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# DIRECTIONAL PROPERTIES OF AN 18-KHZ TRANSDUCER

by

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## ABSTRACT

Several theoretical measures of directivity are given for an 18-kHz transducer that is used in both single-beam and split-beam applications, namely the SIMRAD transducer type 18-11 in the single-beam variant. These are based on an idealized representation of the transducer as a planar array of amplitude-weighted circular elements, with nominal specified parameters. The computed measures of directivity include the average beamwidth at -3 dB level, directivity index, and volume reverberation index, together with related measure of equivalent beam angle.

## RESUME: PROPRIETES DIRECTIONNELLES D'UN TRANSDUCTEUR 18 KHZ

Plusieurs mesures théoriques de directivité sont données pour un transducteur 18 kHz - modèle SIMRAD 18-11 dans sa version monofaisceau - utilisé en monofaisceau mais aussi faisceau scindé. Ces mesures sont basées sur une représentation idéalisées du transducteur constitué par une antenne plane d'éléments circulaires pondérés en amplitude, avec les paramètres nominaux de la spécification. Les calcule de directivité donnent l'ouverture de faisceau moyenne à -3 dB, l'index de directivité et l'index de réverbération de volume ainsi que la mesure de l'angle équivalent.

## INTRODUCTION

Measurement of the directivity properties of a transducer under laboratory conditions may be a relatively simple matter. Measurement of the directivity properties of the same transducer when mounted on the hull of a research vessel may involve almost insurmountable difficulties. Were the directivity unaffected by the mounting, there would be no need for an _in situ_ measurement. Simmonds (1984) suggests, however, that the mounting does have an effect. Under the reported experimental conditions, the effect on the equivalent beam angle was to introduce a variability of the order ±0.5 dB.

The connection between the so-called <u>ex situ</u> laboratory measurement and <u>in situ</u> measurement is unknown. This provides one motivation for computing the beam pattern theoretically and deriving the directivity measures from this. It has earlier been argued (Foote 1992) that theoretically determined directivity measures may be more realistic than those measured in the laboratory, for achieving a better representation of the boundary conditions associated with hull-mounting than can be obtained with a laboratory mounting. This consequently provides a rationale for deriving the directivity measures by computation.

In this work the directivity measures of a new 18-kHz transducer are described. The particular order of addressed topics is the following. (1) The transducer geometry is specified. (2) A theoretical expression is given for the beam pattern of a planar array of amplitude-weighted circular elements, and associated directivity measures are defined. (3) The computational method is described. (4) Results are presented and compared with the manufacturer's specifications.

## TRANSDUCER SPECIFICATION

The new SIMRAD transducer type 18-11 has an operating frequency of 18 kHz. It is composed of 44 identical circular elements aligned on a square grid. The element diameter is 59 mm, and center-to-center spacing along rows and columns is 62.5 mm. Amplitude weighting is employed according to the pattern in Fig. 1, which is repeated in each of the transducer quadrants.

| | | | |
|---|---|---|---|
| 62 | | | |
| 89 | 62 | 89 | |
| 100 | 100 | 62 | |
| 100 | 100 | 89 | 62 |

Fig. 1. Amplitude weights in percentage for elements in the upper right quadrant.

## THEORY AND DEFINITIONS

The beam pattern of a planar array of n circular elements is the following:

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

where $b(\theta,\phi)$ is the array beam pattern in the direction $(\theta,\phi)$, $\theta$ is the polar angle and $\phi$ is the azimuth,

$$b_1(\theta) = \left|2J_1(ka\sin\theta) / (ka\sin\theta)\right|^2 \qquad (2)$$

is the beam pattern of a circular element of radius a, $J_1$ is the Bessel function of order 1, $\underline{k}$ is the wavevector: $\underline{k}=k(\sin\theta\cos\phi, \sin\theta\sin\phi, \cos\theta)$ in rectangular coordinates, $w_j$ is the amplitude of the j-th element, and $\underline{r}_j$ is the position of the same, namely $(x_j, y_j, 0)$ in the implicitly defined rectangular coordinates.

<u>3-dB beamwidth</u> A plane is considered that contains the z- or acoustic axis and whose intersection with the x-y plane makes the angle $\phi$ with the x-axis. The angle $\theta$ at which $b(\theta,\phi)=0.5$ defines the so-called 3-dB angle, for $10 \log b(\theta,\phi) \doteq -3$ dB. The total angle between -3-dB levels on opposite sides of the z-axis is here denoted $\Delta\theta(\phi)$. This is fully defined through the equation

$$b(\Delta\theta/2,\phi) = 0.5 \quad . \tag{3}$$

For the particular transducer array, the symmetry is eight-fold, and the average measure of 3-dB beamwidth is defined thus:

$$\overline{\Delta\theta} = \frac{4}{\pi}\int_0^{\pi/4} \Delta\theta(\phi)\, d\phi \quad . \tag{4}$$

<u>Directivity index</u> The directivity index for discimination of the receiver against isotropic background noise is given by the equation (Urick 1975)

$$DI = 10 \log 4\pi/\int b\, d\Omega \quad , \tag{5}$$

where $d\Omega=\sin\theta\, d\theta\, d\phi$, and the integral is performed over a hemisphere, with $\theta\varepsilon[0,\pi/2]$, $\phi\varepsilon[0,2\pi]$.

<u>Reverberation index</u> This is the two-way analogue of the directivity index, hence measures the discrimination of the receiver against reverberation noise:

$$J_v = 10 \log 4\pi/\int b^2 d\Omega \quad . \tag{6}$$

<u>Equivalent beam angle</u> The integral expression in the argument of equation (6) defines the nominal equivalent beam angle $\psi_o$,

$$\psi_o = \int b^2 d\Omega \quad . \tag{7a}$$

The corresponding logarithmic measure is formally denoted $\Psi_o$,

$$\Psi_o = 10 \log \psi_o \quad . \tag{7b}$$

## COMPUTATIONAL METHOD

Computation of the beam pattern according to equations (1) and (2) is straightforward. Computation of the associated directivity measures is similarly straightforward. Experience has shown that the integrals can be evaluated by a Riemann summation of the integrands, with sufficiently small differential element. This has been done, with observation of numerical convergence to the nearest ±0.01 dB. The assumed speed of sound is 1470 m/s.

## RESULTS AND DISCUSSION

The results are presented in a table for ease of comparison with results from earlier studies.

Table 1. Directivity measures for the SIMRAD transducer type 18-11, with 18-kHz operating frequency, assuming medium sound speed of 1470 m/s. The number of transducer elements is denoted n, and in summing the squared element weights $w_j$, the reference is the maximum weight of unity.

| n | $\Sigma w_j^2$ | $\Delta\theta$ (deg) | $\int b\, d\Omega$ (sr) | DI (dB) | $\int b^2 d\Omega=\psi_o$ (sr) | $J_v$ (dB) | $\Psi_o$ (dB) |
|---|---|---|---|---|---|---|---|
| 44 | 31.69 | 10.76 | 0.0424 | 24.72 | 0.01938 | 28.12 | -17.13 |

To express $\Psi_o$ for other values of the sound speed c, the simple conversion formula is (Foote 1987)

$$\Psi_o(c) = \Psi_o(c_o) + 0.0059\,(c-c_o) \quad , \qquad (8)$$

where $c_o$=1470 m/s, and $\Psi_o(c_o)$ is given in Table 1. The other directivity measures vary similarly with c.

It may be interesting to compare these results with the manufacturer's specifications (SIMRAD 1992). The beamwidth is given as 11±2 deg, which is to be compared with the computed average figure of 10.76 deg, with excursions over planes distinguished by $\phi$ from 10.66 to 10.77 deg. The directivity index is given as 25±1 dB, compared to 24.72 dB here, but with expected excursion of ±0.12 dB for sea temperatures in the range $[0,20]^{\circ}$C. The equivalent beam angle is specified as -17±1 dB, against the predicted figure of -17.13 dB.

These performance measures, if weaker than figures given for standard 38 and 120 kHz transducers (Foote 1990, 1991), are quite reasonable for applications in fisheries research. The availability of an 18-kHz receiver for the EK500 echo sounder system (Bodholt et al. 1989) facilitates its use in scientific applications, as in marine investigations.

A major consideration in adopting the 18-kHz frequency is the substantial increase in system bandwidth that it affords when used with more widely used surveying frequencies, e.g., 38 and 120 kHz. This is especially interesting because of its sampling of a different part of the fish scattering function. Simultaneous observations of scattering at different frequencies, as in Foote et al. (1992), may very well provide a key to scatterer identification, if not in situ target strength too.

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