

System and method for locating intercepted sonar transmissions

Field of the invention

The invention relates generally to passive sonars, and in particular to a system and a method for locating the emissions intercepted by such sonars.

5 Prior art

Passive sonars, in particular those equipping submarines, are provided with a sonar interception (SI) function designed to detect, identify and locate the pulses emitted by active sonars, be they of electroacoustic or natural (biological) origin.

10 The sonar interception function makes it possible to determine the distance of the emitter which represents major information from a tactical standpoint. Indeed, such information for example makes it possible to evaluate the risk of having been detected by the adverse active sonar and to know whether this threat is within weapon firing range (heavy torpedo, sea-to-air missile). Measurement of the distance also makes it possible to determine the kinematics of the source and thus
15 to supply elements which contribute to the classification of the adverse equipment: for example, an element of the underwater fauna might not have the same rate of displacement as a biomimetic active submarine sonar. Finally, faced with an attacking torpedo in active mode, measurement of the distance allows effective deployment of tailored counter-measurements.

20 A plurality of procedures allowing a submariner to ensure this function of instantaneous location during interception exists, such as triangulation, multi-path telemetry, the use of the measurement of level, or else the utilization of wave front curvature (WFC).

Existing sonar emission interception systems based on utilizing wave front
25 curvature (WFC) comprise WFC-type telemeters which use 3 distributed antennas, installed on each side of a submarine. Figure 1 illustrates the basic diagram of WFC based on measurement of delays. Assuming the problem to be plane, knowing that just a single circle passes through three points, two measurements of inter-panel delays can be performed to calculate the bearing and the distance of

the source S with the aid of simple analytical formulae arising from the elementary geometry.

More precisely, the WFC-type location procedure is based on the measurement of delays between three hydrophones (or small panels) assumed to be perfectly aligned: a fore sensor (sensor 1), a central sensor (sensor 2) and an aft sensor (sensor 3). On the basis of the signals originating from each of these three sensors, three instants of arrival (t_1 , t_2 , t_3) are estimated. These instants are thereafter used to estimate two inter-panel delay times Δt_{12} and Δt_{23} according to the following formulae:

- $\Delta t_{12} = t_1 - t_2$ for panels 1 and 2;
- $\Delta t_{23} = t_2 - t_3$ for 2 and 3.

The inter-panel delay times correspond to the disparities of distances traveled by the sound rays:

$\Delta d_{ij} = \Delta t_{ij} \cdot c$ with c , the speed of sound in water, which is assumed known.

The two measurements of inter-panel delay time Δt_{12} and Δt_{23} make it possible to calculate the bearing and the distance of the source with the aid of analytical formulae as described for example in Qihu Li, "Digital Sonar design in underwater acoustics", Springer Verlag 2012.

For the WFC-SI method, the precision of location is often penalized by the poor quality of the measurements of instants t_i even though these measurements must be very precise (of the order of a μs).

Such a method comprises two steps for measuring the inter-panel delay. The first step consists, on the basis of the temporal signal provided by the 3 sensors, in coarsely estimating the 3 instants of arrival of the rising edge of the pulse intercepted by virtue of a thresholding. However, this edge is often insufficiently steep to allow accurate and reproducible measurements as illustrated in Figure 2. A moderate signal rise such as this may be due:

- To the propagation channel if its impulse response is temporally spread;
- To the transfer function of the hydroponic channel;

- To the amplitude modulation used by the adverse active sonar to improve certain aspects of its performance or to the limitations of the emission electronics and of the transducers (bandwidth); or
- to the disturbance caused by other simultaneously present parasitic impulsive signals (jammers, biological noise, impacts, etc.).

This results in a lack of robustness of the measurements performed.

The second step corresponds to the measurement of fine delay which is performed by inter-correlation over all or part of the duration of the pulse, as illustrated in US N° 3978445. Such a measurement requires that the adverse emission has a significant frequency band, this not always being the case (pure frequency pulse). The results obtained on real signals are then insufficient. Moreover, the presence of multipaths, in particular of surface reflections, disturbs the correlation peak and, thereby, that of the measurement of the inter-panel delays.

Moreover, such a method requires the installation of several distributed antennas. Now, the distributed-antenna panels (30) must generally be installed on the submarine (3) as a supplement to a Sideways-looking antenna (31), as illustrated in Figure 3. Moreover, the mounting of such antennas must be done in a very precise manner, thus incurring a significant cost overhead.

General definition of the invention

The invention improves the situation. For this purpose, it proposes a system for sonar pulse location for a submarine comprising:

- two antennas of linear general shape and substantially parallel with each other, arranged on the submarine, the two antennas comprising a detection antenna and a focusing antenna, the detection antenna being of small size with respect to the length of the second antenna, each antenna comprising a set of sensors,
- at least one interception module for determining the direction of a sonar emission emitted by an emitter and intercepted by the detection antenna, and

- a focusing module for determining the distance of the emitter by focusing the paths on the basis of the signals provided by the sensors of the focusing antenna, in the direction of the emission determined by the detection module.

5 According to a characteristic of the invention, the detection antenna may be spatially well sampled.

In particular, the inter-sensor distance of the detection antenna may be strictly less than $\lambda/2$, where λ designates the wavelength of the intercepted signal.

According to another characteristic of the invention, the focusing antenna may be spatially undersampled.

10 In particular, the inter-sensor distance of the focusing antenna may be strictly greater than λ , where λ designates the wavelength of the intercepted signal.

Moreover, the length of the first antenna may be strictly less than 20λ and the length of the second antenna may be strictly greater than 200λ , where λ designates the wavelength of the intercepted signal.

15 According to another characteristic of the invention, the detection antenna may comprise a single segment, associated with a single interception module.

The detection antenna may then be located substantially at the center of the focusing antenna.

20 As a variant, the detection antenna may comprise two segments located at a given distance from each other, while the interception module comprises two auxiliary interception modules each providing an angle measurement corresponding to the associated antenna segment, and an average-calculation module configured to determine the average of the 2 angle measurements provided by the auxiliary interception modules.

25 Each segment of the detection antenna may be located substantially at one end of the focusing antenna.

Each interception module associated with a segment of the antenna may comprise a detector configured to detect the pulses in the surveillance field of the segment

of the associated antenna and a function for measuring the characteristics of the detected pulse.

According to another characteristic of the invention, the measurement function of each interception module is configured to measure the direction and the
5 parameters of the pulse on the basis of the detected pulses.

In one embodiment of the invention, the detection antenna and the focusing antenna may be integrated into the acoustic modules of the same acoustic assembly.

Such an acoustic assembly may comprise a plurality of acoustic modules placed
10 side by side along the same axis, each sensor of the focusing antenna being arranged in a distinct acoustic module of the acoustic assembly.

The sensors of the same segment of the detection antenna may in particular be arranged in the same acoustic module of the acoustic assembly.

According to another characteristic of the invention, the formation of focused paths
15 is carried out over the signal time slice determined by the pulse start and end which are estimated by the detection function.

The formation of focused paths may comprise the determination of the distance of the emitter on the basis of the maxima of the energy integrated in the band and over the duration of the Sonar Interception, for all the concerned points in the
20 distance/angle space.

The formation of focused paths may furthermore comprise beforehand:

- the application of a coarse delay to each signal provided by a sensor of the focusing antenna, the delay being determined on the basis of the sensor number, of the real inter-sensor distance, and of the bearing of the emitter
25 with respect to the axis of the antenna, and
- the application of a fine delay to each signal provided by a sensor of the focusing antenna corresponding to the curvature of the wave front, the fine delay applied to each signal being determined on the basis of the sensor

number, of the real inter-sensor distance, of the bearing of the emitter with respect to the axis of the antenna and of the focusing distance.

5 In one embodiment of the invention, the detection antenna and the focusing antenna may be substantially aligned along the same axis.

The invention furthermore proposes a method for sonar pulse location for a submarine comprising the steps consisting in:

- 10 - providing two antennas of linear general shape arranged and substantially parallel with each other, on the submarine, the two antennas comprising a detection antenna and a focusing antenna, the detection antenna being of small size with respect to the length of the second antenna, each antenna comprising a set of sensors,
- determining the direction of a sonar emission emitted by an emitter and intercepted by the detection antenna, and
- 15 - determining the distance of the emitter by focusing the paths on the basis of the signals provided by the sensors of the focusing antenna, in the direction of the emission determined by the detection module.

The invention thus provides a robust solution for distance location of Sonar Interceptions. The combined use of the two collinear antennas makes it possible to
20 determine the distance of the emitter by focusing in the direction of the intercepted emission, without it being necessary to use several distributed antennas as in the prior art.

The two antennas require a limited number of sensors and therefore give rise to reduced bulkiness, this makes it possible to easily integrate the proposed system
25 with the acoustic modules of a sideways-looking antenna or of a towed linear antenna (also called a "streamer").

The invention thus provides a passive means for determining the distance of the emitter so as for example to evaluate the risk of having been detected by an adverse active sonar or to determine the kinematics of the source.

30 **Description of the figures**

Other characteristics and advantages of the invention will become apparent with the aid of the description which follows and of the figures of the appended drawings in which:

- Figure 1 illustrates the basic diagram of WFC by delay measurement;
- 5 - Figure 2 illustrates the effect of the steepness of the rising edges on the uncertainty of the measurement;
- Figure 3 shows the mounting of the antennas distributed over a submarine;
- Figure 4 is a diagram representing the sonar interception system according to an embodiment;
- 10 - Figure 5 is a diagram representing the sonar interception system according to another embodiment;
- Figure 6 is a directivity chart in terms of bearing and inverse of the distance of an antenna with 3 sensors;
- Figure 7 represents a sideways-looking antenna integrating a focusing antenna
15 and a detection antenna according to an embodiment;
- Figure 8 is a diagram representing focused pathway formation; and
- Figure 9 is a flowchart representing the method of sonar interception pulse location according to an embodiment.

The drawings and the annexes to the description will be able not only to serve to
20 better elucidate the description, but also to contribute to the definition of the invention, if appropriate.

Detailed description

Figure 4 represents a sonar interception location system 100 consisting of two
25 antennas 101-102, substantially parallel with each other, arranged on a

submarine, and of linear general shapes. The two antennas 101 and 102 each comprise a set of sensors (such as 1020 for the antenna 102).

According to one aspect of the invention, the first antenna 101 (also called hereinafter the "detection antenna" or "DET antenna") is configured to intercept
5 sonar emissions (SI) emitted by a source 10 (also called the "emitter"), and is used to determine the direction of these intercepted emissions. According to another aspect of the invention, the second antenna 102 (also called hereinafter the "focusing antenna" or "FOC antenna") is used to determine the distance of the emitter 10 by focusing the paths on the basis of the signals provided by its sensors
10 (1020), in the direction of the intercepted emission.

The detection antenna (101) is advantageously of small size with respect to the length of the second antenna (102).

In particular, the length of the first antenna 101 may be less than 20λ , and may lie in particular between 5λ and 20λ , where λ designates the wavelength of the
15 intercepted signal.

Moreover, the length of the second antenna 102 may be chosen strictly greater than 200λ .

According to a characteristic of the invention, the detection antenna 101 is spatially well sampled. In particular, the inter-sensor distance of the first antenna
20 101 may be strictly less than $\lambda/2$ to obtain good spatial sampling.

According to another characteristic of the invention, the focusing antenna 102 may be spatially undersampled. In particular, the inter-sensor distance of the focusing antenna 102 may be strictly greater than λ to obtain spatial undersampling.

The invention thus uses the formation of focused paths (that is to say taking into
25 account the circular shape of the wave front) carried out by the focusing antenna 102 to locate the intercepted sonar emissions, without it being necessary to use measurements of delay between three antennas mounted on the submarine as in the earlier solutions.

According to one aspect of the invention, the focusing antenna 102 is a linear-shaped antenna comprising a set of sensors 1020 of hydrophone type. Advantageously, the linear-shaped antenna 102 may comprise a limited number of sensors, such as for example a few tens of hydrophones, thereby rendering it spatially undersampled. To prevent such sparseness from causing the appearance of ambiguities in bearing and in distance, the detection antenna 101 is used jointly with the focusing antenna 102.

More precisely, the Sonar Interception location system 100 implements, prior to the focusing step, a step of detecting the sonar pulse with the aid of the spatially well sampled small antenna segment 101 which makes it possible to determine without ambiguity the direction of the intercepted pulse. The focused paths making it possible to determine the distance of the emitter are then formed only in the direction provided by the detection, thereby enabling disturbing ambiguities to be avoided.

The formation of focused paths to locate the source of the emission therefore renders the measurement robust without it being necessary to equip the focusing antenna 102 with a large number of sensors. This therefore makes it possible to cover high frequencies which must be taken into account in the interception functions (for example greater than 20 kHz).

The sonar interception location system 100 thus makes it possible to ensure the robustness of location in terms of distance of the Sonar Interceptions. Moreover, the two antennas 101 and 102 may be easily integrated into the acoustic modules of a sideways-looking antenna or of a linearly towed antenna.

The two antennas, one short for detection 101, the other long for location by focusing 102, may be obtained by using sensors belonging to the hydrophonic coverage of the sideways-looking antennas or a linearly towed antenna. The invention therefore makes it possible to afford a location function to these two types of antenna, without it being necessary to install distributed antennas.

As represented in Figure 4, the sonar interception location system 100 comprises a first interception module 51 to detect the pulses, comprising a detector 510 and

a measurement function in respect of the characteristics of the detected pulse 511. The first module 51 is configured to process the information originating from the antenna 101. In particular, the detector 510 is suitable for detecting the pulses in the surveillance field of the antenna 101, while the measurement function 511 is
5 configured to measure the direction and the parameters of the pulse on the basis of the detected pulses.

The sonar interception location system 100 furthermore comprises a second module for forming focused paths 52 (also called the "focusing module") to carry out a formation of paths focused in the direction provided by the module 51 by
10 utilizing the focusing antenna 102. The pathway focusing is carried out subsequent to the detection implemented by the module 51. The signals provided by the antenna 102 are placed in buffer memory 11 ("bufferized") so as to be used by the focusing module 52. The measurement of the distance of the source is then obtained by searching for the maximum of energy in the band of the SI over all the
15 distance bins (521, 522, 523).

The system for locating intercepted sonar emissions 100 according to the embodiments of the invention exhibit, in particular, sufficient memory capacities to bufferize the hydrophonic signals of the antenna 102 during the detection phase implemented by the module 51.

20 The module 51 can deliver the following parameters which will be able to be used by the module 52:

- a detection bearing;
- an instant of start and of end of the SI; and
- the frequency band of the intercepted pulse and its central frequency.

25 The person skilled in the art will easily understand that the antenna 101 also comprises elements (not represented) for detections and for elementary measurements which are standard to any SI function.

In the embodiment of Figure 4, the two antennas 101 and 102 are substantially linear and mutually parallel. They may in particular be arranged so that the
30 detection antenna 101 is substantially in proximity to the focusing antenna 102 so

as to avoid parallax effects. In particular, as shown in Figure 4, the two antennas 101 and 102 may be substantially aligned along the same axis.

In the embodiment of Figure 4, the detection antenna 101 comprises a single segment which may be placed substantially level with the center of the focusing antenna 102.

As a variant, as represented in Figure 5, the detection antenna 101 may comprise two segments 1011 and 1012 at each end of the focusing antenna 102. The module 51 then comprises two auxiliary interception modules 5101 and 5102, each being associated with one of the segments 1011 and 1012, thereby providing two angle measurements. Each auxiliary interception module 5101 and 5102 comprises a detector 510 and a calculation function 511 as are described hereinabove. In this embodiment, the module 51 also comprises an average-calculation module 53 configured to determine the average of the 2 angles provided by the auxiliary interception modules 5101 and 5102. This average is thereafter dispatched to the module for forming focused paths 52 as described previously. Such geometries make it possible to easily integrate the location method into sideways-looking antennas or towed linear antennas.

According to a particular characteristic of the invention, the width of the angular sector processed by the antenna 101 is chosen such that there are no peaks of ambiguities in terms of angles and distance which appear in this angular sector.

Indeed, the position, in terms of distance, of the ambiguities for a linear antenna with equidistributed sensors and for a bearing in the direction of the source may be determined on the basis of equation 1 hereinbelow:

$$\frac{1}{R_k} = \frac{1}{R_0} + \frac{k}{f} \times \frac{2c}{d^2 \sin^2 \theta_0} \quad (\text{Equation 1})$$

In equation 1,

- R_0 and θ_0 designate the polar coordinates of the source with respect to the center of the antenna 101;
- R_k designates the distance of the k^{th} ambiguity in the direction of the source;
- c designates the speed, and

- d designates the inter-sensor distance (also called the "antenna pitch") of the antenna 101.

By introducing the parameter d_f which represents the Fresnel distance corresponding to d , equation 1 can be expressed as follows:

$$5 \quad \frac{1}{R_k} = \frac{1}{R_0} + \frac{2k}{d_f} \quad (\text{Equation 2})$$

The Fresnel distance d_f is given by equation 3 hereinafter:

$$d_f = (d \sin \theta)^2 / \lambda \quad (\text{Equation 3})$$

10 In equation (3), d designates the inter-sensor pitch, θ designates the bearing, that is to say the incident direction taken with respect to the bow of the submarine, the angles being reckoned positively clockwise, and designates the wavelength i.e. c/f where f designates the frequency of the intercepted signal.

Thus, the distance ambiguities depend on the antenna pitch and not on the length L of the antenna. The effect of the spatial ambiguities related to the undersampling
15 of the focusing antenna 102 is to multiply the number of distance ambiguities. For example, in the directivity chart of Figure 6 obtained for the case of 3 sensors (or panels), for a bearing of 90° , local maxima in the direction of the source are observed. Moreover, in other directions, quincuncial image lobes (ambiguities) may be observed.

20 The representations of the distances in Figure 6 are in terms of $1/R$, which ratio corresponds to the "natural" (i.e. physical) magnitude of the problem (R is in meters).

Two families of ambiguities exist, one corresponding to the spatial ambiguities given by $\sin(\theta_1) = \sin(\theta_2) + k\lambda/d$, and the other corresponding to the ambiguities in
25 distance between these directions and quincuncial (in terms of $1/R$) for the case of an odd number of sensors.

For a source in the direction θ_1 , the closest ambiguity in terms of angle lies in the direction: $\sin(\theta_1) = \sin(\theta_2) + \lambda/d$. Consequently, the angular ambiguities can be lifted

by determining the direction provided by the detection antenna 101. In particular, the detection antenna 101 can be chosen so as to have a sufficiently fine lobe to obtain better precision than $\Delta\theta_{12} = |\theta_1 - \theta_2|$ (with the 3db width of the lobe such that $2\theta_3 < \Delta\theta_{12}$). In particular, the detection antenna 101 can be chosen so as to have a sufficiently fine lobe. For example, a detection antenna 101 substantially equal to about 40 cm may be sufficient to obtain the desired performance above 10kHz (or 15 kHz).

In general, for it to be possible for an antenna of large length (greater than 50 meters), such as the focusing antenna 102, to be spatially well sampled, it is necessary to use a high number of sensors of several thousand per side, this being difficult to achieve in practice. The very low value of the aperture of the main lobe, given by formula $2\theta_3 = 50^\circ \lambda / (kd)$, should also be noted. Accordingly, a focusing processing with such an antenna may not be performed in a panoramic manner since too significant a number of paths would have to be formed (several tens of thousands).

However, the choice of the number of sensors is related to the presence of ambiguities in the bearing-distance plane when the sensors are equidistributed with a spacing of markedly greater than $\lambda/2$. By lifting the ambiguities, the interception system 100 according to the invention then makes it possible to use a relatively low number of sensors for the antenna 102 of large size (for example a few tens of sensors only), with a spacing $> \lambda$.

According to one aspect of the invention, the detection antenna 101 may take the form of a linear antenna furnished with equidistributed and correctly spatially sampled sensors. For example, if the antenna 101 has a length of 40cm, the antenna will be able to be equipped with 24 hydrophones at a pitch of 17 mm to cover the frequencies up to 45 kHz.

The detection antenna 101 and the focusing antenna 102 can be installed in acoustic modules of an item of equipment of the sonar (also called the acoustic assembly), such as a sideways-looking antenna for example.

Figure 7 represents a sideways-looking antenna 80 in which the detection antenna 101 and the focusing antenna 102 are installed.

The sideways-looking antenna 80 may have a rectangular general shape and comprise a set of aligned acoustic modules 800 placed side by side.

5 As represented, the focusing antenna 102 comprises a set of specific interception sensors 1020 (which covers the interception frequency ranges), each installed in the respective acoustic module 800 of the sideways-looking antenna 80 as represented in Figure 7. Moreover, in the embodiment where the detection antenna 101 is formed of a single segment consisting of small closely-spaced
10 sensors 1010, the antenna 101 may also be installed in one of the acoustic modules of the sideways-looking antenna, for example the central acoustic module 800C. One of the sensors 1010 of the antenna 101 may be used jointly by the antenna 102. As a variant, in the embodiment, where the antenna 101 consists of 2 distinct segments, each segment 1011 or 1012 may consist of small closely-
15 spaced sensors and be installed in a respective acoustic module at each end of the sideways-looking antenna (for example the acoustic modules 800G and 800D).

In a variant embodiment of the invention, it is possible to place the antennas 101 and 102 in a similar manner in a towed linear antenna.

20 The person skilled in the art will understand that the antenna 101 may be installed in a distinct acoustic assembly from that in which the antenna 102 is installed. For example the antenna 101 could be mounted on the hull of the submarine or its sail while the antenna 102 is installed in a sideways-looking antenna.

Figure 8 is a diagram illustrating the pathway focusing, according to an exemplary
25 embodiment of the invention.

In the focusing step, the signals originating from a line of hydrophones (1020) which may be placed in the middle, at the top or at the bottom of each module may be utilized. Accordingly, a signal time slice is determined by the pulse start and end information estimated by the module 51. Over this signal time slice, the

focusing of the paths in a fine angular sector around the direction of the SI detected is then performed.

For a linear antenna, the focusing can be carried out in two steps so as to recreate a virtual antenna "tailored" to the direction of pointing (direction of the intercepted sonar emission), that is to say an antenna whose axis X' formed by the sensors is perpendicular to the direction of pointing Y', as represented in Figure 8. The real antenna 102 comprising the hydrophones 1020 corresponds to the axes X and Y, equidistributed according to a pitch p. The elements 3020 of the virtual antenna are spaced apart by a pitch p'.

Figure 9 is a flowchart illustrating the focusing method according to an embodiment of the invention.

In step 120, the signal time slice over which the focusing of the paths is performed is determined by the pulse start and end information estimated by the module 51.

In step 121, so-called "coarse" delays T_k are firstly applied to the K+1 temporal signals (previously placed in buffer memory) provided by the hydrophones 1020 according to the following equation:

$$T_k = k.p.\cos \theta / c \quad (\text{Equation 4})$$

In equation 4, the parameter k designates the sensor number going from - K/2 to + K/2 (antenna of K+1 hydrophones with K even) and the parameter p designates the real inter-sensor distance of the focusing antenna 102.

The "fine" delay δ_k corresponding to the curvature alone is then applied to each signal provided by a hydrophone according to the following formula:

$$\delta_k \approx -P_k'^2 / (2Rc) \quad (\text{equation 5})$$

The fine delay δ_k is then added to the coarse delay T_k .

In equation 5, the parameters $P_k' = kp.\sin(\theta)$ and R represent the focusing distance, and c represents the speed of sound.

For these two operations, the sampled temporal signals may be interpolated to best correspond to the real delays.

The $K+1$ signals thus delayed are then summed in step 122, and thereafter filtered in step 124 in the frequency band of the interception of the SI.

- 5 The signal obtained is squared and the result is summed during the duration of the sonar pulse S_t , in step 125. A set of points in the distance/angle space is thus calculated. The absolute maximum of this angular zone which corresponds to the estimation of the position of the source (absolute maximum of the calculated points) may then be refined by interpolation, in step 126, thereby making it
10 possible to obtain the useful measurement, i.e. the distance of the emitter.

The invention thus makes it possible to use the formation of focused paths in the FOC-SI processing, in the useful frequency ranges in interception (that is to say beyond 10 to 15 kHz) without it being necessary to use an antenna equipped with several thousand specific sensors and processings requiring significant calculation
15 power. The SI system 100 can thus use a very sparse antenna comprising a few tens of hydrophones only, thereby making it easy to achieve a telemeter using the method according to the embodiments of the invention.

Since the focusing imposes delays, robustness to steepness of the rising edge and to the pulses with pure frequency (PF) is ensured. Moreover, except in a
20 narrow angular sector abeam, separation of the multipaths (bottom reflections and/or surface reflection) is obtained "naturally" through the effect of the pseudo-bearings as for any linear antenna. The system proposed by the invention makes it possible furthermore to reject jammers, if they do not appear at the same instant at the same frequency, in an appropriate distance-bearing bin with respect to the SI
25 of interest, doing so for the major part of the duration of the pulse.

Moreover, for certain cases of deflection profile and of disturbance of the acoustics of the FOC antenna, the distance measurement bias is less significant than with the 3 sensors used in conventional WFC-SI systems.

The invention is not limited to the embodiments described hereinabove by way of
30 nonlimiting example. It encompasses all the variant embodiments which could be

envisaged by the person skilled in the art. In particular, the invention is not limited to the schematic antenna shapes 101 and 102 illustrated in the drawings, nor to the relative configurations between the detection antenna 101 and the focusing antenna 102 which are represented in the drawings. Generally, the invention is
5 suitable for any type of antenna of linear general shape for the antennas 101 and 102, and to any relative positioning of the antennas 101 and 102 on the submarine such that the antennas 101 and 102 are substantially parallel to one another. Nor is it limited to particular acoustic assemblies to house the antennas 101 and 102.

Claims

1. A system for sonar pulse location for a submarine, wherein the system comprises:

- 5 - two antennas of linear general shape and substantially parallel with each other, arranged on the submarine, the two antennas comprising a detection antenna and a focusing antenna, the detection antenna being of small size with respect to the length of the second antenna, each antenna comprising a set of sensors,
- 10 - at least one interception module for determining the direction of a sonar emission emitted by an emitter and intercepted by the detection antenna, and
- a focusing module for determining the distance of the emitter by focusing the paths on the basis of the signals provided by the sensors of the focusing antenna, in the direction of the emission determined by the interception module.

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2. The system for sonar pulse location as claimed in claim 1, wherein the detection antenna is spatially well sampled.

3. The system for sonar pulse location as claimed in claim 2, wherein the
20 inter-sensor distance of the detection antenna is strictly less than $\lambda/2$, where λ designates the wavelength of the intercepted signal.

4. The system for sonar pulse location as claimed in any one of the preceding claims, wherein the focusing antenna is spatially undersampled.

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5. The system for sonar pulse location as claimed in claim 4, wherein the inter-sensor distance of the focusing antenna is strictly greater than λ , where λ designates the wavelength of the intercepted signal.

6. The system for sonar pulse location as claimed in any one of the preceding claims, wherein the length of the first antenna is strictly less than 20λ , where λ designates the wavelength of the intercepted signal.

5 7. The system for sonar pulse location as claimed in claim 6, wherein the length of the second antenna is strictly greater than 200λ , where λ designates the wavelength of the intercepted signal.

8. The system for sonar pulse location as claimed in any one of the
10 preceding claims, wherein the detection antenna comprises a single segment, associated with a single interception module.

9. The system for sonar pulse location as claimed in claim 8, wherein the
15 detection antenna is located substantially at the center of the focusing antenna.

10. The system for sonar pulse location as claimed in any one of claims 1 to
7, wherein the detection antenna comprises two segments located at a given
distance from each other, and in that the interception module comprises two
auxiliary interception modules each providing an angle measurement
20 corresponding to the associated antenna segment, and an average-calculation
module configured to determine the average of the 2 angle measurements
provided by the auxiliary interception modules.

11. The system for sonar pulse location as claimed in claim 10, wherein each
25 segment of the detection antenna is located substantially at one end of the
focusing antenna.

12. The system for sonar pulse location as claimed in any one of the
preceding claims 8 to 11, wherein each interception module associated with a

segment of the antenna comprises a detector configured to detect the pulses in the surveillance field of the segment of the associated antenna and a function for measuring the characteristics of the detected pulse.

5 13. The system for sonar pulse location as claimed in claim 12, wherein the measurement function of each interception module is configured to measure the direction and the parameters of the pulse on the basis of the detected pulses.

10 14. The system for sonar pulse location as claimed in any one of the preceding claims, wherein the detection antenna and the focusing antenna are integrated into the acoustic modules of the same acoustic assembly.

15 15. The system for sonar pulse location as claimed in claim 14, wherein the acoustic assembly comprises a plurality of acoustic modules placed side by side along the same axis, and in that each sensor of the focusing antenna is arranged in a distinct acoustic module of the acoustic assembly.

20 16. The system for sonar pulse location as claimed in claim 15, wherein the sensors of the same segment of the detection antenna are arranged in the same acoustic module of the acoustic assembly.

25 17. The system for sonar pulse location as claimed in any one of the preceding claims, wherein the formation of focused paths is carried out over the signal time slice determined by the pulse start and end which are estimated by the detection function.

18. The system for sonar pulse location as claimed in claim 17, wherein the formation of focused paths comprises the determination of the distance of the emitter on the basis of the maxima of the energy integrated in the band and

over the duration of the Sonar Interception, for all the concerned points in the distance/angle space.

19. The system for sonar pulse location as claimed in any one of claims 17
5 and 18, wherein the formation of focused paths comprises beforehand:

- the application of a coarse delay to each signal provided by a sensor of the focusing antenna, the delay being determined on the basis of the sensor number, the real inter-sensor distance, and the angular distance of the emitter with respect to the axis formed by the sensors, and

10 - the application of a fine delay to each signal provided by a sensor of the focusing antenna corresponding to the curvature of the wave front, the fine delay applied to each signal being determined on the basis of the sensor number, of the real inter-sensor distance, the angular distance of the emitter with respect to the axis formed by the sensors and of the focusing distance.

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20. The system for sonar pulse location as claimed in any one of the preceding claims, wherein the detection antenna and the focusing antenna are substantially aligned along the same axis.

20 21. A method for sonar pulse location for a submarine comprising the steps consisting of:

- providing two antennas of linear general shape and substantially parallel with each other, arranged on the submarine, the two antennas comprising a detection antenna and a focusing antenna, the detection antenna being of small
25 size with respect to the length of the second antenna, each antenna comprising a set of sensors,

- determining the direction of a sonar emission emitted by an emitter and intercepted by the detection antenna, and

- determining the distance of the emitter by focusing the paths from the signals provided by the sensors of the focusing antenna, in the determined direction of the sonar emission.