# Phased Array Performance Evaluation with PhotoElastic Visualization

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**Abstract.** New instrumentation and a widening range of phased array transducer options are affording the industry a greater potential. Visualization of the complex wave components using the photoelastic system can greatly enhance understanding of the generated signals. Diffraction, mode conversion and wave front interaction, together with beam forming for linear, sectorial and matrix arrays, will be viewed using the photoelastic system. Beam focus and steering performance will be shown with a range of embedded and surface targets within glass samples. This paper will present principles and sound field images using this visualization system.

**Keywords:** Photoelastic, Visualization, Modeling, Phased Array

## INTRODUCTION

In the industrial venues, phased-array ultrasonic testing has been relatively new (compared to medical applications). Not until recently have internationally recognized standards been available to assess phased-array instrument performance. Today there are ASTM and EN standards available for manufacturers and users to assess performance using typical ultrasonic techniques and electronic equipment. These standards include:

1. ASTM E2491-06 Standard Guide for Evaluating Performance Characteristics of Phased-Array Ultrasonic Examination Instruments and Systems
2. pr EN 16392 consists of the following parts, under the general title Non-destructive testing - Characterization and verification of ultrasonic phased array equipment:

- Part 1: Instruments
- Part 2: Probes
- Part 3: Combined system

At the time of this presentation there is also an IIW (International Institute of Welding) committee working on designing generic blocks for PAUT performance assessments. Calibration blocks used in the pulse-echo techniques described in these standards are usually limited to targets located at a specific depth. Immersion techniques could be used to assess the beam but the results are limited to compression mode assessments as is typical of the limitations of working in a liquid. For assessments of the beam in solids, dynamic aspects of phased-array beams may not be best analyzed by holes or slots at discrete positions. Desired accuracies of the steering and focusing analyses may warrant more detail than machined targets in blocks can provide.

Photoelastic visualization is an option to assess several aspects of phased-array performance. Some of the aspects of acoustic field and instrument analyses that Photoelastic visualization can achieve include:

- Assess element activity
- Determine actual focal depth
- Determine refracted angle

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- Assess spot size
- Visualize grating lobes

## PHOTOELASTIC PRINCIPLES

The principles of photoelastic visualization as used for visualizing acoustic fields have been documented in several places (3) (4), (5), (6).  Whereas the schlieren images are obtained as a result of refractive index changes due to stress gradients, the photoelastic visualization effect is made possible by stresses rotating the polarization direction of the light passing through the specimen.  Hanstead (4) noted that the schlieren technique was generally more sensitive when used to analyze in liquids.  However, the shear stresses that can form in solids are not seen using the schlieren technique but are very easily seen using the photoelastic technique.   The principles of the process are shown in Figure 1.  Conventional ultrasonic transducers and the trigger/delay source are included with the system.  The trigger/delay circuit needs to have any selected external instruments capable of triggering or being triggered (internal/external).  For phased array we utilize instruments such as the PEAK 5PA, the TomoScan Focus and as shown in Figure 1 lower image, the AOS, OEMPA system.  Images presented for the phased array work were produced by the OEMPA system.

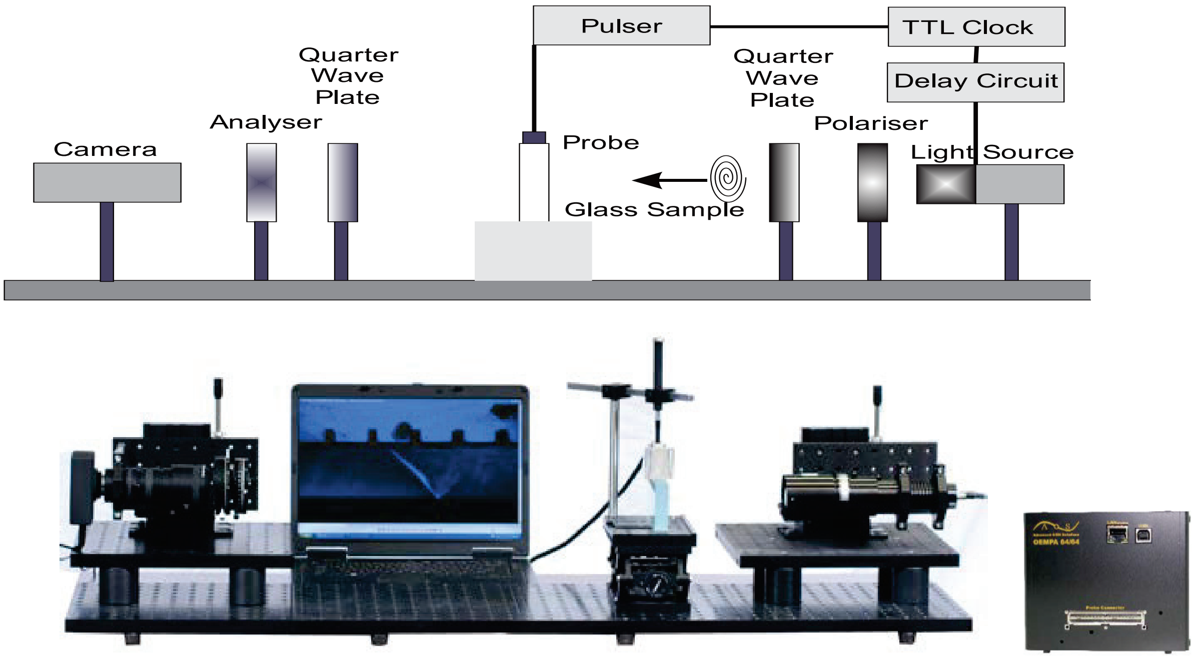


**FIGURE 1.** Photoelastic setup for visualizing acoustic fields.

Strobed light from a high intensity light source is nulled with cross polarizing lenses.  When a pulse is transmitted into the stress-free glass, the local stress changes the condition "stress-free" and causes the light to rotate where the stress occurs.  This introduced pulse-stress change results in a bright region, where the cross-polarization had previously provided a dark-field.

The process requires a clear medium for the light to pass through so the options for photoelastic visualization are limited to clear materials.  In addition, the materials need to have relatively low attenuation.  This eliminates many of the cost-effective polymers.  Ideally, for our applications in comparison of acoustic field properties, the material should have acoustic velocities similar to the metals that are typically tested in non-destructive testing.   Table 1 summarizes some of the properties of the clear materials available.

**TABLE 1.** Properties of clear materials.

| Material | Density (g/cc) | Velocity compression (m/s) | Velocity shear (m/s) | Atten (comp) dB/mm at 5MHz | Atten (shear) dB/mm at 5MHz |
|---|---|---|---|---|---|
| Fused silica | 2.2 | 5970 | 3760 | 0.03 | NA |
| K9 glass | 2.5 | 5830 | 3240 | 0.05 | NA |
| Soda Lime glass | 2.4 | 5840 | 3460 | 0.03 | NA |
| Cross-linked polystyrene | 1.1 | 2350 | NA | 0.18 | NA |
| PMMA | 1.18 | 2751 | 1395 | 0.3 | 0.99 |

Of the materials in Table 1, Soda lime (float) glass and K9 borosilicate glass are the closest matches to steel for velocities and they also have relatively low attenuation values. Glass models can be made in many shapes and sizes. Figure 2 illustrates some shapes used in our assessments.

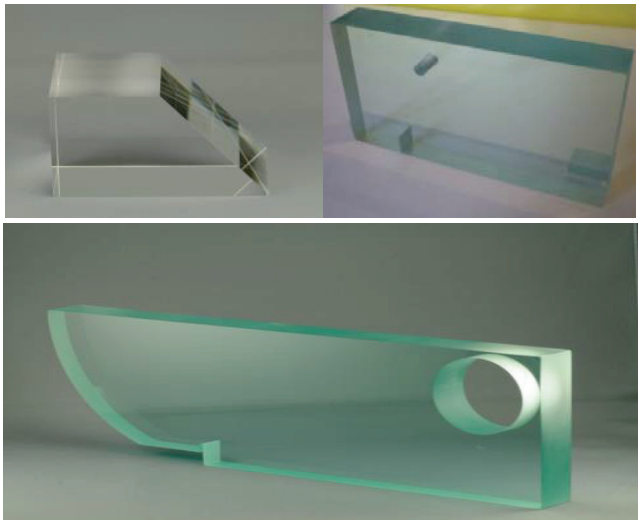

**FIGURE 2.** Samples of glass models used for photoelastic visualization of acoustic fields.

# PHASED-ARRAY PERFORMANCE ASSESSMENTS BY PHOTOELASTIC VISUALIZATION

This paper describes the assessment of several aspects of phased-array equipment and acoustic fields by photoelastic visualization. Aspects considered include:

- Element activity
- Refracted angle
- Beam size
- Focal spot depth accuracy
- Grating lobes

Grating lobes are not specifically addressed here but reference is made to work by Schmitte in a previous paper.

## Element Activity

Activity of an element is one of the assessments required in ASTM E-2192. This is easily seen on a B-scan with a single step focal law that uses one element in each focal law; however it can also be seen in a photoelastic image. In Figure 3 we show how the individual elements might sequence as they are activated moving back from element 64 of a 64 element probe. It is proposed that software designed to view and analyze the presence and intensity would be beneficial for this check.

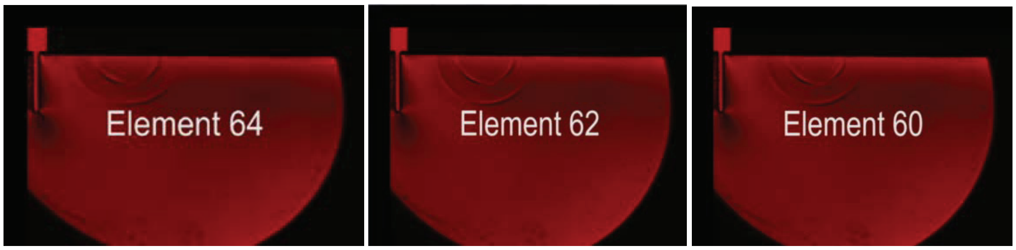


**FIGURE 3.** Element activity performance assessment.

Using the step-by-step through each of the elements the photoelastic process illustrates a similar assessment using the images. The presence (or absence) of the arc determines if the element is functional. To some extent we can use the relative intensity of the arcs in the image to assess uniformity of the element pressures.

## Refracted Angle

One of the main features attributable to the popularity of UT phased-array is its ability to steer the beam electronically. Verification of the accuracy of the focal law is easily done with just a captured image and alignment software. A simple focal law was configured using a 5L64 linear array without a wedge. Sixteen consecutive elements were used to make a 0° focused beam focused at 15mm depth in the glass sample. The software was then adjusted to produce the same focal distance but at increments of 1° up to 5°. Figure 4 illustrates the images captured for the 5° position.

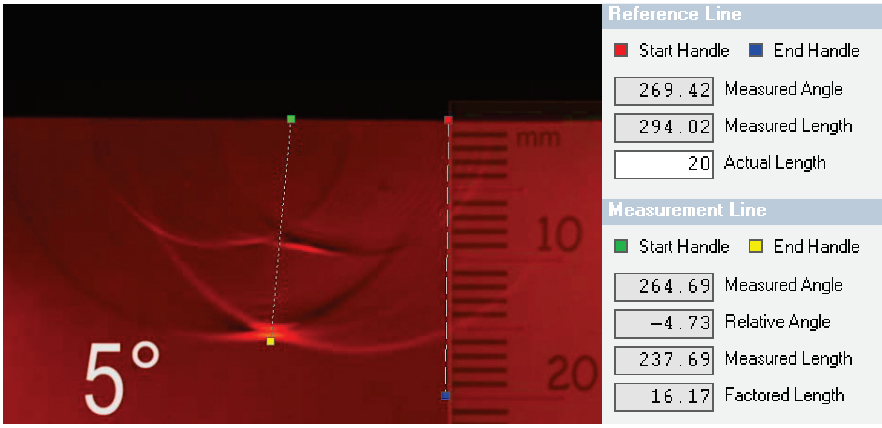


**FIGURE 4.** Focused beam steering to 5°.

To verify the angle accuracy we can use the maximum intensity of the image and the line connecting it to the glass surface. Image Intensity Analysis software allows the angle to be assessed.

- 0° was programmed and we measure 0.09°
- 1° was programmed and we measure 0.77°
- 2° was programmed and we measure 1.5°
- 3° was programmed and we measure 2.96°
- 4° was programmed and we measure 3.49°
- 5° was programmed and we measure 4.73°

A similar process can be done with the refracted transverse mode.

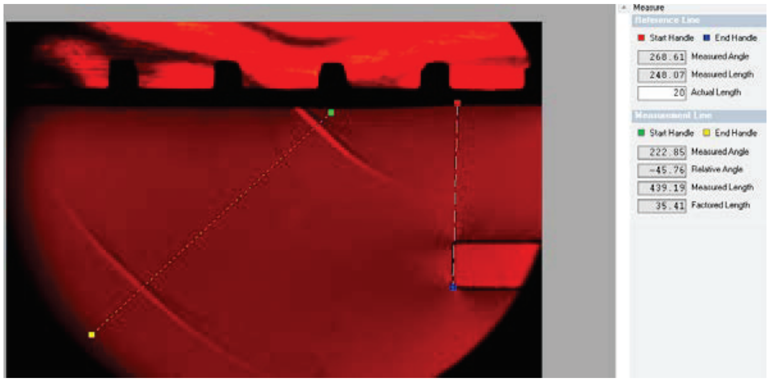


**FIGURE 5.** Refracted 45° transverse mode angle assessment.

With two or more of the images overlaid one on the other, the beam intensity peak at each time interval can be identified and the line connecting the peaks provides the angle of refraction.

In this case the angle is assessed as 45.8°. With an unfocused beam there can be relatively large regions where there is very little change in the beam intensity making a precise location of the peak difficult.

## Beam Size

Beam size determination using the photoelastic image is similar to using the hydrophone technique, in that the one-way transmission is used so measuring the 3dB drop points would provide the same results as the 6dB drop in the pulse-echo mode. Using the focused beam from the 16 element 0° focal law, starting at element 48, the illumination delay was stopped so that the pulse was at approximately the intended focal distance (i.e. 15mm in glass in compression mode). By incorporating a reference item in the photo (in this case the 10mm notch in the glass) we can scale the pixels on the image. Positioning the measurement cursor to cross the peak intensity in the analysis software display, the spot dimensions can be assessed. The base-level intensity is set by the general background and the peak value identified. Setting the level we want to measure the dB drop (e.g. 3dB) the points where the intensity plot cross the 3dB drop points give us the beam size at the focal spot. In the case of the image in Figure 6 we measure 1.65mm. The theoretical near zone for this probe is calculated to be 19mm. When focused at 15mm the estimated spot size is 1.9mm. We would consider the 1.65mm spot size determined by the photoelastic image to be reasonably close to that predicted by theory.

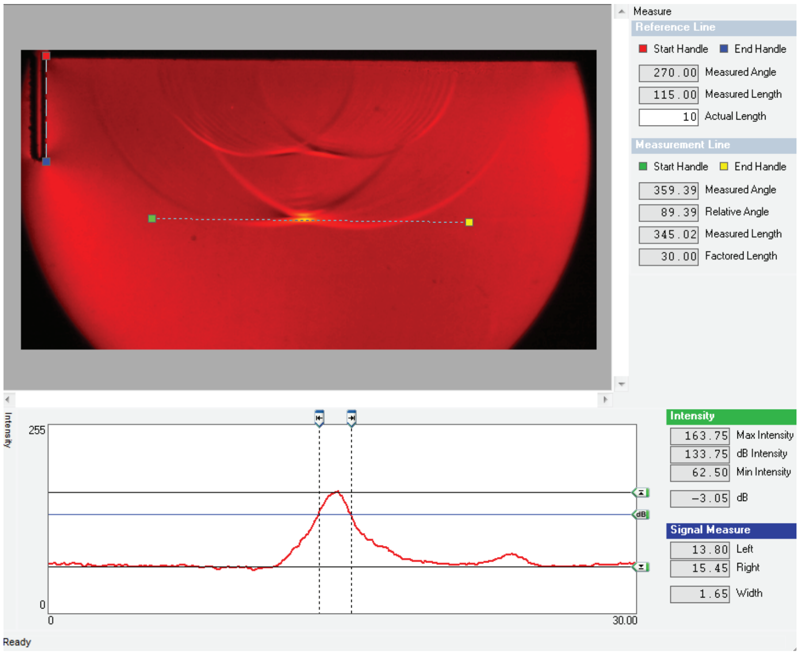


**FIGURE 6.** Assessment of beam focal spot size.

## Focal Spot Depth Accuracy

With photoelastic visualization, formation of the focused beam can be seen dynamically when a video is taken of the beam progressing to its intended focal depth. In the example in Figure 7 a 32 element aperture firing the 16 odd number elements in that aperture is used. This helps visualize the wavelets forming the beam. The focal law was configured to focus the beam at 25mm depth. As we observe the compression mode components of the wavelets advance, the arc they form is seen to converge with a minimum size and maximum intensity at approximately 24mm from the entry surface. This would confirm the focal law and timing control of the elements to provide reasonably good control of the depth focusing.

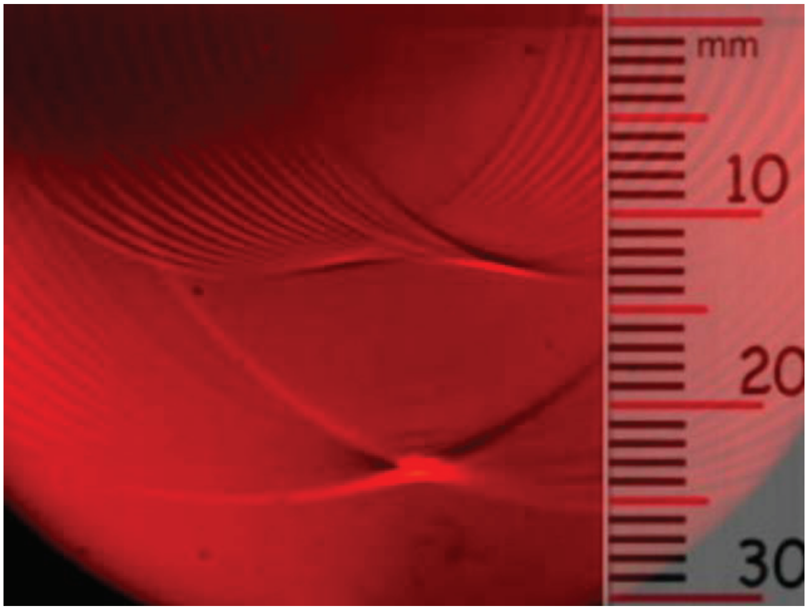


**FIGURE 7.** Assessment of beam focal depth.

## Grating Lobes

Dr. Schmitte at Salzgitter Mannesmann Forschung has developed a technique of integrating image intensities of the photoelastic pulse. By accumulating the intensity changes of each frame of the progression of a phased-array pulse through the glass, he has been able to duplicate the pressure plots modelled using point spread functions and confirmed the modeling of beam intensities of phased-array probes as predicted by the Generalised Point Source Synthesis (GPSS) software from the Fraunhoffer Institute for Industrial Mathematics (Fraunhofer-ITWM). In Figure 8 we used an example from his paper on NDT.net. This used an Imasonic probe 5 MHz, 128 Element, 1 mm Pitch probe mounted without a wedge on a glass sample. The probe was driven by a phased-array unit from Peak NDT Ltd. The image selected illustrates the comparison for 60° shear-mode unfocused focal law made with 16 elements. Although the model considered the parameters for steel, the velocities for steel and glass were sufficiently close that only the attenuations presented any difference (with glass being more attenuative). These compare very closely to the simulated models seen below left.

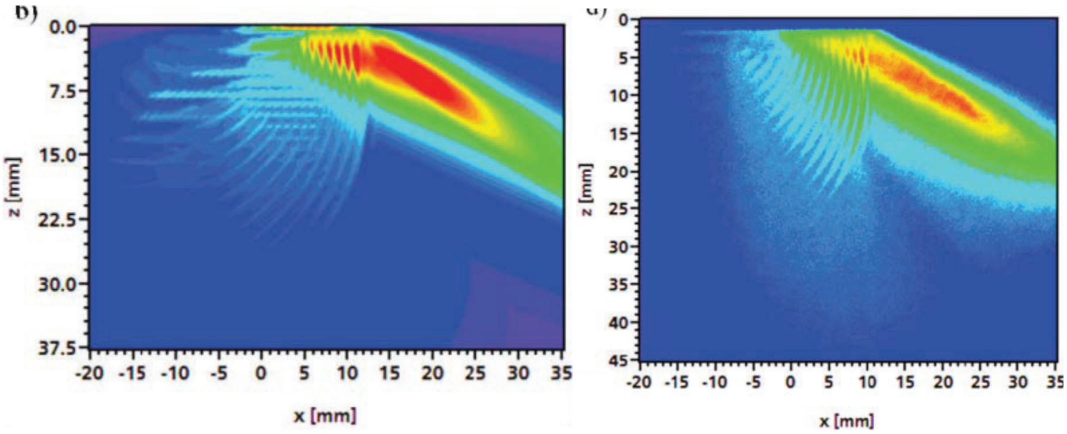


**FIGURE 8.** Comparison of acoustic fields by T. Schmitte. Modelled (left) and measured (photoelastic intensity accumulation (right)...courtesy NDT.net (3).

## CONCLUSIONS

Photoelastic visualization affords a convenient and flexible method of assessing many of the acoustic field parameters assessed in a phased-array system

Signal intensity measurements of the light in photoelastic images provide a good approximation of the acoustic pressures

Further development and advancement of the current IIA software package would benefit the automation process by allowing comprehensive reports to be generated for measurement and validation of element activity, refracted angle, beam size and focal spot depth accuracy. Other areas such as the visualization of severity of grating lobes would also be viable in a software/imaging environment.

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