I.O.S.

THE IOS ACOUSTIC COMMAND AND MONITORING SYSTEM

Part 1 - Operating Principles and Practices

G R J PHILLIPS

Report No 96

1980

NATURAL ENVIRONMENT RESEARCH COUNCIL

INSTITUTE OF
OCEANOGRAPHIC
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Foreword

The system has been developed as a service for U.K. oceanographic science to provide medium range (10 km maximum) remote control and real time monitoring of a wide variety of oceanic sampling equipment. It divides naturally into several categories which have been described in separate parts (some detailed to handbook level). These instruments have been developed to their present level over a number of years and may be subject to further revision and expansion. As and when these are significant, parts will be updated or extended. Many of the instruments have been designed to accommodate the addition of facilities. These facilities must only be added by an engineer fully conversant with the system.

Part One - Operating Principles and Practices.

Future parts will cover

The Shipborne System Mark III,

The Command Release 200 Series and Acoustic Beacon Type H,

Remote Monitoring Systems,

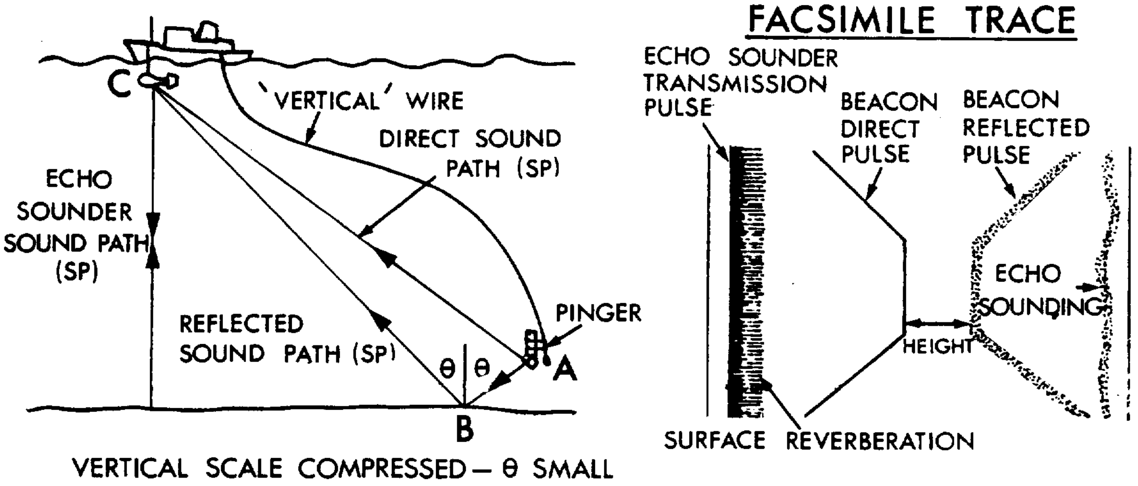
Transponders,

and the

Shipborne System Mark IV.

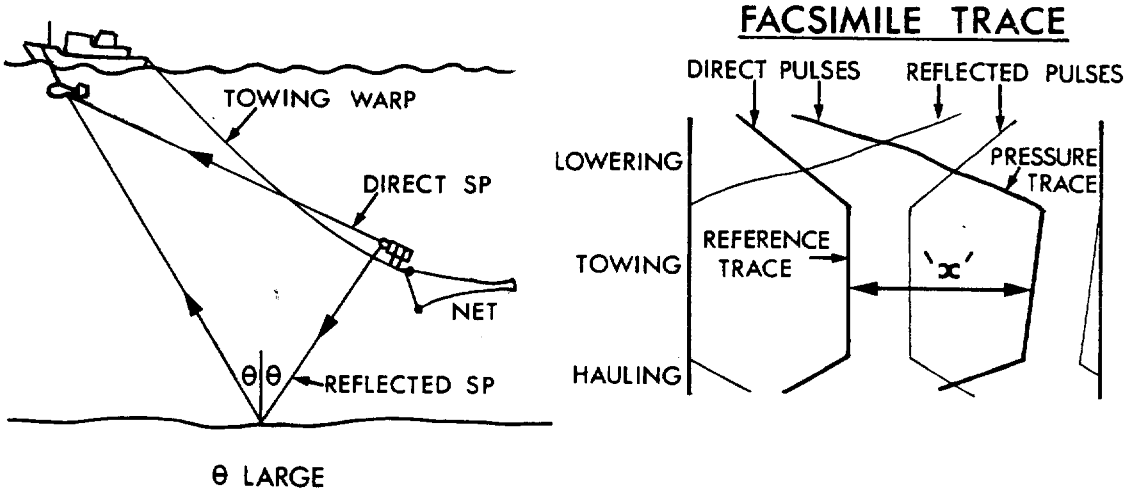
CONTENTS

Figures:



In deep water the height of the pinger above the sea bed is $\approx \frac{AB + BC - AC}{2}$ which is half the time difference between the reception of the direct pulse along path AC and the reflected pulse along path ABC, multiplied by the average sound velocity: time (sec) × sound velocity (m/sec) = height (m).

FIG. 1. 'VERTICAL' WIRE WORK



The separation 'x' is measured and used with the laboratory calibration to determine the depth of the net - bottom reflections from midwater towed pingers are not suitable for depth determination due to the uncertainties in the geometry involved.

FIG. 2. TOWED NET WORK

THE IOS ACOUSTIC COMMAND AND MONITORING SYSTEM

Part 1

Operating Principles and Practices

G.R.J. Phillips B.Sc.

Summary

The development and capabilities of the IOS Acoustic Command and Monitoring System are generally described. A brief account is made of the Historical Background of the system. The important Acoustic and Mechanical Considerations are reviewed with comments on the resulting present generation of acoustic transducers and mechanical hardware. The actual Control and Monitoring techniques used are discussed, outlining present capabilities and limitations and mentioning some possible future extensions.

1. Historical Background

The system has its origins in the days of the National Institute of Oceanography following the development of a full ocean depth, precision echo sounder for geological work. It was realised that the sweep-to-sweep correlation provided by the echo sounder enhanced time-correlated signals in the presence of uncorrelated noise. This meant that bottom echoes from a low power submerged echo sounder (pinger) attached to a vertical wire cast could be resolved if synchronised with the master display. Thus samples taken on the wire could be more accurately positioned in the water column than by relying on 'wire-out' indication, when drift of the ship introduced horizontal tow-off (Fig. 1).

The pinger was further developed to produce two pulses per sweep, one unvarying in time, the second displaced relative to the first by a time interval varied by the output of a pressure transducer. Thus the depth of the pinger was directly measurable, introducing a valuable aid to the fishing of midwater nets for the biologists (Fig. 2). Another requirement at this time from the marine physicists was for medium term (one month to one year) information on currents from moored strings of meters, preferably unaffected by conditions at the surface. Ideally this would be served by a mooring with buoyancy totally below the zone of surface motion. The instrument system required had to locate the mooring and then return it to the surface. The pinger was the obvious location device, but no remote control device was available. Acoustic control was the obvious method using one of a variety of modulation techniques already well developed for radio control, which could not itself be used because radio waves propagate inadequately in water. The only acoustic transducer cheaply available at that time and capable of withstanding the high pressures was very inefficient (the magnetostrictive scroll). The complexity of the digital electronics available and

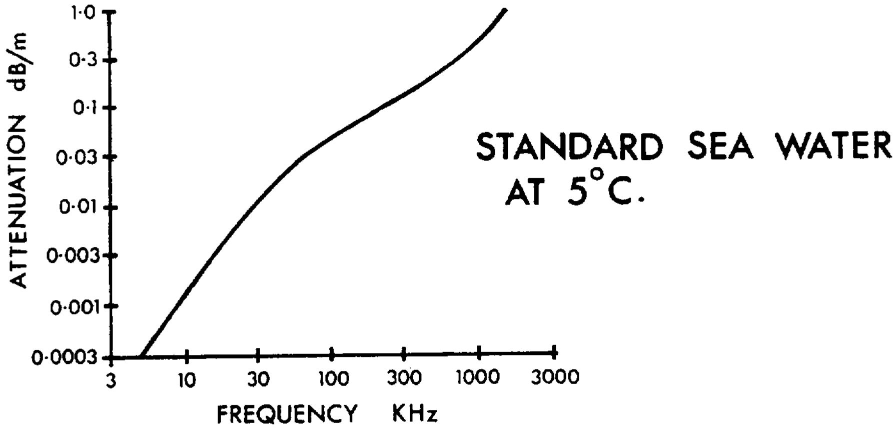
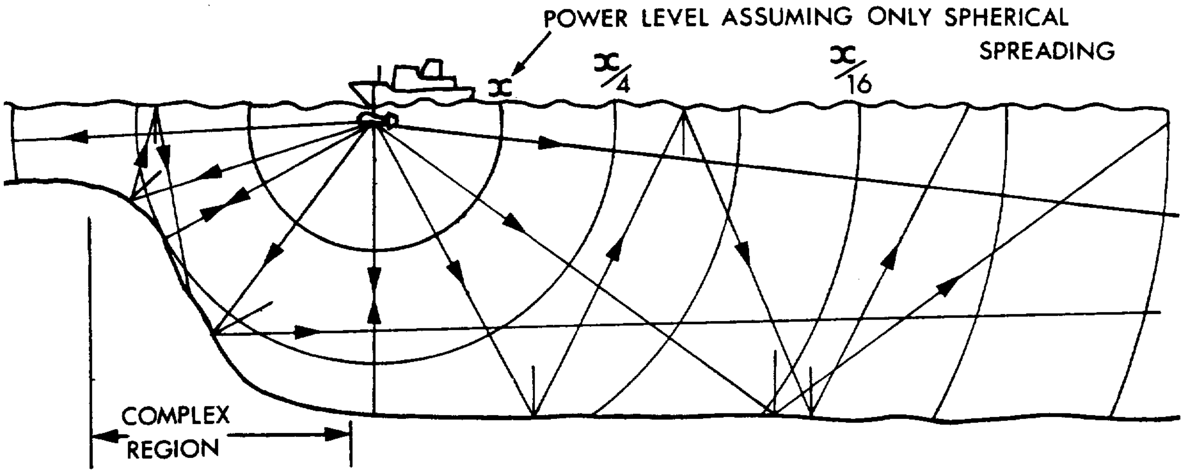
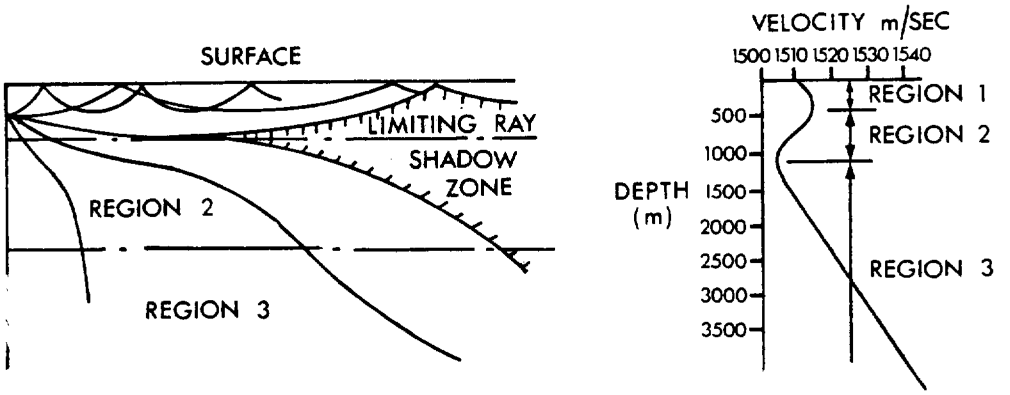


FIG. 3. ABSORPTION GRAPH



Power loss occurs at each reflection - at the frequencies and power levels used by the command system these paths cease to be significant after three or four reflections.

FIG. 4. GEOMETRICAL PROPAGATION



AY DIAGRAM CORRESPONDING TO TYPICAL SOUND VELOCITY PROFILE

FIG. 5. REFRACTIVE PROPAGATION

their requirement for well defined signals rendered digital and even frequency shift keying techniques unattractive. The system chosen was frequency modulation, which is very tolerant of low signal levels, high noise levels, signal amplitude variations, and signal multipaths. After initial problems with transducers and some electronic components were overcome, the system proved itself very reliable.

While none of these early instruments are in use today, they proved the soundness of the principles and form the basis of the wide variety of instruments that make up the IOS Acoustic Command and Monitoring System.

2. Acoustic Considerations

The use of acoustics in the sea for remote control and monitoring is restricted by the propagation properties of sound in the sea and the characteristics of the electric to acoustic converters (transducers) used.

2.1 Propagation is affected in two ways: firstly signal levels are reduced by absorption and spreading; secondly, received signals can appear confused because the same signal may arrive via different paths due to reflections or refractions.

Absorption is defined by the exponential decay rate of the power level of a plane wave signal with range. The decay factor varies with frequency used (Fig. 3). It varies from approximately 1/100 dB per kilometre at 1 kHz, to 1 dB per km at 10 kHz, and 100 dB per km at 100 kHz. A doubling of power is required to overcome 3 dB of power loss.

Losses due to spreading arise from the power radiated from an omnidirectional source illuminating an area that increases with its distance from that source. It is described by the simple geometrical formula for the area of a sphere in deep water or of a cylinder in shallow water. In deep water acoustic intensity is inversely proportional to the distance squared and so four times the original power is required to double the distance achieved. In shallow water intensity is inversely proportional to distance and so at least a doubling of power is required to double distance. In shallow water further complex losses occur due to boundaries.

Signals following alternative paths by reflections from sea bed or surface are fairly heavily attenuated, except at shallow grazing angles. However, they can still be significant if receivers accept signals over a large dynamic range. Multiple refraction paths are caused by variations of sound velocity in the ocean caused by temperature, salinity, and pressure. Signals via alternative refraction paths are often comparable in strength. The effects of refraction

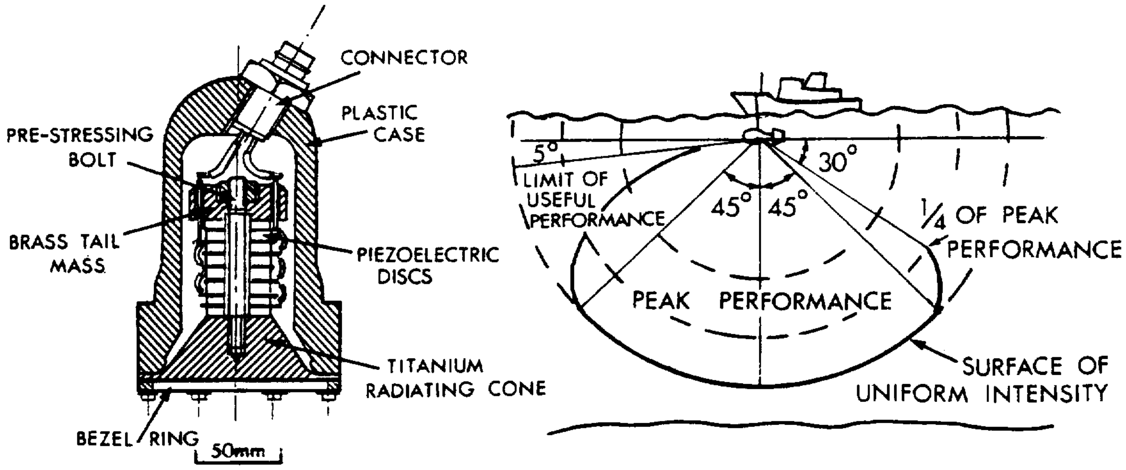


FIG. 6. THE P.E.S. SINGLE ELEMENT TRANSDUCER (construction and directivity)

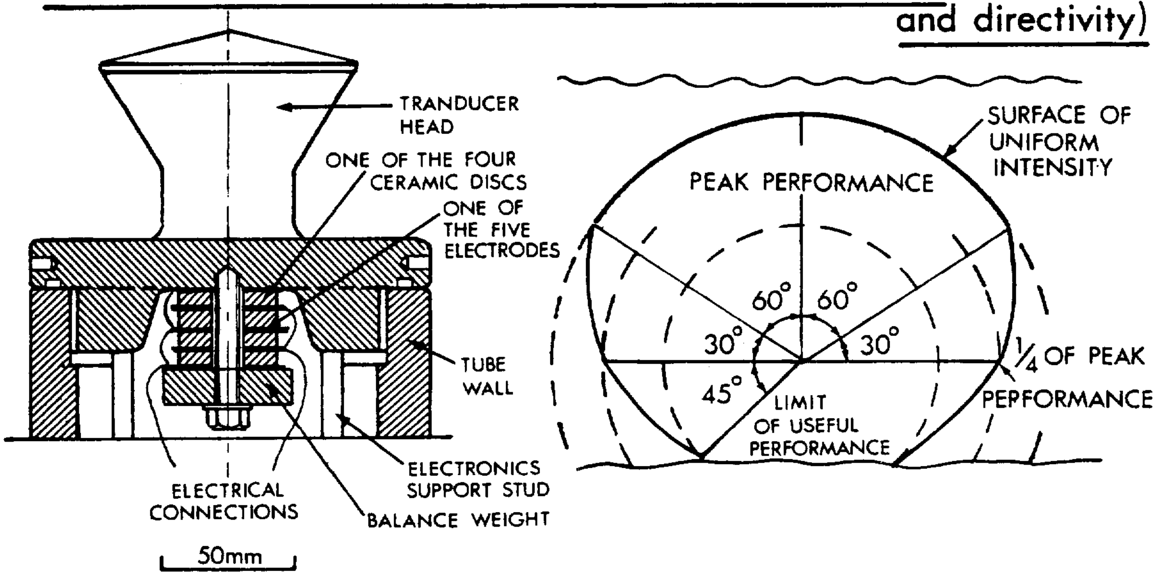


FIG. 7. THE 'MUSHROOM' TRANSDUCER (construction and directivity)

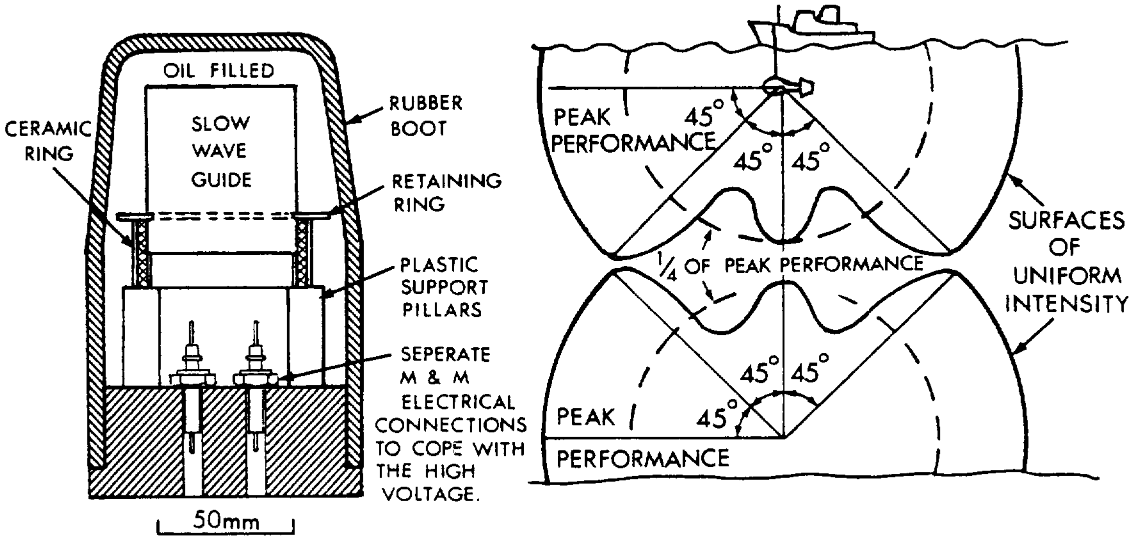


FIG. 8. THE 'CERAMIC RING' TRANSDUCER (construction and directivity)

and reflection are most significant in practice where receivers are at shallow angles (less than 15°) relative to sea bed, surface and sources (Fig. 4 and 5). The received signal is then composed of two or more identical streams of information displaced in time relative to one another. The signal may then be unrecognisable as components add, subtract and confuse.

2.2 Acoustic transducers convert electrical signals to sound in the water and vice-versa. They can be designed to project or receive signals from particular directions better than others (directivity properties). Their physical size is dictated by the wavelength of the sound they are required to operate at (the longer the wavelength the larger the transducer). The power levels they may operate at are restricted by their ability to convert that power usefully into the water.

The choice of a frequency for acoustic command and telemetry in deep water was dictated by practical considerations: operational depth range required was 1000 to 5000 metres; navigational uncertainties could be as large as 2 nautical miles; the equipment had to be light enough to be handled on board ship and supportable on subsurface moorings; available transducers and electronics were restricted in their capabilities; the effects of propagation on the system should be minimal. The choice of ten kilohertz enabled all these criteria to be reasonably met.

The system in use today employs three types of transducer. Two form a complementary shipborne and sea unit system for deep water work (the precision echo sounder (PES) single element and the mushroom transducer all based on piezo-electric stack designs). The other, in two slightly different mechanical forms, makes up the shallow water set (the ceramic ring piezo-electric type).

The PES type transducer (Fig. 6) is one unit of a beam forming array of nine, as used in the narrow beam echo sounder. At least one individual element is independently accessible in the normal PES array. The electrical response peaks at 10 kilohertz, is still reasonable at 9 and 11 kilohertz but is rejecting well by 8 and 12 kilohertz. When used singly it has a maximum and uniform sensitivity over a cone of base angle 90° symmetrically distributed about the perpendicular to its projecting face. The sensitivity outside this cone falls rapidly. In the array the element is basically downward looking and so is limited in usefulness at depths shallower than 500 metres. When mounted to face backwards and downwards at a face angle of 45 degrees a single element has proved to operate the system successfully to 12 kilometres slant range.

The mushroom type transducer (Fig. 7) is based on the PES element, but considerably redesigned and of robust construction to allow a similar performance, without a pressure (depth) limitation. When used in its six inch form its performance is similar to the PES element but its sensitivity is uniform over a 120 degree cone and falls more gradually. Its usefulness above 500 metres is limited for this reason, but is sometimes still preferred due to its robustness.

The ceramic ring type transducer (Fig. 8) comprises a short cylindrical ring of piezo-electric material. The shape of the ring and mode of activation produce a response that peaks radially, is roughly uniform and symmetrical out to angles of 45° to the plane of the ring, and has another but considerably lower axial peak. The theoretical maximum efficiency of the ring is two thirds that of the stack type transducer. The mechanical mounting is designed to optimise the effect of the mounting plate. A silicone rubber insert is used as a slow wave guide to reduce the variability of the secondary (axial) response. The whole assembly, enclosed in an oil filled rubber boot is mounted either on a pressure tube end cap or a towed fish end cap. In ideal conditions using the standard system the operational range is 8 kilometres radially and 2 kilometres axially. Of course this may be modified by propagation constraints in practice.

3. Mechanical Considerations

The marine environment places constraints on the mechanics of an instrument. Environmental considerations include pressure, temperature, corrosion, abrasion and marine organisms. Thus materials and designs chosen must be strong enough to perform correctly to the pressures expected, and be insulated, coated, treated and designed to minimise the influence of corrosion, abrasion and fouling on performance.

Operational considerations are ease of handling, sensor and transducer mountings, electronic and battery packaging, and interconnections. Ease of handling is a major consideration. Instruments must be safely handleable on a wet rolling ship either by a single man, or be designed for easy subdivision into safely manageable packages. Sensors and transducers must be placed such that mountings and any other hardware required by the system has no significant effect on their performance (Fig. 9). Electronic and battery packages can be tailored to a wide variety of situations but early close cooperation between mechanical and electronic designer is essential to optimise designs. The simplest (and best) package for a particular job is very often not the obvious one. Electrical interconnection between instruments and packages are extremely difficult to make reliably. They must be waterproof and pressure-

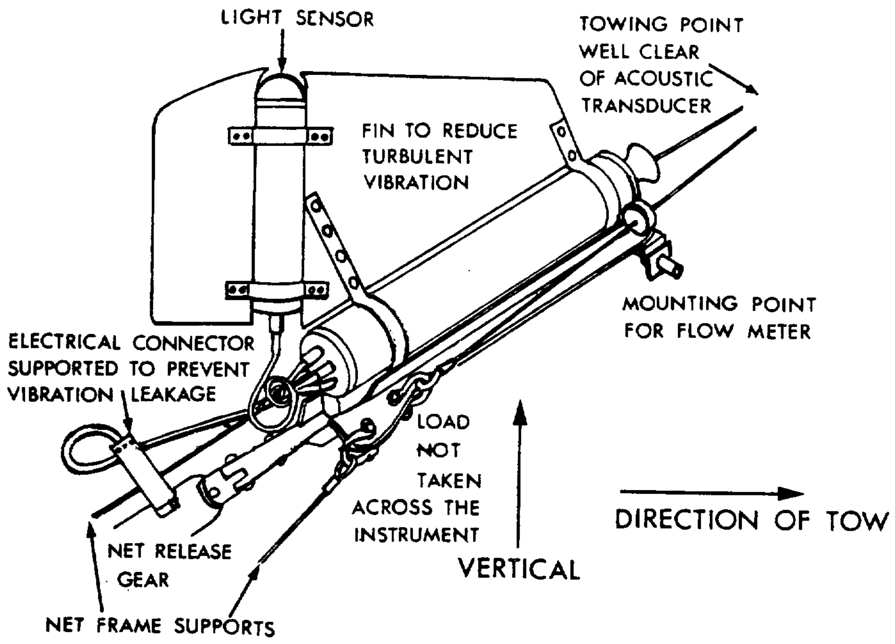


FIG. 9. NET MONITOR WITH FLOW AND LIGHT SENSORS MOUNTED CLEAR OF POSSIBLE OBSTRUCTION

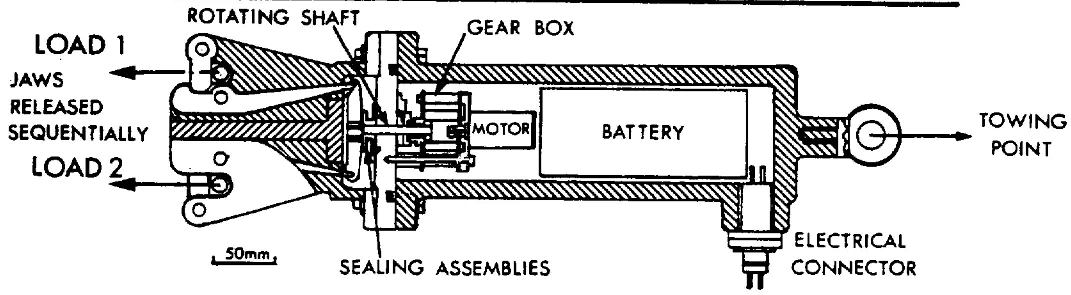


FIG. 10. NET RELEASE GEAR ILLUSTRATING THE USE OF A ROTATING SHAFT

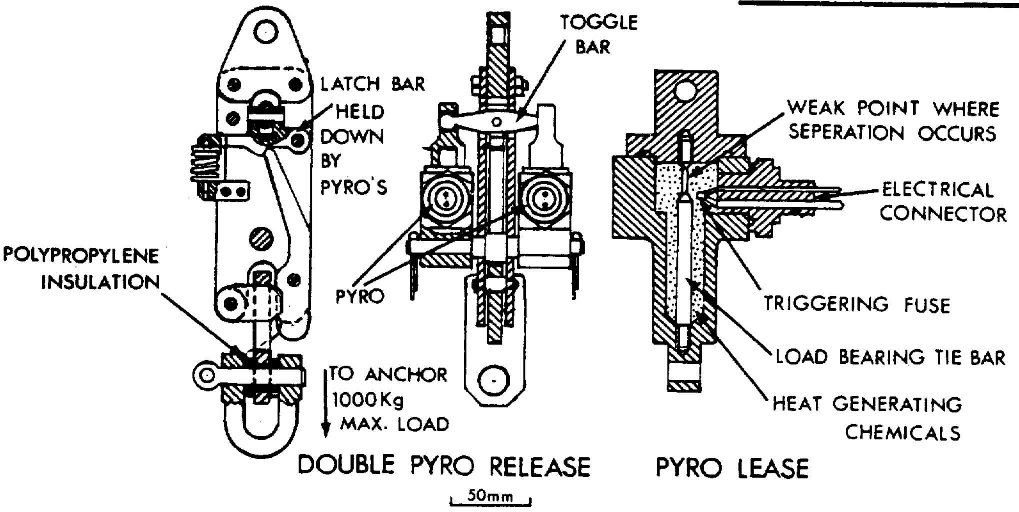


FIG. 11. PYRO RELEASE ASSEMBLY, ILLUSTRATING A PYRO TECHNIC DEVICE AND THE USE OF LEVERS TO ENABLE CONTROL OF A HEAVY LOAD BY A WEAK DEVICE.

proof, be kept as short and as few as possible, used at low voltages where possible, and designed such that failure will not adversely affect the packages themselves.

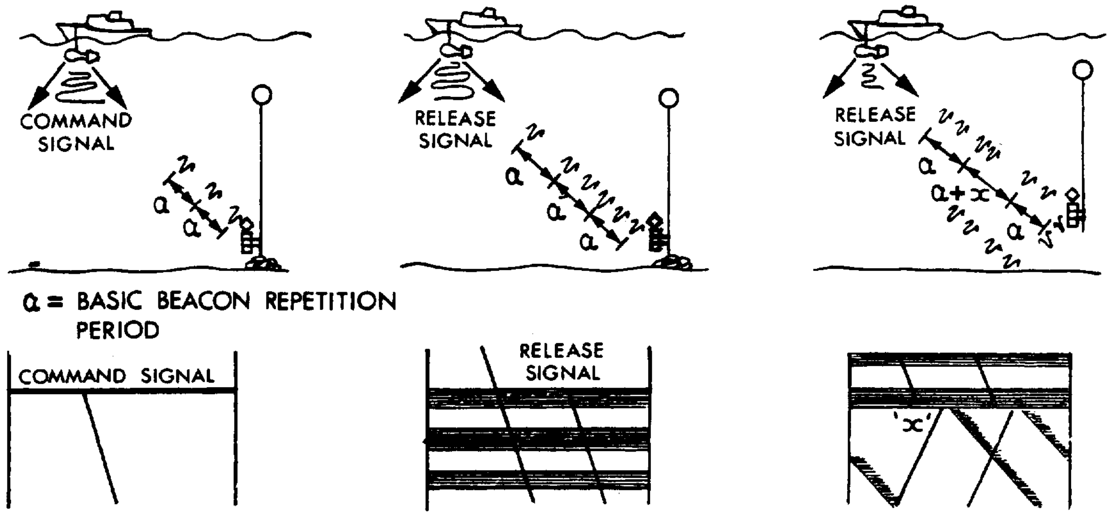
The materials in use within the command and telemetry system today include high strength aluminium alloys for instrument packages, a rigorously quality controlled stainless steel for long term, immersed load bearing and a variety of more usual metals and plastics for towed and vertical wire work. The aluminium alloys are protected by a well defined 'hard anodising' process and a liberal coating of grease before deployment. The only load bearing material presently acceptable for use to periods of one year immersed is stainless steel type 316S16. Even this can suffer severe 'crevice' corrosion after a year and so other materials are continuously being evaluated. Restrictions on materials for short term moorings and for ship lowered wire work are less severe but regular and frequent inspection is essential.

Mechanical operations in the sea are normally performed by rotary or sliding operation of shafts or by pyrotechnics. Rotation of a shaft is probably the easiest and most common technique used but problems arise with seals and the long term effects of corrosion and fouling. Sliding of a shaft is not as versatile unless the system is pressure balanced or does not operate against the ambient pressure. The other problems of rotary shafts also apply. Pyrotechnics operate either by generating heat to melt a component (sometimes carried out entirely electrically) or by generating gas to split a container or move a piston. The disadvantage of pyrotechnics is that they are by nature a 'once only' operation.

The present command system uses a rotating shaft for the multiple operations required by the towed net system (Fig. 10), and pyrotechnic units for long term remote instrument recovery (Fig. 11). The present main pyrotechnic unit uses heat to melt a necked rod and ambient pressure to complete the separation; however it is expendable and expensive. A second pyrotechnic device which is largely re-usable and safer to deploy is undergoing full sea trials. It uses gas pressure to move a sliding piston, which is then assisted by ambient pressure to complete its travel; it does rely on a sliding shaft.

4. Control in Real Time

Control and monitoring in real time of remote instruments is the major use of the system at present. There are two important limitations to this use of sound in the deep ocean. The first is the speed of sound in the sea, approximately 1500 metres per second, which means that a command to an instrument nine kilometres away takes six seconds to reach it and its reply takes a further six



INITIAL INTERROGATION

START OF RELEASE SEQUENCE

MOORING RELEASE

FIG. 12. A CONTROL SEQUENCE ILLUSTRATED BY THE RELEASE OF A MOORING

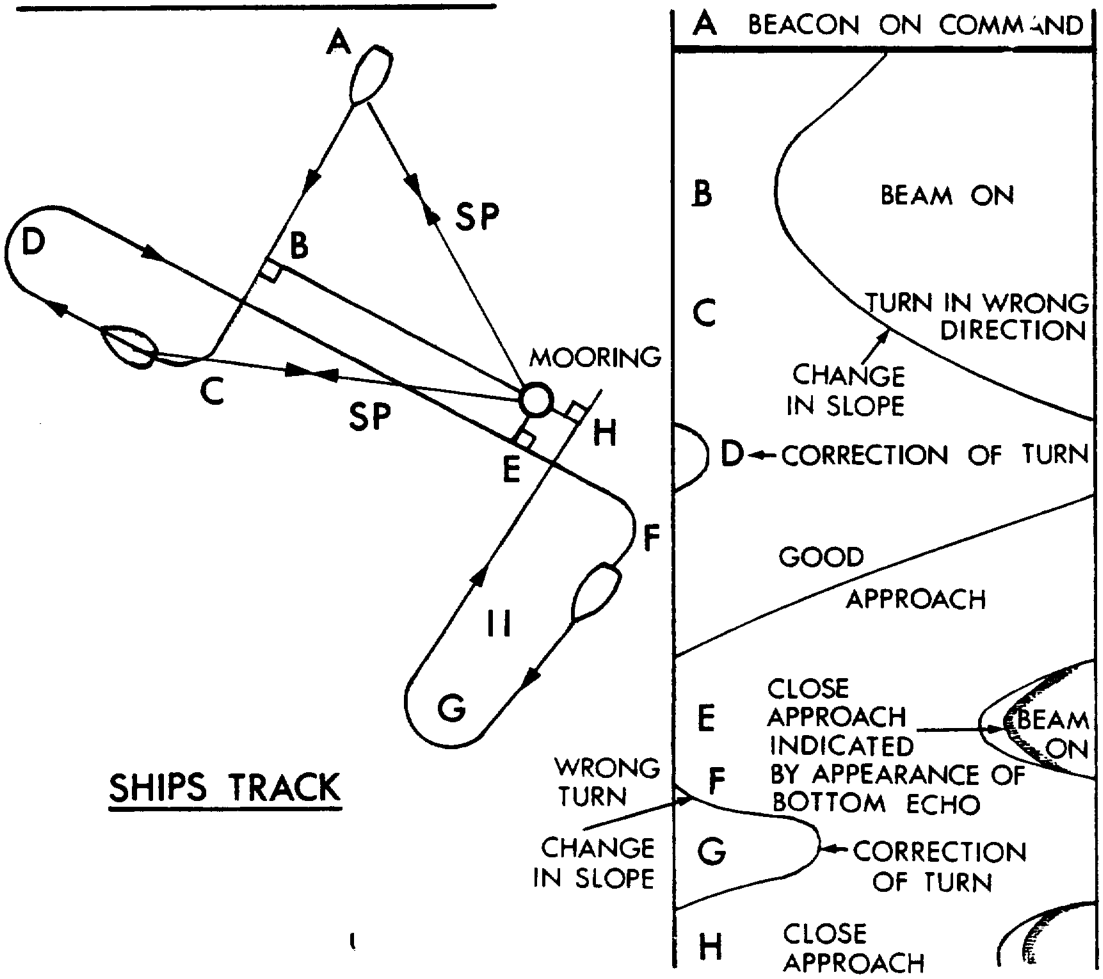


FIG. 13. MOORING LOCATION USING THE DOPPLER SHIFT ON A BEACON SIGNAL FROM THE MOORING

seconds to return. The second is the bandwidth of the sound used which governs the maximum rate at which data can be transferred and resolved.

The speed of response to a control command is governed by the security required of that operation. Operations of location beacons require sensitivity to low signal levels to obtain useful ranges, immunity to the majority of sea noise signals, and immunity from interference with more secure operations if accidentally operated. Safety is an overriding factor where equipment capable of remote action has to be handled above deck level. This requires security against false operation on deck due to noise and requires adequate advance warning of operation should deployment sequences commence accidentally.

The number of commands available using a frequency modulated system based on ten kilohertz is restricted by the usable modulation bandwidth, in this case 100 to 600 Hertz. The number is further restricted by the individual 'channel' bandwidths required and their immunity to harmonic operation. The electronic circuitry in use in the present sea units has been designed to operate at very low power and over the temperature range 0^{o}C to 40^{o}C. This has resulted in a 'channel' spacing of 20 Hertz over the ranges from 240 Hz to 460 Hz for fully remote instruments and from 480 Hz to 600 Hz for attached remote instruments. Several techniques for multiplexing modulation channels are under evaluation for performing many secure commands within one or more instruments without increasing channel requirements.

The ability of the electronics to recognise the modulation frequency sets the fastest possible response of the instrument. This is normally less than one tenth of a second but practical experience has resulted in a controlled lengthening of this time to about threequarters of a second to ensure good rejection of noise. This is the basic response time of all the sea units. In the net monitor unit one operation will begin operation of the release mechanism, but 30 seconds warning of release is provided by the motor. In all the other systems one operation switches on a beacon or transponder only. More secure operations then require many successive operations (typically 32 or 64) and these modes are acoustically resettable before firing if required (Figs. 12 and 15).

5. Monitoring in real time is achieved with a facsimile recorder displaying a time correlated pulse train either from a synchronised beacon or from a transponder. Thus signals repeating at the sweep rate of the recorder build up as lines on the paper. At ten kilohertz the shortest practical pulse length has been found to be two milliseconds and the most suitable monitoring rates are around one or two seconds.

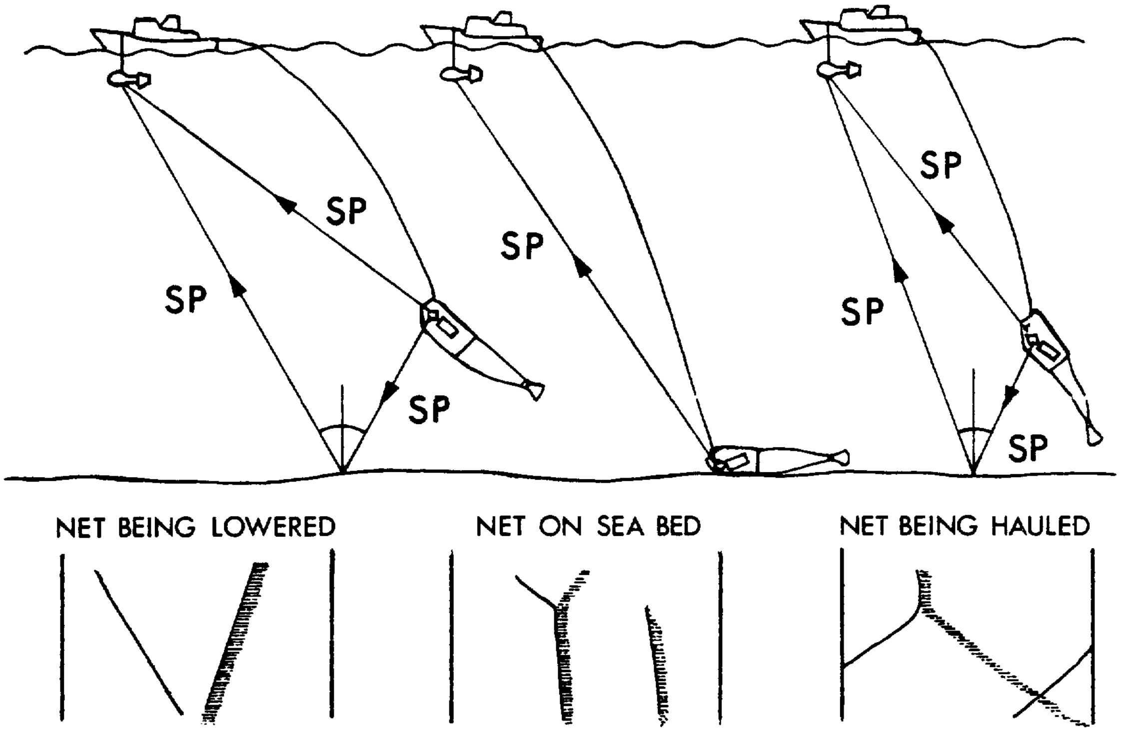


FIG. 14. MONITORING THE OPERATION OF A TOWED BOTTOM SAMPLER

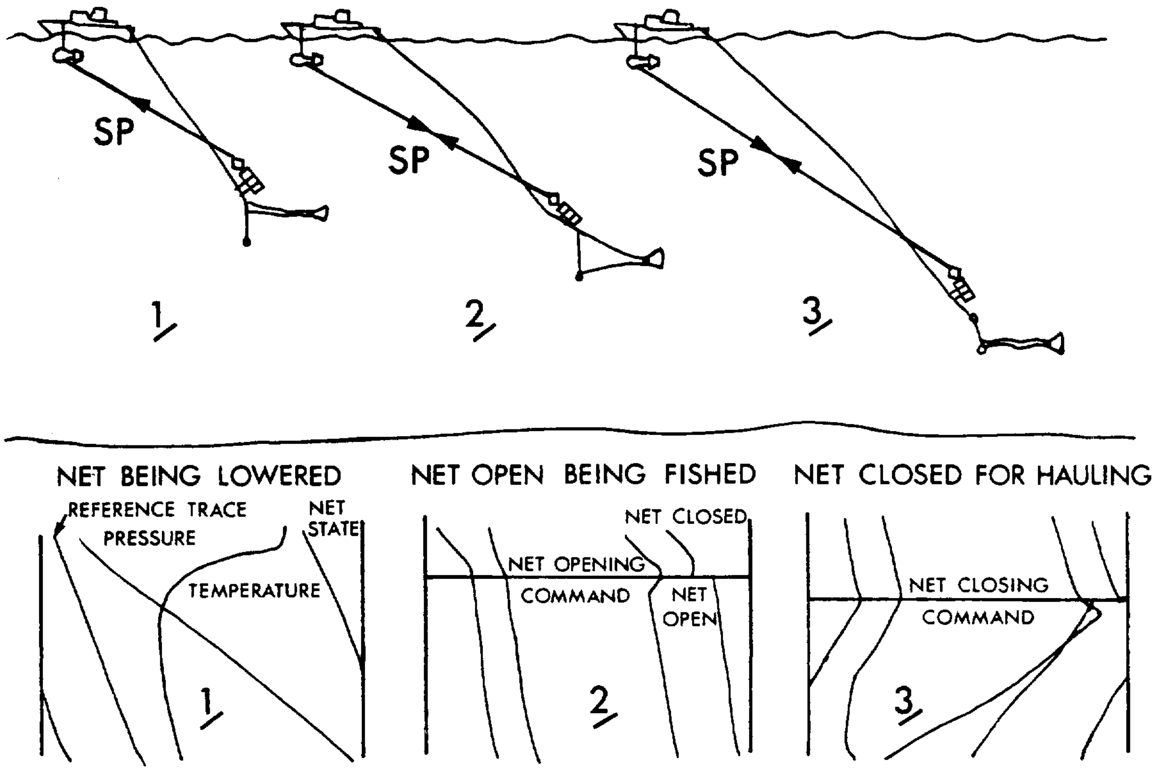


FIG. 15. MONITORING AND CONTROL OF THE OPERATION OF A MIDWATER NET

The simple beacons used as remote echo sounders on vertical wire casts generate one pulse at one or two second intervals. Mounted vertically with the transducer pointing downwards, good direct and bottom reflected signals are obtained in most conditions. Maximum resolution is two milliseconds (three metres) in the 750 metres or 1500 metres full scale display of a 45 cm (18") recorder.

Beacons are used in the CR200 series sea units (the basis of all the IOS fully remote pop-up units). However, they are time coded to repeat at different intervals around once a second (0.90 to 1.18 seconds in 200 millisecond steps). This enables one unit to be tracked in the presence of others by locking the sweep rate of the facsimile recorder to the beacon rate. In this application, as both recorder and beacon are precisely timed using modern crystal circuits, any apparent difference in rate is an indication of relative motion (Doppler shift). Thus, if the ship is steered to decrease the received beacon rate, it is approaching that beacon. When the rates are equal the beacon is either at right angles to that track or directly below the ship. When the rate increases the ship is leaving the beacon. Thus by altering course appropriately a beacon may be accurately located (Fig. 13). In the standard CR200 unit the beacon also indicates (a) the release channel first operation by producing a delayed second pulse running at the same rate as the first, and (b) release relay operation by introducing a delay to the pulse train, giving a 'displacement' of the lines on the recorder (Fig. 12).

The crystal controlled beacon circuit also provides the basic timing for all the more complex telemetry units. The simplest of these units operate as standard beacons with one pulse per sweep but produce extra pulses when internal or external switches are operated. Typical examples include mercury switches, operating at angles of tilt or total inversion (bottom samplers) (Fig. 14), magnetic proximity switches indicating external lever operations (bottoming and limit switches), and switches in other instrument packages (flash operation and film wind on in cameras). This technique may be used in any instrument containing the simple beacon.

A recent addition to the range is the ten kilohertz transponder. It has been used in place of part of the beacon circuitry in a switched mode for location of bottom seismometers, and as a stand alone instrument for location of the top sections of long moorings and the positioning of 'vertical' wires in the presence of strong horizontal current shears. Units reply with a coded pulse train, enabling individual identification and simple event indication such as angle of tilt. They also incorporate various features to prevent self triggering and to minimise sing around operation via bottom and surface reflections.

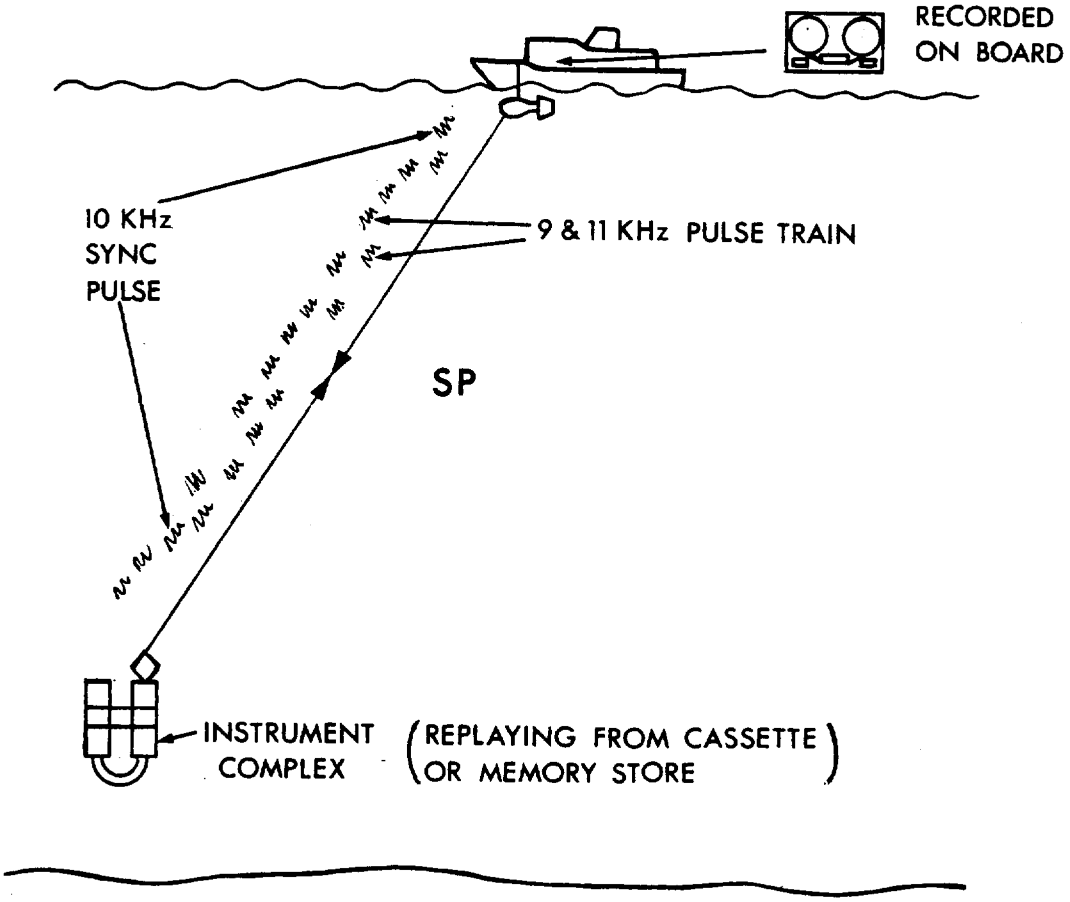


FIG. 16. A POSSIBLE DIGITAL TELEMETRY LINK

Versions of both transponder and CR200 series sea units can be produced with battery capacity for replying continuously for one year and listening for ten years; however, the factors limiting life are mechanical integrity and as yet unproven battery shelf life.

For monitoring non discrete parameters such as pressure and temperature a different technique is used. The sensor output is converted to a frequency which is counted down to a time interval. The system is reset by a pulse repeating at two second intervals, and this 'reference' pulse is transmitted first. When the time interval is complete another pulse is transmitted. The displacement of this pulse from the reference pulse is a measure of the sensor output and thus the parameter being sensed. Therefore as the parameter varies the line produced by the pulse moves across the recorder. Using this technique three or more differently varying parameters may be monitored using the standard system (Fig. 15). In the midwater-net monitor these are pressure, temperature and light and in the bottom-net monitor they are pressure, temperature and distance run. Other discrete parameters can also be simultaneously monitored using the simpler technique. Examples of these are net opening and closing, water flow past the net, and camera operations.

The above techniques have been developed for real time analogue monitoring and control of equipment and are excellent for that purpose. However, the accuracy of scientific measurement using these techniques is restricted by the ability to resolve the displacements on the facsimile recorder used and the jitter caused by relative movement of ship and instrument. A technique for scale expansion is in use but this is restricted in its application and does not relieve the observer of the task of making an analogue measurement at the sample interval required. Electronic pulse detection is being investigated but will require considerable processing to deal with the complex signals received.

6. Digital telemetry

Two alternative techniques for data telemetry have been investigated and show promise. Both convert all the data to 'bit' form and transmit them as an acoustic pulse train in a similar way to normal serial digital information transfer along a cable. One used the presence or absence of a 10 kHz pulse to code '1's and '0's and a precisely repeating extended pulse to synchronise clocks; the maximum bit rate was slow, 250 bits per second. The other used pulses of 9 and 11 kHz to code '1's and '0's and a precisely repeating pulse of 10 kHz to synchronise clocks (Fig. 16); the maximum bit rate was also 250 bits per second. For both techniques the power consumption at the sea unit end is relatively high and a single dominant transmission path is required. However, electronic detection and processing is relatively easy and sensor accuracy can be fully realised. While overcomplicated for real time monitoring work, they could be a valuable tool when used with high resolution remote instruments with limited tape capacity or where recovery and redeployment would be inconvenient or unacceptable.