DIRECTIONAL ECHO SOUNDING

SOME POSSIBLE IMPROVEMENTS IN EQUIPMENT AND TECHNIQUE

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INTRODUCTION

Some recent papers on echo sounding have given a new emphasis on the one hand to the difficulties of interpreting recorder traces from wide-beam systems and to the nuisance of calculating true depth and/or position of measured depth from them [1] (*), and on the other hand to the advantages of using beams of greater directivity (i.e. of narrower beam width) [2, 3, 4]. Although it may clearly be accepted that beam widths of only a few degrees are very advantageous from most points of view, it appears that there are disadvantages of two types :

(*a*) mechanical problems, due to the need for stabilizing the transducer — larger than normal transducers — against ship's motion [2, 3]. It should be noted that electronic solutions are possible [4].

(*b*) more fundamental problems, of which the main one is the fact that on steeply sloping bottoms the received echo is not produced by reflection at normal incidence on the sea bottom, but only by back-scatter; it therefore may be very weak, and undetectable when sounding at the greater depths. To overcome this difficulty it has been suggested that a wide-beam echo sounder should be fitted as well as the narrow-beam equipment [3]. An echo can then be received from a normal-incidence reflection at a point not vertically below the ship.

It is the purpose of the present note to show that more elegant solutions of the second difficulty are possible. To both the systems to be described, electronic stabilization by the method of Ref. 4 may be applied.

INTERFEROMETRIC TECHNIQUES

It has already been shown by work at the British National Institute of Oceanography [5, 8] that very great benefit can be obtained from the exploitation of the secondary lobes in the vertical beam pattern of an echo-ranging system used with a nominally horizontal main beam. The interests of this particular work were the detection of fish and a study of the

(*) The numbers between brackets refer to the bibliography.

geological formation of the seabed, both being concerned primarily with shallow water, and not with a bathymetric survey of deep water. Nevertheless the deliberate exploitation of the secondary lobes, one of which was nearly vertical and provided echo-sounding information, points the way to the solution of the directional echo-sounding problem now to be described.

If the echo-sounding transducer (which is a fairly large one in a system of high directivity) be replaced by two parallel strip transducers separated by a suitable distance, then the directional pattern obtained in the vertical plane containing the line joining the centres of the two transducers is the well-known interferometer pattern consisting of a number of equally spaced lobes all of approximately equal sensitivity (within a reasonable range of angle from the vertical). The system may be represented diagrammatically by the beams 1, 2, 2′, 3, 3′, shown in Fig. 1. It will be realized, of course, that representation of beams in this way is purely arbitrary. It is the present purpose only to explain the basis of the proposed device and not to analyse it in detail; but a brief account of the interferometer principle itself is given in the Appendix. If, with such a system transmitting pulses, the bottom of the sea is quite level, as shown by the line QPQ′ in Fig. 1, then the first echo received — i.e. the echo showing the shallowest depth — is that from the point P at the centre of the vertical beam. Somewhat later, indicating a greater range, are received echoes from the points A, A′; and after this are received echoes from points B and B′. Thus, if Fig. 2 may be regarded as a sort of idealized recorder trace, then on this level bottom echoes will be received as shown on the left-hand side, where the traces have been reduced to lines. Obviously in practice they will be of some width and all except the first will have some indefiniteness.

It is desirable that the length of the strip transducers be approximately equal to their spacing, so that the beam width in the other plane be small and of the same order as the interferometer lobe width. It may also be desirable to provide, at right angles, another pair of strips (making up a square formation) so that the interferometric plane may be changed through 90°.

Assume that the interferometric plane (i.e. the plane of Fig. 1) is at right angles to the ship's fore-and-aft axis. If now the ship moves forward and eventually goes over a part of the bottom with a slope as indicated by the line RPR′, then the first echo received will in the new circumstances be from the point S along the direction OS. The later échoes from greater depth are returned from the points T and T′, and then from the points U and U′ and so on; thus the recorder trace, as idealized, will appear as at the right-hand side of the diagram in Fig. 2. If the bottom changes gradually from the level to the sloping position, then the recorder traces may be expected to vary somewhat as indicated by the thinner lines in Fig. 2. If the slope of the sea bottom lies along the ship's axis rather than across it, then obviously the interferometric plane needs to be turned through 90°.

The choice of lobe width is important in this system, since it is necessary for the distance between echoes on adjacent lobes (such as between the echoes on beams 1 and 2, 2′ at the left-hand side of Fig. 2) to be large enough to give a clear separation on the recorder chart. A suitable lobe width might be about 10°, since the separation between the first two

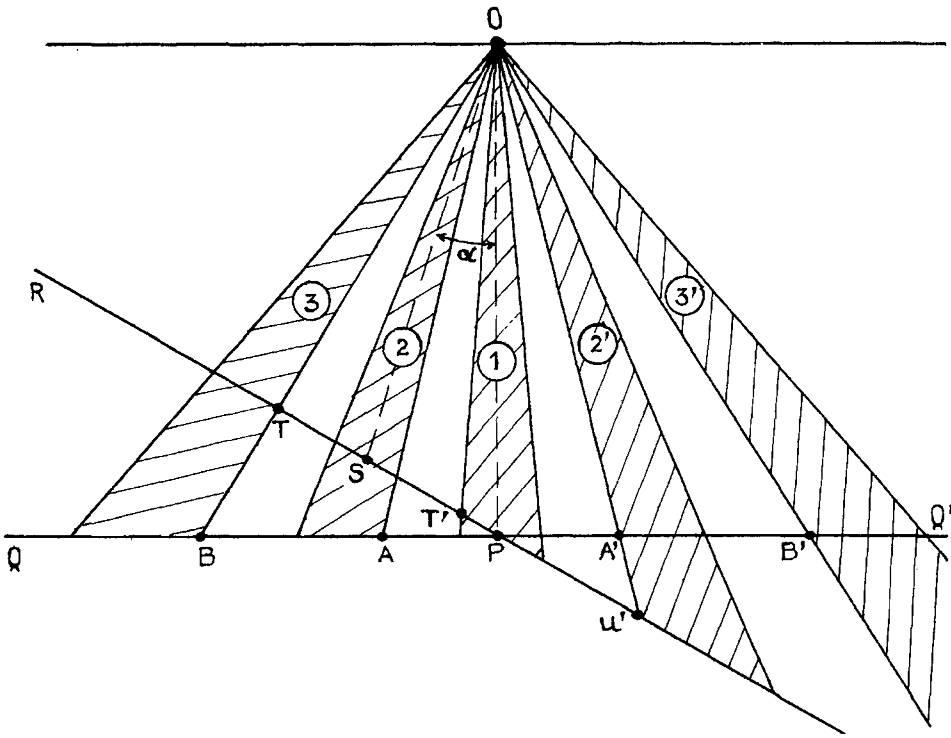

FIG. 1. — Interferometer beams or « lobes ».

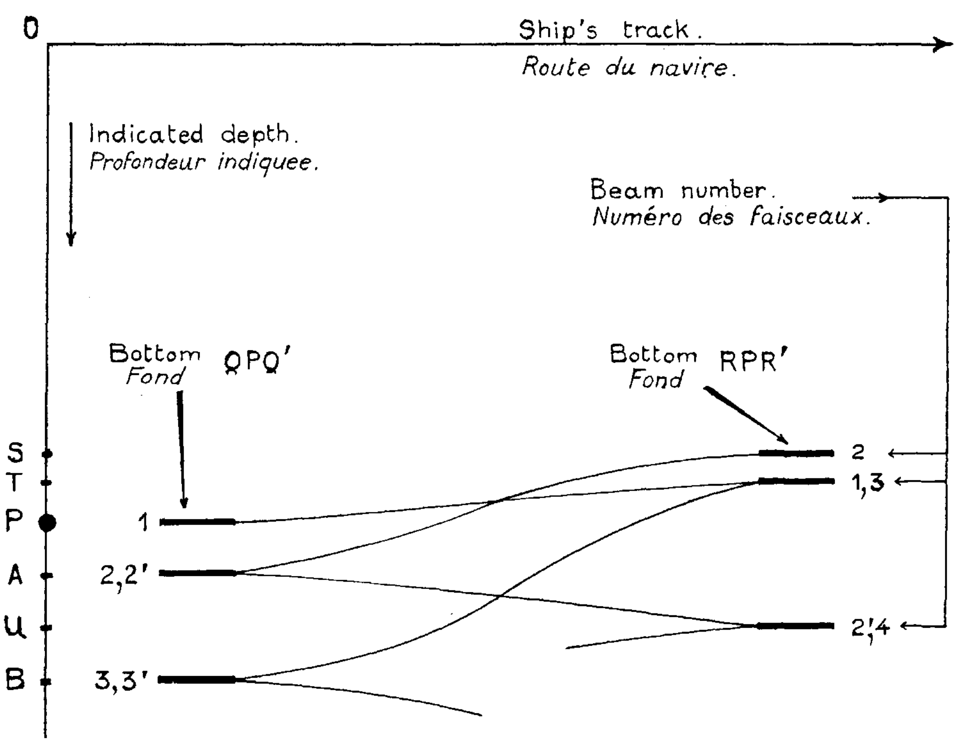

FIG. 2. — Idealized recorder traces.

echoes is then about 4 per cent of the depth. With a 5° lobe width, the separation is only about 1 per cent, which may be insufficient.

There seems no reason to suppose that 10° lobes should not remain distinct up to the greatest depths to be sounded. Of course, velocity gradients in the water will cause some refraction of the beams which may have to be allowed for in calculations; but it seems this effect is likely generally to be small [1].

It is clear from the above discussion that an interferometric system of this kind gives essentially all the information required. From the record, whatever the depth, provided the echo can be detected from nearly normal incidence on the bottom, then the true depth can be calculated if the bottom slope is known; i.e. the method has the same advantage as that which can be claimed for a a wide-beam echo sounder. On the other hand, if the depth is small enough for effective echoes to be detected even at slanting angles of incidence, then the analysis of the set of traces as shown in Fig. 2 can enable the true depth and the bottom slope itself (which need not be assumed uniform) to be determined when neither of these factors is known. This would appear to be a very considerable advantage for the interferometer.

It should also be noted that when true depth is calculated using a wide-beam system, then the bottom slope used to make the slope correction (see ref. 1 and the numerous other references quoted therein) has to be that observed along the ship's track (if only a single traverse of the area is made) since no other information is available (*). Therefore the fact that the interferometer system can have its plane changed easily gives it another advantage.

If the traces on a real echo-sounder record should be very much more confused and indefinite than those idealized in Fig. 2, nevertheless information can be obtained about true depth even when the slope of the bottom is not known. This can be done by inserting other transducers, preferably a fairly continuous set of transducers, between the two forming the interferometer. When all these transducers are connected together a single directional beam with relatively small side lobes will be formed, as with the ordinary directional echo sounder. This can be used to identify the beam position 1 if the echo can be detected from it. By means of phase shifters between the sections of the transducer the direction of the single main beam can be deflected to one side or other of the vertical position and by this means the direction of the beam receiving the first echo can be determined. This is, of course, a complicated way of making a test and is quoted merely to show that positive identification of the lobes is possible.

A greater refinement may be used to keep all the beams labelled all the time. If all intermediate sections of the transducer are provided, and connected together by means of phase shifters which give a phase shift varying rapidly with frequency, and if the pulse is transmitted through them at a number of frequencies simultaneously (all within the effective

(*) It is clear from this that an ordinary wide-beam echo sounder might be greatly improved if its beam were made narrow in the transverse direction while remaining wide from fore to aft. Slope correction based on the slope observed on the record could then be accurate. But with transverse slopes it might become impossible to obtain normal-incidence echoes.

band width of the transducer), then each frequency produces a single main beam, with a direction different for each frequency. The interferometer lobes of Fig. 1 are thus replaced by individual beams, each distinguished by the frequency of its signal. Therefore, on reception, the echo signals can be separated by filters into the individual frequency channels, and presented either on separate recorders, or on the same recorder using for each channel a separate stylus so constructed that a trace of different color is produced for each beam.

THE ELECTRONIC SECTOR-SCANNING ECHO SOUNDER

An account has recently been published [6, 7] of a new type of scanned asdic system in which the whole sector to be explored is illuminated by the transmitted pulse using a wide-beam transmission, but for reception a separate narrow receiving beam is swung over the sector at a very high speed. The swinging of the beam in this way is performed by purely electronic means; the transducer itself does not have to be moved. The swinging can be so rapid that it can cover the whole sector within the duration of a pulse. This means that every direction within the sector is sampled within each pulse duration and thus no information is lost. In effect all directions are looked at simultaneously. The application of this principle to echo sounding in great depths of water is very attractive.

Sector scanning can, of course, be carried out mechanically by swinging the transducer physically. This, however, has the disadvantage that before the direction of the beam may be changed the pulse must travel to and from the bottom, and in great depths this takes a long time. To complete the examination of a sector transverse to the ship's axis therefore takes some time, and in rapidly changing bottom contours much information would be lost. The simultaneous examination of all directions is therefore a great advantage. This has been discussed in one of the previous papers [7]. It would appear to the author that this is the best possible system for survey purposes, as it has all of the advantages of the previously discussed methods without their disadvantages. Its only real disadvantage is indeed in its electronic complications — which in a system covering a large number of beam widths within its scanned sector may be considerable. For best results, the beam width of both transmitter and receiver in the plane at right angles to the plane of scanning should be small. Moreover, as with the interferometer, it is probably desirable to be able to change the plane of scanning through 90°.

The information obtained in this system is most conveniently presented as a B-scan on a cathode-ray tube. The B-scan is one with rectangular axes of bearing and range respectively. The general nature of this type of display can be seen from the photograph in Fig. 3, which shows the profile of a steep slope on the edge of the continental shelf in the eastern Atlantic. This was obtained during trials of the system in December 1959, and the weather was so bad, with the ship rolling through $\pm 30°$ and complete quenching on perhaps 90 to 95 per cent of transmissions, that the quality of the display is far below what would normally be obtained. No other trials have yet been held. It should be pointed out that the equipment used was designed primarily for horizontal echo ranging for fisheries

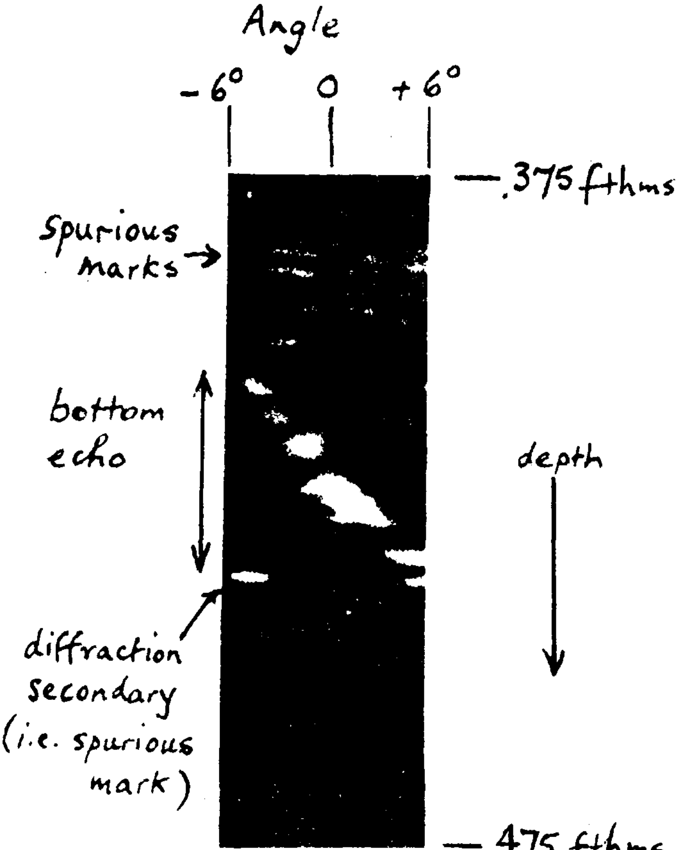

FIG. 3. — Sea-bottom profile on display of electronic sector-scanning echo sounder. (Atlantic, slopes of continental shelf, approx. 47°30′ N, 7°15′ W, 12 Dec. 1959, very bad weather).

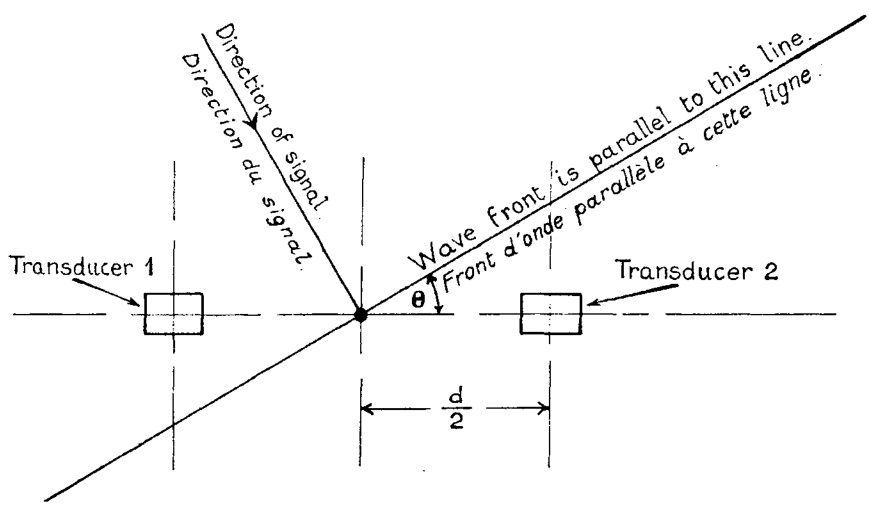

FIG. 4. — *Arrangement of Interferometer.*
(N.B. : In practice the transducers must be long in the axis normal to the plane of the diagram).

research [10], and so had a frequency of 37 kc/s with a beam width (on reception) of 1.5 degrees, scanning on 12-degree sector. The transducer was stabilized against roll. In an equipment designed specifically for echo sounding in deep water, a much lower frequency would be used, and much wider beams; and it seems reasonably certain that the resolution would then be effective even at the greatest depths to be sounded.

The cathode-ray presentation of the information by this system has, of course, a disadvantage in that the record is not permanent; but a method of obtaining an immediate record on chemical paper is now being worked out.

It is obvious that, in addition to giving the advantages of the interferometer system, the electronic sector-scanning echo sounder will also enable virtually 3-dimensional information to be obtained during a survey in a single traverse of an area. This must result in a great saving of survey time; alternatively, if a single traverse is being made on passage, it results in a great increase in the amount of information gathered.

CONCLUSIONS

Two possible improvements in directional echo-sounding equipment and technique have been described. Neither has yet been fully tested in practice, although it is hoped that opportunities to do so will arise before long. It seems clear, however, that any significant improvement in echo surveying in the future will depend on such considerable improvements in the equipment, as the possibilities of very simple systems have probably been exhausted.

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APPENDIX

The Interferometer Principle

Consider two narrow transducers spaced at a distance d between centres, as shown in Fig. 4. Restricting consideration to reception only, let a signal of angular frequency q be incident on the transducers along a direction making an angle θ to the normal to the line joining the two transducers. Then if the midpoint of the line is taken as phase reference, the signals received at the transducer terminals may be expressed as

$$\mathrm{V}\cos\left[qt + \frac{d\pi \sin\theta}{\lambda}\right] \text{ and } \mathrm{V}\cos\left[qt - \frac{d\pi \sin\theta}{\lambda}\right]$$

for transducers 1 and 2 respectively, where λ = wavelength of sound in water at angular frequency q.

There are two ways of treating these signals to make an interferometer, namely, (1) adding them, and (2) multiplying them together. The former is the simpler, but the latter may have some important advantages.

(1) *On adding the signals together,* we obtain

$$2\mathrm{V}\cos\left(\frac{d\pi \sin\theta}{\lambda}\right)\cos qt$$

which may be represented as in Fig. 5 (*a*). Clearly

$$2\mathrm{V}\cos\left(\frac{d\pi \sin\theta}{\lambda}\right)$$

is the envelope of a carrier, and represents (as a function of θ) the directional pattern. But since the signal has to be rectified before it can be used, the effective directional pattern is as shown in Fig. 5 (*b*), where for convenience it is plotted against $\frac{d\pi \sin\theta}{\lambda}$ instead of against θ; it consists of lobes of equal height, with zeros in between. These correspond to the lobes indicated roughly by shading in Fig. 1.

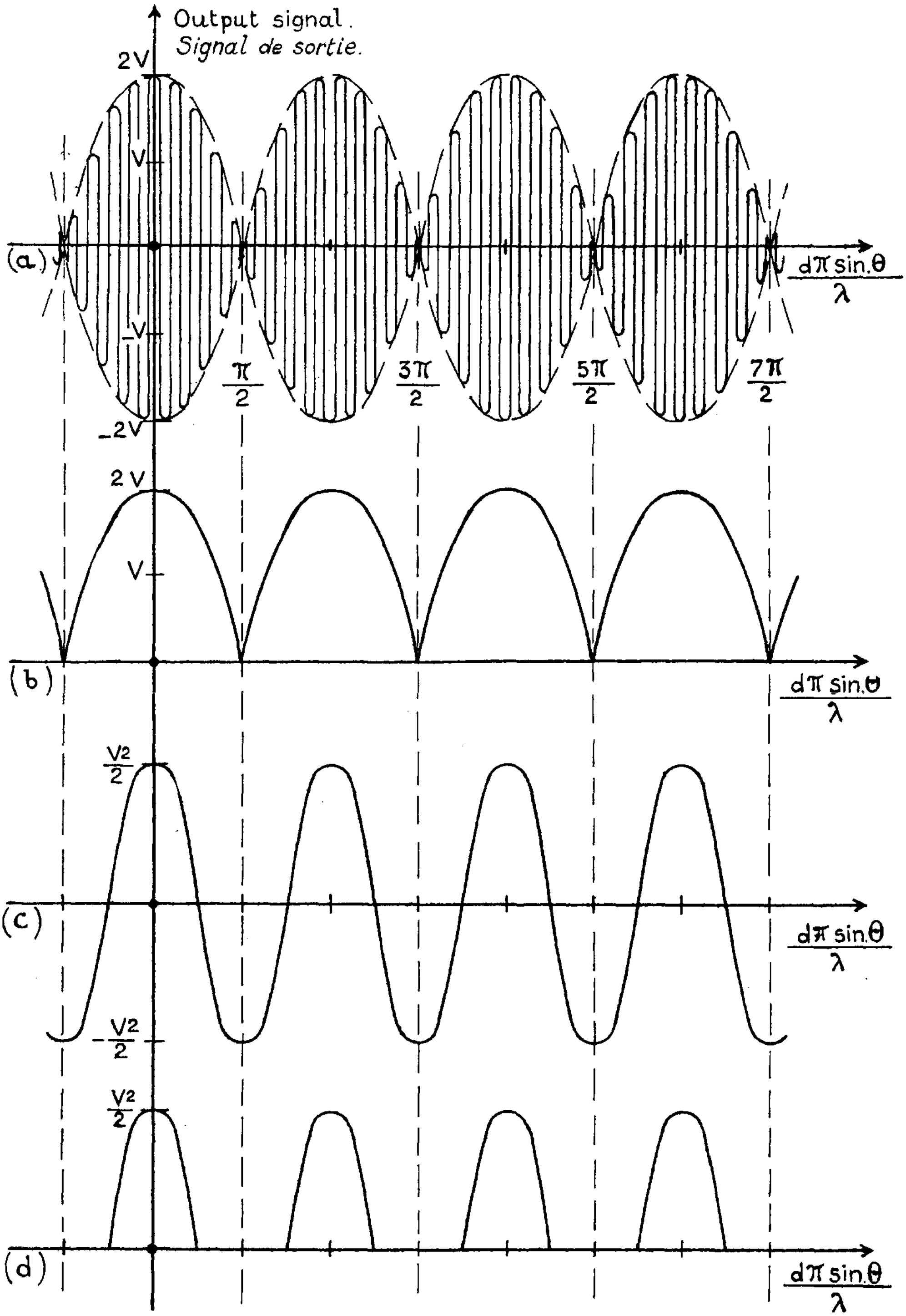
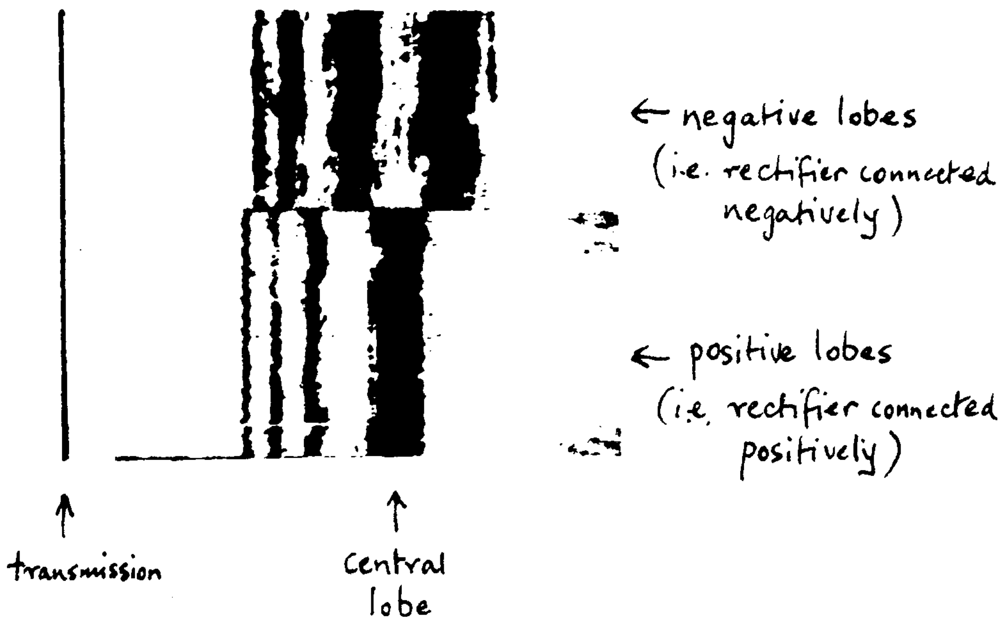


FIG. 5. — Directional patterns of interferometers.
a, b : Additive type; *c, d* : Multiplicative type.



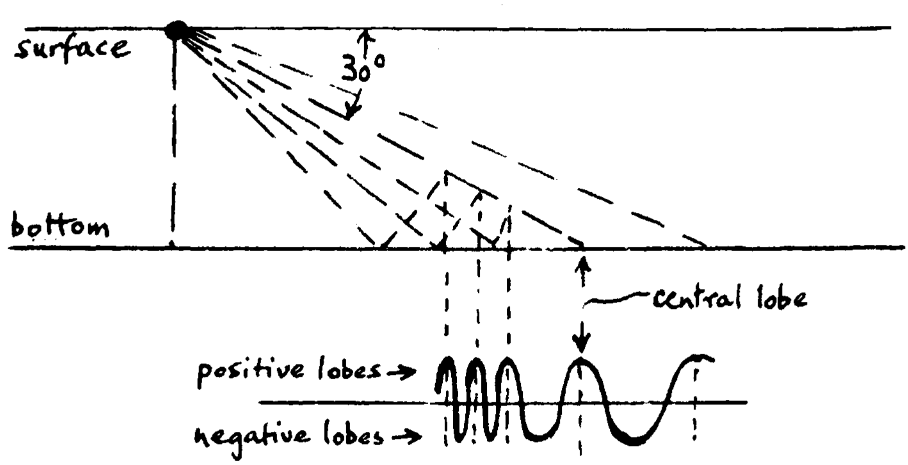


FIG. 6. — Test of Interferometer in Falmouth Bay using multiplicative reception with rectifier.
(a) Chemical-recorder chart; (b) Explanation of chart.

(2) *On multiplying the signals together,* we obtain

$$\frac{1}{2} V^2 \cos 2qt + \frac{1}{2} V^2 \cos \left(\frac{2 d\pi \sin \theta}{\lambda}\right)$$

The first term is a high frequency which we do not require, and it can be removed by a low-pass filter. The second term is a *d.c.* output signal which conveys the directional information, and this is therefore used as the wanted signal. This term (as a function of θ) represents the directional pattern. It is shown in Fig. 5 (*c*) on the same basis as the additive pattern.

It will be observed that the lobes are of only half the width. If now a rectifier is connected in the circuit (following the multiplier and low-pass filter), the negative lobes can be eliminated, and the directional pattern becomes as shown in Fig. 5 (*d*).

It is clear that in the multiplicative pattern of Fig. 5 (*d*) the lobes are more distinct than in the more usual additive arrangement of Fig. 5 (*b*). To what extent this is an advantage in echo-sounding work can be determined only by experiment and experience. But in preliminary experiments in rather artificial conditions it was strongly indicated that the multiplicative arrangement was greatly superior to the additive. A good idea of the operation of the multiplicative system with a rectifier can be obtained from Fig. 6, where results obtained in shallow water are shown. The axis of the beam system was tilted at 60 degrees to the vertical in order to obtain reasonable distances, and the diagram (*b*) shows the geometry of the system; the positive lobes had a spacing of about 12 degrees. The chemical recorder trace in (*a*) shows the actual record obtained. First of all the rectifier was connected to remove all negative lobes; then after the paper had moved on some way, the rectifier was reversed so that only negative lobes remained. These tests show clearly how very distinctly the lobes appear.

There is also a difference between the additive and multiplicative systems in respect of the threshold of detection of signals against a noise background. This is a rather complicated matter because of the effect of the rectification involved in the additive system; it is fully discussed in ref. 9. It is relevant, of course, to the greatest depth at which soundings can be obtained.

We have so far considered only reception. It is possible to have the additive interferometer directional pattern on transmission merely by transmitting the signal from both transducers simultaneously. If plain addition is used on reception also, then the overall directional pattern is similar in shape to that of Fig. 5 (*b*), but with all ordinates squared in magnitude. It is not possible to obtain the multiplicative pattern on transmission, so with multiplicative reception either the transmitting pattern must be as Fig. 5 (*b*), in which case the overall pattern has ordinates which are the product of those of (*b*) and (*d*); or just one of the transducers is used for transmission, leaving 5 (*d*) to represent the overall pattern.