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MAFF techniques for the acoustic survey of pelagic fish stocks, 1979-82

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The authors:

C R Hood, C.Eng. MIERE MIOA and W L Huggins are Higher Scientific Officers in Research Support Group 2 of the Directorate of Fisheries Research, and are based at the Fisheries Laboratory, Lowestoft.

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1. Introduction

Acoustic surveys are used in various areas of the world to assess both the absolute level and/or the relative changes in fish stocks from year to year. These augment the commercial fishing statistics (catch per unit effort (CPUE)) on fished stocks, and egg and larvae surveys on fished and unfished stocks, which may be used to advise on regulating measures such as total allowable catches (TACs) (Pope, 1982).

Errors in any estimate may arise from a number of causes. There are those which arise from fish behaviour, from the problems of shoal identification and from physical problems of the acoustic equipment. Thus, the reliability of an estimate may be complicated by interspecies mixing and for this reason surveying is sometimes best restricted to spawning or other times of aggregation in regions where there is confidence that the area contains a high concentration of a particular species. While the target identification is recognised as a major source of statistical error in the estimate of stock size by acoustic survey, there is at least the possibility of ensuring that the acoustic equipment is functioning at maximum efficiency so that results from different surveys can be considered to be comparable from the physical performance of the equipment.

Historically, the MAFF Fisheries Laboratory, Lowestoft used a different frequency to most others engaged in acoustic surveys. This arose from the work of Cushing and Richardson (1955), who investigated the acoustic response of cod and herring using an echo-sounder at the specific frequencies of 10, 14 and 30 kHz and recommended 30 kHz as the best frequency for herring detection. Kelvin Hughes (now part of Smiths Industries Ltd.) adopted this as the preferred frequency for their fish detection equipment, which is part of the system listed in Section 2. Simrad has developed equipment at 38 kHz which has become widely used and MAFF has recently changed to this frequency in order to conform with other workers in this field.

This report describes MAFF's 30 kHz equipment which was used prior to 1983 but the basic calibration techniques are still used with the present 38 kHz equipment and the information given will be of use with similar equipment irrespective of echo-sounder frequency.

2. The survey equipment

2.1 General description

This consists of an echo-sounder and calibrated towed transducer, coupled to signal processing electronics and recording instruments. The block schematic diagram in Figure 1 shows the layout of the equipment.

A transmitter in the Kelvin Hughes MS 44 echo-sounder energises a transducer towed alongside the vessel in a streamlined vehicle. The transducer is excited with a 0.5 ms burst of electrical energy at 30 kHz and produces a pulse of acoustic energy which propagates downwards through the water column with a defined beam pattern. A fish (or other acoustic reflector) within the acoustic beam produces an echo, which is received by the transducer and converted into an electrical signal. This signal voltage is then applied to the time varied gain (TVG) amplifier which compensates for the distance between target and transducer so that objects of the same target strength give the same voltage signal. The output signal from the TVG amplifier then goes to the Simrad QM echo-integrator which selects by depth and adds together

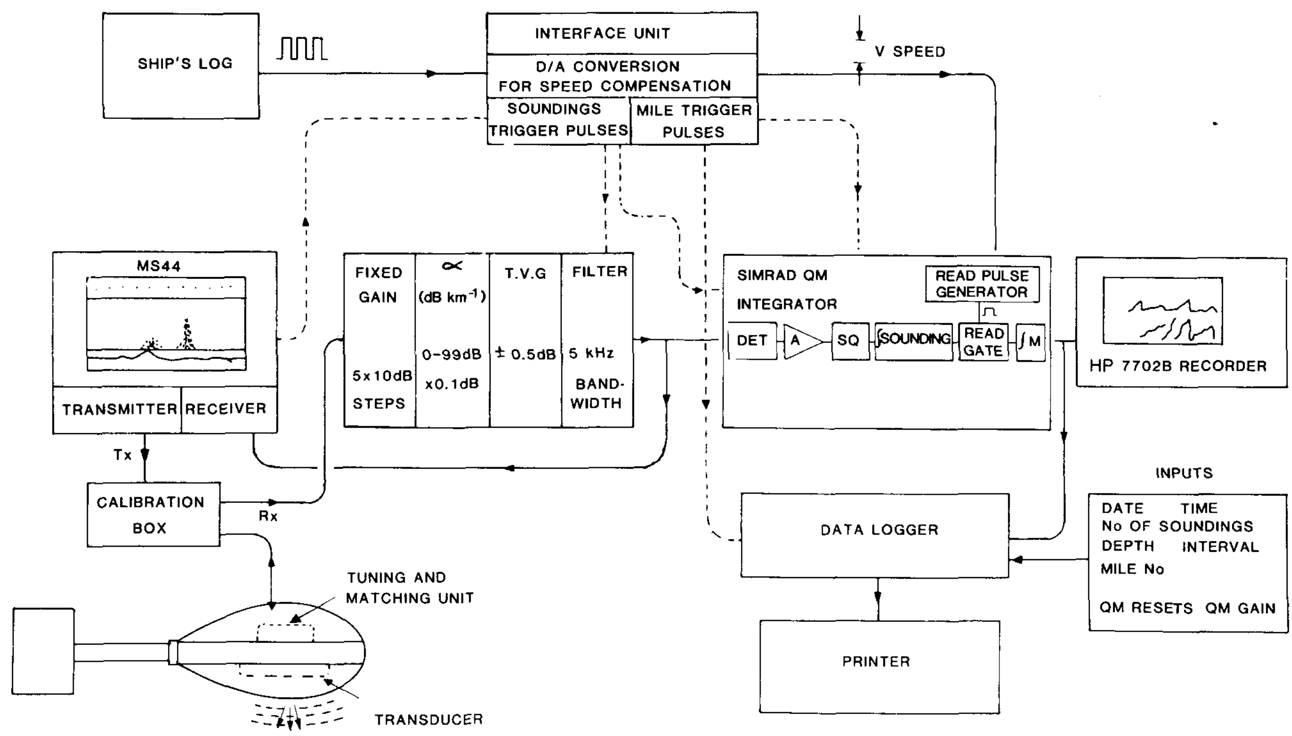

Figure 1 Block schematic diagram of the acoustic survey system.

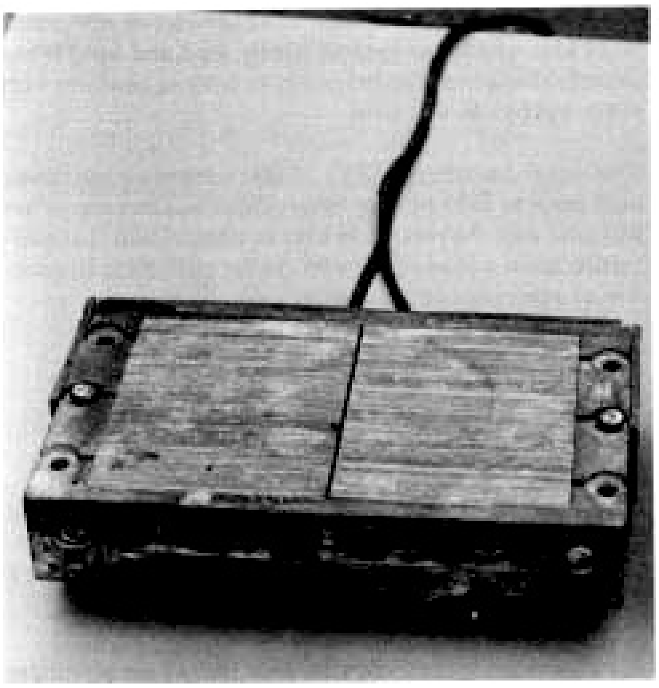

Figure 2 Magnetostrictive transducer. The two transducer sections are each 3λ x 2λ. The nickel alloy laminations and the ends of the exciting coils are clearly visible.

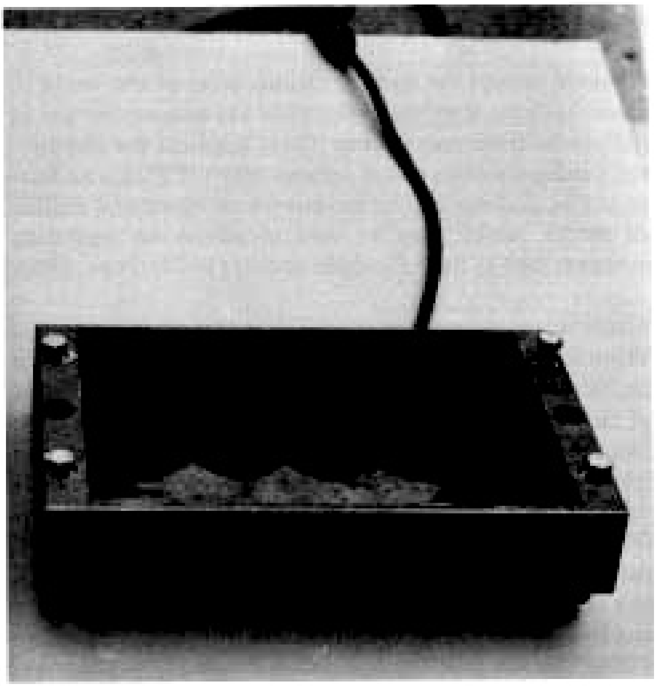

Figure 3 Ceramic transducer. An array of fifteen piston elements can be seen just below the surface of the polyurethane encapsulant.

all the energy of the processed signals received over one nautical mile, the integrated value being displayed continuously by a chart recorder. At the end of each nautical mile, the interface unit directs the data logger to print out the integrated voltages obtained together with other relevant data (depth interval and transmission count): the integrators are then reset to zero and the process repeated. Using species specific target strength (TS) values, this may be converted to biomass which is the weight of living matter per unit area surveyed and expressed in tonnes per square kilometre.

2.2 Essential details of equipment

2.2.1 *Transducers*

Two types of transducer are used, magnetostrictive and ceramic. Both are reciprocal devices in that they can be used for the transmission and reception of acoustic signals.

The magnetostrictive type (Figure 2) is constructed from layers of nickel alloy sheet. The layers are insulated from each other, clamped in a frame, and a coil wound around the limbs of the block of laminations. When a burst of electrical energy (e.g. 30 kHz for 0.5 ms) is applied to the coil windings, the induced magnetic field causes the polarised metal core to change its dimensions and produce a burst of an acoustic energy. This energy is in the form of pressure waves confined to a beam whose shape depends upon the relationship between the physical dimensions of the radiating surface and the acoustic wavelength being radiated. MAFF uses the Kelvin Hughes Humber transducer (6λ x 4λ at 30 kHz) which has an elliptical beam pattern (8.75° x 14.5° at the half power points).

The ceramic transducer (Figure 3) employs the electrostrictive effect and is composed of an array of single elements. Each element is composed of a cylindrical plate of lead zirconate titanate ceramic, sandwiched between metal masses which perform two functions; firstly, to tune the high-frequency ceramic to the required resonant frequency (e.g. 30 kHz) and secondly, to improve the performance of the relatively low efficiency ceramic (50%) to approximately 90%, by matching this to the impedance of the sea water. Acoustic energy is radiated when a change in physical dimension normal to the transducer face (piston) is produced by an electrical impulse applied across the polarised ceramic. The transducer elements are arranged in a pattern to effectively simulate the 6λ x 4λ magnetostrictive survey transducer and the whole is encapsulated in polyurethane rubber.

It is normal to use a towed vehicle to carry the transducer rather than mount it on the hull, since this reduces the effects of the vessel's motion and flow-induced aeration of the water close to the hull. This remote arrangement makes servicing and calibration of the transducer easier.

Maximum power transfer is achieved by electrically matching the transducer to its supply cable and transmitter. The components used for this purpose are fitted into a watertight cylinder fitted to the towed vehicle, electrical connections being made by waterproof connectors on the cable and transducers.

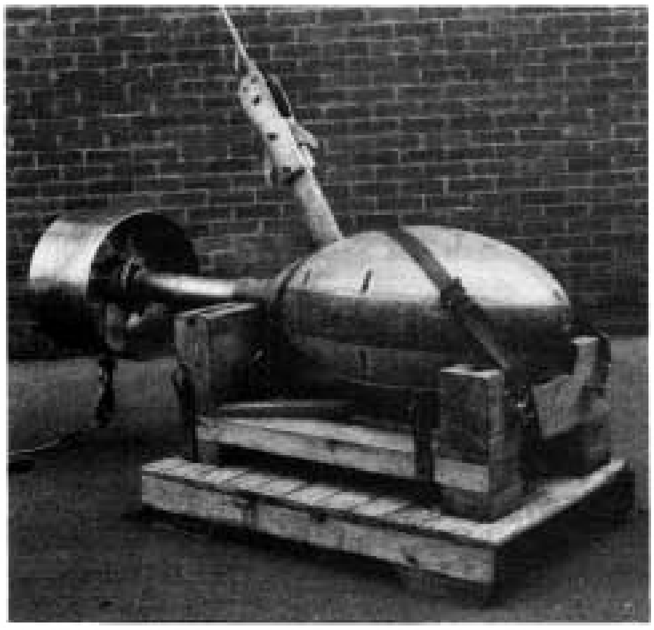

Figure 4 Towed body and cradle. The transducer fitted inside the towed body transmits and receives through an acoustically-transparent window (just visible in the undersurface). A line is attached to the tail as a safety precaution in case the towing cable fails during survey. The cradle is necessary both as protective stowage at sea and as a lifting frame when the body is craned between ship and shore.

2.2.2 *Towed bodies*

The towed bodies are made from a marine quality bronze and stainless steel (Figure 4). The design was adapted from a type used by the Institute of Oceanographic Sciences, Wormley. Streamlining, to improve towing performance by reducing drag and acoustic noise, is achieved by using glass reinforced plastic (GRP) fairings. The lower fairing has an acoustically-clear section beneath the transducer position. The cylindrical tail arrangement helps the body to steer a steady course. It is important for towing stability that this type of body be statically balanced to a horizontal attitude when suspended by the towing arm in air. Two sizes of body are used: the larger is 2.3 m long and weighs 400 kg; the smaller is 1.9 m long and weighs 235 kg. Exact weights vary with the type of transducer fitted and the balancing system used.

2.2.3 *Towing cable*

The towing cable comprises seven electrical cores inside an 11.8 mm diameter contra-laid, non-rotating armour made from either galvanised plough steel (breaking strain 5.6 t) or stainless steel (breaking strain 4.5 t). To enable the body to operate at greater depths, it is necessary to reduce the drag on the towing cable. A smaller towing angle and an acceptable acoustic noise level is then possible. Drag reduction is achieved by streamlining the circular cross-section of the cable using triangular fairing sections. These are made from polyurethane and are attached to the cable with clips (Figure 5). The streamlining effect is such that the hydrodynamic

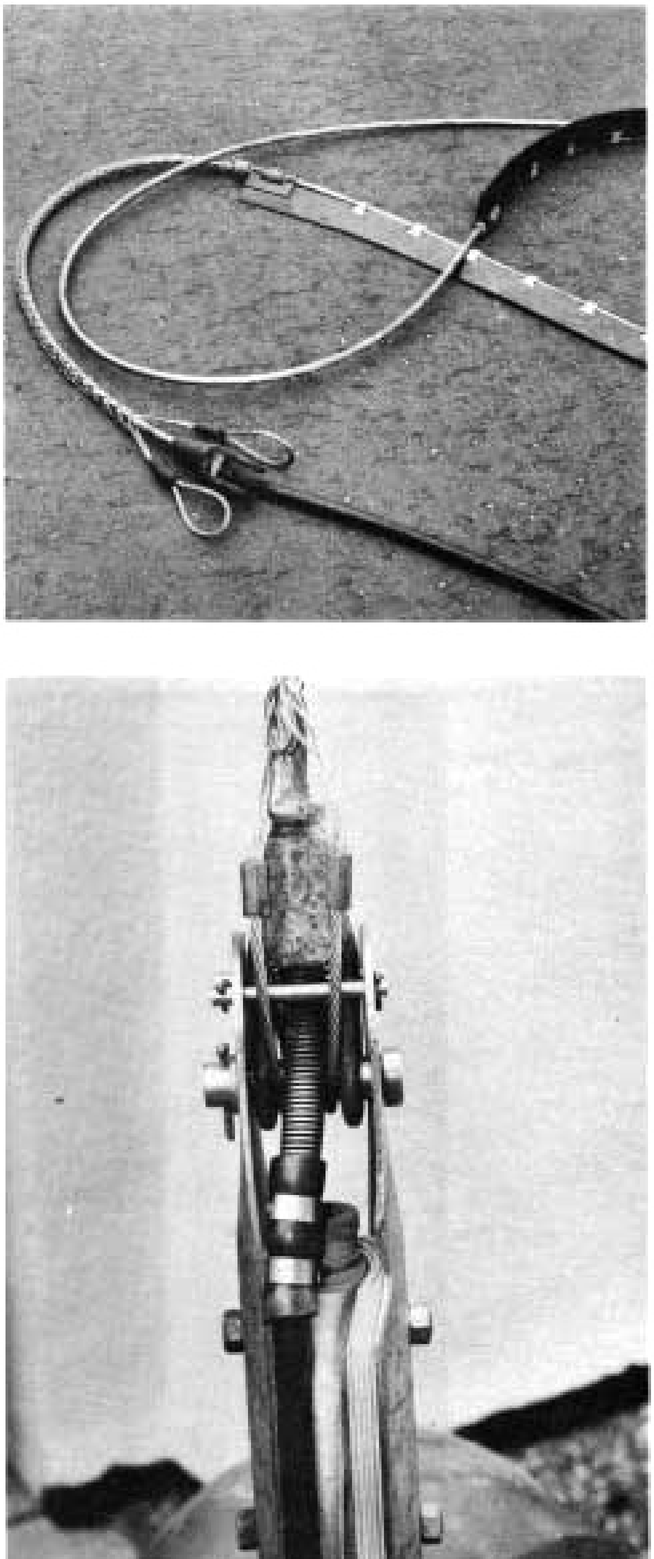

Figure 5 The towing gear. (a) Cable, fairing and termination. The polyurethane fairing swivels on nylon clips, above the stainless-steel mesh safety stocking. (b) The attaching loops and the clevis use the same pin on the towing arm. The clevis is prevented from swivelling and thereby straining the central electrical cores by two additional pins.

drag coefficient is reduced from 1.2 for an unfaired cable to 0.35 for a faired cable.

Attachment of the cable to the pivoted towing arm of the body is by means of a pin and drop-forged socket, in which the cable armour is anchored by an epoxy filler. Magnesium sacrificial anodes are attached to the armour to protect it and the adjacent joint from galvanic action. The shipboard end is attached by a similar drop-forged socket termination for short lengths of tow cable, or wound onto a slip-ring winch drum when long cable lengths are used.

The cable is led over the side (Figure 6) and suspended by a large snatch block fitted with a polyurethane-coated sheave, to take account of the minimum bending radius requirement of the cable and to provide a soft bed for the fairing clips. This snatch block is shackled to a spring accumulator (approximately 16000 N) to cushion the great strain that is placed upon the cable and its towing terminations in rough weather.

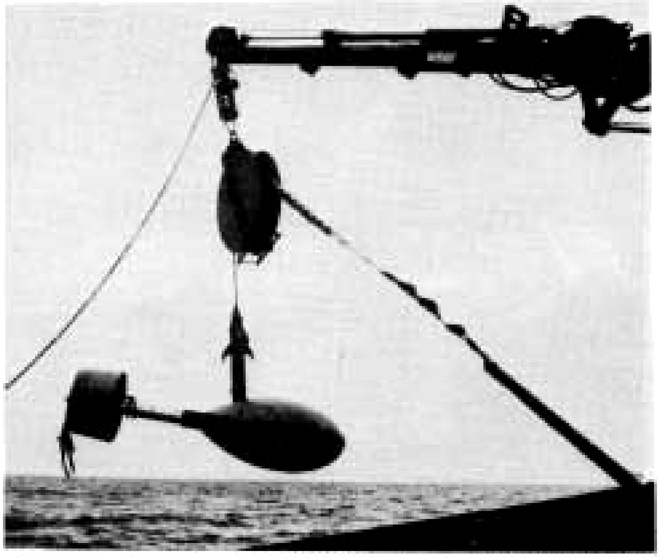

Figure 6 Crane and snatchblocks. The crane is locked into the towing position using a 25 mm steel pin. The large block is suspended by a spring accumulator to minimise damage to the cable, fairing and towing points.

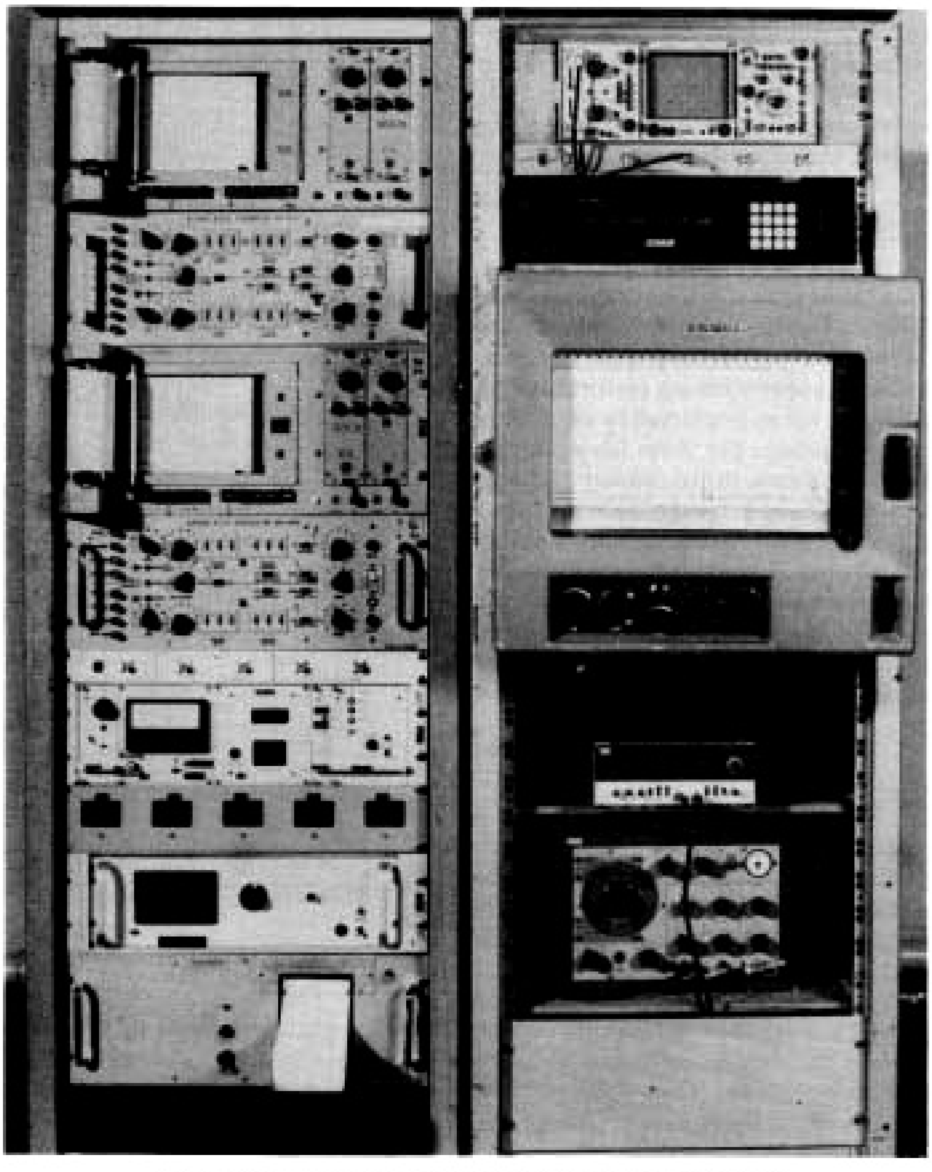

Figure 7 Photograph of the shipboard acoustic equipment.

2.2.4 *Shipboard equipment* (Figure 7)

The MS44 recorder and transmitter These are standard units manufactured by Kelvin Hughes which have been modified to give an improved paper record by displaying range- corrected signals received from the TVG amplifier, and give an undistorted (true sinusoidal) waveform within the transmitted pulse by a modification to the drive circuit of the transmitter.

The Calibration unit performs two functions:

(i) it enables the input or output of calibration signals from the transducer cable; and
(ii) it allows the MS44 to operate either in the 'non-survey mode' (i.e. as a normal echo-sounder using the hull-mounted transducer and internal receiver) or in the 'survey mode' using the towed transducer, TVG amplifier, and paper recorder.

The TVG amplifier, performs three functions:

(i) the amplification of the very small signals from the transducer;
(ii) the compensation for spherical spreading loss using a gain law of 20 logR when measuring fish density on a survey and 40 logR for target strength measurements on single fish;
(iii) the provision of an increase in gain with range to remove the effect due to absorption of energy from the acoustic pressure wave by the medium through which it passes.

The absorption due to a one-way transmission is the product of the attenuation factor α and the range R and is expressed in decibels. For the usual case of two-way transmission (the target acting as an effective source) the compensating gain law is $2\alpha R$. The value of α is a function of the frequency of the acoustic wave and the temperature, salinity and depth of the survey area (see Figure 8 and Table 1a and b). For a given transmitted frequency the effect of a change in temperature is most significant, variations in salinity produce a second order effect only. In the shallow waters of the North Sea, the depth (pressure) effects on α can be ignored (Urick, 1975).

A TVG unit, designed by Hoare (1978) to MAFF specification, incorporates the fundamental laws for the correction of losses due to both range and absorption ($20 \log R + 2 \alpha R$ for biomass estimation, $40 \log R + 2 \alpha R$ for target strength measurement) to an accuracy of $\pm$ 0.5 dB for each of two ranges (short range: 3 m to 150 m, and long range: 12 m to 600 m). The absorption coefficient α can be selected in 0.1 dB steps between zero and 9.9 dB km^{-1} . Six selected preamplifier gains, in increments of 10 dB, are also available.

The Simrad QM echo-integrator The instrument has two integrator channels, each of which independantly stores the energy from the pulses received from the TVG amplifier. The depth at which the integration process starts and finishes can be preset for each channel and is displayed on the echo-

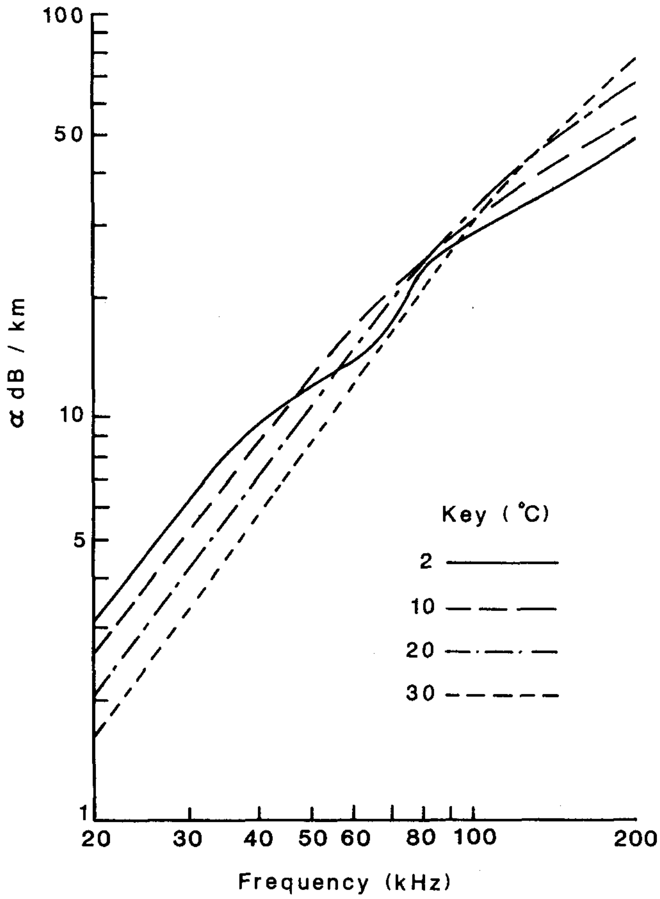

Figure 8 Acoustic wave absorption versus frequency at a salinity of 35 (‰). The change in absorption has been calculated for four temperatures using an equation by Fisher and Simmonds (Mitson, 1983).

sounder paper record. The function of each integrator channel is to detect, amplify, select, square (for proportionality to fish density) and then integrate the signals. The total value of the integrated signals, when summed in the mile integrator, depends on the number of soundings made on the biomass during each mile of survey, but since the sounding rate is fixed the mile integrator output is directly related to variations in ship's speed. This is compensated by converting the digital pulses derived from the ship's speed indicator into an analogue voltage which is directly proportional to ship's speed and is used to automatically control the integration time per sounding (duration of READ pulse). The corrected output is recorded on the Hewlett Packard 7702B paper recorder.

The LOG interface unit synchronises the various parts of the system and provides:

(i) a trigger pulse to the TVG amplifier and QM echo-integrator at each transmission;
(ii) trigger pulses to the QM echo-integrator and the data logger at the end of each nautical mile; and
(iii) a DC voltage proportional to the ship's speed to satisfy the input requirement of the QM echo-integrator 'READ' circuit.

Table 1(a) Sea water acoustic absorption coefficient (dB/km) at 29.3 kHz; depth = 5m. (from Fisher and Simmonds, 1977)

	Salinity (ppt)				
Temp	33.5	34.0	34.5	35.0	35.5
2.0	5.72	5.79	5.87	5.95	6.03
3.0	5.61	5.69	5.77	5.85	5.92
4.0	5.51	5.58	5.66	5.74	5.81
5.0	5.40	5.48	5.55	5.63	5.70
6.0	5.29	5.37	5.44	5.51	5.59
7.0	5.18	5.26	5.33	5.40	5.47
8.0	5.07	5.14	5.21	5.29	5.36
9.0	4.96	5.03	5.10	5.17	5.24
10.0	4.85	4.92	4.99	5.06	5.12
11.0	4.74	4.81	4.88	4.94	5.01
12.0	4.64	4.70	4.76	4.83	4.89
13.0	4.53	4.59	4.65	4.72	4.78
14.0	4.42	4.48	4.54	4.61	4.67
15.0	4.32	4.38	4.44	4.50	4.56
16.0	4.21	4.27	4.33	4.39	4.45
17.0	4.11	4.17	4.23	4.28	4.34
18.0	4.01	4.07	4.12	4.18	4.23
19.0	3.91	3.97	4.02	4.08	4.13
20.0	3.82	3.87	3.92	3.98	4.03
21.0	3.72	3.78	3.83	3.88	3.93
22.0	3.63	3.68	3.73	3.78	3.83
23.0	3.54	3.59	3.64	3.69	3.74
24.0	3.46	3.50	3.55	3.60	3.65
25.0	3.37	3.42	3.47	3.51	3.56

Table 1(b) Sea water acoustic absorption coefficient (dB/km) at 38.0 kHz; depth = 5m. (from Fisher and Simmonds, 1977)

	Salinity (ppt)				
Temp	33.5	34.0	34.5	35.0	35.5
2.0	8.66	8.77	8.89	9.01	9.13
3.0	8.56	8.68	8.79	8.91	9.03
4.0	8.45	8.57	8.69	8.80	8.92
5.0	8.34	8.46	8.57	8.69	8.80
6.0	8.22	8.33	8.45	8.56	8.67
7.0	8.09	8.21	8.32	8.43	8.54
8.0	7.96	8.07	8.18	8.29	8.40
9.0	7.83	7.94	8.04	8.15	8.26
10.0	7.69	7.80	7.90	8.01	8.11
11.0	7.55	7.65	7.76	7.86	7.97
12.0	7.40	7.51	7.61	7.71	7.81
13.0	7.26	7.36	7.46	7.56	7.66
14.0	7.11	7.21	7.31	7.41	7.51
15.0	6.97	7.06	7.16	7.26	7.35
16.0	6.82	6.92	7.01	7.10	7.20
17.0	6.68	6.77	6.86	6.95	7.05
18.0	6.53	6.62	6.71	6.80	6.89
19.0	6.39	6.48	6.57	6.66	6.74
20.0	6.25	6.34	6.42	6.51	6.59
21.0	6.11	6.19	6.28	6.36	6.45
22.0	5.97	6.06	6.14	6.22	6.30
23.0	5.84	5.92	6.00	6.08	6.16
24.0	5.71	5.78	5.86	5.94	6.02
25.0	5.58	5.65	5.73	5.81	5.88

The data logger and printer The 16-channel data logger and printer stores and records the echo-integrator output voltages, cruise information (time, date, etc.) and survey parameters (gate and gain settings, etc.). The information is printed out at the end of each nautical mile of the survey.

3. Practical survey techniques

3.1 Towed body launch and recovery

The towed body (Figure 9) is attached to the towing cable by the forged steel clevis and stainless-steel pin inserted into the towing arm and then secured by a split pin. A secondary attachment is used as a precaution against the loss of the body due to a break in the cable armour from rust or failure of the epoxy joint and comprises a stainless-steel mesh, tapered stocking fitted over the towing cable which, when a pull is applied, contracts and grips the cable armour. A magnesium sacrificial anode (necessary with the galvanised steel armoured cable) can conveniently be inserted between the stocking and armour.

An additional precaution against loss is a stainless-steel safety wire shackled to the body's tail, led aft and securely fixed. This wire must be slack enough not to influence the attitude of the body whilst under tow and yet be able to sustain the shock of its weight if the main cable parts.

The towed body is launched and recovered using its own towing cable, provided that a winch with sliprings is available, otherwise a short cable of fixed length is used. A separate wire rope with attached lifting eyes is used for launching, and recovery is by lowering a ring (already threaded onto the towing cable) until it engages one of the recovery hooks (Figure 10).

Launching on the towing cable requires the cable winch operator and crane operator to work together to lift and swing the body over the side. If the shortening/lengthening of cable due to traversing movements or alteration of jib angles are not correctly followed and compensated, the body may hit the ship's rail and suffer damage to its fairing. For towing without the aid of a slip ring cable winch, a short, fixed length of cable is prepared using another socket termination at the shipboard end. The required length is determined from a knowledge of the run of cable, towing depth and position of the fixing point.

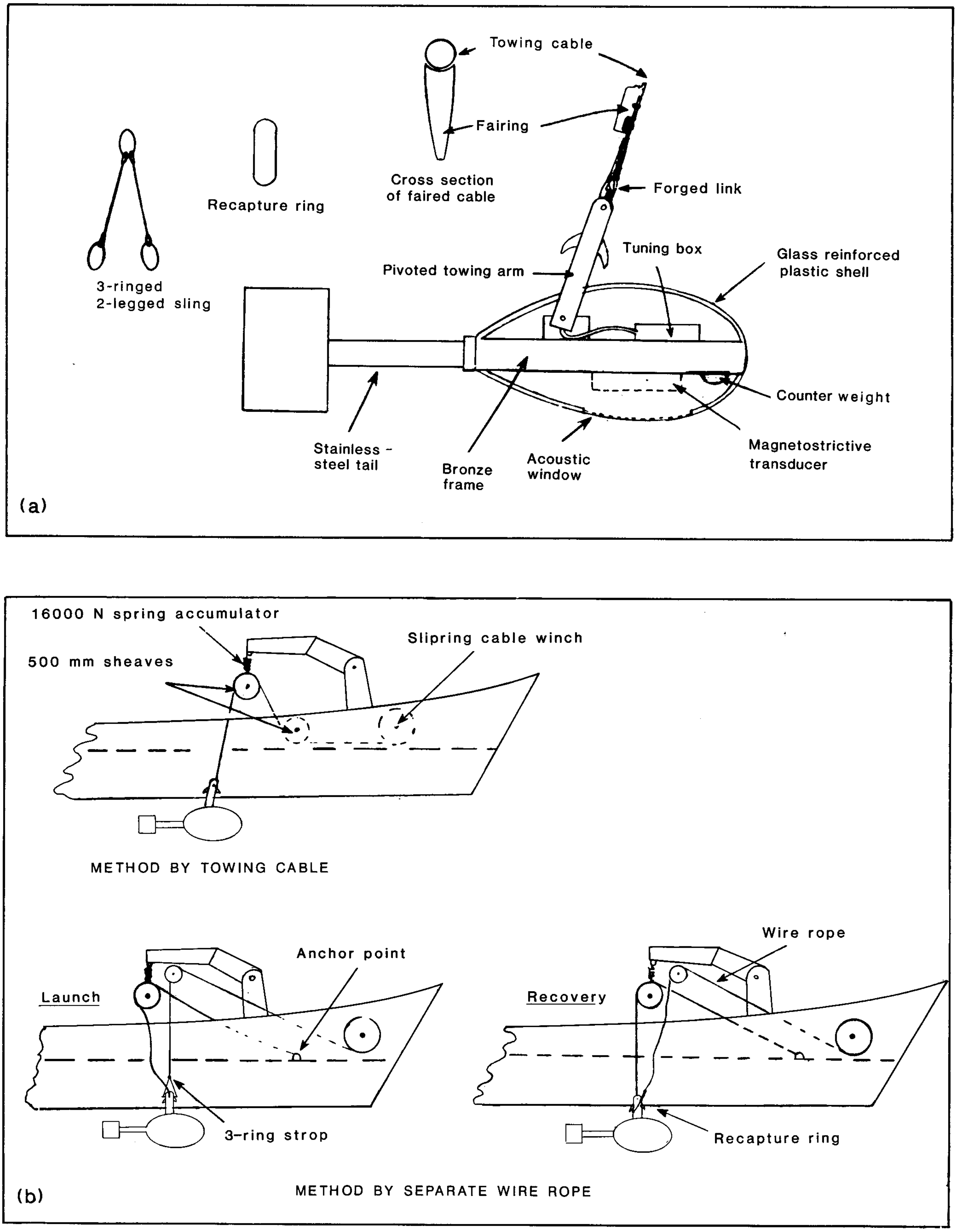

Figure 9 Towed body launch and recovery system: (a) shows the various components of the towed transducer system; (b) shows the two methods of launch and recovery described in the text.

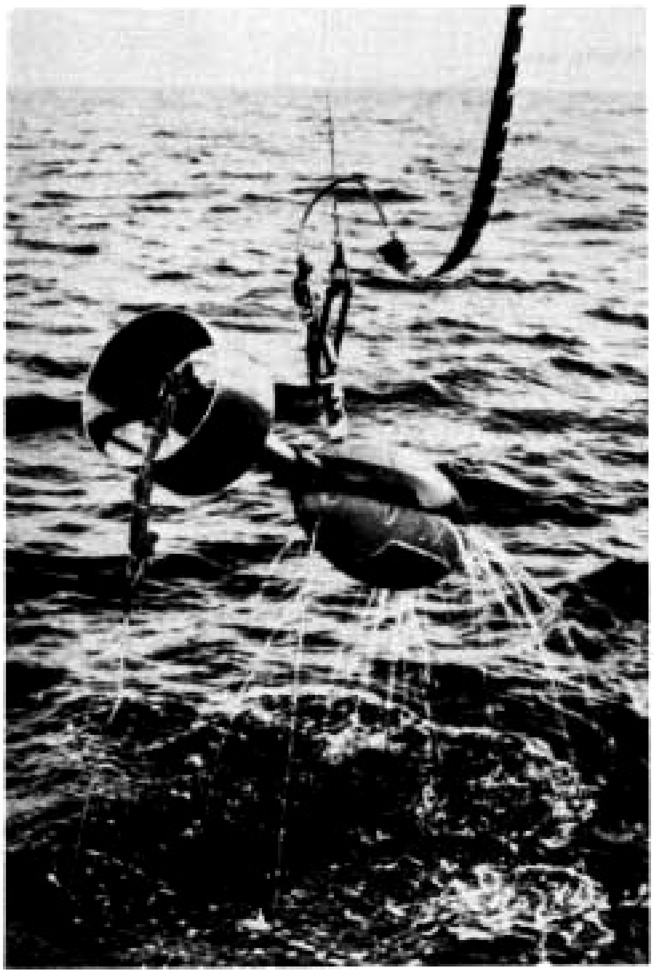

Figure 10 Towed body and towing cable. The towed body is being recovered on a separate wire rope.

The body is lifted from its deck cradle by the crane to just above the ship's rail with the three-ringed, two-legged sling hooked over the two spurs of the towing arm. When the vessel is stopped or just underway, (depending on sea conditions) the crane jib-end is positioned outboard so that the side of the body will just touch the vessel's side. It is swiftly lowered into the water where any swinging induced by ship's roll is quickly damped and damage to the body fairings and transducer prevented. Once the body is lowered to the correct towing depth, and the crane jib swung fully outboard to keep the body away from the vessel, the towing cable becomes taut and the three-ringed, two-legged sling should fall away from the towing arm leaving the body ready for towing.

To recover the towed body the vessel is slowed to minimum steerage way. The recovery ring (already threaded over the towing cable) is removed from its rope and shackled to the recovery wire of the crane, and the wire slackened allowing the link to slide down the towing cable. By keeping forward of the towing cable, the operator endeavours to catch one of the spurs or hooks on the towing arm, preferably the rear-most one. When this is achieved, the recovery winch can take the load from the towing cable and hoist the body up and over the rail using the traverse facility of the crane. The body must not be hoisted higher than necessary since the increased manoeuvring time increases the danger from large amplitude swings on lowering. Care must be taken not to allow the fragile GRP fairing to hit the rail. Finally, the body should be carefully lowered into the deck cradle and secured.

If the vessel has no crane a strong boom (suitably guyed) may be used to hold the body out and away from the ship's side. Shooting and hauling can be effected by an auxilliary wire and whipping drum.

3.2 Cable length, towing angle and depth

Towing angle is dependent upon the size, weight and towing depth of the towed body, the speed of the vessel, the type of cable and amount of fairing used. The depth at which the body tows is usually set clear of the turbulent water flow around the vessel, out of the region where echoes might be received by side lobes of the transducer. The body should also be deep enough to avoid the region of aeration often found near the sea surface.

The following are examples of body and cable towing performance:

> On cruise CORELLA 11/80, the large body was towed at a depth of about 7 m with the towing cable approximately 15° from the vertical, whilst on CLIONE 11/82, using a smaller body, the towing depth was about 7 m and the cable angle approximately 30°. Figure 11 shows the typical variation in towing cable angle against speed for two sizes of towed body. This variation should be taken into account when specifying cable length and towing point. Figure 12 illustrates (in the case of R.V. CORELLA) the effects caused by an ill-chosen cable length and poor towing position.
>
> Curves (a) and (b) relate the noise received by the transducer to the ship's speed. The two noise components of the received signals are due to noise generated by flow over the ship's hull and propeller-generated noise. The latter increases rapidly because the propeller (variable pitch in a Kort nozzle), in addition to becoming noisier as its angle of pitch increase, causes the transducer to swing further aft and assume a position closer to the propeller. The Kort nozzle is a tube surrounding the propeller to increase its efficiency. Therefore, the noise is concentrated just before and just after the nozzle.
>
> Noise curve (a) was the result of the body being towed at a depth of 4 m in the ship's wash which resulted in it becoming unstable and yawing continually. Noise curve (b) was the result of lowering the body until it was stable, at a depth of 7 m, well below the ship's wash. Propeller noise was more pronounced since the body was not only deeper but could also swing further aft. The position at which the propeller noise becomes masked by the Kort nozzle and ship's hull is indicated by the abrupt change in the gradient of this curve.

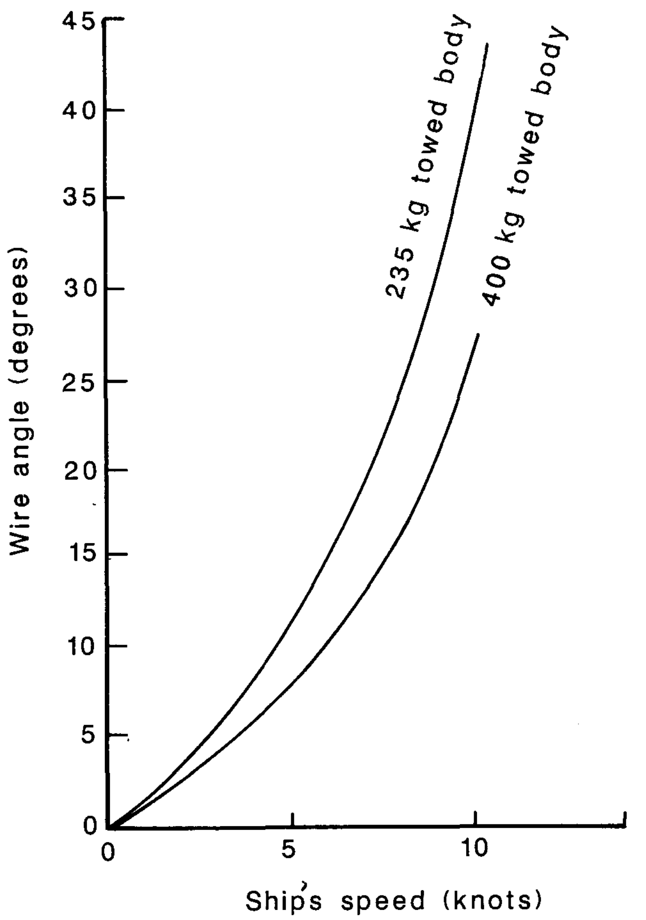

Figure 11 Towing cable angle versus towing speed. The effect of drag on towing cable angle for two weights of towed body (235 kg and 400 kg) can be seen.

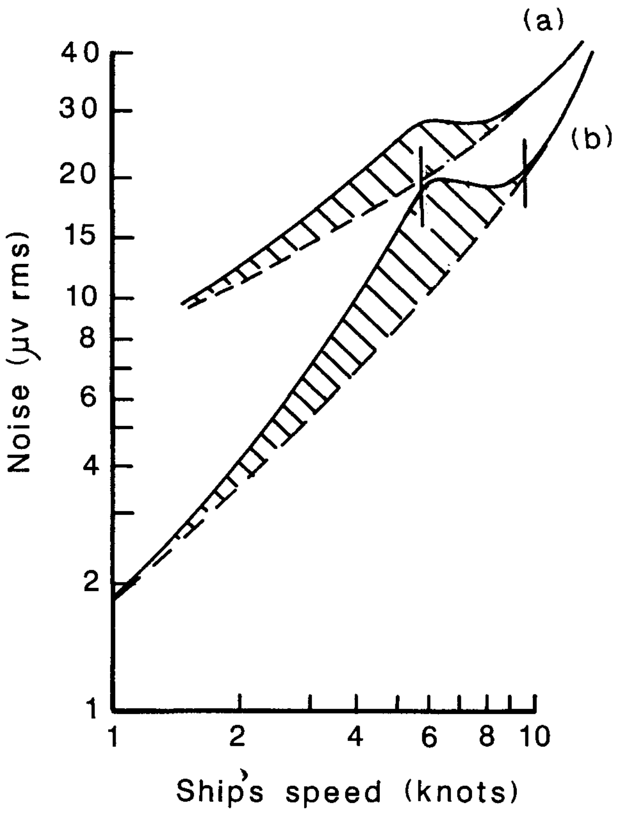

Figure 12 Transducer noise versus towing speed: (a) at 4 m depth in ship's wash; (b) at 7 m depth below ship's wash. The increase in noise is caused not only by the increase in water flow with speed but by the depth and position of the towed body. The shaded portion is thought to be due to propeller noise; the dotted line is the estimated graph of flow induced noise.

In normal circumstances the towed body is kept well away from the ship's stern but, in this case (1979), it was not practical to do so. Later, a hydraulic towing crane, located further forward, and a cable winch, allowing better depth control, eliminated many of the problems described above. However, this example demonstrates the importance of the towing point and the length of cable on the relative position of the transducer and the propeller. In addition, it is important to ensure that the propeller does not generate excessive noise at the survey frequency, and that the equipment has a receiver with a narrow band input filter, to allow detection of genuine acoustic targets against a background of wide band acoustic noise.

3.3 Weather eriects

3.3.1 *Aeration*

Wind-induced bubbles in the upper layers of the sea can cause attenuation of acoustic waves. Investigations have been made by Novarini and Bruno (1982) on the influence that such an attenuation may have on echo-integration surveys; a 30 kHz transducer towed at a depth of 4 m can be subjected to a vertical attenuation of 0.5 dB, due to a 25 knot surface wind. Lowering the transducer to 6 m reduces this attenuation to less than 0.1 dB.

In worsening weather, the echo records must be regularly examined for evidence of aeration indicated either by 'dark patches' on the echo-sounder traces or by an increasing background level on the integrator output. Once aeration is apparent, the survey speed should be decreased to control the formation of hull-induced bubbles (produced mainly from pitch-induced bow waves) and the transducer lowered as far as practical (for deep fish the transducer depth may need to be as great as 10 m). If the transducer must be close to the surface for survey reasons, the accuracy of the biomass estimate may need to be regarded as being of an indicative nature.

3.3.2 *Towed body stability*

The transducer towing point is high, amidships and well outboard to aid towed body launch and recovery and to be clear of the effects of the ship's bow wave and slipstream turbulence. Consequently, the towing point is subjected to a magnified amount of ship's motion. However, this motion is dampened by a spring accumulator at the towing point and by the streamlined towing cable which is kept under tension by the weight of the hydrodynamically-stable towed body. Tests have shown that the motion of the towed body is considerably less than that of the ship, even when the body is subjected to the extra stress of a change in course, or the severe rolling motion incurred by the ship in a beam sea; a maximum angular motion of only 2.7° was recorded by pitch-and-roll sensors mounted in the towed body.

3.3.3 *Survey speed*

In good weather survey speed is limited only by noise picked up from the ship, the flow noise and the towing performance of the towed body for as long as the ship remains reasonably stable. However, MAFF surveys operate at speed of 8 knots which gives the best compromise with present vessels and towed bodies without reducing the efficiency of detection of small fish. In worsening weather, the survey speed has to be reduced, not only because of aeration effects (Sub-section 3.3.1) but also because of movement in the form of 'heave' (vertical motion) and 'slamming' (sudden shock vibration caused by wave action) produces high intensity random noise pulses which obliterate all other targets.

3.3.4 *Simrad QM echo-integrator depth/interval selection*

The selection of the 'depth' and 'depth interval' for integration is largely dependent on the prevailing weather conditions and, hence, the ideal gate selection to cover the aim of the survey cannot always be achieved in poor weather. As stated previously, winds in excess of 25 knots with accompanying sea conditions can reduce the usable water column by several metres near the surface. Also if 'heave' greatly affects the effective depth of the sea bed from transmission to transmission, the depth interval may need to be preset to stop at a point further from the sea bed than desired. When this occurs, or once the interval cannot encompass the required fish depth, the survey is not possible.

3.4 Amplifier and integration gain selection

3.4.1 *TVG amplifier gain adjustment*

Since the TVG amplifier can 'saturate' and, therefore, give an erroneous output, the fixed gain control must be set to cope with the largest input signals expected. The gain level is selected by the engineer who monitors the output throughout the survey. Once signals are seen to reach half the saturation level, the fixed gain is reduced by one step (approximately 10 dB). If signals do reach saturation level, the procedure outlined in Sub-section 9.2.3 of Johannesson and Mitson (1983) should be implemented.

3.4.2 *Simrad QM echo-integrator gain selection*

The gain level on each integration channel is normally selected so that the total channels cover the complete range of echo amplitudes expected during the survey. The output from the highest gain channel which does not saturate would normally be taken as correct. There is always a background noise level which is normally removed statistically during the data analysis. However, in poor weather the background noise can become excessive and mask valuable data and so render the collection of further survey data impossible.

4. Tuning and calibration

Before any calibration is done, the towed transducer and cable must be tuned to the transducer resonant frequency and then matched to the transmitter output impedance. Final tuning of the transmitter ensures that the voltage and current waveforms are in phase. However, although calibrated separately, these three units must be interconnected, since each is electrically interactive, i.e. the transducer must be in the towed body and submerged when calibrating the TVG amplifier, and the TVG amplifier must be switched on when calibrating the transducer.

The survey equipment can then be calibrated as three distinct units:

(a) transducer, towed body, towing cable and transmitter;
(b) TVG;
(c) QM echo-integrator.

4.1 Tuning the transducer and cable

For the two types of transducer used on surveys (i.e. magnetostrictive and ceramic) the tuning method is basically the same, the aim being to tune out the reactive component of the transducer and to match the transducer impedance at resonance to the towing cable impedance.

In the magnetostrictive case (Figure 13) this is achieved by a capacitor (C_T) and transformer (T_M), and in the ceramic case (Figure 14) by a combined inductor (L_T) and transformer (T_T). In both cases the inductance of the towing cable is tuned by a series capacitor (C_S).

Initially, the impedance is measured with the transducer in water and connected by a short length of low inductance test cable to an impedance analyser. The resonant frequency and impedance are measured and, by calculation and experimental checks, the reactive component is tuned out and the resistance transformed to that of the towing cable. The towing cable is then connected between the matching transformer and the impedance analyser and its reactive component tuned out using a capacitor.

The next stage is to connect the towing cable to the transmitter output terminals and, after tuning the output stage to the resonant frequency of the transducer, to measure the voltage and current waveforms and examine their phase relationship. Precision in this procedure is of prime importance to system performance. The transducer characteristics, both as a transmitter and receiver, change rapidly either side of

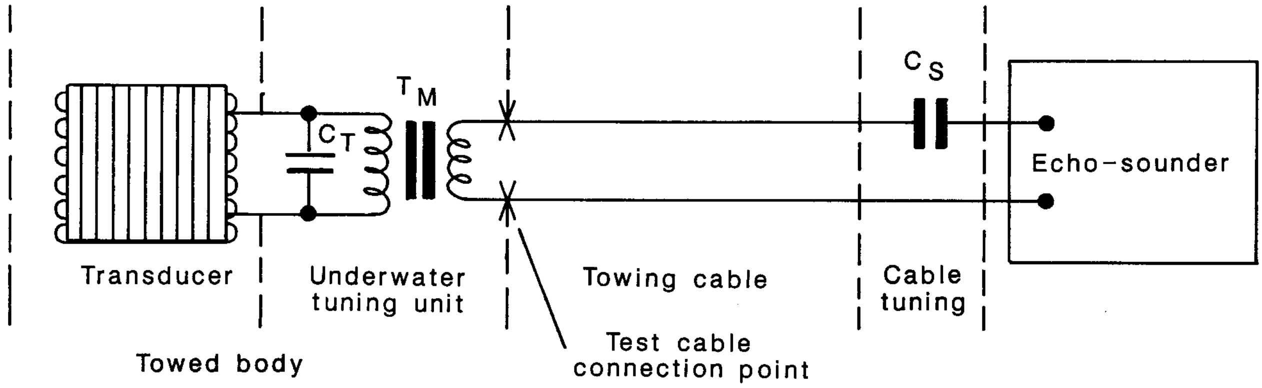

Figure 13 Magnetostrictive transducer tuning/matching. The inductive component of this transducer is tuned out using a parallel capacitor and the impedance matched to the cable using a transformer.

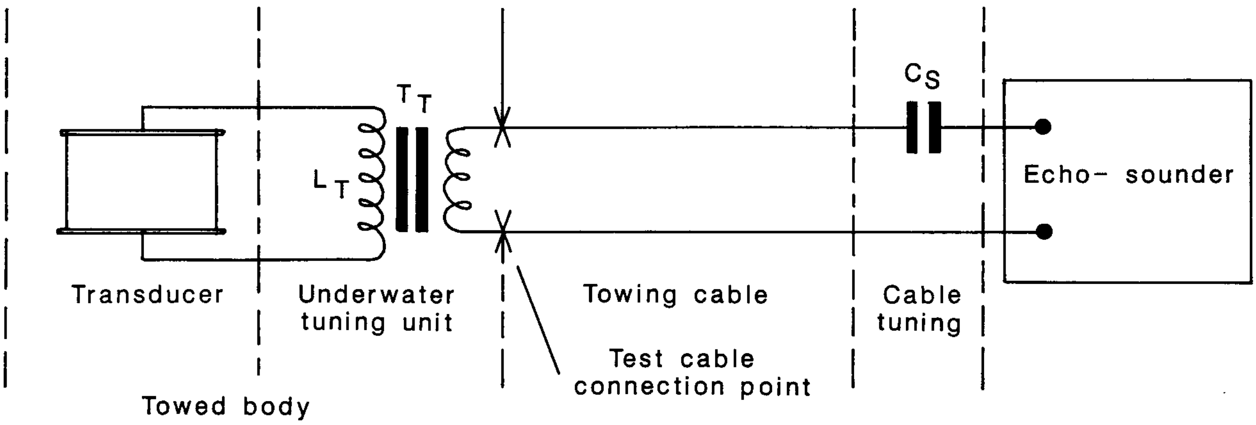

Figure 14 Ceramic transducer tuning/matching. The capacitive component of this transducer and the necessary impedance matching to the towing cable are achieved by using a transformer.

resonance and only a 2% change in transmitter frequency can affect the results from a survey by more than 25%. As the initial tuning has to be made at low power, since high-powered bench test equipment is not available, there may be a need to adjust the cable tuning for zero phase change. After retuning, the power is measured at both ends of the towing cable and the cable power loss determined. Finally, the short length of non-inductive test cable is removed and the power input checked before the start of acoustic calibration.

4.2 Calibration

The technical procedures needed to carry out the calibration of the three component units of the system are detailed in Appendices 1-4.

4.2.1 *Transmitter, towed body, towing cable and transducer*

This part of the calibration procedure involves measuring the acoustic performance parameters (SL + SRT) of the four parts above as one unit; where SL is the source level (a measure of the acoustic power transmitted by the transducer) and SRT is the sensitivity of the transducer as a receiver of acoustic signals. These can be determined in two ways. (The techniques are described in detail in Appendix 1)

Hydrophone method Robinson and Hood (1982) have described a procedure for calibrating the towing cable and transducer. This technique relies on the accurate alignment and precise range measurement between the transducer, test hydrophone and projector in 'free field' conditions. The transducer beam pattern is measured at this time and its equivalent beam angle (see Section 5) is estimated, since it is important to determine the influence of the towed body housing on the transducer performance.

Standard target method The echo received from a tungsten carbide sphere of precisely known target strength is measured. This enables the performance of the equipment to be calculated independently of a test projector or hydrophone. Provided that the sphere can be aligned accurately on the axis of the transducer beam, this method has the advantage of having fewer sources of error. This is because only the voltage generated by the returned echo from the sphere (VRT) involves an acoustic path and is therefore less precise (there are 3 such acoustic paths in the hydrophone method). The parameters of temperature and salinity can be measured precisely; they are necessary to determine TS and also the absorption coefficient (α). The amplifier gain (X), and the distance from the transducer face to the standard target (R) can also be measured precisely.

4.2.2 *The TVG amplifier*

The gain of the TVG amplifier can be controlled by a microprocessor to conform with one of two target situations, namely:

(a) biomass estimation,

$$\text{gain} = (20 \log R + 2 \alpha R) \pm 0.5 \text{ dB} \quad \text{............(1)}$$

(b) target strength measurement,

$$\text{gain} = (40 \log R + 2 \alpha R) \pm 0.5 \text{ dB.} \quad \text{............(2)}$$

The aim of the calibration is to measure the conformity of the TVG amplifier with equations (1) and (2) above. At each of a series of range steps, the departure of the measured gain from the theoretical gain is determined and used as a correction factor in the biomass equation (see Section 5). The procedure is detailed in Appendix 2 and is repeated for all the fixed gain steps (-10, 0, and +10 dB) which may be required during the survey.

4.2.3 *Simrad QM echo-integrator*

This is calibrated by an internally-generated test signal. The integrator output voltage has a value determined by the setting of the gain, depth, interval, ship's speed and number of trigger pulses.

A correction factor is determined by the difference between the measured and theoretical integrator output voltage (see Appendix 3 for details). The QM can also be calibrated with the TVG amplifier in a combined calibration (described in Appendix 4). A detailed description of the QM setting up procedure can be found in the Simrad QM manual.

5. Biomass assessment

5.1 Calculation

Biomass is defined as the weight of living matter (fish) in the survey area and expressed as weight per unit volume or area. It is determined from the integrated echoes recorded during each nautical mile of survey.

The integrator output (V_o) is proportional to fish signal intensity which itself is proportional to fish density. Thus, when V_o is multiplied by an expression derived from electrical and acoustic calibrations of the echo-survey equipment and a knowledge of the species and size of fish, hence target strength, the biomass may be calculated. For convenience, the expression for biomass is separated into a number of parameters as follows:

biomass =

$$V_o \, 10^\wedge \, [(G-(A+B+C+D+E+F))/10] \text{ kg m}^{-2} \text{......(3)}$$

or (converted to t km^{-2})

biomass =

$$V_o \, 10^\wedge \, [(30+G-(A+B+C+D+E+F))/10] \text{ t km}^{-2} \text{...(4)}$$

where

V_o is the integrator output (volts),

30 is the constant converting kg m^{-2} to t km^{-2},

A is the target strength of the fish being surveyed (dB kg^{-1}, dependent on the species and the length distribution determined during the cruise from trawl sampling),

B is the SL + SRT parameter (dB),

C is the mean fixed or static gain of the system (dB, comprises the TVG mean fixed gain and the QM gain including error correction),

D is the equivalent ideal beam angle of the transducer (dB),

E is the duration of the transmission pulse (dB),

F is the pulse repetition frequency (dB),

G is the integrator correction factor (dB). This factor compensates the effect of the integrator system internal time constants on the integrator gain. The input signals are assumed to be undistorted square waves, and the integrator output (V_o) is assumed to be the exact integral of the square of the input voltage:

that is,

$$V_o = \int_o^{t_s} (V_i)^2 \, dt \quad \text{........(5)}$$

where

V_o = output voltage,

V_i = input voltage,

t_s = duration.

However, the gain of the QM echo-integrator is effectively reduced, since the pulse shape of the echo is distorted by the following three system constants (see Appendix 3):

(a) sounding integrator time constant (0.114 s);
(b) mile integrator time constant (0.396 s);
(c) 'read pulse' factor (3.5×10^{-3} per knot or nautical mile per hour).

The echo-integrator output (V_O) is thus:

$$V_O = \int_O^{t_s} [V_i^2 \times 3.5 \times 10^{-3})/(0.114 \times 0.396)]dt$$

$$= [1/12.446] \int_O^{t_s} (V_i^2)dt. \qquad \text{............(6)}$$

Hence, to restore this to be the exact integral of the square of the input voltage, V_O must be corrected by a factor of 12.446 (equivalent to manually setting the read pulse control to 12.446 knots which gives exact integration). The integrator correction factor (G), since the sampling ratė is measured in pulses per minute, is calculated as follows:

$$\underline{G = 10 \log 12.446/60 = -6.83 \text{ dB.}}$$

For convenience, equation (4) is split into two expressions:

$$\text{biomass (t km}^{-2}) = V_O \times \text{biomass factor} \qquad \text{........(7)}$$

where

biomass factor is
$$10^\wedge[(30+G-(A+B+C+D+E+F))/10] \qquad \text{......(8)}$$

This is then used as a fixed term in any series of biomass calculations.

5.2 Example calculation

The following data relate to a herring survey cruise on RV CORELLA (Wood and Johnson, 1983):

Survey mile No. 1066

V_O = 36.4 volts,

A = -35.1 dB (for average fish length of 27.6 cm),

B = SL + SRT = 36.2 dB,

C = 28.95 dB,

D = -16.5 dB,

E = 10 log (0.55×10^{-3} s) = -32.6 dB,

F = 10 log (129.8 pulses per minute) = 21.13 dB,

G = 10 log 12.446/60 = -6.83 dB.

Substituting in equation (8)

$$\text{biomass factor} = 10^\wedge [(30-6.83-(-35.1+36.2+28.95-16.5-32.6+21.13))/10]$$

$$= \underline{128.5.}$$

Hence, biomass for mile 1066 = 36.4 x 128.5

$$= \underline{4678 \text{ t k}^{-2}.}$$

5.3 Overall accuracy

This can be split into two discrete parts: physical (parameters B,C,D,E,F,G of the biomass equation) and biological (parameter A of the biomass equation and fish length and weight sampling by trawl).

The physical (system) calibration accuracy was estimated to be 0.5 dB (± 12%) at a 95% confidence level for the now superseded 30 kHz survey equipment. This excluded the transducer equivalent ideal beam angle (parameter D) which is derived from the solid beam pattern of the transducer when fitted into its towed body. For practical reasons, this was estimated to approximately ± 1 dB from measurements made in two orthogonal planes. Measurements under computer control can now give an accuracy better than 0.2 dB (± 5%) (Simmonds *et al.*, 1984). However, any errors in system calibration are small when compared with biological errors in stock assessment.

Fish target strength (parameter A) is a measure of the total acoustic energy returned to the transducer from one fish and is dependent upon the length, aspect, movement, condition and anatomy of the fish. Tilting movements of the fish with respect to the acoustic wavefront can cause large fluctuations in its target strength but it is assumed that on average the normal dorsal aspect is predominant; there is evidence to support this. Dorsal target strength cannot presently be determined to a value more accurate than ± 1 dB (± 25%) whatever the method of determination employed (c.f. caged fish experiments (Edwards and Armstrong, 1982), or free field *in-situ* observations (Robinson, 1982)). Whilst on survey, the distribution in TS is calculated from frequent length/weight samples by fishing. This is the critical parameter of the biomass equation and the utmost care is taken to ensure that the size range and species proportion of the fish in the survey area are adequately sampled. For example, inefficient sampling of herring concentrations at Iceland in 1980 caused an over-estimation of juvenile herring and an under-estimation of older herring. The result of this was a high biomass estimate which, subsequently, had to be revised in 1981 (Jakobsson, 1982).

Since sampling by fishing is carried out to evaluate the proportion of different size groups of the target species and other species, the survey precision is dependent upon the extent to which size groups of the target species can be viewed in isolation and the basis of precision can be increased by the number of trawl samples made. Although the absolute value of target strength is less important in a time series, there is still a requirement for careful sampling by trawl to obtain the proportional mixture of species. J. G. Pope (personal communication) estimates that for two species mixed in equal proportions the chance of obtaining an accurate sample is in the region of 1 in 2, i.e. 3 dB per haul.

In spawning or wintering areas where survey data are used to monitor annual changes in the size of fish stocks on a time series basis, the year to year repeatability 0.5 dB (± 12%) of SL+SRT calibration is more important than overall accuracy (Hood and Huggins, 1983).

To summarise, if the equipment is checked regularly following the procedure in Appendices 1 to 5, then the error in biomass assessment caused by errors in electrical and acoustic system measurements will be far outweighed by that due to the errors in biological sampling.

6. Acoustic survey engineer's records

6.1 Engineer's report

It is necessary to document a full record of the state of the survey equipment before sailing and to give details of tests prior to and during the cruise. This enables the engineer to relate the present equipment performance to that of previous cruises and provides the scientist-in-charge with a biomass factor for all channel settings. An example is given as Appendix 5.

6.2 Measurements to be performed by the engineer during an acoustic survey

6.2.1 *Measurements to be made at least twice during the cruise*

(i) Measure transmitted power.
(ii) Take photographs of:
  (a) transmitter (Tx) voltage;
  (b) expanded Tx voltage;
  (c) tx current;
  (d) expanded Tx current;
  (e) superimposed expanded (Tx) voltage and current waveforms, (Figure 15a-e).
(iii) Measure water temperature (and salinity if possible).

6.2.2 *Measurements to be made every day, if possible:*

(i) Measure Tx pulse duration.
(ii) Measure the system gain.
(iii) Measure the Tx oscillator frequency.
(iv) Check Tx output voltage, current and phase.

Note: (a) No measurements to be made unless the towed body has been immersed and all electronic equipment has been switched on for at least 4 hours for magnetostrictive transducer, 1 hour for ceramic transducer.
(b) The system gain must be measured at the Tx frequency.
(c) The expanded Tx waveforms should cover the last 3 major cycles only.

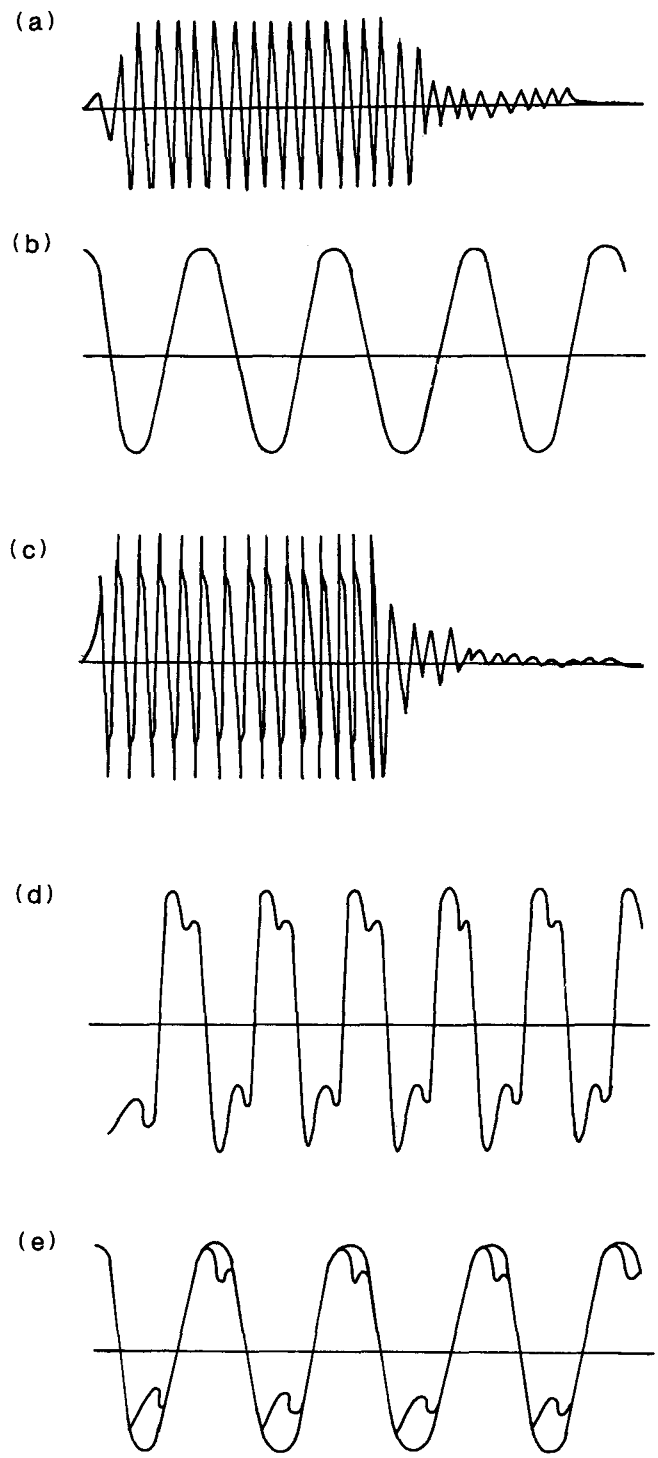

Figure 15 Transmitter voltage and current waveforms: (a) voltage; (b) expanded voltage; (c) current; (d) expanded current; (e) superimposed voltage and current.

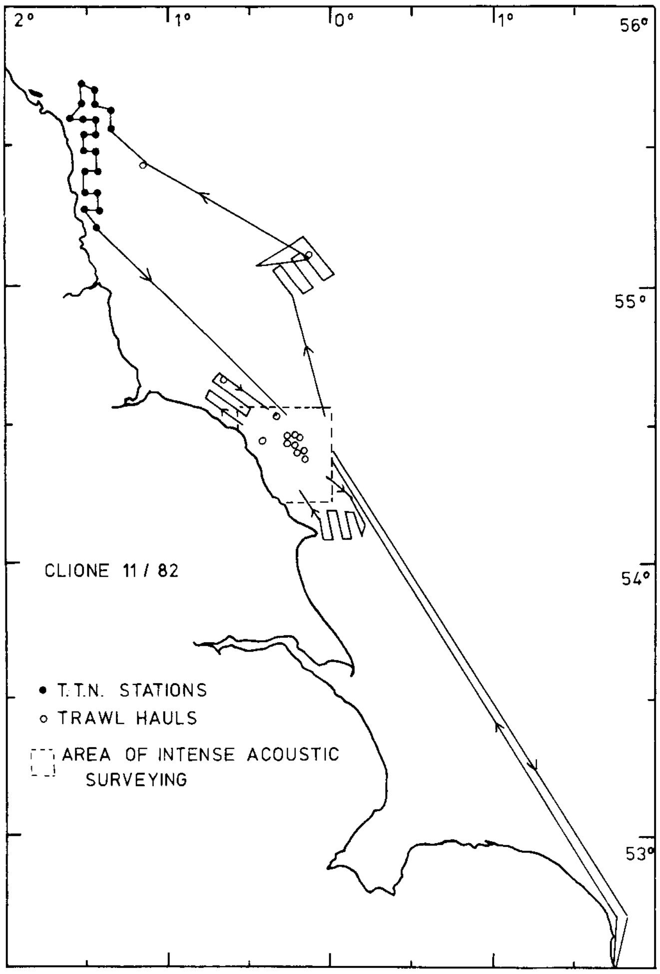

Figure 16 RV CLIONE track chart, 18-30 August 1982 (Wood and Johnson, 1983).

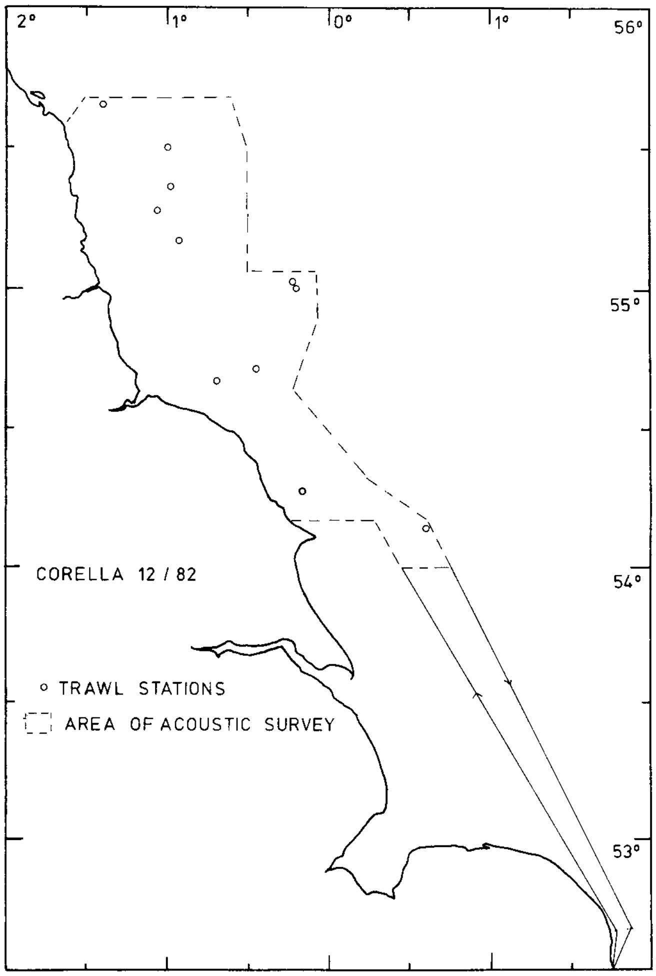

Figure 17 RV CORELLA herring acoustic survey area, 18-30 August 1982 (Wood and Johnson, 1983).

7. Paper records and log keeping

This is an essential feature of the survey exercise. All instrument settings and changes must be rigorously recorded. Examples of paper records and log keeping are given in Appendix 6.

8. Surveying – an example

Extensive surveys of the western and southern North Sea herring stocks were conducted by MAFF during the period 1979-82. The technique of trawl sampling and acoustic surveying over spawning concentrations of herring has been described by Wood (1982) and Wood and Johnson (1983). Independent confirmation of the annual changes in stock have been obtained from herring larval surveys. In 1982, two vessels, R.V. CLIONE and R.V. CORELLA, carried out a joint survey off the Yorkshire coast (Figures 16, 17). The Engineer's Report, the paper records and sample trawl hauls provided the Scientist-in-Charge of the survey with sufficient data to:

(a) locate concentrations of herring;
(b) decide survey strategy;
(c) estimate biomass.

The survey strategy and results are described by Wood and Johnson (1983) from which the following extract is taken:

> 'The chief objectives of the 1982 survey were to locate the August herring spawning concentration at the Longstone (the most important one in that area), and to survey both the pre-spawning and spawning phases of the August spawning concentration off the Yorkshire coast in the Robin Hood's Bay area. Because it had been observed during previous surveys that spawning off Robin Hood's Bay, in the second half of August or at the beginning of September, takes place a few days after the date of the relevant full or new moon (Figure 18; Wood and Johnson, 1983), the survey in 1982 was timed to cover the first 11 days following the new moon which occurred on 19 August.

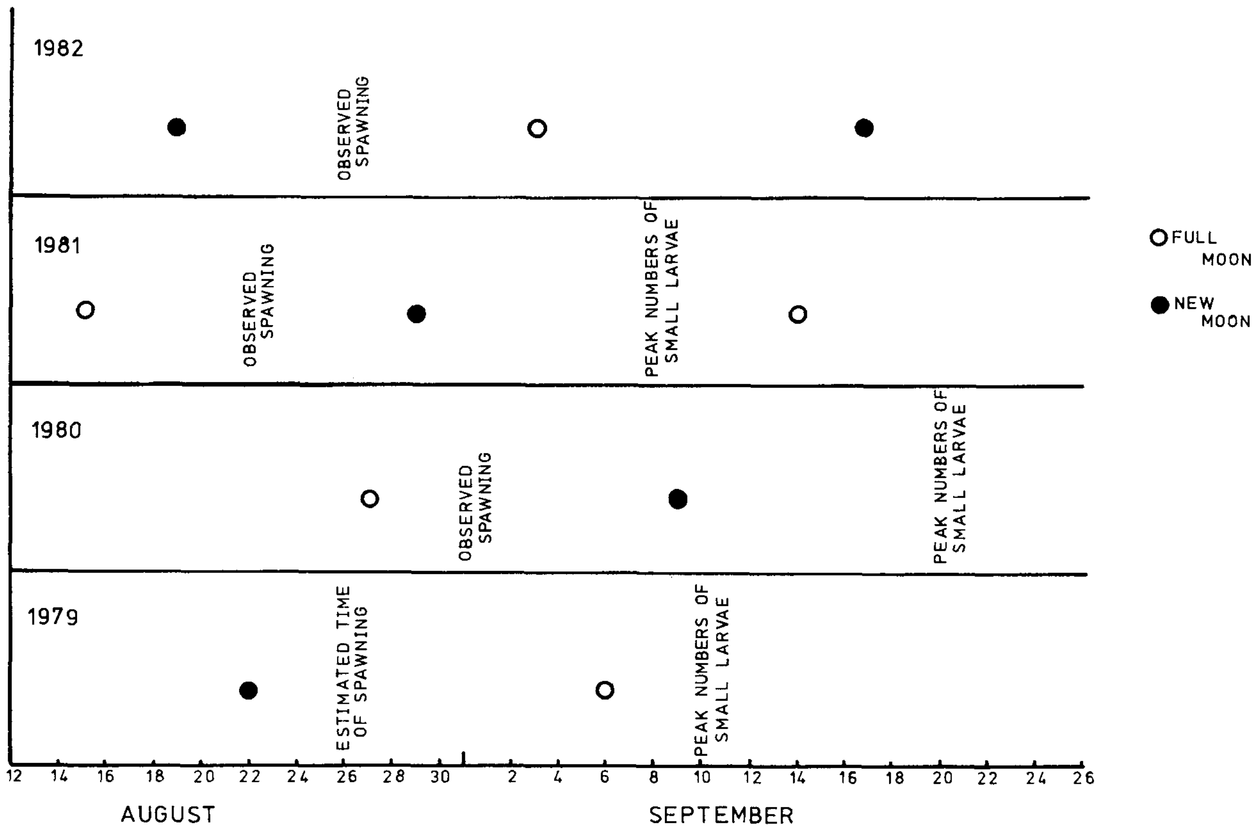

Figure 18 Date of first annual herring spawning off Robin Hood's Bay in relation to the phase of the moon (Wood and Johnson, 1983).

An echo survey was carried out by both vessels during the night of 18-19 August off Robin Hood's Bay (Figure 19) to determine the extent of the area where night-time herring shoals were expected to be distributed (Wood and Johnson, 1983). The following night, using echo-integrators both vessels surveyed the area where echo traces were abundant, the survey tracks of the two vessels being arranged to overlap so that biomass estimates from each could be compared. The results are shown below (Table 2).

Table 2 Comparison of biomass estimates of RVs CORELLA and CLIONE

Date (1982)	Area covered by both vessels	Biomass estimates	Maximum t/km²
19-20 August	102.1 km²	CORELLA 14 494 t CLIONE 14 814 t	511 495

The target strengths used were those recommended by the Planning Group on ICES Coordinated Herring and Sprat Acoustic Surveys (Anon., 1982). That for the night 19-20 August being -34.8 dB/kg, relative to a mean length of 26.2 cm and a mean weight of 162 g.

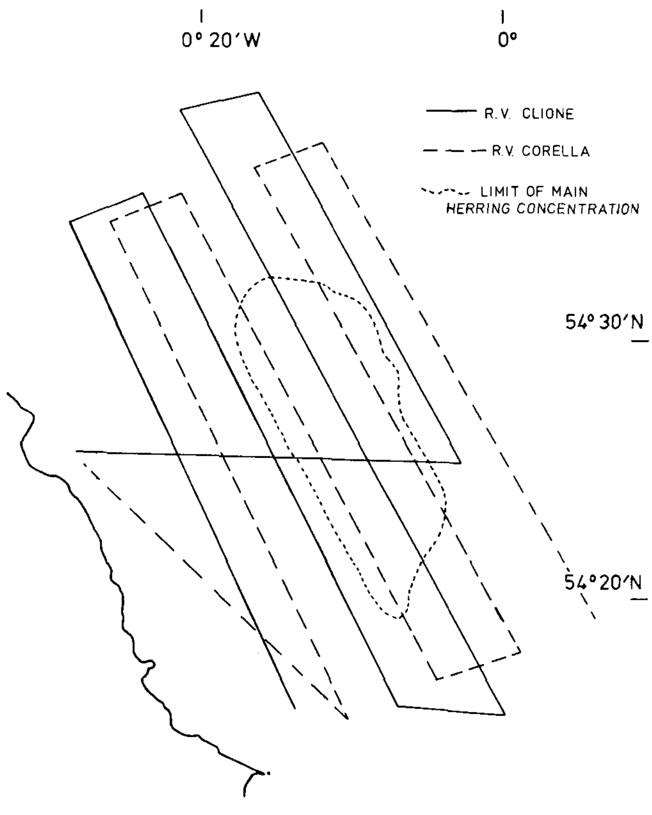

Figure 19 Survey tracks during the night 18-19 August 1982 and area containing majority of herring shoals during hours of darkness (Wood and Johnson, 1983).

9. Remarks

An indirect assessment of fish stocks using acoustics can be achieved to an acceptable confidence level, provided that the procedures and calibration techniques outlined in this report are followed correctly. The equipment must be calibrated at frequent intervals. Equally important is the accurate biological sampling of the surveyed fish stock, which depends upon significant numbers of trawl samples from the areas of the fish echoes being integrated.

However, to achieve the present level of confidence it is important that the survey data be validated by other methods. For example, the relative changes in the adult herring biomass in the central and southern North Sea, recorded by acoustic methods, have been confirmed by the independent assessments obtained by ICES herring larvae surveys (Anon, 1983).

The quality of biomass estimation now being provided can be demonstrated by the results of a two-ship survey made in 1982 (reported above). The research vessels CLIONE and CORELLA (each using identical equipment calibrated in exactly the same way) gave estimates within ±0.5 dB. In 1983, the results from preliminary trials to compare 30 and 38 kHz equipment calibration techniques and performance, although not conclusive showed no significant difference in biomass estimation. Thus, it is predicted that acoustic surveying can be conducted at 38 kHz to the same level of precision and accuracy.

Acknowledgements

The work described in this report would not have been possible without a considerable contribution from present and past members of the Directorate's Research Support Group, particuarly Mr B. J. Robinson and the late Mr L. Cox. The authors are also indebted to Mr M. H. Beach and Mr R. B. Mitson for helpful assistance in the preparation of this manuscript.

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Appendix 1 Calibration of transmitter, towing cable and transducer

1. Determination of the transducer parameter SL + SRT

1.1 Hydrophone method

The arrangement used is shown in Figure A1. The survey transducer, projector and hydrophone are mounted at appropriate depths at suitably distanced stations and can be rotated independently. To reduce the possibility of error, all the auxiliary components of the transducer system, not just the transducer element, are included in the calibration. The detailed calibration procedure is as follows:

(i) The survey transducer alone and then the transducer plus cable are tuned to be resistive at the desired operating frequency. Next, the transmitter is energised and the electrical power into both the cable plus transducer and the transducer alone are measured, to enable the cable loss to be computed.

(ii) Whilst the survey transducer is transmitting, it is aligned with the test hydrophone and the received voltage at the hydrophone measured (Va rms). The true rms voltage of the received waveform must be measured and not the peak or estimated mean value.

(iii) Power is then applied to the test projector which is aligned initially with the hydrophone and then with the survey transducer. The received rms voltages, Vb and Vc respectively, are measured.

From these measurements the following equations are derived:

$$20 \log V_a = SL + SRT_h - (20 \log Ra + \alpha_m Ra) \text{...(A1)}$$

$$20 \log Vb = SL_p + SRT_h - (20 \log Rb + \alpha_m Rb) \text{...(A2)}$$

$$20 \log Vc = SL_p + SRT - (20 \log Rc + \alpha_m Rc) \text{...(A3)}$$

SL_p and SL are the projector and survey transducer source levels, SRT_h and SRT are the receiving sensitivities of the hydrophone and the survey transducer respectively, α_m is the acoustic attenuation in dB m^{-1}, and Ra, Rb, Rc are the respective ranges in metres.

From equations (A1), (A2), (A3):

$$SL + SRT = 20 \log \left(\frac{Va\ Vc}{Vb}\right) + 20 \log\left(\frac{Ra\ Rc}{Rb}\right) + \alpha_m(Ra+Rc-Rb) \text{ dB} \quad \text{......(A4)}$$

Note: The parameter SL + SRT is related to the electrical power input to the transducer. The power must be noted at the time of calculation.

1.2 Standard target method

A tungsten carbide sphere or a copper sphere is suspended by a monofilament nylon line to be precisely on the transducer axis. The position of the target should be chosen so as to be well away from any other secondary targets (e.g. surface reflections or nearby objects).

The acoustic performance parameters are calculated from

$$SL + SRT = VRT - TS - X + 40 \log R + 2 \alpha R \text{.....(A5)}$$

where

SL = source level in dB//1μPa//1m,

SRT = reception sensitivity of transducer in dB//1V/1μPa,

VRT = rms voltage across transducer terminals due to standard target echo in dB V^{-1},

TS = target strength of standard target in dB,

X = measuring amplifier gain in dB,

R = range in metres,

α = attenuation due to absorption in dB km^{-1}.

Note: Use of parameter SL + SRT

The SL + SRT parameter is inserted as parameter B in the biomass equation (see main report, Section 5).

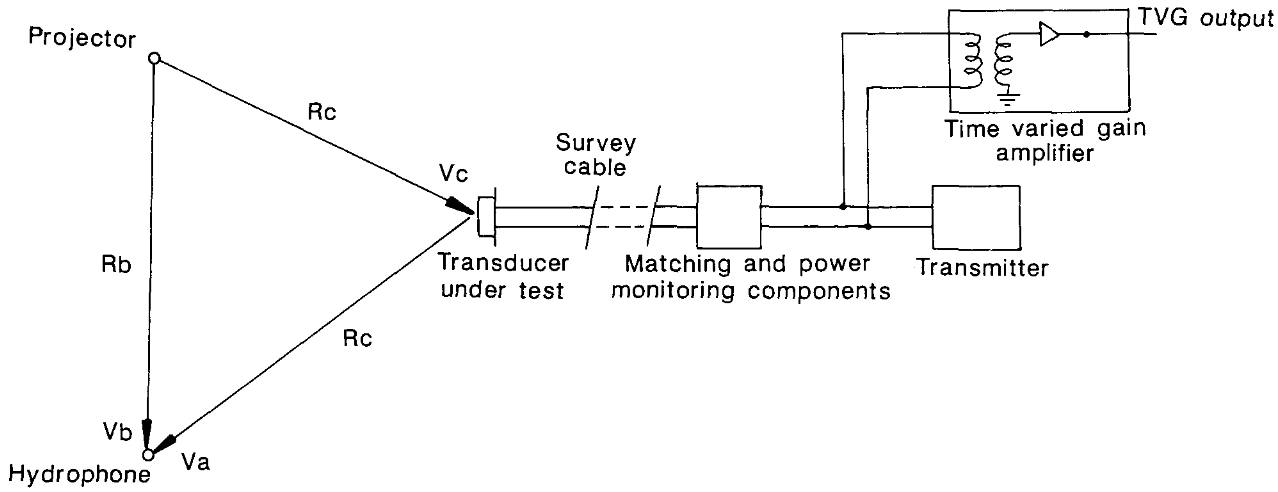


Figure A1 Transducer calibration by hydrophone. The projector, hydrophone and transducer are immersed at approximately equal distances apart in a volume of water large enough for the test to be unaffected by reflections or standing waves (i.e. free-field conditions).

Appendix 2 Calibration of TVG amplifier

This is required to determine the mean fixed or static gain (correction factor) of the TVG amplifier, and is calculated by measuring the total gain of the amplifier (dB) at a series of range steps and then subtracting the corresponding theoretical TVG component (dB).

1. TVG receiver gain (measured)

(i) A signal generator, calibration unit, double beam oscilloscope (CRO), and frequency counter are connected as shown in Figure A2.

(ii) the equipment should be allowed to warm up for at least 1 hour and the input and output of the TVG amplifier must be terminated correctly by connections to the transducer and QM echo-integrator before commencing calibration.

(iii) A CW signal, set to the survey frequency, is displayed on one channel of the CRO as a reference. It is also injected into the TVG (via the 100:1 attenuator) and the other output displayed on the other channel of the CRO.

(iv) The peak-to-peak voltage of each waveform is taken at a specific point in time (Figure A3) and the TVG gain is calculated, the 100:1 attenuator being allowed for. This process is repeated throughout the depth range at the points, where theoretical values have been calculated and the average voltage ratio 100 V_{out}/V_{in} used for calculating the TVG gain as follows:

$$\text{TVG receiver gain (measured)} = 20 \log [100V_{out}/V_{in}] \text{ dB} \quad \text{...(A6)}$$

The injected signal amplitude must be reduced with increase in time (range) as the amplifier gain increases, otherwise the amplifier will saturate and give incorrect results.

2. TVG receiver gain (theoretical)

This is calculated using equation (A7) for a series of range points.

$$\text{TVG receiver gain (theoretical)} = 20 \log R + 2(\alpha \times 10^{-3})R \text{ dB} \text{......(A7)}$$

where

$R = 0.5\, c\, \Delta$ (m),

and

c = speed of acoustic waves in seawater (m s^{-1}) (see Table A1),

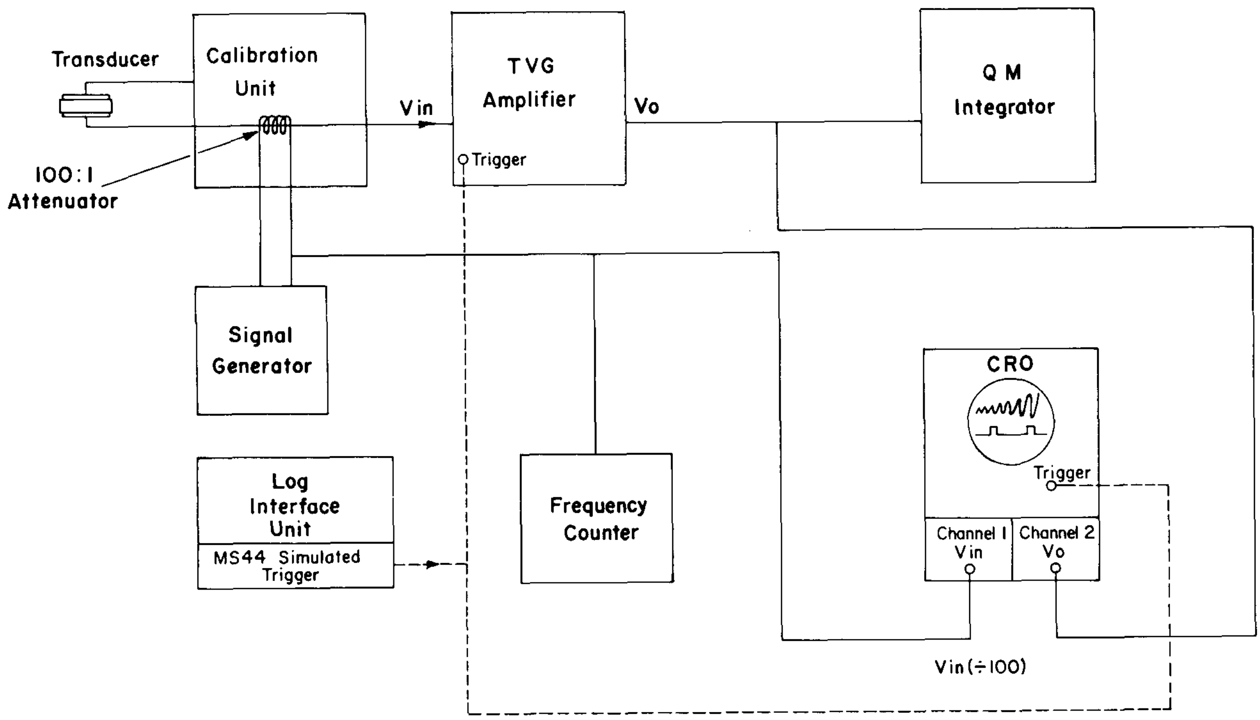


Figure A2 TVG amplifier calibration. A schematic diagram showing the connections between the various units. The transducer must be connected to the TVG amplifier to provide the correct input impedance. The signal generator impedance of 0.1 ohms does not affect the calibration.

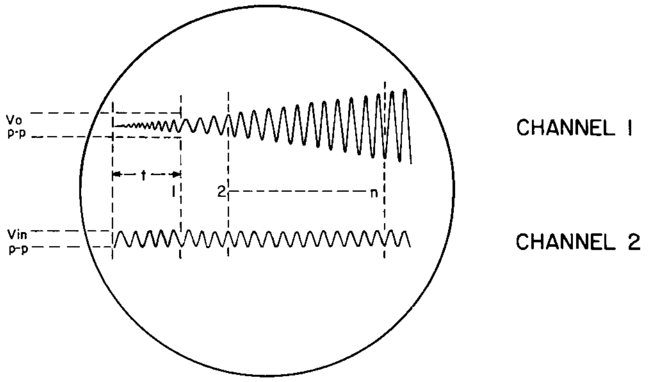


Figure A3 C.R.O. display. The amplifier gain is calculated for a number of steps by reading the output and input voltage on the display.

Table A1 Speed of acoustic waves in sea water (ms^{-1}) at a depth of 5 m. (from Mackenzie, 1981)

Temp	Salinity (⁰/₀₀)				
(°C)	33.5	34.0	34.5	35.0	35.5
2.0	1 456	1 457	1 457	1 458	1 459
3.0	1 460	1 461	1 462	1 462	1 463
4.0	1 465	1 465	1 466	1 467	1 467
5.0	1 469	1 469	1 470	1 471	1 471
6.0	1 473	1 473	1 474	1 475	1 475
7.0	1 477	1 477	1 478	1 479	1 479
8.0	1 481	1 481	1 482	1 482	1 483
9.0	1 484	1 485	1 486	1 486	1 487
10.0	1 488	1 489	1 489	1 490	1 490
11.0	1 492	1 492	1 493	1 493	1 494
12.0	1 495	1 496	1 496	1 497	1 498
13.0	1 499	1 499	1 500	1 500	1 501
14.0	1 502	1 502	1 503	1 504	1 504
15.0	1 505	1 506	1 506	1 507	1 507
16.0	1 508	1 509	1 509	1 510	1 510
17.0	1 511	1 512	1 512	1 513	1 513
18.0	1 514	1 515	1 515	1 516	1 516
19.0	1 517	1 518	1 518	1 519	1 519
20.0	1 520	1 520	1 521	1 522	1 522
21.0	1 523	1 523	1 524	1 524	1 525
22.0	1 525	1 526	1 526	1 527	1 527
23.0	1 528	1 528	1 529	1 529	1 530
24.0	1 530	1 531	1 531	1 532	1 532
25.0	1 533	1 533	1 534	1 534	1 535

Δ = time delay from zero to point of measurement (ms),

α = absorption in seawater ($dB\ km^{-1}$).

3. TVG correction factor

(i) The fixed gain (which is used in the biomass equation) is determined from equations (A6) and (A7) for each range point and a mean value determined.

TVG fixed gain = [TVG measured gain - TVG theoretical gain] dB. ......(A8)

(ii) The calibration is repeated for any other switched setting of fixed gain which may be used.

(iii) If a pulsed input is used instead of CW, the measurements are taken at the midpoint of the pulse, and modify the range factor R as follows:

$0.5c(\Delta + 0.5\tau)$ ......(A9)

where

Δ = time delay from zero to the leading edge of pulse (ms)

τ = the pulse duration (ms).

(iv) For calibration in the target strength mode the appropriate gain law is:

TVG receiver gain = $40 \log R + 2(\alpha \times 10^{-3})R$ dB...(A10)

Note: Use of TVG correction factor

The TVG correction factor is combined with the QM echo-integrator correction factor to give parameter C in the biomass equation (see main report, Section 5).

Appendix 3 Calibration of Simrad QM echo-integrator, MkII

This is required to determine the actual fixed gain of the QM echo-integrator for gain settings of 0, 10, 20 dB, and is achieved by comparing the actual and theoretical performance for a defined input.

1. Calibration equipment

This is set up as shown in Figure A4. The additional items required are ship's speed simulator and distance log interface unit.

2. Echo-integrator description

The echo-integrator performance is measured by injecting an internally generated 1V rms sine wave to simulate a fish echo input. The injected signal is processed in precisely the same manner as fish echoes (refer to Figure A5) as follows:

(i) Detector – since the integrator measures the area under the voltage waveform the signal waveforms must first be rectified, the integral of an unrectified sine wave being zero.

(ii) Delay line – 0.5 ms for 'bottom stop' circuit, not used.

(iii) Gain/threshold amp – sets overall signal amplification from 0 to 40 dB in 10 dB steps (the threshold control, which is incorporated, is always set to zero)

(iv) Signal gate – two controls (depth and interval) fix the position and length of time that the signals are integrated

(v) Adder – part of the threshold system, not used.

(vi) Squarer – this is switched on by selecting the ∫ nautical mile function (the position always used) and the signal is squared and thus made proportional to fish density. (Fish density is proportional to acoustic intensity which is the square of the acoustic pressure measured at the transducer face.)

(vii) Sounding integrator – this measures the area under the envelope of the amplified, gated and squared signal wave form. However, because of a time constant in the integrator (114 x 10^{-3}s) which distorts the squared signals, the output is not exactly the integral of the input (this is allowed for in the biomass calculations). After each sounding, the integral in 'held' for a period to enable this to be 'read' by the mile integrator and then 'reset' by the 'hold/reset' switch.

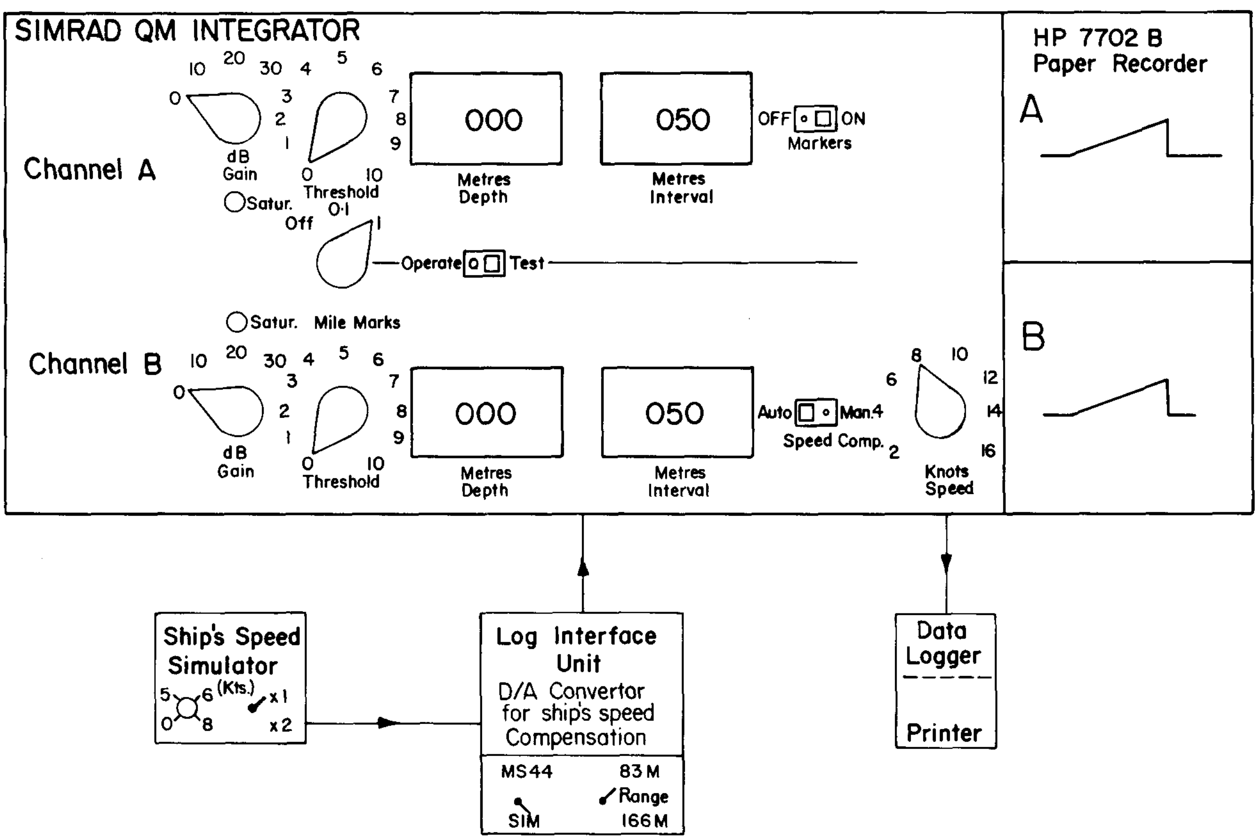


Figure A4 Simrad QM echo-integrator calibration diagram. A simplified layout of the front panel of the QM echo-integrator and ancilliary test equipment. The integrator is operated in the 'self test' mode with simulated inputs of transmission pulse, trigger and ship's speed.

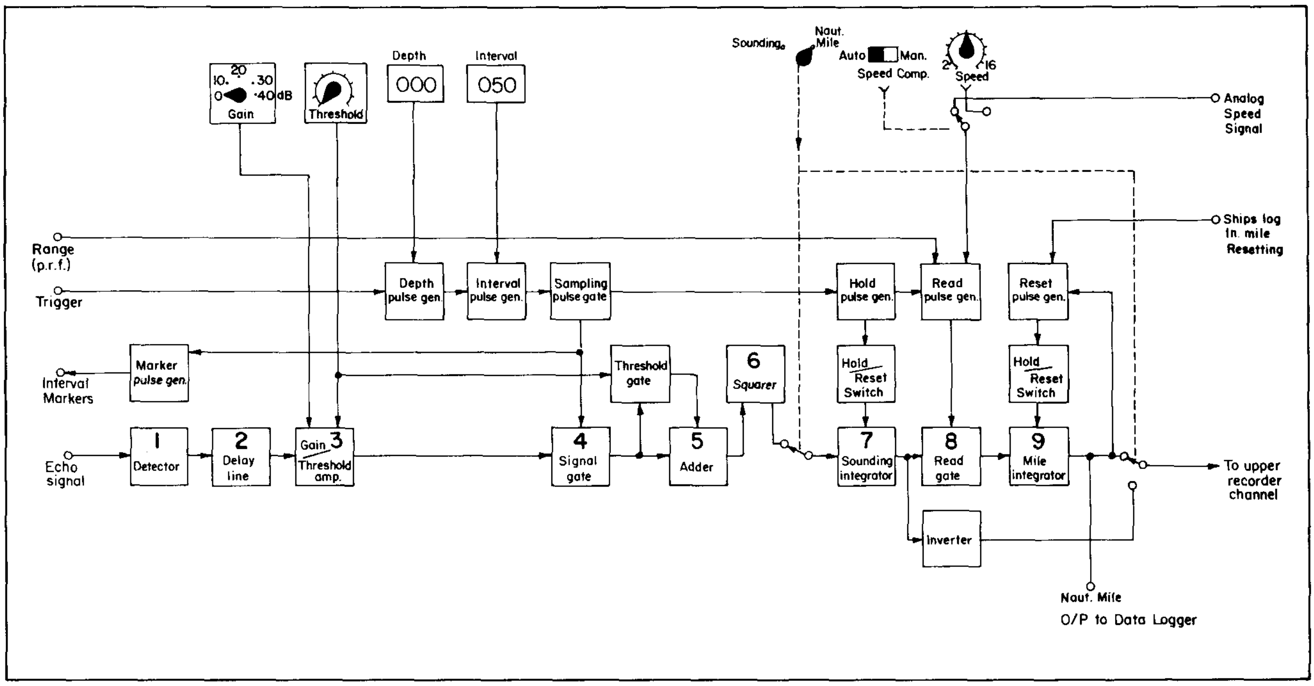


Figure A5 Simrad QM echo-integrator block diagram. A block diagram of one integrator channel, the functions of the numbered stages are explained in the text.

(viii) Read gate – this is controlled by a 'read pulse' generated by a voltage from the ship's speed indicator (log) which automatically compensates for variations in ship's speed to make the integration dependent only on distance travelled. It restricts the signal to the mile integrator to 3.5 ms per knot. This speed correction is allowed for in the biomass calculation.

(ix) Mile integrator – this sums the integral voltages generated by the sounding integrator during each nautical mile and gives a proportional voltage output. During the test, this takes the form of a steadily rising sawtooth waveform which on reaching 10V resets to zero automatically. (When on survey, the echo-integrator output rises in a series of steps proportional to the biomass of fish detected per sounding.) The mile integrator time constant of 396 ms reduces the output to less than the exact integral for the same reason as in the sounding integrator. This is also corrected in the biomass calculation.

3. The calibration procedure.

3.1 Determination of the measured value of Vo for a simulated survey.

(i) The ship's speed simulator is set to the survey speed (normally 8 knots) and the 'MS44/simulator' switch on the log unit set to simulate 83m range.

(ii) The QM echo-integrator controls are set thus: speed compensation control to 'automatic'; gain '0 dB'; threshold '0'; metres depth '0'; metres interval '50'; 'operate/test' switch to 'operate'.

(iii) The HP7702B paper recorder is switched on and run for a period to check for zero drift and adjusted if necessary.

(iv) The 'operate/test' switch is set to 'test' mode and simultaneously a time check is made either by triggering the data 'printout' or by using a stopwatch. The echo-integrator paper recorder pen should be seen to rise linearly with time.

(v) After a specified period (7.5 min at 8 knots is equivalent to 1 nautical mile), the simulated survey is stopped and the echo-integrator output (V_O) and number of simulated transmissions recorded, either by calculation using the transmission rate and time, or by using the data logger and printer.

3.2 Calculation of the theoretical values of Vo for a simulated survey

The 1V rms sine wave input is gated and integrated to become a number (n) of positive going square waves (unit integral) of duration, g, amplified X^2 times, such that,

$$V_O = (1X)^2.g.n. \qquad \text{............(A11)}$$

where

X is the echo-integrator gain [X = antilog (dB gain/20)],

n is the number of simulated transmissions during the test,

g is the duration of the gate, allowing for two-way transmission (i.e. g equals twice the interval setting divided by the speed of acoustic wave in sea water ($c \approx 1500$ m s^{-1})).

Substituting for t in Equation (A11)

$$V_O = (1X)^2.n.2.g.c^{-1} \qquad \text{............(A12)}$$

where

G is the sampling gate ('metre interval'),

c is the speed of acoustic waves in seawater.

However, as stated previously, since the echo-integrator output is reduced by the sounding and mile integrator time constants (114 ms, 396 ms) and the 'read pulse' length (3.5 ms x speed) the output expression becomes:

$$V_O = X^2.2.\frac{G}{1500}.n.\frac{1}{114 \times 10^{-3}}.3.5 \times 10^{-3}.U.\frac{1}{396 \times 10^{-3}}$$

$$= 1.034 \times 10^{-4}.X^2.G.n.U. \qquad \text{............(A13)}$$

where

G is the sampling gate (interval) in metres, and U the simulated speed.

3.3 Determination of the echo-integrator correction factor

The theoretical output voltage is compared with the measured value and a correction factor determined thus:

$$\text{correction factor} = 10 \log [V_O \text{ measured}/V_O \text{ theoretical}] \text{ dB} \qquad \text{............(A14)}$$

For greater accuracy, time constants and read pulse duration must be measured for each unit, and also a more precise value for the speed of acoustic waves calculated.

Note: Use of echo-integrator correction factor

The echo-integrator correction factor is combined with the TVG correction factor to give parameter C in the biomass equation (see main report Section 5).

Appendix 4 Calibration of TVG amplifier/QM echo-integrator combined

The aim is to calibrate the TVG amplifier and the QM echo-integrator as one combined unit. A CW signal is injected at the TVG amplifier input (Vin), and the resultant QM echo-integrator output (V_O) is recorded. A set of calibrations for all possible TVG and integrator gain settings is achieved by inserting V_{in}, V_O and the fixed parameters of the system into a computer programme.

1. Calibration equipment

This is arranged as in Figure A6, the additional equipment required being:

ships log simulator; calibration unit; signal generator; programmable calculator; oscilloscope and frequency counter.

2. The calibration procedure

2.1 Determination of the measured value of Vo

(i) The ship's log simulator is set to survey speed (8 knots) and is connected to the 'ships log' input located at the rear of the log interface unit.

(ii) The QM echo-integrator is set to:
automatic speed compensation;
0 dB integrator gain;
0 dB integrator threshold;
the gate depth and interval are set to the average values for the survey area.

(iii) The TVG amplifier is set to: 0 dB gain; and α dB km^{-1} (α calculated from salinity and temperature records).

(iv) A CW signal (V_{in}), at the survey frequency, is injected at the TVG amplifier input via the calibration unit 100:1 attenuator.

(v) Finally, the QM echo-integrator output (V_O) is measured, and the number of transmissions (n) noted.

2.2 Calculation of the theoretical value of V_O

The QM echo-integrator output voltage (V_O) is the product of the voltage injected at the TVG amplifier input, the TVG amplifier gain and the QM echo-integrator gain.

In survey mode at 0 dB fixed gain, the TVG amplifier gain is defined as:

$$\text{TVG gain} = 20 \log R + 2\alpha R \qquad \text{............(A15)}$$

where

the gain changes as the range (R) varies from the start to the finish of the range sampling gate, (R_O) and (R_t) respectively.

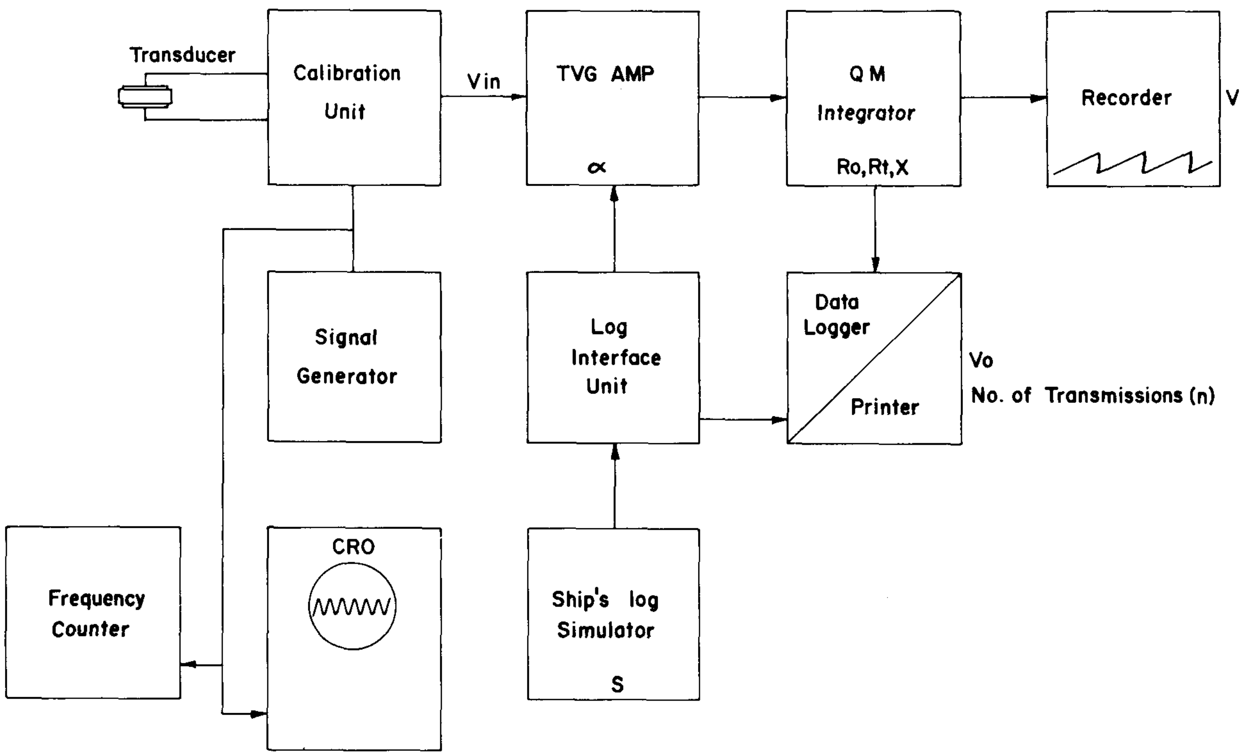


Figure A6 Combined TVG amplifier/Simrad QM echo-integrator calibration diagram. The diagram shows the arrangement of survey and test equipment necessary for this calibration.

Hence the input voltage to the integration stage is V_A (equation A15):

$$V_A = V_{in}\ [10^{\frac{20 \log R_o + 2\alpha R_o}{20}} . 10^{\frac{20 \log R/R_o + 2\alpha (R-R_o)}{20}}]$$

............(A16)

where

the first term is the TVG gain at R_o, and the second term defines the increase in gain during the sampling interval.

The echo-integrator unit operates on the input voltage (V_A) to give an output voltage, V_o, such that:

$$V_o = [V_{in} . 10^{\frac{20 \log R_o + 2\alpha R_o}{20}} \times]^2 \int_{R_o}^{R_t} [10^{\frac{20 \log R/R_o + 2\alpha (R-R_o)}{20}}]\ dR$$

$$\times\ 1.034 \times 10^{-4} . X^2 . n.U.$$ ......(A17)

which reduces to:

$$V_o\ (\text{theoretical}) = [V_{in} 10^{\frac{20 \log R_o + 2\alpha R_o}{20}}]^2 \times$$

$$[[10^{ka(Rt-R_o)} . (Rt^2 . D^2 - 2R_t D + 2)] - [R_o^2 . D^2 - 2R_o D + 2]] / R_o^2 D^3$$

$$\times\ 1.034\ 10^{-4} . X^2 . n.U.$$ ......(A18)

where

V_{in} is the voltage injected at the TVG amplifier,

X is the QM echo-integrator gain [$X = 10^{\frac{\text{'dB gain'}}{20}}$],

n is the number of soundings (transmissions) during the test,

U is the simulated speed,

R_o is the QM depth setting (m),

R_t is the sum of the QM depth and interval settings (m),

k_a is $\frac{4\alpha . 10^{-3}}{20}$,

D is $k_a l_n(10)$,

α is the absorption factor (dB km^{-1}).

The integrator factor of 1.034×10^{-4} is an average figure. For precise calibration, the time constants described in Appendix 3 must be measured for each unit.

2.3 Determination of the combined correction factor

The measured output voltage is compared with the theoretical value and the combined correction factor is determined thus:

combined correction factor =

$$10 \log [\frac{V_o\ \text{measured}}{V_o\ \text{theoretical}}]\ \text{dB.}$$ ......(A19)

Note: Use of the combined correction factor

The combined correction factor is parameter C in the biomass equation (see main report, Section 5).

3. Example calibration

Table A2(a) Test setting up information

Transducer:	TRDC 9
T.V.G. number:	1
alpha dB/km:	4.9 acoustic wave speed assumed: 1493 m s^{-1}
short/long range:	short
QMs used:	red and yellow
depth:	10 m
interval:	80 m, 40 m, 10 m
set auto Yes/No	Yes Set speed: = 8 knots
threshold:	0
T.V.G. gain set dB:	0, -10
QM gain set dB:	0, 10, 20
Inject frequency:	28.65 kHz

Table A2(b) Test Results

TVG, QM (gain dB)	Interval (m)	V_{in} mV (rms)	No. of transmissions	QM echo-integrator output volts (dB)				Calculated system gains (dB)			
				A Y	B Y	A R	B R	A Y	B Y	A R	B R
0,0	80	0.517	364	6.23	6.63	7.02	6.61	24.37	24.64	24.89	24.63
0,10	40	0.517	324	8.82	9.22	9.56	9.52	24.41	24.61	24.77	24.75
0,20	10	0.518	442	6.36	6.53	6.70	6.76	24.47	24.58	24.69	24.74
-10,0	80	1.632	408	6.66	7.08	7.51	7.05	24.18	24.45	24.71	24.43
-10,10	40	1.632	299	7.92	8.29	8.62	8.58	24.32	24.51	24.68	24.66
-10,20	10	1.632	473	6.63	6.81	7.02	7.08	24.39	24.51	24.64	24.67

Appendix 5 Survey engineer's report

The documentation performs two functions:

checks equipment performance;

gives biomass factor calculation using equations 7 and 8 from Sub-section 5.1

biomass
$= V_0 \, 10^\wedge [(30+G-(A+B+C+D+E+F))/10]$ t km^{-2};

where parameter

A = target strength,

B = SL+SRT,

C = system gain,

D = equivalent ideal beam angle,

E = 10 log [pulse duration],

F = 10 log [PRF (ppm)],

G = QM echo-integrator constant.

Extract from acoustic survey cruise documentation (Tables A3-A12)

Vessel/cruise:	CLIONE 11/82
Scientist-in-charge:	R. J. Wood
Engineer:	W. L. Huggins
Survey aim:	Bank herring stock assessment
Location:	West Central North Sea
Dates:	18-31 August 1982.

Table A3 Transducer specifications

Towed body:	TM2
Towing depth:	5m
Transducer used:	HM2-314A
Cable:	Towing cable 2
Equivalent ideal beam angle (ψ) used (dB):	-16.5 dB
Calibration data source:	MAFF, 1982 (unpublished)
SL + SRT parameter	38.24 dB at 681W transmitter power

Table A4 Transmitter tests

Type:	MS 44
Frequency	28.57 kHz. Date checked: 19 August 1982 28.37 kHz. Date checked: 20 August 1982 28.86 kHz. Date checked: 28 August 1982
Pulse rep. rate:	129.5 ppm. Date checked: 19 August 1982
Pulse duration	0.51 ms

Table A5 Transmitter output power measurements

Date	Volts (Vp-p)	Current (Ip-p)	Phase (ϕ) (degrees)	rms power (watts)
19 Aug 1982	525	11.1	21	681
20 Aug 1982	516	11.2	20	679
28 Aug 1982	528	11.0	20	682

Comments:
a. For magnetostrictive transducer, use only the last three major cycles of V & I waveforms for the above power calculation.
b. 'rms' power = Vp-p x Ip-p x cos(ϕ) x 0.125.
c. Record water temperatures (and salinity if possible) at time of above measurements.

Table A6 T.V.G. receiver settings

T.V.G. Unit:	1
Bandwidth:	5 kHz
Any hydrographic measurements taken Yes/No:	Yes values: sea temperature 12.5°C
Alpha setting:	4.8 dB km^{-1}
Acoustic wave speed:	1500 m s^{-1}
Long- or short-range setting:	short

Table A7 Log interface calibration

Serial number: 1

Speed	Volts
5 knots	3.078
6 knots	3.743
8 knots	5.052
10 knots	6.247
12 knots	7.436

Table A8 Target Strength (biomass parameter A)

Fish Length (cm)	Value of A T.S. (dB kg^{-1})
23	-34.2
	-34.6
27	-34.9
	-35.3
31	-35.6

Table A9 SL+SRT calculation (biomass parameter B)

Results

Date	rms power (watts)	SL+SRT (dB)
19 Aug 1982	681	38.24
20 Aug 1982	679	38.23
28 Aug 1982	682	38.26
	mean	38.24

Table A10 System gain (biomass parameter C)

	QM setting (dB)	System gain (dB)
Yellow A	10	30.78
Yellow B	20	40.78
Red A	0	21.01
Red B	10	31.11

Table A11 System biomass parameters fixed for duration of cruise

Parameter D	Equivalent ideal beam angle = -16.5 dB
Parameter E	10 log pulse duration = -32.92 dB
Parameter F	83 m range
	10 log PRF = 21.13 dB
Parameter G	QM constant = 6.83 dB

Table A12 Calculated biomass factor per QM channel

Cruise CLIONE 11b/82 Herring survey

'Yellow' channel A
T.V.G. gain = 0 dB
QM gain = 10 dB
MS 44 range = 83 m

Fish length (cm)	23	25	27	29	31
Biomass factor (t km^{-2} V^{-1})	46.13	50.58	54.20	59.43	63.68

'Yellow' channel B
T.V.G. gain = 0 dB
QM gain = 20 dB
MS 44 range = 83 m

Fish length (cm)	23	25	27	29	31
Biomass factor (t km^{-2} V^{-1})	4.61	5.06	5.42	5.94	6.37

'Red' channel A
T.V.G. gain = 0 dB
QM gain = 0 dB
MS 44 range = 83 m

Fish length (cm)	23	25	27	29	31
Biomass factor (t km^{-2} V^{-1})	437.5	479.7	514.0	563.6	603.9

'Red' channel B
T.V.G. gain = 0 dB
QM gain = 10 dB
MS 44 range = 83 m

Fish length (cm)	23	25	27	29	31
Biomass factor (t km^{-2} V^{-1})	42.76	46.88	50.23	55.08	60.32

Appendix 6 Examples of paper records and log keeping.

These are illustrated in Figures A7 to A9 and Tables A13 and A14 referring to R.V.CLIONE – Cruise 11/82 – Herring Survey

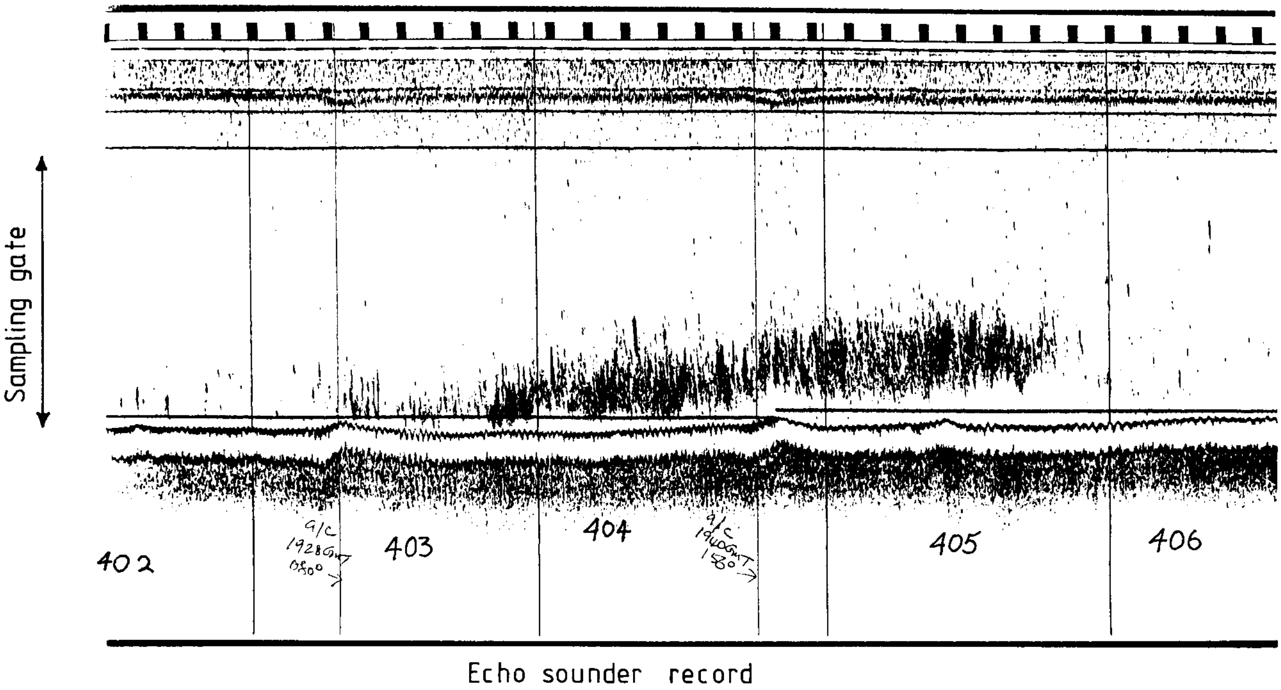
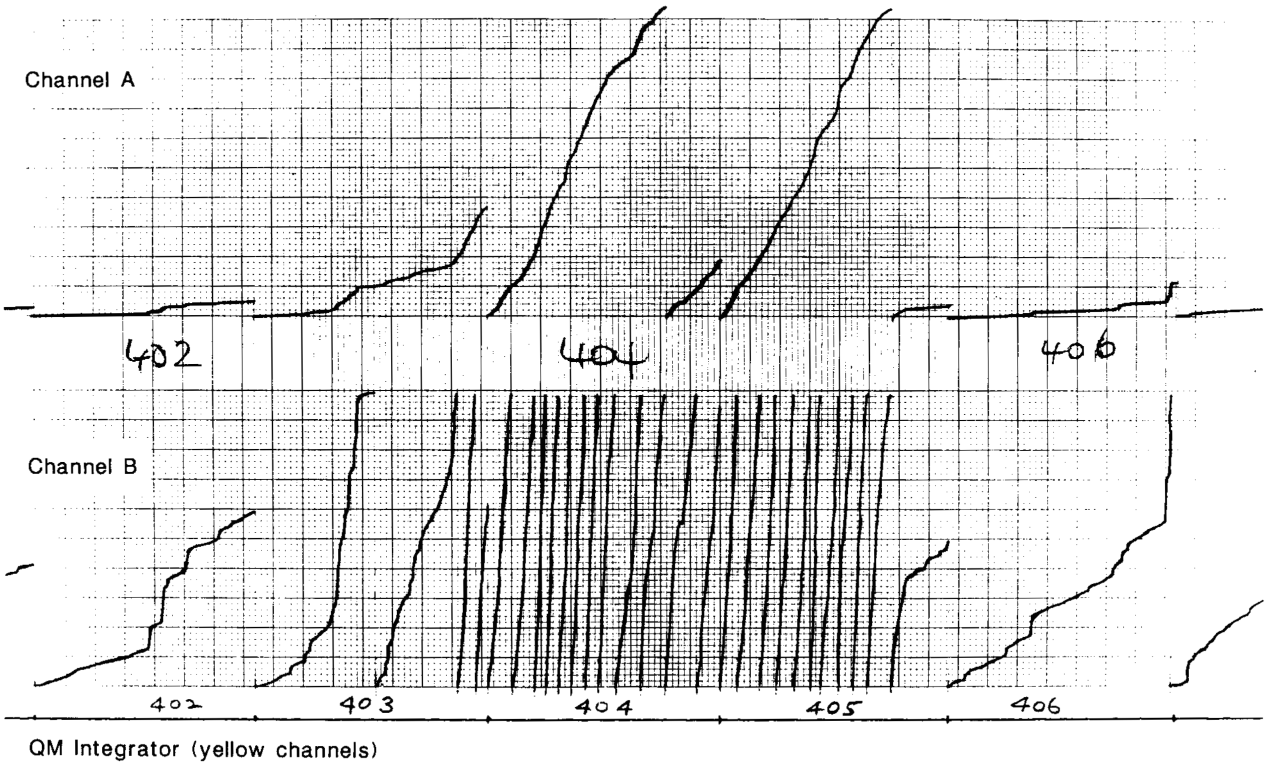


Figure A7 An echo record of a herring concentration. The sampling gate is indicated by the continuous horizontal line above and below the shoal; reduced by 1 metre towards the end of mile 404 in the proximity of a sand ridge.

Table A13 Details from the data logger for mile 404

Channel	Data	Explanation of code
14	00001	RED INT: RESETS 'A' (0); RESETS 'B' (1):
13	01011	YELLOW INT: RESETS 'A' (1); RESETS 'B' (11):
12	02.73 V	RED INT: OUTPUT VOLTAGE 'B' (2.73 V):
11	01.35 V	RED INT: OUTPUT VOLTAGE 'A' (1.35 V):
10	08.05 V	YELLOW INT: OUTPUT VOLTAGE 'B' (8.05 V):
09	01.75 V	YELLOW INT: OUTPUT VOLTAGE 'A' (1.75 V):
08	00998	NUMBER OF SOUNDINGS PER MILE (998):
07	00010	RED INT: FIXED GAIN 'A' (0 dB); 'B' (10 dB):
06	10020	YELLOW INT: FIXED GAIN 'A' (10 dB); 'B' (20 dB):
05	15036	RED INT: START SAMPLE (15 m); FINISH SAMPLE (36 m):
04	10041	YELLOW INT: START SAMPLE (10 m); FINISH SAMPLE (41 m):
03	19412	TIME: 1941 hours GMT
02	23082	DATE: 23 AUGUST 1982:
01	04040	MILE OF SURVEY (404)

Note: Rationalising each output to 10 dB gain, the four channels gave 13.5, 12.73, 11.75, 11.805 volts respectively.



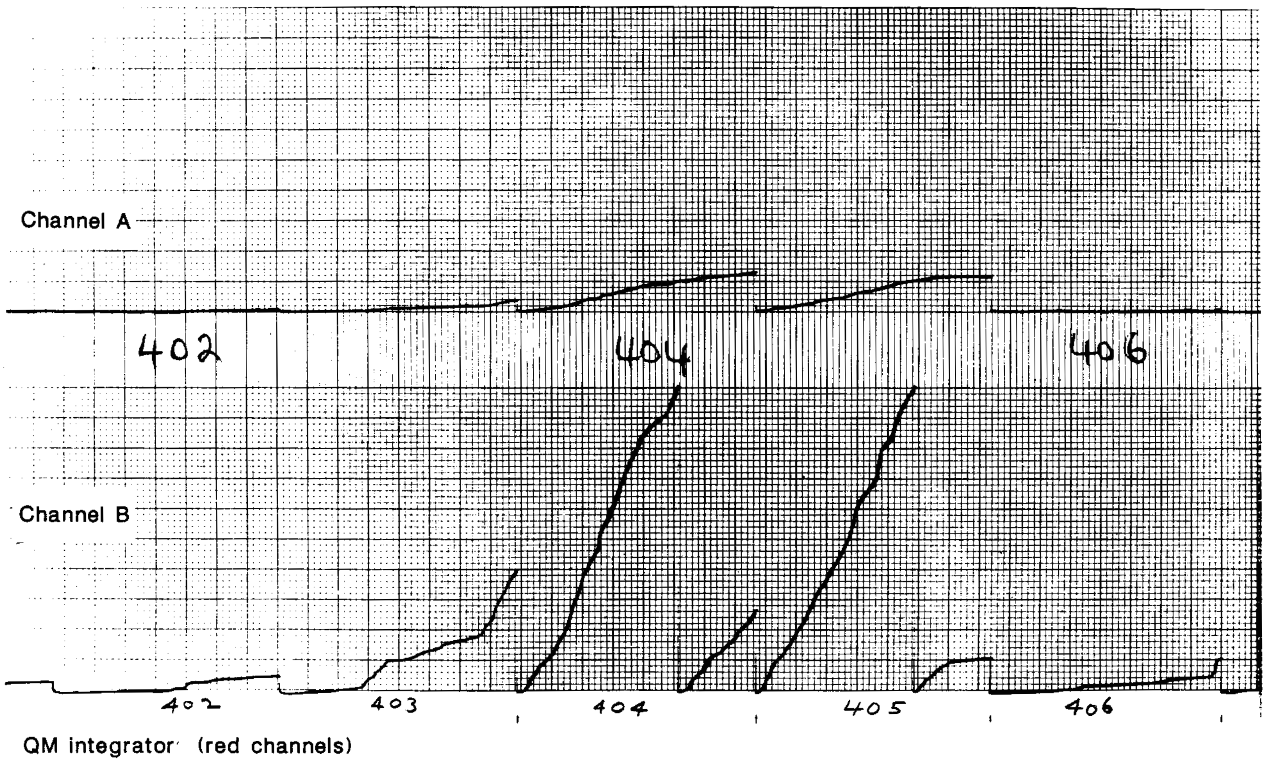


Figure A8 Pen records of the Simrad QM echo-integrator outputs on the four channels for miles 402-406. Full scale is 10 volts. The pen deflection and the number of 're-sets' per mile per channel depend on the integrator gain setting for each channel.

Table A14 Details from log sheet for miles 402-412

Mile	Date 1982	Time (GMT)	Yellow Depth	Yellow Interval	Red Depth	Red Interval	No. of TX's	Yellow A 10 dB	Yellow B 20 dB	Red A 0 dB	Red B 10 dB	Resets Yellow A	Resets Yellow B	Resets Red A	Resets Red B	Remarks	V_0 at 10 dB equiva-lent	Biomass (t km^{-2})
402	23 Aug	1926	10	42	15	37	953	0.51	5.91	0.08	0.58	0	0	0	0	Some small shoals near bottom	0.58	28.42
403	23 Aug	1933	10	42	15	37	995	3.49	5.40	0.42	4.05	0	3	0	0	a/c 1928 GMT 080°. Diffused trace near bottom	4.20	210.00
404	23 Aug	1941	10	41	15	36	998	1.75	8.05	1.35	2.73	1	11	0	1	a/c 1940 GMT 156°. Heavy continuous trace off bottom	13.50	675.00
405	23 Aug	1948	10	41	15	36	982	0.42	4.73	1.21	1.18	1	10	0	1	Heavy continuous trace off bottom	12.10	605.00
406	23 Aug	1956	10	41	15	36	977	1.08	0.04	0.14	1.20	0	1	0	0	A few small spots	1.40	70.00
407	23 Aug	2003	10	40	15	35	975	0.76	8.60	0.10	0.83	0	0	0	0		1.00	50.00
408	23 Aug	2011	10	40	15	35	970	0.51	6.10	0.06	0.55	0	0	0	0		0.55	26.95
409	23 Aug	2018	10	40	15	35	974	0.52	6.11	0.07	0.57	0	0	0	0		0.57	27.93
410	23 Aug	2026	10	40	15	35	972	0.47	5.54	0.06	0.52	0	0	0	0		0.52	25.48
411	23 Aug	2033	10	39	15	34	967	0.55	6.33	0.07	0.60	0	0	0	0		0.60	29.40
412	23 Aug	2041	10	38	15	33	970	0.47	5.57	0.06	0.51	0	0	0	0		0.51	24.99

Note: The data that are recorded at the end of each nautical mile of survey serve as a useful guide on the survey progression and a plot on V_0 on the survey grid (see Figure A9) pin-points areas of high fish concentration. Once the length distribution of the shoals has been determined from trawl samples, the biomass is calculated (final column)

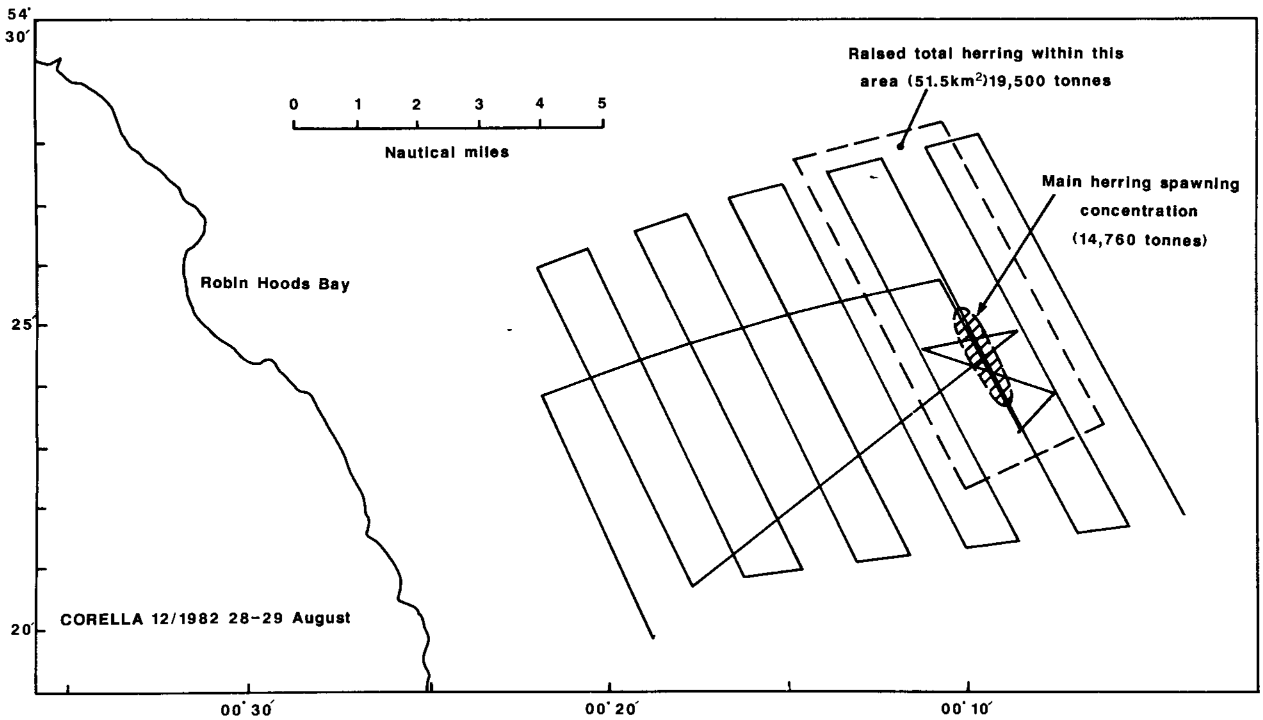


Figure A9 Survey grid showing fish density. This consists of a series of parallel tracks laid in an area defined by: previous work; information received from working vessels or from earlier exploratory surveys. As the survey proceeds, a guide to fish density is plotted from the variation in integrator output voltage. The major shoals are located thus for closer investigation.