# MEASURING FISH TARGET STRENGTH AND SHOALING DENSITY using A HIGH RESOLUTION SCANNING SONAR

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ABSTRACT

The use of computer aided digital signal processing now permits the target strength in a single resolution cell of a scanning sonar to be measured with a high degree of accuracy. The basic factors influencing the design of such a system are described and the application of this technique to the study of fish target strengths and the distribution of fish density within a shoal discussed. Various forms of data presentation have been developed and are illustrated in relationship to the estimation of biomass.

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## INTRODUCTION

The use of a high resolution, within-pulse, sector scanning sonar, developed at the Admiralty Research Laboratory (now the Admiralty Marine Technology Establishment) for fish detection, was first demonstrated at sea in 1955 (1). In 1968 the ARL prototype equipment was provided on loan to the Ministry of Agriculture, Fisheries and Food Research Laboratory at Lowestoft, and installed on their research vessel RV CLIONE. Since that time this type of scanning sonar has been used extensively for many types of fisheries research applications.

To some extent, however, the scanning sonar has remained a somewhat qualitative tool in that the presentation of all the sonar information, whether in real time or recorded, has remained visual. Considerable data can be assimilated in this form, fish movements can be studied, fish reaction to trawls monitored, and even single fish detected but it has proved impossible, or at least extremely difficult, to measure the target strength of single fish and to measure biomass. Cushing (2), for example, has described one method that has been employed, involving the estimation of packing density from the photographic records of the sonar information displayed on a conventional B-scan cathode ray tube display. However, to exploit the full potential of the very high information rate of the scanning sonar, for this type of large, relatively random agglomeration of individual targets extending in three dimensions, ideally requires some form of computer assisted data analysis.

The development of high speed digital signal processing now permits the amplitude information in a single resolution cell to be stored, identified and digitally recorded for subsequent analysis and the sonar data can therefore be examined in much greater detail than has hitherto been possible.

This technique could permit the determination of the target strength of an individual fish from in situ measurements and the assessment of shoal size, packing density and biomass.

## 2. FISH DETECTION USING A SCANNING SONAR

The scanning sonar developed by ARL operates at a frequency of 305 kHz and has become the prototype for the design of several equipments now in use or under commercial development. The application of digital signal processing will, therefore, be outlined with reference to the parameters of this particular system. The design and performance of this sonar have previously been described (1,3) and only the basic factors that influence the measurement of target strength and the digitisation system will be detailed here.

This sonar ensonifies a sector of $30^\circ$ and by the use of modulation scanning techniques, steers the direction of maximum sensitivity of the receiving array across the $30^\circ$ sector at a rate of 10,000 scans per second. This scan speed is matched to the pulse length of 100 μs and defines a range resolution of 0.075 m. The receiving array is 0.75 m in length ($150\lambda$) giving a nominal beamwidth (3 dB) of $0.33^\circ$. In the system at present in use, a degree of array shading has been incorporated to reduce side lobe levels, resulting in an operational beamwidth of approximately $0.4^\circ$. In the non scanned plane the beamwidth is about $7^\circ$. The detection range of the sonar is limited by the pulse repetition rate to 186 m (200 yards), and at that range the sensitivity of the equipment is such that a target strength of appzoximately - 20 dB can be detected against noise.

Azimuth resolution must be defined with some care, for in the scanned plane the near field, as defined by $D^2/\lambda$ , where D is the transducer aperture, extends to a range of 107.5 m. Within the near field region, which extends to over half the useful detection range, azimuth resolution is no longer defined by the nominal $0.4^\circ$ beamwidth. The effective beamwidth does, however, reduce in the nearfield region and reaches an optimum at a range of about 0.6 $D^2/\lambda$. Figure 1 shows some measurements that were carried out on the prototype equipment to establish the practical, operational azimuth resolution at sea, resolution here being measured in terms of the transducer aperture. This data was obtained by using two small floats as targets and establishing the linear separation required to define a detectable visual resolution on the sonar display. The effective resolution was found to be very close to that defined by theory in the far field, and provide an effective resolution, practically equivalent to that defined by the nominal beamwidth down to ranges of about 60 m.

The basic resolution 'cell' of the sonar in the scanned plane, at ranges in excess of about 60 m can therefore be calculated as:-

$0.007 \times 0.122 \times 0.075\ R^2\ m^3$ where R ia range in metres

or approximately 0.65 cubic metres at a range of 100 metres, and in broad terms this gives a resolution cell of 1 cubic metre at a useful working range of 125 m. The size of the resolution cell as a function of range is shown in figure 2.

At these ranges, however, the dimensions of the resolution cell in range, azimuth and depth (for conventional azimuth scanning) are very different and this factor may give rise to some difficulty in the final interpretation of the sonar data. For this mode of scanning, for example, a single 0.1 m length fish, in either the head or tail aspects will occupy more than one resolution cell in range and if the echo is returned equally from all parts of the fish, the total energy of the echo return may be distributed over several resolution cells. In fish that have gas bladders however, the principal contribution to the target echo has been identified to be from the swim bladder itself, and it is reasonable to assume therefore that for these fish at least, the majority of the acoustic return will be confined to a single resolution cell. When scanning in the azimuth plane the depth extent of the cell is relatively large, some 12 m at 100 m range. In some circumstances, when examining small shoals, this depth extent may be more than sufficient to ensure that all the shoal is well centred with regard to the vertical directivity characteristics of the transmit/ receive system and it will be unnecessary to compensate the measured target strengths for position in the sonar beam. In other conditions, however, the depth extent of the shoal may exceed the vertical beam coverage. In these cases further information will be required about the shoal dimensions and this could be ontained by operation of the sonar in the depth scanning mode of operation.

## 3. TARGET STRENGTHS

Most target strength measurements of fish have been made at dorsal asepct and to some extent, ignoring the possibility of tilt and roll, this allows a reasonably simple relationship to be established between fish size, frequency and target strength in that the target strengths so obtained are independent of orientation in the horizontal plane. In the horizontal and near horizontal planes, however, the target strengths of fish are known to be highly directional and, in general terms, possibly a 20 dB difference exists between the target strengths that are measured at broadside compared with those that are obtained in the head or tail aspects. Although the scanning sonar may be used in the depth sounder mode of operation where the dorsal aspect target strengths are pertinent the power of the scanning sonar lies in its area search capability in the forward search mode of operation, using either azimuth scanning or depth scanning, and in these cases the fish are viewed at horizontal, or near horizontal aspects. General consideration will therefore be confined tothese modes of operation.

Love (4) has developed an empirical relationship giving the target strength of fish in the broadside orientation:-

$$T = 24.1 \log L - 4.1 \log \lambda - 33.2 \text{ dB}$$

where L and are measured in feet, this equation being valid in the range $1 \leq L/\lambda \leq 100$.

On the basis of this equation the maximum broadside target strength of a single fish at 305 kHz can be obtained, Table 1.

If we now consider the maximum possible packing densities of these fish, and follow the assumptions of Davies and Vent (5) that the maximum packing density occurs when there is approximately 0.2 body lengths between adjacent fish in a shoal and that under normal monotypic schooling conditions the spacing would be about 0.5 body lengths, it is possible to calculate, in very approximate terms what the packing density is likely to be for various sizes of fish. Assuming that the shoals are composed of equally sized individual fish arranged in parallel rows and the width and depth of the fish equals 0.2 body lengths, shoaling density can be approximated from:-

$$P = \frac{1}{(d+L)(d+0.2)^2 L^3} \quad \text{fish per cubic metre}$$

where d is the number of body lengths between individual fish and L is the fish length in metres.

Then for d= 0.5 $\quad P = \frac{1.36}{L^3}$ fish per cubic metre

and for d = 0.2 $\quad P = \frac{5.2}{L^3}$ fish per cubic metre

The number of fish per cubic metre as a function of fish length for normal shoaling is shown in Table 1.

Assuming the reasonably valid approximation that the target strenghts of fish in a single resolution cell will add incoherently, and neglecting all other complicating factors such as the effects of multiple scattering in the mass of the shoal, and the attenuation through the shoal of the incident sound, the effective target strength in a cubic metre cell can then be determined as a function of fish length; this is shown in Table 1. These figures indicate that for normal shoaling densities we may expect target strengths of between -6 dB and -12 dB per $m^3$ and for maximum packing densities target strengths as high as 0 dB per $m^3$.

The difference in the target strength of a single fish and the target strength of a cubic metre of a fish shoal at maximum packing density is about 37 dB in the case of fish 0.1 metre in length, but reduces to only about 7 dB for fish of length 1 metre. This range of target strengths may be expected to be maintained irrespective of target orientation, assuming that all the fish within the shoal are similarly orientated with respect to the sonar. However, a large shoal at 100 metres range, for example, may well extend across the full $30^{\circ}$ sector viewed by the sonar. In this case there will be a difference in the aspect presented by the fish to the sonar at the two edges of the sector of +/- $15^{\circ}$. This effect could be more serious in the head and tail aspects where the directivity pattern of the fish is more highly lobed than in broadside aspects. If an assumption can be made that all the fish comprising a single shoal are approximately all of the same size then some information concerning the size of the fish comprising the shoal can be obtained from the range of target strengths involved. The greater the range of target strengths recorded in single resolution cells, the smaller will be the fish comprising the shoal.

The target strengths shown in Table 1 for each cubic metre can be interpreted directly in terms of biomass, using established relationships between target strength and weight of fish. In the broadside aspect a target strength of about -20 dB per kilo is appropriate and this yields a figure of approximately 30 kilos for a target strength of -6 dB per cubic metre. At the other extreme many of the resolution cells at the fringes of a shoal will contain but a single fish. The minimum target strength recorded should thus be that due to a single fish and the orientation should be established with reference to the general movement of the shoal as a whole.

Thus, at at range of 125 m with this scanning sonar we can define a resolution cell of one cubic metre, and at this range also we can detect, at least in the broadside aspect, a single 0.1 m length fish with adequate signal to noise ratio. To deal with the complete range of target strengths that it is necessary to encompass it is required to have the capability for dealing with single resolution cell target strengths that may vary over a range of nearly 40 dB.

## 4. DIGITISATION OF SONAR DATA

The sonar receiver directivity pattern is steered across the $30^\circ$ sector in 100 µs, the time taken for the sound to travel one pulse length in the water. Successive scans follow at 100 µs intervals and the sonar information from each scan is conventionally presented line by line on a B scan display. Each scan line therefore represents the basic block of sonar information from a range gate of 0.075 m across the $30^\circ$ sector. For ranges of 186 m, 2,500 such scans are made. For the purposes of digitisation each scanned line must be divided into a numberof cells which must fit conveniently into the storage system. Although the nominal beamwidth of the system is $0.4^\circ$ it is probably more exact in this context to consider the number of independent channels of information that are available when considering the sampling rate that is required.

If s is the spacing between the individual elements of the array (element length) the sector over which the receiver can be deflected is given by:-

$$\theta_s = 2 \sin^{-1} \frac{\lambda}{2s}$$

which, in the case of the present sonar where $s = 2\lambda$

$$\theta_s = 30^\circ$$

For small $\theta_s$, $\theta_s = \lambda / s$

and as the far field beamwidth is given approximately by $\theta = \lambda / D$

$$\theta_s / \theta = D/S = N$$ the numbe of elements in the array.

This means that the number of independent directional channels available in the far field is approximately equal to the number of receiving channels. For the $30^\circ$ sector, therefore, with 75 channels a convenient number is 80, defining a sampling frequency of 800 kHz. This sampling frequency achieves the basic requirement of the Nyquist sampling rate, being approximately twice the highest frequency component appearing in the demodulated output. In the complete range gate extending to 186 m there are, therefore 80 x 2,500 resolution cells and if all the sonar information is to be stored it would be necessary to provide sufficient storage capacity to deal with all the amplitude information in 200, 000 individual cells. When this equipment was designed, several years ago, it was not considered to be either necessary or cost effective to provide for the digitisation of all the information in this complete range gate. There were many reasons for this decision, several of which have already been mentioned. The first 60 m of the range, for example, is of doubtful value for the type of research envisaged because of the rather complex variation in the dimensions of the basic resolution cell will range, and at ranges greater than 150 m the detection of a single small fish becomes marginal. Probably a range gate of about 75 m would be optimum from a cost effectiveness aspect for this type of research, but for this prototype equipment it was decided to restrict the range gate still furhter to one of 25 m, bearing in mind the extent of the computer analysis time that may be involved. It is also possible in the final system evolved to increase the range gate at the expense of resolutions. For in many types of operation, hydrographic survey, for example, a range resolution of 0.075 m is hardly ever required. With a range resolution of 0.30 m, providing a stored gate of 100 m more than adequate definition can be achieved for most purposes, particularly in the video display where the resolution is already limited by the display tube itself.

A shift register system was chosen for storage, each major shift register has a capacity of 1024 bits and can thus store nearly 13 lines of sonar information. In total 25 shift registers, of 1024 bits, at 80 bits per line form the store giving a total storage capacity of 25,600 bits and which is equivalent to 320 lines.
The amount of amplitude information that it is desired to store defines the number of bits required in the amplitude word. To cover the dynamic range suitable only to store sufficient information to reproduce an acceptable video picture probably requires no more than a four bit word due to the very restricted range that can be discerned on the normal TV-type screen. For this type of investigation, as has been shown, a dynamic range of nearly 40 dB is required if possible. The present digital system has therefore been designed on the basis of a six bit word to carry the amplitude information. This is equivalent to a linear amplitude ratio of 64, or a range of 36 dB. Use of a logarithmic amplifier at the input to the system could give the equivalent of a 64 dB dynamic range, with a 1 dB resolution capability. The total capacity required for the store is therefore 6 x 25,600 bits or 153,600 bits. A total of six shift register lines is therefore used, and a block diagram of the system is shown in figure 3.

## 5. RECORDING

The sonar information from a single transmission is stored on line in the shift register bank. From there it may be recorded digitally in slow time onto a simple, low cost, digital cassette tape recorder. Recording time for one range gate is about 40 seconds. The packing density is 31.5 bits /mm ( 800 bits per inch), the tape speed being 152 mm/sec (6 ips). the minimum length of tape in a single cassette is 86 m, so that 9 frames can be recorded on each side of the tape, or 18 frames per cassette. Alternatively, the video signal can be recorded in analogue form and digitisation carried out at a later date. Digitisation of the data directly, however, enables the retention of a goo dsignal to noise performance.

## 6. SYSTEM CALIBRATION

To permit the direct measuremend of target strengths it is necessary to establish a reliable calibration technique, or alternatively to provide local standard reference targets, although the latter may not be generally possible at sea.

The present AMTE system has now been in operation for a number of years and has achieved a high degree of reliability and stability in the reproducibility of the calibration. The receiver itself is provided with an internal calibration system which allows the receiver gain to be checked from the input of the transducer elements through the amplifiers and signal demodulator to the output. The receiving and transmitting transducers have now been in use for nearly twenty years and are thus now well aged and provide stable units to the sonar system. Similarly the transmitter provides a high degree of reliability and stability of output. Direct calibration has been used to set up the internal signal injection facility as a local reference calibrated in terms of target strength. Three types of reference target have been used to cover the range of target strengths that are of interest. For the low target strength region, -40 dB to -20 dB, standard spheres are used; for target strengths ranging from -20 dB to 0 dB simple spheres become too large to handle easily and to cove this range, both biconic diabolos and focussing spheres have been employed. The latter can give much higher target strengths for a given size than normal, air filled, sph res and have the advantage over biconics that they are reasonably omnidirectional. Calibration in this manner has been found to be self consistent using a number of different targets and now only requires infrequent spot checks to comfirm the calibration of the transmit/receive system.

The whole receiving system is linear, except at the detection stage. Here the characteristics of the demodulator have to be taken into account in the computer data analysis programs.

The sonar is provided with an automatic time varied control of gain which compensates the incoming signal for attenuation and spherical spreading. This correction coul, in principle, be applied by the computer, but this does have some interaction with the linearity of the detection system. It is obviously preferable to ensure that a -10 dB target for example, presents the same voltage level to the detector independent of the range of the target. In this context the relatively short range gate of 25 m chosen has a considerable advantage in that at a range of 125 m a change of gain of only about 7.5 dB is required to compensate for both spreading and attenuation. The compensation required can be determined practically by the use of standard targets of identical size positioned within the range gate and if so required the computer can use this data not only to normalise the amplitude data against target strength, but also to provide the correct time varied gain compensation. A further advantage of the short range gate is the fact that the size of the resolution cell may be considered as constant over the small increase in range involved, although this approximation must be treated with caution for even over a 25 m increase in range, the size of the resolution cell can increase by some 50%. figure 2.

## 7. SIGNAL PROCESSING

Once the sonar information has been digitised it is possible to use various computer aided analysis techniques to assist in the presentation of information for future reference. The basis for all these is the ability to compute directly the target strength in any resolution cell. The simplest form of computer output that is used is that of the A-scan format. In this case the A-scan can be used either to present information from the complete $30^{o}$ sector, or, alternatively to gate out any particular bearing and present an amplitude A scan, much in the same way as a side-scan sonar, to any degree of azimuth resolution up to that of the receiver resolution itself. Figure 4 shows an example of fish detection using this type of presentation. In this case the display is very similar to that obtained from a conventional sonar or echo sounder where the echoes have been normalised to target strength in a similar manner. In this case the fish were almost certainly Mackerel and the maximum target strength recorded in a single resolution cell is shown to be -20 dB. The lowest target strengths recorded is -40 dB which can then be taken as the target strength of a single fish. The noise level is at a general level of -48 dB.

At the time of the recording the fish shoal was swimming approximately normal to the direction of the sonar axis, and thus the fish were nearly in the broadside-on aspect. The shape of the shoal at this time was circular with a void of fish in the middle. This A scan shows that not only was there a void in the centre of the shoal as could easily be defined on the sonar video display, but also that the majority of the fish at this instant are concentrated at the nearest and furthest limbs of the shoal, and are packed at much higher density. Whilst the A scan allows a quick assessment to be made of the peak target strengths involved, all bearing information in the sector is lost in this elementary form of presentation.

The B-scan type of display which preserves all the amplitude information is a pseudo - 3D or 'waterfall' type of presentation shown in figure 5. In this figure the amplitude is made proportional to target strength and can be quantitised in any suitable steps. Normally the computer would present this information in approximately real geographical coordinates, but for the purposes of presentation here the coordinates have been distorted to produce a picture of the required size. In this case a calibration target at the far range on a bearing of about $-10^{\circ}$ provides a direct method of target strength determination, and gives a reference level of -10dB. The fish detected he e are therefore very large, probably cod, and only 28 cells are occupied. The target strength resolution in this case is set at 1 dB per line, the target strengths therefore range form -6 dB to -1 dB, with only a single cell giving a peak target strength of -6 dB. All other cells yield target strengths of between -9 and -11 dB. This recording was also made when the fish were known to be in a broadside aspect to the sonar. Table 1 indicates that the target strength of a large cod could certainly approach these target strength levels, and that a target strength of -6 dB could be achieved with maximum packing density per cubic metre.

A second example of this type of data presentation is shown in figure 6. On this occasion the sonar is operating in the depth scan mode and this recording was made on RV CLIONE using the MAFF sonar. The sea surface is shown on the left and the sea bed is on the right. In this case the sonar has been calibrated with reference to a standard sphere and this sets the maximum level at -20 dB. Minimum recorded level is -41 dB which can be attributed to a single fish. In this experiment the fish were swimming towards the stationary ship and were therefore in the head-on aspect at the time of the recording. Small, 15 to 20 cm Whiting were being caught predominantly in the area at the time and a target strength of -41dB does not seem to be unreasonable for a fish of this size in this orientation. Each increment in target strength level corresponds to as increase of 3 dB in target strength. An increase of 3 dB in target strength is approximately equal to a doubling of the number of fish in a resolution cell. Figure 6 shows three small shoals of fish and a considerable number of individual fish; the shoals appear to relatively compact and of reasonably high fish density. The highest target strength of -20 dB, compared with the target strength of an individual fish of -41 dB indicates that there are some 27 fish in an individual cell. At the maximum packing density for 0.2 m length fish there would be greater than 600 fish per cubic metre according to Table 1. At the range of detection of these shoals, approximztely 60 m, the resolution cell is only about 0.23 cubic metres in volume and hence the sonar indicates a packing density maximum of 560 fish per metre cubed. The packing density however does vary from cell to cell, although in most cases it is fairly high.

A second method of indicating the packing density can be achieved by means of the contour plot. Contour plot programs have been developed to examine these sorts of density distributions and this technique applied to the results of figure 6 is illustrated in figure 7. In this example only the fish shoals have been contoured, the whole picture being restored to true geographical coordinates by the computer. The small arrow indicates the direction of the incident sound. Only four grey levels have been used and therefore each contour represents a 5 dB change in target strength level. The contour plot reveals that although the packing density in some cells is very high, not all the cells necessarily contain even a single fish. By using contour plots such as this it is possible to study very rapidly the characteristics of the shoal packing density within the shoal itself to within the limitations previously mentioned of the unknown degree of attenuation of sound through the shoal itself and the effect of multiple scattering within the shoal. Figure 8 shoes a further example of contour plotting, this time in the examination of part of a shoal of much greater dimensions than those of figure 7. On this occasion the type of fish comprising the shoal is unknown.

For the estimation of biomass a direct print out of the target strength data in numerical form may be preferred. Figure 9 shows a typical example of this form of presentation, which has been limited in extent to only cover the part of the range gate filled by the shoal. In this case the target strength in each cell is displayed and can be normalised directly with reference to the equipment calibration. For ease of display only the digits 0-9 are used, to cover the dynamic range of 30 dB in 3 dB steps. Once again we make the assumption that the target strength increases by 3 dB for each doubling of fish numbers within a single resolution cell. Then, as the digit 3 is the lowest figure recorded, and this target strength is considerably in excess of the noise background which is not recorded here, this almost certainly represents the detection of a single fish. The maximum target strength shown is depicted by the digit 9 which occurs in eight cells only. This corresponds to a target strength of -20 dB. The single fish target strength is the -38 dB. In this case the shoal was probably of Mackerel, which were being fished in considerable numbers at the time. The general length of the fish caught was between 25 cm - 30 cm, which is the correct order of magnitude for a target strength of -38 dB and for a fish that has no swim bladder. This particular

This particular shoal was observed for a considerable period of time during which it was moving slowly across the sector at nearly constant range, and hence the fish were probably in the broadside aspect. During the period of observation the shoal shape altered considerably, figure 4, for example was taken when the shoal was nearly circular in form, with a central void. Several recordings of the shoal structure were made during this time and three independent estimates were made of the numbe s of fish that comprised the shoal.

The computer program identifies and sums all the resolution cells with the same target strength and these are shown at the bottom of the print out. In the range gate shown here there are a total of 5,650 cells, of which 1,767 are occupied. On the basis of a 3 dB increase in target strength per fish doubling this indicates that there was a total of 6,617 fish in the shoal. The other samples, made at five minute intervals gave figures of 6,112 and 5,740 fish. The latter figure,however, known to be a considerable under estimate of the total as in that particular case a calibration inject signal had been included which masked the complete dilineation of a number of cells across the centre of the shoal. The shoal statistics in the form of packing density histograms are shown in figure 10 for the three cases. Although in each case recorded the shoal shape had altered considerably, from the relatively compact form of figure 9, through a circular formation, figure 4, to finally an outline in the form of a figure 9, the relative distribution of fish within each amplitude cell remained reasonably constant, and the overall estimate of fish numbers were similar to within about 500 in a total of approximately 6,000.

The range of detection of this shoal was at a mean range of about 70 metres. The maximum fish packing density in this shoal was therefore about 200 per cubic metre; this figure seems to be reasonable for this size of fish.

A further development of this work has been in the use of two scanning sonars simultaneously, utilising two different frequencies. A second scanning sonar is now in operation, working at a frequwncy of 150 kHz, which also scans a $30^{o}$ sector. In this case the azimuth resolution is about half that used at 305 kHz, about $0.7^{o}$, and the directivity in the non scanned plane is also about half that of the higher frequency equipment. The transmitted pulse length, however, remains at 100 us giving the same range resolution capability. This means that the resolution cell is approximately four times the size at 150 kHz compared with 305 kHz. A reduction in frequency by a factor of two implies a reduction in target strength of little more than 1 dB, therefore the target strength in each resolution cell could increase by up to5 dB if the fish were distributed in a uniform manner throughout the shoal. Obviously, however, for a single fish per resolution cell the target strength would be hardly changed. Figure 11 shows an application of this method. A single small shoal is detected here; on the left hand side detection is at 150 kHz and at the right hand side detection is at 300 kHz. Both sonars are in exact synchronisation, the information from the 305 kHz sonar having been delayed by 50 us to permit display side by side. A calibration signalhas also been included and is associated with the 305 kHz equipment. The shoal shape as delineated by the two sonars is seen to be approximately identical as far as gross distribution is concerned. The type of fish in the shoal is unknown, but the tar et strengths are very high. This shoal, in fact, was detected at nearly the extreme range of the 305 kHz sonar, at ranges of between 160 and 180 metres, and the use of a dynamic range of 18 dB shown here still indicates that the lowest signals are clear of the background noise level. The calibration defines a target strength of OdB, and this shoal therefore is probably a densely packed shoal of small fish.

The two frequency system, has, as yet, not been fully exploited, it does, however, provide a second, independent, method of determining the fish density instantaneously. This may be of value when the extent of the shoal in the non scanned plane is greater than the linear extent of the higher frequency sonar in that direction. The results from the 150 kHz equipment with its wider beamwidth will then indicate any gross error in the determination of the biomass.

A second method that can be utilised is to use the two sonars in a crossed array formation, one for azimuth scanning and one for depth scanning. In this fashion the depth extent of the shoal may be depicted at the same time as the azimuth extent is delineated.

## 8. CONCLUSION

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 the biomass, although the problems associated with fish orientation and the attenuation of sound through the shoal still remain to be solved. This type of processing can also provide further dividends. Digital recording provides a method of achieving the high signal to noise ratio in the record system that is required for this type of measurement and digital storage gives a simple method of temporarily recording a single frame for more extensive on-line examination. In this case the frame can be replayed at high speed and will provide a flicker - free picture on any short persistence cathode ray oscilloscope.

The present digitisation system has proved to be extremely versatile in operation and has so far been used in conjunction with three different scanning sonars. A further facility that is available permits the averaging of up to eight successive transmissions, which in static conditions can be an advantage in some circumstances. In the depth scanning mode, as shown in figure 6, the sea bed and the sea surface can be examined. This permits measurement of both surface reverberation levels and the sea bed backscattering target strengths to be determined in absolute terms. A simole computation from the depth scan measurements can also provide a method of determining the sea bed contours.

Since the time that the prototype equipment was produced the cost of such digital storage systems has reduced considerably, and at the same time the speed of operation of analogue to digital converters has increased. Present day technology can therefore produce a system at moderate cost that will provide a simple and economical digital signal processing system for use with scanning sonars in fisheries research that will enable them to be used in a very much more quantitative fashion than has hitherto been possible.

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Fig 1 NEAR FIELD RESOLUTION OF AMTE SCANNING SONAR

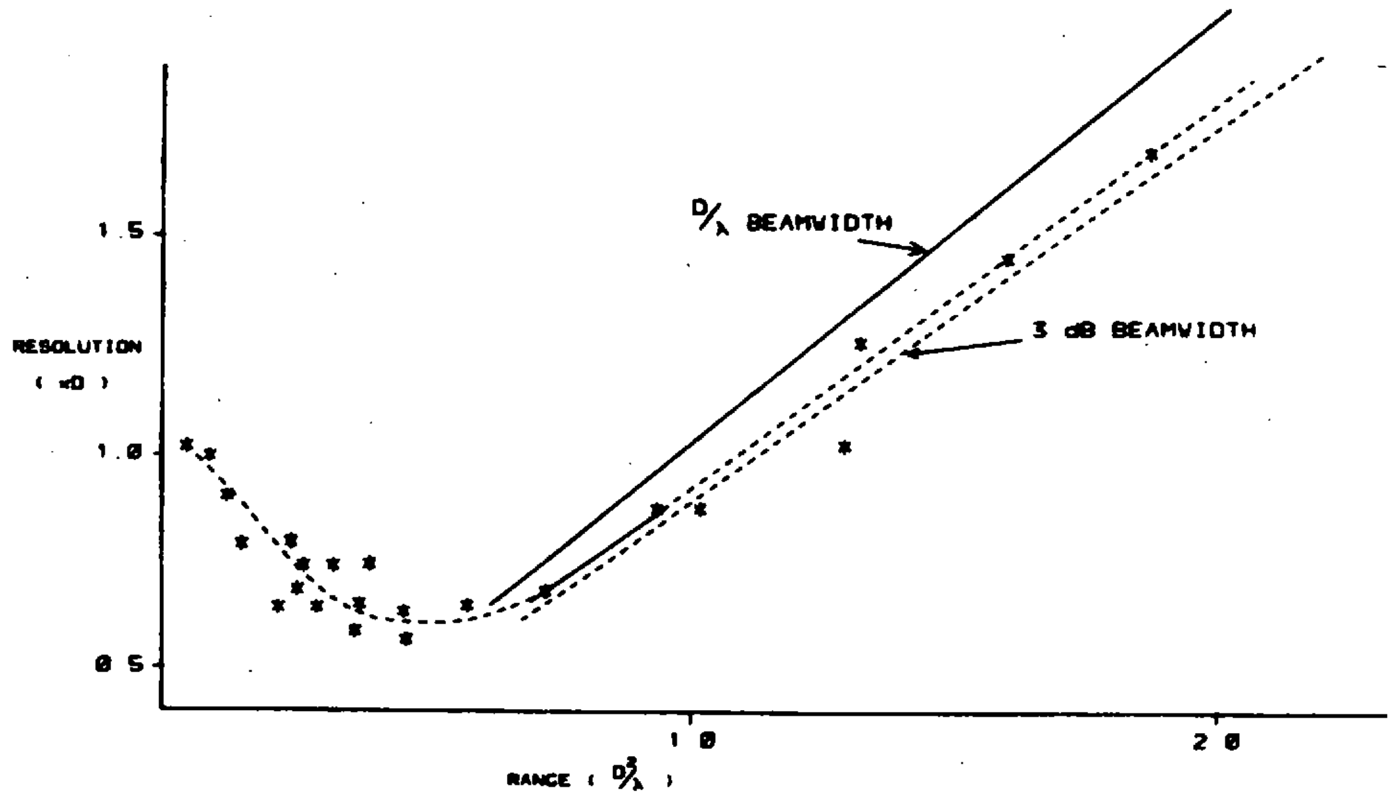
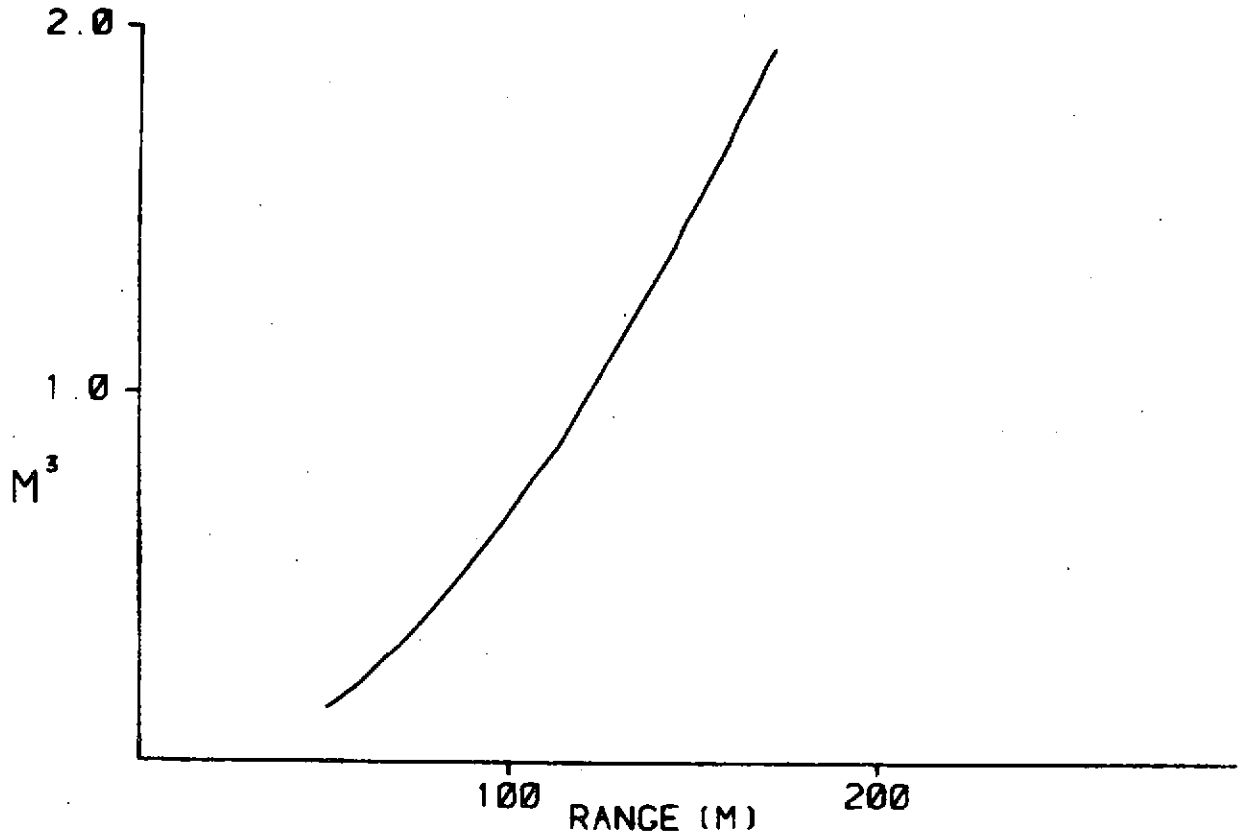
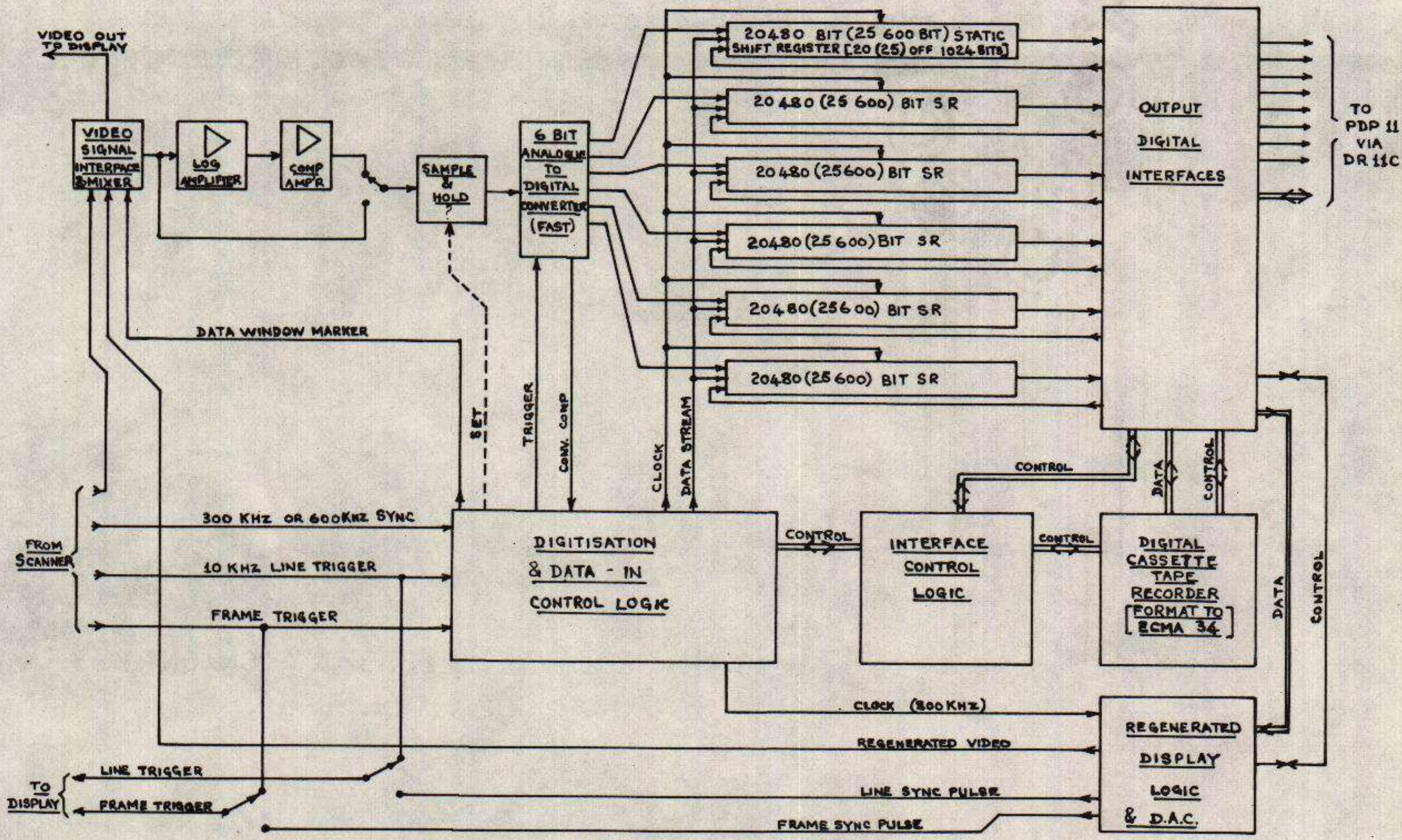


Fig 2  SCANNING SONAR RESOLUTION CELL






DIGITISATION OF SCANNER

BASIC LAYOUT OF SYSTEM

FIG 3

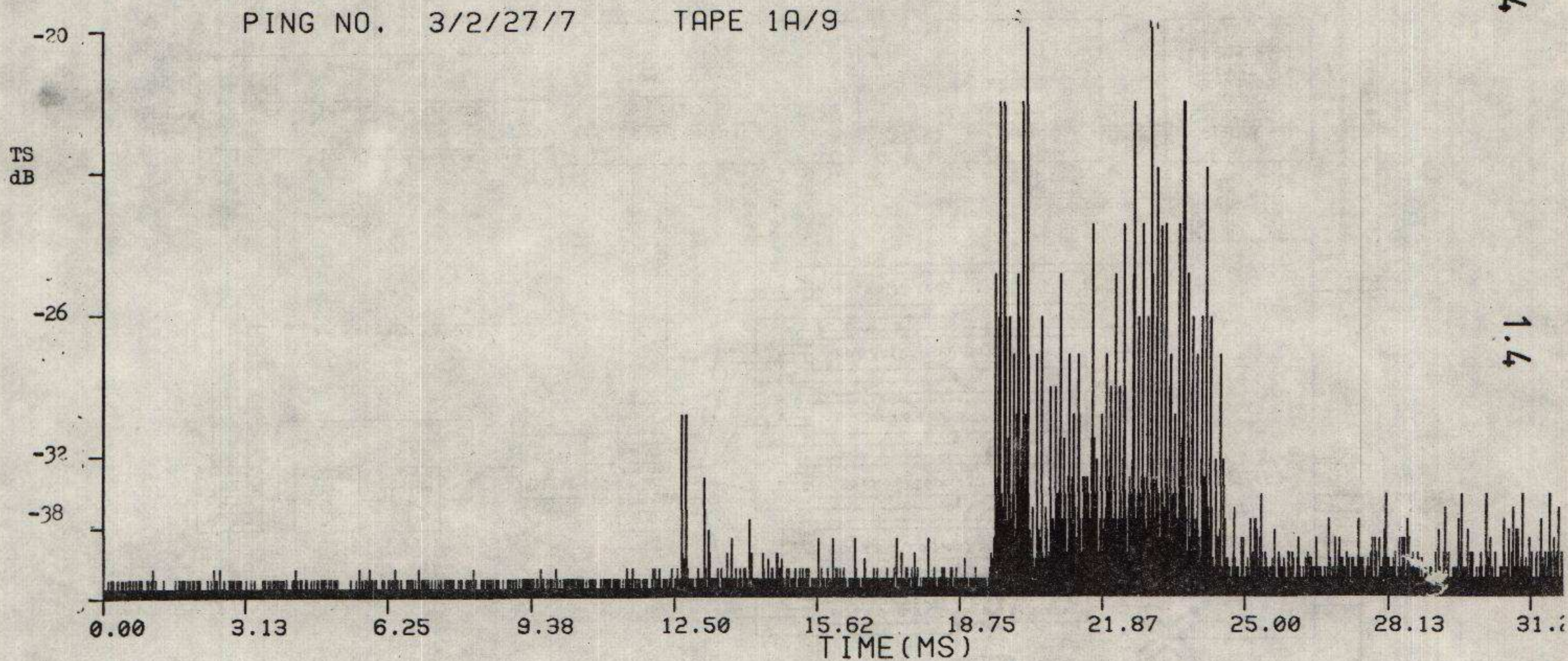
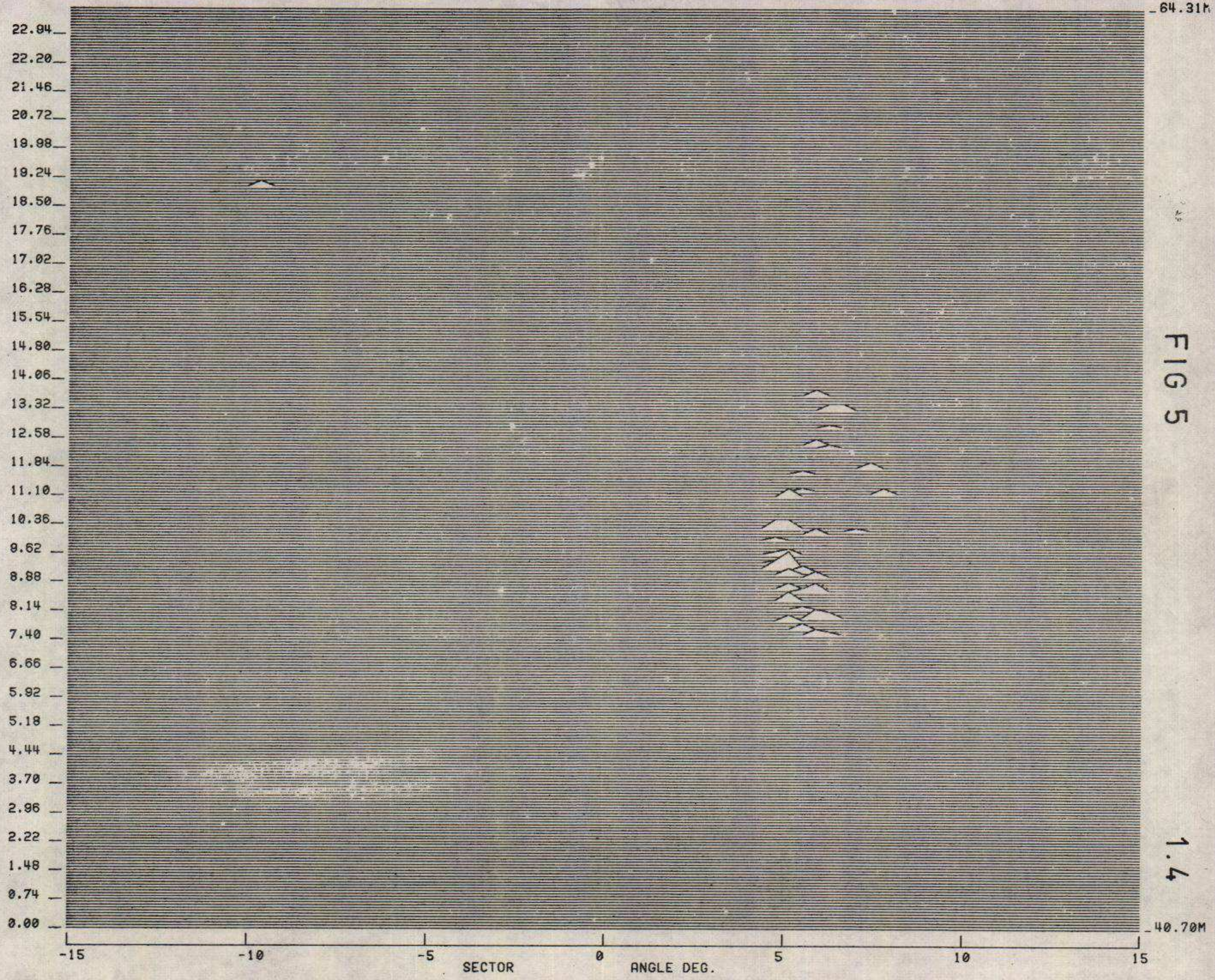

PING NO. 3/2/27/7 TAPE 1A/9
TS dB
-20
-26
-32
-38
0.00
3.13
6.25
9.38
12.50
15.62
18.75
21.87
25.00
28.13
TIME(MS)

FIG 4

1.4



22.94
22.20
21.46
20.72
19.98
19.24
18.50
17.76
17.02
16.28
15.54
14.80
14.06
13.32
12.58
11.84
11.10
10.36
9.62
8.88
8.14
7.40
6.66
5.92
5.18
4.44
3.70
2.96
2.22
1.48
0.74
0.00
64.31M
40.70M
-15
-10
-5
0
5
10
15
SECTOR ANGLE DEG.


FIG 5

1.4

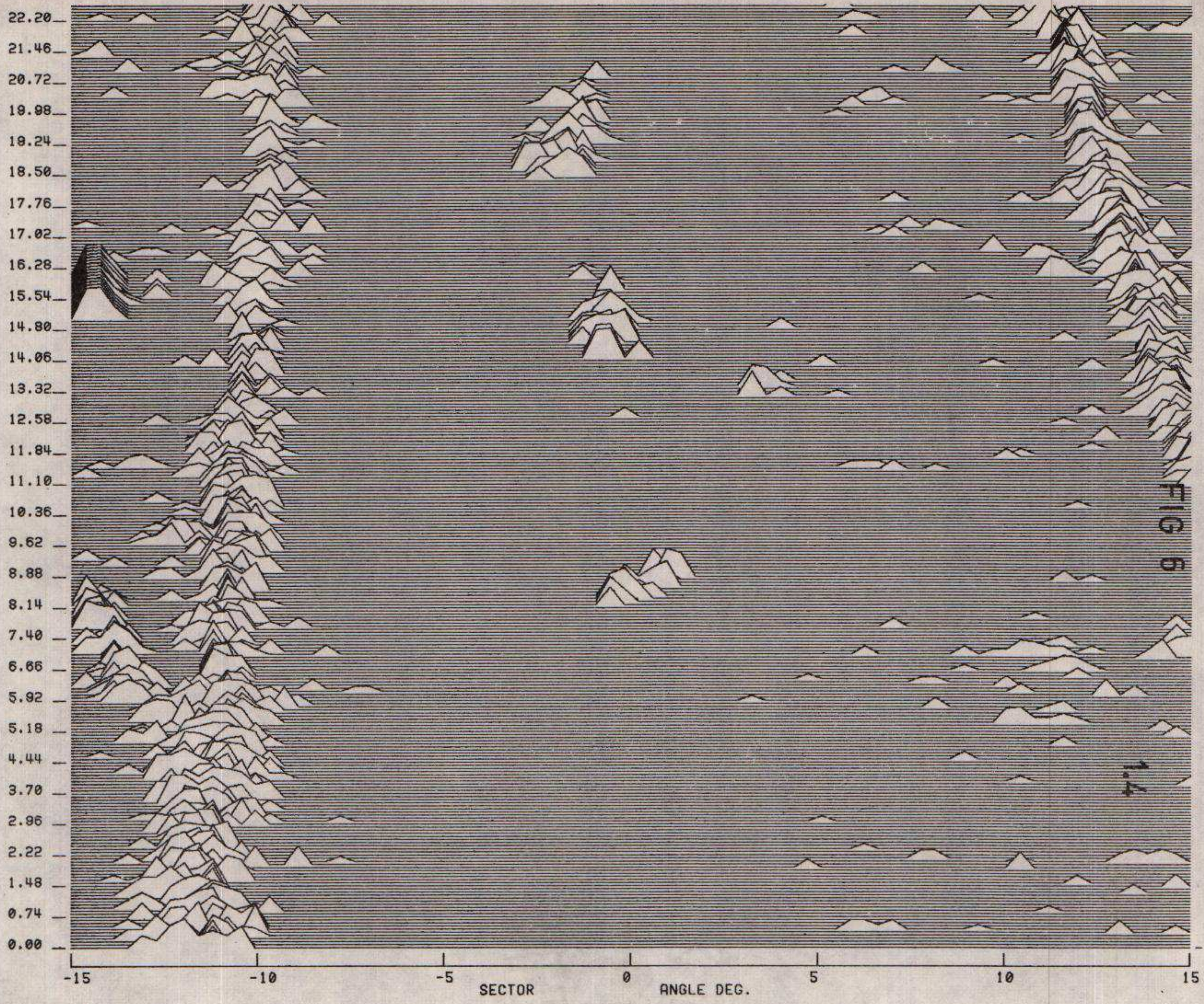
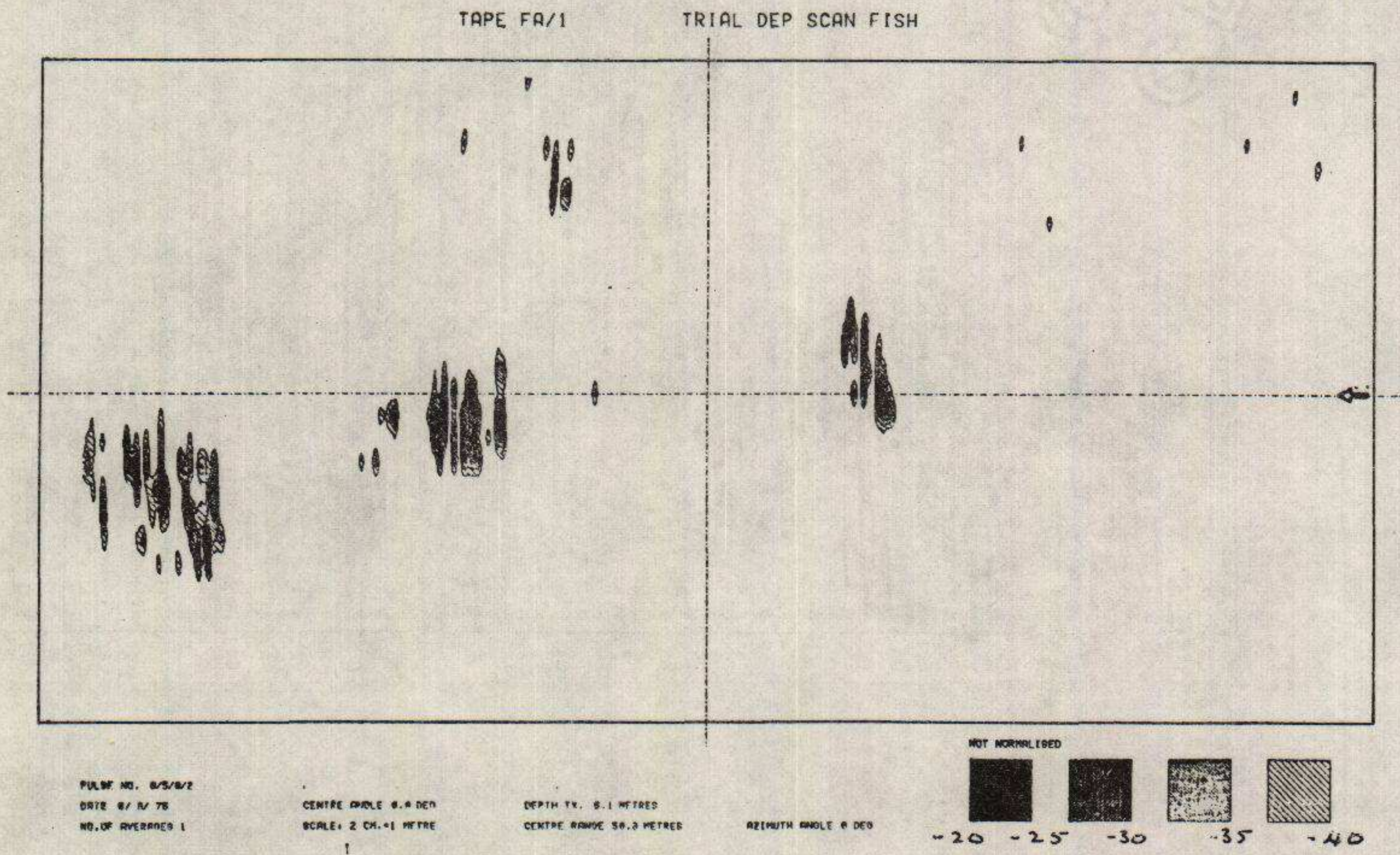

22.20
21.46
20.72
19.98
19.24
18.50
17.76
17.02
16.28
15.54
14.80
14.06
13.32
12.58
11.84
11.10
10.36
9.62
8.88
8.14
7.40
6.66
5.92
5.18
4.44
3.70
2.96
2.22
1.48
0.74
0.00
-15
-10
-5
0
5
10
15
SECTOR ANGLE DEG.
1.4

FIG 5

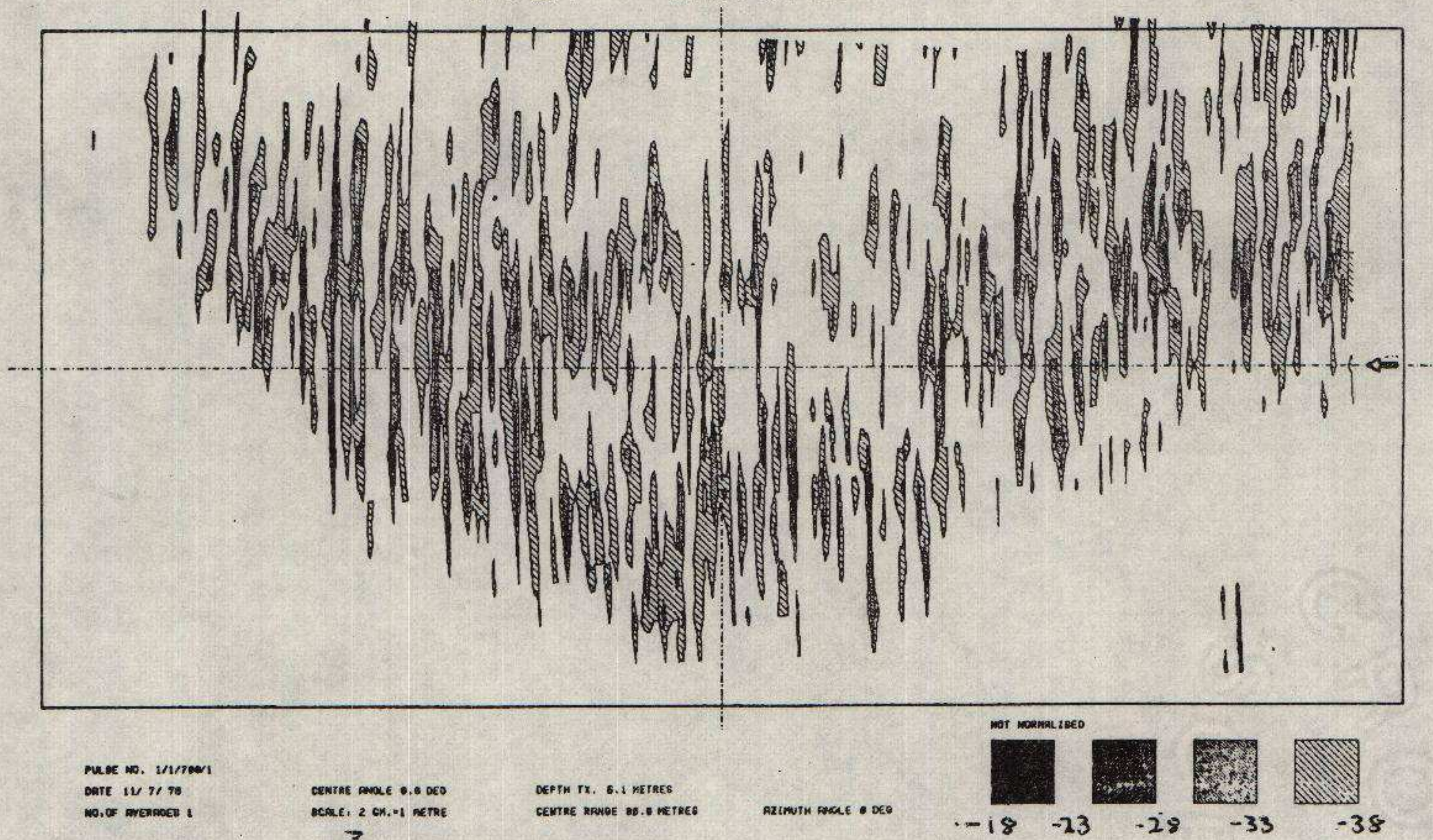

TAPE FA/1
TRIAL DEP SCAN FISH
PULSE NO. 8/5/8/2
DATE 8/ IV/ 78
NO.OF AVERAGES 1
CENTRE ANGLE 0.0 DEG
SCALE: 2 CM.=1 METRE
DEPTH TX. 8.1 METRES
CENTRE RANGE 58.3 METRES
AZIMUTH ANGLE 0 DEG
NOT NORMALISED
-20
-25
-30
-35
-40

8

FIG 7

1.4

TAPE JA/1 TRIALS L/G FISH




PULSE NO. 1/1/700/1
DATE 11/ 7/ 78
NO.OF AVERAGES 1

CENTRE ANGLE 0.0 DEG
SCALE: 2 CM.=1 METRE

DEPTH TX. 6.1 METRES
CENTRE RANGE 88.0 METRES

AZIMUTH ANGLE 0 DEG

FIG 8

1.4

FIG 9

1.4

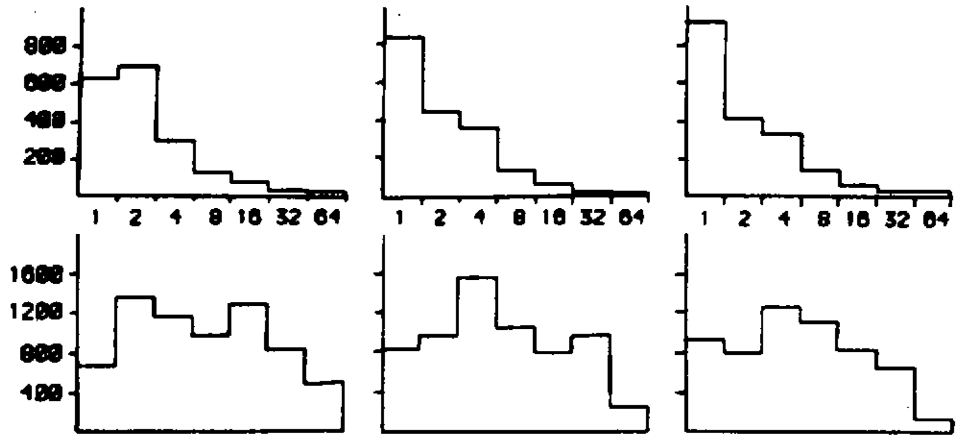
```
72.446  ...................................................3..3...3.........3........... 260
        ......................................................3.3....................... 259
        ..............................3.....................3.......3................... 258
        ..................3...................................34.33..................... 257
        ................................................................................ 256
        ....................................................3.....3..................... 255
        ............................34.....3....3........3......454.......3............. 254
        ..3.........................344..........................34.......3....3........ 253
        ............................343..........................33..................... 252
        .........................................................3...................... 251
71.706  .............................43.......33..................34.....3.............. 250
        ................................................................................ 249
        ................................3...................3..45.444333.......3........ 248
        ....3.........................3................................................. 247
        ............................345653.3.....3..3............4.44................... 246
        .33.3...........4............33.3...........3........444674.4................... 245
        ....3..............................................34435645544...3.............. 244
        3..45..43.3....43....3.3.....34464...........4446537754453.3.444........3......3 243
        ..3.543......4..3...43...3....4554.444....3453688645.65.454444.43....3...3.44.5 242
        3..34........3.3.3.........3.........3.....434645644457754.54343..3.........43.. 241
70.966  ..44......3.......33.........4334.4..343...4473575455544.43.4.3..4.3..3..3.34..3 240
        ...............4..33333..........54....4..4433575...4753.445.4...33.......343... 239
        .33.43......44....3..3..3.....3.........3764578633.35544564.......4.......3.3...3. 238
        44.33333.3.4.4356..333.4..3.4445555443..4468977889887865354.55545544.44445344444 237
        444.3.344...334.34....3..3.3.544.3.....35.36483776545.45.53436.....3..4443.543.. 236
        3..4454.........3.43..53...3....334....3..4.54.4365536535444..........3....43...3 235
        3465...3..........34..3.34............34....33664.764456774555455.45....4.4.33.3. 234
        ....5444433..4....44.5..43.......34..4.343.43.7668757.64.636...433.43444345..334 233
        .3...3...3..3.....34.3..3..3.4..3345...3..444465.65785..564...45333....333534454 232
        3.3.3.44433..333443.......4.43.544444434434476457768788673.664445534....333.4445 231
70.226  .444.4.43..3.....3...43...4454454.444434679856775354.4636555.3.44...3454.4..44 230
        ....44.3...3...........3..........434.......44.354775.65.76453654.34....34....543 229
        .45.44.4.....33.44..44..4.53.3..56.54...34774745786...65.44565.3.33...45.4..34.. 228
        ......3.4.4...3..4..33..53..3..343..34....45354567567665775........3.344.4.44..3 227
        ..3.4.4...4..........5.443.......4343554644475667879774846353.3645.3..33534333... 226
        ......3...33...................3..34..34544..4..3.454443.5.3.343.43.......3...33.. 225
        4.3.4433......4.33.......3...3..6544.34653447654.687.46..554.353..3..........443. 224
        .44....44.3..4.........3..44.....34.444..5..4553.4.43766645544.33..........33...3... 223
        .3...3....3...3.....4......4...3......54..53..55.5.4.36877464.444.444..3...3.4.3..4 222
        ....53.454...5.4.....5.3.........53454.55..3554665765465.4........444.33344333.... 221
69.486  ....3433..43..........................434...334.3.55377765565.3.356434.4.3.....334.3.. 220
        ..3..33....3....3.44...........3.3.......3...453.3.65.55.443...3.....3...3.....4 219
        3..3543..344..344.3.444.4.......5.3..453.35.3466.4.34.6.....4.................... 218
        ....4.........3......34.........445....3435654..3786353.344.365.344...4564...4543 217
        .....5.4.3.....3.33.3...3.......355.3.33.444555.4544454.....44................... 216
        3...33...33.........................33.4....3443344..55.53.4...3.3.4..333.3554...4.4 215
        ..................43..4........3454.4.44343344..447555653....34.....3..3343...443 214
        ...446........4.45..3....3.3....4654444....4.664653456664.4.3445..34.3....33.....3 213
        ....3...........3.....................354.3..4...367444455544..........3.......44....3.. 212
        3......4...3............3........33464.555.44..554434.4........4....333.........33.. 211
68.746  .3...4.4....453...4..44............4636..644553455.587435...3..44433.......3443..4.3 210
        ...3...44.......3..44....3....4..3..6644.66556776543.4....4455.3.3...44.54....3.. 209
        ..3..3...3............................555545743..4.43..4...........3..4....3....3...... 208
        ...............3................454.4...33...4..4.4..........................3.. 207
        ...............43................3333..44.576433...3...................3........ 206
        ............3..3.3...............33.444345376.4....4.333.4..3..........34....... 205
        .......4.........................364....44.33.....3............................. 204
        .3334..45564......3.3633.3....43..67798567453...464443.....3.3...4.3.............. 203
        3...3....465.53......4433......3.4.5677986745.465456.43..3..34.344553.......43553. 202
        ....4....464.34..3...3...4....33....378534763.4..44..3......4..3..554..3.......53. 201
68.006  ............3345.33..........................33.356744444.3..........33.....3...44......4.. 200
        ..3........6.5.........3...................57677655434...............4........34..........3 199
        ...........4.53.........3....3..3......4694735434...545334..3.34..3344.43..........4.4 198
        3...5..3337543........43...........5..4669636453353.34.33...3343...345............3.. 197
        ..........4.4..........3................4...47855433.44..43.........34....453..........453. 196
        ......................................3....................3.................... 195
        ................................................................................ 194
        ................................................................................ 193
        ................................................................................ 192
        ................................................................................ 191
67.266  ................................................................................ 190
```

STATISTICS OF TARGET STRENGTH OCCURRENCE

9 8     8 27     7 80     6 120     5 279

4 632     3 621

TOTAL NUMBER OF "OCCUPIED" CELLS IS 1767




TOTAL FISH IN CELL

SAMPLE 1
6617

SAMPLE 2
6112

SAMPLE 3
5740

Fig 10

1.4

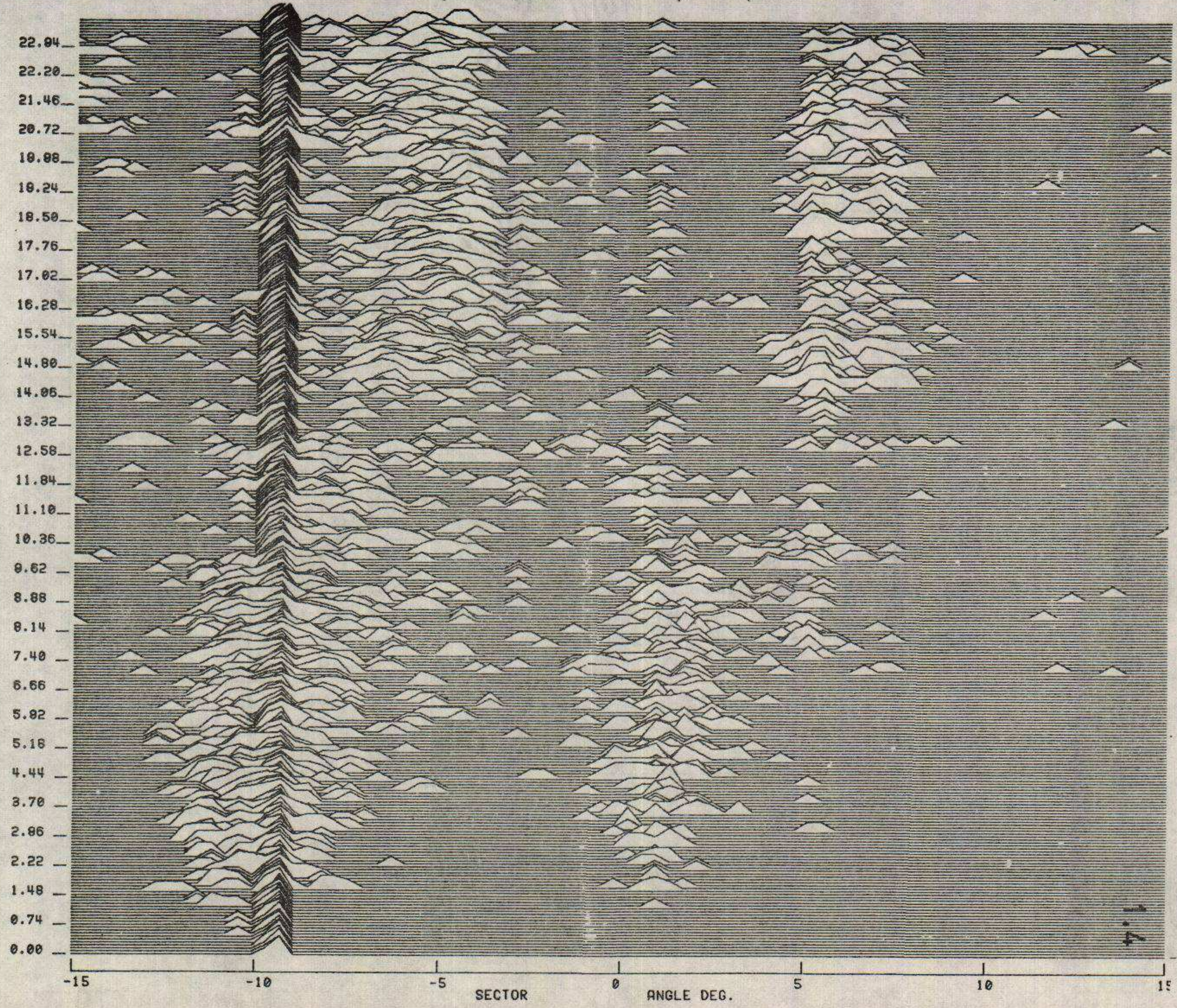

22.94
22.20
21.46
20.72
19.98
19.24
18.50
17.76
17.02
16.28
15.54
14.80
14.06
13.32
12.58
11.84
11.10
10.36
9.62
8.88
8.14
7.40
6.66
5.92
5.18
4.44
3.70
2.96
2.22
1.48
0.74
0.00
-15
-10
-5
0
5
10
15
SECTOR ANGLE DEG.
1.4

FIG 11

| FISH LENGTH $L$ m | TARGET STRENGTH (300 kHz) TS dB | NORMAL PACKING DENSITY D fish $m^{-3}$ | 10 log D | NORMAL TS dB per $m^3$ | MAXIMUM TS dB per $m^3$ |
|---|---|---|---|---|---|
| 0.1 | -37.5 | 1360 | 31 | -6 | 0 |
| 0.2 | -30.3 | 170 | 22 | -8 | -2 |
| 0.3 | -25.9 | 50 | 17 | -9 | -3 |
| 0.4 | -23.0 | 21 | 13 | -10 | -4 |
| 0.5 | -20.6 | 11 | 10 | -11 | -5 |
| 0.6 | -18.8 | 5 | 7 | -12 | -6 |
| 0.7 | -17.2 | 4 | 6 | -11 | -5 |
| 0.8 | -15.8 | 2.6 | 4 | -12 | -6 |
| 0.9 | -14.3 | 1.8 | 2.5 | -12 | -6 |
| 1.0 | -13.4 | 1.3 | 1.1 | -12 | -6 |

TABLE 1 Target Strength, Packing Density And Target Strength Per $m^3$ As A Function Of Fish Length At Broadside Aspect And 305 kHz