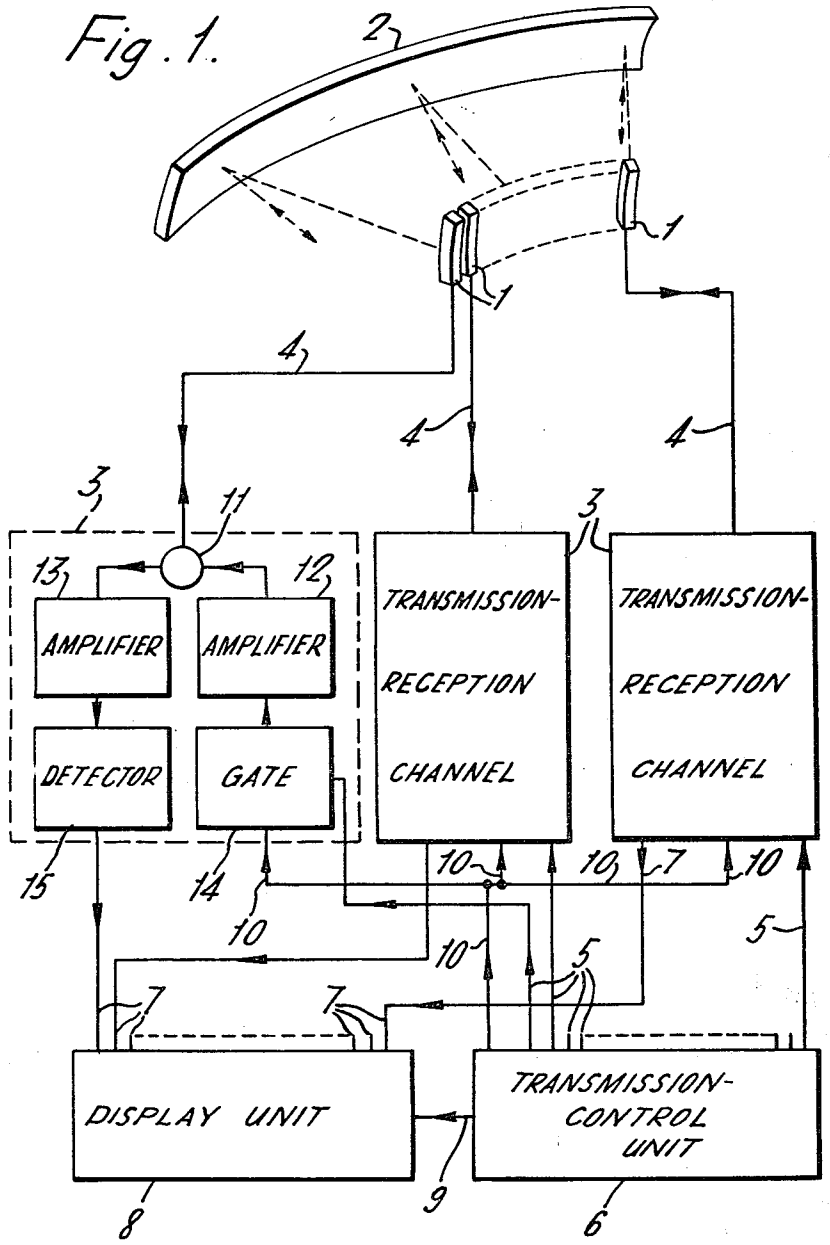
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ECHO-RANGING APPARATUS

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Fig. 1.



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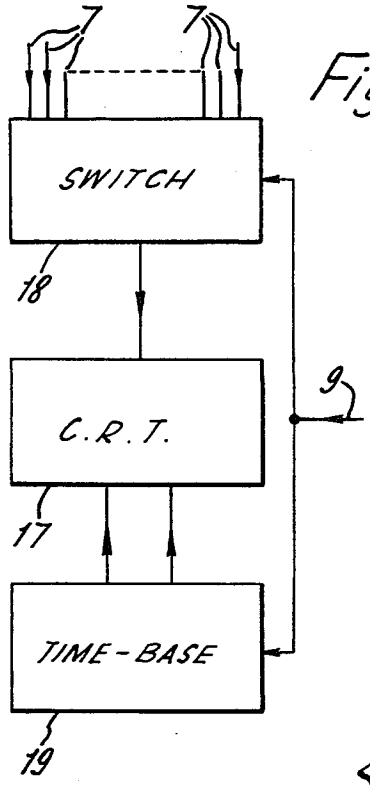
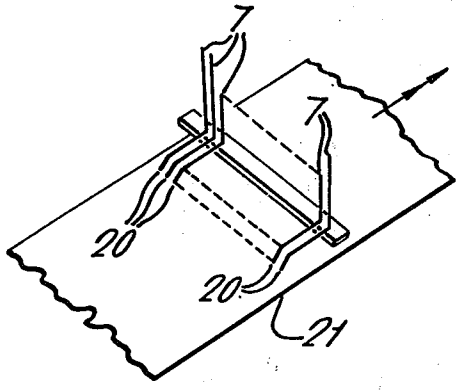


Fig. 2.

Fig. 3.



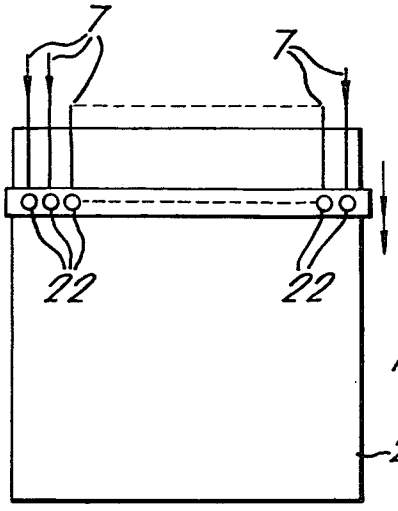


Fig. 4.

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face of a spherical, concave reflector 2 of rectangular aperture. The transducers 1, which are electrostrictive transducers are associated respectively with seventy separate transmission-reception channels 3, each transducer 1 being coupled to its respectively-associated channel 3 via an electrical path 4. The channels 3 are each coupled via an individual electrical path 5 to a common transmission-control unit 6, and via an individual electrical path 7 to a common display unit 8, the two units 6 and 8 being interconnected via an electrical path 9. Electrical carrier-wave oscillations are supplied to the seventy channels 3 via a common electrical path 10 from the unit 6.

The transducers 1 and reflector 2 are mounted externally of the hull of the ship below the water surface, with each transducer 1 substantially upright and with the longer aperture-dimension of the reflector 2 horizontal. Under control of the common transmission-control unit 6, the channels 3 supply pulses of the carrier-wave oscillations via the paths 4 to the transducers 1 to cause the transducers 1 to emit into the water, and towards the reflector 2, corresponding pulses of acoustic oscillations. These acoustic pulses are reflected from the reflector 2 in a general direction inclined downwardly from the ship, the reflector 2 being tilted downwardly slightly with respect to the transducers 1 so that the transducers 1 do not obstruct the reflected pulses. Each individual transducer 1, since it is situated on the focal surface of the reflector 2, acts together with the reflector 2 to produce a beam of pulsed acoustic energy inclined downwardly in elevation. Since the transducers 1 are closely positioned side-by-side around the focal surface, the seventy transmitted beams are closely spaced angularly with respect to one another in azimuth, the transducers 1 in combination with the reflector 2 thereby transmitting seventy separate beams of pulsed acoustic energy equally inclined downwardly in elevation, but fanning out from one another in different directions throughout a limited azimuthal sector centered on the ship. If any of the transmitted acoustic energy is reflected back as an echo from one of these directions, then this reflected energy is accordingly directed by the reflector 2 to the particular transducer 1 giving rise to transmission in that direction. Reception of an echo by any transducer 1 generates therein an electric signal that is passed via the appropriate path 4 to the associated channel 3. After amplification and detection, the electric echo signal is passed via the relevant path 7 for display by the display unit 8. Synchronisation of the time-base of the display with the transmission of the acoustic pulses is achieved by means of an electric signal supplied to the unit 8 via the lead 9 and coordinated in its timing with the supply of pulses from the channels 3 to the transducers 1.

The use of the separate channels 3 in the reception of the echo signals ensures that the directional information relating to each echo is preserved, the directional acuity being dependent upon the width of beam originating from each transducer 1 via the reflector 2, and also upon the number of transducers 1 (and thereby the number of separate beams used) for the sector covered. In the present example, each beam has a half-power width of 0.32 degree in the plane of the longer aperture-dimension of the reflector 2 and a half-power width of two degrees in the plane of the shorter aperture-dimension, the seventy beams being distributed uniformly throughout a sector of thirty degrees. The wavelength of the acoustic energy in water is in this case 0.6 centimetre and the reflector 2 has a focal length of fifty centimetres with longer and shorter aperture-dimensions of ninety-five and fifteen centimetres respectively. (The width of the beam in degrees and measured in the plane of either aperture-dimension is in the present case approximately $51\lambda/X$ where λ is the wavelength and X the relevant aperture-dimension.) Each transducer 1 has a length, measured substantially parallel to the shorter aperture-dimension of the reflector 2, of 2.4 centimetres, and a width, measured substantially parallel to the longer aperture-dimension, of 0.38 centimetre.

The width, in particular, of each transducer 1 is chosen to be as small as possible consistent with efficient operation, in order that a large number of transducers 1 can be accommodated side-by-side on the focal surface to produce a correspondingly large number of beams within the sector, and thereby ensure a high degree of acuity. In this respect, the width is chosen by reference to the distribution of energy that obtains on the focal surface of a concave spherical reflector of circular aperture and illuminated with acoustic energy from infinity. To a large extent the energy received in the latter case is concentrated in a central circular region of the distribution pattern, the radius R of this circular region, the Airy disc, being related to the focal length F and the diameter D of the aperture, and to the wavelength λ, by the formula:

$$R=1.22F\lambda/D$$

With the specific values of focal length (fifty centimetres) and wavelength (0.6 centimetre) quoted above in relation to FIGURE 1, a reflector having a circular aperture of diameter ninety-five centimetres gives rise to an Airy disc having a radius of 0.38 centimetre. A substantial part of the energy distributed within the Airy disc is concentrated in the central area bounded by a circle of half this radius, so that useful reception of the energy can accordingly be made by a transducer extending across this central area alone, that is to say, over a width of 0.38 centimetre. By analogy, useful reception of energy from the spherical reflector 2 of rectangular aperture, is achieved parallel to the longer aperture-dimension of ninety-five centimetres over a width of 0.38 centimetre in the focal surface, that is to say, over the width chosen for each transducer 1. The transducers 1 in this case are positioned side-by-side along an arc of the focal surface extending through thirty degrees at a radius of fifty centimetres; with a width of 0.38 centimetre each, seventy transducers 1 are accordingly readily accommodated along this arc, to give efficient reception of echoes from seventy angularly-spaced directions within the sector of thirty degrees.

The length of each transducer 1 measured parallel to the shorter aperture-dimension of the reflector 2, is chosen as 2.4 centimetres on a similar basis to choice of the width. Consideration is given in this instance to the Airy disc applicable to a concave, spherical reflector having a circular aperture of fifteen centimetres, the radius R of this disc being 2.4 centimetres.

Considering the apparatus of FIGURE 1 in greater detail, each transmission-reception channel 3 includes a transmit-receive switch 11, and it is to this switch 11 that the associated transducer 1 is coupled via the relevant path 4. A transmitter-amplifier 12 and a receiver-amplifier 13 are both connected to the switch 11 within the channel 3, the switch 11 serving to isolate the amplifier 13 from pulsed electric carrier-wave signals supplied by the amplifier 12 for transmission to the transducer 1 via the path 4, and also to isolate the amplifier 12 from the path 4 while echo signals are being passed from the transducer 1 to the channel 3 via the path 4. The pulsed carrier-wave signals are supplied through the amplifier 12 from a gate 14, the gate 14 receiving from the common transmission-control unit 6 the signals supplied to the channel 3 via the paths 5 and 10. The unit 6 supplies a train of gating pulses to the lead 5, and these pulses control operation of the gate 14 to pass to the amplifier 12 corresponding pulses of the electric carrier-wave oscillations supplied from the path 10. The carrier-wave oscillations in the present example have a frequency of two-hundred-and-fifty kilocycles per second, and each pulse of oscillations has a duration of thirty microseconds.

During the intervals between successive pulses supplied to the path 4 via the amplifier 12 and the switch 11, echo signals passed via the path 4 to the channel 3 are passed through the switch 11 to the amplifier 13. The amplifier

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ECHO-RANGING APPARATUS

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ABSTRACT OF THE DISCLOSURE

A sonar system includes a side-by-side array of electromechanical transducers mounted on the focal surface of a spherical reflector to transmit and receive acoustic waves in respective directions throughout a sector of surveillance. Each transducer has its own transmitting and receiving channels, and a display unit common to the receiving channels displays each detected echo with a directionality dependent upon which of the receiving channels detected that echo.

This invention relates to echo-ranging apparatus.

The invention is particularly, although not exclusively, concerned with sonar apparatus, that is to say with echo-ranging apparatus in which acoustic wave energy (of frequency not necessarily within the audibile-sound range) is propagated in, for example, the sea. Although of especial application to sonar apparatus using acoustic wave energy, the invention is also applicable to radar apparatus using electromagnetic wave energy.

Surveillance of a defined angular sector in azimuth or elevation, whether in water or space, is conventionally carried out by sweeping a beam of the appropriate acoustic or electromagnetic wave energy through the sector, the directions from which echoes are received during the sweep providing directional information as to the echo-producing bodies, the "targets," within the sector. Reception of the echoes with the required degree of directional acuity is normally carried out using the same transducer or aerial array as used for transmitting the beam of waves, the array having, by reciprocity, directional beam-characteristics for reception corresponding to those for transmission. Various proposals have been made for sweeping a transmitted beam and its corresponding received "beam" through a sector of surveillance, but these involve either undesirable mechanical movements or somewhat complicated electronic methods of varying the phasing with respect to one another of a multiplicity of electric signals. Where a pulsed beam of wave energy is transmitted and the whole angular range of the sector is to be scanned within the duration of each pulse, there is the added disadvantage that the minimum duration of transmitted pulse that can be used is limited by the maximum speed of beam-sweeping obtainable in those circumstances.

It is an object of the present invention to provide echo-ranging apparatus that can be used to avoid the above disadvantages.

According to the present invention echo-ranging apparatus comprises a multiplicity of echo-receiving elements arranged such that different elements receive echoes from different directions throughout an angular sector, a multiplicity of reception channels coupled respectively to said elements for detecting echoes received by the elements, and means for providing a representation of at least the directions within said sector from which echoes detected as aforesaid are received, the representation of direction of reception of each such echo being provided in accordance with whichever of the reception channels detects that echo.

With echo-ranging apparatus according to the invention therefore, there is no requirement for mechanical or electronic scanning of the sector under surveillance (and accordingly there is no untoward limitation imposed by maximum speed of scanning), since the echoes from the different directions within the sector are received by the different echo-receiving elements. These elements may be mounted side-by-side on, or near, the focal surface of a concave reflector. The reflector may be a spherical or cylindrical reflector with the elements mounted as a single-dimensional array, or, in the case of the spherical reflector, as a two-dimensional array.

The echo-ranging apparatus may be sonar apparatus, the echo-receiving elements being electromechanical transducers (for example, electrostrictive transducers of barium titanate) for receiving acoustic echoes, and being mounted closely side-by-side to receive echoes from different closely-spaced angular directions throughout the sector. When used with a spherical or cylindrical concave reflector, the minimum angular spacing that can be obtained between the directions of reception is dependent to a substantial extent upon the closeness with which the transducers can be accommodated side-by-side on the focal surface. The size of each transducer is in this respect preferably chosen to be as small as usefully practicable with regard to the distribution in the focal surface of echo-energy received from the relevant direction by that transducer. The use of a small size enables a large number of transducers to be accommodated to cover any particular angular sector with a high degree of directional acuity.

According to a feature of the present invention, sonar apparatus comprises a concave spherical or cylindrical reflector, a multiplicity of electromechanical transducers mounted closely side-by-side around an arc of the curved focal surface of the reflector for receiving via the reflector acoustic echoes from a multiplicity of closely-spaced angular directions throughout a predetermined sector, different ones of said transducers receiving echoes as aforesaid from different ones of said directions, a multiplicity of reception channels coupled respectively to said transducers for detecting echoes received by the transducers, and a display unit for providing a display of both direction and range from which echoes detected as aforesaid are received, the representation of direction of reception of each displayed echo being provided in accordance with whichever of the reception channels detect that echo.

The closely-spaced directions of reception may be equally angularly-spaced from one another throughout the sector.

The electromechanical transducers, as mentioned earlier, may be electrostrictive transducers, and may be, for example, of barium titanate.

Sonar apparatus in accordance with the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

FIGURE 1 is a schematic representation of the sonar apparatus, only one of a multiplicity of transmission-reception channels of the apparatus being shown in detail;

FIGURE 2 is a block schematic representation of a display unit of the sonar apparatus shown in FIGURE 1;

FIGURE 3 illustrates an alternative form of the display unit; and

FIGURE 4 illustrates a further alternative form of the display unit.

The sonar apparatus is for use on a ship to receive acoustic echoes from underwater "targets." The "targets" may be fish or other underwater objects spaced from, or on, the bottom, and the bottom may in itself be a "target."

Referring to FIGURE 1, seventy identical and elongated electromechanical transducers 1 are mounted closely side-by-side around a portion of the spherical focal sur-

13, which has automatic gain control, amplifies each echo signal and passes this to a detector 15, the resultant, detected signal being supplied from the channel 3 to the common display unit 8 via the relevant path 7.

The display unit 8 provides, in accordance with the signals it receives via the seventy paths 7, a display indicating both the direction and range from which echoes are received by the apparatus. Signals representing echoes received from different bearings are received by the unit 8 via different ones of the paths 7, the particular path 7 involved in each case signifying the relevent di ection. The timing of the received echo in relation to the transmitted pulse provides, in the conventional manner, a measure of the range from which the echo is received. The actual construction of the display unit 8 is not of primary importance, but it can conveniently be as shown in FIGURE 2.

Referring to FIGURE 2, the display is provided by a cathode-ray tube unit 17, the unit 17 being connected to the paths 7 one at a time and in turn through an electronic switch 18. The switch 18 receives, in common with a time-base unit 19, the synchronisation signal supplied via the path 9 from the common transmission-control unit 6, and this serves to coordinate the stepping sequence of the switch 18 with the time-base of the display. The time-base unit 19 supplies to the unit 17 time-base waveforms appropriate to the representation in Cartesian coordinates of range against bearing, that is to say, appropriate to a Type B display. In this display, the echoes are indicated by intensity modulation of the cathode-ray trace, all the paths 7 being connected to the time-shared unit 17 in turn as the trace is swept progressively across the bearing-axis of the display. The full sweep of the trace, and hence the sampling of all seventy paths 7, takes place within the duration of a transmitted pulse, that is to say, all within thirty microseconds.

Where, from a practical standpoint it is desired to avoid the need for a sampling switch such as the switch 18, a form of display unit 8 not involving time-sharing may be used. Alternative forms of the unit 8 not involving time-sharing are illustrated in FIGURES 3 and 4.

Referring to FIGURE 3, the seventy paths 7 are connected respectively to seventy recording pens 20 that are carried together, but spaced from one another, across the width of a recording paper 21. The paper 21 moves slowly lengthwise under the pens 20 and is marked by them in accordance with the echo signals received, the particular position in each vase being indicative, by its distance across and along the paper 21 respectively, of the bearing and range from which the relevant echo is received. It may be arranged that the same length of paper 21 moves under the pens 20 during repeated recording sequences so that the representations of corresponding echoes received during the successive sequences are correlated with one another in the record.

Referring to FIGURE 4, the seventy paths 7 are in this case connected respectively to seventy indicating lamps 22. The lamps 22 (which may be, for example, neon or gallium-arsenide lamps) are carried together, but spaced apart from one another, across the width of a rectangular display area 23. The lamps 22 are moved together from one end to the other along the length of the area 23, the lamps 22 emitting light in response to signals supplied from the paths 7. The position across the width of the area 23 and along its length at which light is emitted, indicates the bearing and range from which an echo is received.

The apparatus described above with reference to FIGURE 1 provides constant surveillance, with a high degree of acuity, throughout the defined angular sector, and does this without the need for any mechanical or electronic method of repeatedly sweeping or scanning the sector with a narrow beam of acoustic energy. Accordingly, since there is no limitation imposed by beam-scanning speed, there is no untoward restriction on the duration of transmitted pulse used. These advantages are achieved simply and economically, the need to provide the multiplicity of separate transmission-reception channels 3 being readily met using, for example, techniques involving printed-circuit construction. Clearly, the channels 3 could be simplified by arranging that the function of each is limited to reception, transmission being carried out by means of a unit common to all the transducers 1. This would not necessarily lead to economy and more efficient operation, owing to the fact that the power required from the common transmission unit would be some seventy times that required from each individual channel 3. Additionally, there would be the need to effect very rapid switching of connections to the transducers 1 between the periods of transmission and reception. In order to avoid this switching, separate transducers for transmission and reception could be used, transmission being made by a transducer not associated with the reflector 2.

With the separate transmission-reception channels 3, the transmission of pulses from the different transducers 1 may be effected concurrently or sequentially, and may also be made conveniently using different carrier frequencies as between these transducers 1. The use of different carrier frequencies in this manner can be practical importance in distinguishing between echoes received from the region where side-lobes of adjacent transducers 1 overlap one another. The side-lobes of the transducers 1 could be reduced by shaping the transducers 1 themselves, but the same effect might be achieved more readily by shaping of the reflector 2.

Simplification in the construction of the reflector 2 can be achieved using a cylindrical rather than spherical, concave form. The aberration introduced if the spherical reflector 2 is replaced by a cylindrical reflector having its axis of curvature parallel to the shorter aperture-dimension, is dependent upon this dimension and the radius of curvature involved. Provided that the change in acoustic path-length introduced at any point in the aperture is substantially less than a quarter of the relevant wavelength, the aberration for normal purposes can be expected to be small.

With the sonar apparatus described with reference to FIGURE 1, directional acuity is obtained throughout a sector in one plane only. If directional acuity is required in both elevation and azimuth, then a two-dimensional array of transducers rather than the one-dimensonal array of FIGURE 1, can be used with a spherical reflector' If a square array is used with a reflector of circular aperture, then the same directional acuity can be obtained in both planes. The echo signals derived by the separate channels of the two-dimensional array may be used to provide a two-dimensional display "picture" of the water at a selected range, targets in the plane normal to the acoustic beams at this range being represented in the display at positions corresponding to the positions in the plane. The acoustic signals transmitted in this case can be continuous wave (CW) instead of pulsed; it may be necessary in certain cases to increase the frequency of these signals in order to obtain the desired acuity.

Display techniques involving stereoscopic effects, real or simulated, may be employed with the apparatus. Additionally, by displacing the array of transducers 1 slightly with respect to the reflector 2, the range at which targets are in focus can be selectively adjusted. By suitable choice of the parameters of the array and reflector 2, a small depth of field can be obtained, targets within focus being presented for display with partial elimination of targets out of focus. A stop, positioned at the centre of curvature of the reflector 2, may be used to limit the exit- and entry-angle of acoustic energy with respect to the reflector 2, and thereby ensure uniform acoustic illumination across the effective aperture of the system.

The sonar apparatus described above with reference to FIGURE 1 may clearly be used on the ship to provide

either a forward or a sideways-looking search. The plane of the sector of search may be vertical instead of horizontal as described, and in this case it may be arranged that each beam is inclined, downwardly, to the vertical. A display limited to the bottom of the water and the region just above it can in these circumstances be obtained simply by arranging that the unit 8 displays in sequence the detected signals applied via the paths 7. The earliest echo of the bottom received by the apparatus after transmission of a pulse, is that originating from the beam of least inclination to the vertical, so that by selecting the detected signal on the lead 7 appropriate to this beam, and then the detected signals on the other lead 7 in sequence thereafter, a display limited to the bottom and its adjacent region of water over a substantial distance, can be achieved with a high degree of acuity.

Although the apparatus of the present invention is referred to in general terms as "echo-ranging" apparatus it is to be understood that in its broadest aspect the invention as described and claimed herein, does not necessarily involve measurement of range, the term echo-ranging being used simply to refer to the kind of apparatus in which sensing of echoes is utilised.

We claim:

1. Echo-ranging apparatus comprising: means for receiving echoes from a multiplicity of different directions throughout a predetermined angular sector, said means comprising an echo-reflector having a concave reflecting surface that is of circular arc in section, and a multiplicity of echo-receiving elements mounted side by side around the focal surface of said reflector to receive echoes via said reflecting surface from respective ones of said directions, said elements being mounted in a circular arc concentric with said arc of section; a multiplicity of reception channels coupled respectively to said echo-receiving elements for detecting echoes received by said means; and further means coupled to said reception channels for providing a representation of at least the directions within said sector from which echoes detected as aforesaid are received, said further means providing representation of direction of reception of each such echo in accordance with whichever of the reception channels detects that echo.

2. Echo-ranging apparatus according to claim **1** wherein the reflector is a spherical concave reflector.

3. Echo-ranging apparatus according to claim **1** whereing said further means includes means for displaying detected echoes each in accordance with the direction and range from which that individual echo is received.

4. Echo-ranging apparatus according to claim **3** wherein said further means comprises a display device and a switch for coupling the reception channels in turn to the display device to receive from the reception channels sequentially signals in accordance with echoes detected by the different reception channels.

5. Echo-ranging apparatus according to claim **3** including a multiplicity of echo-recording devices, and means coupling different ones of the recording devices to different ones of the reception channels to record echoes detected by the different channels.

6. Echo-ranging apparatus according to claim **5** including a recording surface, and a multiplicity of spaced pens for marking the recording surface in accordance with echoes detected by the different reception channels.

7. Echo-ranging apparatus according to claim **3** including a multiplicity of indicating devices, and means coupling different ones of said indicating devices to different ones of the reception channels to provide indication of echoes detected by the different reception channels.

8. Echo-ranging apparatus according to claim **7** wherein the indicating devices are spaced lamps.

9. Echo-ranging apparatus according to claim **1** including a multiplicity of separate transmission channels coupled respectively to said elements for supplying electric carrier-wave oscillations thereto, each said transmission channel being individually actuable to supply said carrier-wave oscillations to its respective one of said elements, each said element being responsive to the supply of said carrier-wave oscillations from its respective one of said transmission channels to emit corresponding acoustic energy.

10. Echo-ranging apparatus according to claim **9** wherein said carrier-wave oscillations are pulsed oscillations, each said element emitting pulses of acoustic energy alternating with the reception of echoes.

11. Sonar apparatus comprising: a concave reflector having a curved focal surface, said reflector being of circular arc in section; a multiplicity of electromechanical transducers mounted closely side-by-side around said curved focal surface of the reflector for receiving via the the reflector acoustic echoes from a multiplicity of closely-spaced angular directions throughout a predetermined angular sector, said transducers being mounted in a circular arc concentric with said arc of section to receive echoes as aforesaid from respective ones of said directions; a multiplicity of reception channels coupled respectively to said transducers for detecting echoes received by the transducers; and a display unit for providing a display of both direction and range from which echoes detected as aforesaid are received, said display unit including means for representing each displayed echo with a direction of reception in accordance with whichever of said reception channels detects that particular echo.

12. Sonar apparatus according to claim **11** wherein said directions are equally angularly-spaced from one another throughout said sector.

13. Sonar apparatus comprising: a concave spherical reflector having a spherical focal surface; a multiplicity of electromechanical transducers mounted closely side-by-side on said focal surface for receiving via the reflector acoustic echoes from a multiplicity of closely-spaced angular directions throughout a predetermined angular sector, different ones of said transducers receiving echoes as aforesaid from different ones of said directions; a multiplicity of reception channels coupled respectively to said transducers for detecting echoes received by the transducers; and a display unit for providing a display of both direction and range from which echoes detected as aforesaid are received, said display unit including means for representing each displayed echo with a direction of reception in accordance with whichever of said reception channels detects that particular echo.

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