NEAR FIELD TO FAR FIELD – UNDERWATER COMPACT RANGE SETUP

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Abstract: *Target echo strength is by definition a far field property of a scatterer. However, geometrical constrains often limit the ability to measure in the far field. A variety of methods have been proposed so far to overcome this issue, most of them under the limiting assumption of single scattering. We suggest incorporating compact range (CR) measurements in order to mimic far field propagation in the near field regime. In this talk, I will give a brief overview of the numerical near field to far field transforms, describe the considerations taken into account in order to plan a compact range setup, and present preliminary results of such measurements.*

Keywords: *Target echo strength, near field to far field transformation, compact range*

1. INTRODUCTION

Target echo strength measurements are a key ability in underwater acoustics, and require measuring or estimating the far field frequency response of the object under test. As water tanks have limited dimensions and open water measurements are often challenging in terms of noise and complexity, several methods are applied in order to perform reliable and reproducible far field frequency response. As an initial step, scaled models that will fit the water tank size are often used. However, a minimal wall thickness must be used in order for the model to be produced. It is very probable that measuring in the near field cannot be avoided.

Once a near field measurement was performed, the far field response can be estimated by several ways, elaborated on chapter 2. The first one is direct calculations that are very consuming in terms of time and computational resources. A collection of near field to far field algorithms was developed in order to overcome this. They present a notable computational advantage, but all rely on the assumption of single scattering. Far field response of targets that include resonators, reflectors and generally multiple scattering centres is not guaranteed to be successfully reconstructed by these algorithms.

We suggest taking a different approach and building an underwater compact range setup, similar to the ones used in radar cross section measurements. This method, and our suggestion to apply it to underwater target echo strength measurements are described in chapter 3.

2. FAR FIELD RECONSTRUCTION FROM NEAR FIELD MEASUREMENTS

The most straight forward approach for far field estimation from near field measurements is by direct integration. The general form for a spherical scan is given by the following equation [5]:

$$U(\theta, \phi) = \frac{ik}{2\pi} \int_V \rho(r') \frac{e^{i2\pi|r-r'|}}{4\pi|r-r'|} d^3r' \tag{1}$$

U is the far field radiation pattern, θ, ϕ are the elevation and azimuthal angles, k is the wave number, ρ is the reflectivity distribution. The integral is calculated on a sphere of volume V encapsulating the model. The exact formulation may differ for a different geometry of the setup ([1] [2] [3] [4] [6] [7]).

The main limitation of this method is the fact that it requires a very large number of sampling points and great computational power (see for example [2]). For example, in order to compute the response of a 1 [m] long object to a 15 [kHz] signal, spatial Nyquist resolution will result in 10^8 sampling points, and several weeks of measurements and processing. Thus, this method is rarely used.

A set of near field to far field algorithms was developed to reduce calculation time and allow feasible measuring methods [5] [6]. One of them is the circular near field to far field transform. A version of this transform was successfully implemented in our group for several models [5] [8]. The Achilles' heel of these methods is that they may not take into account multiple scatterings, resulting in inaccurate results for complex models.

3. COMPACT RANGE SETUP FOR UNDERWATER ACOUSTICS

Compact range is a very common method in radar cross section measurements. It relies on the similarity between far field propagation and the phase added by a lens or more commonly, a parabolic reflector, as can be seen in ***Table 1*** [8] . In addition, the optical path can be doubled by reflecting the scattered wave with a secondary reflector.

Propagation to distances greater than the Fraunhofer distance of a source *f(x,y)*	Propagation through a thin lens of a source given by *f(x,y)*
$\lvert g(x,y)\rvert^2 = \frac{1}{\lambda^2 d^2}\left\lvert F\left(\frac{x}{\lambda d},\frac{y}{\lambda d}\right)\right\rvert^2$	$\lvert g(x,y)\rvert^2 = \frac{1}{\lambda^2 f^2}\left\lvert F\left(\frac{x}{\lambda f},\frac{y}{\lambda f}\right)\right\rvert^2$

Table 1: analogy between far field propagation to a distance d and propagation through a thin lens with a focal length f. The source is given by a function f(x,y), where x and y are dimensions of plane perpendicular to the beam propagation,and λ is the wave length. In both cases the outcome is the fourier transform of the source, denoted by F.

The measurements took place in Israel's Underwater Centre of Excellence, in Rafael's underwater test facility. It is a 10 [m] wide, 20 [m] long and 10 [m] sweet water tank. Despite its unique size, some of the measurements are still held in the near field regime. This is due to fact that model scaling is limited (usually by a minimal size of wall thickness). The tank facility is controlled environment, seismically isolated, with very low background noise, making it ideal for testing new methods, such as the compact range.

An underwater acoustic reflector is considerably difficult to implement, thus our design includes an acoustic lens as the phase changing object. The lens has a focal length of 2 [m] and is made of Rexolite. It has a 50 [cm] diameter. The model used is two Tungsten-Carbide spheres, 38 [mm] diameter large, that were separated 18 [cm] apart. The spheres were hanged from an automatic rotator, their centre of rotation aligned with the centre of the lens, as can be seen in the schematic drawing in ***Fig. 1***. The transmitter/receiver was fixed at the focal plane of the lens by a designated instrument, as can be seen in ***Fig. 2***. This instrument was held with a crane hook and aligned by four ropes.

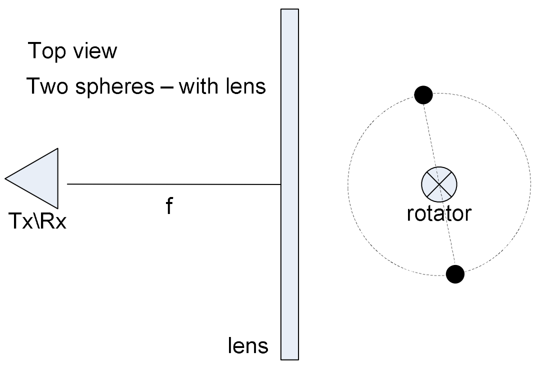

Fig. 1: A schematic drawing of the compact range setup.

This setup was truly monostatic, allowing a 1[ms] pulse to be transmitted for each angle of the target. The data processing included a frequency window, interpolation to a finer grid, match filter with the transmitted signal and background subtraction. Then a Fourier transform was applied and then calibration according to a measurement of a single sphere, with a known frequency response.

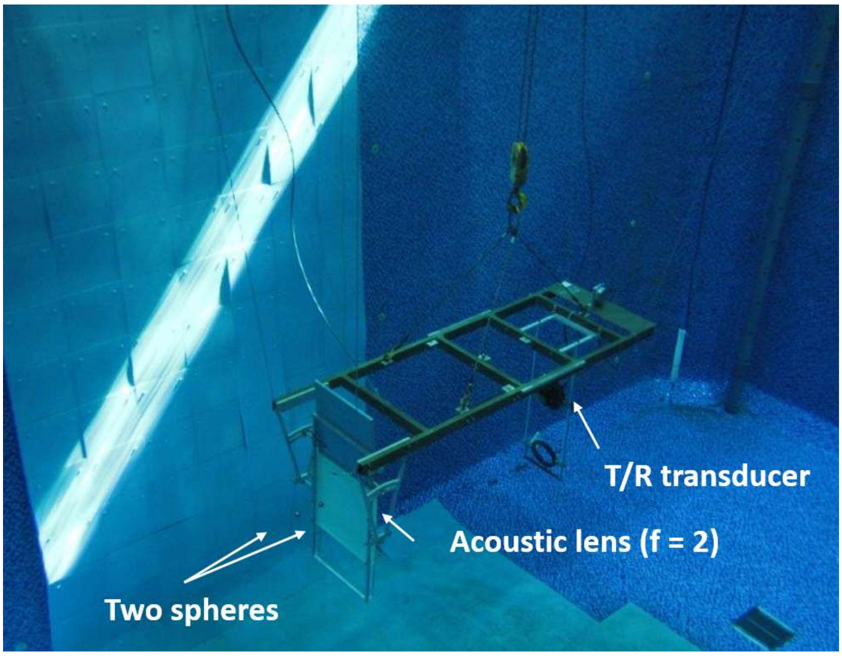

Fig. 2: A picture of the compact range setup.

4. RESULTS

The time domain data, after match filtering is displayed on ***Fig. 3***. The frequency domain, compared with theoretical calculation can be seen in ***Fig. 4***.

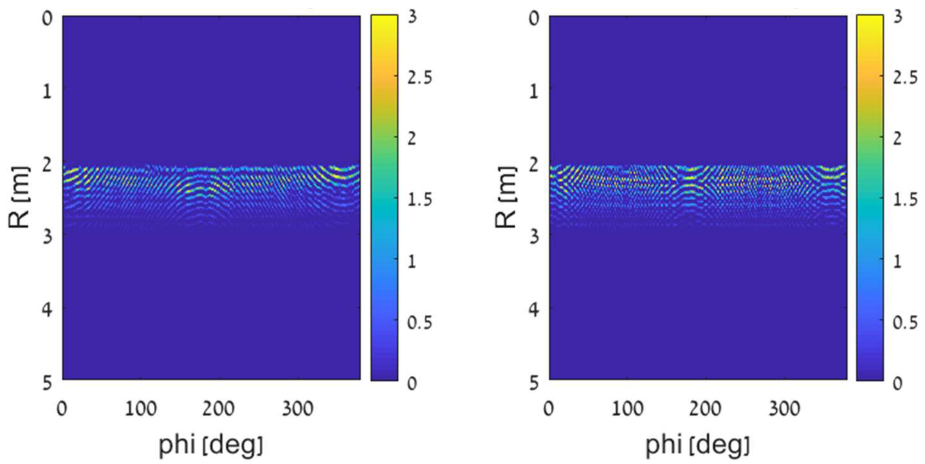

Fig. 3: time domain data of compact range setup. Left: measurement of a single 38 [mm] sphere. On the right: measurement of two 38 [mm] spheres, 18 [cm] apart.

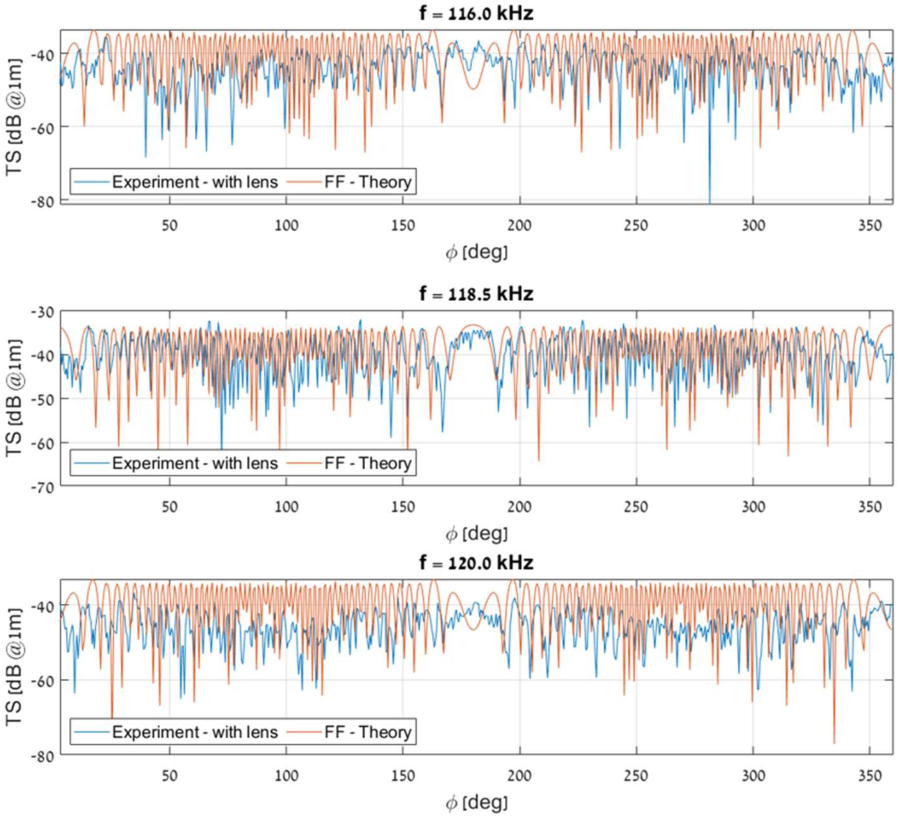

Fig. 4: Frequency response of two spheres, calculated by compact range measurement, compared with the far field response.

The frequency response calculated from compact range measurements followed prominent features expected from the theoretical calculation. Mainly, the width of the central feature and a rapid nulls structure.

Nevertheless, the experimental frequency response was found to be very noisy, probably due to high level reverberation from the instrument holding the lens and the transducer. These caused a rather complicated background subtraction, and yet noisy frequency response. The first conclusion drawn consequently is when repeating this experiment, a different method should be used in order to fix the transmitter/receiver at the focal point of the lens.

One should also note that the main advantage of the compact range method is the ability to reconstruct far field response of multiple scatterings. We are planning to use this method with a model containing multiple scattering, e.g. a dihedral or trihedral corner reflector.

5. SUMMARY

A compact range setup complemented with an arsenal of near field to far field transformation algorithms can allow target echo strength estimation where geometrical constrains prevent a far field measurement. This method does not rely on Born approximation, hence it might be handy for complex models, comprised of reflectors and resonators.

Future work may include a large lens which will allow measuring large objects. In order to enlarge the lens' active area while keeping its width reasonable, a gradient index acoustic lens may be considered.

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