

PATH-FORMING ADAPTIVE PROCESSING FOR ACTIVE SONAR

The present invention relates to the general field of active array antennas. It relates to the adaptive antenna processing methods for active sonars, primarily in Doppler mode, that make it possible in particular to reduce the nuisance caused by the reverberation of the seabed.

Generally, the adaptive antenna processing offers many advantages. The implementation of such processing in a detection system equipped with an array antenna notably enables the system to fight effectively against interference, to have an enhanced angular resolution, or even to benefit from a reduction of the received noise level, this noise being able, for example, to correspond to the sound reverberation originating from the seabed.

As is known, such processing can be applied to the signal received by a multi-sensor antenna, either directly on the signal obtained at the sensor output or to the signal obtained after the formation of reception channels, a reception channel being formed by grouping together a number of the sensors forming the antenna bearing in mind that all or some of the sensors that make up the antenna can be used to form channels.

The different outputs used by the processing constitute what are conventionally called the "references" or the "degrees of freedom" of the processing. Obviously, the more degrees of freedom there are, the more efficient the adaptive processing can be with respect to the nuisances to be overcome.

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The implementation of an adaptive channel forming processing relies on a fundamental step consisting in producing the estimation of the covariance matrix of the signals produced by the different references.

Generally, it should be considered that the size of the covariance matrix that can relevantly be estimated is a function both of the bandwidth of the signal used and of the duration of the time interval during which the spatial correlation of the noise field measured by the antenna does not significantly vary. In other words, with the size of the matrix corresponding to the number of references used, it is found that the number of references that can usefully be taken into account is a direct function of the bandwidth of the signal and of the stationary state duration of the noise picked up by the antenna.

Thus, in the case of submarine detection, the stationary state of the noise field measured by a sonar antenna is generally several seconds. Moreover, the bandwidths of the signals processed make it possible to perform observations with a rate of acquisition of independent observations of the order of kilohertz. Consequently, it is possible, in such a context, to consider covariance matrices comprising around 100 to 1000 elements. However, in some applications, in particular in active sonar in Doppler mode (CW mode for example), where the processing is performed at the matched filter output, the available band widths are from around one Hz to a few tens of Hz, so that it is only possible to estimate matrices that have dimensions of a few units. It follows therefrom that the number of references, of degrees of freedom, must be reduced and chosen according to the desired noise reduction objectives.

With regard to the active sonar systems, the adaptive processing on sensors theoretically makes it possible to have the maximum number of degrees of freedom. However, the implementation of such processing is not generally possible because it leads, by virtue of the large number of references considered, to prohibitive covariance matrix estimation times, which are

incompatible with the observation times imposed by the operation of the sonar, particularly in Doppler mode. This is why different known techniques are implemented to reduce the number of degrees of freedom.

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The technique most commonly employed to reduce the number of degrees of freedom consists in forming reception channels on all the sensors of the antenna, these channels pointing in the direction of the noise
10 sources to be eliminated, and in performing the adaptive processing at the output of these channels. However, this technique, known as "full array beam space adaptive beam forming" has the drawback of requiring a prior selection of the reference channels
15 pointing in the directions of the noise sources to be eliminated, and of managing this selection on the basis of the operational scenario.

Another known technique, called "subarray adaptive
20 beamforming", consists in grouping the sensors so as to divide the antenna into adjacent sub-antennas, and in forming conventional reception channels for each sub-antenna then in recombining these channels adaptively. This technique, although suitable for eliminating
25 occasional interference sources, does not however deal with the case of interference caused by spatially widespread noise sources, such as the noise formed by reverberation on the seabed or the noise of the carrier ship itself in shallow waters, these noises having a
30 correlation distance that is short in relation to the distance between the phase centers of the sub-antennas.

A variant of the subarray adaptive beamforming processing technique, using identical parallel sub-
35 antennas, is notably described in the French patent No. 0111106 delivered to the applicant on 05/12/2003. This variant does not however make it possible to have a sufficient number of degrees of freedom to effectively

eliminate the spatially very widespread interference sources.

5 One aim of the invention is to propose a solution that makes it possible to perform an adaptive antenna processing that makes it possible to effectively overcome the disturbances caused by spatially widespread noise sources such as, in particular, the noise reverberated by the seabed.

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To this end, the subject of the invention is a method for forming adaptive reception channels for a detection system comprising a multi-sensor antenna, the forming of adaptive channels making it possible to eliminate a
15 spurious signal or a noise, the method comprising:

- a first step of forming N interlocked sub-antennas, each sub-antenna n comprising a number of identical sensors, the phase centers of the sub-antennas exhibiting a given offset relative to one
20 another;

- a second step of forming, for each sub-antenna n , M primary reception channels, from the sensors forming the sub-antenna considered;

- a third step of forming M secondary reception
25 channels, each secondary channel m being formed from the primary channels m corresponding, for the N sub-antennas, to the same direction of observation, this step is performed by implementing an adaptive processing of the signals produced by the primary
30 reception channels.

According to the invention, the sensors forming one and the same sub-antenna are also determined so that the phase centers of any two sub-antennas n and n' are
35 separated from one another by a distance less than the spatial correlation distance of the noise or of the spurious signal that is to be eliminated.

In an implementation suited to a detection system operating in narrowband mode, the third step of the method according to the invention carries out the following operations:

- 5 - a first operation of estimating, for each secondary channel m , the covariance matrix $\tilde{\Gamma}(m)$ of the signals $V_n(m, t)$ (54) formed in the direction m for all the N sub-antennas; the estimated covariance matrix $\tilde{\Gamma}(m)$ then being inverted;
- 10 - a second operation of determining, for each channel m , the phase-shift vector $\vec{d}(m)$ defined by the following relationship:

$$[d(m)]_n = \exp(i2\pi \frac{f_0}{c} \vec{u}_m \cdot \vec{s}_n)$$

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in which f_0 designates the center frequency of the signal and $\vec{u}_m$ a unitary vector in the direction of pointing of the channel m ;

- 20 - a third operation of actually forming the M adaptive secondary reception channels by determining the signal $V_s(m, t)$ corresponding to each of the channels m , the signal $V_s(m, t)$ being defined by the relationship:

$$V_s(m, t) = \frac{\left[\vec{d}(m) \right]^T \cdot \hat{\Gamma}^{-1}(m, t)}{\left[\vec{d}(m) \right]^T \cdot \hat{\Gamma}^{-1}(m, t) \cdot \vec{d}(m)} \cdot \vec{V}(m, t)$$

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In an implementation suited to a detection system operating in wideband mode, the third step performs an initial operation of breaking down the spectral band of the received signal into spectral sub-bands k , so that
 30 the signal corresponding to each sub-band is a narrowband signal; then, for each spectral sub-band k , the following operations:

- a first operation of estimating, for each secondary channel m , the covariance matrix $\tilde{\Gamma}(m, t, k)$ of

the signals $V_n(m, t, k)$ formed in the direction m for all the N sub-antennas; the estimated covariance matrix $\tilde{\Gamma}(m, t, k)$ then being inverted;

- a second operation of determining, for each channel m , the phase-shift vector $\vec{d}(m, k)$ defined by the following relationship:

$$[d(m, k)]_n = \exp(i2\pi \frac{f_k}{c} \vec{u}_m \vec{\delta}_n)$$

- in which f_k designates the center frequency of the sub-band k and $\vec{u}_m$ a unitary vector in the direction of pointing of the channel m ;

- a third operation of actually forming the M adaptive secondary reception channels by determining the signal $V_s(m, t, k)$ corresponding to each of the channels m , the signal $V_s(m, t, k)$ being defined by the relationship:

$$V_s(m, t, k) = \frac{\left[\vec{d}(m, k) \right]^+ \cdot \hat{\Gamma}^{-1}(m, t, k)}{\left[\vec{d}(m, k) \right]^+ \cdot \hat{\Gamma}^{-1}(m, t, k) \cdot \vec{d}(m, k)} \cdot \vec{V}(m, t, k).$$

The signals $V_s(m, t, k)$ obtained for each spectral sub-band are then combined with one another by Fourier transform during a final step, to form the overall signal $V_s(m, t)$ corresponding to the channel m .

According to a preferred implementation of the method according to the invention, the estimation $\tilde{\Gamma}(m)$ of the covariance matrix of the signals $V_n(m, t)$ is produced from the following relationship:

$$\hat{\Gamma}(m, t) = \sum_{t'=-T/2}^{T/2} \vec{V}(m, t+t') \cdot \left[\vec{V}(m, t+t') \right]^+$$

in which $\vec{V}(m, t + \tau)$ represents the vector of the signals corresponding to the M primary channels and $[\vec{V}(m, t + \tau)]^*$ the conjugate transposed vector of this vector.

5 According to a particular implementation, suited to a Doppler operation of the detection system, the method according to the invention comprises an additional step of Doppler analysis of the received signal, this additional step being able to be implemented before or
10 after the second step; the steps following this additional step being implemented in parallel, on each of the duly formed Doppler channels.

According to a particular implementation, the Doppler
15 analysis applied is an analysis by multi-copy correlation which consists in correlating the received signal with copies of the transmitted signal affected by different given delays.

20 According to a particular implementation, suited to the case where the sub-antennas forming the overall antenna exhibit a spatial ambiguity, in a direction m' , in relation to the direction m considered, the third operation performed by the third step of the method
25 according to the invention consists in computing, in addition to the signal $V_s(m, t)$, the signal $V_s(m', t)$ defined by the following relationship:

$$V_s(m', t) = \frac{\left[\vec{d}(m') \right]^* \cdot \hat{r}^{-1}(m, t)}{\left[\vec{d}(m') \right]^* \cdot \hat{r}^{-1}(m, t) \cdot \vec{d}(m')} \cdot \vec{V}(m, t)$$

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in which m' corresponds to the ambiguous direction in relation to the main direction m .

Another subject of the invention is an application of
35 the method according to the invention to a system comprising a linear antenna formed by sensors separated

from one another by a constant distance d , an application in which the first step proceeds with the formation of N interlocked linear sub-antennas. In this application, each sub-antenna is produced by associating the signals received by sensors separated from one another by $N \cdot d$. The sub-antennas are, moreover, offset from one another by a distance d so that the phase centers of the sub-antennas thus produced exhibit an offset d relative to one another.

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Another subject of the invention is an application of the method according to the invention to a system comprising a planar antenna formed by sensors arranged in rows and columns and separated from one another by a constant distance d , an application in which the first step proceeds with the formation of N interlocked planar sub-antennas. In this application, each sub-antenna is produced by associating the signals received by sensors positioned on rows and columns separated from one another by $N \cdot d$. The phase centers of the sub-antennas thus produced also exhibiting an offset d in rows or in columns relative to one another.

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The features and advantages of the invention will be better appreciated from the following description, a description which is based on the appended figures which represent:

- figure 1, a block diagram showing the different steps of the method according to the invention;

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- figure 2, an arrangement of the sensors of a linear antenna corresponding to an exemplary implementation of the first step of the method according to the invention;

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- figures 3 and 4, arrangements of the sensors of a planar antenna corresponding to another exemplary implementation, of the first step of the method according to the invention;

- figure 5, a block diagram detailing the different operations implemented by the third step of

the method according to the invention, in a particular implementation.

Figure 1 gives a presentation of the different steps of the method according to the invention. The latter mainly comprises:

- a first step 11 of forming N sub-antennas;
- a second step 12 of forming, for each sub-antenna, M primary reception channels, from the sensors forming the sub-antenna considered;
- a third step 13 of forming M secondary reception channels, each secondary channel m being formed from the primary channels m corresponding, for N sub-antennas, to the same direction of observation. This step is performed by implementing an adaptive processing detailed below.

The object of the first step of the method according to the invention is to construct a first association of the sensors of the antenna in groups forming N distinct reception sub-antennas, each group comprising, for example, an identical number K of sensors. The sensors are here grouped together so as to form N subsets, in other words, N sub-antennas, having a given overlap. The N identical sub-antennas constitute a spatial subsampling of the array of sensors forming the overall antenna.

According to an essential feature of the invention, the grouping of the sensors is produced so as to form N interleaved sub-antennas, the N phase centers of which are separated from one another so that the maximum distance separating the phase centers of the two sub-antennas is less than the spatial correlation distance of the noise or of the spurious signal that is to be eliminated. On this, it will be recalled that the spatial correlation distance is defined as the maximum distance that can separate two given sensors beyond which the signals received by the sensors are no longer

correlated. In the case of two sub-antennas, this correlation distance defines the maximum distance that can separate the phase centers of these sub-antennas.

5 According to the invention, the arrangement of the sensors of the antenna has formation of the different sub-antennas can be produced in different ways provided that the duly formed sub-antennas have phase centers situated at the desired distance from one another.
10 Figures 2 to 4 present two arrangements as nonlimiting exemplary implementations.

Figure 2 presents an exemplary grouping of the sensors of a linear antenna that makes it possible to satisfy
15 the abovementioned condition of spacing of the phase centers. Figure 2 presents the simple example of an antenna comprising sixteen sensors 25 evenly spaced apart from one another by a distance d which constitutes the pitch of the overall antenna. This
20 pitch is, as is known, defined so as to avoid the appearance of array lobes. In this application, the sensors forming the antenna are grouped so as to form $N = 4$ interleaved linear sub-antennas each comprising four sensors spaced apart from one another by a pitch
25 equal to $N \cdot d = 4d$ and exhibiting a longitudinal offset of length d in relation to one another. Consequently, with such an arrangement of the sensors, four interleaved sub-antennas are defined which have phase centers 21 to 24 spaced apart from one another by a
30 distance d , so that the maximum distance which separates them, here equal to $3d$, is substantially less than the correlation distance of the noise.

Similarly, figure 3 presents an exemplary grouping of
35 the sensors of a planar antenna that makes it possible to satisfy the abovementioned condition of spacing of the phase centers. Figure 3 presents the simple example of an antenna comprising 36 sensors 33 evenly spaced apart from one another by a distance d , arranged at the

intersections of rows and columns evenly spaced apart from one another by a distance d substantially less than the correlation distance of the noise considered. In a manner similar to the example of figure 2, the sensors 33 forming the antenna are here grouped so as to form $N = 2$ interleaved planar sub-antennas having a longitudinal offset (one-dimensional) of length d in relation to one another. Consequently, with such an arrangement of the sensors, two interleaved sub-antennas are defined which have phase centers 31 and 32 spaced apart from one another by a distance d which satisfies the distance condition described previously.

Also similarly, figure 4 presents an exemplary grouping of the sensors 44 of a planar antenna that makes it possible to satisfy the abovementioned condition of spacing of the phase centers. Figure 4 presents the simple example of an antenna comprising thirty-six sensors 44 evenly spaced apart from one another by a distance d , arranged at the intersections of rows and columns evenly spaced apart from one another by a distance d substantially less than the correlation distance of the noise considered. However, unlike the example of figure 3, the sensors 44 forming the antenna are here grouped so as to form $N = 3$ interleaved planar sub-antennas having a longitudinal offset (one-dimensional) of length d in relation to one another either along one of the alignment axes of the sensors or along the other alignment axis. Three interleaved sub-antennas are thus defined, having phase centers 41, 42 and 43 spaced apart from one another by a distance d which satisfies the distance condition described previously.

The main function of the second step 12 of the method is to use a grouping of the sensors in sub-antennas as is done in the first step so as to form, for each sub-antenna, reception channels called primary panoramic channels. During this step, the formation of panoramic

channels can be done in different known ways. It can also be done in the time or frequency domain.

Thus, the formation of primary panoramic channels can be done conventionally, the signals received by the different sensors of one and the same sub-antenna being affected by a delay corresponding to the direction of pointing and added together, with a possible weighting.

The formation of primary panoramic channels can also be done by channel synthesis with constant directivity, according to a method, known from the prior art, which consists in dividing the total bandwidth of the received signal into N narrow sub-bands (or sub-channels). Each sub-channel n has a center frequency f_n and a typical width $c/(10L)$, L representing the length of the sub-antennas.

For each sub-band or sub-channel, hypothetical sensors are then defined whose positions are themselves defined by spatial interpolation of the positions of real sensors forming the antenna, so that the positions of the hypothetical sensors have spacings that are proportional to the physical spacings separating the real sensors on the sub-antenna for a reference frequency f_r chosen from the center frequencies f_n . The frequency f_r corresponds to the sub-channel for which the hypothetical sensors coincide with the real sensors of the sub-antenna. The proportionality ratio is here equal to the ratio of the frequency of the sub-channel n to the reference frequency.

Thus, if $\vec{r}_i$ designates the physical position of the sensor i of the sub-antenna considered and $\vec{r}_i^{(n)}$ the position of the hypothetical sensor for the sub-channel of frequency f_n , for all the sensors of the sub-antenna considered, $\vec{r}_i$ and $\vec{r}_i^{(n)}$ satisfy the following relationship:

$$f_n \left| \vec{r}_k^{(n)} - \vec{r}_l^{(n)} \right| = f_r \left| \vec{r}_k - \vec{r}_l \right| \quad [1]$$

The primary channels are formed in each sub-channel in a conventional manner, by delay plus summation of the signals of the corresponding hypothetical sensors. The functions of directivity of the channels formed at the frequencies f_n from the hypothetical sensors of the sub-antennas considered that are thus reconstructed are then identical, hence the designation "channel forming with constant directivity". Consequently, the signal of the primary channel output is obtained by recombining by Fourier transform the signals of the channels formed at the frequencies f_n .

Moreover, the formation of primary panoramic channels can also be done adaptively, the response of each sensor then being optimized according to the direction considered. However, adaptive forming can prove difficult to implement because of the number of sensors that each sub-antenna still comprises.

Be that as it may and regardless of the method used, there is thus determined, for each direction m of the space considered, the complex temporal signal $V_n(m, t)$ of the reception channel formed in the direction m for the sub-antenna n , n varying from 1 to N . $\vec{V}(m, t)$ then designates the column vector made up of the N complex components $V_n(m, t)$.

The third step 13 of the method according to the invention produces the formation of actual adaptive channels. This is facilitated by the fact that primary reception channels have already been formed on completion of the second step. According to the invention, this step can be carried out by implementing any known appropriate method for forming adaptive reception channels from existing reception channels.

The rest of the text illustrated by figure 5 proposes, by way of a particular implementation, a method that makes it possible to carry out this third step.

- 5 As figure 5 illustrates, the third step of the method according to the invention can be performed by implementing the following three operations:

- a first operation 51 of estimating, for each
10 channel, each direction of observation, m , the covariance matrix $\tilde{\Gamma}^{(m)}$ of the signals $V_n(m, t)$ 54 formed in the direction m for all the N sub-antennas. The estimated covariance matrix $\tilde{\Gamma}^{(m)}$ is then inverted.

- a second operation 52 of determining, for each
15 channel m , the phase-shift vector $\vec{d}^{(m)}$, this vector $\vec{d}^{(m)}$ being the vector to be applied to the signal $\vec{V}(mt)$ corresponding to the channel m considered.

- a third operation 53 of actually forming the M
adaptive secondary reception channels and of
20 determining the signal $V_m(t)$ corresponding to each of the channels m .

For each direction of pointing m , the operation 51 of
estimating the covariance matrix $\tilde{\Gamma}^{(m)}$ is performed on
25 the basis of the signals of the primary channels formed in the direction m for each of the N sub-antennas.

This covariance matrix can, according to the invention, be estimated by any known method, the direct method
30 described in the patent application filed by the applicant for example. This method exploits the input signals over a given duration T , a duration which corresponds to the a priori estimated duration of the signal from the observed target. This duration can be
35 formed by a continuous time interval or by several successive unconnected time intervals. Consequently, the covariance matrix is obtained by integration of the

signal received for each channel m over $T+1$ time samples. It is expressed as follows:

$$\hat{r}(m,t) = \sum_{t'=-T/2}^{T/2} \vec{V}(m,t+t') \cdot [\vec{V}(m,t+t')]^* \quad [2]$$

5 in which $\vec{V}(m,t+t')$ represents the vector of the signals corresponding to the M primary channels and $[\vec{V}(m,t+t')]^*$ the conjugate transposed vector of this vector.

The parameter T is here determined as a function of the
10 number of sub-antennas (i.e. references) considered, so as to satisfy the condition $BT \geq N$.

It should be noted that this averaging over a duration T has the effect of applying a low-pass filter to the
15 variations of the covariance matrix in a bandwidth of width $1/T$. Consequently, in order not to lose information, the estimation of the matrix must be renewed with a rate greater than $2/T$.

20 The inverse matrix $\hat{r}^{-1}(m,t)$ is then computed.

The operation 52 of determining the phase-shift vector $\vec{d}(m)$ of the secondary antenna formed from the N sub-antennas consists in computing the components of this
25 vector from the following expression:

$$[d(m)]_n = \exp(i2\pi \frac{f_0}{c} \vec{u}_m \cdot \vec{\delta}_n) \quad [3]$$

in which f_0 designates the center frequency of the
30 signal for the frequency sub-channel considered and $\vec{u}_m$ a unitary vector in the direction of pointing of the channel m .

Consequently, the actual operation 53 of forming the
35 secondary channels consists in computing the signal

$V_s(m,t)$ corresponding to each channel m by means of the following relationship:

$$V_s(m,t) = \frac{\left[\vec{d}(m) \right]^* \cdot \hat{r}^{-1}(m,t)}{\left[\vec{d}(m) \right]^* \cdot \hat{r}^{-1}(m,t) \cdot \vec{d}(m)} \cdot \vec{V}(m,t) \quad [4]$$

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It should be noted that it may prove necessary to form a number of secondary channels associated with one and the same set of N primary channels $\vec{V}(m,t)$ pointing in the directions characterized by m . Such is in particular
 10 the case if the secondary sub-antennas formed exhibit a spatial ambiguity which can be lifted by adjusting the geometry of the phase centers of the secondary antennas. Such is, for example, the case of an antenna
 15 consisting of parallel linear sub-antennas whose phase centers are situated perpendicularly to the axis of the sub-antennas. The operation 53 then consists in computing, in addition to the signal $V_s(m,t)$, the signal $V_s(m',t)$ defined by the following relationship:

$$V_s(m',t) = \frac{\left[\vec{d}(m') \right]^* \cdot \hat{r}^{-1}(m,t)}{\left[\vec{d}(m') \right]^* \cdot \hat{r}^{-1}(m,t) \cdot \vec{d}(m')} \cdot \vec{V}(m,t) \quad [5]$$

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in which m' corresponds to the direction(s) that are ambiguous in relation to m . The signals $\vec{V}(m',t)$ then correspond to an angular domain complementing that of $\vec{V}(m,t)$ and are processed and displayed in a similar
 25 manner.

The signals $V_s(m,t)$ and, where appropriate, the signals $V_s(m',t)$ output from the adaptive secondary channels are then processed in a manner known from the prior art:
 30 post-integration(s) over the duration of the target, normalization, detection etc.

Thus, as can be observed through the preceding relationship, the estimation of the covariance matrix $\tilde{\Gamma}(m)$ associated with N signals forming the primary channel corresponding to m makes it possible to form an adaptive secondary channel for each direction of observation m (or several secondary if the primary channels are ambiguous, that is to say if they have the same response for different directions in space).

The method for forming adaptive secondary channels described previously offers in particular the advantage, through the step of estimating and inverting the covariance matrix, of proceeding with the construction of a spatial filter which, applied to the signals produced by the primary reception channels, advantageously makes it possible to construct secondary reception channels that take account of the environment in an optimal manner. Thus, in the case of strong interference, the spatial filter constructed implicitly takes into account the real response of the antenna in the direction of the interference sources and compensates it, which confers on the method extremely advantageous interference suppression characteristics.

It should be noted that, in the method according to the invention as described in the preceding text, the step 13 of forming secondary channels is described for a configuration in "narrowband" mode operation, that is to say a configuration in which the bandwidth B processed and the dimensions of the antenna are such that, for any two sub-antennas n and n' out of the N sub-antennas, the following relationship is observed:

$$\frac{c}{B} \gg |\vec{\tilde{O}}_n - \vec{\tilde{O}}_{n'}| \quad [6]$$

c here representing the speed of propagation of the signal in the medium considered. As for $\vec{\tilde{O}}_n$ and $\vec{\tilde{O}}_{n'}$, these represent the vectors joining the phase center of

the secondary antenna formed to the phase center of the sub-antennas n and n' considered.

If this condition is not observed, a wideband method, known from the prior art, must be used, by dividing the bandwidth into frequency sub-channels satisfying the condition [6], and by applying the adaptive processing described previously in each frequency sub-channel k . The output signal $V_s(m,t)$ of the adaptive secondary channel m considered is then obtained by recombining by Fourier transform the signals $V_s(m,t,k)$ obtained for the different frequency sub-channels. Each signal $V_s(m,t,k)$ is defined by the following relationship:

$$V_s(m,t,k) = \frac{\left[\vec{d}(m,k) \right]^+ \cdot \hat{\Gamma}^{-1}(m,t,k)}{\left[\vec{d}(m,k) \right]^+ \cdot \hat{\Gamma}^{-1}(m,t,k) \cdot \vec{d}(m,k)} \cdot \vec{V}(m,t,k) \quad [7]$$

in which the quantities $\vec{d}(m,k)$ and $\hat{\Gamma}(m,t,k)$ correspond for each sub-channel k to the quantities defined by the relationships [2] and [3].

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As figure 1 illustrates, the method for forming channels according to the invention is generally integrated at the start of the signal processing chain of the system which implements it. However, inasmuch as the waveform transmitted by the system is appropriate (CW transmission or, more generally, ray comb code transmission), the system generally applies a Doppler analysis processing to the received signal. This processing is then integrated in the method according to the invention in the form of an additional step 14 during which the Doppler analysis is performed. The processing applied may for example consist, in a known manner which is not described here, in correlating the input signal with Dopplerized copies of the transmitted signal, that is to say replicas of the transmitted

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signal affected by frequency offsets corresponding to different moving object observation hypotheses. The consequence of the integration of this step of Doppler analysis (i.e. of multi-copy correlation) in the method
5 for forming channels according to the invention is that the processing steps following this step 14 are implemented in parallel, on each of the duly formed Doppler channels. The processing described previously can then be applied in an identical manner to each of
10 the Doppler channels, the signal $V_s(m,t)$ then representing the signal corresponding to the adaptive secondary channel m for the Doppler channel considered.

According to the invention, the additional step 14 of
15 Doppler analysis can be executed, as figure 1 illustrates, before or after the step 12 of forming the primary reception channels.

CLAIMS

1. A method for forming adaptive reception channels for a detection system comprising a multi-sensor antenna,
5 the forming of adaptive channels making it possible to eliminate a spurious signal or a noise, characterized in that it comprises:

- a first step (11) of forming N interlocked sub-antennas, each sub-antenna n comprising a number of
10 identical sensors, the phase centers of the sub-antennas exhibiting a given offset relative to one another;

- a second step (12) of forming, for each sub-antenna n, M primary reception channels, from the
15 sensors forming the sub-antenna concerned;

- a third step (13) of forming M secondary reception channels, each secondary channel m being formed from the primary channels m corresponding, for the N sub-antennas, to the same direction of
20 observation, this step is performed by implementing an adaptive processing of the signals produced by the primary reception channels;

the sensors forming one and the same sub-antenna being determined so that the phase centers of any two sub-
25 antennas n and n' are separated from one another by a distance less than the spatial correlation distance of the noise or of the spurious signal that is to be eliminated.

30 2. The method as claimed in claim 1, characterized in that, the operation of the detection system being a narrowband mode of operation, the third step (13) carries out the following operations:

- a first operation (51) of estimating, for each
35 secondary channel m, the covariance matrix $\tilde{\Gamma}^{(m)}$ of the signals $V_n(m, t)$ (54) formed in the direction m for all the N sub-antennas; the estimated covariance matrix $\tilde{\Gamma}^{(m)}$ then being inverted;

- a second operation (52) of determining, for each channel m , the phase-shift vector $\vec{d}(m)$ defined by the following relationship:

$$[d(m)]_n = \exp(i2\pi \frac{f_0}{c} \vec{u}_m \vec{\delta}_n)$$

5 in which f_0 designates the center frequency of the signal and $\vec{u}_m$ a unitary vector in the direction of pointing of the channel m ;

- a third operation (53) of actually forming the M adaptive secondary reception channels by determining
10 the signal $V_s(m,t)$ corresponding to each of the channels m , the signal $V_s(m,t)$ being defined by the relationship:

$$V_s(m,t) = \frac{\left[\vec{d}(m) \right]^* \cdot \hat{\Gamma}^{-1}(m,t)}{\left[\vec{d}(m) \right]^* \cdot \hat{\Gamma}^{-1}(m,t) \cdot \vec{d}(m)} \cdot \vec{V}(m,t)$$

15 3. The method as claimed in claim 1, characterized in that, the operation of the detection system being a wideband mode of operation, the third step (13) implements an initial operation of breaking down the spectral band of the received signal into spectral sub-
20 bands k so that the signal corresponding to each sub-band is a narrowband signal; then, for each spectral sub-band, the following operations:

- a first operation (51) of estimating, for each secondary channel m , the covariance matrix $\tilde{\Gamma}(m,tk)$ of
25 the signals $V_n(m,t,k)$ (54) formed in the direction m for all the N sub-antennas; the estimated covariance matrix $\tilde{\Gamma}(m,tk)$ then being inverted;

- a second operation (52) of determining, for each channel m , the phase-shift vector $\vec{d}(m,k)$ defined by the
30 following relationship:

$$[d(m,k)]_n = \exp(i2\pi \frac{f_k}{c} \vec{u}_m \vec{\delta}_n)$$

in which f_k designates the center frequency of the sub-band k and $\vec{u}_m$ a unitary vector in the direction of pointing of the channel m ;

- a third operation (53) of actually forming the M adaptive secondary reception channels by determining the signal $V_s(m,t,k)$ corresponding to each of the channels m , the signal $V_s(m,t,k)$ being defined by the relationship:

$$V_s(m,t,k) = \frac{\left[\vec{d}(m,k) \right]^+ \cdot \hat{r}^{-1}(m,t,k)}{\left[\vec{d}(m,k) \right]^+ \cdot \hat{r}^{-1}(m,t,k) \cdot \vec{d}(m,k)} \cdot \vec{V}(m,t,k);$$

the signals $V_s(m,t,k)$ obtained for each spectral sub-band being combined with one another by Fourier transform during a final step, to form the overall signal $V_s(m,t)$ (16) corresponding to the channel m .

4. The method as claimed in one of claims 2 or 3, characterized in that the estimation $\hat{r}(m)$ of the covariance matrix of the signals $V_n(m,t)$ is produced from the following relationship:

$$\hat{r}(m,t) = \sum_{t'=-T/2}^{T/2} \vec{V}(m,t+t') \cdot \left[\vec{V}(m,t+t') \right]^+$$

in which $\vec{V}(m,t+t')$ represents the vector of the signals corresponding to the M primary channels and $\left[\vec{V}(m,t+t') \right]^+$ the conjugate transposed vector of this vector.

5. The method as claimed in any one of the preceding claims, characterized in that it comprises an additional step (14) of Doppler analysis of the received signal, this additional step being able to be implemented before or after the second step of the method; the steps of the method following this additional step (14) being implemented in parallel, on each of the duly formed Doppler channels.

6. The method as claimed in claim 5, characterized in that the Doppler analysis applied is an analysis by

multi-copy correlation which consists in correlating the received signal with copies of the transmitted signal affected by different given delays.

5 7. The method as claimed in any one of the preceding claims, characterized in that, each of the sub-antennas exhibiting a spatial ambiguity, in a direction m' , in relation to the direction m considered, the operation
53 then consists in computing, in addition to the
10 signal $V_s(m, t)$, the signal $V_s(m', t)$ defined by the following relationship:

$$V_s(m', t) = \frac{\left[\vec{d}(m') \right]^T \cdot \hat{r}^{-1}(m, t) \cdot \vec{V}(m, t)}{\left[\vec{d}(m') \right]^T \cdot \hat{r}^{-1}(m, t) \cdot \vec{d}(m')}$$

in which m' corresponds to the ambiguous direction in relation to the main direction m .

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8. An application of the method as claimed in any one of the preceding claims to a system comprising a linear antenna formed by sensors separated from one another by a constant distance d ; the step (11) of forming N
20 interlocked linear sub-antennas being performed by associating the signals received by sensors separated from one another by $N \cdot d$, the sub-antennas being offset from one another by a distance d ; the phase centers of the sub-antennas thus produced exhibiting an offset d
25 relative to one another.

9. An application of the method as claimed in any one of claims 1 to 7 to a system comprising a planar antenna formed by sensors arranged in rows and columns
30 and separated from one another by a constant distance d ; the step (11) of forming N interlocked planar sub-antennas being performed by associating the signals received by sensors positioned on rows and columns separated from one another by $N \cdot d$, the phase centers of
35 the sub-antennas thus produced exhibiting an offset d in rows or in columns relative to one another.