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Use of parametric acoustic sources to generate neutrino-like signals

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ABSTRACT

It is not easy to design a calibrator system able to reproduce the time and directivity patterns of the acoustic pulse produced in an ultra high energy neutrino interaction. Linear arrays of acoustic transducers with coherent emission have been proposed, but it might result in a long array with many elements, increasing the cost and making the deployment and operation much more complex. In this paper, we evaluate the possibility of using an alternative approach using parametric acoustic sources to generate neutrino-like signals. This non-linear acoustic effect can also be applied to transient signals allowing to generate them by a "special modulation" at a larger frequency. The technique has the advantage of being much more directive since the directivity of the parametric source is similar to that of the large frequency used, and therefore it will result in a much more compact design with fewer sources. Here, we present the studies performed with planar transducers in a tank to evaluate the possibilities of the technique, which seems very promising according to our results.

1. Introduction

The possibility of calibrating and testing acoustic neutrino telescopes with neutrino-like signals is an essential aspect not only to check and monitor the sensitivity of the different acoustic sensors, but also to train and tune the detector, and to test the system and its reliability [1]. In this sense, the use of acoustic transmitters is foreseen in every experiment of this kind. However, due to the nature of the acoustic pulse produced in an ultra high energy neutrino interaction (i.e., a very directive 'pancake' short bipolar pulse), it is not easy to design a system able to reproduce the time and directivity patterns whilst bearing in mind practical issues such as ease of deployment and operation.

Different solutions have been proposed to have acoustic sources from transducers able to reproduce the time pattern, i.e., the bipolar signal [2–5]. However, much difficulty seems to appear when dealing with the directivity pattern. The simplest approximation to do it could be to build a linear array of acoustic transducers with coherent emission [2]. This approach will result in a long array with many elements, increasing the cost of the acoustic transmitter and complicating the deployment and operation of it, and consequently limiting its use. In this paper, we evaluate the possibility of using an alternative approach using parametric acoustic sources to generate neutrino-like signals. This technique would have the advantage of being much more directive since the directivity of the parametric source is similar to that of the large frequency used, and therefore, it will result in a much more compact design with fewer sources, allowing compact designs with ease of deployment and operation.

In this paper the basics of the parametric acoustic source and how this effect could be used for the emission of neutrino-like signals in underwater neutrino telescopes are described. Afterwards, we present some studies and measurements done to understand the emission of neutrino-like signals using acoustic parametric sources. These studies will help to evaluate the feasibility of the technique and will give us the necessary input for the final design of the acoustic transmitter to reproduce neutrino-like signals based on the parametric effect.

2. Parametric acoustic sources for neutrino calibration

Acoustic parametric generation is a well-known non-linear acoustic effect, which is quite extensively studied and it has important applications in underwater acoustics, especially to obtain directive acoustic sources. This effect appears, for example, when there are two intense monochromatic acoustic beams with close frequencies travelling together along the medium (water, for example). Under these circumstances, in the region of non-linear interaction, secondary beams with sum, difference, double frequencies and harmonics appear. The main application consists of producing a directive low-frequency beam by using the difference frequency generation from two close high-frequency beams. At high frequency it is easy to have directive beams, property which is maintained for the secondary beams. Moreover, since the high-frequency components are rapidly absorbed, for

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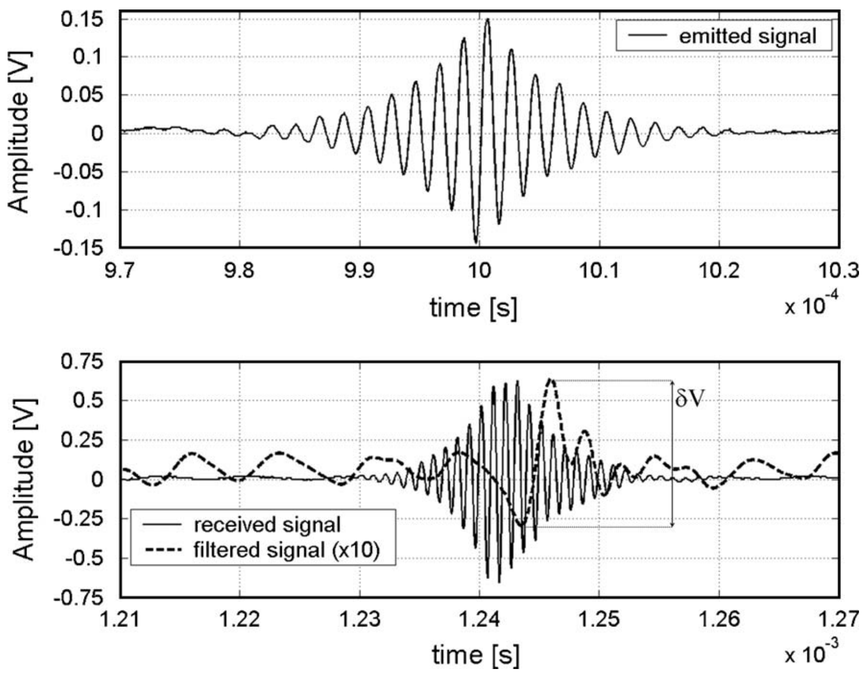

Fig. 1. *Top*: signal used for emission (1 MHz transducer). *Bottom*: signal measured at the receiver (solid line) and the bipolar signal obtained after applying the low-pass filter (dashed line).

large-range applications, just this secondary low-frequency component is available.

The parametric acoustic sources have some advantages with respect to traditional linear radiating systems, such as the opportunity of obtaining narrow directional patterns at small overall dimensions of primary transducer, the absence or low level of side-lobes in a directional pattern on a difference frequency, and a broad band of operating frequencies of radiated signals. For all these reasons, this kind of sources is widely used in underwater acoustics: sonar, communication, etc.

The same effect can be used for transient signals [6] as it is possible to generate a short signal by a "special modulation" at a larger frequency in such a way that the pulse interacts with itself in the medium providing the desired signal due to the sum (integral) of difference frequencies from the spectral content of the short modulated signal. Theoretical and experimental studies show that the shape of the secondary signal is basically the second derivative of the envelop of the primary signal, where the pressure amplitude is proportional to the square of the primary pressure amplitude, and depends on the non-linear acoustic parameter, besides other parameters of the medium. To determine the signal for the emission we have used the following expression:

$$p(x,t) = \left(1+\frac{B}{2A}\right)\frac{P^2 S}{16\pi\rho c^4 \alpha x}\frac{\partial^2}{\partial t^2}\left[f\left(t-\frac{x}{c}\right)\right]^2$$

where P is the pressure amplitude of the primary beam pulse, S the surface area of the transducer, $f(t-x/c)$ the envelop function of the signal, which is modulated at the primary beam frequency, x the distance, t the time, B/A the non-linear parameter of the medium, ρ the density, c the sound speed and α the absorption coefficient. With this, $p(x, t)$ is the expected parametric signal. In our studies we would like to have for $p(x, t)$ a bipolar signal, and for this we have selected a first time derivative of a Gaussian function with a sigma of 5 μs. The envelope function $f(t-x/c)$ was calculated by integrating the expression.

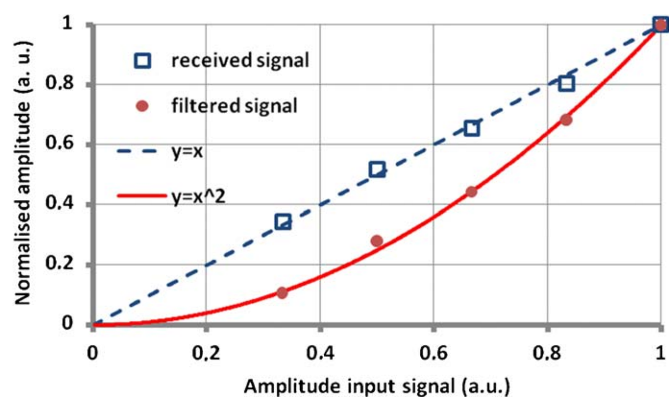

Fig. 2. Intensity of the received and bipolar (filtered) signal as a function of the primary beam intensity.

3. Studies to evaluate the technique

In this section, we present a study to obtain a neutrino acoustic signal from a planar transducer using the parametric effect in a small tank. Certainly, this lab study is still far from being an ideal calibrator for neutrino telescopes, but it can be very useful to evaluate the feasibility of the technique and set the basis for the final design of the calibrator using the parametric technique.

3.1. Experimental setup

The study of the generation of neutrino-like signals using parametric acoustic sources has been done in a $1.10 \times 0.85 \times 0.80\,m^3$ tank. Two fixed planar transducers namely Reson TC3027 and Reson TC3021 were used as emitters, with 1 and 2 MHz resonances, respectively. A Reson TC4014 hydrophone mounted on a mobile mechanical motor with a precision better than 0.1 mm was used as receiver. This hydrophone has a flat frequency