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(71) Applicant *(for all designated States except US):* SEA SCAN TECHNOLOGY LTD. [GB/GB]; Unit 6, Crown Avenue Industrial Estate, Tredegar, Gwent NP2 4EF (GB).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)* : PHILLIPS, Peter, Stanley [GB/GB]; Sunny View, Llwyndu, Abergavenny, Gwent (GB).

(74) Agent: GIBSON, Stewart, Harry; Urquhart-Dykes & Lord, Business Technology Centre, Senghennydd Road, Cardiff CF2 4AY (GB).

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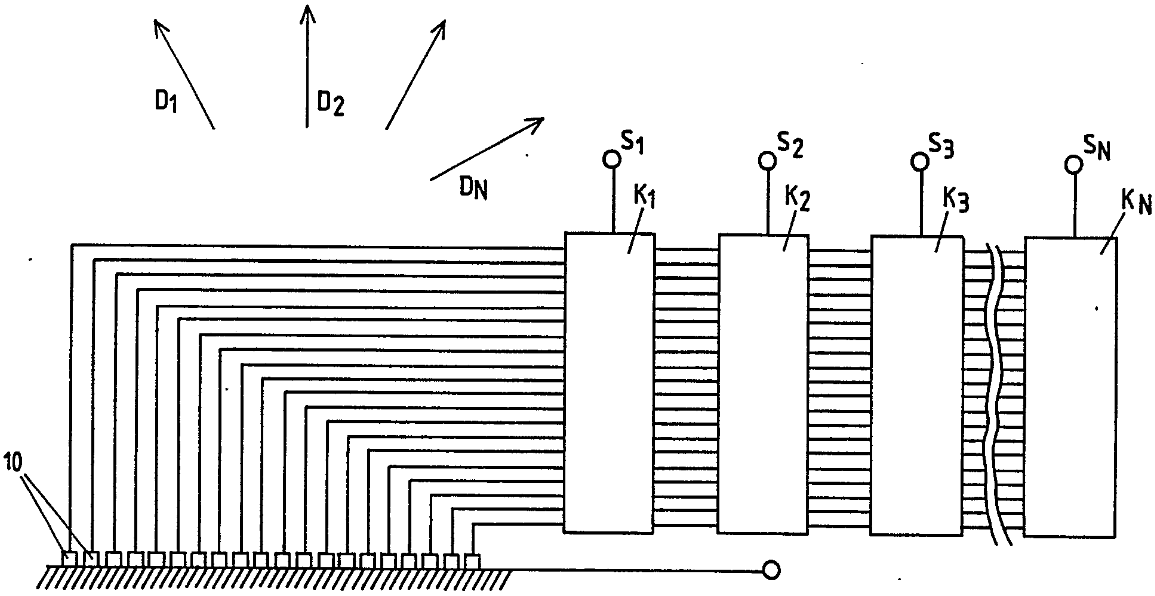

(57) Abstract

A sonar surveying system includes a receiving transducer which comprises an array of sensor elements (10) the outputs of which are connected to a plurality of banks KI to KN of delay elements, and means for summing the outputs of the delay elements of each respective bank to provide simultaneously a corresponding plurality of output signals SI to SN, one from each bank, representing sonar beams received from respective directions D to DN. A parallel processing system is provided for simultaneously processing the plurality of output signals SI to SN.

* See back of page

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SONAR SURVEYING SYSTEM

This invention relates to a sonar surveying system for surveying an ocean bed or the like.

Recent years have seen an unprecedented increase in the exploitation of the ocean environment for commercial, social and scientific purposes. This, together with a tendency towards larger vessels for the movement of cargoes, has produced a growing demand for accurate offshore surveys.

Commercial exploitation purposes require precise measurements of the sea floor and the larger vessels produce requirements for accurate depth measurements in harbour approaches. Objects located on the sea floor require the use of a high resolution sea floor profiler if they are to be detected.

Sonar surveying systems are known which can map the sea floor or objects thereupon. These systems consist of basically three types, namely echo sounding sonar, side scan sonar and sector scanning sonar.

Echo sounding sonar systems use a single transmit/receive transducer comprising an active element which beams a pulse of sound vertically downwards. A measure of the time delay between transmission of the pulse and reception of the reflected signal from the sea floor then gives the depth of water at that point.

Side scan sonar systems use a pair of sonar transducers for obtaining sea floor profiles on either side of the survey vessel. Each transducer transmits a short sound pulse sideways and downwards. These sonar transducers each comprise a number of active elements 10 arranged in a linear array as shown in Figure 1a. Each returning sound signal, produced by the backscatter of the transmit pulse, produces signal outputs from these elements. By summing the signals from each element to provide a signal S out, an overall increased directional sensitivity is achieved - this being broad in elevation (Figure 2) and narrow in azimuth (Figure 1). This is termed the beam pattern of the transducer 12. The transducer therefore only receives data from a narrow azimuth angle perpendicular to the face of the transducer. Thus each transmission results in gathering a line of seafloor data perpendicular to the transducer face to a maximum range dependent on the frequency and power of the side scan system.

Hence the ship is steered along a known track to scan a broad swathe of sea floor and the return signals from the sea floor are used to build up a profile of the sea bed based upon the amplitude of the returns.

In order to avoid problems due to sudden changes in temperature or salinity, the transducers may be deployed on a submersible or "fish" towed below the layers of water which are subject to the sudden changes.

Sector scanning sonar systems use similar transducer arrays as side scan systems. However by introducing time delays on the signals from the individual elements 10 of the transducer, the angle which the narrow beam pattern (in azimuth) makes to the face of the transducer can be varied. This is known as "steering" the beam pattern. Thus on one sonar transmission the output signals from the elements 10 are subjected to respective time delays before summing, producing a line of sea bed data from a predetermined angle to the transducer face; on subsequent transmissions different time delays produce lines of data from different directions. Thus a fan of sea bed data can be built up, using different time delays KI to KN for respective directions KI to KN as shown in Figure 3.

The major disadvantage of the last two systems lie in their inability to produce precise measurements of ocean depths at known positions from the data received. In order to obtain accurate depths at fixed points, echo sounding techniques must be employed. This method however is very time consuming and expensive, because in order to survey a given area A the ship must be steered in a grid pattern over that area with depth soundings at regular intervals DS, as shown in Figure 4.

I have now devised a sonar surveying system from which both depth and position information can be derived. This system can be used in a side scanning mode or in a sector scanning mode.

In accordance with this invention, there is provided a sonar surveying system including a receiving transducer which comprises an array of sensor elements the outputs of which are connected to a plurality of banks of delay elements, and means for summing the outputs of the delay elements of each respective bank to provide simultaneously a corresponding plurality of output signals, one from each bank, representing sonar beams received from respective directions.

Preferably a parallel processing system is provided for simultaneously processing the plurality of output signals. Preferably this parallel processing system comprises one or more parallel processing elements such as the transputer manufactured and sold by Inmos of Bristol, England.

For a side scan or sector scan sonar surveying system, a second transducer is mounted a predetermined distance above the first transducer and comprises a second array of sensor elements the outputs of which are connected to a second plurality of banks of delay elements, and means for summing the outputs of the delay elements of each respective bank of the second plurality to provide simultaneously a corresponding second plurality of output signals, one from each bank of the second plurality, representing sonar beams received by said second receiving transducer from said respective directions.

Preferably the processing system processes the output signals in pairs, one from a bank of delay elements in the first plurality and the other from a bank of delay elements in the second plurality and representing a sonar beam received from a predetermined direction, said pair of output signals being processed to determine the phase difference therebetween and to determine the amplitude of the received sonar beam.

An embodiment of this invention will now be described by way of example only and with reference to the accompanying drawings, in which:

FIGURE 1 shows in plan view a transducer comprising a linear array of active sensor elements the output signals from which are summed together;

FIGURE 2 is a side view showing a sonar pulse being transmitted from a transducer and reflected from the sea floor;

FIGURE 3 shows in plan view a transducer comprising a linear array of active sensor elements the outputs of which are passed through respective delay elements and then summed to represent a beam received from a direction predetermined by the delay elements;

FIGURE 4 shows a typical course followed by a survey vessel over an area A if regular depth soundings are necessary to determine the depth of the sea floor below the survey ship;

FIGURE 5 shows a transducer of a survey system in accordance with this invention;

FIGURE 6A is a diagram to show two transducers of a side scan or sector scan sonar surveying system and a sonar return approaching them at an angle a to the vertical;

FIGURE 6B is a diagram to show the depth of and horizontal distance to the point of reflection;

FIGURE 7 is a diagram to show the relation of the phase difference between the signals from the two transducers of Figure 6A, relative to the depression angle a;

FIGURE 8 is a diagram to illustrate the different attitude variations which can occur in a "fish" on which the transducers are mounted;

FIGURE 9 is a general block diagram of a sonar surveying system in accordance with this invention;

FIGURE 10 is a block diagram of the electronic system mounted in the fish;

FIGURE 11 shows a lookup table used to convert measured phase angles to depression angles; and

FIGURE 12 is a block diagram of a parallel processing system in the fish for processing the signals from the two transducers.

The sonar surveying system comprises two portions, one housed in a water tight pressure vessel and the other being carried onboard the ship. The two portions of the system are linked by a high speed data link. The pressure vessel may be mounted directly to the survey ship, or within a towed fish, or within a remotely operated submersible. The ship-borne unit provides control for the overall system and includes recording facilities and also facilities to provide on-line VDU displays of attitude, sonar amplitudes and sea floor profiles.

A transducer of the system is shown in Figure 5 and comprises a linear array of active sensor elements 10. The outputs from these sensor elements are passed through successive banks KI ... KN of delay elements, the outputs of each bank being summed to provide respective output signals SI - SN corresponding to sonar return beams received from respective directions DI - DN. In accordance with this invention, the output signals SI - SN are processed simultaneously, so that a display can be generated representing a visual image of the sea floor over a broad angle of view as seen from the location of the transducer. The system comprises two such transducers TRl and Tr2 as will now be explained with reference to Figures 6a and 6b: each of transducers Trl and Tr2 is as shown in Figure 5, each with its several banks of delay elements to provide pairs of output signals (one from Trl and the other from Tr2) related to a return beam received from a respective direction.

Referring to Figure 6a and 6b, the main principles of the side scan sonar interferometer will be described. Transducers Tr1 and Tr2 are disposed one above the other, spaced apart a short distance $N\lambda$(where λ is the wave length of the transmitted wave). A sonar pulse is transmitted from one transducer e.g. Tr2.

The sonar return is at a depression angle a, such that the depth D of, and horizontal distance Ds to, the point of reflection is given by R Cos a and R Sin a respectively, where R is the absolute range of the reflection. The sonar return will reach the upper transducer Tr2 slightly after the lower transducer Tr1, because the path length to the upper transducer is greater by the amount X. Hence the phase difference between the output signals of the two transducers is given by:

$$Q = 2N\pi \text{Cos } a$$

It will be seen from the above relation that the phase angle Q will experience a 0 to 360 degree phase shift N times for a change in depression angle a from 0 to 90. This is shown graphially in Figure 7 as a number of phase "fringes" for a value of N = 3. Thus, for N >1, there is an anomaly in the phase angle to depression angle relationship. To eliminate this anomoly it is necessary to detect the absolute phase of the signal, from the sea bed, first detected by the transducers after the sonar transmission pulse. The system may use two methods.

In one, a first return phase detector detects the absolute time delay of the first return. In the other, use is made of the vertical depth data obtained from a precision echo sounder, previous sea floor profile data and the beam pattern of the transducer, to estimate the position and hence the absolute phase of the first return. The two methods can be used in a complementary verification mode or in a stand alone mode, the operating mode being selected via the main shipboard operator interface.

The initial first return data is then used to locate a pointer in a phase-to-depression angle lookup table. Subsequent phase data is then used to track phase/depression angle pairs through this lookup table, ensuring that the conversion to depression angle uses the correct phase fringe. This is explained later.

Phase is measured by a digital phase meter using zero crossing detectors starting and stopping high speed counters. This information is fed to an online parallel processing system which performs a running average on the phase angle values, organizes the data from port and starboard transducers, adds attitude, status, echo sounder, pressure data etc. information and outputs the result to the main ship board parallel processing system. The number of values of phase angles being used by the averager are set by the operator.

Errors due to changes in the attitude of the transducers as they scan the sea bed are eliminated retrospectively by software running on the main processing system. This software requires the measurement of the six possible attitude variations, these being roll, pitch, yaw, heave, surge and sway and are shown graphically in Figure 8. An attitude sensing package consisting of gyros and accelerometers is incorporated in the fish to measure these values.

Figure 9 shows the main components of the survey system, these being the fish electronics FE, operator interface (control and analysis parallel processing system) PE, high resolution graphic displays GD, digital mass storage medium ST and position fixing equipment PF (which includes systems for measuring any offset of the fish from the main ship's position fixing equipment). Data from the fish is sent over a high speed bidirectional data link LN to the ship-borne unit SU. This stores all incoming data from both the fish and position fixing equipment onto the digital recording media. Some online analysis of the data is also performed to give samples of the sea floor profiles hence enabling the qualty of the survey data to be monitored. The system PE is also used to communicate with the parallel processing system housed in the fish thus enabling online changes to be made to the operating parameters of the overall surveying system.

Figure 10 shows the fish electronics in block diagram form, comprising pre-amplifiers PRE1 and PRE2, Automatic Gain control Amplifiers AGC1 and AGC2, parallel processing signal acquisition element P2, sonar pulse generator SP, data acquisition system DA, digital phase meter DP, first return phase meter FD, system status and alarms circuit SSA, parallel processing control and communications elements P1 and envelope detector ED. The system shown in Figure 10 is simplified in that it assumes only one signal from each of Tr1 and Tr2: the manner in which the multiple signals SI to SN from each transducer are handled will be explained with reference to Figure 12.

Under control of the operator the power, duration and repetition rate of the sonar pulse is set by P1 via a set-pulse board SP, a Power amplifier PA generating the necessary power to drive the transducer Tr2. A precision clock is also initiated at transmission time. Immediately after the sonar pulse (or "ping") is transmitted the data acquisition system DA under the control of P1 multiplexes the attitude data to the surface, and data from a status and water alarms circuit SSA is also transmitted at this time. The system then awaits the detection of the first return, whereupon the absolute phase is determined by the first-return phase meter FD, this data being stored for later reference. The time, as determined by the precision clock, is also recorded at the detection of the first return. Both the clock and absolute phase data are transmitted to the surface for use in the later analysis. The first return detector FD also enables the digital phase meter DP allowing phase data to be transmitted to the element P2 for processing.

The digital phase meter DP uses zero crossing detectors to start and stop digital counters - these counters being fed from the Automatic gain control amplifiers AGC1, AGC2 which maintain their signal outputs at a constant level. The zero crossing detectors connected to transducer Tr1 via PRE1 and AGC1 are used to enable the other detectors connected to TR2 in sequence so that the measurement is always of the phase on Tr2 with respect to Tr1. Phase differences are measured between zero crossing detections occurring as the signal level passes from a negative to a positive voltage (positive-going detection) and for signals passing from a positive to a negative voltage (negative-going detection).

Phase values for both positive- and negative-going detections are then transmitted to the parallel processing element P2 (one digital sample consisting of a pair of these phase values). P2 then performs a running average on these digital samples, the number of values used in this averaging processing being preset by the operator. This eliminates DC drift in the preamplifiers and AGC's.

An envelope detector consisting of an A to D converter ED (Figure 10) feeds amplitude data to the parallel processing element P2. Here it is combined with the averaged phase angle data, for transmission to the surface unit. This enables traditional side scan sonar plots to be produced from the equipment to assist in the analysis of survey data. This data is also used to detect areas of poor signal return.

The system has been described for one sided scan. To produce information from port to starboard of the fish the following circuits would be duplicated:- preamplifiers, AGC's, envelope detector, digital phase meter, first return detector and microcomputer signal and analyser as marked in Figure 10.

The final signal processing is performed by the shipborne parallel processing system PE which uses a series of algorithms to process the data. The raw data is firstly stored on the digital mass storage media ST for later analysis. The phase data is then converted to a depression angle by use of the lookup tables shown in Figure 11. The value of the first return enables the pointer P to be positioned in the correct place in this table; subsequent values of phase are then used to search in the search window W around pointer P for a conversion value to depression angle pointer P is then updated to a new position by the last phase value converted.

The conversion is inhibited when the signal level falls below a predetermined minimum, set by the number of values in the averaging process whose amplitude falls below a set level (as detected by the envelope detector) exceeding a predetermined minimum. This eliminates errors that can occur due to shadow areas where signal levels fall below the general noise level. A value of depression angle, equal to that extracted from the last piece of acceptable data, is then used as the current value and a flag is attached to this data which is used to indicate poor data areas on the ship-board displays. Roll errors are then corrected.

A conversion is then made from depression angle range R to a depth/distance matrix. The absolute range R is determined by measuring the speed of sound in the sea at the survey site, then using the data from the clock to determine the range of the first return. Subsequent ranges to this are then predetermined by the digitizing rate of the system. Position data is then added - with corrections for yaw, pitch, heave, surge, sway and any offset of the fish from the main ship's position - to produce the depth/position matrix. Finally this data is displayed on the graphics display GD in different formats as required by the operator. Hard copies can be obtained on a proprietary graphics plotter GP as required.

As the initial signal processing is performed by an essentially "soft" system the characteristics of this processing can be altered in the field, by the ship-board main computer. Hence the range of values of the averaging algorithm may be changed to suit the particular type of sea floor being surveyed, the digitizing rate of the system changed, and/or the separation of the transducers altered and new lookup tables down-loaded from the ship. Other alterations such as fine tuning of the power, duration and repetition of the transmit pulse are also available. Finally the transducers may be changed so that different sonar transmission frequencies can be used and the system parameters altered accordingly. Thus the system performance can be optimzed with regard to sea floor profiles, fish flying height above sea floor, overall range required, and accuracy of measurement required.

Hence it can be appreciated that the above surveying system may be implemented at differing transmission frequencies and digitizing rates. Further the number of beams formed may be varied up to 20 or more. The system may then be used to obtain data either side of the direction of travel using one or more beam patterns or looking in the direction of travel using one or more beam patterns.

The above is achieved by expanding the parallel processing elements and associated interferometers (comprising the pre amps, AGC's and phase meters, etc). as shown in Figure 12. A first group of parallel processing elements (transputers) is provided, each element of the group receiving a pair of signals, one from Tr1 and the other from Tr2. Element T11 for example receives the summed output S1 from the first delay bank K1 of Tr1 and the corresponding summed output from the first delay bank or Tr2, and so on. T11 determines the phase difference between Tr1 and Tr2 for the respective return beam direction, also the amplitude of this return beam. This data is passed to a parallel processing element T12 of a second group of such elements, together wth the corresponding data from two other elements T21 and T31 in the first group. The outputs of each set of three elements in the second group is passed to a further parallel processing element, and so on. There may be any number of processing elements in the first group, each set of three being connected to one element in the second group, and so on until there is a single final element to which all the data of the lower order elements are passed: the final element (as T_3 shown in Figure 12) passes the phase and amplitude data from all channels to a final output, for transmission to the ship-borne equipment.

The detection of the time delay between reception of the same signal on Tr2 after reception by Tr1 (Figure 6a) may also be varied by using correlation techniques. Here the signal time delay between the two transducers can be determined by using parallel processing elements to perform a correlation on the two received signals. Correlating the signal from the transducer Tr2 farthest from the sea floor, (the reference) with respect to the signal received from the transducer Tr1 nearest the sea floor will result in a time delay being introduced into the signal from Tr1 to produce maximum correlation. The maximum correlation point hence gives the signal time delay between Tr1 and Tr2 = X*C where C = speed of sound in water. Thus the path difference X can be computed and hence the depression angle a. The sonar transmission signal for the correlation technique could be a single frequency, a chirp, a pseudo random binary sequence, a frequency modulated sweep - linear or non linear, etc.

CLAIMS

1) A sonar surveying system, including a receiving transducer which comprises an array of sensor elements the outputs of which are connected to a plurality of banks of delay elements, and means for summing the outputs of the delay elements of each respective bank to provide simultaneously a corresponding plurality of output signals, one from each bank, representing sonar beams received from respective directions.

2) A sonar surveying system as claimed in claim 1, further comprising a parallel processing system for simultaneously processing said plurality of output signals.

3) A sonar surveying system as claimed in claim 2, comprising a second receiving transducer mounted a predetermined distance above the first transducer and comprising a second array of sensor elements the outputs of which are connected to a second plurality of banks of delay elements, and means for summing the outputs of the delay elements of each respective bank of the second plurality to provide simultaneously a corresponding second plurality of output signals, one from each bank of the second plurality, representing sonar beams received by said second receiving transducer from said respective directions.

4) A sonar surveying system as claimed in claim 3, in which the processing system processes said output signals in pairs, one from a bank of delay elements in the first plurality and the other from a bank of delay elements in the second plurality and representing a sonar beam received from a predetermined direction, said pair of output signals being processed to determine the phase difference there between and to determine the amplitude of the received sonar beam.

5) A sonar surveying system as claimed in claim 4, in which the processing system comprises a first group of parallel processing elements, each element of the first group processing said output signals in pairs, a second group of parallel processing elements, each element of the second group receiving the outputs of three elements of the first group, and at least one further parallel processing element receiving the outputs of three elements of the second group.

6) A sonar surveying system as claimed in claim 5, further comprising a second processing system which receives the output from a final parallel processing element of the first processing system, and processes that output to provide a visual image of the terrain being surveyed.

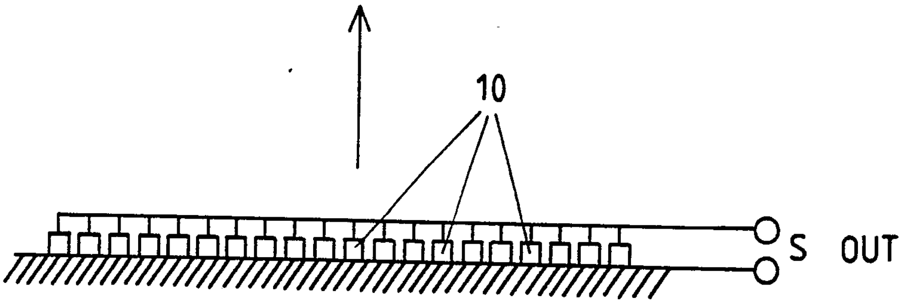

FIG. 1

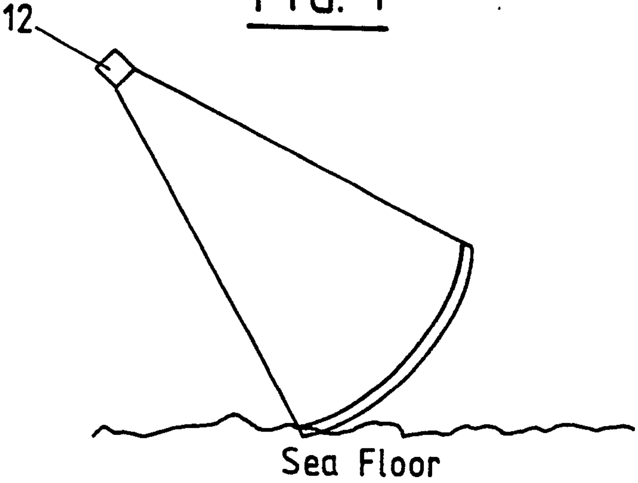

FIG. 2

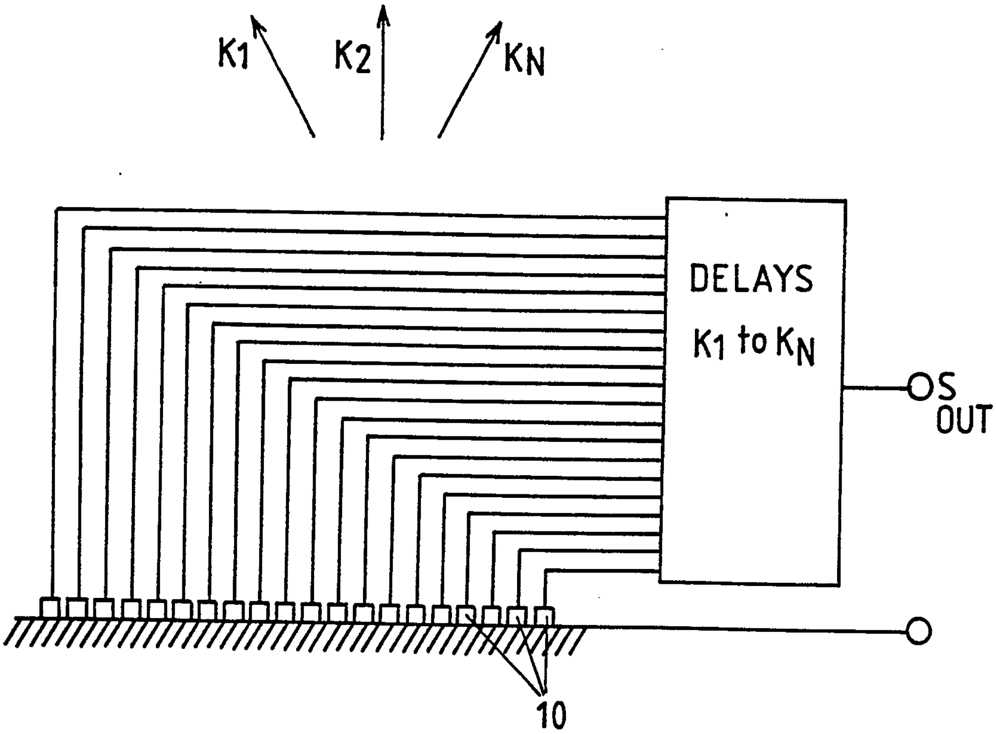

FIG. 3

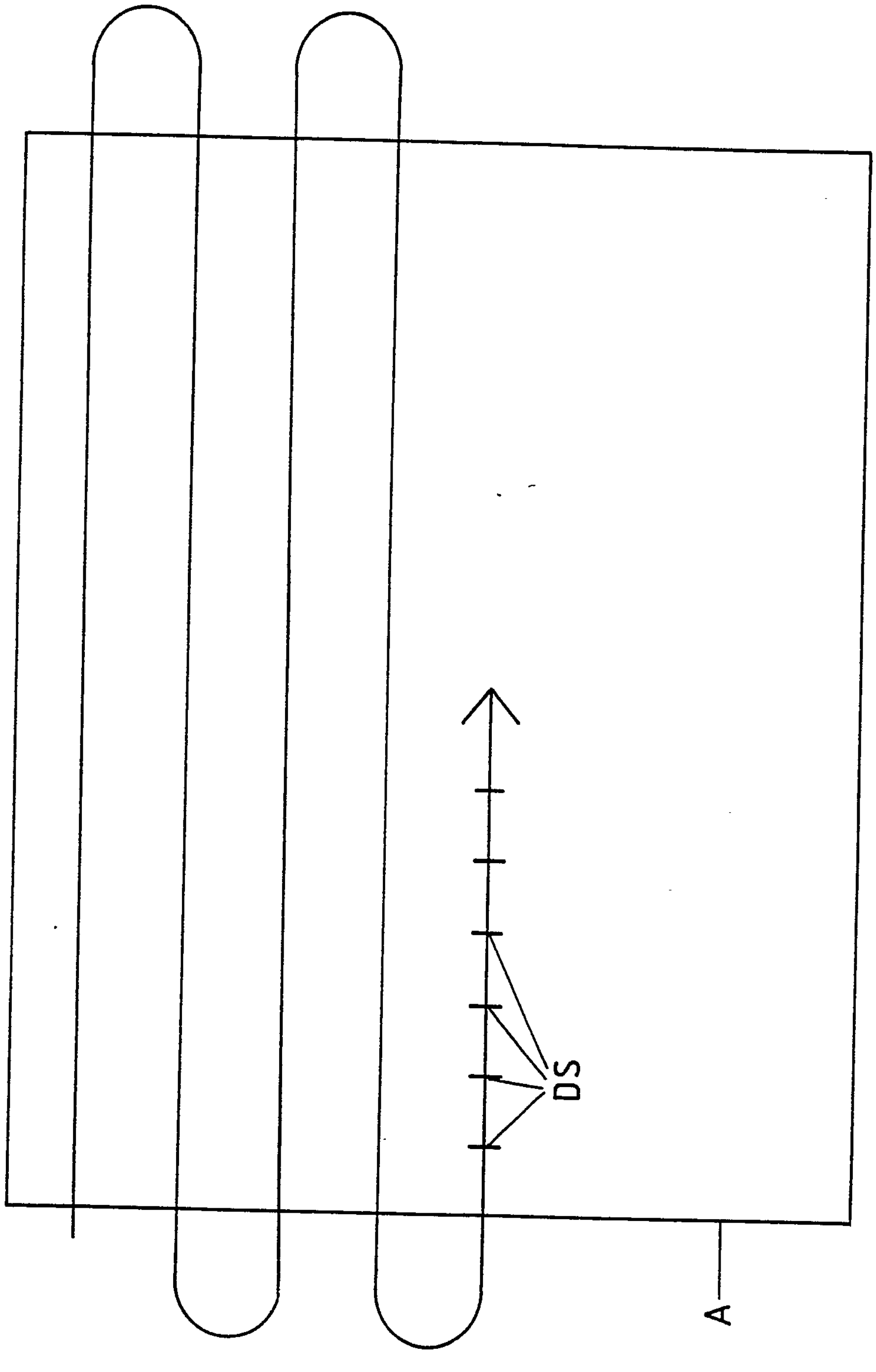

FIG. 4

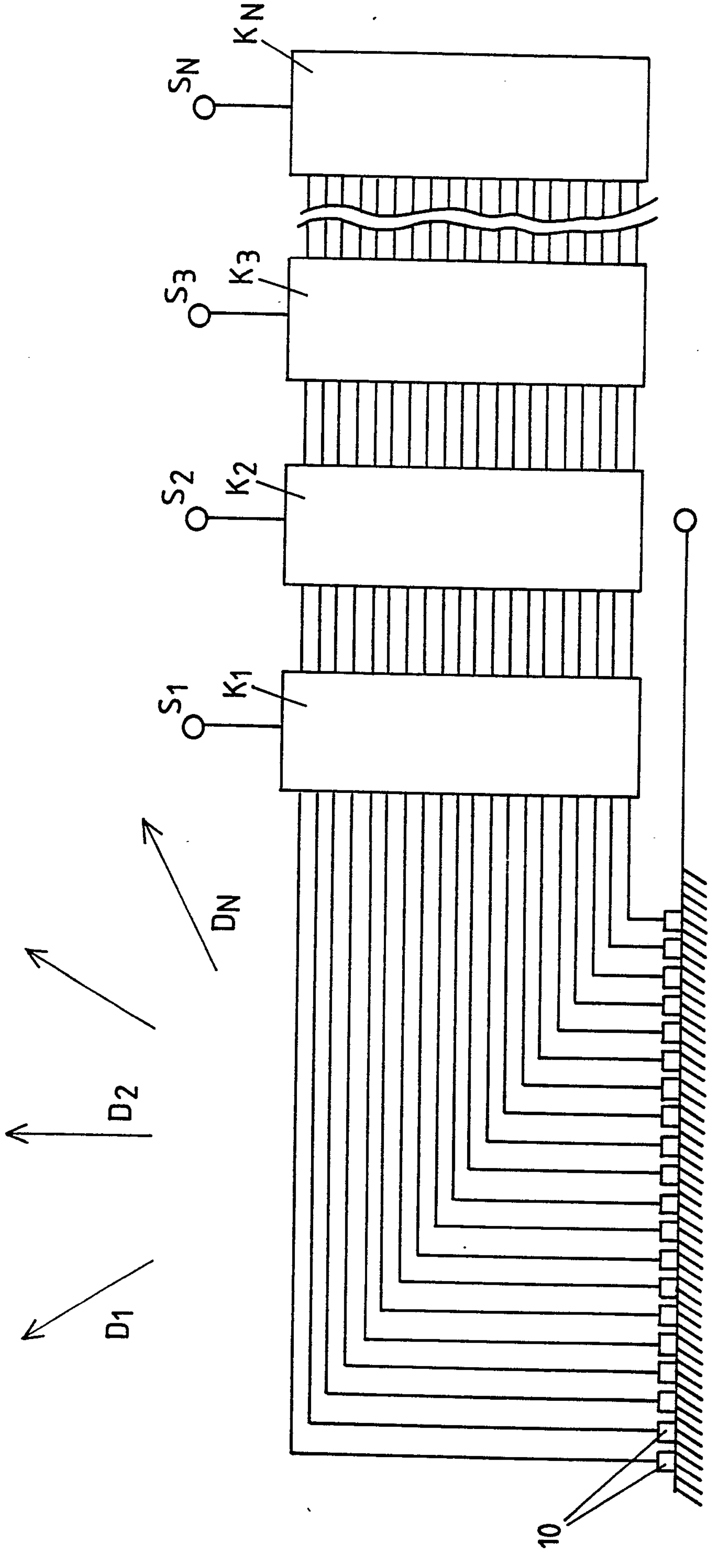

FIG. 5

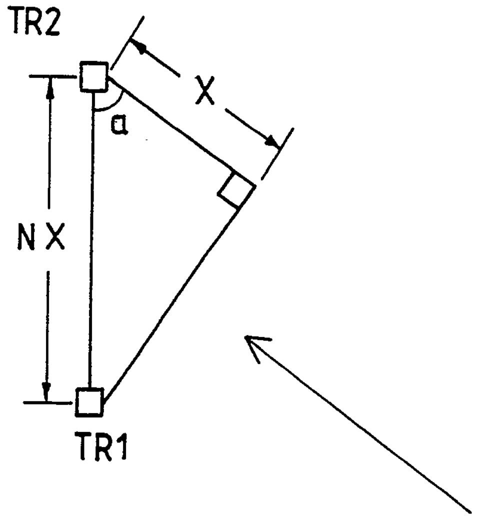

FIG. 6a

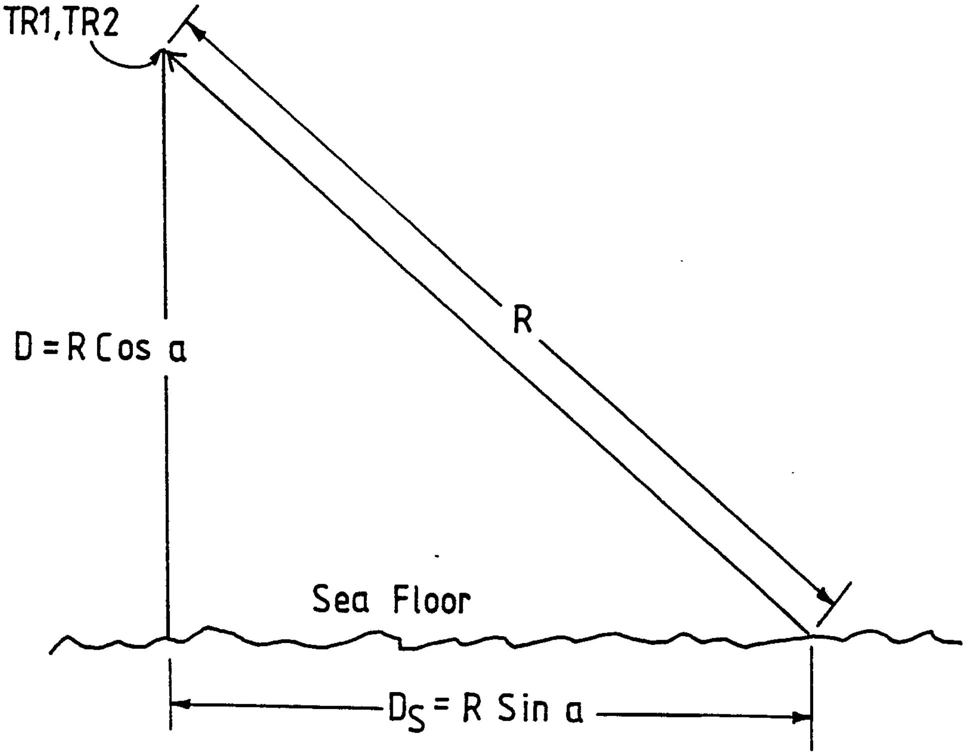

FIG. 6a

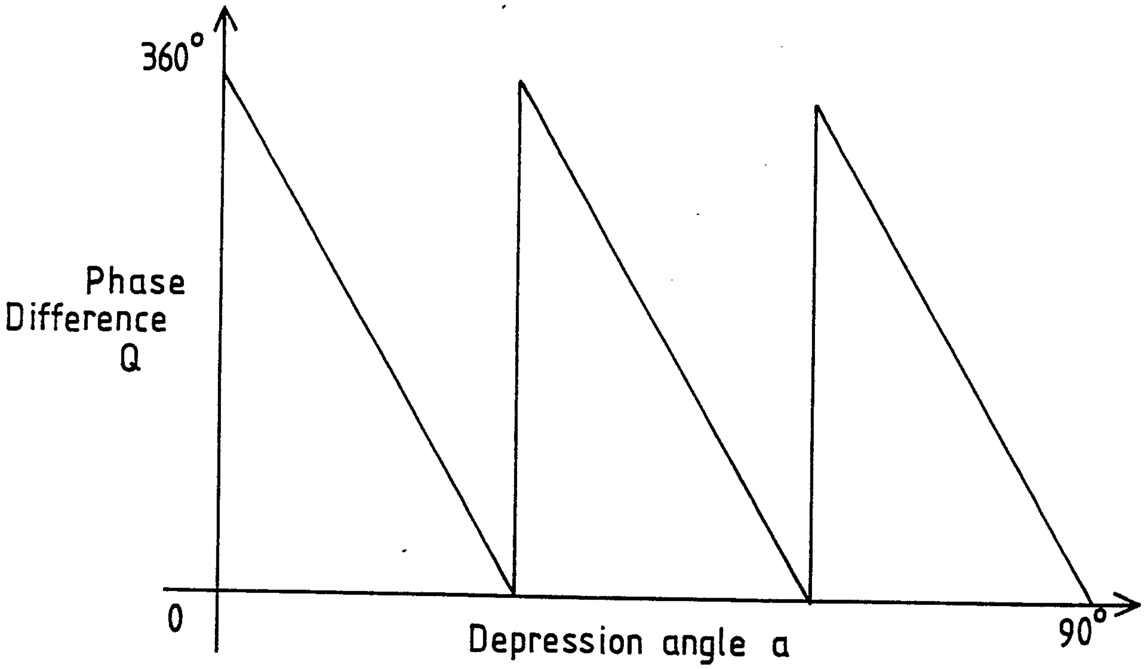
360°
Phase
Difference
Q
0
Depression angle a
90°

FIG. 7

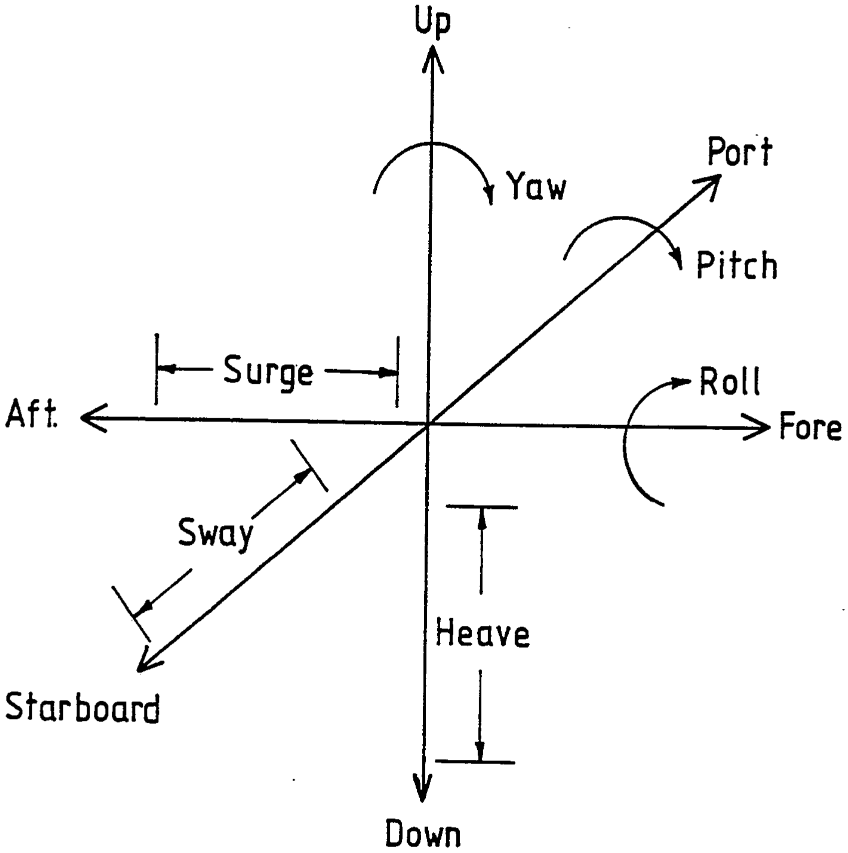
Up
Yaw
Port
Pitch
Surge
Roll
Aft.
Fore
Sway
Heave
Starboard
Down

FIG. 8

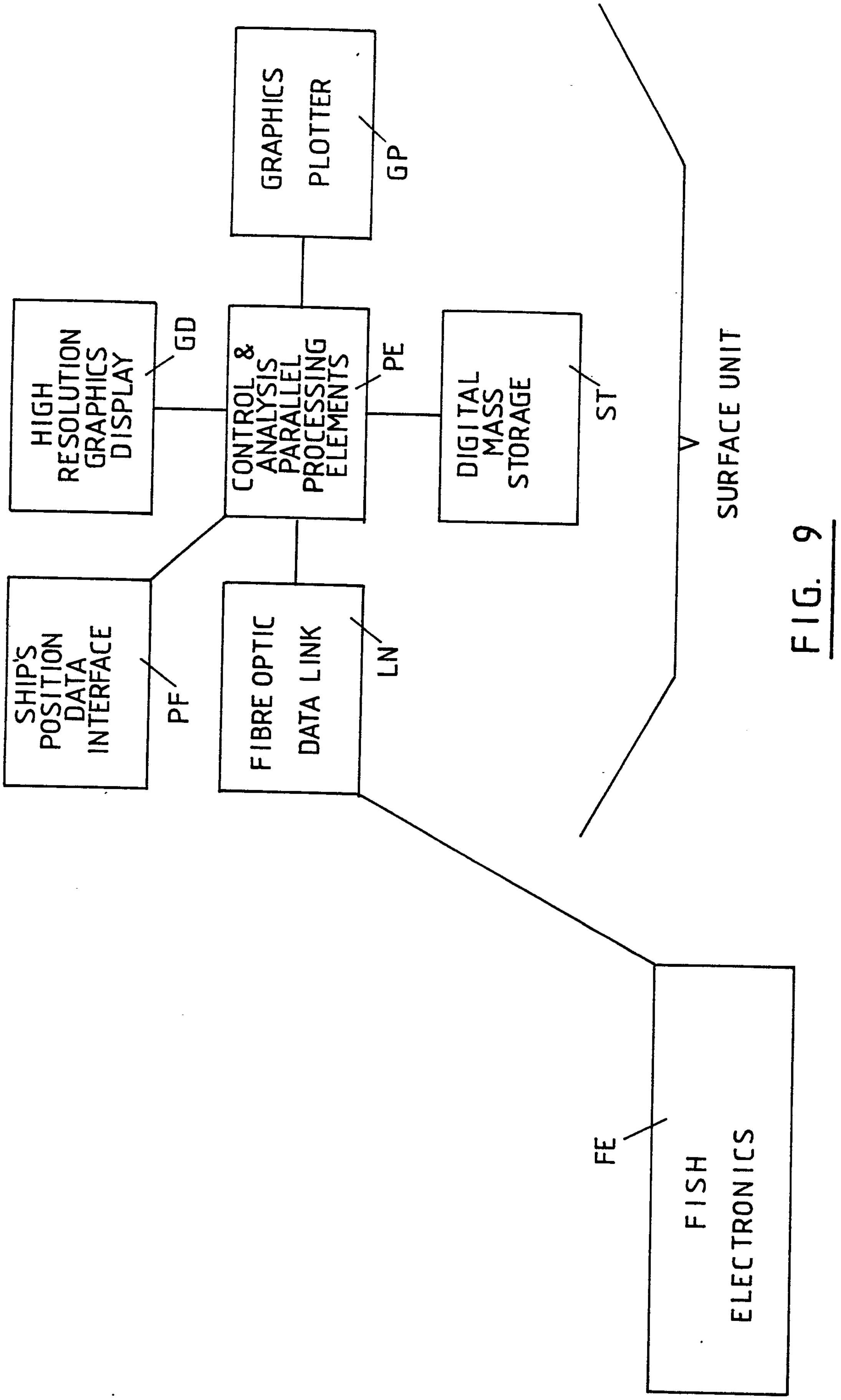
GRAPHICS PLOTTER
GP
HIGH RESOLUTION GRAPHICS DISPLAY
GD
CONTROL & ANALYSIS PARALLEL PROCESSING ELEMENTS
PE
DIGITAL MASS STORAGE
ST
SHIP'S POSITION DATA INTERFACE
PF
FIBRE OPTIC DATA LINK
LN
SURFACE UNIT
FISH ELECTRONICS
FE

FIG. 9

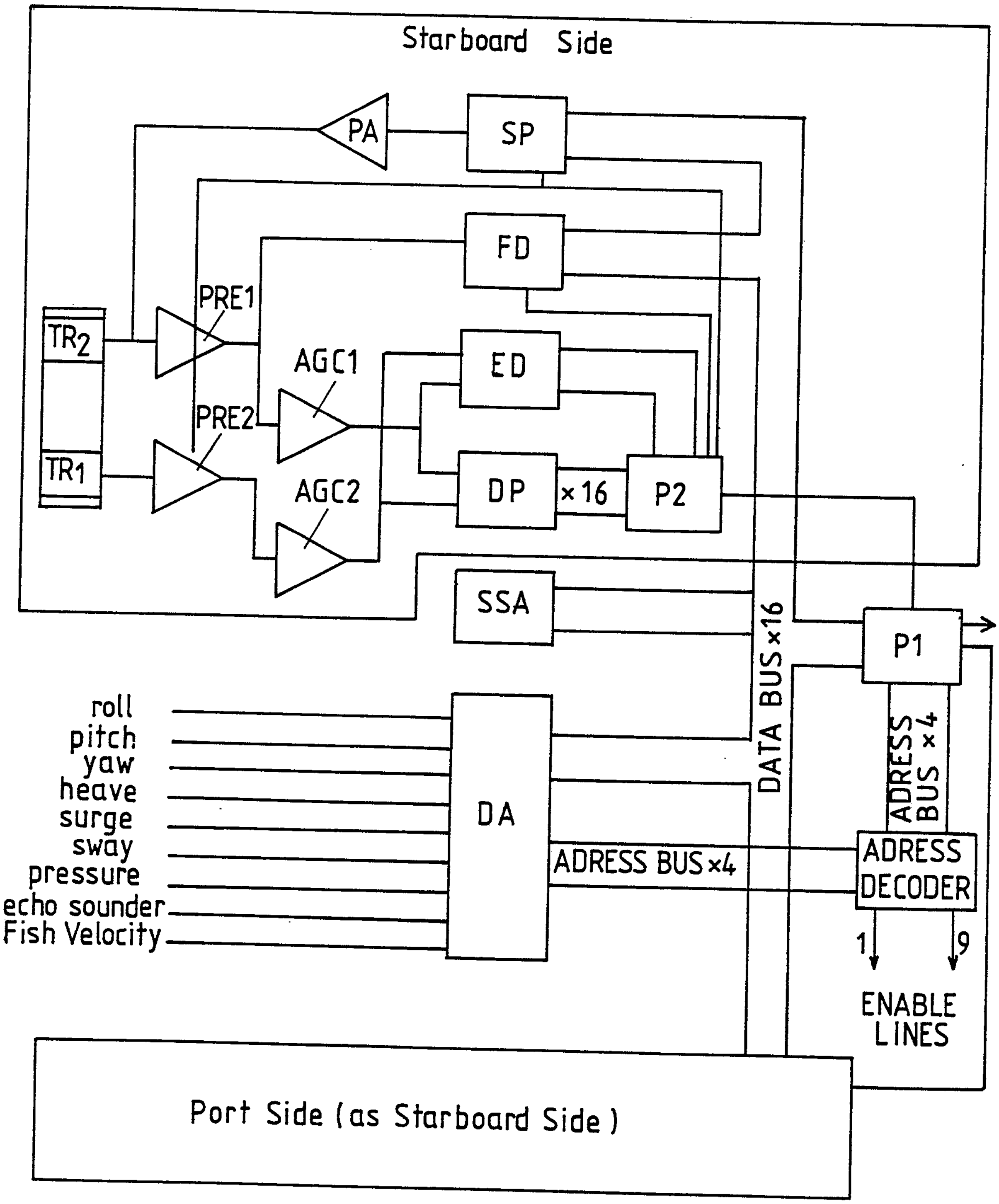
Starboard Side
PA
SP
FD
PRE1
TR2
AGC1
ED
PRE2
TR1
AGC2
DP
×16
P2
SSA
DATA BUS ×16
P1
roll
pitch
yaw
heave
surge
sway
pressure
echo sounder
Fish Velocity
DA
ADRESS BUS ×4
ADRESS BUS ×4
ADRESS DECODER
1
9
ENABLE LINES
Port Side (as Starboard Side)

FIG. 10

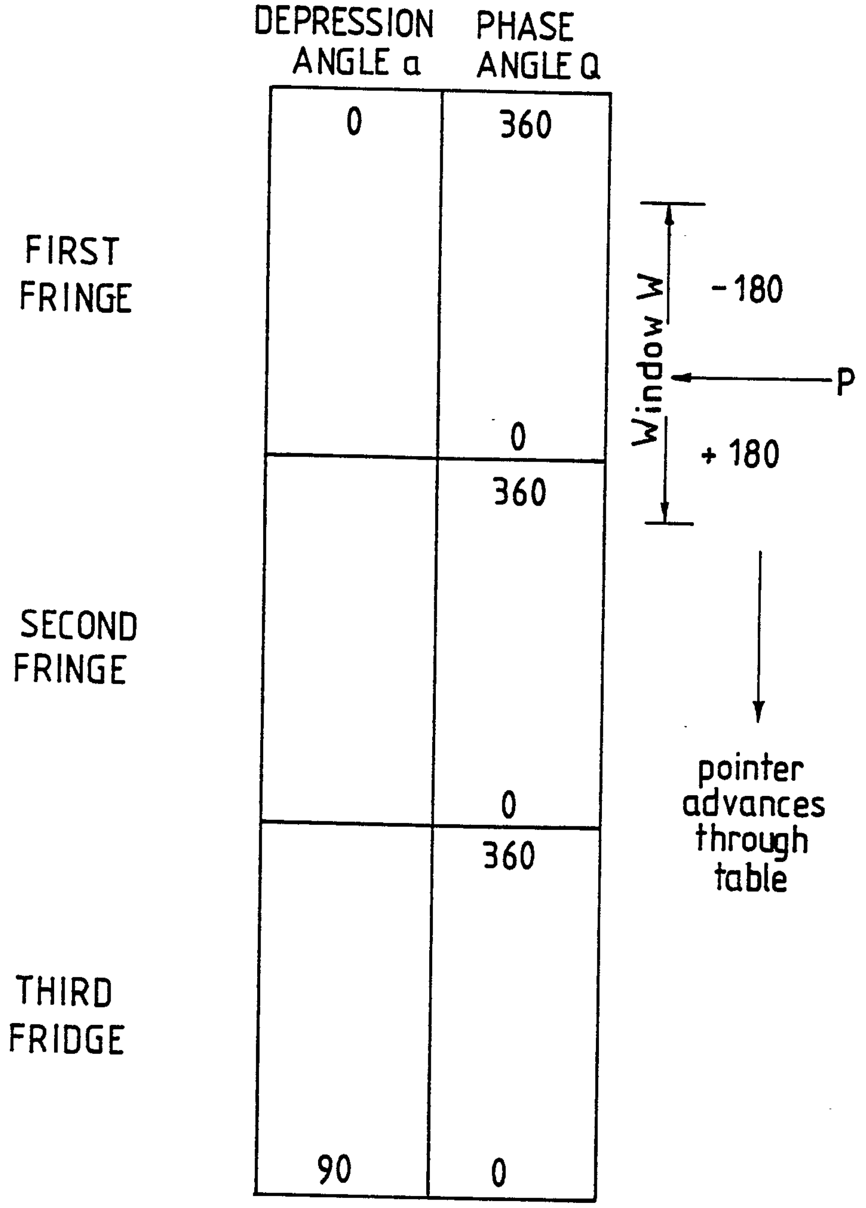
DEPRESSION ANGLE a
PHASE ANGLE Q
0
360
FIRST FRINGE
0
360
SECOND FRINGE
0
360
THIRD FRIDGE
90
0
Window W
-180
P
+ 180
pointer advances through table

FIG. 11

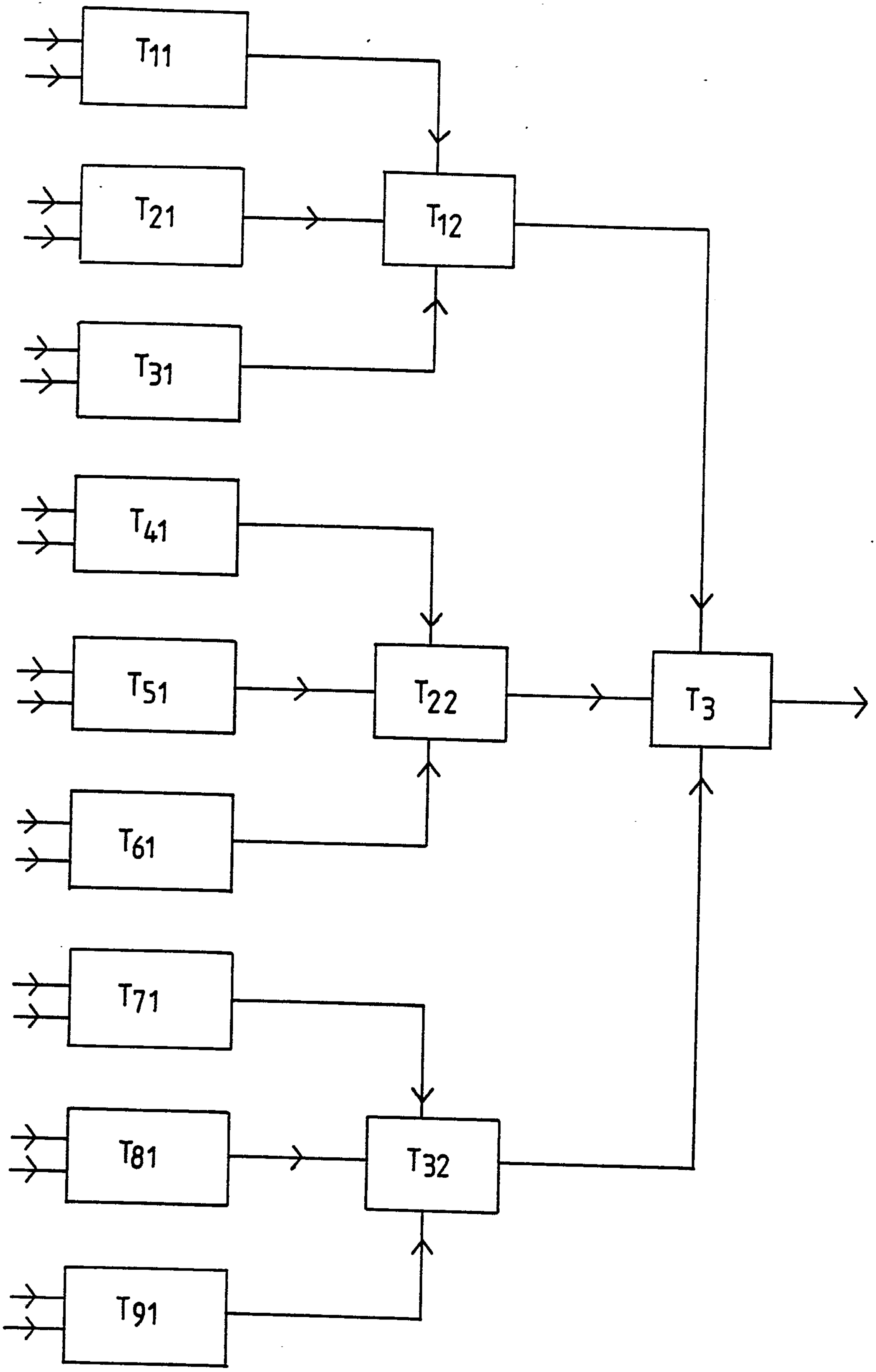

FIG. 12

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 90/01291

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^5: G 01 S 15/89, G 10 K 11/34

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^5	G 01 S, G 10 K

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	US, A, 3742436 (JONES) 26 June 1973 see figure 6; columns 5-8	1,2
Y	--	3
Y	EP, A, 0070494 (SINTRA ALCATEL) 26 January 1983 see page 9, line 17 - page 11, line 16	3
A	--	4-6
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* Special categories of cited documents: [10]

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IV. CERTIFICATION

Date of the Actual Completion of the International Search 14th November 1990	Date of Mailing of this International Search Report 29. 11. 90
International Searching Authority EUROPEAN PATENT OFFICE	Signature of Authorized Officer M. Peis M. PEIS

Form PCT/ISA/210 (second sheet) (January 1985)

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. GB 9001291

SA 39180

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 20/11/90
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