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EQUIVALENT BEAM ANGLES FOR SEVERAL STANDARD TRANSDUCERS

by

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ABSTRACT

Nominal values for the equivalent beam angle are given for several transducers. These are the standard split-beam transducers designed for the SIMRAD EK500 scientific echo sounder, with operating frequencies of 38 and 120 kHz, and the new two-beamwidth SIMRAD ES5 transducer, with operating frequency of 38 kHz.

RESUME: ANGLES EQUIVALENTS DE PLUSIEURS TRANSDUCTEURS

Les valeurs nominales des angles équivalents sont données pour plusieurs transducteurs. Ceux-ci sont les transducteurs standard à faisceau scindé prévus pour le sondeur scientifique SIMRAD EK500, avec les fréquences de travail 38 et 120 kHz, et les nouveaux transducteurs à double faisceau SIMRAD ES5, pour la fréquence de 38 kHz.

INTRODUCTION

An important parameter in the basic equations used to determine fish density acoustically is the equivalent beam angle (Forbes and Nakken 1972, MacLennan 1990). This is conventionally defined purely as a property of the transducer. It generally depends on the detection threshold, thence backscattering cross sections of target organisms too (Foote 1988). However, even in the general case with high signal-to-noise ratio, the effective value is equal to the nominal value.

There are a number of methods for determining the nominal value ψ_o of the equivalent beam angle. The most practicable of these depends on knowledge of the beam pattern, from which ψ_o can be computed. Such knowledge is often contained in measurements of the beam pattern, but it may also be derived by theoretical calculation.

Transducer manufacturers often specify ψ_o in data sheets accompanying the transducer. However, the method of determining the quantity is seldom specified. The frequent practice of at least one manufacturer in representing the beam pattern by miniature polar plots in one or two planes cannot inspire confidence in the accompanying value of ψ_o. This author's repeated experience in receiving data sheets stamped "approved" that obviously pertain to other transducers than the indicated one is similarly persuasive of the unreliability of manufacturer-specified data.

User determination of ψ_o, hence also beam pattern, is thus recommended. This may be done by measurement (Simmonds 1984, 1987, Ona and Vestnes 1985, Reynisson 1985, 1986, 1987, Degnbol 1988), which may include the effect of mounting (Simmonds 1984), or by computation based on knowledge of the transducer geometry. This is the approach adopted here.

The object of this investigation is theoretical specification of the nominal values of the equivalent beam angle for three split-beam transducers. These are the SIMRAD ES38B, ES5, and ES120. The values previously presented (Foote 1989) for the 38-kHz transducers, the ES38B and ES5, are revised; the value for the 120-kHz transducer, the ES120, is presented for the first time. It is hoped that by presenting the several values together, the user will be helped in assigning values to ψ_o.

DEFINITIONS

The nominal value ψ_o of the equivalent beam angle is defined as the integral of the product of farfield transmit and receive beam patterns, b^2, over the hemisphere with axis $\theta=0$ coincident with the acoustic axis:

$$\psi_o = \int_0^{2\pi} \int_0^{\pi/2} b^2(\theta,\phi) \sin\theta \, d\theta \, d\phi \quad . \tag{1}$$

For an array of n identical elements in the same plane with center positions $\underline{r}_j$ and relative amplitude weights w_j, the one-way farfield beam pattern is (Foote 1990)

$$b(\theta,\phi) = b_1(\theta,\phi) \left| \sum_{j=1}^{n} w_j \exp(i\underline{k}\cdot\underline{r}_j) \Big/ \sum_{j=1}^{n} w_j \right|^2 \quad , \tag{2}$$

where $b_1(\theta,\phi)$ is the single-element beam pattern and $\underline{k}$ is the wavevector. For square elements with side length 2a,

$$b_1(\theta,\phi) = \left| \frac{\sin(ka \sin\theta \cos\phi) \, \sin(ka \sin\theta \sin\phi)}{(ka \sin\theta)^2 \sin\phi \cos\phi} \right|^2 \quad . \tag{3a}$$

For circular elements with diameter 2a,

$$b_1(\theta,\phi) = \left| \frac{2 J_1(ka \sin\theta)}{ka \sin\theta} \right|^2 \quad , \tag{3b}$$

where $J_1(\cdot)$ is the Bessel function of first kind and first order (Jahnke and Emde 1945).

TRANSDUCER GEOMETRIES

The transducer elements for the 38-kHz transducers are square with side length of 30 mm. They are arranged on square grids with center-to-center distances of 32 mm along rows and columns. Amplitude weightings for the several transducers are indicated in Figs. 1 and 2 for a single quadrant, the others being derived by symmetry.

0	0	70	100	100
0	70	70	100	100
70	70	100	100	100
100	100	100	100	100
100	100	100	100	100

Fig. 1. Relative amplitude weights of elements in the upper left quadrant of the SIMRAD ES38B transducer.

0	78	78	100	100	100	100
78	36	36	36	36	78	100
78	36	36	36	100	100	100
100	36	36	100	100	100	100
100	36	100	100	100	100	100
100	78	100	100	100	100	100
100	100	100	100	100	100	100

Fig. 2. Relative amplitude weights of elements in the upper left quadrant of the SIMRAD ES5 transducer. All elements are used to form the narrow beam. The elements to the lower right of the drawn boundary form the wide beam.

The transducer elements for the 120-kHz transducer are circular with diameter of 10 mm. The elements are arranged on a square grid with center-to-center distances of 11 mm along rows and columns. Amplitude weights for the elements are shown in Fig. 3.

0	0	0	75
0	100	75	100
0	75	100	100
75	100	100	100

Fig. 3. Relative amplitude weights of elements in the upper left quadrant of the SIMRAD ES120 transducer.

PERFORMANCE MEASURES

In addition to the nominal value of the equivalent beam angle ψ_o, together with its logarithmic expression Ψ_o, a second basic measure of transducer performance is computed. This is the directivity index for isotropic noise (Urick 1983):

$$DI = 10 \log \frac{4\pi}{\int b \, d\Omega} \quad , \tag{4}$$

where the integral is tantamount to Eq. (1) but with single occurrence of b.

The equivalent beam angle is, correspondingly, a measure of directivity for volume reverberation. In particular, the analog to Eq. (4) is the directivity index for volume reverberation,

$$J_V = 10 \log \frac{4\pi}{\int b^2 \, d\Omega} \quad . \tag{5}$$

COMPUTATIONAL METHOD

The integrations in Eqs. (1) and (4) have been performed slavishly on a digital computer by Riemann sums. By symmetry, the integration was performed over the octant $\theta \in [0,\pi/2]$, $\phi \in [0,\pi/4]$, of the unit hemisphere. A grid of points was chosen with even spacing in θ and even spacing in ϕ. The values for constant θ were averaged and weighted by the area over the unit hemisphere between $\theta-\Delta\theta/2$ and $\theta+\Delta\theta/2$, namely

$$2\pi[\cos(\theta-\Delta\theta/2) - \cos(\theta+\Delta\theta/2)] \quad ,$$

where $\Delta\theta$ is the spacing in θ, with proper treatment of the endpoints at $\theta=0$ and $\theta=\pi/2$.

Several criteria were used to determine the number of points on the integration grid spanning the defined octant. The first is that a previous result obtained with use of the powerful integration routine D01FCF from the NAG Library (1984) be duplicated. This was the computation of ψ_o for the SIMRAD 70-kHz split-beam transducer, which result was presented by Foote (1987). Repetition of the computations for substantially finer grids ensured the second criterion of numerical convergence. In brief, subdivision of the range of θ by 180 and that of ϕ by 16 gave results that agreed to within 0.02 dB in the worst case for results obtained using subdivisions of 5000 and 200 for θ and ϕ, respectively.

The computations were performed on a digital computer with 32-bit single-precision floating-point word size. Computations for the subdivision 180-16 were performed in single precision, while those for the extreme subdivision 5000-200 were performed in double precision.

RESULTS AND DISCUSSION

The results are presented in the table. These apply to a medium sound speed of 1470 m/s. They may be extrapolated to other sound speeds by use of the relation (Foote 1987)

$$\Psi_o(c) = \Psi_o(c_o) + 0.0059(c - c_o) \quad , \tag{6}$$

where c_o=1470 m/s.

Table 1. Nominal values ψ_o of the equivalent beam angle and other performance measures of three SIMRAD split-beam transducers.

Transducer	Beamwidth mode	Frequency (kHz)	$\int b\,d\Omega$ (sr)	DI (dB)	$\int b^2 d\Omega = \psi_o$ (sr)	J_v (dB)	Ψ_o (dB)
ES38B	Single	38	0.0171	28.67	0.00798	31.97	-20.98
ES5	Narrow	38	0.00852	31.69	0.00374	35.26	-24.27
ES5	Wide	38	0.0169	28.70	0.00760	32.18	-21.19
ES120	Single	120	0.0340	25.67	0.0135	29.69	-18.70

It is emphasized that the present work specifies nominal values of the several parameters. In general, for application to fish and other marine organisms, the threshold effect should be considered. Use of the effective equivalent beam angle ψ, however, will not upset use of the nominal value ψ_o in calibrating acoustic equipment. The place to apply ψ is the same as that where the mean backscattering cross section is applied. This is at the data processing stage where the values of area backscattering coefficient are converted to physical quantities of scatterer density.

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