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UNDERWATER ACOUSTIC COMMUNICATIONS: A REVIEW AND BIBLIOGRAPHY

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INTRODUCTION

The literature surrounding the subject of underwater acoustic communications is, in some respects, surprisingly scant. This is particularly the case if one concentrates only upon that material directly concerned with actual underwater communication systems. For example, covering that particular area and excluding general review papers whilst searching back over the past two decades, the authors have retrieved only some sixty titles.

In this paper we have deliberately chosen to take a broader view of underwater communications, to include consideration of the acoustic channel. In so doing, we have drawn upon material which, if not exactly remote from the topic of communications, is none the less of substantially wider scientific interest and application. The paper thus divides into four broad areas of interest, which are "Review and Fundamental Papers", "The Channel", "Engineering Aspects of Underwater Communications" and "Specific Communication Systems".

It must be said that, insofar as the first and second of these areas are concerned, there has been a distinct need to prune the available material, in order to fit within the space allocated to this paper. Hopefully the pruning and the organisation of the material as a whole, although idiosyncratic, will yet leave a useful collection of references for those who wish to pursue further the subject of underwater acoustic communication.

REVIEW AND FUNDAMENTAL PAPERS

In compiling this section, it has been necessary to eliminate a significant number of titles which only provide a low-level review for a general audience. That stated, one such paper by Anderson [1] is included, since it sets the scene in underwater communications as of two decades ago, and neatly reviews the major difficulties which, then as now, revolve around the problems of reverberation and multipath transmission and high attenuation at high acoustic frequencies. Quazi and Conrad [2] also contribute an interesting historical insight and make the suggestion that parametric transmission, because of its ability to establish pencil-beam transmission at relatively low frequencies, with physically small transducers, might have particular advantage in avoiding surface and sea-floor reflections and thus minimising or eliminating the corruptive effects of multipath transmission.

Parametric sonar might be less attractive than Quazi and Conrad suggest, since high directivity at a frequency approaching one of the parametric primaries is, in any case, readily achieved using conventional transmission. One of the remaining advantages of the parametric method is that transmissions using the lower, secondary frequency are less strongly attenuated, in water, than conventional transmissions at the primary frequency. For many applications this advantage would be offset by the poor power efficiency of parametric conversion. Another potential advantage is the possibility of making use of the extreme frequency agility of the secondary frequency. At least in sofar as bandwidth is concerned, the absolute width of sweep of the secondary cannot in any case exceed the primary bandwidth. Finally, the added complexity of a parametric projector would increase cost and could adversely affect robustness.

Acoustics is not, of course, the only method of obtaining underwater communication. The paper by Tregonning [3] outlines state-of-the art and problem areas, as identified during a one-day symposium at the Society for Underwater Technology. The symposium covered acoustical, cable, fibre-optic, electomagnetic and laser methods. On a rather more selective basis, an excellent review, specifically aimed at acoustic telemetry, is provided by Baggeroer [4].

Turning finally to more fundamental material, covering in some detail the mathematical basis of the subject, we have papers by Middleton [5] and by Urick [6].

THE CHANNEL

In discussing the nature of the acoustic channel, since it must necessarily dictate the engineering of the communication system, we consider first a sequence of papers concerned with what might best be described as channel models [7] - [24]. By this we intend to refer primarily to overall end-to-end channel transfer functions of varying complexity, mathematical "models" of channel response and models relating to specific phenomena, such as surface and sea-floor reflection. Of particular mention as a ready source of copious information for the pragmatist who wishes to establish computer models with minimum effort, is the Generic Sonar Model [20],[21] .

Moving on from the definition of the channel model, the communication engineer is instinctively inclined to investigate channel capacity, in an information theoretic sense. Three references to papers by Hummels [25], Kwon and Birdsall [26] and Rowlands and Quinn [27] cover this topic. It is interesting to question the significance of a classical information theoretic approach to such a problem. As with more conventional above-water communications, such an approach can provide only upper bounds to performance, perhaps significantly far removed from practical operating levels.

A large body of work is represented in the next section of the bibliography, which covers measured channel characteristics [28] - [45]. Here we see the accumulation of data in both real-sea and test-tank experiments which may provide input for the successful use and extension of the various channel models. A sequence of papers by Gulin and co-workers is concerned with establishing temporal amplitude, phase and frequency as well as spatial correlations for signals reflected from randomly rough surfaces [30] - [36]. Other papers, particularly those by Jobst and Dominijanni [37] and by Veenkant [43] discuss channel stability.

In a separate section we consider the subject of noise as a major corrupting influence [46] - [51]. Urick [50] provides, in his book "Ambient Noise in the Sea", a broad account of this topic with an extensive bibliography. Dunbar [47] considers the under-resourced area of acoustic noise in the vicinity of oil extraction platforms, a subject also touched upon much earlier by Lagoe [48]. The book "Mechanics of Underwater Noise" by Ross [49] provides an excellent background to such studies, which are currently in great need of re-inforcement.

Although, in a later section, we review a selection of papers concerned with the subject of "anti-multipath strategies", it seems appropriate to introduce at this stage a set of papers concerned with multipath identification, partly because the topic should be of fundamental interest and partly because, in future system designs, perhaps more particularly for long-range communication, knowledge of the nature of the multipath structure of the channel might assist in establishing self-training "machine intelligent" processing systems. Papers by Fjell [52] and by Hassab [53],[54] explain how to acquire such information via the cepstrum analysis technique. Although we remain sceptical of this, they further suggest that the cepstrum approach is intrinsically superior to evaluation of the autocorrelation function in identifying delay-domain attributes of a received signal. Two further papers describe actual multipath investigations in the Atlantic [56] and Pacific [57] Oceans.

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Here we consider first the estimation of error probability [58] - [67]. Papers by Aboteen et al. [58],[59], by Andrews and Turner [60] - [62] and by Maras et. al. [63] - [66] address various aspects of these problems. Some element of field experiment is contained within the papers by Andrews and Turner. Next we turn to the topic of devising error protection codes for underwater communication systems [68] - [73] and follow this with papers on anti-multipath strategies [74] - [78].

The section concludes with two papers concerned with aspects of timing and synchronisation [79],[80].

SPECIFIC COMMUNICATION SYSTEMS

This area has been considered under two headings, although further subdivision would be possible. The larger class of systems is concerned with aspects of through-water communication [81] - [109]. No particular attempt has been made to isolate high efficiency or high rate systems since such descriptors seem often to be incorrectly or at least ill-advisedly used in underwater applications.

The second, smaller, class is concerned with penetrator telemetry, where the signal must first pass through a significant layer of (relatively) highly attenuating ocean floor sediment. Such systems are employed for a variety of geo-technical tests [110] - [112].

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