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UNDERWATER ANTENNA COMPRISING A TRANSDUCER ARRAY
5 COMPOSED OF A PLURALITY OF ELECTROACOUSTIC TRANSDUCERS

The invention relates to an underwater antenna of the generic type defined in the precharacterizing clause of claim 1.

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A known composite sound transducer array (US 5 950 291, Figure 2) has a composite body in which rods or elements composed of piezoelectric or electrostrictive ceramic material, for example PZT, are embedded in soft
15 polymer, for example polyurethane with tiny hollow polymer balls. Thin electrodes are fitted to the lower and upper outer surface of the composite body and make contact with the ends of the ceramic elements.

20 One known ultrasound transducer (DE 100 52 635 A1) has a composite body composed of plastic with a multiplicity of ceramic elements, which are embedded in the plastic, extend between the upper face and lower face of the composite body, and are composed of
25 piezoelectric or electrostrictive ceramic. The upper face and lower face of the composite body are each coated with an electrode, which makes contact with the ceramic elements at the end. The ceramic elements are in the form of small plastic-sheathed ceramic rods
30 which are arranged in rows, like a matrix, such that they abut directly against one another. The free space which remains between the sheathed small ceramic rods is filled by a plastic, for example resin or polyurethane. The electrodes on the outer surface of
35 the composite body make contact with all of the groups, or selected groups, of small ceramic rods, thus resulting in an electroacoustic transducer or an arrangement of electroacoustic transducers, a so-called

array. An array such as this has a wide frequency bandwidth, a high transmission power and high reception sensitivity.

- 5 In a known, linear ultrasound antenna with a multiplicity of cuboid transducer elements which are arranged in rows separated by a gap and are composed of piezoelectric material (US 4 460 841), sidelobes in the directional characteristic of the antenna are reduced
10 by mechanical amplitude shading, in that the cuboid, piezoelectric transducer elements which are arranged alongside one another are designed with cuboid lengths which decrease from the transducer element located in the antenna center to the transducer elements which are
15 located at the two antenna ends. For example, the cuboid lengths are reduced in such a way that the external contour of the antenna is elliptical. The individual transducer elements are cut from a piezoelectric ceramic plate on which there are
20 electrode surfaces.

The invention is based on the object of providing an underwater antenna with a wide frequency bandwidth in a manner which is simple to manufacture and has
25 transmission and/or reception directions which point in different directions at the same time, with a high degree of attenuation of the sidelobes in the transmission and/or reception characteristics.

- 30 According to the invention, the object is achieved by the features in claim 1.

The underwater antenna according to the invention has the advantage that the formation of the electrodes,
35 which are in the form of strips, in the stated manner, in the individual sectors of the composite plate result in acoustic power being emitted from the individual

transducer arrangements in a very simple manner, decreasing from the center of each transducer arrangement towards its edge, thus leading to a considerable reduction in the sidelobe in the transmission and reception characteristics, also referred to as the directivity, in the transmission and reception directions. The design of the electrodes in the form of strips results in the so-called mechanical shading without individual transducer elements having to be grouped in a manner which is complex to manufacture. All that is required is a simple physical embodiment of the electrodes on a plate which has solid electrode surfaces on both sides and is composed of composite material, and this can be done by etching using a wet-chemical process. In this case, the electrodes which are in the form of strips are separated from one another and from the other solid electrode surface on the composite body. Those areas of the solid electrode surfaces on the composite body which are not used by the transducer arrangement can - but need not - be removed. The underwater antenna according to the invention can be produced with very small dimensions, so that it can be fitted without problems even to physically small, autonomously acting or remotely controlled underwater vehicles.

The reduction in the transmission power amplifiers required to drive the transducers resulting from the mechanical shading that is used makes a particular contribution to cost saving, since these power amplifiers represent expensive components. While a power amplifier must be available for "electronic shading" for each electroacoustic transducer, the number of power amplifiers required for the antenna according to the invention, as a result of the formation of groups of transducers, corresponds only to the number of transducers within a group, which

transducers have to be driven with a different phase shift in order to produce a desired main lobe (beam) in the directional characteristic (pattern) of the antenna. If all of the transducers are driven in phase, and the main lobe direction of the directional characteristic is therefore at right angles to the plane of the antenna, then only a single power amplifier is now required, with a high degree of freedom from sidelobes.

Expedient embodiments of the underwater antenna according to the invention, together with advantageous developments and refinements of the invention, are specified in the further claims.

Different antenna configurations can be produced by the choice of the number of transducer arrangements on a composite plate, and their distribution on the composite plate.

If, according to one advantageous embodiment of the invention, four transducer arrangements are provided on the composite plate such that their longitudinal axes, which extend transversely with respect to the width of the stepped electrodes, are radially aligned and are offset through 90° with respect to one another, then an underwater antenna can be configured which has transmission and reception directions, one of which points in the ahead direction, one astern, and in each case one to port and starboard, when the underwater antenna is arranged appropriately on a carrier, for example a marine vessel. By way of example, this makes it possible to produce an underwater antenna for a Doppler log, which operates on the Janus principle, with low manufacturing and installation costs.

If, according to one advantageous embodiment of the invention, two transducer arrangements are formed on the plate, whose electrodes which are in the form of strips are aligned such that the strip lengths run parallel to one another, and if the plate is attached to the bottom of an underwater vehicle such that the strip lengths are aligned parallel to the vehicle longitudinal axis, then a side looking sonar can be produced in a technically simple manner which in each case has a transmission and reception beam inclined towards the seabed on the port side and the starboard side.

If, according to one alternative embodiment of the invention, a plurality, for example four, of transducer arrangements are provided in the composite plate, such that the longitudinal axes of the transducer arrangements which extend in the strip width of the electrode which is in the form of a strip are aligned parallel to one another, and if the composite plate is arranged on the lower surface of an underwater vehicle such that the longitudinal axes of the transducer arrangements are aligned approximately parallel to the vehicle longitudinal axis, then the strip which is "ensonified" by the antenna on the seabed can additionally be made quite narrow by combination of the signals received by the transducer arrangements transversely with respect to the ahead direction. The main lobe direction of the directional characteristic is inclined electrically with respect to the plane of the plate through an inclination angle in the ahead direction of the underwater vehicle, and can be scanned electronically about the vertical axis of the underwater vehicle.

The invention will be described in more detail in the following text with reference to exemplary embodiments which are illustrated in the drawing, in which:

- 5 Figure 1 shows a side view, illustrated schematically,
 of an autonomous underwater vehicle fitted
 with an underwater antenna,
- 10 Figure 2 shows a plan view of the underwater antenna
 in the direction of the arrow II in Figure 1,
- 15 Figure 3 shows a side view of the underwater antenna
 in the direction of the arrow III in Figure
 2,
- 20 Figure 4 shows a section along the line IV-IV in
 Figure 2,
- 25 Figure 5 shows a section along the line V-V in Figure
 2,
- 30 Figure 6 shows the same illustration as in Figure 2 of
 an underwater antenna according to a further
 exemplary embodiment,
- 35 Figure 7 shows the same illustration as in Figure 2 of
 an underwater antenna designed for a side
 looking sonar,
- Figure 8 shows a detail in the form of a schematic
 illustration of hard wiring for the
 transducers in the underwater antenna as
 shown in Figure 7, with power amplifiers,
 phase shifters and a transmission generator,
- Figure 9 shows the same illustration as in Figure 2 of
 an underwater antenna which can be scanned

electronically about the vertical axis of the underwater vehicle.

The autonomously acting underwater vehicle 10, a side view of which is illustrated schematically in Figure 1, is fitted with an underwater antenna 11 having a transmission and reception characteristic, also referred to as a directional characteristic, the antenna plane of whose main lobe 12 is directed at an inclination angle towards the seabed 14, so that a strip 15 is "ensonified" on the seabed 14, which strip 15 is very narrow in the forward direction of the underwater vehicle 10, and is broader transversely to this. In conjunction with appropriate signal processing, an underwater antenna 11 such as this can be used, for example, to scan the seabed 14 and to survey its topography, or to detect, locate and if required to classify objects located on the seabed 14.

The underwater antenna 11 which is arranged on the lower surface of the underwater vehicle 10 is illustrated, in the form of a schematic plan view, in Figure 2. The underwater antenna 11 comprises an electroacoustic transducer arrangement 30, which has a flat composite body 16 composed of composite material, with ceramic elements embedded in a polymer and composed of piezoelectric or electrostrictive ceramic. A plurality of ceramic elements are covered on each end face by a common electrode in each case, in order to form the individual electroacoustic transducers 13 in the transducer arrangement 30. The section illustrations in Figures 4 and 5 each show the design of the composite body 16. Column-like ceramic elements 18 are polarized at right angles to the outer surfaces of the composite body 16, for example being arranged like a matrix in rows and columns, and being isolated from one another by the polymer 17. An upper solid

electrode surface 19 is applied to the upper outer surface of the composite body 16, and a lower solid electrode surface 20 is applied to the lower outer surface of the composite body 16. Each solid electrode surface 19 or 20 makes contact with all of the ends of the ceramic elements 18. In order to form the electroacoustic transducers 13 in the transducer arrangement 30, the solid electrode surfaces 19, 20 are separated, for example by etching using a wet-chemical process, such that a plurality of ceramic elements 18 on each end face are in each case covered by a common upper electrode 21 and a common lower electrode 22. In this case, as can be seen in the plan view in Figure 2 and in the section illustration in Figure 4, the electrodes 21, 22 on the end faces of the ceramic elements 18 are in the form of strips with a long strip length and a shorter strip width, with the electrodes 21 and 22 being arranged in a row or rows with a separating gap, seen in the direction of the strip width. In Figure 4, the gaps, which run in straight lines, between the electrodes 21 on the upper outer surface of the composite body 16 are annotated 23, and the gaps, which run in straight lines, between the electrodes 22 on the lower outer surface of the composite body 16 are annotated 24. Alternatively, it is possible to incorporate the electrodes 21 or 22, which are in the form of strips, in only one of the two solid electrode surfaces 19 or 20, by etching in the respective gaps 23 and 24. The strip width of the electrodes 21, 22 which are in the form of strips is chosen to be the same, while the strip length of the electrodes 21, 22 decreases from the two central electrodes 211 towards each of the outer electrodes 212. In this case, the decrease in the strip length is mirror-image symmetrical with respect to the strip center, that is to say the longitudinal axis 25, running in the strip width, of the transducer

arrangement 30 or of the composite body 16. This reduction in the strip length of the electrodes 21, 22 results in the transducers 13 which are arranged in a row on the longitudinal axis 25 of the composite body 16 having a different number of ceramic elements 18, so that the acoustic power output from the underwater antenna 11 decreases from the antenna center towards the antenna edge. This so-called shading, which is achieved mechanically, further suppresses unavoidable sidelobes in the transmission and reception characteristic of the underwater antenna 11 in the main lobe 12. In order to additionally reduce sidelobes occurring transversely with respect to the main lobe direction 12 of the underwater antenna 11, the composite body 16 has concave curvature in the direction of the strip length, as can be seen in the side view of the composite body 16 illustrated in Figure 3.

In the exemplary embodiment of the underwater antenna 11 illustrated in the form of a plan view in Figure 6, the composite body 16 as described above for the transducer arrangement 30 is formed with the transducers 13 in a sector of a plate 26 composed of composite material, which has the same structure as the composite body 16. The composite plate 26 has the same design as that illustrated in Figures 4 and 5, and likewise has solid electrode surfaces 19, 20 on its outer surfaces, with these solid electrode surfaces 19, 20 making contact with the end faces of the ceramic elements 18. In the exemplary embodiment in Figure 6, the composite plate 26 has four such sectors with transducer arrangements 30, as illustrated in Figure 2 and as described above. The four transducer arrangements 30, to be more precise the longitudinal axes 25 of the transducer arrangements 30 extending in the radial direction of the circular plates 26, are

offset through a circumferential angle of 90° with respect to one another, so that the electrodes 21, which are in the form of strips, of in each case two mutually diametrically opposite transducer arrangements
5 run parallel to one another. The electrodes 21, which are in the form of strips, are once again cut out of the solid electrode surfaces 19, 20 of the composite plate 26, in which case the remaining area of the solid electrode surface 19 which has been cut off from the
10 electrodes 21, 22 which are in the form of strips, can remain on the composite plate 26 since it is not used electrically. Once again, the circular composite plate 26 is curved in order to reduce the sidelobes which occur transversely with respect to the main lobe
15 direction 12 of the underwater antenna 11, with the composite plate 26 assuming a shape like a hollow mirror.

The underwater antenna 11 sketched in Figure 6 is preferably attached to the underwater vehicle 10 such
20 that two longitudinal axes 25, which are aligned with one another, of the longitudinal axes 25 of the total of four transducer arrangements 30 are aligned parallel to the longitudinal axis of the underwater vehicle 10,
25 and two mutually aligned longitudinal axes 25 are aligned at right angles to this. This results in the underwater antenna 11 having a total of four main lobes 12, one of which points ahead, one astern, one to starboard and one to port. By way of example, an
30 antenna configuration such as this makes it possible to provide a Doppler log based on the "Janus principle".

It is, of course, possible to provide a different number of transducer arrangements 30 in corresponding
35 sectors of the composite plate 26. The circumferential angle through which the transducer arrangements 30 are then offset with respect to one another depends on the

number of transducer arrangements 30 provided. It is, of course, also possible for the composite plate 26 to be square, rectangular or to have some other shape. The underwater antenna can be arranged on any desired floating and/or submerged carriers, for example additionally on surface vessels or on submarines.

The underwater antenna illustrated in the form of a plan view in Figure 7 is designed for a side looking sonar and is arranged on the lower surface of the underwater vehicle 10 (Figure 1), with the vehicle longitudinal axis of the underwater vehicle 10 being symbolized by the arrow 29 in Figure 7. The composite plate 26 is designed in the same way as that described with reference to Figure 6, but is rectangular with only two transducer arrangements 30, each of which is formed in one sector of the plate 26. The transducer arrangements 30 are arranged on the plate 26 such that their longitudinal axes 25 are aligned with one another, and such that the electrodes 21 are therefore aligned with their parallel strip lengths in the two transducer arrangements 30 parallel to one another. The plate 26 is attached to the bottom or the lower surface of the underwater vehicle 10 such that the longitudinal axes 25 of the transducer arrangements 30 which are aligned with one another are aligned transversely, preferably at right angles, to the vehicle longitudinal axis 29 of the underwater vehicle 10. Each transducer arrangement 30 "ensonifies" a strip 15 to port and to starboard on the seabed 14, provided that the transducers 13 are driven with an appropriate phase shift, as is illustrated in the direction forward of the underwater vehicle 10 in Figure 1. Because of the mechanical "shading", described in detail above, of the transducer arrangements 30, the directional characteristic of the underwater antenna 11 has no

sidelobes, or has only very greatly reduced sidelobes directed, in particular, towards the seabed 14.

The inclination angle α of the main lobe 12 of the directional characteristic of the two transducer arrangements 30 to starboard and port is set by driving the transducers 13 with a phase shift, as is illustrated in the form of circuitry in Figure 8. By way of example, this is based on the assumption that in each case six transducers Nos. 1 to 6 are combined in parallel-operated groups 31 in each of the two transducer arrangements 30, and are driven with a phase shift at the transmission frequency f_s via power amplifiers 32. The exemplary embodiment of the transducer arrangements 30 with a total of twenty-four transducers 13, as illustrated in Figure 7, then results in four parallel-operated groups 31 of six transducers 13 each. The inclination angle α of the main lobe 12 of the directional characteristic of each transducer arrangement 30 to starboard and port is given in a known manner by:

$$\cos \alpha = \frac{\varphi \cdot \lambda}{2\pi \cdot d} \text{ where } \lambda = \frac{c}{f_s},$$

where φ is the phase shift with respect to the reference phase 0° , c is the speed of sound in water, and d is the geometric distance between the transducers 13. With six transducers 13 per group 31, this results in a phase shift between the feed currents to be applied to successive transducers 13 at the transmission frequency f_s of 60° in each case. The inclination angle α is fixed, and does not vary, corresponding to the fixed geometric distance d between the transducers 13. The inclination angle α can be changed only by varying the numbers of transducers 13 within the groups 31, although this necessitates

reconfiguration of the wiring of the transducers 13, and a change to the phase drive.

The transducers 13 are driven in the correct phase via the power amplifier 32. For this purpose, phase shifters 33 are arranged between a transmission generator 34 at the transmission frequency f_s and the power amplifiers 32, and correctly set the phase angle of the feed currents supplied to the power amplifiers 32. It is advantageous to use the same power amplifiers 32 for driving the two transducer arrangements 30, so that only a single set of power amplifiers 32 is required for the two transducer arrangements 30, the number of which power amplifiers 32 is dependent on the number of parallel-operated groups 31 of transducers 13 in one transducer arrangement 30. This makes it possible to keep the number of the power amplifiers 32 low, and to save considerable costs, since power amplifiers represent quite expensive components. In order to allow both transducer arrangements 30 to be driven by the same set of power amplifiers 32, the outputs of the power amplifiers 32 are connected not only to the transducers 13 in one transducer arrangement 30, but also to the transducers 13 in the other transducer arrangement 30. Since the main lobe in the directional characteristic of one transducer arrangement 30 is at an inclination angle α to the plate plane of the composite plate 26, and the main lobe direction 12 of the directional characteristic of the other transducer arrangement 30 is at an inclination angle of $180^\circ - \alpha$, the transducers 13 for the starboard side must be driven with a different phase shift to that for the transducers 13 on the port side, which can be achieved by means of suitable wiring for the transducers 13 in the two transducer arrangements 30, as is illustrated in Figure 8. If the sequence of the transducers 13 in each transducer arrangement 30 is

in each case defined starting at the narrow outer face of the composite plate 26 such that successive transducers 13 are allocated rising numbers (No. 1, No. 2, ... No. 6; No. 1, No. 2, ... No. 6; No. 1 ...)

5 then all the transducers 13 with the same numbering can be connected to the same power amplifier 32. By way of example, Figure 7 shows the two outer transducers 13 with the number 1. The numbering of the other transducers 13 is shown in Figure 8. The phases used to

10 drive the individual power amplifiers 32 are entered in the phase shifters 33 arranged upstream of the power amplifiers 32 in Figure 8.

The underwater antenna 11, a view from the underneath

15 of which is shown in Figure 9, has a plurality of transducer arrangements 30 whose longitudinal axes 25 are aligned parallel to one another and to the vehicle longitudinal axis 29. The four transducer arrangements 30 are once again provided in sectors on a plate 26

20 composed of composite material, having the same structure as the composite body 16 in Figure 2. If the individual transducers 13 in each transducer arrangement 30 are driven with a phase shift such as that illustrated for a transducer arrangement 30 in

25 Figure 8, then the main lobe direction 12 of the directional characteristic of the underwater antenna 11 will be inclined at an inclination angle α to the plane covered by the vehicle longitudinal axis and lateral axis, as is illustrated in Figure 1. The strip 15

30 "ensonnified" by the antenna 11 on the seabed 14 is quite narrow both in the direction ahead of the underwater vehicle 10 and transversely with respect to this. If all the transducers 13 in one transducer arrangement 30 are now additionally driven with a

35 constant phase shift, while maintaining the phase drive for the individual transducers 13 in the groups 31 as is illustrated in Figure 8, and the constant phase

shift is changed appropriately from one of the transducer arrangements 30 to the next subsequent transducer arrangement 30, then the main lobe direction 12 of the underwater antenna 11 can be scanned about the vertical axis of the underwater vehicle 10, that is to say transversely with respect to the longitudinal axis 29 of the underwater vehicle 10 in Figure 9, with the scan angle being governed by the phase shifts from one transducer arrangement 30 to another. The additional phase offset is achieved by connecting a common phase shifter upstream of all of the phase shifters 33 for the transducers 13 in the groups 31 of a transducer arrangement 30, as is illustrated in Figure 8, with this common phase shifter providing the appropriate phase shift for the feed current coming from the transmission generator 34, in advance. This special antenna configuration makes it possible to produce a high-resolution detection sonar (forward looking sonar) which scans transversely with respect to the direction of travel of the underwater vehicle 10 and involves relatively little manufacturing effort. The "mechanical shading" achieved by the geometry of the transducer arrangements 30 in particular largely suppresses the disturbing sidelobes at right angles to the scanning plane of the directional characteristic of the underwater antenna 11.

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PATENT CLAIMS

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1. An underwater antenna having at least one
transducer arrangement (30) which comprises a
plurality of electroacoustic transducers (13) and
has a composite body (16) composed of composite
10 material which is composed of piezoelectric or
electrostrictive ceramic elements (18) embedded in
a polymer (17), with a plurality of ceramic
elements (18) being covered on each end face by in
each case one common electrode (21, 22) in order
15 to form a transducer (13), characterized in that,
in order to produce a plurality of transducer
arrangements (30), sectors which spatially bound
their composite bodies (16) in a plate (26) are
composed of the same composite material with solid
20 electrode surfaces (19, 20) which are arranged on
their plate outer surfaces and make contact with
the ceramic elements (18), and those areas of at
least one of the solid electrode surfaces (19, 20)
which cover the sectors are subdivided into
25 electrodes (21, 22) which are in the form of
strips and have a strip width which is
considerably less than the strip length, which
strips are located alongside one another,
separated by a gap seen in the direction of the
30 strip width, and in that the strip lengths of the
electrodes (21, 22) are designed such that they
decrease from the central electrode (211) towards
the two outer electrodes (212).
- 35 2. The underwater antenna as claimed in claim 1,
characterized in that the strip width of the
electrodes (21, 22) is the same.

3. The underwater antenna as claimed in claim 1 or 2, characterized in that the decrease in the strip length is symmetrical with respect to the strip center.
4. The underwater antenna as claimed in one of claims 1 to 3, characterized in that the sectors with the areas of the at least one solid electrode surface (19, 20) which are subdivided into electrodes (22) in the form of strips are offset with respect to one another through the same circumferential angle, which is governed by the number of transducer arrangements (30).
5. The underwater antenna as claimed in claim 4, characterized in that four transducer arrangements (30) are formed in the composite plate (26) with a longitudinal axis (25) running transversely with respect to the strip length of the electrodes (21) which are in the form of strips, and the longitudinal axes (25) which run radially with respect to one another are offset through a circumferential angle of 90° with respect to one another, so that the electrodes (21) which are in the form of strips of in each case two mutually opposite transducer arrangements (30) run parallel to one another.
6. The underwater antenna as claimed in claim 5, characterized in that the composite plate (26) is arranged on a water craft (10) such that one of the longitudinal axes (25) of the transducer arrangements points ahead, one astern, one to starboard and to port.

7. The underwater antenna as claimed in claim 5 or 6, characterized in that the composite plate (26) is curved like a hollow mirror.
- 5 8. The underwater antenna as claimed in claim 4, characterized in that two transducer arrangements (30) are formed in the composite plate (26) such that the electrodes (21) which are in the form of strips in the two transducer arrangements (30) run
10 parallel to one another, and in that the composite plate (26) is arranged on the lower face of an underwater vehicle (10) such that the strip lengths of the electrodes (21) which are in the form of strips are aligned approximately parallel
15 to the vehicle longitudinal axis (29).
9. The underwater antenna as claimed in claim 8, characterized in that the transducers (13) in each transducer arrangement (30) are split into groups (31) which are operated in parallel and have the
20 same number of transducers (13), and in that, in order to incline the main lobes (12) of the directional characteristics of the transducer arrangements (30) to starboard on the one hand and to port on the other hand through an inclination
25 angle (α) with respect to the plate plane of the composite plate (26), those transducers (13) which follow one another inwards in each transducer arrangement (30) from the outer edge of the composite plate (26) within the parallel-operated
30 groups (31) in the two transducer arrangements (30) are driven with a phase shift via in each case one power amplifier (32), which is shared by the two transducer arrangements (30).
- 35 10. The underwater antenna as claimed in claim 9, characterized in that the power amplifiers (32)

are hard-wired to the associated transducers (13) in the parallel-operated groups (31) of the two transducer arrangements (30).

- 5 11. The underwater antenna as claimed in one of claims 1 to 3, characterized in that the plurality of transducer arrangements (30) are formed in the composite plate (26) such that the longitudinal axes (25) of the transducer arrangements (30) which extend in the strip width of the electrodes (21) which are in the form of strips are aligned parallel to one another, and in that the composite plate (26) is arranged on the lower surface of an underwater vehicle (10) such that the longitudinal axes (25) of the transducer arrangements (30) are aligned approximately parallel to the vehicle longitudinal axis (29).
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- 20 12. The underwater antenna as claimed in claim 11, characterized in that the main lobe (12) of its directional characteristic is electronically inclined with respect to the plate plane of the composite plate (26) through an inclination angle (α) in the direction ahead of the underwater vehicle (10), and can be scanned electrically about the vertical axis of the underwater vehicle.
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