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The parametric propagation in underwater acoustics: experimental results

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In underwater acoustics, detection of buried objects in sediments (cables, mines, . . . ) is a complex problem. Indeed, in order to ensure sufficient penetration depth in marine sediments, low frequencies have to be used, implying a low resolution. A solution proposed to solve this problem is the parametric emission based on the nonlinear properties of seawater. This method can generate a low frequency wave from two directional high frequencies beams.

The aim of this work is to present experimental results of a parametric propagation. Experiments have been carried out in a water tank in various configurations. These experimental measurements are then compared with simulation results obtained with a numerical model based on a fractional-step method presented at the Underwater Acoustic Measurements conference in 2011.

1 Introduction

In order to detect buried objects in marine sediments, low frequency has to be used, implying a low resolution. A solution to solve this problem is the parametric emission. The aim of this work is to present experimental results of a parametric propagation.

A model based on a fractional-step numerical method introduced by Christopher and Parker [1] was presented at the Underwater Acoustic Measurements conference in 2011 [2]. In this method, the normal particle velocity is introduced by [3] : 

$$\nu = \nu_0 e^{i\phi_n}$$

Equation (2) allows to take into account possible inclination and focalization of the transducer [2].

In the case of a parametric emission, two high frequency waves \(f_1\) and \(f_2\) are emitted in order to generate a wave at beating frequency \(f_l = f_1 - f_2\) (with \(f_2 > f_1\)) by nonlinear interactions.

The parametric ratio \(p\) is defined as the ratio between the average of primary frequencies over parametric frequency :

$$p = \frac{f_0}{f_l} \text{ with } f_0 = f_1 + f_2$$

In order to avoid creating even lower frequencies than \(f_l\) by interactions between harmonics, parametric ratio is a half-integer : \(p = n + \frac{1}{2}\) with \(n\) as a non-zero integer [6]. In this case, \(f_1\) and \(f_2\) are multiples of the parametric frequency : \(f_1 = (p - \frac{1}{2})f_l\) and \(f_2 = (p + \frac{1}{2})f_l\).

On the transducer surface, only the primary frequencies harmonics components are initialized, the other components are equal to zero.

The numerical model can take into account the transmission at the water/sediment interface and propagation in the sediments [2]. In the following of this paper, only the results in the water are presented.

2 Numerical modeling

Numerical modeling previously proposed [2] for nonlinear propagation is a frequency domain approach based on the Burgers equation and the angular spectrum method. A numerical solution of Burgers equation is obtained with a split-step operator. Over sufficiently small steps, the effects of nonlinearity, diffraction and attenuation can be treated independently. Knowing the normal velocity field for a plane \(z\), the particle velocity profile \(\nu\) at position \(z + \delta z\) is given by [3] :

$$\nu(z + \delta z) = \nu(z) + \left(\overline{\nu_A} \cdot \nu + \overline{\nu_N} \cdot \nu + \overline{\nu_D} \cdot \nu\right) \delta z$$

(1)

where \(\overline{\nu_A}\), \(\overline{\nu_N}\) and \(\overline{\nu_D}\) are respectively the attenuation operator, the nonlinear operator and the diffraction operator which expressions are detailed in [2], [4] and [5].

The propagation modeling is divided into three steps [3] :

- Diffraction over substep \(\frac{\delta z}{2}\), nonlinearity and attenuation over \(\delta z\), and second diffraction over substep \(\frac{\delta z}{2}\).

Moreover, several substeps are used for the calculation of the nonlinearity and attenuation effects over the distance \(\delta z\) in order to improve the stability of the code .

To model nonlinear propagation, the wave is decomposed into different harmonic components :

$$\nu(x, y, z, t) = \frac{1}{2} \sum_{n=-\infty}^{\infty} \nu_n(x, y, z)e^{i\omega_n t}$$

(2)

where \(\nu_n(x, y, z) = |\nu_n| e^{i\phi_n(x, y, z)}\) and \(\phi_n(x, y, z)\) are respectively the complex amplitude and the phase of the \(n\)th harmonic \((\omega_n = n\omega)\) at the point \((x, y, z)\). The equation (2) allows to take into account possible inclination and focalization of the transducer [2].

In the case of a parametric emission, two high frequency waves \(f_1\) and \(f_2\) are emitted in order to generate a wave at beating frequency \(f_l = f_1 - f_2\) (with \(f_2 > f_1\)) by nonlinear interactions.

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In order to avoid creating even lower frequencies than \(f_l\) by interactions between harmonics, parametric ratio is a half-integer : \(p = n + \frac{1}{2}\) with \(n\) as a non-zero integer [6]. In this case, \(f_1\) and \(f_2\) are multiples of the parametric frequency : \(f_1 = (p - \frac{1}{2})f_l\) and \(f_2 = (p + \frac{1}{2})f_l\).

The numerical model can take into account the transmission at the water/sediment interface and propagation in the sediments [2]. In the following of this paper, only the results in the water are presented.

3 Experimental set up

Experimental measurements are performed in a water tank of 1.5m × 1.5m × 1m filled with fresh water. The water temperature is about 12°C and measured celerity is \(c_0 = 1450\) m.s⁻¹.

A global scheme of the device is shown in Figure 1.

![Figure 1: Experimental configuration](image-url)
A 3D positioning system is used to move the transducer. An arbitrary waveform generator (BNC 625A) is used to provide a synthetic signal which is the sum of the two primary frequencies (Figure 2).

![Figure 2: Normalized emitted signal for an average value of the primary frequencies $f_h = 1$ MHz.](image)

This signal is then amplified by a linear power amplifier (ENI AQ-300 RF) with a gain of 55 dB and applied to the transducer. Two circular piston transducers, with a diameter of 0.5 inch, are used (Valpey-Ficher ISO104GP and ISO204HR). Nominal frequencies of the transducers are respectively 1 MHz and 2.25 MHz.

The sound pressure fields generated in water are measured with two hydrophones (Figure 3): a needle hydrophone (Precision Acoustics PVDF ultrasonic SN 950) for the primary frequencies and a Reson TC4034 for the parametric frequency.

![Figure 3: The two hydrophones used: Precision Acoustics PVDF ultrasonic SN 950 (top) and Reson TC4034 (bottom).](image)

The sound pressure fields are visualized on an oscilloscope (Tektronix TDS-3014b) connected to a computer by a GPIB port for acquisition and treatment.

4 Results

The first test was conducted for an average frequency $f_h = 1$ MHz. The parametric ratio $p$ is 3.5 and the parametric frequency is $f_l = 285$ kHz.

![Figure 4: Experimental pressure fields (dB ref 1 µPa) for the primary frequencies at 0.86 MHz (left) and 1.14 MHz (right).](image)

Figure 4 shows the measured pressure fields for the primary frequencies at 0.86 MHz and 1.14 MHz. The highest levels measured, of about 198 dB, occur around the Fresnel distances: between 1.5 and 4 cm for $f_1 = 0.86$ MHz and between 2 and 5 cm for $f_2 = 1.14$ MHz. As expected, the beam is narrower for the higher frequency.

The measured pressures for the primary frequencies are input to theoretical model to compare experimental and theoretical results.

![Figure 5: Theoretical pressure field (dB ref 1 µPa) for the primary frequency at 0.86 MHz.](image)

Figure 5 shows the theoretical field for the first primary frequency. The diffraction figure is more detailed on the theoretical pressure field but the level values, the beam size and the position of the maximum value are the same than experimental measurement.
Experimental and theoretical pressure fields are presented in figure 6 for the parametric frequency at 285 kHz. The measured pressure field has been normalized because the sensibility of the hydrophone need to be checked.

In the theoretical field, there is an increase of the level in the interaction area of the primary frequencies. However, measured level is higher than expected in the near field, which is confirmed in normalized axial evolution curves presented in figure 7.

The axial evolution of the experimental and theoretical normalized levels of the primary frequencies are presented in figure 8. There is a distance shift for the maximum value of the second primary frequency probably due to the precision of the celerity measure or a bad alignment between transducer and hydrophone.

Beamwidths for the primary frequencies are respectively 6° for 0.86 MHz and 8° for 1.14 MHz. For the parametric frequency, experimental beamwidth is 7° and there is no sidelobe.
The second test was conducted for an average frequency \( f_h = 2.25 \) MHz. The parametric ratio is 7.5 and the parametric frequency is \( f_l = 300 \) kHz.

Measured pressure fields obtained for an average frequency of 2.25 MHz are presented in figure 11 for the primary frequencies and in figure 12 for the parametric one. A little inclination of the transducer can be observed. As expected, the Fresnel distance is higher, which implies than parametric effects occur further, and the beamwidth is lower (3°) for the primary and parametric frequencies than an average frequency of 1 MHz.

### 5 Conclusion

Experiments have been carried out in a water tank. Experimental results were been compared with simulation ones for a parametric emission.

If general evolutions of the pressure fields are in agreement with the theoretical results, unfortunately there is a significant difference for the parametric level. The problem may be due to changes in the hydrophone calibration.

The next set of measure have to be carried out in sediments (sand) for buried object detection.

### References


