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SONAR IN FISHERIES

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An echosounder for fish target strength measurement

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1. Introduction

In the application of echosounders to fish counting it is desirable that two main conditions should be satisfied. Firstly, the sampling volume of the apparatus should be accurately defined. Secondly, the receiver output should provide a direct measure of the target strength of objects within the sampled volume. It would also be useful if the beamwidth of the echosounder could be easily adjusted to suit particular operating conditions so that the probability of occurrence of multiple targets within the pulse volume could be minimised.

In the case of conventional echosounders the sampling volume is dependent on target level. Also, even if a time varied gain facility is provided, it is not possible to interpret the receiver output directly in terms of target strength, since a target of any particular strength appearing on the acoustic axis will normally give rise to the same receiver output as a larger target in some off-axis direction. In the method of fish counting used at Aberdeen these limitations are circumvented by recording the frequency distribution of echo amplitudes as a function of depth, and converting on a statistical basis to an equivalent distribution of target strengths.

This paper describes the operating principle of an echosounder at present under development at the Marine Laboratory, Aberdeen, which is intended to provide a better approximation to the ideal performance than has been available so far and thus enable the processing of fish counter data to be considerably simplified.

2. Principle of operation

It is possible to produce a system having zero sensitivity to signals incident from outside some desired solid angle if the direction of every target with respect to the acoustic axis is determined. Those echoes corresponding to targets without the desired beam angle are then eliminated by a gate which is controlled in accordance with target direction. In principle, it is then possible to apply continuous correction to the amplitudes of echoes which pass this acceptance test in order to eliminate the remaining variation in sensitivity within the beam. So long as appropriate time varied gain is provided, the system output can then be calibrated in terms of target strengths.

By way of illustration let us consider a system based on a four element linear transducer array of length L, as depicted in Figure 1. We wish to detect a target in the plane normal to the transducer surface containing axis AB.

2(a) Uniformly insonified targets

The medium is assumed to be uniformly insonified and the wavefront of the received acoustic signal makes an angle θ to the axis of the array.

Figure 2 is a block diagram of a simplified version of the proposed receiver system, from which it may be seen that incoming signals are processed simultaneously in two channels. The first of these, which we shall call the measuring channel, generates the basic echo amplitude information in the conventional manner, by summing the individual element outputs without relative shift. This results in the usual directional response, as depicted in Figure 3, of the form

$$D_M = \frac{\sin(\frac{\pi L}{\lambda} \sin\theta)}{\frac{\pi L}{\lambda} \sin\theta} \qquad (1)$$

where D_M is the normalised directional function of the measuring channel. Correction for spreading loss and attenuation is performed by a time varied gain amplifier having a $[40 \log_{10}R + 2\alpha R]$ characteristic.

The second channel provides a reference signal which enables those received signals within the desired acceptance angle to be identified. The reference signal is derived by generating a set of sinusoidal signals of standard amplitude from the outputs of the receiving elements, in such a manner that the phase relationships of the element outputs are maintained. These standard signals, at the frequency of the incident acoustic wave, are then summed before detection to produce an output whose amplitude depends only on target direction. In fact, the directional response of the reference channel is equivalent to the response of a hypothetical array of omnidirectional elements corresponding in position and sensitivity to the actual elements of the receiver. The corresponding normalised directional function is

$$D_R = \frac{\sin\left[\frac{\pi L}{\lambda} \sin\theta\right]}{4\sin(\frac{\pi L}{4\lambda} \sin\theta)} \qquad (2)$$

as depicted in Figure 4.

Control of receiver beamwidth is achieved by accepting for analysis only those measuring channel signals (v_M) for which the corresponding reference signal (v_R) exceeds a predetermined threshold (v_T), as determined by the comparator in Figure 2. For example, the resulting directional response for a threshold level -3 dB with respect to the on-axis value of the reference signal is shown in Figure 5. Under these circumstances there remains a small variation in sensitivity within the acceptance angle. Side lobes also persist, corresponding to the diffraction secondaries of the reference channel directional function, although they are much reduced in extent.

The effective sensitivity within the acceptance angle is made more uniform by evaluating the ratio $\frac{v_M}{v_R}$, as indicated in Figure 2, and regarding the result as the calibrated output. The normalised directional function then becomes

$$D_S = \begin{cases} \dfrac{\sin(\frac{\pi L}{4\lambda}\sin\theta)}{\frac{\pi L}{4\lambda}\sin\theta} & \text{for } v_R > v_T \\ 0 \text{ for } v_R < v_T \end{cases} \tag{3}$$

as depicted in Figure 6.

The maximum measurement error for a target within the main beam is then given by

$$E_{MAX} = \frac{\sin(\frac{\pi L}{4\lambda}\sin\theta_T)}{\frac{\pi L}{4\lambda}\sin\theta_T} \tag{4}$$

in which θ_t is the smallest value of θ for which v_R equals v_T. For example, a reference threshold of -3 dB would result in a maximum error of -0.18 dB.

The worst case side lobe sensitivity relative to the main beam would be given by

$$K_{SL} = \frac{\sin[\pi - \frac{\pi L}{4\lambda}\sin\theta_T]}{[\pi - \frac{\pi L}{4\lambda}\sin\theta_T]} \cdot \frac{\frac{\pi L}{4\lambda}\sin\theta_T}{\sin[\frac{\pi L}{4\lambda}\sin\theta_T]}$$

$$\text{i.e. } K_{SL} = \frac{\frac{\pi L}{4\lambda}\sin\theta_T}{[\pi - \frac{\pi L}{4\lambda}\sin\theta_T]} \tag{5}$$

This would have a value of -18 dB for a reference threshold of -3 dB.

2(b) Operation in conjunction with narrow beam transmitter

It has been assumed in the above discussion that the targets are uniformly insonified. In the interest both of efficient use of acoustic power and side lobe suppression, a narrow beam transmitter is preferable. Using a single array for transmission and reception, compensation for transmitter directivity can be achieved by evaluating the ratio $v_M/(v_R)^2$ as the system output. The overall directional function then becomes $D_S{}^1 = (D_S)^2$, so that both the maximum error and side lobe suppression are doubled.

3. Practical implementation

Figure 7 depicts the main features of a receiver for a prototype 150 kHz fish counting echosounder based on a pulse height analyser. The transducer is a 4 x 4 array of 5λ wide square elements. The reference channel standard signals are obtained by symmetrically limiting the individual element outputs and filtering after summation to recover the reference signal. Rejection of signals originating outside the desired acceptance angle is achieved by blocking the analyser sampling pulse.

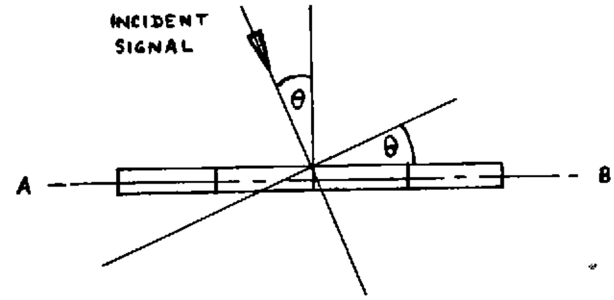
4. Conclusion

A signal processing technique has been described for an echosounder exhibiting a good approximation to a uniform sensitivity conical beam and enabling direct measurement of target strength.

5. Acknowledgements

The author wishes to thank Messrs R E Craig and S T Forbes for helpful discussions.

1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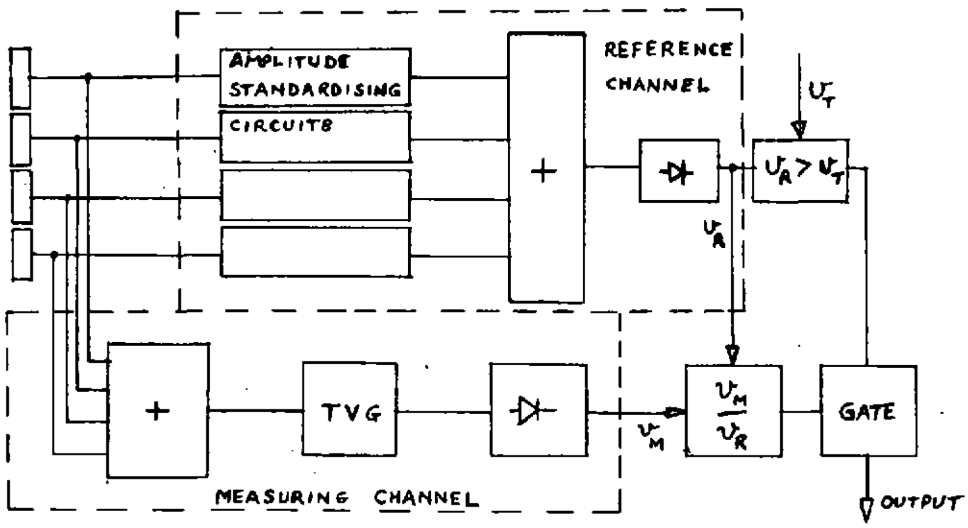
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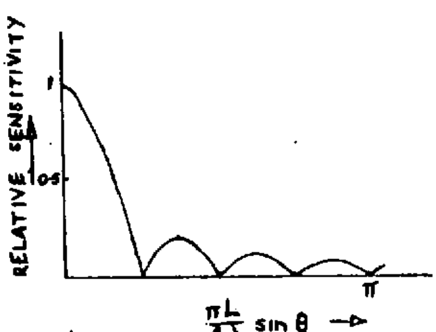
3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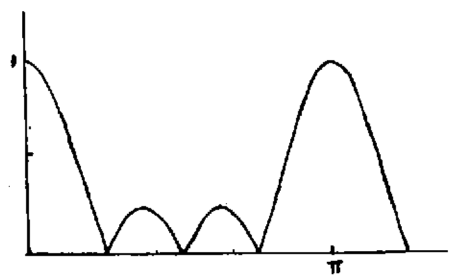
0.5
π
$\frac{\pi L}{4\lambda} \sin\theta$

4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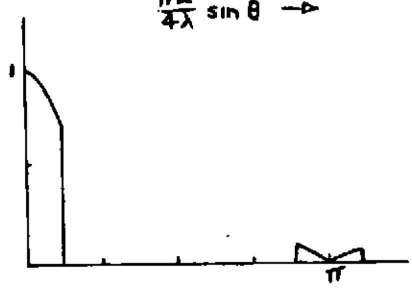
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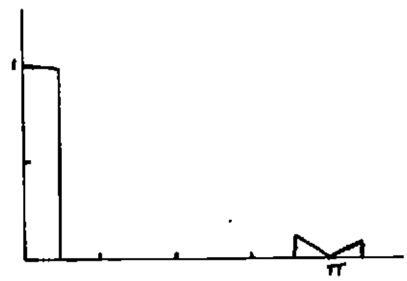
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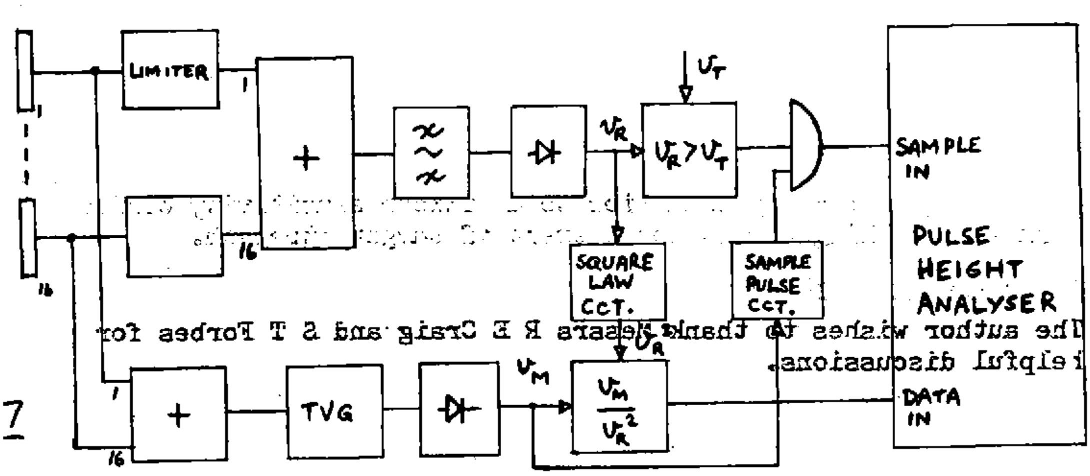
LIMITER
1
16
+
V_R
$V_R > V_T$
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SAMPLE IN
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