MEASURING THE FREQUENCY RESPONSE FUNCTION OF A SEVEN-OCTAVE BANDWIDTH ECHO SOUNDER

Kenneth G. Foote (1), Philip R. Atkins (2), Claire C. Bongiovanni (2), D. T. I. Francis (2), Peter K. Eriksen (3), Mette Larsen(3), and Tom Mortensen (3)

(1) Institute of Marine Research, PO Box 1870 Nordnes, N-5024 Bergen, Norway
(2) School of Electronic and Electrical Engineering, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK
(3) RESON A/S, Fabriksvangen 13, DK-3550 Slangerup, Denmark

1. INTRODUCTION

Knowledge of the frequency response function of a scientific echo sounder is necessary in order to make effective use of the instrument. In fact, the determination of the frequency response function is part of a more general calibration procedure. This enables the system performance to be monitored, as, for example, to ensure stability of operation. Definition of system characteristics through the frequency response function otherwise enables absolute measurements to be made.

A specific aim of the present work is to render the echo sounder developed under the EU RTD contract "Broadband acoustic scattering signatures of fish and zooplankton (BASS)" capable of determining absolute frequency spectra of resolved individual scatterers such as fish and zooplankton. Here a specific band of the new system is examined, that spanning the range 40-100 kHz, and the frequency response function is determined by a simple single-waveform single-target method. This is then compared with the measured frequency response function. The method is critiqued and a more general solution to the problem is mentioned.

2. PRINCIPLE OF MEASUREMENT

Determination of the frequency response function rests on the measurement of a standard target on the acoustic axis and in the farfield of the transducer, and on the relation of this to the transmitted waveform and form function of the standard target. The connection of these terms is now derived.

The echo sounder transmits a signal of known electrical waveform. This is transformed at least slightly as it passes through the system and more so when exciting the transducer. A single standard target in the transducer farfield is insonified, and the incident signal waveform is further transformed by the spectral characteristics of the target. The resulting echo is registered by the same transducer and subsequently amplified and filtered. This so-called received signal can be related to the preceding transformations by a series of convolutions in the time domain or by a product of the respective spectral response functions. The latter is the present approach.

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The received signal spectrum $S_R(\nu)$ is thus the product of the generated electrical transmit signal, $S_T(\nu)$, the response function of the transmit amplifier and of the transducer in transmit mode, $H_T(\nu)$, the form function of the standard target, $F(\nu)$, the acoustic path loss, $P(\nu)$, and the response function of the transducer in the receive mode combined with other receiver filtering, $H_R(\nu)$,

$$S_R(\nu) = S_T(\nu)H_T(\nu)F(\nu)P(\nu)H_R(\nu), \qquad (1)$$

where ν is the frequency in Hertz. The effect of the medium on transforming the signal waveform because of frequency dependent absorption and dispersion is neglected, which is a reasonable approximation for the comparatively short ranges where it is possible to measure target spectra. However, these effects can be incorporated within the acoustic path loss, $P(\nu)$, if necessary.

Expressing the product of system transmitter and receiver response functions in equation (1) through a single overall system response function,

$$S_R(\nu) = S_T(\nu)H(\nu)F(\nu)P(\nu) \qquad (2)$$

In this equation, $S_T(\nu)$ is known by specification of the transmit signal, $F(\nu)$ is known *a priori* since the target is standard, $S_R(\nu)$ is known by measurement, and $P(\nu)$ is predictable as a result of the target-sonar geometry. The system transfer function $H(\nu)$ can thus be determined by simple division,

$$H(\nu) = \frac{S_R(\nu)}{S_T(\nu)F(\nu)P(\nu)} \qquad (3)$$

The principle of measurement is thus to record the echo from a standard target suspended on the acoustic axis in the farfield of the transducer, determine its spectrum $S_R(\nu)$, and divide this by the product of transmit signal spectrum $S_T(\nu)$, the acoustic path loss $P(\nu)$ and target form function $F(\nu)$, when non-vanishing. In fact, as discussed below, the response function $H(\nu)$ remains undetermined in spectral regions where $S_R(\nu)$ is significantly affected by noise or where $S_T(\nu)F(\nu)$ is small, but these possibilities are ignored for the moment. For simplicity in this work, the magnitude of the response function is determined, eliminating the need to consider phase.

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3. MATERIALS AND EXPERIMENTAL METHODS

The BASS system is a very broadband echo sounder system with seven nominally octave-bandwidth transducers spanning the frequency range 25 kHz - 3.2 MHz. The system has been described elsewhere [1]. Of particular interest is the transducer with the largest relative bandwidth, namely that spanning the second frequency band 50-100 kHz, but with an effective bandwidth of 40-100 kHz [4, 7].

This transducer, among others, was used during the third sea trial of the system, conducted during the period 9-18 October 1998. The system platform was the R/V "Johan Hjort", and the venues were fjords along the west coast of Norway. The measurements described here were made in Vestfjorden just west of Skova on Lofoten at N68 09', E14 30' and in Romsdalsfjorden at N62 41', E7 00'.

A number of standard targets were suspended on a single 30 m line of monofilament nylon attached to the transducer frame at a selected point to ensure suspension on the acoustic axis. The targets were precision solid homogeneous elastic spheres composed of electrical-grade copper or tungsten carbide with 6% cobalt. The spheres were wetted in a solution of ordinary dish-washing detergent and fresh water, and then immediately immersed without further handling. The system was lowered to 10 m depth and the measurements commenced.

The transmit signal was a 10 ms chirp pulse, with a frequency range 38-110 kHz. The receive signal for the range 15-30 m is shown in Figure 1.

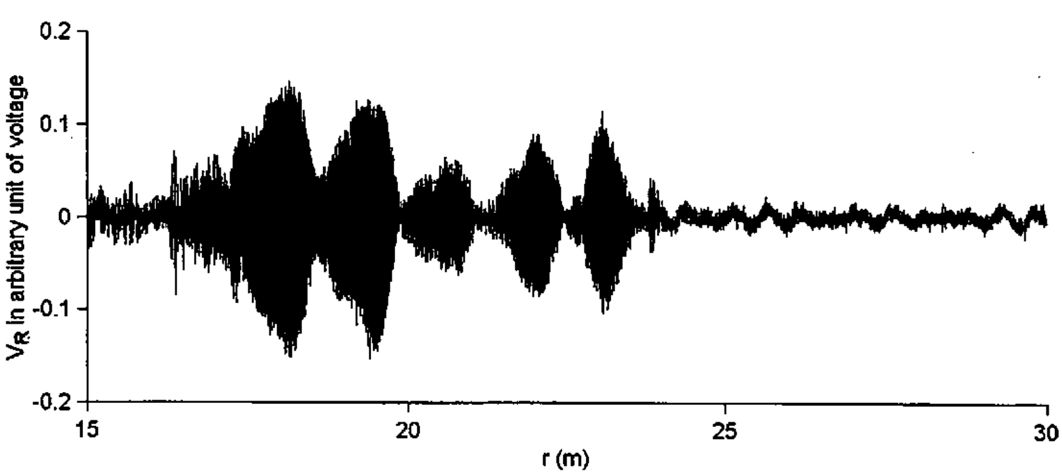

Figure 1. Receive signal for target CU64 with the system at 10-m depth.

The result of performing matched filtering with the specified transmit signal is shown in Figure 2.

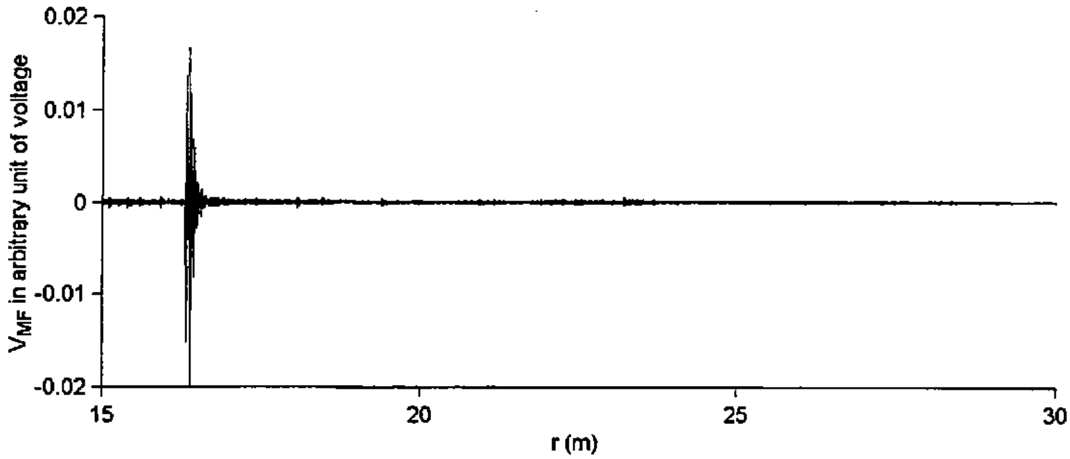

Figure 2. Matched-filter output signal for the target echo shown in Figure 1.

The echo signal at the range of 16.5 m is due to a 64 mm diameter copper sphere, designated CU64. Its echo spectrum is derived from the corresponding segment shown in Figure 1 and an average over 142 sets of data is shown in Figure 3. The experiment was repeated with the same target at 250 m depth, giving similar results, with a maximum difference of 1.5 dB at a frequency of about 102 kHz.

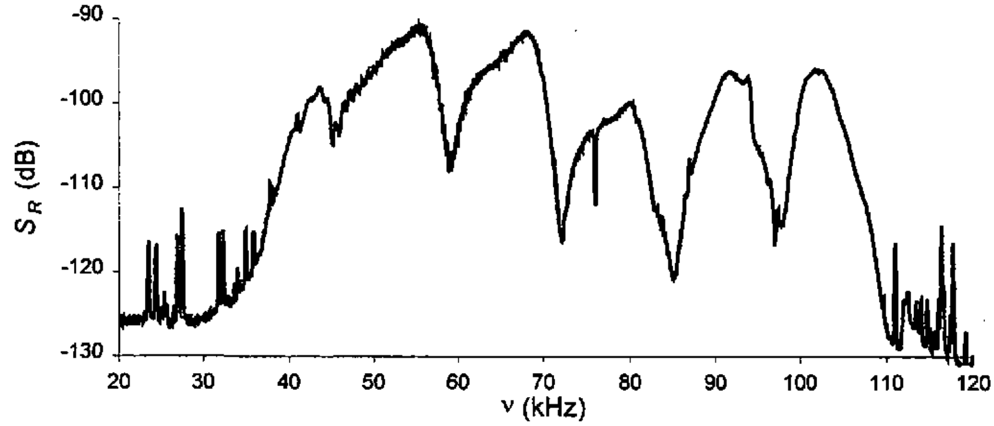

Figure 3. Echo spectrum of target CU64 derived from the signal shown in Figure 1.

Embedded in this echo spectrum is the frequency response function of the echo sounder system for the transducer operating in the frequency range 40-100 kHz. This is extracted by the division indicated in equation (3). Two ingredients of this are the transmit signal spectrum

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$S_T(\nu)$, which is derived through the Fourier transform of the transmit signal, and form function $F(\nu)$. This second function is derived by the standard series solution to acoustic scattering by a solid homogeneous elastic sphere. Reference is made to Faran [2] and Hickling [6], but using the correct expression derived from Goodman and Stern [5], as qualified in Foote [3]. The computations were performed for a medium density and sound speed determined by the temperature and salinity as measured by CTD-sonde at the sphere depth, namely 11.66 deg C and 32.31 ppt, hence with density 1024.56 kg/m^3 and sound speed 1490.5 m/s. Two of the material properties of the sphere are specified in [3], namely the density 8947 kg/m^3, and longitudinal-wave sound speed 4760 m/s. However, the shear-wave sound speed is assumed to be 2278 m/s, slightly less than the nominal value of 2288.5 m/s found earlier, in an attempted refinement for the particular sphere. The magnitude of the form function corresponding to a range of 1 m is given in Figure 4.

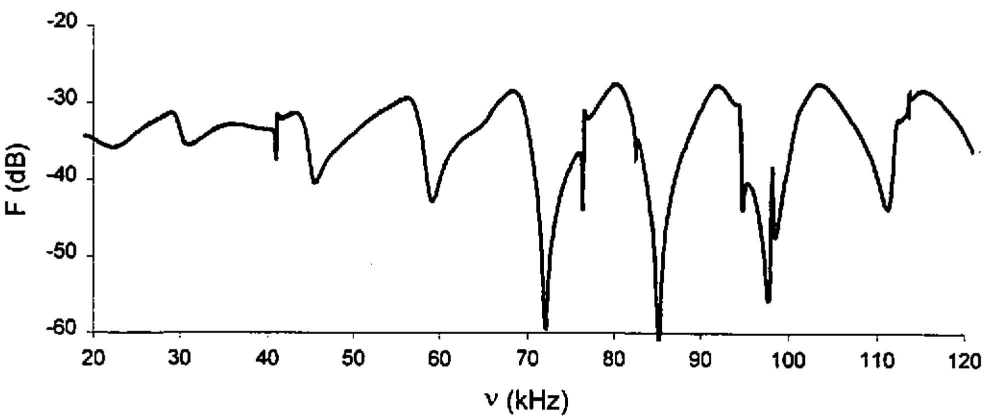

Figure 4. Magnitude of the form function for the target CU64 at a range of 1 m over the frequency band 20-120 kHz.

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4. RESULTS AND DISCUSSION

Division of $|S_R(\nu)|$ by the product $|S_T(\nu)F(\nu)P(\nu)|$ yields the desired result for $|H(\nu)|$. This is shown in Figure 5.

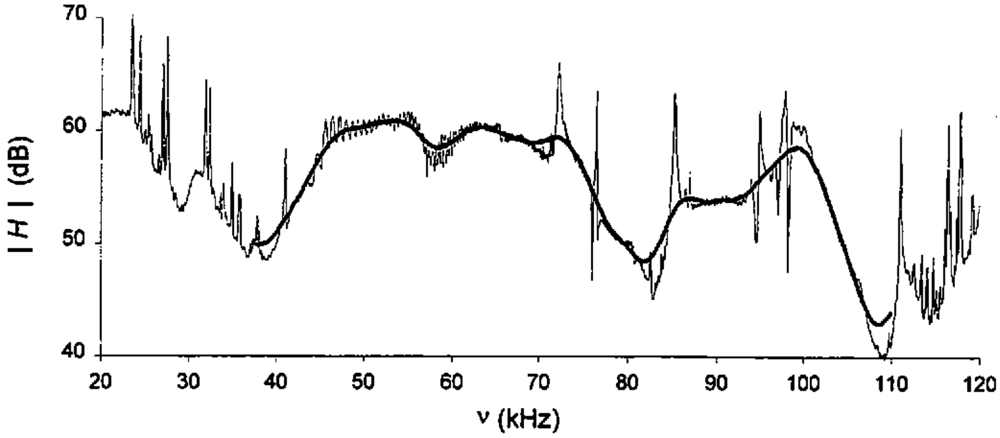

Figure 5. Estimated frequency response function (computed : thin line, smoothed : thick line) of the BASS echo sounder with attached transducer covering the bandwidth 40-100 kHz.

As earlier suggested, there are limitations to the specification of $H(\nu)$ by the single-waveform single-target method used here. In particular, $H(\nu)$ might not be determined for zero or low values in the product $S_T(\nu)F(\nu)$. Low values of $S_T(\nu)$ can be encountered outside the range 40-110 kHz. A discrete set of frequencies (46, 59, 72, 85, 98 kHz) are excluded by low values in the theoretical form function $F(\nu)$.

There is a remedy to both of these problems, namely the use of multiple transmit waveforms and of two or more standard targets, especially spheres, with differing form functions.

Changing the waveform will change the spectrum. Rather simple changes to the broadband transmit waveform, for example, to its shape and duration, will produce spectra where troughs in one spectrum are matched by peaks in the other, at least to an extent.

Similarly, changing the standard target will change the form function. Spectral regions of weak backscattering by one standard target can be offset by strong backscattering by the other standard target. Use of additional standard targets can achieve adequate coverage of an arbitrarily large spectral region, guaranteeing avoidance of nulls in the denominator in equation (3).

Alternatively, the use of an optimization principle for determining the standard target properties, for example, sphere material and diameter, might lessen or even avoid weak backscattering regions in the first instance. This would reduce the need for multiple targets, but pragmatic considerations, for example, due to constraints on the target strength, will restrict freedom of choice here.

In practice, determination of the frequency response function can be achieved through a single deployment, because multiple standard targets can be attached to the same suspension line, and the transmit waveform can be modified as necessary. In fact, this has already been done, but the results are reserved for a fuller treatment of the general solution to the problem of broadband-system calibration.

In the meantime, a smoothed curve for the frequency response has been plotted on Figure 5, where problematic values have been replaced by the mean value over a range of 4 kHz.

This approximate frequency response function is now compared (Figure 6) with the function as measured at RESON A/S [7]. Adjustment has to be made as the latter represents only the transducer's response H_{transd}, while the former is for the complete system and depends on the transmit and receive amplification gain factors and termination impedances.

The difference is expected to be roughly independent of frequency. A constant value has therefore been subtracted from the computed frequency response function in order to derive the frequency response of the transducer.

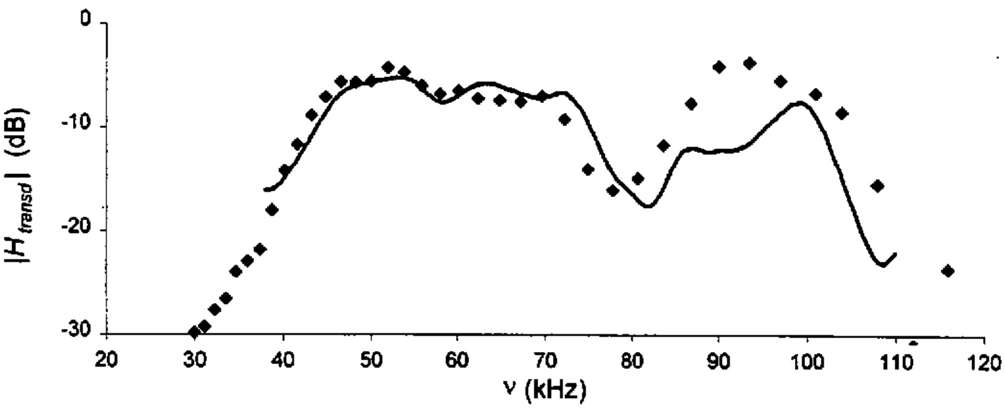

Figure 6. Estimated frequency response function of the 40-100 kHz transducer (—), together with the laboratory measurement (♦).

There is a good agreement between the two curves between 40-80 kHz. The difference observed for higher frequencies may be due to differences in termination impedances.

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5. CONCLUSIONS

A simple procedure for determining the frequency response function of a broadband echo sounder has been developed and illustrated for the BASS instrument, with a transducer spanning the frequency range 40-100 kHz. This involves measurement of the echo due to a standard target, a precision sphere, suspended on the acoustic axis. The method is not general insofar as noise or minima in the product of transmit signal spectrum and form function may preclude determination of the response function. Remedies by the use of multiple transmit waveforms and multiple standard targets have been mentioned.

6. ACKNOWLEDGEMENTS

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