General and Endocavitary Probe: The core major external components that make up a general and endocavitary probe are:

1) Connector
2) Cable
3) Probe Housing

The general problems associated with these three components are related to physical trauma; tears in the cable, bending relief separation, bent pins in the connector, cracks in the probe housing, and yellowing of the cable from over-cleaning, or using non-OEM specified cleaning materials. Frequent visual inspections are recommended as the failures mentioned above can be repaired fairly inexpensively if caught early. We also recommend the HTM obtain a 10x loupe for the visual inspection process.

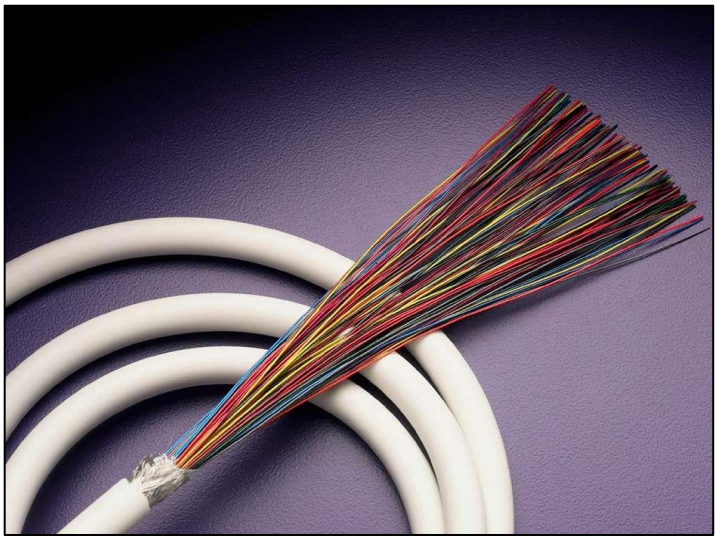
Connector: Internal to the connector are the following sub-components:

1) Circuit boards populated with passive signal filtering components, multiplexers, and other control electronics
2) Termination board, or flex circuits
3) Connector pin assembly (or pin-less assembly as shown below)



Pin-less connectors like the one shown to the right are notorious for carbon deposits. These deposits can cause the system to fail to recognize the probe is connected. An eraser from a #2 pencil can be used to remove the carbon deposit by gently rubbing the affected area. Standard pined connectors (ZIF, zero insertion force) generally have issues with bent pins, make sure you examine this carefully at each PM.

Cable: In general, there are 100 to 162 45-gauge co-axial wires internal to the probe cable. Because they are so small, they are also very fragile. Broken wires in the cable can result in loss of image quality, color spiking in the CFM mode, and audible noise in spectral Doppler (CW and PW) mode. Examine the cable for tears and for flattening of the cable due to being run over by the system. Color flow mode is useful to examine for testing suspected breaks in the cable, by gently wiggling the cable while in the CFM mode. For cardiac probes CW Doppler often is the first mode to reveal cable wire or termination issues – via audible noise when the cable is gently wiggled.



Probe Housing: Internal to the probe housing are the following sub-components:

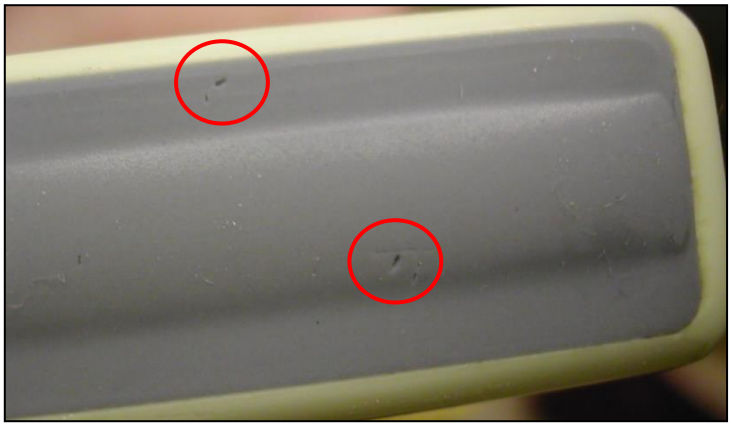
1) Flex circuit interconnect (shown below)
2) Acoustic stack (shown below)
3) Control electronics (not in all probes)

The most common issue with this component is lens delamination. This often occurs due to frequent cleaning with alcohol-based solutions which dries out the lens causing separation from the acoustic stack. Another frequent failure is cracks in the probe housing due to droppage. These need to be looked at very carefully with a 10x loupe (see following page) as they may present an HAI issue via cross-patient contamination.

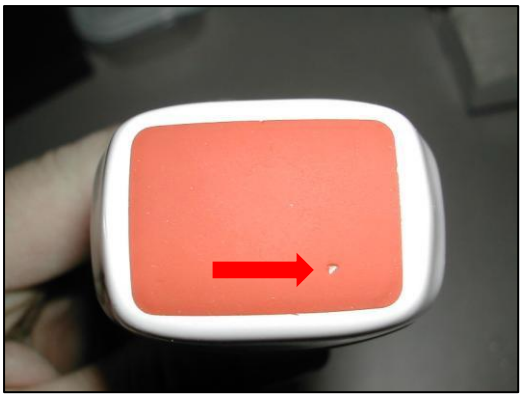
Common Probe Failures

The proper care and regular testing of diagnostic ultrasound probes substantially influences the level of operating expense related to the ultrasound systems in your department and across the hospital. Experience has shown that more than 70% of ultrasound service calls are in some fashion probe related. Published studies worldwide have also shown that improperly functioning probes can materially and negatively impact the results of an ultrasound examination. However, probe failures, when discovered early enough, can, more often than not, be repaired and restored to a full operational condition, potentially saving the department tens-of-thousands of dollars per year in operating expense. This guidebook presents the HTM with a few examples of common probe problems and how to spot them in a timely manner; while effective repairs can still be made. Further, probe testing suggestions are presented to insure optimal performance from the probe as well as obtaining the longest effective use of the product. A number of these examples also demonstrate how the potential risk for patient cross-contamination and HAIs can happen. On the probe photos that follow cross-contamination risk will be labeled HAI. Physical damage to the outside of a probe housing, a lens, or the cable can also lead to: fluid ingress and electrical leakage failure (shock risk to either the patient or the user, or both – see sample warning from OEM user manual below, and lens hole sample). These types of failures should result in the immediate removal of the probe from clinical service until repaired or replaced.

> ⚠ **WARNING**
> **A small hole in the outer layer of the transducer opens a conductive path to grounded metal parts of the transducer. The secondary arcing that could occur during defibrillation could cause patient burns. The risk of burns is reduced, but not eliminated, by using an ungrounded defibrillator.**



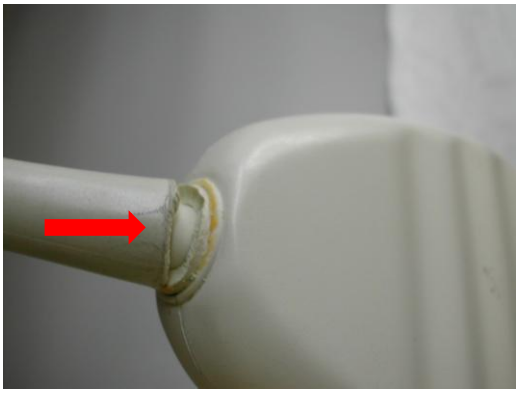
10x Loupe



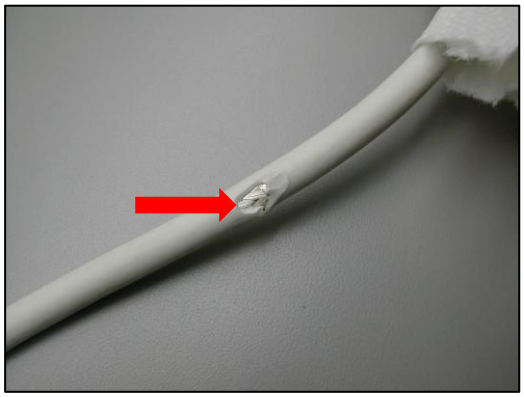
Pin-hole damage to the lens – electrical leakage

Crack in housing - HAI

Teeth drag marks in TEE bending rubber
Fluid ingress risk and electrical leakage



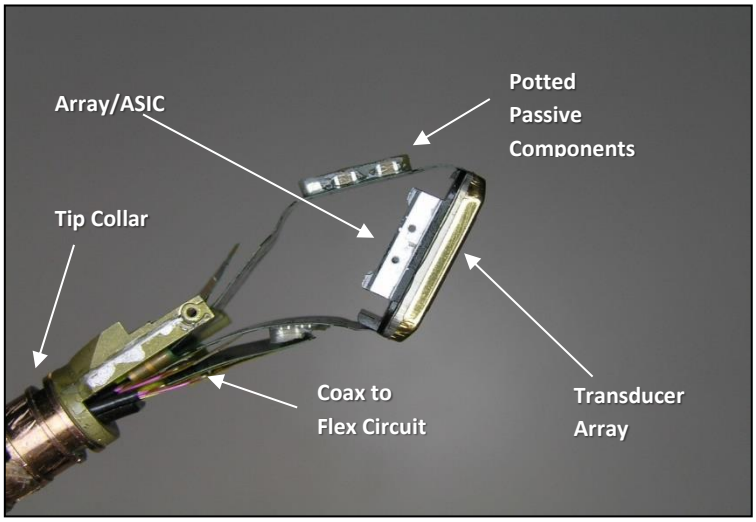
Strain relief tear - HAI



Cable tear – Electrical leakage risk

Lens damage – HAI and electrical leakage

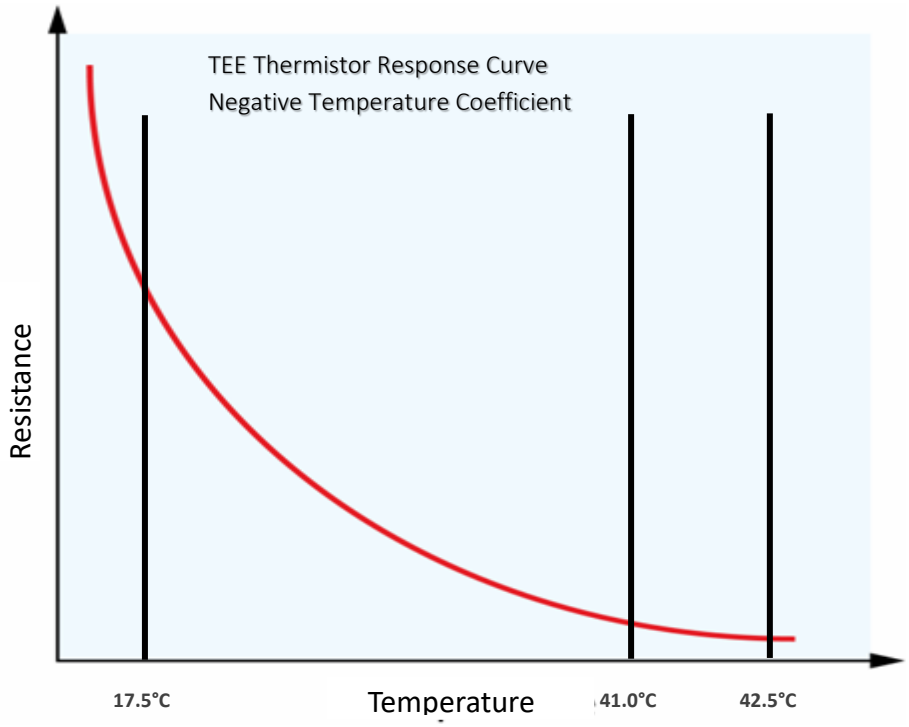
TEE Probe: TEE probes are designed to last a relatively long time (3 to 5 years), but only if the instructions for use, cleaning, storage, and testing outlined in the OEM's user manuals are followed. For example, the following language is from a GE TEE user guide: "*The expected service life of the 6VT-D probe is 5 years, provided the user follows the maintenance and care instructions on this card and in the user manual*." For example, when bite-guards are not consistently used, TEE probes are especially susceptible to damage to the bending area of the insertion tube (see Photo below), often allowing fluid ingress which can damage the various electronic components in the acoustic stack, shown below in the Philips X7-2t probe.



Philips X7-2t 2D Matrix Array TEE Probe

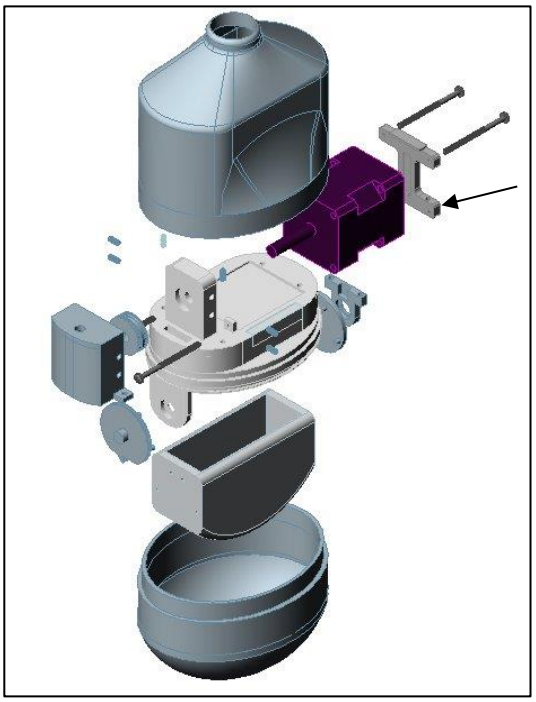
In addition to control and processing electronics TEE probes (and other various endocavitary probes) also have a thermistor embedded in the acoustic stack that monitors the aperture temperature to prevent overheating and patient injury (i.e., IEC 60601-2-37 limits patient contact material to 43°C). These thermistors operate on a negative temperature coefficient as shown in the graph below. The system will not allow a TEE to run if it senses a temperature at or below 17.5°C or above 42.5°C. The system will display a warning to the user if the temperature hits 41°C that an automatic freeze will occur soon. If the temperature is at or below 17.5°C the system will simply not initiate the probe but display an error message. If the thermistor is defective then the probe will not initialize, but the displayed error message may not indicate that it is a defective thermistor.

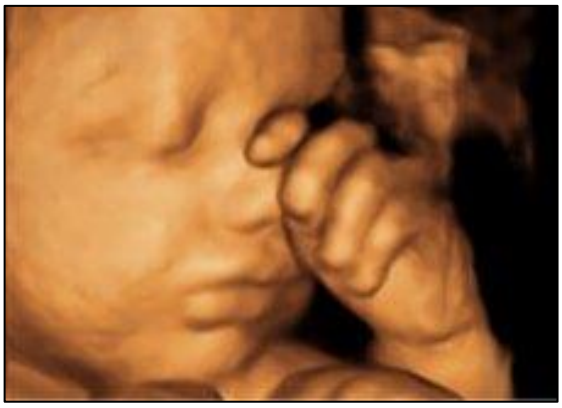
Note for Graph
The low-end cutoff is due to the rapid rise in resistance; the system can no longer determine if the thermistor is still functional or if it is open.



3D/4D Wobbler Probes

These probes are 1D curved and linear array probes that are swept mechanically through a predetermined arc (based on clinical application) via a stepper motor in an oil filled cap. The digital stepper motor links the 1D probe position with an acquired image. The image slices are then put together in the ultrasound system to form the 3D fetal image shown below. These probes are somewhat heavy and are often dropped. Lens damage and oil leakage are two of the main problems from trauma. The internal step motor and the Hall-effect devices are also a common source of failure, in this case the system will either stop the probe from trying to initialize, or the probe will try and start giving a slight jerky feeling while it is held in your hand. These types of failures are repairable.





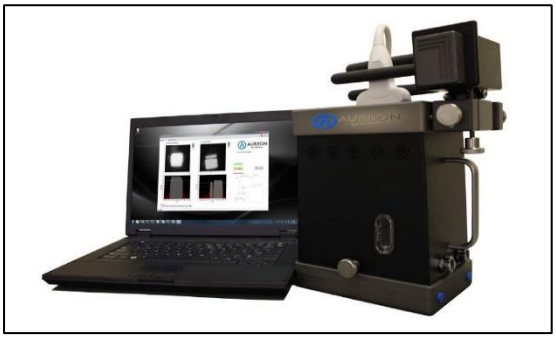
Probe Testing and Evaluation

Probe testing begins with a visual inspection of the transducer contact or wear-surface. As the name implies, frequent use can wear or damage this surface, permitting caustic fluids, gels, or microorganisms' admittance to the inner portions of the probe. A simple 10x magnifying glass, or loupe, is needed for this inspection.

In the section on element damage, the acceptance/rejection criterion is determined by the number of elements damaged within the array and their location. This criterion emerges from a set of experiments that tested image quality versus the number of failed elements. Fewer than three lost elements do not seem to markedly affect gray scale image quality. On the other hand, greater than 4 elements seriously degrade the image quality. Doppler studies with various patterns of dead elements indicates that as few as two consecutive dead elements can lead to an underestimation of actual velocity, as well as offer ambiguity relative to flow direction and flow organization.

Shown in **Figure 3** on the following page is an Aureon image detecting two dead zones in a Philips model X6-1 2D Matrix Array probe (black area at bottom). For comparison, a completely functional probe is shown directly above the defective array image. The X6-1 probe has more than 9,000 elements within the 2D array matrix. The graphical display to the left of the image is the measured amplitude of the signal being detected. This probe was producing sub-optimal images prompting the sonographer to ask Acertara personnel to test the probe to find out the root cause. The probe was under warranty and was replaced at no charge by the OEM.

The photo shown below is the Aureon™ probe analysis system from Acertara Acoustic Laboratories. On the following pages are images of the energy content being emitted from the aperture of the array under test. Note the compromised elements in the area of the torn lens in the **Figure 2**. Aureon can be used with any commercially available probe, including the most complex; the 2D matrix array probes.



Aureon

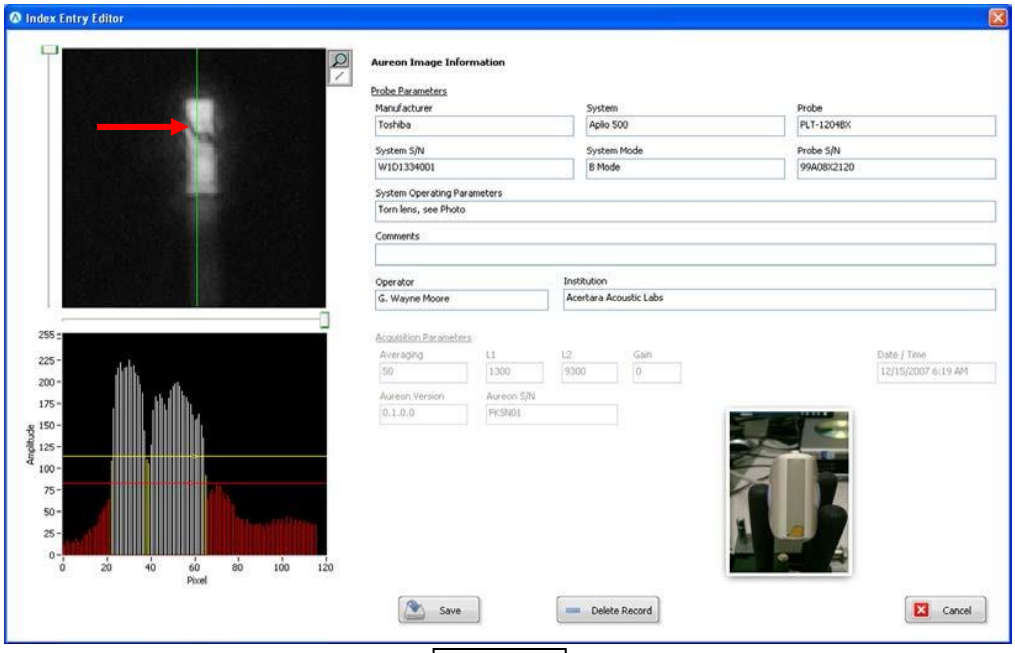


Figure 2

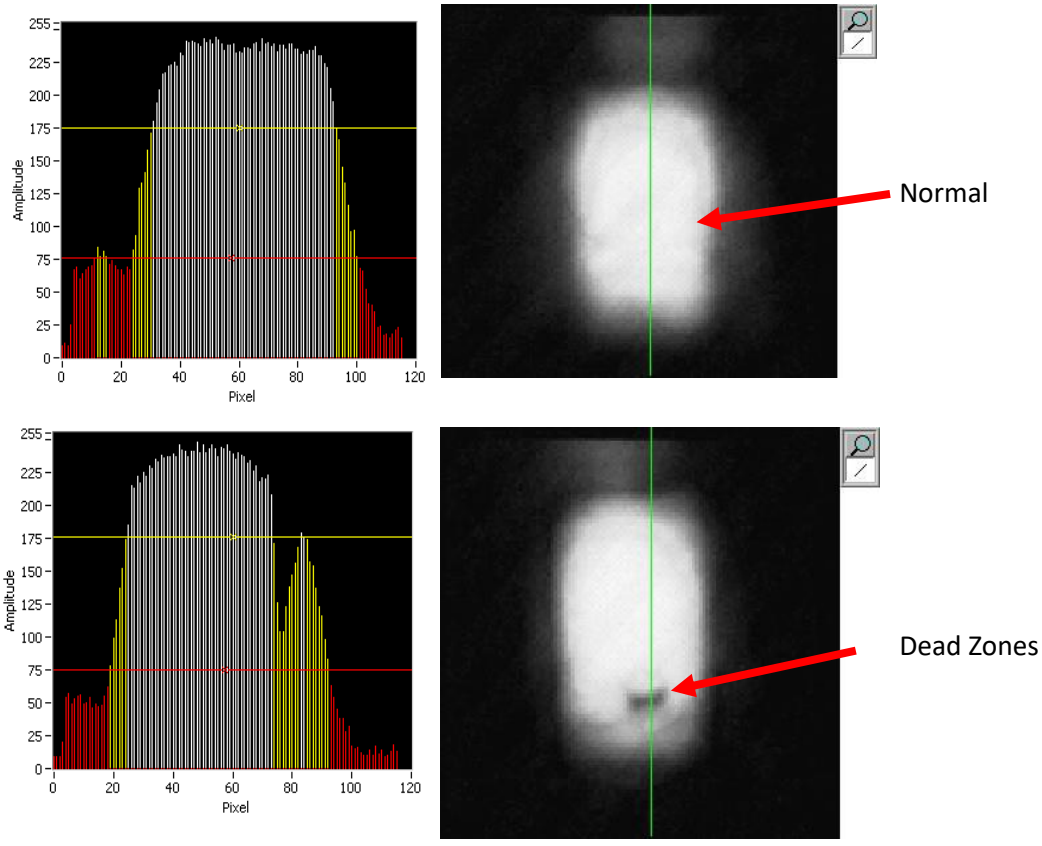
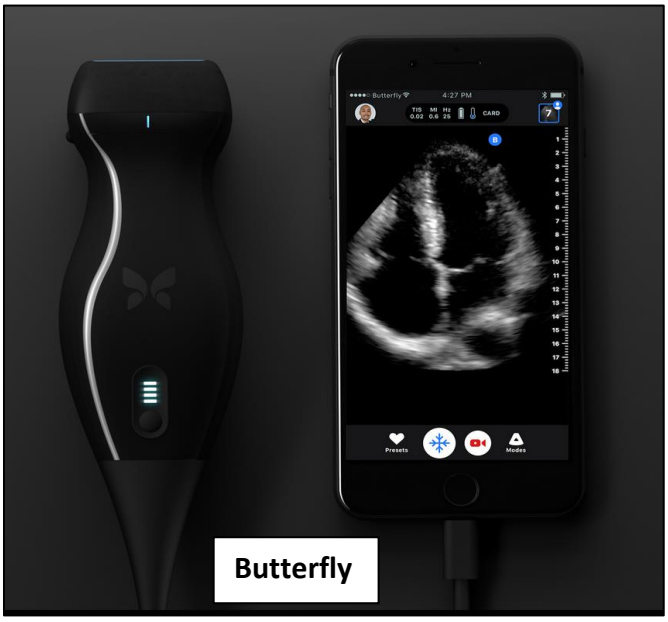
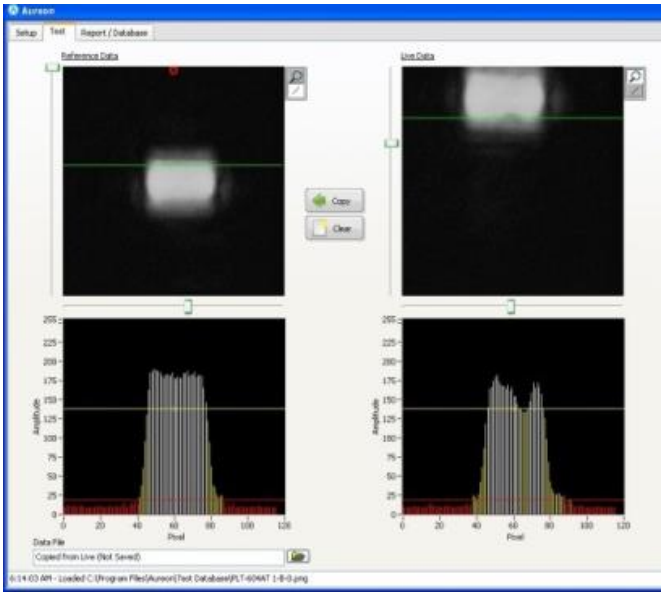
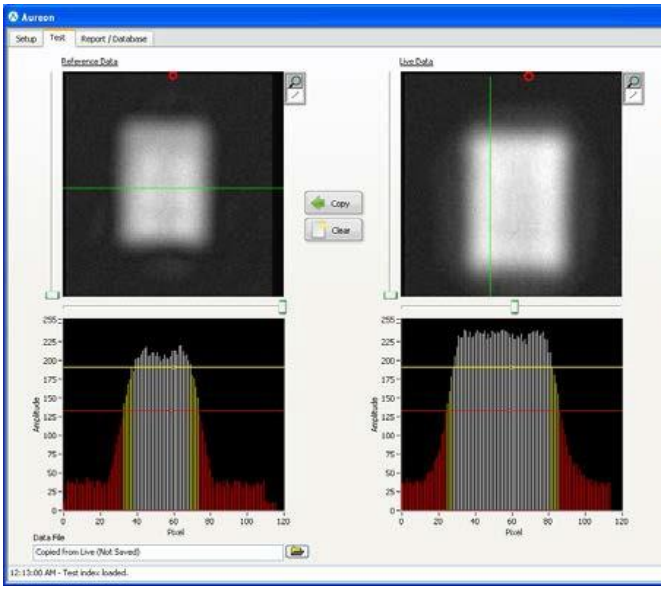


Figure 3

Aureon is an important testing tool for the newest probe/smart phone devices currently on the market, specifically the hand-held devices such as the Butterfly unit shown below, as well as wireless devices such as the Clarius unit, also shown below.

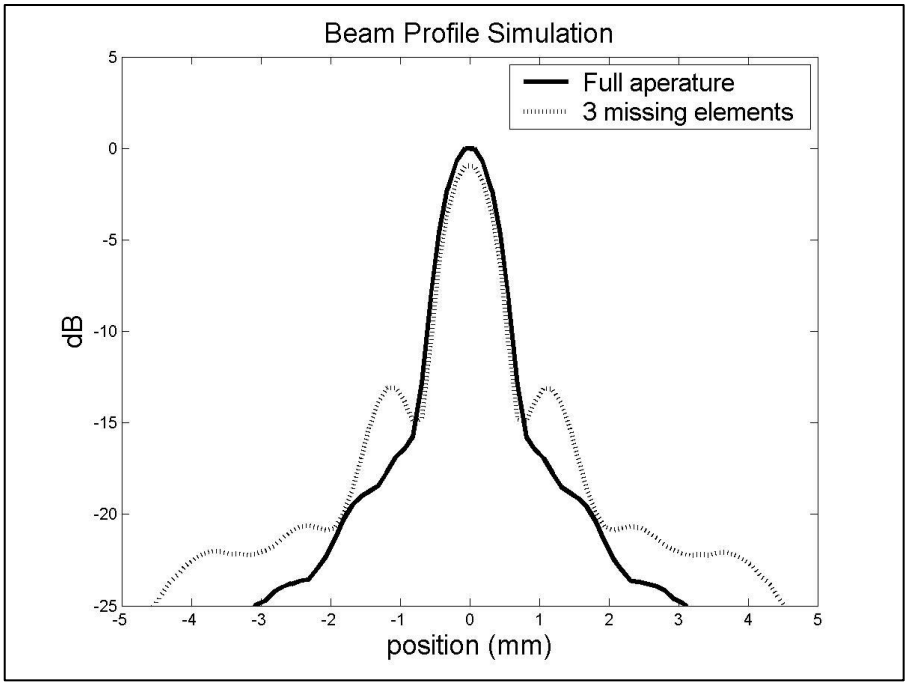


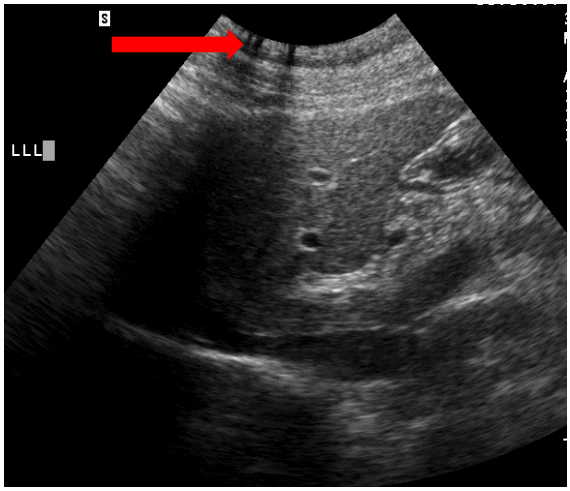




Impact of Dead Elements

As discussed earlier, both detail and contrast resolution are dependent on the integrity of the beam profile. In the beam profile simulation shown below one can easily see the negative impact of dead elements on the sharpness of the beam profile – specifically an increase in both the noise floor as well as the introduction of side lobes; both of which substantially reduce the overall image quality of the ultrasound image. Again, as shown in the image below as few as three dead elements in a 128-element array can significantly impact the clarity of image.

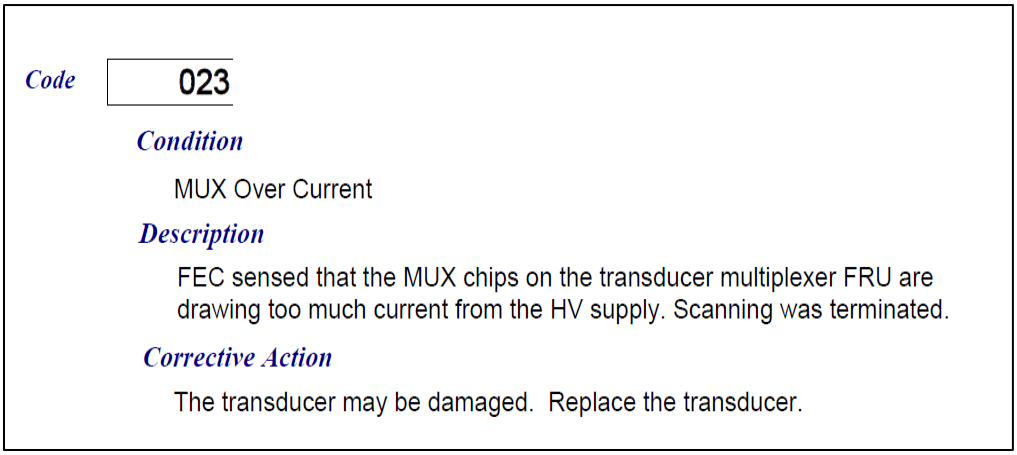




Multiple dead elements - effect on image

Transducer Error Codes

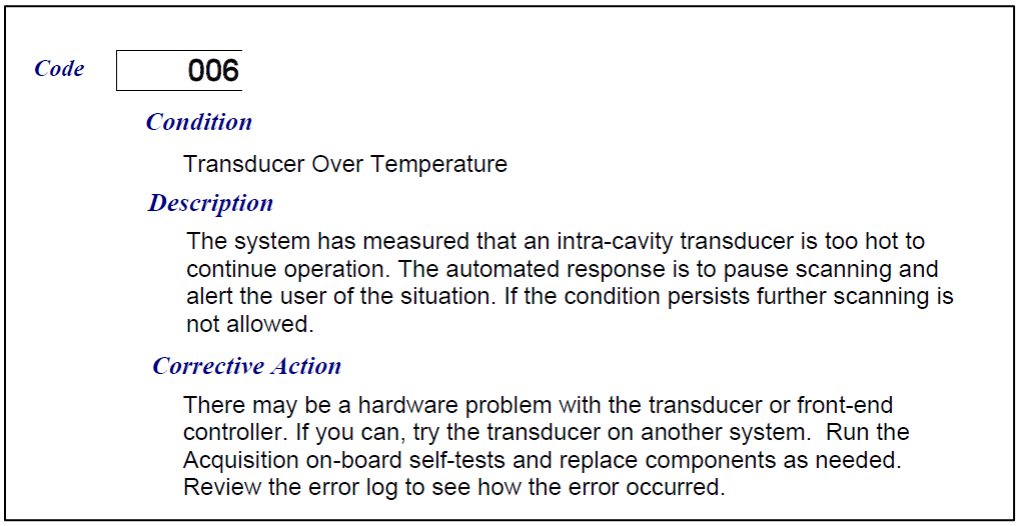
Frequently OEMs provide error codes, displayed on the ultrasound system monitor, when a transducer failure is detected. These error codes generally point to an electrical failure in the probe related to the thermistor (TEE probes see Page 15), electronics near the acoustic stack (e.g., ASIC), or electronics in the connector (e.g., multiplexers - MUX). More often than not these error codes do not specifically tell you what the failure is, instead the error message uses general language such as “Mux Over Current” (see Code 023 below). Also in the example shown below, the corrective action simply says to replace the transducer. Opening the connector and troubleshooting the MUX circuit to find the offending component(s) and replacing them can potentially be a viable option to simply replacing the probe, as these components are normally off-the shelf devices.



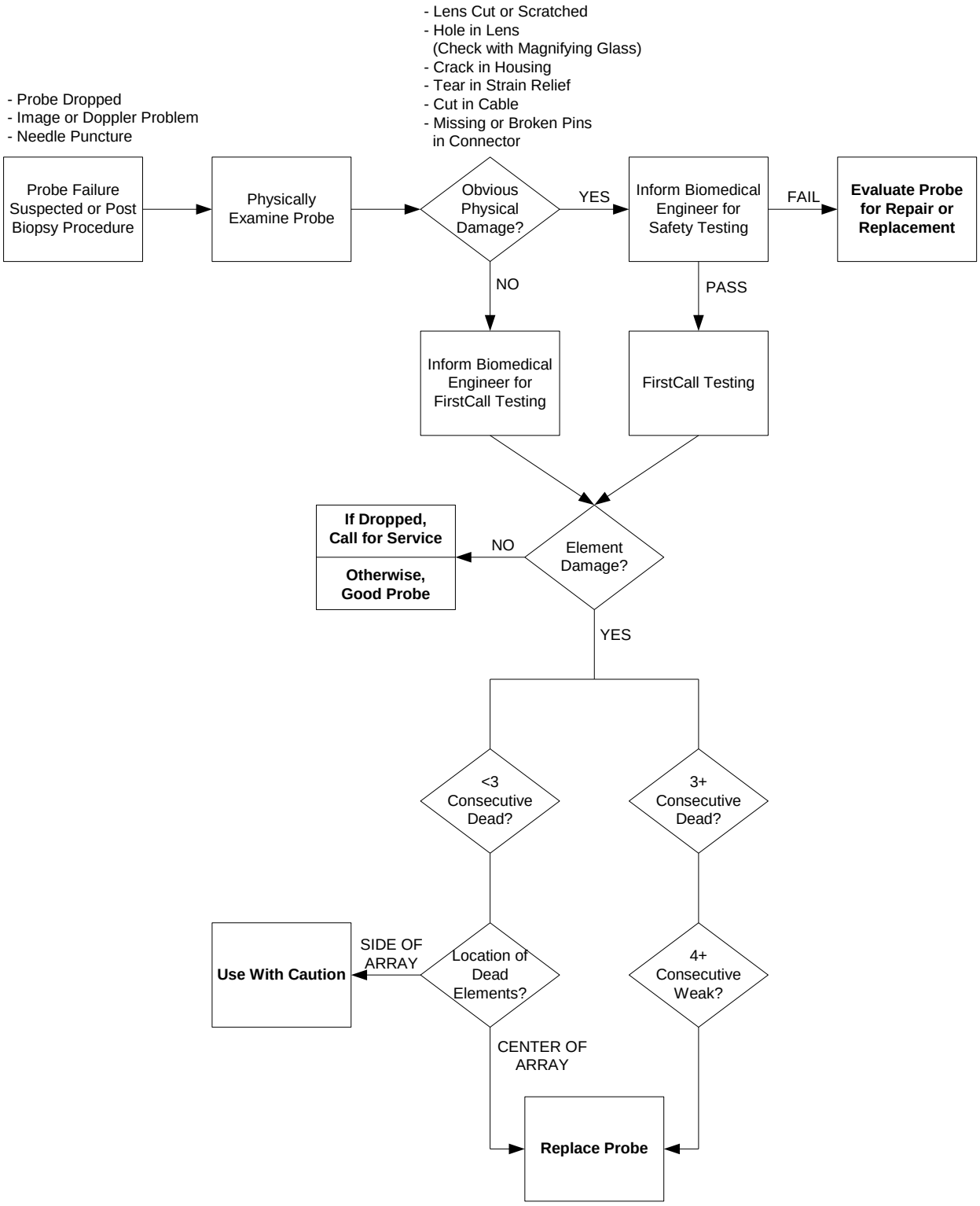
Transducer Error Code

There are certain types of electronics in some transducers that cannot, however, be troubleshot or replaced as they are proprietary devices and not readily available, for example ASICs (e.g., Philips X6-1, X7-2t, and X5-1). Mechanically steered 3D curved array probes also provide error messages indicating motion faults which can either be in the front-end electronics of the system, or in the 3D probe itself. The failure mode can be isolated to the system or the probe by testing the probe on another system. If the failure follows the probe from system-to-system, then it is most likely the probe.

An example of error code (Code 006) shown on the ultrasound system monitor (Philips) when probe aperture overheating occurs:



Troubleshooting probes, a consistent, systematic method for troubleshooting probes begins with a flow chart that provides some direction in identifying cause and effect, as shown on the next page. Using this method can also frequently shine a light on processes or work flow within the ultrasound department that may be damaging probes. Keeping good records of your probe QA outcomes is essential to reducing probe related costs to your institution. Essential to the troubleshooting process is access to test equipment that can objectively provide insight into the operation of the probe. The outcome of this testing will also inform your decision on whether a damaged probe can be repaired, and if it can be repaired for a reasonable cost. Experience has shown that probes have multiple types of failures, some easier to identify than others. The key for developing diagnostic skills is consistency in the approach to troubleshooting both probes and systems. It takes time and patience.



Probe Troubleshooting Flow Chart

Conclusion

Throughout this short Guidebook we have underlined the importance of testing probes when they are brand new, the reason is simple – they will never perform better than when they are new! Establishing baseline performance for new probes is key to managing them properly over time and will generally provide the HTM with early warning indications of probe disfunction. Probes can be repaired with a high degree of success if the problem is caught early in the failure process. Remember, the key to successfully managing probes in your care is consistency.

Thanks for reading this short tutorial - I hope you found it worthwhile. For more extensive material please contact us and ask about our “Blue Paper” series. Also, we would like to invite you to try our probe repair service; with this paper you have a code below which will give you a 25% discount from our normal repair price for the first probe you send in.

PROBE REPAIR CODE**: 35@4GH^Y**

Other Useful References

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