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Optimal study and analysis of the directivity of acoustic antennas multi-sensors

***Abstract** An acoustic antenna is made up of several separately accessible sensors, ie whose individual outputs are physically available. We can then model its directivity diagram by playing on the amplitude and phase distribution of its elements. In this paper we have studied the directivity of an acoustic antenna in order to obtain an optimal and precise result by using a Hamming window to have as few side lobes as possible and a single main lobe.*

Streszczenie.** Antena akustyczna składa się z kilku oddzielnie dostępnych czujników, tj. Których indywidualne wyjścia są fizycznie dostępne. Następnie możemy modelować jego diagram kierunkowości, grając na amplitudzie i rozkładzie fazowym jego elementów. W tym artykule zbadaliśmy kierunkowość anteny akustycznej w celu uzyskania optymalnego i precyzyjnego wyniku przy użyciu okna Hamminga, aby mieć jak najmniej płatów bocznych i jeden płat główny. (Badanie i analiza optymalnej kierunkowości anten akustycznych wieloczujnikowych**)

Keywords: Acoustic antenna, antenna directivity, main lobe, side lobes.
Słowa kluczowe: Antena akustyczna, kierunkowość anteny, listwa główna, listwy boczne.

Introduction

The acoustic antenna is made up of groups of sensors, or sensors. At a given distance, the sensitivity of an acoustic antenna is generally not the same regardless of the direction considered and this is what the directivity of an acoustic antenna consists of [1, 2].

The directive acoustic antenna has a definite interest in emission, when it comes to focusing sound waves in a particular direction. However, their value is limited when it comes to locating sources of noise [3].

We can divide acoustic antennas into two general classes based on their directivities: if the sensitivity of an acoustic antenna is always the same in all directions, the antenna is said to be isotropic or omnidirectional; otherwise we say that the antenna is directive. The term directivity summarizes the directional characteristics of an antenna: it reflects the spatial (or angular) variations in the sensitivity of the antenna, with respect to the incident wave [4].

The outputs of an acoustic antenna can be assembled and processed in several ways to achieve different effects. For example, it is possible to obtain main lobe antennas oriented in various directions, side lobe antennas of the same level, antennas without side lobes, super-directive antennas and optimal antennas [5].

We can therefore model the directivity diagram of the antenna, and subsequently modify its signal-to-noise ratio, by adjusting the amplitude and phase distribution of its elements.

The measurement of the characteristics of spaced emitting sources is carried out by an antenna processing which consists, in a way, in constructing an image of the medium from the signals picked up by the sensors forming the antenna. The role of this processing is therefore to perform spatial filtering so as to separate the different components of the acoustic field as well as possible: sound sources and background noise. Spaced sound sources are understood to mean sources sufficiently distant from the antenna to appear as point-like. On the other hand, we will admit that a sensor is a sensitive, punctual element, which measures the acoustic field in which it is located without altering it by itself [6, 7].

The objective of this paper is to study the directivity of an antenna made up of several sensors. For this, we start from the assumption that the received wave is plane. We will start with the study of the directivity of an acoustic antenna. First we will start by defining the sound pressure as well as the output signal of the antenna formed by a number N of sensors.

Then, we deal with the influences and impacts of the parameters which are the number of sensors and the distance between the sensors, on the signal output of the acoustic antenna, in order to obtain an optimal and precise result of the response of the sensor. antenna (no side lobes, maximum power).

Finally, to attenuate the effect of the side lobes, the output signal of the acoustic antenna is multiplied by a so-called Hamming-type apodization window. Simulations have shown the effectiveness of using the Hamming window on the acoustic antenna.

The reminder of this paper is organized as follows. In Section 2, the directivity of an acoustic antenna is presented in this section. the optimal study of the directivity of an acoustic antenna formed by several sensors is illustrated by the simulation of an acoustic antenna formed by N sensors in section 3. Finally, concluding remarks are drawn in Section 4.

Antenna and directivity

We consider an acoustic receiving antenna and a far-field sound source. It is very common in antennae to admit that the means of promoting the detection of a signal carried by a plane wave is to obtain, by means of the acoustic antenna and in the direction of this antenna, the most strong directivity possible [5, 8].

Let be an acoustic antenna formed of N point elements. The complex directivity is a function:

- the frequency f,
- of two space parameters defining the direction of the plane wave, these two parameters are the polar angles: the colatitude θ and the bearing φ and they are united under the name $\Omega = g(\theta,\varphi)$
- of Ω_0 which is the direction in which the output of the antenna is maximized as a result of the application to the different elements of a suitable distribution of phase shifts. Ω_0 also defines the direction of orientation of the main directivity lobe and is called the directivity path [9].
- and weighting coefficients a_1, a_2,… a_n which allow to model the directivity diagram of the antenna. These coefficients can be complex.

The complex function $x = f(\Omega, \Omega_0, a_1, a_2, \ldots a_n)$ gives the amplitude and the phase of the voltage observed at the output of the antenna in the presence of a plane wave of direction Ω and frequency *f*. The output is defined as the sum of the voltages coming from the various sensors of the antenna, through, if necessary, a weighting (or a filtering) assigned to each element.

For a given frequency *f*, for a fixed directivity channel Ω_0 and for a set of assigned $(\mathrm{a}_1, \mathrm{a}_2, \ldots \mathrm{a}_\mathrm{n})$ weighting coefficients, the normalized complex directivity function is defined by [5]:

(1) $$d(\Omega) = \frac{x}{x_{\max}}$$

The plot of the modulus of this directivity function as a function of a polar angle constitutes the normalized directivity diagram of the acoustic antenna. This diagram shows a main lobe, or two main lobes of directivity (front lobe and rear lobe) and lobes of lesser amplitude called secondary lobes. The normalization makes it possible to compare the different directivity diagrams and to determine their characteristics such as the opening of the main lobe at half power and the level of the secondary lobes [10, 11, 12].

The main lobe is characterized by its opening at -3dB. This width corresponds to the angle between the two directions located on either side of the axis corresponding to the maximum level of the main lobe [13]. The width of the main lobe is inversely proportional to the frequency. To have good lateral resolution, it is therefore sufficient to increase the frequency, but this to the detriment of the range due to greater absorption of energy by the medium.

Fig. 1 shows an example of a directivity function.

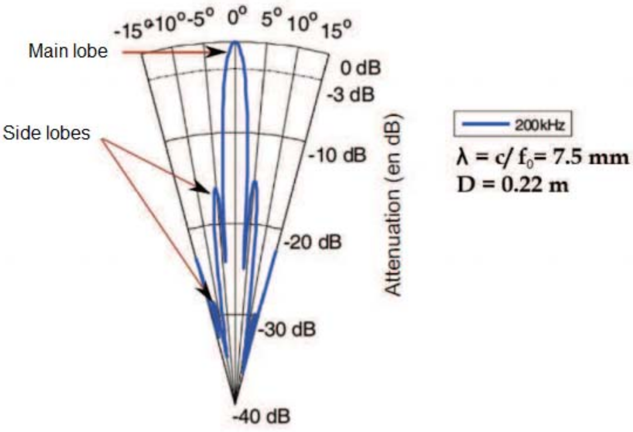

Fig. 1. Example of directivity function of a circular transducer

The study of the directivity of an antenna with several sensors has different applications in real life, including localization via detection such as sonar. The active side-view sonar system often consists of two transmitting receiver antennas attached to either side of a fish towed by a boat using a power carrier cable. This fish usually sails near the bottom. The beam emitted by the lateral sonar is characterized by a narrow lateral opening (in bearing). On the other hand, on site, the vertical opening is high (50 to 80 degrees for each side). The objective of this design is to allow good resolution in bearing and to have a large swath (Figure 2).

Many low-range, high-resolution sonars are dual-frequency and can switch to frequencies around 100 kHz to 500 kHz near targets or areas of interest to improve bearing resolution. The repetition frequency of the pings increases accordingly.

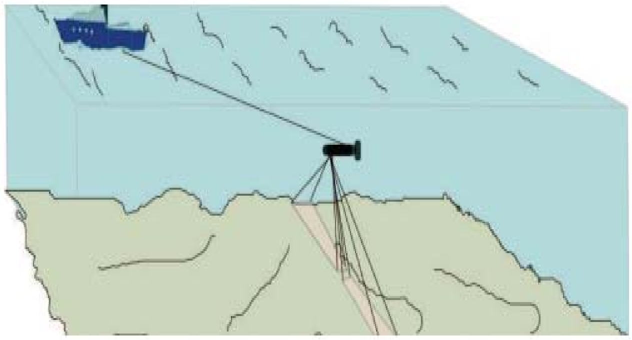

Fig. 2. Example of towed side sonar

Simulation results

In our simulation, we consider an acoustic antenna formed from N sensors. The sound pressure observed by a sensor is defined by the following equation:

(2) $$p(t) = \mathrm{e}^{\left(2j\pi f_0\left(t+\left(\frac{l\sin\alpha}{c}\right)\right)\right)}$$

For the N sensors, the output of the acoustic antenna is described by the following expression:

(3) $$x(t) = \sum_{i=1}^{N} p_i(t)$$

We first plot the variation of the modulus of x(t) as a function of the angle alpha.

Four simulation scenarios will be proposed for the study of the directivity of an acoustic antenna. The first corresponds to the nominal case, the second concerns the case of the variation of the distance between two sensors, the third case concerns the increase of the sensors and reduction of the distance between two sensors and the last case use of the Hamming window.

Case 1: Nominal case

We consider in this case 6 sensors the distance between two sensors *l = 1.2m*, the frequency f_0 = *3000 Hz* and the sampling frequency *fe = 1 Hz*. We first plot the variation of the modulus of *x (t)* in alpha function.

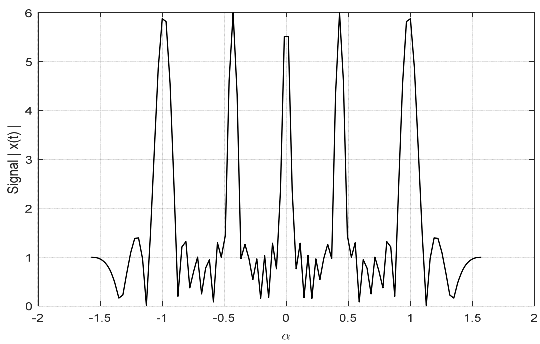

Fig. 3. Antenna array beam patterns

We plot the directivity diagram *D* as a function of alpha in polar coordinates with an acoustic antenna of 6 sensors equidistant of 1.2 m. The advantage of polar coordinates is that it is easier to visualize the angle at which the main lobes are.

Figures 3 and 4 show the presence of the main lobes and secondary lobes.

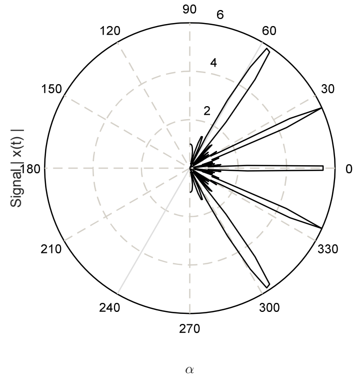

Fig. 4. The results simulations in a polar radiation pattern

Case 2: Variation of the distance between two sensors

The goal of this scenario is to find a solution to attenuate the amplitudes of the sidelobes and have only one main lobe. The idea in this scenario is to vary the distances between two sensors.

The simulation parameters of this scenario is the distance between two sensors *l = 4m* and *N = 6*.

In this scenario, increase the distance between two sensors. From Figures 5 and 6, there is an increase in the number of main lobes. As for the width of the main lobe, it is more precise than that of Fig. 2 but are narrower.

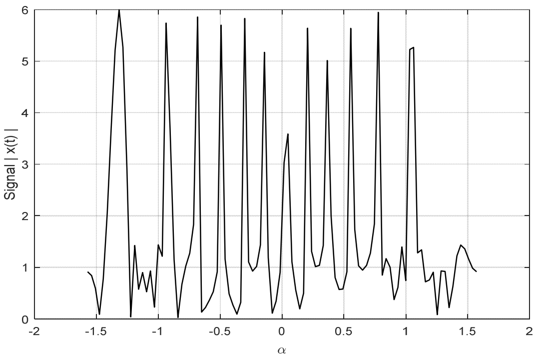

Fig. 5. Antenna array beam patterns

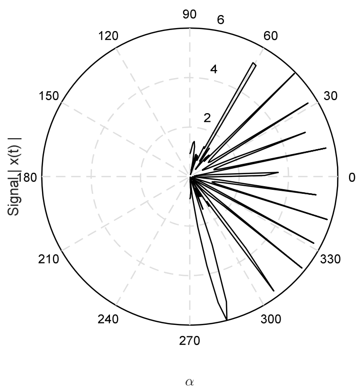

Fig. 6. The results simulations in a polar radiation pattern

Increasing the distance could not remove the side lobes.

Case 3: Increase in sensors and decrease in distance between two sensors

In this scenario, we will decrease the distance between two sensors to erase the other lobes and increase the number of sensors to be more precise and therefore reduce the width of the main lobe. The distance between two sensors is here 0.3 m with a number of 10 sensors.

From figures 7 and 8, we notice that the width of the main lobe is smaller and therefore more precise than in the two previous scenarios.

We find that there are too many lobes, so this proposed solution does not result in an optimal, acoustic antenna.

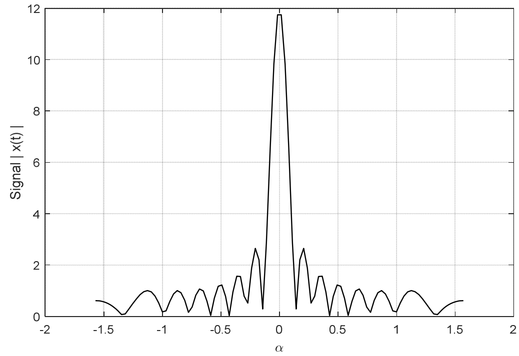

Fig. 7. Antenna array beam patterns

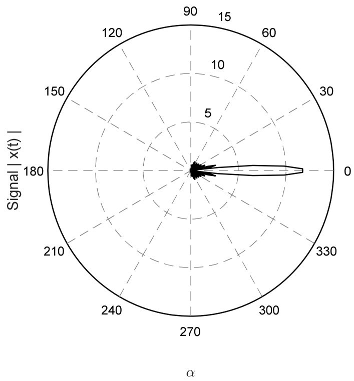

Fig. 8. The results simulations in a polar radiation pattern

The last one: Addition of the Hamming window

In Scenarios 1, 2, and 3, we did not get a single main lobe for the antenna output signal. The solution proposed in this last scenario is to attenuate the effect of the side lobes and to have a single main lobe, the acoustic pressure is multiplied by a so-called Hamming-type apodization window [11].

Figures 9 and 10 show the efficiency of using a Hamming window. We notice from these figures that we have only one main lobe and the secondary lobes are diminished.

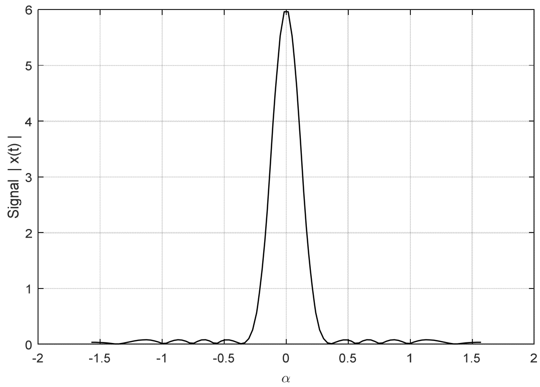

Fig. 9. Antenna array beam patterns

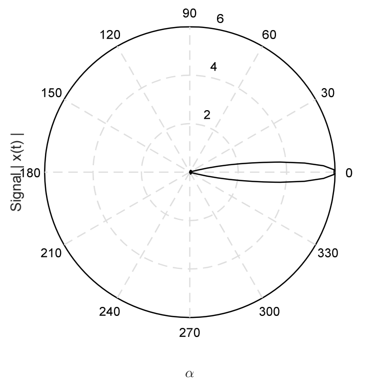

Fig. 10. The results simulations in a polar radiation pattern

Conclusion

In this paper, the goal is achieved to obtain a single main lobe. To do this, the distance between two sensors has been reduced to erase the other secondary lobes and the number of sensors has been increased to be more precise and therefore to reduce the width of the main lobe. You get the expected result, that is, a single main lobe and diminished side lobes. The precision is optimal and we can simulate our graph in polar coordinates with a radar

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