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AN UNDERWATER ACOUSTIC TELEMETER FOR USE IN A MULTIPATH CHANNEL

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Introduction

The data-rate of underwater acoustic communication links is often severely limited by the occurrence of multiple-path propagation. Over very long ranges (tens of kilometres or more) a multipath structure may arise due to ray-bending caused by thermal effects, but the major cause of multipath interference is the reflection of the transmitted signal at a boundary such as the sea surface. In the usual situation where there is some relative motion between the reflecting areas of the boundary and the transmitting and receiving transducers, then the effect on a CW signal is to randomise its envelope and to impart to it properties similar to those of the envelope of the sum of a sinusoidal signal and narrow-band Gaussian noise. One important difference, however, between this and real noise is that it is multiplicative rather than additive, and the effective signal-to-noise ratio may not be improved by the simple expedient of raising the transmitted power. The effective SNR is dependent upon many factors including the transmitter and receiver beam patterns and the prevailing geometry, but during a previous meeting the author presented the results of some practical measurements on a typical trawling telemetry link (ref. 1) when the rms value was determined as 1.20. Clearly an attempt to convey information over such a link by means of amplitude modulation of the carrier would fail in these circumstances, and also the frequent fading of the received signal to near-zero amplitude would prohibit the direct use of frequency modulation. The only information that is conveyed by the presence of a signal at the receiver (whether this has propagated via the direct path or by way of reflection) is that the transmitter is radiating; the CW signal could be interrupted at the transmitter to send a slow series of long pulses (separated such that the interference from one pulse had died to zero before the arrival of the next), but the information rate would be limited to 1 bit/symbol and the rate of sending symbols would be restricted by the multipath spreading time. The bit-rate of such a system may be increased by reducing still further the pulse rate in order to establish long gaps between consecutive pulses, and then to impress sampled analogue information as modulation of the interval. However, with a typical multipath spreading time of 2 mS in the case of medium range trawling telemetry (from ref.1) then the relayed analogue bandwidth would not be much in excess of 50 Hz, and the merits of PIM and PRFM lie more in their reliability and economy of transmitter design rather than in any high data-rate capability.

High Data-rate Telemeters

Ideally, a telemeter would incorporate the facility of distinguishing between the desired direct-path signal and the unwanted multipath interference, and of selecting only the former. If this could be done without imposing any new restriction on the transmitted signal, then the original information capacity of the communication link (without multipath effects) would be restored. In general, the wanted and unwanted contributions at the receiving hydrophone are of the same frequency, but of different times of arrival (in the case of the transmission of a short pulse) and directions of arrival. Thus there are two methods of distinguishing between the signals which may be exploited to remove the multipath interference and restore, or at least improve, the data rate, and these were the subjects of two contemporary research projects undertaken by Birmingham University. The directional approach is discussed by Nesbitt in a companion talk (ref. 2), whilst from now on in this talk the time-gating approach only will be considered.

The Time-gating System

The principle of operation of a telemeter based on this system relies upon the assumption that the wanted signal will arrive at the receiver first, followed only after a time delay by the interfering reflected signal. In the case of the majority of telemetry links, the wanted signal will be that that has propagated via the geometrically direct path between the transmitting and receiving transducers and the unwanted interference will be that reflected from the sea surface. It is easily shown that, in this situation, the reflected signal will reach the receiver delayed (compared to the direct-path signal) not less than T_o given approximately by:-

$$T_o = \frac{2d_1d_2}{C_oR} \qquad \text{...(1)}$$

where d_1 and d_2 are the depths of the transmitting and receiving transducers, R the horizontal range between them and C_o the velocity of sound. Thus any transmission of duration less than T_o will not suffer from multipath distortion at the receiver.

After the period T_o has elapsed then the reflected signals from the sea surface will begin to arrive, and as time continues these will gradually die away until finally they disappear into the noise level. In general, they will continue for a time not exceeding T_1 after their commencement where T_1 depends upon such factors as the transmitter and receiver beam patterns and the roughness of the reflecting surface. After T_1, it is then possible to receive a further transmission of period T_o which will again be free from multipath interference, either from itself or from the previous transmission. In this manner transmissions of duration T_o may be sent at the rate of $1/(T_o + T_1)$ per second. If the available bandwidth is B, then the time-bandwidth product per transmission becomes:-

$$P = BT_o \quad \text{per pulse} \qquad ...(2)$$

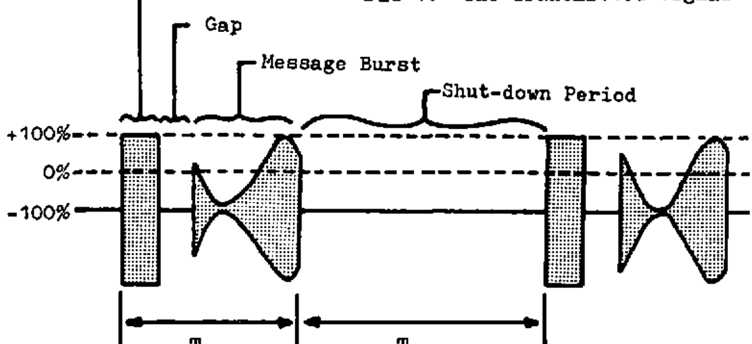
$$P = \frac{BT_o}{T_o + T_1} \quad \text{per second} \qquad ...(3)$$

and the relayed information rate is therefore equivalent to that of a continuously operating telemeter with a bandwidth numerically equal to P. Thus, unlike PRFM and PIM systems where the data-rate is limited according to the multipath spreading time, the time-gating system has an information rate determined by the available bandwidth (which is usually restricted by the transmitting transducer).

The Experimental Telemeter

For most purposes in underwater communication it would not be acceptable that the data flow should be restricted to periodic wideband bursts. Therefore an integral part of this form of antimultipath telemeter is a device that will convert continuous input information into a form suitable for transmission, and then rejoin the received information bursts to recreate a continuous signal. Implicit in this specification is some form of data-storage device, and this must have a capacity sufficient to store the information contained in one transmission pulse. It is not intended to describe details of circuitry here, but essentially the experimental telemeter incorporated a series of fifteen sample-and-hold stores based on FET gates, in which were sequentially stored analogue samples taken of the signal to be relayed (sampled above the Nyquist rate). As the fifteenth store was being recorded, a process was initiated whereby all fifteen stores were sequentially scanned at high speed, thus time-compressing the original continuous signal into a series of bursts separated by long gaps. The inverse operation was performed at the receiver, writing the incoming information bursts onto a series of fifteen stores and reading out continuously. For reasons of reliable synchronisation of the

FIG 1. The Transmitted Signal



receiver decoder with the incoming signal it was considered desirable to precede each transmission with a constant-amplitude prepulse (the knowledge that this was of constant amplitude was also used at the receiver for the purposes of automatic gain control), and the transmitted signal was as shown in Fig. 1 (illustrated for the case of 100% modulation with a sine wave).

Conclusions

The experimental antimultipath telemeter was tested under trawling conditions over a range of 300 metres, and the relayed bandwidth achieved was from DC (because the AGC is acting on a non-information-carrying part of the transmission) to over 400 Hz. Some difficulty was experienced in practice with the transmitting transducer, which continued to 'ring' for some time after the cessation of the driving signal. The practical effect of this was to cause some spillage of energy from the prepulse into the information-carrying period of the transmission, causing an apparent additive noise at the cycling frequency. Because of this artifact the signal-to-noise ratio at the output of the receiver decoder was reduced from the 30 dB of the acoustic link to some 15 dB, although the bandwidth of the telemeter was unaffected. The decision to include within the transmitted signal a prepulse and gap did, however, cause a reduction of some 40% of the maximum theoretical information rate of the telemeter. Both the above problems could be overcome by transmitting the synchronisation signal in an adjacent channel via a separate transducer, although the prepulse AGC facility would have been lost. Nevertheless, despite the artificial impairment of the SNR, the data-rate actually achieved by the experimental telemeter was more than 2000 bits/sec, which considerably exceeds that achieved by any previously existing telemeter operating under similar conditions.

References

1) "Some Practical Measurements of a Trawling Telemetry Link", G.C. Goddard. (Paper to the BAS Meeting on "Sonar and Communication Systems" Birmingham University, Nov. 1968).

2) "An Electronic Tracking System for Acoustic Telemetry" R. Nesbitt and H.O. Berktay. (Companion Paper).