



Standard Practice for Characterization and Verification of Phased Array Probes¹

This standard is issued under the fixed designation E2904; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This standard practice covers measurement procedures for evaluating certain characteristics of phased-array ultrasonic probes that are used with phased-array ultrasonic examination instrumentation.

1.2 This standard practice describes means for obtaining performance data that may be used to define the acoustic and electric responses of phased-array ultrasonic probes including contact (with or without a wedge) and immersion linear phased-array probes used for ultrasonic nondestructive testing with central frequencies ranging from 0.5 MHz to 10 MHz. Frequencies outside of this range may use the same methods but the testing equipment may vary.

1.3 When ultrasonic values dependent on material are specified in this document, they are based on carbon steel with an ultrasonic wave propagation speed of 5920 m/s (± 50 m/s) for longitudinal wave modes and 3255 m/s (± 30 m/s) for transverse or shear wave modes.

1.4 This document describes the characterization and verification procedures that are to be carried out at the end stage of the manufacturing process of phased array probes. This document does not describe the methods or acceptance criteria used to verify the performance of the entire phased array ultrasonic instrument and probe.

1.5 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

¹ This practice/guide is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.06 on Ultrasonic Method.

Current edition approved Nov. 1, 2012. Published December 2012. DOI: 10.1520/E2904-12.

2. Referenced Documents

2.1 *ASTM Standards*:²

E1065 Practice for Evaluating Characteristics of Ultrasonic Search Units

E1316 Terminology for Nondestructive Examinations

3. Terminology

3.1 *Definitions*:

3.1.1 For definitions of terms used in this practice, see Terminology E1316.

3.1.2 *Technical Specification of the Phased Array Probes*:

3.1.2.1 *datasheet*—defined as specification. This is the document that defines the general geometry and expected performance of a specific model or part number.

3.1.2.2 *certification*—defined as measured performance of an individual probe. This is the document that reports the measured performance of a specific probe (specific to a serial number).

3.1.2.3 *probe type*—contact or immersion.

3.1.2.4 *probe shape and size*—probe form and dimensions.

3.1.3 *Terminology for Array Probes*:

3.1.3.1 *active aperture*—pitch times the number of elements.

3.1.3.2 *cross-coupling*—also called “cross-talk.” An undesirable condition where array elements are activated, electrically or acoustically, by adjacent elements.

3.1.3.3 *element width*—in a rectangular element, the acoustic element’s short dimension.

3.1.3.4 *element length*—in a rectangular element, the acoustic element’s long dimension. See *passive aperture* (also called element elevation) and Fig. 2.

3.1.3.5 *element pitch (or pitch)*—the distance between the centers of two adjacent array elements.

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard’s Document Summary page on the ASTM website.

Element #1 Waveform

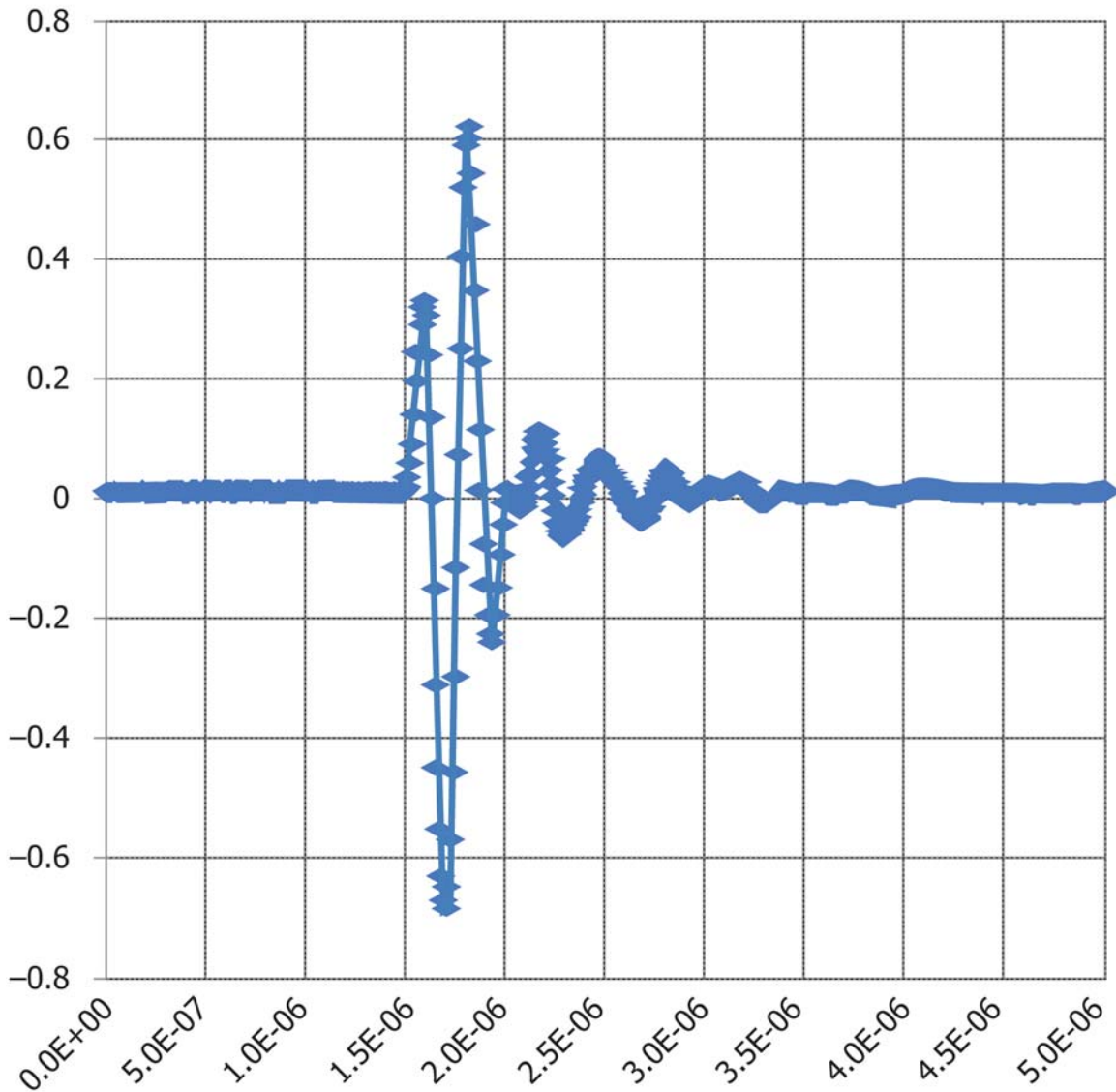


FIG. 1 Schematic Showing Digitization Rate

3.1.3.6 *passive aperture*—the dimension of an array element’s length.

3.1.3.7 *saw cut*—also called “kerf,” space or gap. The space between adjacent elements.

3.1.3.8 *virtual probe*—a group of individual array elements, pulsed simultaneously or at phasing intervals to generate a larger acoustic aperture.

4. Summary of Practice

4.1 The physical, acoustic and electrical characteristics which can be described from the data obtained by procedures outlined in this guide are described as follows.

4.2 *Physical Aspects*—Identification and physical dimension aspects of the probe should be noted. Details to be noted are described in 7.1.

4.3 *Center Frequency, Bandwidth And Time Response*—Section 7.2 describes procedures for determining center frequency, bandwidth and time response of the individual elements of the linear array probe.

4.4 *Sensitivity Range Of Elements*—Section 7.3 describes a procedure to determine variation of sensitivity from one element to the next based on a fixed input voltage.

4.5 *Probe Sensitivity*—The overall sensitivity performance of all the elements in the array is assessed in the procedure described in 7.4.

4.6 *Element Crosstalk*—A procedure for assessment of damping between elements to eliminate crosstalk is provided in 7.5.

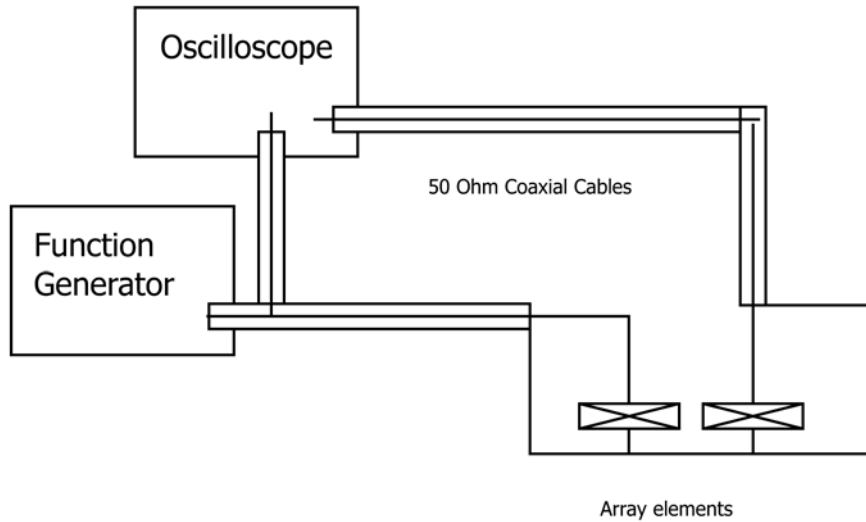
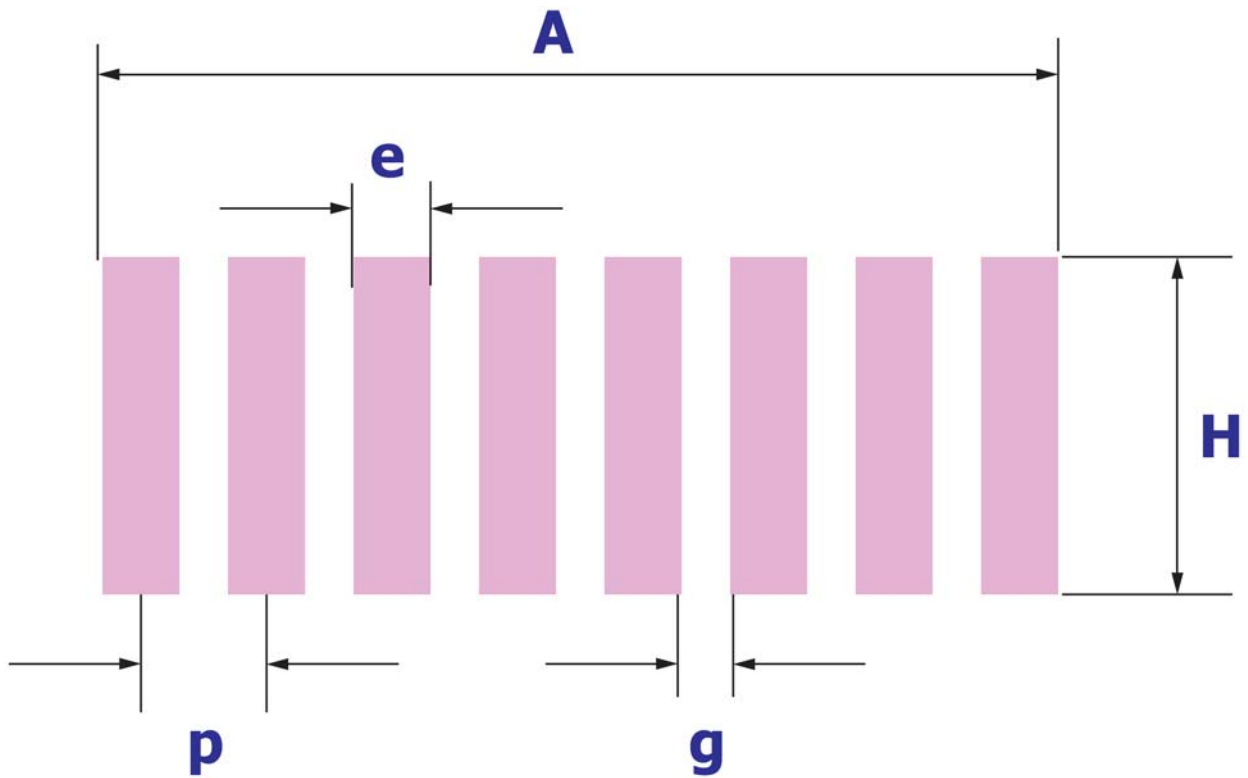


FIG. 2 Two-Channel Schematic Showing Measurement Technique for Crosstalk



Legend:
 A = active aperture (number of active elements x element pitch)
 H = passive aperture
 e = element width
 p = element pitch
 g = saw cut between elements (also called kerf or gap)

FIG. 3 Schematic of Key Parameters for Linear Arrays

5. Significance and Use

5.1 This standard practice is intended to provide standardized procedures for evaluating linear phased-array ultrasonic

probes. It is not intended to define performance and acceptance criteria, but rather to provide data from which such criteria may be established.

5.2 Implementation may require more detailed procedural instructions in a format of the using facility.

5.3 The measurement data obtained may be employed by users of this guide to specify, describe, or provide performance criteria for procurement and quality assurance, or service evaluation of the operating characteristics of linear phased-array ultrasonic probes. All or portions of the standard practice may be used as determined by the user.

5.4 The measurements are made primarily under pulse-echo conditions. To determine the relative performance of a probe element as either a transmitter or a receiver may require additional tests.

5.5 While these procedures relate to many of the significant parameters, others that may be important in specific applications may not be treated. These might include power handling capability, breakdown voltage, wear properties of contact units, radio-frequency interference, and the like.

5.6 Care must be taken to ensure that comparable measurements are made and that users of the standard practice follow similar procedures. The conditions specified or selected (if optional) may affect the test results and lead to apparent differences.

5.7 Interpretation of some test results, such as the shape of the frequency response curve, may be subjective. Small irregularities may be significant. Interpretation of the test results is beyond the scope of this standard practice.

5.8 Certain results obtained using the procedures outlined may differ from measurements made with phased-array ultrasonic test instruments. These differences may be attributed to differences in the nature of the experiment or the electrical characteristics of the instrumentation.

5.9 The pulse generator used to obtain the frequency response and time response of the probe must have a rise time, duration, and spectral content sufficient to excite the probe over its full bandwidth, otherwise time distortion and erroneous results may result.

6. Instrumentation

6.1 *Electronic Instruments:*

6.1.1 The type of instrument(s) used for the tests specified in Section 7 shall be the same as that indicated on the Certification report and **Table 2**. They shall also be compliant with the applicable verification standard for the inspection unit.

6.1.2 The following equipment is required in order to evaluate the probes in compliance with this standard:

6.1.2.1 A pulser/receiver with a minimum bandwidth of 20 MHz, digitizing to 100 MHz, or better, or an oscilloscope (or equivalent) with a minimum bandwidth of 100 MHz.

6.1.2.2 Digitizing should be able to get 10 samples in maximum slope of waveform, as illustrated in **Fig. 1**.

6.1.2.3 A frequency spectrum analyzer with a minimum bandwidth of 100 MHz or a digital oscilloscope/converter capable of performing fast Fourier transforms (FFT), and/or waveform capture and digital analysis.

6.1.2.4 A phased array instrument may be used with a minimum bandwidth of 20 MHz.

6.1.2.5 An impedance analyzer.

6.1.2.6 A waveform generator with burst-mode capability for a sine wave at the nominal frequency of the probe.

6.1.3 The following additional equipment is optional:

6.1.3.1 A hydrophone with an active diameter two times smaller than the central ultrasonic wavelength of the probe being tested, but no less than 0.5 mm.

TABLE 1 List of Variables for Probe Manufacture and Testing

Information Needed	Information Type (C, I, M) ^A	Optional or Required	Observations
Name of Manufacturer	I	Required	
Probe type	I	Required	
Instruments and settings used in the test process	I	Required	See Table 2
Test conditions	I	Required	Coupling medium, sound path, target, fixturing
Probe Dimensions or shape	M or I	Optional	See Table 2 Casing dimensions
Element shape and size (active and passive apertures)	I	Optional	Arrangement of the array(s)
Relative position of array in housing	I	Optional	Dimensions and geometry of the array(s) Location of first or last element in relation to the housing
Pitch, gap between elements, element width, length and dimensions	I	Required	Pitch, gap between elements (saw cut), and element dimensions (length and width)
Connector type	I	Required	
Dimensions and material of integrated wedge	I	Optional	Applicable to contact probes Dimensions and geometry of integrated wedge(s)
Wiring	I	Optional	Cable length and external diameter
Center frequency, bandwidth, and time response	M	Required	
Relative Sensitivity Range of the Elements	M or C in dB	Required	Basic voltage indication of each element
Probe sensitivity	M	Required	
Electrical Impedance	M, I	Optional	
Probe crosstalk	I or C in dB	Optional	Must state medium if crosstalk reported

^A Legend:

C = Calculations

I = Information

M = Measurement

TABLE 2 Instrumentation and Target Requirements

NOTE 1—Table 2 gives a list of the instrumentation requirements to evaluate arrays.

Instrument and Target	Optional or Required	Comments
Instrument model	Required	
Instrument certification date	Required	
Instrument serial number	Required	
Instrument settings	Required	As needed to duplicate the test. Example: pulse voltage, pulse shape, pulse width, gain settings, filters, receiver impedance
Target type/material	Required	
Target standardization date	Optional	
Coupling medium	Required	
Average sound path	Required	Distance or time
Test fixturing	Optional	

6.2 Test Blocks and Other Equipment:

6.2.1 For Contact Arrays with Integral Wedges:

6.2.1.1 Blocks made of the same material as the wedge (acrylic, polystyrene, etc.) in shapes complementary to the wedge, allowing sound paths to be equalized.

6.2.2 For Contact Arrays (Replaceable Wedge or Direct Contact):

6.2.2.1 Blocks with parallel surfaces made of the material specified in the datasheet.

6.2.3 Immersion Testing for Immersion Arrays:

6.2.3.1 A large, flat reflective target. The lateral dimension of the target shall be large enough that spurious echoes do not interfere with the return signal. The thickness of the block shall be equal to at least five times the wavelength of the probe being tested, calculated based on the sound velocity in the target material.

6.2.3.2 The water temperature in the immersion tank should be maintained at room temperature during characterization of the immersion probes in conjunction with the instrument(s).

7. Procedures

7.1 Physical Aspects:

7.1.1 *Method*—Perform a visual inspection of the probe.

7.1.1.1 Confirm that an identification marking is provided on the probe housing.

7.1.1.2 Assess dimensional characteristics as required.

7.1.1.3 Assess sealed edges as required.

7.1.1.4 Assess electrical connections as required.

7.1.1.5 Assess integral wedge surfaces as required.

7.1.2 *Acceptance Criteria*—Make sure the probe is properly identified and assembled and that there are no signs of physical deterioration, which could reduce the reliability of the probe. For in-service applications, either compare calibration results against the initial standard, or send probe back to manufacturer for re-certification.

7.2 *Center Frequency, Bandwidth and Time Response (Waveform Duration)*—See Annex A1, Annex A2 and Annex A4 in ASTM E1065 for guidelines.

7.2.1 Measurements shall be taken on each element of the probe.

7.2.2 For immersion probes, the target is placed at a water path as referenced in section 6.2, typically at the natural focus, in accordance to the datasheet. Measurements shall be taken under normal incidence on any one of the detectable return echoes from the test block.

7.2.3 For contact probes, the measurement shall be taken via direct contact (water or gel couplant) on the test block defined in section 6.2.

7.2.4 The transmitter pulse should be a shock excitation having a duration of one-half cycle of the nominal probe frequency.

7.2.5 *Acceptance Criteria*—The values obtained for the frequency, bandwidth, and time response are the suggested values of each element.

7.2.6 Exceptions for tolerance can be based on extenuating circumstance, like cable length, element impedance.

7.2.7 Center Frequency (F_c):

7.2.7.1 Average of all elements must be within $\pm 10\%$ of the central value specified.

7.2.7.2 Range of center frequency for all elements must be within $\pm 10\%$ of the center frequency average for all of the elements.

$$F_{c_{avg}} = \pm 10\% \text{ of the nominal frequency of the probe}$$

$$F_{c_{min}} > 0.9 * F_{c_{avg}}$$

$$F_{c_{max}} < 1.1 * F_{c_{avg}}$$

7.2.8 Relative Bandwidth (BW):

7.2.8.1 Average of all elements must be \geq a value specified by the manufacturer. If appropriate, further agreement on the specifications can be made with the client.

7.2.9 Time Response (Waveform Duration):

7.2.9.1 Time Response (waveform duration) may be specified at a variety of amplitude values below the maximum. Typically these values are -20 dB and -40 dB, measured per ASTM E1065.

7.2.9.2 Average of all elements must be \leq a value specified by the manufacturer. If appropriate, further agreement on the specifications can be made with the client.

7.2.9.3 Average Time Response < value specified by manufacturer. If appropriate, further agreement on the specifications can be made with the client.

7.3 Relative Sensitivity Range of the Elements within a Probe in Pulse-Echo Mode:

7.3.1 Measurements shall be taken in the same conditions as the center frequency, bandwidth, and pulse duration measurements.

7.3.2 In the case of probes with integrated wedges, the measurement will be taken on the complementary test block defined in section 6.2, which will enable each of the elements to be placed in conditions identical to the ultrasonic path.

7.3.3 The reference echo amplitude of each element is measured (in volts). The sensitivity of each element is calculated in dB based on the following formula:

$$\text{Sensitivity of an element} = 20 \log (V_{\text{element}} / V_{\text{excitation}})$$

7.3.3.1 Sensitivity variation (gain deviation) for an array = Maximum sensitivity of an element minus minimum sensitivity of an element within an array.

7.3.3.2 In most cases for an array, V_{element} is amplified and must be accounted for in the sensitivity calculation.

7.3.3.3 $V_{\text{excitation}}$ = Excitation voltage of an element or a reference voltage defined as excitation voltage into a 50 Ohm load

7.3.4 *Acceptance Criteria*—The sensitivity variation (gain deviation) of each element shall fall within limits specified by the manufacturer or an agreed specification—typically this value is ± 2 dB or ± 3 dB.

7.4 *Probe Sensitivity*—The relative probe sensitivity is calculated using the arithmetic mean of the sensitivity measurement of all elements in one array.

7.4.1 *Method*—Measurement taken with the same conditions as section 7.4.

7.4.2 *Acceptance Criteria*—This number should be agreed upon by the manufacturer and the customer. In the case of standard products, it shall be defined by the manufacturer—typically this value is ± 2 dB or ± 3 dB.

7.4.2.1 The acceptance criteria are typically defined after the manufacture and test of a statistically significant number of probes.

7.5 *Phased Array Crosstalk:*

7.5.1 *Method*—If required, the manufacturer shall commit to a phased array crosstalk value (measured in dB). Typically, this should be performed in immersion, for adjacent elements, using instrumentation defined with the end-user. The technique should involve exciting one element and listening on an adjacent element.

$$\text{Crosstalk value} = [20 \log (V_{\text{receive element}} / V_{\text{excitation element}})]$$

$$V_{\text{excitation element}} = \text{Measured voltage on excitation element}$$

$$V_{\text{receive element}} = \text{Measured voltage received on adjacent element}$$

7.5.1.1 *Typical Set-up:*

(1) Excitation: sine wave burst at nominal frequency, 10 ± 1 volt, 5–10 cycles

(2) Infinite medium, such as a water bath where the water path is long enough to exclude extra signals from the crosstalk measurement. Recommended minimum path length to any reflector is 1 in. (25 mm).

7.5.2 *Acceptance Criteria*—The phased array crosstalk shall be acceptable to the end-user. The crosstalk specification shall be defined for each probe as an output of the design validation.

8. Report

8.1 **Table 1** provides a list of information that should be detailed in the manufacturer’s probe certification report in conjunction with this standard (I = Information, M = Measurement). Note that some of the information is optional. The certification report shall also provide information about the instrument used for testing and test conditions.

8.2 The manufacturer should indicate the temperature range corresponding to normal use of the probe and any special conditions related to storage or protection during transport.

8.3 The report should declare compliance to this document. Probes that are compliant with this Standard shall have a certification report which includes the statement: “This device is in compliance with ASTM E2904.”

9. Keywords

9.1 characterization; phased array; probes; ultrasonic

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org). Permission rights to photocopy the standard may also be secured from the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, Tel: (978) 646-2600; http://www.copyright.com/