Interference Patterns in Reverberation

by

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Introduction

Extensive reverberation studies have been carried out in the shallow waters of the Bristol Channel, as first reported in [1]. Many causes of reverberation structure or patterning have been found, one being the interference between the various normal modes. Very clear examples of such interference have already been reported in one-way propagation, including several cases in the same Bristol Channel area e.g. [2], but it is interesting to see the effect in the reverberation.

Main Results

The simplest results have been obtained when echo-ranging at a carrier frequency of 1 kHz, using a correlation signal-processing system. During night-time in the summer the chief scatterers at intermediate and longer ranges are fish, or to be particular, pilchard, which are well dispersed in range but not in depth. Only the first two normal modes are effective at intermediate ranges, these beat together in space to give a regular modulation of the marking intensity on a range-time display, with modal interaction distance about 2 nautical miles.

In order to calculate the expected pattern it is convenient to start with an approximate formula [3] for the interaction spacing L in terms of a slightly enhanced water depth H and a wavelength λ,

$$L = 8H^2/3\lambda .$$

More complete calculations show that for isovelocity water in the present application the approximation is better than 1 in 10^4, much less than the uncertainty in the parameter values, and less than the error in treating layered water as isovelocity.

Figure 1(a) shows the mean depth profile in front of the arrays, and 1(b) shows values of $1/L$ for various states of the tide (Mean Low Water Springs, Mean Tide Level and Mean High Water Springs). $1/L$ is important because it determines the rate of change with range r of the pattern phase. In fact the number of pattern cycles is simply

$$m = \int_0^r \frac{dr}{L}$$

as shown in figure 1(c).

Three quantitative tests of these ideas are possible. Figure 2 shows a plot of the measured ranges of the reverberation maxima, referred to Mean Low Water Springs, together with the theoretical line from figure 1(c). There is good general agreement, but some discrepancy at the closer ranges. This is in part due to uncertainty in the depth of the fish with a corresponding uncertainty of 0.5 in the value of m, noting that to get a clear pattern the fish need to be predominantly in either the top half or bottom half of the water column.

Figure 1(c) shows that the range scale of the pattern depends on the height of the tide. Taking the mean for 21 clean patterns the estimated time of range extremum occurs only 12 min after the appropriate High or Low Water.

Lastly figure 3 compares experiment and calculation for the range amplitude of the patterns in nautical miles, as they vary through the tide, all results being corrected to the Mean Springs Tidal Height Range. Agreement is good, but there is some spread at the longer ranges which may be associated with layering effects.

Other Features

The story so far has lacked its central feature, since the records themselves cannot be reproduced here, and for the same reason we now provide only a list of the modifying effects and other features seen.

(a) In reconciling theory and experiment account should properly be taken of the small separation of source and receiver, of the unequal excitation of the modes, of the smearing due to the finite 100 Hz pulse bandwidth, of the equipment response associated with the correlation processing and the automatic gain control, and of the effect of shear flow as well as layering.

(b) Interference modulation is also seen on the collections of discrete tracks of shoals of fish seen in the summer daytime. But this effect with its tidal variation is easily confused on the records with the actual movement of the scatterers on the tidal stream.

(c) Quite complicated interference effects have been seen more recently at 2 kHz, with intertwined tidal depth change and tidal streaming patterns.

(d) The close-range bottom reverberation is also modulated. The effects in (c) and (d) involve several modes, and allow estimates of the effective number in agreement with [2] etc.

(e) Occasionally the fish change depth from the top half to the bottom half of the water column, or vice versa, and produce a relatively sudden phase reversal in the recorded interference pattern.

(f) Regular diffuse patterns have also been seen in 6.5 kHz GLORIA long-range sonar records taken by the Institute of Oceanographic Sciences in 1975, apparently due to the interference of the first two normal modes in the surface duct.

Conclusion and Acknowledgements

The observed interference effects are explicable and are interesting in their own right, but in addition throw light on propagation mechanisms and on fish behaviour. We wish to acknowledge the considerable contribution of colleagues, especially J. Revie, in taking the records.

References

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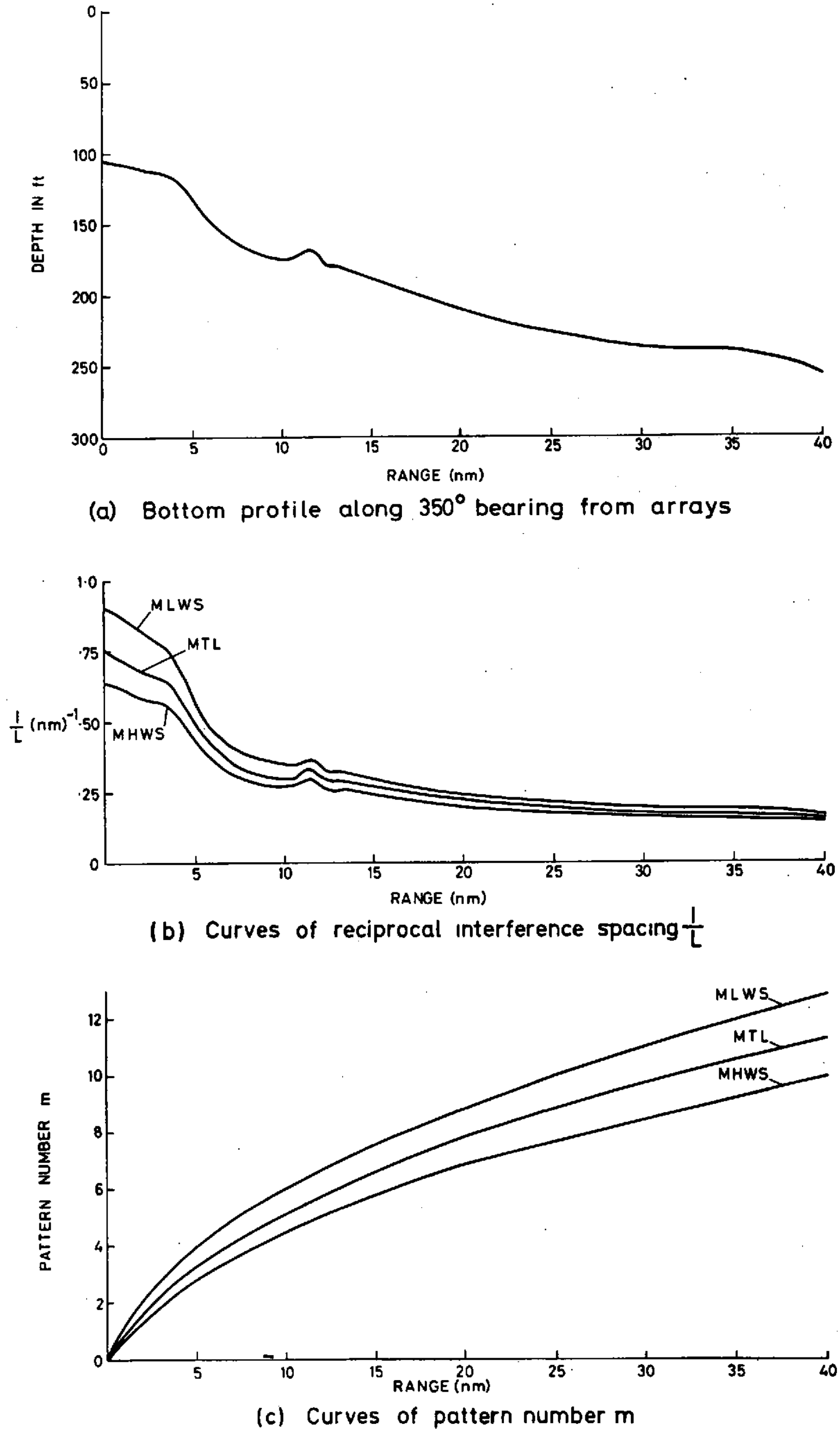

(a) Bottom profile along 350° bearing from arrays

(b) Curves of reciprocal interference spacing $\frac{1}{L}$

(c) Curves of pattern number m

FIG.1 PARAMETERS OF INTERFERENCE PATTERNS FOR THREE TIDE STATES

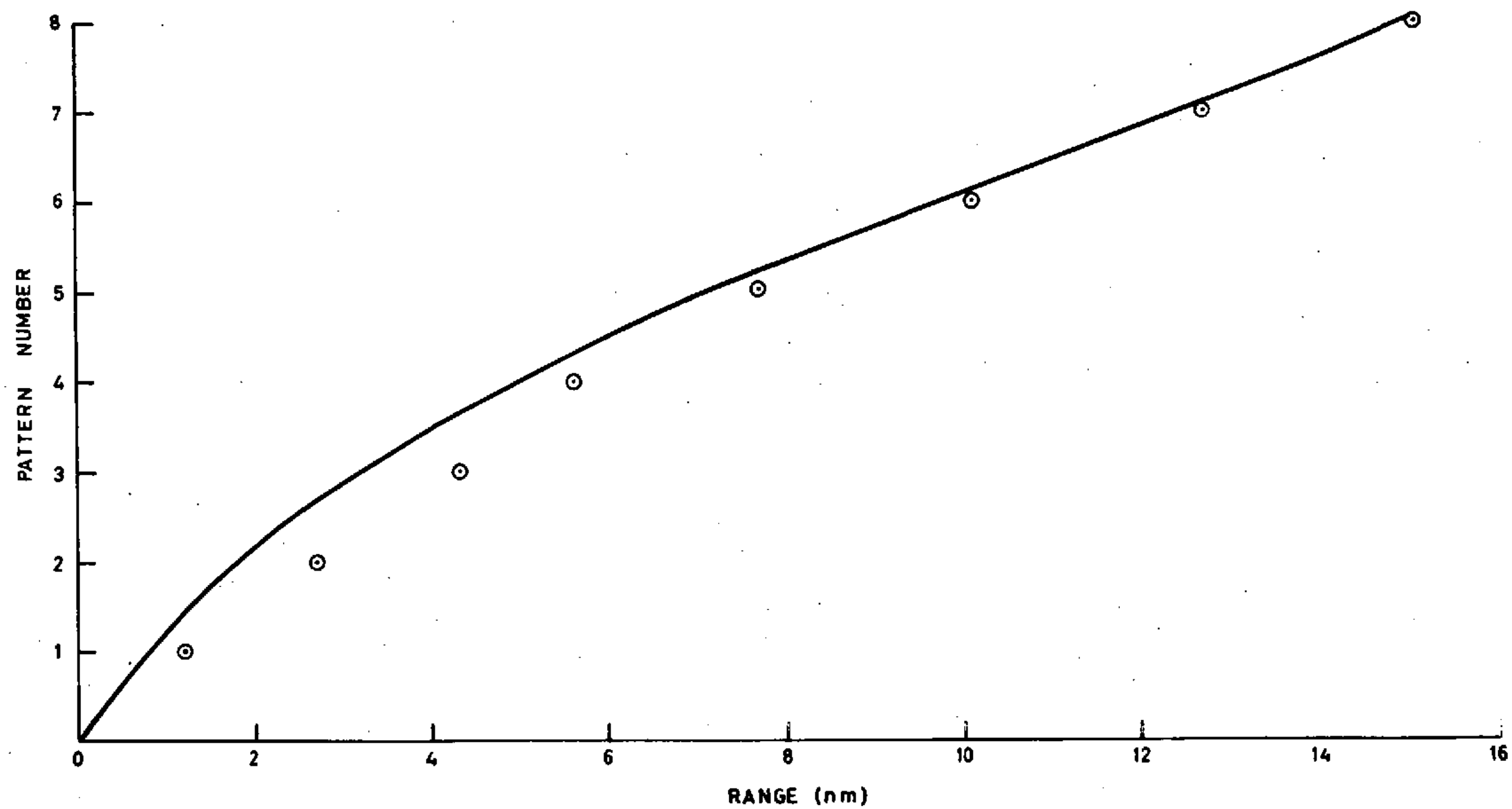

FIG.2 RANGES OF NIGHT FISH PATTERN INTENSITY MAXIMA
25th MAY 1963

5.1

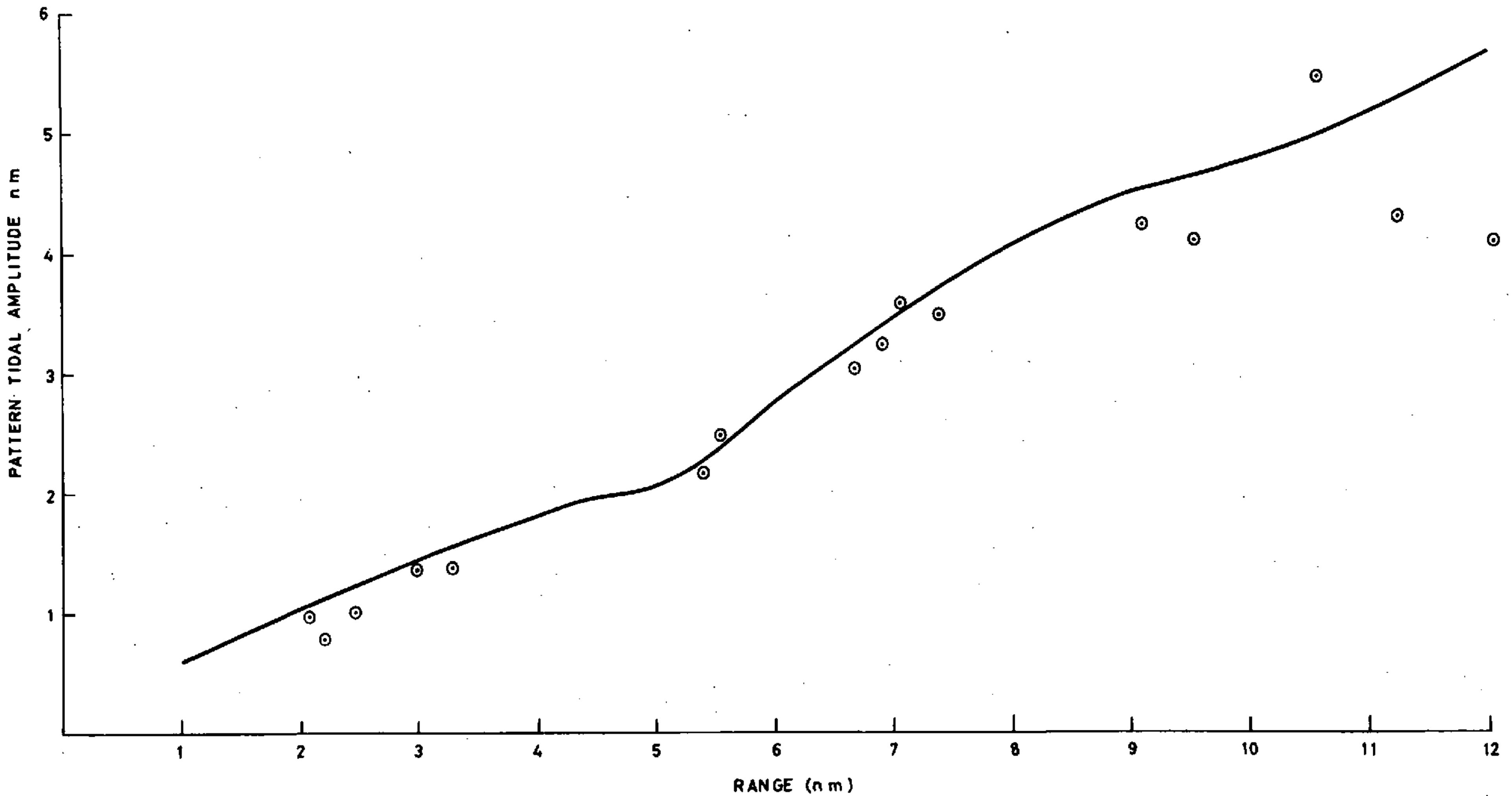

FIG.3 PATTERN TIDAL AMPLITUDE PLOTTED AGAINST RANGE