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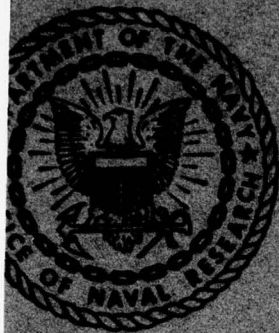
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UNDERWATER SOUND REFERENCE LABORATORY REPORT

A PROPOSED SET OF STANDARD CONVENTIONS
FOR SPECIFYING THE ORIENTATION
OF UNDERWATER SOUND DEVICES

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USRL REPORT NO. 29
3 November 1952

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**A PROPOSED SET OF STANDARD CONVENTIONS
FOR SPECIFYING THE ORIENTATION
OF UNDERWATER SOUND DEVICES,**

by

10 John M. Taylor, Jr.

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U. S. NAVY UNDERWATER SOUND REFERENCE LABORATORY

O. M. Owsley, Director

P. O. Box 3629

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A PROPOSED SET OF STANDARD CONVENTIONS
FOR SPECIFYING THE ORIENTATION
OF UNDERWATER SOUND SOURCES

ABSTRACT

A set of standard conventions for specifying orientations used in making underwater sound measurements on sonar gear is proposed. The method is now in use at the USRL in data reporting within the Laboratory and in USRL publications. Advantages claimed are simplicity and universal applicability.

U.S. NAVY UNDERWATER SOUND RESEARCH LABORATORY
G. E. GILBERT, DIRECTOR
P. O. Box 2512, Groton, Virginia

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A PROPOSED SET OF STANDARD CONVENTIONS FOR SPECIFYING THE ORIENTATION OF UNDERWATER SOUND DEVICES

INTRODUCTION

The USRL has over a period of many years used various methods of specifying the orientation of hydrophones, projectors, dome-transducer assemblies, and other items of underwater sound equipment in its technical memoranda, reports, and correspondence. None of these has been entirely satisfactory and each has generally been applicable to only one specific situation. That other organizations engaged in underwater acoustics have had similar difficulties is evident from reports and correspondence received at this Laboratory.

A set of conventions has now been devised which appears capable of specifying orientations adequately and unambiguously, and to be more universally applicable than any method heretofore used.

The proposed method departs from previous methods in several ways. All elements of the equipment are placed in a three-dimensional coordinate system and their positions are given by stating the coordinates of a position vector assigned to each. Specifying a "plane of directivity" and the use of such terms as "vertical" and "horizontal" in describing directivity patterns are avoided by stating the coordinates of the axis of rotation.

This method is now in use at the USRL on a trial basis. An earlier form of it has been described in USRL correspondence, in USRL Calibration Memoranda circulated to certain activities for which the USRL has made measurements, and in a paper submitted to the *U. S. Navy Journal of Underwater Acoustics*. On the basis of experience gained during the initial trial period, however, some modifications to the method have been found desirable. This report describes the method with all the latest modifications.

DESCRIPTION OF THE METHOD

The three-dimensional coordinate system shown in Fig. 1 is used. The coordinates of point P in this system are (r, θ, ϕ) , where r is the distance OP , θ is the colatitude angle measured between the positive Z axis and the line OP , and ϕ is the azimuth angle measured between the positive X axis and the line OQ (the projection of the line OP on the XY plane). The angle θ has a range from 0 to 180° and is always positive; ϕ has a range from 0 to $\pm 360^\circ$ and is positive when measured from the positive X axis toward the positive Y axis (i.e., the right-hand rule applies).

A vector is defined, for the purpose of this discussion, as a line determined by a point P and the point O (the origin of coordinates). The vector is therefore fully specified by giving only the coordinates of point P . Furthermore, the

direction of the vector is the quantity of interest and the length is completely immaterial, which allows us to dispense with the coordinate r and specify vectors in terms of the two coordinates θ and ϕ .

In this discussion, the term "measured transducer" or simply "transducer" means the transducer whose characteristics are to be depicted by either directivity patterns or frequency response curves. The term "reference transducer" means the second transducer that is necessary in any measurement; it is the sound source in a measurement of receiving characteristics, and it is the standard hydrophone in a measurement of transmitting characteristics.

Transducers, domes, and other elements of sonar equipment (all types of enclosures and attachments for transducers will be referred to in what follows as "domes") will be oriented in this coordinate system by means of position vectors fixed to that particular element. These vectors must originally be assigned to the device by means of a sketch, using actual physical reference marks on the device, if necessary. General classes of items may be established, however, as is done for transducers and the common type of sonar dome in this report.

A single position vector is not sufficient to fully specify the orientation of an object in a three-dimensional coordinate system, since rotation about the vector itself is in general physically possible. Such a rotation about the position vector as an axis could not be specified by this method unless a second vector were used also, so we introduce the following restrictions: (1) Transducers will be placed in the general coordinate system so that the transducer Y axis coincides with the Y axis of the general coordinates, and rotation about this axis only is allowed; i.e., the position vector is restricted to the XZ plane. (2) Domes will be placed in the general coordinate system so that the dome Z axis coincides with the Z axis of the general coordinates, and rotation about this axis only is allowed; i.e., the position vector is restricted to the XY plane.

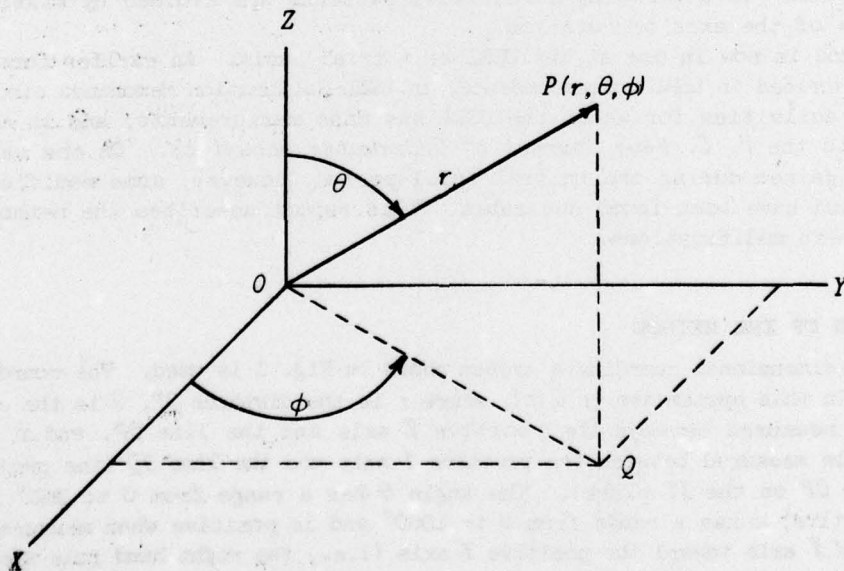


Fig. 1. Coordinate system

These restrictions concern placement of the transducer and the dome in the general coordinate system only, and do not restrict relative orientation between transducer and dome, since the system allows the dome to be rotated in azimuth and the transducer to be tilted; neither do these restrictions apply to the 360° rotation performed for the purpose of determining directivity.

The *measured transducer* will be placed in its coordinate system with the transducer center at the origin of coordinates. "Transducer center" is defined as the point on the transducer from which distance measurements are made and about which the instrument is rotated in making directivity measurements.

Transducers which fit into well-defined classes may be described by type designations as shown in Figs. 2 through 6. The position vector for these types will lie along the X axis of the transducer. An easily recognized reference mark on the instrument is essential. Transducers which do not fit into one of these established types will require a simple sketch to fix the coordinate system.

The orientation of the transducer in the general coordinate system will be specified by the coordinates $(\theta, \phi)_m$ which fix the position vector in the system. Since this vector is restrained to the XZ plane, ϕ_m will always be 0° and might possibly be dropped from the notation, but it is retained for consistency and to avoid the use of such expressions as " $\theta_m = 30^\circ$ ".

Scanning transducers operating with scanning switches and lag lines usually bear a "000 Bearing" mark which can be used as the reference mark. The direction of the main beam of such transducers relative to the reference mark (or the position vector) may be altered by rotating the scanning switch, however. This angular offset of the beam can be specified by giving the coordinates $(\theta, \phi)_s$.

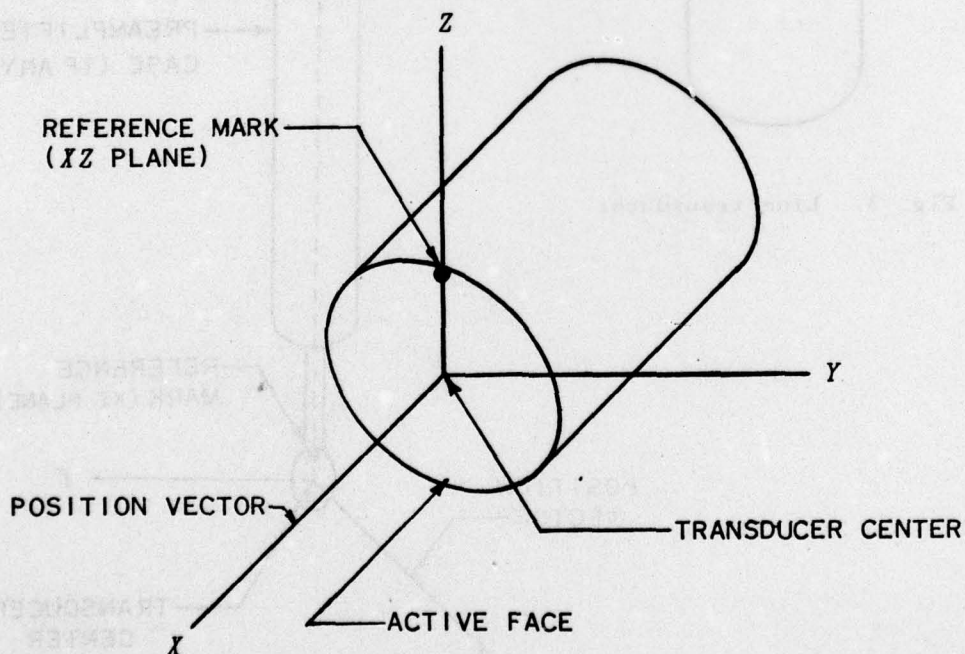


Fig. 2. Piston-type transducer

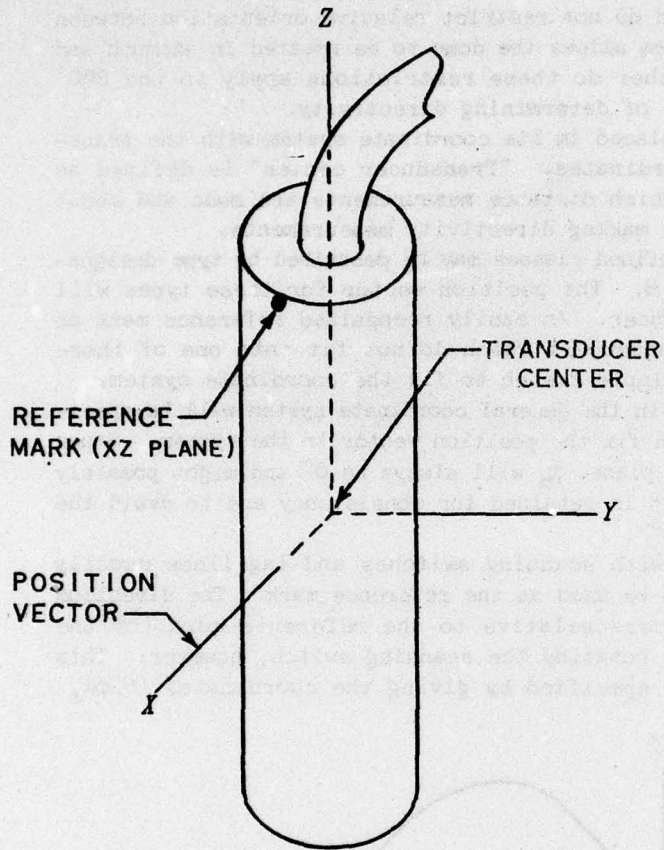


Fig. 3. Line transducer

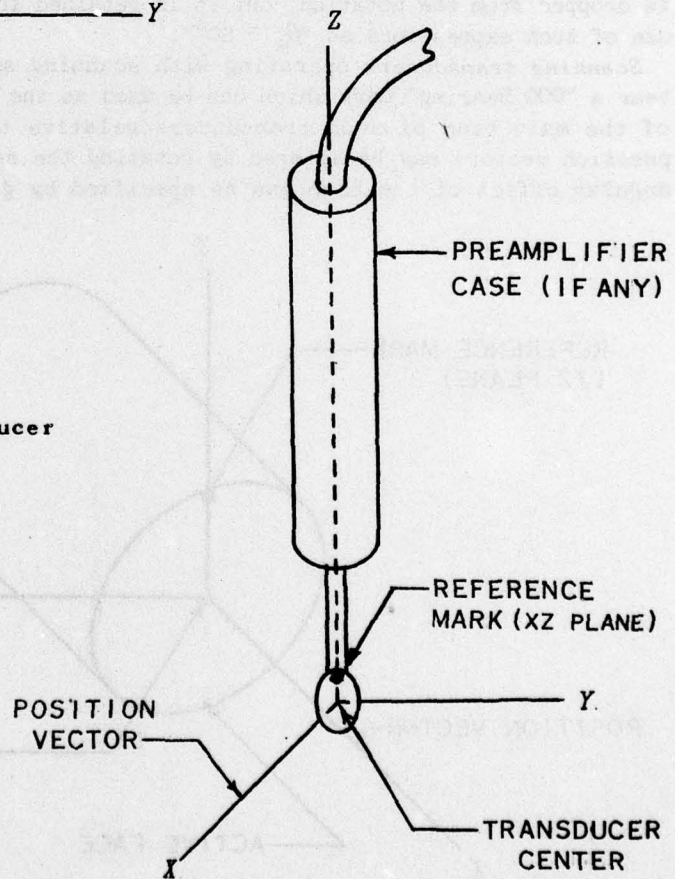


Fig. 4. Probe hydrophone

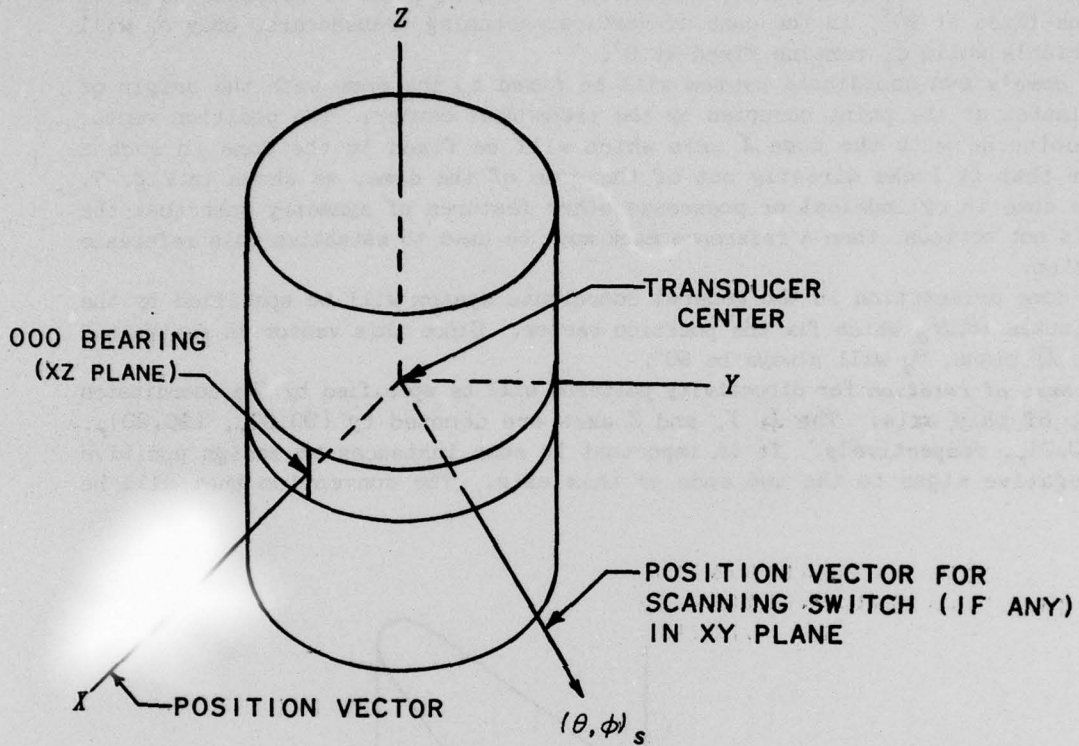


Fig. 5. Cylindrical azimuth-scanning transducer

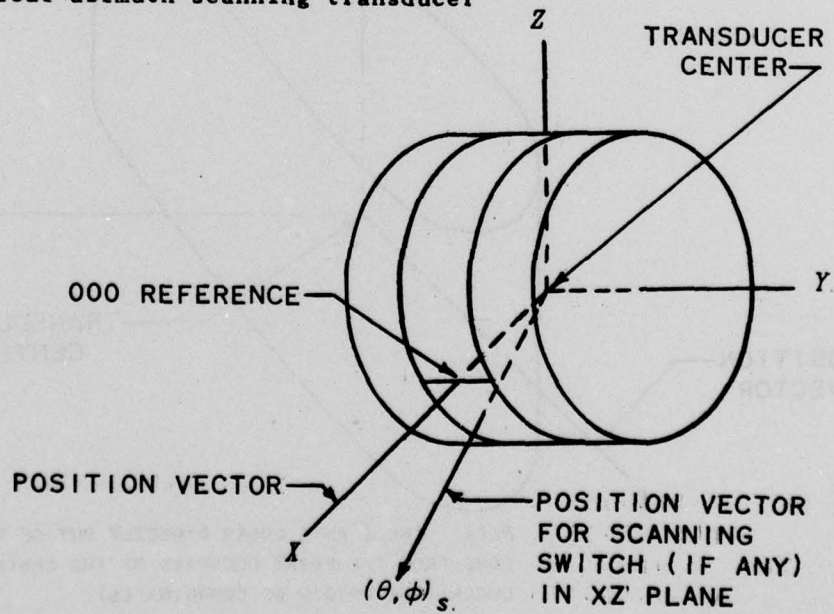


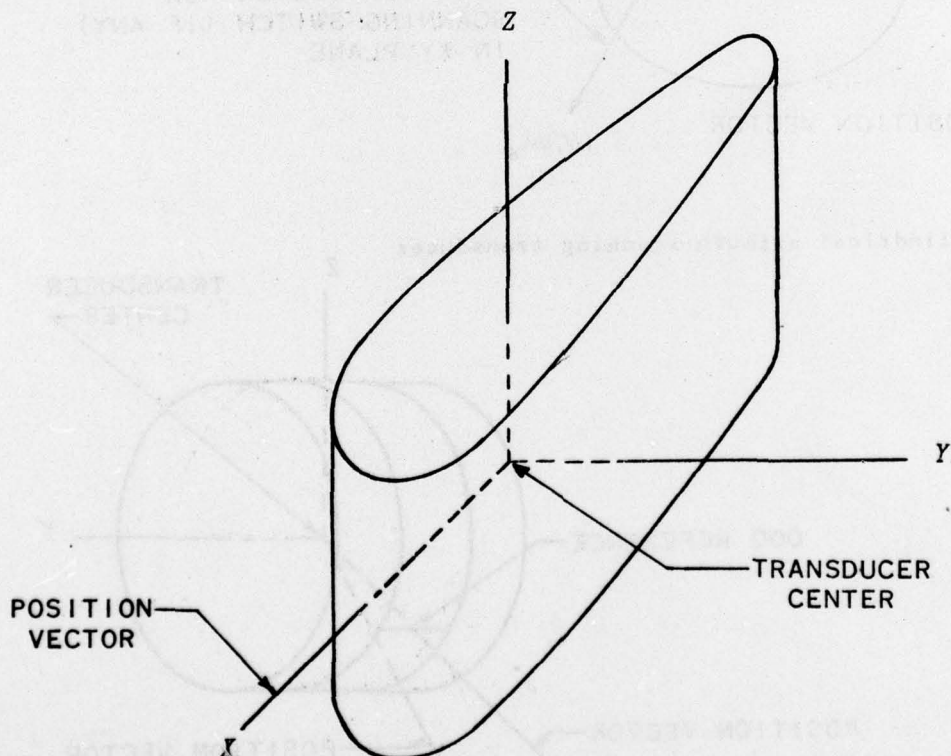
Fig. 6. Cylindrical vertical-scanning transducer

In the case of azimuth-scanning transducers, only ϕ_s will be variable while θ_s remains fixed at 90° ; in the case of vertical-scanning transducers, only θ_s will be variable while ϕ_s remains fixed at 0° .

The dome's own coordinate system will be fixed to the dome with the origin of coordinates at the point occupied by the transducer center. The position vector will coincide with the dome X axis which will be fixed to the dome in such a manner that it looks directly out of the nose of the dome, as shown in Fig. 7. If the dome is cylindrical or possesses other features of symmetry such that the nose is not obvious, then a reference mark must be used to establish this reference direction.

The dome orientation in the general coordinate system will be specified by the coordinates $(\theta, \phi)_d$ which fix the position vector. Since this vector is restrained to the XY plane, θ_d will always be 90° .

The axis of rotation for directivity patterns will be specified by the coordinates $(\theta, \phi)_r$ of this axis. The X , Y , and Z axes are denoted by $(90, 0)_r$, $(90, 90)_r$, and $(0, 0)_r$, respectively. It is important in some instances to assign positive and negative signs to the two ends of this axis. The convention that will be



Note: THE X AXIS LOOKS DIRECTLY OUT OF THE NOSE OF THE DOME FROM THE POINT OCCUPIED BY THE CENTER OF THE TRANSDUCER (THE ORIGIN OF COORDINATES)

Fig. 7. Dome

used here is that the vector $(\theta, \phi)_r$ points in the positive direction; that is, upward out of the paper on which the pattern is plotted. For example, $(90, 90)_r$ means that the positive Y axis is the positive end of the axis of rotation and $(90, 270)_r$ means that the negative Y axis is the positive end of the axis of rotation.

The reference transducer will be positioned in the coordinate system by specifying the coordinates $(r, \theta, \phi)_t$ of the point P_t occupied by its center. The units of r will be centimeters. It will be assumed that the reference transducer is so oriented at the point P_t that its main beam lies along the line OP_t in the direction of the origin of coordinates. The intersection of the line OP_t with the surface of the measured transducer establishes the 0° position on the directivity pattern and the direction of sound incidence for frequency response calibrations. Note that the coordinates $(r, \theta, \phi)_t$ are used to denote a point and not a vector.

NOTATION

The system was originally evolved and has been explained above using groups of numerals in parentheses with an identifying lower-case letter as a subscript. It has also been reported in other places using this notation. In actual practice, however, another system of notation has come into use for several reasons, chief among which are: (1) subscripts are not conveniently made with a typewriter, (2) lower-case letters are sometimes hard to distinguish from each other when handwritten. The lower-case subscript has therefore been dropped in recent usage in favor of a capital letter preceding the parenthesis. This change in notation in no way affects the operation of the method itself.

The relations between the two systems of notation are very clear and direct, and no difficulty should be experienced in going from one to the other. The following shows equivalent expressions in the two systems:

$$\begin{aligned} (r, \theta, \phi)_t &\equiv \mathbf{T}(r, \theta, \phi) \\ (\theta, \phi)_d &\equiv \mathbf{D}(\theta, \phi) \\ (\theta, \phi)_m &\equiv \mathbf{M}(\theta, \phi) \\ (\theta, \phi)_s &\equiv \mathbf{S}(\theta, \phi) \\ (\theta, \phi)_r &\equiv \mathbf{R}(\theta, \phi) \end{aligned}$$

When it is necessary to use more than one group of coordinates in describing a measurement, they are written on the same line separated from each other by semicolons. The order is of little consequence, but the following seems to be natural for most people:

$$\mathbf{T}(r, \theta, \phi); \mathbf{D}(\theta, \phi); \mathbf{M}(\theta, \phi); \mathbf{S}(\theta, \phi); \mathbf{R}(\theta, \phi)$$

DISCUSSION

This method has been applied to a number of old USRL projects in which much more cumbersome methods of describing orientations were used. No situation has yet been discovered in which its use did not bring about considerable simplification. A few representative examples of the use of the new method are given in the Appendix to illustrate the general applicability and the simplifications it

introduces. The possibilities for further elaboration, should it become necessary, appear to be almost limitless.

It should be pointed out that the actual physical arrangement of the measurement set-up is often quite different from the picture presented by this method. The actual rigging of the instruments for measurements is governed by mechanical difficulties as well as the acoustical effect of surface, bottom, and various other features of the surroundings on the results. It is not always practicable, for example, to mount a transducer for measurement with its Y axis horizontal, although these conventions always depict the transducer in this position.¹

Some of the advantages claimed for this method are:

(1) It constitutes a standard set of conventions which, if generally adopted, could simply be referred to without having to explain the system each time it is used. Furthermore, workers in the field of underwater sound would need to be familiar with only one method of describing orientations instead of having to become familiar with a new one for each new report or equipment.

(2) The method readily permits specification of orientation for measurement set-ups that previously required elaborate special explanation--for example, directivity patterns measured by rotating the transducer about an axis that does not cause the position vector of the measured transducer to sweep out a plane surface. Patterns made in this manner depict the directivity in a conical surface rather than in a plane, and the time-honored terms "plane of directivity", "vertical pattern", and "horizontal pattern" cannot be used to describe them. Interest in this type of pattern appears to be increasing.

Another advantage, which is far from inconsequential, is that the notation is convenient for either handwriting or typewriting. It contains no subscripts and no characters not available on a standard typewriter keyboard.

Correspondence containing comments and criticisms of this proposed set of conventions from other workers in the field of underwater sound are invited.

1. If it should ever be necessary to distinguish "up" or "down", another vector could be added. This vector could be $V(\theta, \phi)$ to indicate the "vertical" direction, or $G(\theta, \phi)$ to indicate the direction of gravity.

DIRECTIVITY OF
5E HYDROPHONE No. ____
T(100,0,0); M(90,0); R(90,0)

This says that the reference transducer was oriented on the Z axis of the hydrophone at a distance of 100 cm, that the 5E hydrophone was rotated about its X axis, and that the 0° direction on the directivity pattern is the positive Z axis of the hydrophone.

Example 5. Suppose that we have a cylindrical, azimuth-scanning transducer with a scanning switch and lag line. The transducer will ordinarily have a "000 Bearing" mark on its circumference denoting the dividing line between element number 1 and the last numbered element. This mark can be taken as the reference mark. This type of transducer is oriented as shown in Fig. 5. A "horizontal" directivity pattern measured by leaving the transducer fixed and rotating the scanning switch through 360° beginning at the "000 Bearing" point would be labelled

DIRECTIVITY OF
XYZ TRANSDUCER No. ____
T(300,90,0); M(90,0); S(90,0); R(0,0)
Transducer fixed
Scanning switch rotated

This tells that the reference transducer was located on the X axis of the transducer at a distance of 300 cm, that the 0° direction of the directivity pattern is the positive X axis of the transducer, that the scanning switch was rotated through 360° from the "000 Bearing" mark. The axis of rotation has been specified in this example, but it is really superfluous, since the scanning switch can only be rotated about the Z axis.

The same pattern might have been measured with the scanning switch rotated from the positive Y direction through 360° ; i.e., the 0° position on the directivity pattern would have corresponded to the positive Y axis of the transducer. In this case, the pattern would be labelled

DIRECTIVITY OF
XYZ TRANSDUCER No. ____
T(300,90,90); M(90,0); S(90,90); R(0,0)
Transducer fixed
Scanning switch rotated

Example 6. Suppose the azimuth-scanning transducer to be enclosed in a dome in its normal position; i.e., the position vector of the dome lies along the positive X axis of the general coordinates. Several kinds of directivity patterns of this combination can be made. The label

DIRECTIVITY OF
XYZ TRANSDUCER No. ____
IN PQR DOME
T(300,90,0); M(90,0); D(90,0); S(90,0); R(0,0)
Transducer and dome fixed
Scanning switch rotated

indicates that the reference transducer was located on the positive X axis of the

scanning transducer at a distance of 300 cm, that the dome position vector lay along the positive X axis of the scanning transducer, that the scanning switch was rotated through 360° beginning at the general positive X axis, and that the 0° direction on the directivity pattern corresponds to the positive X axis of the scanning transducer.

The label

DIRECTIVITY OF
XYZ TRANSDUCER No. ____
IN PQR DOME
T(300,90,0); M(90,0); D(90,0); S(90,0); R(0,0)
Scanning switch fixed
Transducer and dome rotated

indicates the same situation as above, except that the scanning switch was fixed to correspond to the 000 Bearing point on the transducer and that the pattern was made by rotating the dome-transducer assembly.

Example 7. Suppose the same dome and transducer assembly discussed in Example 6 were used, but that the dome was rotated about the transducer through an angle of 90° so that the position vector of the dome now lies along the positive Y axis of the transducer. Several possibilities for patterns with this arrangement exist. Two of them will be given. The label

DIRECTIVITY OF
XYZ TRANSDUCER No. ____
IN PQR DOME
T(300,90,0); M(90,0); D(90,90); S(90,0); R(0,0)
Scanning switch fixed
Transducer and dome rotated

indicates that the reference transducer was oriented at a distance of 300 cm on the positive X axis of the scanning transducer, that the dome position vector lay along the positive Y axis of the scanning transducer, that the scanning switch was fixed in the positive X direction, that the entire transducer-dome assembly was rotated about the general Z axis, and that the 0° direction on the directivity pattern corresponds to the positive X direction in the general coordinates.

The label

DIRECTIVITY OF
XYZ TRANSDUCER No. ____
IN PQR DOME
T(300,90,0); M(90,0); D(90,90); S(90,0); R(90,90)
Scanning switch fixed
Transducer and dome rotated

indicates that the reference transducer was oriented at a distance of 300 cm on the positive X axis of the scanning transducer, that the dome position vector lay along the positive Y axis of the scanning transducer, that the scanning switch was fixed in the positive X direction, that the entire transducer-dome assembly was rotated about the general Y axis, and that the 0° direction on the directivity pattern corresponds to the positive X direction. This pattern represents the directivity of the assembly in the XZ plane of the general coordinates.

Example 8. It may be of interest to determine the effect of the dome on the transmission of sound through various planes in the dome. The label

DIRECTIVITY OF
XYZ TRANSDUCER No. ____
IN PQR DOME
T(300,90,0); M(90,0); D(90,45); S(90,0); R(90,90)
Scanning switch fixed
Transducer and dome rotated

indicates that the reference transducer was located on the positive X axis at a distance of 300 cm, that the dome position vector lay in the general XY plane midway between the positive X and positive Y axes, that the scanning switch was fixed in the positive X direction, that the entire transducer dome assembly was rotated about the general Y axis, and that the 0° direction on the directivity pattern corresponds to the positive X axis of the scanning transducer.

Example 9. It is sometimes of interest to determine the directional characteristics of a transducer at some direction other than normal to the axis of rotation. The resultant plane plot in this case actually represents a conical surface of directivity. The MCC section of an azimuth-scanning transducer that deflects the beam at an angle below the horizontal provides such a case. If the angle by which the beam is deflected is 30° , a pattern of this type would be labelled

DIRECTIVITY OF
XYZ TRANSDUCER No. ____
MCC SECTION
T(300,120,0); M(90,0); S(90,0); R(0,0)
Transducer fixed
Scanning switch rotated

This pattern, although plotted on a plane surface, actually represents a cone having a vertex angle of 120° . This label indicates that the reference transducer was located in the general XZ plane at a distance of 300 cm and in a direction at 30° below the positive X axis, that the scanning switch was rotated about the general Z axis, and that the 0° direction on the pattern corresponds to the intersection of the XZ plane with the conical surface.

Example 10. Earlier models of scanning transducers were of the piston type, such as shown in Fig. 2, which were capable of two-axis rotation inside the dome. The position of such transducers relative to the dome has generally been specified in the past by two angles—one known variously as "azimuth", "bearing", or "train" angle; the other known as "tilt" angle. Directivity patterns were labelled either "horizontal" or "vertical" to distinguish the "plane of directivity". A pattern which would have been called, in this earlier nomenclature, a "Vertical Pattern, Azimuth Angle 45° , Tilt Angle 30° " would be labelled as follows according to the proposed new method:

DIRECTIVITY OF
DEF TRANSDUCER No. ____
IN PQR DOME
T(400,120,0); D(90,45); M(120,0); R(90,90)
Transducer and dome rotated

Example 11. If the same physical orientation as in Example 10 were used, except that the assembly was rotated about the general Z axis, a conical pattern would result. Such a pattern would be difficult to specify in the older nomenclature, but would be labelled as follows if the proposed method is used:

DIRECTIVITY OF
DEF TRANSDUCER No. ____
IN PQR DOME
T(400,120,0); D(90,45); M(120,0); R(0,0)
Transducer and dome rotated