

ATLAS ELEKTRONIK GmbH
Bremen

5 METHOD FOR EMITTING AND RECEIVING WAVE ENERGY

The invention relates to a method for emitting and receiving wave energy of the generic type defined in the preamble of Claim 1.

10

Such a method is used for locating targets, that is to say for determining the position of targets in a surveillance area or for transmitting identification signals for the identification friend/foe, in which
15 identification signals with predefinable coding are radiated, the coding of which is known only to authorized parties.

In a known method for the identification friend/foe
20 (US 3 733 552), noise which can be interpreted as thermal noise by unauthorized parties is continuously transmitted on a transmission channel. In the spectrum of this noise, part-spectra, which can be correlated with one another, are fitted for information
25 transmission in that part-spectra are notched out and from these part-spectra, part-spectra which can be correlated with one another by means of frequency shifting are inserted into the gaps produced. This ensures that the message is transmitted well
30 camouflaged in the noise. However, the difficulty of detection by an unauthorized party is only very large if the bandwidth of the transmission channel is very large since only this ensures that the unauthorized party cannot perform the signal processing necessary
35 for detection within the time available to him. In addition, the further disadvantage is that when a message is transmitted from ship to ship, unknown Doppler shifts occur due to the water as a consequence

of relative movement between transmitter and receiver, which require considerable effort at the receiving end for detecting and decoding the identification signal in order to achieve unambiguous information about the degree of correspondence of the received signal with the transmitter signal.

In a known method for locating targets (EP 0 631 153 B1), a transmitter radiates a carrier signal onto which a chaotic code is impressed. The code does not have a fixed sequence length but an arbitrarily selected one. As a result, the individual pulsewidth of the transmitted pulses can be made very narrow in order to obtain good distance resolution and, at the same time, the number of pulses in each sequence can be made very large in order to achieve maximum range which is not limited by the coding. The coding is resistant against monitoring and analyzing by receivers which do not have the coding sequence. In the authorized receiver, which is placed at the location of the transmitter itself for the purpose of locating targets, the transmitted signal emitted and reflected at the target is received and the received signal is correlated with the transmitted signal. The indication of correlation is used as indication of the position of the target. Even if the unauthorized receiver cannot decode the transmitted signal coded in this way, he can still detect it and conclude from the fact of the reception of the signal that there are actively locating opponents in the environment and initiate corresponding counter measures.

The invention is based on the object of specifying a method of the type initially mentioned, in which the transmitted signals radiated by the transmitting antenna are concealed in the background noise and can only be detected by authorized receivers.

According to the invention, the object is achieved by the features in Claim 1.

5 The method according to the invention has the advantage that the radiated signals are distinguished by a large bandwidth without characteristic lines in the spectrum so that the auditory impression is noise-like and the transmitted signals are camouflaged well in the ambient noise of the background. At the same time, their energy
10 is distributed over a wide frequency range so that narrow-band Fourier transformation cannot be used for achieving an improvement in the detection performance. Detection of the transmitted signals generated according to the invention is only possible by means of
15 a structural analysis according to chaos theory by means of which the deterministic structure of the transmitted signals, which cannot be detected in the temporal course of the transmitted signal itself, can be extracted. By comparing the structural measure,
20 obtained by this analysis, of the received electrical signal picked up at the receiving antenna, with the structural measure of the transmitted electrical signal, the transmitted signal can be reliably detected in the output signal at the receiving end.

25 The method according to the invention can be used both to detect targets by means of so-called active location, and to determine their position, and to carry out communication between transmitter and receiver
30 which can be used, e.g. for the so-called identification friend/foe. In both cases, the probability of the transmitting party revealing himself is very low due to the camouflaging of the transmitted signals in the ambient noise, since neither the target
35 located by means of the transmitted signals nor third parties monitoring the transmitting area can detect the radiation of the transmitted signals.

The method according to the invention is preferably used in underwater sound technology or underwater acoustics, but can also be applied in the medium of air, e.g. for radar location of targets or for the
5 identification friend/foe in fighting aerial targets.

Suitable embodiments of the method according to the invention, with advantageous developments and
10 embodiments of the invention, are obtained from the further claims.

According to an advantageous embodiment of the invention, the temporal course of the electrical signal is derived from the chaotic-deterministic oscillation
15 characteristic of a model, the oscillation characteristic of which can be varied by means of at least one parameter. An example of such a model is a pendulum of revolution, known as Pohl pendulum, with
20 unbalance, the oscillation characteristic of which can be described by a differential equation. The variable parameters are the spring constant of a restoring spring, the amplitude and frequency of an external excitation, the damping constant of an abrasive friction, the mass and the lever arm of the unbalance
25 and the damping constant of an eddy current brake. The solution of this differential equation is a chaotic-deterministic time series which provides the temporal course of the electrical signal. At least one of the variable parameters of the differential equation is
30 utilized as control parameter for the iterative variation of the differential equation. In the example of the Pohl pendulum, for example, the current through the eddy-current brake can be used as control
parameter.

35

To be able to characterize the structure of the electrical signal generated, which cannot be detected in the temporal course itself, by means of a structural

measure which is required at the receiving end for detecting the transmitted signal, a characteristic of the signal, namely the dimension of the structure of its mapping in an at least two-dimensional space is, according to a preferred embodiment of the invention, predetermined and the at least one variable control parameter is varied iteratively until the desired dimension has been achieved. This dimension is characteristic of the electrical signal which is radiated via the transmitting antenna and is used for detecting the radiated signal in the received signal at the receiving end.

According to a preferred embodiment of the invention, the fractal dimension of the two-dimensional mapping of the electrical signal is calculated as dimension.

In the text which follows, the invention is described in greater detail by means of an exemplary embodiment illustrated in the drawing, of a method for the active location of a target. In the drawing:

Figure 1 shows a block diagram for illustrating the part of the method at the transmitting end,

Figure 2 shows a block diagram for illustrating the part of the method at the receiving end,

Figure 3 shows an angular variation $\alpha(t)$ of a chaotic-deterministic oscillation of a model for generating the temporal course of an electrical signal with deterministic-chaotic structure,

Figure 4 shows a diagram for explaining the function block return map in the block diagram of Figure 1 and 2,

5 Figures 5 and 6 show two diagrams for explaining the function block "fractal dimension" in Figures 1 and 2.

10 In the method described in the text which follows, for the active location of targets located in the water, by means of which both the targets can be acquired, i.e. detected and the position (distance and bearing) of the individual targets can be determined, sound energy is radiated into the medium of water at the transmitting
15 end and wave energy backscattered from the medium is received at the receiving end. For this purpose, a transmitting antenna 11 which radiates the sound energy within a wide sector of space or all around, is used at the transmitting end and a receiving antenna with
20 directional characteristic is used at the receiving end, by means of which the peak of the received wave energy and its direction of incidence is determined. For this purpose, the transmitting antenna 11 is supplied with a wide band electrical signal at the
25 transmitting end and the signal radiated at the transmitting end is detected in the received signal picked up at the receiving antenna 12 at the receiving end. The time between the emission of the transmitted signal by the transmitting antenna 11 and the reception
30 of the radiated signal by the receiving antenna 12 is measured and the measured time is used for calculating the distance between the transmitting antenna 11 and the target.

35 So that the locating of the target by the transmitting signal radiated once or several times with a particular period is not noticed by the target itself, the transmitted signal is concealed in the ambient noise of

the target by a corresponding formation of the electrical signal feeding the transmitting antenna 11. At the receiving end, in contrast, the transmitted signal reflected from the target can be eliminated from
5 the ambient noise of the receiving antenna 12 in the received signal of the receiving antenna 12.

For this purpose, in principle, the electrical signal for feeding the transmitting antenna 11 is generated
10 with a temporal course which has a deterministic-chaotic structure, and for the detection at the receiving end, a structural measure is used which characterizes the deterministic-chaotic structure of the electrical signal. As is shown in detail in the
15 block diagram of Figure 1, first the temporal course of the electrical signal is derived from the chaotic-deterministic oscillation characteristic of a model, the oscillation characteristic of which can be varied by means of a selected parameter, called control
20 parameter in the text which follows. For example, in the first method step 11 "differential equation model", the differential equation of a pendulum of revolution with unbalance, of a so-called Pohl pendulum, is used as model, the variable parameters of which are the
25 spring constant of a restoring spring, the amplitude and frequency of an external excitation, the damping constant of an abrasive friction, the mass and the lever arm of the unbalance and the damping constant of an eddy-current brake.

30

The complete differential equation of such a Pohl pendulum is:

$$\Theta \cdot \ddot{\alpha} = D \cdot [a - a_e \cdot \sin \omega_e t] + m \cdot g \cdot r_o \sin \alpha - k_{d1} \frac{v_\alpha}{|v_\alpha|} - k_{d2} \cdot v_\alpha \cdot I^2$$

35 where the restoring moment is

$$M_{Ruck} = D [\alpha - \alpha_e \cdot \sin \omega_e t],$$

the moment of unbalance is

$$M_m = m \cdot g \cdot r_o \sin \alpha ,$$

5

the moment of abrasive friction is

$$M_{schleif} = -k_{d1} \frac{v_\alpha}{|v_\alpha|} \text{ and}$$

10 the moment of the eddy-current brake is

$$M_{wirbel} = -k_{d2} v_\alpha \cdot I^2$$

where:

15

α = instantaneous angle variable

v_α = angular velocity

a_α = angular acceleration

t = time

20

D = spring constant of the restoring spring

m = mass of unbalance

r_o = distance of the unbalance from the axis of rotation

g = acceleration due to gravity

25

θ = total moment of inertia

α_e = amplitude of the excitation

ω_e = angular frequency of the excitation

k_{d1} = damping constant of the constant abrasive friction

30

k_{d2} = damping constant of the eddy-current damping

I = current through the eddy-current-generating coil.

35

If all parameters are permanently predetermined and only one parameter, in this case the current I through the eddy-current-generating coil, is left as variable control parameter, the following function is obtained.

$$\alpha = f(t, I),$$

which is used for simulating the temporal course of the
5 electrical signal, where α is the signal amplitude. The
solution of this differential equation with permanently
predetermined parameters and the assumed input or
control parameter I leads to a time series of the
signal which is created from the differential equation
10 with method step 14 "calculating of the time series of
the signal". Figure 3 diagrammatically shows the
chaotic oscillation of the Pohl pendulum for a time
segment. The simulated electrical signal has the same
temporal course, where α is the instantaneous amplitude
15 variable of the signal. .

The time series of the electrical signal is mapped in a
multi-dimensional space in which its deterministic
structure can be recognized, and a dimension of the
20 structure of the map is determined. In the exemplary
embodiment, the time series is mapped in a two-
dimensional phase space by means of a so-called return
map in method step 15. As is shown in Figure 3, the
lower crest points are used as the selected
25 characteristic of electrical signal for this purpose.
Optionally, however, the upper crest points or the time
intervals between the crest points or instantaneous
values of the electrical signal occurring in the same
time intervals can be used. It is also possible to use
30 as selected characteristic the time segments of the
penetration points of a Poincaré section. With respect
to the Poincaré section, reference is made to Crighton
Dowling "Modern Methods in Analytical Acoustics",
Springer-Verlag London Ltd., 1992, page 698 ff.. The
35 result of the return map thus produced of the
electrical signal in the two-dimensional phase space is
illustrated in the diagram of Figure 4. The return map
is produced in such a manner that the lower crest

values α_{new} of the electrical signal are plotted along the ordinate of a two-dimensional coordinate system and its previous values α_{old} are plotted along the abscissa. It can be seen clearly that a considerable data
5 reduction has occurred due to the return map. The mapping in two-dimensional space reveals a structure. This structure, which in this case is derived from the chaotic oscillation of the Pohl pendulum according to Figure 3, only for reasons of simplified
10 representation, also reproduces the structure, obtained by return map from the time series, of the electrical signal with the amplitude variable α .

To be able to characterize this deterministic-chaotic
15 structure of the signal, a dimension is calculated for the structure of the map. In the exemplary embodiment, the so-called fractal dimension d_F is selected as dimension for the structure. With respect to the term and to the calculation of the fractal dimension,
20 reference is made to Edward Ott, "Chaos in Dynamical Systems", Cambridge University Press 1993, page 69 ff, or Dr. Roman Worg "Deterministisches Chaos" (Deterministic chaos), Bibliographisches Institut & F.A. Brockhaus AG, 1993, page 125 ff. Calculation
25 methods for the fractal dimension d_F are, for example, the grating method (GV), the distance analysis method (AV) and the magnification-multiplication method (VV). In the exemplary embodiment of Figure 1, the grating method (GV) is used for calculating the fractal
30 dimension d_F in method step 16. In this grating method, the map is systematically covered with a grating in two-dimensional space by squares with a side length ε . In this process, the side length ε is increasingly reduced and in each case the number N of squares is
35 determined which are encountered by the map. Such a coverage of the map with a grating is shown in Figure 5. If ε is systematically reduced in size starting from a relatively large value, a relationship

$N(\varepsilon)$ is obtained between a number N of the squares affected and the side lengths ε . If $N(\varepsilon)$ is log-log-plotted over $1/\varepsilon$, a straight line is obtained, the slope of which is an approximation of the fractal dimension d_F .

Such a straight line which, for example, has a slope of 1.36, is shown in Figure 6. Since a return map of a stochastic signal without any deterministic structure results in a fractal dimension $d_F = 2$, a slope of less than 2 is an index of a deterministic structure in the temporal course of the signal. The magnitude of the slope, i.e. the fractal dimension d_{F1} is a dimension of this structure.

To obtain in the temporal course of the electrical signal a desired deterministic structure which is required for detecting the signal in the ambient noise received via the receiving antenna, a value of the fractal dimension d_F is predetermined as default dimension d_{FV} with a permissible tolerance range $\pm s$, for example 1.1 ± 0.1 in block 19. In method step 17, the dimension for the deterministic structure of the electrical signal generated, calculated via the fractal dimension d_{FV} , is compared with the default dimension. If the comparison shows that the fractal dimension d_F calculated in method step 16 as dimension for the deterministic structure of the electrical signal is not within the tolerance range $\pm s$, i.e. the calculated fractal dimension d_F is greater than $d_{FV} + s$ or less than $d_F - s$, the variable parameter of the model, the current I through the eddy-current-generating coil in the exemplary embodiment, is changed with the method step 18 "input of control parameter". Method steps 14-17 with generation of the electrical signal by calculating the time series from the modified differential equation, the mapping into the two-dimensional phase space by return map, the

determination of the dimension of the structure of the map by calculating the fractal dimension d_F are repeated and the dimension is again compared with the default dimension. As long as no match of default dimension d_{FV} and dimension d_F which is within the tolerance range $\pm s$ is found during the comparison, method steps 14, 15 and 16 are continuously repeated by again changing the control parameter in method step 18, until a match is achieved.

10

If a match is found in the tolerance range, the electrical signal generated last, that is to say the electrical signal which has been generated with the value of the at least one variable parameter of the model leading to the match, is released for feeding the transmitting antenna 11. For this purpose, a gate 20 is opened and the electrical signal is applied to the electrical transformers of the transmitting antenna 11 after filtering, determination of the bandwidth and the transmitting period and after amplification in Block 21.

The electrical signal is radiated as sound signal into the water by the transmitting antenna 11, backscattered from a target located in the area of the sea within range of the transmitting antenna 11 and received via the receiving antenna 12 placed at the location of the transmitting antenna 11. Due to the chaotic-deterministic structure of the transmitted signal, the latter is concealed in the ambient noise of the target so that the target cannot detect the transmitted signal and thus cannot draw conclusions with respect to an opponent located in the area of the sea and which is actively locating. At the location of the receiving antenna 12, the backscattered transmitted signal is also concealed in the ambient noise of the receiving antenna 12, but can be detected with the aid of the knowledge of the structural measure, that is to say the

dimension of the deterministic structure of the transmitted signal.

Figure 2 shows the method steps for receiving the transmitted sound signal, performed at the receiver end, in a block diagram. The sound energy incident at the receiving location is received by means of the receiving antenna 12. The receiving antenna 12, used as so-called linear antenna in the exemplary embodiment, has a multiplicity of hydrophones 22 arranged equidistantly in a row. Such a linear antenna is known as towed array or as a flank array attached to the hull of the boat, sometimes also called side streamer. All hydrophones 22 are operated together and by appropriate signal processing of all electrical output signals of the hydrophones 22 in a so-called beam former 23, a directional pattern of the receiving antenna 12 is formed, the axis of greatest acoustic sensitivity of which is at right angles to the receiving antenna 12 or can be tilted at an acute angle $-90^\circ > \theta < +90^\circ$ to the normal of the receiving antenna 12. Structure and operation of the beam former 23 is known and described, for example, in US 4 060 792 or DE 21 14 373 A1 or in DE 100 27 538.

The electrical output signal at the output of the beam former 23, called the received signal picked up at the receiving antenna 12 in the text which follows, is again mapped in the same multi-dimensional phase space by means of the same method as the electrical signal during the generation of the transmitted signal. Since the return map has been selected there, the mapping into the two-dimensional phase space is performed here, too, by means of return map (method step 25) and the fractal dimension d_F is calculated as dimension for the structure of the map (method step 26). In method step 27, it is determined whether the dimension d_F corresponds to the known default dimension d_{FV} within

the tolerance range $\pm s$. The default dimension d_{fv} and the permissible tolerance range $\pm s$ are known at the receiving end and are input via an input block 29. If a match within the tolerance range $\pm s$ is given, it is
5 determined by this means that the transmitted signal radiated by the transmitting antenna 11 has also been received at the receiver end. The received signal is now released for evaluation. For example, in the case of a match of the dimension for the deterministic
10 structure of the output signal with the default dimension within the tolerance range $\pm s$, a gate 30 is opened at which the tilt angle θ of the receiving antenna 12, instantaneously set in each case by the beam former 23, is present. The tilt angle θ is shown
15 as bearing of the target in a display unit 31. The time from emission of the transmitted signal by the transmitting antenna 11 to the reception of the transmitted signal reflected or backscattered from the target by the receiving antenna 12 is measured by means
20 of a timer, not shown here, and from this the range r between the locating system and the target is calculated. The range r is also indicated in the display unit 31. With bearing θ and range r , the position of the target is acquired.

25
Apart from target detection, the method according to the invention can also be used for identification friend/foe. Since the default dimension for the transmitted signals emitted for identification
30 friend/foe is known to all friendly vehicles, only the friendly vehicles can detect the identification signals which are concealed in the ambient noise. The hostile vehicles, which do not have this information, are not able to detect these transmitted signals in the
35 received ambient noise. As a result, the probability of revealing the group of vehicles operating with identification friend/foe is greatly reduced, on the one hand, and, on the other hand, it is ensured that

hostile vehicles cannot simulate the identification signals and thus cannot camouflage themselves by an imitated identification friend/foe.

- 5 The method according to the invention is not restricted to its application in underwater technology by means of sonar systems. It can also be used for emitting and receiving electromagnetic wave energy by means of radar systems in the medium of air.
- 10
- Instead of a return map, the signal can also be mapped into a multi-dimensional phase space by Poincaré plotting, attractor plotting or Lorentz plotting or by a phase space representation. With respect to these
- 15 terms, the literature reference specified above is referred to.

PATENT CLAIMS

1. A method for emitting and receiving wave energy, in which a transmitting antenna (11) is fed with an electrical signal at the transmitting end and the signal radiated by the transmitting antenna (11) is detected in the received electrical signal picked up from a receiving antenna (12) at the receiving end, the electrical signal is generated with a continuous temporal course which has a deterministic-chaotic structure, and characterized in that a structural measure characterizing the deterministic-chaotic structure is used for detecting the signal in the received signal.
2. The method as claimed in Claim 1, characterized in that the temporal course of the electrical signal is derived from the chaotic-deterministic oscillation characteristic of a model, the oscillation characteristic of which can be varied by means of at least one control parameter.
3. The method as claimed in claim 2, characterized in that, as a model, the differential equation of a pendulum of revolution with unbalance (Pohl pendulum) is used, the variable parameters of which are the spring constant of a restoring spring, the amplitude and the frequency of an external excitation, the damping constant of an abrasive friction, the mass and the lever arm of the unbalance and the damping constant of an eddy-current brake.

4. The method as claimed in claim 2 or 3, characterized in that the electrical signal, generated with an assumed value of the at least one variable parameter of the model, is mapped into a multi-dimensional phase space, that a dimension of the structure of the map is determined and compared with a default dimension, that the generation of the electrical signal, its mapping into a multi-dimensional phase space and the determination of the dimension of the structure of the map are repeated with in each case an altered value of the at least one variable parameter of the model, until a match, located within a tolerance range ($\pm s$), of the dimension with the default dimension has been reached, and that the transmitting antenna (11) is fed with the electrical signal which has been generated with the value of the at least one variable parameter of the model leading to the match, and the default dimension is utilized as structural measure for the detection at the receiving end.
5. The method as claimed in Claim 4, characterized in that the received electrical signal of the receiving antenna (12) is mapped into a multi-dimensional phase space at the receiving end, a dimension of the structure of the map is determined and compared with the default dimension, and that, when dimension and default dimension match within the tolerance range ($\pm s$), detection of the signal is recognized.
6. The method as claimed in Claim 4 or 5, characterized in that a characteristic quantity of electrical signal is used for mapping the electrical signal into the multi-dimensional phase space and the same quantity is used for mapping

the received signal into the multi-dimensional phase space.

7. The method as claimed in Claim 6, characterized in
5 that as characteristic quantity,
 - the peaks of the amplitude or
 - the troughs of the amplitude or
 - the space between the amplitude peaks or
 - the space between the amplitude troughs or
 - 10 - the space between the transition points of the
amplitude through an arbitrarily selected
amplitude threshold or
 - amplitude samples taken in identical time
intervals or
 - 15 - intersections of Poincaré sections are
detected.
8. The method as claimed in one of Claims 4-7,
20 characterized in that the mapping into the two-
dimensional phase space is performed by means of a
return map in which the values of the
characteristic quantity in a predetermined signal
segment are picked up successively in time from
the electrical signal or received signal and are
25 alternately allocated to one and the other
coordinate in a two-dimensional coordinate system.
9. The method as claimed in one of Claims 4-7,
30 characterized in that the mapping into the multi-
dimensional phase space is performed by means of a
Poincaré plot or an attractor plot or a Lorentz
plot or a phase-space representation.
10. The method as claimed in one of Claims 1-8,
35 characterized in that a fractal dimension of the
two-dimensional map is calculated as dimension of
the structure of the map.

11. The method as claimed in Claim 10, characterized
in that the fractal dimension is calculated in
accordance with the magnification - multiplication
method (VV) or in accordance with the grating
5 method (GV) or in accordance with the distance
analysis method (AV).
12. The method as claimed in Claim 10 or 11,
characterized in that a value of the fractal
10 dimension between 0 and 2 is selected as default
dimension.
13. The method as claimed in Claim 1, characterized in
that the transmitting and receiving antenna,
15 arranged in the water, has electroacoustic
transducers.