
AMERICAN NATIONAL STANDARD

Procedures for Calibration of Underwater Electroacoustic Transducers

ANSI/ASA S1.20-2012

Accredited Standards Committee S1, Acoustics

Standards Secretariat
Acoustical Society of America
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Secretariat:

Acoustical Society of America

Approved February 17, 2012 by:

American National Standards Institute, Inc.

Abstract

This standard establishes measurement procedures for calibrating underwater electroacoustic transducers. It is a revision of American National Standard S1.20-1988 (R2003). Both primary and secondary calibration procedures are specified for frequencies from a few hertz to a few megahertz. Procedures are specified for determining the measurable characteristics of free-field receive voltage sensitivity, transmitting response, directional response, voltage coupling loss, impedance, and equivalent noise pressure. Measurement uncertainty analysis is introduced for these measurement types, with identification of common error sources. Equations are given for the following derived characteristics: beam pattern, directivity factor and index, equivalent two-way beam width, acoustic power output and level, electrical power input, transmitting efficiency, open-circuit effective bandwidth, and quality factor. Annexes have been included to address: A) free-field calibration in a laboratory tank, B) medium correction factors, C) measurement of sensitivity and response—infrasound and low audio-frequency range, D) phase of free-field voltage sensitivity via reciprocity method, E) nonlinear effects including cavitation, and F) standard-target method for calibrating active sonars.

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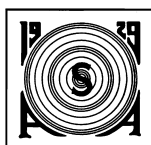
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Foreword

[This Foreword is for information only and is not a part of ANSI/ASA S1.20-2012 American National Standard Procedures for Calibration of Underwater Electroacoustic Transducers.]

This standard comprises a part of a group of definitions, standards, and specifications for use in acoustics. It was developed and approved by Accredited Standards Committee S1 Acoustics, under its approved operating procedures. Those procedures have been accredited by the American National Standards Institute (ANSI). The Scope of Accredited Standards Committee S1 is as follows:

Standards, specifications, methods of measurement and test, and terminology in the field of physical acoustics, including architectural acoustics, electroacoustics, sonics and ultrasonics, and underwater sound, but excluding those aspects which pertain to biological safety, tolerances, and comfort.

This standard establishes measurement procedures for calibrating underwater electroacoustic transducers and describes forms for presenting and assessing the resultant data. Both primary and secondary calibration procedures are specified for the frequency range from a few hertz to a few megahertz.

This standard is not comparable to any existing ISO Standard.

This standard includes six Informative Annexes.

At the time this Standard was submitted to Accredited Standards Committee S1, Acoustics, for approval, the membership was as follows:

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Working Group S1/WG 9, Calibration of Underwater Electroacoustic Transducers, which assisted Accredited Standards Committee S1, Acoustics, in the development of this standard, had the following membership.

R.M. Drake, Chair

K.G. Foote	R.M. Logan	S.P. Robinson
S.E. Forsythe	J.A. Meyers	P.D. Theobald

Suggestions for improvements of this standard will be welcomed. They should be sent to Accredited Standards Committee S1, Acoustics, in care of the Standards Secretariat of the Acoustical Society of America, 35 Pinelawn Road, Suite 114E, Melville, New York 11747-3177. Telephone: 631-390-0215; FAX: 631-390-0217; E-mail: asastds@aip.org.

American National Standard

Procedures for Calibration of Underwater Electroacoustic Transducers

1 Scope

This standard establishes measurement procedures for calibrating underwater electroacoustic transducers and describes forms for presenting and assessing the resultant data. It is a revision of American National Standard S1.20-1988 (R 2003).

2 Normative references

ANSI S1.1-1994 (R 2004) *American National Standard Acoustical Terminology*

ANSI/ASA S1.8-1989 (R 2011) *American National Standard Reference Quantities for Acoustical Levels*

3 Terminology

For the purposes of this standard, the terms and definitions given in ANSI S1.1-1994 (R 2004) apply, except where otherwise specifically re-defined herein.

4 Letter symbols

Letter symbols used in this standard comply with those given in ANSI/IEEE Std 260.4-1996 *American National Standard Letter Symbols and Abbreviations for Quantities Used in Acoustics* (revision and redesignation of ANSI Y10.11-1984), ISO 80000 *Quantities and Units*, ANSI S1.1-1994 (R 2004) *American National Standard Acoustical Terminology*, and ANSI/ASA S1.8-1989 (R 2011) *American National Standard Reference Quantities for Acoustical Levels*. Additional letter symbols, when utilized, are defined within this standard.

5 Applications

5.1 Application statement

Primary and secondary calibration procedures are specified for the frequencies from a few hertz to a few megahertz.

5.2 Measurement types

Procedures are specified for determining the measurable characteristics of free-field sensitivity (more specifically identified as “free-field voltage sensitivity,” a receive voltage measurement), transmitting current response, transmitting voltage response, directional response, voltage coupling loss, impedance, and equivalent noise pressure.

5.3 Transmit and acoustic boundary considerations

Transmit drive conditions and acoustic boundaries can significantly affect the quality of acoustic transmit signal measurements and therefore the quality of the computed measurement parameters. Care should always be taken to work within device-specific operating ranges and under known acoustic conditions.

5.4 Annexes

The annexes provided with this standard address other related subject matter and are provided for informational purposes. These annexes address free-field calibration in a laboratory tank, medium correction factors, measurement of sensitivity and response—infrasonic and low audio-frequency range, phase of free-field voltage sensitivity via reciprocity method, nonlinear effects including cavitation, and standard-target method for calibrating active sonars.

6 Procedures for measuring performance characteristics

6.1 Preparing transducers for measurement

Transducers must be properly prepared for measurement to ensure an accurate calibration. It is especially important that all surfaces be clean and free of air bubbles.

6.1.1 Use of wetting agents

To ensure proper acoustic coupling of the transducer to the water, a wetting agent should be applied to the active face of the transducer after it has been thoroughly cleaned and before it is immersed for acoustic stabilization^[1] (reference clause 6.1.2). The effectiveness of the cleaning operation can usually be determined by observing the meniscus while the transducer is being lowered into the water. Breaks in the meniscus are indicative of inadequately cleaned areas. When other structure is included along with the transducer (such as a sonar dome), that structure must also be thoroughly cleaned and treated with a wetting agent.

6.1.2 Acoustic stabilization

Before any calibration measurements are made, the transducer should be placed in the water at the proper test depth for a period of time sufficient for the transducer to attain temperature and hydrostatic pressure equilibrium with the medium. This procedure and that recommended in clause 6.1.1 should help ensure a bubble-free active face. The proper test depth is usually dependent upon the device being measured, the geometry of the test tank, and the required conditions.

The characteristics of some transducer materials are very dependent on temperature.^[2] It is thus essential that temperature equilibrium be established and that the temperature also be measured and recorded. The stability of the transducer response is one factor in determining temperature equilibrium.

6.1.3 Determine effective acoustic center

American National Standard ANSI S1.1-1994 clause 7.48 defines the effective acoustical center of a projector as the “point source from which sound pressure varies inversely as distance.” In this revision, the more commonly used terminology of “acoustic center” has been preferentially selected to replace the terminology “acoustical center.” The acoustic center is the point used to reference the position of the projector and for measuring the distances through which any axis of rotation must pass. In practice, the physical geometric center of the projector is used as the acoustic center estimate with experimental verification of the adequacy of this position. This is accomplished by a distance-loss experiment; that is, the sound pressure from the projector must be inversely proportional to the distance from the acoustic center to the point of measurement, given allowance or compensation for the effect of acoustic absorption.

The concept of an acoustic center applies by definition only to a projector. A hydrophone is presumed to be in a sound field of plane progressive waves where the sound pressure amplitude is independent of position. In practice, of course, this is not true, and the hydrophone position is that of its acoustic center when viewed as a projector. The test of a hydrophone's acoustic center is the same as that for a

projector; that is, when the hydrophone is placed at two or more sufficiently distant points from a source of spherical waves, its output should be inversely proportional to the distance, again making allowance or compensation for acoustic absorption.

6.1.4 Test for farfield

In a farfield, the acoustic pressure produced by a projector at points sufficiently distant from the projector for spherical divergence (reference clause 6.13 and 6.36 of ANSI S1.1-1994) will vary inversely with the distance from the effective acoustic center of the projector, provided that correction is made, if needed, for the attenuation due to scattering and absorption. This latter attenuation will not usually be significant at the usual separation distances of a few meters as is typical for laboratory and most open-water acoustic test sites and for frequencies less than about 500 kHz; therefore, any correction factors for such cases can be neglected. As test range and/or frequency increases, however, measurement conditions should be carefully evaluated, especially with regard to the test medium and frequency range of operation, to determine if any substantial attenuation effect is evident (reference Annex B). The “inverse-distance” rule, $1/\text{range}$, provides a test for farfield conditions. In addition, if this test and a calibration are to be valid, the magnitude of the signal-plus-noise must exceed the noise by a factor appropriate for the accuracy desired (at least 20 dB for about ± 1 dB error).

For transducer calibrations in the presence of reflecting boundaries, selection and orientation of the measuring and measured transducers can be such that their angular deviation loss (clause 7.65 of ANSI S1.1-1994) will minimize the effect of reflections. In some instances, such as measurements in a tank, the pulsed-sound technique may be required to produce an effective farfield. In this method, a pulse of sound long enough to simulate steady state at the measured transducer is used with a gated receiving system for reception of the direct signal and suppression of all signals due to reflections (reference Annex A).

Spherical wave divergence, as that which would be obtained from a true point source, is approximated for hydrophones/transducers by setting up test distances beyond some minimum value such that:

$$d > \frac{\pi a^2}{\lambda} \text{ and } d > a, \quad (1)$$

where a is the largest radius of a piston source or half the length of a line source, d is the distance between the acoustic centers of the two transducers, and λ is the wavelength of the sound.^[3] These criteria shall be observed for all test configurations to assure that farfield conditions are evident at the time all measurements are taken.

Physically, the requirement that the transducer look like a point source means that the variation in distance from the measuring position to any place on the surface of the transducer must be small in comparison with a wavelength or the distance.

NOTE The terminology used in this standard from this point on uses “free-field” to designate the type of measurement taken and that farfield conditions existed at the time those measurements were taken. By definition (clause 6.06; ANSI S1.1-1994) free-field represents an idealized case where the test location is free from boundaries. This is actually rarely the case completely; however, commonly accepted practice is to designate these measurement types with a “free-field” qualifier.

6.1.5 Acoustic alignment and orientation

Before beginning any measurement set, the orientation of the devices used in acoustic testing must be positioned to some known or referenced orientation. This positioning is preferably made via an acoustic alignment by adjusting the orientations of the in-water devices to achieve a maximum peak response, typically accomplished at the higher frequencies of operation (where the directionality of the devices are more pronounced). Orientation to a reference mark on the in-water devices is also a common approach.

In either case, the alignment methodology should be recorded and any coordinate system used should be documented (clause 7.3).

6.2 Receive sensitivity methods and measurement conditions

There are two primary methodologies that are used to determine the receive sensitivity of a hydrophone. A primary calibration technique is employed to establish the receive sensitivity of a hydrophone when no reference hydrophone is available. A secondary comparison calibration technique is employed when a known sensitivity reference hydrophone is available for use and can be used to compare to an unknown hydrophone to obtain its receive sensitivity characteristics.^[4]

The choice of the technique employed for primary calibration depends upon the frequency range to be covered with consideration also given to the physical size and attributes of the test device. The free-field reciprocity method, using either continuous wave or short-duration pulsed sinusoidal sound waves, is adequate for most of the ultrasonic and audio-frequency range. A coupler reciprocity method may be used to cover the infrasonic and lower audio-frequency range in which the longer wavelengths make it difficult to obtain a free-field. This latter technique is usually limited to relatively small hydrophones due to the requirement to fit within the confines of a small test vessel. This methodology is performed in a limited number of acoustic test facilities; therefore, overview information on this technique has been provided in the annex only (reference Annex C).

The secondary calibration method requires the use of an *a priori* calibrated standard reference hydrophone to determine the sound pressure level in the water. The hydrophone to be calibrated is subjected to a known sound pressure level, with computations then performed to deduce the receive sensitivity. The technique incorporates an underwater sound projector with a known sound pressure transmission performance attained via the use of a standard reference hydrophone. The quantitative measured values of separation distance and relevant input voltage, current, and/or power are used in the receive sensitivity computations.

When several characteristics of one transducer are measured, care should be taken that temperature, hydrostatic pressure, electrical grounding, acoustic load, and other environmental conditions remain constant. Those conditions that could affect the measurement results must be specified.

All measured characteristics are assumed to apply for the steady-state condition, unless specifically stated otherwise. When pulsed-sound techniques are used, the pulse duration and shape must be such that steady-state, free-field conditions are essentially realized.^[4]

6.3 Measurement of sensitivity and response-audio and ultrasonic frequency range

[See ANSI S1.1-1994 Clauses 7.10, 7.49, 7.50, 7.53 and 7.54.]

6.3.1 Procedures for primary calibrations of free-field sensitivity and transmitting response

6.3.1.1 Reciprocity theory

[See Bibliography for references to Reciprocity Theory.]

6.3.1.2 Requirements for a reciprocal transducer as a basis of reciprocity calibrations

The execution of a primary reciprocity calibration requires the use of two transducers that must be reciprocal in nature. A reciprocal transducer is one that must be linear and reversible (capable of both active and passive operation). Reversibility implies that if two reciprocal transducers are coupled acoustically, the ratio of the driving current in the first transducer to the open-circuit voltage across the terminals of the second or receiving transducer, called the open-circuit transfer admittance (clause 7.18;

ANSI S1.1-1994), is equal to the ratio that would be observed if the functions of transmission and reception were reversed. Before any presumption of being reciprocal, the transducers intended for use in a reciprocity calibration should be tested against one another to verify the open-circuit transfer admittance equivalency for the two cases (clause 7.08, ANSI S1.1-1994).

6.3.1.3 Primary free-field voltage sensitivity measurements

The magnitude and phase of the free-field voltage sensitivity of an electroacoustic transducer can be determined by a three-transducer reciprocity calibration. Use of this procedure requires three transducers (a projector, P , the hydrophone, H , to be calibrated, and a reciprocal transducer, T , that can be used as both a hydrophone and a projector). A series of three projector-hydrophone measurements is made using either P or T as a projector and H or T as a hydrophone; drive current and receive voltage are measured. The measurements are made under free-field conditions (clause 6.06; ANSI S1.1-1994) with the hydrophone and transducer successively located in the farfield of the projector. The three experimental arrangements are indicated in Figure 1. The input current and output voltage values are both complex; i.e., they include both amplitude and phase.^[4]

For each arrangement, the distance is that measured between acoustic centers.

Arrangement	Input Current	Projector	Hydrophone	Output Voltage
1	i_{PH}	P	H	e_{PH}
2	i_{PT}	P	T	e_{PT}
3	i_{TH}	T	H	e_{TH}

Figure 1 – Transducer arrangements for reciprocity calibration

The complex receive sensitivity, $(M_e)_H$, for the hydrophone is given by:

$$(M_e)_H = \sqrt{\left(\frac{4\pi e_{PH} e_{TH} i_{PT} d_1 d_3}{j\omega \rho e_{PT} i_{PH} i_{TH} d_2} \right) \exp\left(j \left(\frac{\omega}{c} \right) (d_1 + d_3 - d_2) \right)}, \quad (2)$$

where

ω is the angular frequency in radians per second,

c is the sound speed of the surrounding medium in meters per second,

ρ is the density of the surrounding medium in kilograms per cubic meter,

i_{PH} , i_{TH} , and i_{PT} are the measured drive currents in amperes,

e_{PH} , e_{TH} , and e_{PT} are the measured receive voltages in volts,

d_1 is the distance between the projector, P , and the hydrophone, H , in meters,

d_2 is the distance between the projector, P , and the transducer, T , in meters,

d_3 is the distance between the transducer, T , and the hydrophone, H , in meters.

The assumed time dependence $\exp(j\omega t)$ has been suppressed for convenience.

The SI derived pressure unit is the pascal (Pa) ($1 \text{ Pa} = 1 \text{ N/m}^2$). The derived unit of free-field voltage sensitivity $(M_e)_H$ is the volt per pascal, 1 V/Pa . The free-field voltage sensitivity is expressed in decibels referenced to 1 V per micropascal, dB re $1 \text{ V}/\mu\text{Pa}$ [clause 6; Reference Quantities; ANSI/ASA S1.8-1989]. After conversion to decibel units, the sensitivity value obtained is lowered by the quantity of 120 decibels to properly reflect the reference pressure of 1 micropascal.

6.3.1.3.1 Magnitude of free-field voltage sensitivity

For most applications, the usual requirement is to quantify only the magnitude of the free-field voltage sensitivity of an electroacoustic transducer. This is typically a simpler measurement to make than one involving phase since positioning of the transducers for sensitivity magnitude is not as critical as for phase. For a magnitude only calibration, the free-field voltage sensitivity is given by:

$$|(M_e)_H| = \sqrt{J \left(\frac{e_{PH} e_{TH} i_{PT} d_1 d_3}{e_{PT} i_{PH} i_{TH} d_2} \right)} \quad (3)$$

where J is the reciprocity parameter (clause 7.57; ANSI S1.1-1994) and is defined as:

$$J = \frac{2d_0}{f\rho}, \quad (4)$$

where f is frequency in Hz; ρ is the density of the surrounding medium in kilograms per cubic meter; and d_0 is the reference distance of 1 m.

6.3.1.4 Transmitting current response

With the arrangements and conditions shown in Figure 1 and the corresponding voltage and current measurements, the magnitude of the transmitting current response of a projector, P , at a frequency, f , and at the distance $d_0 = 1 \text{ m}$ in a specified direction is given by:

$$|(S_i)_P| = \left| \frac{e_{PT} e_{PH} i_{TH}}{J e_{TH}} \right|^{(1/2)} \left| \frac{d_2 d_1}{d_3 i_{PH}} \right|, \quad (5)$$

The SI derived unit of transmitting current response, $(S_i)_P$, is the pascal meter per ampere, $1 \text{ Pa} \cdot \text{m/A}$. The transmitting current response level is expressed in decibels re one micropascal meter per ampere, 1 dB re $1 \mu\text{Pa} \cdot \text{m/A}$ (clause 6; Reference Quantities; ANSI/ASA S1.8-1989).

It should be noted that by definition, the transmitting current response is referenced to 1 m. Equation (5) specifically allows extrapolation to this 1 m distance. In practice, the projector may not exhibit farfield performance at 1 meter; a test for farfield, as identified in clause 6.1.4, therefore, should always be undertaken when utilizing the projector at the required test distance.

6.3.1.5 Transmitting voltage response

With the arrangements and conditions shown in Figure 1 and the corresponding voltage and current measurements, the transmitting voltage response, $(S_e)_P$, of projector, P , at a frequency, f , and at the distance $d_0 = 1 \text{ m}$ in a specified direction is given by:

$$|(S_e)_P| = \left| \frac{i_{PT} i_{PH} e_{TH}}{J i_{TH}} \right|^{(1/2)} \left| \frac{d_2 d_1}{d_3 e_{PH}} \right|, \quad (6)$$

The SI derived unit of transmitting voltage response, $(S_e)_p$, is the pascal meter per volt, $1 \text{ Pa} \cdot \text{m}/\text{V}$. The transmitting voltage response level is expressed in decibels re one micropascal meter per volt, $\text{dB re } 1 \mu\text{Pa} \cdot \text{m}/\text{V}$ (clause 6; Reference Quantities; ANSI/ASA S1.8-1989).

It should be noted that by definition, the transmitting voltage response is referenced to 1 m. Equation (6) specifically allows extrapolation to this 1 m distance. In practice, the projector may not exhibit farfield performance at 1 m; a test for farfield, as identified in clause 6.1.4, therefore, should always be undertaken when utilizing the projector at the required test distance.

6.3.2 Procedures for secondary sensitivity and response calibrations

6.3.2.1 Secondary free-field voltage sensitivity measurements

In a secondary calibration, the hydrophone sensitivity is determined by comparison to a reference hydrophone with a known sensitivity. The method typically requires less time than executing a primary calibration since fewer test conditions need to be established and measured.^[4]

The secondary calibration of a hydrophone requires a projector for use as a sound source. The sensitivity of the reference hydrophone used should be stable and characterized *a priori* for the temperature and pressure at which the measurement is undertaken.

A comparison calibration is made by placing the reference and the unknown hydrophones successively in the same position in the acoustic pressure field of the projector. For lower frequency measurements, it may be possible for the two devices to be configured side by side and simultaneously ensounded by the projector.

The magnitude of the free-field voltage sensitivity $|(M_e)_H|$ of the measured hydrophone for the secondary calibration technique is given by:

$$|(M_e)_H| = |(M_e)_{ref}| \left[(e_H i_{pref}) / (e_{ref} i_{pH}) \right], \quad (7)$$

where

$(M_e)_{ref}$ = free-field voltage sensitivity of the reference hydrophone,

e_H = open-circuit voltage output of the hydrophone being calibrated,

e_{ref} = open-circuit voltage output of the reference hydrophone,

i_{pref} = drive current of the projector while receiving on the reference hydrophone,

i_{pH} = drive current of the projector while receiving on the hydrophone being calibrated.

The SI derived pressure unit is the pascal (Pa) ($1 \text{ Pa} = 1 \text{ N}/\text{m}^2$). The derived unit of free-field voltage sensitivity $(M_e)_H$ is the volt per pascal, $1 \text{ V}/\text{Pa}$. The free-field voltage sensitivity is expressed in decibels referenced to 1 V per micropascal, $\text{dB re } 1 \text{ V}/\mu\text{Pa}$ [clause 6; Reference Quantities; ANSI/ASA S1.8-1989]. After conversion to decibel units, the sensitivity value obtained is lowered by the quantity of 120 decibels to properly reflect the reference pressure of 1 micropascal.

If the reference and unknown hydrophones are so different in size and directivity that the measurements cannot be made with the two of them successively at the same position, a correction for any distance loss must be applied to the affected open-circuit voltage (e_H in Equation (7) should be multiplied by the ratio of the unknown-hydrophone distance to reference-hydrophone distance).

Unlike primary receive sensitivity calibrations, a provision for extracting a complex receive sensitivity (magnitude and phase) is not undertaken for comparison calibrations. A relative phase comparison can be performed if both the reference hydrophone and unknown are rigged relatively close to one another for the test to assure that they are both exposed to the same complex pressure field. Measurement accuracy is extremely sensitive to frequency, however, and severely limits the application of this approach to anything but the very lowest frequencies. This technique has a high degree of uncertainty associated with it, however, and resulting test data are not appropriate to be reported as a calibration.

6.3.2.2 Transmitting current response

A secondary characterization of a projector can be obtained by using a standard hydrophone to measure the generated sound field. The hydrophone must be located at sufficient distance, in the specified direction, for a spherically divergent sound field to exist at that spot. The extrapolated sound pressure at 1 m then is determined by multiplying the measured sound pressure at the remote point by the ratio, d , of the distance in meters at that point from the acoustic center of the projector to the reference distance (1 m). The transmitting current response (clause 7.54; ANSI S1.1-1994) is given by:

$$|S_i| = \left| \frac{e_{\text{ref}}}{i_p (M_e)_{\text{ref}}} \right| d, \quad (8)$$

where

- S_i = transmitting current response of the projector,
- e_{ref} = open-circuit voltage output of the standard hydrophone,
- d = ratio of the distance between the acoustic center of the projector and the hydrophone and the reference distance of 1 m,
- i_p = current flowing at the projector electric input terminals,
- $(M_e)_{\text{ref}}$ = free-field voltage sensitivity of the reference hydrophone.

The SI derived unit of transmitting current response (S_i) is the pascal meter per ampere, $1 \text{ Pa} \cdot \text{m/A}$. Transmitting current response level is expressed in decibels re one micropascal meter per ampere, dB re $1 \mu\text{Pa} \cdot \text{m/A}$ [clause 6; Reference Quantities; ANSI/ASA S1.8-1989].

It should be noted that by definition, the transmitting current response is referenced to 1 m. Equation (8) specifically allows extrapolation to this 1 m distance. In practice, the projector may not exhibit farfield performance at 1 m; a test for farfield, as identified in clause 6.1.4, therefore, should always be undertaken when utilizing the projector at the required test distance.

6.3.2.3 Transmitting voltage response

The procedure is similar to that described in 6.3.2.2. The transmitting voltage response (clause 7.53; ANSI S1.1-1994) is given by:

$$|S_e| = \left| \frac{e_{\text{ref}}}{e_p (M_e)_{\text{ref}}} \right| d, \quad (9)$$

where:

- S_e = transmitting voltage response of the projector,

e_{ref} = open-circuit voltage output of the standard hydrophone,

d = ratio of the distance between the acoustic center of the projector and the hydrophone and the reference distance of 1 m,

e_p = signal voltage applied to the projector electrical input terminals,

$(M_e)_{\text{ref}}$ = free-field voltage sensitivity of the reference hydrophone,

The SI derived unit of transmitting voltage response, S_e , is the pascal meter per volt, $1 \text{ Pa} \cdot \text{m/V}$. The transmitting voltage response level is expressed in decibels re one micropascal meter per volt, $\text{dB re } 1 \mu\text{Pa} \cdot \text{m/V}$ [clause 6; Reference Quantities; ANSI/ASA S1.8-1989].

It should be noted that by definition, the transmitting voltage response is referenced to 1 m. Equation (9) specifically allows extrapolation to this 1 m distance. In practice, the projector may not exhibit farfield performance at 1 m; a test for farfield, as identified in clause 6.1.4, therefore, should always be undertaken when utilizing the projector at the required test distance.

6.4 Directional response of sensitivity and response measurement

[Reference clause 7.62 of ANSI S1.1-1994.]

6.4.1 Procedure

Directional response patterns describe the response or sensitivity of a transducer as a function of the direction of the sound waves (bearing), as if a distant field point of observation or a distant source of sound were moved over a spherical surface with radius equal to the distance from the transducer to the field point or sound source. In practice, the field point of observation or point of sound transmission is held fixed in the water and the transducer is rotated in space. It is recommended that directional response patterns be made at two or more distances to the field point to ensure validity of the assumed farfield condition. The measured or rotated transducer may be projecting or receiving sound.

Consideration of the intended use of the transducer with respect to the possible location of field points that would be interrogated (for receive) or ensonified (for transmit) should be undertaken to assure that the needed characterization is measured. A coordinate system is typically assigned for use with the transducer and desired planes of rotation are identified. Depending upon the intended use, it is common to address directional response patterns in each of three orthogonal planes. These are commonly designated as the XY, XZ and YZ planes (reference clause 7.3).

With the advent of more sophisticated positioning equipment, inclusive of 3-axis scanning devices, a more rigorous assessment to include three-dimensional directional response measurements can be realized. These scanning devices allow the placement of the field observation point at a user-defined location. For these measurement varieties, it is significant to assure that all actual test distances are normalized to the same reference distance such that the proper amplitude is reported in the directional response pattern.

Special consideration should be given to measurements involving a transducer mounted within a dome. The material comprising the dome can alter the acoustic response of the enclosed transducer. For these cases, typically, measurements are made of the transducer as a stand-alone unit and enclosed within the dome. This also allows an assessment to be made of the effect of the dome material on the overall system performance.

The accuracy and method of positioning the transducer within the coordinate system also must be stated. Reporting requirements for this measurement type are addressed in clause 7.4.

6.5 Voltage coupling loss

To facilitate the use of an electroacoustic element having a high electrical impedance, the element may be combined with an electric network such as a preamplifier (or a transformer). A piezoelectric hydrophone often will consist of an element and preamplifier. The free-field voltage sensitivity may be specified in terms of the open-circuit element voltage if the effect of the preamplifier is known. A voltage coupling measurement will be required to determine the ratio of the open-circuit output voltage of the element to the open-circuit output voltage of the electrical network. The measurement of voltage coupling requires the ability to inject a calibration signal into the front end of the preamplifier and then measure the resulting end of cable output. This latter method requires that the preamplifier and transducer have a design that *a priori* incorporates this ability. The voltage coupling otherwise should be addressed as a bench-top measurement, provided that the preamplifier input can be accessed^[4].

6.6 Electrical impedance and admittance measurements

6.6.1 Method of measurement

Impedance or admittance of a transducer shall be measured as the complex electrical impedance or admittance across the same terminals at which the associated sensitivities and responses are measured with normal acoustic loading. The type of bridge or measurement technique used shall be compatible with the operational conditions of the transducer (balanced or unbalanced) [clause 7.13 and 7.15; ANSI S1.1-1994].

6.7 Equivalent noise pressure

[Reference clause 7.69 and 7.70 of S1.1-1994.]

6.7.1 Measured value

When the noise level of the transducer and associated network used for sound reception is sufficiently high, it is possible to determine the noise voltage (clause 3.25; ANSI S1.1-1994) through use of a signal analyzer with a narrow-band filter. Generally, the ambient water noise is too great to permit measurement of the equivalent noise pressure. If the electrical impedance of the hydrophone is not appreciably affected by its acoustical load, this measurement can be made with the hydrophone suspended in air or vacuum in a soundproof chamber. For some hydrophones, the noise is due to the associated network, and the acoustic sensing unit can be replaced for this measurement by a simple equivalent electrical network.

From the measured noise voltage, e_n , and the filter characteristic, the inherent root-mean-square open-circuit noise voltage, e_{en} , of the transducer, due to noise in a band 1 Hz wide, is calculated from the expression:

$$e_{en} = e_n (\delta_0 f)^{1/2} / (\delta f)^{1/2}, \quad (10)$$

where

δf = the bandwidth of the test equipment;^[5]

$\delta_0 f$ = the reference bandwidth (1 Hz).

This root-mean-square open-circuit noise voltage, e_{en} , and the free-field voltage sensitivity give the equivalent noise pressure of the hydrophone:

$$p_{en} = \frac{e_{en}}{M_e}, \quad (11)$$

where

p_{en} = transducer equivalent noise pressure in micropascals at the frequency, f (hertz),

M_e = free-field voltage sensitivity in volts per micropascal at the frequency, f (hertz).

NOTE 1 The free-field voltage sensitivity, M_e , and the noise voltage, e_n , must refer to (or be measured at) the same electrical terminals. The equivalent noise pressure level can be expressed in decibels re 1 micropascal.

NOTE 2 If the equivalent noise pressure level of the transducer is a function of secondary variables, such as ambient temperature or pressure, the applicable value of these quantities should be stated.

7 Data reporting

7.1 Data reporting requirements

Technically, any calibration is valid only at the time of calibration since test conditions can never be duplicated exactly. However, accurate measurement of environmental conditions can significantly increase the range of applicability of calibration by allowing for correction or compensation for changing medium properties. At the least, when results are reported, the environmental conditions, pertinent preparations and electrical set-up details must be included. These include all conditions that may influence the response of the device, such as:

- a) Time and date;
- b) Water temperature;
- c) Hydrostatic pressure or depth of immersion;
- d) Test medium (fresh or salt water usually; specify salinity if available, pH, other chemical compositions and/or particulate content may also be important especially if measurements are to be made at high frequencies);
- e) Test separation distances;
- f) Type of mount or rigging used;
- g) Electrical connection termination (balanced or unbalanced);
- h) Duration of soaking time and any wetting/preparatory procedures used;
- i) Orientation of the transducer (reference clause 7.3) and whether the alignment was done manually or acoustically;
- j) Acoustic pressure levels experienced by the hydrophone (for receive response measurements);
- k) Voltage levels applied to the transducer (for transmit response measurements).

7.2 Format of data presented

Sensitivity and response data are typically plotted in decibels as the ordinate and logarithmic frequency as the abscissa. In some situations, such as displaying the quality factor of a transducer, a linear frequency scale may be used. The preceding guidelines are general in nature and data presentation should cater to the character and purpose of the data set.

Axes or data tables must be labeled using appropriate SI units. For example, the reference sound pressure in water is 1 micropascal and the reference distance is 1 m (clause 6, Reference Quantities, ANSI/ASA S1.8-1989).

7.3 Specification of orientation

Whenever the orientation of the device under test may affect measurement results, it is important to report the orientation of the device during acoustic measurements. Clause 7.3.1 defines the axes that have been used traditionally for this, but other options may be used as long as accurate reporting is maintained. Orientation must be defined such that results can be duplicated in subsequent tests without significant errors due to orientation.

This may be accomplished with:

- a) The use of a unique feature of the device or permanent marking for reference;
- b) Photographs;
- c) Detailed sketches;
- d) Coordinates and rotation angles such as those defined in clause 7.3.1.

7.3.1 Defined coordinate system

A left-handed rectangular coordinate system for specifying orientation is defined in this clause.

Polar coordinates using r , θ and ϕ are shown in Figure 2 with the effective acoustic center [clause 7.48, ANSI S1.1-1994] of one transducer at the origin. How these coordinates are assigned must be clearly indicated and preferably augmented by means of a sketch or photograph. The coordinate system is considered fixed with respect to the transducer. Only the positive X, Y and Z axes are shown.

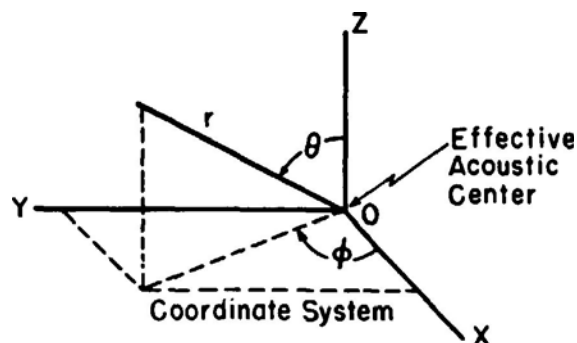


Figure 2 – Left-handed polar coordinate system

ϕ is the azimuth angle; θ represents pitch angle referenced to the surface. The orientation of the transducer in the coordinate system shall conform to the following system whenever possible.