Proceedings of the Institute of Acoustics

SEISMIC STREAMER TRACKING, PAST, PRESENT AND FUTURE

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INTRODUCTION

Early seismic surveys, primarily conducted for research, used a single towed acoustic source and a separate towed receiver. Signal processing was limited to analogue circuits providing a single trace, recording echos from the sea bottom and from the underlying geology. The quality of the data was extremely poor and provided little information for interpreting the structure.

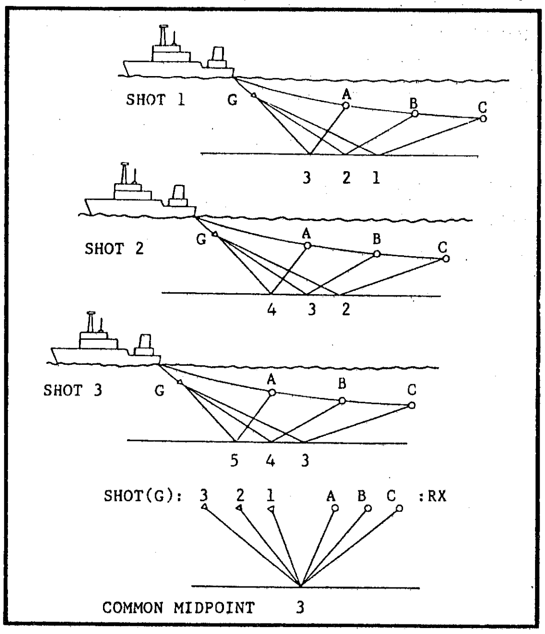
By replacing the single receiver with a series of receivers at regular intervals (forming a streamer), a more complex picture could be produced. Whereas the single receiver produced a single trace corresponding to each point in the survey, the streamer produces a number of traces. All those traces, where the mid-points between the source and the receivers are co-incident, have effectively described the same physical point of the underlying structure. However, because the angle between the source, the mid-point and the receivers increases for receivers further along the streamer, their traces view the structure from different angles. This information is used to reconstruct a single improved trace from all those with a 'common mid-point' (CMP). The result, called the CMP stack, describes the underlying geology as if it were interrogated by a source and receiver positioned directly above the mid-point (at zero offset).

OBTAINING A CMP STACK

G is the gun, shot at intervals 1, 2 and 3.

A, B and C are individual receivers on the streamer.

Traces from three shots with a common mid-point to form a gather.



In addition to producing an improved signal response, in the form of the CMP stack, these common mid-point traces (CMP gather) can be used to infer information about the velocity structure of the underlying rocks [1]. It has been demonstrated [2, 3] that the radius of curvature of the emerging wavefront reflected from an interface between two layers, as viewed by the traces in the CMP gather, is related to the difference in velocity between the layers.

Although these techniques, based around the concept of grouping traces into a CMP gather, have been accepted for use in traditional 2-D surveys (where a single section of the geologic structure is surveyed) they have not adapted well to the more rigorous demands of 3-D surveys where the whole of an area is surveyed and the resulting data analysed in every dimension.

Of particular concern is the accuracy with which the actual mid-point of each trace can be located. This is because the assumption that all the mid-points in a gather are coincident is not true. This is due to cable feathering (the streamer does not follow the line of path) and is referred to as mid-point scatter. Although a 2-D survey can ignore this problem with little effect on overall quality, 3-D surveys are much more sensitive to the problem. Furthermore it is necessary to ensure adequate coverage of the survey area in order to prevent spatial aliasing, which can only be achieved by the accurate location of every mid-point. The effects of mid-point scatter are reduced by re-grouping traces into gathers based on the actual locations of their mid-points (a procedure called binning) [4].

Effective binning and adequate coverage can only be achieved if mid-points can be accurately located. This, in turn, depends upon locating the acoustic sources and receivers accurately with respect to some known point (normally the survey vessel, which is itself located by satellite positioning and other navigation systems). This task has been complicated by the ever increasing complexity and diversity of the seismic acquisition hardware. Streamers are tending to become much longer, with three kilometres in general use and up to six kilometres for special cases. The number of streamers has also increased, with two as a standard but often more. In a recent advance one company has even employed twin streamers in a vertical configuration (over/under) in an attempt to improve quality and reduce weather down time [5].

In a modern seismic system the positions of the receivers along the streamer are determined from compass bearings recorded by units attached along the length of the streamer. The bearing information is collected by a computer system and applied to a sophisticated mathematical model of the streamer's shape. This ensures optimum use of the data whilst filtering out erroneous results. However compass systems do have some serious short comings. They are not effective in locating the start and attitude of the streamer with respect to the ship. Their effectiveness is reduced along the length of the streamer as well as at high latitudes. Finally their absolute accuracy is not sufficient to meet current requirements.

In the quest to improve upon the accuracy of compass based systems, it has become generally accepted that new positioning techniques must be employed to either replace or supplement the existing technology.

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REQUIREMENTS FOR STREAMER POSITIONING

The complete positioning system should be capable of providing CMP locations to within ±5m or better. This accuracy should be maintained along the full length of the streamers which are generally between 1.5 and 3km but may extend to as long as 6km. The configuration of these streamers will be variable. A single streamer is seldom used for 3-D surveys with two or more being preferred. These streamers may typically be separated by 50m.

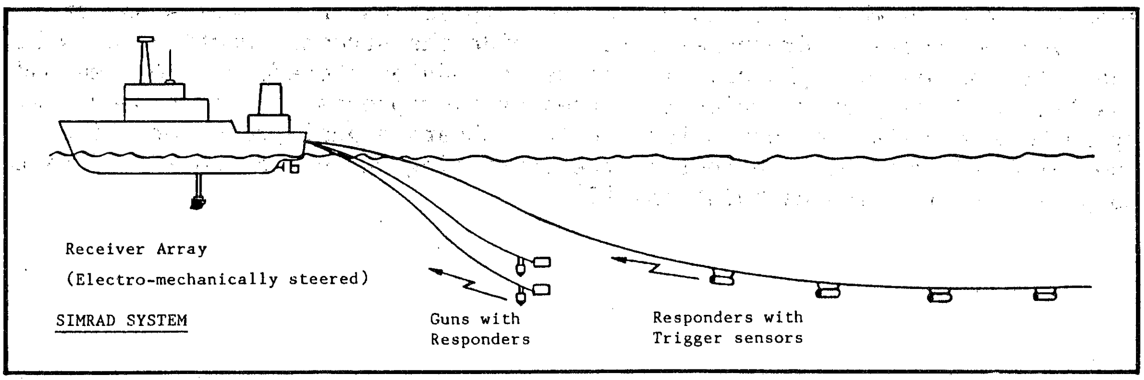
In order to achieve these requirements the functions of the positioning system can be divided into four. Positioning the front-end of each streamer, determining their overall shape, measuring the separation between each streamer, and positioning their ends.

Compass systems are adequate for fulfilling the second task, determining the streamer's shape, except at higher latitudes where they must be supplemented. Radio positioning can be used to track the tail buoy, although this still requires an assumption to be made about the position of the end of the streamer with respect to the tail buoy. Radio positioning has also been used for front end monitoring although this requires surface floats to be attached to the streamer tow cables which is not popular with many companies. Radio positioning also has many general drawbacks which does not make it suitable for stand alone operation.

The most promising approach to fulfilling some or all of the above tasks is acoustic positioning. Several systems have been developed and tested mainly for stand alone operation, and these are described below.

SIMRAD HPR

The Simrad system uses a narrow beam transducer which can track transponders/responders on airguns and on streamers. It is essentially a super short baseline technique relying upon the phase difference across a multiple element transducer to provide bearing information, and the transit time to provide range information. The narrow beam transducer is mounted on a shaft and penetrates the hull via a gate valve. The beam is electronically steered in the vertical plane and is mechanically rotated in the horizontal plane.



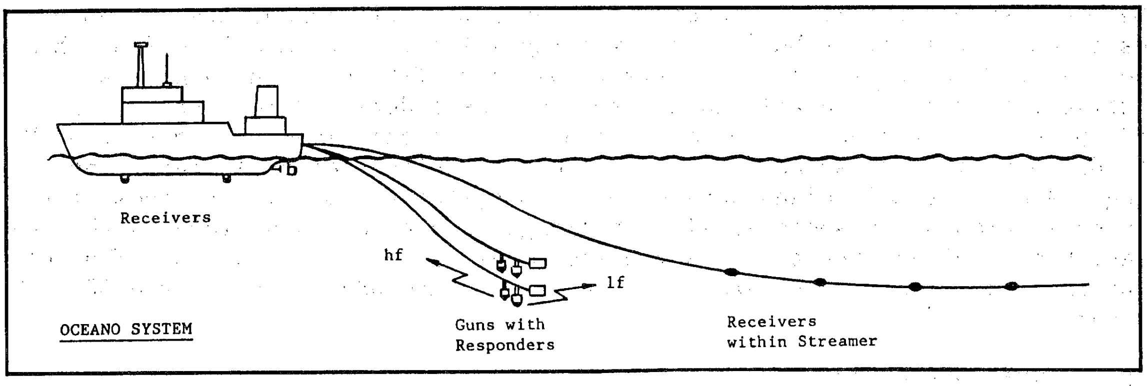
The system operates synchronously allowing the beam to be pointed to each airgun responder and then the streamer responders in turn, this sequence taking around 8 seconds for a 3000m maximum responder range which includes the time taken to track up to 6 gun responders. Each airgun responder is electrically connected to the onboard processing electronics which controls the output powers and provides the synchronised trigger. A control line in the streamer carries a coded signal which is detected by the clipped on responders (birds) causing them to transmit a synchronised signal. As no electrical connections are made between the streamer and responder, the latter are fitted with batteries [6].

A significant advantage of this system is its use of responders which improve the overall detection probability as no forward acoustic path is involved and there is no need to receive pulses in the poor signal to noise conditions close to the streamer at long ranges. Another benefit of responders is a reduction in the period of time to collect a data set as only single way pulse slant times are involved.

The Simrad system does have some inherent disadvantages which include the high bearing accuracy required to obtain results at the longer ranges. The claimed accuracy is 0.5° but to this must be added any installation tolerance which will create a bias. 0.5° is equivalent to 26m positional error at 3000m, this being well short of the performance being pursued by the survey companies. In the case of multiple streamers which are towed to one side of the towing vessel a major source of bearing inaccuracy arises from the non-isotropic nature of the medium in the horizontal plane due to the ship's wake. The resulting refraction causes the 'rays' to be bent and a corresponding error to occur in the bearing estimate. This poor acoustic environment also effects the range estimates as the speed of sound is very variable and difficult to determine. The Simrad system with its complex hull transducer station is relatively expensive and requires the ship to be specially fitted out.

OCEANO ALS

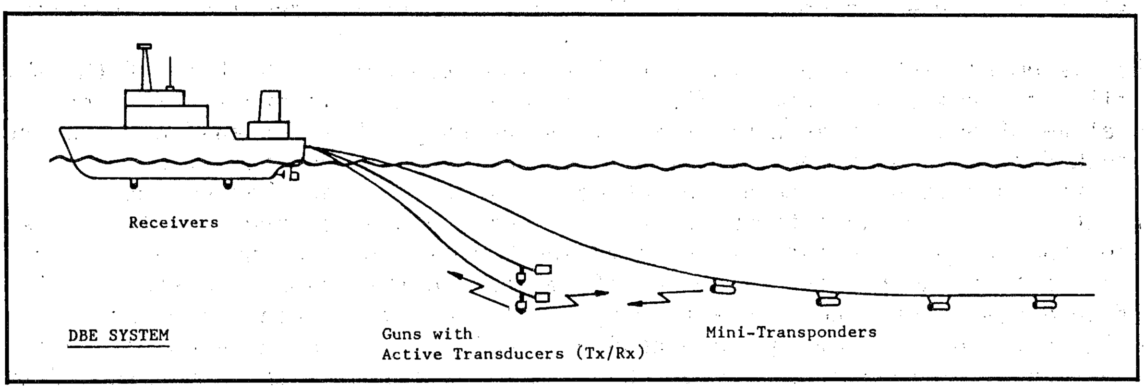
The Oceano system uses short baseline acoustic positioning techniques to position each of a pair of gun arrays which in turn position receiving elements in the streamer. The initial short baseline is formed by a pair of transducers penetrating the ship's hull in the fore-aft axis or athwartships which are used to provide ranges to acoustic modules fitted to each of the gun arrays. The acoustic modules which are cabled to the ship act as transmitters and are received by special hydrophones fitted inside the streamer sections as well as the hull mounted hydrophones. The acoustic modules therefore form a second baseline with respect to which the streamer hydrophones are positioned. All hydrophone signals are routed back to the onboard signal processor which times the pulse arrivals with respect to the initiating pulse and provides data to a computer for position calculations [7].



The Oceano system has advantages such as reduced dependance on acoustic paths through the wake (although at longer ranges this is still a potential problem) and simpler streamer deployment and recovery as no 'birds' are attached. The one way only acoustic path is also an advantage but the need to receive within the streamer cable is not ideal both in terms of the beam angle requirement and the higher noise environment aft of the ship. As for the Simrad system at the longer ranges (>1000m) small errors in range timing coupled to uncertainty in the value of the speed of sound will cause errors in excess of ±10m assuming that a 100m gun array baseline is used and its dimension is accurately known. Gun baseline measurement errors will further worsen the solution. In order to minimise baseline errors an additional pair of h.f. transducers are incorporated with the gun arrays. These higher frequency devices give greater timing resolution, hence improving the baseline estimate, but they do complicate the system. The system arrangement is such that it is not flexible.

DBE SST

DBE's current system uses its series 3000 multi-frequency control and telemetry equipment operating at around 30kHz, ie at the upper end of Simrad's band and between Oceano's l.f. and h.f. bands. The choice of operating frequency is difficult and is an inevitable compromise with the lower frequencies giving better propagation performance and the higher frequencies giving higher timing resolution and physically smaller devices for transmission.



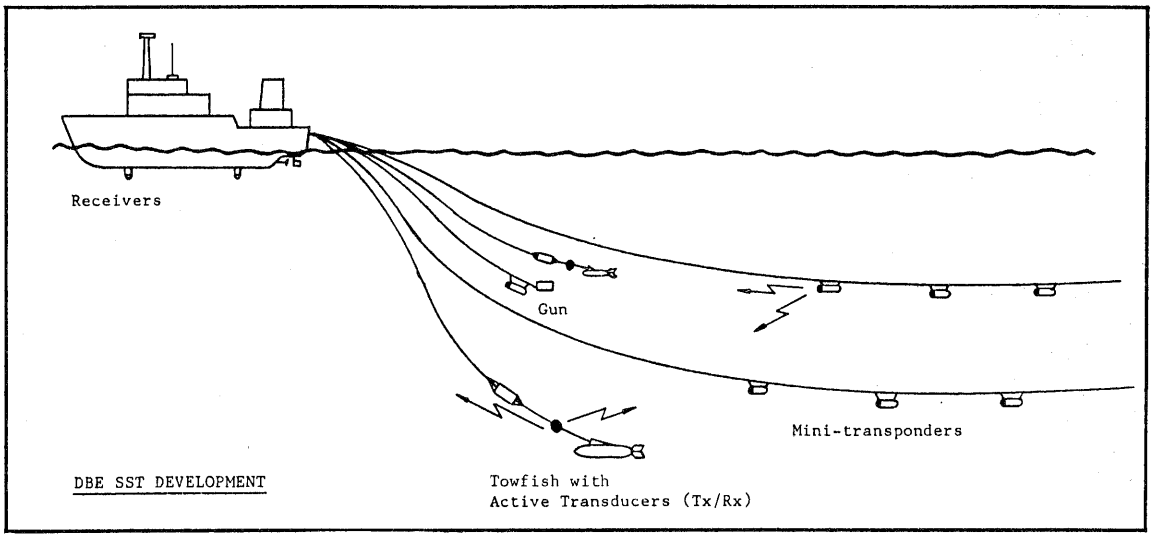
The DBE system is similar to Oceano's using a pair of transducers at known positions on the ship's hull to provide the initial short baseline from which are measured the positions of active transducers fitted to the gun arrays. (Active transducers are able to transmit as responders and receive as hydrophones). In order to obviate the need for specialised streamers the DBE 'birds' are mini transponders replying to the active transducer interrogation ping. Again the main disadvantages of this system are similar to those for Oceano's which are associated with the longer ranges and additionally the lower statistical reliability of two way pulse travel using transponders. The self contained independent hardware and compact size are advantages of the DBE system.

DBE INTEGRATED APPROACH

None of the systems considered meet all the outlined market requirements and therefore offer compromise solutions which will suit specific applications differently. The demand for higher and higher quality data from seismic surveys and for economy in producing them is reflected in the performance specifications for modern 3D seismic survey streamer positioning systems. Unfortunately the need to accurately locate streamers at longer ranges (>1000m) gives acoustic positioning systems a great deal of trouble. The disturbance of the acoustic medium due to the ship's wake and the firing of the guns results in range limited detection which is exacerbated by the short baseline giving increasing positional errors with increasing range. An added disadvantage of any system using these techniques is the relatively long frame time for each position fix. As time passes the current systems will find less and less favour with the survey companies who will look for an integrated approach using other sensors capable of providing better answers.

After consultations with Horizon Exploration who have previously used the DBE system and with Seismograph Services Limited who currently use a DBE system in a modified manner, DBE are developing their acoustic positioning system to provide coverage of the guns and the front-end of the streamers. This development work is being financially supported by the Offshore Supplies Office and will yield improvements which concentrate on providing the accurate location of the start of each streamer, an area of considerable uncertainty, whilst giving total flexibility to accommodate any reasonable streamer configuration. The output is intended to be integrated into a complete positioning system as well as providing an independent assessment of quality.

The system consists of a fixed short baseline attached to the hull of the ship, similar to previous systems. This baseline is used to locate an extended baseline of active transducers towed from the ship. These transducers can be attached to the gun frames or towed independently, and consist of an electronics unit with a separate detachable acoustic head that can be orientated to provide optimum cover. In addition, the transducer element is strengthened to withstand the repetive shock caused by the guns. An integral pressure transducer provides depth information to the on-board system. The software system uses this data to project all received ranges onto the horizontal plane, allowing the extended baseline to be towed below the guns and associated disturbance or altered should the transmission path be affected by water conditions, such as a thermocline.



The extended baseline can range up to eight mini-transponders (modified to provide a streamlined shape and improved receiver characteristics) attached to any part of the system within a range of 1000m. As already discussed, it is not reasonable to expect a high degree of accuracy at ranges beyond 1000m.

All four transducers forming the two baselines, communicate their range data to the on-board equipment. Cycle time is obviously limited to the two-way travel time at maximum range, plus processing overheads. This is expected to be about three seconds, although it is more likely that a single cycle will be performed for each shot-point.

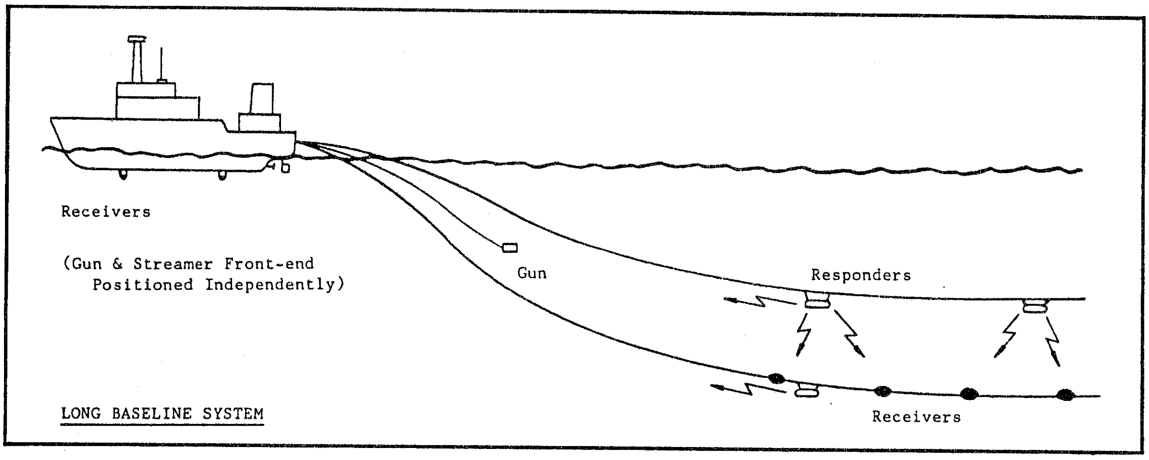
The processing will be performed by an IBM micro computer, attached to the dedicated hardware system controlling the subsea units. The software system, written in Ada for maximum reliability, is designed to combine data integrity with system flexibility. Processing will involve dynamic windowing, redundancy checks, data smoothing and statistical analysis. Checks are included to monitor the performance of each unit and raw data can be stored for later analysis. Processed data, in the form of three dimensional cartesian co-ordinates, referenced to a user defined co-ordinate space are transmitted to a remote host for integration into the complete positioning system. A high resolution graphics screen displays various data including a plan view of the system indicating actual positions and average positions.

THE FUTURE

The previous systems, intended to provide full positioning using acoustics, were not successful in this aim. Any acoustic system employing a short baseline or super short baseline technique suffers from a fundamental restriction in range which is limited further by poor or unusual weather conditions. Furthermore, DBE and others have experienced difficulties when mounting the baseline transducers in proximity to the guns. The operation of the guns stresses the units often causing premature failures and disturbs the water such that acoustic propagation is adversely affected, a point which is being addressed by the DBE system currently under development.

The system being developed by DBE is still a short baseline approach but recognises the above limitations and instead focuses on optimising performance within a useful range. However, in doing so it only addresses the task of positioning the front-end of the streamers. Any future developments should attempt to overcome the inherent range limitations of these techniques if they are to be successful in achieving all the requirements.

One approach, which has recently been investigated at DBE, is to form a long baseline of responder units attached along one streamer's length, and corresponding lines of receivers attached to the remaining streamers. By fixing the positions of the front end units (either by extending the system to two fixed units on the ship's hull, or by an independent means), the positions of adjacent units can be calculated down the whole length of the streamer. If more receivers than responders are placed on each streamer, then the additional data can be used to increase the accuracy and reliability of the position fixes.



An additional feature of this design is the responder output waveform. Each unit can be programmed with a multi-frequency signature that ensures the highest probability of detection using a digital multi-frequency correlator. By changing this signature between cycles, the throughput rate can be drastically increased without interference from reverberations. This approach is believed to be necessary to ensure maximum availability of the system under all operating conditions. The recent use of over/under twin streamers to reduce weather downtime emphasises still further the need for systems to optimise their transmission techniques to combat the worsening acoustic environment.

To satisfy the last task for this system, to position the end of each streamer, the end responder can be replaced by an active transducer and a transponder attached to the tail buoy. This provides enough data to position the streamer ends with respect to the tail buoy, which is positioned with respect to the ship by other means such as microwave ranging or GPS (satelite).

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SUMMARY

The basic requirement for any modern seismic streamer tracking system is to provide total positional information to better than 5m. All current systems in the field fall well short of providing this and changes in the performance of the acoustic elements of the system will not, in themselves, produce the necessary tracking improvement because of the fundamental nature of the problem - a poor acoustic environment near the sea surface behind the towing ship. There is therefore a need to design systems capable of accepting this limitation by tackling the problem in a different way acoustically and by integrating other sensors (eg depth, magnetic) to realise a total solution.

It should be noted that the need to identify the position of a streamer also exists for the military. Passive towed arrays are used to take advantage of the low transmission loss of low frequency sound, generated by vessels, for detection, classification and tracking purposes. The beamforming techniques used which take advantage of the long acoustic aperture of the towed array, also need to know the position of all elements in the array. Although military operational requirements demand covert (ie silent) techniques, some of the proposed commercial techniques previously described are being evaluated for use in performance assessment trials. The spin-off from this type of work will be of direct value to solving the seismic streamer tracking problem.

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Proceedings of the Institute of Acoustics

AMPLITUDE MODULATED CONTINUOUS EMISSION ACOUSTIC RANGING TECHNIQUE

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INTRODUCTION

A wide range of sonar systems now exists, operating at acoustic carrier frequencies of up to 700kHz, and covering distances from a few metres to many kilometres, and for purposes which include navigation, detection, location and classification of underwater objects and echo-sounding [1].

In the majority of sonar systems, target discrimination is achieved by using the pulse/echo technique whereby the range to any particular target can be estimated from the echo-return time and the speed of sound in water. In order to achieve accuracy closely spaced targets, short pulse lengths and consequently wide bandwidth systems are required with the attendant penalty of noise susceptibility.

An alternative to the conventional pulse/echo technique for which a high degree of range resolution is claimed is the use of a frequency modulated carrier, range being calculated from the frequency difference between transmitted and returned signals. Such systems present major problems however, and complex circuitry is required for their realization in hardware.

A need was identified for a simple ranging system capable of accurate measurement of distance to a single target underwater, for example the sea-bed, ship's hull etc., one possible application being use for altitude control of a remotely operated vehicle (ROV). This paper describes such a system, in which a carrier is amplitude modulated at selected modulating frequencies and transmitted continuously and range is calculated from the phase difference between transmitted and received signals. Accuracy is ultimately limited by the accuracy of phase shift measurement at the carrier frequency.

CONCEPT OF THE RANGEFINDING TECHNIQUE

This ranging technique is based on the linear phase delay of the received signal with respect to the transmitted signal due to the finite time taken by the wave front to travel from the transmitter to the receiver via the reflecting surface [2]. In the present system, in addition to the carrier frequency f3, two low frequency sinusoidal signals at f1 and f2 are used to modulate the carrier sequentially. The phase shift of the modulating frequency with the longest wavelength gives the first approximation to the range, and the phase shift of the