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AUTOMATIC GAIN CONTROL FOR A SIDE SCAN SONAR IMAGING SYSTEM

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INTRODUCTION

Side Scan Sonar is now widely used as a hydrographic survey tool. In its simplest form, it comprises an underwater body, (Towfish) a Signal Processing Unit, and a Graphics Recorder. Acoustic transmissions from transducers in the towfish, insonify narrow strips of sea bed to each side of the towfish and the resulting acoustic reflections are received by the same transducers. Pre-amplifiers in the towfish send the received signals up to the survey vessel by way of electrical conductors in the tow cable. On the survey vessel, the received signal is fed to a Signal Processing Unit which must reduce the wide dynamic range of the incoming signal to a range suitable for display on a line scan, grey scale, graphics recorder or a raster scan V.D.U. The signal received from each strip of sea bed is presented as a single line on the display using intensity modulation to represent signal strength. As the Towfish moves forward, adjacent strips of sea bed are insonified and the returning signals are presented as adjacent lines on the display, thus building a picture of the sea bed. The normal display format presents the track of the vessel and Towfish along the centreline of the display, with range to port and starboard shown to the left and right of centre respectively.

THE DYNAMIC RANGE PROBLEM

The received echoes vary in strength over a very wide range depending on numerous factors, one of which is the nature of the reflecting surface. It is this variable which generally contains the information being sought. The problem is to accept an incoming signal with a dynamic range, which may exceed 90 dB, and reduce it to a dynamic range of 20 to 24 dBs, which can be displayed on a grey-scale printer producing hard copy records, or a visual display unit. The signal variation generated by scattering from the sea bed occupies a small proportion of the total dynamic range. If a simple compressor is used the dynamic range of these wanted signals becomes so compressed that their contrast on the display medium is reduced to a very low value, verging on the invisible. The solution is to devise a means of removing the gross variations in input signal level whilst allowing the small variations caused by scattering, to be amplified, to fully utilise the dynamic range of the display medium. This can result in a high contrast image with a good grey scale. This process is frequently known as normalisation. In order to normalise the incoming signal it is helpful to understand the fundamental processes causing its wide variation. There are four main contributers:-

(1) Water column spreading and absorption losses during both transmit and receive signal propagation.

(2) Change in source level and receive sensitivity with direction due to transducer beam patterns.

(3) Change in scattering performance of the sea bed with grazing angle of the incident wavefront.

(4) Change in scattering performance of the sea bed due to its material composition. This is the variable containing information to be displayed and it must not be normalised.

TRADITIONAL SOLUTIONS

All solutions involve passing the incoming signal through an amplifier where gain can be varied to normalise the signal at the output. This is generally known as the Sonar Amplifier. The solutions differ in the way in which the Sonar Amplifier gain is controlled.

Traditionally, two methods have been used. The earliest approach presented the operator with a set of controls enabling him to control the gain of the sonar amplifier as a function of time, see Fig. 1. This allowed the operator to correct for the gross effects of spreading and absorption losses as these are a function of range and range is proportional to time. A typical set of controls would allow an initial value of gain to be set which would remain constant from the instant of transmission until the expiry of a delay, also under operator control, at which time the sonar amplifier gain would be ramped with time to some maximum value. The rate of ramping and the maximum value would also be under operator control. The operator would have two such sets of controls, one for the port channel and one for starboard. The setting of the controls is determined by the operator observing the record as it is produced in real time and making iterative adjustments to keep the sonar signal within the dynamic range of the display medium, over the whole of the selected sonar range. Continual small adjustments are required throughout the duration of a survey. This process requires considerable skill and experience. It is also highly subjective. Furthermore, the gain/time law which the operator can manipulate with the controls available to him, can only ever be a crude approximation to the ideal law required at any instant. This results in records which exhibit areas where the dynamic range of the display medium has been exceeded and detail has been lost.

A more recent technique attempts to eliminate the operator controls by implementing fixed law corrections to normalise the unwanted variables caused by spreading, absorption, beam patterns and grazing angle.

The fixed corrections for spreading and absorption losses are calculated from the sonar equations. The beam pattern and grazing angle corrections both require a knowledge of the angle between the instantaneous slant range vector and the sea bed, see Fig. 2. This is calculated from a knowledge of the height of the towfish above the sea bed which is an additional variable the system has to measure, preferably automatically. The corrections are based upon numerous assumptions, the most important of which are:-

(1) The sea bed is horizontal.

(2) The propagation conditions at the survey site conform with the sonar equations.

(3) The beam patterns of the towfish in use conform with the model used to generate the corrections.

(4) The towfish is swimming horizontally and is not subject to roll.

(5) The towfish height being used in the correction process at any instant is correct.

Clearly there are many circumstances where these assumptions are invalid by varying degrees. Even when all the assumptions are valid, the dynamic range of signals produced by differing sea bed materials can still exceed the dynamic range of the display medium. This is particularly true of sonar targets which glint rather than scatter. Furthermore, any automatic system used for measurement of fish height will be confronted with the problem of deciding where the sea bed is when passing over scours, gullies or ridges. Some manual intervention is usually required. There are many situations where both the manual and fixed law techniques prove inadequate. A strong target at far range is an example where the gain is set for sea bed scattering and the sonar amplifier is suddenly saturated by the strong target, producing a record showing no detail on the target. With a manual system and an alert operator it may be possible to recover the situation and obtain target detail, but this inevitably results in loss of sea bed detail around the target. Another example is that of surveying up a sandy beach, against a rocky coastline. The fixed law system has entirely the wrong range/gain profile. The manual system will normally have insufficient range of control to enable the operator to obtain detail over the whole range, even if he could make changes fast enough to cope with the changing terrain.

AN ALTERNATIVE APPROACH

In trying to devise an alternative approach to overcome the deficiencies of the existing techniques it rapidly became apparent that the fixed law system was too inflexible by its very design. There are too many variables that it cannot be programmed to correct for. The manual gain control system appeared to have more potential if it could be made to react more quickly and have far more comprehensive control over the range/gain profile. This was achieved by dividing the range into a large number of segments, see Fig. 3, and processing the return signal from each of these with a unique gain value applied to the sonar amplifier. The gain is selected to allow the average level of the signal across the whole range segment to produce mid grey on the display medium grey scale. Because the gain value is held constant for the duration of the segment, signal variations about the average level produce high contrast grey scale changes. The gain values for successive segments are held in a digital memory and are applied to the sonar amplifier in time sequence following the transmit pulse. It follows that the sonar amplifier, which amplifies the return signal at the operational frequency of 100 KHz, has digital gain control. It covers a range of 94.5 dB in 1.5 dB steps. Fig. 4 shows a simplified diagrammatic representation of the system. The segment gain is generated by taking the average signal amplitude over that segment, digitising it and calculating the difference between it and a reference value. The difference is then weighted and added to the current gain control word, the result of which will then be applied to the next sonar return. Positive differences decrease the gain and negative differences increase it. In other words it is a negative feedback system. The reference value is chosen to correspond with a signal amplitude which would produce a mid grey on the display medium grey scale. The negative feedback system is, therefore, continually trying to normalise any input level to mid grey on the display. The gain control word is updated with each succesive sonar return. However, the rate at which the gain can change in any one segment is dependant on the relative values of the current gain control word and the weighted value of the current difference word. Large weightings cause the current sonar return to have a large effect on the gain word which results in large gain changes for very few sonar returns. The gain change time constant is therefore controlled by the weighting applied to the current sonar return.

In a practical working system, each range segment requires control over both gain and time constant.

The negative feedback system is continually trying to normalise the signals in all range segments to give the same grey level on the display. The time constant determines how long it takes to reach the mid grey level following a change in signal level at the input. Clearly, if a short time constant is used the system will react quickly to normalise fast high amplitude changes, as generated, for example by small rock outcrops on a muddy sea bed. By the same reasoning, it will rapidly suppress an extended length signal, such as that generated by a reef or harbour wall or uniform area of clay. It is most important that genuine features are not suppressed and therefore, a relatively long time constant is essential.

So far, only the steady state operation has been described. In practice, the transient conditions of switch-on and range changing have to be catered for. Both of these conditions produce rapid and massive signal changes at the input of the sonar amplifier. If the normalising feedback loop is programmed with a long time constant, as has already been shown is necessary, then a normalised and usable record will not appear for many tens of seconds, possibly minutes after switch on or range change. This is not acceptable. However, the solution is fairly simple. On switch on or range change, the weighting value, which is applied to all range segments, is set to a high value, producing a short time constant, and then rapidly ramped to a low value corresponding to the time constant necessary for steady state operation. This ensures that the range/gain profile is acquired rapidly; in fact to the operator, there appears to be no delay.

The system as described so far still has one problem. Because a long time constant has to be used to preserve large sea bed features, the sudden appearange of strong targets can still exceed the dynamic range of the display medium until the normalisation process has had time to adapt. Ideally the system requires an adaptive time constant which distinguishes between large change in signal strength and small changes, and applies a short time constant to the larger changes. A simple version of this scheme has been implemented by dividing the display dynamic range into two bands, see Fig. 5. Assuming the full display dynamic range is $\pm$ 10 dB about the mid grey level, then an inner band of $\pm$ 5 db is defined. If the average signal level for any range segment lies within the inner band, the segment is processed on a long time constant.

This adaptive system has been in use now for over three years in the Waverley 3000 Side Scan Sonar. The robustness of the control algorithms employed has been proved in a wide variety of situations. They are optimised to provide the maximum sea bed detail over the whole of the selected range. The range/gain profile can take up any shape required, even reducing gain with range. Manual and fixed law systems cannot do this.

The three plates illustrate some of the capabilities of the system. Plate 1 shows the passage of the towfish over a reef. The rocks of the reef can be seen quite clearly, standing proud of the sea bed return, without saturation of the record. Similarly, the pipeline passing through the reef can be seen with as much detail immediately under the towfish as it can at mid range. It is also important to recognise that this record was obtained at a single pass, without any operator intervention and that if a further pass were to be made along the same track, an identical record would be produced; no operator subjectiveness. Plate 2 illustrates the system's ability to display extended features (the large grey areas) despite its normalising characteristics. At the same time, it has adapted to the sharp features of the pipelines out to the full range of 150m. Plate 3 shows an operators nightmare; a bland sea bed scattered liberally with massive rock pinnacles. They produce intense echos at close range but the detail still shows through and extends out to 300m range.

Users of the Sonar 3000 system will be familiar with the way it displays echos from the water column between the towfish and the first sea bed return. With a manually driven system, the operator would normally turn the initial gain to a low value to prevent the first sea bed return from saturating the record, and thereby suppress the water column echos. The adaptive system turns the gain up in the presence of low signals and displays them. This characteristic can be of great value in studies of mid water turbulence, scattering particles of targets. The adaptive processing can of course be applied to the signals from any sonar transducer array and the adaptive algorithms optimised for other purposes.

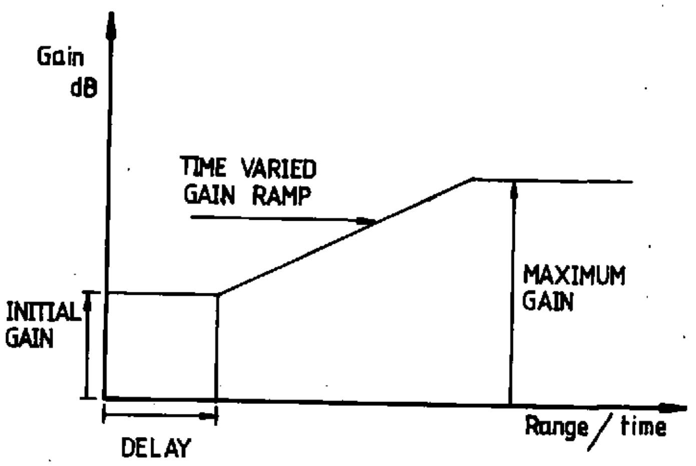
As a final example, the system can and has been used for measuring target echo strengths automatically. The received signal strength of a sonar return or transmission can be measured if the receiving transducer and its preamplifier are calibrated and the sonar amplifier gain and output level are known. This adaptive system will keep the output signal within the dynamic range of the sonar amplifier, at the same time, outputting the gain control word used at any instant to achieve this condition. The sonar amplifier output signal and related gain word may be stored on tape for later analysis.

CONCLUSION

Range Adaptive Gain (RAG) processing, originally developed to reduce the load on side scan sonar operators, is now proving itself to be more effective in obtaining general survey records than traditional systems. It has also been used for water column studies and to automate target strength measurements.

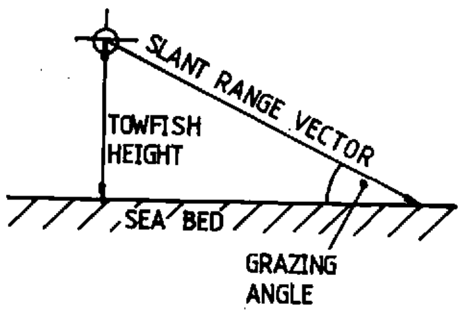
The next stage in side scan signal processing is to produce better "feature recognition" algorithms to enhance the contrast even further. This will eventually help to reduce the very labour intensive activity of record interpretation.

FIG. 1



OPERATOR CONTROLS IN A TYPICAL MANUAL SIDE - SCAN

FIG. 2



FIXED LAW GEOMETRY

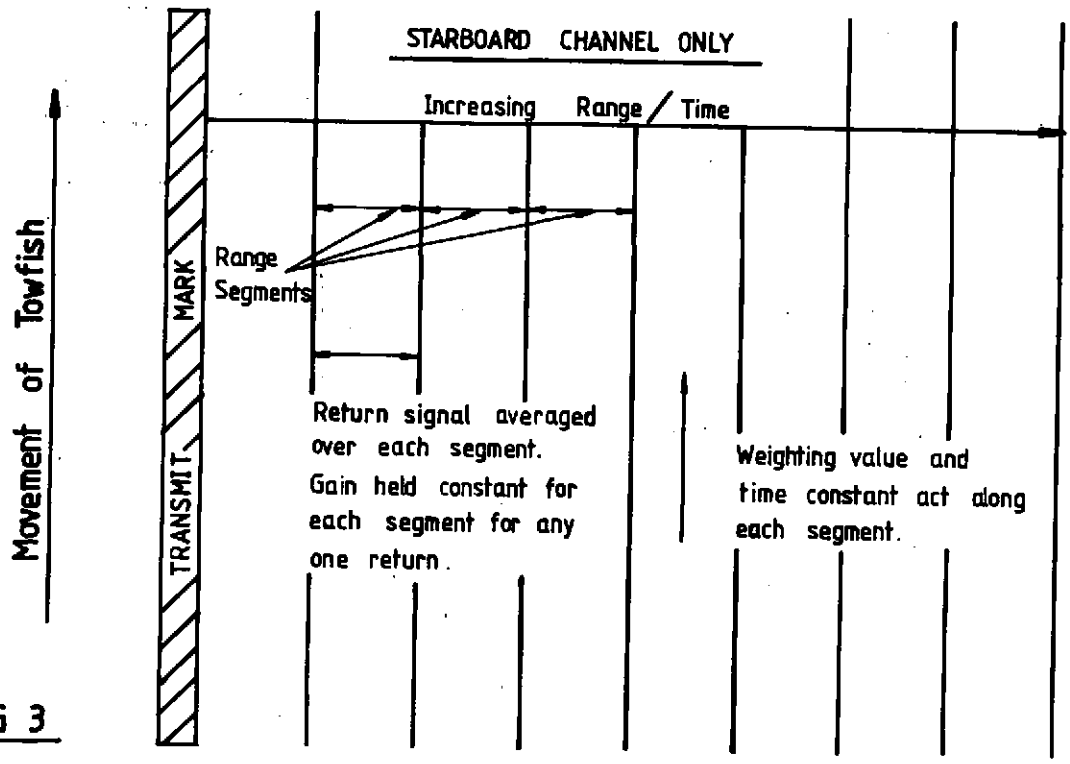
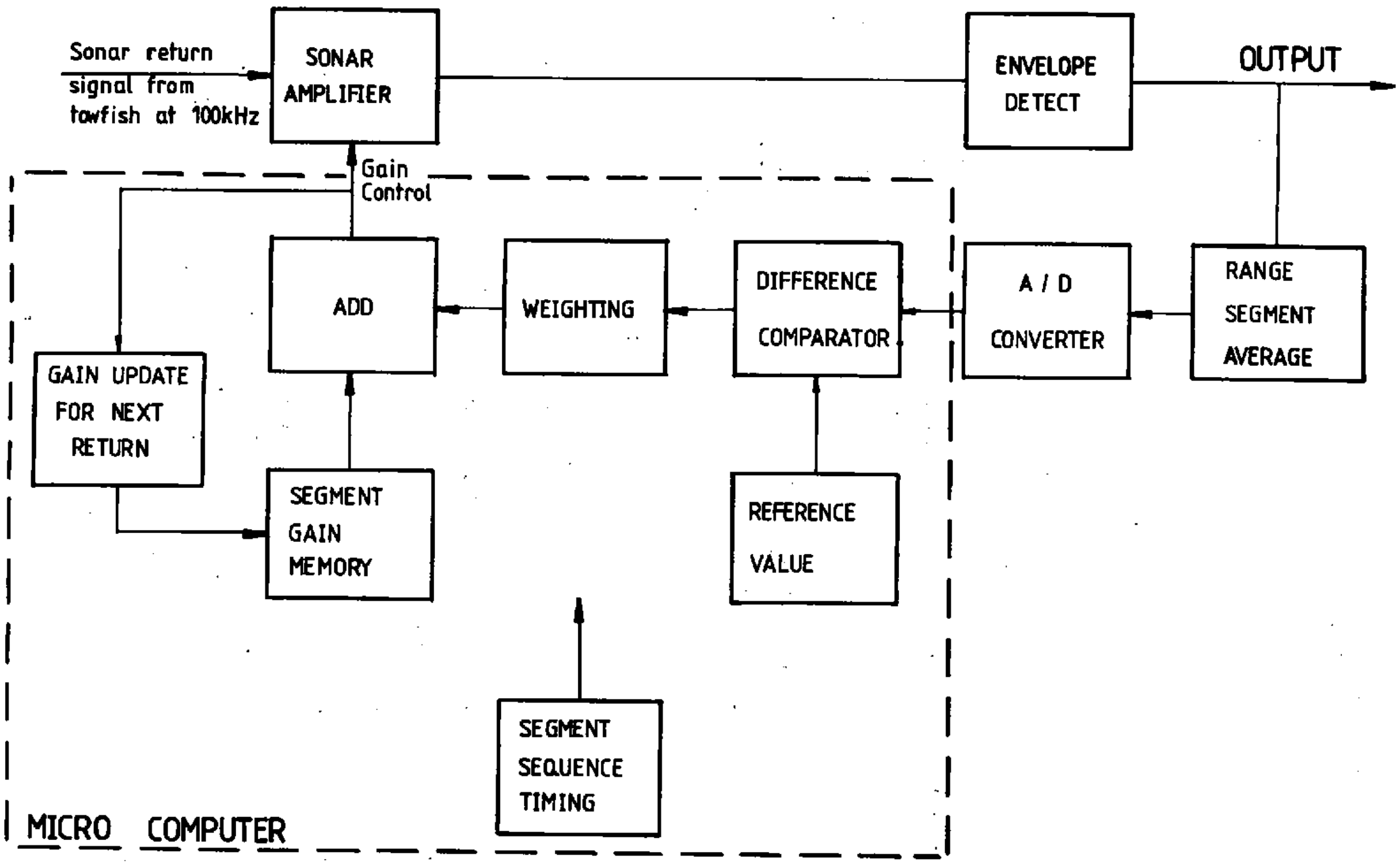


FIG 3



SIMPLE ADAPTIVE SYSTEM

FIG 4

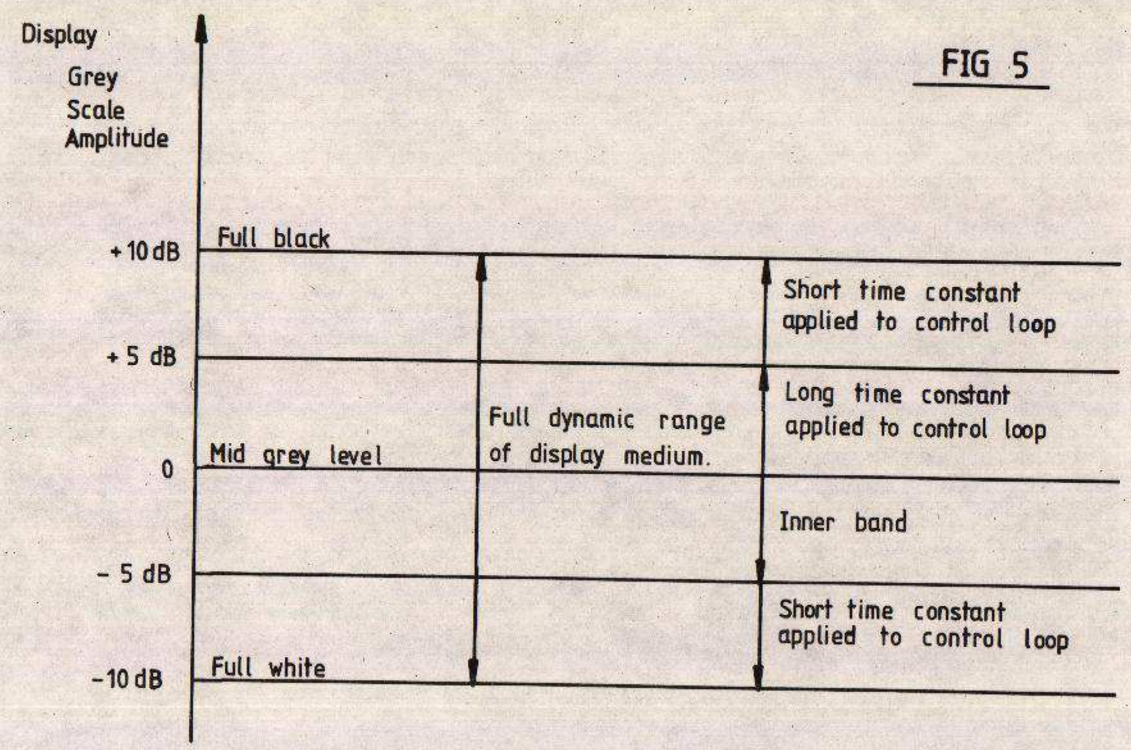


FIG 5

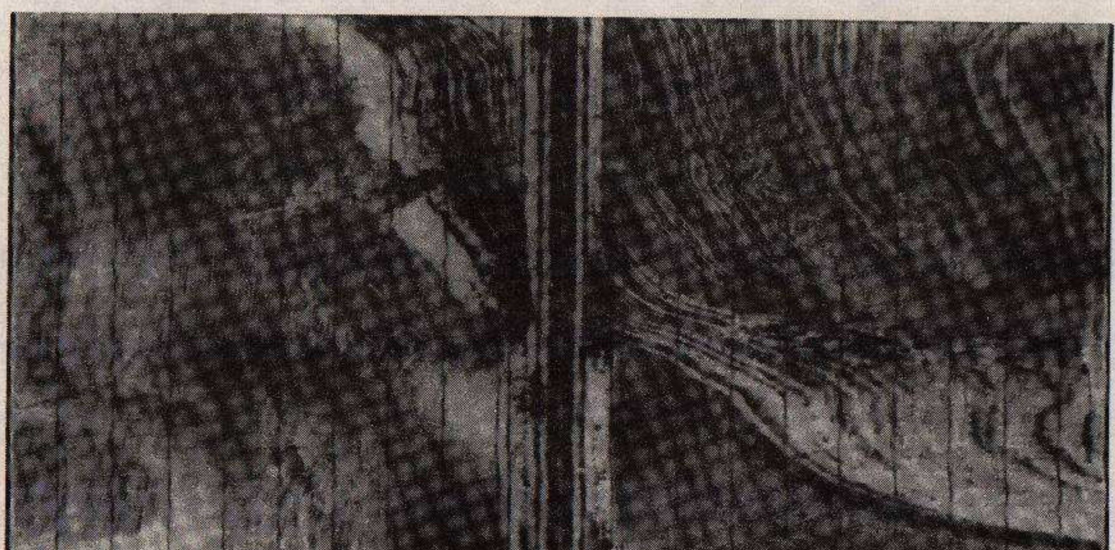


PLATE 1 UE SONAR 3000 SIDE-SCAN 300 m total SWATHE

WINFRITH PIPELINE THROUGH REEF AT WARBARROW BAY

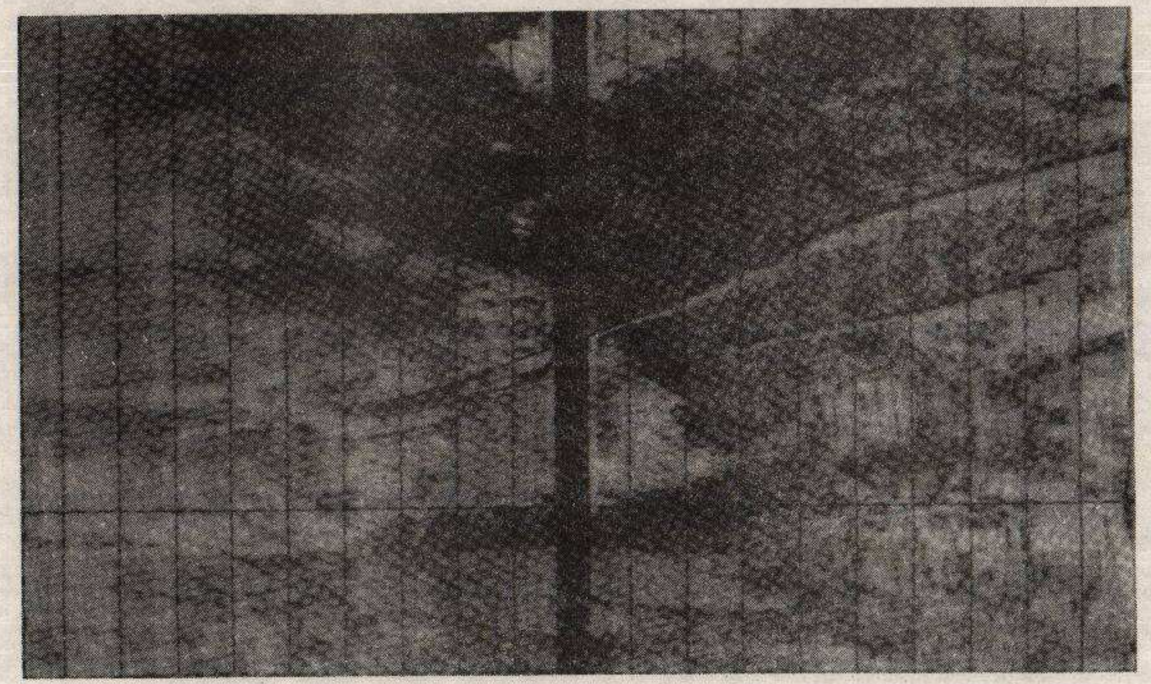


PLATE 2 UE SONAR 3000 SIDE-SCAN 300m total SWATHE

PIPELINES AND SEA BED TEXTURE OFF WEYMOUTH HARBOUR

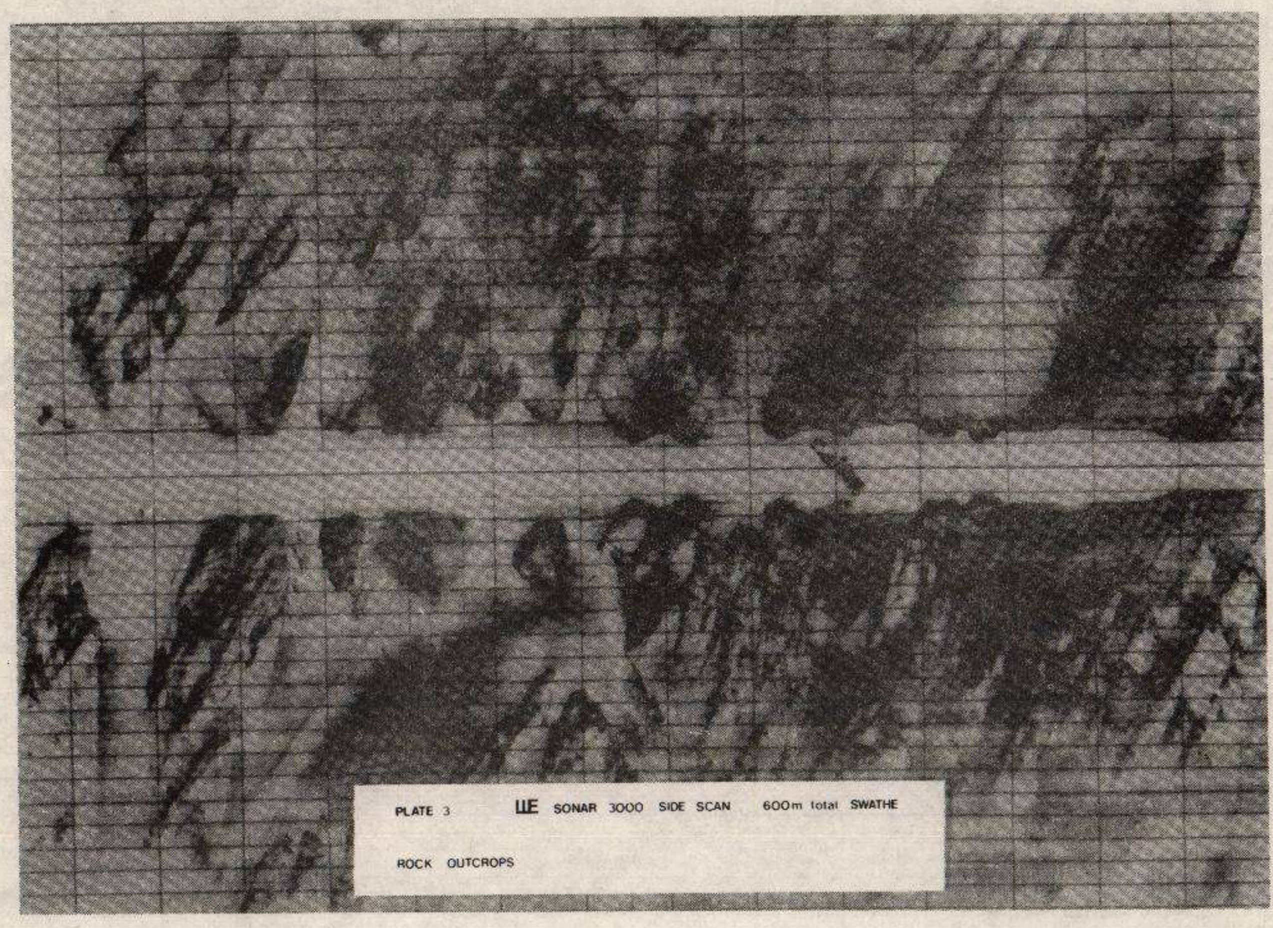


PLATE 3 UE SONAR 3000 SIDE SCAN 600m total SWATHE

ROCK OUTCROPS