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# SPHERES FOR CALIBRATING AN ELEVEN-FREQUENCY ACOUSTIC MEASUREMENT SYSTEM

by

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## ABSTRACT

Calibration of a single resonant transducer by standard sphere is a simple matter. How does one calibrate an array composed of eleven different resonant transducers spanning the frequency range from 27 to 710 kHz? A solution is given by specifying the diameters and target strengths of four precision ball bearings made from tungsten carbide with 6% cobalt binder.

## RESUME: SPHERES D'ETALONNAGE POUR UN SYSTEME DE MESURE ACOUSTIQUE A ONZE FREQUENCES

L'étalonnage d'un seul transducteur résonnant par sphère standard est une chose simple. Comment peut-on étalonner un ensemble de onze transducteurs résonnant avec une gamme de fréquences de 27 à 710 kHz? La solution consiste en spécifiant les diamètres et les index de réflexion de quatre sphères de précision en carbure de tungstène au 6% de cobalt.

## INTRODUCTION

Most scientific echo sounding systems are designed for narrowband operation with a single resonant transducer (Mitson 1984). This is understandable both because of the comparative newness of the acoustic application and because of the overall complexity of such systems. However, the limitations of so-called single-frequency systems have long been recognized (Cushing and Richardson 1955), and a number of wideband systems, pulsed or multi-frequency, are in use or under planning.

Calibration of narrowband systems is a straightforward matter. Calibration by standard target is the established procedure for the comparatively low frequencies used in fisheries research (Foote et al. 1987). Calibration of wideband systems presents a new problem, for which several different solutions exist.

Several plankton-measuring systems have been or are calibrated by the principle of self-reciprocity (Urick 1975). Examples include the four-frequency system of Holliday and Pieper (1980), which spanned the range 0.54-3.08 MHz, and the 21-frequency system of Holliday et al. (in press), which spans the range 0.1-10 MHz. The newer system is also occasionally calibrated by comparison with standard transducers or hydrophones.

The wideband fish-measuring system used at the Marine Laboratory, Aberdeen (Simmonds 1986, Simmonds and Copeland 1986), is calibrated by the standard-target method using a 38.1-mm-diameter ball bearing composed of tungsten carbide with 6% cobalt binder (MacLennan 1982). This is possible because the frequency range of the system, 27-54 kHz, is well below that of the first resonance of the particular target.

A similar standard-target technique appears to be used by Bondarenko and Novicov (in press) for calibrating their fisheries-directed parametric acoustic array over the range 5-50 kHz. Mentioned targets include 60-mm-diameter spheres of copper and duralin and a 100-mm-diameter foam plastic ball.

This work is concerned generally with calibrating wideband systems composed of multiple discrete frequencies whose range is intermediate to those of the several cited examples. The particular system that is addressed here is the zooplankton-measuring acoustic system under development at the Institute of Marine Research, Bergen. The frequency range, 27-710 kHz, is spanned by eleven frequencies, with the aim of examining animals of sizes 1-50 mm (Anon. 1988).

## SYSTEM DESCRIPTION

The object acoustic system is composed of eleven resonant transducers. The respective frequencies and corresponding receiver bandwidths are shown in the Table. Pulse durations are 0.3 and 1.0 ms.

The system is to be used in sea water. The design range of salinity is 22-35.3 ppt, and that of temperature is 0-16$^{o}$C.

## METHOD

It is desired to find a calibration procedure that can be used in the field with the eleven-transducer array suspended at arbitrary depth. The standard-target method is adaptable, but given the range of frequencies, it is unlikely that a single target can be found that is suitable for all frequencies. The design principle is therefore adopted that the number of calibration spheres be limited. Avoidance of resonances is adopted as a second design principle. In addition, a nominal target strength of -40 dB is sought, at least for the lowest frequencies.

The first candidate calibration target is the 38.1-mm-diameter tungsten carbide ball bearing described by MacLennan (1982). Examination of its frequency response function suggests its suitability for use at seven of the eleven frequencies. These include all frequencies from 27 to 200 kHz excepting 88 kHz. The sphere is unfavorable here because of the nearness of the first resonance, for which the wavenumber-radius product is roughly 7.4.

Tungsten carbide is also an advantageous material for frequencies above 200 kHz because of its hardness. Sphere diameters are determined in accordance with the optimization method described by Foote (1982). The same maximum in the scattering frequency response function is used for each of the three highest frequencies; its characteristic wavenumber-radius product is roughly 15.6. The diameters are thus 29.0, 19.5 and 10.3 mm at the respective frequencies 252, 375 and 710 kHz.

In keeping with the design principle to limit the number of spheres, these three spheres are considered for use at 88 kHz. The 29.0-mm-diameter sphere is preferred because its target strength is nearest the design value of -40 dB.

Target strengths are computed for each of the tungsten carbide spheres at the pertinent design frequency. The material density is assumed to be 14900 kg/m$^3$, and the longitudinal and transverse sound speeds 6853 and 4171 m/s, respectively (MacLennan and Dunn 1984). The receiver frequency response function is assumed to resemble that of a standard SIMRAD 38 kHz echo sounder (Foote 1982), but translated to the particular center frequency and scaled according to the bandwidth. Computations are performed for medium sound speeds corresponding to the design range of hydrography, hence from 1430 to 1510 m/s. Computations have been repeated for pulse durations of both 0.3 and 1.0 ms for each sound speed, and the results averaged in the correct, intensity domain.

## RESULTS

The results are shown in the Table. The reference value of target strength, 0 dB, applies to an idealized perfectly reflecting sphere of radius 2 m.

The Table is intended to be used in the following way. During a calibration exercise, the salinity and temperature are measured at the depth of calibration. The local sound speed is computed according to a standard formula, e.g., that of Mackenzie (1981), or table. The corresponding target strength for each sphere is obtained from the Table, by interpolation as necessary. The value thus extracted is rounded off to the nearest 0.1 dB.

## DISCUSSION

Solution of the posed problem of calibrating an eleven-frequency system is obtained with respect to several constraints. These are that the standard-target method be used, that the number of spheres be limited, that resonances in the scattering frequency response function be avoided, Table. Computed dependence of target strength, in decibels, on medium sound speed c, in meters per second, for each of eleven pairs of resonant transducers and calibration spheres. The center frequency ν and receiver bandwidth BW associated with the transducer are expressed in kilohertz. The sphere diameter 2a is expressed in millimeters.

| ν | 27 | 38 | 70 | 88 | 107 | 120 | 151 | 200 | 252 | 375 | 710 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BW | 3.0 | 3.0 | 3.4 | 3.3 | 3.2 | 3.0 | 3.7 | 3.0 | 4.5 | 8.9 | 6.2 |
| c \ 2a | 38.1 | 38.1 | 38.1 | 29.0 | 38.1 | 38.1 | 38.1 | 38.1 | 29.0 | 19.5 | 10.3 |
| 1430 | -40.21 | -41.78 | -40.24 | -43.68 | -40.58 | -40.22 | -39.82 | -39.22 | -41.86 | -45.32 | -50.86 |
| 1440 | -40.30 | -41.92 | -40.40 | -43.82 | -40.44 | -40.02 | -39.74 | -39.34 | -41.68 | -45.14 | -50.69 |
| 1450 | -40.39 | -42.04 | -40.56 | -43.92 | -40.26 | -39.83 | -39.58 | -39.45 | -41.54 | -44.99 | -50.53 |
| 1460 | -40.48 | -42.14 | -40.75 | -43.98 | -40.08 | -39.68 | -39.41 | -39.52 | -41.45 | -44.90 | -50.44 |
| 1470 | -40.59 | -42.22 | -40.93 | -43.99 | -39.89 | -39.56 | -39.24 | -39.50 | -41.45 | -44.89 | -50.43 |
| 1480 | -40.70 | -42.28 | -41.11 | -43.96 | -39.73 | -39.50 | -39.10 | -39.40 | -41.52 | -44.96 | -50.50 |
| 1490 | -40.82 | -42.33 | -41.26 | -43.88 | -39.60 | -39.49 | -39.01 | -39.24 | -41.64 | -45.08 | -50.62 |
| 1500 | -40.94 | -42.35 | -41.41 | -43.78 | -39.51 | -39.54 | -38.98 | -39.06 | -41.78 | -45.22 | -50.76 |
| 1510 | -41.06 | -42.35 | -41.52 | -43.64 | -39.46 | -39.62 | -39.01 | -38.90 | -41.88 | -45.32 | -50.87 |

and that the nominal target strength be as near -40 dB as is reasonable. The solution has been further limited by choice of tungsten carbide with 6% cobalt binder as the sphere material. The elastic properties of this are well known, and its sintering in precision spheres is an established industrial process. The result is specification of the diameters of four spheres. These and corresponding target strengths are given in the Table.

The same solution method could be applied to other multiple-frequency systems. A candidate is the new SIMRAD EK500 scientific echo sounder (Bodholt et al. 1988), which is designed to operate with three transducers simultaneously and synchronously. Another candidate wideband system is that developed by Zakharia (in press), with linear-period chirp signal spanning the range 50-75 kHz. The advantage of a several-target solution over that of the single-target solution of Simmonds (1986) is better control of target strength over selected portions of the frequency band.

In any case, important practical work remains to determine just how to suspend one or more spheres to calibrate a multiple-frequency multiple-transducer system.

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