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# DESIGN OF A SONAR FOR FISH COUNTING

By

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## INTRODUCTION

Some three years ago the Marine Laboratory commenced a study of the feasibility of making population assessments by echosounder. The species of prime interest was the herring of the northern North Sea.

The study involved a review of work in progress elsewhere, a decision about the most suitable kind of equipment to use, and consideration of the statistical mathematics required for the interpretation of results. The choice of equipment, and of the resolution required, was of course influenced by the known facts about the distribution of herring.

It was felt that the counting and sizing of individual echoes would provide more information than an integration method, as it offered the prospect of classifying fish in accordance with their target strength (T decibels). To make this a practical method for routine surveys a degree of automation was required, so that the observational task aboard ship could be kept to reasonable proportions.

Since the population density of herring can be at times very high (as much as 10 or 20 per cubic metre in daylight schools) it was decided to aim for the highest degree of resolution attainable within the available funds. Our previous experience suggested that an acoustic frequency of 400 kHz was about the optimum, offering a practical range of about 150 m, and a total beamwidth of about $1\frac{1}{2}°$, using a transducer small enough to mount in a towed body of reasonable weight, around 80 kg (Fig. 1).

## EQUIPMENT

### *ECHOSOUNDER*

A trial equipment incorporating a commercial pulse height analyser was manufactured and used from "Explorer" in July 1967 and 1968. This proved reasonably successful, and a more compact equipment is now

Contribution given in honour of Gunnar Rollefsen at his 70th birthday.

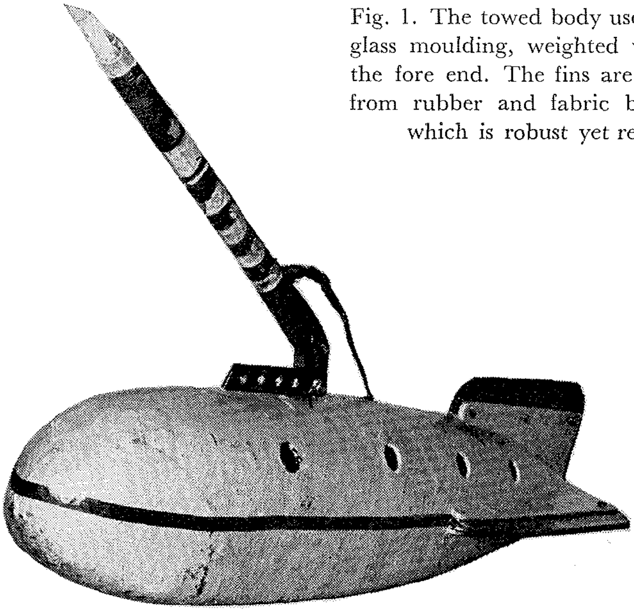

Fig. 1. The towed body used is a fibre-glass moulding, weighted with lead at the fore end. The fins are constructed from rubber and fabric belt material which is robust yet resilient.

under construction, incorporating improved techniques. The principal characteristics of the new echosounder are as follows:

Frequency 400 kHz.

Transducers—circular PZT of 18 cm or 48 $\lambda$ diameter.

Nominal beamwidth 0.011 radians or 0.75° half angle to 3 db point.

Range resolution—better than 15 centimetres, nominal pulse length 100 $\mu$ sec.

T.V.G. as 40 Log R $\times$ 0.18 R (R $=$ range in metres).

Acoustic transmit power about 400 watts. Source level about 138 db ref. 1 $\mu$ bar at 1 metre.

Transducers in a towed body which also houses a preamplifier of 40 db gain.

Very low noise levels; the RMS noise referred to the transducer is about 0.1 $\mu$V.

Effective range for fish counting about 160 metres; for sea-bed echoes about 400 metres.

All timing functions are now controlled by a 100 kHz crystal oscillator. The output of this is divided by a series of 9 decades in integrated circuit form. By conventional use of inverters and gates, output pulses are derived to control transmissions, T.V.G. start and stop, and analyser functions, which will be described later. The 1 kHz decade output is used also to control the motor speed of a precision paper recorder, which acts as a monitor on the correct working of the whole system, and also provides short-term information about targets. The transmission is derived by gating a crystal oscillator to a conventional transistor push–pull output stage.

The receive system consists at present of a preamplifier with a gain of around 40 db feeding an Eddystone radio receiver to which the time-varied gain (T.V.G.) is applied. The intermediate frequency (I.F.) output of the Eddystone receiver at 720 kHz is tailored to suit the pulse analyser, and the audio circuits left feeding a speaker which is quite distinctive in alerting the operator to fish echoes.

The T.V.G. voltage is derived as the sum of two exponential sweeps, the start and rate of both being accurately controllable.

### *PULSE HEIGHT ANALYZER*

The analyser used is a Laben 400 channel machine, slightly modified to suit the particular application. Such analysers are adaptable to many modes of use, but we confine ourselves here to a standard procedure. Analysis begins 10 milliseconds after transmission, and sorts echoes into 20 time intervals each of 10 milliseconds duration. In other words echoes are classified into twenty depth intervals, the first being from 7.5 m to 15 m, and the last being 150 m to 157.5 m.

Echoes falling into each of these time intervals are classified into twenty amplitude channels, each of 80 millivolts amplitude, and a back-bias of 80 millivolts is applied. Thus the first amplitude channel is 80–160 millivolts, and the last amplitude channel is 1.60 to 1.68 volts. By using a logarithmic amplifier these channels can be converted to decibel levels.

At the end of a predetermined period, the analyser feeds the stored data to a teletype machine to provide both a printed record and a punched tape for subsequent computer processing. At the same time, the stored information is erased, so that after print out the sequence can be repeated.

Thus we have the potential, using a standard instrument, to make a detailed analysis of echo information.

In water less than 157 m depth, the sea-bed echo would give rise to spurious counts. Hence it is necessary to eliminate it. This general problem of sea-bed elimination (S.B.E.) was originally dealt with by stopping the analyser 3 milliseconds before the appearance of the sea-bed echo. The timing for this function was derived from the previous sea-bed echo. This is not precise enough to allow demersal fish to be counted, hence an alternative is being adopted. This is the provision of a transmitted pre-pulse at 300 kHz, which can be used in two ways.

(a) The pre-pulse is transmitted 200 $\mu$ seconds in advance of the main transmission. Receipt of the 300 kHz sea-bed echo shuts down the analyser. Thus we have an S.B.E. system allowing fish to be counted to a distance of 20 or 30 cm above the sea-bed.

(b) Where detailed analysis of the depth distribution of demersal fish is required, the pre-pulse can be made to occur 20.2 milliseconds before the main transmission. The 300 kHz sea-bed echo is now used to start the analyser, which then is swept through its time channels in 20 milliseconds instead of its standard 200 milliseconds, thus sampling a 15-metre layer above the sea-bed.

## *GENERATION OF SAMPLING PULSES*

The pulse analyser is designed to deal with pulses of rise times less than 1 microsecond, whereas rise times of fish echoes in this case are of the order of 80 microseconds. The envelope of the echo signal thus has the characteristic of a slowly varying signal so far as the machine is concerned, and in such a case sampling pulses are required to select the instants for amplitude measurement. The principle used for this is illustrated in Fig. 2. If the incoming pulse is differentiated, a zero-crossing

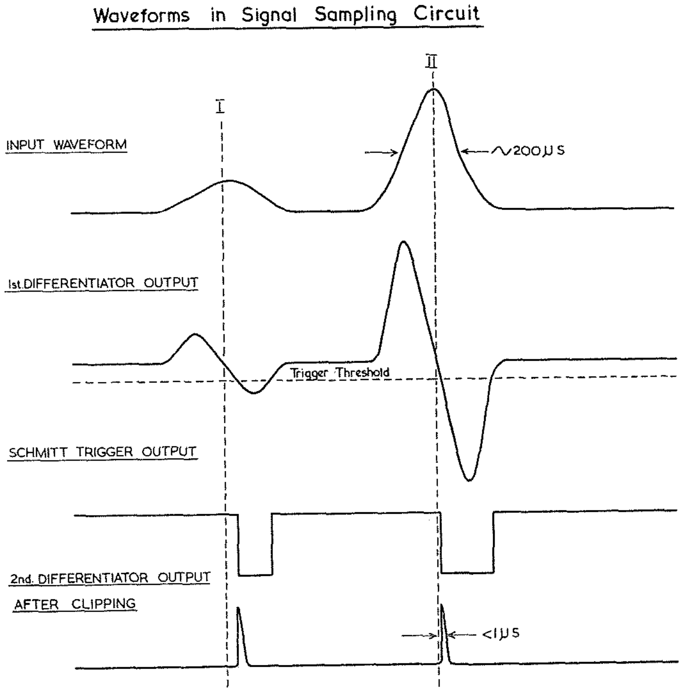

Fig. 2. Waveforms in the signal sampling circuit.

occurs very close in time to the pulse peak. If this differentiated signal is over-amplified to square it, and differentiated again, we can by selecting the appropriate polarity obtain a sampling pulse suitable to trigger the analyser, and occurring at the appropriate instant. The squaring amplifier is in fact a Schmitt trigger, whose threshold is set at a low level to avoid timing errors, as shown in I and II. It is important that this "signal selector" system should be of adequate sensitivity so that it is not itself the limiting factor in echo detection. It is desirable rather that calibrated back-bias control on the analyser should determine the minimum echo height for a count.

### *RECORDING MONITOR*

The working of the analyser produces information pulses when an echo goes into the magnetic core store, and for instance when an echo overflows the top channel. Bearing in mind the original concept, it was desired to ensure that the working of the system could be made obvious and the information displayed immediately in a conventional form. To do this a Mufax paper recorder was employed, the speed being controlled by the same crystal clock as programmed the transmit and analysis cycles. Thus the recorder runs in synchronism with the transmissions in the usual way. It was arranged that storage of an echo by the analyser would generate a 1 millisecond marker pulse, and overflow of the top channel would produce a 7 millisecond marker pulse. Thus fish echoes counted produce small ticks, and the sea-bed echo produces a long mark. If the system is working as intended, a normal-looking recording results which is closely analogous to that of a conventional echo-sounder. It should be noted, however, that the recorder cannot be made to carry as much information as the analyser, as the range resolution on paper cannot be pushed to much less than 1 m. The analyser by contrast gives the full resolution of the acoustic system, its own internal limits in this respect corresponding to a range resolution of about one cm or less.

## ANALYSIS

It is easy to predict the distribution of echo amplitudes from a known distribution of targets, but the inverse process is a little more difficult. In the treatment that follows no attempt is made to sort out all the statistical implications, a task we feel to be more appropriate to a professional mathematician. Thus we attempt here to lay down the problem, and an outline solution in such a way as to stimulate more sophisticated mathematical analysis. It will however be evident that the nature of the directivity function is the determinant of the statistical accuracy attainable. If it were practical to produce a beam of definite angular width, at the edge of which the acoustic energy dropped from a standard value to zero sharply, then very significant results could be obtained even from small numbers of targets. However it will be well enough understood that such a situation can only be approached by the adoption of parameters much more extreme than have been contemplated here, though if a much smaller maximum range were acceptable, as it might be in a plankton counter, one could greatly improve matters in this respect.

The prime assumption made in the present treatment is that the T.V.G. has been so arranged that the echo from a small target is independent of range, i.e. allowance has been made for spreading loss and for attenuation in the medium.

Information is obtained in the form of signal levels. It is based on 20 or 50 minutes' survey, and is printed out and punched on paper tape by the teletype machine.

However the information is wanted in another form, as a distribution of target strengths.

Since the T.V.G. is a full correction, the echo of any target is independent of range. The amplitude depends only on the angular coordinates of the targets.

The essential part of the treatment is to assume some density of fish, and deduce the echo distribution that would result. We then use this to deduce density from echo distribution.

Consider any range slice lying between $R_1$ and $R_2$ in the beam, and let the solid angle be k. The volume in the range slice is

$$\int_{R_1}^{R_2} kR^2 dR = 1/3\, k\,(R_2^3 - R_1^3)$$

Thus if there be $N_1$ targets per cubic metre in this range slice, of target level —40 db, the number contained in the solid angle k is $1/3\, N_1 k(R_2^3 - R_1^3)$.

We now have to consider the directivity pattern of the equipment. This can be obtained theoretically by combining the transmit and receive directivities. Better, it can be obtained by direct field trial at some suitable range, e.g. 100 m. The complete way to show the results is to plot a cross-section of the beam and we may suppose this to have been done. (Fig. 3.) The levels chosen are arbitrary and have been chosen so as to include a suitable gain for our purpose. Since the beam angle is small, the area within a contour measured in $(\text{radian})^2$ corresponds to the solid angle in steradians.

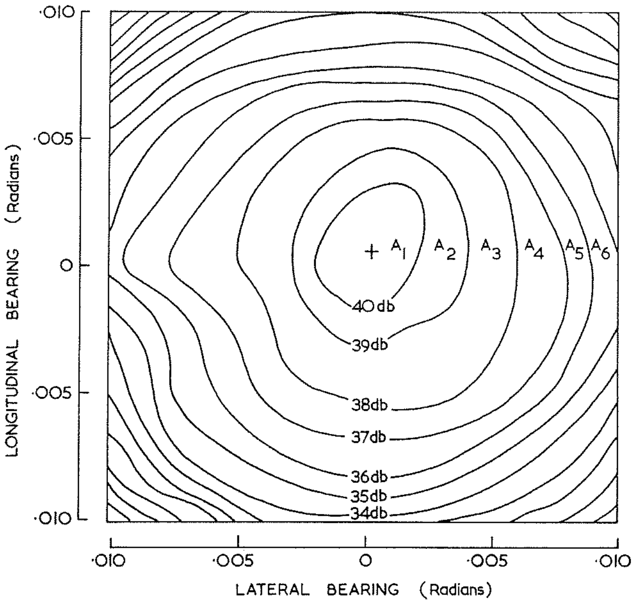

Fig. 3. Cross-section of acoustic beam pattern.

The —40 db targets will be detected only in the centre area $A_1$, and the echoes will be between 0 and 1 db. We call this channel 1. The number of echoes in this class is $N_1 \cdot 1/3\, k(R_2^3 - R_1^3)$ where we now know $k = A_1$.

Now consider there to be $N_2$ targets present of target level —39 db. These will give $N_2 \cdot 1/3\, A_2(R_2^3 - R_1^3)$ echoes in channel 1 plus
$N_2 \cdot 1/3\, A_1(R_2^3 - R_1^3)$ echoes in channel 2
—— and so on.

Suppose an eventual count in this depth slice was $n_1$ echoes in channel 1, $n_2$ in 2, $n_3$ in 3 and so on. Then we see that

$$\left(\frac{3}{(R_2^3 - R_1^3)}\right) . n_1 = A_1N_1 + A_2N_2 + A_3N_3 \ldots + A_{20}N_{20}$$

$$\left(\frac{3}{(R_2^3 - R_1^3)}\right) . n_2 = A_1N_2 + A_2N_3 \ldots + A_{19}N_{20}$$

$$\left(\frac{3}{(R_2^3 - R_1^3)}\right) . n_3 = A_1N_3 \ldots + A_{18}N_{20} \text{ etc.}$$

giving 20 sets of equations.

A general solution can be found in the form

$$\left(\frac{R_2^3 - R_1^3}{3}\right)N_1 = B_1n_1 + B_2n_2 + B_3n_3 \ \ldots \ + B_{20}n_{20}$$

$$\left(\frac{R_2^3 - R_1^3}{3}\right)N_2 = B_1n_2 + B_2n_3 \ \ldots \ + B_{19}n_{20}$$

$$\left(\frac{R_2^3 - R_1^3}{3}\right)N_3 = B_1n_3 \ \ldots \ + B_{18}n_{20} \text{ etc.}$$

where the coefficients $B_1$, $B_2$ . . . $B_{20}$ are dependent only on the acoustic beam shape. A computer can put in the range corrections and print out the desired data in the form of target density as a function of target strength.

The estimate of mean density has finally to be divided by the number of transmissions.

## ACCURACY

In order of importance, the accuracy of the system is dependent on (a) knowledge of the attenuation of sound in sea water, which determines the constants of the time-varied gain; (b) accuracy of determination of the beam pattern. When these are sufficiently known to give confidence, it may be worth introducing a correction for ship speed, which causes the transmit and receive beam patterns to be displaced relatively by a small angle. It must also be accepted that roll or pitching of the towed body, if accurately known, would give rise to calculable corrections.

## PRELIMINARY SURVEY

A preliminary survey was carried out east of the Shetlands during August 1968. As, at this stage, the analyser output was being printed, not punched, a full analysis cannot be presented. However, some indication of the nature of the observations will be helpful. Transmissions were made every two seconds, data were recorded for twenty minutes in every half hour and printed out during the remaining ten minutes. The total number of counts in any half hour period varied enormously, from zero to over one thousand. During preliminary trials the gain was set at a level where very few counts were recorded in the highest amplitude channel, and during the survey only a very few echoes overspilled this level, indicating that the gain setting was about right for the population being sampled. Two samples of Mufax record are shown in Figs. 4 and 5, Fig. 4 showing a large mid-water school with some fish traces near the bottom in 110 m, while Fig. 5 shows a more scattered population.

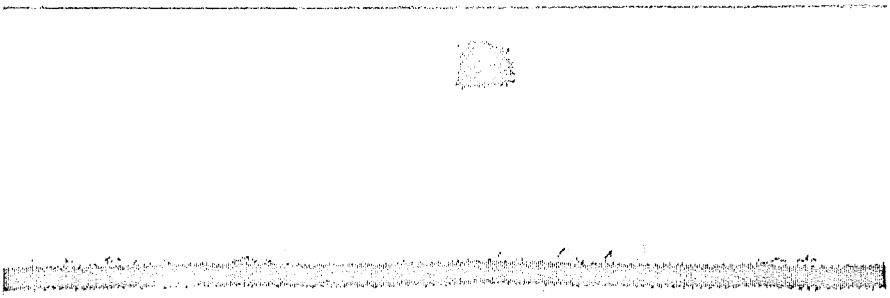

Fig. 4. Sample record from the Mufax precision recorder, used to monitor the system. The record shows a large shoal and demersal fish and covers 2 miles in 110 m depth.

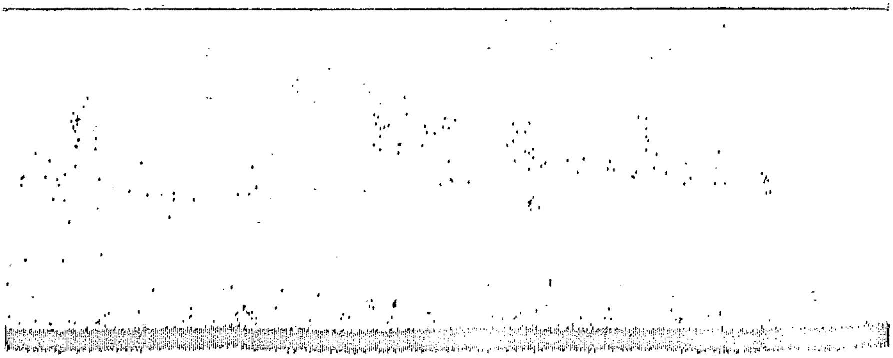

Fig. 5. Sample record from the Mufax precision recorder, used to monitor the system. The record shows scattered fish and covers 2 miles in 130 m depth.

Total counts recorded during a selected 24-hour period amounted to 845 for the region of depth of less than 52.5 m, and 6,561 for the region below 52.5 m. After applying corrections for range, this gave a pelagic fish estimate of 845 per million cubic metres for the upper zone, and 322 per million cubic metres for the deeper region. The selected period involved a north–south steam about fifty miles east of the Shetland Islands. Since paper tape was not in use at that stage, a full analysis cannot be given, nor were the various calibrations sufficiently advanced for this to be offered as a serious fish assessment.

It will be clear that a great deal of work remains to be done, in particular on transducer measurements, and in general on acoustical target strengths of fish. It appears, that the technique can give a great deal more information about pelagic fish populations and distribution than has been hitherto available.

## SUMMARY

The paper described (a) A very high resolution echo-sounder, (b) A method of sorting echoes by amplitude and range, (c) A study of the analysis required to transform from distribution of echoes to distribution of targets.

Under (a) the main parameters were—frequency 400 kHz—range resolution 15 centimetres—beam angle to half-power point 0.011 radians.

The equipment for recording echoes (b) is a pulse height analyser. Echo information is stored in twenty range intervals, each subdivided into 20 categories of amplitude.

It was shown (c) that the process of determining target distribution from echo distribution can be dealt with by computer, and resolves itself into a correction for angular spread of the beam, followed by a transformation to allow for the directivity pattern. This latter transformation is equivalent to solving twenty simultaneous linear equations for each range element. The coefficients of the equations are constants for the equipment, thus the set can be solved once, and the result applied to each successive range element by a simple programme.

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