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

by

Dr J C Cook
Dr A Rushworth
Admiralty Marine Technology Establishment
Teddington, Middlesex, England

ABSTRACT The characteristics of three scanning sonars, presently in use at the Admirlaty Marine Technology Establishment, and operating at frequencies of 300kHz, 150kHz and 75kHz are described. The performance of a system for digitally recording the information from these sonars is detailed. A six bit (64 levels) analogue to digital conversion is employed at such a rate as to maintain the basic accuracy of the sonars. This data is recorded onto digital cassettes following ECMA 34 standards. The recorded information can be replayed into a PDP 11/40 computer via a digital highway for subsequent laboratory analysis. The processed data is then presented in various graphical three dimensional formats, examples of which are shown. The use of this analysis and representation is illustrated with reference to the use of the scanning sonar in three different modes of operation, namely echo sounding, forward search and depth scanning.

A system is described that continuously records whole successive frames of sonar information onto an instrument recorder using a multitrack digital recording technique. This system can also capture a frame of data into a random access memory of 512 pixels by 512 pixels of eight bit resolution (256 levels) and display the sonar picture in B scan format on a conventional colour TV monitor. The range and bearing are represented by the vertical and horizontal positions of a point whilst the echo intensity can be represented as one of 127 colour levels using a colour look-up table technique.

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 demonstrated to outside civil authorities and found application, particularly in the field of fisheries research (1). In recent years, the impetus given firstly for 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 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 and analysis techniques have remained substantially the same over the years. The application of digital signal processing and recording systems can now provide the means, for example, of applying pattern recognition techniques, contouring sea bed profiles, and estimating marine biomass and target strength data from basic sonar signals.

The application of computerised signal processing to three scanning sonar systems covering a frequency range of two octaves is described. The prototype digitisation system has now been in operation for a number of years and is at present being updated.

1 THE SONAR SYSTEM

An electronic scanning sonar generally ensonifies a specified volume of the sea (or area of the sea bed) using a separate transmitting transducer. Scanning is normally restricted to the receiver only and by subdividing the array into the appropriate number of elementary receivers suitable phase shifts may be applied to each individual output to steer the direction of maximum sensitivity of the array across the sector. The scanning frequency is matched to the pulse length so that the whole sector is scanned once in the time taken for the acoustic pulse to travel one pulse length in water. Scanning is continuous so that as echoes are received from each range increment they may be uniquely identified with resolution 'cells' defined in both range and azimuth. In the non scanned direction the resolution can only be specified in relationship to the beamwidth in that direction.

A complete 'picture' is built up in this way of the echo structure of the ensonified sector up to a range ultimately defined by the sonar parameters of the equipment. Conventionally the sonar information is presented in the form of a B-scan display in a Bearing (X deflection) - Range (Y deflection) matrix, the sonar signal itself providing the Z modulation, using a long persistence phosphor. Three modulation scanning sonars are now in use, operating at carrier frequencies of approximately 75kHz, 150kHz and 300kHz and these can be operated either singly or in synchronisation.

The 300kHz system employs a 150 λ long receiving array, with some measure of array shading to reduce unwanted side lobes and this results in an overall beamwidth in the scanned direction of 0.4°. The beamwidth in the non scanned plane is approximately 7°. The transmitted pulse length is 100 μs and the scanned sector 30°. This sonar can detect a -45dB target at a range of 100m and a 0dB target to ranges of approximately 300m. The performance of this type of sonar when installed on the fisheries research vessel 'CLIONE' has been reported in reference (3).

The measured resolution of the sonar has been determined to be very close to that defined by theoretical predictions (4) and provides a resolution capability approximately equivalent to that defined by the nominal beamwidth down to ranges of 60m. The basic resolution 'cell' of the sonar, at ranges in excess of 60m may therefore be calculated as:

$$0.007 \times 0.123 \times 0.075 \times R^2 \text{ cubic metres}$$

where R is the operative range in metres.
The effective volume resolution (Figure 1) gives a resolution cell of 1 cubic metre at a useful working range of 125m.

For the 150kHz equipment the basic parameters of the signal processing is very similar to those of the 300kHz sonar, the identical scanning frequency, 30° sector and transmitted pulse length being preserved to give the same range resolution capability of 0.075m. The receiving array has an aperture of 90 λ and a nominal beamwidth of 0.56°. The detection range for a 0dB target is well in excess of 400m but for normal operation the range of detection is generally limited to about 375m defined by a pulse repetition frequency of 2Hz. The beamwidth in the non scanned direction is 10° and with these design parameters the resolution cell at 200m range is approximately 5 cubic metres.

At 75kHz it is not practical to maintain the transmitter pulse length at 100 μs due to bandwidth problems, and at this frequency the pulse length is increased to 0.5 milli-seconds and the appropriate scanning rate is 2kHz. The effective range resolution is therefore 0.375m. A 45λ long receiver array with a beamwidth of about 1.1° in the scanned direction is employed with a beamwidth in the non scanned direction of 22°. For this sonar the sector has been increased to 60° and the range of detection of a OdB target in normal low sea states is well in excess of 800m. A 1Hz pulse repetition rate is normally used, limiting the accepted range gate to 750m. The volume resolution cell at 600m range is now nearly 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, giving the same amplitude of signal for a specific target independent of range.

2 METHODS OF OPERATION

The three sonars provide long range detection with a short range, very high resolution, target delineation capability. The versatility of the arrangement is enhanced by the use of the equipment in any one of three modes of operation.

2.1 Azimuth scanning mode

This is used for forward search applications, where the long axis of the transducer is horizontal and the array is scanned in the horizontal plane, (Figure 2). In this case the target on the sea bed is delineated in both range and azimuth.

2.2 Depth Scanning

When the transducer is rotated so that the major axis of the transducer is vertical, scanning will take place in the vertical plane. The receiver beam is then scanned from the sea surface to the sea bed and the profile of the sea bed contours can be examined. This type of operation can be used for hydrographic survey applications and the determination of the free depth of water above bottomed hazards such as wrecks (5).

2.3 Depth Sounder Mode

A second method of depth contouring can be achieved by tilting the transducer to point straight down and rotating the major axis of the transducer to the athwart ships. In this arrangement the system can be used in the echo sounder mode for across track profiling, and has recently found application in the monitoring of bottom laid oil pipe lines.

In all the applications described above the sonar will operate simultaneously in the passive reception mode. A continuous source of noise in the far field will appear as a target at all ranges on the appropriate bearing. An example of the use of this system is in the monitoring of sea bed noise associated with the movement of sediments and sand waves under the influence of tidal flow (6). The use of small transponding fish tags has enabled fish to be tracked at large ranges in excess of that possible by using the active mode alone.

3 LIMITATIONS OF THE CONVENTIONAL SYSTEMS

The video display is normally the only method available for real time analysis and is adequate for short range use where a higher frame rate can be employed to give a reasonable flicker free display. For the long range sonar with an up-date of 1Hz or less, this type of display becomes practically unusable for locating and tracking small targets. Permanent recording is generally provided by photographic methods, or alternatively by some form of analogue tape recorder. Photographic recording has a severe limitation, however, particularly for research applications, in making quantitative measurements.

The detail of structure that may be obtained of sea bed reverberation, for example, now requires not just a single measurement of backscatter strength to define a given area, but ideally requires a considerable number of simultaneous measurements to be made as the area can now be surveyed in great detail. The sonar originally developed at AMTE was provided with a calibration method by which a signal could be injected across the inputs to the sonar thus establishing a comparison signal to which other target levels could be related. Calibration by this method, however, is time consuming and somewhat inaccurate and when undertaken at sea becomes impossible to use when more than a single target is of interest.

A means by which all these drawbacks may be eliminated is now provided by the implementation of digital signal processing to the analogue output of the basic signal processor, and by subsequent computer based analysis. By this means the 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 hitherto been possible.

4 DIGITISATION OF THE SONAR DATA

The scanning sonar achieves a very high data rate compared with the conventional sonar, 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 0.075m 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 eight 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 6.3) 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 initial 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, for example, it may be necessary to detect a single fish with a target strength of -37dB (single 0.1m 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 cassettee replay unit.

4.1 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 32ms duration (256ms for the 75kHz sonar), delayed in units of 1ms (5ms 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.

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.

4.2 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.

4.3 The Mk 11 Recording System

The incoming signal from the signal processing unit is again digitised to a six bit amplitude word, and this information is distributed over 13 tracks of an Ampex PR 2200 instrument recorder operating in the direct wideband 2 mode Each scan line is digitised at a precisely defined sampling rate, the ADC sampling being initiated by the recognition of the line synchronising pulse. Two six bit data values are packed into a 16 bit word along with a line flag, frame flag and a parity bit. A validity flag is incorporated into this 16 bit word which is set positive for valid data and zero for packing data. The 16 bit words are then distributed between the instrument record tracks in serial form at a density of 10K bits per inch. The digitisation and down loading of the data to the instrument recorder is achieved in real time.

4.4 The Mk 11 Replay System

On replay, the signals from the 13 tracks are passed to deserialisers which decode and deserialise the data. The bit parallel words complete with the appropriate flags are then passed via a DR 11 C direct memory access module to the computer. The replay unit buffers the data and checks the validity and parity flags. This data is reorganised into bit format acceptable to the computer. A digital to analogue converter is incorporated into both record and replay units for downstream monitoring. The data, held in the computer may subsequently be reduced and analysed using the display facilities.

4.5 The Display System

The display uses a conventional 625 line colour TV 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 by 512 pixels, each of 8 bit amplitude. The top 6 bits of the 8 bit plane store holds the sonar data, the remaining 2 bits are available for annotation and graphics which may be shown simultaneously with the sonar information.

The transfer of data to the frame store is controlled by a fast running software system based on integer arithmetic. The use of 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 mini computer has direct access to any picture point in the store so that it can either read information from the frame 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 TV monitor. 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. Two display formats can be used. 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 TV monitorby 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 may be held indefinitely in the store for detailed examination.

A 'window' facility is available whereby only a limited selected area of 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, 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.

5 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.

5.1 Computer Hardware

The computing facility is based on a DEC PDP 11/40 mini computer. The system has a 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 RT 11 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.

5.2 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 DR 11 C 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.

5.3 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 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.

5.4 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 angle. 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.

5.5 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 was done so that a scaling ratio of 50:1 could be used. 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.

5.6 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.

5.7 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.

6 APPLICATIONS

The use of the digitisation and scanning sonar system can be illustrated by its utilisation for hydrographic survey and fisheries research. The requirement for accurate and detailed hydrographic surveys has increased due to the use of deep draught ships operating in the relatively shallow waters of northern Europe. To produce a typical high density survey using conventional echo sounding sonar involves the survey ship crossing the sea bed in a large number of closely spaced tracks. Any hazards such as isolated rock pinnacles or wrecks can completely escape detection by this tedious method of survey. The use of scanning sonars, coupled with the digital signal processing described, can provide a long range search capability and detailed depth profiling to give an integrated system for high precision surveys.

For fish detection, and in particular for fisheries research, there exists an immediate requirement for fish stock surveys to be undertaken with a reasonable degree of precision. The UK for example has a need for both herring and mackerel stock assessment. The high resolution scanning sonar provides the capability for this type of work.

6.1 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 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 the size of the fish to be approximately 0.3m in length. The highest target strength of -11dB suggests a maximum packing density of 50 fish m^{-3} (4), which is about 'normal' for this size of fish. The statistics of target strength occurrence provided by the tabular listing program gives a total fish count of 13,700 fish. For this size of fish this implies that the shoal has a biomass of 6400 Kgs.

A very small shoal of a distinct ring shape is shown in the three representations of Figures 5, 6 and 7. The vertical line (Figure 7) is 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.

6.2 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 8 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 allow sea bed profiling to be achieved at much longer ranges of up to 750m.

6.3 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 conditions 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 9 a, 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 10 a, b and c show the respective sea bed profiles computed from this data and presented in true coordinates. 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 $\pm$ 50m either side of the ships path at an average sampling distance of about 2m.

Figure 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 $\pm 30^{\circ}$ can be estimated from this type of data.

CONCLUSIONS

The use of digital signal processing in association 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.

REFERENCES

1. VOGLIS, G.M. and COOK, J.C. Underwater applications of an Advanced Acoustic Scanning Equipment. Ultrasonics Vol 4 Jan 1966.

2. COOK, J.C. and MACKAY, J.M. A precise sonar for Hydrographic Surveying. National Electronics Review V7 No 1 Jan-Feb 1971.

3. MITSON, R and COOK, J.C. Shipboard Installation and Trials of an Electronics Sector Scanning Sonar. Conference paper at Electronic Engineering in Ocean Technology 21-24 Sept 1970. Inst of Elec & Radio Engineers Conference Proceeding No 19.

4. COOK, J.C. and RUSHWORTH, A. Measuring Fish target strength and shoaling density using a High Resolution Scanning Sonar. Institute of Physics Underwater Acoustics Group. Proceedings of Conference 'Acoustics in Fisheries' 26,27 Sept 1978.

5. COOK, J.C. Some Practical Applications and Limitations of High Definition Depth Scanning Sonars. Proceedings of NORSPEC 70 Conference The North Sea Spectrum 117 - 130.

6. VOGLIS, G.M. and COOK, J.C. A new source of acoustic noise observed in the North Sea. Ultrasonics Vol 8 1970.

DISCUSSION

T. Totten Do you have a feel for the relative performance of pseudo 3-D displays and those using intensity modulation?

J.C. Cook For our purposes the number of display levels available using intensity modulation is not sufficient. One disadvantage this type of display has is, in fact, that if hidden-line techniques are used to make the display more acceptable to the eye there is the possibility of small targets getting lost behind slower larger targets on the same bearing. On the other hand, intensity measurements can be made directly, which is not normally possible using intensity modulations. We have no experience from the point of view of initial detection in noise or reverberation-limited conditions.

J.W.R. Griffiths In the use of the system as an echo-sounder there is obviously a problem if side-lobes on certain types of sea beds. Is it possible to use deconvolution to get around this problem?

J.C. Cook A side-lobe suppression program has been developed and has proved very successful in circumstances where high echo levels from such targets as sea beds at normal incidence cause side-lobe interference across other parts of the sector. (This is mentioned briefly in the published paper Sect. 5.2.)

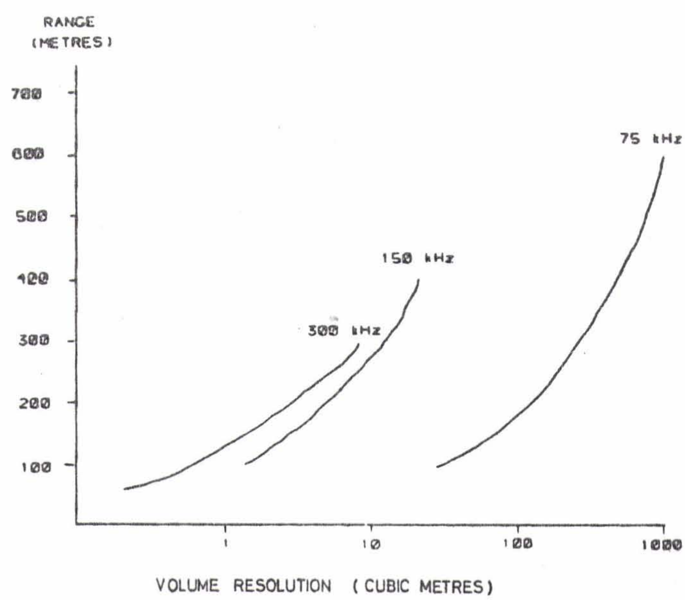

FIG. 1 THE SCANNING SONAR RESOLUTION CELL AS A FUNCTION OF RANGE

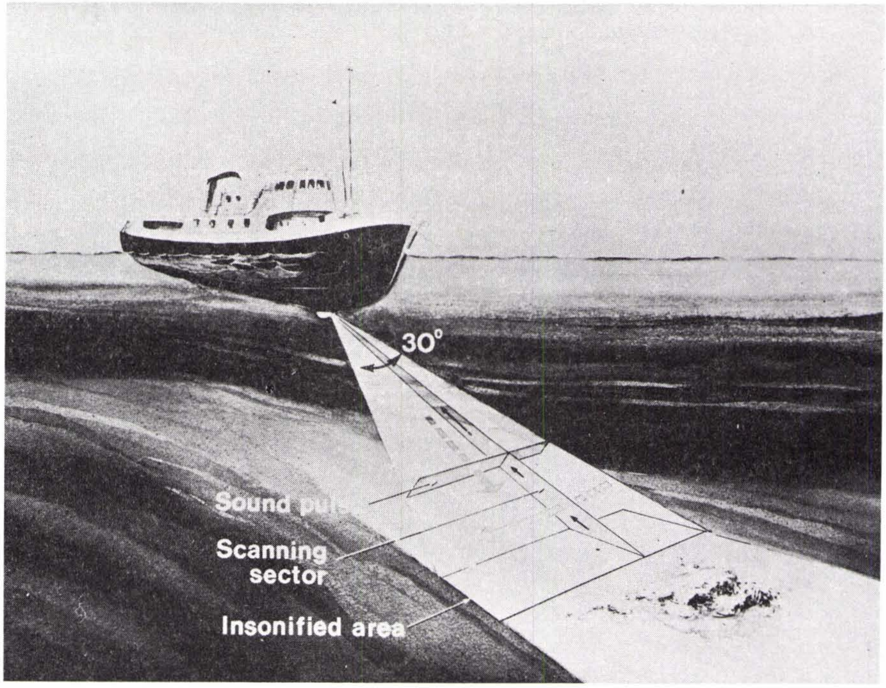

FIG. 2 THE SCANNING SONAR IN AZIMUTH SCANNING MODE

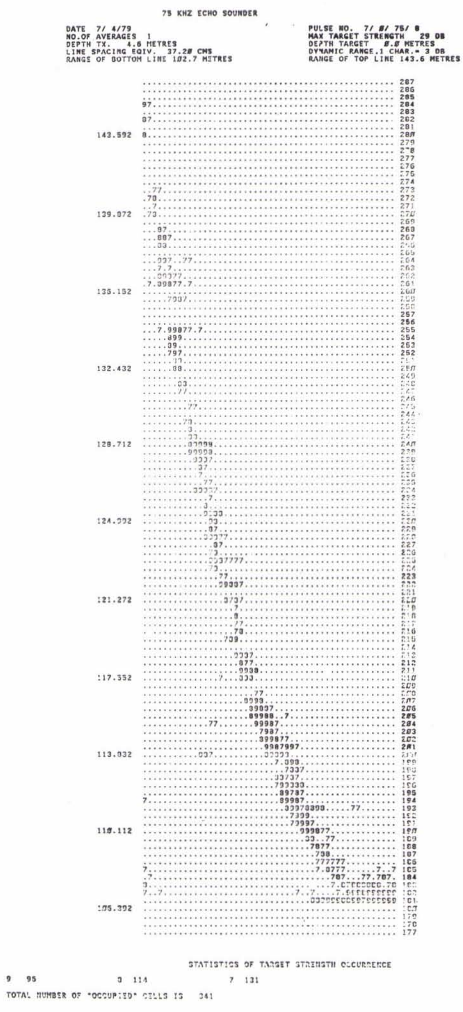

FIG. 3 AN EXAMPLE OF A TABULAR LISTING OUTPUT OF 75 kHz SONAR OPERATING IN DEPTH SOUNDER MODE

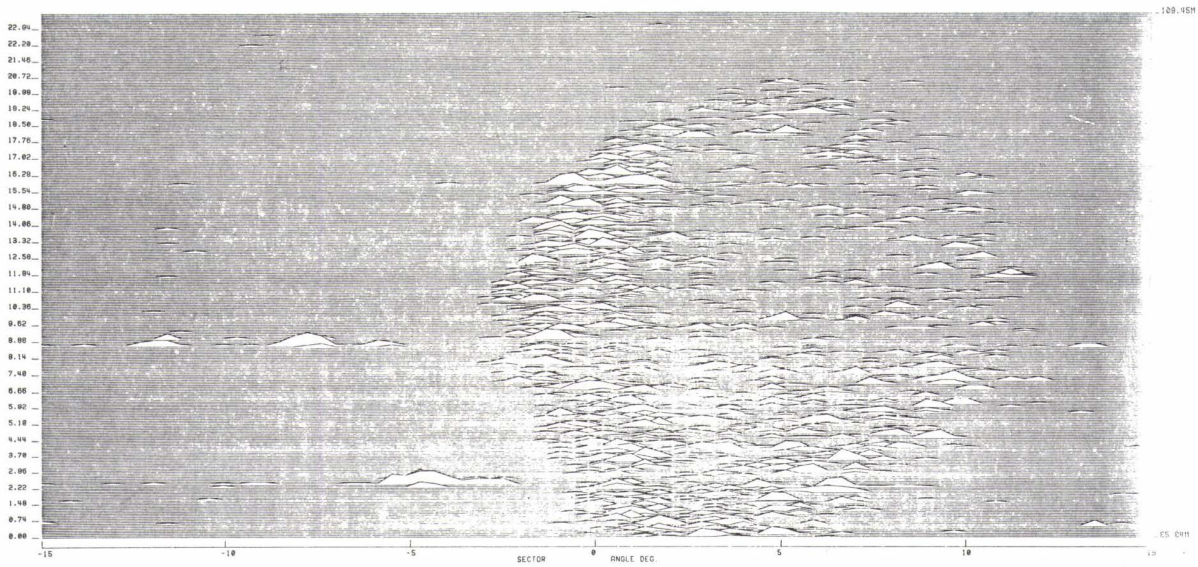

FIG. 4 AN EXAMPLE OF A HIDDEN LINE PLOT SHOWING A FISH SHOAL DETECTED WITH THE 300 kHz SONAR OPERATING IN AZIMUTH SCAN.

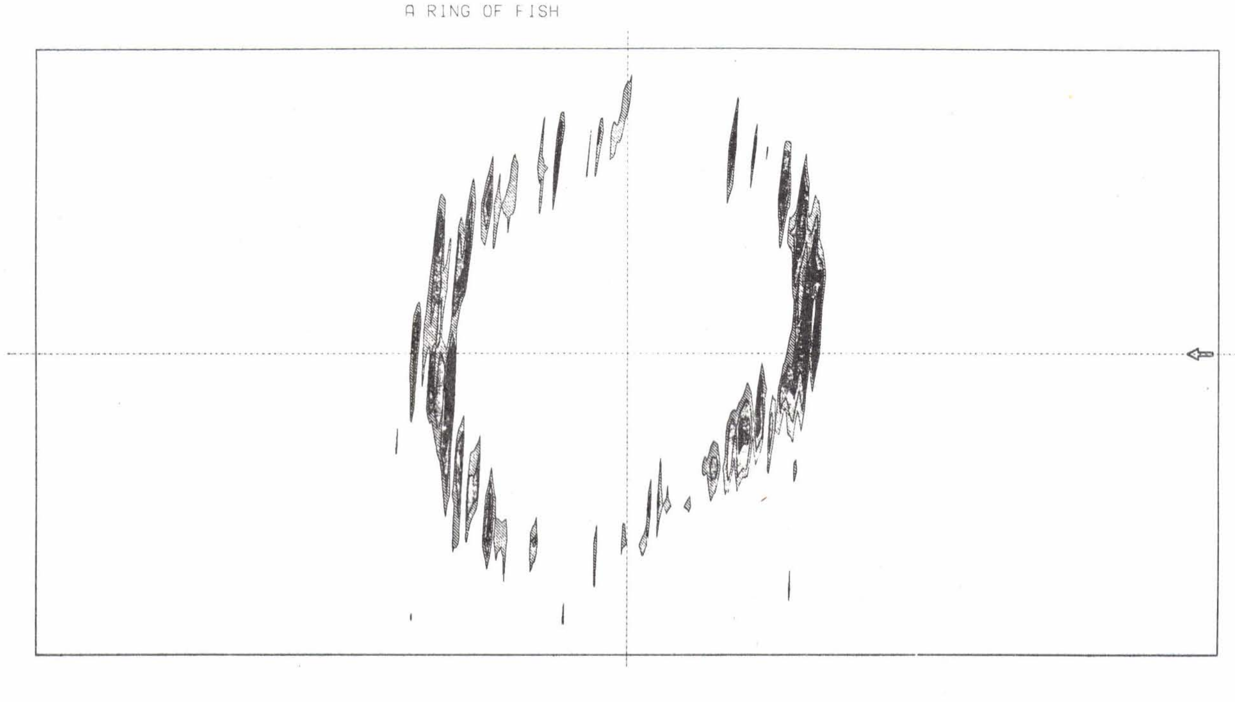

FIG. 5 AN EXAMPLE OF A CONTOUR PLOT SHOWING A VERY DISTINCT RING OF FISH.

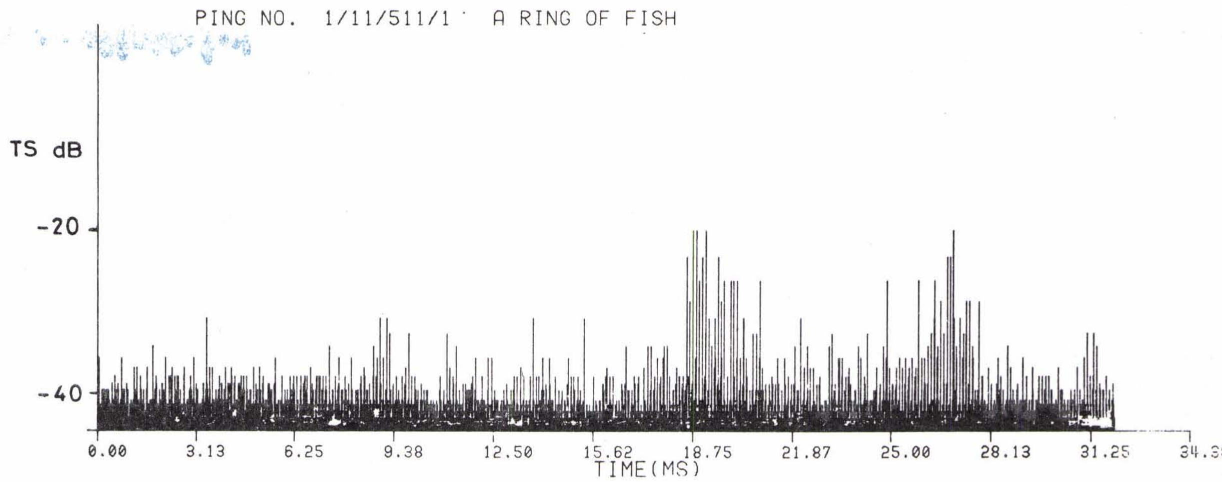

FIG. 6 AN EXAMPLE OF THE A-SCAN FORMAT PRODUCED FROM THE RING OF FISH DATA SHOWN IN FIGURES 5 AND 7.

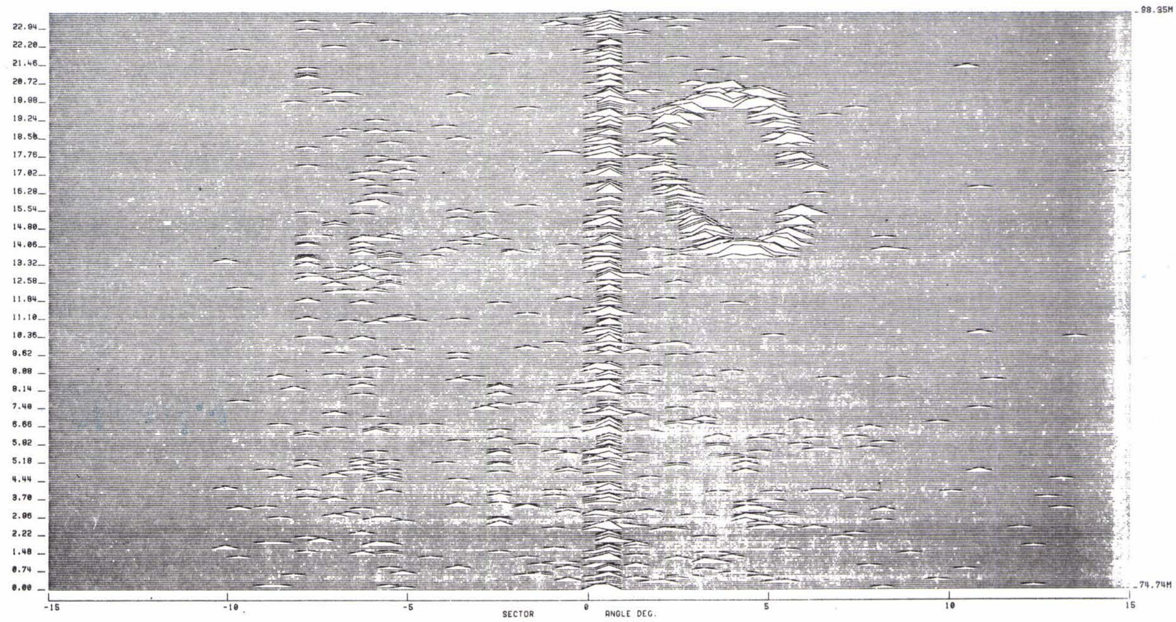

FIG. 7 A HIDDEN LINE PLOT OF THE RING OF FISH.

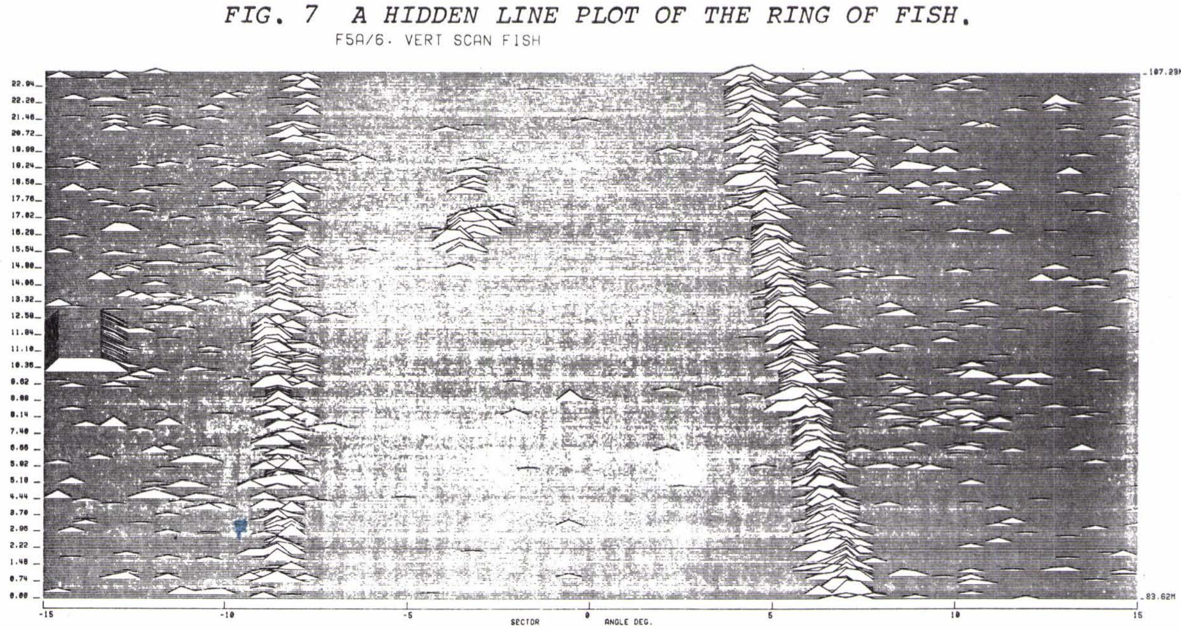

FIG. 8 A HIDDEN LINE PLOT FOR THE 300 kHz SONAR IN VERTICAL SCAN MODE. SHOWS SEA SURFACE TO LEFT AND SEA BED TO RIGHT WITH SOME MID-WATER FISH.

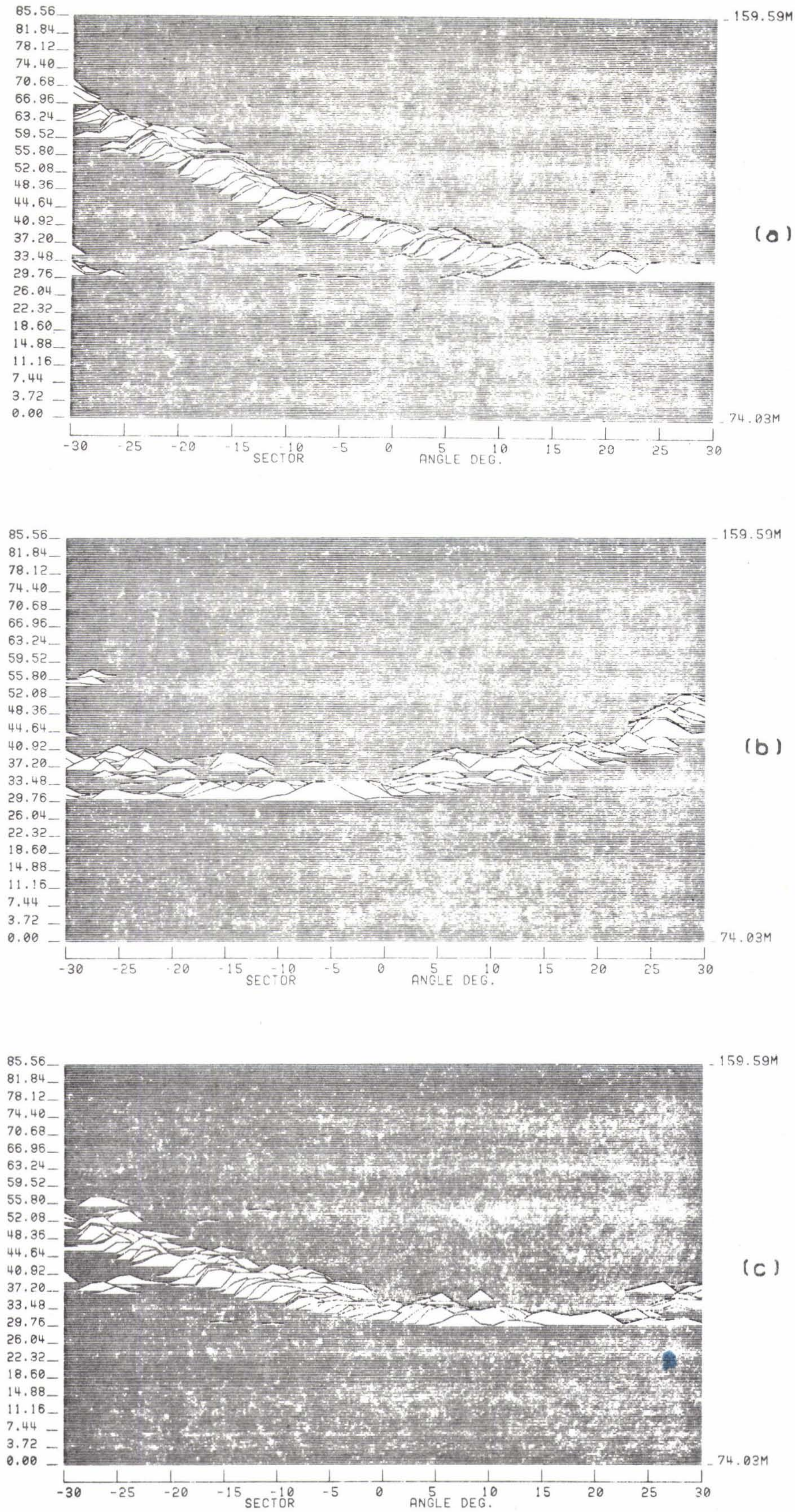

FIG. 9 HIDDEN LINE PLOTS FOR THE 75 kHz SONAR IN DEPTH SOUNDER MODE SHOWING DIFFERENT SLOPED SEA BOTTOMS.

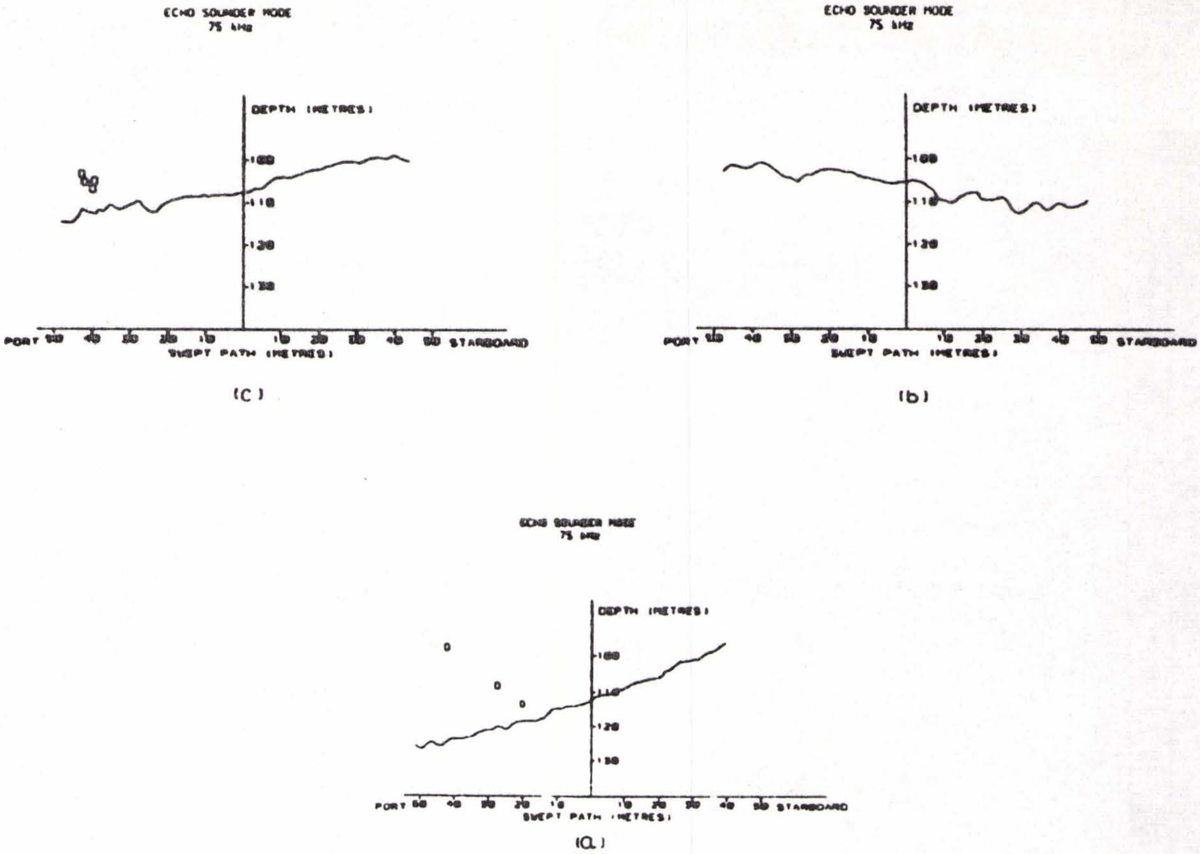

FIG. 10 BOTTOM PROFILES COMPUTED FROM THE DATA GIVEN IN FIGURE 9.