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DIGITAL SIGNAL PROCESSING OF HIGH RESOLUTION WITHIN-PULSE SECTOR SCANNING SONARS

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INTRODUCTION

High resolution within-pulse sector scanning sonars were first developed at the Admiralty Marine Technology Establishment (AMTE) Teddington, over 30 years ago. In 1964 the use of this type of equipment was first demonstrated to outside civil authorities and soon found application by MAFF, Lowestoft, in the field of fisheries research (1). In more recent years the impetus given firstly by the requirement for more precise hydrographic surveys (2), and then by the exploration for North Sea oil, has resulted in the present development of a number of commercial sonars, all based on the same principle of modulation scanning.

The full potential of this type of sonar has, however, remained relatively unexploited and the sonar display, recording and analysis techniques employed have remained substantially the same over the years. All present at-sea systems use a long persistence cathode ray tube to display the sonar information and this display provides the only analysis tool available to the operator. For short ranges (< 200 metres), where a reasonably high data up date can be maintained, this type of display is reasonably satisfactory but picture 'flicker' can easily produce operator fatigue. For longer range sonars of the type described in this paper with a frame rate of 1Hz or less, this type of display becomes practically unusable for locating and tracking small targets.

Permanent records are generally made photographically using still or cine cameras, which are expensive to operate, or by analogue tape recorders which have a limited dynamic range. In the first case the signal amplitude information available for subsequent analysis is extremely limited and from tape recordings the data analysis problems are nearly identical to those confronting the on-line operator, with the difference that a particular frame can be reviewed as many times as is found necessary.

Both the live display and the present system used for recording data thus suffer from severe limitations, particularly for research applications where quantative measurements are required. The detail of structure that may be obtained from a single sonar transmission concerning the target strength of for example a fish shoal, requires not just a single measurement to define the peak target strength of the whole shoal, but ideally a considerable number of simultaneous measurements of target strength to be made so that an indication of the distribution of fish density within the shoal can be determined.

The sonar originally developed by AMTE was provided with a calibration method by which a signal could be injected across the inputs to the sonar thus establishing a reference signal to which other target levels could be related. Calibration by this method, however, is time consuming and somewhat unreliable and when undertaken under dynamic conditions at sea becomes impossible to use when more than a single target is of interest.

A means by which all these limitations may now be removed is provided for by the application of digital signal processing techniques to the analogue output of the basic signal processor and by subsequent computer based analysis . By this means the signal amplitude information in each individual resolution cell may be stored, identified and digitally recorded. The sonar data can now, therefore, be examined in much greater detail than has previously been possible and provides the means of applying pattern recognition techniques, contouring the sea bed profile and estimating marine biomass and target strength from the basic sonar signal. Digital recording can preserve a higher signal to noise ratio than is possible by analogue methods and can employ conventional instrumentation tape recorders. The digital storage of the sonar data, frame by frame, permits the high speed playback onto conventional CRO displays or television monitors thus eliminating any disturbing flicker effects and permitting daylight viewing. The sonar data can also be applied to a colour monitor providing an extension of the amplitude scale normally discernable on monochrome displays.

A further dividend may be obtained from a Random Access Memory type of storage device by using a form of pseudo electronic stabilisation of the video picture on the final display. Whilst this cannot provide a true stabilisation of the transducer it will generate a steady picture on the display in position, independent of ship's roll pitch and yaw. This may be of some advantage where full mechanical stabilisation is not available, particularly in the depth scanning mode of operation.

This paper describes work undertaken at AMTE during the last few years applying digital techniques to an integrated system consisting of three scanning sonars operating at frequencies of approximately 300kHz, 150kHz and 75kHz. This frequency coverage permits the investigation of target strength variation over a range of frequencies covering two octaves, and provides a unique combination of high resolution capability associated with long detection range.

2. THE SONAR SYSTEM

The three sonars are provided with two hydraulically operated training devices. The transducers for the two high frequency sonars are mounted on one of these and can operate in complete synchronisation whilst the 75kHz sonar has a completely independent system. Each unit can be trained in azimuth, tilted through 90° into the echo sounder mode or rotated through 90° into the vertical (depth scanning mode). The characteristics of these sonars are summarised in Table 1.

Frequency kHz	300	150	75
Sector scanned Deg	30	30	60
Pulse length μs	100	100	500
Range resolution metres	0.075	0.075	0.375
Scan frequency kHz	10	10	2
Array length λ	150	90	45
Beam width (Horizontal) Deg	0.4	0.56	1.1
Beam width (Vertical) Deg	7.0	10	22
Detection range OdB target m.	300	400	800
Number of channels	75	45	45
D^2/λ metres	112	81	40.5

Table 1

The measured resolution of the sonars has been found to be very close to that determined by theoretical predictions, and in the case of the 300kHz sonar (3) has been shown to provide a resolution capability in azimuth approximately equivalent to that defined by the nominal beamwidth to ranges of 60 m (0.6 D^2/λ). The overall performance of this type of sonar when installed in the fisheries research vessel CLIONE has been reported in reference (4). The resolution cell of the sonars is defined by the combination of pulse length, the horizontal and vertical beamwidths, and the range, and is shown in figure 1 for the three sonars. For the 300kHz sonar this results in an effective volume resolution of 1 cubic metre at a range of about 125 m; for the 75kHz sonar the volume resolution cell at 600 m range is approximately 1,000 cubic metres.

Each sonar is provided with various gain control systems which allow the performance to be optimised for particular operational roles. For general research purposes described in this paper a Time Varied Gain (TVG) system is used which compensates the gain for spherical spreading and absorption, thus a given target provides a constant amplitude of signal echo at the output independent of range.

3. DIGITISATION OF THE SONAR DATA

The scanning sonar achieves a very high data rate compared with conventional sonars, and the bandwidth of the information from the 300kHz sonar is approximately 400kHz. This data rate is the highest associated with all the scanning sonars described and the system requirements will therefore be detailed in relation to this particular equipment.

With a 4Hz information up-date, 2,500 scans are made, each scan corresponding to a 0.075 m range increment. A sampling frequency of 800kHz is used, which is in accordance with the requirements of basic sampling theory, being approximately twice the highest frequency component appearing in the demodulated output.

When this digitisation system was designed, several years ago, it was not considered to be cost effective, or indeed necessary, to provide for storage of all the information in the complete range gate. For general surveying a much lower storage capacity could be used, either averaging over a number of scan lines, or by selecting every eighth or tenth line for storage and display. When it is required to use the full resolution capabilities of the equipment it is generally for the close inspection of a relatively small target for identification purposes. The plotting of sea bed contours in the depth sounder mode (section 5.3) is an example of this, and for this purpose again a much reduced storage capacity can be tolerated. For the prototype equipment, therefore, it was decided to limit the storage capacity to the equivalent of 320 scan lines for the 300kHz sonar in view of the storage components then commercially available.

There are, however, a few occasions where an extended range capability at high resolution is desirable. Amongst these are the detailed examination of underwater hazards such as wrecks, inspection of oil rigs and the monitoring of dykes. The new storage system under development will, therefore, be provided with a full range storage capacity. A shift register system was chosen for the inital development, the new system being based on a Random Access Memory matrix of 512 x 512 storage capacity.

The amount of amplitude information that it is necessary to store determines the number of bits for the amplitude word. To cover the amplitude range necessary to reproduce a reasonably acceptable video picture probably requires no more than a four bit word due to the relatively restricted number of grey levels that can be discerned on the normal TV-type screen. This storage capacity is, however, insufficient for many research applications. For fisheries research (3), for example, it may be necessary to detect a single fish with a target strength of -37dB (single 0.1 m length fish in the broadside aspect) or to estimate the target strength in one resolution cell of a closely packed shoal, which for the same type of fish, in the same orientation, and at maximum packing density could approach a figure of 0dB per cubic metre. The difference in target strength evidenced in a single shoal could therefore be of the order of 40dB. This order of dynamic range is generally more than sufficient for most other applications and the system was therefore based on the use of a six bit word to carry the amplitude information, this is equivalent to a linear amplitude ratio of 64 or a range of 36dB.

The shift register store is arranged in six planes, one plane for each bit of the 6 bit amplitude word. Each shift register chip has the capacity for 1024 bits and so a total of 25 shift registers are required for each bit plane in order to digitise 320 lines, taking 80 samples per line, or for the 75kHz sonar, 512 lines taking 50 samples per line. The digitiser itself consists of two separate units, the digitiser and the cassette replay unit.

3.1 The Digitiser

This unit samples the signal at a little over 8×10^5 samples per second to a six bit resolution and stores them in a solid state store (the main shift registers, MSR's). The data is sampled over a time window of 32 ms duration (256 ms for the 75kHz sonar), delayed in units of 1 ms (5 ms for the 75kHz equipment), from the transmission initiation signal. The sampling of each scan line is synchronised to the scanning of the sonar. The stored data is converted, for display purposes, to analogue form and can be displayed either at the normal sonar frame rate or at a higher rate of 31Hz to give a flicker free picture on a conventional short persistence oscilloscope tube.

DIGITAL SIGNAL PROCESSING OF HIGH RESOLUTION WITHIN-PULSE SECTOR SCANNING SONARS

The digitiser transfers the data from the MSRs to the cassette replay unit. Eighteen frames can be recorded on a standard cassette. The format and parity of the data is checked automatically when it is replayed from the cassette tape into the digital store. The digitiser has an averaging facility which will average 2, 4 or 8 successive sonar transmissions.

3.2 The Cassette Replay Unit

The cassette replay unit consists of a cassette tape transport deck, phase encoding and decoding circuits, byte compilation circuits, interblock gap detection circuits and is parallel interfaced for replay into a PDP 11/40 mini computer via a DR 11 C digital highway. Block formatting is used so that on replay into the computer the digital flow can be stopped at the end of each block to allow time for the computer to perform numerical operations and checks.

Within the block the data is organised into bytes of 8 bits of the form ABXXXYYY, where XXXYYY are the six bits from the ADC, A is the parity bit for XXX and B the parity bit for YYY. After 240 bytes of data there follows a block check character (one byte) which is incorporated to give longitudinal parity checks on a byte basis. Odd parity is used throughout.

As the state of digital techniques has advanced it is now more practical to devise a system that will digitally record each successive whole frame of data. Such a system is now being developed and again consists of two units, a recording system and a computer controlled replay system as shown in figure 2.

3.3 The Mk 11 Recording System

The incoming signal from the signal processing unit is again digitised to a 6 bit amplitude word, and this information is distributed over thirteen tracks of an Ampex PR2200 instrument recorder operating in the direct wideband 2 mode. Each scan line is digitised at a precisely defined sampling rate. For the 300kHz sonar 80 samples are made per scan line in order to preserve the azimuth resolution of 0.4°. For the 150kHz and 75kHz sonars only 50 samples are taken per scan line to preserve their respective azimuth resolutions of 0.56° and 1.1°. The ADC sampling is initiated by the recognition of the line synchronising pulse, thus a particular digitisation in any one line has the same time relationship to the line pulse as the same digitisation in any other line.

Two 6 bit data values are packed into a single 16 bit word along with a validity flag, line flag, frame flag and a parity bit. The validity flag is set positive for valid data and zero for packing data. Packing data is used as dummy values to allow the serialisers to unload their information to tape even if some of the serialisers do not contain genuine data. The frame flag and line flag are set to one, if a frame synchronisation or line synchronisation pulse has occurred immediately prior to digitising the first 6 bit data value of the 16 bit word. The 16 bit words are then distributed between the instrument recorder tracks in serial form at a density of 10K bits per inch. Serial form is used in preference to parallel format in order to eliminate problems associated with dynamic skew. Digitisation and down loading of the data to the instrument recorder is achieved in real time. It is, therefore, possible to continuously digitise and record whole successive frames of sonar data.

3.4 The Mk 11 Replay System

On replay the signals from the 13 tracks of the instrument recorder are passed to deserialisers which decode and deserialise the data. The bit parallel words complete with the appropriate flags are then passed via a DR11B direct memory access module to the PDP11/40 computer. The replay unit buffers the data and first checks the validity flag, for genuine data, and parity flag. This data is then reorganised into parallel bit format acceptable to the computer. A digital to analogue converter is incorporated into both the record and replay units to allow downstream monitoring on an oscilloscope. The data field in the computer may subsequently be reduced and analysed using the display facilities.

3.5 The Display System

The display uses a conventional 625 line colour T.V. monitor operating at an interlaced frame rate of 50Hz. The data to be displayed is passed from the computer to the display system's random access frame store of 512 x 512 pixels each of 8 bit amplitude. The top 6 bits of this 8 bit plane store holds the sonar data, the remaining 2 bits are available for annotation and graphics which maybe shown simultaneously with the sonar information.

The transfer of data to and from the frame store is controlled by a fast running software system based on integer arithmetic. The use of computer software to control the frame store introduces a large amount of flexibility into the system. The reading and writing process for the frame store are independent, can operate simultaneously and can be completely asynchronous. The minicomputer has direct access to any picture point in the store so that it can read information from the store, write information to it or remove data from the picture, modify it and replace it. At all times the contents of the frame store can be displayed on the T.V. monitor for operator observation. In addition the store is bit selectable so that any part of the 8 bit word can be read or modified.

The frame store and colour look-up tables are controlled by software to display the sonar data in either of two formats. The whole sonar frame can be displayed in a series of up to six columns each holding 512 scan lines of data or alternatively any range gate of 512 lines can be shown using the full width of the T.V. monitor by reading each data cell into six successive picture points. The colour look-up tables allow the echo intensity to be represented as a particular colour. Any frame of the sonar data maybe held indefinitely in the store for detailed examination.

A "window" facility is available whereby only a limited selected area of the incoming data is overwritten. The window area can be designated as either a portion of the picture to be written into the store or as a portion of the store to be protected with the remainder of the picture being entered in memory. A hardware cross wire facility is also included, generated by a graphics tablet and controlled by the computer. These cross wires are mixed into the video after the store and do not corrupt the store data. They can be used to specify data points or window boundaries and, therefore, form an interactive facility.

DIGITAL SIGNAL PROCESSING OF HIGH RESOLUTION WITHIN-PULSE SECTOR SCANNING SONARS

4. COMPUTER BASED ANALYSIS

The digital analysis system has now been in use for a number of years and a series of programs have been written to process the data received from various modes of operation.

4.1 Computer Hardware

The computing facility is based on a DEC PDP11/40 mini computer. The system has 25K words of memory and a hard wired arithmetic unit. Three discs, each of 1.2M words capacity provide additional storage and operate under the DEC RT11 system. Additional devices include a laboratory peripheral system, a decwriter and a Versatec 1200 A electrostatic printer plotter. This mini computer is host to a Tektronix 4081 interactive graphics system.

4.2 Computer Software

The transfer of data from the digital tape to the computer is handled by a mixture of hardware and software. The tape replay unit hardware converts the 8 bit word read from tape into 8 bit parallel format for the DR11C to transfer. The hardware aligns on word and block boundaries, but not on record boundaries, nor does it do any parity or format checking. The tape driver software institutes and controls tape movements, checks validity of ambles, checks byte and long parities, unscrambles data and converts it into computer internal format. The data is written away for use by other programs and up to 70 sonar transmissions can be entered on a single disc. The raw data from the disc may be operated upon in several ways. Each transmission can be normalised in target strength values by the use of information from standard targets. The data may be operated on by 'picture enhancement' routines, an example of which is for the supression of unwanted sidelobe effects. This takes into account that the sonar directivity response is not ideal but has a sidelobe response of a general sin x/x pattern. A correction can be applied to the raw data to remove first order effects of these sidelobes.

The sonar data may be represented in several forms for further analysis and visual interpretation and these will be considered individually.

4.3 Tabular Listings

This provides possibly the simplest form of output and consists of a tabular listing of the target strength values, in each resolution cell of the range-bearing matrix. The table has 80 columns corresponding to the 80 digitised azimuth cells and 320 rows corresponding to the 320 digitised scan lines, for both the 300kHz and the 150kHz sonars. For the 75kHz sonar there are 50 columns and 512 lines. Only one character can be used to represent the target strength value, due to the device constraints , and hence to cover the required dynamic range of say 30dB, using only the digits 0 through 9, each numeric increment represents a 3dB change in target strength. By using the full alpha numerics available a target strength resolution of 1dB can be accommodated. A cut off level is available whereby all target strengths below a selected level are represented by a full stop. This aids readability by the suppression of all but the target of interest in high signal to noise conditions. This form of output

(Figure 3) has a major failing in that the aspect ratio is incorrect. The magnitudes of target highlights, however, are very easily obtained from this form of presentation which can be produced very quickly on a line printer.

4.4 Hidden Line Plots

This is a pseudo three dimensional graphical output. A Cartesian axis system is used where the X axis is made proportional to azimuth and the Y axis is made proportional to range. The Z axis represents the target strength for that region of space given by the XY co-ordinate. The effective Z axis is represented by a line parallel to the X axis, whose distance from the X axis represents the magnitude of the Z quantity, in this case the target strength. Such a line is produced for each of the digitised 320 scan lines (512 scan lines for the 75kHz sonar). Each successive scan line is offset along the Y axis to give range information. This form of output is made more visually acceptable by using a hidden line routine.

This representation of the target strength distribution (Figure 4) has an approximately true aspect ratio, which aids the positioning of targets. Unfortunately, true X-Y positioning is not obtained, but is given in terms of range R and sin θ, where θ is the target bearing. The target strength values are not easily obtained from these plots as it entails measuring the height of the corresponding peak deflection. The hidden line routine also introduces a possible source of error in that a small target echo may be 'lost' behind a larger echo.

4.5 Contour Plots

The target strength data results in an array or matrix of target strength values. This grid can be converted into contour lines and the program shades these to aid readability. The contour plots are converted from R and sin θ co-ordinates to X-Y co-ordinates before plotting.

The contour plot routine only considers data from a rectangular zone whose position and orientation in the sector can be specified. This allows a scaling ratio of 50:1 to be used on the size of graph plotter available. With the given scaling ratio in true co-ordinates the location of points on an exact target strength matrix is possible. The direction of ensonification is indicated by a small arrow. The magnitude of the echo is given by the contour level. The number of different contours has been restricted to about 4 or 5 and therefore each contour level usually represents a 4 or 5dB range of target strength values. This type of contour presentation is illustrated in Figure 5.

4.6 A Scan Format

Conventional sonars provide resolution only in time, and for any single range resolution cell only a single echo is recorded. In this case the target strength data is normally presented as a function of range only, in A scan format. To aid the comparison of scanning sonar data with this form of low resolution information it is necessary to degrade the data from the scanning sonar by combining all azimuth data at a given range. The recorded azimuth information can be recombined by the computer over any given number of azimuth cells to simulate a sonar with a transducer beamwidth of any resolution less than that of the scanning sonar up to that defined by the sector width of 30°. This target strength data can be produced in histogram format where each column represents a new scan line or alternatively a non histogram presentation is available where each successive range cell is printed out as a line parallel to the Y axis as shown in Figure 6. The length of the line is proportional to target strength and its position on the X axis represents range.

4.7 Interactive Graphics Terminal

A recent addition to the computer hardware has been a Tektronix 4081 interactive graphics system. This facility provides both refresh display facilities for dynamic pictures, and storage display facilities to allow large amounts of graphics information to be displayed simultaneously. The terminal has internal programming to permit operation in a 'stand alone' mode but it can also be used in a host environment. When the equipment is mated to the basic computer system this permits a more rapid analysis of the digital data to be adopted by the use of superposition and split screen techniques.

5. APPLICATIONS

The use of these digital techniques can be illustrated by their application to fisheries research, hydrographic survey and the monitoring of the movements of divers in work associated, for example, with the oil industry.

5.1 Azimuth Scanning

A hidden line plot of a small fish shoal and two standard targets detected with the 300kHz sonar is shown in Figure 4. As this shoal was moving steadily across the field of view, the fish were probably in the broadside aspect. If it is assumed that the minimum target strength recorded is that of a single fish and that the target strength in a single resolution cell increases by 3dB for each doubling of fish numbers, it is possible to estimate the shoal biomass.

The lowest fish target strength measured is -27dB indicating that if the fish has an air bladder the fish are approximately 0.3m in length. The highest target strength of -11dB suggests a maximum packing density of 50 fish per cubic metre (3), which is about 'normal' for this size of fish. The statistics of target strength occurrence provided by the tabular listing program gives a total estimated fish count of 13,700 fish. For this size of fish this implies a shoal biomass of 6,400 kgs.

A very small shoal of distinct ring shape is shown in three representations in Figures 5, 6 and 7. The vertical line (Figure 7) is the recording of the noise radiated from a small boat being used to identify the fish. The broadside target strength of these fish is -37dB indicating their size to be only 0.1m.

It is of importance to know at what range it is possible to monitor diving operations from the parent vessel and hence a knowledge of the intrinsic target strength of divers is essential. Figure 8a shows a free swimming diver detected at a range of approximately 88 metres, with the body in the head-on position. Also included is a calibration signal equivalent to a target strength of -34dB at 100m range. The maximum target strength of the diver from this aspect is found to be -27dB. The echo extends over a range extent of about 1.3m which corresponds fairly well with the range extent to be expected in this orientation. Lesser echoes are obtained from the extremities of the body. The first maximum in the target echo appears at a range of about 0.3m from the head (probably from the compressed air bottles carried on the back) and further high target strengths appear at ranges of between 0.525m and 0.67m from the first echo (almost certainly from the chest cavity). The chest cavity itself to the first approximation, may be considered to be nearly spherical with a diameter of about 0.3m, and corresponds to a target strength of -22dB. As in this orientation the swimmer's lungs are somewhat shadowed by the rest of the body, this figure is in fair agreement with the observed figure.

Figure 8b shows a second detection of a diver in an orientation of about 45°, with the head at closer range. This plot illustrates the use of the equipment in the dual frequency mode. Detection made here using both the 300kHz and the 150kHz equipment delayed slightly in time so that it appears on the display to be shifted to the right. The diver on this occasion was carrying out a circular search and a series of echoes from the trail of air bubbles can be seen at greater ranges. Nearly masking the 150kHz detection is the indication of the passive reception of radiated noise from the diver's air valves, a feature unrecorded at 300kHz. The maximum target strength recorded here is -18dB which agrees well with the predicted figure for the chest cavity and the compressed air bottles which in this orientation probably cannot be resolved from one another.

5.2 Depth Scanning

This mode of operation can be used to examine fish distributions in depth and is also of use in survey work. The example given in Figure 9 obtained with the 300kHz sonar shows the sea surface on the left, the sea bed on the right and a midwater fish shoal. From the sonar calibrations the maximum target strength in this shoal is -20dB and the minimum -41dB. This shoal was moving towards the sonar and the fish were, therefore, in head on aspect. The fish were identified as small whiting some 0.15m to 0.20m in length which agrees with the measured target strength values.

As both the sea surface and sea bed are clearly delineated the water depth can be computed. The sea surface and bed are separated in bearing by 15° at the near range of 84m giving a water depth of approximately 22m. The 75kHz sonar when used in this mode of operation will allow sea bed profiling to be achieved at much longer ranges of up to 750m.

5.3 Echo Sounder Mode

The 75kHz sonar's combination of long range detection, high resolution, and a large scanned sector makes it suitable for use as a high precision echo sounder. At 800m range the area of resolution is just over 4000 sq metres. The target strength of a mud sea bed, which is the worst condition under which the equipment is likely to be used, is no less than -40dB m^{-2} and hence as the detection capability of this sonar is well in excess of a 0dB target at this range all sea beds will be delineated out to the full range of 750m accepted.

Three 'hidden line' plots of bottom profiling in this mode are shown (Figures 10a, b and c), ranging from the near flat to very steep, in an average water depth of about 100m. In two cases targets, probably small shoals of fish, can be detected near to the sea bed. Figures 11a, b and c show the respective sea bed profiles computed from this data and presented in true co-ordinates. At this depth the area of the resolution cell is about 60 sq metres and over a flat sea bed the bottom profile can be sampled in depth over a distance of ± 50m either side of the ships path at an average sampling distance of about 2m.

Figures 3 shows a tabular listing of the target strength data for the maximum slope condition. For a flat sea bed the range of the bottom would increase symmetrically about centre bearing. The back-scattering strength of the sea bed at various angles up to ± 30° can be estimated from this type of data.

CONCLUSIONS

The use of digital signal processing in associated with a sector scanning sonar can provide a direct method of measuring the target strength of fish and biomass, although the problems associated with fish orientation and the attenuation of sound through the shoal still remain to be solved. The integrated system is equally well suited to producing detailed and accurate hydrographic surveys.

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Fig 1 The Scanning Sonar Resolution Cell as a Function of Range

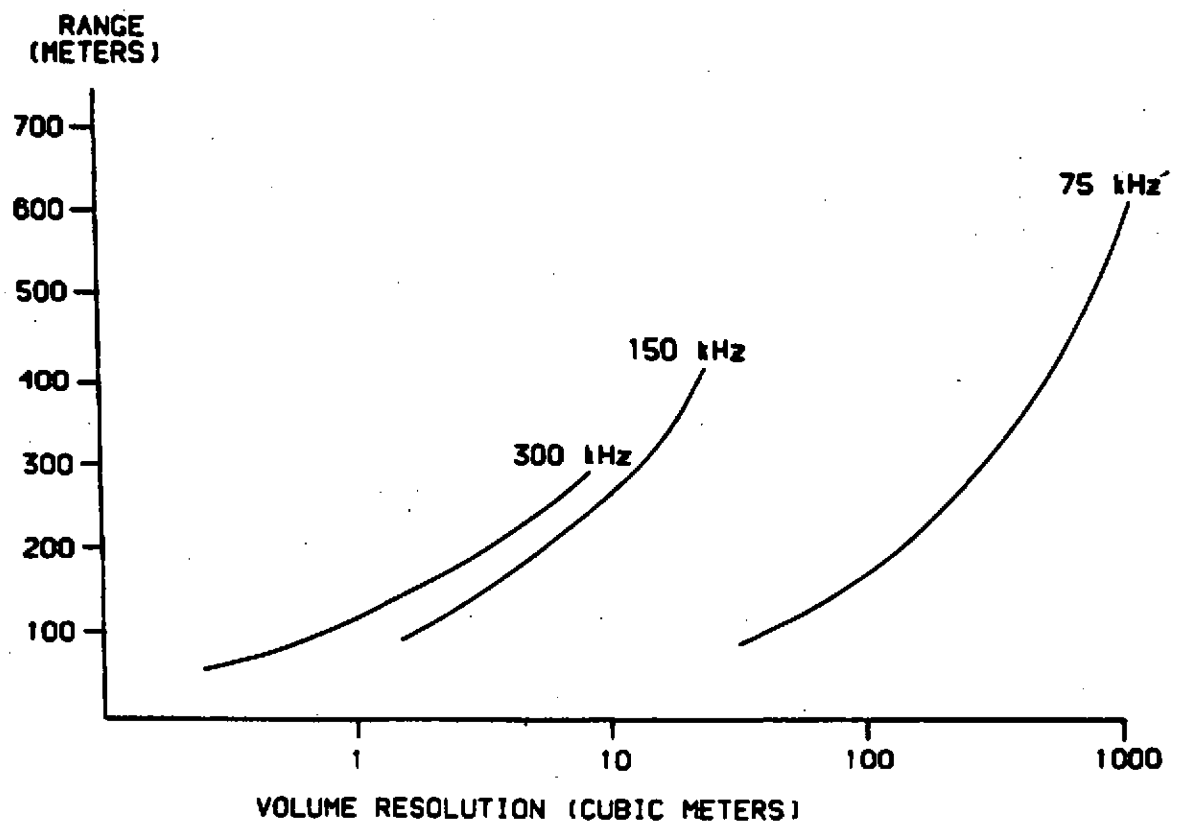
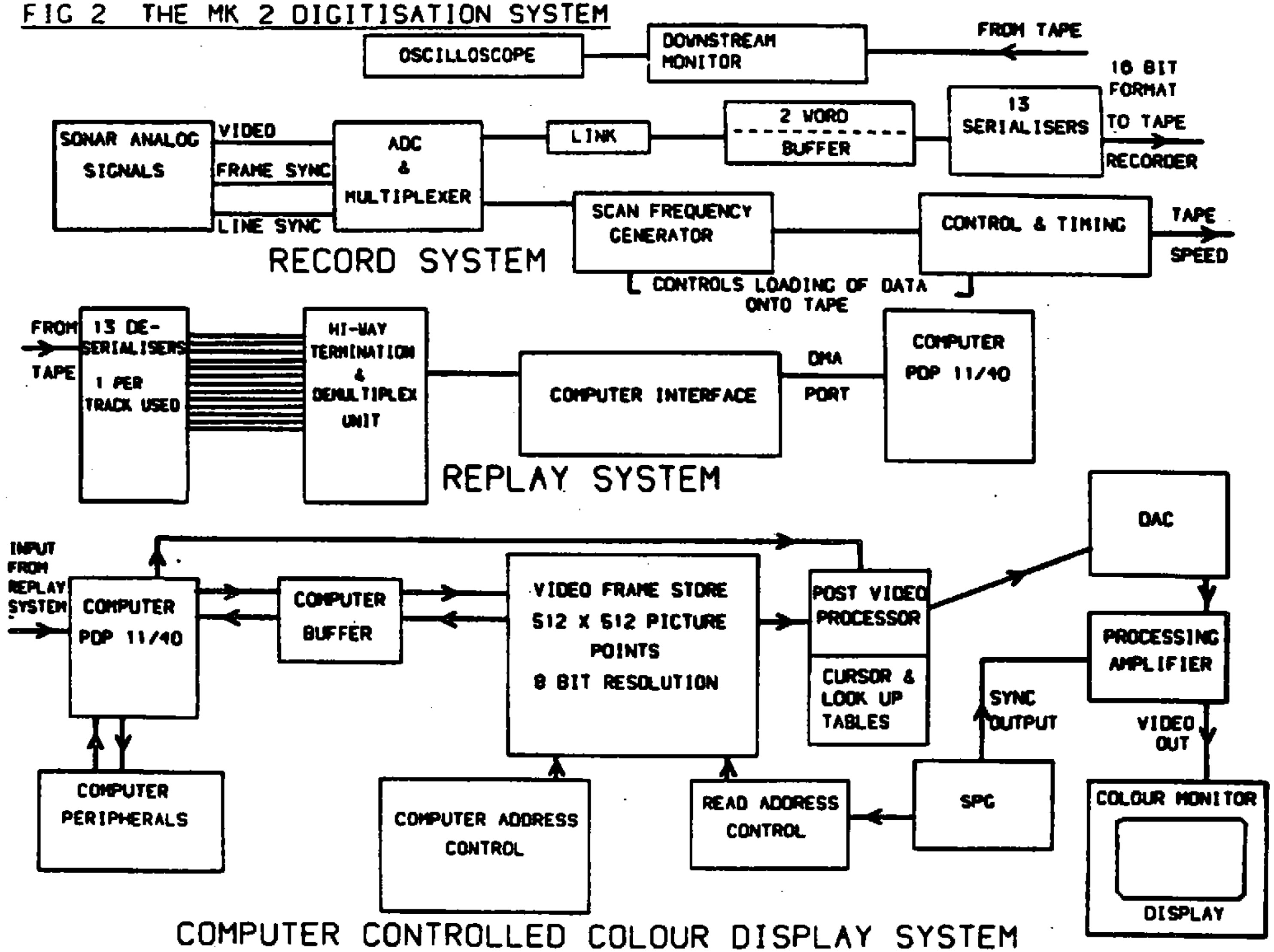


FIG 2 THE MK 2 DIGITISATION SYSTEM



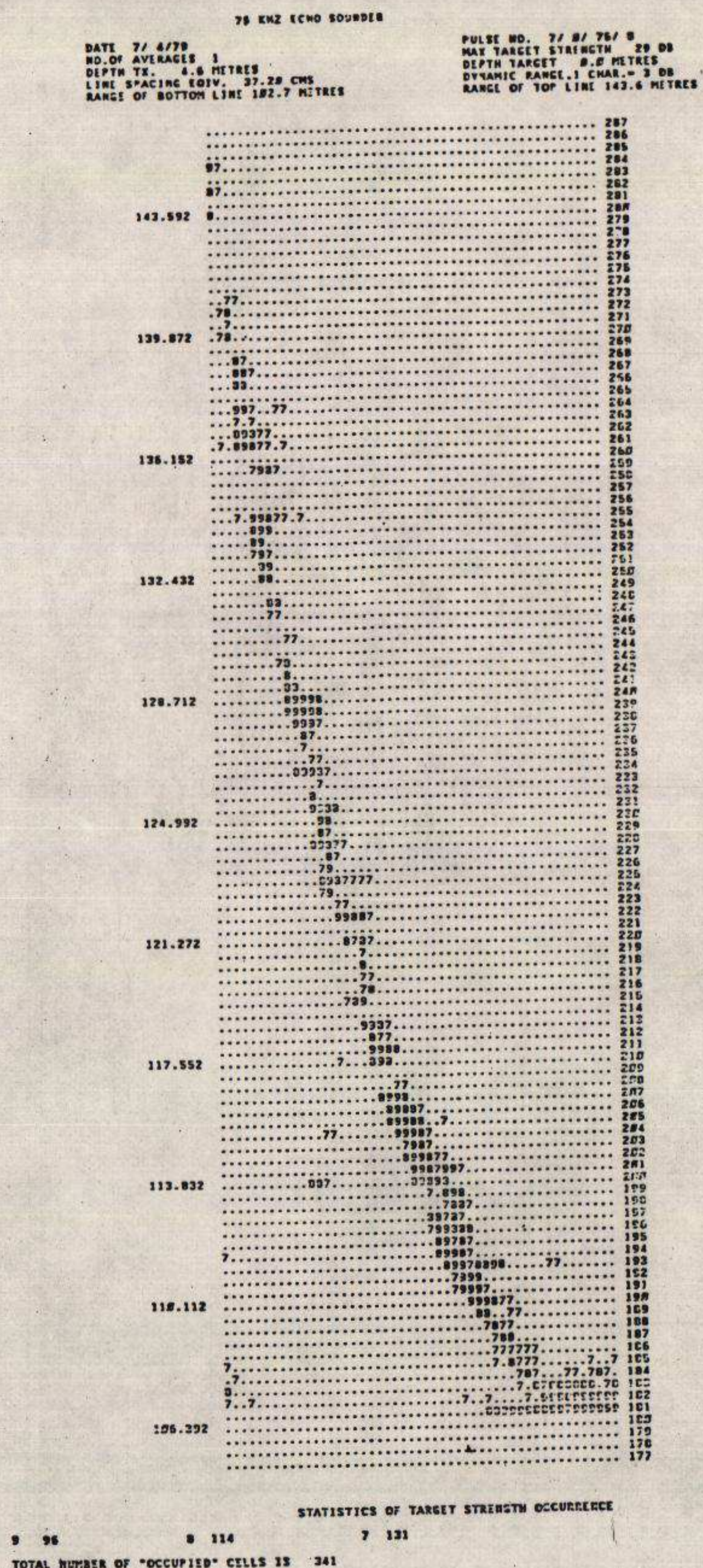


Fig 3 An Example of a Tabular Listing Output for 75kHz Sonar Operating in Depth Sounder Mode.

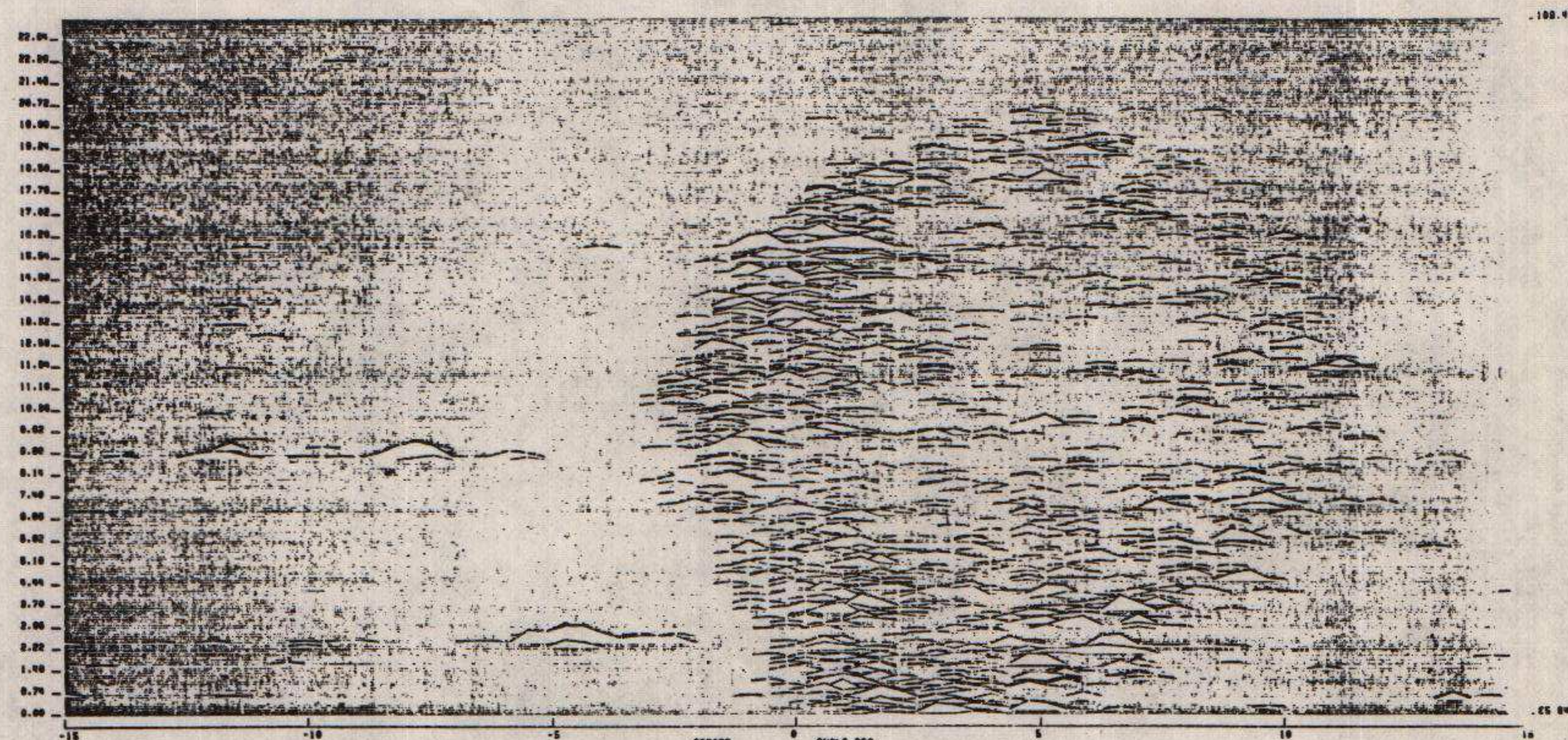


Fig 4 An Example of a Hidden Line Plot showing a Fish Shoal detected with the 300kHz Sonar Operating in Azimuth Scan

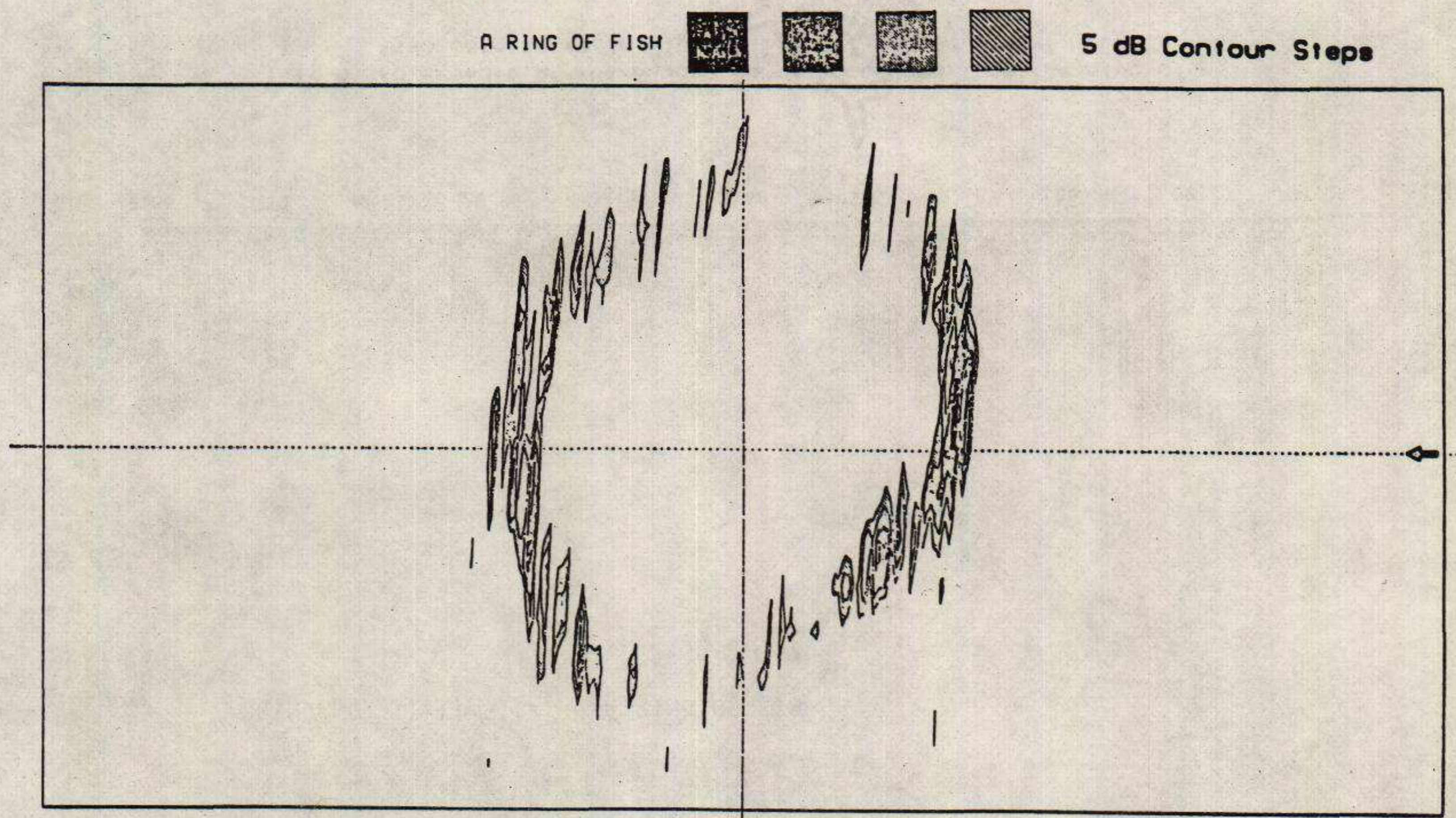


Fig 5 An Example of a Contour Plot showing a very distinct Ring of Fish

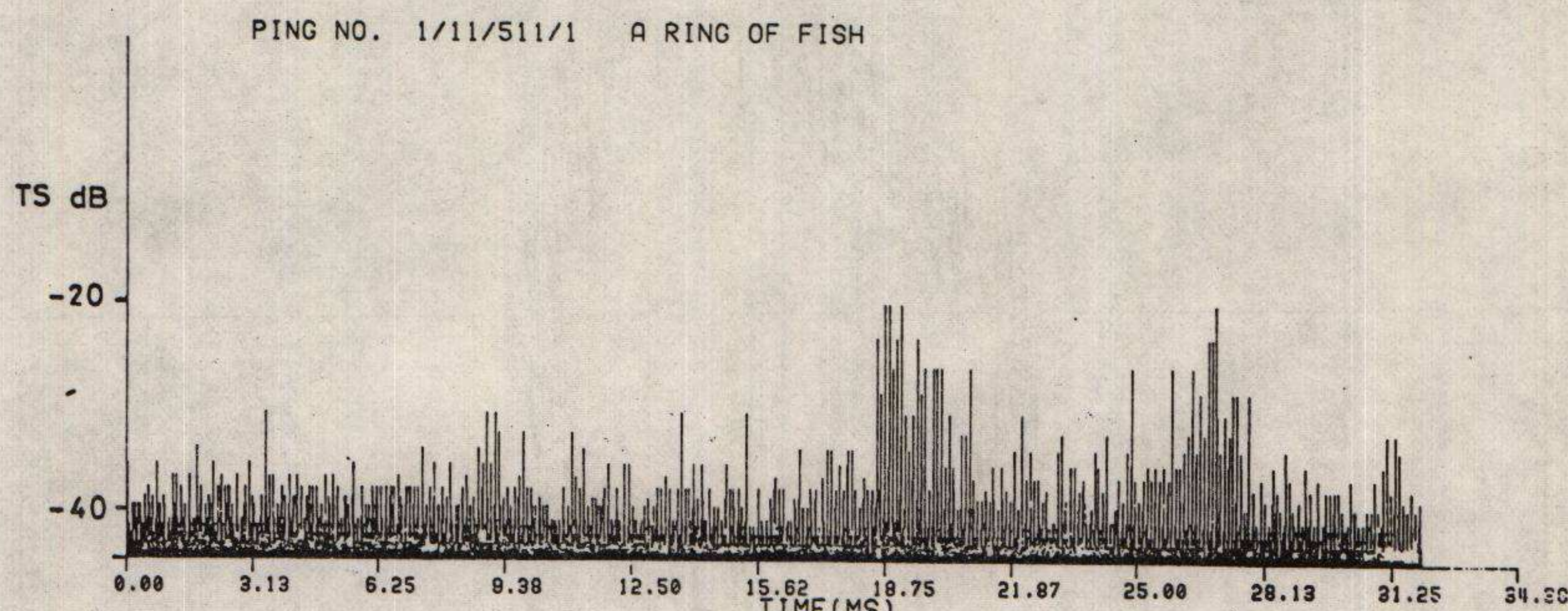


Fig 6 An Example of the A Scan Format produced from the Ring of Fish data shown in Figures 5 and 7

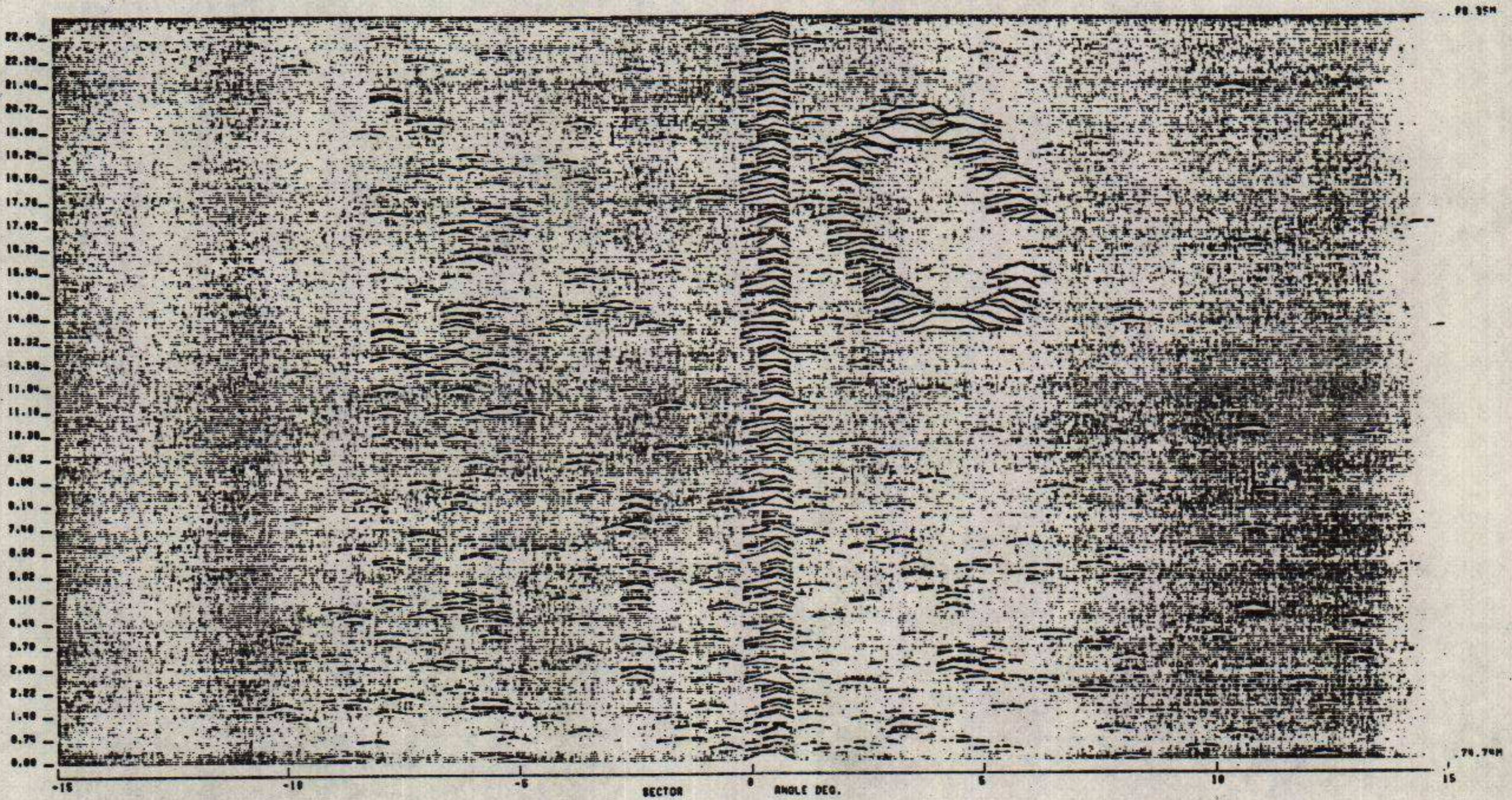
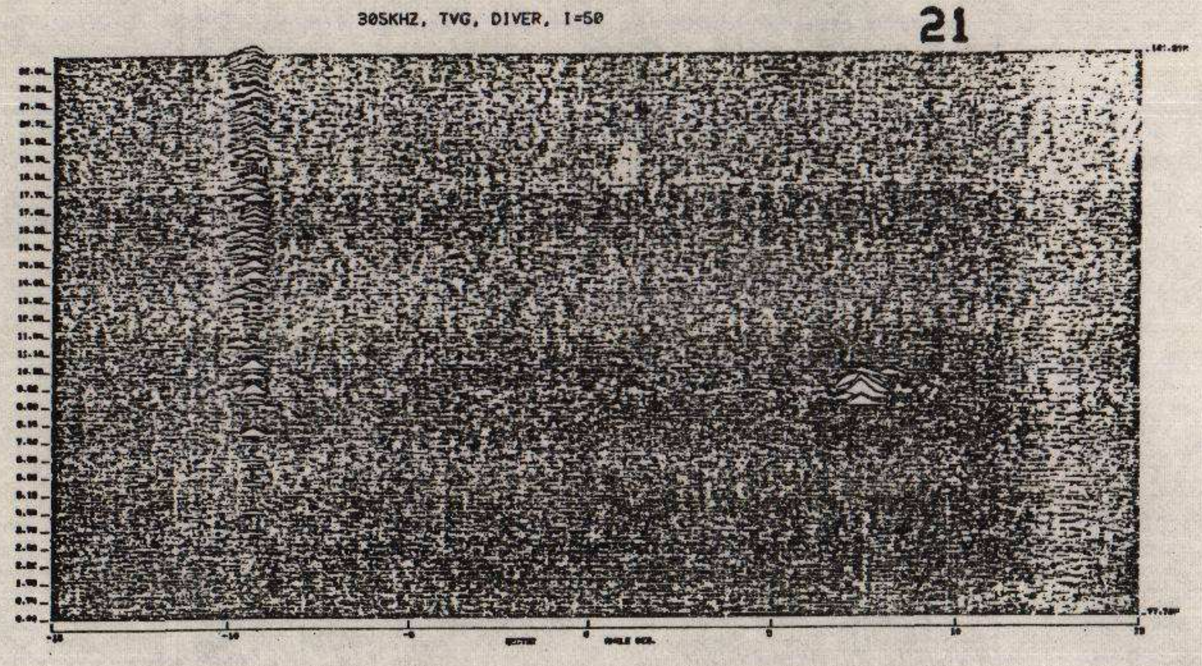
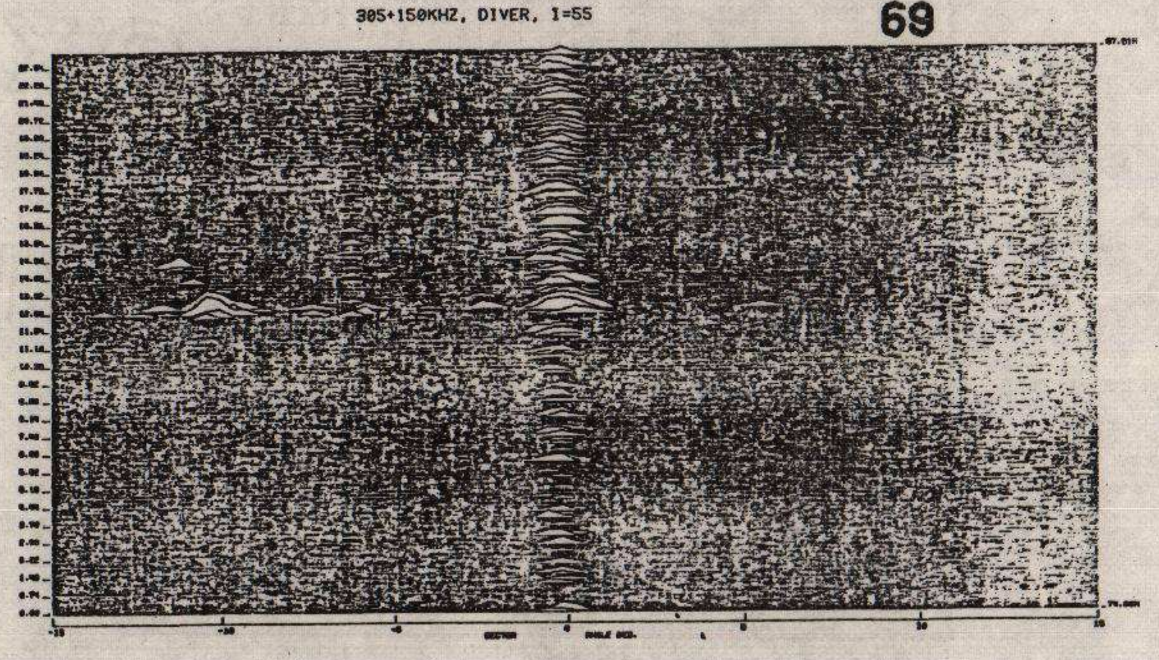


Fig 7 A Hidden Line Plot of the Ring of Fish.



(a)



(b)

Fig 8 A Hidden Line Plot of a Diver Detected With a) 300 kHz Sonar And b) 300 kHz and 150 kHz Sonars Operating Simultaneously

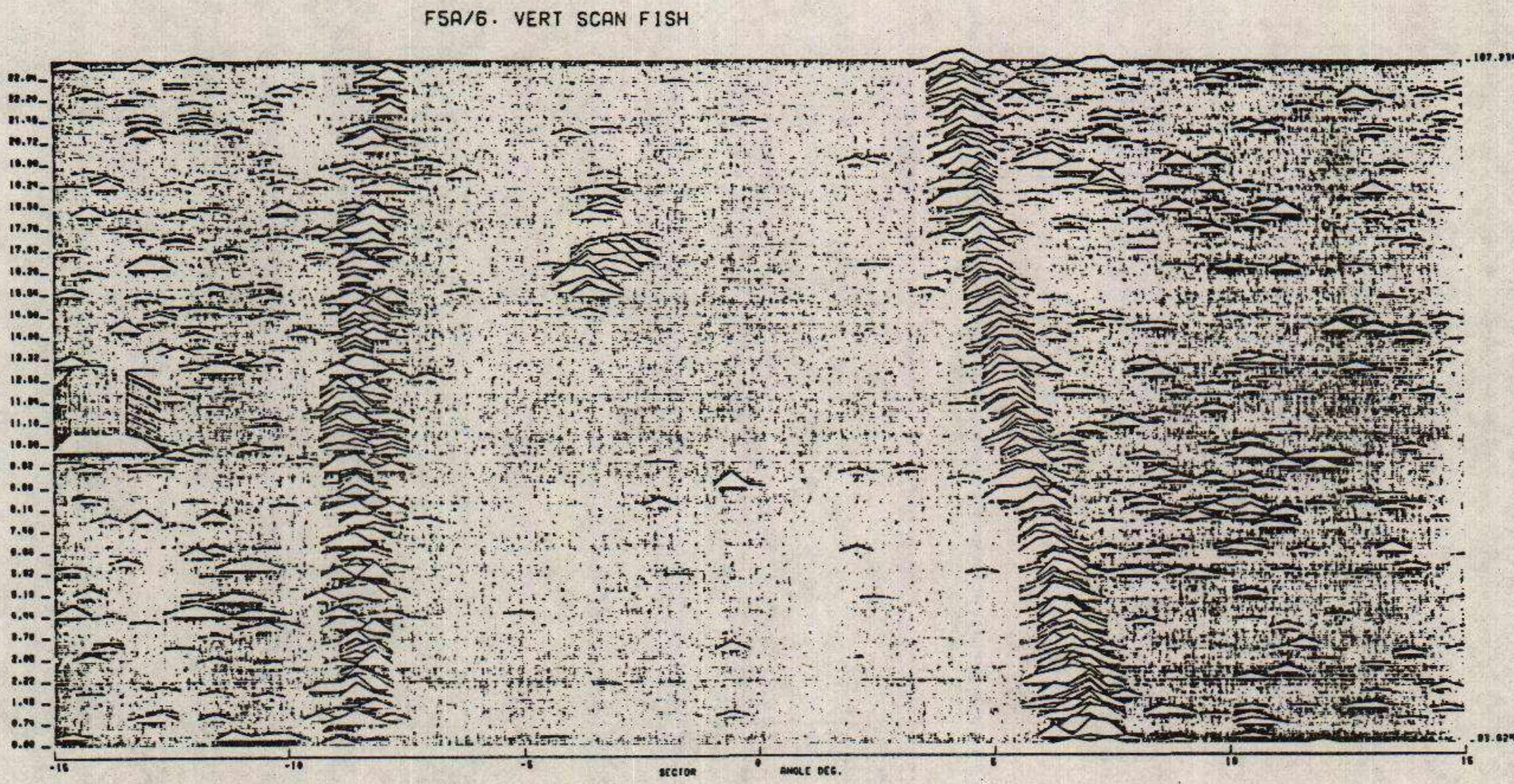


Fig 9 A Hidden Line Plot for the 300kHz Sonar in Vertical Scan Mode. Shows Sea Surface to Left and Sea Bed to Right with some Mid-Water Fish.

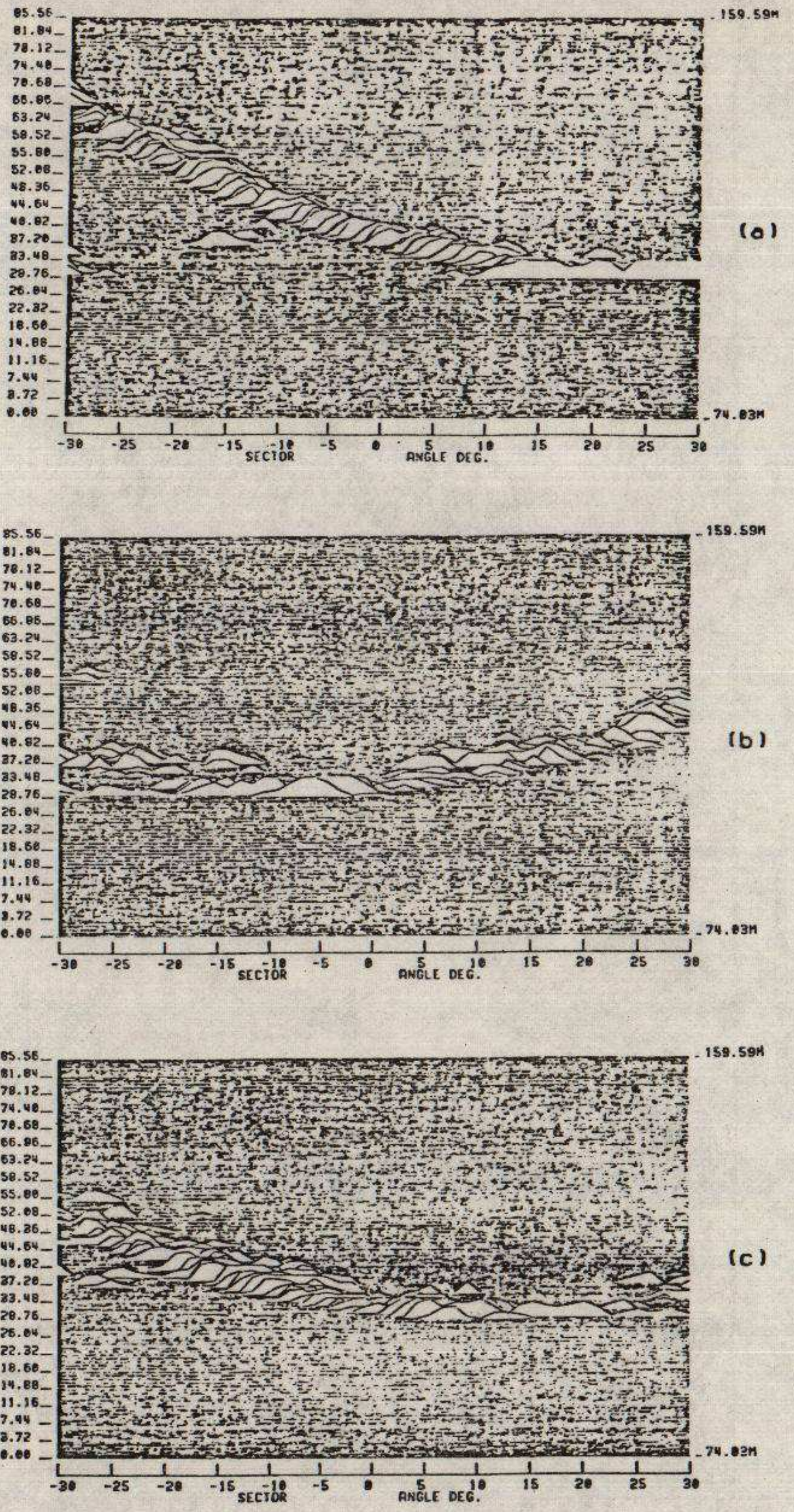


Fig 10 Hidden Line Plots for the 75kHz Sonar in Depth Sounder Mode showing different Sloped Sea Bottoms

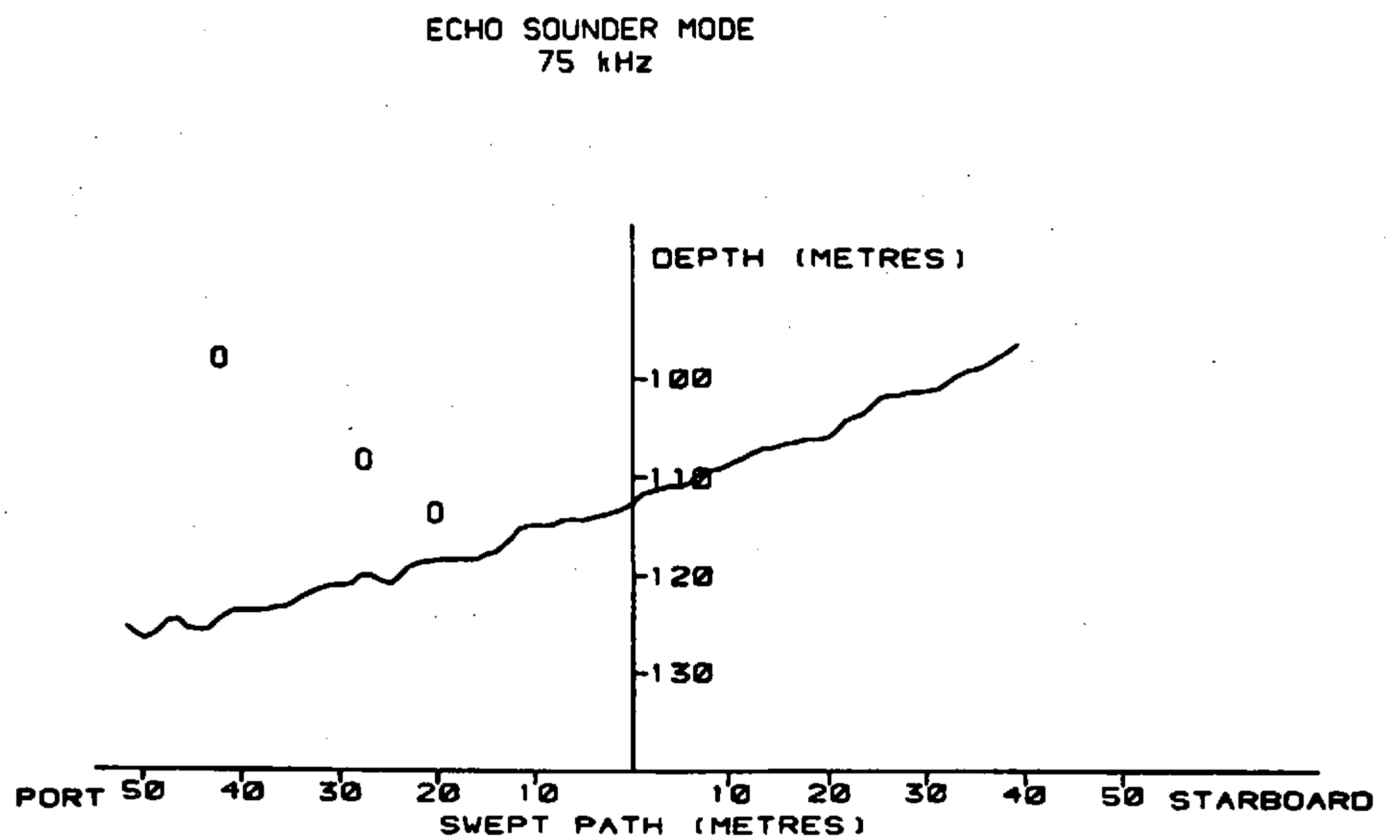


Fig 11a Bottom Profiles Computed From The Data Given in Figure 10a

ECHO SOUNDER MODE
75 kHz

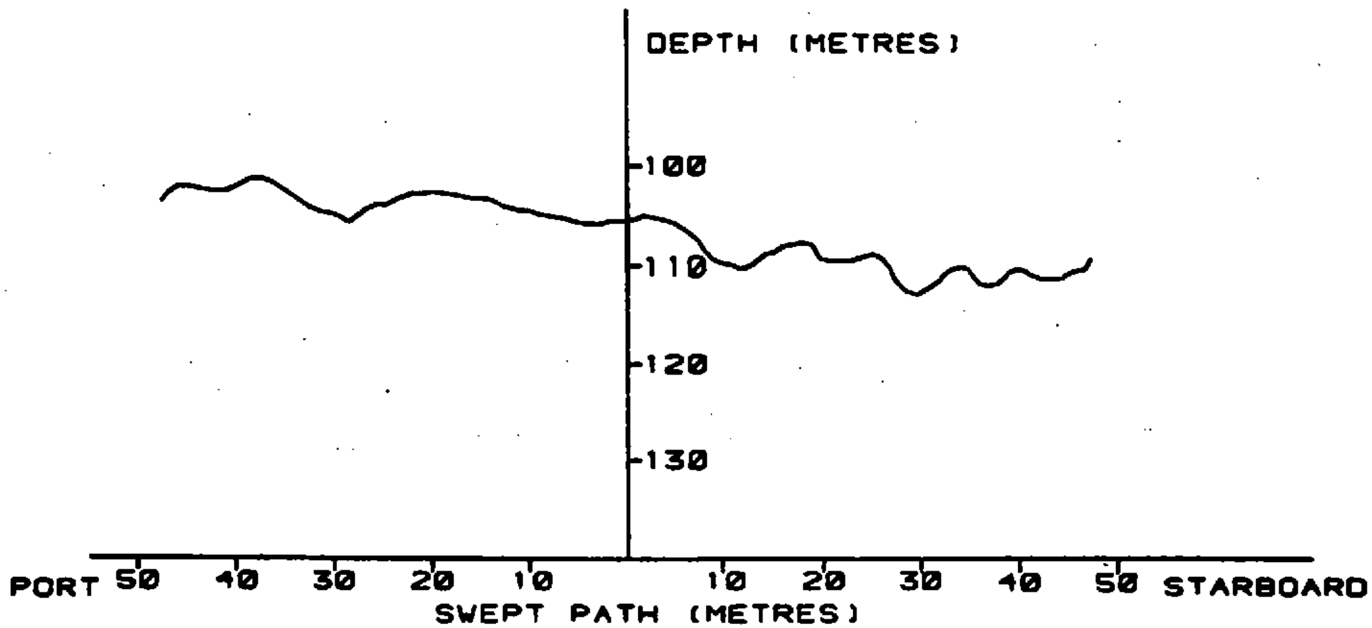


Fig 11b Bottom Profile Computed From The Data Given in Figure 10b

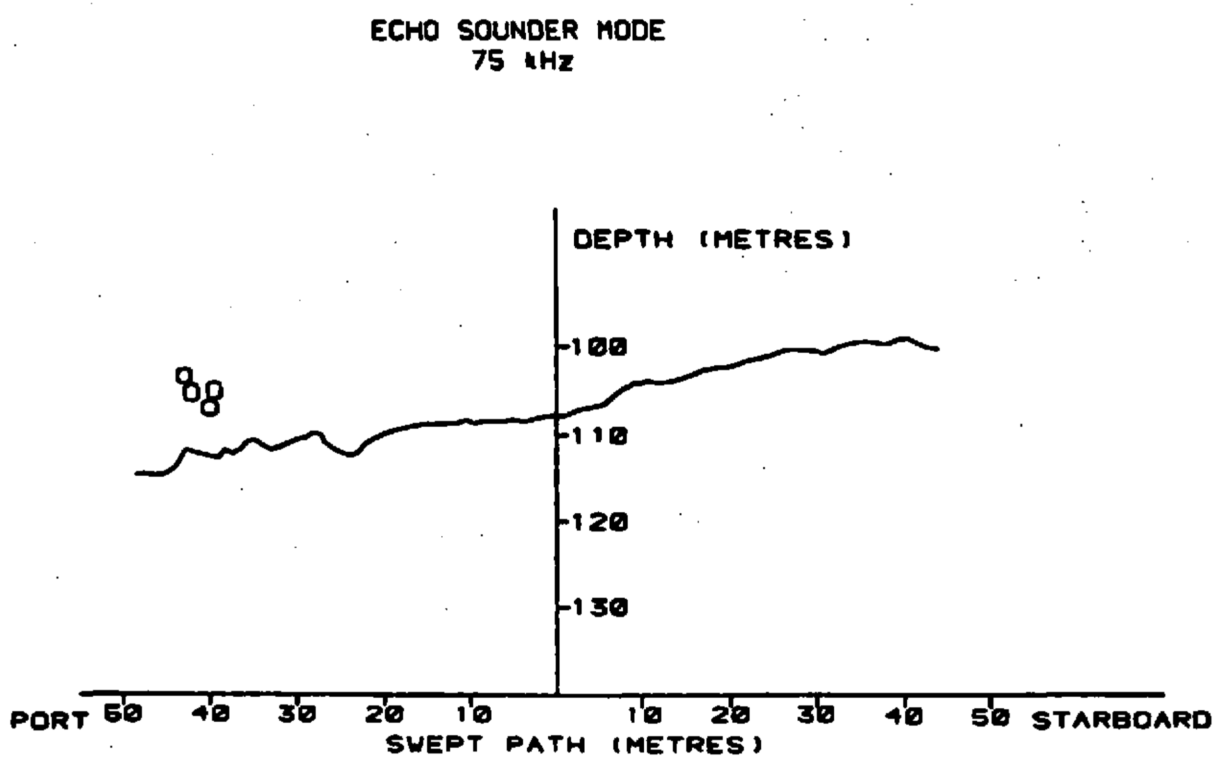


Fig 11c Bottom Profile Computed From The Data Given in Figure 10c